Assortment of Weather Articles

Below are the first of many more articles I plan to place here. Hot references in these are directed to a new window(s). Those for graphics at my site should open a new window for each. Those for another WWW site should open only one new window for all of such pages. This is done so that you can continue reading the article while browsing. Though displays using different PC's, systems, and browsers vary, these pages should appear best using 800×600 pixels and a base font size of 11 or perhaps 12.

Forest and City NY Temperatures - 3/13/200, revised 4/18/2002

Long-term trends for New York City and Indian Lake, and a brief disussion of the possible effects causing differences - especially vegetation.

Coriolis and Centrifgual Forces - 8/12/1998

A description of these apparent atmospheric forces with equations.

Relative Vorticity - 7/7/2001

A mathematical descrpition with a few physical examples.

19-20 December Snow Event - 12/22/2000

An analysis of the dynamical contributions to the snow band and enhancement over the Poconos from the coastal Low.

Central Park, NY Snow Stats - 10/25/2000

Can't argue with a complete record of snow stats since 1870 ! Here's a brief analysis and discussion of them.

Stratospheric Ozone Depletion & the Antarctic Ozone Hole - 2/16/1997

Stratospheric ozone depletion, emphasizing the Antarctic ozone hole and its measurement from outer space.

Ultraviolet Solar Radiation: Effects and UV Index - 2/23/1997

Ultraviolet solar radiation, emphasizing its harmful effects, its measurement, and the UV Index.

Clouds - 3/2/1997

Clouds, emphasizing types and formation.

Cloud Forecasting - 3/9/1997

Cloud forecasting is discussed, including an example from this week and one from almost a year ago.

A Method for Determining Mid-latitude Seasons - 3/16/1997
A discussion of mid-latitude seasons and their determination using equal seasonal temperature change.

Some Factors Influencing Global Seasons - 3/23/1997
Some factors influencing global seasons are discussed, particularly tropical monsoons, the ITCZ, and topographical effects.

Spring Snowmelt - 3/31/1997
Spring snowmelt is discussed, emphasizing snow water content estimation in mountainous regions of the northwest United States.

The California Cooperative Surveys - 4/13/1997
The California Cooperative Snow Surveys are discussed, including measurement and monitoring methods.

Basic Origins of Solar Energy - 4/27/1997
A discussion of basic origins of solar energy and how our atmosphere influences it.

Solar Energy, Clear Sky Effects - 5/4/1997
Ways clear skies affect solar energy in our atmosphere is discussed, particularly aerosol scattering and absorption.

Influence of Clouds on Solar Energy - 5/12/1997
Influence of clouds on solar energy, particularly shadowing and transmittance estimation

Terrestrial Solar Energy Applications - 5/20/1997
Terrestrial solar energy energy applications are discussed, emphasizing photovoltaics and solar cars.

U.S. Weather Forecasts on the WWW - 6/2/1997, revised 9/11/1999
A discussion of most accurate and efficient sources.

A few Southern Hemisphere Weather Analysis Topics - 6/10/1997
Air circulation around Highs and Lows in each hemisphere and orientation of weather charts is discussed.

A Weather Forecasting Menu - 6/17/1997, occasionally updated
A simple menu for weather forecasting for a specific location using WWW info is discussed.

HI (Heat Index) - 6 / 25 / 1997
A discussion of the heat index, its use, its calculation, and information for preparing for great heat stress episodes.

A Wet-Bulb Temperature Equation - 7 / 2 / 1997
Discussion of a wet-bulb temperature equation, emphasizing its use for calculation of dew point and relative humidity using psychrometer measurements.

Consequences of Wet-Bulb Process Regarding Snow - 7 / 9 / 1997
A discussion of a wet-bulb equation, emphasizing real precipitation and consequences regarding snow with temperatures > 0 °C.

Plotted Surface Charts - 10 / 23 / 1998
The first things you should know to analyze like a pro.

A Detailed Isobaric Surface Analysis - 11 / 29 / 1998
An example illustrating differing station densities - Note : contains 1.15 MB of JPG's.

Height & Pressure Coordinates - 1 / 10 / 1999
Relationships of basic atmospheric height and pressure coordinates

Upper Air Charts - 1 / 21 / 1999
Basic upper air chart construction and analysis

Upper Air Chart Analysis - 2 / 17 / 1999
A discussion of analysis techniques with examples.

Upper Air Analysis of a Storm - 2 / 23 / 1999
Example using the 2-4 January 1999 Great Lakes region storm.

Kinked Contours - 5 / 8 / 1999
A brief discussion of why these are often seen on weather charts.

Climate Normals, Part 1 - 8 / 4 / 1999
A description of basic climate normals and their calculation.

Climate Normals, Part 2 - 8 / 10 / 1999
Discussion of an alternative calculation method and interpretation.

Home Page

Forest and City NY Temperatures

An interesting consideration regarding the global warming issue is the effect of local terrain.
The site (please see footnote) :

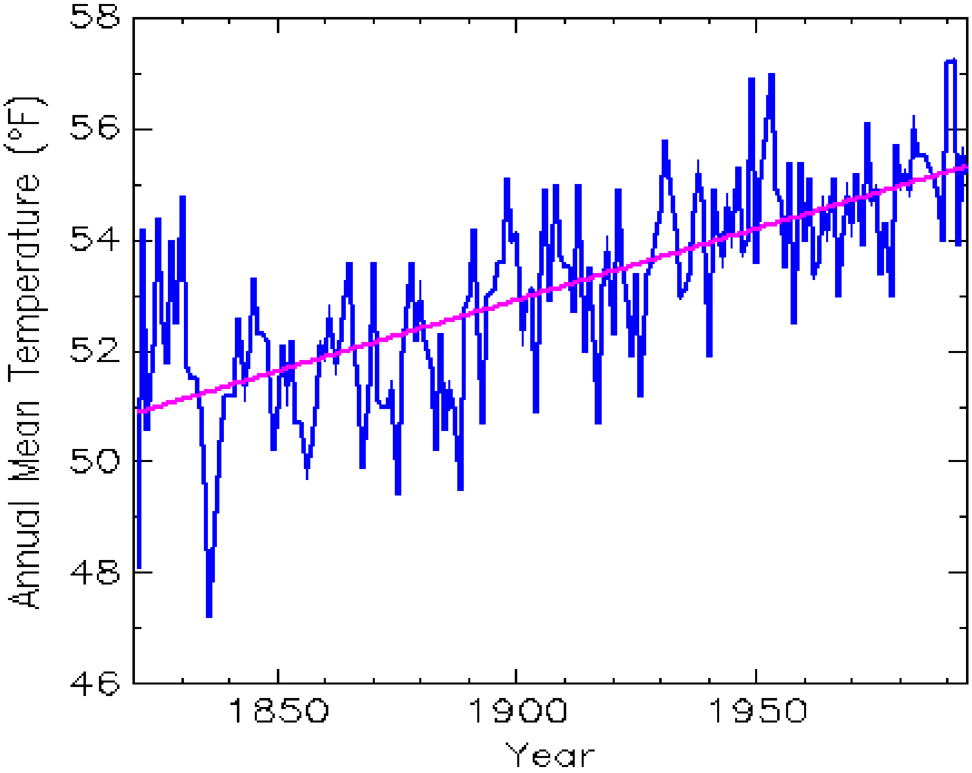
http://www.co2science.org/center.htm

includes U.S. climate data using which you can make plots to study any aspect of this issue which interests you :

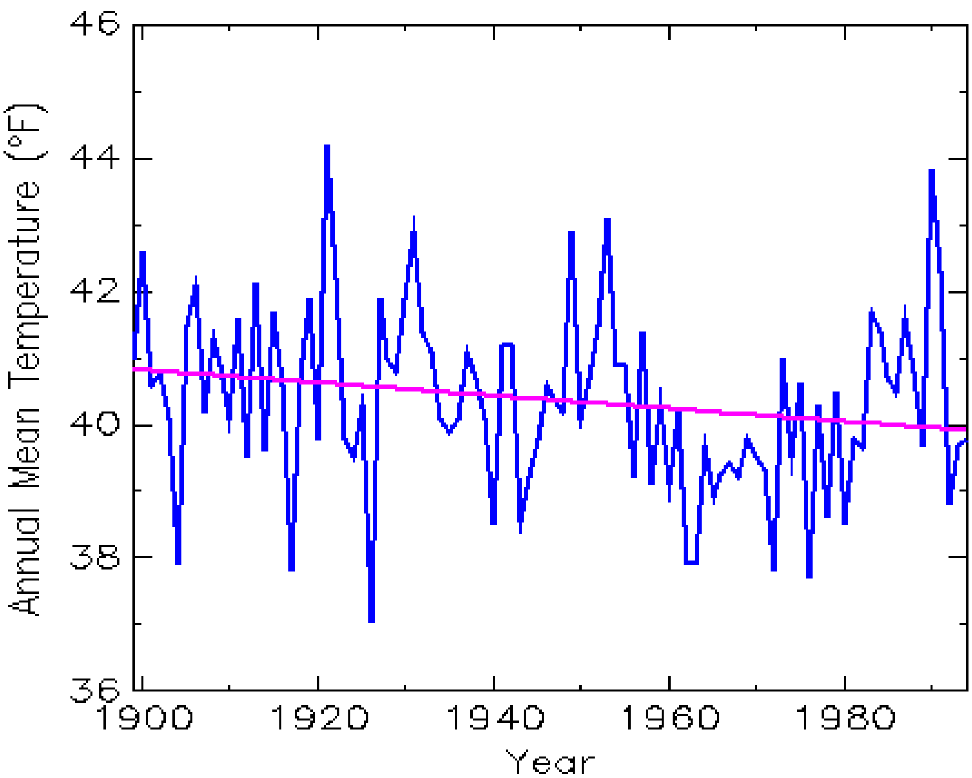
http://www.co2science.org/ushcn/ushcn.htm

I did this to a small extent, and some of my preliminary findings are interesting and surprising. As an example, I compared the existing data for 2 locations in NY - New York City (NYC) and Indian Lake (IL). The latter is a town well embedded in the south central Adirondacks, near Lake Adirondack. Using its coordinates of 43.76 °N, 74.29 °W & 1660 feet elevation, the surrounding terrain can be seen quite well here. I've never been there, so can't provide specifics regarding the type of vegetation, soil, etc. - though I imagine it is in the middle of a largely forested region.

To determine something about a warming climate, the most logical choice is first plotting average temperatures for the entire station histories. Though the plot for NYC shows the expected 4 °F increase since the beginning of industrialization :

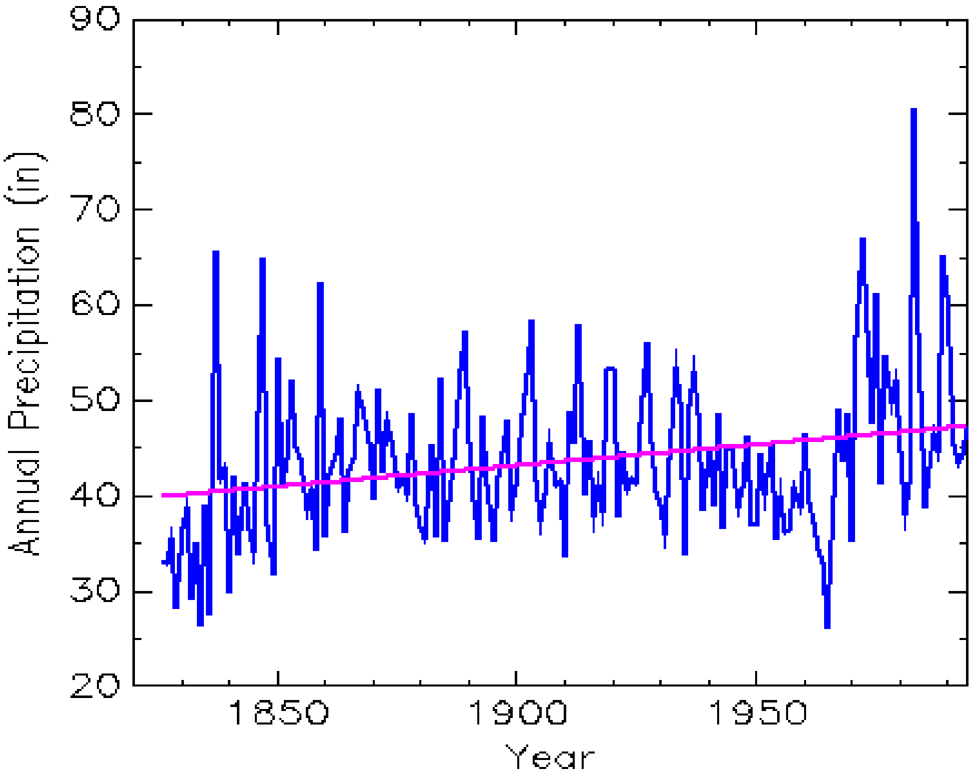


that for IL shows a 1° decrease during the 20th century :

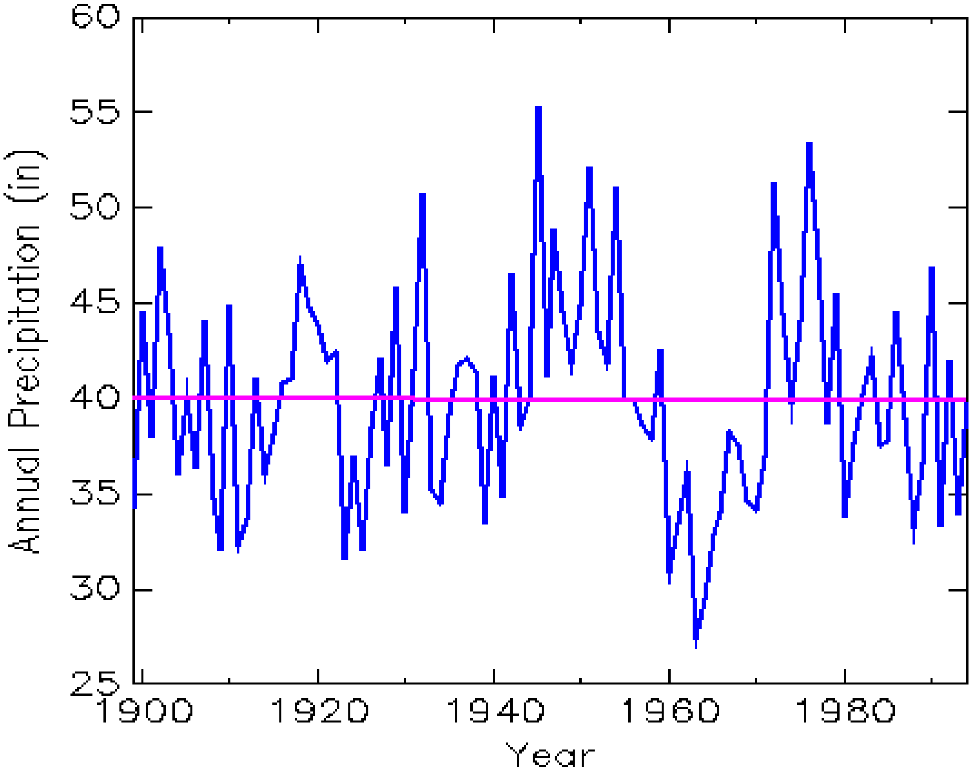


Among the many things which may be responsible for this, those which seem most likely

to
me are effects of urbanization and vegetation. During these same periods, a small increase
of annual average precipitation is noted at NYC :

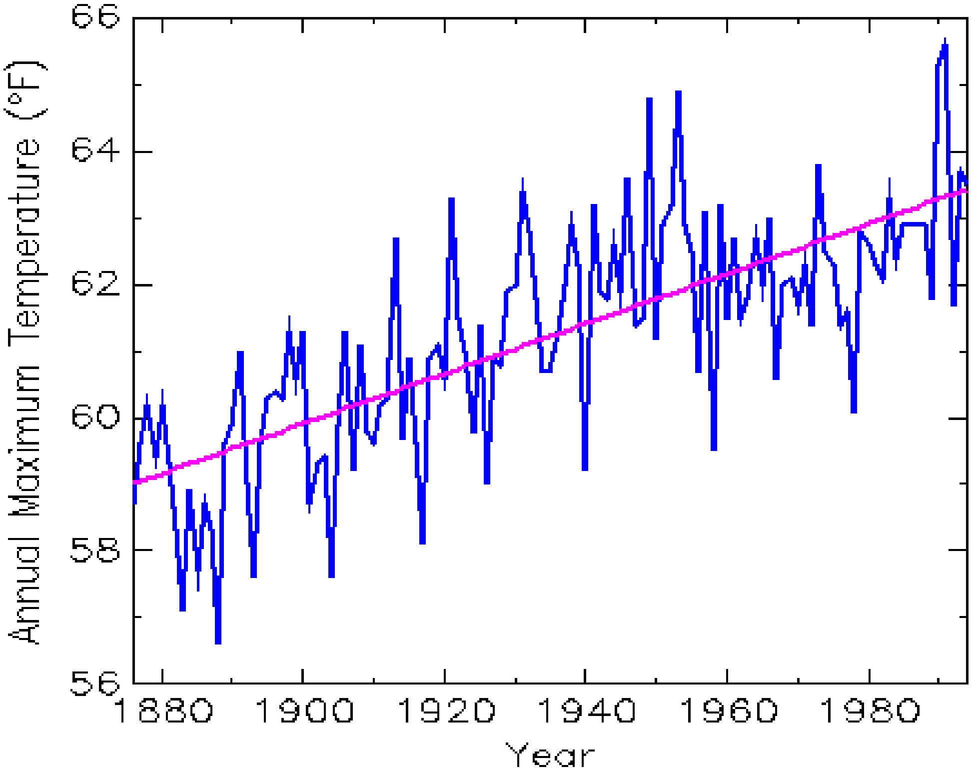


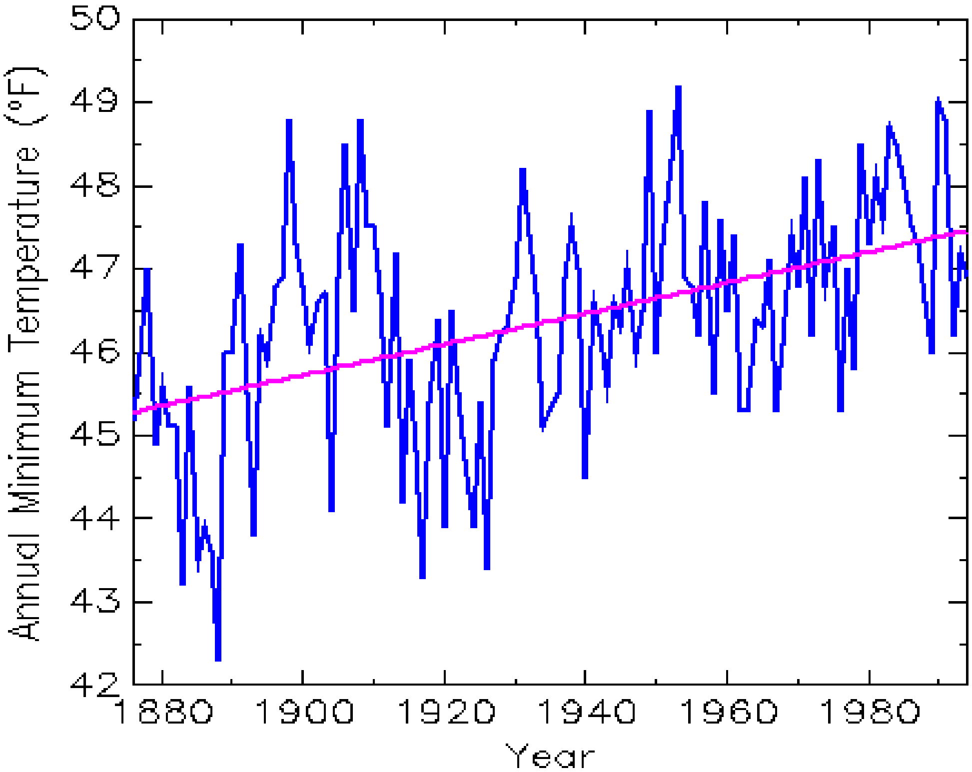
and no significant change at IL :



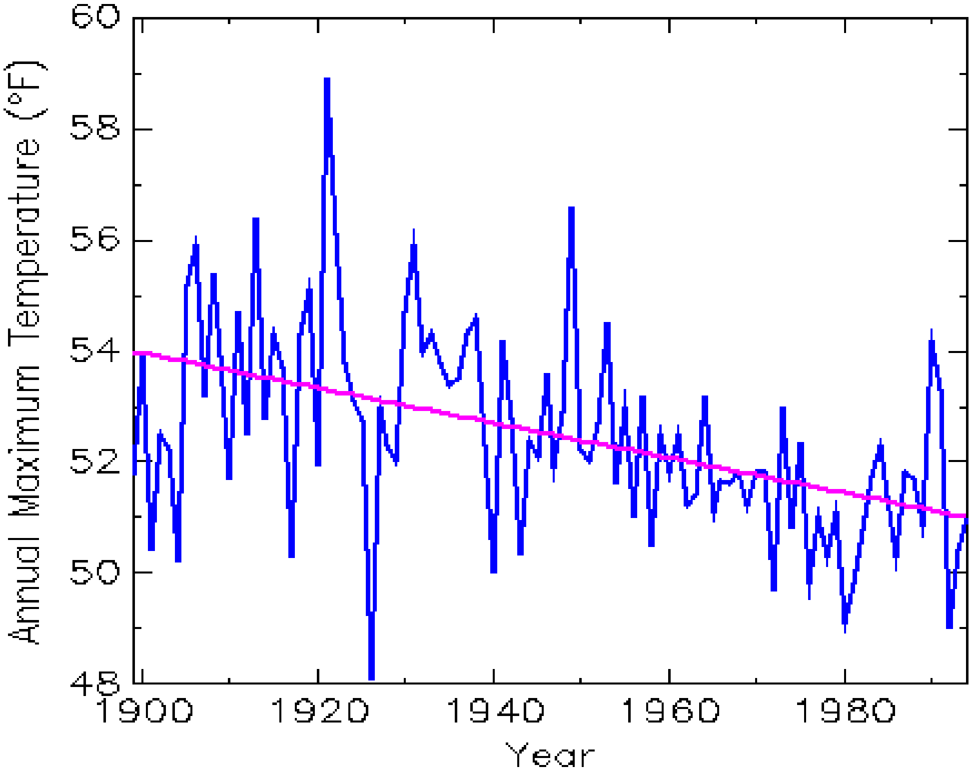
Note that these trends are determined using linear regression, and though the temperature
trends above are quite apparent, those for precipitation (being much more variable) are
less so.

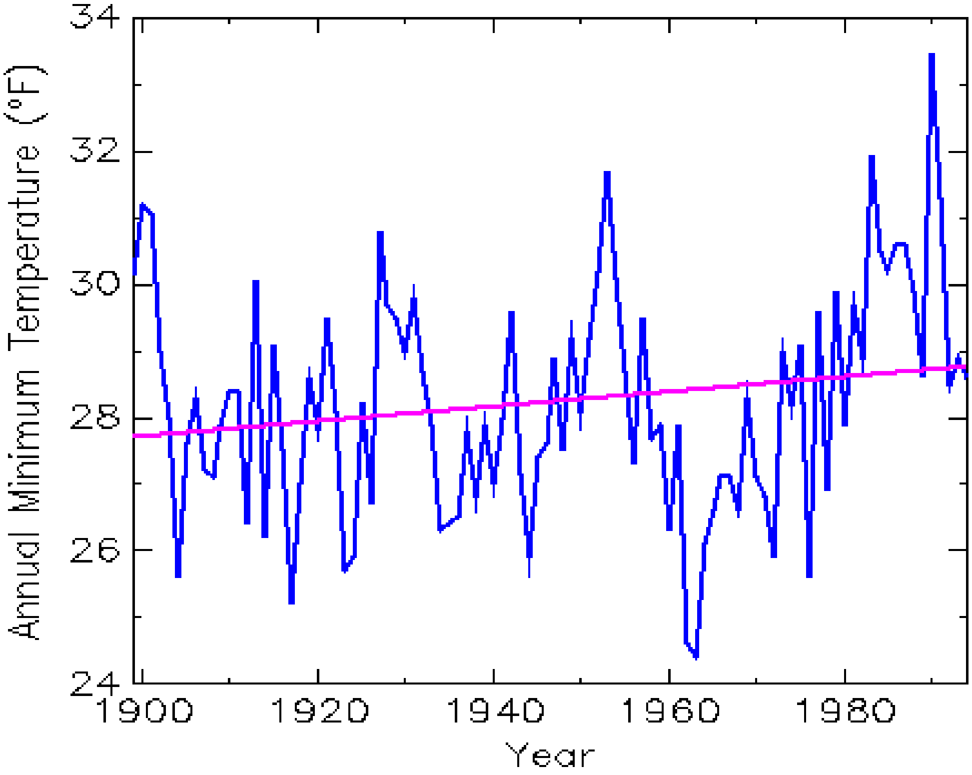
Examining maximum and minimum temperatures, it can be seen that though both increased for
NYC - minimum not quite so much as maximum :





the maximum decreased quite significantly at IL, but the minimum slightly increased :

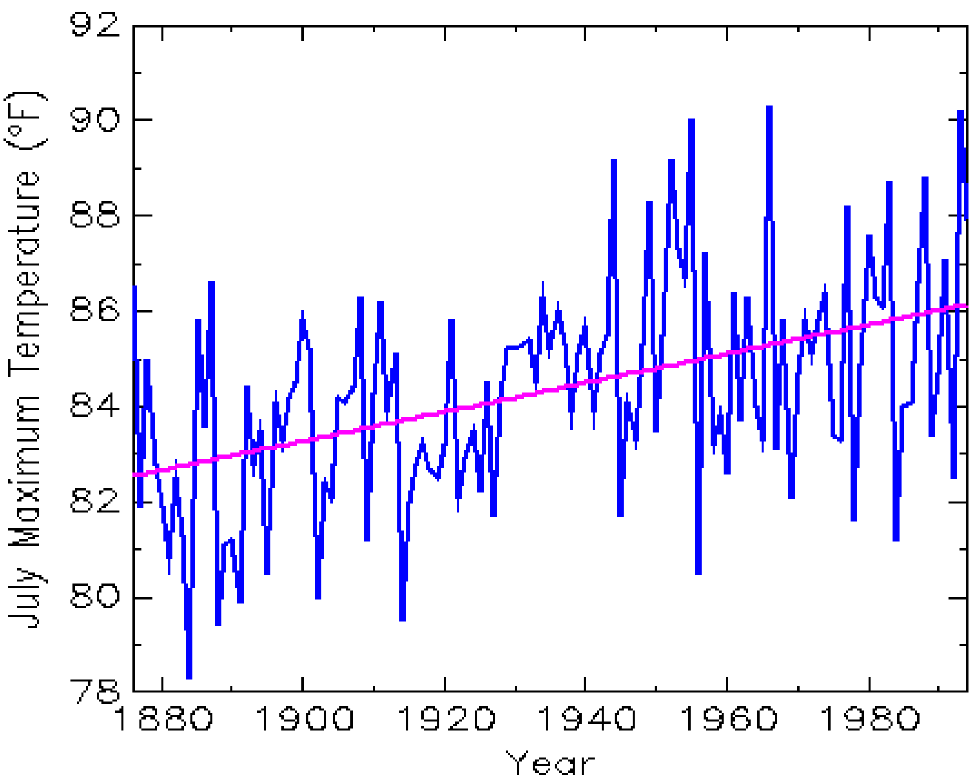




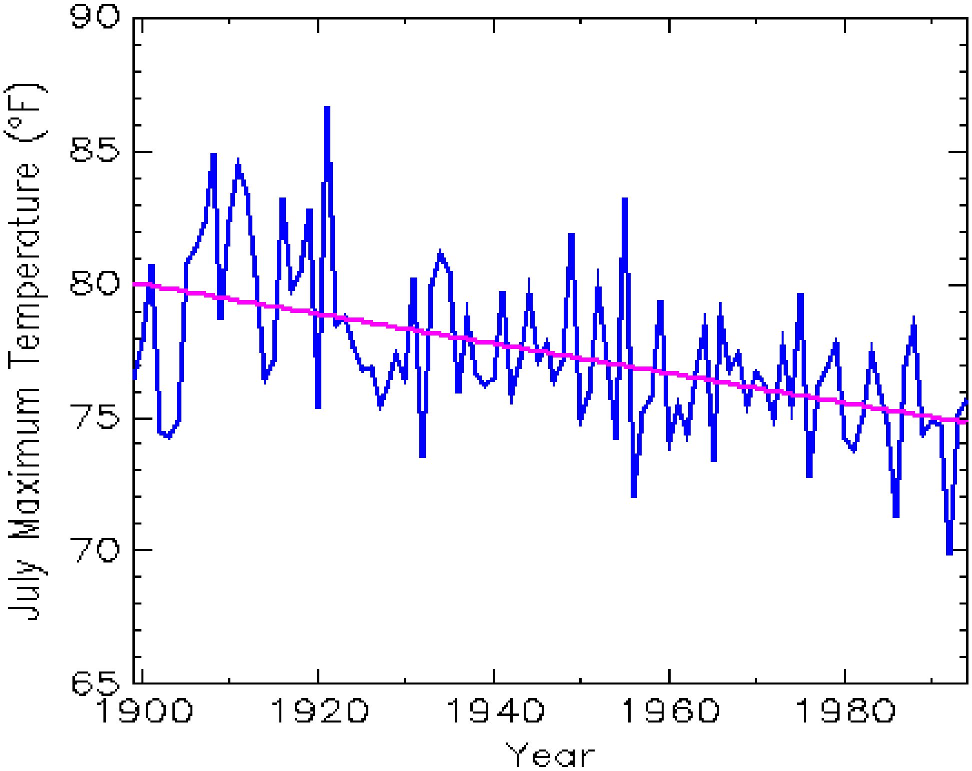
This is characteristic of the urbanization and vegetation effects, though mentioned [here](#) is
that an attempt was made to remove "biases" in the data becuase of the effects of urbanization

(and other sources such as moving the station). Adjustments for IL are probably small, though
those for NYC may be masking a much larger increase. Seeing the actual data would be much
better - maybe I can do this sometime later.

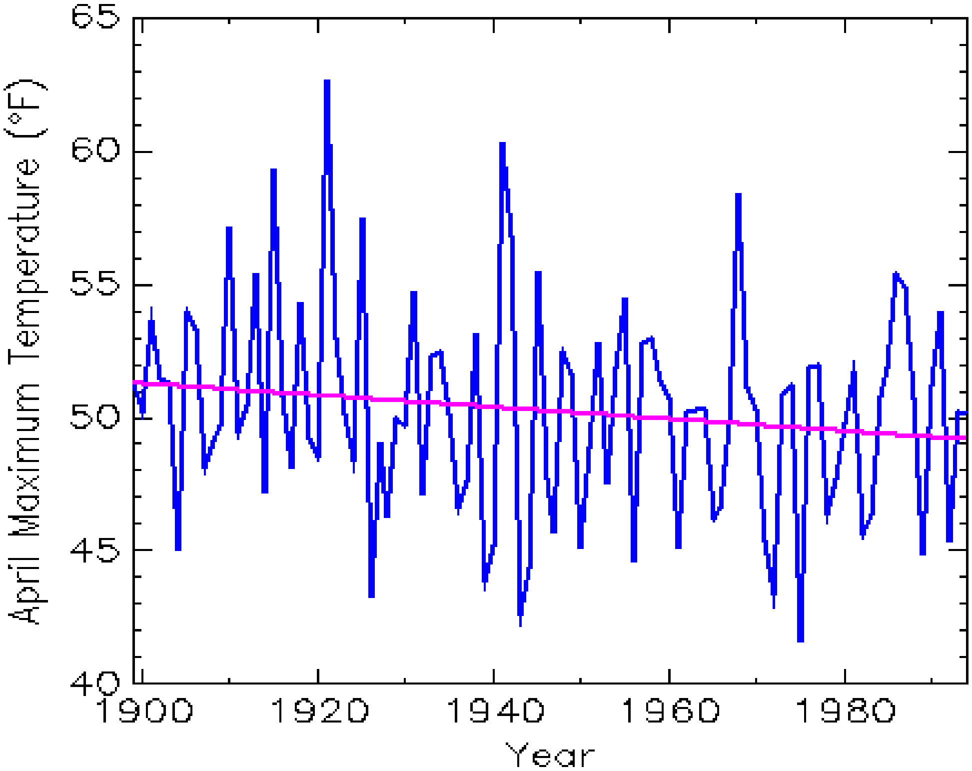
Though the NYC July maximum increased comparably with the annual average :

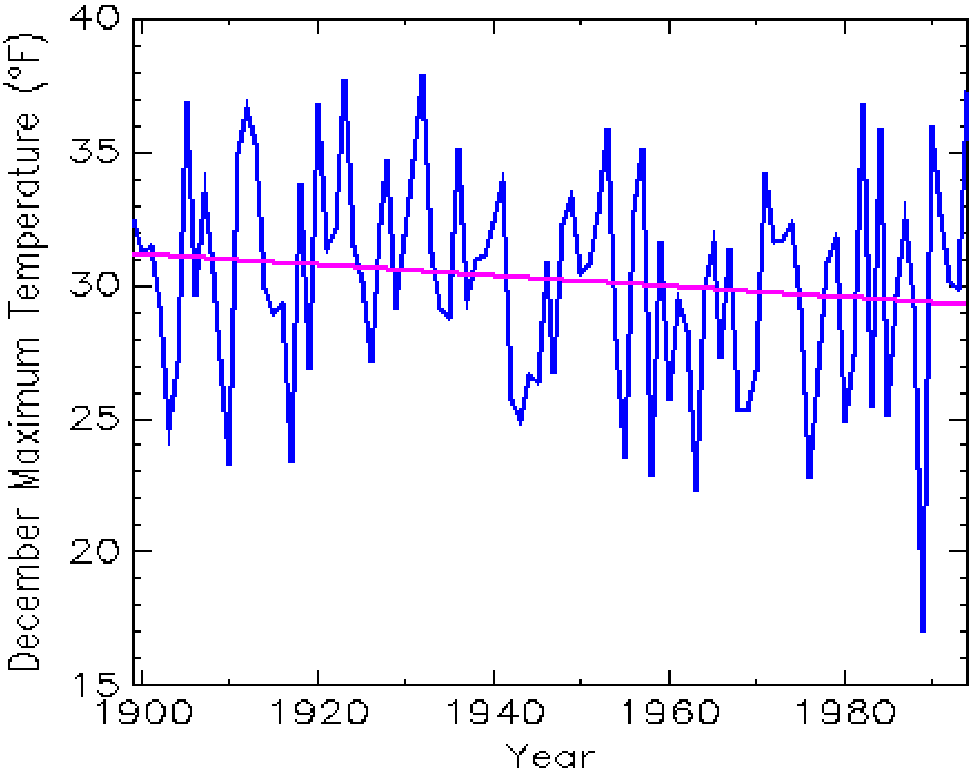


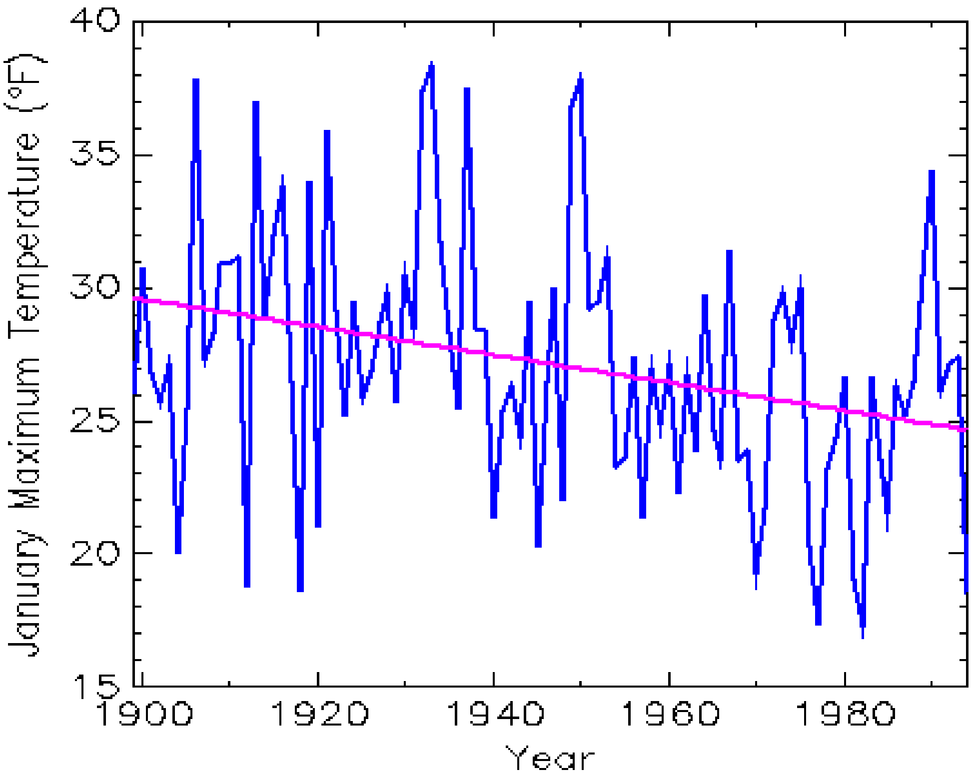
that for IL decreased 5° ! :



An average maximum of 80° seems awfully high for 1660 feet in the Adirondacks - perhaps the
instrment shelter was improved during the years to minimize the effects of solar radiation on
the readings - though the more sensitive modern thermometers should increase maxima slightly.
If the cooling effect of more abundant vegetation in the Adirondacks (which an increase of
CO2 probably would cause) is responsible, it should be apparent in data for other months.
For comparison, I show plots for April, December, and January :


April Maximum Temperature (°F)
65
60
55
50
45
40
1900
1920
1940
1960
1980
Year


December Maximum Temperature (°F)
40
35
30
25
20
15
1900
1920
1940
1960
1980
Year



Though the large change is lacking for April & December as suspected, the decrease for January is as large as July's. I suppose this indicates that too much should not be assumed from the July plot - vegetation effect is insignificant during January. There could be many reasons why that is so much colder - probably because of snowfall trends and/or synoptic climatology. I.e., a slight shift of wintertime flow regimes. This could be responsible for the summertime trend also, though flow regimes tend to be much weaker and less significant then. Thus I think the vegetation effect is the likely cause - something which is clearly apparent to me in the Poconos.

Several particularly noteworthy periods occurred here since I've taken observations. Though maxima were more variable, minimum temperatures were between 61 & 68° each day from July 16 to August 1, 1999 (July 1999 data, August 1999 data). They were also very consistent during July 2001 - most often between 53 & 60°. In this largely forested area, the vegetation seems to act as a temperature control.

During the past 3 years, some of the warmest days of the year were during "spring" (May 2000, May 2001, April 2002). This was with rather dry ground for May 2000 & 2001. Few or

no leaves
were on the trees and vegetation not grown much. The midday sun is high, and days are becoming
long. During July 2000, the average maximum temperature was 71.2°, and the minimum was 57.3°.
It was a wet spring & summer, and more than 6 inches of rain fell during both June & July
(2000 monthly data). I purposely placed my mercury thermometer (which does not record brief
spikes well) in a particularly shady area that summer to see what type of readings I'd get.
It does illustrate the effect of vegetation and wet soil quite well. The 87° maxima May 7, 8,
& 9 of 2000 were the highest of the year and the 90° April 17, 2002 a good possibility also.
That is common in India before the monsoon establishes, but I suppose it is unusual here -
though there is also that tendency preventing a similar type of day to be so warm here during
summer, and the Poconos are not nearly so expansive as the Adirondacks. Central Park in New
York had a maximum of 96° April 17, 2002 - yet the lack of vegetation and warm flow aloft from
the Catskills were probably large factors. They are typically more than 6° warmer than my
location during a similar sunny day at each.

To see if a vegetation or urbanization effect may be prevalent elsewhere, I examined data for
a few other locations around NE PA and did find a small decreasing trend of temperatures for
other rural locations such as Montrose & Towanda, with increases at developed cities such as
Stroudsburg. Some global warming researchers claim that the warming trend remains significant
even after their attempts of removing the urbanization effect, though the data for Indian Lake
suggests that perhaps a location must be well removed from any large urban center to truly
note the effect. I recall that a recent NASA study using satellites showed a very slight
decrease of global temperature. Cities are still relatively small areas globally, so perhaps
it was detecting a more significant influence from the remote areas. This is (of course)
preliminary, and statements with much certainty would require much more research.

Data for embedded images :

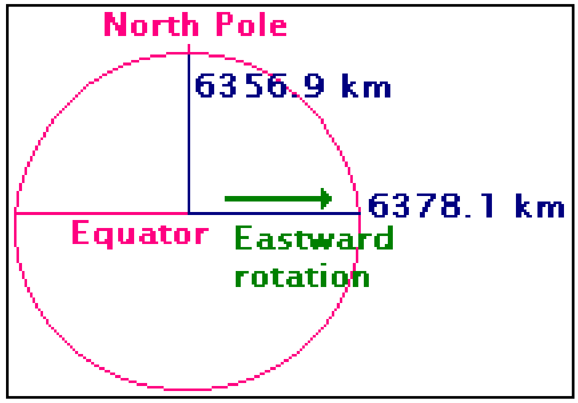
Reference :

Easterling, D.R., Karl, T.R., Mason, E.H., Hughes, P.Y., Bowman, D.P., Daniels, R.C. and
Boden, T.A. (Eds.). 1996. United States Historical Climatology Network (U.S. HCN) Monthly
Temperature and Precipitation Data. ORNL/CDIAC-87, NDP-019/R3. Carbon Dioxide Information
Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Home Page

Coriolis and Centrifugal Forces

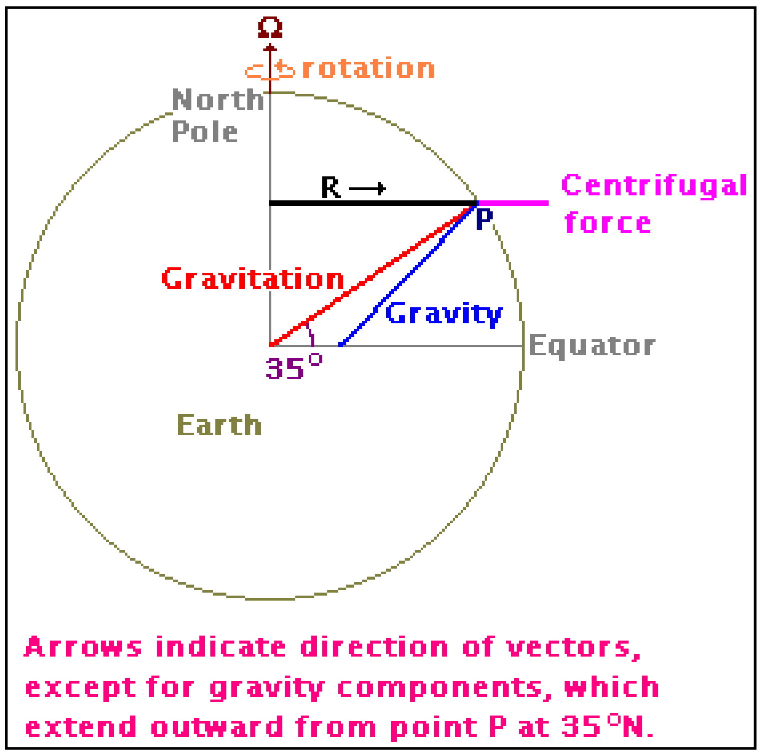
Date : 12 August 1998



This feature I begin discussing dynamics analysis, beginning with apparent forces because we live on a rotating oblate spheroid. Thus, meteorologists speak of differences among **inertial** and **rotating** reference frames. I don't necessarily know why they are called *frames*, but the former is motionless (inert), as if the earth were not rotating, as the latter implies. Though we don't often notice rotational effects in our atmosphere, even considering storm movement and local winds, 2 apparent forces - centrifugal and coriolis - are important on Earth and in our atmosphere. Neither are true forces, but they are called such because they behave as if they were (with this understood).

Centrifugal Force

Centrifugal force is what you experience on a merry-go-round - the tendency for you to continue forward (and off the edge unless you hold on) rather than around. It is a component of Earth's gravity, which is the combined effect of gravitational force and the much smaller centrifugal force. An equation describing gravity is :



$\mathbf{g} = \mathbf{F_g} + \Omega^2 \mathbf{R}$

F_g : Gravitational force
Ω : angular (rotation) speed of Earth = 7.292116×10^{-5} radians/sec

as illustrated. Boldface variables indicate vector quantities. You may notice that the value for Ω means that the Earth rotates once every 23 hr, 56 min, 4.09 sec (86164.09 sec) - orbit around the sun accounting for the additional time of a 24-hour day. 2π radians is once around the globe (circle), so :

2π radians/ 86164.09 sec = 7.292116×10^{-5} radians/sec

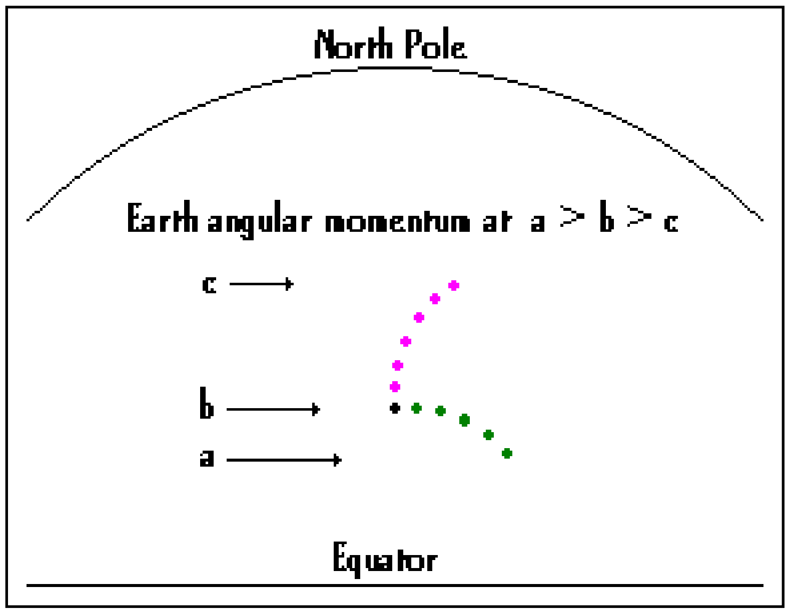
You may recall that F_g at a location is the sum of gravtitations from all objects according to

the Law of Gravitation, close and massive objects influencing this much more than those lighter and further away. Comparing magnitudes of the 2 terms of the above equation for the gravity component perpendicular with Earth's rotation axis (no centripetal acceleration parallel with it) at 35 °N (mks units - please notice that a radian is a (Earth) radius - about 6369900 m) :

g_x = (9.79747) (cos 35°) = $\underline{8.02562}$ m/sec^2
$\Omega^2 R$ = $(7.292116 \times 10^{-5})^2$ (6369900) (cos 35°)
= 2.77462×10^{-4} m/sec^2 = $\underline{.0277462}$ m/sec^2
F_{gx} = $g_x - \Omega^2 R$ = 8.02562 - .02775 = $\underline{7.99787}$ m/sec^2

indicates that the centrifugal term is very small. I.e., spacing of red & blue lines on the diagram above is quite exaggerated.

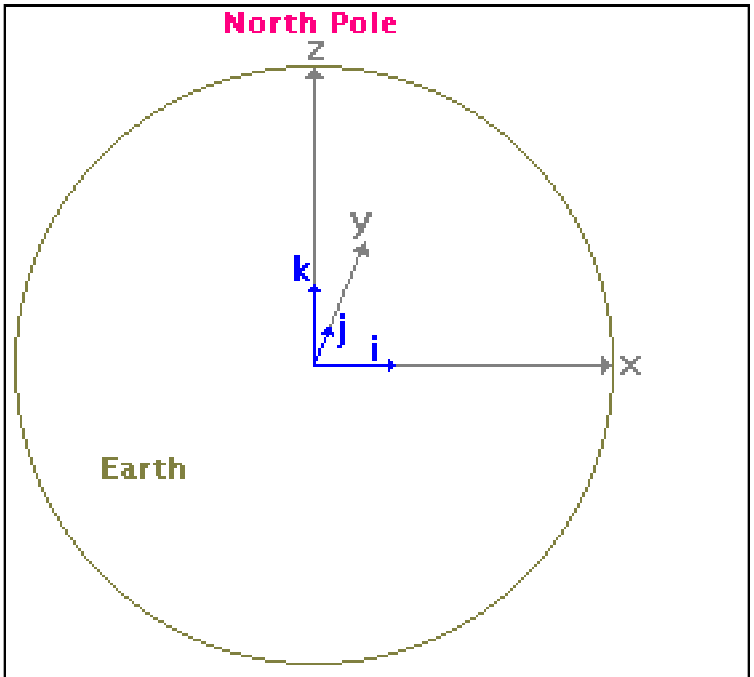
Coriolis Force



As indicated above, Earth's rotation speed varies latitudinally. Because of this and momentum conservation, horizontally-moving objects slightly curve. A simplified way of thinking of this is if an object moves such that its angular momentum is increased from that of Earth's below, it moves to a location of larger Earth angular momentum, and vice-versa. For example, an object moving northeastward in the Northern Hemisphere increases its angular momentum and is moving toward a region with less angular momentum (planet moves slower toward Pole). Thus it turn southeastward (right) and rises (larger angular momentum further from Earth's center).

Mathematical Description

Perhaps the best description of these apparent forces is mathematical. This (present) section paraphrases that in Holton's An Introduction to Dynamic Meteorology. You can read pages of descriptions and illustrations of the Coriolis Effect which can be stated using a few vector equations as he does. The gist of the mathematical argument is that a (simple) cross product of Earth's rotational axis (vector) and an object's velocity (vector) describes Earth's rotational affects.



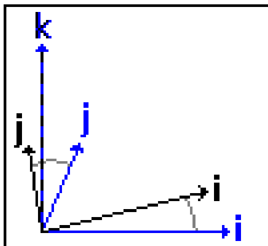
y vector is perpendicular with both x & z vectors, pointing directly way from screen. It is drawn as shown for illustration. Both x & y vectors are in the equatorial plane. z vector is Earth's rotation axis, north as positive chosen.

The total derivative for an arbitrary vector A in an inertial reference frame (subscript a) is :

$$d_a A/dt = i\, dA_x/dt + j\, dA_y/dt + k\, dA_z/dt$$

and in a rotating frame (no subscript, but primed axis unit vectors and components) is :

$$dA/dt = i'\, dA'_x/dt + j'\, dA'_y/dt + k'\, dA'_z/dt$$



Unit vectors along coordinate axes for inertial and rotating reference frames. If intial position is same, rotating ones are as shown some time later.

$$\underset{1}{dA_a/dt} = \underset{2}{dA/dt} + \underset{3}{(di'/dt\, A'_x + dj'/dt\, A'_y + dk'/dt\, A'_z)}$$

relates these equations. Change of A in the inertial frame (1) equals its change in the rotating frame (2) plus rotation's affect (3). If you imagine the i' unit vector rotating (di'/dt) along the equator (unit vector pointing eastward), you may be able to envision that it turns left as Earth rotates, the cross product $\Omega \times i'$ mathematically describing this. Similarly for the j' & k' unit vectors. Thus, the above equation can be written:

$$dA_a/dt = dA/dt + \Omega \times A$$

which is a general expression relating total derivatives of a property in inertial and rotating reference frames.

An expression for how Earth's rotation affects velocity in the inertial frame is desired. Considering a position vector r and the above equation,

$$d_a\mathbf{r}/dt = d\mathbf{r}/dt + \Omega \times \mathbf{r}$$

Because velocity V (Holton used U for this) is time rate of change of position, dr/dt,

$$\mathbf{V}_a = \mathbf{V} + \Omega \times \mathbf{r}$$

This mathematically states that velocity the inertial frame equals that in the rotating frame plus rotation affects. Similarly as for r above,

$$d\mathbf{V}_a/dt = d\mathbf{V}_a/dt + \Omega \times \mathbf{V}_a$$

Substituting for V_a from the equation directly above it,

$$\begin{aligned} d\mathbf{V}_a/dt &= d/dt(\mathbf{V} + \Omega \times \mathbf{r}) + \Omega \times (\mathbf{V} + \Omega \times \mathbf{r}) \\ &= d\mathbf{V}/dt + d/dt(\Omega \times \mathbf{r}) + \Omega \times \mathbf{V} + \Omega \times (\Omega \times \mathbf{r}) \end{aligned}$$

You may notice that $d\Omega/dt = 0$ (Earth rotation is ***very*** nearly constant), so using the calculus' chain rule,

$$d/dt(\Omega \times \mathbf{r}) = d\Omega/dt \times \mathbf{r} + \Omega \times d\mathbf{r}/dt = (0)\,\mathbf{r} + \Omega \times \mathbf{V}$$

You can also calculate (or use the right hand rule) to see that :

$$\Omega \times (\Omega \times \mathbf{r}) = \Omega \times (\Omega \times \mathbf{R}) = -\Omega^2 \mathbf{R}$$

as R is defined further above. Thus,

$$d\mathbf{V}_a/dt = d\mathbf{V}/dt + 2\,\Omega \times \mathbf{V} - \Omega^2 \mathbf{R}$$

1 2 3 4

the sought expression. This mathematically expresses that velocity (e.g., wind direction and speed) change in an inertial reference frame (1) equals velocity change in a rotating reference frame (2) plus the Coriolis Effect (3) plus centripetal acceleration (4) (which is negative because it acts the opposite direction of R). Thus, the difference of velocity ***changes*** (i.e.,

turning of moving objects) in these reference frames is the Coriolis Effect and Centrifugal forces, though the *absolute* velocities greatly differ because our planet rotates @ 1040 mph at the Equator.

Interpretation

Considering the above equation, you should envision that centripetal acceleration always acts directly toward and perpendicular with Earth's rotation axis. Regarding the cross product for Coriolis Effect, because Earth's rotation axis is naturally chosen as the vertical coordinate axis, only the 2 terms involving it are non-zero :

$$2\,\Omega \times V = 2\,\Omega\,(-\,i\,V_y + j\,V_x)$$

This equation is not extremely useful for analysis on Earth's curved surface, but it does clearly illustrate that Coriolis force only turns wind components in or parallel with the Earth's equatorial plane (x-y plane in the inertial frame), none parallel with Earth's rotation axis, as Hess mentions; and that it acts only perpendicular with winds, and does so both horizontally and vertically at a specific location on Earth (where horizontal is tilted with respect to the inertial frame mentioned here). Soon I hope to describe the most typically used meteorological coordinates, which illustrate the idea that the Coriolis force turns winds to the right in the Northern Hemisphere and left in the Southern Hemisphere, as illustrated above - maximum at the Poles, minimum at the Equator, proportional with horizontal wind speed, and much more relevant for large than small-scale wind regimes.

A quite useful mathematical operation for meteorological analysis is the total derivative. My previous discussion describes advection, which is part of this (and cross products). The total derivative is the time rate of change of a property (T) of an air parcel. Using Cartesian coordinates, this is :

$$dT/dt = \partial T/\partial t + \partial T/\partial x\; dx/dt + \partial T/\partial y\; dy/dt + \partial T/\partial z\; dz/dt$$

Thus,

$$\underbrace{dT/dt}_{1} = \underbrace{(\partial T/\partial t)}_{2} + \underbrace{(V_x\,\partial T/\partial x + V_y\,\partial T/\partial y + V_z\,\partial T/\partial z)}_{3}$$

If you read the relevant feature, you may recognize :

$$V_x\,\partial T/\partial x + V_y\,\partial T/\partial y + V_z\,\partial T/\partial z = V \bullet \nabla T$$

as advection of T. So another way of writing this equation is :

$$\underset{1}{dT/dt} = \underset{2}{\partial T/\partial t} + \underset{3}{V \bullet \nabla T}$$

$\partial T/\partial t$ is the local rate of change of T. So if T were temperature, for example, the equation is simply a way of mathematically describing that the total temperature change you experience at a location (1) equals local changes (2), which may be because of solar or infrared energy exchange for example, plus advection (3), which is air transport from another location. If T is a vector quantity, such as wind (V) in this feature's example, total derivative is calculated for each of the vector's scalar components :

$$dV_x/dt = \partial V_x/\partial t + V \bullet \nabla V_x$$
$$dV_y/dt = \partial V_y/\partial t + V \bullet \nabla V_y$$
$$dV_z/dt = \partial V_z/\partial t + V \bullet \nabla V_z$$

because the gradient of a vector is not meaningful.

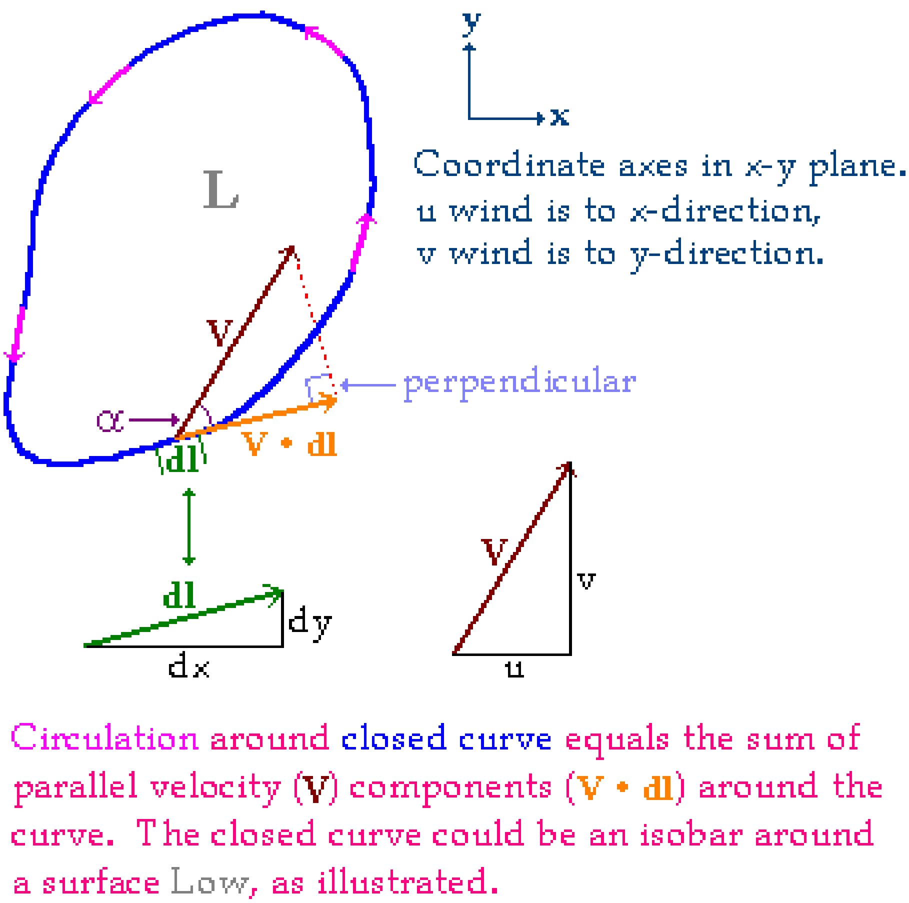
Home Page

Relative Vorticity

Many atmospheric flows are observed as **circulating**. Geostrophic, gradient, cyclostrophic, and inertial flows are idealized examples of such. In this article, I discuss a convenient way of quantifying this property of a flow; called **vorticity**. This article uses some ideas and illustrations from Hess' [Introduction to Theoretical Meteorology]() and Holton's [Introduction to Dynamic Meteorology]().

Mathematical Description

Considering a plane, closed curve in a fluid :



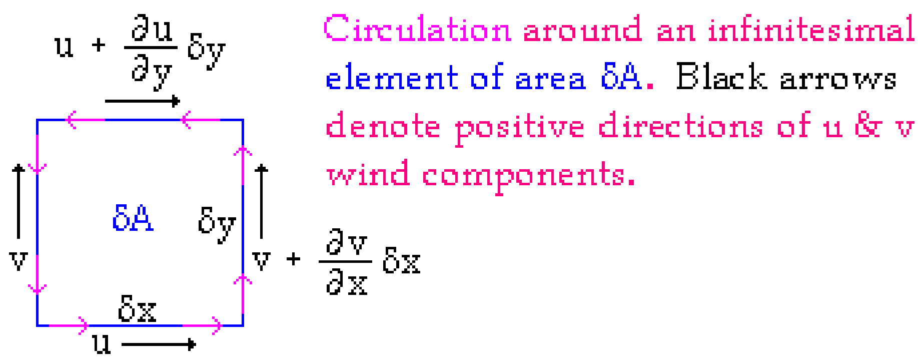
the circulation (C) around this curve is :

$$C = § \mathbf{V} \bullet \mathbf{dl} = § V (\cos \alpha)\, dl = § (u\, dx + v\, dy)$$

as illustrated above. Note that the nonbold V is the magnitude of the bold vector **V** velocity. Note that a dot product simply multiplies the parallel components of 2 vectors, as illustrated (u is parallel with the x-axis, and v parallel with the y-axis). The symbol § denotes a line integral, meaning that integration is performed around the entire closed curve. Recall that an integral is another form of summation. Thus, **the equation above is simply a summation of the components of wind parallel with** (tangent to) **the curve**. Mathematical convention is that **circulation is defined as numerically positive when counterclockwise** (as shown) **and negative when clockwise**. Recalling flows around Highs and Lows, you should see that **circulation around a normal Northern Hemisphere Low is thus positive, and around such a High is negative**.

Relative Vorticity

Solving the equation for circulation is very difficult for such a shape as above, so let's consider a simpler one :



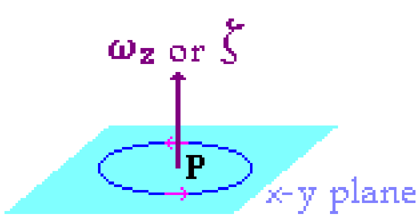
Supposing this as an infinitesimally small plane horizontal area (which δ's denote), the circulation around it is :

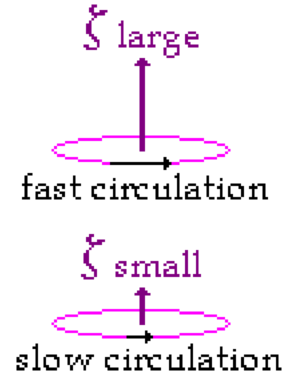
$$\delta C = u\,\delta x + (v + (\partial v/\partial x)\,\delta x) - (u + (\partial u/\partial y)\,\delta y) - v\,\delta y = (\partial v/\partial x - \partial u/\partial y)\,\delta x\,\delta y$$

obtained performing the line integral around the area to direction shown. ∂ denotes a partial derivative. Noting that the differential area $\delta A = \delta x\,\delta y$ and considering the limiting value of δA approaching 0 (infinitesimally small area shown vanishes), the equation can be written :

$$\lim_{\delta A \to 0} \delta C / \delta A = \partial v/\partial x - \partial u/\partial y = \omega_z = \zeta$$

ω_z or ζ : vertical component of relative vorticity





This states that the vertical component of relative vorticity equals circulation ÷ area @ the limit of area approaching 0 (i.e., at a point - **P** in the diagram). Though the point circulation shown occurs in the x-y (horizontal) plane, it is considered a **vertical component** (z-component) because the circulation is positive (using the right hand rule) around the vertical (z) axis.

Doing similar calculations for circulation around the x &; y axes (in the y-z & x-z planes) and recalling that the velocity vector **V** = **i** u + **j** v + **k** w yields the horizontal components of relative vorticity :

x-component : $\lim_{\delta A \to 0} \delta C / \delta A = \partial w / \partial y - \partial v / \partial z = \omega_x$

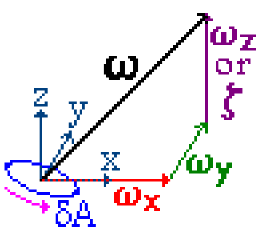
y component : $\lim_{\delta A \to 0} \delta C / \delta A = \partial u / \partial z - \partial w / \partial x = \omega_y$

Combining the components in 3-dimensional space and using the definition of cross-products and the del operator (∇), you may see that :

$$\lim_{\delta A \to 0} \delta C / \delta A = \mathbf{i}\, \omega_x + \mathbf{j}\, \omega_y + \mathbf{k}\, \omega_z = \nabla \times \mathbf{V} = \omega$$

ω : Relative vorticity vector

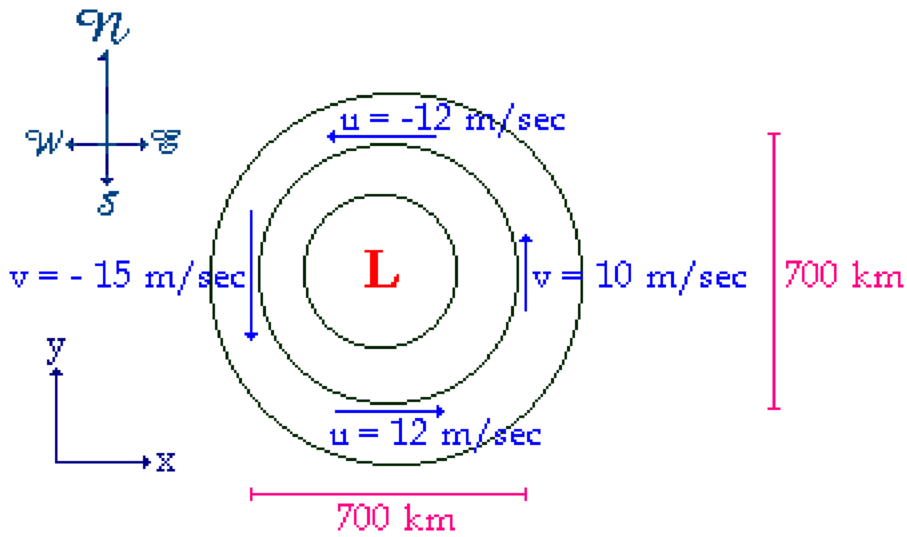
For which δA is the infinitesimal area normal (perpendicular) to ω, around which the total circulation occurs. Thus strictly speaking, **relative vorticity ω is the curl of the velocity vector**.



Note that **the vertical component of relative vorticity ω_z is given the special symbol ζ**. This is done because synoptic scale horizontal winds are typically about 100-1000 times stronger than vertical winds (for example, 20 m / sec compared with 5 cm / sec aloft), so the large scale vertical component is dominant (and thus most often used). This is not always so for mesoscale and microscale phenomena such as supercell thunderstorm circulations. ζ is often simply called "vorticity", with the understanding that its vertical component is meant. I believe ζ was chosen because it is the Greek letter corresponding with the letter z, referring to the vertical axis.

Typical magnitudes

Similar with divergence, synoptic and large mesoscale relative vorticity magnitudes are typically about 10^{-4} sec^{-1}. A rough estimation can be made using typical wind speeds around an idealized synoptic cyclone of typical scale :



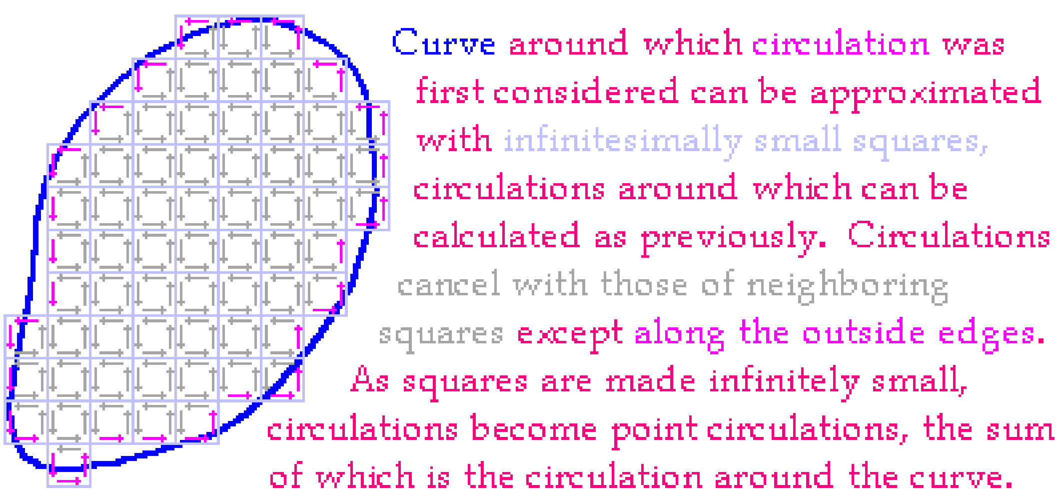
Computing the partial derivatives as finite differences (this is not strictly correct, but does provide an idea of orders of magnitude), mks units used :

$\zeta \cong \Delta v / \Delta x - \Delta u / \Delta y = \{((10) - (-15)) / 700000\} - \{((-12) - (12)) / 700000\} = 49 / 700000 = 7 \times 10^{-5}$ sec^{-1}

Synoptic scale magnitudes tend to be greater aloft, where winds are typically stronger, than near the surface; though localized magnitudes can be much greater in near-surface circulations (do such a calculation for a tornado or hurricane eyewall, for example).

Important ideas

Though relative vorticity is defined for point locations as illustrated, air circulation around a region is the sum of vorticities at all points contained therein :



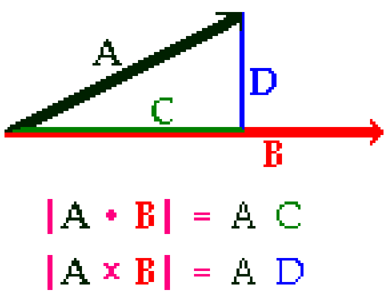
Mathematically,

$$\oint (u\,dx + v\,dy) = \iint (\partial v / \partial x - \partial u / \partial y)\,\delta x\,\delta y$$

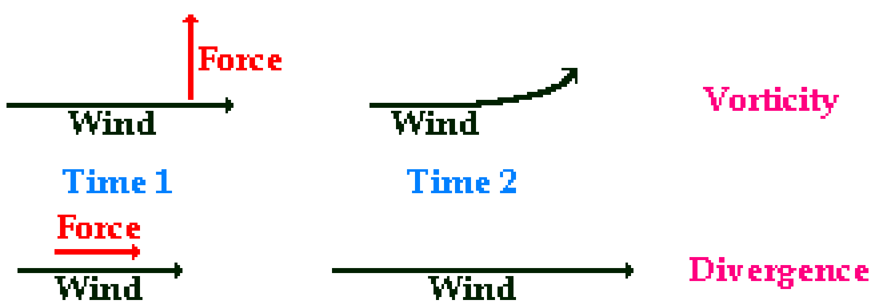
relating circulation and relative vorticity as described above. (This is for the vertical component, but other components can be done similarly.) This is a useful relation for air circulations such as those typically occurring around Lows & Highs, thru trofs and ridges aloft, hurricanes, and tornadoes, among others; and equations above are valid for a defined outer boundary involving these.

Relative vorticity has a perpendicular *characteristic* compared with divergence (they can't truly be perpendicular because one is a scalar and the other a vector). Note that :

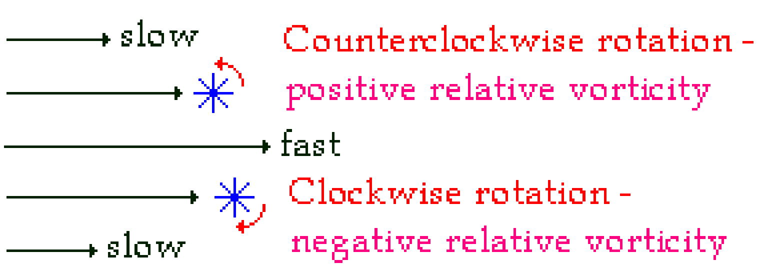
Divergence = D = $\nabla \cdot \mathbf{V}$
Relative vorticity = ω = $\nabla \times \mathbf{V}$



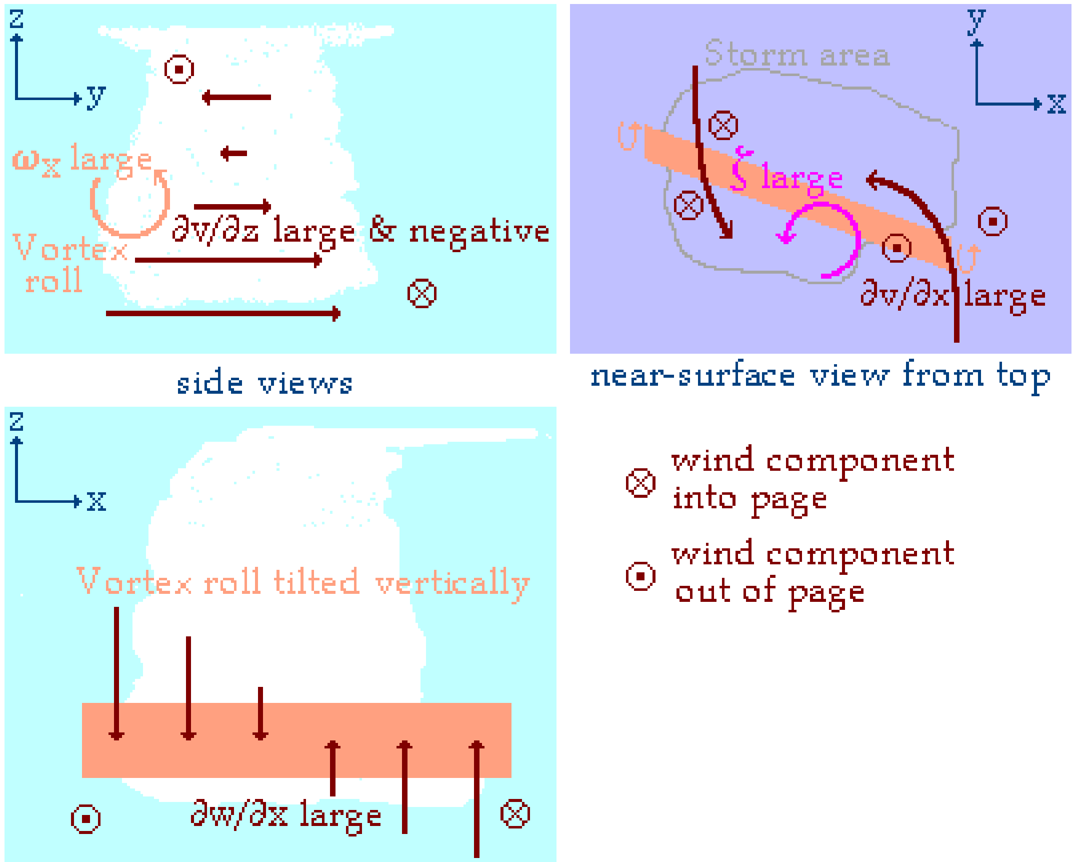
The only mathematical difference being that one is a dot product of the del operator with wind velocity, the other a cross product. Magnitudes of dot products and cross products do indeed result from multiplication with perpendicular vectors. Thus, a purely divergent flow does not circulate, and a purely circulative flow is nondivergent * (because they contain no common component). Thus, a force parallel with the wind is associated divergence, and a force or stress perpendicular with the wind is associated with relative vorticity :



I mention "or stress" because relative vorticity is nonzero in a straight but sheared flow :

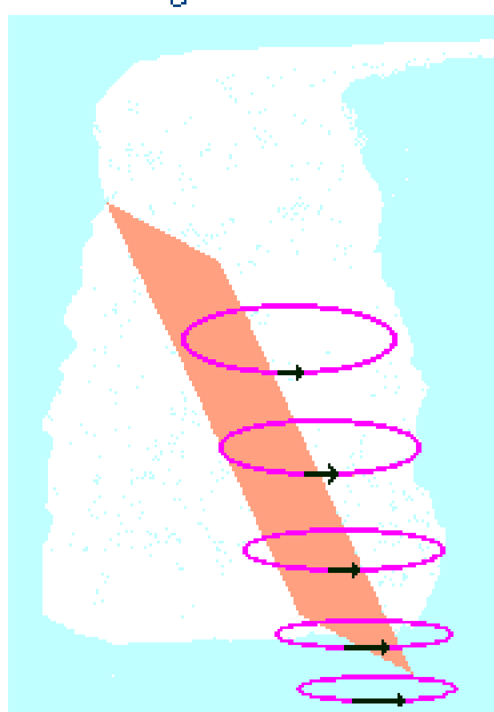


Though no force would be necessary for sustaining this flow, a shear stress exists. An object embedded in the flow such as the pinwheel shown would experience this stress and its rotation would be the response. Many people consider such a rotation in an environment with great vertical wind shear a very important contributor to development of tornado circulations :



Top 3 figures illustrate wind flows in a strong developing storm - perhaps a supercell. A cyclonic near-surface flow devlops in the horizontal (x-y) plane. Strong vertical wind shear in the y-z plane can cause a horizontal vortex roll generally along the x-axis. Differential vertical motions in the x-z plane can tilt this flow, causing it to quasi-align with the cyclonic near-surface flow. The final consqeuence may be a very strong, rather vertically aligned horizontal circulation as shown to the right.

a later general side wiew



Differential vertical velocities in a storm's vicinity can tilt an initially strong horizontal relative vorticity component, contributing to development of a strong vertical vorticity component (strong circulation in the horizontal plane), which then can be augmented via vertical stretching (the mechanism for which I hope I can discuss later).

*** A misconception ?**

Some people explain that a purely vortical flow is nondivergent and a purely divergent flow nonvortical showing that $\nabla \cdot (\nabla \times \mathbf{V}) = 0$, and that $\nabla \times (\nabla \cdot \mathbf{V})$ is non-existent; thus stating that the divergence of the vorticity is 0 and the vorticity of the divergence is non-existent. I do not think this is true because $\nabla \cdot (\nabla \times \mathbf{V})$ is not vorticity divergence, just as $\nabla \cdot \mathbf{V}$ is not "velocity divergence", as is sometimes called. It is **air divergence -** the air diverges, not the velocities - velocities simply illustrate how the air moves. I can indeed show vorticity vectors which diverge; but **air** in a purely vortical flow does not diverge (thus $\nabla \cdot (\nabla \times \mathbf{V}) = 0$).

Home Page

19-20 December 2000 Snow Event

Below are some charts depicting the thermal gradient moving across our region which evidently
was the main contributor to the band of precipitation 19-20 December 2000. A brief discussion
is included, though to a large extent, they are presented for those interested to peruse.
They are named as such :

9251200t.gif

The first 3 letters refer to the level : sfc - surface, 925 - 925 mb, etc.; the next 4, date
& UTC time; and the next 1 or 2, the feature being shown : t - temperature, ta - temperature
advection, p - sea level pressure, c - divergence (convergence), v - absolute vorticity, and
va - absolute vorticity advection. For 2 maps "-lg" refers to larger scale surface plots (other
being smaller scale). E.g., the chart above illustrates temperature contours at 925 mb at 19
December 1200 UTC.

All of the charts are (approximately 1.6 MB) :

Upper air

925 mb temperature, 12 UTC
925 mb temperature avdection, 12 UTC
925 mb divergence, 12 UTC
850 mb temperature, 12 UTC
700 mb temperature, 12 UTC
500 mb temperature, 12 UTC
500 mb absolute vorticity, 12 UTC
500 mb absolute vorticity advection, 12 UTC
300 mb, 12 UTC
300 mb divergence, 12 UTC
925 mb temperature, 00 UTC
925 mb temperature avdection, 00 UTC
925 mb divergence, 00 UTC
850 mb temperature, 00 UTC
700 mb temperature, 00 UTC
500 mb temperature, 00 UTC
500 mb absolute vorticity, 00 UTC
500 mb absolute vorticity advection, 00 UTC
300 mb, 00 UTC
300 mb divergence, 00 UTC

Surface

Surface temperature, 12 UTC
Surface divergence, 12 UTC

Surface temperature, 15 UTC
Surface divergence, 15 UTC
Surface temperature, 18 UTC
Surface divergence, 18 UTC
Surface temperature, 21 UTC
Surface divergence, 21 UTC
Surface temperature - large scale, 21 UTC
Surface divergence - large scale, 21 UTC
Surface temperature, 00 UTC
Surface divergence, 00 UTC
Sea level pressure, 12 UTC
Sea level pressure, 18 UTC
Sea level pressure, 00 UTC
Sea level pressure, 06 UTC

They all open to one window, and may be downloaded & used as desired - perhaps organized in a directory. Units should be obvious except for convergence. I actually have no idea what they are in Digital Atmosphere - they are not adjustable nor specified. Because of the light winds in the region, I don't think they can be greater than x 10^-6 /sec. Absolute vorticity is x 10^-5 /sec. Advections are probably mks units using the base values shown. Note that contours on surface convergence for 21 UTC are inconsistent with others - nothing I can do about this.

Note that the links below open in groups of the same 2 or 3 windows for each topic discussed.

Charts are primarily for the time period of 12-00 UTC, or 7 AM EST - 7 PM EST 19 December 2000. This is the time the precipitation band (see surface charts for band oriented SSE to NNW) - wish I could find radar charts that aren't copyrighted) primarily moved over central to eastern PA. Near the end of this period, the band began circulating around the developing cyclone to our ESE over the Atlantic.

The strengthening temperature gradient during the period from the surface to 700 mb can be noted comparing the 12 & 00 UTC temperature charts for each level. Note that the gradient increased about 10-12 deg C quite consistently in the lower troposphere (e.g., 8501912t.gif & 8502000t.gif). At 500 mb in the mid troposphere, it increased slightly less than half that much. Note that much of the increase was simply advection - both cold air advection from the

W (e.g., 9251912ta.gif) and advection of the stronger gradient to our SSW (e.g., 9251912t.gif & 8501912t.gif). The surface temperature gradient similarly strengthened.

The difference among the 12 & 00 UTC charts seem to imply that convergence of warm, southerly flow with an easterly component at many locations near the Atlantic coast and colder westerly flow from our W was a great contributor. If so, the large amounts of convergence expected are not seen in the charts though. Convergence occurred at 925 mb at 12 UTC (e.g., 9251912c.gif), though definitely not strong; and it was noticeably absent at the surface (e.g., sfc1921c.gif) and at 925 mb at 00 UTC (9252000c.gif) - the band of convergence being to our S & E then. Divergence was actually present quite often at the surface. I include the larger scale charts to show that this was not only true here (perhaps surface heating under clearer skies S & E of the cloud band was quite significant for increasing the temperature gradient). Although surface convergence was large during the morning, the heavier precipitation generally did not occur until much later during the day and early-mid night. I had less than an inch of snow at 5 PM EST (22 UTC). Until then, many radar echoes which appeared very strong went overhead and only caused light snow - sometimes very light. Is that much time really required for the heavier precipitation to develop ? My snow total was about 2.3 inches at 7 PM EST (00 UTC), and the final total about 5.8 inches (the last half inch worth or so of light snow did not add to the accumulation because of compaction & blowing). The heaviest periods were around 7:20-8:10 PM EST (about an inch) and 12:15-1:10 AM EST the 20th (about an inch & a half). The point I am making is that the heaviest snow over the Poconos occurred while the band was wrapping around the coastal Low (sfc2000p.gif, sfc2006p.gif). Note that the Low is certainly W of the southerly winds with 70 deg F temperatures at 00 UTC - the analysis program does not consider wind direction for surface isobars - but the 06 UTC position is good.

I included the 300 mb charts to illustrate that although strong winds aloft were present, it doesn't appear that a jet streak was. The 500 mb charts also indicate vorticity maxima & even in a banded type of pattern (5002000v.gif); yet because winds were rather parallel with the

band, its advection was not large (5002000va.gif). It corresponded with the area of activity
though, and is associated with some divergence near the top of the troposphere at 300 mb
(3002000c.gif); so I suspect mid-upper toposphere dynamics also contributed - even if for
no other reason than creating a favorable environment for sustaining the lower level activity.
Yet too much should not be assumed with such sparse observations 12 hours apart.

Below are seasonal snow stats for Central Park (main site), ordered from low to high amounts
(inches). Ties were ordered randomly (note 3 values of 50.7). They are in 12 groups of 10
and 1 group of 11 in the center. The central value of the central group is the median, 25.6
inches - more snow reported during half the seasons & less during half. The mean (average)
is 28.04 inches. Left of each group, the average ending year of that group is noted. Left
of the middle group (above & below the median value), the average ending year of all seasons
less & more than the median are noted. This grouping shows that largest snow seasons tend
to be earlier during the period of record - particularly note the 2nd-6th largest groups are
between 1906.6 & 1921.7. The average ending year of all data is 1935. The very snowy winter
of 1995-96 broke the previous record by 12.4 inches.

	SEASON	J	A	S	O	N	D	J	F	M	A	M	J	TOT
	1972-73	0	0	0	T	T	T	1.8	0.8	0.2	T	0	0	2.8
	1918-19	0	0	0	0	0	0.3	0.3	0.5	2.7	T	0	0	3.8
	1931-32	0	0	0	0	2.0	0.1	0.8	1.8	0.6	T	0	0	5.3
	1997-98	0	0	0	0	T	T	0.5	0.0	5.0	0	0	0	5.5
	1877-78	0	0	0	0	T	0	6.1	2.0	0	0	0	0	8.1
	1988-89	0	0	0	0	0	0.3	5.0	0.3	2.5	0	0	0	8.1
	1900-01	0	0	0	0	0	0.1	2.0	7.0	T	0	0	0	9.1
	1996-97	0	0	0	0	0.1	T	4.4	3.8	1.7	T	0	0	10.0
	1941-42	0	0	0	0	0	0.3	6.4	1.9	0.5	2.2	0	0	11.3
	1954-55	0	0	0	0	T	0.1	2.6	5.2	3.6	0	0	0	11.5
1948.4														
	1950-51	0	0	0	0	T	3.8	3.2	1.9	2.7	0	0	0	11.6
	1930-31	0	0	0	0	T	5.7	0.5	3.6	1.8	T	0	0	11.6
	1994-95	0	0	0	0	T	T	0.2	11.6	T	T	0	0	11.8
	1991-92	0	0	0	0	T	0.7	1.5	1.0	9.4	T	0	0	12.6
	1998-99	0	0	0	0	0	2.0	4.5	1.7	4.5	0	0	0	12.7
	1979-80	0	0	0	T	0	3.5	2.0	2.7	4.6	T	0	0	12.8
	1958-59	0	0	0	0	T	3.8	1.5	0.4	6.7	0.6	0	0	13.0
	1985-86	0	0	0	0	T	0.9	2.2	9.9	T	T	0	0	13.0
	1974-75	0	0	0	0	0.1	0.1	2.0	10.6	0.3	T	0	0	13.1
	1989-90	0	0	0	0	4.7	1.4	1.8	1.8	3.1	0.6	0	0	13.4
1975.8														
	1899-00	0	0	0	0	T	0.1	1.0	6.5	5.8	0	0	0	13.4
	1929-30	0	0	0	T	T	6.3	3.5	3.8	T	T	0	0	13.6
	1928-29	0	0	0	T	T	2.0	2.3	9.3	0.2	T	0	0	13.8
	1949-50	0	0	0	0	0.5	1.1	0.4	8.5	1.4	1.9	0	0	13.8
	1871-72	0	0	0	0	0.3	3.9	1.8	3.0	5.1	T	0	0	14.1
	1927-28	0	0	0	0	T	2.1	2.7	4.0	5.7	T	0	0	14.5

1952-53	0	0	0	0.5	1.7	7.5	4.1	0.4	0.9	T	0	0	15.1
1937-38	0	0	0	T	0.8	0.7	6.5	T	0.7	6.4	0	0	15.1
1912-13	0	0	0	0	0.8	11.4	0.3	2.6	0.2	T	0	0	15.3
1970-71	0	0	0	0	0	2.4	11.4	T	1.3	0.4	0	0	15.5
1928.4													
1936-37	0	0	0	T	3.2	T	6.5	3.4	2.5	T	0	0	15.6
1953-54	0	0	0	0	2.2	T	12.7	0.5	0.1	0.3	0	0	15.8
1962-63	0	0	0	T	T	4.5	5.3	3.7	2.8	T	0	0	16.3
1999-00	0	0	0	0	0	T	9.5	5.2	0.4	1.2	0	0	16.3
1888-89	0	0	0	0	1.5	0	4.0	7.0	4.0	0	0	0	16.5
1975-76	0	0	0	0	T	2.3	5.6	5.0	4.4	T	0	0	17.3
1961-62	0	0	0	0	T	7.7	0.6	9.6	0.2	T	0	0	18.1
1875-76	0	0	0	0	0	0.5	1.5	12.5	3.8	0	0	0	18.3
1920-21	0	0	0	0	T	1.7	3.5	13.3	T	0.1	0	0	18.6
1987-88	0	0	0	0	1.1	2.6	13.9	1.5	T	0	0	0	19.1
1946.6													
1980-81	0	0	0	0	T	2.8	8.0	T	8.6	0	0	0	19.4
1967-68	0	0	0	0	3.2	5.5	3.6	1.1	6.1	0	0	0	19.5
1951-52	0	0	0	0	T	3.3	6.2	2.8	7.4	0	0	0	19.7
1905-06	0	0	0	0	0	1.0	1.5	6.0	11.5	0	0	0	20.0
1908-09	0	0	0	0	1.0	2.9	11.3	0.8	4.3	T	0	0	20.3
1885-86	0	0	0	0	0	T	13.5	5.3	1.0	1.0	0	0	20.8
1897-98	0	0	0	0	2.3	4.0	9.0	1.3	2.0	2.5	0	0	21.1
1965-66	0	0	0	T	0	T	11.6	9.8	T	0	0	0	21.4
1956-57	0	0	0	0	T	0.9	8.9	7.0	2.6	2.5	0	0	21.9
1926-27	0	0	0	T	T	11.7	5.7	4.6	0.2	0.1	0	0	22.3
1935.0													
1879-80	0	0	0	0	2.5	5.4	2.5	4.0	8.3	0	0	0	22.7
1971-72	0	0	0	0	T	T	2.8	17.8	2.3	T	0	0	22.9
1986-87	0	0	0	0	T	0.6	13.6	7.0	1.9	0	0	0	23.1
1973-74	0	0	0	0	0	2.8	7.8	9.4	3.2	0.3	0	0	23.5
1943-44	0	0	0	0	T	T	4.8	7.7	4.8	6.5	0	0	23.8
1984-85	0	0	0	0	T	5.5	8.4	10.0	0.2	T	0	0	24.1
1889-90	0	0	0	0	0	6.0	0	1.0	17.0	0.3	0	0	24.3
1964-65	0	0	0	0	0	3.1	14.8	2.5	2.8	1.2	0	0	24.4
1992-93	0	0	0	0	0	0.4	1.5	10.7	11.9	0	0	0	24.5
1976-77	0	0	0	0	T	5.1	13.0	5.8	0.6	T	T	0	24.5
1956.7													
1981-82	0	0	0	0	0	2.1	11.8	0.4	0.7	9.6	0	0	24.6
1990-91	0	0	0	0	0	7.2	8.4	9.1	0.2	0	0	0	24.9
1910-11	0	0	0	0	T	6.6	1.3	13.3	3.5	0.5	0	0	25.2
1983-84	0	0	0	0	T	1.6	11.7	0.2	11.9	0	0	0	25.4
1891-92	0	0	0	0	0	0	12.3	0.1	12.0	1.0	0	0	25.4
1948.75													
1969-70	0	0	0	0	T	6.8	8.4	6.4	4.0	T	0	0	25.6
Median													
1939-40	0	0	0	0	T	3.1	3.5	12.0	5.3	1.8	0	0	25.7
1920.71													
1894-95	0	0	0	0	0.5	4.0	9.5	9.0	4.0	T	0	0	27.0

1932-33	0	0	0	0	0	9.4	T	12.8	4.8	T	0	0	27.0
1944-45	0	0	0	T	T	6.7	12.3	8.1	T	0	0	0	27.1
1982-83	0	0	0	0	0	3.0	1.9	21.5	T	0.8	0	0	27.2
1947.8													
1909-10	0	0	0	0	0.8	9.0	11.1	5.0	1.3	0	0	0	27.2
1923-24	0	0	0	0	0	1.5	2.5	11.9	3.1	8.5	0	0	27.5
1869-70	0	0	0	0	0	5.3	1.1	9.3	9.6	2.5	0	0	27.8
1921-22	0	0	0	0	T	7.3	9.4	7.2	3.9	0	0	0	27.8
1902-03	0	0	0	0	0	14.4	4.5	9.8	0	0	0	0	28.7
1914-15	0	0	0	0	0	2.6	3.8	4.5	7.7	10.2	0	0	28.8
1890-91	0	0	0	0	0	11.4	10.0	5.3	2.1	T	0	0	28.8
1978-79	0	0	0	0	2.2	0.5	6.6	20.1	T	T	0	0	29.4
1911-12	0	0	0	0	1.0	8.5	13.0	2.5	4.5	T	0	0	29.5
1942-43	0	0	0	0	T	8.5	9.5	4.4	7.1	T	0	0	29.5
1916.9													
1924-25	0	0	0	0	T	0.9	27.4	1.3	T	T	0	0	29.6
1901-02	0	0	0	0	0.1	1.5	6.1	15.8	6.5	0	0	0	30.0
1968-69	0	0	0	0	T	7.0	1.0	16.6	5.6	0	0	0	30.2
1946-47	0	0	0	0	0	1.3	5.5	17.7	6.1	T	0	0	30.6
1945-46	0	0	0	0	3.7	15.6	4.2	7.9	T	T	T	0	31.4
1881-82	0	0	0	0	T	1.3	17.5	9.3	2.8	0.5	0	0	31.4
1903-04	0	0	0	0	0	6.3	15.5	5.0	5.4	T	0	0	32.2
1925-26	0	0	0	0.8	0.1	0.9	3.1	26.3	1.2	T	0	0	32.4
1886-87	0	0	0	0	T	10.3	6.6	9.0	2.0	5.0	0	0	32.9
1870-71	0	0	0	0	0	3.0	15.9	12.1	0.1	2.0	0	0	33.1
1915.9													
1935-36	0	0	0	0	2.7	6.6	12.1	10.3	1.5	T	0	0	33.2
1907-08	0	0	0	0	T	5.3	10.0	14.6	3.5	0	0	0	33.4
1955-56	0	0	0	0	1.0	3.3	1.2	2.7	21.1	4.2	0	0	33.5
1934-35	0	0	0	T	T	1.0	23.6	7.2	2.0	T	0	0	33.8
1884-85	0	0	0	0	0.4	10.6	4.6	14.5	4.1	T	0	0	34.2
1917-18	0	0	0	0	0.3	14.1	13.2	3.7	0.6	2.6	0	0	34.5
1880-81	0	0	0	0	1.4	11.5	11.5	8.8	2.3	0	0	0	35.5
1878-79	0	0	0	0	0.1	5.5	17.3	11.3	1.5	0	0	0	35.7
1893-94	0	0	0	0	0	5.3	9.3	20.5	0	1.0	0	0	36.1
1873-74	0	0	0	0	2.0	9.3	6.6	19.0	T	0	0	0	36.9
1906.6													
1938-39	0	0	0	0	12.8	1.7	10.3	5.5	7.0	T	0	0	37.3
1940-41	0	0	0	T	2.2	3.0	9.2	5.4	19.2	0	0	0	39.0
1959-60	0	0	0	0	0.5	15.8	2.5	1.9	18.5	0	0	0	39.2
1876-77	0	0	0	0.5	0.1	12.4	20.5	0.4	6.5	0	0	0	40.4
1913-14	0	0	0	0	T	0.3	1.3	17.4	21.5	T	0	0	40.5
1883-84	0	0	0	0	0	22.5	10.3	8.0	2.3	0	0	0	43.1
1896-97	0	0	0	0	5.0	13.0	11.3	11.0	3.3	0	0	0	43.6
1882-83	0	0	0	0	14.0	0	9.4	10.1	10.0	0.5	0	0	44.0
1957-58	0	0	0	0	T	8.7	9.2	10.7	15.9	0.2	0	0	44.7
1963-64	0	0	0	0	T	11.3	13.3	14.1	6.0	T	0	0	44.7
1921.7													

1887-88	0	0	0	0	0.3	9.0	11.0	3.0	22.3	0	0	0	45.6
1895-96	0	0	0	0	0	0.3	3.0	9.5	30.5	3.0	0	0	46.3
1948-49	0	0	0	0	T	25.3	6.4	10.7	4.2	0	0	0	46.6
1919-20	0	0	0	0	T	8.8	8.2	25.3	5.3	T	0	0	47.6
1874-75	0	0	0	0	0	0.1	14.5	4.5	15.3	13.5	0	0	47.9
1904-05	0	0	0	0	0.5	21.6	18.4	5.8	1.8	0	0	0	48.1
1892-93	0	0	0	0	6.3	3.0	16.0	17.8	6.1	0.5	0	0	49.7
1916-17	0	0	0	0	T	14.5	5.8	12.2	11.7	6.5	0	0	50.7
1915-16	0	0	0	0	T	8.1	0.7	13.1	25.5	3.3	0	0	50.7
1977-78	0	0	0	0	0.2	0.4	20.3	23.0	6.8	T	0	0	50.7

1913.7

1966-67	0	0	0	0	0	9.1	1.4	23.6	17.4	T	0	0	51.5
1933-34	0	0	0	0	0.5	14.9	0.1	27.9	8.6	0	0	0	52.0
1906-07	0	0	0	0	1.0	0.3	11.0	21.8	13.3	5.8	0	0	53.2
1993-94	0	0	0	0	T	6.9	12.0	26.4	8.1	0	0	0	53.4
1960-61	0	0	0	T	0	18.6	16.7	18.2	1.2	T	0	0	54.7
1898-99	0	0	0	0	19.0	1.5	5.3	25.3	4.8	0	0	0	55.9
1872-73	0	0	0	0	3.5	27.0	10.6	18.8	0.4	0	0	0	60.3
1922-23	0	0	0	0	1.0	8.0	24.5	18.8	8.1	T	0	0	60.4
1947-48	0	0	0	0	T	29.6	15.3	13.6	4.7	0	0	0	63.2
1995-96	0	0	0	0	2.9	11.5	26.1	21.2	13.2	0.7	0	0	75.6

1940.2

Mean : 28.04   Standard deviation : 14.275 (n) 14.329 (n-1)

Below are some notable streaks - years (seasons) : average snowfall , additional comments.

1927-1932 (5) : 11.8
1996-1999 (3) :   9.4
1996-2000 (4) : 11.1

1872-1888 (16) : 34.9
1872-1875 (3) : 48.4
1872-1877 (5) : 40.7
1993-1996 (3) : 46.9
1915-1918 (3) : 45.3
1913-1918 (5) : 41.0

1949-1955 (6) : 14.6 , all 11.6-19.7
1981-1985 (4) : 25.3 , all 24.1-27.2

Though streaks of both types occur, I think that if either are more significant, it is probably those for small amounts. The 1927-32 streak with an average of only 11.8 inches would certainly get the talk of global warming going these days 😉 That of 1996-99 is less than 10 inches, and extending that to 2000 makes it 11.1. I think a safe bet would be that they get more than 14.3 inches this season, such that the 5-year record

won't be
broken.

Considering large amounts, the 1872-88 streak is most notable to me - 16 years of almost 7 inches above average. I don't think anything like this would happen these days, and I think it is good evidence that the climate of those times was significantly colder - for whatever reason - especially considering that the same amount would probably be reported as a greater one now than then. Even so, much of this warmer climate may be because of the urban heat island. Regarding the others, even with the 1st & 7th largest seasonal amounts, the 1993-96 period could not break the 3-year record of 1872-75. Note that the 5-year record of 1913-18 does not differ from the mean as much as the 5-year low record. A person might expect it would, because the former is unlimited and the latter has a lower limit of 0. Thus the short-term streaks of large amounts seem rather absent.

2 streaks I find interesting are those listed at the bottom - 6 & 4 season periods with very consistent snow amounts. Note that the one near the median occurred during the early 1980's & the one of much less during the warm early 1950's.

Stratospheric Ozone Depletion & the Antarctic Ozone Hole

Date : 16 February 1997

Many people are aware that ozone protects us from **harmful ultraviolet (UV) solar radiation**, and that **ozone amounts are decreasing**. Perhaps not so many are aware of its **great variability in our atmosphere** during the seasons and even during days. Episodes of low stratospheric ozone have been at observed at many locations, transported by upper air winds. Among most notable have been Australian episodes, close to the earth's South Pole where ozone amounts have recently been very low during the Antarctic Spring. This feature provides a brief examination of stratospheric ozone and its depletion, emphasizing the seasonal 'ozone hole' over Antarctica.

If not for ozone, the stratosphere would not exist. Ozone's great absorption of harmful near UV radiation at approximately 12 - 40 km altitudes causes heating, which defines the stratosphere as a region at which temperature increases with increasing altitude. Stratospheric ozone measurements are obtained many ways. Ground observations have been taken since the 1920's, later **balloon** and **aircraft** observations, and then **satellite** observations. A Total Ozone Mapping Spectrometer obtained measurements on the Nimbus 7 satellite from 1978-1991 and Russia's Meteor 3 satellite during 1991-1994, and presently operates on NASA's Earth Probe satellite and Japan's Advanced Earth Observing satellite. Many ground-based observations are taken, which is how the 'ozone hole' was **first discovered** at the British Antarctic Survey's Halley station during 1985. (Nimbus 7 measurements indicated such activity prior to that, but not so convincingly.)

Recent atmospheric ozone time-series profiles from **Alfred Wegener Institute's Neumayer arctic research station** also clearly indicate **remarkable Antarctic ozone decreases** between late August to early December of each year. The plots indicate ozone Dobson Unit amounts. You may notice some **maximum amounts** during Antarctic Spring (e.g., day 275) of about **65** DU ! For reference, 400 Dobson Units refer to a column of ozone which would be 4 millimeters thick at standard pressure and temperature at earth's surface (.4 atm-cm). Not a large amount to protect us, but sunlight contributes to ozone formation (and its dissociation), a sort of natural protection. Thus, a person *might assume that the long Antarctic night is responsible for the 'ozone hole'*. It contributes, but stratospheric chlorine chemistry and the circumpolar vortex (flow around the cold South Pole during winter) are more responsible. Perhaps most responsible is **sulfates from volcanic eruptions**, such as Mount Pinnatubo during June 1991. Nearly all of the **seasonal ozone reduction** is observed in the **lower stratosphere**, where such volcanic aerosols tend to reside. Such a decrease is **much** less during the Arctic Spring; and in fact, ozone amounts at most northern hemisphere locations are maximum during Spring.

Why is this relevant ? **Stratospheric chlorine** (catalyst mainly responsible for ozone depletion reactions) , particularly from chloroflourocarbons is estimated to have **quadrupled since 1950**, which is causing ozone depletions of as much as 20% per decade at the South Pole to amounts typically about 2-9% at mid-latitudes, with very little change at the equator, where most ozone forms and is transported elsewhere by stratospheric air flow. Only relatively recently have significant actions such as the Montreal Protocol been taken to decrease use of chloroflourocarbons, which is estimated by some researchers to allow ozone to develop to normal amounts during the next century.

Next week, I plan to include a brief discussion of UV radiation forecasts and their use for daily activities.

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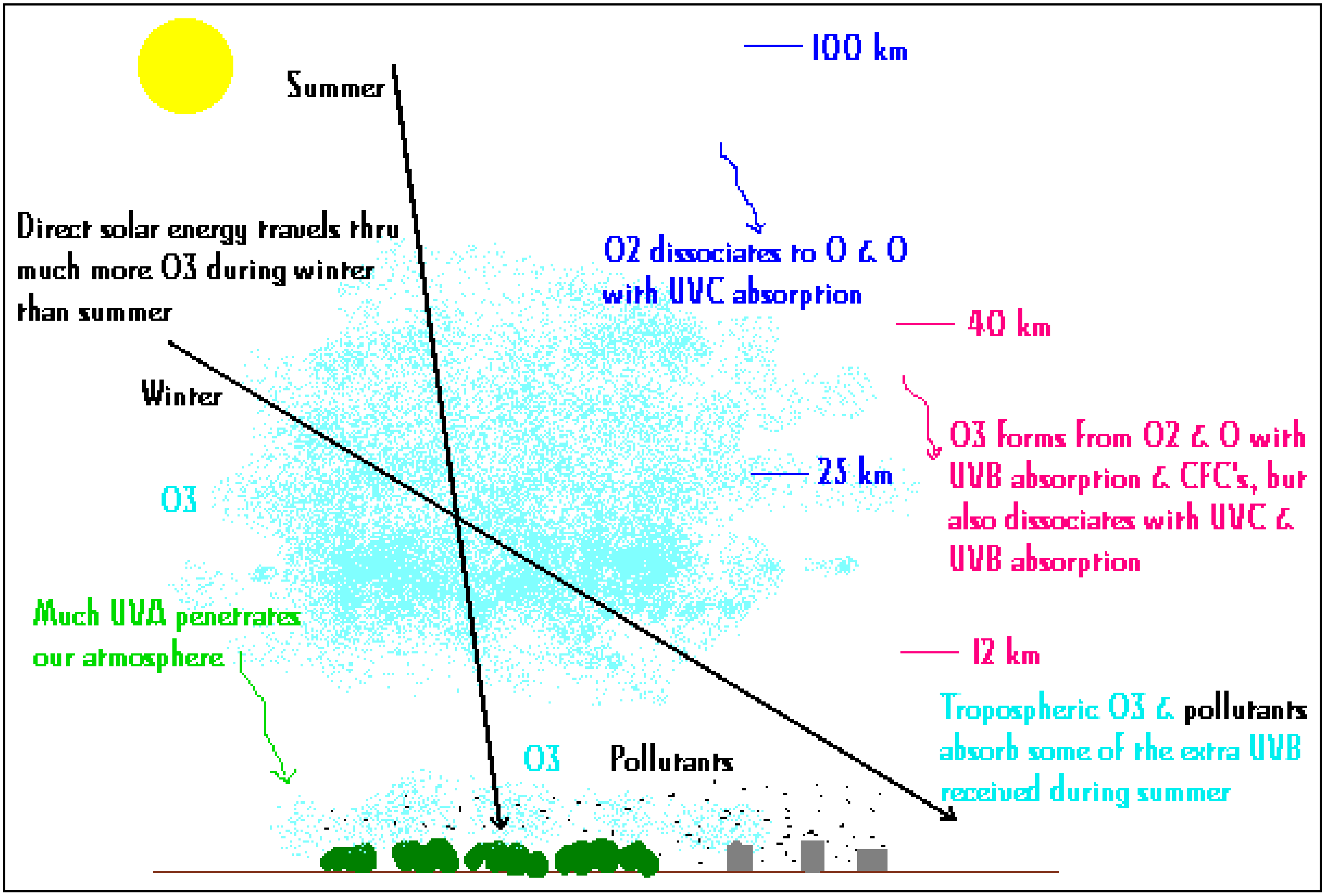
Ultraviolet Solar Radiation : Effects and UV Index

Date : 23 February 1997

Ozone depletion is important to us for mainly one reason - effects of solar ultraviolet (UV) radiation to life on earth. This includes land vegetation, animals, sea creatures and vegetation, and of course humans. Among the most noticeable effects of UV radiation is **skin erythema**, more commonly known as sunburn. Such is typically harmless - research indicates that our sun is a significant source of vitamin D. An old saying is applicable - anything with moderation is fine - but overdoses of UV radiation can cause skin diseases (1), (2), such as **(squamous) cell carcinomas**, and much worse, **melanomas**. The former is often well-treatable, especially if detected early. The latter is very dangerous, and can often be fatal. Both are caused by sustained overexposure to UV radiation, though the milder forms from brief intense exposure. Some researchers estimate that 12-30 % of our population may sometime be affected by such skin diseases.

A very small portion of all solar radiation is UV, and even less reaches ground. As mentioned last week, our atmosphere contains a sort of natural protection from UV radiation. Sunlight is a contributor to both formation and destruction of ozone, as an idealized diagram indicates :



Even vegetation is a natural protection, abundantly emitting (tropospheric) ozone near ground during very warm and hot days, which effectively absorbs much of the UV radiation which penetrates stratospheric ozone. UV radiation is commonly classified according to 3 types, depending on wavelength :

- **UVA** - wavelength approximately 330-400 nm (nanometers = 10^{-9} meters)
- **UVB** - wavelength approximately 290-330 nm
- **UVC** - wavelength approximately 200-290 nm

Shortest wavelengths are most harmful to us (higher frequency, thus greater energy). UVC is most (very) harmful, UVB harmful, and UVA not so harmful. As indicated above, UVC is essentially all absorbed in our upper atmosphere. Stratospheric ozone absorbs most of UVB, but that which penetrates to ground is of concern. Most UVA penetrates to ground, but is healthy for us. Thus, discussion of tropospheric UV radiation effects and actions to protect from it mainly involves UVB.

UVB is measured many ways - from ground, balloons, and space. Ground-based measurements are most relevant, being where the problem is. The Yankee Broadband UVB-1 Pyranometer and the Scanning UV Spectroradiometer are examples of instruments which measure UVB. The former measures total energy amount in the UVB portion of the solar spectrum, the latter measures amount at specific regions of the UV spectrum, among other spectral regions. Such measurements can be used to monitor UVB amounts, as demonstrated with current amounts in Philadelphia, PA measured by Solar Light Co. You may notice from the graph that measurements are often expressed as **Minimum Erythema Dosage** (**MED**). 1 MED (1 J/cm^2) is thought to be the amount necessary to cause a fair-skinned person to begin to become sunburned. For reference, it is about 1/350 the equivalent energy of an hour of strong summer noontime sunshine at midlatitudes. Not much, but enough to cause lots of trouble. As hinted at, this depends greatly on who is exposed to UVB. Negroid people tend to be very resilient, one skin disease case occurring for approximately every 60 fair-skinned people. Hispanics tend to be about 10 times more resilient than fair-skinned people. More cases are observed for men than women, but that may be mainly because they are outdoors more.

To quantify effects mentioned regarding public awareness, the National Weather Service uses a UV Index, routinely included with other official current weather forecast products (image) (text). UV Index is also forecast by the Australian Bureau of Meteorology, among others. It indicates *expected danger* of UVB rays. Rays are **most dangerous near solar noon**, as indicated in the idealized diagram and tabulated, so near-noontime conditions are a main consideration for calculating the UV Index.

Daily ozone measurements (N Hem) (S Hem), combined with stratospheric wind forecasts aid forecasting of the UV index. Fortunately, UV solar radiation is *less difficult to forecast* than total solar radiation because **clouds** attenuate UVB significantly less than other solar energy wavelengths (much of which is near infrared). Thus, a good cloud forecast is required, but not so much as it might otherwise be - which leads to next week's topic.

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Clouds

Date : 2 March 1997

> Rows and flows of angels' hair
> And ice cream castles in the air
> And feathered canyons everywhere
> I've looked at clouds that way
>
> But now they only block the sun
> They rain and snow on everyone
> So many things I would have done
> But clouds got in my way
>
> I've looked at clouds from both sides now
> From up and down, and still somehow
> It's cloud illusions I recall
> I really don't know clouds...at all
>
> From *Both Sides Now*, by **Joni Mitchell**

Or so a popular song states. Clouds are an excellent first topic for a person to study to learn about and forecast weather. They bring rain and snow, they shadow our sun to keep weather cool, etc. It is the weather topic which first interested me a **long time ago** (but several years after that song was written !). Last week I mentioned usefulness of cloud forecasts for the solar UV Index. Before we get ahead of ourselves...this week clouds are discussed, next week forecasting them.

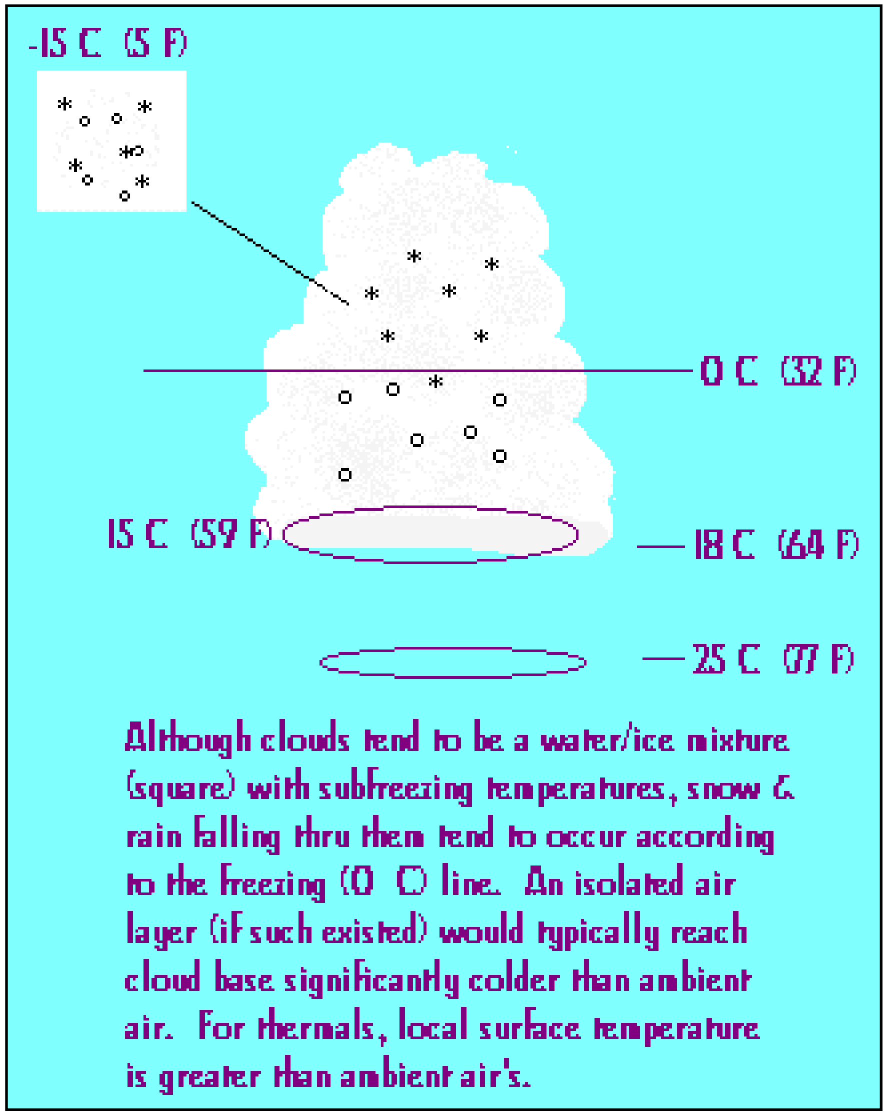
Clouds are organized masses of tiny water droplets and / or ice crystals. Many clouds exist in our atmosphere no more than a few minutes, while other persist for many hours or days (fog). The 2 very basic types of clouds are **cumuliform** (heaps) and **stratiform** (layers). 3 altitude categories are typically defined, from observation that typical cloud types tend to form in one of them. High clouds contain the prefix **cirro**, which derives from the Latin word cirrus - a curl of hair. Middle clouds contain the prefix **alto**, from the Latin word altus, meaning high (but evidently, not as high as cirriform clouds). Other clouds are considered as low clouds. Combining the 2 basic types with the 3 altitude categories, cloud types are :

Altitude Category	Type	Typical Altitude (1000 ft)
High	Cirrus	16-32
	Cirrocumulus	18-31

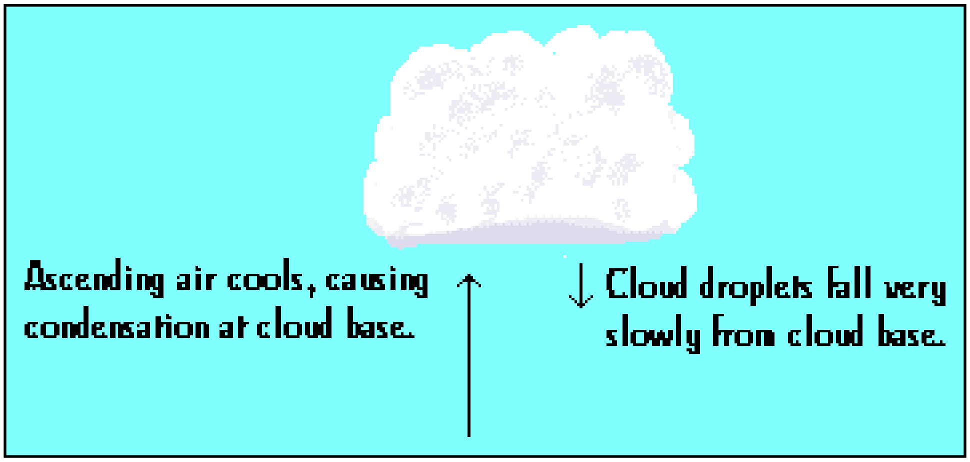
	Cirrostratus	15-25
Middle	Altocumulus	8-19
	Altostratus	8-18
Low	Cumulus	3-9
	Cumulus Congestus	2-8
	Towering Cumulus	2-8
	Cumulonimbus	1-7
	Stratocumulus	2-7
	Nimbus	1-8
	Fractus	1-7
	Stratus	0-6

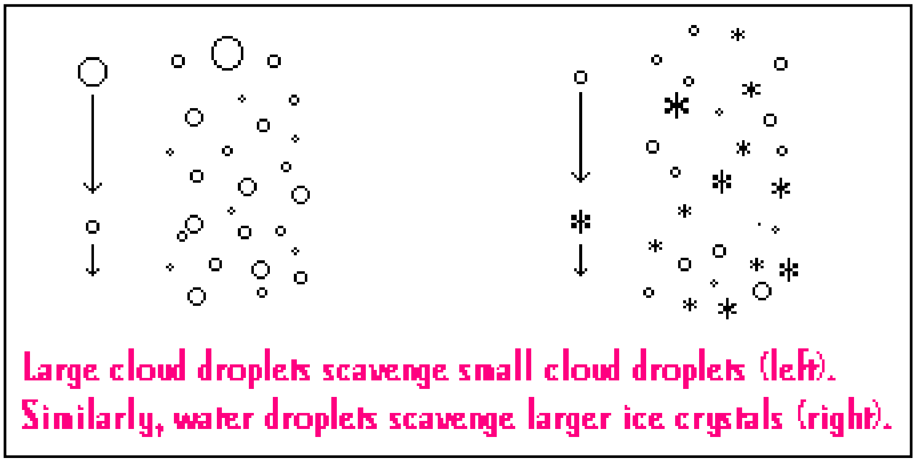
Sources for cloud images : Gordo's cloud gallery, Roger's Skypix , PSC Cloud Boutique , Cloud Types - WW2010

Cumulonimbus and nimbus (more commonly called nimbostratus) are the main **precipitation producers**, though light precipitation occasionally occurs from cumulus and altostratus, and drizzle from stratus. Fractus clouds are often seen beneath bases of such rain clouds, especially cumulonimbus. Many subclassifications exist, describing clouds according to locations and methods of formation. E.g., altocumulus castellanus are often late morning precursors to afternoon thundershowers. Many other cloud types occur because of peculiar atmospheric temperature profiles, topographic waves, and other effects.



Cloud formation is quite complicated. Clouds form at locations of rising air. Ascension rate varies from several centimeters / sec in broad cloud layers such as altostratus, to tens of meters / sec in massive cumulonimbus towers. Such motion typically cools air because environmental lapse rate (temperature decrease with increasing height) is less than temperature decrease of an unsaturated ascending air parcel (because of expansion). Because less water vapor can exist as temperature decreases, relative humidity increases. Once relative humidity becomes 100 % (approximately - see below), condensation (phase change of water vapor to liquid water) begins, causing **cloud droplet** formation (after which temperature decrease of ascending air is less because of heating from condensation). At the center of each cloud droplet is at least one speck of 'dirt' - sea salt, smoke particles, clay, fungus, pollen...some sort of **condensation nucleus** (a few of which are unnatural substances). If no condensation nuclei were present, relative humidities of much greater than 100 % would be necessary for cloud droplets to spontaneously form. Sufficient nuclei exist though, such that condensation occurs when relative humidity becomes *very* slightly greater than 100 % (condensation occurs on some hygroscopic nuclei when relative humidity is significantly < 100 % - largely responsible for haze). Cloud droplet diameters are a fractions of a micrometer (μm - millionths of a meter), growing to about 20 μm as diffusion of water vapor to them occurs. (A human hair is approximately 90 μm thick, so cloud droplets are visible - especially directing a bright light on them during a foggy night.) After a sufficient number of clouds droplets form, a cloud exists, composed of billions of droplets of various sizes. Because their sizes vary, air drag on them does. Thus, they slowly fall at different rates, causing largest droplets to collect smaller ones, a process called **collision-coalescence**. Actually, *fall* is relative - not very strong updrafts or turbulence is sufficient for moving them upward - in a cloud you would see quite a variety of these moving up & down along with the horizontal wind, among a general descending motion. Cloud droplets fall only a few tens of meters per hour, and tend to evaporate when falling thru drier air below cloud base (height at which condensation began). Thus, cloud base height often appears fixed :



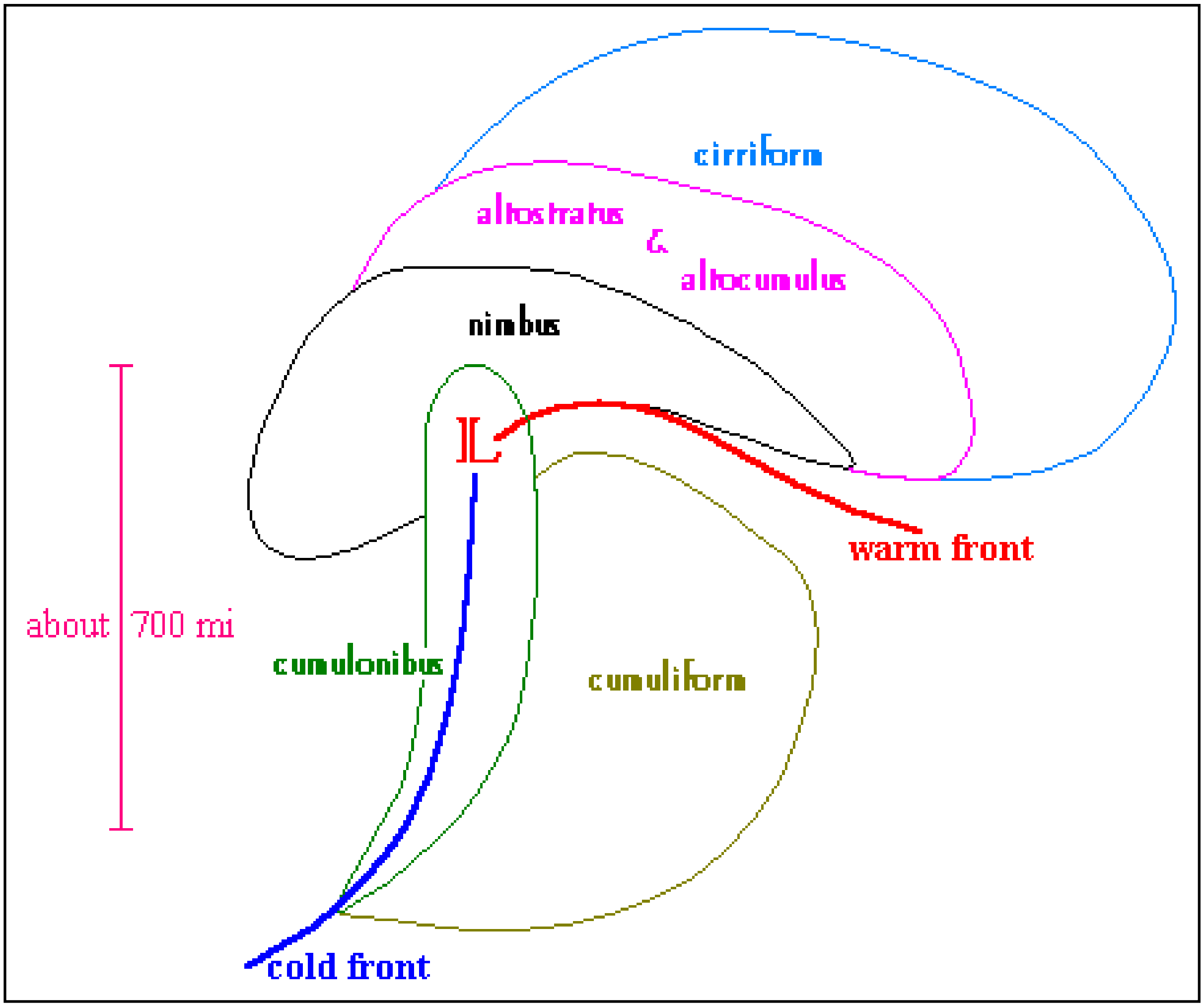


When enough collisions occur, **cloud drops** of diameters of approximately 10 to 100 µm form. When cloud drops become large, they quickly form drizzle-sized drops as large as 1 millimeter (mm = 1000 µm) diameter, largest drops scavenging smaller ones, then raindrops of approximately 1-5 mm diameter. Thus, **rain** !

Ice crystal formation in clouds is very similar. Because water only freezes during 0 °C (32 °F) temperature if a surface exists for such to occur, **supercooled water** (water with temperature < 0 °C) is common in clouds. Cloud droplets tend to form at temperatures to as low as -15 °C, sometimes as low as -60 °C in tropical cumulonimbus ! That is typically true with soluble condensation nuclei. Specific nuclei (insoluble) are very efficient for ice crystal formation, some during temperatures as high -4 °C, but typically not unless temperature is @ most -10 °C. Such nuclei include silver iodide and lead iodide (often used for weather modification), ferrous oxide, and volcanic materials. Thus, many clouds contain **mixtures** of ice crystals and water droplets, which is important regarding precipitation processes because ice crystals grow quicker via diffusion than water droplets (lower saturation vapor pressure) and water droplets fall much quicker than ice crystals, freezing to them very effectively. Such is referred to as the "Bergeron process", and is responsible for much of the precipitation in our atmosphere.

Thus, cirriform (except some cirrocumulus) and some altostratus and altocumulus clouds consist of ice crystals, where air tends to be cold. Others contain water droplets or water / ice mixtures. You may notice that cumulonimbus clouds have very well-defined edges (and sometimes bases), indicating water droplets, but poorly-defined tops, indicating mainly ice crystals. The anvil-shaped tops (thunderheads) are cirriform clouds being blown off the tops of cumulonimbus clouds by very strong winds near the tropopause.

Preferred areas of formation for each cloud type exist, in relation to weather systems. A typical Low which might be seen on a weather map is shown, with cloud types often associated with it :



I refrain from drawing continuous cloud masses associated with fronts as is often depicted because very seldom does such an idealized situation occur, but clouds specified **tend** to form where indicated. Relatively warm air gradually ascends at broad areas ahead of warm fronts, causing middle and high altitude clouds there, and warm air locally rapidly ascends at areas (sometimes continuously) ahead of cold fronts (more commonly, ahead of upper air trofs, thus not always along or exactly parallel to a surface front), causing low cumuliform clouds and showery precipitation.

So much for the basics regarding clouds and their formation. I plan to discuss cloudiness forecasting next week !

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Cloud Forecasting

Date : 9 March 1997

Discussion of UV Index hinted that accurate cloud forecasts are useful, and last week clouds were discussed. This week, cloud forecasts are discussed.

If you mention **cloud forecast** to a person, words such as *clear*, *partly cloudy*, *increasing cloudiness*, *variable cloudiness*, *cloudy*, *overcast*, etc. would likely first come to mind, being associated with notions of what they represent. No strict definitions exist for those that I am aware of. Consider if you wish, the following categories :

Category	Abbreviation	Opaque Sky Coverage
Clear	SKC	no significant cloudiness
Few	FEW	less than 1/10
Scattered	SCT	1/10 - 5/10
Broken	BKN	5/10 - 9/10
Near Overcast	NOC	more than 9/10, but not overcast
Overcast	OVC	no clear areas

Very similar categories are used for standard meteorological observations and plotted surface weather charts, except for NOC, which I include. If a person is observant, (s)he can often notice that cloudy skies are not always overcast, very small breaks often existing. A person should be aware that opaque sky coverage is referred to, though categories can be defined to include semi-transparent clouds. Because thin clouds such as cirrostratus can often transmit as much as 80 % of incident solar energy, such a distinction should be made. When observing cloudiness, I use 20ths of sky cover, though such determination is difficult and sky conditions often transient. METAR code is used for reporting weather observations at airports, though such reports are often translated to plain language for the public. Consider if you wish, METAR reports for DET (Detroit City Airport (MI)) for 10 MAR 1997. They indicate an area of alto types of clouds moving over the region, developing and advected by westerly winds aloft, as GOES 8 satellite images from NOAA / NESDIS & UCAR illustrate (1) (2) (3).

When forecasting cloudiness, a person should consider :

- Weather regime, as depicted by surface & upper air charts
- Existing cloudiness (e.g., satellite & radar images)
- Influence of the diurnal (day / night) cycle
- Local effects
- How weather systems are expected to evolve

Detail of cloud forecasts is often determined by how far in the future such are valid for. Those for several days from present must (obviously) often be general, while those near present can be quite specific. To predict cloudiness, predicting **formation of weather systems** (e.g., surface Highs and Lows, upper air trofs) is very helpful. Specific cloud types and characteristics tend to be related to these, because of forces on air in their vicinity.

Satellite imagery is helpful for identification of clouds and their characteristics, and most useful for forecasting near-future cloudiness. You may notice some resemblance between clouds associated with a real cyclone and those indicated in the previous drawing. Images are obtained from 2 basic satellite types - geostationary and polar-orbiting. 3 types of imagery are mainly used to monitor cloudiness - visible (VIS), infrared (IR), and water vapor (WV). Each is helpful for specific purposes, but **VIS images** tend to **most clearly depict cloudiness**. You may notice differences regarding how cloudiness is depicted on each image, WV images tend to indicate moisture (or lack of it) in the middle to upper troposphere (thus, subsiding dry air intrusions to cyclone areas, inhibiting cloudiness). High resolution is very helpful for images, some meteorological satellites' being 1 km, but most available ones 4 or 8 km. Sounding data is very useful, but balloon soundings quickly become old, as our atmosphere is constantly changing. Satellite soundings can sometimes be used though, providing current atmospheric profiles.

When forecasting cloudiness, a person should be aware of how the **diurnal** (day / night) **cycle** influences it. Such is much more evident during warm weather, cumulus clouds often growing quite large during afternoon & evening, dissipating during night. Many people are familiar with morning fog, especially after rain occurred the previous night. Other more subtle things occur, such as evening cooling of clouds causing them to subside and dissipate if the environmental lapse rate is favorable, perhaps causing some light snow showers to fall out of them during winter as snow crystals precipitate out; and mountain-valley flows causing local cloudiness (or lack of it). Cloudiness tends to be most abundant during late afternoon and early evening, and least so during late morning, solar energy often heating clouds, causing them to dissipate. Some local effects should be considered though; such as lake breezes, which can cause clear weather to prevail near shores during afternoon, and lake-effect cloudiness, which can be responsible for some quite hefty snows downwind of the Great Lakes during very cold weather.

For times longer than several hours in the future, computer model forecasts are more helpful to forecast cloudiness than imagery (ETA model panels & details). With an initial set of observations (mainly balloon soundings), forces which cause vertical air motions, which greatly influence cloudiness, can be calculated. Much of cloud forecasting is presently done with computer models, forecasters using such info as guidance, while using other info (e.g., satellite images, knowledge of local effects, and the diurnal cycle) to often improve such forecasts. Model output parameters & statistics are often used as further guide to forecasting cloudiness. Model forecasts shown are for Detroit, MI (DTW, not DET) for 10 MAR 1997. (I chose DET for the observations, being more reliable than those from DTW.)

Images for the eastern Great Lakes almost a year ago (20 MAR 1996) illustrates a storm system as depicted on a surface chart, satellite image, and computer model forecasts (ETA) (1) (2). A surface Low developed south of the Ohio Valley states, developing northward and even slightly westward. You may notice that the surface chart and computer model forecast do not correspond exactly - model forecasts are not always correct. The surface Low formed over Ohio *much earlier* than 7 UTC, but the ETA model forecast did not indicate it there until 12 UTC. Thus, radar imagery shows heavy precipitation significantly farther west over southern MI than the computer forecast indicated. 7-8 inches of snow occurred during the early morning of 20 MAR near Detroit, MI, after several hours of steady rain, with some 50 mph NNE winds gusts.

Such major events are often discussed, but some of the most challenging forecasts are for areas of clouds which are unnoticed by many people, but can be important for some activities & applications, such as the UV Index, solar car racing (which requires solar energy for power), viewing comet Hale-Bopp, etc. For such events, trying to be very specific regarding cloudiness is quite helpful. Consider if you wish, 10 MAR NGM model relative humidity GIFs for DET, comparing them with surface observations and satellite images previously shown. The model forecast indicates moisture moving over the region associated with a weak surface Low, but cloudiness was not exactly as portrayed. Thus, some knowledge of cloud behavior and interpretation is required to use computer model forecasts effectively.

I plan to discuss seasons next week, as Vernal Equinox approaches.

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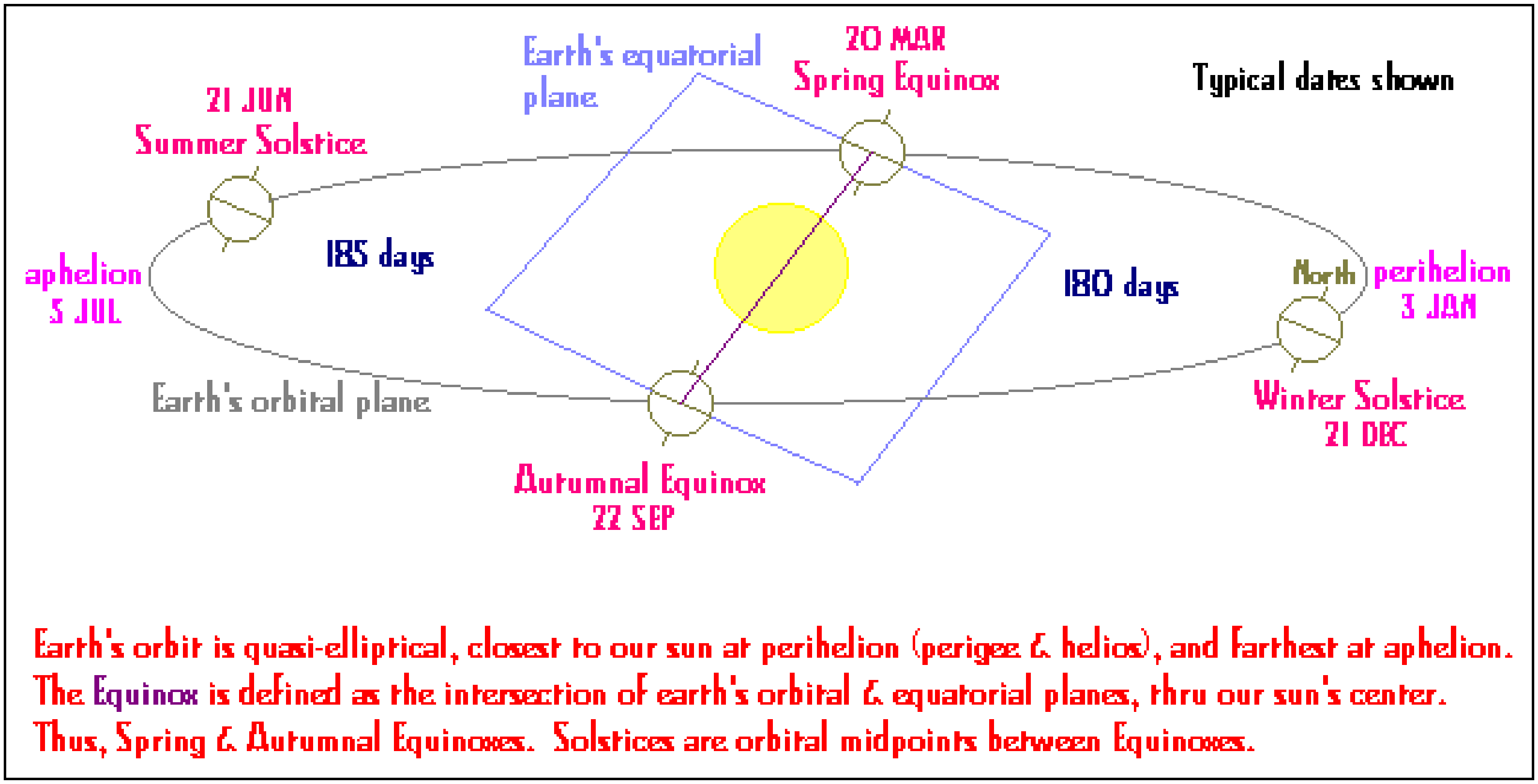
A Method for Determining Mid-Latitude Seasons

Date : 16 March 1997

As Spring Equinox approaches, you may be wondering : "I know the calendar says it's Spring, but sure feels like Winter to me" (especially in the NE U.S. early this week). Some of the largest snows have occurred during 'Spring'; e.g., 25 inches during 23-24 March at Kansas City, MO - their largest storm total ! Detroit, MI's largest of 24.5 inches occurred *during April* ! Perhaps the calendar lies...

Most people are familiar with astronomical seasons :



Winter being from Winter Solstice to Spring Equinox, etc. **Equinox** is a latin word for **equal time**, and specifically is the intersection of earth's orbital and equatorial planes, thru our sun's center. If we had no atmosphere, our planet's Northern Hemisphere would be coldest near Winter Solstice and warmest near Summer Solstice. Things would be quite simple, and no life would exist. In our complicated atmosphere though, air and water require time to heat, and circulate to distribute heat acquired. Thus, meteorological seasons are often defined as :

Season	**Months**
Winter	December, January, February
Spring	March, April, May
Summer	June, July, August
Autumn	September, October, November

indicating almost a month lag from seasons according to solar elevation angle (e.g., lowest 3 months from about 5 NOV to 5 FEB). That is okay as an approximation, but the situation is more subtle. Not only does solar elevation angle change more abruptly near equinoxes than solstices, but geometry causes us to experience a more abrupt change from Winter to Summer (or vice-versa) than it or our calendar indicate :

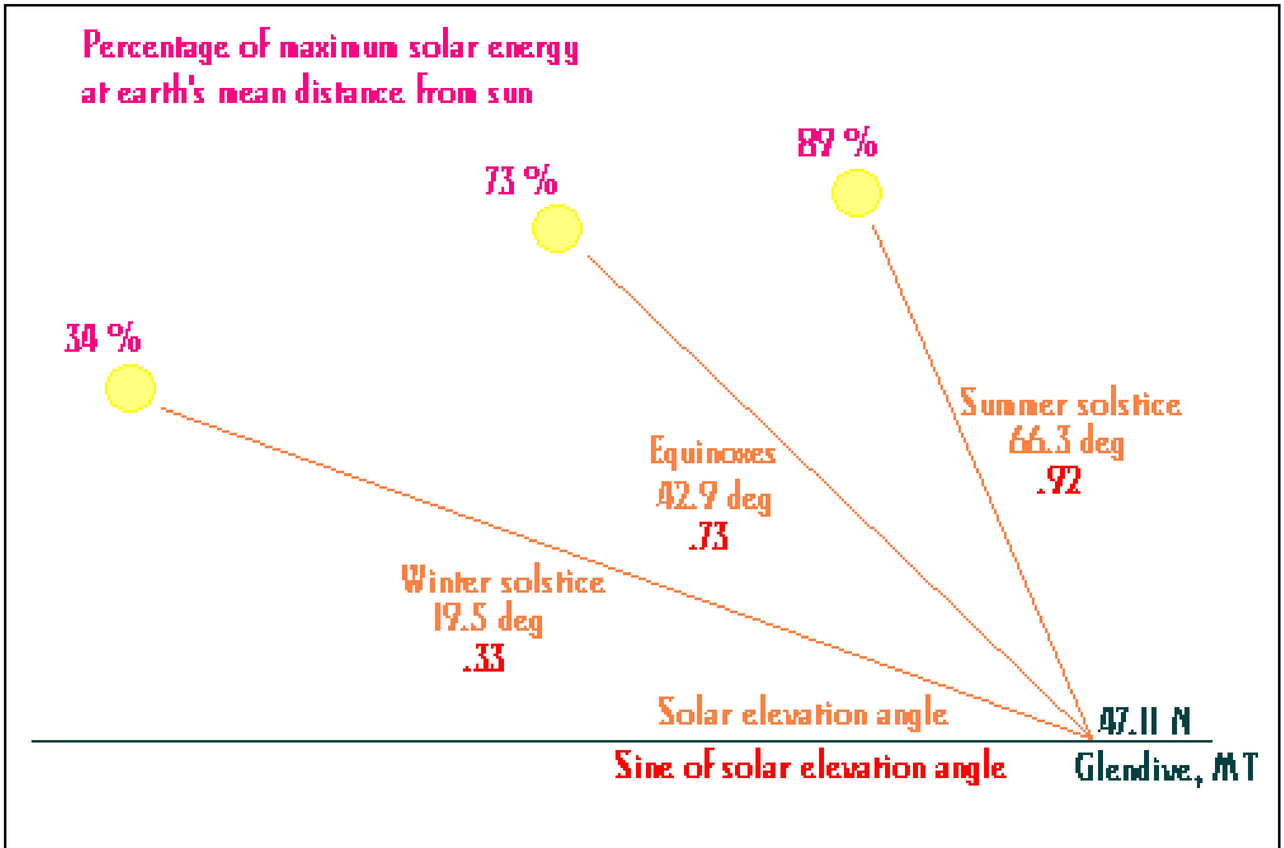
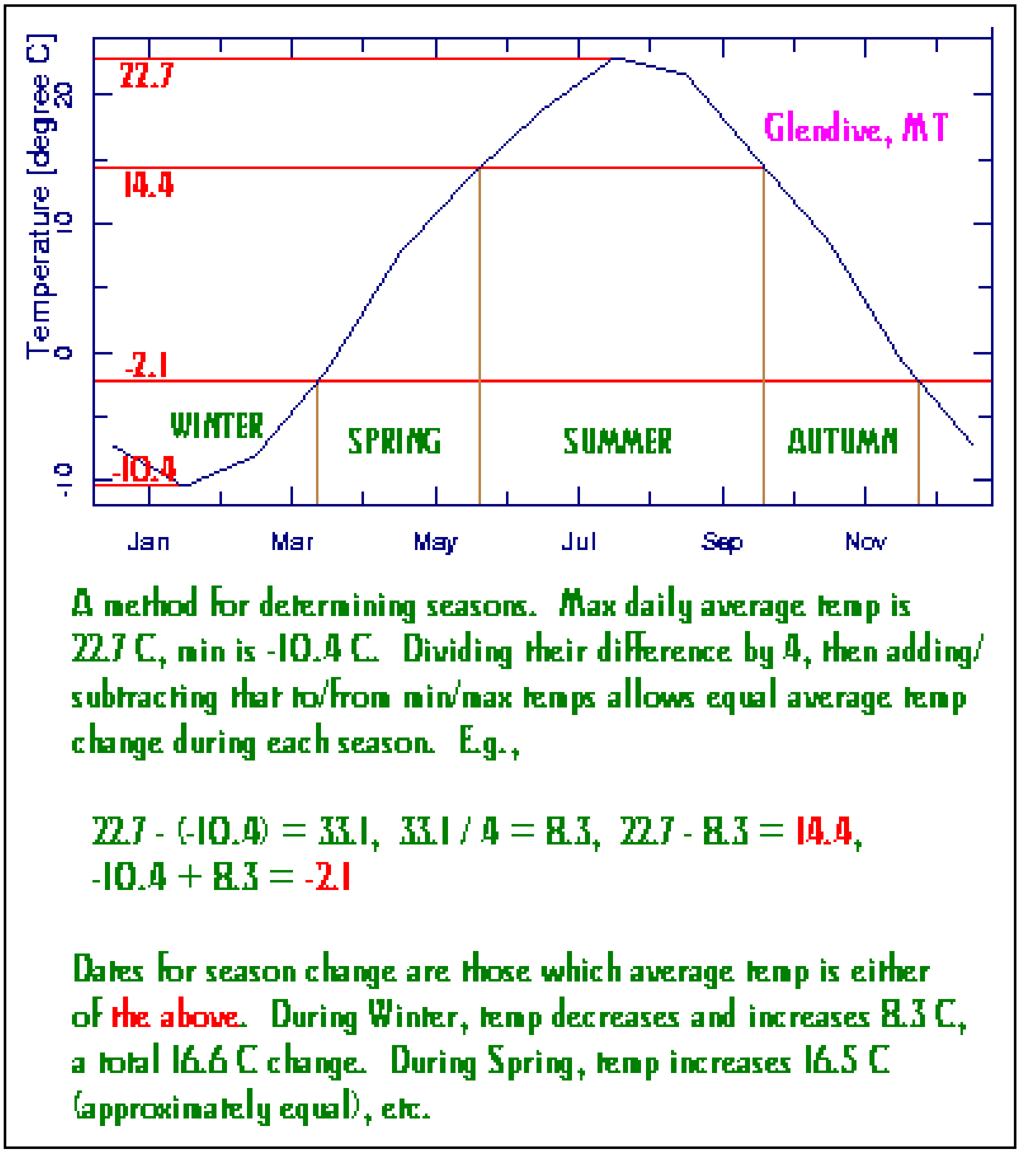


Illustration of changing solar elevation angle and its consequences. Although an approximately equal number of days elapse during astronomical Winter and Spring, the solar energy reaching our atmosphere is much more like the Summer Solstice than Winter Solstice situation at the Equinoxes.

@ Spring Equinox, our sun has made about **2/3** of its change from Winter to Summer situation, though only about **1/2** the days elapse.



Does a better way to determine seasons exist ? Vegetation, harvest times, and other activities (fish spawning, etc.) all indicate changing seasons. Quite often, growing seasons are referred to. On the diagram to the right, the graph indicates average temperatures (from monthly averages) obtained for Glendive, MT from the Lamont-Doherty Earth Observatory climate browser. I defined 4 seasons according to equal temperature changes during each. (Better ways exist to calculate this, but it can suffice.) You may notice that Summer and Winter according to this are about 4 months, Spring and Autumn about 2. Spring and Autumn are transitional seasons between our long, dark winters and long, hot summers (at middle and high latitudes). Is the data for Glendive typical ? To help answer that question I decided to *randomly* select 16 locations, one for each Region as defined in the Old Farmer's Almanac. I wouldn't believe many of their daily forecasts, but their seasonal ones can often be useful. The regions are very well-chosen, consistent climates occurring in each, if they must be limited to 16. Below is a listing of seasonal graphs according to Region (Region number, location, lat, lon ; elevation) :

1 Ripogenus Dam, ME 45.88 °N, 69.18 °W ; 294 m
2 Charlotteburg, NJ 41.03 °N, 74.43 °W ; 232 m
3 Fredericksburg, VA 38.32 °N, 77.4 °W ; 27 m
4 Asheville, NC 35.43 °N, 82.55 °W ; 659 m
5 Saint Leo, FL 28.33 °N, 82.27 °W ; 58 m
6 Elmira, NY 42.08 °N, 76.78 °W ; 256 m
7 Hopkinsville, KY 36.83 °N, 87.50 °W ; 180 m
8 Scottsboro, AL 34.68 °N, 86.05 °W ; 187 m
9 La Porte, IN 41.60 °N, 87.62 °W ; 247 m
10 Medford, WI 45.13 °N, 90.35 °W ; 448 m

11 El Dorado, KS 37.82 °N, 96.83 °W ; 408 m
12 Amarillo, TX 35.23 °N, 101.7 °W ; 1099 m
13 Lakeview, OR 42.22 °N, 120.37 °W ; 1455 m
14 Needles, CA 34.77 °N, 114.62 °W ; 279 m
15 Portland, OR 45.60 °N, 122.60 °W ; 7 m
16 Chulta Vista, CA 32.62 °N, 117.08 °W ; 17 m

You may notice a very similar trend among them, mainly because they are all for the continental United States (some almost appear identical). Many more of the graphs are in the eastern than western U.S., and as luck determined, a large void exists among these because Region 13's choice was in Oregon, Region 10's in Wisconsin, and Region 14's in California...the beauty & ugliness of randomness ! Thus, you might wish to think of this a geographical distribution according to population rather than area. Maximum *daily average* temperature at Needles, CA is interesting (almost 35 °C (95 °F) !), one of the hottest places in the U.S. You may notice that seasonal lag is greater for western than eastern locations, influenced by cold ocean currents during Spring. Averaging for the locations **determines seasons** as :

Season	**Dates**	**Duration**
Winter	23 NOV - 16 MAR	115 days
Spring	17 MAR - 26 MAY	70 days
Summer	27 MAY - 23 SEP	120 days
Autumn	24 SEP - 22 NOV	60 days

Average temperatures are near 20 °C (68 °F) at many locations during the beginning of Summer, meaning maximum temperatures are in the 70's to low 80's (°F) at some locations, so this method is realistic (as well as logical).

These seem to agree well with experience, though adjustments for other factors (some mentioned above) might be appropriate. E.g., plants still bloom during May and perhaps even June, but many places become like a little jungle during July & August ☺ Ice requires time to melt, and lakes remain warm during 'Autumn', etc. Considering all of such things, the following dates may be more realistic :

Season	**Dates**	**Duration**
Winter	28 NOV - 22 MAR	116 days
Spring	23 MAR - 1 JUN	70 days
Summer	2 JUN - 29 SEP	120 days
Autumn	30 SEP - 27 NOV	59 days

This does not consider precipitation, which can be responsible for types of seasons. Consider if you wish, annual monthly precipitation averages for 3 locations. Data for Saint Louis, MO is typical of much of the continental United States, heaviest precipitation often with abundant showers during late Spring & early Summer. Data for Phoenix, AZ illustrates the monsoons caused by a large-scale heat Low which often develops over our desert southwest states during late Summer & early

Autumn. Another type of late-season precipitation maximum is illustrated for data from Wawa, Ontario (at the east side of Lake Superior), from **lake-enhanced** precipitation. The maximum amounts during August & September are caused by that and mean position of jet streams aloft, which begin southward progression then. The small maximum during November would be greater if snow were measured more effectively, lake-effect snow greatly contributing to it.

Such considerations are important regarding world climates, which often are not so easily defined as in the continental U.S., which is the feature for next week.

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Some Global Factors Influencing Seasons

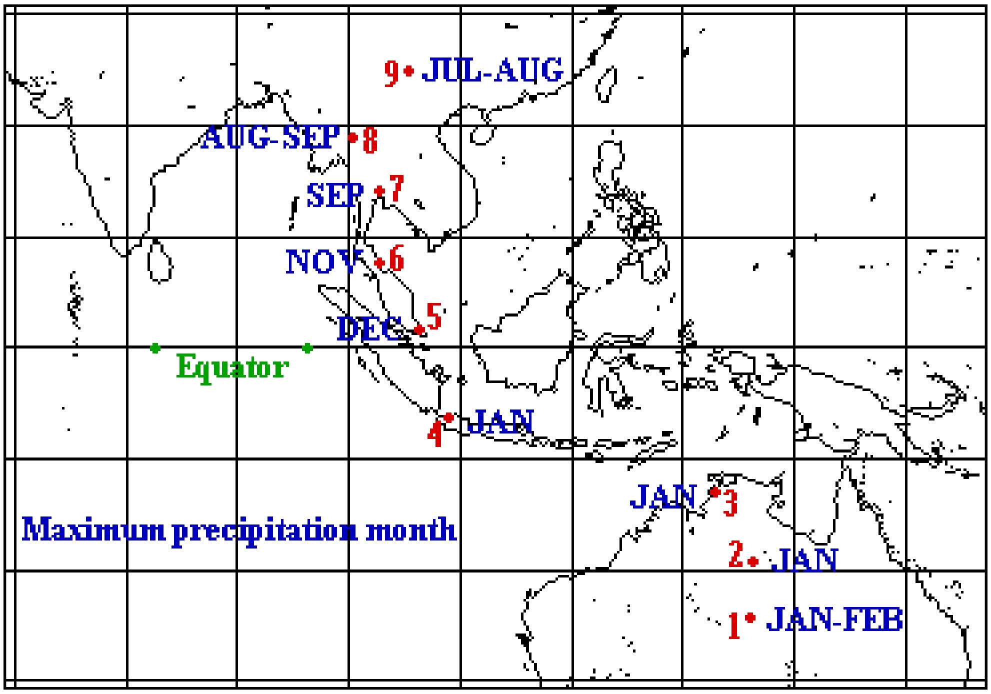
Date : 23 March 1997

Globally, seasons are not so easily defined as for mid-latitude locations, for which astronomical seasons are reasonable. The main reasons for such are that solar elevation angle and day length do not change much at low latitudes. As most everyone is aware of, seasonal temperature variations are small near our equator, increasing greatly toward our poles; as indicated from monthly averages for Jakarta, Indonesia and Dzardzan, Russia (in Siberia) obtained from Lamont-Doherty Earth Observation's interactive climate server. Near the Tropics (i.e., Capricorn & Cancer) over land, enough temperature change occurs such that seasons can be defined by them, as indicated in a similar graph for Alice Springs, Australia.

Thus, tropical seasons are most effectively defined according precipitation; a **wet season** or alternating wet and dry seasons often occurring. Global surface pressure regimes indicate several features, among which are semi-permanent subtropical Highs (pressure areas), and a semi-continuous Low near the equator, often called the monsoon trof. Thus, a pressure gradient exists, causing the easterly winds toward the equator to prevail in tropical regions, and westerly winds toward the pole in mid-latitude regions. The Intertropical Convergence Zone (ITCZ) is the location of convergence of NE and SE trade winds. It is not a permanent nor continuous feature, but its effects can often be seen on global satellite images (main site) as convection in a semi-continuous cloud and / or precipitation band near the equator (typically much more noticeable during July-December).

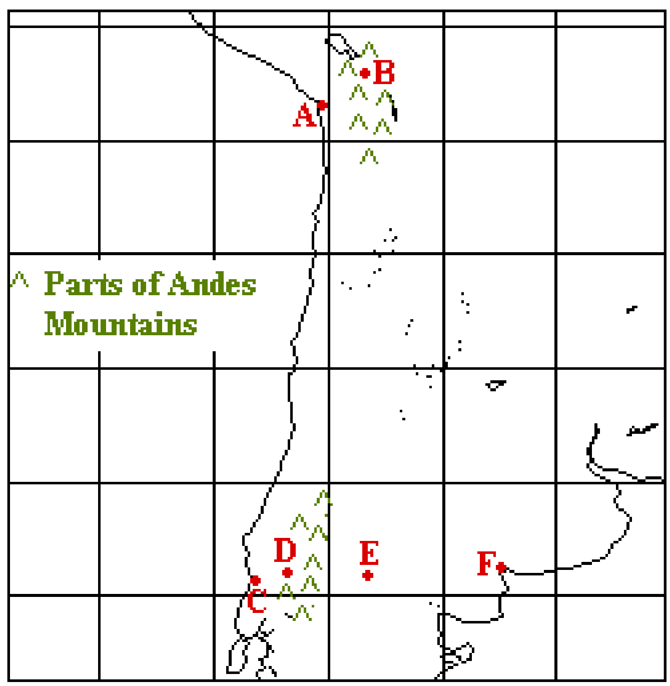
A combination of seasonal monsoons, summer sea surface temperature increase, and movement of the ITCZ largely determines tropical seasons. Consider if you wish, a map from the Xerox PARC Map Viewer, on which I include tropical locations approximately between the Tropics of Capricorn & Cancer (location, lat, lon; and elevation) :

1 Alice Springs, Australia 23.8 °S, 133.9 °E ; 537 m
2 Tennant Creek, Australia 19.63 °S, 134.17 °E ; 375 m
3 Darwin, Australia 12.4 °S, 130.8 °E ; 31 m
4 Jakarta, Indonesia 6.18 °S, 106.83 °E ; 8 m (approx.)
5 Singapore, Singapore 1.37 °N, 103.92 °E ; 18 m
6 Songkhla, Thailand 7.2 °N, 100.6 °E ; 4 m
7 Bangkok, Thailand 13.73 °N, 100.57 °E ; 2 m
8 Chiang Mai, Thailand 18.78 °N, 98.98 °E ; 312 m
9 Kumming, China 25.02 °N, 102.68 °E



A precipitation maximum occurs once during an average year at each location, about a month or 2 after our sun is most directly above a location at more poleward locations (after establishment of monsoons), and near the time when ocean temperatures are maximum at locations near the equator. Thus, rather than 4 seasons, 2 basically occur - a wet season and a dry (or less wet) season. The wet season often occurs for several months, approximately coinciding with astronomical Summer in each hemisphere. Locations in India are well-known for their noticeable wet season as monsoon winds flow from the Indian Ocean.

Such a wet season does not occur at all tropical locations though. E.g., northern coastal Chile is notorious for lack of rainfall, measurable rain not being reported at some locations for **decades** (and even centuries !). Consider 2 locations near each other, Arica, Chile **(A)** and La Paz, Bolivia **(B)**. Precipitation difference is remarkable, caused by the consistent easterly winds (SE trades) over the region, flowing up & down the Andes Mountains. Though in the tropics, a small temperature variation is all that can define seasons in Arica, and a very small precipitation maximum (perhaps caused by westerly jet streams *very occasionally* affecting the region during the Southern Hemisphere Winter).



Further south, cyclones in the westerlies greatly influence weather, precipitation being similar to that on the western United States - abundant on the prevailing windward South American shore and adjacent mountains, sparse downwind of the mountains, and relatively abundant again near the eastern shore, as indicated on global average precipitation maps. The following graphs for locations of similar latitude in South America (location, lat / lon ; elevation) :

C Valdivia, Chile 39.62 °S ; 73.07 °W

D Flor De Lago, Chile 39.2 °S, 72.1 °W ; 300 m
E Cipoletti, Argentina 39 °S, 68 °W ; 265 m
F Bahia Blanca, Argentina 38.73 °S, 62.17 °W ; 75 m

more specifically depict this.

Thus, latitude, land / sea areas, and topography largely determine climate and consequently seasons. At middle and high latitudes, Spring and Autumn are transition seasons between much longer warm and cold seasons, the change more abrupt nearer the poles; and tropical seasons tend to be caused by precipitation more so than temperature, wet and dry (or less wet) seasons being typical. Topography and global wind regimes can locally influence such factors quite significantly.

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Spring Snowmelt

Date : 31 March 1997

I just finished discussing seasons, mentioning 2 weeks ago that largest snows often occur during early Spring. Well, as I type this, snow is falling here in Mount Pocono, PA - about a foot and still accumulating - the largest storm snow total during this year ! Of course, tomorrow is April; so the snow shouldn't stay around very long. Temperatures of 50's to 60's during the end of this week should make most of the foot & a half or so of snow a recent memory then. Thus, I picked a timely topic. Next week I plan discussion of the California Cooperative Snow Surveys.

Regarding snowmelt, another type of season is often referred to - the **water year**, 1 October - 30 September. Snowmelt obviously occurs at all elevations where snow falls, but most relevant to hydrology are the large snowpacks which occur yearly at high elevations, particularly in the Rockies and northwest United States. In fact, permanent snowpacks (i.e., glaciers) exist in some parts of the Rockies. Most notable episodes involving snowmelt are those associated with storms, during which rain contributes to major flooding problems, such as occurred during this mid-winter in the Pacific Northwest (1), (2), especially if a large snowpack exists. Snowmelt contributes to dam breakages and other problems. More commonly, snowmelt mainly occurs during April-July, months during which large snowpacks as deep as 40 feet melt during a long process for which most rivers, dams, and other structures can handle well. Long range weather forecasts can help hydrologists at various river forecast centers prepare for changing conditions. Hydrological forecasts (1), (2) are issued, and watches and warnings when necessary.

Accurate assessment of existing snowpacks is essential for their forecast. This is done both with human and airborne surveys. Gamma rays emitted from elements in shallow soil beneath snow are absorbed by snow, water, and ice directly above. Knowledge of background amount and measurements allow accurate snowpack water equivalent estimation, which is interpolated for areas between measurement locations. Human surveys are essential for verification of remote data, often accurate to within a centimeter for large-scale areas. Consider if you wish, current snowpack water equivalent for the northwest United States, indicating a potential of nearly 100 inches of snowmelt at very high locations. When snow first falls, about 8.5 inches of snow will melt to 1 inch of water (if very heavy). Compaction occurs as snowpacks develop during winter, such that the ratio becomes about 3:1 during January and 2:1 during May. Thus, a snowpack with a water equivalent of 100 inches during late March might be 250 inches thick.

Elevations where snowpacks remain presently vary from about 2000 feet north to 9000 feet south, and amounts are above normal in much of the northwest United States.

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California Cooperative Snow Surveys

Date : 13 April 1997

The California Cooperative Snow Surveys do perhaps the best analysis of Spring snowmelt. A glance at geography of the region can provide good reasons why. California is situated in a place where probably few people should live. It's dry (much is desert) and interspersed with mountains. Not the kind of mountains typically seen in the eastern U.S. - green and flourishing with vegetation. Because of the lack of moisture, water is a commodity, which should be shared & distributed wisely. Desalination is possible, but water resources are best used considering conservation and distribution using a series of rivers, dams, and reservoirs. The source of much of the water in the region is precipitation during the wet season (Winter), especially snow at high elevations. Several hundreds of inches of snow fall yearly, most at peaks of mountains. As stated very well by the snow survey people, snow for many Californians is an 'out of sight, out of mind' type of thing, yet greatly influences their lives. Though it all eventually melts at southern locations, Mount Shasta in the north is capped by a snow / ice glacier year round. Such locations can have a climate and weather of their own, as illustrated in an interesting article from long ago. Not so typical thundershowers can turn a beautiful location to a private hell for a day.

Snow surveys are very helpful to accomplish objectives stated above. Many methods are used to monitor water resources in snowpacks. These include gamma radiation remote sensing using aircraft, using snow sensors (snow pillows), and taking snow core samples. The California Cooperative Snow Surveys mainly do the latter 2, among other things. Snow core samples provide the most reliable data, good for verification of data measured using less reliable methods. A nice description of the a snow core survey is provided at the CSS WWW site. More than 300 snow courses are established in the Sierra Nevada and surrounding mountainous regions, from which various snow core samples are weighed monthly, mainly to determine snow water content. They are located to best determine contribution of snowmelt to river and reservoir systems. Over 100 snow sensors are distributed above major river systems, for continuous data availability. Such abundant data is very valuable for modelers, hydrological planners, and researchers. Current measurements indicate large snowpacks in much of the central and northern mountains, water equivalents of 30 - 60 inches still existing at high and cold locations, but much of the snow below 5000 - 6000 feet has now melted. Amounts are typical for this time of year (no great surprises or flooding), which is exactly what the California Department of Water Resources likes, making their jobs easier. After abundant rains during December and January with rapid snowmelt at middle elevations and associated flooding, mudslide, and other problems, February and March were much drier than normal, such that snowpacks which were once very thick are currently only average at south and central locations, above average northeast, and below average northwest. These can be compared with current airborne measurements of aerial extent and water equivalent of snow cover. This clearly illustrates usefulness of local snow surveys for providing detailed verification data.

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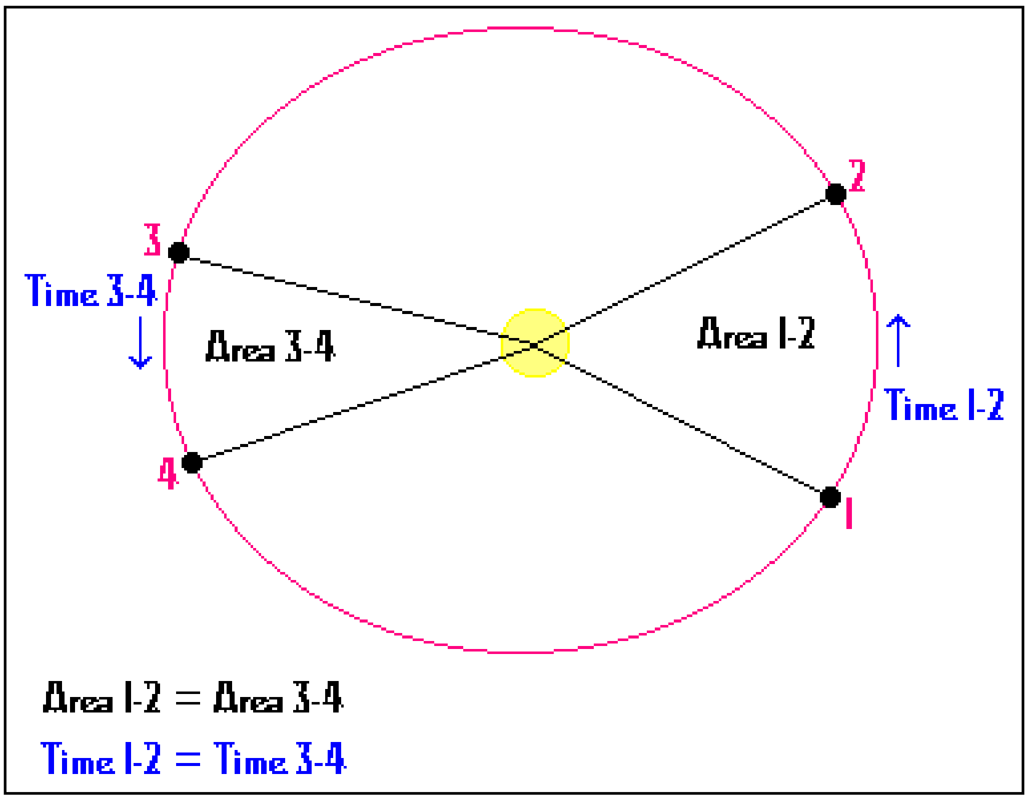
Basic Origin of Solar Energy and Atmospheric Influence

Date : 27 April 1997

Solar energy* (S) is an extensive topic (like many) though, which can be discussed weekly during an entire year. I mention that any link in this article with * is from the definition list, so you don't always access them, but know they are defined. This week I describe its origination to basic influence of our atmosphere, next week specific atmospheric affects (particularly clouds), and the subsequent week how this resource is used. So I suppose this will be solar energy month !

Our Sun



Sol (our sun) is a rather average star in our Milky Way Galaxy. It is almost the exclusive energy-provider for Earth, and ultimately causes our weather. Its diameter is 1391900 km, 109 × Earth's (distances, etc. are best estimates). Average Sol to Earth distance (not precisely) is called an astronomical unit* (AU), and is 149570000 km. (Planetary spacing in our solar system indicates that distance from Sol to Mercury might more appropriately be called such.) Earth's orbit around Sol is quasi-elliptical, so distance between them varies 3.3% during a year. A planetary orbit inscribes equal areas during equal times, so that Earth's orbit is slowest at aphelion* and fastest at perihelion*. Other geologic time-scale motions of Earth are supposed. Milutin Milankovitch studied those in an attempt to better understand their relationships with long term climate changes, particularly glaciations.

Thermonuclear fusion reactions of light elements cause the enormous heat produced in Sol. Most are proton fusions of H to He. For an idea of the number of molecules in our sun, occurrence of those reactions averages 14000000000 years. With a total mass of 1.991 x 10^{30} kg though, a person can easily imagine a sufficient number occur so Sol continues burning. Because 10000000 °K is required for proton fusions (so collisional energy can overcome electrical repulsion), a significant portion of the solar core must be that temperature or greater.

Extending outward from the core region a radiation-convection zone is supposed, where cooling and expansion against gravity occurs until an upper granular layer and photosphere (solar 'surface') is reached. On the photosphere are sunspots and various other features, sunspots being locally cool regions, typically 4000 °K, compared to the average 5800 °K photospheric temperature. Sunspots appear dark on the photosphere (contrast), and can cover significant portions of the solar surface. They do not decrease emitted S as much as expected because hot, bright faculae surround them. S flux can decrease fractions of a % during vigorous sunspot activity though. (Such is much less variation than thickness change of a cloud blocking our sun usually causes on Earth.) An approximately 22 year sunspot cycle occurs, during which 2 activity maxima and minima occur, polarity of associated magnetic fields reversing during those. From photospheric features, a rotation period varying from approximately 25 days along our sun's equator to 34 at its poles is evident. Above our sun's photosphere are the chromosphere, solar flares and prominences, and a corona. Hot gases which scatter S the photosphere emits may mainly cause the corona. Its temperature is 500000 - 2000000 °K, but it is so diffuse that it emits much less energy than the photosphere does. The solar magnetic field keeps the corona is mainly within a few solar radii of Sol. Some parts of the corona overcome the pull of that field, and a solar wind of plasma continually flows outward from Sun. The terrestrial magnetic field diverts the solar wind around our earth, protecting us from harmful particles, often causing magnificent auroras ! The corona's great temperature causes far ultraviolet (UV) and X-ray electromagnetic (EM) radiation* emission. Such is absorbed by N_2, O_2, N, O, H, and He at altitudes above 50 km in our atmosphere. O_3 (ozone) at altitudes of 12-50 km and near our earth's surface protects us from harmful photospheric near UV EM radiation. Only near UV, visible (VIS), and near infrared (IR) S significantly remains, entering the troposphere. Photospheric temperature causes a .47 µm peak S "wavelength" emission, and very nearly all is emitted between .25 and 4 µm (1 cm = 10 000 µm).

Extraterrestrial Solar Energy Flux

The solar constant is mean S flux* perpendicular with the solar beam in outer space, at mean distance from Earth's center to Sol. It is 1370 W / m^2. Although it is not a constant flux, I feel it is appropriately named; being extremely reliable and consistent. Earth's orbit causes varying extraterrestrial S flux* between approximately 1329 and 1421 W / m^2.

Interaction of Solar Energy with Our Earth's Atmosphere

When S enters our atmosphere, it is absorbed and scattered, and some is transmitted directly thru, unaltered. Considering all S reaching our earth's surface, 10% is near UV, 45% VIS, and 45% near IR. As no coincidence, our eyes sense EM radiation between .38 and .72 µm (1 µm = 1000 nm), the portion of the EM spectrum* for which S we receive is most intense. After atmospheric scattering, peak S wavelength is .55 µm, reasons for which are discussed below. Thus, an ex-professor of mine, Volker Mohnen states "Our eyes are electromagnetic sensors in the visible wavelength region.".

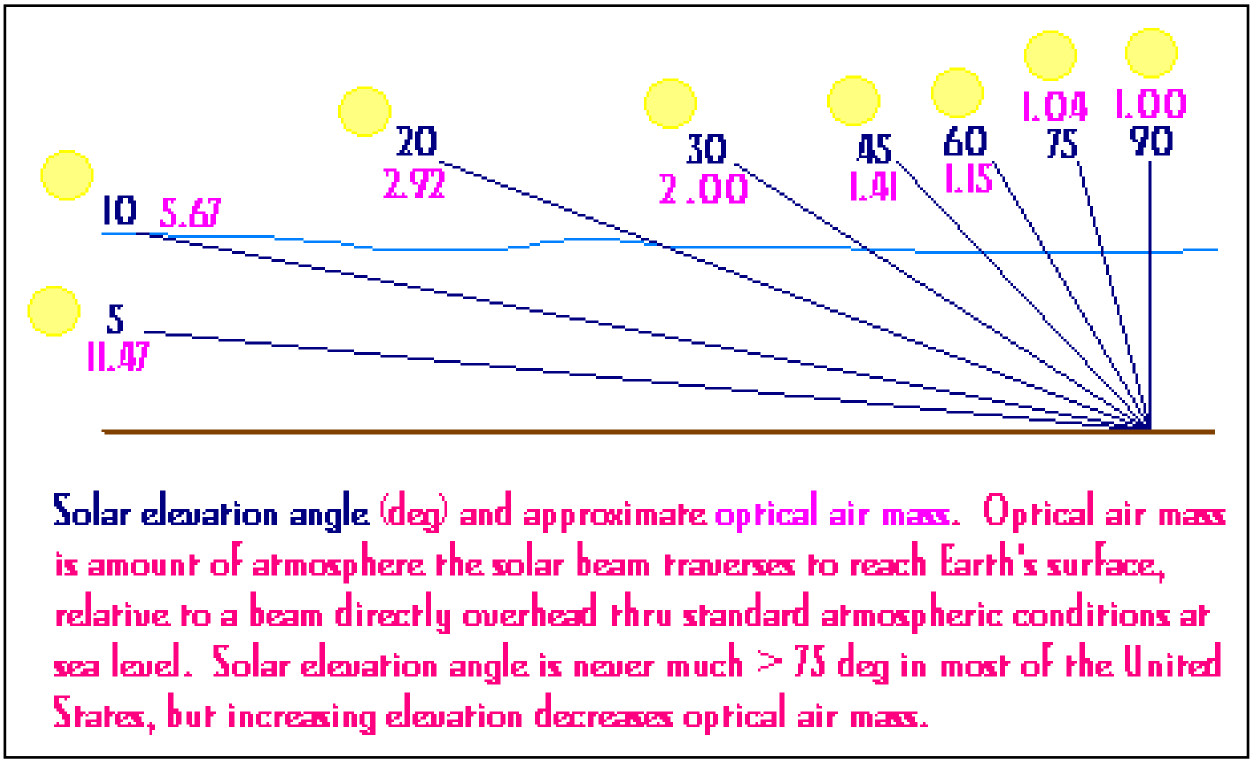
Atmospheric constituents can be categorized in 2 groups - molecular and aerosols. Molecular constituents are gases of dry air in our atmosphere and water vapor. Dry air is quite homogeneous up to an altitude of around 80 km, and its main volumetric components are :

Component	Symbol	% of Dry Air
Nitrogen	N_2	78.09
Oxygen	O_2	20.95
Argon	A	.93
Carbon Dioxide	CO_2	.03
Water Vapor	H_2O	variable
Others		small

Water vapor concentration is quite variable, and can occupy as much as 5% of atmospheric volume. Aerosols are suspended particles in the molecular air, such as dust, smoke, and pollen. Even clouds can be correctly be considered as consisting of aerosols, because they are organized masses of water droplets and / or ice crystals. The main S absorbers in our atmosphere are aerosols, water vapor, ozone, carbon dioxide, and diatomic oxygen. All atmospheric constituents scatter some S, their size mainly determining scattering characteristics. Molecular scattering, for which S wavelength is significantly longer than molecule size, occurs rather equally to all directions (isotropic). Aerosol scattering tends to be predominately to a forward direction, aerosol size and shape determining distribution of scattered EM radiation. Molecular scattering tends to be inversely proportional to wavelength (λ) to the 4^{th} power :

Molecular scattering ~ $1 / \lambda^4$

S near the blue end of the EM spectrum is scattered preferentially, and only when optical air mass* is quite large is S near the red end of the EM spectrum abundantly scattered :

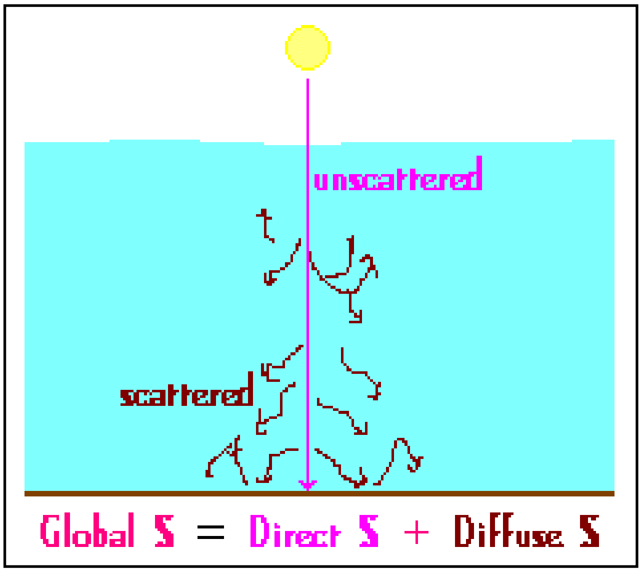


Aerosol scattering is similar, but not nearly as extensive, tending to be inversely proportional to wavelength :

Aerosol scattering ~ $1/\lambda$

Thus, when a person looks at a cloudless sky, they typically see a light blue background color (molecular scattering), with a white-yellow solar disc surrounded by a yellow-orange circumsolar* region (aerosol scattering). During cloudless days with a very clean atmosphere, a purplish tinge in the sky can sometimes be seen, suggesting that very little aerosol scattering is occurring. Those colors all shift to longer wavelengths as solar elevation* decreases, causing pink-red sunsets typically seen.

Solar Energy Components at Ground



Solar energy in our atmosphere consists of 2 components* - direct, the unscattered solar beam; and diffuse, scattered. An expression for global S, all S in our atmosphere is :

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Global S  =  Direct S  +  Diffuse S
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Direct S flux, diffuse S flux, and global S flux are such fluxes incident to a specific orientation, which I plan discussion of later regarding S usage. When mentioning global S flux with no further specification, that incident to horizontal is usually assumed (a natural reference for it). More precisely, the term global horizontal S flux can be used. Same for direct and diffuse S flux. People often use the terms direct normal S flux and even global normal S flux to specify those incident to a surface directly facing our sun (normal to the solar beam). Diffuse S can be considered to consist of several components. They include downward-scattered sky diffuse solar energy, ground-reflected solar energy, and backscattered solar energy (after ground reflection and including multiple scattering). Cloud-transmitted and cloud-reflected solar energy can also be specified. Magnitudes of each can be estimated for various sky and terrain conditions.

Atmospheric solar energy is modeled using both detailed analysis of radiative transfer equations, using attenuation coefficient for specific dry air constituents and cloud droplet/crystal distributions, and also parameterizations using transittances as estimates of bulk scattering and absorption properties of basic dry air constituents and clouds. The former is theoretically fine, but often impractical. From the previous discussion regarding scattering, it should be clear that under cloudless skies, diffuse S tends to be blueish, leaving direct S a bit reddish. This has significant consequences regarding S usage, particularly solar cell performance. I plan discussion of such topics later.

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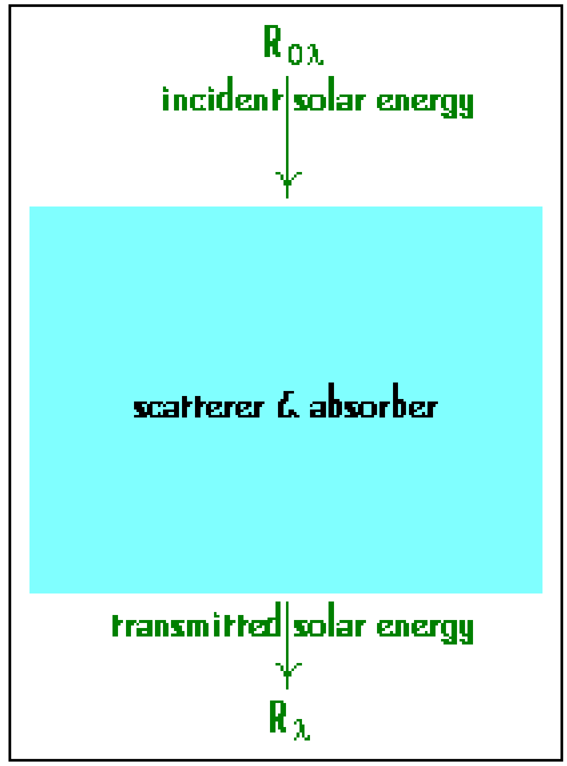
Solar Energy, Clear Sky Effects

Date : 4 May 1997

Before I discuss how clouds influence solar energy (**S**), I first discuss the influence of a clear sky. This topic maybe a little dull, but for those who are reading these articles weekly, it is a necessary topical transition.



For calculation of direct **S**, the concept of **transmittance** is often used. Transmittance of a medium is the fraction of incident electromagnetic (EM) radiation which passes thru it. Thus, it is all neither scattered nor absorbed. Monochromatic (single wavelength) transmittance can be expressed as

$T_{\lambda} = R_{\lambda} \ / \ R_{0\lambda}$,

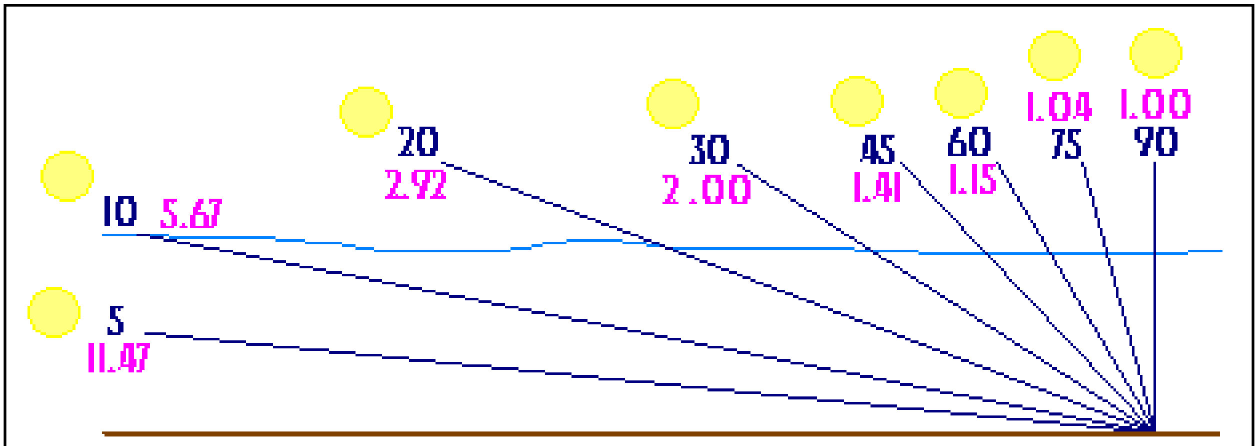
in which $R_{0\lambda}$ represents incident EM radiation **intensity** (**S** flux per unit wavelength) at wavelength λ, and R_{λ} that after passing thru a medium. When the medium is our atmosphere, an **optical depth** (τ_{λ}) is typically defined such that transmittance is $1 / \boldsymbol{e}$ ($\boldsymbol{e}$ = 2.718281...) for a value of 1. I.e.,

$I_{\lambda} = I_{0\lambda} \, \boldsymbol{e}^{-\tau_{\lambda}}$,

in which $I_{0\lambda}$ & I_{λ} are expressed as for $R_{0\lambda}$ & R_{λ}, except for **S** intensity. Because our atmosphere is very rarely standard, an **attenuation coefficient** is defined as

$\tau_{\alpha\lambda} = \tau_{\lambda} \, m$,

in which m represents optical air mass :



Solar elevation angle (deg) and approximate optical air mass. Optical air mass is amount of atmosphere the solar beam traverses to reach Earth's surface, relative to a beam directly overhead thru standard atmospheric conditions at sea level. Solar elevation angle is never much > 75 deg in most of the United States, but increasing elevation decreases optical air mass.

Thus, more air penetration means more attenuation (less transmittance). Optical depths can be defined for specific atmospheric constituents. Their combined transmittance affects are assumed multiplicative :

$I_\lambda = I_{0\lambda}\ T_1\ T_2\ T_3\ ...$

in which 1, 2, 3 ... refer to specific constituents. Thus

$I_\lambda = I_{0\lambda}\ \boldsymbol{e}^{-\tau_{\alpha_1\lambda}}\ \boldsymbol{e}^{-\tau_{\alpha_2\lambda}}\ \boldsymbol{e}^{-\tau_{\alpha_3\lambda}}\ ...\ ,$

I_λ being direct **S** intensity after penetration thru our atmosphere.

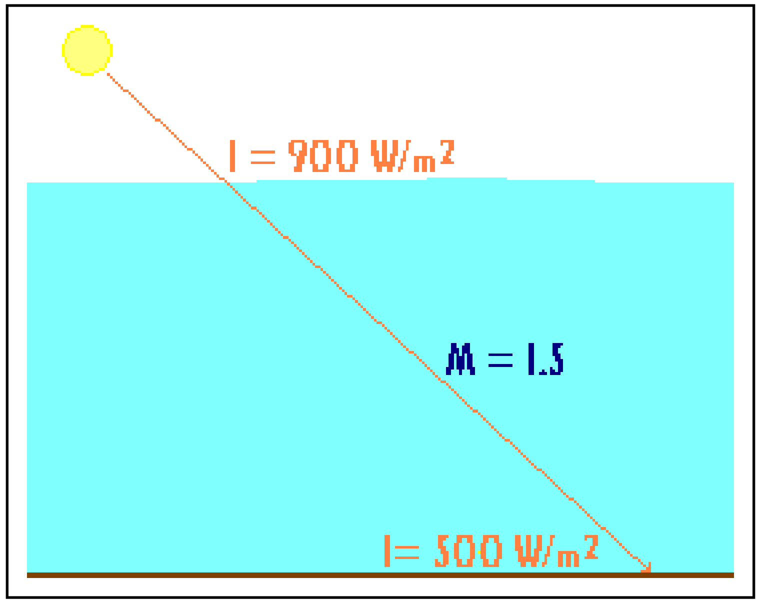
Total direct **S** can be calculated, integrating spectral contributions (among wavelengths) :

$I = \int I_\lambda\ d_\lambda$

Detail of such calculations is dependent on number of constituents, many sometimes considered. A standard simplification is representation of the primary atmospheric affects, each as 'constituents' : e.g., molecular scattering, aerosol scattering, aerosol absorption, water vapor absorption, ozone absorption, and 'uniformly mixed' gas absorption. The latter category includes many of the constituents previously mentioned. Their total attenuation is relatively small, thus calculation is greatly simplified. Affects of aerosol scattering and absorption are often combined, transmittance represented with an aerosol optical depth. Quite often the entire atmosphere is considered as a 'constituent', all **S** wavelengths simultaneously considered. I.e.,

$I = I_0 \, e^{-\tau_\alpha}$,

in which τ_α is a single atmospheric attenuation coefficient.



A person may ask how such coefficients are determined. The process is the reverse of what I just wrote - **S** must first be measured to determine coefficients. As a simple example, suppose that during a clear day, **extraterrestrial S flux** is 900 W / m^2, **direct S flux** is 500 W / m^2, and optical air mass is 1.5. Thus,

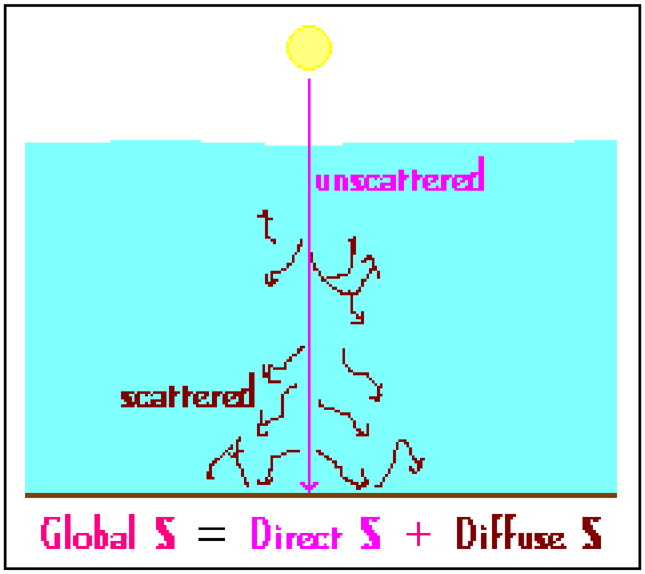
$I_0 = 900$, $I = 500$, $m = 1.5$

$I = I_0 \, e^{-\tau_\alpha} = I_0 \, e^{-\tau m}$,

$\tau m = -\,ln(I / I_0) = -ln(900 / 500) = .165$,

$\tau = .165 / m = .165 / 1.5 = .11$,

an atmospheric optical depth .11. Optical depth for specific constituents are thus defined. When considering many constituents, the problem is obviously more difficult than this simple example, since each significantly contribute at many wavelengths. The situation is more complicated for diffuse **S** flux, consisting of complex directionally-dependent scattering from air molecules and aerosols of various sizes and shapes and including ground reflection and multiple backscattering. A helpful concept though, is definition of the 3 basic **S** components -



global, direct, and diffuse. If 2 of the components can be specified (e.g., measured), the 3rd is known, a concept often utilized in practical applications. An example is the Atmospheric Radiation Measurement Program's Multi-Filter Rotating Shadowband Radiometer. Using a rotating band for shadowing direct sunlight (shadowband), it allows global and diffuse **S** measurements for 6 wavelengths, specifically chosen to yield info regarding aerosol, water vapor, and ozone attenuation. Corrections must be made for how the shadowband influences diffuse **S** measurement. Particularly, circumsolar radiation is blocked, which can be a very significant portion of diffuse. A sample of diffuse **S** distribution (actually, visible light) during a clear day nicely illustrates this. Among features you may notice are

- The circumsolar area - a very bright sky near the solar disc (which is occulted)
- The dark area at middle to high sky elevations opposite the solar disc
- Horizon brightening, caused mainly by ground reflection

From many measurements and a few clever ideas, researchers have quantified these affects, making broadband diffuse **S** estimation accurate for well-known terrain and atmospheric conditions.

Active sensing is useful for determination of clear sky **S** distribution. An example is Atmospheric Radiation Measurement Program's Cloud and Radiation Testbed Raman Lidar imager. Similarly for standard meteorological radars, a laser pulse is sent in the atmosphere, and the return signal provides info regarding atmospheric water vapor, aerosol content, and radiation polarization. The instrument is particularly useful for continuous water vapor soundings, as comparisons of LIDAR and balloon sounding data illustrate. Those are daytime measurements, including some corruption of data because of solar radiation. Nighttime images are more impressive ! Water vapor quite significantly influences clear sky **S**, its absorption occurring mainly in near infrared EM radiation bands. Clouds are sensed particularly well, but such discussion is for next week.

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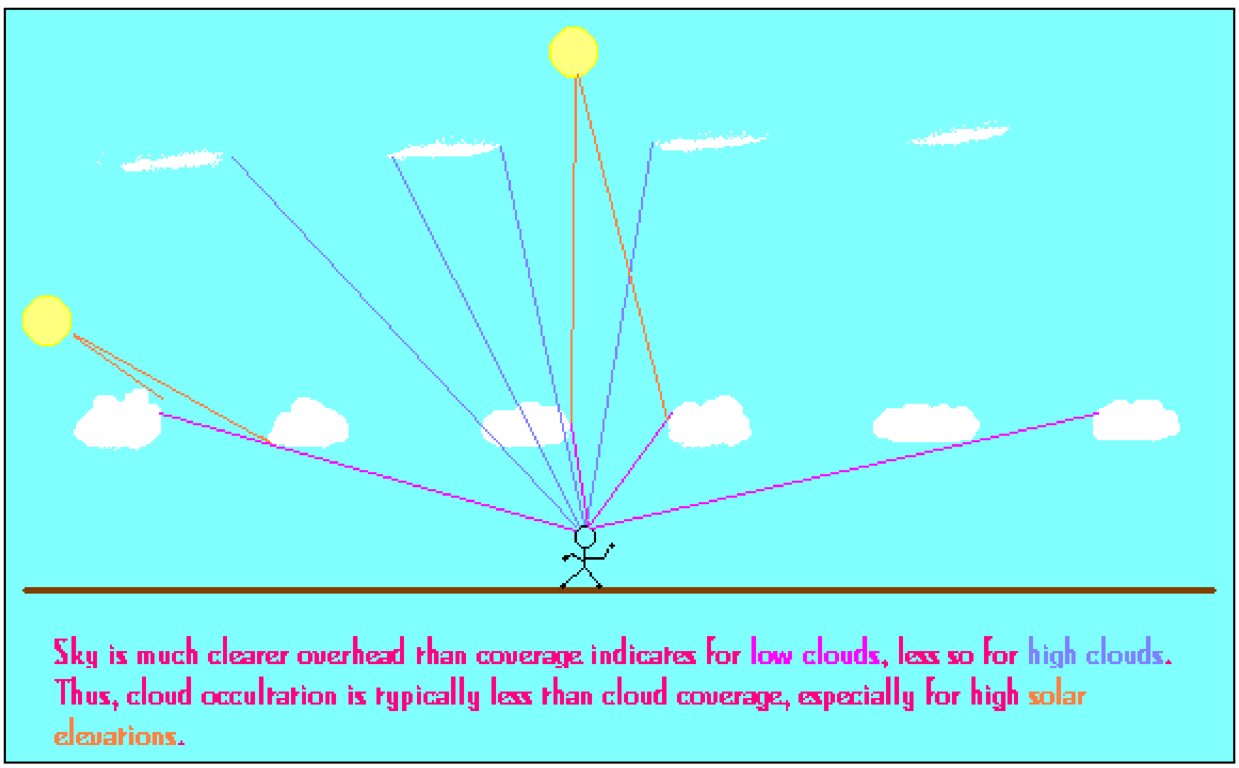
Influence of Clouds on Solar Energy

Date : 12 May 1997

Clouds influence solar energy (**S**) more than any other atmospheric constituent, and their effects are most difficult to estimate. **S** for clear skies can often be estimated within a few % of observed amounts, but estimates within 10 % for cloudy skies are good. Ice crystals and water droplets which clouds consist of scatter and absorb most incident **S**, except for very thin clouds, such that transmitted **S** is often only that which is diffusely scattered thru them in a forward direction. Rigorous cloud **S** modeling requires specification of droplet densities and distributions, and measurements are made attempting determination of typical properties of specific cloud types. After such is estimated, equations of radiative transfer can be solved. Doing so typically requires approximation of clouds as **plane-parallel** - extending indefinitely in all directions, with finite and constant thickness, liquid water content, and droplet distribution. Since real clouds are rarely so uniform, they typically reflect less **S** than plane-parallel clouds indicate. Such is better represented by fractal clouds.

I won't discuss many of the above topics (you can read more if interested). Description of bulk effects of clouds is more simple and often more practical. Consider if you wish, the problem of forecasting **S**. Assuming clear sky effects are estimated well, such requires an accurate forecast of clouds and representation of their effects. No plane-parallel or fractal clouds would pass overhead (though the latter approximates reality better), but clouds of various shapes for various durations. Methods similar to the fractal method are used to model this situation also, but I discuss a method using **cloud shadowing fraction** and **average transmittance**. If those parameters can be estimated well, so can **S**.

Most **S** penetrating our atmosphere is direct (from the solar beam), so cloud shadowing info should be specified for accurate estimation. Below I discuss topics relevant for accomplishing this.

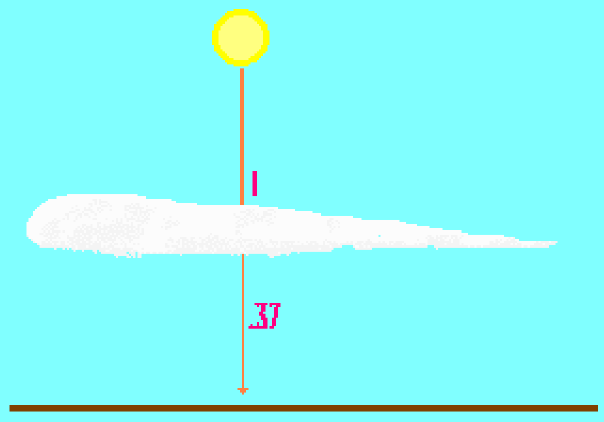


Cloud occultation implies a cloud shadowing the solar disc. A person may assume that during a time period, fractional cloud occultation would equal fractional (observed) cloud coverage, but such is rarely true. Because of an observer's perspective (on ground), clouds appear stacked along the horizon, such that they are more separated overhead than their fractional coverage indicates. Thus, *fractional cloud occultation is typically less than observed cloud coverage* - difference being greatest for greatest solar elevation angle and lowest cloud base; though typically greater with very small solar elevation angle. An equation relating these is :

$$\mathbf{Co} = (\mathbf{Cc})^{\mathbf{x}} ,$$

for which **Co** represents fractional cloud occultation, **Cc** represents fractional sky coverage (cloud coverage), and **x** is typically about 1.1 for high clouds, 1.25 for middle clouds, and 1.5 for low clouds. E.g., suppose stratocumulus clouds are observed as covering 6/10 of the sky (**Cc** = .6). If **x** = 1.6, then **Co** = .44. Though more than half of the sky appears covered, the solar disc is blocked less than half the time. Similarly as for transmittances, this is determined opposite as described - **Co** & **Cc** are measured to determine **x** which is typical for specific clouds at specific altitudes. [Whole sky imagers] are used for determination of both cloud occultation and **S** distributions under cloudy skies.

A related concept is **cloud shadowing fraction**. This is different from fractional cloud occultation, because it is fraction of direct **S** which clouds scatter or absorb. Thus it only equals **Co** for perfectly opaque clouds. If clouds are semi-transparent, some direct **S** will penetrate them.

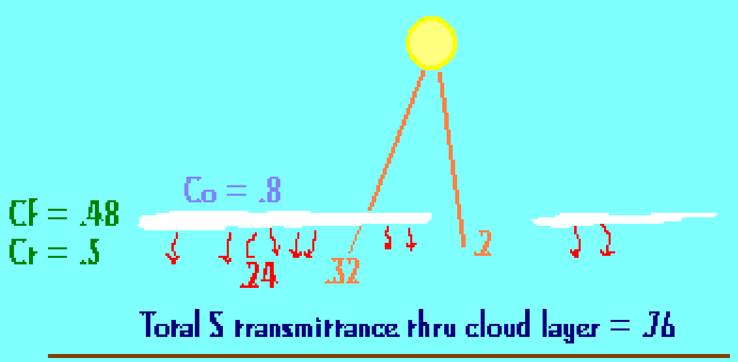


Cloud shadowing fraction is fractional scattering and absorption of the direct solar beam, .63 for the overcast sky illustrated above.

Last week, I described transmittance as fraction of incident radiation which penetrates a medium. In the simplified discussion, only penetration of a direct beam was considered. Such an approximation is not good for clouds, since most transmitted **S** is scattered thru them as diffuse **S**. **Cloud transmittance** implies penetration of all **S** (direct and diffuse). Typical cloud transmittances are :

Cloud type	Transmittance
Cirrus	.80
Cirrocumulus	.85
Cirrostratus	.69
Altocumulus	.48
Altostratus	.35
Nimbus	.11
Stratocumulus	.25
Cumulus	.26
Cumulus congestus	.24
Cumulonimbus	.18
Stratus	.15
Fractus	.33

These vary quite significantly as altitude, cloud depth and water content, and solar elevation angle do, but numbers above are a useful reference. Before anyone becomes upset, saying that cumulonimbus clouds seemingly transmit almost no sunlight, let me remind them of all the sunlight reflected to ground from their peripheries. These are average transmittance estimates. Consider if you wish, the example to the right. Suppose a semi-transparent cloud layer has fractional cloud occultation .8 and average transmittance .7 (e.g., cirrostratus). If it transmits .4 of direct **S**, its cloud shadowing fraction is .48 (it scatters or absorbs that much of the solar beam). .76 of all solar energy penetrates the cloud layer, with direct **S** penetration .52. For accurate representation of this cloud layer, .76 of all **S** must penetrate it. Thus, it can be *represented as an opaque cloud with coverage .48 and average transmittance* .5. Approximating such thin clouds as opaque clouds (regarding direct and diffuse **S** transmittance) simplifies forecasting and modeling.

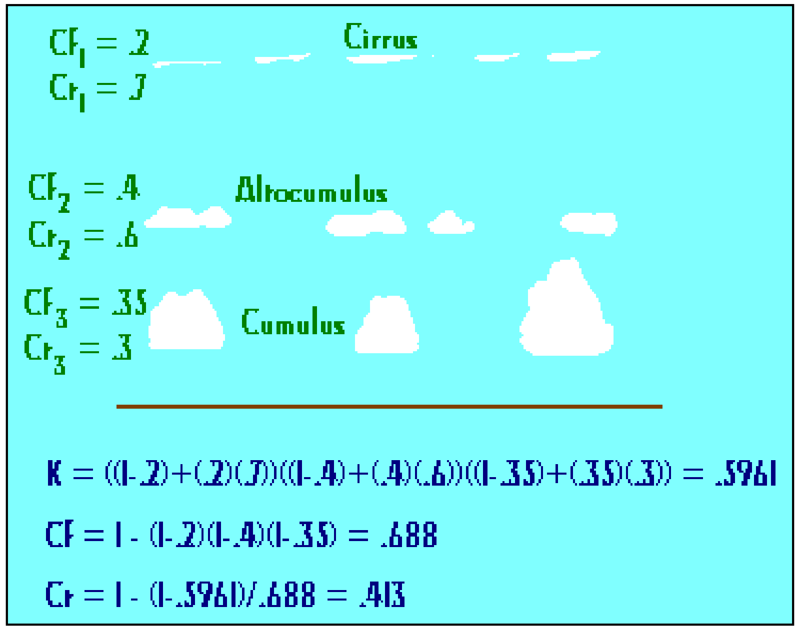


Cloud occultation is .8, average transmittance .7.

Thus, .56 of available S is transmitted thru clouds.

If the cloud transmits .4 of incident direct S, it transmits (.8)(.4) = .32 of the solar beam, thus .56 - .32 = .24 as diffuse S.

.2 + .32 = .52 of the total solar beam is transmitted, thus cloud shadowing fraction (Cf) is .48, and because diffuse S is .24 thru clouds, average transmittance (Ct) is .5.



If several cloud layers exist, a cloud shadowing fraction and average transmittance for each can be supposed, as described above. If such are randomly distributed in the sky, their combined cloud shadowing fraction (**Cf**) and average transmittance (**Ct**) can be estimated as follows :

$\mathbf{K} = \prod \{(1-\mathbf{Cf}_j) + \mathbf{Cf}_j\, \mathbf{Ct}_j\}$

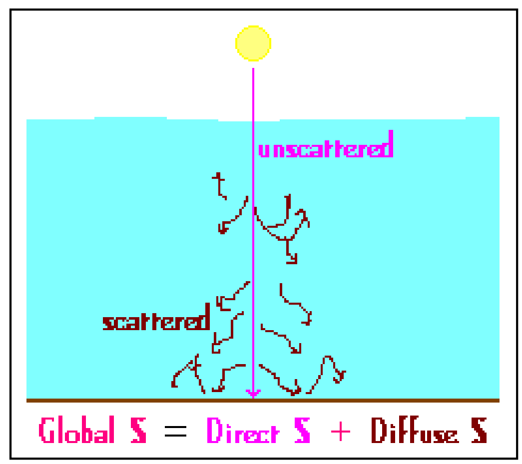
$\mathbf{Cf} = 1 - \prod (1 - \mathbf{Cf}_j)$

$\mathbf{Ct} = 1 - (1-\mathbf{K}) \;/\; \mathbf{Cf}$

for j cloud layers. $\prod$ represents a product of quantities.

Several unrealistic things are included in the above, main ones being assumptions that clouds are evenly distributed in the sky during a specific period and that transmittance of low clouds is not influenced by higher clouds. Because **S** of specific wavelengths is preferentially transmitted, low cloud transmittances are greater with high clouds above them than without. Clouds may tend to stay in one part of the sky, occulting our sun more or less than randomly. When all of such things are considered, the **magic clouds** for **S** estimation are obtained - those which estimate the radiative properties of real clouds. For the example above, **Cf** = .70, **Ct** = .46 may be the best choice. Thus, *a single cloud shadowing fraction and average transmittance* can be used as an approximation of all clouds (expected) in a sky during a specific period, which is convenient if quick and reasonably accurate solar energy estimates are required.

Magic clouds can be specified for various sky conditions using direct and diffuse **S** measurements. E.g., suppose partly cloudy skies exist, during which time clouds gradually but rather randomly drift overhead. If any 2 of the 3 main **S** components are measured during that interval, magic clouds can be specified for that period. E.g., suppose that during a period (e.g., 30 min), the following measurements are obtained under a sky of scattered cumulus and cirrus clouds :



GLB = 805.6 W/m^2 **DIR** = 629.9 W/m^2 , thus **DIF** = 175.7 W/m^2

GLB, **DIR**, and **DIF** representing average global, direct, and diffuse **S** flux respectively. Suppose that during a clear sky (determined either from measurements during time sun is unshadowed* or accurate modeling), **DIR** = 912.4 is expected for such conditions. Thus, during the period

Cf = 1 - 629.9 / 912.4 = .3096 ,

and a broadband **S** model can then be used to determine what **Ct** is necessary to produce **GLB** = 805.6 during the period with such a **Cf**. Such a model may indicate **Ct** = .3257, for example.

Thus, **S** measurements can be used for specification of typical cloud shadowing fraction and average transmittance of various cloud types. Using a cloud forecast, parameters **Cf** & **Ct**, determined as illustrated above, can be inserted in a **S** estimation model.

*When doing so, care should be taken that no significant augmentation occurs because the solar disc is near the edge of a cumuliform cloud (probably because of reflection off the cloud edge). Near solar noon, I've briefly measured global **S** fluxes as great as 1357 W / m^2 - more than the extraterrestrial amount !

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Terrestrial Solar Energy Applications

Date : 20 May 1997

Unfortunately, the story of solar energy (**S**) applications is one of high cost and low efficiency Inexhaustibility, and cleanliness also though Some use the majority of available **S**, but for others, system efficiencies of nearly 10 % are sometimes considered good. The most common methods of terrestrial **S** use are solar thermal, photovoltaic, and simple air heating. Solar thermal is a term for use of **S** for heating fluids. Parabolic mirrors and reflectors are often used, with a pipe filled with fluid at its focal point. Distribution of **S** components (discussed in previous features) is a consideration because only direct **S** energy is efficiently collected using this method. Thus, a reason for considering cloud occultation, shadowing fraction, etc. for forecasting this. System efficiencies can be quite large, dark pipes absorbing most incident **S**. Photovoltaics is a term for semi-conductors which convert **S** to electricity. When exposed to **S**, electrons flow across the surface of solar cells. System efficiencies are very small though, only seldom greater than 20 %. Efficiencies of typical silicon-based solar cells are 10-18 % (most at the low end), and galluim arsenide solar cells 18-24 %. Thus, when researchers speak of breaking solar cell efficiency records, such is analogous with running a quarter mile during about 42 sec while a drag racer can do that in about 6 sec Peak absorption for solar cells is for near infrared electromagnetic radiation (about .8-.85 µm), very little absorption of blue (thus diffuse **S**) occurring. Solar air heating is achieved by exposing dark walls to solar energy, a method which can be used for much more than heating air. This is largely efficient because such materials absorb **S** well.

When solar power is mentioned, residential applications are often thought of. Other **S** applications include solar ponds, in which algae develops during warm and sunny conditions (which can be used as fuels), lights, radios, appliances, and personal computers. The most logical application (though requiring plenty energy) is solar air cooling. Unlike for solar air heating, **S** is most available when cooling is desired. Being completely free from external energy sources is possible (though presently rather expensive). Well-designed systems can provide as much power (main site) as would otherwise be required. I don't discuss these applications much, but abundant WWW resources exist.

I discuss topics I've been more involved with, e.g., geometry and estimation of **S** collection. Photovoltaic arrays consist of solar cells, typically grouped in a module. Each module is typically about a half square meter, though sizes greatly vary. Typical terrestrial solar arrays are only slightly more that 10 % efficient, such that a .5 m^2 array converts about 60 W with an incident **S** flux of 1000 W / m^2. Such a **S** flux with a standard spectral distribution, optical air mass 1.5, and 25 C temperature is called standard test conditions, which can be simulated and used as a reference for solar cell and array characterization. It is so called, because it approximates typical Summer midday conditions at midlatitudes. E.g., if a solar array module is rated at 60 W, such is approximately the energy obtained under typical sunny conditions facing a direction generally toward our sun. Collection is often worse, though tracking arrays can collect close to their rated amount for several hours during a day. If a solar array must be stationary, it is best if tilted equatorward at a slope angle approximately equal to the noontime solar zenith angle. If it must be stationary during an entire year, a slope angle equal to the local latitude is approximately best. Reflection of surroundings, mirrors, etc. should also be considered, and such affects can be modeled for various sky conditions, and averages obtained using climate data for specific time periods (e.g., a week, month, or year). Such data is available from the National Renewable Energy Lab, though a user should be aware that data for most locations is estimated using correlations with weather data from other sites. Such estimation is not always accurate, and the site includes discussion of such issues.

Perhaps the most exciting solar energy applications involve transportation. Solar boats have been constructed, some of which circumnavigate, and solar cars have been built and raced. I believe the first solar car race was the Tour de Sol in Switzerland during 1985. During 1982, Hans Tholstrup constructed and drove a solar car, Quiet Achiever, across Australia, from Perth to Sydney. During that time, he began envisioning a race for such vehicles across Australia, which became the World Solar Challenge (WSC). It involves professional, university, and high school teams, and is raced on a 3010 km route in the beautiful Australian desert from Darwin to Adelaide during the Southern Hemisphere Spring (late October or early November). The race is during a time of year before heat becomes awful, but temperatures can be more than 100 °F at northern locations not near shore. Rules, dates, and related info can be obtained from race organizers. You may notice that the race route is chosen such that cars go poleward, mostly with the sun at their backs (the noon solar beam is approximately directly over Katherine that time of year). Such increases solar energy collection for car's arrays, most which which slope backward for aerodynamic smoothness. Northern Territory University's entire solar car tilted sideways for increased solar energy collection during the 1993 race ! The first WSC was raced during 1987, won by GM's Sunraycer. A part of the Stuart Highway (the main race route) in the Northern Territory was not yet paved then - a tire change being required entering & exiting it ! Paul MacCready greatly contributed to its design and construction, and George Ettenheim (then from AeroVironment) to the Sunraycer Team's efforts with weather, logistic, and strategic info. The race has recently been dominated by Japanese teams, Honda's Dream winning the previous 2 races, requiring only 4 9-hour days with a few media stops during 1996. The main reason for absence of North American teams among the leaders is differing race regulations between the WSC and Sunrayce, which only allows terrestrial grade solar cells and lead acid batteries. Most collegiate teams can't afford a million dollar solar array for the WSC !, and corporate teams have not recently entered.

Another race planned to commence about a month from now is Sunrayce. Established with large contributions from the U.S. Department of Energy and General Motors, it involves collegiate teams from North America. The present race is a 10-day event from Indianapolis, IN to Colorado Springs, CO. University of Michigan won the first 2 races, during which I was a fortunate participant (and our WSC teams which finished 3rd & 11th). Though the 1990 Sunrunner was very well designed, our 1993 Maize & Blue was particularly aerodynamically smooth and shaped well for solar energy collection, and well-engineered, though a few problems existed. Perhaps I'll include more info regarding this (particularly solar energy estimation) as a much larger separate feature ☺

The Winston Solar Challenge is a race for high school students, and was developed with a more educational than competitive philosophy, though it is also becoming a road race as those previously mentioned. Maybe someday they'll win the WSC ☺

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U.S. Weather Forecasts on the WWW

Date : 2 June 1997, revised 11 September 1999

Purpose

A question once posed to me regarding a site where these articles once were was "Yeah ! - but where do I get weather forecasts ?"). Today (2 June) I asked a person where on the WWW a weather forecast described to me was obtained. The response was 'I just started clicking on things...'. So perhaps describing this seemingly obvious task is a good idea. Many WWW sites include weather forecast info - most from the National Weather Service (NWS), but many from media and other sources. Below I describe only United States (U.S.) weather forecasts, being most accustomed with it. Perhaps I'll describe foreign info some future time, but it is less abundant on the WWW. I'll only describe sources from which such info is free, though several paid subscription services are available.

If you are in the Poconos, I (of course) suggest you use my forecasts, and compare them with others if you wish. Though I am only 1 man doing his best (fighting the good fight), I have no imposed time or format restrictions and generally change them when they become significantly inaccurate (though obviously can't *always* do so).

NWS Forecast Products

Among information publicly available (and most others), I think the National Weather Service's (NWS) is generally most accurate and reliable. Too bad if this seems like an advertisement; but it is what I've observed, and is part of what tax dollars pay for. They include forecasts to 5 days in advance. The NWS products people are most familiar with are short-term, zone, and state forecasts. **Short-term forecasts** are also called **NOWCASTS** (example), and must be very current if useful. Detailed descriptions of weather at local areas for the next 6 hours or so is included (during active weather) - sometimes for specific locations. **ZONE forecasts** (example), made for specific state zones (example), include a **1-2 day forecast and a (extended) 3-5 day forecast**. The 1-2 day forecasts are **daily forecasts** of the type most people are familiar with, which include a general description of precipitation (and a probability estimate), temperature, cloudiness, and wind. The 3-5 day forecasts are not so site-specific, and are usually the same for a small state or large portions of a large one. They are similar with the extended forecasts included in **STATE forecasts** (example). These include a general description of precipitation, cloudiness and temperature for a state, or particular sections for large ones. These 3 products form the basis of weather forecast info, and will be adequate for many user's wishes. Many people also like seeing current observations with the forecasts, though if weather at your location interests you, you can already see much of those 😉 Supplemental products include special weather statements, advisories, and severe weather watches and warnings. These products can be the most desired and relevant. One of many NWS sites at which interpretation of each of these products in their many forms is described is the San Francisco forecast office (I chose this because of good organization and detail of descriptions included.).

Sources for NWS Forecasts

So if I am making such a big deal of official forecasts, where are they obtained ? A direct source for NWS forecasts is the Interactive Weather Information Network. Though the acronym IWIN claims some sort of victory I am unaware of, among its advantages are that info is quickly obtained, and usage requires no special meteorological knowledge. You can see the current forecasts, with weather summaries and many other products. Active warnings (though the WWW is not so reliable for time-sensitive warnings) are easily accessed using their graphics page. Sites for local NWS offices also include this information, though I am not sure if as quickly available.

Among many other sources for official weather information, University of California at Davis has a site including official U.S. forecasts and much other information. Similar info can be obtained from University of Michigan's Weather Underground, including current conditions (though they should clearly mention sources for the official forecasts shown). Ohio State University's Weather By State includes many of the products described above and more. A similar menu for States is included at College of DuPage's NEXLAB site. Its fine organization makes use very convenient and efficient, with times of weather products shown next to their links. Another excellent site for NWS forecasts and much other text info is the Texas A&M's Weather Interface. Using it requires a 3-letter station code or 2-letter state ID, but it is a very quick and convenient source for **many** types of weather data.

Commercial and Unofficial Sources for Forecasts

These sites include abundant weather info for the U.S. and worldwide. Weather forecasts can be obtained at each of the major commercial & media sites, e.g., CNN, Intellicast, USA Today, and The Weather Channel. Here is an example of a city forecast for Mount Pocono, PA or the nearest location from each of those, respectively (1) (2) (3) (4), though many other products are included, with descriptions. The Weather Channel's include the NWS zone forecast, which they consdier a "detailed forecast".

More info can often be obtained from local sites, mainly media or academic, some including quite interesting weather descriptions. Many exist, likely at least one for your area (in U.S.). Too many exist to list here, but a site particularly useful to locate these along with regular net resource sites and search engines is WeatherNet's site listings. Though not implying these examples are representative of all of such sites, examples are WBRC weather (from a TV station) and Lancaster Area Forecast (from Millersville University's Meteorology Department). Such pages can sometimes include specific locally-relevant information you won't see elsewhere, though *should* always include the time a forecast was issued.

Summary

You can conveniently access NWS forecasts using the Interactive Weather Information Network or The Weather Underground, and the NWS San Francisco link for interpretation of products, you can access weather forecasts from major media sites, some of which are mentioned above, which include descriptions of their own products, or you can access local weather forecasts mainly from media or academic sources, using search engines and/or WeatherNet to locate those for a location of interest. That is a sufficient answer to the question originally posed, but later I plan to discuss ways you can be your own weather forecaster.

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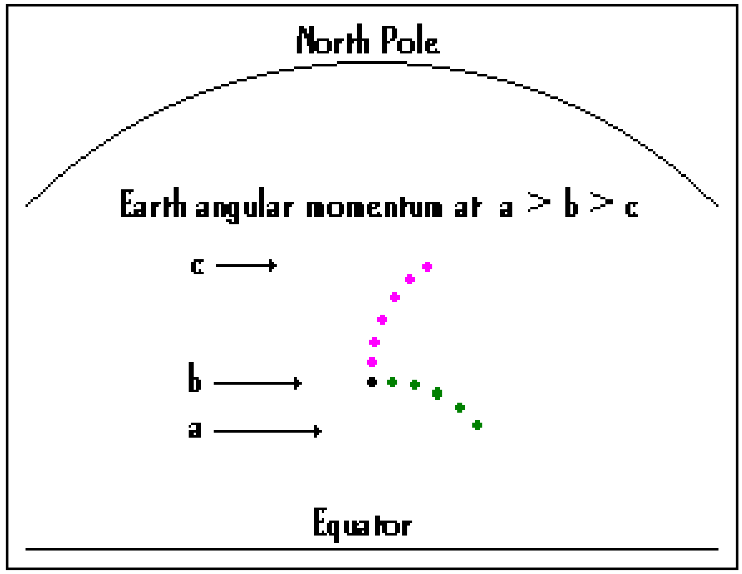
A few Southern Hemisphere Weather Analysis Topics

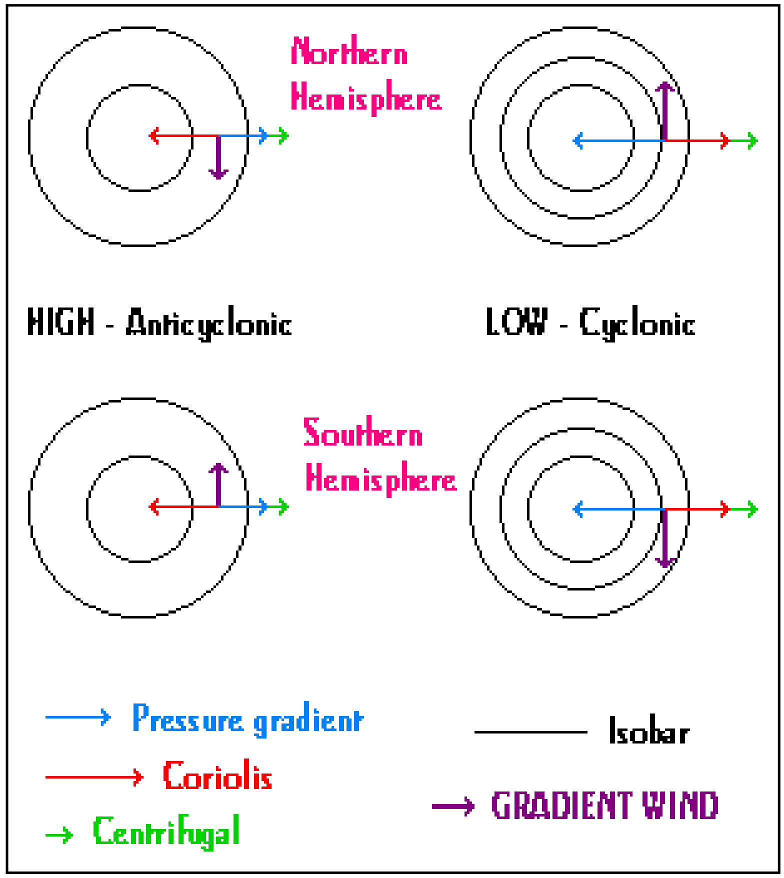
Date : 10 June 1997

We live in a Northern Hemisphere-biased world, because much of our early population resided there. Thus, North Pole at the top of a map, South Pole at the bottom; which is fine until you consider things with no such preference - e.g., processes such as weather. Looking down on the North Pole, our earth rotates counterclockwise (as many things do - almost everything except clocks ☺) Among consequences of this rotation is apparent deflection of moving objects relative to our quasi-spherical, rotating Earth. The reason for this is **angular momentum conservation**. Such can be illustrated doing the following experiment : Quickly spin a wheel in the middle of a rod holding it, with the wheel rotating vertically. Sit on a stool which can easily rotate. Turn the wheel sideways, such that it spins horizontally. If the wheel spins clockwise, the stool spins counterclockwise (much slower, with a heavy person on it); and vice versa - conserving angular momentum. Similarly, an object moving poleward in the Northern Hemisphere is deflected eastward (magenta), because our earth moves fastest relative to its rotation axis at the equator, decreasing to no motion at the poles. More angular momentum further south (**b**) than north (**c**), thus when the object moves north, it deflects east because it has additional angular momentum our earth does not have. Similarly, an object moving eastward (green) deflects south, again conserving angular momentum.



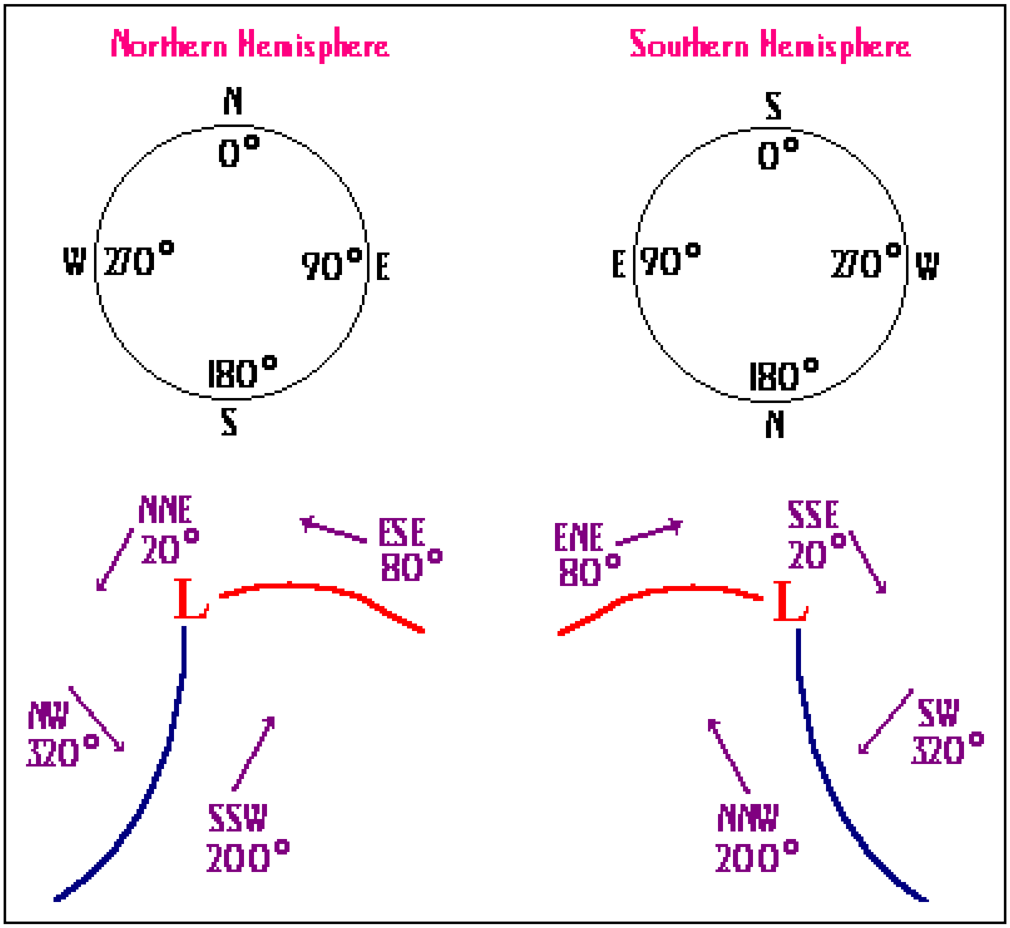
An object deflects to the right of its direction of motion in the Northern Hemisphere for all situations.

Similar arguements illustrate that moving objects in the Southern Hemisphere deflect left of their direction of motion. An apparent force can be imagined causing such, which is often called the Coriolis force.



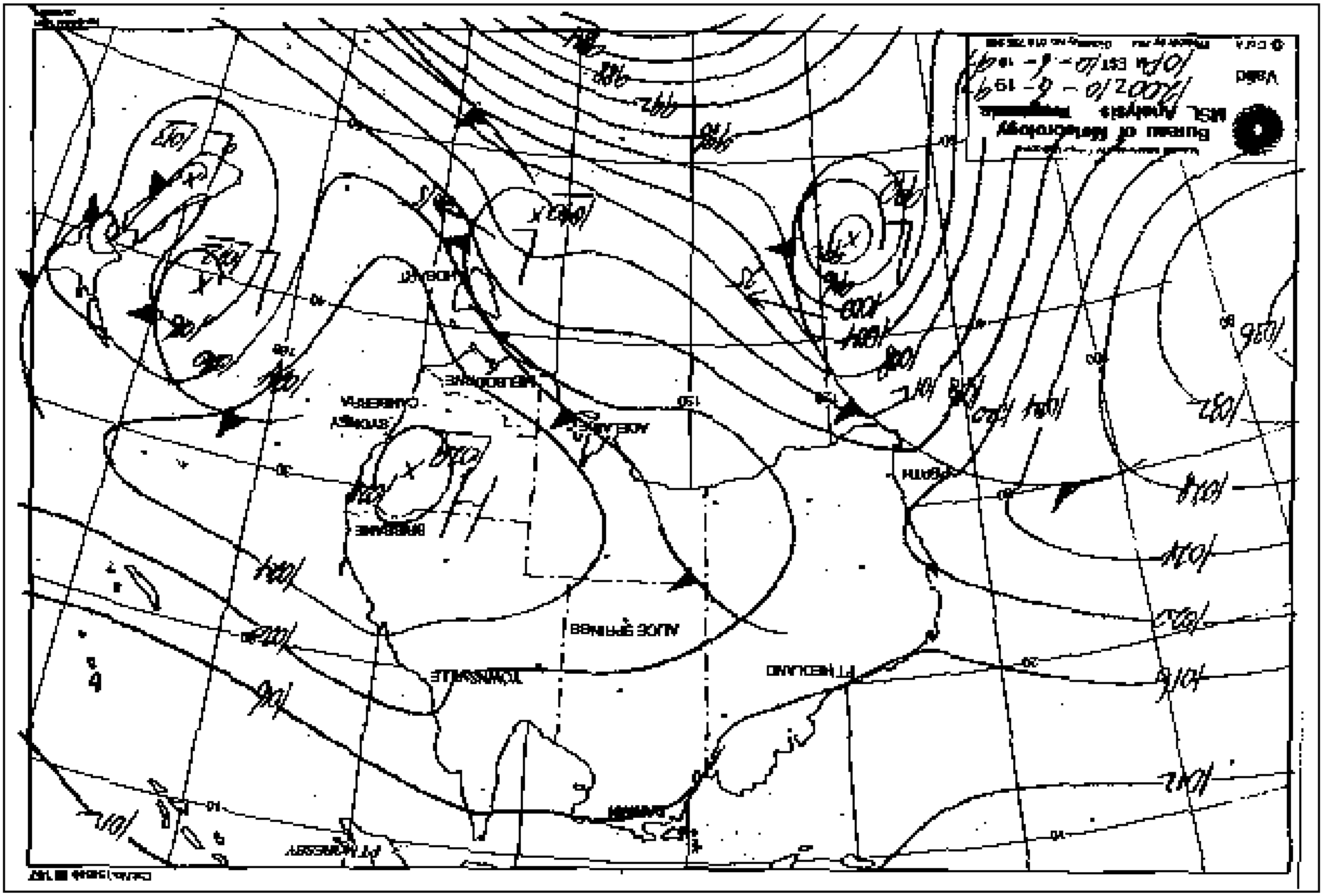
When considering air motion, the only 3 real forces on air are **gravity**, **pressure**, and **friction** forces. The Coriolis force is imaginary, and a centrifugal force can also be imagined because of a tendency for air to remain moving straight in curved flow. Neglecting friction and assuming gravity is exactly balanced vertically with bouyancy (hydrostatic balance), consequence of balance of the remaining forces is the **gradient wind** meteorologists often speak of, which is illustrated for the Northern and Southern Hemisphere.

A consequence of the 'Coriolis' deflection is a balance such that winds flow in an opposite sense around High and Low pressure areas in either hemisphere. For similar pressure gradients, an anticyclonic gradient wind is faster than a cyclonic one because pressure gradient *and* centrifugal forces balance Coriolis force (proportional with gradient wind speed) for that situation.



Because of the opposite rotation, weather maps appear different for each hemisphere. For example, [Southern](#) and [Northern](#) Hemisphere surface analyses. The weather is basically same wherever on this planet you may go, only the mathematical magnitudes changes (regarding vorticity, etc.). If we place the Pole at the top of Northern Hemispheric maps, then why not do so for Southern Hemispheric ones also ? Such is a more natural depiction, but you'll see that standard Southern Hemispheric maps are *upside-down*. Because of the opposite air flow, circulation is illustrated similarly to the Northern Hemisphere, except for the fact that mid-latitude weather mainly moves from right to left instead of left to right (which many people read anyway), because upper air winds tend to blow from the west in either hemisphere, with low pressure north and high pressure south :

With the South Pole on top (example map for 10 JUN, 12 UTC from [Australian Bureau of Meteorology](#) :



pressure systems, fronts, etc. all appear same as for the Northern Hemisphere. So why isn't this done ? If the South Pole is defined as 0 degrees, positive counterclockwise (opposite the Northern Hemisphere), winds from a specific direction have similar meteorological significance, as illustrated.

Some maps include the Pole in the center, which is unbiased, but impractical for local, non-polar regions. So everyone should now begin printing 'upside-down' maps ☺

Home Page

A Weather Forecasting Menu

Date : 17 June 1997, occasionally updated

The WWW is filled with abundant sources of weather information, but this can be a blessing or a curse. Though having so much information available is nice, only a small amount will likely interest you any particular time. In this article, I present a simple, compact menu which allows me to access the basic information I use for making a weather forecast very quickly and efficiently.

The menu is very simple and contains necessary information for a semi-experienced weather forecaster to forecast effectively using the WWW. No graphics or anything unnecessary are included (though some things can be *added*). Using this menu (or a similar one designed for your location of interest) requires familiarity with basic and some sophisticated meteorological products, but anyone interested about weather can probably use portions of it effectively. It was designed with a basic philosophy of emphasizing current data in mind. **When I make a weather forecast, I tend to examine data in the following order** :

1. On-site observation
2. METAR and other surface observations
3. Satellite and radar images
4. Sounding data and upper air charts
5. Weather watches / warnings, special weather statements
6. Weather summaries and forecast discussions
7. Numerical model output
8. NWS and other forecasts (NOW, Zone, State, etc.)
9. Numerical model maps (NGM, RUC, AVN, etc.)
10. Other information

A reason for this is that observed data is what interests me (i.e., what will the observed data (i.e., weather) be at some future time ?), so it is what I emphasize. In the menu, links for surface observations are included first, then radar & satellite images, surface & upper air plots, skew-T diagrams, NWS forecast and warning info, numerical guidance products, and model forecasts. I actually don't particularly emphasize skew-T diagrams because although they can be very important, the atmosphere can greatly change from observation time. Thus, more recent (though neither as accurate nor always available) satellite soundings or programs which allow a user to manipulate observed sounding data are preferable.

I don't mean to underemphasize official forecasts & warnings - especially the warnings should be given close attention. Yet the purpose of this menu is making a forecast yourself - to the greatest extent you are comfortable with !

Links are chosen for best possible view of weather likely to affect the Pocono Mountains region. Now a further description of the menu and reasoning for its construction.

`SFC :  PA-E  PA  NY  NJ  MD  OH  VA  DE   FSL      DATA :  TAM  SUA  UCD  IWIN  FSU`

The SFC heading is for surface data. The first link is surface reports from the PA Department of Environmental Protection. Next, the most recent METAR (surface) observations are listed for nearby states from the College of DuPage site. The DATA heading is for various forms of data. I can't describe all of what's available, but you can get most meteorological text data & products at these sites - browse to see what's available.

`RN :  DIX  BGM  CCX  PBZ  DOX  LWX  BUF  DIXA  BGMA  CCXA   REG  REGA  CUS  CUSA   NE`

NEA
RT : DIX BGM CCX PBZ DOX LWX BUF DIXA BGMA CCXA REG REGA RNE RNEA CUS CUSA
RI : DIX BGM CCX PBZ DOX LWX BUF DIXA BGMA CCXA RN RNA RS RSA CUS CUSA

Radar images. Links in the first heading (RN) are from the the NWS and a regional image and animation from Unisys Weather. Those in the next heading (RN) are from WeatherTap, which requires a small subscription fee. Though those from the NWS are free, I like some of the views WeatherTap provides and their animations load quicker - though their NEXRAD images have an uncanny ability of being 10-15 minutes late only when storms pass our region. Links in the last heading are images from Intellicast.

The first set of links for each (7) are NEXRAD base reflectivity images, the next set (3) are animations for radars nearest the Poconos, and the next set are regional and continental U.S. composites and their animations. These sites have other types of images I occasionally use such as radial velocity and precipitation amount estimates not included here.

SI : BWIV ALBV DTWV CUSV BWII ALBI DTWI CUSI CUSW NEV NEI CUW GVIS GIR GWV
SA : BWIV ALBV DTWV CUSV BWII ALBI DTWI CUSI CUSW NEV NEI CUW HRVT

Satellite images. The SI heading is for images, SA for animations - each for the same regions. Though because it fits better there, I include the high resolution visible image from WeatherTap (HRVT) with SA.

The first set of links is from UCAR. The first 3 links are high-resolution visible regional images, the 4th for the continental U.S. The next 4 links are infrared images for the same regions. The 9th link is a water vapor image - only available for the continental U.S. UCAR also has images using other bandwidths - those I include are only those which I use most often. The next set of links is from Unisys - NE U.S. visible & infrared images and the continental U.S. water vapor image. The last set of links is from NASA's Global Hydrology and Climate Center. Note that these links are not included with the animation group because you must specify whether you want an image or animation. I tend to avoid images with colorized backgrounds, because this sometimes can only be done with a loss of data - i.e., some shades are assumed as ground though are clouds (or vice versa).

SP : NE SE MW EC CUS ALB BWI DTW S-T : IAD BUF PIT WAL OKX ALB SL LI/PW

The SP heading is for surface plots. The first set is regional & continental U.S. maps from Unisys, and then next regional views from UCAR's Real-Time Weather Data site. Charts from each site has its advantages. Sea level pressures are plotted on the Unisys ones, which provide a wider scale view. Altimeter settings are plotted on UCAR's, which provide a more narrow scale view but greater station density. When I want to see all data, I use the FSL link in the SFC section. As for many other links here, the root site of this - NOAA's Forecast Research Division - has abundant information. The S-T heading is for skew-T, log P diagrams. The first 5 are for nearby locations, the next link the satellite derived soundings mentioned above, and the final link the lifted index & precipitable water chart from the collection of NWS fax charts (you may prefer this index). They have surface charts and other information also - though this particular chart is better than most others of the same type on the WWW because it shows the values at sounding locations - not simply contours using these. These require a TIFF plug-in or viewer.

SEA : SST OSD GLT UAN : 850 700 500 500P 300 200 UAU : 850 700 500 300 200

The SEA heading is for sea and lake surface data. SST shows nearby sea surface temperatures and other ocean features from the NOAA's Office of Satellite Data Processing and Distribution (OSDPD), OSD includes various sea surface charts and offshore data from Penn State University, and GLT Great Lakes temperatures from NOAA's Coast Watch.

The headings UAN & UAU are for upper air plots from the NWS & UCAR sites. The 850 is an 850 mb chart, etc. The 500P is a polar stereographic Northern Hemisphere 500 mb chart - so the mid-tropospheric global wave patterns can be seen.

NWS : NOW ZONE STATE AFD-E AFD-C CLI-S CLI-A WARN SWS 12/24 36/48 3-6 6-10

NWS forecast, warning, and climate information. The first set of links is for the most commonly used NWS text products - NOW, ZONE, & STATE forecasts, area forecast discussions from the offices in Mount Holly, NJ (E for east PA) & State College, PA (C for central PA), climatic summaries for Avoca & Allentown, then those goofy warnings & special weather statements ☺ The next set of links are forecast charts ranging from 12 hours to 10 days.

NG : EFOU NFOU NMOS AMOS MMOS MISC : RUC20 EPRO READY NCEP

The NG heading is for numerical guidance products. E refers to the ETA model, N the NGM, A the AVN, and M the MRF. FOU refers to the FOUS product, MOS the MOS. Thus AMOS is the MOS product derived from the AVN. Note that AVN & MRF MOS are the same for day 3 - the 3-day AVN is used for the MRF (medium range forecast) version of the global spectral model. For the MOS products, I link to those from AVP (Avoca). The ABE (Allentown) is probably better for low areas SE of the Poconos. These are linked to from Ohio State University's PA page.

The MISC heading is for miscellaneous model charts and data. RUC20 is charts the experimental 20 km RUC model. This can be very helpful during snowstorms other other events. Using the most recent data, it can often forecast features the standard models don't. EPRO are model soundings from the 40 km ETA and READY is the NOAA page from which the soundings (for many other models also) and much other current model data can be accessed. A problem with this can be too much instead of too little information. NCEP links to their model page. When new model forecasts are available, and they'll be so here before anywhere else.

ETA : SFC 0 SFC 6 SFC 12 SFC 18 SFC 24 SFC 30 SFC 36 SFC 42 SFC 48 SFC 54 SFC 60
RHL 0 RHL 6 RHL 12 RHL 18 RHL 24 RHL 30 RHL 36 RHL 42 RHL 48 RHL 54 RHL 60
PREC 850 0 850 6 850 12 850 18 850 24 850 30 850 36 850 42 850 48 850 54 850 60
SNOW 700 0 700 6 700 12 700 18 700 24 700 30 700 36 700 42 700 48 700 54 700 60
500 0 500 6 500 12 500 18 500 24 500 30 500 36 500 42 500 48 500 54 500 60
2AG 0 2AG 6 2AG 12 2AG 18 2AG 24 2AG 30 2AG 36 2AG 42 2AG 48 2AG 54 2AG 60

NGM : SFC 0 SFC 6 SFC 12 SFC 18 SFC 24 SFC 30 SFC 36 SFC 42 SFC 48
RHL 0 RHL 6 RHL 12 RHL 18 RHL 24 RHL 30 RHL 36 RHL 42 RHL 48
PREC 850 0 850 6 850 12 850 18 850 24 850 30 850 36 850 42 850 48 STA
700 0 700 6 700 12 700 18 700 24 700 30 700 36 700 42 700 48

500 0 500 6 500 12 500 18 500 24 500 30 500 36 500 42 500 48

AVN : SFC 0 SFC 12 SFC 24 SFC 36 SFC 48 SFC 60 SFC 72 SFC 84 SFC 96 SFC 108 SFC 120
RHL 0 RHL 12 RHL 24 RHL 36 RHL 48 RHL 60 RHL 72 RHL 84 RHL 96 RHL 108 RHL 120
PREC 850 0 850 12 850 24 850 36 850 48 850 60 850 72 850 84 850 96 850 108 850 120
700 0 700 12 700 24 700 36 700 48 700 60 700 72 700 84 700 96 700 108 700 120
500 0 500 12 500 24 500 36 500 48 500 60 500 72 500 84 500 96 500 108 500 120

ETA, NGM, and AVN model forecasts for Surface, Relative Humidity, 850 mb, 700 mb, and 500 mb from Unisys & University of Wisconsin. Links are also included for total precipitation & snow (PREC, SNOW) and model status (STA). Unisys provides an excellent explanation regarding use of these charts. When using those for ETA & NGM, please be aware that the SFC plots show 6-hour precipitation for hours 6, 18, 30, & 42, but 12 hour values for hours 12, 24, 36, & 48. Note that some AVN charts are from Unisys and some from University of Wisconsin. I prefer the Unisys because they fit in a normal 800×600 screen, but do not go past 72 hours. All of the AVN and many other charts can be obtained from Wisconsin's site (for some reason, their menu does not currently link to any AVN images past 72 hours either, though they have them).

I download successive model images using FlashGet and then animate those I choose manually at the rate I wish using ACDSee. I usually use the Unysis & CMC ones, though the NCEP are available first and their extended ETA goes to 84 hours and AVN to 126 hours.

REG 00 : 0 12 24 36 48 REG 12 : 0 12 24 36 48
GLB 00 : 0 12 24 36 48 60 72 84 96 108 120 144 168 192 216 240
GLB 12 : 0 12 24 36 48 60 72

PTP 00 : 12 18 24 30 36 42 48 WYO : ETA NGM AVN RUC
PTP 12 : 12 18 24 30 36 42 48 MRF9 : 9P

These are primarily Environment Canada spectral model forecasts. REG are those with the regional configuration and GLB with the global configuration, 00 for the 00 UTC run, 12 for the 12 UTC. PTP are detailed winter weather charts. Though large & small map versions are available for all time periods, I usually like the large ones for the winter charts and for the initializations on which examination of details may be important, but the smaller ones for forecast periods on the standard charts to save time. The only difference for links is the _50 for small charts & _100 for large ones in the URL. The WYO header is for model images from the University of Wyoming. A nice feature about these charts is that you can choose various parameters that are unavailable from other sites. For example, you can plot 850 mb relative humidity for the possibility of low level cloudiness even if the 850-500 mean relative humidity is low. MRF9 is the 9-panel (9P) MRF from Unisys, providing little detail but a basic view of the forecast weather patterns.

4P : ETA : 0 6 12 18 24 30 36 42 48 54 60
NGM : 0 6 12 18 24 30 36 42 48
AVN : 0 12 24 36 48 60 72

These are 4-panel charts of most of these same ETA, NGM, & AVN charts above. Though showing different parameters and less detail, this is good if you want to see the complete model run quicker.

MRF 1 : 0 ½ 1 1½ 2 2½ 3 3½ 4 4½ 5 5½ 6 6½ 7 7½ 8 8½ 9 9½ 10
MRF 4 : 0 ½ 1 1½ 2 2½ 3 3½ 4 4½ 5 5½ 6 6½ 7 7½ 8 8½ 9 9½ 10

Medium Range Forecast model forecasts from Unisys - single panel (MRF 1) & 4-panel (MRF 4) charts. These provide more parameters and detail than the 9-panel chart, but require much longer to download.

When forecasting weather, I use different links according to different situations. For most, examining surface data (SFC) first is a good idea, to see current conditions. If precipitation is a concern, I next examine the radar (RT, RN, RI) links (if in a hurry, perhaps first), and for many situations the satellite (SI, SA) links. This provides a good 3-D impression of the atmosphere, and how it may be changing. I examine the local NEXRAD images and animations (most often DIX & BGM, but perhaps CCX if echoes are moving consistently from the W or DOX if northward). I tend to view the regional radar images and animations to see larger scale precipitation movement and development. The 700 mb chart (or sometimes 500 mb) can indicate precipitation movement also. 700 mb can often be thought of as a steering level for precipitation cells, and vertical air motion there indicates cloud and precipitation development. 500 mb can often be thought of as a steering level for storm systems, and vorticity can be used to determine development - particularly its advection (thermal vorticity advection is often better). Often I will then look at the numerical guidance data to obtain objective forecasts, free from influence of human opinion (other than the fact the we program the models ☺). I next view the relevant NWS info. During storms, the NOW forecast is helpful. The ZONE forecast is often helpful for the near future, and warnings (WARN) and special weather statements (SWS) should be heeded, and often contain local storm information more useful than NEXRAD imagery. Next, I'll examine model forecast images. Because so many are available, I may indeed use most of my time doing this. An advantage of the CMC charts is that the 00 UTC product contains a forecast for the next 240 hours (10 days !) - available sooner than the MRF. For NGM & ETA forecasts, I most often examine SFC and RH panels, focusing on time periods which interest me and maintaining continuity. This gives a good idea of cloudiness and precipitation expected, and development of surface Highs and Lows. The model forecasts can often be compared with observed weather developments to make further forecast adjustments. I can write much more regarding this - perhaps for another article. Other images have special uses. 850 mb forecasts indicate temperature near lower parts of clouds during snowstorms, helpful for determining precipitation type, though sometimes the atmosphere can be colder than freezing at 850 mb, but warmer than freezing between that and 700 mb (or above). So looking at the 700 mb forecast temperatures and (model) soundings may be very helpful. Though I do not include 300 mb forecasts in the menu, they are available - simply replacing the "500" with "300" in the appropriate links. These can be helpful - similar concepts often considered for 500 mb analysis are often just as relevant and applicable as for 300 mb. The 2AG ETA panels provide a "perfect prog" temperature forecast - which can be quite useful, though often require adjustments for mountainous regions. Only if weather more than a few days in the future interests me do I examine the MRF forecasts.

Hopefully you can understand how this menu helps me to forecast weather effectively using WWW information and the 10 topics for emphasis previously mentioned. The basic method described above must be modified for specific situations, and data not included can be quite helpful also. Thus, I use this menu as my browser Home link and bookmark other desired data the menu does not include. I can usually use this menu & the techniques described to effectively make a forecast in 20-30 minutes, because it is designed for maximum efficiency. Perhaps I can suggest links for a similar menu for you, and you may certainly download & modify it for your purposes.

Home Page

HI

Date : 25 June 1997

How are you ? During early Summer, weather in the eastern U.S. seemed much more like Autumn, but now heat characteristic of our longest season is being felt. This week I discuss an appropriate topic for this time of year - **Heat Index** (HI). This is also called **apparent temperature**. It is an estimate of the temperature which causes equivalent discomfort as existing conditions if dew point temperature is 14 °C (57.2 °F). I.e., if dew point temperature is > 57.2 °F, heat index is > ambient temperature and vice-versa, as a chart illustrates.

Charts & diagrams can be found at many WWW sites - formulas are more difficult to find though. After searching enough, I found different ones at 2 sites (and probably didn't find some ☺). One formula is from USA Today's WWW site (their chart is very excellent, though I've seen a few incorrect expressions in related humidity equations). Too many significant figures are included, considering that a person is doing well measuring temperature within a degree F and relative humidity within a few %. It can be more conveniently written :

$$\mathbf{HI} = -42.38 + 2.049\,\mathbf{T} + 10.14\,\mathbf{R} - .2248\,\mathbf{T}\,\mathbf{R} - .006838\,\mathbf{T}^2 - .05482\,\mathbf{R}^2 + .001229\,\mathbf{T}^2\,\mathbf{R} + .0008528\,\mathbf{T}\,\mathbf{R}^2 - .00000199\,\mathbf{T}^2\,\mathbf{R}^2$$

HI represents heat index (°F), **T** temperature (°F), and **RH** relative humidity (%). For example, suppose **T** = 93 °F and **RH** = 60 %. You can verify that **HI** = 107.4 during such conditions. I do not use ° for expressing heat index because it is not a (real) temperature - only estimation of a supposed equivalent one. Because various formulas are used, heat index charts may not exactly correspond, but are all similar. A few sites include meteorological calculators, using which you can determine heat index. I suppose a definitive reference for this is contained in an NWS Fort Worth, TX office report :

> Rothfusz LP. The heat index "equation" (or, more than you ever wanted to know about heat index). Fort Worth, Texas: National Oceanic and Atmospheric Administration, National Weather Service, Office of Meteorology, 1990; publication no. SR 90-23.

which I don't see available anywhere on the WWW (please inform me if you know of its location).

@ least 6 factors significantly affect human comfort : temperature, humidity, wind speed, insolation, skin type, and clothing. Effects of heat & humidity are explained at many WWW sites, so I don't state specifics regarding how sweat causes cooling when evaporation occurs, etc. Nor much about health considerations, though I think a good rule-of-thumb is being aware of what your body is indicating. I.e., if you are thirsty, drink water; and if you aren't, don't force it on yourself (contrary with what some people say). Mentioning a few things regarding recognizing developing conditions and interpretation of pertinent weather information may be helpful though.

For planning activities well in the future, knowledge of the general weather regime is helpful. Medium Range Forecast model images are helpful for determining such. For reasons too involved for a brief explanation, a strong upper air ridge typically indicates hot weather during summertime. If surface winds are from a favorable direction for high humidity (e.g., a trajectory from the Gulf of Mexico), conditions are favorable for great heat stress. Consider if you wish, the following example : A recent 500 mb chart from Purdue's WXP (description of upper air charts - now at Unisys Weather) indicates a broad ridge over the SE U.S. A surface chart (description of surface chart) indicates southerly winds are prevalent there. Thus, you may expect large heat indices. Largest values (> 100) for this situation were in eastern North Carolina to eastern Maryland, where temperatures were near 100 °F. Indices over most of Florida were < 100, though dewpoints of mid-upper 70's were larger, indicating that temperature is the main consideration, and humidity a modification of comfort. Considering the cyclonic circulation around Lows and anticyclonic circulation around Highs previously discussed, you can determine conditions above and forecast them.

Routine weather products provide temperature information, but the NWS provides much information - including long-term forecasts and specific heat advisories for situations when heat stress can become threatening.

Home Page

A Wet-Bulb Temperature Equation

Date : 02 July 1997

Among other things, last week's feature included criticism of moisture equations. Now here's your chance to criticize me. Continuing with a similar topic, I explain a few things regarding a wet-bulb equation. Among the most common usenet weather questions concern such things as "If I know temperature and dew point, how can I calculate relative humidity ?" I'm not gonna write an ONA (often needed answers page) because one already exists, but below I offer some explanations it does not include, for satisfaction of curiosity & usefulness.

During a wet-bulb process, air and water vapor coexist. Some of the vapor is condensed, or water vapor is evaporated in air, saturating it. During these isobaric processes, water vapor content changes, and air volume adjusts accordingly. Vaporization latent heat is responsible for all temperature change (no ice crystals assumed). The governing equation for this process is :

$$(M_d\ C_{pd} + M_v\ C_{pv})\ dT = -\ L_v\ dM_v \qquad [1]$$

M_d : dry air mass

M_v : water vapor mass

C_{pd} : dry air specific heat, constant pressure

C_{pv} : water vapor specific heat, constant pressure

L_v : vaporization latent heat

T : temperature

The right term represents latent heat change (i.e., heat loss because of evaporation) and the left term air temperature change caused (i.e., dry air & water vapor components). This process occurs when measuring wet-bulb temperature using a psychrometer (evaporation causes wet-bulb cooling). (Standard definitions use liquid water specific heat rather than water vapor specific heat (and neglect this small term). If anyone can convincingly explain why this is so, I'll change my formula. I don't think the air around the wet bulb contains significant liquid water, and thermal equilibrium between it & the surrounding air is achieved via conduction, allowed to occur as long as necessary.) Dividing with M_d produces :

$$(C_{pd} + R\ C_{pv})\ dT = -L_v\ dR \qquad [2]$$

for which water vapor mixing ratio (R) is :

$$R = M_v/M_d \qquad [3]$$

Hopefully, using R is not confusing (typically used for gas constants). Given dry and wet-bulb readings, T and T_w, this equation can be integrated to calculate mixing ratio :

$$\int_{R,R_w} dR = - \int_{T,T_w} (C_{pd} + R\ C_{pv})/L_v\ dT \qquad [4]$$

You may notice that because both R and L_v are functions of T, directly solving the integral is difficult if not impossible. It can be solved as a series of sums, or using a representative value for R & T during the wet-bulb process. The latter using an average is not a bad approximation. Doing so produces :

$$R = R_w + ((C_{pd} + R^{\sim}\ C_{pv})/L_v)(T_w - T) \qquad [5]$$

$$R^{\sim} = (R + R_w)/2 \qquad T^{\sim} = (T + T_w)/2 \qquad [6]$$

$$L_v = 2500800 - 2370\ T^{\sim} \qquad [7]$$

You may notice that R_w refers to saturation mixing ratio for T_w. During this discussion and in equations, all **temperatures** are **°C**, all **pressures mb**, and all other **units MKS** unless noted else. (Thus L_v is expressed as J / kg / °K, etc.)

Equations for water vapor pressure are useful for solving the wet-bulb equation. Experiments have indicated that a specific amount of water vapor can exist at a specific temperature. Such values are tabulated, and several equations have been developed to express this. One such equation is Wexler's :

$$E_s = 6.112\ e^{(17.67\ T/(243.5 + T))} \qquad [8]$$

If E_s (saturation vapor pressure) is known, T can be determined using the following equations :

$$X = \ln(E_s/6.112) \qquad [9a]$$

$$T = 243.5\ X/(17.67 - X) \qquad [9b]$$

Mixing ratio relates with vapor pressure as follows (derivation not shown for brevity) :

$$R = z\ E\ /\ (P - E) \qquad [10]$$

$$E = R\ P\ /\ (z + R) \qquad [11]$$

$z = .62197$: water vapor molecular mass / dry air molecular mass

Distinction between (existing) vapor pressure (E) and saturation vapor pressure (E_s) should be noted.

Saturation vapor pressure defines the dew point temperature (T_d), I.e., **if air cools** isobarically **until saturation** occurs, **temperature attained is the dew point**.

Relative humidity (H) is defined as :

$H = E / E_s$ [12]

E represents vapor pressure existing in air, and E_s is evaluated for this with temperature T (i.e., **humidity relative** with air as if it were **saturated at existing temperature**).

Although weather reports often include temperature and relative humidity, such is a rather after the fact statement. Hygrometers can measure relative humidity (but must be calibrated), and dew cells dewpoint, but commonly dry & wet-bulb thermometers are used. Thus, dew point and relative humidity are often obtained from such measurements. Above are equations necessary for such calculations.

Calculating dew point and relative humidity using (1) involves the following procedures :

1. **Calculate L_v** using T_w & [7]

2. **Calculate R_w** using [8] & [10] with T_w & E_w (= E_s with T = T_w)

3. **Calculate $R^\sim$** using [6] (use $R^\sim = R_w/2$ initially)

4. **Estimate R** using [5]

5. **Repeat 3 & 4 until R converges** (should only require 2 or 3 iterations)

6. **Calculate E** using [11]

7. **Calculate T_d** using [9]

8. **Calculate H** using [12]

Example : Suppose **T** = **25.0 °C** (77.0 °F), $\mathbf{T_w}$ = **16.0 °C** (60.8 °F), and **P** = **1000.0 mb**

1) $L_v = 2500800 - 2370(16.0) = \mathbf{2462880}$
(last 2 digits insignificant)

2) $E_w = 6.112\, e^{(17.67\ (16.0)/(243.5 + 16.0))} = 18.169$
$R_w = (.62197)(18.169)/(1000.0 - 18.169) = \mathbf{.011510}$

3) **R~** = .011510/2 = **.005755**

4) **R** = .011510 + ((1006.3 + (.005755)(1850))/2462880)
(16.0 - 25.0) = **.007794**

5) **R~** = (.007794 + .011510)/2 = **.009652**
R = **.007767**
R~ = **.009639**
R = **.007768**
R~ = **.009639**
R = **.007768** (converged)

6) **E** = (.007768)(1000.0)/(.62197 + .007768) = **12.335**

7) X = ln(12.335/6.112) = .70215
$\mathbf{T_d}$ = (243.5)(.70215)/(17.67 - .70215) = **10.076**

8) $E_s = 6.112\ e^{(17.67\ (25.0)/(243.5\ +\ 25.0))} = 31.674$
H = E / E_s = 12.335/31.674 = **.38942**

Because of imprecise equations and measurement difficulties, answers above should be expressed as $\mathbf{T_d}$ = **10.1 °C** (50.1 °F) & **H** = **.389** (38.9 %), if that accurate, though keeping more significant figures during calculation is fine.

You may notice similarity between (5) and an equation for calculating water vapor pressure in the ONA :

$$E = E_w - (.00066\ (1 + .00155\ T_w))(P)(T - T_w) \qquad [13]$$

E_w representing saturation vapor pressure for T_w.

An advantage of the method illustrated is that variation of R & L_v with temperature is included (and small variation of C_{pd} & C_{pv} also, which is done for tabulated values shown below). For [13], coefficients are chosen which best fit typical meteorological data. For the example, the ONA's equation produces $\mathbf{T_d}$ = **9.77 °C**. The ONA contains much info regarding wet-bulb measurements and errors involved.

An interesting consequence of the wet-bulb process is a minimum wet bulb temperature for a specific dry bulb temperature (i.e., with no water vapor initially present - T_d = 0 °K = -273.15 °C), determined using R = 0 in [5]. I won't show required calculations here, but these temperatures for a wet-bulb temperature 0 °C (32 °F) are :

P (mb)	T (°C)	T (°F)
1050	8.99	48.2
1000	9.44	49.0
950	9.94	49.9
900	10.49	50.9
800	11.81	53.2
700	13.50	56.3
600	15.76	60.3

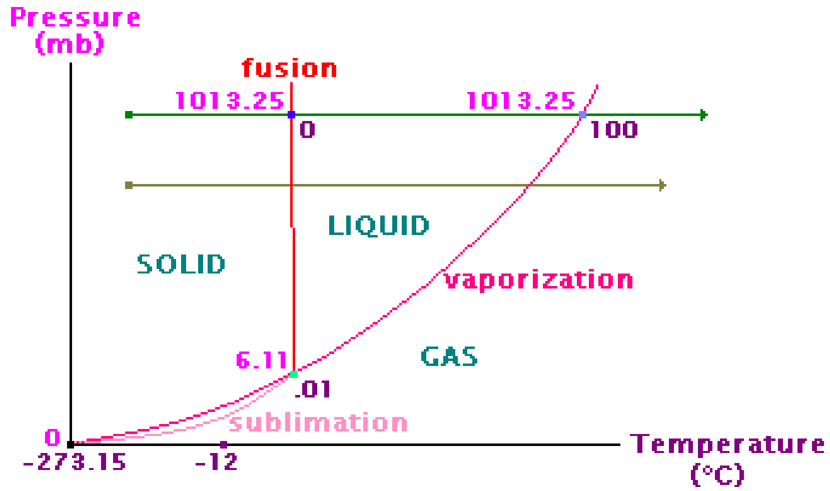
These temperatures are sometimes thought of as a quasi-upper limit for snow, the idea being that as snow falls, evaporation causes local temperature (i.e., around the snow) to approach the wet-bulb temperature. That requires **melting and evaporation** and **sublimation** though, which I plan discussion of next week.

Home Page

Consequences of Wet-Bulb Process Regarding Snow

Date : 9 July 1997

Continuing last week's discussion, I now mention modification of the wet-bulb process considering **melting** and **sublimation** (change from solid to gas phase). Examination of the phase diagram of water :



Phase diagram for water. Curves indicate phase changes : fusion (freezing/melting), vaporization (condensation/evaporation), and sublimation/ deposition. The green line indicates processes which occur as temperatures changes for standard atmospheric pressure 1013.25 mb. When water is heated to 0 °C, melting occurs, and to 100 °C, boiling occurs. Freezing temperature remains very close to 0 °C, but for small atmospheric pressures (e.g., high elevations), boiling temperature greatly decreases, as the olive line indicates. A specific amount of vapor pressure always exists above water - the value along the vaporization curve. This is called saturation vapor pressure, which depends only with temperature. It is 0 for absolute 0, increasing to 6.11 mb at .01 °C, and to 1013.25 mb at 100 °C. Pressures for which sublimation (ice to vapor) and vaporization occur differ for temperatures < 0 °C. This difference is largest near -12 °C, as indicated. The vaporization curve is extended for temperatures < 0 °C because supercooled water can exist, though rarely observed for temperatures < -40 °C. The triple point is that for which all 3 phases of water exist at equilibrium - pressure 6.11 mb (166 X less than standard) & temperature .01 °C.

indicates that sublimation is impossible for temperatures > .01 °C (32.02 °F). All melting occurs very near 0 °C (32 °F). Because supercooled water is common in our atmosphere, both sublimation and evaporation occur if temperatures are less than that, though supercooled water is very rare with temps < -40 °C (or °F). Saturation vapor pressure is shown on the diagram for specific temperatures along the evaporation and sublimation curves. An approximate relation for evaporation was provided last week :

$$E_s = 6.112\, e^{(17.67\, T/(243.5 + T))} \qquad [1]$$

An approximate relation for sublimation (from *Atmospheric Thermodynamics*) is :

$$E_s = 10^{(10.55 - 2667/T_k)} \qquad [2]$$

for which T_k represents temperature expressed as °K. Clouds typically contain a mixture of water droplets and ice crystals, amounts being similar for temperatures near -12 °C (10 °F). This should be considered when doing thermodynamic calculations for clouds.

Last week's discussion dealt more with ideality and definitions than reality. Sure...we can define a wet-bulb process, dew point, and relative humidity, but how relevant is such for each real process considered ? Why does a person typically feel much cooler after exiting a swimming pool than after being soaked with sweat after strenuous exercise during a hot day ? You'll probably say 'the pool water was cooler', so the person's body is cooler to begin with. Yes, and each contains impurities (as does rain). During the (ideal) wet-bulb process, temperature on the wet-bulb begins as ambient air temperature (hopefully). Thus, using the wet-bulb equation :

$$\int_{R_w,R} dR = - \int_{T_w,T} (C_{pd} + R\ C_{pv})/L_v\ dT \qquad [3]$$

I could justify using averages between ambient and wet-bulb temperatures for R & L_v :

$$R = R_w + ((C_{pd} + R^{\sim}\ C_{pv})/L_v)(T_w - T) \qquad [4]$$

Our atmosphere is much more complicated. Similarly as for the swimming example, temperature of precipitation falling from clouds is often much less than air it is falling thru. Thus, when meteorologists use the wet-bulb temperature for estimating air temperature during rain, such is approximate. Observed temperature is often a few °C less - mainly because of cold downdrafts associated with precipitation, but also because the cold precipitation cools air via conduction, and because of the wet-bulb process. Considering the wet-bulb process only, latent heat transfer occurs at the temperature of precipitation. Thus, L_v is larger than for the ideal wet-bulb process, causing R_w - R to be less; meaning wet-bulb temperature is less. Such a difference is very small, typically only hundredths of a °C though. Using the example from last week, we may consider a 'wet-bulb process' because of precipitation rather than a psychrometer. Supposing precipitation temperature is 14.0 °C, [4] becomes :

$$.007791 = R_w + (1006.3 + R^{\sim}(719.3))/2467600)(T_w - 25.0)$$

which you can verify that T_w = 15.98 °C solves (rather than 16.0 °C). I.e., other reasons are much more significant.

My main reason for this discussion though is frozen precipitation, which includes snow. The real process for this is much different than ideal also. Snow falls from clouds, sometimes initially with a temperature significantly < 0 °C. Thus, sublimation can initially occur. It then may fall thru air with temperature > 0 °C. If air surrounding a snowflake is > 0 °C, melting must occur, but if not, then sublimation can continue. Such modeling has been done to great detail. Using the wet-bulb equation last week, I tabulated maximum temperatures for which wet-bulb temperature is 0 °C. This week I include melting also. For simplification, I consider melting and evaporation independently. During melting,

$$C_{pd}\ dT = - L_f\ dR \qquad [5]$$

using a similar equation to that last week; L_f representing fusion latent heat. Because melting is first considered, terms associated with water vapor change are unnecessary (you may recall that initially R = 0 for this situation). After this temperature change, the wet-bulb process proceeds as discussed previously. For example, with P = 900 mb, T = 32 °C, and R = .004249. Thus [5] becomes :

$$dT = - (333700)(.004249)/1006.0 = - 1.41$$

Thus, the tabulated value becomes 10.49 + 1.41 = 11.90 °C

The new table is :

P (mb)	T (°C)	T (°F)
1050	10.20	50.4
1000	10.71	51.3
950	11.28	52.3
900	11.90	53.4
800	13.40	56.1
700	15.32	59.6
600	17.88	64.2

Melting requires more than 1 °C (more than 2 °C at 600 mb). Because of considerations I've previously mentioned, observed temperature should be less than ideal. Thus values tabulated above should realistically be slightly greater (larger ambient temperature required for observed 0 °C 'wet-bulb temperature'). This means that snow is possible with temperatures much > 0 °C, especially at high elevations in dry climates. I don't think air should be extremely dry because although cooling snow, evaporation will occur too quickly for it to survive to ground. I've heard reports of snow with temperatures in the 50's °F in the western U.S., and have witnessed snow with temperatures in the upper 40's several times (mainly during Spring in Michigan).

Maximum temperature I have observed snow during is 54 °F. Perhaps someday someone will tell me such was not possible, but it was my best estimate. Such occurred during 10 October 1994, a description of which I posted to the sci.geo.meteorology usenet discussion group (later response to my first usenet post ☺ - you may notice I still described many things incorrectly then). As I stated, several things in lower Michigan make such an occurrence possible during early Autumn.

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Plotted Surface Charts

Date : 23 October 1998

My previous discussion (not here yet) of the equations of motion illustrated reasons why atmospheric circulations which are not small (and most which are) are cyclonic around Lows and anticyclonic around Highs. This is now a good time for the first discussion of this series dealing directly with weather forecasting - a discussion of the surface weather chart.

Often simply called a **weather map**, this is an analysis tool - usually for the purpose of accurate weather forecasting. Meteorologists consider many other charts weather maps also; but even so, this is the most important because it depicts near-ground atmospheric conditions (where we live). Because you can't experience conditions at all places @ once, such depiction is very helpful. Though many conventions exist, no rules do for creating a weather map, per se. Most of you probably @ least once saw a TV weather map with personified features - mean-looking clouds with lightning bolts, a happy sun, etc. If you browse the WWW, you'll see many different kinds of surface charts also. Consider if you wish, those from the following sites :

- Unisys Weather - main site
- Weather.com - main site
- National Weather Service (requires TIF viewer) - main site

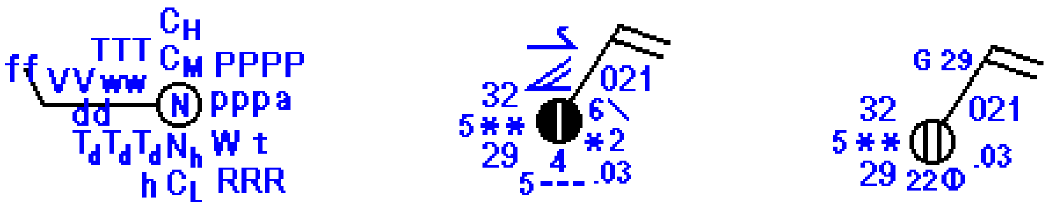
Each chart has associated with it an intended audience and purpose (some not specifically for the WWW). Quite often, separate charts for different weather elements such as temperature are provided - a surface chart not intended as a thorough depiction of weather conditions. Many common elements exist though, no matter which type of depiction is used. These include air masses - broad areas of quasi-homogeneous weather conditions - and their movement (thus winds), temperatures, and areas of storms. I think the way these charts differ is not so much *what* they portray, but the *interpretation which is required*. Some people like seeing the big red L's and blue H's, fierce blue cold fronts with sharp teeth, and gentle red warm fronts with rounded teeth; and others can recognize a baroclinic zone seeing nothing other than plotted data ☺ Speaking of which, let's look at how 'surface' data is plotted.

Somewhere, the origin of almost any weather map is a map with plotted data (main site). Maps (usually for larger areas) using such plots are called **synoptic charts**. Among meanings of the word *synoptic* are a synopsis and/or account from the same view. Weather observations are routinely made at hundreds of U.S. and many other locations - hourly or more frequently during rapidly changing weather. The observation and dissemination process is a story of its own, the Federal Meteorology Handbook #1 (FMH-1) being a useful references for standards used. The primary means of communicating these observations are SYNOP reports and METAR reports. A close inspection of the format of these codes and information contained is quite helpful, if not memorization if you envision using these frequently. Reading SYNOP reports is very difficult, but reading basic METAR reports is not so difficult, and these (example (main site)) are a significantly better description of weather conditions than typical reports (example). Using these reports most effectively is a story of its own also - I mention these now so the source for the 'surface' data on the plotted charts is clear.

Why do I place the word *surface* in single quotes, you may ask ? I do so because the data described is not really surface data, but near-surface data; and weather maps often illustrate weather well above the surface. Frankly, the weather which concerns me most is around 5 feet above ground - the cold wind on my face, etc.; and that's precisely where most standard temperature measurements are; though wind is typically measured higher -

about 3 - 10 meters (10 - 33 feet).

Below is the standard form for surface data plots and 2 examples. If you are unfamiliar with this, it'll be more clear after reading below.



Standard Form   Complete   Practical

Sample 111 Group (land surface SYNOP report, 00fff group optional)

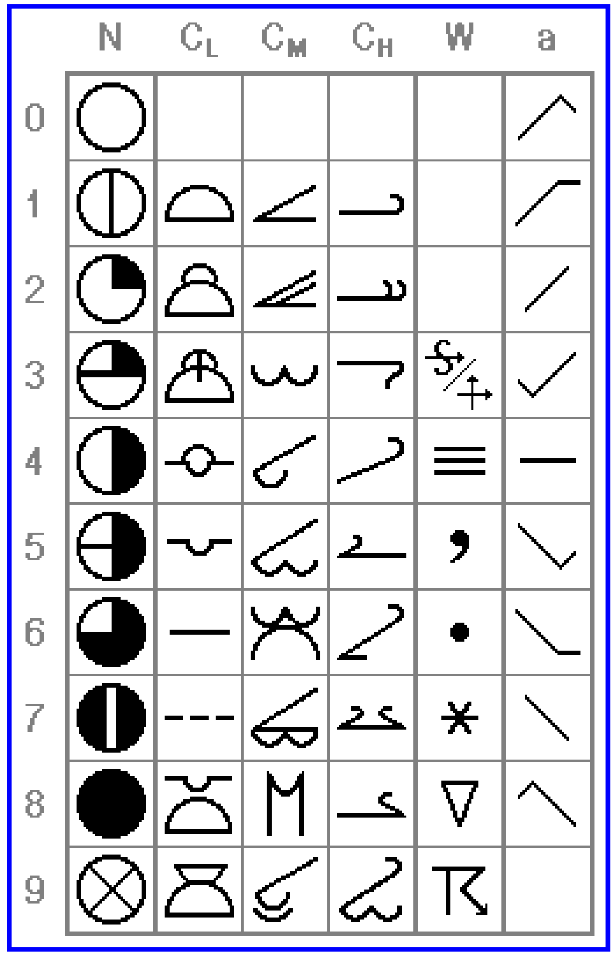
i_Ri_xhVV	Nddff	00fff	1sTTT	$2sT_dT_dT_d$	3PPPP	$4P_sP_sP_sP_s$	5appp	6RRRt	$7wwW_1W_2$	$8N_hC_LC_MC_H$	9GGgg
11558	70320		10002	21019	30021	49865	57006	60017	77172	84728	90300

Corresponding METAR report

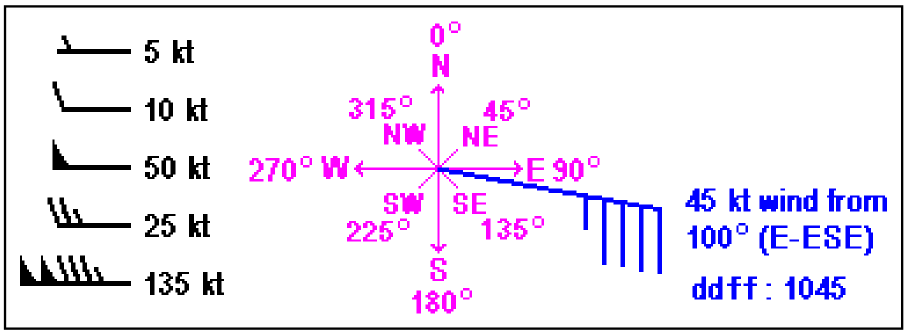
KZZZ 220300Z 03020G29KT 5SM -SN SCT022 BKN040 BKN180 00/M02 A2959 RMK SLP021 P0002 60003 T00021019 57006

s : positive value if 0, negative if 1
h : lowest cloud base height = 2200 feet = 670 m.
VV : horizontal visibility 5 miles
N : total cloud coverage 7 octas (7/8)
dd : wind direction 30°
ff : wind speed 20 knots
TTT : temperature = .2 °C = 32 °F
$T_dT_dT_d$: dewpoint = -1.9 °C = 29 °F
PPPP : pressure corrected to sea level 1002.1 mb
$P_sP_sP_sP_s$: station pressure 986.5 mb

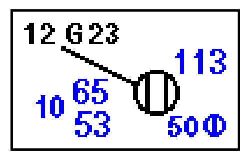
a : pressure steadily decreasing
ppp : pressure decrease .6 (6/10) mb
RRR : precipitation .03 (3/100) of an inch
t : precipitation accumulated during past 3 hours
ww : present weather - continuous light snow
$W_{1,2}$: past weather - snow (W_1 typically plotted)
N_h : low cloud coverage 4 octas (4/8)
C_L : fractus of bad weather (Fs for this)
C_M : thick altostratus or nimbostratus (Ns for this)
C_H : cirrostratus neither increasing nor covering sky

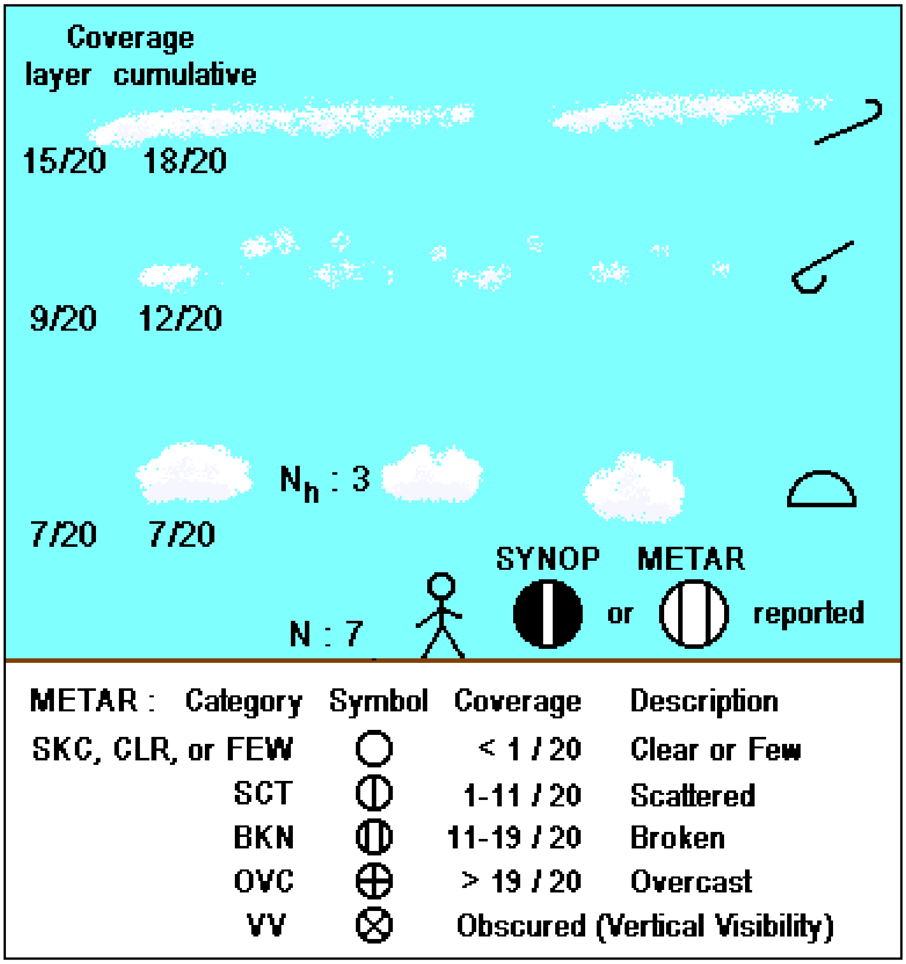


Both plots contain abundant weather information *for one place and time*, so a map of these can contain abundant information *for many places @ one time* - a synoptic chart ! The standard form is designed for SYNOP reports, each of the codes shown corresponding with part of the [SYNOP format](). The coded data is not plotted as is, but done so such that a plot is more meaningful - the code is used for data transmission. Thus, temperature and dewpoint are shown as whole degrees (usually Fahrenheit in U.S., but Celsius (stupid units) elsewhere), visibility as miles, and accumulated precipitation as inches, among others. Descriptive symbols were developed for past and [present weather]() characteristics (weather symbols), cloud types, and pressure tendencies (click on image to right for descriptions and / or downloading individual symbols) and winds - indicating direction wind blows from and speed. Plotting winds is quite simple - a flag is 50 kt (or 25 m / sec for metric), a long stem is 10 kt (or 5 m / sec), and a short stem 5 kt (or 2½ m / sec), as illustrated :



Very seldom will all of this be plotted. Though the NWS fax surface charts contain station plots using the standard form, most relevant variables are generally reported or plotted. Typically these are present weather, sky cover, temperature and dewpoint, wind, and pressure. Wind barbs are very common, though sometimes I like plotting only the shaft and printing the speed at its end (quite useful when specifically forecasting winds). Thus, I show a couple **practical station plots** (above & right). These are the forms on most of my plotted charts. Note that several variables are not plotted. This is mainly because METAR reports are the most common source of data. This presents no problem - the form of the plot need not be changed. I show variables most useful for a typical situation, though which variables are plotted depend what your purposes are. Note the symbols below the station circle. Though Canadian surface reports include cloud type (and are typical reported exactly @ the hour), U.S. ones don't (and are most often reported 15 - 5 minutes before the hour). Each include cloud base height and cumulative coverage (from ground up) for each cloud layer though :





When you're out & about, the primary aspect of clouds you probably notice is **ceiling**. As the name suggests, this is the lowest opaque broken or overcast layer. If a daytime ceiling is low, chances are the sky is drab; if high or non-existent, skies are likely bright. This is significant for many other reasons - abundant solar heating with high or non-existent ceiling, and many aviation concerns, for example. Cloud ceiling is shown on a weather depiction (requires TIF viewer). Though intended for aviation, weather depictions are excellent supplements for satellite images, on which cloud base heights can seldom be estimated well. One thing I hope I'm making clear is reasons why reports of current weather at many sites (i.e., CNN, USA Today, Intellicast) can be misleading. How many times did you see a report of mostly cloudy or overcast skies, then go outside to a bright, sunny sky covered with transparent cirriform clouds ? I plot ceiling unless it is too high for much significance, then I plot the lowest cloud layer as illustrated - a scattered layer at 2200 feet - or perhaps both. It's my map - I'd make the rules if they existed ☺ - though a couple good characteristics of any station plot are clarity and compactness.

Am I suggesting downloading METAR reports and plotting stations on a map every hour like a fool ? Well, I did that many times before PC's were common (actually every 2 or 3 hours was doing well - and base charts are obviously needed), and still sometimes do for special situations; though unless you write a plotting program, chances are you won't get exactly the type of plot you want *quickly*. Evidently, being a computer geek is part of being an effective modern-age meteorologist...speaking of which, let's see what choices you have then ☺

Among many other fine features, Digital Atmosphere can be used for making rather customized surface plots from downloaded METAR reports. You can choose most variables and regions you wish on color maps including topography; and can even let the program do some analysis. Downloading the reports requires time though - you can sometimes get a detailed current plotted chart slightly quicker at one of the several sites which provide these (examples shown) :

- UCAR
- Unisys Weather
- University of Illinois Weather Visualizer
- Plymouth State College Weather Center

and more importantly can be doing something else the meantime. The Weather Visualizer is a good idea which someone probably stole from me; though if you experiment with it, you'll see that densely-populated maps plot very poorly. You want as much data as possible ? Those from UCAR & Ohio State are best regarding that. A good feature of the bottom 3 sites is archived charts - Unisys' twice daily @ 00 & 12 UTC for several years, the others hourly for the past day or so.

Plotting the map is half the battle - I plan discussion of surface chart analysis as the next feature of this series.

The graphics on this page and weather symbols are mine. If you use them (or the text) elsewhere, please properly credit me. Perhaps I'll have similarly *neat-looking* present weather symbols also sometime - though if you know of a site which already have them, please inform me so I don't proverbially reinvent the wheel (again)

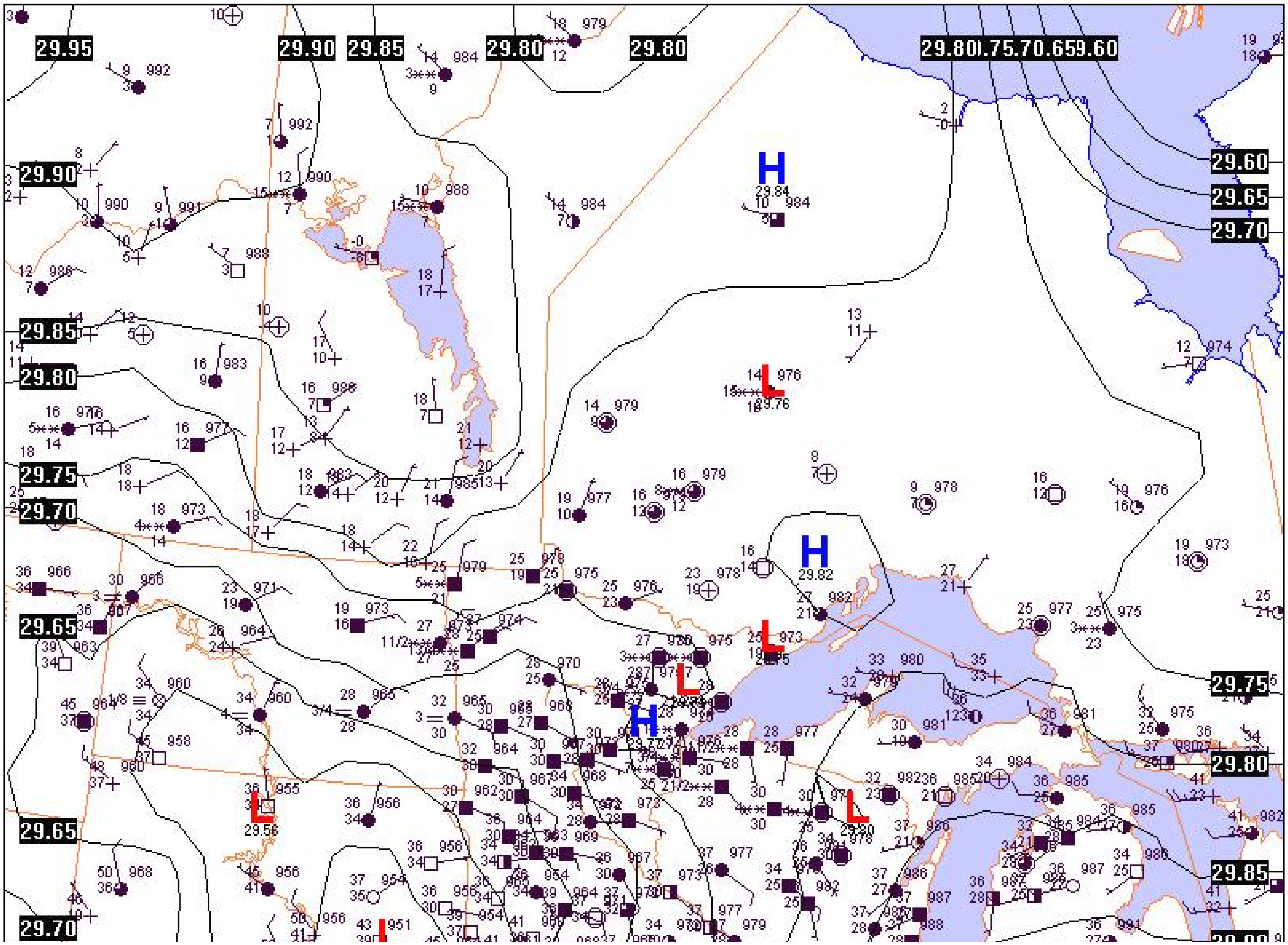
Home Page

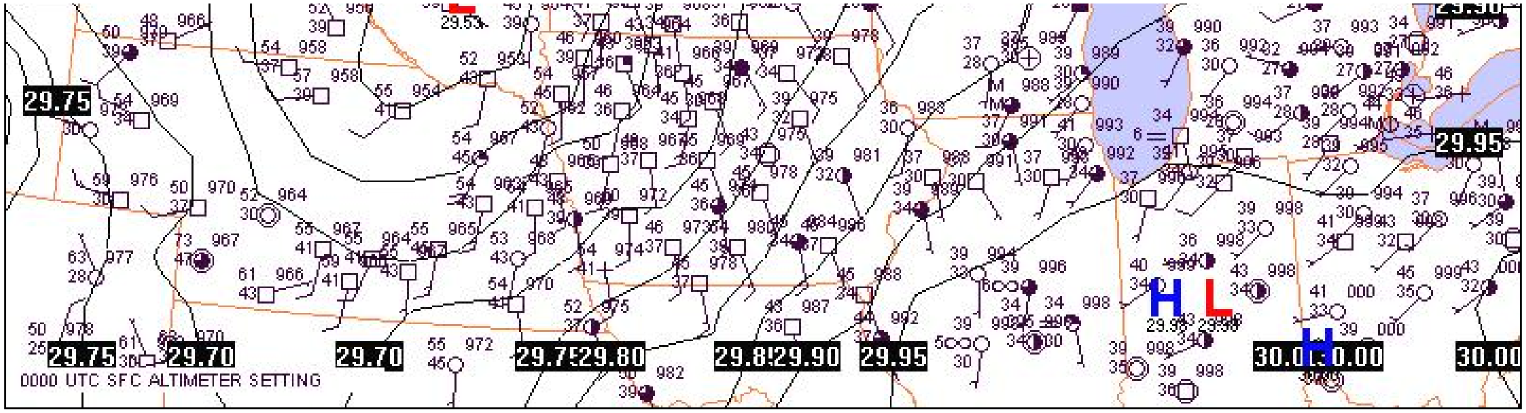
A Detailed Isobaric Surface Analysis

Date : 29 November 1998

Though the detailed surface analysis of the previous article (not yet here) makes many weather features evident, hand-plotting and analyzing is a laborious task - so much so that doing this for NWS North American surface charts (with generally less detail and much less data) once required teams including an analyst for each region. Now their surface charts are computer-plotted, with isobars objectively-analyzed (example - requires TIF viewer). This method, though not presently with quite the flexibility of hand-plotting, is now possible using a PC. For this, I recommend Digital Atmosphere. Using it, you can choose dimensions and color of your base map, add many geographical parameters of your choice, and select among many station model options; though plots can overlap if too densely-packed (a problem sometimes unavoidable hand-plotting even).

Below is a 00 UTC 16 NOV 1998 surface analysis for basically the same region using Digital Atmosphere :

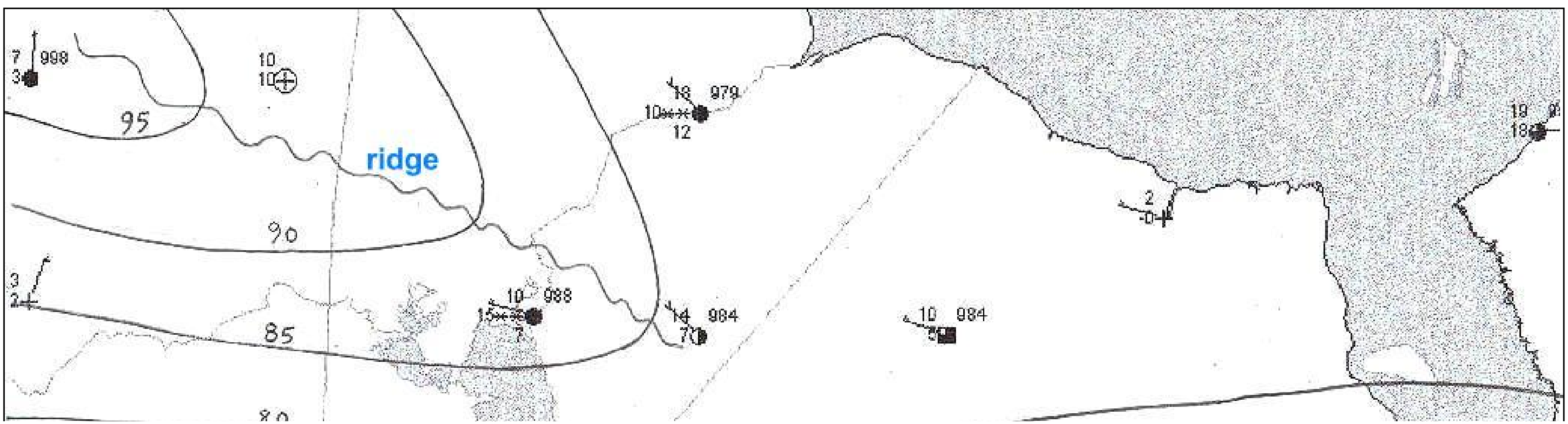


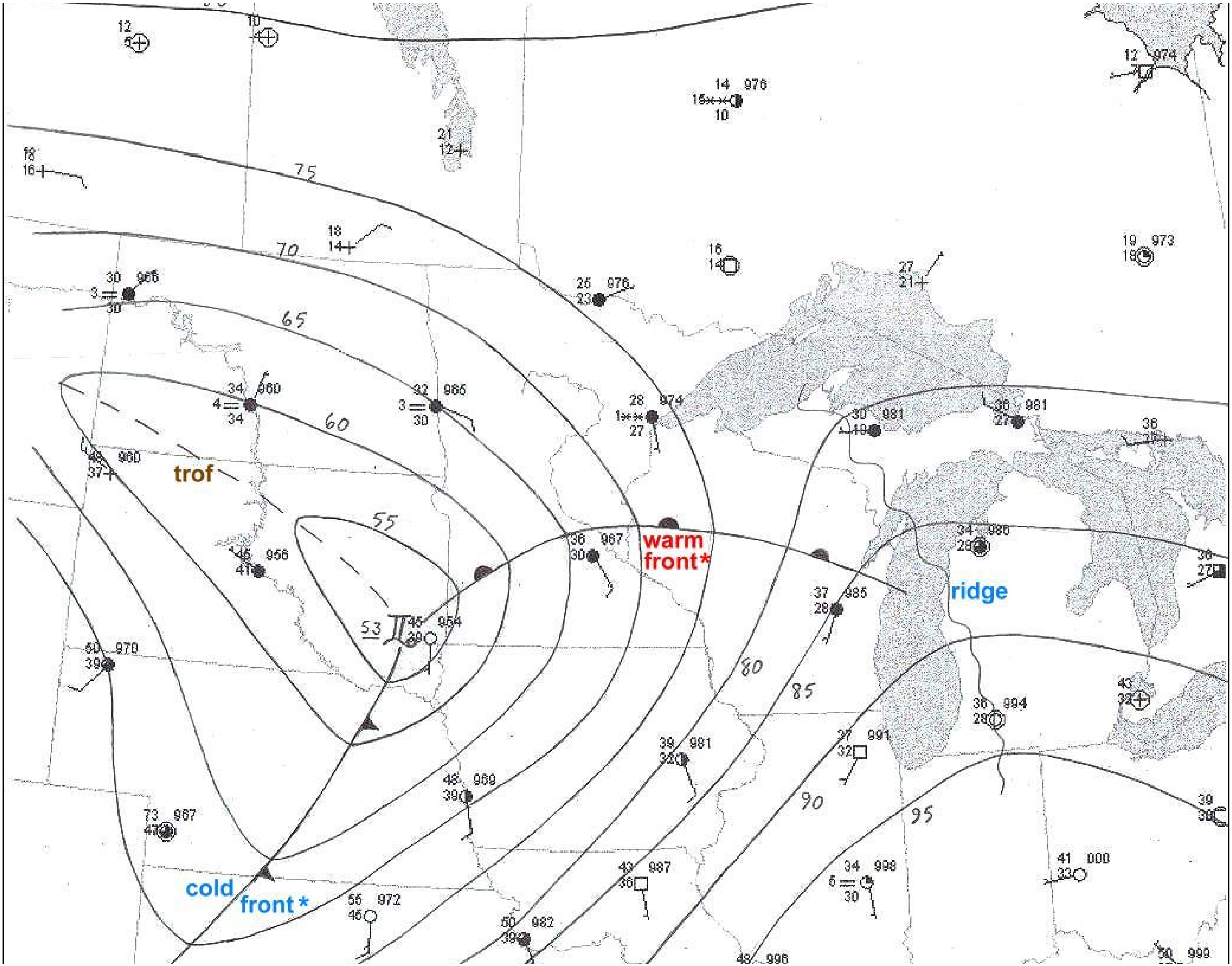


85% of stations are plotted so cluttering is minimized, though all are used for the isobaric analysis. Isobars are analyzed using their nearest neighbor method using a smoothing coefficient of .20 and no additional smoothing passes. This provided what I feel is the best objective analysis - isobars are not too jagged, nor so smooth such that some features such as the ridge / trof couplet over the Dakotas to northern Wisconsin are not visible. A local Low is analyzed in the trof extending northwestward from the main Low over southeast South Dakota, and a local High northwest of Lake Superior. Altimeter settings rather than sea level pressures are plotted, which adds detail for this map (because more were reported and plotted) and quite possibly is more representative for this situation. (Altimeter settings use difference among station readings and the standard atmosphere, and a standard atmosphere from station elevation to sea level. Sea level pressure estimates use temperature at a station for adjusting station readings using a specific lapse rate. Thus, altimeter settings would be perfectly representative for a map of flat terrain, and sea level pressures would be perfectly representative if temperatures varied with the specified lapse rate on variable terrain.)

More so than suggesting the idea of letting a PC do the laborious tasks, I illustrate in this article a **detailed isobaric analysis** and **advantages of using as much data as possible**. Below I present **hand-analyzed isobars** on the 00 UTC 16 NOV 1998 chart with **15 %, 40 %, and 80 % of data plotted and a preliminary analysis** using Digital Atmosphere for station plots. (You can compare these charts with those at some WWW sites for station densities *typically* used.) These analyses were admittedly done after the previously-shown charts. Thus I ignored what I knew about the complete analysis the best I could. **Place your mouse over letters on each for comments and reasoning for my analysis. Clicking on letters with asterisks provides another illustrative graphic**.

Below is the chart with **15 % of data plotted**. With relatively few observations, the best which can usually be done is a smoothed analysis. This generally linearly-interpolated - the best reasons for doing anything significantly different is bad data and drawing isobars closest together where winds are strongest. Place mouse over words or the script L for more commentary.

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70
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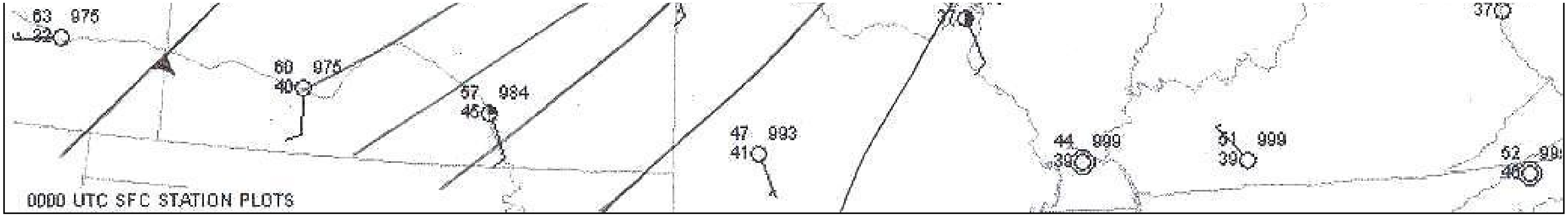
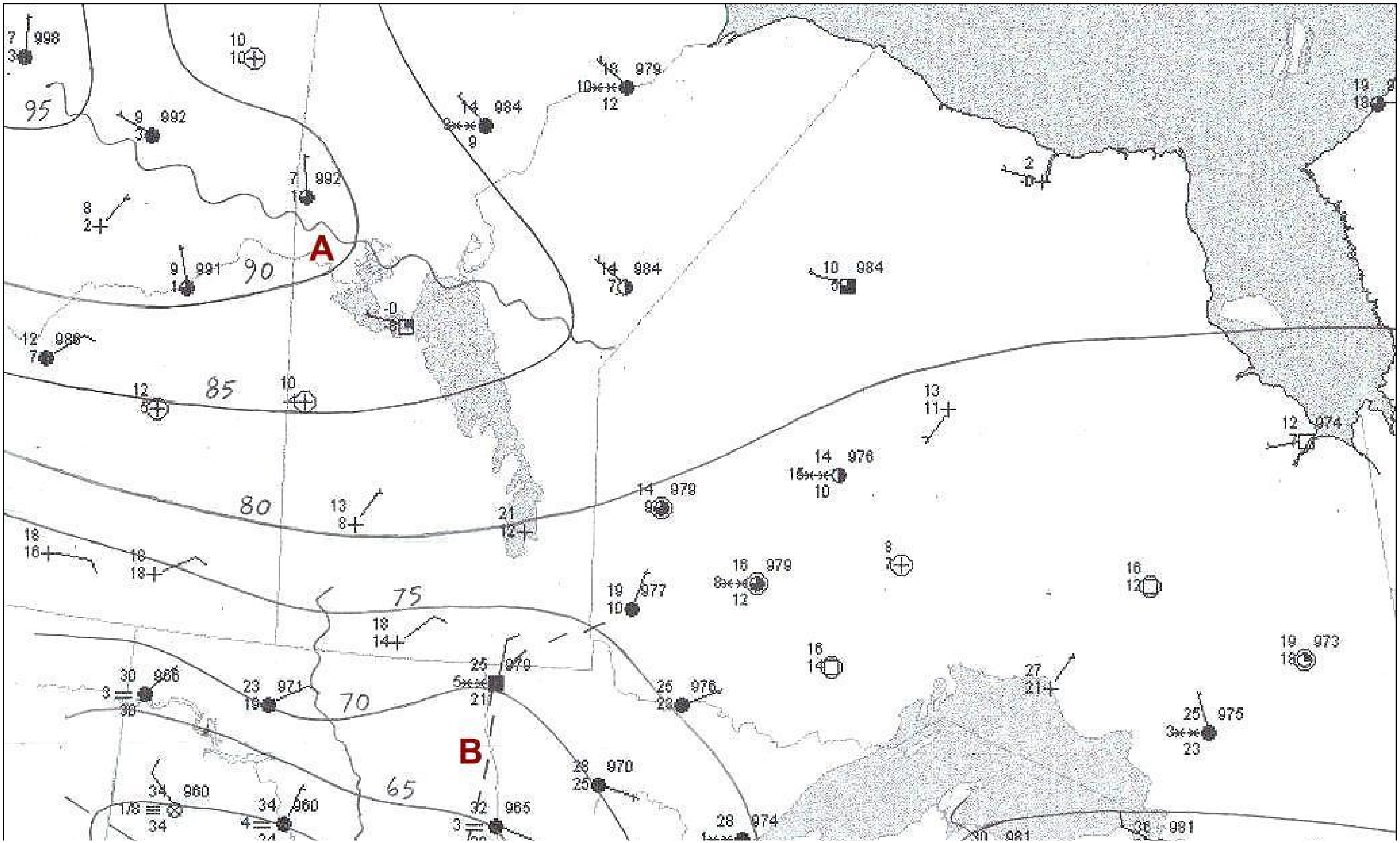
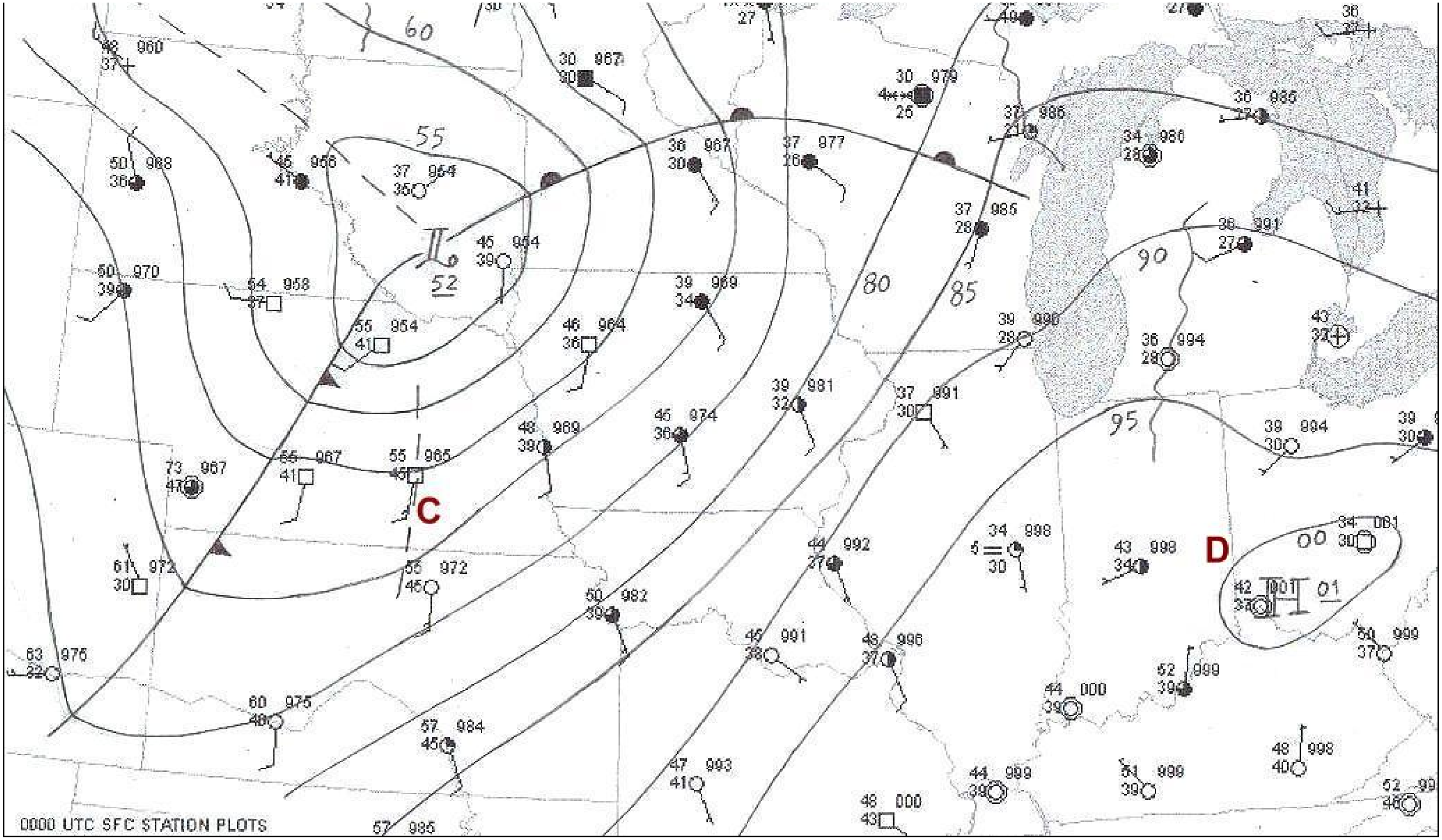
front *

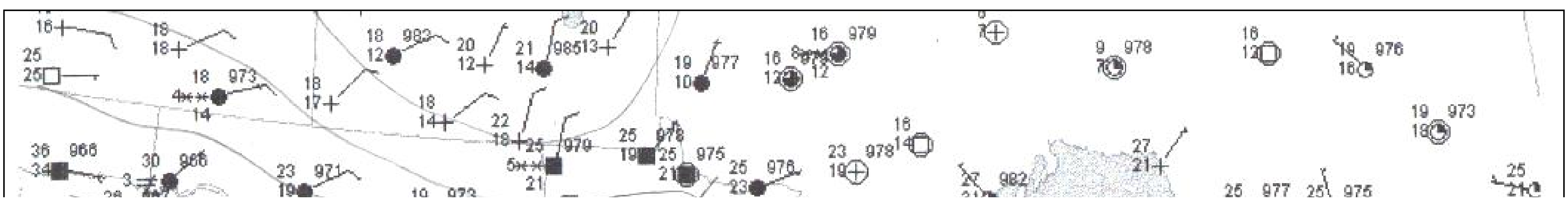


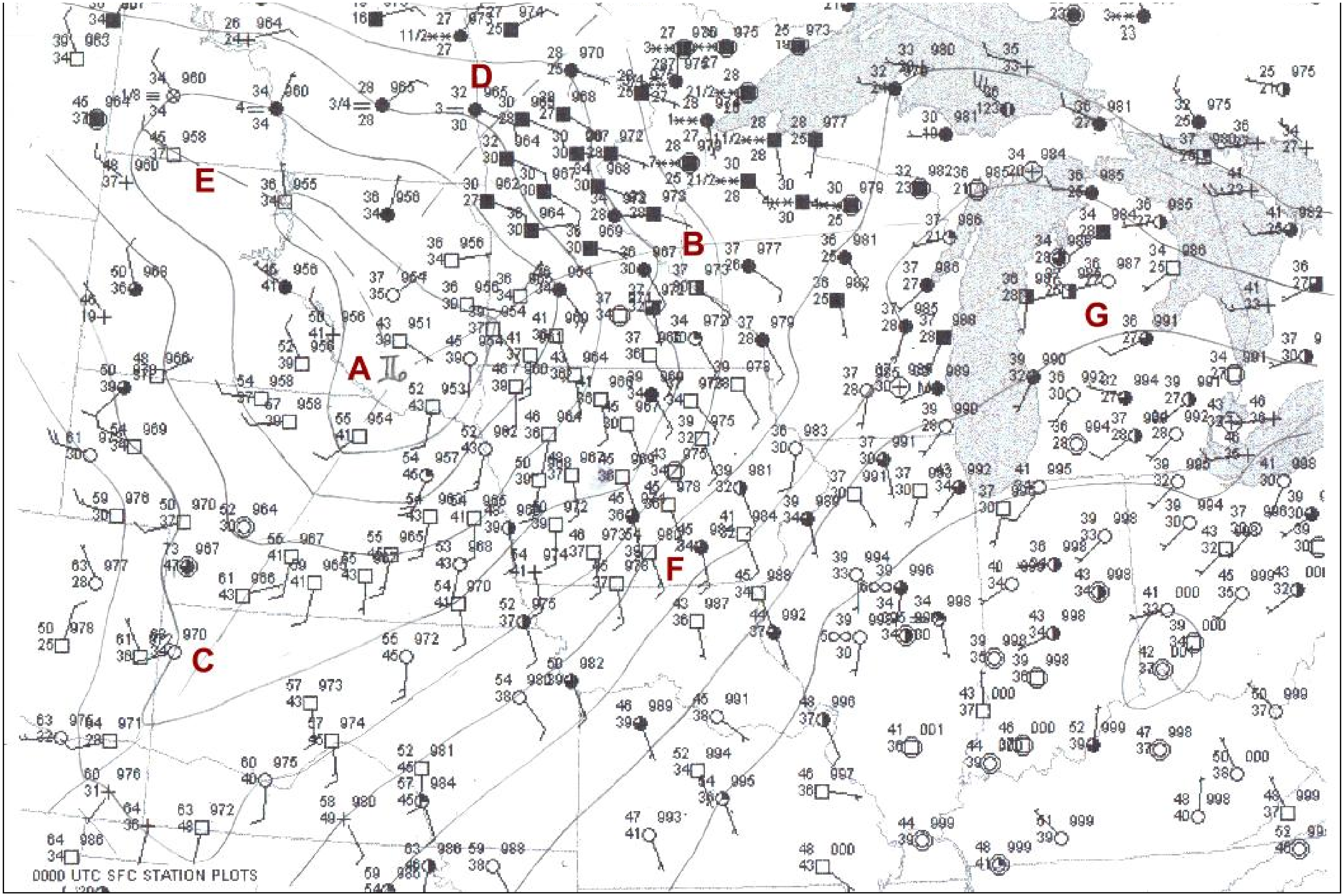
Below is the chart with **40 % of data plotted**. More detail is visible.



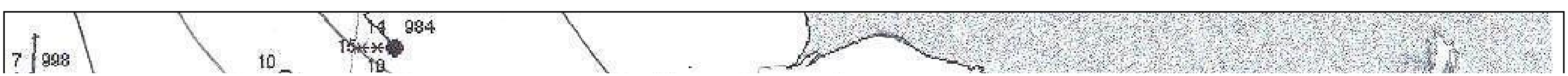


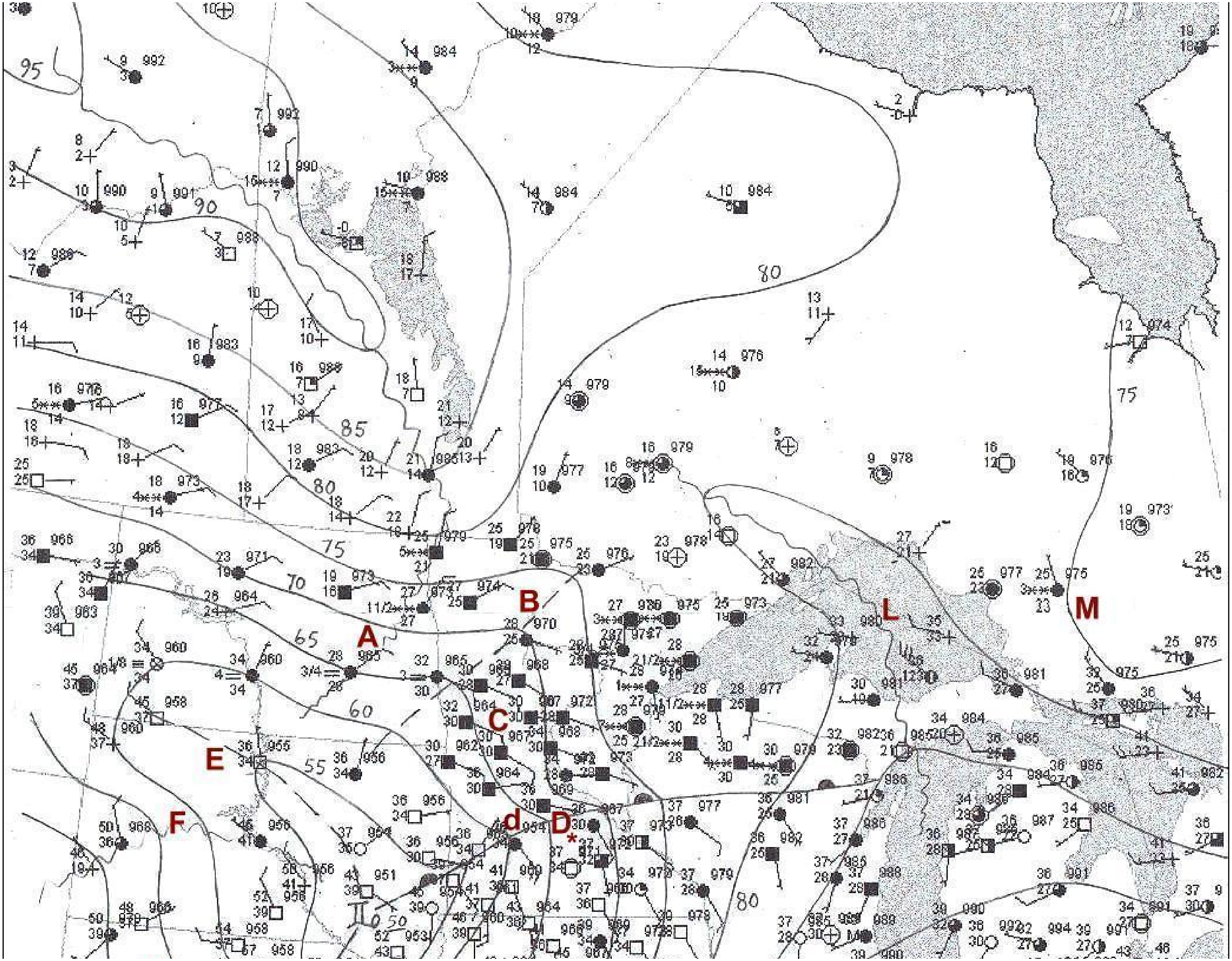
Below is a **preliminary analysis for the chart with 80 % of data plotted**. This is my initial sketch of a reasonable final analysis (which the 80 % chart is - all data could be plotted, but that clutters the map, mainly with observations near those already plotted). The region of the cyclone is focused on. The map letter comments mention many considerations for final analysis.





Below is the chart with **80 % of data plotted**. I think this isobaric analysis is better than that on the hand-plotted map (shown in an article not yet here) because it contains more data - altimeter settings rather than sea level pressures. Main features are similar though, with a few new ones.

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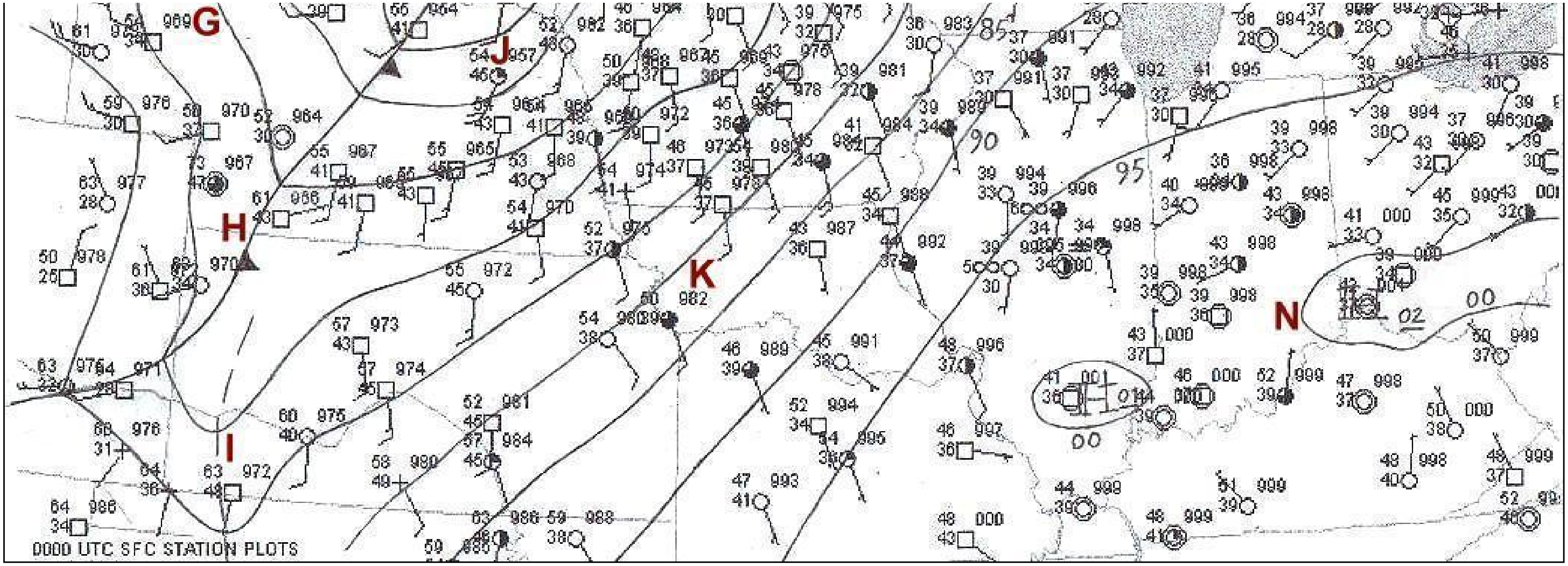


Hopefully seeing how analysis changes as more stations are included is helpful. An advantage of objective analysis such as Digtial Atmosphere provides is that **all data can be used in the analysis, even if plotting it would make the map unreadable**.

Home Page

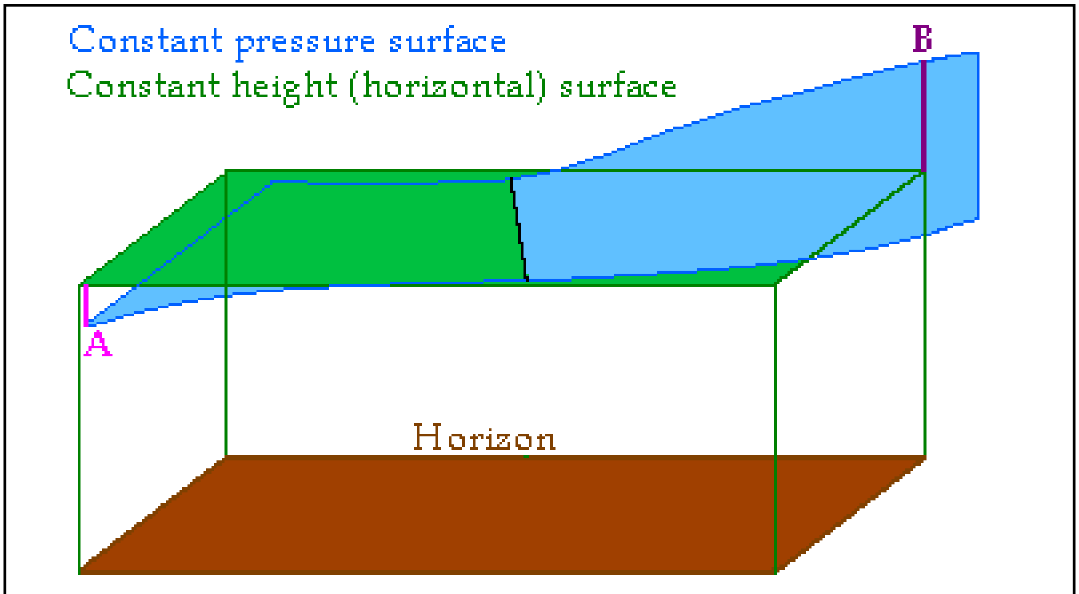
Height & Pressure Coordinates

Date : 10 January 1999

Introduction

Scientifically forecasting our weather involves an estimate of the behavior of an air and water vapor atmosphere above the surface of a planet (Earth). Though surface conditions primarily concern us, forecasting success requires accurate prediction of atmospheric flow aloft. Similar with surface charts, **upper air charts** are used for this.

Pressure as a Vertical Coordinate



Along A, pressure on the constant height surface is less than that on the constant pressure surface; similarly, height on the constant pressure surface is less than that on the constant height surface. Thus, A is the low pressure/height area of this region. Vice-versa, B is the high pressure/height area.

As illustrated below, **upper air analysis** is much more convenient using **pressure** rather than height as the reference **vertical coordinate**. Other than in violent atmospheric circulations with locally rapid accelerations such as tornadoes, pressure always decreases with increasing altitude (else an upward acceleration greater than gravity's downward acceleration is necessary). Thus for all practical purposes, pressure is a continuously and smoothly decreasing function with respect to elevation (height above mean sea level). Just as the horizontal direction defines a surface of constant elevation or height, a surface of constant pressure can also be defined. Just as our previous surface pressure analysis was for a constant height of mean sea level, upper air air analyses are done for constant pressures (surfaces) aloft.

Pressure and Height Gradients

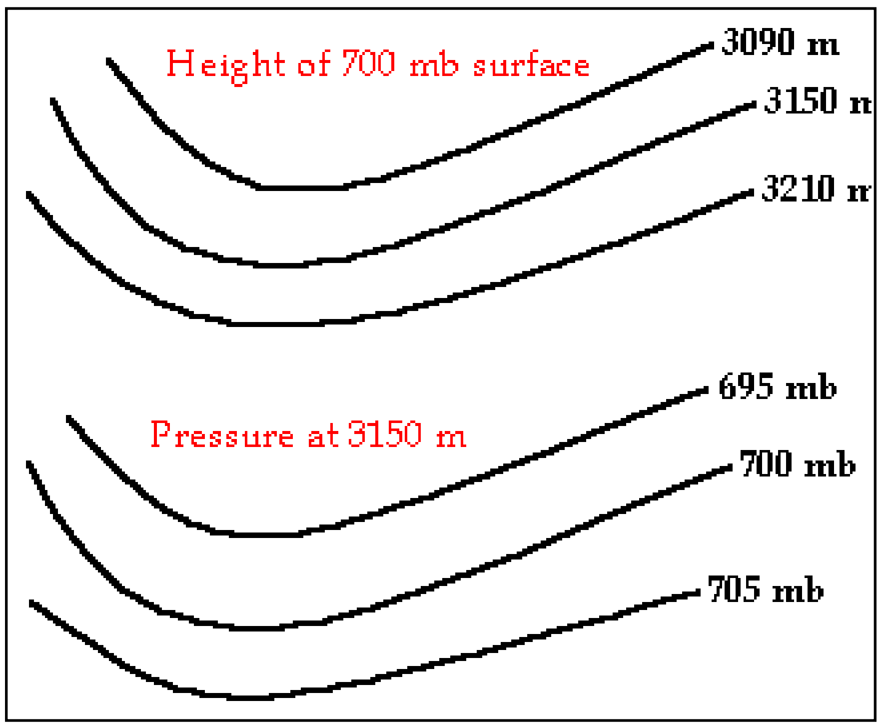
For mathematical analysis, transformations among height and pressure coordinates are necessary. Particularly, pressure gradient is 0 on a constant pressure surface (no change of pressure along a constant pressure surface), but height gradients exist (height changes along a constant pressure surface). We shall see that **a height gradient on a constant pressure surface is analogous with a pressure gradient on a constant height surface**. The required transformation is :

$$[\partial P / \partial x]_z = - [\partial P / \partial z]_x [\partial z / \partial x]_P$$

A B C

P : pressure

for which $[---]_a$ implies the quantity --- in brackets is valid for constant values of the variable a. Thus, the above equation states that the partial derivative of pressure with respect to horizontal on a constant height surface (A) equals the negative of the partial derivative of pressure with respect to height at some place along the horizontal (B) times the partial derivative of height with respect to horizontal on a constant pressure surface (C). You may recall in a previous discussion (not yet here) that hydrostatic balance implies :



$$\partial P / \partial z = - \rho g$$

ρ : density
g : Earth's gravitational acceleration

Thus,

$$[\partial P / \partial x]_z = \rho g [\partial z / \partial x]_p$$

I.e., **pressure gradient on a constant height surface is proportional with height gradient on a constant pressure surface**, as illustrated above & right.

You may notice that because constant height & pressure surfaces do not exactly correspond (as illustrated earlier), neither do the contours on corresponding maps, though the 700 mb & 3150 m contours would be exactly same for these maps for those height & pressure.

Geopotential Height

Geophysical scientists define **geopotential** (Φ) at a height z above mean sea level as :

$\Phi = \int_{0,z} g \, dz$

Because gravity is nearly constant in our atmosphere,

$\Phi \cong g_o z$

g_o : standard gravitational acceleration at mean sea level = 9.80665 m / sec^2

Energy = Mass × Acceleration × Distance, and specifically, Potential Energy = m g z (assuming constant g). So as its name implies, Mass × geopotential is the gravitational potential energy a mass has if suspended at height z. More subtle dynamical meteorological consequences of this exist which I hope I can discuss later, but my purpose for mentioning it now is for describing **geopotential height** (**Z**) :

$Z = \Phi / g_o$

which is **used instead of height for most forms of meteorological upper air data**. The main reason why is that mathematical analysis of dynamical equations is much easier after doing this. Perhaps you can see that for most locations (particularly aloft) geopotential height underestimates height; but this difference is generally small where weather occurs in our lower atmosphere (generally a few meters or less) - enough so that the difference is often ignored. The mention of "height" on a meteorological *upper air sounding or chart* more likely means geopotential height than actual height. This assumption is not very good above the tropopause though.

Next

Now we are in a position for a discussion construction and use of upper air charts.

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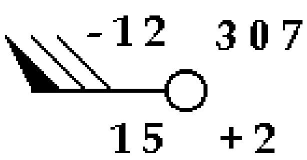
Upper Air Charts

Date : 21 January 1999

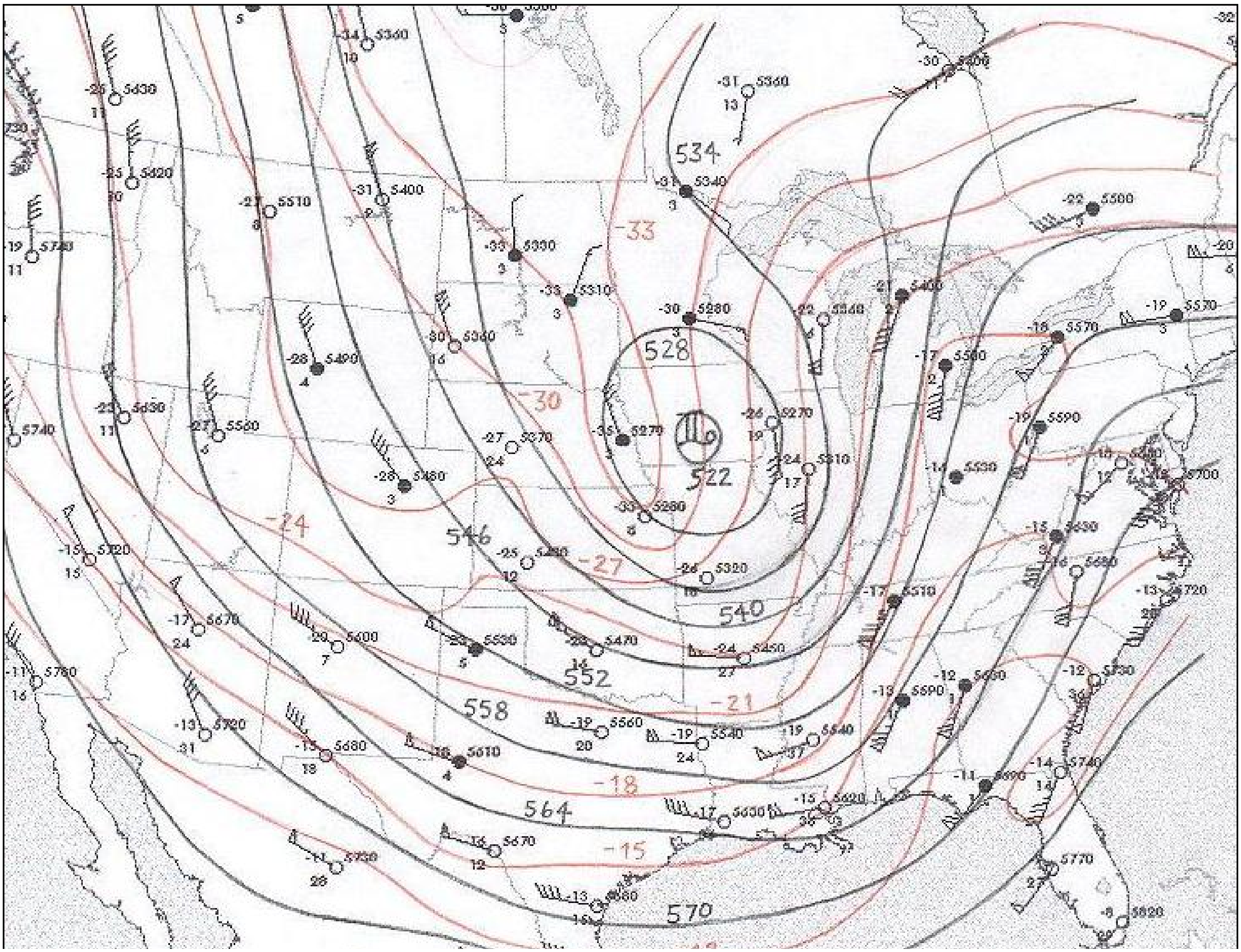
The standard form of an upper air station plot consists of temperature, humidity, wind speed and direction, and geopotential height at a specific pressure :

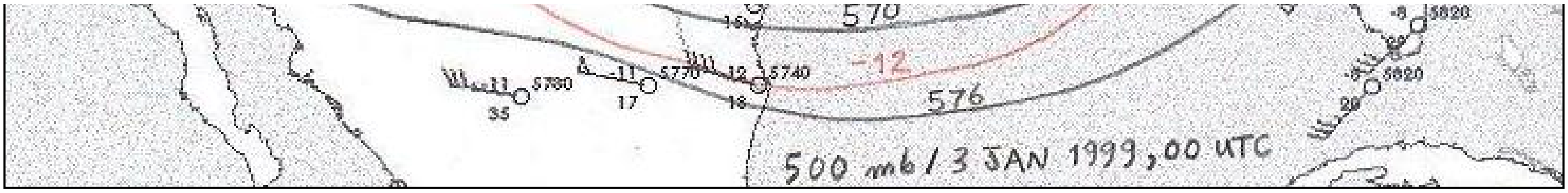


Wind : West (270°) @ 70 knots
Temperature : -12 °C
Dew point depression : 15 °C
Geopotential height : 3070 m
Geopotential height change : +20 m

700 mb station plot. Dew point depression of 15 °C implies dew point temperature of -27 °C. Last digit is omitted from geopotential height, and change is typically that during the past 12 hours. Station circle is filled if dew point depression is 5 °C or less.

Upper air analysis **on constant pressure surfaces** is most meteorologically useful, and height and temperature contours are typically included :





On the above 500 mb chart, geopotential height (black - decameters) and temperature (red - °C) contours are subjectively analyzed. The station plots were made using [Digital Atmosphere](), and slightly differ from the station model shown above. Dew point temperature is plotted on the bottom right rather than height tendency. A closed Low was over the northern Great Lakes, associated with snows of more than a foot over much of the region, and nearly 2 feet near the SW Lake Michigan shore.

Balloon Soundings

Similar with surface observations, upper air observations are (obviously) required for such a chart. This is primarily accomplished with balloon soundings (main site) at specified locations. A radiosonde (radio-transmitted sonde) is released. As it rises and drifts with the wind, the plotted variables are measured. Readings are obtained for mandatory and significant pressure levels. Mandatory levels are 1000, 925, 850, 700, 500, 400, 300, 250, 200, 150, and 100 (and 50 & 10 ?) mb. Significant levels are those in between at which temperature lapse rate or wind change significantly (more than a specific threshold - the precise values of which I am unaware of). Thus, the temperature plot is quite accurate and smoothly varies. A sounding is considered successful if 400 mb is reached. When sufficient soundings are made over a region nearly simultaneously (*nearly* can be an hour or more different), an upper air chart is made for each mandatory pressure, all readings plotted at the point of release (though the balloon drifts many miles - a significant source of error for upper atmospheric charts, actually). This radiosonde data is (of course) the source for atmospheric soundings previously discussed.

Direction of Gradient Wind

You may recall in a previous discussion (not yet here) that the **gradient wind** at a constant height such as sea level blows **parallel with isobars**, with low pressure to the left / right of the wind vector in the Northern / Southern Hemisphere. This statement can be equally made for **height contours** at a constant pressure as depicted on upper air charts. This can be illustrated mathematically, rewriting the gradient wind equation previously shown :

$$1 / \rho \, [\partial P / \partial r]_z = s^2 / r + f\, s$$

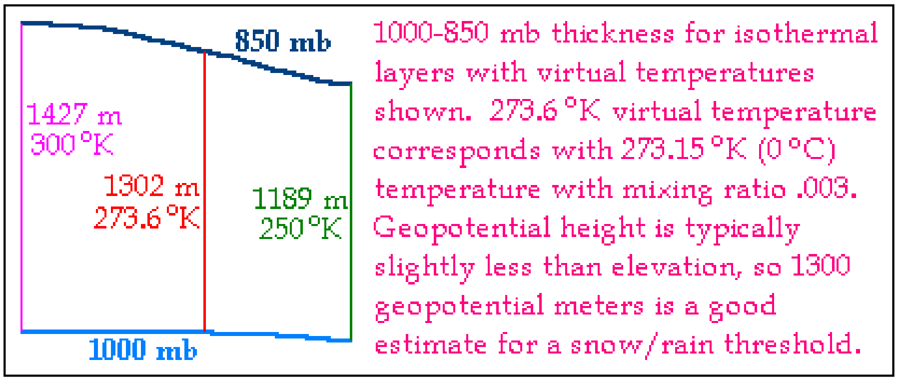
replacing pressure gradient on a constant height surface with height gradient on a constant pressure surface :

$$g \, [\partial z / \partial r]_P = s^2 / r + f\, s$$

Thus, the basic interpretation of the equation does not change - ***horizontal* gradient winds blow parallel with both isobars and height contours, and are stronger where isobars or contours are most closely-spaced**. Please notice that geopotential height contours as typically plotted slightly differ from this, but a similar transformation for geopotential height can also be made. You may notice that winds on the 500 mb chart above generally follow this rule, though actual winds vary quite significantly from gradient winds for some places such as Albuquerque, NM.

Thickness

In a previous feature (not yet here), I illustrated how virtual temperatures determine pressure differences between fixed altitudes. Another way of thinking of this is that virtual temperature also determines height difference between pressure surfaces (standard values for gravity & dry air composition used for diagram) :



Thus **between 2 pressure levels**, a **deep layer** is relatively **warm**, and a **shallow layer** relatively **cold**. The term **thickness** is used when referring to **distance between 2** of such **layers**. Thickness has many uses, but because of this correspondence with temperature, the most common is use as a guide regarding wintertime precipitation type. Observations indicate that 1000-700 mb geopotential thickness of 2840 m and / or 1000-850 mb geopotential thickness of 1300 m are approximate thresholds between rain and snow.

Waves in the Upper Air Flow

More important than thickness though is that height contours reveal the upper air flow and waves in it. Though the chart for the continental U.S. and southern Canada above reveals only part of a wave - a strong low pressure trof - a hemispheric 500 mb chart (main site, geopotential height colored) reveals series of trofs and ridges. We shall see that these waves largely determine large scale weather features such as cyclones and anticyclones; and because temperature determines positions of the geopotential height contours as illustrated, global distribution of heating and cooling ultimately determine those.

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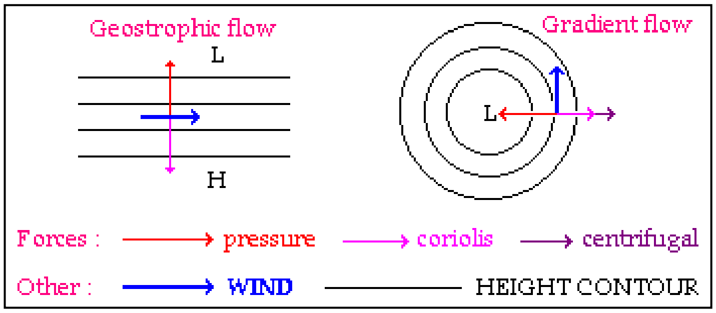
Upper Air Chart Analysis

Date : 17 February 1999

Before I show many more upper air charts for a snowstorm this January, I must explain how they are analyzed; so I can discuss only the analyses and their consequences regarding weather in the next article. A review of the concepts of **geostrophic and gradient winds** is helpful. These are illustrated to left with their force balances. Because centrifugal force exists only in **curved flow, gradient wind** is valid for it - if it can be [considered valid - see item 17 in scetion B](#) ([main site](#)); but **geostrophic wind** only for **straight flow**. **Both neglect friction**, which is not a bad approximation above the atmospheric boundary layer (ABL), especially in the middle atmosphere. **Both flow parallel with isobars and (geopotential) height contours, which are nearer where winds are strongest**. "How near?" is actually a rather important question for chart analysis, as shown below.



Contour Spacing

The gradient wind equation using polar coordinates is :

$$g\,\partial z/\partial r = f\,s + s^2/r$$

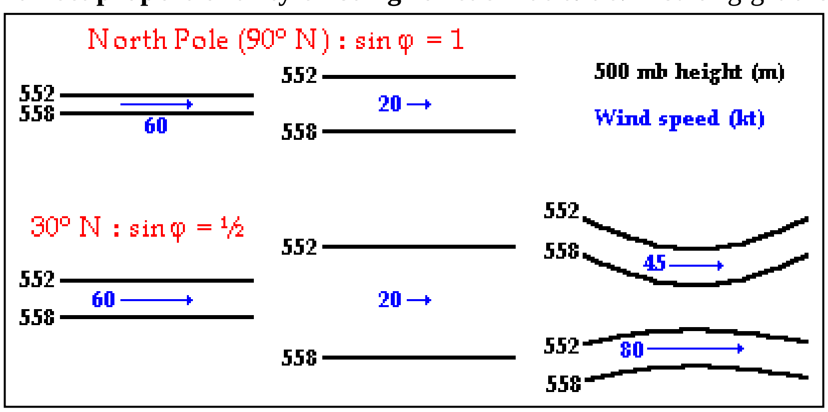
1 2 3

z : height on a constant pressure surface g : gravity force s : wind speed f : coriolis parameter = $2\,\Omega \sin\varphi$, φ : latitude r : flow radius (or radial direction)

for which p denotes partial derivative. Term 1 is pressure gradient force, term 2 is coriolis force, and term 3 is centrifugal force. As curved flow becomes straight, flow radius becomes infinite; such that centrifugal force becomes 0. Thus **for geostrophic winds**, **a specific pressure gradient corresponds with a specific wind speed**;

$$s = (g\,\partial z/\partial r)\ /\ (2\,\Omega \sin\varphi)$$

a direct proportionality existing for each latitude. A strong gradient means contours are close together. For example, if winds were geostrophic, height contours would be 3 × further apart for 20 kt winds than for 60 kt winds at 30 °N. Geostrophic wind speed is **inversely proportional with the sine of latitude** though, so height contours would be twice as close at the North Pole than at 30 °N for 60 kt winds at each. If a little confusing, then the diagram to left may help. I thought avoiding further complication using geopotential height would be best here, which requires small adjustments because of latitudinal and vertical variations with respect to height.

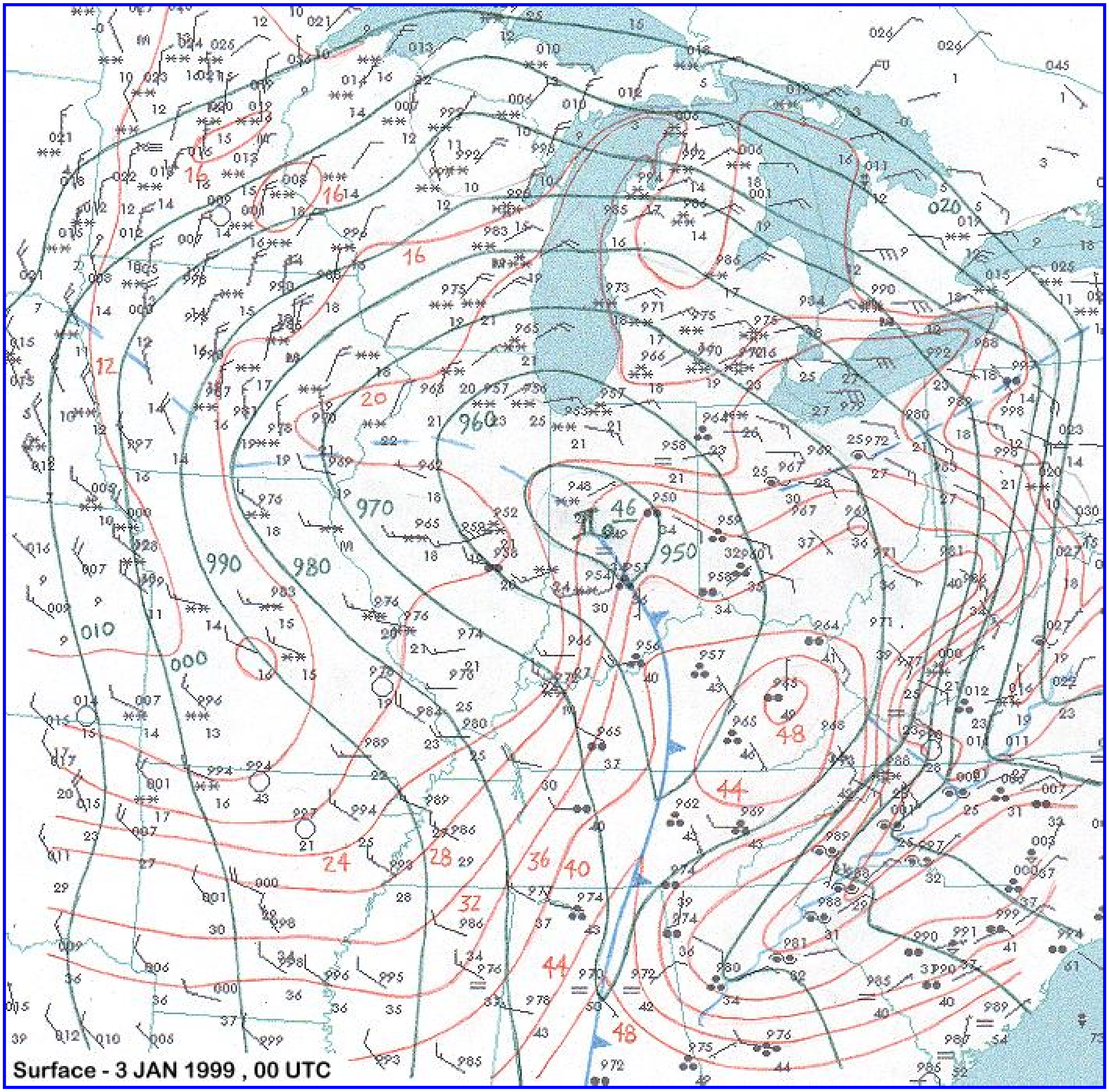


Perhaps you can see that for curved flow (gradient winds), this exact proportionality is not true because of term 3. If you recall our coordinate system, s is positive for counterclockwise flow (normal Northern Hemisphere cyclonic flow); so pressure gradient is balanced with an extra term. Thus **for the same height gradient** (contour spacing), **winds are weaker for positive flow and stronger for negative flow**. For normal atmospheric situations where applicable, the curvature term 3 is typically smaller than the coriolis term 2. So for the above example of 60 kt winds at 30 °N, wind would be perhaps 45 kt for cyclonic flow or 80 kt for anticylonic flow as illustrated.

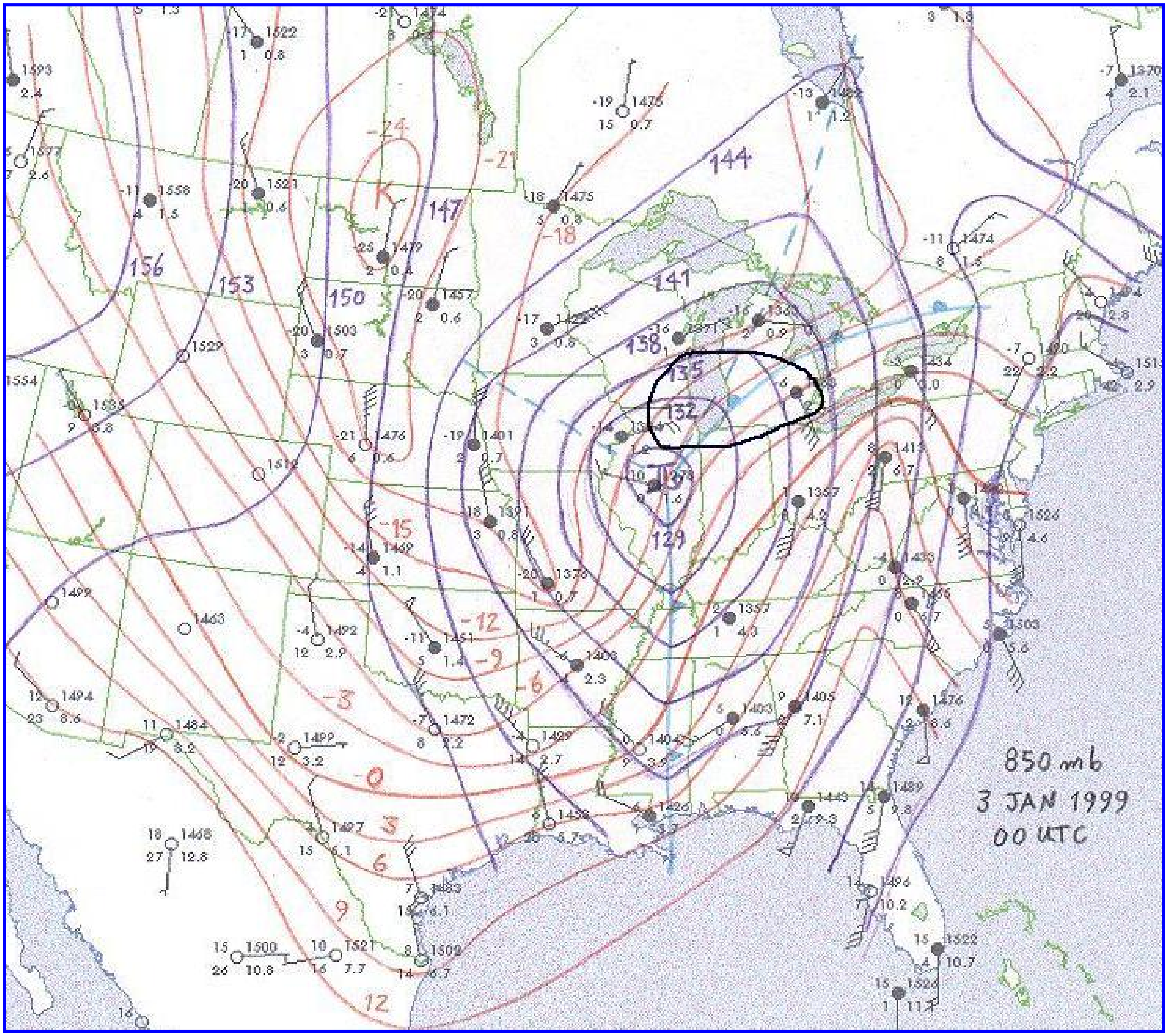
Analysis Techniques

Below are a surface, 850 mb, and 500 mb charts for 00 UTC 3 January 1999 (6 PM CDT 2 January 1999). A strong snowstorm was occurring over the southwest Great Lakes and surrounding regions @ that time - **click on images (which open in a new window) for additional commentary, but commentary is best read after the entire text of this article is** :

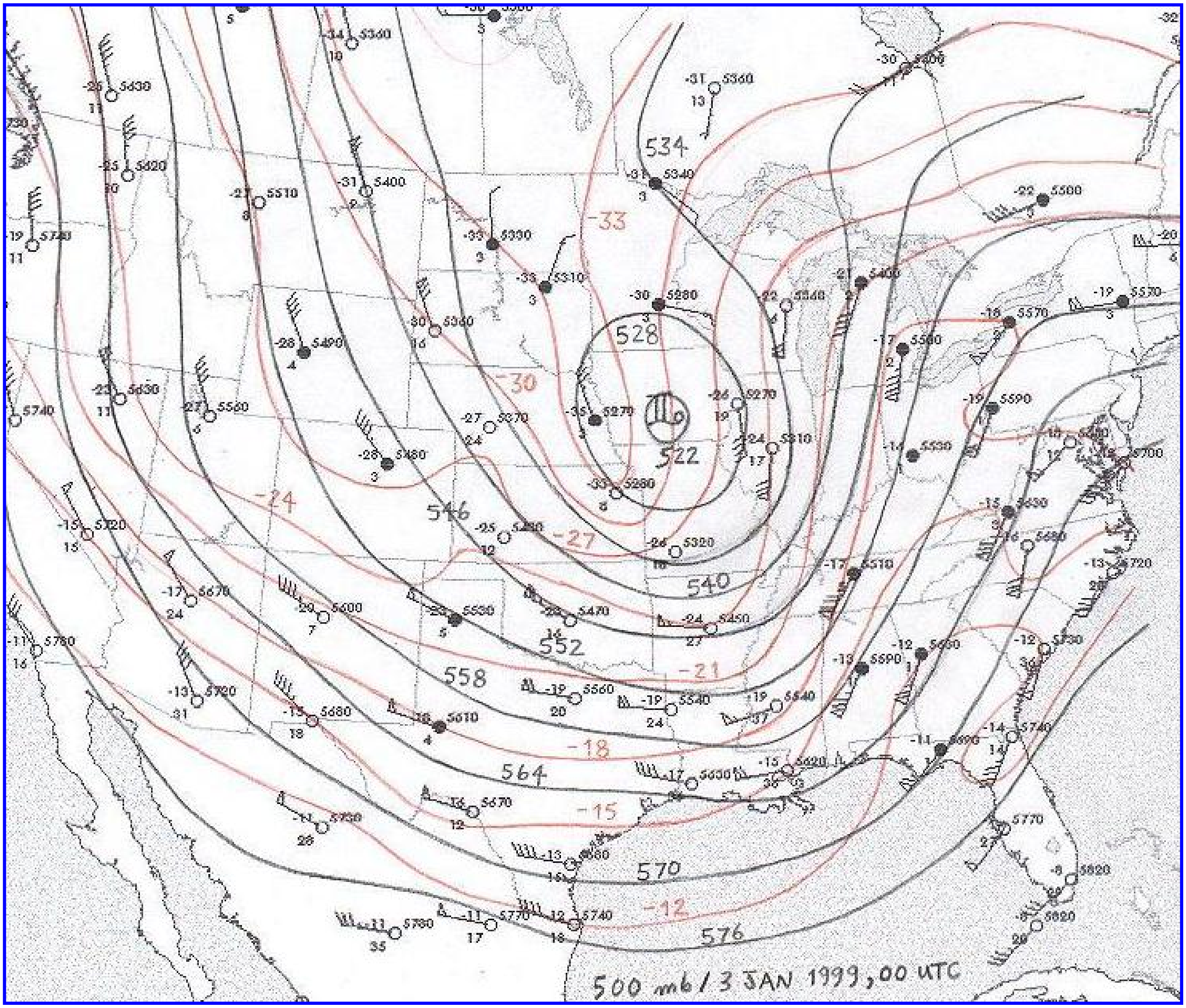
Surface chart



850 mb chart



500 mb chart



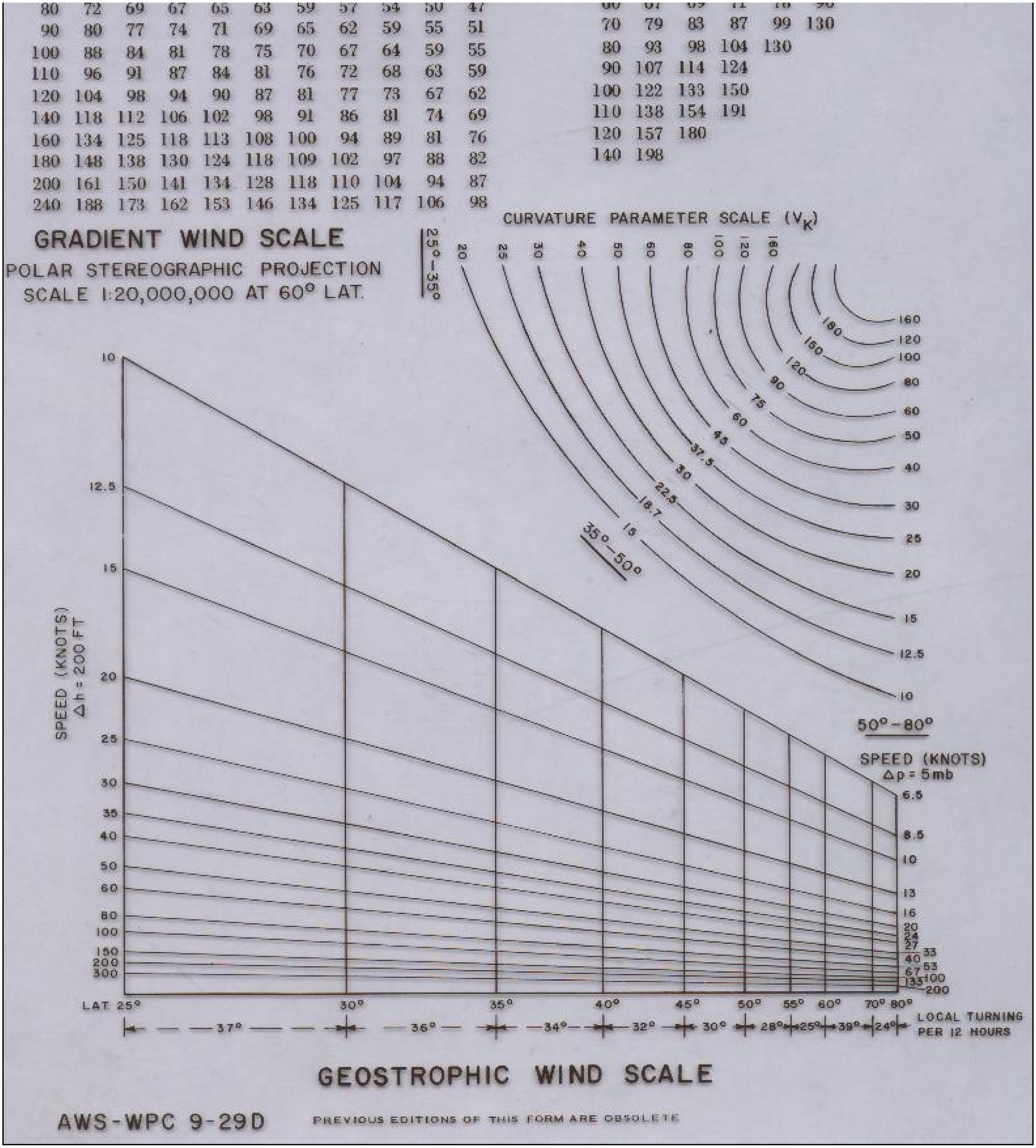
Let's first consider height contours on the upper air charts (850 & 500 mb). Height contours above the atmospheric boundary layer should generally be parallel with winds. This is not exactly so for several reasons - the most important of which are (geostrophic) flow adjustment processes, relatively small amounts of friction, and influence of convective disturbances and mesoscale (generally a few to a few hundred km spatial scale) storm circulations. The latter is not so important for a winter storm such as this. Regarding spacing, linear interpolation is almost never bad - often a good first approximation; but then should be adjusted for wind speed. As illustrated above, contour spacing should be roughly inversely proportional with wind speed (twice as close together for twice as fast winds, etc.), with adjustments for curvature and latitude. This is not a strict rule, but gradient wind is not a bad approximation above the ABL. Before objective analysis was so common, graphical guides such as that shown below were used :

← V_K Cyclonic Curvature →

↓V_G	10	15	20	25	30	40	50	60	80	100
50	47	45	44	43	42	40	39	37	35	33
55	51	49	48	47	46	44	42	40	38	36
60	55	54	52	50	49	47	45	43	41	38
70	64	62	59	58	56	53	51	49	45	43
80	72	69	67	65	63	59	57	54	50	47
90	80	77	74	71	69	65	62	59	55	51

← V_K Anticyclonic →

↓V_G	10	12.5	15	20	25	30
40	43	43	44	46	49	52
45	48	50	51	53	57	62
50	54	56	57	61	66	75
55	60	62	64	69	77	95
60	67	69	71	78	90	
70	79	83	87	99	130	



This is a transparent plastic object which can be placed over a map of the specified projection and scale. The bottom diagram shows how height / pressure contours correspond with geostrophic wind speeds. Characteristics mentioned above of how contour spacing corresponds with geostrophic wind speed are evident - spacing of straight contours on a map should theoretically be the distance slanted lines are from the bottom horizontal line. The series of curves to its upper right are curvature parameters for gradient winds. Please notice that the numbers shown are not curvature radius r as defined above. They are actually opposite - 0 corresponding with a straight contour line and increasing numbers corresponding with sharper curvature. The 2 tables above list how gradient wind speeds should be adjusted from geostrophic values for specific curvature radii. This is not presented for use, but simply as a good illustration of some of the concepts discussed, how they affect chart analysis, and a practical solution for dealing with this. An analyst would not examine every curve & line, making sure that they correspond with the guide; but do spot checks for making sure the analysis is generally accurate and consistent, and use it for questionable regions and realism of supposed small-scale features such as shortwave trofs (small wavelength trofs). I don't think I have any maps of the type this is valid for, so the main thing I use it for now is a hard, flat writing surface 😉 If you want this diagram further explained though, please ask.

Contours of surface altimeter settings are similar with geopotential height contours; though with friction being much more important, winds tend to flow toward low pressure and away from high pressure as well as around. The same basic characteristic of strong winds corresponding with close contours exists, though factors such as flow over variable surfaces and sometimes inconsistent wind measurement heights make a strict equation impossible.

A general tendency you likely notice is how contours can sharply vary at the surface but become progressively smoother further aloft. This is mainly because of surface friction, that fronts are generally best defined near the surface, that most atmospheric turbulence occurs in the lower atmosphere, and because surface data is much more abundant than aloft. If more data were available aloft, perhaps those maps wouldn't appear quite as smooth. I suppose I analyzed the 500 mb chart a little like a klutz, but the worse problem would be portraying features which aren't present. Some shortwave trofs and microridges may be present at 500 mb which aren't analyzed, but my advice is not assuming so unless you have good evidence that such features exist - such as a locally sharp height gradient which corresponds well with shifting or turning winds, a clearly associated feature on satellite or radar imagery, etc. I had neither of the available for this analysis, but I think the charts are sufficient for illustrative purposes.

Regarding isotherms, linear interpolation is often very good. Exceptions may be locations where you know a gradient is likely sharper because of a surface front, cloudy or clear areas, etc. These should also be smooth unless a good reason is known why they shouldn't.

For any type of contours, be aware of an undesirable tendency of steering around stations. Remember that the data is not perfect, and drawing a curve which does not interpolate can be correct. Some data points may be grossly unrepresentative, and probably should be ignored. I mention a few examples above along with the charts.

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Upper Air Analysis of a Storm

Date : 23 February 1999

Let's consider how upper air flow affects development of weather systems. My article illustrating a detailed surface analysis (not here yet) concerned a small storm system most typical of those in North America. This one features the more unusual (and probably interesting) case of a large snowstorm, which dropped 2 feet at most favorable locations near the southern west shore of Lake Michigan and more than a foot over much of the Great Lakes region. This article involves detailed analyses of 500 mb and 850 mb charts, precipitation type and its relation with predictive weather parameters, and snowfall maps.

Large Scale Features

The storm occurred 2-3 January 1999, as a strong cyclone developed over the southern Plains states and strengthened while moving over the Great Lakes. A peek at the associated large scale weather patterns as depicted on Unysis' WXP weather chart archive is helpful. The primary features you should notice are development and movement of the surface cyclone between 1 & 4 January,

Surface chart : 1 January 1999, 00 UTC
Surface chart : 1 January 1999, 12 UTC
Surface chart : 2 January 1999, 00 UTC
Surface chart : 2 January 1999, 12 UTC
Surface chart : 3 January 1999, 00 UTC
Surface chart : 3 January 1999, 12 UTC
Surface chart : 4 January 1999, 00 UTC

that such **development occurred in a region of large temperature gradient** (temperature shown at upper left of each station plot), and the associated upper air situation - particularly at 500 mb (middle atmosphere) especially the trof aloft which develops in the flow over the NW U.S. and strengthens while moving southeastward, and the cold closed Low which subsequently formed over the middle U.S.

Detailed Analysis

Many upper air charts are presented, showing the storm's evolution and relevant features. **1.86 MB of 17 charts must load**, so please be patient. Make sure your Disk Cache is @ least 2048 kB (using Netscape, click Edit, Preferences, Advanced, then Cache - probably something similar for other browsers) and grab a snack or something ☺ You can e-mail me for suggestions if you have trouble downloading everything. I think showing these is quite useful, so I place them and the related discussion on a separate page (same link as above).

Next

Hopefully this retrospective analysis of a major snowstorm was an instructive example. Many more aspects can be discussed, but the above is most helpful for achieving our goal of **forecasting** such events, which we'll soon be doing here.

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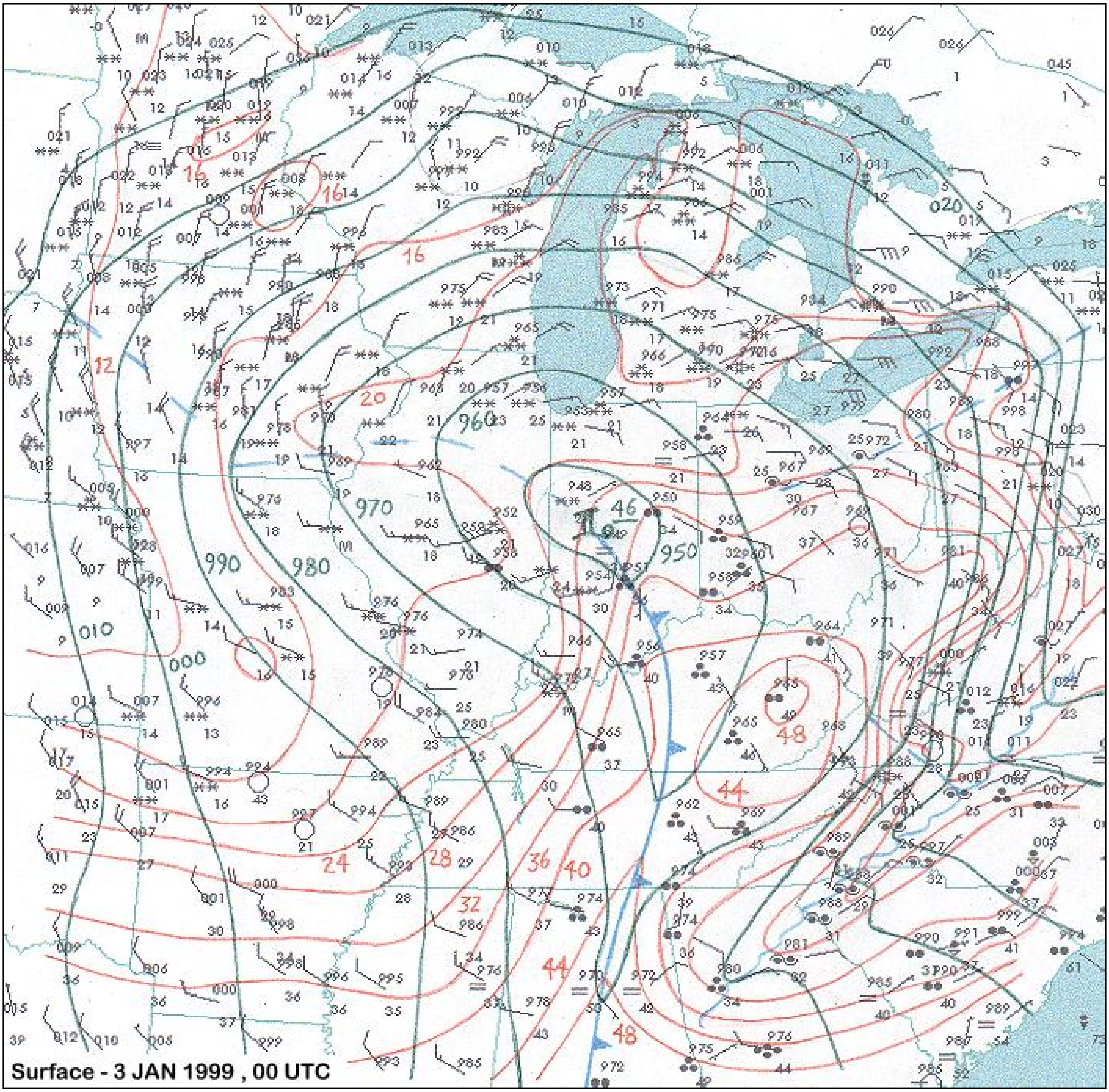
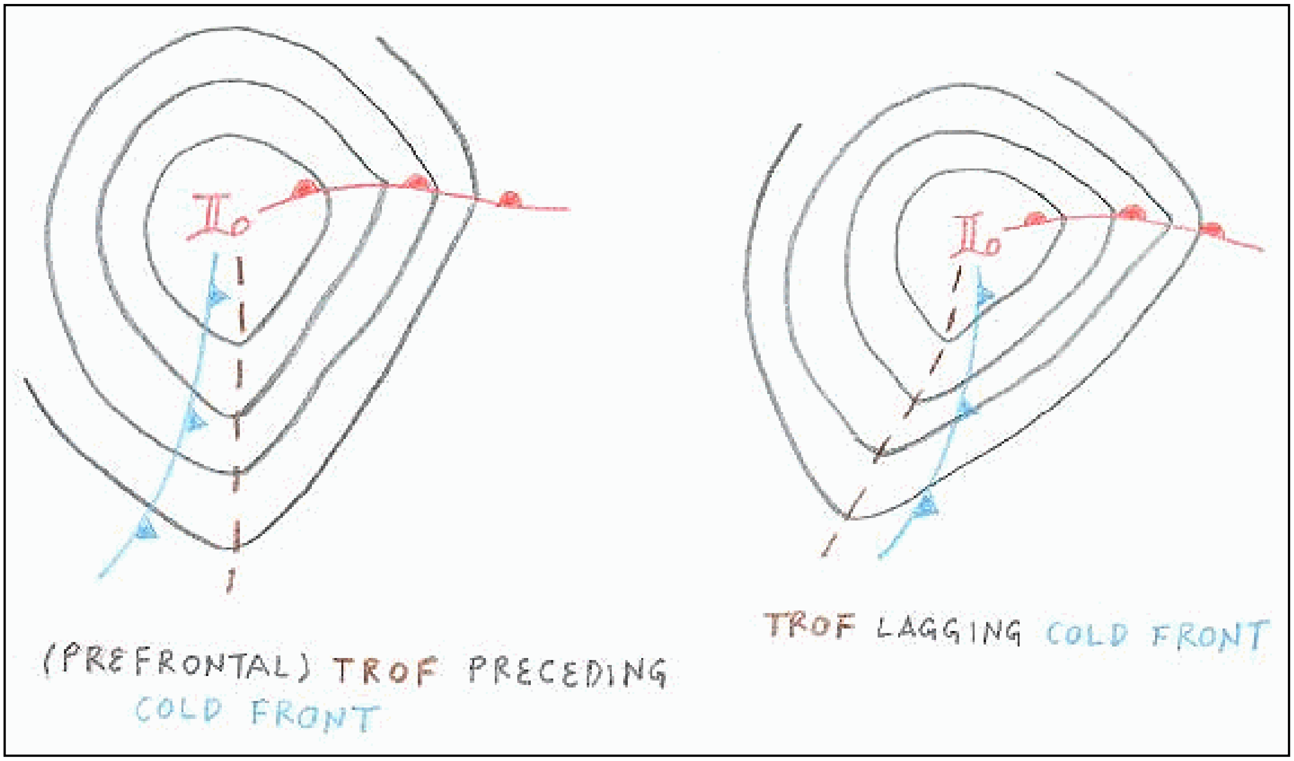
Kinked Contours

Date : 8 May 1999

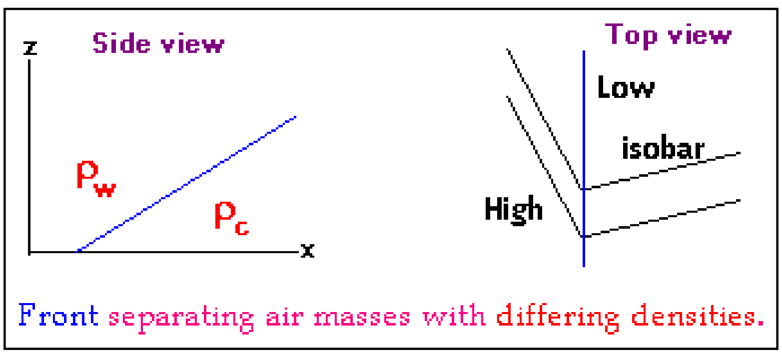
If you look at weather analyses more than occasionally, I am sure that some time you saw a map which looks like this :



I presented this map previously (not yet here) as an example of a detailed isobaric analysis. The feature I particularly refer to here is the shape of the isobars at the front. Though observations often indicate that isobars kink along a front as shown, the situation may be more subtle. Actually, the shape shown may be valid for a trof (or localized minima) of **any type of contour**, not only isobars. A surface trof coinciding with a front is a special case of the general situation for which the trof line may lag or much more often precede the front (i.e., a prefrontal trof) :



A **front** is obviously not an infinitesimally small boundary between cold and warm air (strictly, dense and light air) as depicted, but a **transition zone** between 2 such air masses. In the AMS publication Mesoscale Meteorology and Forecasting, Howie Bluestein presents a discussion of fronts which includes among more complicated things a simple frontal model. A sloping frontal boundary separates air masses of differing densities as illustrated below :



He called the x-axis above the y-axis, but I thought that might be a bit confusing. He took the right diagram from Petterssen's Weather Analysis and Forecasting book. The equation :

$dP = \partial P / \partial x \, dx + \partial P / \partial z \, dz$

P : surface pressure

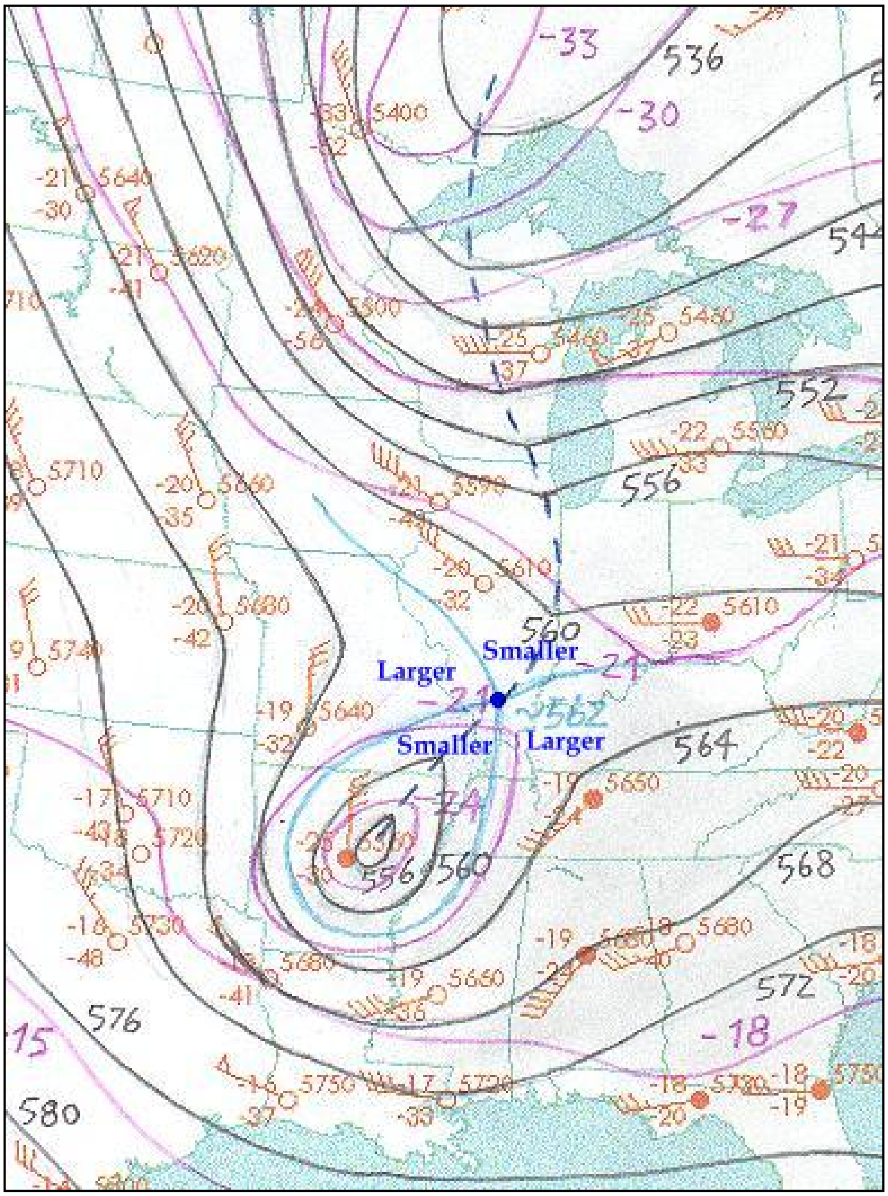
is pressure change, written as differential form. Thus he mentions that the simple equation :

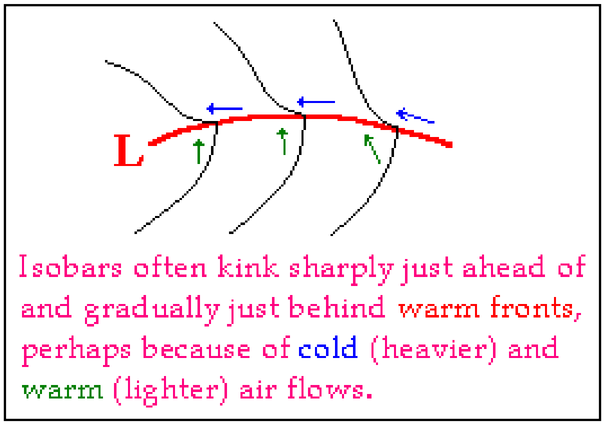
$dz / dx = ([\partial P / \partial x]_c - [\partial P / \partial x]_w) \; / \; (g\,(\rho_c - \rho_w))$

ρ : density

relates variables in the diagram. Subscripts c & w refer to cold & warm sides of the frontal boundary, respectively. Please notice that dz / dx (Δz / Δx, which is (change of z) ÷ (change of x)) is simply slope of the front. Examination of the equation suggests that the greater the pressure gradient is on the cold than the warm side, the greater the slope of the front. You probably notice that pressure gradients are typically greater behind cold fronts than ahead of them, thus they are depicted as sloping more steeply. That's also a reason for the strong, cold, gutsy winds behind them. I am straying from the main purpose of the article though.

My main purpose is discussion of shapes of isobars along fronts. Please notice the kink drawn along the front. The greatest pressure gradient is shown on the cold side of the fronts, as discussed above. Though such a simplification can be helpful, pressures and densities are not really discontinuous along a front. Furthermore, a 500 mb analysis from this winter indicates that contours may kink at those altitudes also :





Fronts are generally poorly defined if existent there, though temperature gradients and sharp wind turns or shifts are evident in the data. The point I hope I am illustrating here is that not only do the geopotential height contours likely kink, but so do the isotherms and probably *any* contours including a curve of localized minimum values with larger values on either side. In my previous discussion of a detailed surface analysis, I speculated about a thermodynamical reason isobars may kink at fronts. That was probably incorrect, if for no other reason because such a relatively small temperature difference wouldn't likely cause such a large hydrostatic pressure difference. Confused yet ☺ If so, I apologize; but consider the following :

On the 500 mb chart above, a closed Low is embedded in a larger broad trof. A unique single contour must exist in the geopotential height field which exactly meets from either side, as illustrated. A geometrical term probably exists for this, of which I am unaware. But that's my argument - the point at approximately 5620 gpm which **must** exist illustrates that the kinks seen on weather charts probably are more because of a geometrical necessity than (thermo)dynamics. Thus, I think of no good reason why the kink should exactly correspond with the front as typically drawn, per se; though dynamics *tend* to cause such an occurrence because of gradient wind considerations (wind shift should roughly correspond with sharp pressure gradient).

Comments ? Disagreements ? Questions ? If so, please inform me.

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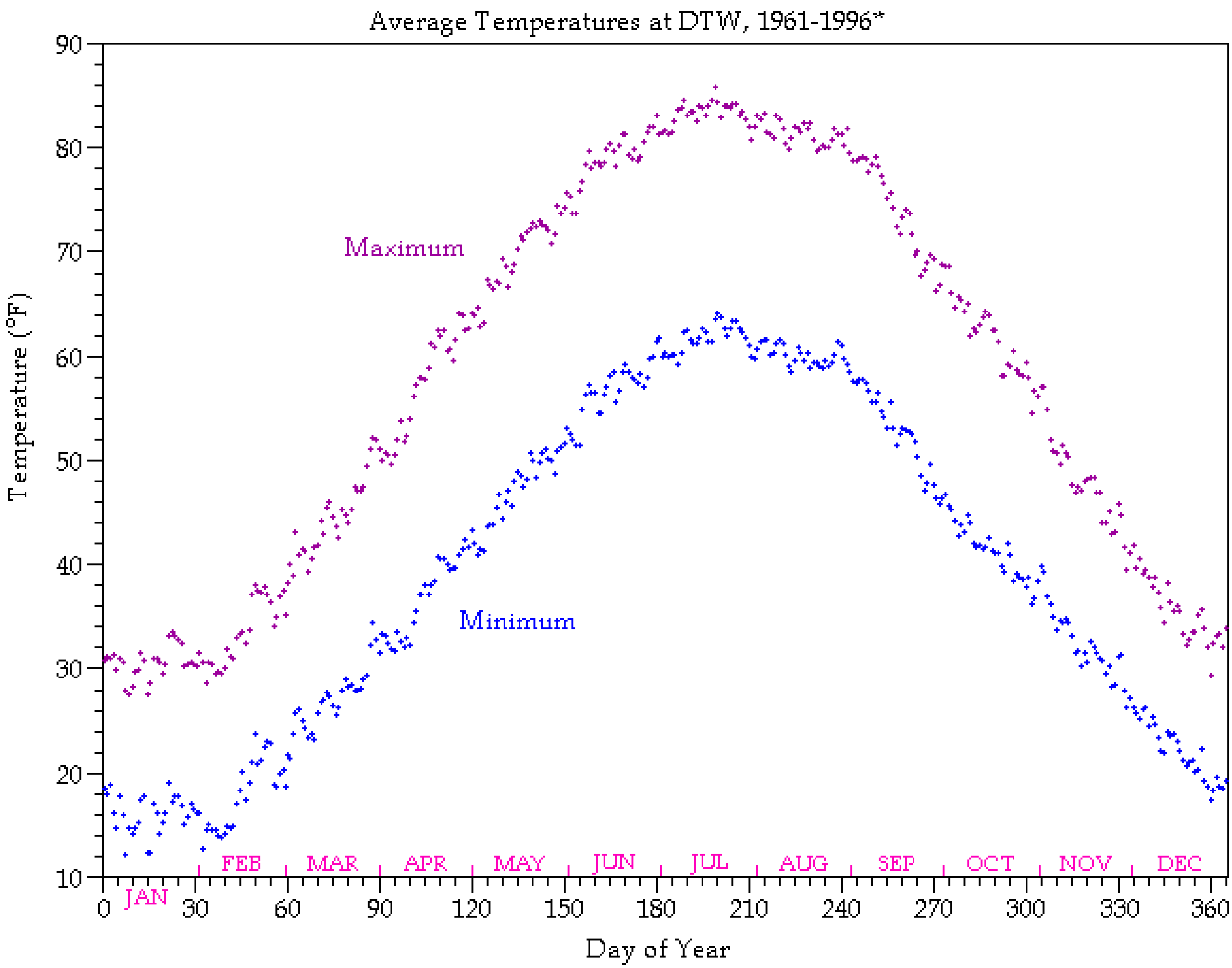
Date : 4 August 1999

Climate Normals, Part 1

During most TV weather reports and some others, you'll see a mention of **normals**, particularly normal high and low temperatures (main site). Because of weather's inherent variability, many people realize that a day when maximum and minimum temperatures equal the normals is quite rare. Meteorologically speaking though, the term does not have the typical connotation - such as something usual or expected. Instead, a **normal** refers to the **average or smoothed average of a meteorological parameter**. Though seemingly simple, this can become quite complicated; as illustrated below. Thus the word normal refers more so to a statistical sense - likely chosen because plot of daily average temperatures for a year :



often closely resembles a (statistical) normal distribution.

Climate Normals

At a National Climatic Data Center (NCDC) WWW site, the term **climate normal** is defined as being the arithmetic average of a meteorological element during a 30-year period. As further explained at that site though, this is actually only true for annual and monthly normals, but not daily normals. The number 30 was likely chosen because it is often the smallest number for which a sample of data is considered statistically significant. I.e., if daily values are considered, fewer than 30 data points won't likely create meaningful or reliable statistics (though the exact number is arbitrary - 29 points is obviously not much different than 30). Too many years is undesirable, because climates can change. Thus, the most recent 3 decades provides a reasonable notion of what the current average weather should be.

Monthly and Annual Normals

Monthly normals are determined as the **average of all monthly values** during a 30-year period :

$$T_{mnorm} = (\Sigma_{y=1,30} \Sigma_{d=1,k} T_{yd}) \ / \ (30 \ k)$$

T_{mnorm} : monthly normal
y : year number of the 30-year period
d : day of month with k days
T_{yd} : value of parameter T during year y & day d

For example, for a 31-day month (k = 31), 30 × 31 = 930 values are averaged if the record is complete. T above could represent minimum or maximum temperature, for example. The **average of the 12 monthly normals** determines the **annual normals** :

$$T_{anorm} = (\Sigma_{m=1,12} T_m) \ / \ 12$$

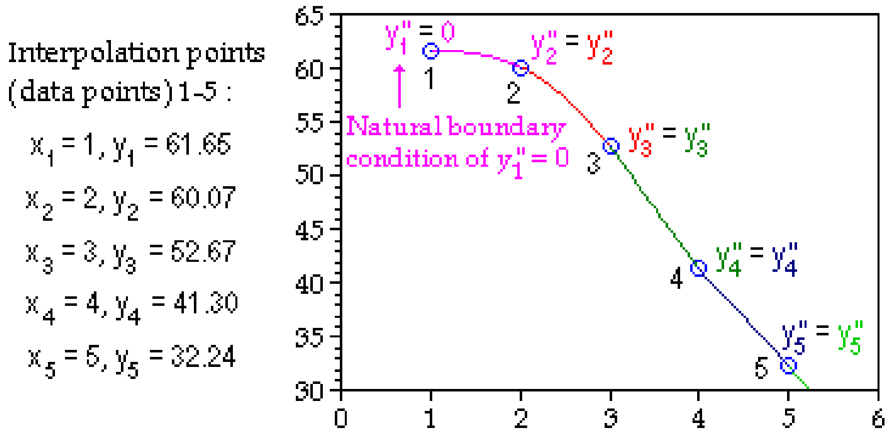
T_{anorm} : annual normal
m : number of month

Daily Normals

As mentioned, calculation of these slightly differs from the definition stated above. Though people seemingly don't mind monthly normals which irregularly vary, daily variations such as shown above is not tolerated. Common sense says that if climate were unchanging for an infinite number of years, such averages should smoothly vary. Thus rather than using discrete averages, **daily normals** are calculated from **smoothly varying curves**. Below I show that this attempt is only as good as the monthly normals are. (Though many more values determine monthly normals, persistent spells of unusual weather cause them to significantly differ from the supposed ideal distribution also).

Cubic Spline

As described in a referenced link above, daily averages are not used for computing daily normals. Instead, a cubic spline is fit thru monthly normals. These are cubic (3rd degree) polynomials which are used for interpolating (passing directly thru) a series of data points. This is done such that the value of a function and its 2nd derivative match at the interpolation points. Considering the following diagram :



Cubic spline interpolates data points with a smoothly varying function and continuous 2nd derivative.

The following equations define the cubic spline (for which i = 1 to 5 is shown above) :

$$y = A\, y_i + B\, y_{i+1} + C\, y_i'' + D\, y_{i+1}''$$

$$A = (x_{i+1} - x) \;/\; (x_{i+1} - x_i)$$
$$B = (x - x_i) \;/\; (x_{i+1} - x_i)$$
$$C = (A^3 - A)(x_{i+1} - x_i)^2 \;/\; 6$$
$$D = (B^3 - B)(x_{i+1} - x_i)^2 \;/\; 6$$

Perhaps you recognize equations A & B as linear interpolation formulas between points x_i & x_{i+1}, such that A = 1 & B = 0 at $x = x_i$ and A = 0 & B = 1 at $x = x_{i+1}$, with intermediate A & B values between those points. y derivatives are :

$$y' = (y_{i+1} - y_i) / (x_{i+1} - x_i) - (3A^2 - 1)(x_{i+1} - x_i)(y_i'') / 6 + (3B^2 - 1)(x_{i+1} - x_i)(y_{i+1}'') / 6$$

$$y'' = A\, y_i'' + B\, y_{i+1}''$$

My purpose for writing all this is to illustrate the interpolation property of a cubic spline. Similarly as for above, for the interval between x_i & x_{i+1}, A = 1 & B = 0 for $y'' = y_i''$, and A = 0 & B = 1 for $y'' = y_{i+1}''$. Thus, y_i'', y_{i+1}'', y_{i+2}''... are 2nd derivatives at the interpolation points. Thus values of the interpolation points determine y (the function) and its 2nd derivative (curvature). So the curves pass thru the interpolation points and their curvatures match there, providing the smooth curve thru them sought.

For climate normals, the values x_i, x_{i+1}, x_{i+2}... represent months along the abscissa, and the y_i, y_{i+1}, y_{i+2}... are mean monthly values (of a weather parameter such as minimum temperature) along the ordinate.

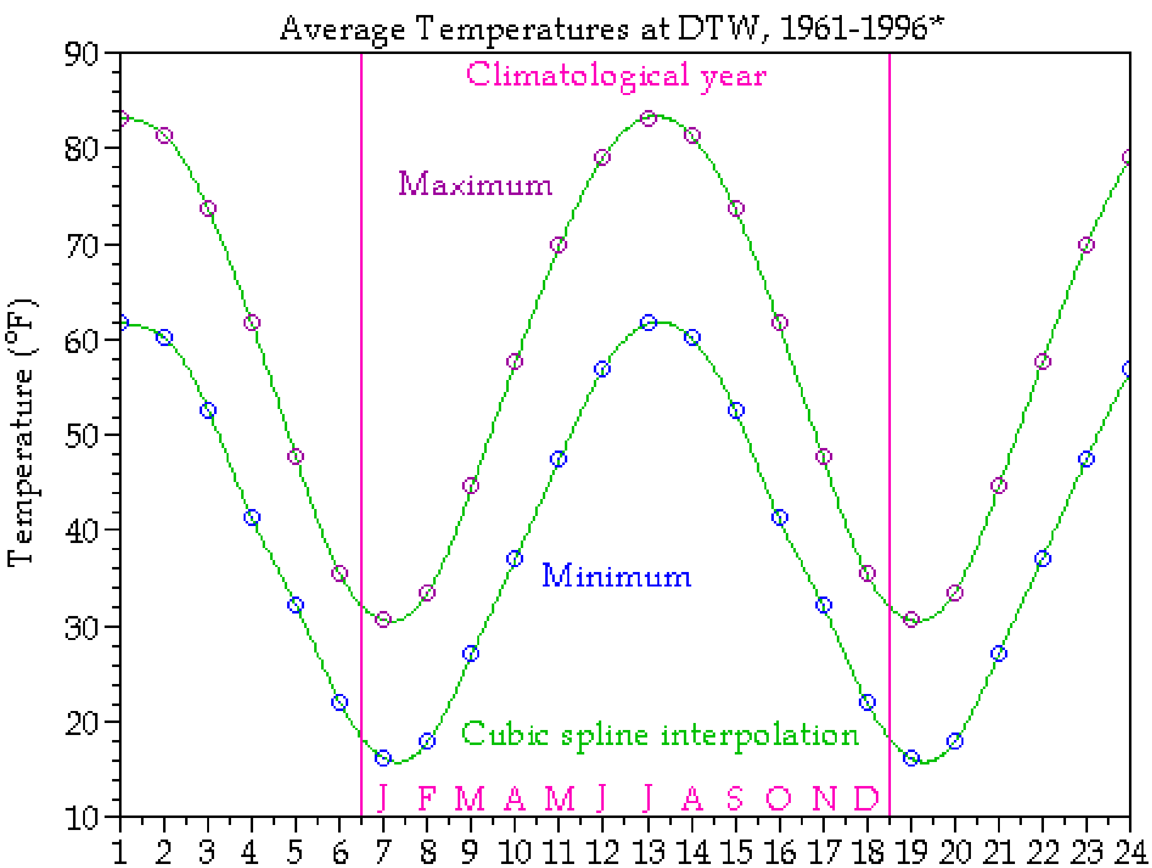
Evaluating the equation for 1st derivative (y') for $x=x_i$ for the intervals (x_{i-1},x_i) & (x_i,x_{i+1}) and equating these yields the following equation for y_{i-1}'', y_i'', & y_{i+1}'' :

$$(x_i - x_{i-1})(y_{i-1}'')/6 + (x_{i+1} - x_{i-1})(y_i'')/3 + (x_{i+1} - x_i)(y_{i+1}'')/6 = (y_{i+1} - y_i)/(x_{i+1} - x_i) - (y_i - y_{i-1})/(x_i - x_{i-1})$$

Considering N interpolation points, this provides a system of N-2 equations for the N unknown values of y''. 2 more conditions are needed for a solution. These are typically boundary values, the most common being natural boundary conditions of $y_1'' = y_N'' = 0$. Using those, the above equation is typically solved as a matrix equation for the y'' values. Then these values can be inserted into the equation for y to calculate its value at any point x (between each pair of x_i & x_{i+1}). I omit these gruesome details here.

Calculation of Daily Normals

If you are following the discussion this far, you probably realize that the cubic splines will generally vary smoothly except perhaps at the endpoints where boundary conditions are arbitrarily chosen. As mentioned in the links above, the official solution to this problem calculates the cubic splines for 24 monthly values, repeating the months of July-December before a year of data, and the months of January-June after a year of data. I did this for a 36-year period, reasons for which are explained in the next article :

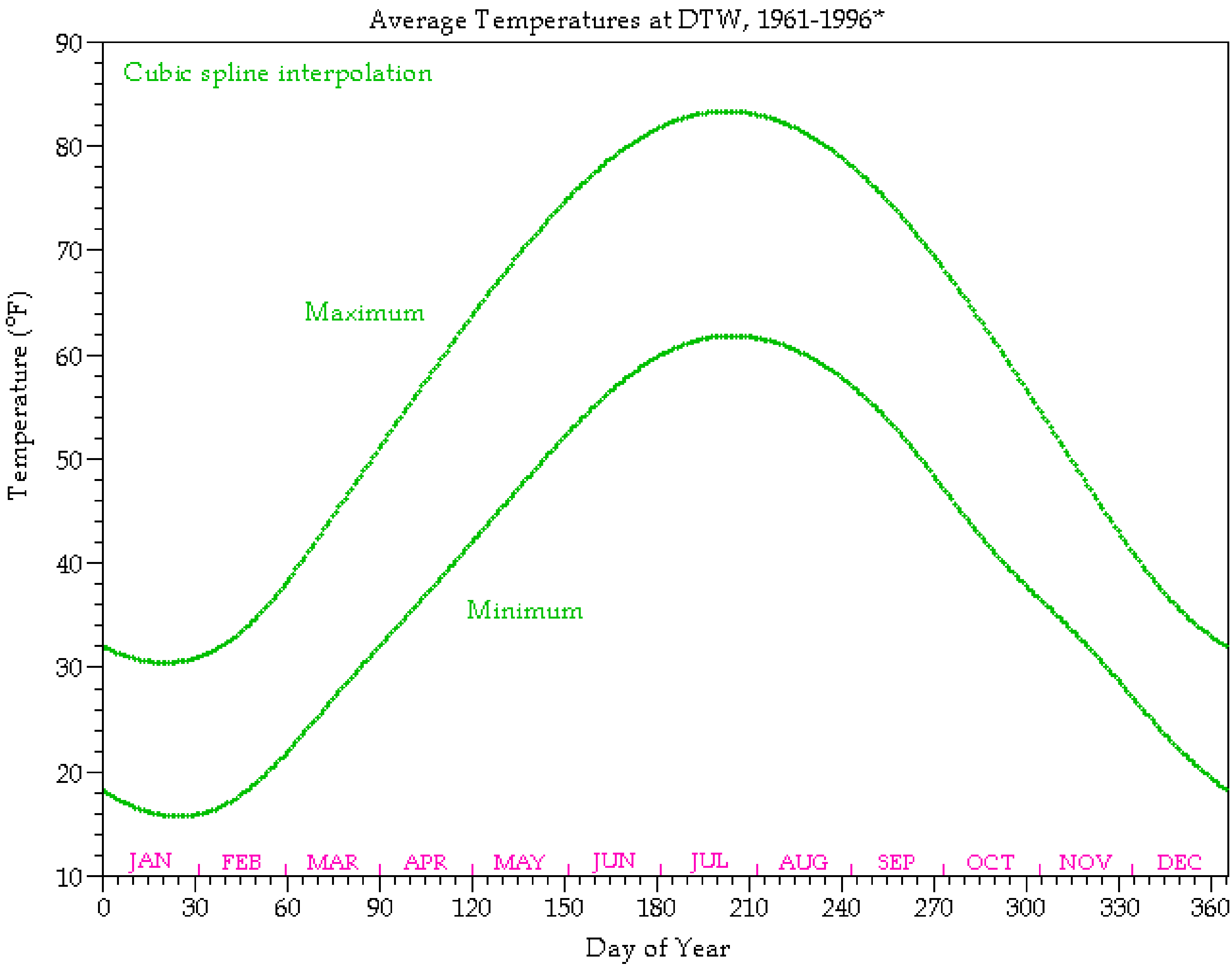


Then the cubic splines for the central 12-month period should be a smoothly varying curve with very similar values at the beginning and end of a year, as illustrated.

After this is done, the problem is then mapping the monthly (x,y) values to daily values. Considering the number of days during each month, counting February 29 as ¼ day :

Month	Days of year	Midpoint
JAN	0-31	15.5
FEB	31-59.25	45.125
MAR	59.25-90.25	74.75
APR	90.25-120.25	105.25
MAY	120.25-151.25	135.75
JUN	151.25-181.25	166.25
JUL	181.25-212.25	196.75
AUG	212.25-243.75	227.75
SEP	243.25-273.25	258.25
OCT	273.25-304.25	288.75
NOV	304.25-334.25	319.25
DEC	334.25-365.25	349.75

the formulas for such mapping can become rather complicated. For example, the mean value for January corresponds with noon January 16 (day 15.5), but the mean for February with .125 of a day after midnight February 15 (day 45.125). The period between the means for July & August can be easily be split as 31 equal periods between noons of the 16th of each month, because both months are 31 days. Showing all the gruesome details here would be too long, but doing this provides a first set of smooth daily normals - (36-year period for these) :



cubic splines interpolating the monthly normals. A problem though is that the average of these daily normals during a month or year no longer equals the monthly or annual normals (unless because of freak chance). So they are then **adjusted** so that the **daily normals in the tables you see do equal the monthly (and thus annual) normals when averaged**. This is accomplished using both a modification of the cubic spline and manual editing where necessary. Thus the **final daily normals are modified cubic spline interpolations of the monthly normals**.

Disclaimer

I am not sure if the official method uses natural boundary conditions or the type of daily mapping I describe above, but the basic method is as described above. Some adjustments are also made if a station's locations or surroundings change significantly, if some data is missing, etc., which are mentioned at the NCDC site. Special types of calculations are made for probabilities of precipitation and frost & freeze dates, and for variances of parameters. My main purpose here though is a discussion of the basic temperature and precipitation normals most often shown.

Examples

Now that the methods of calculating normals are discussed, I provide some examples next article, and discuss their representativeness.

* August 1960 data for DTW - Detroit Metro airport (in Romulus, MI) used because that for 1996 was missing.

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Climate Normals, Part 2

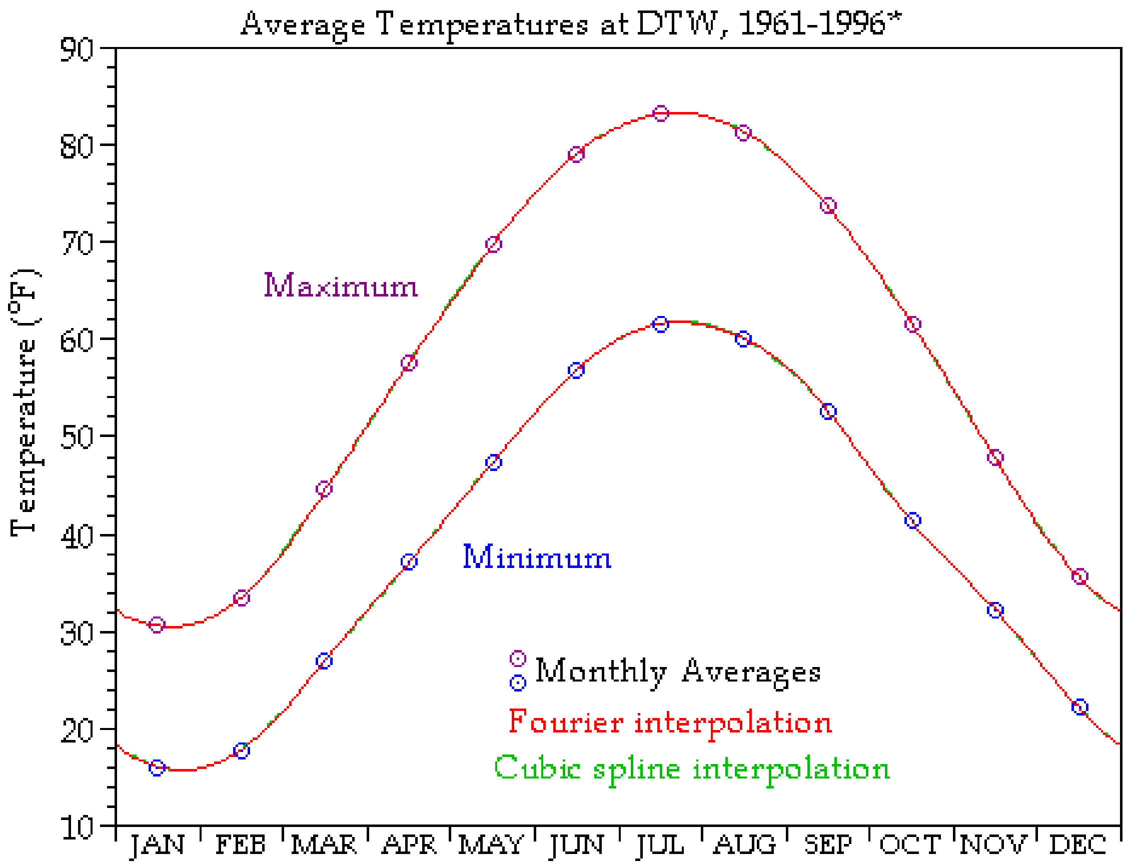
Date : 4 August 1999

Last article I described the methods of calculating climate normals, not much mentioning their interpretation and uses. These issues can become quite involved - much more so than a rather short article as this can thoroughly disucss. Thus I mention a few of the more relevant ideas and show a few specific examples.

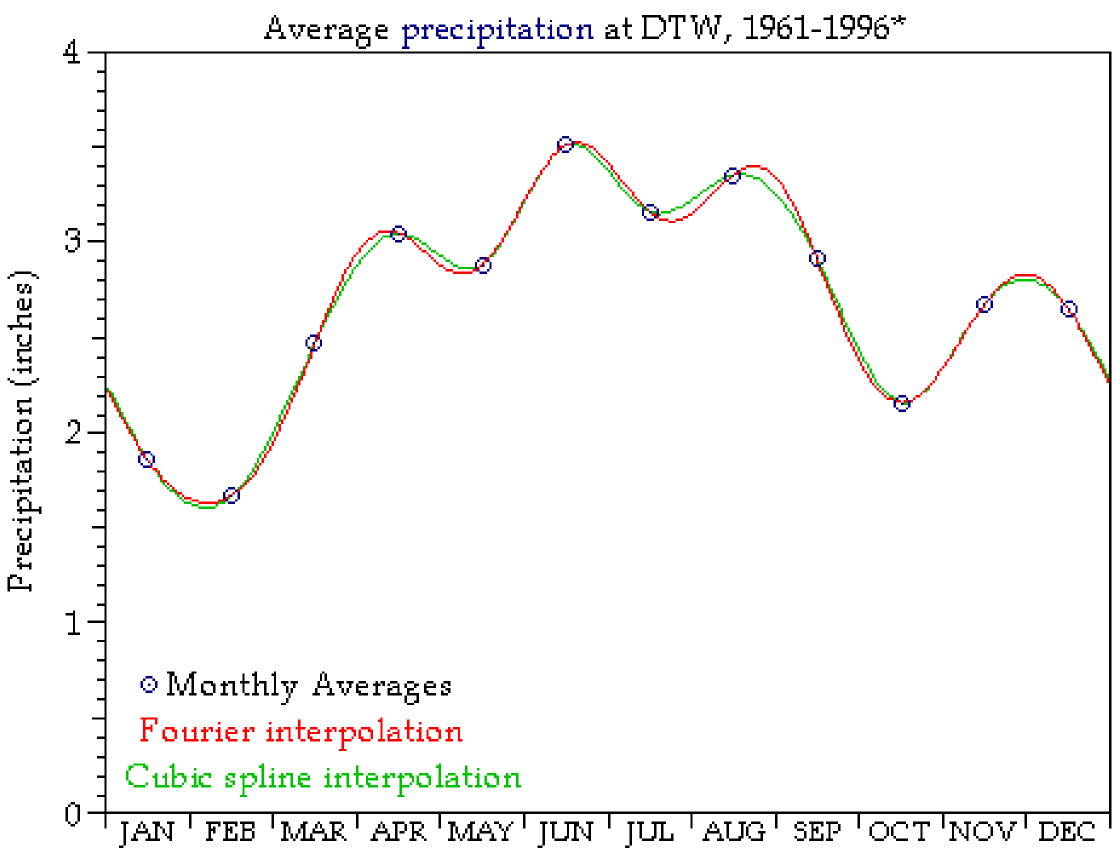
One of Chuck Doswell's many fine essays deals with the issue of the notion of "normal" weather, with a rather practical though perhaps unconventional perspective. Though certainly aware of the definitions involved, he argues that the only thing truly normal about weather is its **variability**, and any discussion of "normal" weather must consider this. This (of course) refers to the common rather than statistical connotation of the word normal, the latter of which perhaps causes great confusion.

On the other proverbial hand, some people think the definition of normal is fine, but they should perhaps be calculated differently. Cathy Smith (maintainer of a fine Boulder, CO weather & climate site) mentioned to me a Journal of Climate article (reference and abstract) regarding a study of climate normals for which predictive skill of the normals was considered. This showed that climate normals for that (predictive) purpose were best if fewer (than 30) years were used and if they were recalculated annually. This makes sense considering that the 930 monthly values I previously mentioned are much more than statistically significant. Using climate normals for predicitve purposes differs from the notion of a climate normal being the average weather for a very large or infinite number of years, the latter of which is perhaps absurd considering how changes of the solar system may make the weather we currently experience much different from the average for all years of Earth's existence and that a location as we consider it would not even exist that long. Enough of things about which I am no expert.

I now discuss something I am a @ least a little of an expert about - the climate the Detroit-Ann Arbor, MI region, for which I showed a couple diagrams last article. I say that because I am a meteorologist who lived there most of my life, with an interest regarding weather. Seeing climate statistics is one thing, but also experiencing the weather provides a better understanding of what is causing those statistics. Below are monthly climate normals and interpolation curves for DTW (Detroit Metro Airport) in Romulus, MI for temperature :



and precipitation :

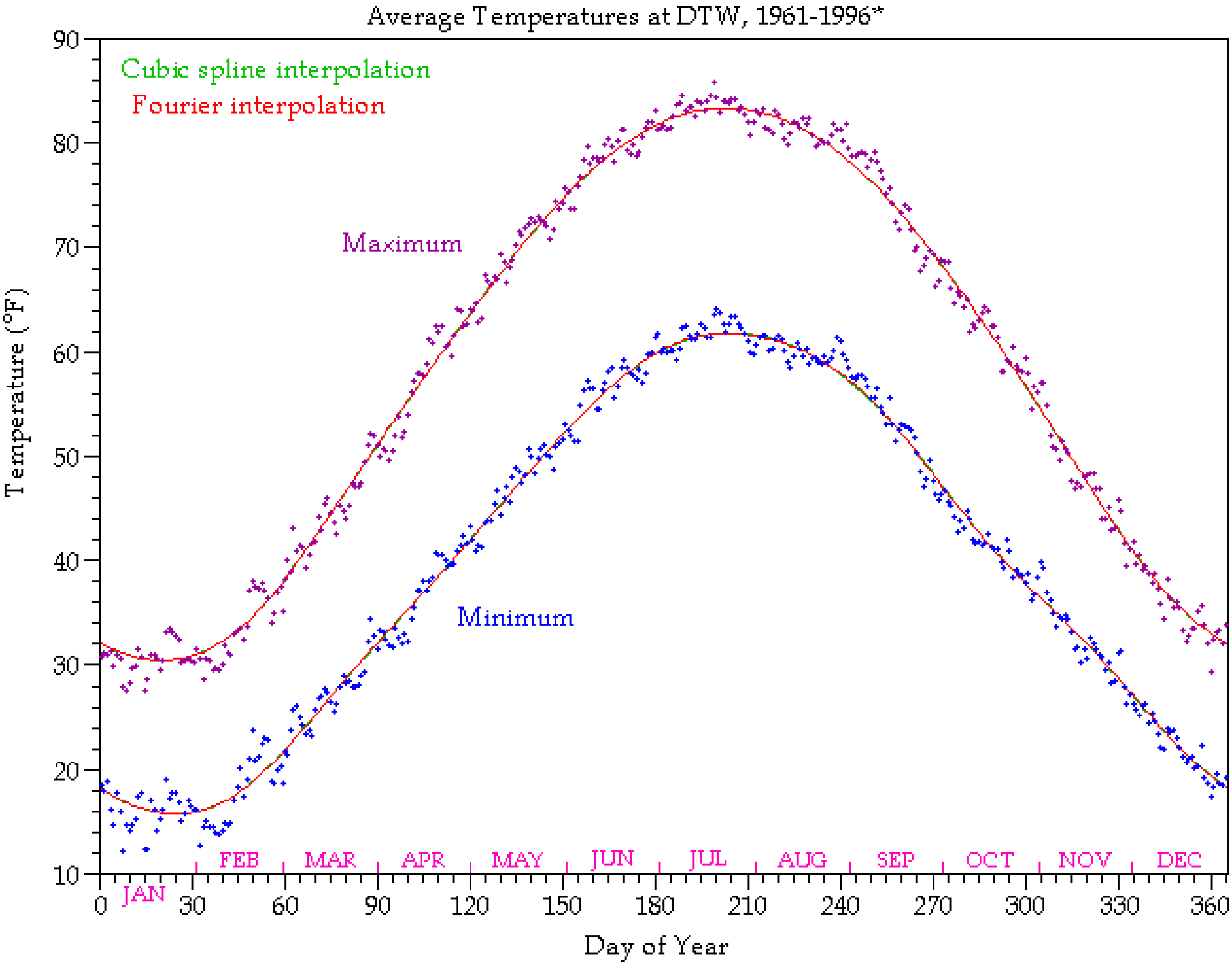


using data obtained from the Utah Climate Center. 2 unconventional things for these (which actually make little difference) are that I use a 36-year period, and I include a **Fourier series interpolation** along with the cubic spline interpolation.

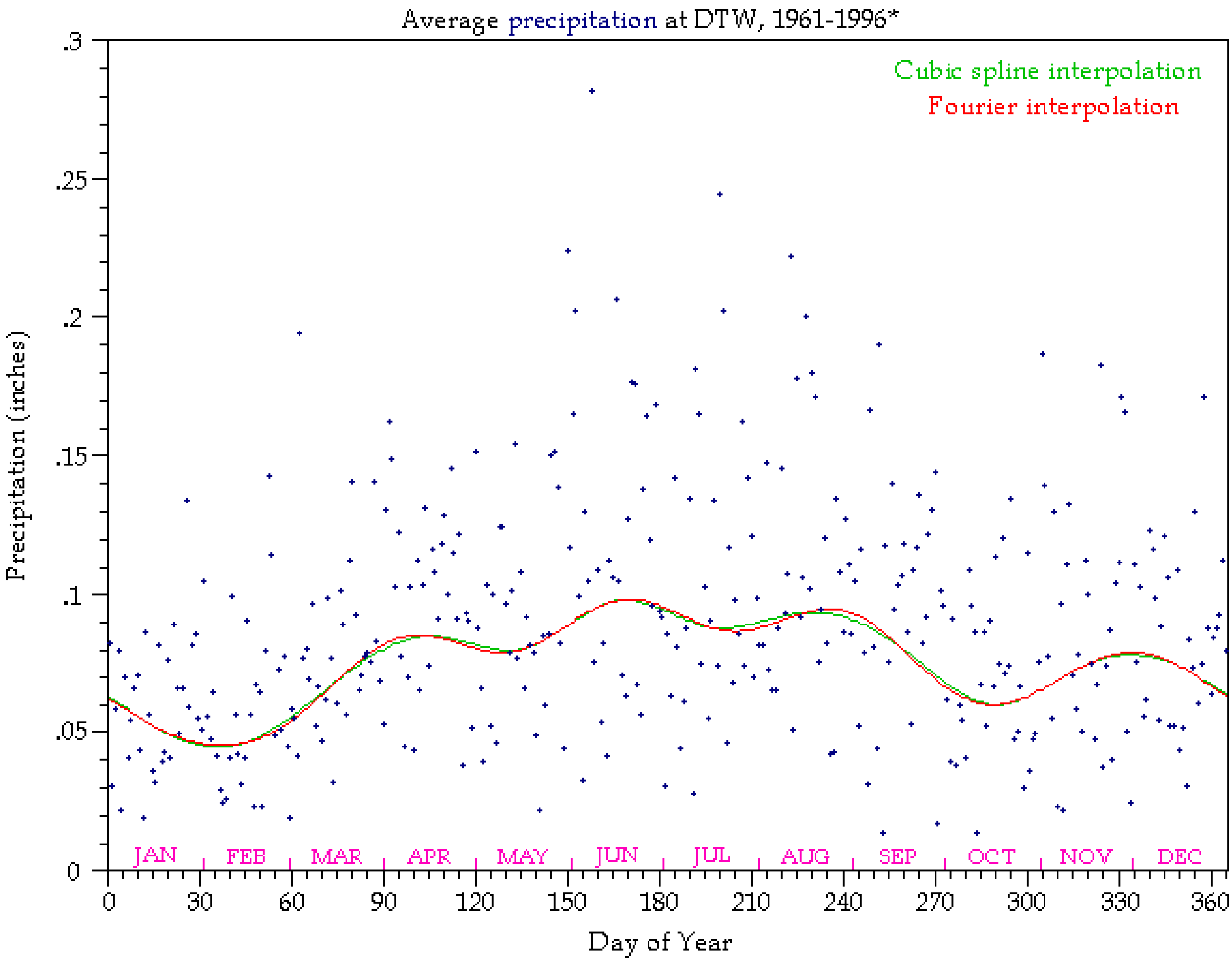
A series of **smooth periodic functions**, Fourier series should interpolate yearly climate and much other periodic weather data well (beginning and ending of year are same). Fourier series interpolation has the advantage of being a **global interpolation** (one function for the entire interval) rather than a **local interpolation** as the cubic splines are (combinations of cubic polynomials at portions of the interval). Thus, it may portray seasonal variability better. This is not evident on the temperature plot (for which interpolations are almost identical); but on the precipitation plot, the cubic spline rides the proverbial roller coaster from one point to the next, whereas the Fourier series more so interpolates all points. A very relevant question is why should the monthly averages even be **interpolated** ? As illustrated in Doswell's essay, the normals can quite significantly change from one decade to the next. Quite possibly, July precipitation at DTW is really more than that during August, when the jet stream is typically well north of there. I suppose a good answer would be that if you want climate averages for reference purposes, anything which does not interpolate the monthly averages should darn closely do so, lest they greatly differ from them the *opposite* way they should !

I chose 36 rather than 30 years because the data set extends from 1959-1996, and I wanted the largest number of years divisble with 4 (thus no February 29 bias). Considering some of the above, perhaps much fewer than 30 years should be used (though if you want unbiased normals, the number should be divisible with 4). Another consideration is natural cyclical processes which may affect climate. Among these are the sunspot cycle and ENSO. The sunspot cycle is approximately 11 years (regarding numbers of them), and ENSO cycles are generally thought to be 3-7 years ? ENSO events which clearly affect worldwide climate are seemingly rare, but the quasi-periodic changes of solar flux associated with sunspots (even if only a few tenths of a %) should be climatologically significant. Unfortunately, the least common multiple of 4 & 11 is 44 ☹

Following my mapping procedure previously explained, I then calculated daily normals for temperature :



and precipitation :



Viewing this perspective, the difference of interpolation methods seems quite minimal indeed. Though generally very close to the daily average temperatures, the normals are nowhere close to many of the precipitation averages. This illustrates the idea of statistical significance perhaps better than I can explain. Only occurring about 25-40 % of days (depending with season), being quasi-lognormally distributed (rather than the quasi-normal distribution of temperatures), daily precipitation amounts generally include a sample of only 7-18 non-zero points rather than 36.

Staring at the daily normal plots, you likely notice some differences among averages and normals which are probably real and would be evident if an infinite number of years with the same climate characteristics of the period could be used.

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