MOUNTAIN METEOROLOGY —

KNOW BEFORE YOU GO!*

by

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No element of the Sierra environment is potentially more useful to the sailplane pilot than the weather. The pilot must share the airspace with it in one form or another every time he flies. So his flight success and safety are directly related to his understanding of the significance of various weather phenomena. A fundamental grounding in soaring meteorology is essential. Soaring pilots in the Sierra are particularly fortunate in having, at Reno NWSFO, a group of enthusiastic meteorologists fully versed in briefing for sailplane weather needs. Virtually all have visited, forecast and briefed pilots on competition and record flying work. Use them -- they are there to help every Sierra soaring pilot!

Over-all Considerations

In the Sierra, typical weather includes the usual frontal movement, along with thunderstorms and their associated squall lines and occasional fog. As this sea of air moves across uneven terrain, it changes further and sometimes unpredictably into localized 'mini-weather' systems that take on their own violent form.

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Since forecast accuracy is influenced tremendously by what is known and measured, the unpredictable micrometeorology and relative scarcity of reporting stations in the Sierra can result in a lack of weather information vital to the soaring pilot.

When planning Sierra flights, consider the following:

- Weather trends over a large area surrounding the planned flight route, according to all information available from your preflight briefing;
- The visibility through a wet canopy is not nearly as good as the ground visibility reported on a teletype or on your handwritten notes from the briefer;
- If you've had a weather briefing, give some thought to an alternative course of action in case the forecast does not hold up; if you have been briefed or get briefings while aloft on existing weather at en-route stations, remember that the weather *between* reporting points may not be as good as the weather shown *at* the reporting stations;

- Contacting someone near the intended goal or turn point before you leave, by *telephone* or *mountain radio*, who can give a current, on-the-scene evaluation of existing weather conditions.

If the decision is made to launch, the pilot should then:

- Be alert to the possibility of *heavy sink and severe turbulence* when flying in the lee of mountains under low ceilings;

- Beware of *ceiling fluctuations* -- ceilings have been known to drop as much as *2,000 feet per minute* in certain sections of the Sierra, and Foehn windows can close with terrifying suddenness;

- Beware of *low stratus* in narrow canyons that can effectively block VFR flight in a sailplane;

- Be alert to *temperature* and *dew point* spread in winter wave flying, not only locally but over a large surrounding area. When the *trend* is *closure*, fog can occur; be prepared to land if they approach each other closer than 5°F. If landing areas are widely scattered, it is time to *stop flying*!

If severe turbulence is encountered, the pilot should:

- Slow down immediately to rough-air maneuvering speed, maintain control of *pitch attitude* and allow minor airspeed and altitude fluctuations;

- Land long before control becomes questionable! Some soaring pilots have landed in gusts and steady surface winds of 40-60 mph. When help was available at the touchdown point, they saved their sailplanes; others have 'flown' their ships *on the ground* for extended periods (a few for sometimes several hours) before help came, or have seen their ships destroyed when they tried to leave them;

- The same winds that blow day and night in the Sierra affect the trailer -- loaded or unloaded. Trailers and ships *must* be *securely* tied down or be attended *at all times* if damage to either is to be avoided. Don't forget that *untethered* bird or box can do costly damage to neighbors if permitted to 'fly' under severe wind conditions.

Sierra Winds

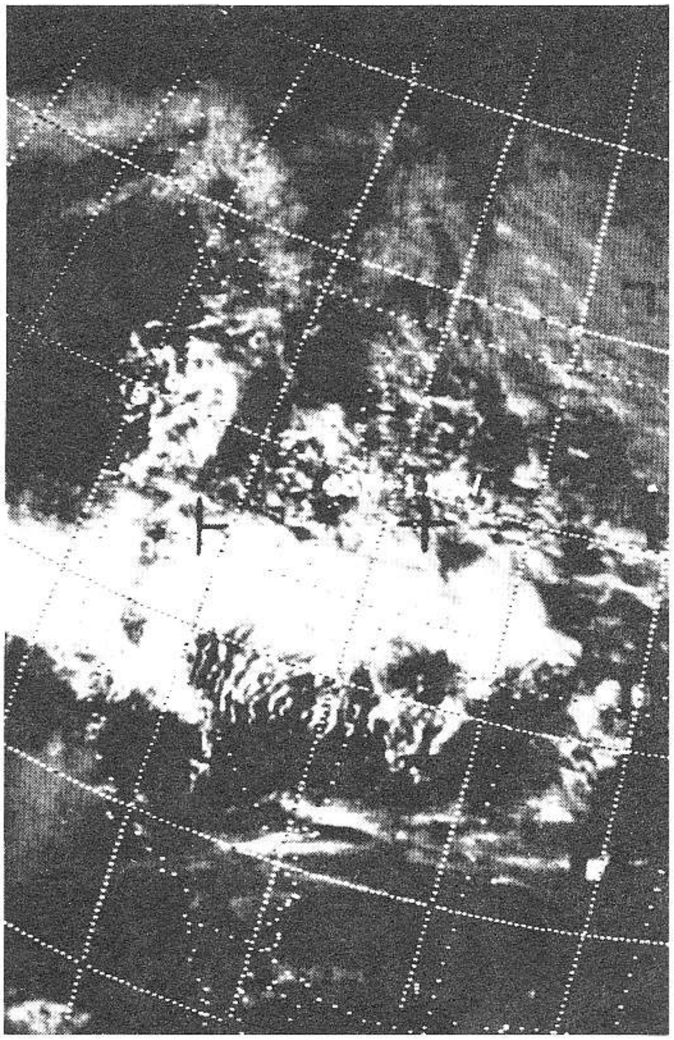
Most soaring pilots generally understand the primary effect of air-mass circulation on flying. There are, however, certain characteristics of wind flow over Sierra terrain that deserve serious study. This wind flow may be compared to the flow of water over a boulder-strewn river bed. As in water, the result is 'waves'.

In the mountains, terrain interference with the steady flow of wind causes lift and sink to follow logical patterns. The shape of the terrain in its relation to the wind, the heating of slopes exposed to the sun, and the steeply sloping ridges with jagged cuts where the wind currents are accelerated by a venturi effect, are all easily predictable. The moving air mass surges up and over -- then being equally influenced by the opposite in terrain features on the lee side, goes down with almost unbelievable velocity -- sometimes thousands of feet per minute. Terrain influence may cause the air again to rise and descend, in classic wave action, for as much as hundreds of miles on the lee side of a mountain range (see Satellite photo).

Any abrupt change in angle between the terrain and wind flow can be expected to cause moderate to severe turbulence, depending upon the instability of the existing air mass. Frontal passages can generally be expected to produce moderate to severe turbulence and wind shear so intense that the structural integrity of the sailplane may be jeopardized. The strongest period of wind flow are usually seasonal, strongest in the fall and winter months. In summer, the strongest wind flow will be found at higher altitudes, with the surface areas yielding more thermal effect than destructive turbulence, except under extremely unstable air mass conditions such as thunderstorms.

Careful study of the wind phenomena leaves us with some generally acceptable rules-of-thumb for the soaring pilot:

- Ridge level winds over 25 knots indicate that the pilot should proceed with caution. When winds are 30-40



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knots or more, stay on the ground -- winds aloft are usually much more intense than surface winds;

- Near and on ridges, speed up well above stalling speed but not beyond rough-air maneuvering speed;

- In wave conditions, there is often turbulent lift at the leading edge of rotor; however, rotor can produce winds 180° different from fundamental flow, especially under the rotor at low altitudes;

- Winds aloft in the mountain west are predominantly westerly; however, surface winds tend to flow upward from the valley from around noon till late evening, due to the unequal heating of the sunny slopes and shaded valleys; early in the day lift is on the peaks, so 'head for the hills';

- In late evening, this flow pattern may reverse due to rapid cooling of the air near the ridgeline or higher peaks, creating downslope winds and valleys full of 'green air'.

The inherent risk of flying over rugged Sierra terrain is increased due to the lack of acceptable landing areas. On the other hand, the proficient soaring pilot will be constantly prepared to turn down slope or toward less forbidding terrain while en route. If he must land, the pilot has no choice but to maintain control of the sailplane as long as it will fly, and have the skills to land short and precisely.

Can you rely on forecasts?

How good are Sierra forecasts and services? A pilot should understand the limitations as well as the capabilities of present-day meteorology. The meteorologist understands some atmospheric phenomena and has watched them long enough to realize that his knowledge of the atmosphere certainly is not complete.

Soaring pilots who understand the limitations of observations and forecasts usually are those who make the most effective use of them. The safe pilot continually views avaiation forecasts with an open mind. He knows that weather always is changing and consequently that the older the forecast, the greater the chance that some part of it will be wrong. Weatherwise pilots consider forecasts professional advice rather than an absolute surety. To have complete faith in them is almost as bad as having none at all.

Recent studies indicate the following:

- Up to 12 hours -- and even beyond -- a forecast of acceptable weather (ceiling 3000 feet or more and visibility three miles or greater) is much more likely to be correct than a forecast of conditions below 1000 feet or below one mile;

- If poor weather is forecast to occur within three to four hours, the probability of occurrence is better than 80 percent;

- Forecasts of poor flying conditions during the first few hours of the forecast period are most reliable when there is a distinct weather system, such as a front, a trough, precipitation, etc. There is a general tendency to forecast too little bad weather in such circumstances;

- The weather associated with fast-moving cold fronts and squall lines is the most difficult to forecast accurately;

- Errors occur when attempts are made to forecast a specific time that bad weather will occur. Errors are made less frequently, of course, when forecasting that bad weather will occur during some *period* of time;

- Surface visibility is more difficult to forecast than ceiling height. Visibility in snow is the most difficult of all visibility forecasts. Skill in these forecasts leaves much to be desired.

Sierra Weather Specifics -- Waves and Thermals

Nevada is famous for its soaring weather -- at times, infamous. Mostly sunny, hot days during the summer make it excellent thermal soaring country while fall through spring finds some of the world's best waves being generated by the Sierra Nevada. As a result the National Weather Service Forecast Office at Reno, in the heart of Sierra soaring activity, has developed numerous techniques and considerable experience over the years in providing weather support to the soaring community(1).

Thermal Soaring

While wave soaring research has languished in recent years (likely attributable to the rising costs), greater application of available atmospheric sounding data has benefited thermal soaring from mid-May to mid-October.

The fact that the Great Basin lies in the lee of the Sierra and has numerous valley elevations coincidental with the standard 850-millibar level gives the weatherman a valuable starting point in analyzing thermal activity from radiosonde observations (called raobs). An even more important fact is that the temperature and humidity profile within the Great Basin is very homogeneous and is usually well represented by the Winnemucca raob data. Under strong wind-flow conditions, an extrapolation of data from a raob station windward of Winnemucca usually gives better results in determining thermal activity for locations in the immediate vicinity of the Sierra.

On several occasions soaring pilots have inquired how the weather forecasters of the National Weather Service Office in Reno predict weather for soaring. Most admit there has been a combination of cautious research, known as trial and error, along with perserverance and an undying challenge to perfect this highly specialized form of aviation weather briefings. Thermal soaring has been the focus of attention and most rewarding.

The following details regarding thermal soaring will familiarize the layman soaring pilot with the techniques employed by the forecasters in Reno.

Terminology

The following is a list of soaring weather terminology.

Trigger temperature:	The surface temperature reached when the temperature on a sounding (raob) at a point 4000 ft above the surface is lowered dry adiabatically to the surface (2). See Fig. 1.
Maximum temperature:	Forecast highest surface temperature taken for the day under standard conditions, usually 6 ft above ground. See Fig. 1.
Maximum thermal altitude:	Altitude determined from forecast highest surface temperature expected for the day when raised up the dry adiabatic lapse rate curve to intercept the actual raob sounding. In arid regions in the lee of the Sierra this usually coincides with cloud base. See Fig. 1.
Thermal index:	A value derived from taking the maximum temperature raised up the dry adiabatic lapse rate curve and then compared to actual raob sounding temperatures at points of 5000 ft (850 mb) and 10,000 ft (700 mb) MSL or equivalent AGL. The value is the difference in °C from the projected maximum temperature adiabatic curve to the observed raob temperatures at the same height levels. Expressed as negative numbers when maximum-temperature adiabatic

lapse rate point is warmer than actual sounding temperature point. In general, higher negative number produce better soaring (3). See Fig. 2.

850-500 lapse rate: Difference in °C of observed or occasionally extrapolated raob soundings between the two levels.

'K' value: A value derived by adding the 850-mb dew point algebraically to the 850-500 mb lapse rate and then subtracting the 700-mb dew point depression, all from observed raob data (K = (850 mb temp - 500 mb temp) + (850 mb dewpt) - (700 mb depres). This value uniquely takes into account any moisture added at lower levels which can detect enhanced buoyancy for convective or thermal activity and is mainly used as a tool for determining the likelihood of thunderstorms (3). See Fig. 3.

Showalter stability index: A measure of the local static stability of the atmosphere, expressed as a numerical index. This index is determined by raising an air parcel from 850 mb dry adiabatically to the point of saturation, then saturation-adiabatically to 500 mb. At the 500 mb, the temperature of the parcel is compared to that of the environment; the magnitude of the index is the difference between the two temperatures. If the parcel is colder than its new environment, the index is positive; if warmer, the index is negative.

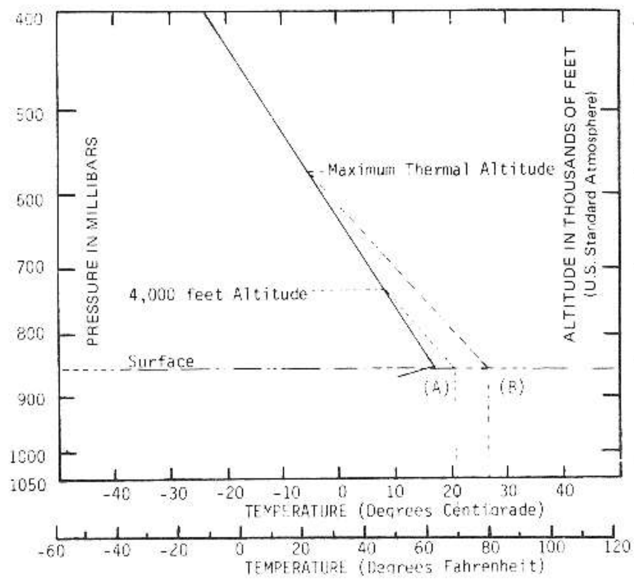

Figure 1. Point (A) is the trigger temperature which is determined by lowering a point on the actual sounding dry adiabatically to the surface from 4000 ft. This example indicates a trigger temperature of 70°F. Point (B) is the forecast maximum temperature (80°F) which is raised along the dry adiabat to intercept the actual sounding and produce a maximum thermal altitude (15,000 ft). This is a typical early morning raob representative of WMC (which will be repeated in following Figures).

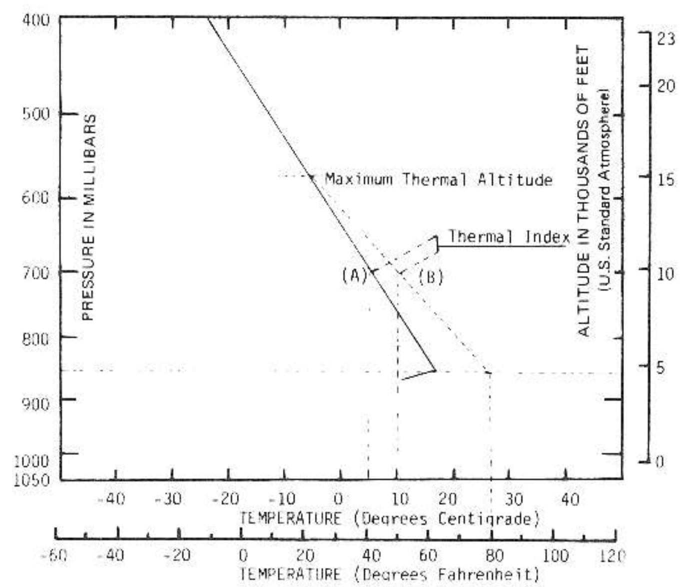

Figure 2. The thermal index is the difference expressed in degrees centigrade from a point on the projected maximum temperature adiabat to the actual sounding at the same level. This example is computed at 700 mb (10,000 ft) with Point (B) subracted from (A) for a thermal index value of -5.

Cumulonimbus phenomena usually fail to develop for index values greater than +4, whereas showers and thunderstorms become increasingly evident as index values decrease from +4 (4). See Fig. 4.

Using these terms

Comments on these terms used in soaring weather briefings will help clarify the methods of application by Reno forecasters. The trigger temperature is widely accepted as the point when thermal strength will be sufficient to commence soaring operations. The forecast time for occurrence is generally a selection of half-hour interval, with some cases up to an hour, depending upon microscale weather conditions -- for example, cloud cover, winds or temperature advection. The height of 4000 ft has been a confusing aspect to some people. It is geared toward a pilot conducting safe and sustained soaring flight. Competition directors should be aware that sailplanes off tow at 2000 feet and fully loaded with water ballast may encounter difficulties as opposed to a sailplane carrying no ballast at this initial thermal cycle period.

Maximum temperature forecasts are a very critical and integral part of the soaring weather briefing. Achieving an error of less than 2 degrees is highly desirable since a larger error will affect the projected maximum altitude. Experience in using local objective aid to forecast maximum temperatures is essential. The soaring pilot should rely on the temperature forecasts of the National Weather Service, taking into account the

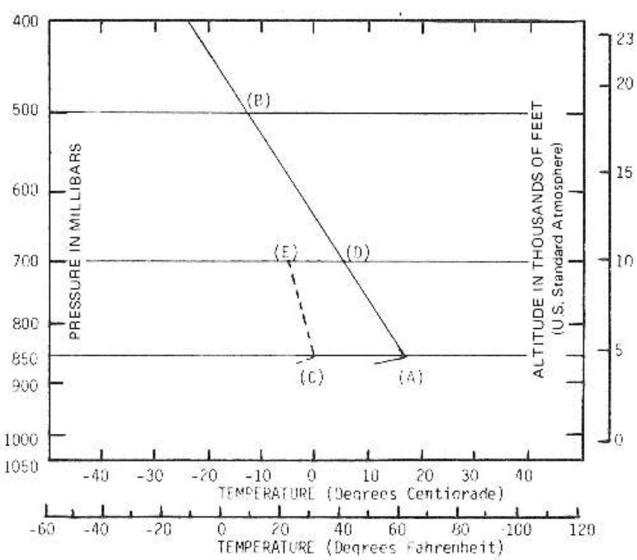

Figure 3. The "K" value computation begins with the 850-500 mb lapse rate (a 850 mb temp of 16°C (A) and the 500 mb temp of -13°C(B)) indicates 29°C, then add the 850 mb dew point of 0°C (C), subtract the 700 mb dew point depression value of 10°C (an absolute therm determined by subtracting point (E) from (D)). Finally the total of this mathematical process yields a "K" value of 19. The "K" value is influenced by the position of the points (E) and (C) in relationship to points (D) and (A), respectively and of course the slope of the lapse rate between (A) and (B).

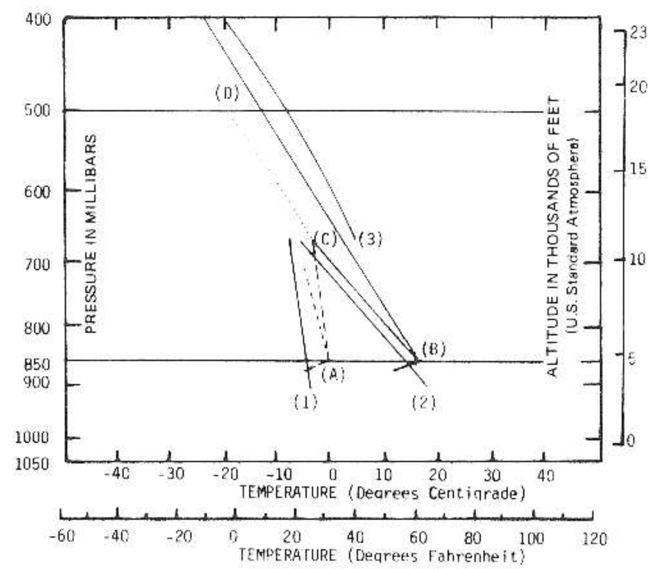

Figure 4. The method for computing the stability index can be complicated for the layman soaring pilot: point (A) is raised parallel along a humidity mixing ratio line (1), (B) is raised parallel along a dry adiabatic temperature line and (C) is the intersection point of lines formed from (A) and (B); from (C) lifting continues along the moist (saturation) adiabatic curved line (3) until reaching the 500 mb level at (D). This example indicates a stability index of +7.

necessary adaptation to the field of sailplane operation.

On a short-range basis, the afternoon maximum temperature can be fairly accurately predicted by using local objective aids, along with the necessary corrections for altitude for all the soaring ports of operation along the Sierra. Only the time of maximum temperature is shifted ahead of the normal heating pattern when convective or cirriform clouds, precipitation or winds enter the weather picture. During air-mass changes in the Great Basin, the recovery from cold air advection is slow and the maximum temperature is delayed until later in the afternoon. Usually maximum temperatures are given over a range of one or two hours in the afternoon.

The maximum thermal altitude, being dependent on predicting the maximum temperature, is still a very important tool for planning cross-country flights. Experience indicates a close relationship between maximum thermal altitude and convective cloud base in the lee of the Sierra. Of course, when cumulonimbus (CBs or cu-nims, whichever you prefer) develop, the cloud base may lower rapidly another 2000 feet or so. Convective cloud bases in the summer along with the northern Sierra generally run 12-15,000 feet MSL, sloping still higher to near 18,000 feet MSL over the southern tip of the Sierra.

Many soaring pilots across the nation have become enthusiastic in applying the thermal index. A thermal index value of -3 is recognized as the threshold for minimal normal soaring conditions. Indices of -1 and -2 imply barely flyable conditions which should be reserved for expert pilots and higher performance sailplanes. These occasions do occur rather infrequently along the Sierra. Thermal indices of -5 to -9 are considered best for soaring weather as any higher negative number tends to produce overdevelopment.

The thermal index can give the soaring pilot overconfidence and, upon close observation, can conceivably lead a pilot with little weather knowledge into white-knuckling uneasiness. The first problem with this index is that the numerical difference between a -3 and -5 type soaring day is truly small, which is not too helpful for determining a good day from a near bad one. A slight miscalculation could alter the expectation for many soaring pilots. The next problem of the index is that it is determined by only looking at one and occasionally two levels on the raob sounding. This is analogous to checking the frosting in a layered cake and trying to determine the true ingredients of the cake. Isothermal layers and temperature inversions can easily miss detection by these spot checks.

During a regional contest conducted at Minden in 1975, a very good illustrative example occurred. A thermal index of -6 the day before had become a -5 the next day, erroneously still pointing out good soaring conditions. However, an isothermal layer of 3000 feet between 7000 to 10,000 feet MSL completely and adversely changed the soaring weather for that day. A day-to-day change entailing 10-15°F of advection either cooling or warming can result in the same thermal index with totally different soaring results. The thermal index can be primarily applied to the field of soaring operation to determine the strength of the soaring, but then the 850-500 mb lapse rate, 'K' value and stability index are used to get the best direction for cross-country flights.

The 850-500 mb lapse values are easily applied to cross-country soaring. First, plot the values at Medford, Boise, Oakland, Vandenburg AFB, Edwards AFB (if possible) as well as Winnemucca, Ely and Yucca Flat. Then, using contoured isopleths, determine the lapse rate over the field of operation. Normally, flights are planned to the area of steepest or greatest lapse rate, turning short of areas where overdevelopment is likely to occur.

Lapse rates of 850-500 mb along the Sierra during the summer can offer some insight into weather conditions and subtle changes in a sailplane's expected rate of lift. Based upon many observations, an 850-500 mb lapse of 20-24 give generally a 'blue thermal' (clear skies) condition, a lapse rate of 24-28 gives a gradual increase in the amount of convective clouds, while lapse rates of 28-34 tend to produce convective clouds maturing into showers or thunderstorms. Areas of higher or steeper lapse rates normally cause overdevelopment to a virtually overcast condition with embedded showers. All convective activity is contingent upon total moisture available -- on occasion 'blue thermals' may exist with higher lapse rates. The steeper lapse rate yields greater rates of lift. The 850-500 mb lapse rates of less than 20 tend to give weak lift, then up to 25 produces moderate lift, for values up to 30 strong lift, and values to 34 give very strong lift. Values above 34 along the Sierra give strong rise to overdevelopment.

'K' value -- help or confusion?

The introduction of the 'K' value into soaring has somewhat bewildered the soaring pilot. Could it be some magical weapon that meteorologists could use in some self-redeeming attempt to offer a precise soaring weather briefing? Not entirely, but do not cast it

'K' value	Convective activity	General soaring lift performance
Lower than -10	None	Less than 300 Fpm
-10 to +5	Blue thermals*	300-600 Fpm
+5 to +10	Increasing convection	500-700 Fpm
+10 to +15	Isolated strong vertical extent	600-800 Fpm
+15 to +20	20% coverage thunderstorms	700-900 Fpm
+20 to +25	20% to 40% coverage thunderstorms	800-1000 Fpm
+25 to +30	40% to 60% coverage thunderstorms	900-1100 Fpm
+30 to +35	60% to 80% coverage thunderstorms	1000-1200 Fpm
+35 and higher	Greater than 80% coverage thunderstorms	1100-1300 Fpm

*Blue thermal conditions can deliver strong lift rates of times, especially with unusually clear skies intensifying heating for thermals.

aside as just another number. Its performance so far is encouraging. 'K' values are on a linear scale and determined from morning raobs. Again, plot the 'K' values at the various raob stations and analyze the values in smoothed isopleths. Determine the 'K' at the field of operation. Flight planning follows the same procedures as when using the 850-500 mb lapse, since both quantities are very similar except for the important difference of the moisture variable being inserted in the 'K' calculation. After many computations and numerous analyses of the 'K' chart for western America, here is a table for the general application to soaring weather and a general lift performance for soaring which incorporates the guidance and knowledge left us by my fellow worker Richard E. Hambidge.

Usually each category for lift rate covers the maximum-temperature afternoon period, with an occasional increase of lift strength by an additional 200 fpm. In recent years the better soaring flights were made with 'K' values in the mid 20's to low 30's.

The 'K' value has become a useful tool as it depicts the likelihood of convective thermal markers. Furthermore, it has successfully been used to attain a Diamond distance flight from Minden to Winnemucca and return when the +15 'K' isopleth was properly analyzed and predicted to remain along this favorable route. The influx of moisture northward along the backside (east slope) of the Sierra can be ascertained from wind patterns and 'K' values increases at Yucca Flat, Edwards AFB and Vandenburg AFB raob stations. These surges of moisture slip up the Owens Valley, reaching the Bridgeport-Alpine County area where the Sierra bends from a southeast/northwest to a north/south orientation. Here climatological records show increased precipitation enhanced by greater convective activity caused by a microscale eddy formed from winds passing over this change in the topographical feature. The first signs of strong convection in this 'bend' area of the Sierra are usually visible from Reno and observant meteorologists incorporate these hints into their successful weather briefings.

One good reason to make the switch to the 'K' value application to soaring is that it is routinely issued in air-mass trajectory forecasts received at major National Weather Service offices throughout the nation. (Note: The thermal index is not similarly disseminated). The 'K' value is forecast 24 hours ahead and has been fairly reliable in Nevada, but has been less successful in coastal regions west of the Sierra. Just the projected trend in the 'K' values is a very helpful objective aid.

Stability index

The stability index is treated in the same fashion as the 'K' value. This is probably the oldest of useful convective tools. It too is linear with higher positive values being stable, 0 for neutral and larger negative numbers denoting increasing instability. However, as mentioned earlier, a SI of +4 is more representative of threshold instability in the western states. Occasionally this useful parameter cannot be computed due to the dryness encountered at 850 mb.

Let's summarize these indices in their application to soaring weather:

Threshold values			Over-development
The thermal index	-3	Improves--the larger the negative	-9
850-500 mb lapse rate	+20	Improves--the larger the positive number	+34
'K' value	-5	Improves--the larger the positive number	+28
Stability index	+14	Improves--the smaller the positive number	+4

Winds play a strong supportive role in thermal soaring in the Sierra, varying from acting lightly as catalysts for driving thermal activity up ridges to totally over-reacting and wiping out thermals entirely (1). Soaring pilots have become increasingly aware of convective activity formed along the Sierra early in the afternoon, then rapidly pulled eastward toward the thermal trough in the southeastern portion of Nevada later in the day. While greater congestion occurs as convective clouds get added orographic lifting moving eastward, some benefit is derived by having more visible cloud streets paralleling the ridges. Despite the numerous ridges leeward of the Sierra, there are convergence zones that can turn a cloud street into a 'super-expressway' for the forecaster to offer soaring pilots, in their quest for Diamonds or other challenging tasks along the Sierra.

Thermal activity along the lee of the Sierra is ideally suited for aiding both novice and expert soaring pilots. The challenge of setting 100-, 300- and 500-km speed records has already been accomplished, with new records in the offing. Forecasters in Reno find the challenge a fascinating way to approach micro-meteorology.

Thermal index

Because of demands placed upon meteorologists by the soaring community for accurate forecasts of rates of lift from thermals, here is the latest method for determining the rate of lift for sailplanes venturing out in the midst of the Sierra. Unfortunately, little research has been done in this area, probably due to the lack of reliable data. The study by Lindsay and Lacy (2) is a notable exception. It was found, from somewhat limited data, that a correlation does exist between the maximum altitude obtained while thermaling and the maximum lift rate experienced. It was also found that the thermal index also showed some correlation.

The thermal index has been used in the mountainous west, but experience has shown that while it is an objective forecast aid, it is not very reliable in situations when it should be. The index which basically gives a measure of available energy below 10,000 feet is apparently a good forecast tool for 'flat-landers'. However, since most soaring enthusiasts over western Nevada don't even feel comfortable until they thermal above 10,000 feet (3), one can see the limitations of the thermal index in mountainous terrain.

At the Reno forecast office of the National Weather Service, we recognized the necessity of developing a good objective method for forecasting rates of lift over the mountainous terrain of western Nevada to meet the demands of the rapidly growing number of soaring enthusiasts. The problem was that we had no data on which to conduct our research. Fortunately the difficulty of the lack of data was largely solved during what may be an historical first in the anals of competitive sports. At the 1975 Region II Soaring Championships held at Minden, scores of pilots, while in the heat of battle, graciously still found the time to systematically report generally very reliable data. In fact we obtained a volume of information beyond our most optimistic expectations. This provided a firm foundation and the most significant feature of the data was that for each day we had many reports from numerous sailplanes milling around the western Nevada skies. This makes the information much more reliable than isolated reports where such things as pilot's skill, luck, etc. can creep into the reports.

Another fortunate thing happened during this data-collection period. On two consecutive days the thermal index was essentially the same. However, one day was a very enjoyable one for glider pilots while the next was excellent for leaving one's ship in the trailer and relaxing.

The situation was ideal. There was now sufficient reliable information to at least tentatively develop an objective method for forecasting maximum lift rates. Since the two aforementioned days were inherent in the data, this would provide increased confidence in any scheme that could be devised.

It can be easily shown using the idea of 'parcels' of air and thermodynamic equations along with some simplifying assumptions and mathematical gyrations that vertical accelerations in the atmosphere are a function of the displacement experienced by the 'parcel,' the lapse rate, and the initial temperature. Since lapse rates are to a certain degree 'known' from meteorological soundings and maximum altitude (displacement) was already found to correlate with lift rates this appeared to be a good place to start. Many schemes were attempted and the 'soaring' index described below is the final result. The objective aid was used during the 1975 National Standard Class Championships with good results. Feedback from individual and group soaring sorties throughout the summer of 1975 indicated that the method is quite reliable.

The Soaring Index

The first step in computing the index is to determine the ambient or environmental air temperature 4000 feet above the surface. For example, at Minden this would be at 8700 feet MSL. Many soaring enthusiasts will notice that lowering the air dry adiabatically from 4000 feet AGL to the surface is the method used to determine the trigger temperature. Thus we can label the ambient temperature at 4000 feet AGL as the temperature at the 'level of minimum effective convection' or LNEC (see Fig. 5). The next step is to determine the maximum altitude that thermal activity will reach through the day. At Reno it has been found that the maximum temperature for the day raised dry adiabatically to the intersection of the ambient sounding provides an excellent objective method of forecasting maximum thermal altitude. Thus we can refer to the ambient air temperature at this elevation as the temperature at the 'level of maximum effective convection' or LXEC.

The maximum displacement can be objectively forecast and a lapse rate (LNEC - LXEC) can be determined from observed data. Theory says that these two variables can be combined to give an indication of maximum lift rates. From the data the following empirical equation was developed:

$$\text{Soaring index} = 3\left(\frac{Z}{10^2} + 10t\right)$$

where

Z = max altitude of thermals in feet ASL

t = LNEC - LXEC in degrees centigrade

and the Soaring Index (SI) is given in feet per minute for Standard Class (or 15-meter Class) sailplanes.

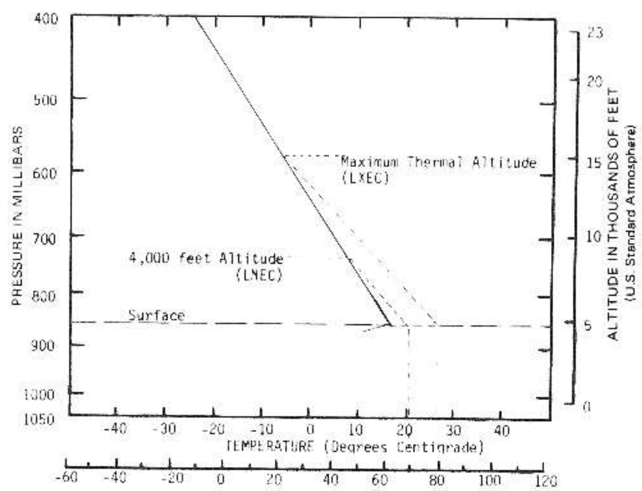

Figure 5. The soaring index is computed for the maximum thermal altitude of 15,000 ft and difference of 13°C (LNEC (8°C) minus LXEC (-5°C). In the following formula:

$$\text{Soaring index} = 3\left(\frac{1.5 \times 10^4}{10^2} + 1.3 \times 10^2\right) = 840$$

(which is expressed as 840 fpm for expected rate of lift). This soaring index can be computed for any raob sounding. Should higher 'K' values coincide with this basic rate of lift, the meteorologist should consider increasing the value another 200 fpm.

As an example, if the maximum altitude to which thermals are forecast to reach is Z = 20,000 feet and if the ambient temperature at 20,000 feet is minus 10°C and the temperature at 4,000 feet AGL is +20°

$$t = 20 - (-10) = 30$$

and

$$\text{Soaring index} = 3\left[\frac{2x10^4}{10^2} + 10^1\ (3x10^1)\right]$$

$$= 3[2x10^2 + 3x10^2]$$

$$= 1.5x10^3 \text{ fpm}$$

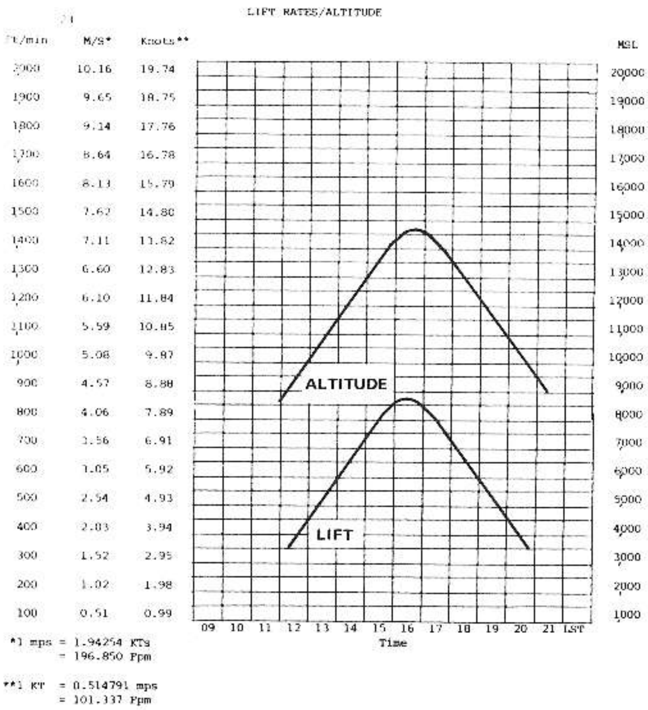

Figure 6. Using the soaring index values for anticipated temperatures at hourly intervals between the time of trigger temperature and maximum temperature continuing until sunset produces a rate of lift curve for the day as well as corresponding altitude curve. Reliable data are attained by meteorologists because the normal spread of these temperatures is relatively small (usually on the order of 10 to 20°F).

As with any 'objective' aid, subjective modifications are at times necessary. Downslope winds that effectively wash out valleys require no modifications since thermal activity will continue over the mountains. However, if winds aloft are sufficiently strong (dependent upon air mass stability) the winds may shear off thermal activity. Especially critical are winds near ridge levels since the mountain-induced thermals may be inhibited by the same reasoning that washes out the valleys. Overdevelopment or cloud cover in general will also require modifications as heating to sustain thermals may be cut off before the maximum potential can be reached. Perhaps the most difficult problem arises when differential temperature advection occurs -- that is when the air mass is warming or cooling at different rates at different altitudes due to the horizontal transport of air.

It was the combination of these and other subjective modifications to the soaring index that are at times necessary. The request to provide a curve of expected lift rates at different times through the day at the 1975 U.S. Standard Class Championships prompted the attempt to use the method to construct such a curve. In the expanded case, the index is computed by the same method previously described. The temperature expected at any hour is then used to forecast the expected maximum lift rate at that particular time. (See Fig. 6). The scheme has displayed reliable skill and as a result it is possible to compute a curve depicting the maximum altitude and strength of thermals throughout the day. (Note: If the altitude at the trigger temperature is plugged into the formula for the soaring index (there will be no lapse rate yet) the value derived is barely capable of maintaining a Standard Class sailplane aloft, helping to clear the air over the mysterious 4000 foot level inherent in the trigger temperature. Allowances for increased sink rates of sailplanes at various altitudes are responsive automatically through the use of this formula).

It has also been found that this new objective index is essentially 'universal,' that it can be applied to meteorological data at any location.

Wave conditions

Wave conditions for soaring over the Sierra are varied and complex depending upon the time of year. The most favorable conditions are from mid-October to mid-May. The migration of the polar frontal storm track southward in the fall and then returning northward in the spring is the best bet for good wave flights.

The inherent stability in the approaching warm front produces the 'classic' wave condition with wave cloud (altocumulus standing lenticular clouds) and wisps of a rotor cloud. A small problem had existed for the soaring pilot because, in earlier analysis schemes, the synoptic weather analysis would very often correctly place surface cold fronts coming in off the Pacific coast, but would omit warm fronts as their characteristics were not easily detectable from surface observations. Now this problem has been corrected by using very timely weather-satellite pictures that unerringly display cloud patterns associated with warm fronts. Likewise the cold and occluded fronts are easily observable from weather satellite pictures as they surge in over the Sierra. Weather satellite pictures will be the biggest boon to soaring pilots interested in record free distance and out-and-return flights as well as altitude records.

Favorable wave conditions have been recorded on the Sierra and leeward to the Rocky Mountains. This may indicate the possibility of a day-long free distance record flight to the east, starting on a Sierra wave and finishing on thermals.

For shorter Diamond distance and related badge flights, weather satellite pictures indicate wave conditions triggering from the northern Sierra (Alpine County northward) for flights into Idaho, Utah and Wyoming. Another set of conditions, not yet explored by soaring flights, are the wave conditions off the southern Sierra (Alpine County southward) into southern Utah, Colorado and northern New Mexico. This latter condition is usually spawned by a subtropical jet stream visible at times by weather satellite over Baja California which migrates northward across the southern Sierra. In most winter conditions the polar jet stream is the triggering source.

In combination with the polar jet stream crossing the Cascades of the Pacific Northwest and northern Sierra, and with the subtropical jet stream over the southern Sierra, there unfolds the possibility of a record out and return flight that will exceed the renowned ridge-running efforts of our eastern soaring cousins. However, this wave configuration has seen only limited exploration by western soaring pilots. Any starting point from Mt. Shasta or northward, running to the southern tip of the Sierra and back, is feasible.

In addition to the visual weather satellite pictures, infrared satellite pictures continue throughout the night and greatly assist in the preparation of the coming day long flights.

Jet stream analysis

Probably the next most helpful tool for projecting wave conditions is the wind-speed analysis in the vicinity of the jet streams as depicted on the 300-millibar chart. This is roughly at the 30,000 foot level where planned long flights along or from the Sierra will need to originate.

In a kind word for the National Weather Service's computer, it has developed routinely prognostic 300-mb charts extending ahead for up to 36 hours with uncanny accuracy. Maximum wind impulses are readily pushed along the jet stream and the results of these changes in the wind flow can be verified by watching changes in cloud patterns and wave conditions over the Sierra. The empirically derived threshold conditions for wave development taken from a 300-mb chart require a wind speed of 65 knots normal to the Sierra and decreasing at a rate of 10 knots per 5000 feet which gives a 25-knot surface wind speed along the Sierra crest.

	Altitude (feet)	Wind speed (knots)
(300) mb	30,000	65
	25,000	55
	20,000	45
	15,000	35
	10,000	25

This pattern, when augmented with computerized wind-forecast products for the appropriate time interval, can give insight to the real extent of wave conditions.

Generally, wave characteristics change depending on one's position north or south of the midpoint along the zonal axis (maximum wind speed) in the polar jet stream. More favorable conditions for soaring will be found on the southern portion of the jet stream. Here a 'blue wave' (clear sky) wave condition begins blending toward increasing amounts of lenticular and added rotor clouds as the midpoint of jet stream core is reached. The northern portion finds the development of a 'wet wave' (considerable cloud cover) and visible Foehn wall in the lee of the Sierra. Soaring in these latter conditions usually finds the flight confined to a narrow chimney with overdevelopment of clouds and a great deal of turbulence.

Stronger jet streams usually produce conditions favorable for higher altitude flights in the primary wave and trigger a hydraulic jump leeward which is also a good condition for higher altitudes.

Weather dangers

Wave soaring in the Sierra should not go without comment on the possible dangers that are weather related. First, turbulence involved in penetration and at various altitudes is generally light on the southern edge of the wave but increases as the flight heads to the northern portion of very strong jet streams. As such turbulence increases, the condition may become violent and the soaring pilot may desire to have a transplant of a 'cast iron stomach' and a sailplane of similar reinforced construction. Second, while wind conditions for launch may be light, later return to a landing site along the lee of the Sierra may find strong surface winds that greatly reduce the landing safety factor. Last, but not least, are the problems of icing, both airframe and inside the canopy. Again, the degree of airframe icing tends to follow the same pattern in relationship to the jet stream as that of turbulence. Experienced pilots flex the control surfaces on the sailplane frequently during the flight to insure against loss of flap and brake control.

Several schemes for determining a wave condition in the Sierra have been tried recently with some success. A very simple assessment of the synoptic weather pattern of an approaching front into the Sierra moving against a quasi-blocking high pressure area over Utah usually results at least in wave conditions along the Sierra. The prognostic position of the polar and subtropical jet stream on the 300-mb chart across the Sierra are invaluable (Fig. 7). This method is very helpful in determining the durating of wave conditions. A nomogram involving surface pressure gradient and maximum wind up to 20,000 feet developed by Prof. Peter Lester and the Air Force works well as long as the pressure gradient exists.

This problem leads to headaches for the weatherman when, for example, thermal low-pressure troughs of nearly equal intensity are formed in central California and the Great Basin but a vertical sagging jet stream increases the winds over higher mountain peaks in the Sierra. This produces a very localized wave condition in spite of a negligible pressure gradient. Another problem is one of isolated wave conditions that can be formed when wind flow follows a course parallel to rather than normal to the Sierra -- generally any wind of 25 knots or more at peak level, with a gradual sustained increase aloft, may work to form at least a small wave.

Of all the wave soaring weather schemes used, the one involving the 'six-day cycle' is least likely to help.

Viva Sierra!

The oft-publicized feud between eastern and western soaring pilots will likely be rekindled as western soaring pilots tackle the Sierra with a better understanding of the weather. Can the fact the lofty Sierra poke massive rocks above the treeline prevent western pilots from taking their stand among distance-soaring greats? The analogy that eastern skiers were faster because their trees were closer together than for their western counterparts, and likewise for the eastern soaring pilot, can only

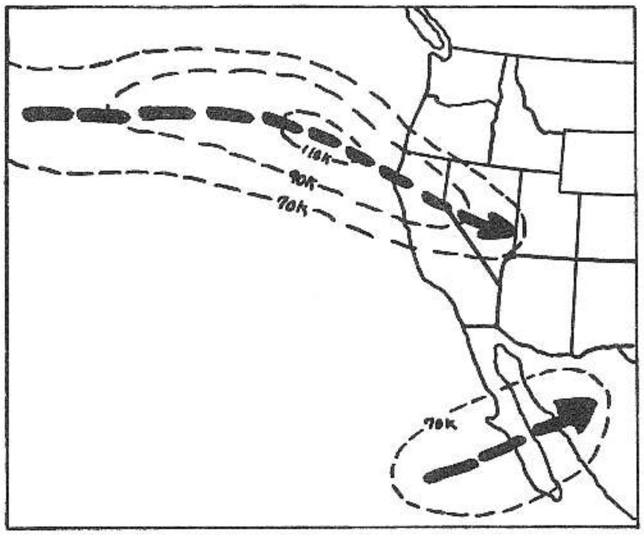

Figure 7. This is a depiction of wind speed analysis of a polar jet stream over the Sierra and a subtropical jet stream over Baja at 300 mb (30,000 ft) both actual and 36-hour prognostic charts are readily available at National Weather Service Forecast Offices. Weather and strength of wave conditions changes in relationship to the position north or south of the core of maximum wind speed and the speed of impulses, i.e. 100 knots embedded within the jet stream.

lead to this logical conclusion: because their trees are closer together the easterner must be suffering from a narrow point of view. Viva Sierra!

REFERENCES

1. Hill, Chris, 1975, "Downslope Wash-Out". *Soaring*, November 1975.

2. Lacy, S. J. and C. V. Lindsay, 1972. Soaring Meteorology for Forecasters. Forecasters Handbook No. 3, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Washington, D.C., 73 pp.

3. Moffat, George, 1974, "Winning on the Wind". *The Soaring Press*.

4. Hambidge, R. E., 1967. "K" Chart Application to Thunderstorm Forecasts Over the Western United States. Western Region Technical Memorandum No. 23, Environmental Science Services Administration, U.S. Weather Bureau, 9 pp.

5. Huschke, R. E., ed., 1959. *Glossary of Meteorology*. American Meteorological Society, Boston, Mass., 638 pp.

6. Federal Aviation Administration and National Oceanic and Atmospheric Administration, 1975 (Rev.) Aviation Weather for Pilots and Flight Operations Personnel, AC 00-6A. Department of Transportation, Flight Standards Service and Department of Commerce, National Weather Service, Washington, D.C., 219 pp.