WEATHER TO FLY

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THERMAL FORECASTING

Much has been written through the years on thermal development and thermal forecasting for the purposes of soaring flight, including many fine articles now present in *"Soaring"* Magazine archives. Other than just mentioning a few rudimentary concepts of thermals and because of the published wealth of information, the subject of thermals within these immediate articles of mine in "*Weather-to-Fly*" should simply be construed as an abridged review. However, I would like to provide a few insights and background in regard to thermal concepts and forecasting based on empirical information seen through the years and as conveyed to me courtesy of far more experienced soaring pilots and meteorologists. I am including a list of references that detail thermal development and thermal strength forecasting that can be studied at the leisure of the reader. (See *"References and Library Building"*).

In the July issue of *Soaring*, enhancement of thermal development by elevated terrain was deliberated. In the August issue we discussed air density differences resulting from differential heating of the air adjacent to the ground and that the density of warmer air is less than the relatively cooler air surrounding it. This less dense air is more buoyant and results in upward vertical motion known as a thermal. A majority of cross-country soaring is accomplished by use of thermals that occur in an air mass that responds to surface heating with the development strong lapse temperature conditions with altitude over a broad area. (Reminder: In meteorological definitions, "lapse" refers to a decrease in a given parameter.) Because thermals develop in an air mass their development is generally not restricted to areas of orographic features that are required for the development of ridge and mountain wave lift. Thermal development needs differential surface heating in combination with an air mass that has or will develop a temperature lapse rate at or exceeding the dry adiabatic lapse rate (DALR) over the lower layer of the atmosphere to an altitude sufficient to make cross-country soaring possible in the course of the flying day. (Moisture contributions to the development of thermals or upward vertical air motion will be addressed in a future article.)

Evaluating the weather for potential soaring flight has always been a challenge. The most successful long cross-country soaring pilots are those who are good observers and evaluators of the weather situation *and* are prepared to launch as soon as the lift is available that can support soaring flight. Assisting in this evaluation, the soaring community has relied on the concept of the Thermal Index (TI) for decades (See *"The Thermal Index"* by H.Higgins). *The* TI is intended to be a predictor of dry thermal presence and quantify the maximum altitude of those thermals. The TI is the Celsius temperature difference at a given altitude (often given for the 850-millibar and/or 700-millibar pressure level on an upper air temperature sounding) between the ambient air as measured by a morning sounding and the temperature at that level along the dry-adiabat that intercepts the expected surface maximum temperature. The *"Glider Flying Handbook"* concisely describes the TI at a given level or altitude as *"the temperature of the air parcel having risen at the Dry Adiabatic Lapse Rate subtracted from the ambient temperature"* (See Diagram #1: *"The Thermal Index"*). The TI provides some degree of illustration emphasizing the point that air density differences, i.e., air temperature differences and not high temperatures, drive thermal development.

Having been developed from observed and recorded lift rates and the altitudes reached during soaring flights, and subsequent analysis of morning temperature soundings, the TI is a soaring community "standard" for forecasting useful thermal maximum altitudes and inferring relative lift rates. Relative lift strength is deduced that the greater the absolute value of the "negative" TI then likely is the greater thermal lift. For clarification to my students I always comment in regard to the TI and its meteorological convention of the "minus" number that is necessary for thermal development. Remember what a thermal is all about – at any point where a thermal is rising, the air temperature within the thermal is higher (the air warmer) than the ambient air outside of the thermal's boundaries. The meteorological convention of this situation being a "minus" number is derived from

Definitions: "Convection" and the "Convective Condensation Level (CCL)"

"Because the most striking meteorological results of convective motion occur in conjunction with the rising current of air (strong updrafts or thermals, cumulus, etc.) convection often is used to imply upward vertical motion." (*Glossary of Meteorology, p.133*).

"The CCL is the height to which a parcel of air, if heated sufficiently from below, will rise adiabatically until it reaches saturation (condensation of the average moisture content over the approximately lowest 1500 feet of the atmosphere). The CCL approximates the base height of cumulus clouds which are, or would be, produced by surface heating." (The author's redefining of the CCL courtesy of NWS Reno Internet Website *"Soaring Terms and Definitions"*).

the TI Definition. However, the physics of buoyancy in regard to the needed temperature difference is the concept to absolutely remember, i.e., the air in the thermal must be warmer than the air outside the thermal.

Following on the heels of Higgins' publishing of the TI in 1963, research was done by meteorologist Charles Lindsay in analyzing a series of flights by Mario Piccagli in a Standard Austria from 1963 to 1969 in the mountains around Frederick, Maryland. Piccagli's flights led to empirically-derived regression equations that were published under the auspices of the National Weather Service in "*Forecasters Handbook No. 3, Soaring Meteorology for Forecasters.*" The analysis of those flights attempted to objectively determine and describe the relationships between maximum altitudes and lift rates reached in soaring flight with the depth of the DALR, including relating thermal strength to the initial height of the Convective Condensation Level (See "Definitions; *Convection* and *Convective Condensation Level, CCL*").

The results of Piccagli's flights and Lindsay's analysis specified:

1) A correlation of the maximum height of the thermals with the height of the dry adiabatic lapse rate;

2) Lift is stronger in a dry ("blue" or no-cloud) thermal that reaches a greater altitude (deeper) than one that is lower (shallower);

3) Convection or rising air inside the cumulus cloud is an extension of the thermal's rising air below the cloud;

4) That for a given altitude, lift under a cumulus cloud will usually be stronger than for that same altitude in a dry thermal;

5) Air has to be heated enough to become dry-adiabatic through at least the lowest 3000 feet of altitude before the sailplane encountered lift rate of 100 ft/min or greater; and,

6) It was Higgins study that suggested a potential temperature increase of 3 degrees Celsius or greater (a TI of -3 or less) provided a good chance for sailplanes to reach the altitude of that temperature difference.

Following Lindsay and his analysis of Piccagli's flights in the mid-Atlantic Region of the United States, feedback graciously provided by the 1975 Regional Contest Pilots in the Minden area of Western Nevada provided a soaring data set for evaluation by National Weather Service (NWS) Meteorologists Chris Hill and Doug Armstrong that resulted in the development of an objective aid for forecasting thermal strength. Edited by John Joss in "*SoarSierra*," this objective aid was labeled the "Soaring Index, SI". (See *SoarSierra*, pp. 23-28). While the TI provides a forecast estimate of thermal height – and only a relative and very subjective estimate of thermal strength based on the surface temperature in its relationship to the lower atmosphere lapse rate – the SI algorithm quantified an estimate of thermal strength (See Diagram #2: *The Soaring Index*).

The assumption on the application of the TI and the SI in estimating thermal presence is that the air mass represented by the morning sounding is not influenced by synoptic-scale changes in the course of the soaring day. But even given the ever changing nature of any air mass, on the average the SI has proved to be a reliable forecast aid in describing the quality of a thermal soaring day for the Intermountain West Great Basin and especially if its output is applied in comparison to previous days' forecasts as a trend.

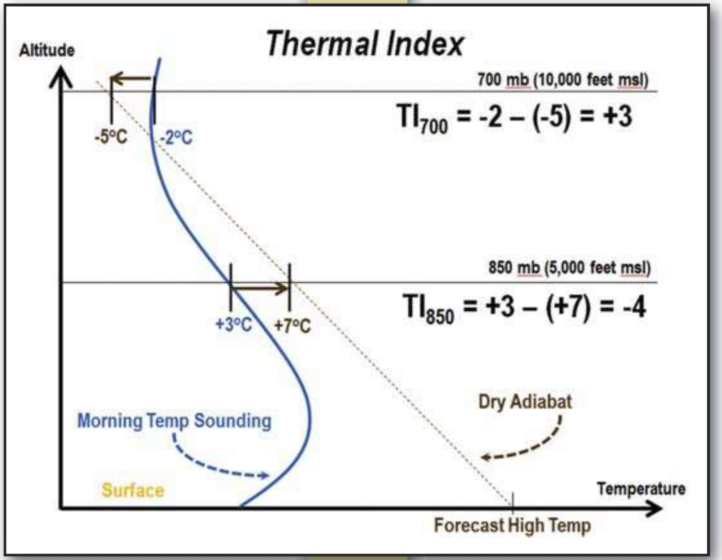
There are a few interesting notes that need to be emphasized to put these two empirically derived soaring aids – the TI and the SI – into proper perspective. Geography and climate are crucial in understanding the logic behind the aids' outputs. As mentioned, the TI was developed from observations of soaring flight in the mid-Atlantic area with its modest vertical terrain variation (modest in comparison to the Intermountain West), higher average atmospheric relative humidity, more extensive vegetative ground cover, and higher soil moisture content. Conversely the SI was developed utilizing pilot feedback from the Great Basin with its large vertical variation in terrain, dry soil, minimal vegetation, and very low atmospheric moisture. As published in numerous soaring textbooks and articles, the altitude where a TI value of -3 occurs is considered to be the useful "top of the lift."

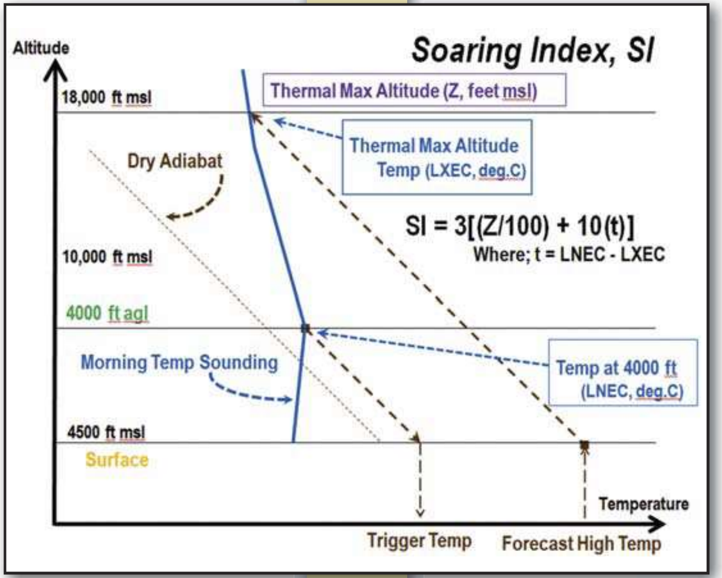
Understanding the climate of the mid-Atlantic region and that the effect of the incoming solar energy in its heating of the surface is mitigated by the amount of moisture present in the air and soil, the top of the useful lift would usually not reach the intersection of the DALR with the morning temperature sounding (given no large scale synoptic atmospheric changes during the day).

Observed in the Western U.S. with terrain contributions enhancing thermal production and drier conditions, incoming solar energy efficiently raises the sensible temperature of the lower atmosphere as the surface heats. The intersection of the DALR with the morning temperature sounding in the SI is quite frequently the top of useful lift as opposed to "capping" thermal altitudes at a value of -3 as depicted by the TI.

Observed in Hill's and Armstrong's own data set as well as utilizing one of the results of Picaggli's flights, the strength of thermal lift is a function of the depth of the surface-heated, convectively-mixed, lower atmospheric layer. The deeper the convectively mixed lower atmospheric layer, then generally stronger is the lift rate of the thermal. The SI's forecast for thermal strength is comprised and a function of two terms, the maximum altitude of the thermals and a solid lapse condition where there is a good decrease in temperature with altitude.

In summary, differential surface heating results in lower atmospheric level temperature differences. These temperature differences lead to air density differences. In combination with a favorable upper air temperature profile that favors development of a strong temperature lapse condition during the day, thermal soaring flight is then possible. The "soaring standard" *Thermal Index* provides an estimate of atmospheric mixing or thermal height and subsequently an inference of relative thermal strength. The "Great Basin" (author's descriptor) *Soaring Index* in its quantifying forecast for thermal strength underscores the contributions of *both* maximum thermal altitude for the day and temperature differential from the surface to aloft. I have addressed these two thermal





forecast indices to underscore the concepts that are necessary to understand thermal development. I acknowledge that there are several other soaring indices and forecast aids, and variations of those aids, used around the world. But the meteorological physics and concepts for the thermal process are consistent. An additional factor that needs to be addressed in the future is a discussion of atmospheric moisture in its role of de-stabilizing of the air mass and contributions to thermal development.

Note that I have discussed these particular thermal forecast indices for the expressed purpose of understanding thermal development. Subsequent technological advances in computer speed and the ability to apply more detailed atmospheric physics has resulted in many more numerical soaring forecasts and forecast atmospheric model outputs in my lifetime. The worldwide contributors to soaring in this computer environment are simply too many to know or list but they are thanked on behalf of all the meteorologists and soaring pilots who now daily use the fantastic atmospheric model output for planning soaring flight.

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Soaring Meteorology Publishing Pioneers

At the risk of omitting significant contributors to understanding soaring meteorology and as a soaring meteorologist myself for many years, I would like to acknowledge the published works of those with whom I am familiar. Their compilation of soaring meteorology and pioneering publishing has furthered the understanding of "modern" soaring meteorological concepts for soaring pilots and meteorologists:

- Harry Higgins' work and derivation of the *Thermal Index*;
- Australian Meteorologist and pilot C.E. "Wally" Wallington, NWS Meteorologist Charles V. Lindsay, and British Meteorologist and pilot Tom Bradbury on fine pioneer publishing work to describe meteorological elements (not just "thermal" related) relevant to modern soaring flight;
- NWS Meteorologists Chris Hill and Doug Armstrong for their work in development of the *Soaring Index* and providing the precedent for acceptance of soaring parameters and forecasts within the NWS; and,
- A notable "computer-era" reference to Navy Research Laboratory Meteorologist and pilot Dr. John "Jack" Glendening for his development and subsequent availability of numerical soaring forecasts. Besides the actual computations, access of "Dr Jack's" internet website also provides excellent definitions of significant soaring meteorological aspects.