WEATHER TO FLY

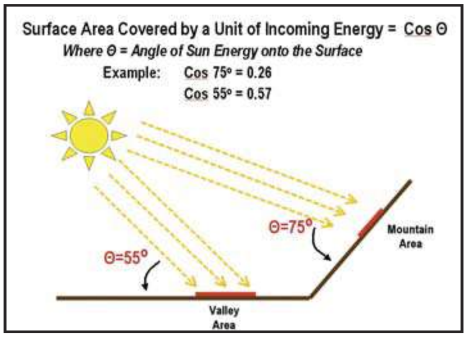
BY DAN GUDGEL

Elevated Heat Sources

In continuing dialogue on atmospheric lift processes and as I start to lay the groundwork (pun intended) for discussions about thermal lift development, I am reminded of a question that has been asked of me through the years: *"Why do thermals start sooner over higher terrain than adjacent valleys or flat ground?"* With occasional exceptions, generally thermal or convection initiation does tend to start over sloped terrain, hills, or mountains sooner than terrain with minimal slope. Other aspects of thermal development such as terrain texture and color and atmospheric stability will be addressed within future articles.

All energy comes from the sun in one form or another on Earth. Differential surface heating combined with an atmosphere that has a large lapse rate, i.e. a temperature decrease with altitude approaching or exceeding the dry adiabatic lapse rate, results in the development of pockets or streams of rising air that the soaring community knows as thermals. Thermals are buoyant because of less dense air within the thermal than that of the surrounding air. Several factors speed the initiation of thermal development around and on elevated terrain that I would like to review in this installment of *"Weather to Fly."*

Being closer to that of an insulator, the air is a very poor conductor of energy and as such, the air is heated by the conduction process only within a few inches of its contact with the earth's surface. However, surface warming of the air develops a density difference between that of the air warmed and adjacent air that begins a convection process. By convention in meteorology, convection is implied to mean upward vertical motion unless otherwise defined (and sailplane pilots know convection as a "thermal.") Because surface heating is necessary to warm the air immediately adjacent to the earth's surface, the degree and rate of surface heating varies the intensity and speed of thermal development. Again, heating of the air immediately adjacent to the ground is a direct result of the heating of that ground by the sun. The rate and intensity of the ground's heating is directly proportional to the amount of energy received from the sun per unit area of the surface of the earth. The more direct or closer to perpendicular that the sun's incoming energy shines on a given area then the more intense is the surface heating. Conversely, the shallower the angle that the sun shines on a given surface area then the weaker is the surface heating. Given the slope of topographic features such as terrain inclines, small hills, or mountains, incoming solar energy is made more intense on the earth's surface because of the high angle or steepness of the energy's impingement on the surface ***(See Diagram #1; Surface Area Covered by a Unit of Incoming Energy)***. In the example provided in Diagram #1, a unit of incoming energy with a *55°* angle is "spread" over a surface length that is twice as long a length with a *75°* angle.



Overnight surface-based temperature inversions often develop in many synoptic (large-scale) weather situations that

Energy to Evaporate Water versus Raising Water/Air Temperatures

DEFINITIONS:

The ***"Heat of Vaporization"*** is the energy required to change the state of water molecules from liquid to gas (water vapor). For molecules of water to evaporate, sufficient kinetic energy must be available to overcome the liquid-phase intermolecular forces. Sensible temperature (or degrees of temperature) is a descriptor of this molecular kinetic energy.

A substance's ***"Latent Heat"*** is the heat absorbed per unit mass by a substance in a reversible, isobaric (equal pressure)-isothermal (equal temperature) change of phase.

The ***"Specific Heat"*** of a substance is the energy required to raise the temperature of one kilogram of a substance by one degree Kelvin (Celsius):

- The Specific Heat of Dry Air at 0 degrees Celsius = 1.006 joules/gram-degC
- The Specific Heat of Water at 0 degrees Celsius = 4.186 joules/gram-degC

One ***"Joule"*** is a unit measurement of energy equivalent to 0.2389 calories. (CRC Tables)

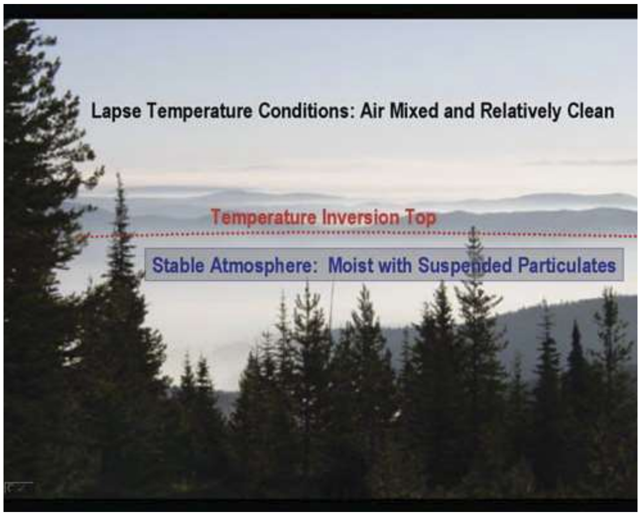
ENERGY REQUIREMENTS:

The energy required to change the phase of water varies with temperature but, nonetheless, it takes a tremendous amount of energy to change phase. At zero degrees Celsius, it takes 597.3 calories/gram or 2500 joules/gram of energy to change the phase of water from liquid to its gaseous state at that same temperature. For simply changing the sensible temperature one degree Celsius and by comparing the Specific Heat of Dry Air to that of Water, it takes approximately four times as much energy to raise the temperature of a given mass of water to that of an equivalent mass of dry air, i.e., 4.186 vs. 1.006 joules/gram-degC., respectively.

result in late morning through afternoon thermal development. By definition of a temperature inversion, the air closer to the ground is colder than the air aloft so initial incoming solar energy heating the ground must heat the cooler surface air several degrees to reach a point of convection. However, higher terrain above such surface-based temperature inversions is able to reach convection temperature sooner as there is no cooler air pooled at the surface that must be overcome for convection initiation.

In conjunction with temperature inversions, atmospheric attenuation becomes a factor in the inhibition of thermal development in valleys. As nighttime surface-based temperature inversions develop, the cooled air next to the surface is stable. Man-made pollutants or releases from nature put into the near-surface stable atmosphere are not encouraged to mix-out because of the lack of motion within a stable atmosphere. Pollution or moisture remains suspended for longer periods than similar releases into the atmosphere above any such inversions. Dirt and pollution from man-made sources is an obvious source of suspended matter. However, nature also contributes natural pollutants in the form of haze, suspended moisture, and vegetative debris such as pollens. Suspended matter or pollutants in the atmosphere reflect, scatter, and/or absorb incoming solar energy. This attenuation of the incoming solar energy reduces the strength of the solar energy reaching the surface. Ridges or mountains protrude above temperature inversions and the atmosphere is drier and relatively cleaner in regard to suspended matter that would inhibit surface heating due to attenuation. ***(See Picture #1: Temperature Inversion)*** Again, without as much suspended material as the result of better atmospheric mixing above surface-based inversions, there is less attenuation of incoming solar energy onto the slopes of higher terrain thus enabling heating of the surface in the mountains to be more efficient than adjacent valley ground.

While higher terrain can have varying degrees of vegetation, the surface of higher terrain is often dry as slope promotes water run-off. Since a large amount of energy is required to vaporize water for the change-of-state from liquid water to water vapor, drier ground warms quicker as moisture presence requires more energy to raise the sensible temperature the same as a dry surface ***(See Text Box #1: Energy to Evaporate Water versus Raising Water/Air Temperatures)***. In addition to a drier surface, if the higher terrain's surface also has more exposure to the incoming solar energy due to less vegetation and/or better solar collectors such as dark rocks then the rate at which the higher terrain's surface warms will be faster than the more moist, lower terrain.



Referencing the relationship of pressure and density ***(See Text Box #2: Equation of State for Dry Air)***, the density of the air decreases with an increase in altitude as pressure decreases with an increase in altitude. Or, in other words, the density of the air lying against the surface of hills, ridges, and mountains is less than lower-lying valleys and terrain. As the surface of the mountains warms from the incoming solar energy, a specific volume of air lying next to the higher terrain has less mass to warm than an equal volume of air (with more mass) at a lower altitude ***(See Text Box #3: Difference in Air Mass at 850mb vs. 1000mb)***. Even if the aforementioned factors for heating the air immediately adjacent to the surface of higher terrain versus adjacent flatter terrain were not providing significant difference in the energy received, altitude puts less mass for a specific volume adjacent to the higher terrain. With less mass in a specific volume of air to warm, the sensible temperature will rise faster in the air next to the higher terrain. This faster warming of the smaller mass in a specific volume of air results in a faster convection initiation or thermal triggering adja-

Equation of State for Dry Air

Defining Variables:
P = Pressure (in millibars or grams/centimeter^2 or mass/area)
☐ = Density (in grams/ centimeter^3 or mass/volume)
R = Specific Gas Constant
T = Absolute Temperature (in degrees Kelvin)

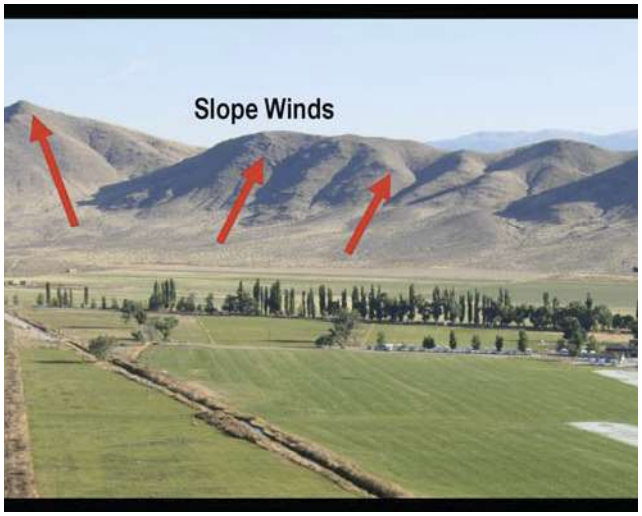
EQUATION OF STATE FOR DRY AIR:

P = ☐R T

In referencing the equation, note the relationships of the variables:

Pressure, **P**, is proportional to Density, ☐, and/or Absolute Temperature, **T**.
Or,
Density, ☐, is directly proportional to the Pressure, **P**;
Or,
Density, ☐, is inversely proportional to the Temperature, **T**.

As defined by the equation, a pressure increase results in a density increase, and conversely a pressure decrease leads to a density decrease. A temperature increase will result in an air density decrease, and conversely a decrease in temperature will increase the air density mass).



cent to higher terrain.

In micro-scale (scale size covering less than 2.5 miles) and meso-scale meteorology (scale size greater than 2.5 miles to hundreds of miles), temperature driven wind circulations abound that have implications for aviation. These circulations are recognized in the form of sea breezes, so-called shear lines, slope winds, and mountain-valley breezes. Sea breezes and shear lines will be covered in forthcoming installments of *Weather-to-Fly*. Slope winds and mountain-valley breezes are density- or temperature-driven winds and they fit nicely in the current discussion of density and pressure. As we have discussed density of the air decreasing with a decrease in pressure, referencing Text Box #2 and the Equation of State for Dry Air, density also decreases with an increase in temperature. Differential heating of the terrain due to the aforementioned slope effects generates density differences in the air along a slope. As the slope heats quicker than lower terrain, air along the slope concurrently increases in temperature and decreases in density because of that surface heating. Being more buoyant, the air begins to rise up the slope. This movement of air up a slope is known as ***slope wind***. This slope wind from the differential surface heating not only results in convection initiation (a thermal) upon reaching the top of the slope and releasing into the air, air movement along the slope can also act as a "thermal trigger" by kicking pockets of warmed air off the slope as the slope wind rises upward along the slope ***(See Picture #2: Slope Winds)***. Slope winds up steep terrain with chutes or gorges can result in large wind gradients close to the terrain and pose a soaring hazard due to the change in the wind component across the wing span of the glider ***(See Picture #3: Favorable Terrain for Strong Slope Winds)***. As the day progresses, the more rapid heating of higher terrain surrounding a valley results in a more general up-valley wind flow that manifests itself in winds along mountain slopes angling upward <u>and</u> across slopes ***(See Picture #4: Mountain-Valley Wind)***. Again, this density-driven wind flow can act as a thermal trigger to pockets of warmed air on mountain slopes or even the valley floor itself.

Difference in Air Mass at 850 Millibars vs. 1000 Millibars

Essentially the mass of the atmosphere above any point on the surface of the Earth exerts a pressure or force on that point. With any increase in height above the surface of the Earth, the amount of mass in the atmosphere above that height is in direct proportion to the decrease in pressure at that height (see the relationships defined in ***"Text Box #2; Equation of State of Dry Air").***

In meteorology, the "Standard Atmosphere" at Mean Sea Level (MSL) is defined in different units of pressure:

- 14.7 pounds per square inch; or,
- 29.92 inches (760 millimeters) of mercury, or, • 1013.25 millibars (mb).

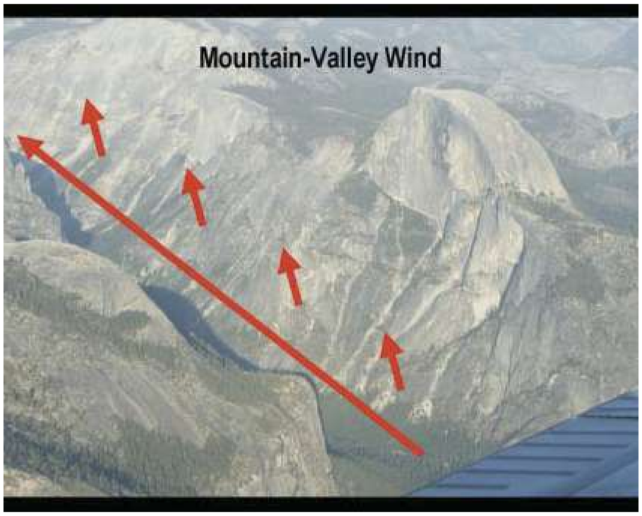
By unit cancellation of the "Equation of State of Dry Air," the relative amount of mass (or expressed as density in mass/volume) at a given height above some point on the surface is the pressure at that height divided by the observed surface pressure:

Relative Density = (Pressure at Altitude) / (Pressure at the Surface)

Example Question: What is the percentage of mass of the air column above a pressure level of 850mb (~4800 feet MSL) versus the amount of mass at a pressure level of 1000mb (~400 feet MSL)?

Answer: *850mb / 1000mb = 85%*

The air at 850mb of altitude is 85% of the density of the air at a surface point that has an observed pressure of 1000mb. The amount of energy required to raise the temperature of the mass of air at 850mb of pressure would need to be only 85% of that energy received at a surface with an observed pressure of 1000mb.



Summarizing, there are several factors that support convection initiation or thermal trigger earlier from higher terrain as ***"elevated heat sources"*** than adjacent valleys or lower topographic features:

1) The slope of the terrain enables the sun to provide more energy per unit area;

2) The lack of surface-based temperature inversions at the elevations of higher terrain results in minimal atmospheric attenuation of incoming energy due to comparably less atmospheric man-made or natural particulates and haze. With the air aloft generally drier, atmospheric haze and its energy attenuating characteristics is minimized;

3) Being at the top of a valley's temperature inversion or slightly above, air adjacent to higher terrain is already warmer than air at the bottom of the temperature inversion on the adjacent valley floor. Less warming of the air is required to reach thermal trigger at those altitudes near the top of the temperature inversion;

4) The surface of the ground, even if not varying in its ability to absorb and reflect energy by color or texture, is drier on mountain slopes so temperature increases faster with less incoming solar energy lost to water evaporation processes;

5) With less mass in a given volume of air adjacent to higher terrain compared to the same volume of air over an adjacent and lower altitude valley floor, incoming solar energy is able to raise the sensible temperature faster to thermal trigger; and,

6) Temperature/Density driven air movement along slopes and mountains acts as a thermal kicker by its very movement along mountain slopes as well as resulting in thermals releasing from the tops of mountain slopes, ridges, and peaks.

References:

"*General Meteorology*", Horace Robert Byers, McGraw-Hill Book Company, Third Edition, c.1959

"*Glossary of Meteorology*," American Meteorological Society, Edited by Ralph E. Huschke, c.1959.

"*Smithsonian Meteorological Tables*," Prepared by Robert J. List, Smithsonian Institution, c.1961.

"*Handbook of Chemistry and Physics*," Edited by Robert C. Weast, Chemical Rubber Company, 48th Edition, c.1968.