Micro-climates:
Understanding the earth's surface heat budget from space

Introduction
Even within a few tens of kilometers, there may be significant variations in surface temperature on the earth's surface, perhaps reaching 5 to 10 degrees Celsius. Examples include

1. urban heat island
2. cool forest adjacent to a warm corn field
3. cool irrigated field adjacent to a warm pasture
4. cool lake near warm land
5. cool mountain top/ warm valley
6. cool shadow versus a warmer sunlit area

Patterns of small scale temperature variations can be mapped using the thermal bands on Landsat, ASTER or MODIS, using the emitted long-wave radiation and inverting the Planck Function. Such measurements require clear skies. Even though these thermal bands lie in good "atmospheric windows", in moist climates, corrections for long-wave absorption and emission in the atmosphere are required. Corrections may also be required if the emissivity of the surface is less than unity. It is important to distinguish between the surface temperature (derived from radiation) and the air temperature just above the surface.

Deriving a predictive theory for microclimates is challenging due the large number of processes influencing the heat budget of the earth's surface. These are

1. Short wave radiation from the sun is given by

$$R = S_S(1-a)\cos(\phi)$$

where S is the solar constant, a is the albedo and phi is the angle between the slope-normal-vector and the sun. If the terrain is in shadow, only "blue skylight" hits the surface.

2. Evaporation of water from the surface or the melting of ice or snow (EM)

3. Exchange of heat with the air above the surface

   $S = K(T_A - T)$ where K is an exchange coefficient

4. Radiative cooling to space

   $L = (1-\varepsilon)\sigma T^4$ where epsilon is the emissivity of the atmosphere.

5. Heat storage; heat brought to the surface from below associated with time variation of surface temperature.

These processes are described in books and articles on the Atmospheric Boundary Layer and Microclimates. The surface temperature (T) takes on a value that allows all of these processes to balance, i.e.

$$d(storage)/dt = R + S - EM - L$$

If we scan through the above process equations, we can identify the spatially varying surface properties that might cause spatial temperature variations. These are: albedo, sun angle, water phase change, and roughness (exchange coefficient). If large changes in elevation are involved, variation in air temperature and atmospheric emissivity may cause surface temperature variations. As one rises in the atmosphere, the air temperature in the free atmosphere usually drops at a rate of about 6.5 degrees per kilometer. Also, as less atmospheric mass lies above, the atmospheric emissivity decreases at higher altitudes.

Estimating terms in the heat budget equation

In addition to mapping out the patterns of surface temperature, it is sometimes possible to deduce the reasons for these temperature variations using satellite data. Here are some examples of helpful calculations.

1. The short wave radiation input can be analyzed by computing the slope and aspect of each pixel and comparing with the position of the sun. The slope and aspect can be computed from the DEM using the supplied filters in ERMapper. We need to know the zenith angle and azimuthal angle of the vector that rises perpendicularly from the earth surface. We also need to know the zenith angle and azimuthal angle of the sun, at the time of the image. The sun angle is sometimes available in the image header. If not, it can be computed from the date, time and location (see special website). To predict regions of shadow, one might use ERMapper's sun shading routines. Knowing how directly the sun hits the pixel, we can then deduce the albedo from the reflected radiance. Snow will have a much higher albedo than soil or vegetation.

2. The longwave radiation to space can be determined from the observed radiative temperature using the Stephan-Boltzman Law. The atmospheric emissivity is the fraction of the emitted radiation that is trapped by greenhouse gases (e.g. $\varepsilon \sim 0.7)$. On very high mountains, the atmospheric emissivity may approach 0, as so little gas lies above.

3. On mountain slopes, the free air temperature can be determined from a nearby balloon sounding. These soundings can be found from the U. of Wyoming website http://weather.uwyo.edu/upperair/sounding.html. Specify the time, date, location and format.

4. Some surface properties may be available if the landcover can be classified and identified. Surface covers such as snow, forest, soil/rock and open water should be identifiable from their reflective signatures.

Statistical investigations

The relative importance of different processes may be seen with simple scatter plots or regression lines.

1. Temperature versus elevation. Compare with balloon sounding.
2. Temperature versus aspect. Note the role of sun angle.
3. Temperature versus albedo. Note the role of albedo (direct or indirect).
4. Temperature versus NDVI. Note the role of vegetation (perhaps due to evaporative cooling)
5. Histogram of temperature. Note any clusters at zero Celsius due to melting snow or ice.

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