THE WEATHER SENSORS FOR SLR2000

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INTRODUCTION

SLR2000 [Degnan 2001] needs pressure, temperature and humidity data to correct range measurements for refraction, as does any other SLR system. However, SLR2000 is a fully autonomous system, with no operator present, so it will have additional requirements for weather data. First are the system health and safety issues. Under conditions of precipitation, fog, wind blown dust or high winds, the dome must be closed in order to protect the telescope, the mount, and the dome itself. In addition, tracking may have to be suspended when the temperature goes outside the operating range of the mount, specifically 20^o to 120^o F. Furthermore, a near-real-time map of the sky showing clear, haze and cloud is required, in order to track as efficiently as possible. This will allow the telescope to be pointed toward areas of clear sky, and when the sky is completely overcast operations will be suspended.

To meet our requirements we have purchased three commercially made weather instruments and built a fourth one. The outdoor portion of the system is shown in Figure 1. The Paroscientific measures pressure, temperature, and humidity. The Belfort-Young combines a wind vane and propeller to measure wind direction and speed. The Vaisala senses precipitation and estimates the horizontal visibility. The fourth instrument is a thermal infrared cloud detector that we built ourselves. The following sections describe these instruments, explain their function in the SLR2000 system, and address their hardware and software interfaces.

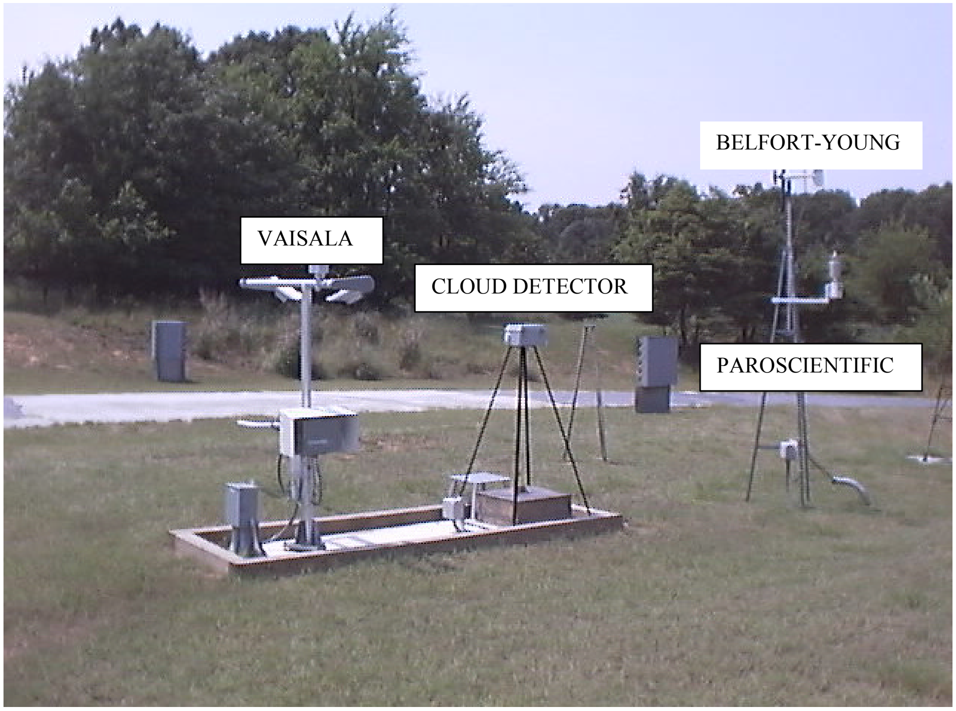

Figure 1. The suite of weather instruments in the field at Goddard's Geophysical and Astronomical Observatory.

PAROSCIENTIFIC, BELFORT-YOUNG AND VAISALA

The Paroscientific model MET3 shown in Figure 2 consists of a pressure transducer, a temperature sensitive resistor, and a humidity sensitive capacitor. Each of these is wired to an analog to digital converter, and the converters are part of a serial communication circuit. The accuracy of the Paroscientific is +/- 0.1 mB pressure, +/- 0.5 ^{o}C temperature, and +/- 2 % in humidity, which is sufficient for refraction correction. There is very little drift over the course of a year. More information on Paroscientific and the model MET3 are available on their Web site at http://www.paroscientific.com/.

Figure 2. The Paroscientific model MET3.

In the Belfort-Young model 05103 pictured in Figure 3, wind speed is sensed by a helicoid propeller. A permanent magnet attached to the shaft induces a sinusoidal AC signal in a stationary coil with a frequency proportional to the wind speed. Wind direction is sensed by rotation of a potentiometer on the vertical shaft of the weather vane. With a reference voltage applied to the potentiometer, an analog voltage proportional to azimuth angle is produced as output. The Belfort-Young exceeds our requirements for wind data and we have seen no failures in two years of operation. More information is available at http://www.belfort-inst.com/.

Figure 3. The Belfort-Young model 05103 and a grounding rod.

The Vaisala model FD12P shown in Figure 4 contains a near-infrared transmitter in one of its arms and a corresponding receiver in the other. Since the two arms are about 30 degrees out of line, infrared light can only reach the receiver if it is forward scattered by particles of precipitation falling between the arms. Signal processing software analyzes the voltage output from the receiver, along with the current temperature, to determine the type and intensity of precipitation and the horizontal visibility. The results are reported serially. The Vaisala precipitation data is qualitative, indicating rain, snow, sleet, etc though it does report light, medium, or heavy intensity. We have not had any failures in two years of testing, and the instrument is widely used at airports. Finally, our visual estimates of horizontal visibility have always agreed with the Vaisala. Additional details can be found at http://www.vaisala.com/.

Figure 4. The Vaisala model FD12P. The small box atop the left arm is the DRD12.

Figure 5 is an example of Vaisala FD12P precipitation sensing over the course of 20 minutes plotted with diamond shapes. At about minute 10 you can see that the intensity increases from none to light, and then to heavy. The Vaisala package also has a model DRD12 analog sensor that registers a voltage decrease when an exposed portion of the circuit gets wet, and that is plotted with squares. Notice that there is good correspondence between the two indicators at the onset of precipitation.

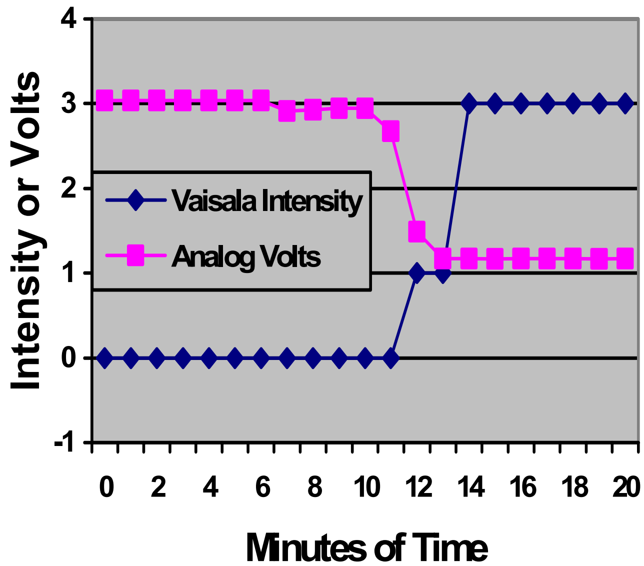

Figure 5. Vaisala precipitation sensing.

Figure 6 shows the distribution of horizontal visibility over the course of one year. In our location in Greenbelt Maryland, the visibility is fairly evenly distributed from 0 to 50 km. In other locations it would probably be more skewed toward the long or short end of the scale.

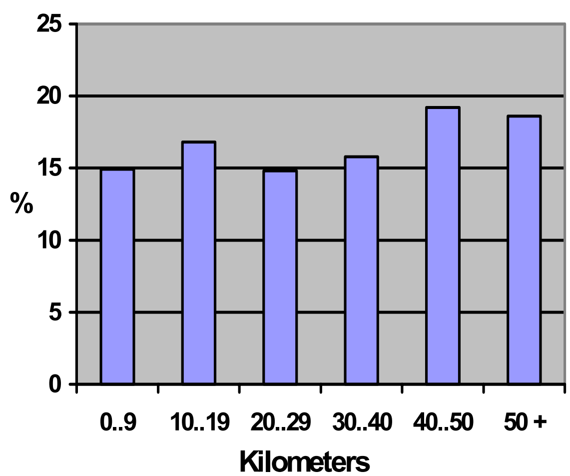

Figure 6. Vaisala histogram of visibility.

The combined functioning of the Paroscientific, Belfort-Young and Vaisala are demonstrated in Figure 7, as it shows the response of all three instruments to the passage of a weather front. In the top panel the Paroscientific indicates a steady drop in pressure until about 12:00 UT at which time it levels off. At the same time the Vaisala is indicating moderate to heavy precipitation (by lower values on this graph), and the visibility is also very low. The Belfort-Young reveals winds from the east with high gusts at about the time of this pressure change. After 12:00 the pressure begins to rise, marking the change of weather systems. Precipitation ceases a short time later, visibility increases dramatically, and the wind swings around the west. Finally the humidity drops as the air becomes dry. However the temperature only rises a little over the course of the daylight hours, because this front was a cold weather system.

During SLR2000 operations, the meteorology software will be under the control of the Overseer program on the Data ANalysis (DAN) computer [McGarry et al, 2001]. Sampling intervals will be on the order of once per second for wind; 10 seconds for pressure, temperature and humidity; and 30 seconds for precipitation and visibility. The software includes error checking and error reporting, and if a serial communications fault is detected the affected channel is closed and re-opened and communication with the affected instrument is re-initialized. The results are available to the Pseudo-Operator (POP) computer through shared memory.

The Belfort-Young is an analog instrument as is the DRD12 portion of the Vaisala. The FD12P side of the Vaisala, as well as all of the Paroscientific and the cloud detector communicate serially. The cloud detector is described in more detail in the following section.

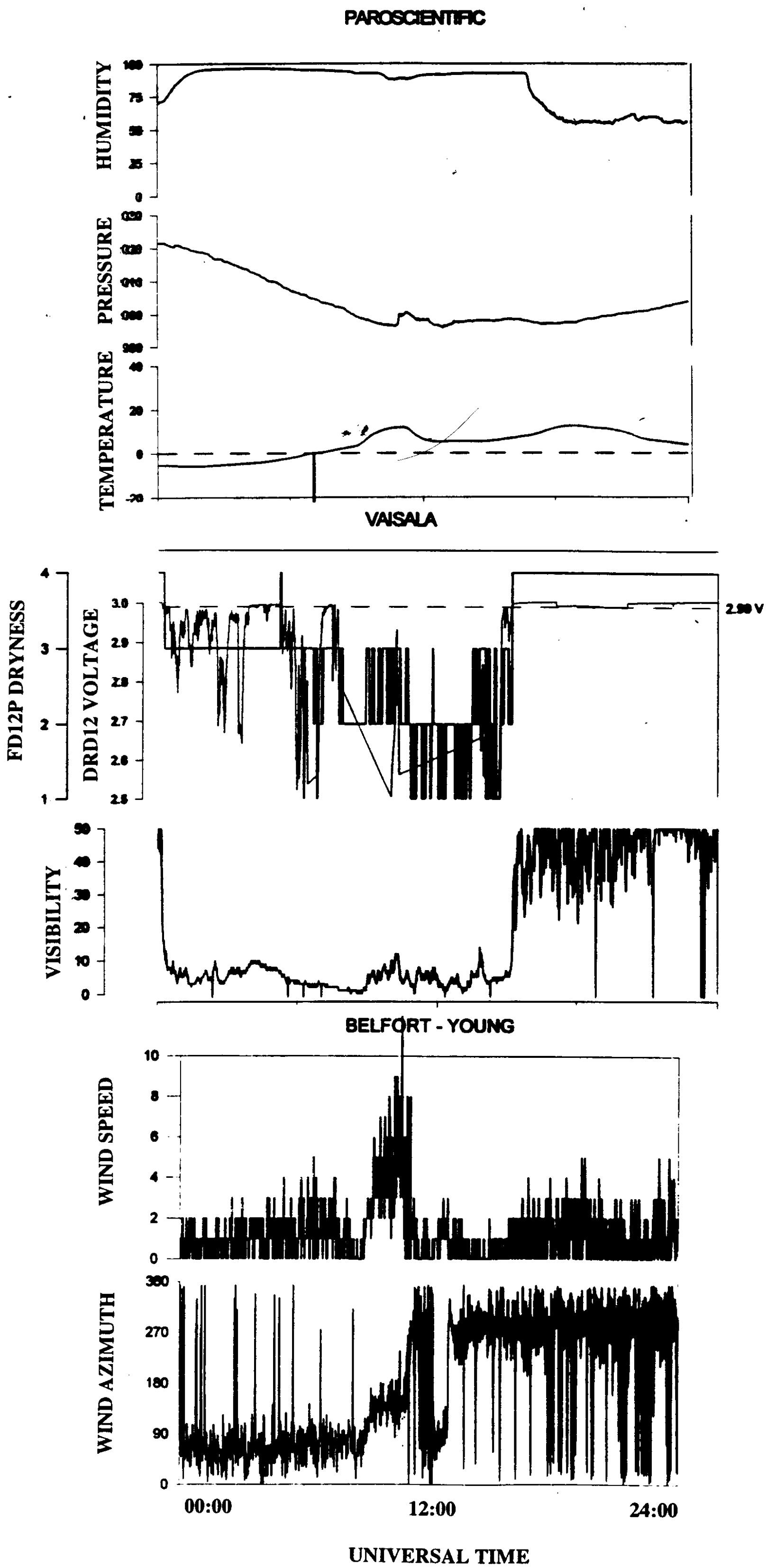

Figure 7. A day-in-the-life of the weather instrument suite.

SKYCAM IMAGER

The fourth instrument in the suite of SLR2000 meteorology sensors is the SkyCam imager. We built this instrument because at the time we began there were no cloud detectors that worked well at night, and the only available daytime cloud sensor cost several hundred thousand dollars.

The SkyCam consists of a thermal infrared camera pointed downward toward a convex mirror that images the sky above 10 degrees elevation. Figure 8 shows a schematic and Figure 9 is a picture of our prototype. Notice the box containing the infrared camera and the convex mirror.

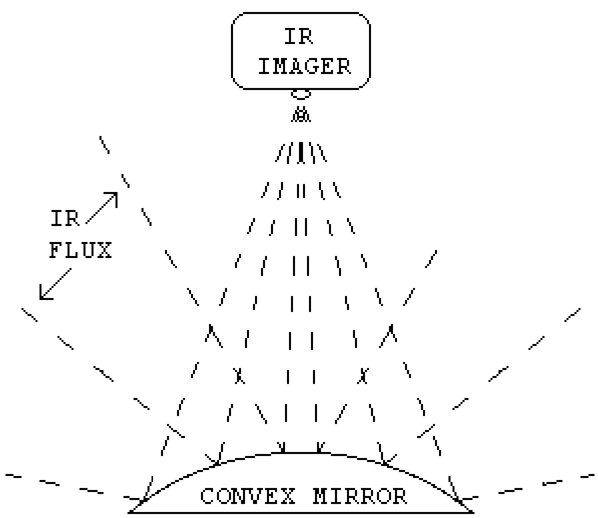

Figure 8. SkyCam schematic.

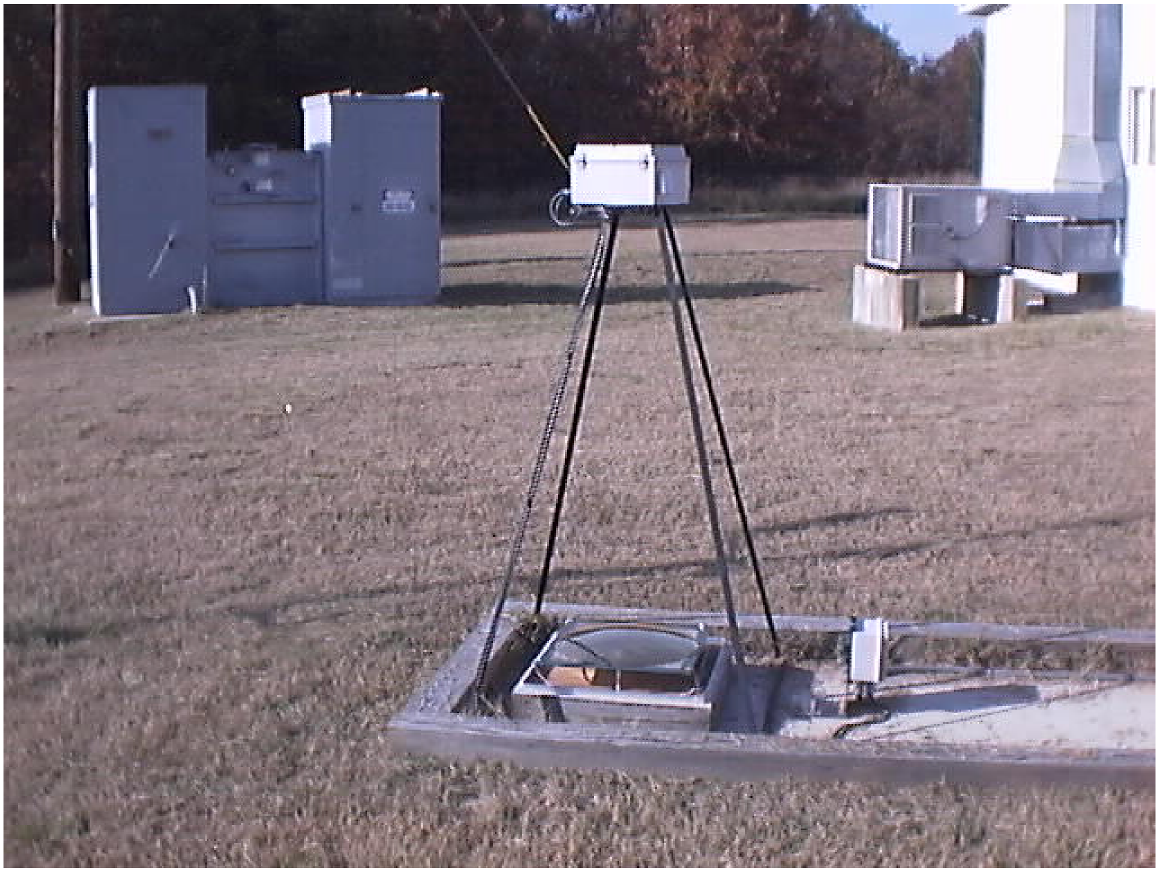

Figure 9. SkyCam in the field.

We chose thermal infrared because there is little sensitivity to sunlight, so the instrument works the same by day and by night. Figure 10 displays the black-body radiation curves for the Sun at 6000 degrees K and the Earth at 288 degrees K. Notice that the peak of the Earth's black body curve is near 10 microns, which is the central wavelength for our camera. Figure 11 shows that at 10 microns there is also good visibility through the atmospheric gases even at sea level, as indicated by these low absorption percentages.

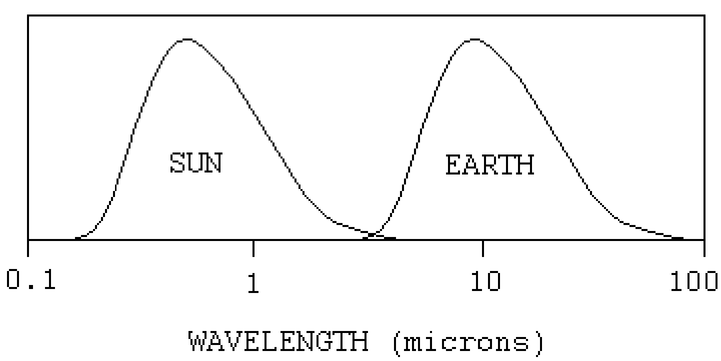

Figure 10. Blackbody radiation curves of the Sun and Earth.

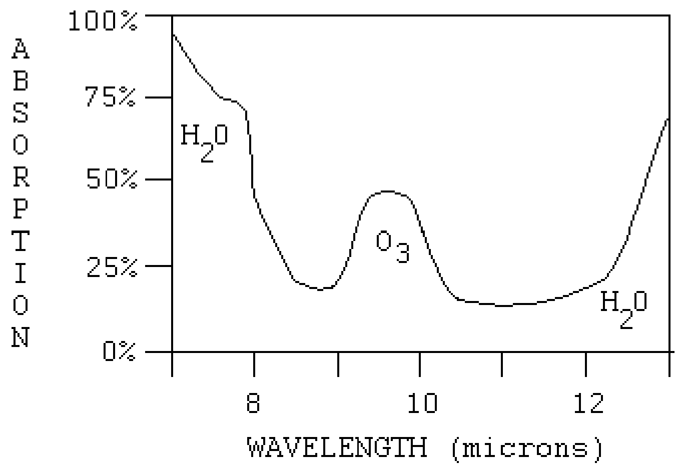

Figure 11. The absorption window at 10 microns.

The SkyCam imager works by the principal that sky transparency is correlated with temperature. The reason is that low lying clouds such as overcast are very opaque, while higher clouds such as cirrus are more transparent. Because of the lapse rate (or cooling with altitude) the lower clouds are warmer and the high clouds are cooler. For completely clear skies the temperature will be lower still. Thus the clearness of the sky should be correlated with the temperature contrast between the sky and the ambient temperature on the ground. Since there are several lapse rates (as plotted in Figure 12) the correspondence will not be perfect.

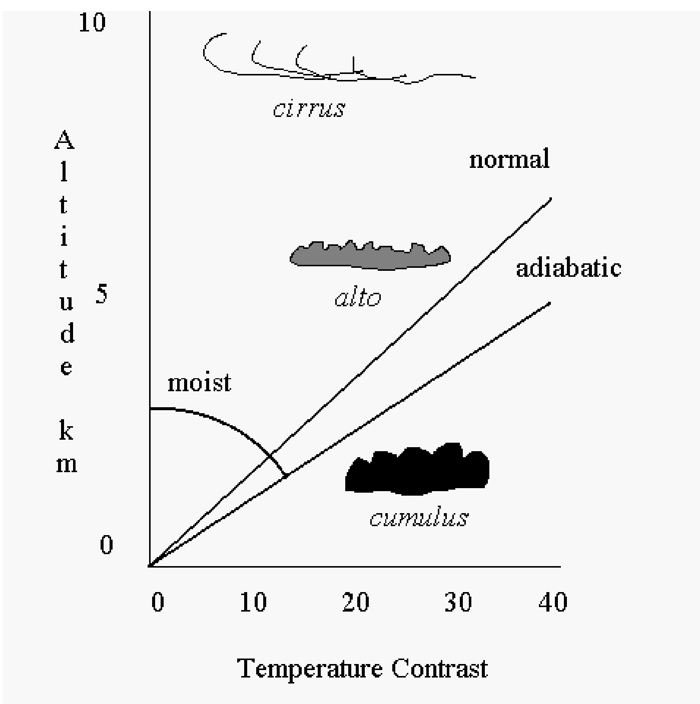

Figure 12. Lapse rates and typical cloud heights.

Figure 13 shows that what work in principal also works in practice. The best fit line is transparency versus logarithm of temperature difference, and it demonstrates that high transparency correlates with a large temperature contrast. Furthermore, really thick clouds (indicated in the lower left) strengthen the correlation, though they could not be included on this graph or fitted with the line. They had to be excluded because the extinction, deduced from the apparent brightness of the Sun and of stars was too large measure. The right vertical axis indicates transparency for two-way ranging at zenith and at 30 degrees elevation.

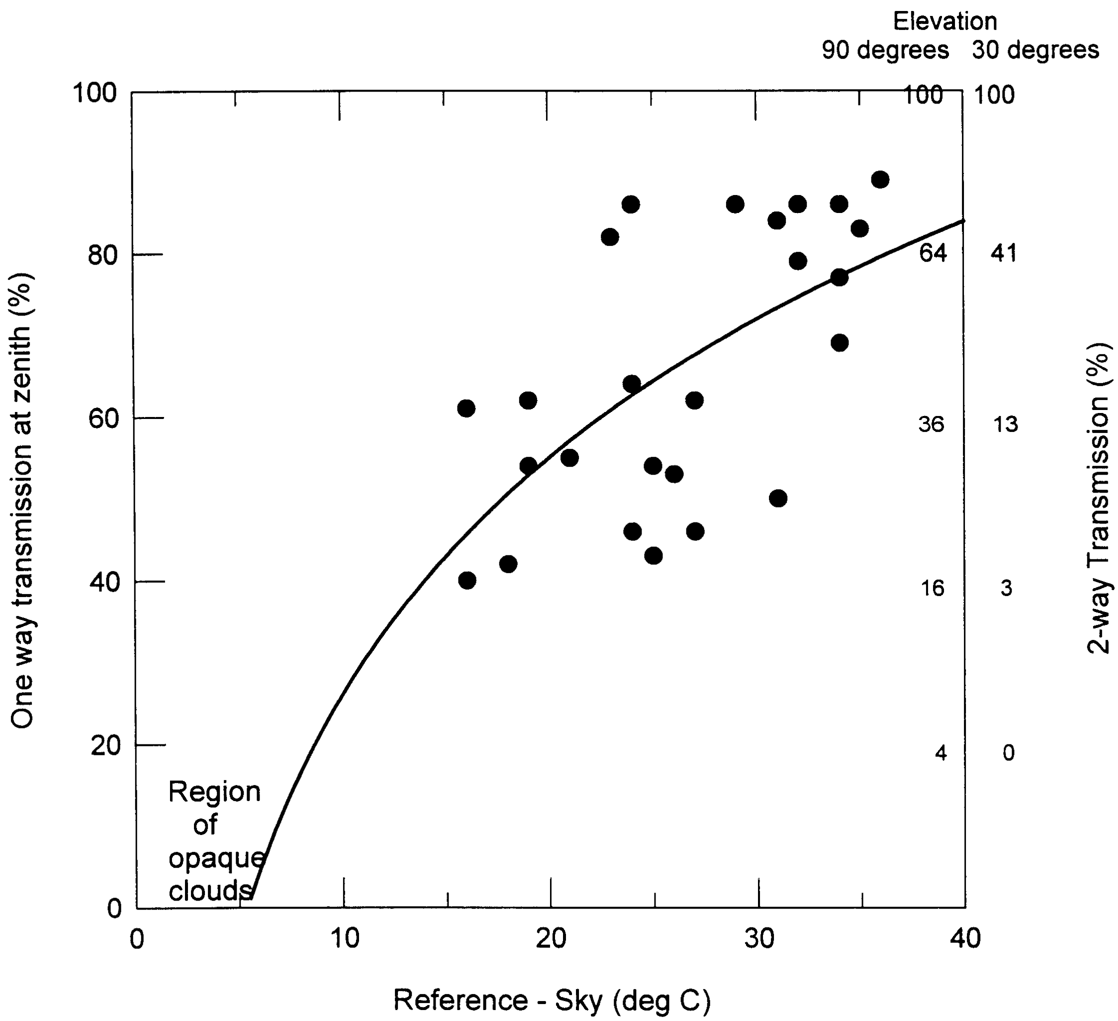

Figure 13. Transparency correlates with temperature contrast. Temperatures were measured from SkyCam images. Transparency was derived from data taken with a solar photometer and with a telescope and stellar photometer.

Figure 14 is an example of an infrared thermogram of the sky where cooler temperatures from about 17 to 25 degrees C are shown in black and grey, while warmer temperatures from about 25 to 33 degrees are shown in colors. Most of the north and east are clear, as indicated by the cooler greys and blacks. A cloud covers the zenith and extends to the southwest. Another cloud is about 40 degrees to the south.

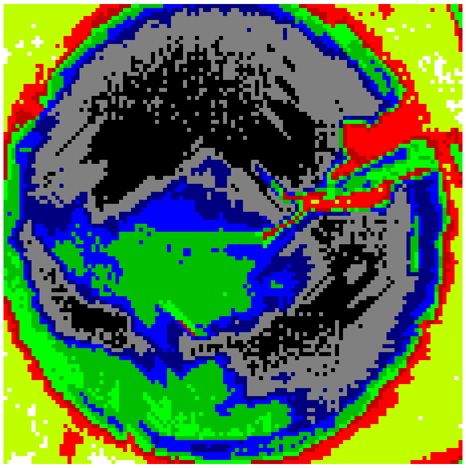

Figure 14. Daytime thermogram. North up, east right.

Figure 15 shows a nighttime thermogram with temperatures ranging from 4 to 21 degrees. The same color scheme is used, and reveals that the east and west are cloudy while there is a clear patch at zenith extending to the north and south.

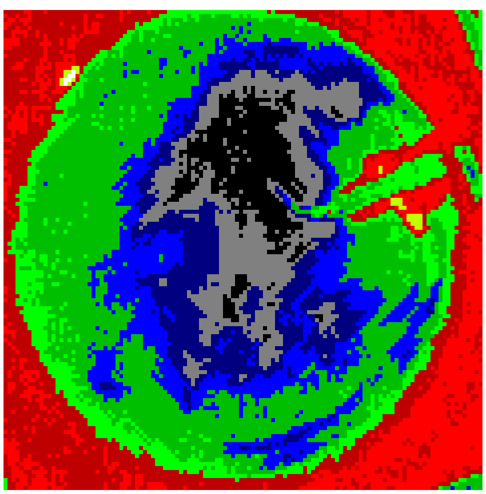

Figure 15. Night time thermogram. North up, east right.

On Figures 14 and 15 a support arm on an earlier version of our prototype is visible in the upper right. The improved prototype now in use has four thin arms instead of one thick one to support the camera. The reflection of the camera and vanes are removed from the thermograms by interpolation, thus leaving an unobstructed view of the sky.

A time-lapse movie of clouds passing over the SLR2000 prototype site can be viewed by clicking on the file named **cloud.mpg** on this CD.

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