Infrared Sky Camera: The Production Model

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Abstract

A thermal infrared imager for mapping the changing cloud cover from zenith down to about 10^{o} elevation over a laser tracking facility has been developed. Atmospheric transparency is distinguished by the difference between the sky temperature and the ambient air temperature at ground level. Clear sky is indicated by a temperature more than 20^{o} C cooler than ambient, and the qualitative results 'clear, haze and cloud' have proven to be very reliable during two years of development and testing. The instrument is comprised of a 10 micron detector that produces a 120x120 pixel thermogram, and a convex electroplated reflector which is situated underneath the detector and in its field of view. After two years of prototype development a new production model has recently been manufactured.

1. Introduction

During the past two years we have developed an instrument for mapping the cloud cover over an SLR2000 facility. This instrument could be used at any other tracking station just as easily, since the data are transmitted on a serial communication line, thus it may be integrated with practically any user-supplied computer system. This paper describes how the instrument works, summarizes the development and testing of a prototype, and concludes with a discussion of the production model of the instrument that has recently been manufactured.

The first thermal infrared cloud detector was invented by Werner (1973), who built an instrument containing a commercially made radiation thermometer consisting of a thermistor bolometer mounted inside of a temperature controlled blackbody cavity. This instrument observed different parts of the sky by means of a 2-axis motorized mirror. An optical chopper alternately reflected target radiation and blackbody radiation to the bolometer. Werner compared cloud measurements with radiosonde data to demonstrate the accuracy of the radiometer measurements.

Hull et al. (1994) followed up on the thermal infrared detector concept with an instrument designed around a single channel HgCdTe photoconductive liquid-nitrogen cooled detector. An altitude-altitude mount driven by stepping motors was used for scanning, and clouds are detected based on temperature contrast in the resulting picture of the sky.

2. Principles of Infrared Cloud Detection

Clouds emit IR radiation according to their temperatures, which can be as warm as the surface air temperatures for low altitude clouds like fog, or as much as 10 or 20 degrees Celsius cooler for medium and high altitude clouds like cirrus. In the absence of clouds, clear sky generally registers more than 20 degrees cooler than ambient. These temperature contrasts depend on how strongly the clouds are emitting, which in turn depends on their actual temperature and optical depth. For thick relatively warm clouds the IR temperature simply reflects the surface air temperature. At higher altitudes, the air and the clouds are cooler due to the lapse rate of the atmosphere. Goody (1995) indicates a rate of about -10^{o} C per kilometer of altitude. Furthermore the high clouds tend to be more transparent, so thin cirrus clouds register a larger temperature difference.

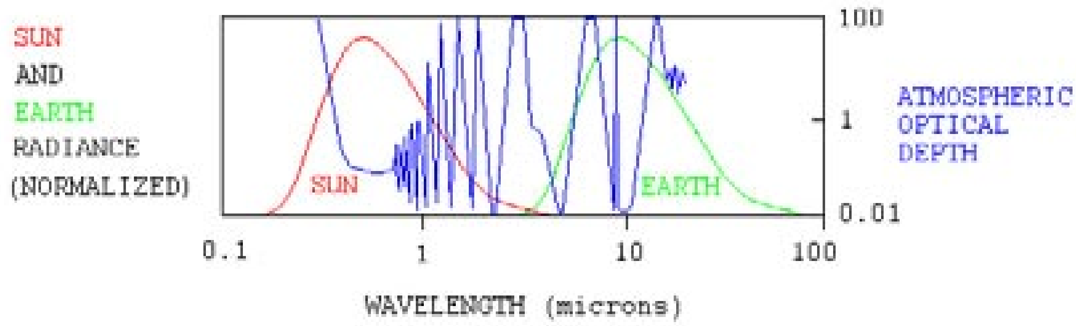

FIGURE 1. RADIANCE SPECTRUM AND OPTICAL DEPTH

A thermograph is an IR imager that produces a two dimensional 'temperature picture', so it is an ideal device for distinguishing clouds from clear sky. We selected a 10 micron thermograph to take advantage of the corresponding window in the water vapor absorption band of the atmosphere which only contains a small ozone feature. Thermography also has the advantage that it works as well during daylight or at night, because the Sun is not a powerful source of thermal IR flux. Figure 1 shows the radiance of the Earth and Sun from 0.1 to 100 microns, in addition to the atmospheric optical depth. The data for the figure were adapted from Cox (2000)

3. Instrument Description

Our design uses a convex mirror to re-image the sky for the relatively narrow field of view of the detector as shown in Figure 2. We considered using a fish-eye lens but the lens manufacturers we contacted were not interested in designing such a lens in germanium, as needed for IR transmission.

We experimented with several kinds of mirrors. The evaporated gold surface of our first mirror degraded too quickly in the field. We also investigated metal plated acrylic but found that the technology was not yet mature. Good results were obtained however with a test sample of electroplated metal, which resisted weathering for more than a year in the field.

FIGURE 2. INFRARED SKYCAMERA

The next step was to have a mandrel (or form) machined from an 18” block of stainless steel. This was an expensive item, but the replicated reflectors are more reasonable in cost. Our mandrel has been used to produce two reflectors, one of gold and the other of rhodium. Both of these metals have proven to be efficient IR reflectors and both have been durable. Designing our own reflector also allowed us to achieve sky coverage down to about 10 degrees elevation.

A supporting mechanism made of welded aluminum angle stock holds the thermograph above the mirror. The early prototype version of our instrument had a weather-proof plastic box protecting the thermograph at the top of the instrument. The thermograph in the production model shown in Figure 2 is built into a NEMA-4 industrial enclosure that is used in the field without any additional protection.

The IR sensitive detector component is a linear array of 120 silicon thermoelectric elements that is scanned across the image plane to produce a 120 x 120 matrix of IR intensity. No cooling of the silicon array or chopping of the radiation is required. The scale of the sky at the focal plane is approximately 1.3^{o} per pixel. Thermal calibration is automatically applied to the matrix to produce a thermogram, which is usually displayed as a false color image in order to facilitate interpretation by a human. The detector is calibrated from -50^{o} to 100^{o} C to permit recording of the colder temperatures of the sky.

Each pixel of the thermogram results in a 16-bit binary number, and the 14,400 pixel image together with its header combines to make a 29,000 serial packet of information. This data is obtained from the detector through an RS-232 port at speeds up to 115,000 baud, so that a thermogram may be downloaded in a few seconds.

4. Data Processing and Testing

A C-language program was written for DOS for analysis of the thermograms and for serial communication with the camera. A screen from this program captured from a computer monitor is shown in Figure 3. The image on the left is a thermogram, while that on the right is a cloud map. The menu of commands is visible at the bottom of the screen.

Warmer temperatures are shown as red , while cooler ones are gray and black in the thermogram and the display scale beneath it indicate a temperature range of 3^o to 32^o C. The warmer temperatures in the east and west (left and right) portions of the sky indicate the presence of clouds, while cooler temperatures near zenith and to its north and south reveal clear sky.

The thermograph plate and supporting vanes in the left image were removed from the thermogram by interpolation as the first step in producing the cloud map. Then the ambient temperature at that time, 29^o C, taken from the image of the thermograph plate (an object at ambient temperature) was modified by the 10^o and 20^o C temperature contrast criteria for haze and clear sky, and applied to determine areas of clear, haze and cloud. Hence, cloudy sky is warmer than 19^o C, hazy sky is between 9^o and 19^o C, and clear sky is cooler than 9^o C.

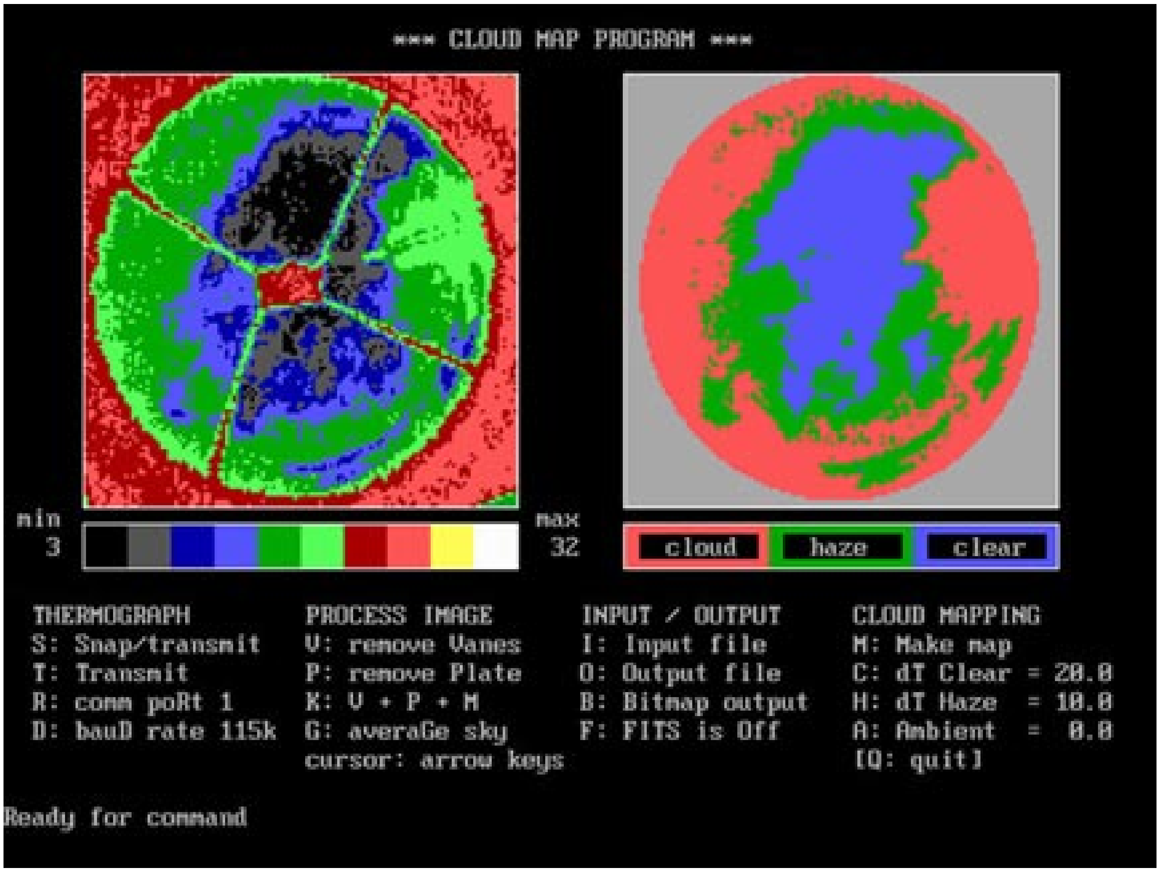

FIGURE 3. THERMOGRAM AND CLOUD MAP

The results from the sky camera are generally in agreement with visual estimates of sky cover and have never been grossly in disagreement (where one source judged the sky to be clear and the other judged it cloudy).

5. Summary

We have developed and prototype and a production version of an infrared cloud mapping device. The instrument operates by distinguishing sky clarity on the basis of the thermographic temperatures, where cooler readings indicate clearer conditions. A prototype was tested in the field for two years and gave reliable results. A production model has now been manufactured at a Raytheon facility in Indianapolis.

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