# Deployment of an Infrared Thermometer Network at the Atmospheric Radiation Measurement Program Southern Great Plains Climate Research Facility

*V.R. Morris and C.N. Long*
*Pacific Northwest National Laboratory*
*Richland, Washington*

*D. Nelson*
*Cherokee Nation Distributors*
*Stilwell, Oklahoma*

## Introduction

To infer information about vertical distribution and character of cloudiness across the Southern Great Plains (SGP) domain, downwelling infrared thermometers are being deployed at the SGP extended facilities. The sky brightness temperature measurements are sampled at a rate of 5 Hz to capture the inherent variability under cloudy and partly cloudy conditions. Conditional sampling of these data detect periods of clear-sky and opaque clouds. A methodology was produced to account for the intervening atmosphere to infer cloud effective brightness temperatures, cloud height, and longwave effective sky cover.

## Objectives

One of the primary uses of these data is to test and combine them with satellite measurements. While satellite data affords good spatial coverage across the area, it only provides a “snapshot” every half hour and has known weaknesses, especially in inferring such quantities as low cloud base heights, low cloud amounts, and detection of few or smaller clouds (Genkova et al. 2005). Having the additional infrared thermometer (IRT) retrieval points for comparison and testing will allow refining of the retrievals by cloud situation (Genkova et al. 2003). The IRT measurements from the surface can be used to estimate cloud base heights (Morris and Long 2005), the methodology working better for low cloud base heights than for high clouds. By combining the data from the IRTs and satellites, improving both spatial and temporal resolution, nominal estimates of cloud base heights will be able to be produced for the twenty-one locations of the SGP extended facility network.

One application of these data is in support of the Broadband Heating Rate Profile project, a comprehensive effort by the Atmospheric Radiation Measurement (ARM) Program science team to provide a critical tool for evaluation of radiation measurements, radiative transfer models, and the specification of the relevant atmospheric properties, with a key focus on clouds. The spatial variability of clouds across the SGP site must be included for the Broadband Heating Rate Profile to provide a realistic estimate of heating rates for the SGP area as simulated by single column models.

In addition, there is currently work (Takara and Ellingson 2003, Long et al. 2005, Hinkelman et al. 2005) underway to use sky brightness temperature measurements in conjunction with other typical surface radiation and meteorological data to infer such quantities as clear-sky downwelling longwave radiation, longwave cloud effect, longwave effective sky cover, and sky/cloud classification. All of these quantities are of use for inferring information about the distribution and character of cloudiness across the SGP domain. The new IRT network will both enhance the ability to infer these quantities and decrease their uncertainty.

## Testing and Development

Every ARM Climate Research Facility includes IRTs as part of its instrument suite for obtaining downwelling and upwelling radiation measurements (Morris 2006). The sky/cloud and ground-surface temperature measurements by the IRTs at the North Slope of Alaska and Tropical Western Pacific sites are obtained by sampling the analog voltage output every 2 seconds and averaging the values every minute, similar to the Solar Infrared Radiation Station at SGP.

During the 2003 Cloudiness Intercomparison field campaign at SGP, a sky-scanning IRT with a sample interval of 0.1 second was collocated with the production downwelling IRT, with a sample interval of 2 seconds. Results of the zenith measurements (Figure 1) suggested that the decorrelation time of the narrow, 2.6° field-of-view dictated a higher sampling frequency to capture the inherent variability under cloudy and partly cloudy conditions.

To prevent water from pooling in the lens, the downwelling IRTs are directed downward to a front-surface gold mirror that reflects energy from the zenith. At the central facilities, on-site technicians clean the instruments every day to make sure their optical properties are not compromised. However, because of the range covered by the extended facilities at SGP, they are visited only once every 2 weeks. This required a significant design modification to prevent contamination of the lens and gold mirror.

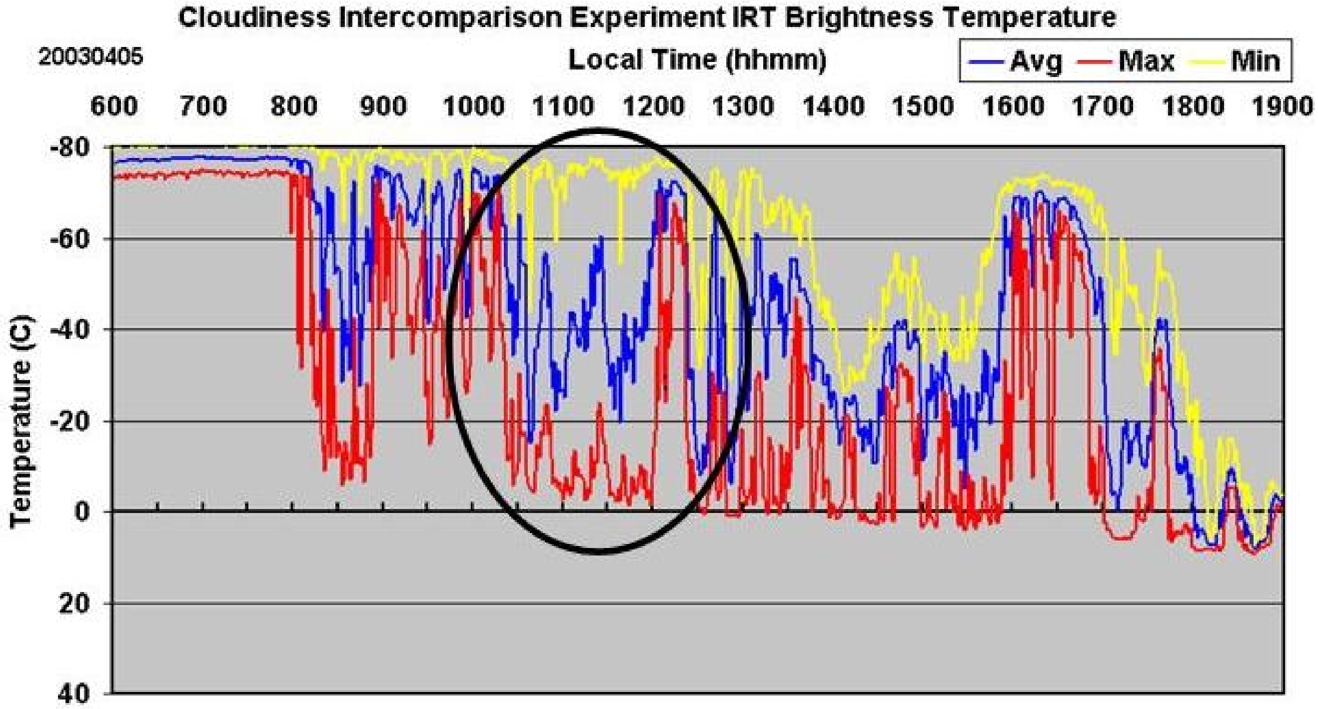


**Figure 1**. A time series of 1-minute average, minimum, and maximum IRT sky brightness temperatures during the Cloudiness Intercomparison field campaign. Results indicate that mean temperatures are difficult to interpret under cloudy skies. The study suggests a 5 Hz sampling strategy for clear/opaque cloud detection using conditional analysis.

## Mirrors

The gold mirrors previously used with the downwelling IRTs had a protective coating of silicon monoxide that proved to be inadequate in withstanding the environment and the necessary cleaning at the ARM sites. Several mirror options from different vendors were examined for durability, reflectivity, availability, size, and cost. Mirrors prepared at the Pacific Northwest National Laboratory (PNNL) with a more durable coating of silicone dioxide were tested at the Tropical Western Pacific site at Nauru, the site that had proven to be the harshest on the mirrors. The results of the test clearly showed (Figure 2) that the gold mirror with a protective coating of silicon dioxide was much more durable than those with the standard coating, even in the sea-salt environment of Nauru.

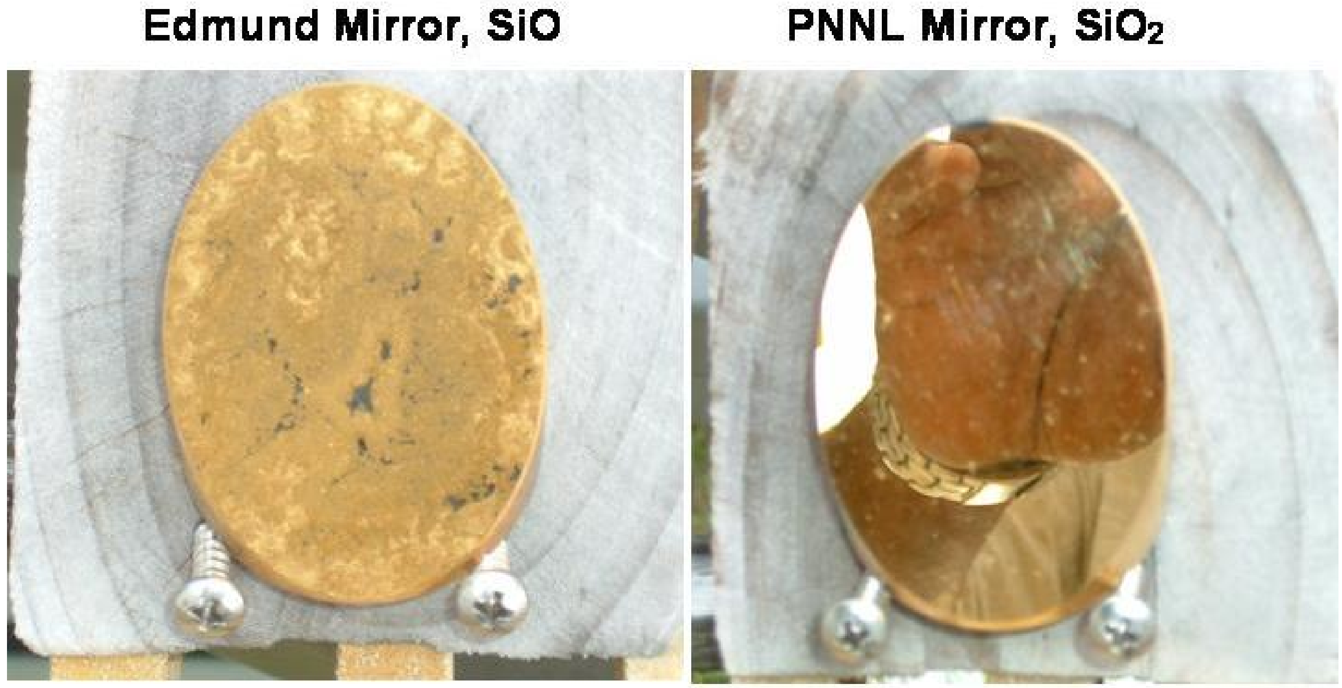


**Figure 2**. Photos of the standard gold mirror (left) with a protective coating of silicone monoxide and the same type of mirror coated by PNNL (right) with silicone dioxide. This shows the results of the mirror study after 10 weeks at Nauru. The operators cleaned the two mirrors in the same manner (water rinse only) and frequency (daily) as the SKYRAD IRT mirror.

## Cleaning System

Different methods were developed to address the issue of infrequent cleaning and were tested at the SGP guest instrument facility. One method was an automated mirror-washing system that was originally developed at PNNL for broadband radiometer domes, using an event timer, an automotive windshield washer pump, a small 3-CFM blower, and a 12-VDC power supply (Figure 3). However, problems arose with different cleaning fluids that were tested and the use of an alcohol/water mixture, needed to prevent freezing during the winter months, would have required an environmental impact study before deployment.

An alternate system using positive airflow was developed at SGP that uses a 29-CFM filtered fan, no cleaning solution, and fewer moving parts. This operational enclosure was selected for deployment to prevent contamination of the gold mirror.

**Figure 3**. A photo of the mirror washer system test and control units during development and acceptance testing at the SGP guest instrument facility.

## Data Acquisition

Analyses of the Cloudiness Intercomparison results suggest that a sampling rate of 5 Hz is sufficient to capture the variability in the narrow field-of-view. Furthermore, the IRTs have a serial output option that can provide, in addition to brightness temperature, measures of internal reference temperature and other diagnostic information. A bias in the measurement is introduced if the internal temperature is not maintained. Different methods of serial data acquisition were tested that included adding the IRT to the existing SIRS data logger, using an independent data logger capable of recording the serial output, and using commercial software that was compatible with the existing computer at each extended facility. Finally, a new data acquisition program was developed that is capable of logging the IRT serial data at a rate of 5 Hz. This system was tested for compatibility with the Linux© computers at the SGP extended facilities and selected for deployment.

## Deployment

The IRTs purchased for this deployment are a newer model than those currently used at the ARM Climate Research Facility with an extended temperature range to allow measurements of sky brightness temperature as low as -100°C (Table 1). The new IRT is housed in a steel enclosure to prevent contamination of the lens and mirror between the biweekly maintenance visits to the SGP extended facilities (Figure 4). Prior to deployment, fourteen of the new, extended-range IRTs were compared with each other and with the Atmospherically Emitted Radiance Interferometer (AERI) at the SGP central facility (Figure 5).

| **Table 1**. Specifications of the ARM Infrared Thermometer | |
|---|---|
| **Instrument** | **Heitronics KT19.85II Infrared Radiation Pyrometer** |
| Spectral response | 9.6 to 11.5 μm |
| Temperature measuring range | 173 to 473 K |
| Temperature resolution (emissivity – 1, response time-0.1s | ±1.85 K At 223 K |
| Accuracy | ±0.5 K |
| Optical field of view (f-120 mm) | 2.64 |
| Sample rate | 5 Hz |
| Operation temperature range | -20° to 60°C |

**Figure 4**. Photos of the IRT at SGP extended facilities (EF)15 showing the system from both inside and out. A filtered fan pressurizes the enclosure, with venting through an open port in the top of the enclosure. The IRT views the sky through this port with the aid of a gold mirror. The air circulation keeps moisture and dust from building up on the mirror surface.

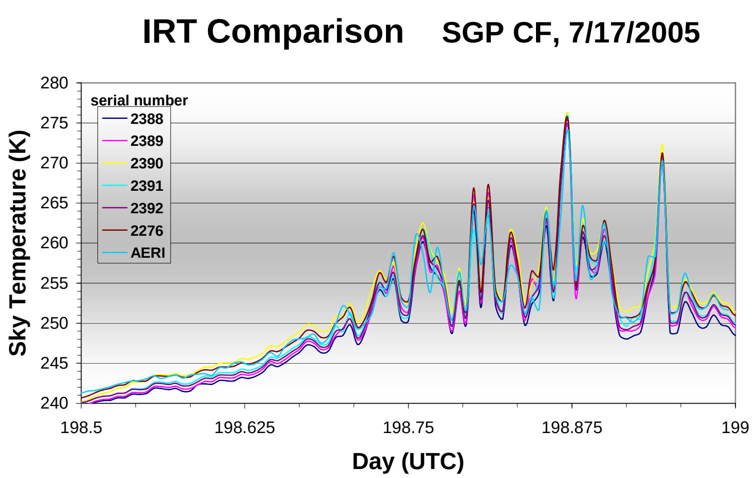


**Figure 5**. A time series of measurements by six of the new IRTs that were intercompared with AERI prior to deployment.

To ensure adequate coverage of the SGP domain throughout the installation schedule, IRT deployments have been carefully selected among the EF to eliminate “clustering” effects (Figure 6). This plan helps to minimize large gaps in the coverage area until the balance of the IRTs can be installed. The first field deployment occurred in May 2005 at EF15 because of its proximity to the central facility. Following a short period for system testing, development of the data object design, and data quality review, additional IRT systems were installed in August 2005, first at EFs 5, 8, 10, 16, and 20 and then EFs 6, 7, 9, 11, and 19. Integrated data collection began in November 2005, with information soon flowing to the ARM Data Archive. In January 2006, an IRT was deployed at EF13 to replace the existing system at CF1. Deployment at the remaining EFs is planned to begin in 2007.

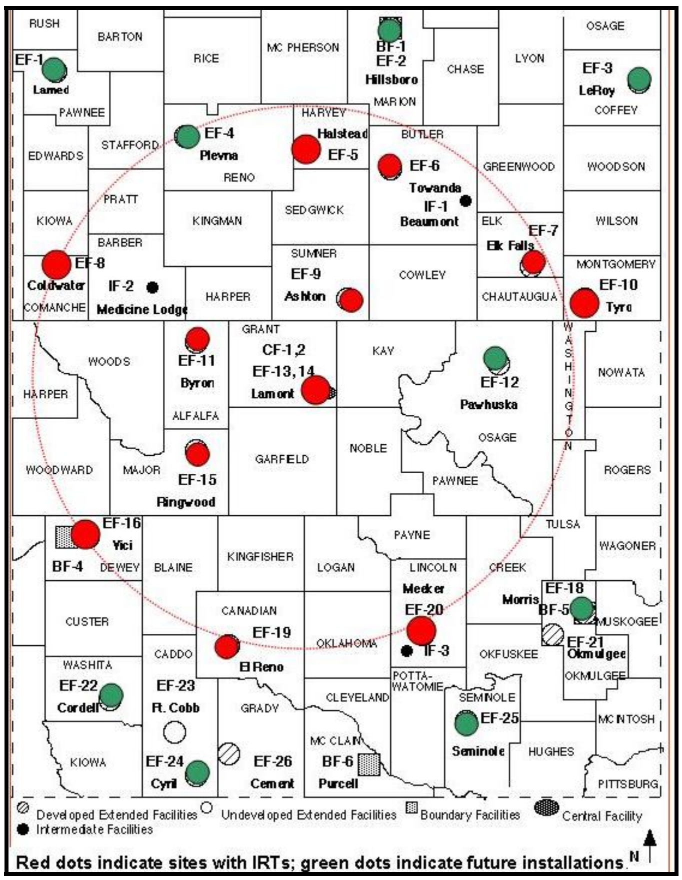


**Figure 6**. A map of the SGP Climate Research Facility denoting extended facilities with the new IRTs installed (red) and locations of future installations (green).

## Cloud Temperature Detection

Conditional sampling of the data, based on an evaluation of 2-second running standard deviations of the 5-Hz samples and the analysis of 1-minute frequency histograms (Figure 7), can detect periods of clear-sky and opaque clouds. A methodology has been produced to approximately remove the contribution of water vapor in the intervening atmosphere to infer radiating temperatures of three cloud layers

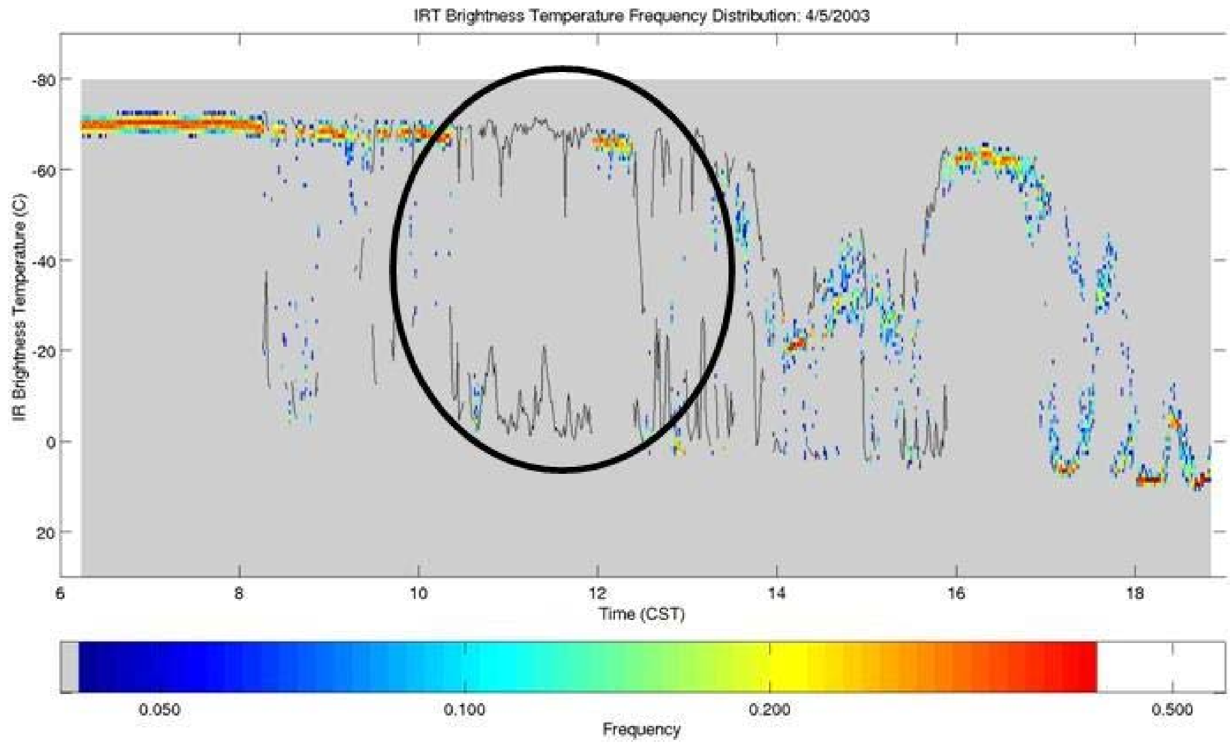


**Figure 7**. A histogram demonstrating conditional sampling of the IRT sky brightness temperatures.

(Figure 8). The cloud radiating surface height can be estimated by an empirical relationship with optical thickness and radiating temperature. These estimates agree well with direct measurements of the cloud height by other instruments (Figure 9). The longwave effective sky cover can be inferred by adapting the methodology of Takara and Ellingson (2003) that uses equivalent AERI and broadband longwave data. The data from the IRT network also enhances existing surface and satellite cloud measurements and increases the possibility of calculating broadband heating rate profiles at the EFs.

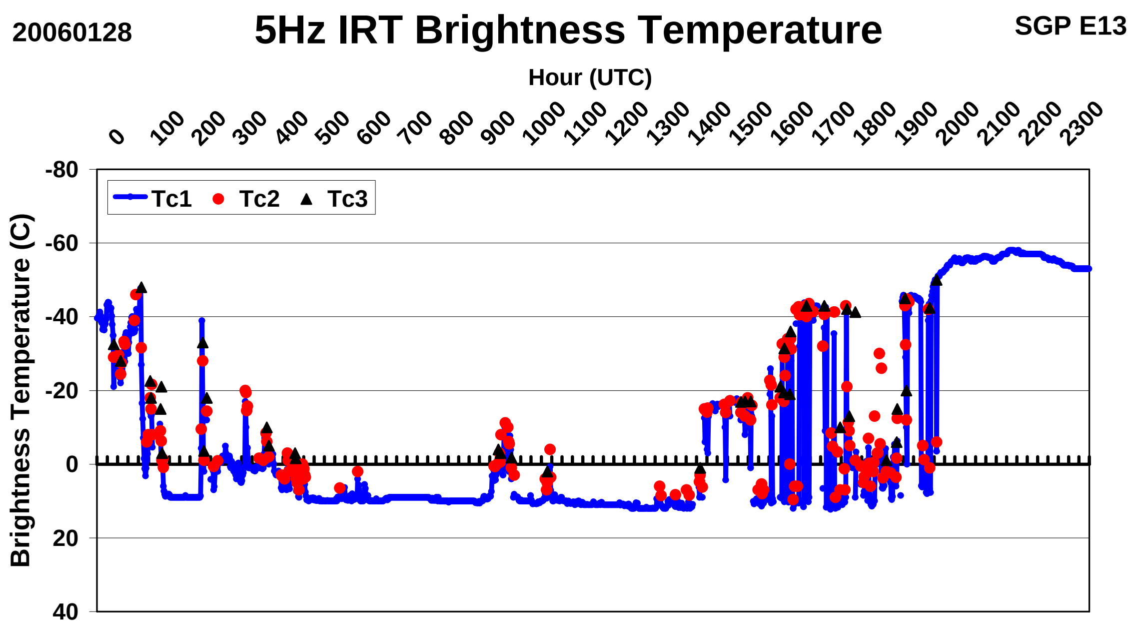


**Figure 8**. A time series of cloud temperature detection of low (blue), middle (red), and high (black) cloud layers.

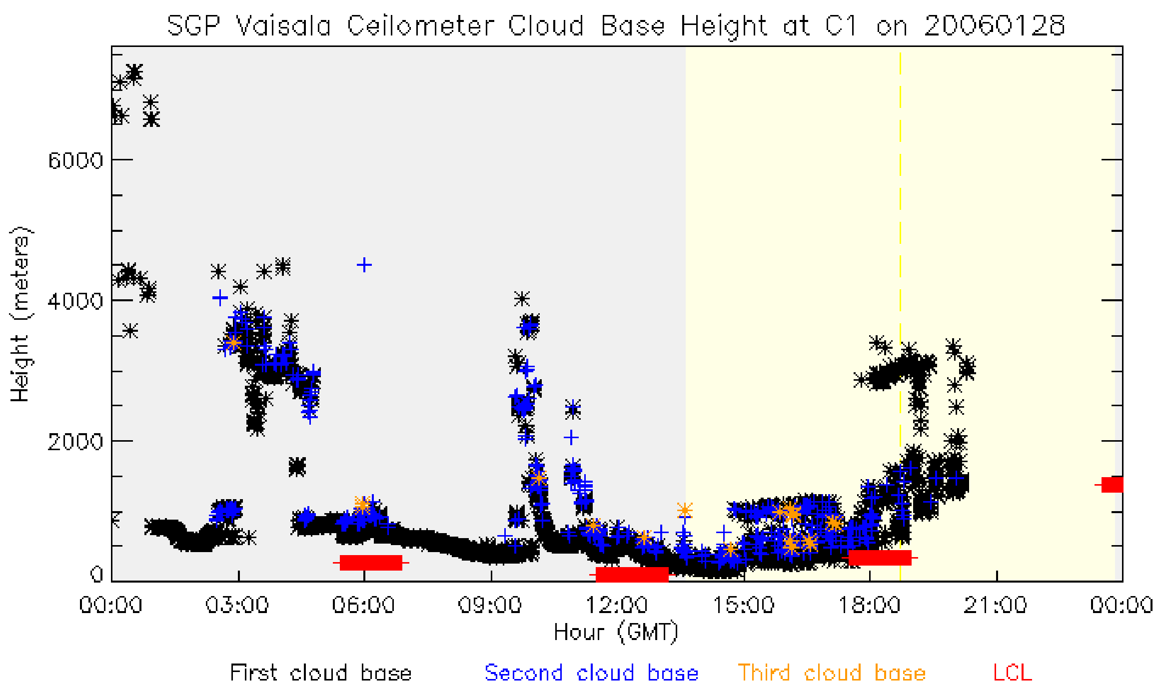


**Figure 9**. A time series of low (black), middle (blue), and high (orange) cloud heights measured by the Vaisala Ceilometer for the same day as the previous figure.

## Summary

To increase our ability to study the cloud and radiative variability on the scale of global climate models, a network of IRTs is being installed throughout the SGP site for the purpose of measuring cloud base temperature and estimating cloud base height across the domain. Twelve extended-range IRTs have been deployed, enclosed in a positive airflow system to keep the IRT mirror surface clean and free of dew or frost, thereby providing more accurate measurements. A serial data acquisition program was developed to obtain sky brightness temperature measurements at a rate of 5 Hz, compared to 1-minute averages of 2-second samples produced with the IRTs at other sites. This sample rate allows the IRT network to more accurately capture the variability under cloudy and partly cloudy conditions across the SGP domain. Additionally, data ingest and post processing codes were developed, including a methodology to account for the intervening atmosphere below the cloud to infer cloud effective brightness temperatures. These measurements will enhance existing SGP surface and satellite cloud measurements to help improve calculations of heating rate profiles.

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