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Simultaneous Lidar and All-Sky IR Camera Observations to Measure Cloud Transmission

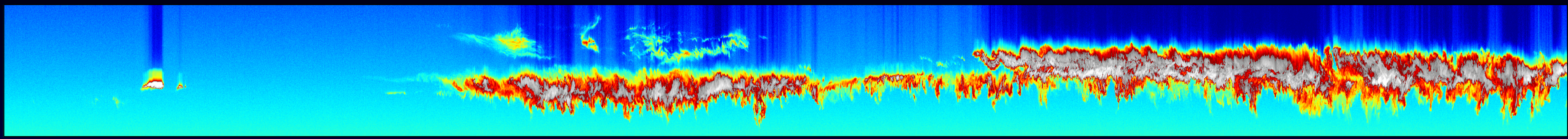


Figure 1 (above) - Raw return from ALE's long range receiver on the night of Oct. 24, 2010 showing cirrus clouds building over Albuquerque. Each pixel horizontally spans one 0.66s scan and vertically one 3.75m range bin.

Figure 2 - A picture of the UNM Campus observatory shown during the combined observing campaign. The large dome on the left houses ALE, the smaller dome to the right houses a small wide-field photometric telescope and the ASIVA camera system is the small gray box behind and between the two domes.

ALE - Astronomical LIDAR for Extinction

ALE is an eye-safe, 527nm micropulse LIDAR on an alt/az mount designed for unattended operation in an astronomical observatory environment. ALE will provide real-time continuous monitoring and precise quantitative measurements of the amount and sources of atmospheric extinction, *e.g.* low-lying aerosols, dust or smoke in the troposphere, or high cirrus.

ALE's 0.3m beam expander transmits 80µJ pulses at 1500Hz into the atmosphere along sensibly the same optical path as the telescope it is supporting. Molecules, aerosol particles and cloud droplets and crystals all scatter and absorb the transmitted light, some of which is scattered back at ALE where it is captured by the 0.67m long range receiver telescope and 100mm short range receiver.

The light received by ALE is collected by photomultiplier tubes, the signals of which are measured both by a photon counting system (high precision measurements at long range) and high-speed digitizer (high speed measurements at short ranges). The combination of these two measurement systems on each of the two receivers allows simultaneous high-precision measurement of aerosols in the boundary layer (200+ m) and Rayleigh scattering from the stratosphere (20+ km) and everything between.

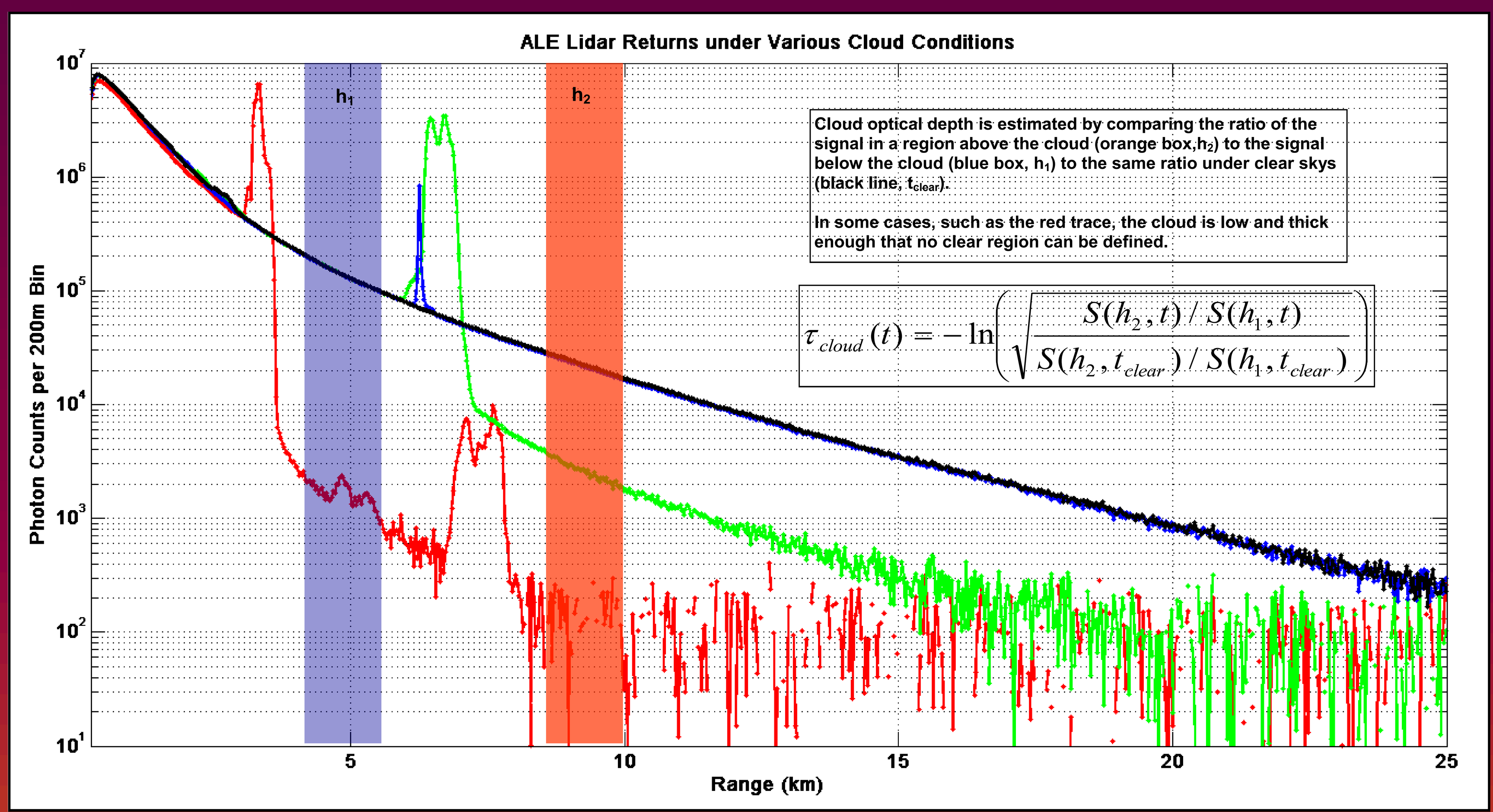


Figure 7 (above) - Example lidar scans from ALE's long range photon counting channel under various levels of cloud cover, corresponding to the same examples shown in Figure 8 respectively. The black trace was taken early on the night of Oct 24, 2010 and is typical of very clear conditions. The blue trace shows the very first cirrostratus forming, corresponding to the little cloud on the far left of Figure 1, with a visible OD of ~0.0025. The green trace shows increased cloud thickness with OD of 1.15, corresponding to the clouds to the right of Figure 1. The red trace shows several cloud layers from Oct 23, 2010 that are essentially opaque, the lowest level alone with OD > 3.

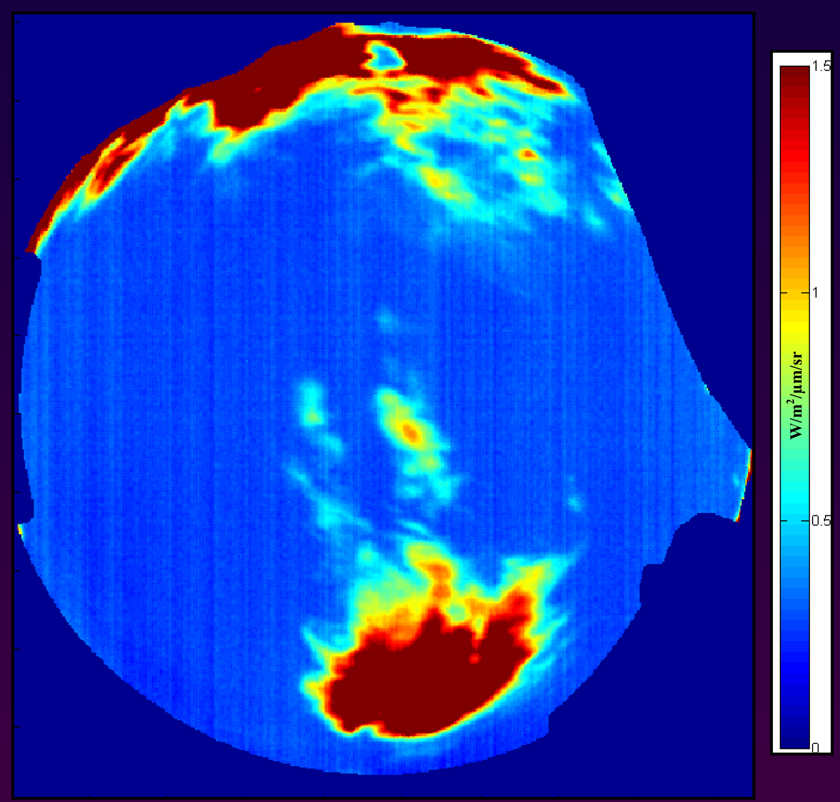
Figure 9 (below) - Pretty picture of dispersing cirrus clouds over Albuquerque on Nov 17, 2010. Ooooooh! Ahhhhhh!

Cloud Thermal IR Radiance and Visible Optical Depth

Thermal IR observations in the 10 micron window have long been used at observatories to detect the presence of clouds by measuring the contrast in downwelling thermal radiance between clear and cloudy sky. The ability of these techniques to measure thin cirrus at high altitudes, the sort of clouds that typically ruin otherwise photometric conditions, has always been limited by the low temperatures and the low emissivity of ice crystal clouds at high altitudes.

Lidar, on the other hand, is quite effective at measuring both the presence and optical depth of thin cirrus clouds, well below 1% transmission losses. A lidar can only operate in one direction at a time and thus is limited in its ability to measure transmission over wide fields of view.

To test this instrumental combination, the ASIVA all-sky infrared camera has been deployed since the end of October 2010 at the UNM Campus Observatory in Albuquerque, NM, the location of the Astronomical Lidar for Extinction (ALE). The two instruments were operated together under varying amounts of cloud cover and when observing conditions permitted.



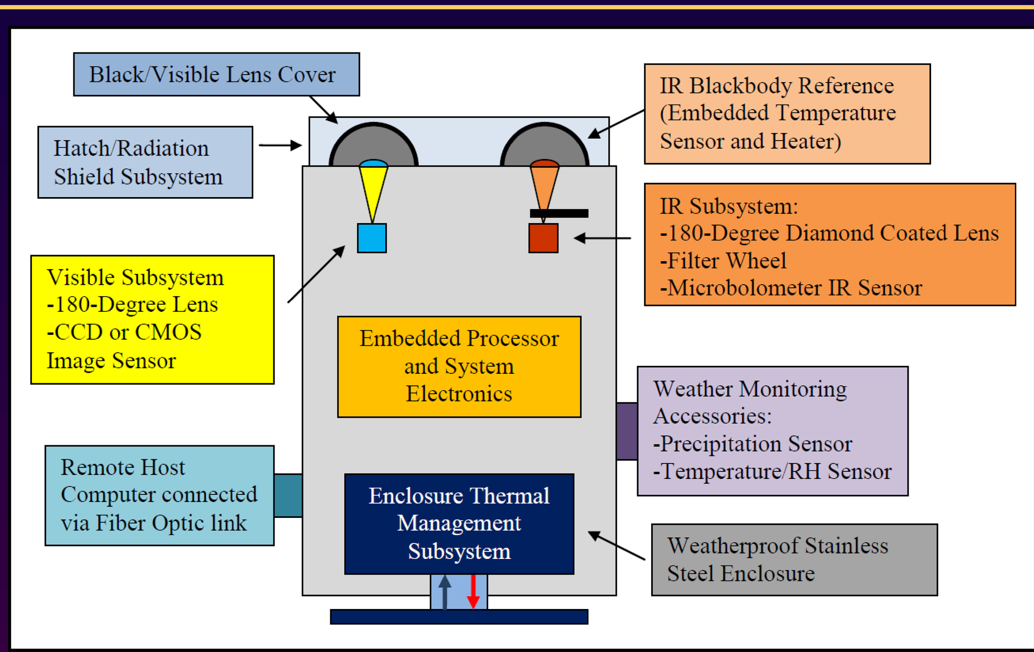
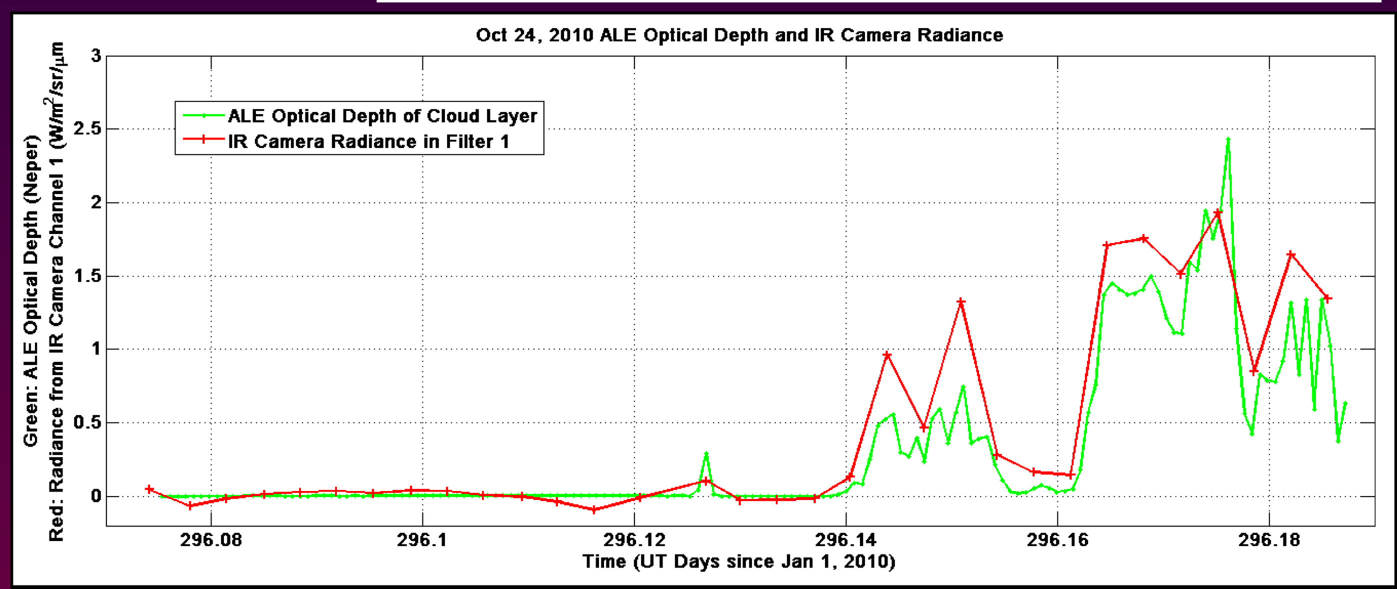
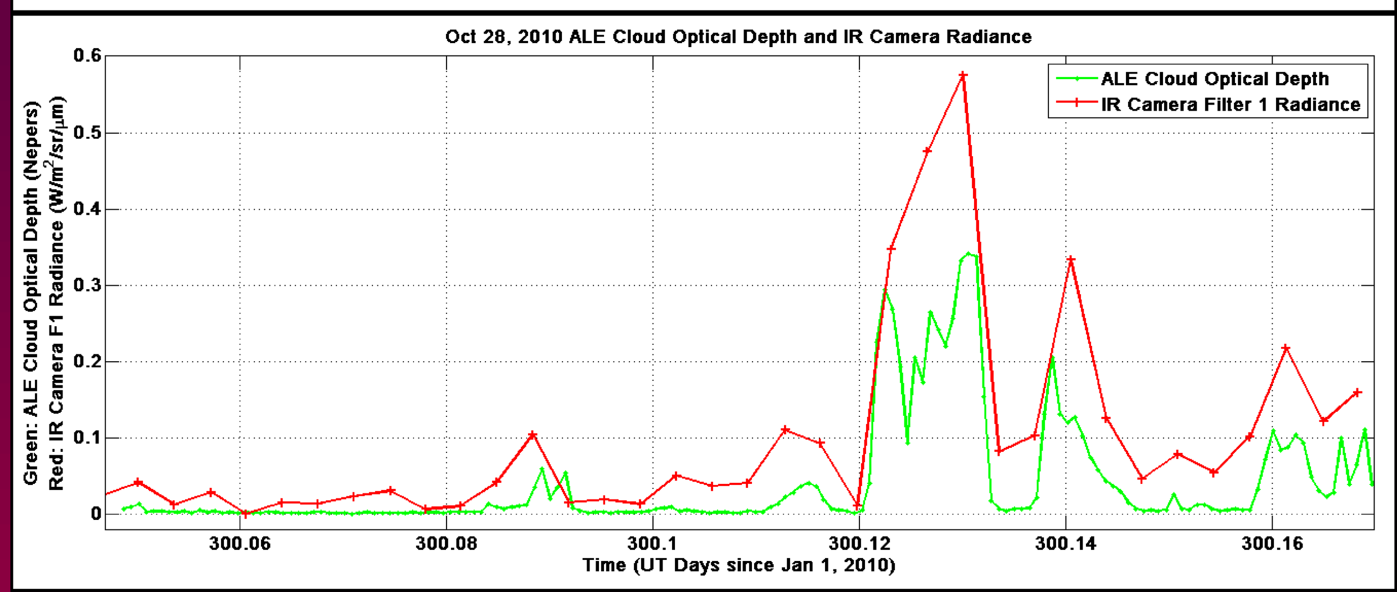


Figure 3 (left) - An image under clear conditions has been subtracted from a cloudy image. The thinnest clouds near zenith have lidar measured optical depth ~0.01 (i.e. a 1% transmission loss).
Figure 4 (above) - Block diagram of ASIVA system.

Figures 5 & 6 (right) - Zenith radiance measured by ASIVA is compared to ALE measured visible cloud optical depth. These two quantities should be proportional, though the exact relationship depends on cloud temperature, droplet size and phase and the intervening water vapor, which also emits in the 10 micron region.





Thermal Sky Imagery and Lidar Together

Cloud location and optical depth affects the operations of both small telescopes and large surveys. Thermal IR cameras continue to become cheaper and more readily available. Lidar systems considerably smaller than ALE can detect the presence of clouds with transmission losses of <0.1%. Thus, the two can be deployed affordably to characterize and optimize the observing environment.

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Special thanks to the 2010 Optics and Instrumentation class at UNM for braving the cold winter weather to obtain these data.

Figure 2 - ASIVA deployed at the UNM Campus Observatory for the test campaign. The left panel shows the unit with its weatherproof lid closed. The upper right shows the lid open, exposing the visible (above) and infrared (below) fish eye lenses. The cover houses two calibration screens shown bottom right, the left screen provides a dark reference for the visible image and the right a temperature controlled blackbody calibration source for the infrared camera.

ASIVA– All-Sky Infrared and Visible Imager

ASIVA is a multi-purpose autonomous visible and infrared sky imager designed for both astronomical and meteorological monitoring built by the Solmirus Corporation and purchased by LSST to evaluate the utility of IR and visible all-sky imagery to inform the scheduling process.

The infrared imager is built around a FLIR Photon 640 uncooled VOx microbolometer core, with 512 x 640 - 25 µm pixels with a NETD of 50mK at its nominal 30Hz frame rate. The fisheye optics are a custom built diamond coated germanium lens system with a 5.9mm focal length (f/1.4) and yield a 180 degree diameter image circle which fits entirely on the detector. A six position filter wheel allows the selection of bands to isolate emission from various atmospheric components (cloud, H_2O, O_3). For the results reported here, only the data acquired in the 10-12 micron band is used. The video frames are acquired digitally via the 14-bit LVDS output and co-added into sets of 8 - 1.6s frames. ASIVA provides several data products, including sky radiance, difference and r.m.s. images to detect cloud motion and evolution, and sky quality products.

Both cameras are covered by a movable lid, shown above in Figure 2, that provides protection from elements when not in use and a calibration source. In between sets of measurements, ASIVA measures the signal obtained from looking at the blackbody calibrator, the temperature of which is measured via three RTDs. Long term calibration and stability can be monitored by active heating of the blackbody and measuring the resulting radiance image.

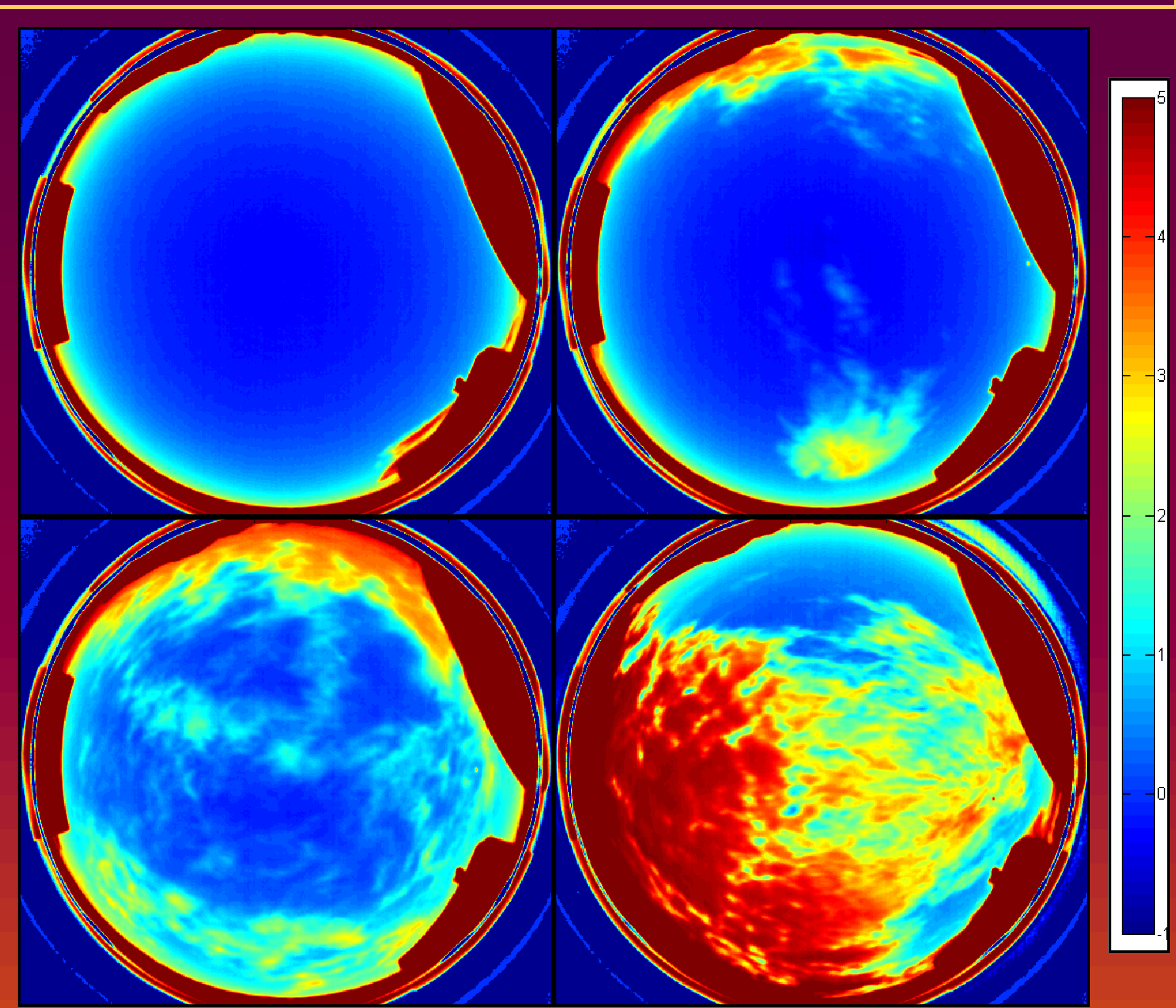

Figure 8: Example all-sky IR images taken with the ASIVA under varying cloud conditions showing irradiance in W/m²/µm/sr. The upper left shows a typical clear sky image followed by images of increasing clouds of the night of Oct 24, 2010, also depicted in Figure 1. See Figure 7 for corresponding lidar data.