Sky Monitoring Techniques using Thermal Infrared Sensors

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Atmospheric Monitoring

- The atmospheric channel has a great impact on the channel capacity at optical wavelength due to
  - Cloud Blockage
  - Atmospheric Absorption
  - Day Time Sky Radiance
  - Atmospheric Turbulence

Atmospheric monitoring for Ka-band propagation
can have interest in the techniques
utilized for the characterization of the optical channel itself

Monitoring the Atmospheric Optical Channel

- The JPL optical comm group is conducting an Atmospheric Monitoring Program at Table Mountain Facility (TMF) in Wrightwood (CA) consisting in the deployment of a number of sensors for
- Atmospheric Transmittance Monitoring
  - Atmospheric Visibility Monitoring (AVM) for the day/night time monitoring of stars' irradiance flux.
    - Multiyear Effort
- Daytime Atmospheric Transmittance and Sky Radiance Monitoring
  - CIMEL sun-photometer: to be included in the worldwide AERONET program.
  - Ready to be deployed starting April-06

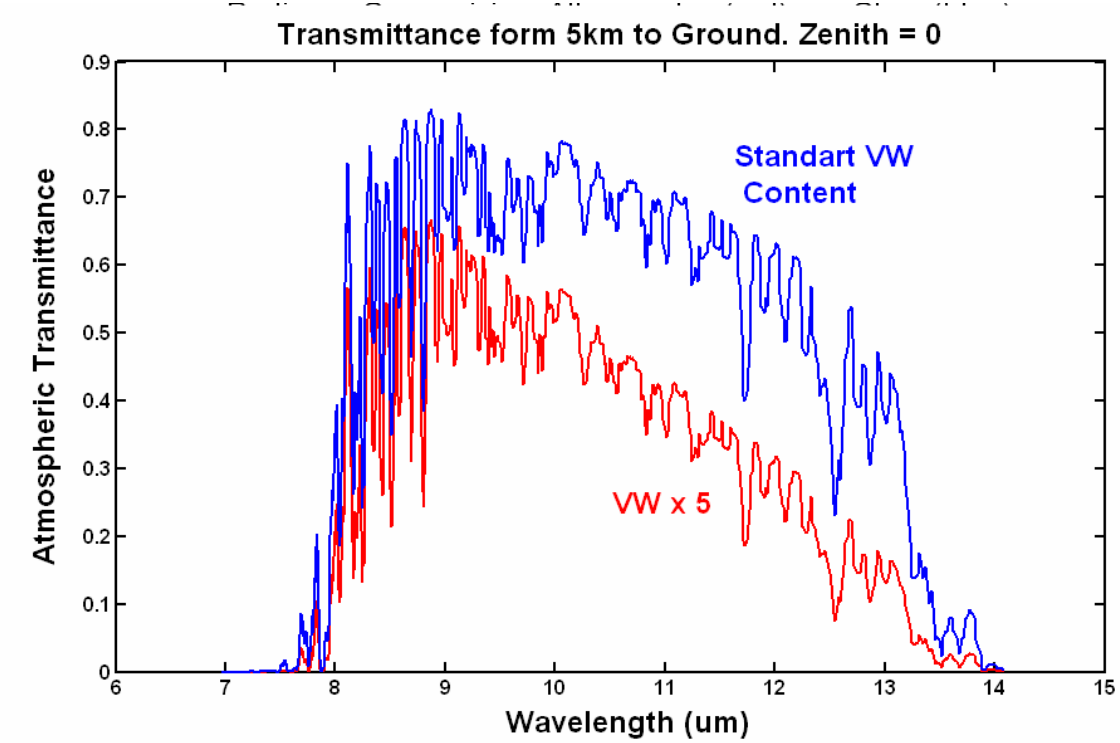
Monitoring the Atmospheric Optical Channel

- Atmospheric Turbulence monitoring
  - DIMM-MASS system, for the characterization of the atmospheric coherence length (r_o) and the profiling of the refractive index structure parameter (C_n^2).
  - At low elevation, turbulence effects (fading) must be taken into account at Ka-band.
  - Ready by April 2006

- Cloud Monitoring and Statistics
  - All sky visible camera system: already operational since January 06. Operational only Daytime.
  - **<u>Other (night/day) thermal infrared camera: to be deployed starting June 06.</u>**

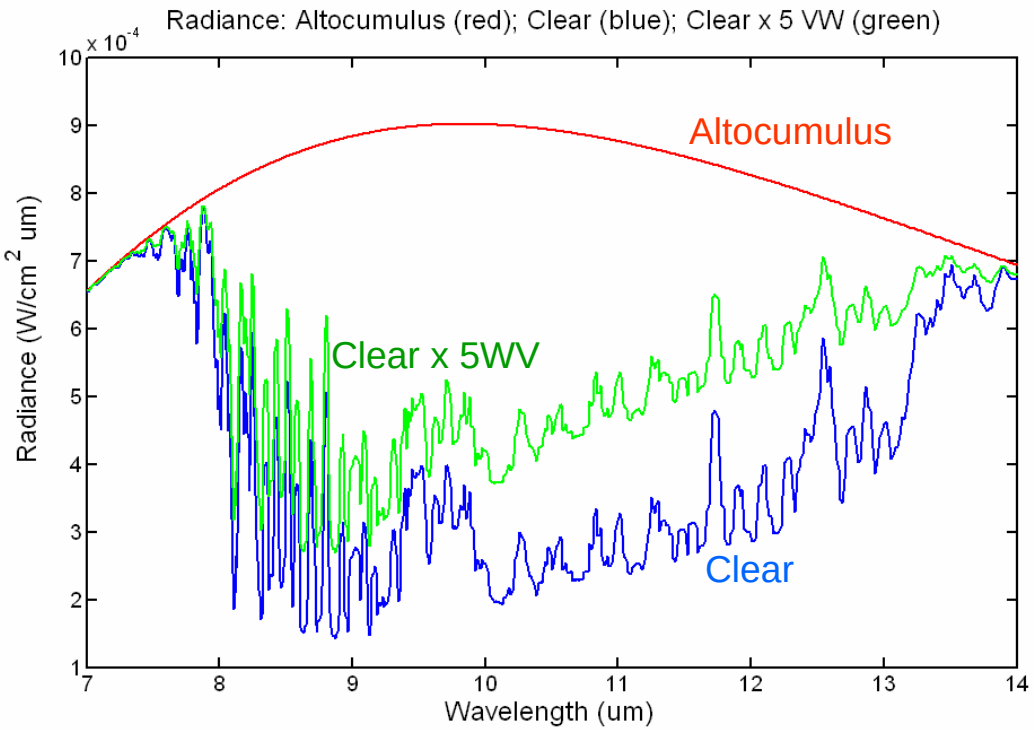
Atmospheric Transmittance

- The atmospheric transmittance is relatively high in the infrared band.
- In the 8-14 μm bandwidth, the transmittance is relatively unaffected by aerosols. The main factors is given by the water vapor content and ozone (above the troposphere).
- Serendipitly, the 7-14 μm bandwidth is an operation range for a number of commercially available uncooled microbolometer camera.



Thermal Infrared Sky Radiance

- The sky radiance in the thermal infrared band is dominated by the self thermal emission of the atmosphere instead the sun light related scattering: Independent of day/night measurements
- Thermal emission from Clouds is a high contrast signature day and night over the sky.
  - The contrast is lessened by water vapor emission in the atmosphere.
- Contrast in the emission of the atmosphere can be easily measured by today uncooled microbolometer camera
  - **PHOTON OEM by FLIR to be used at TMF**
- Estimation of the cloud emission can lead to information on cloud height, water vapor, and nature.



Photon OEM Camera

•Recent introduction of high performances and low cost thermal infrared camera models suggested their use for sky monitoring

Benefits

- Excellent Uniformity and Dynamic Range Across a Wide Operating Temp Range (-40°C to +75°C)
- 2X Digital Zoom Enables Close-Up Imaging and Electronic Pan/Tilt in Zoom Mode
- External Sync Input Allows Control of FPA Integration Start Time
- 2-second Turn-On Time for "On-Demand" Applications
- Better Detection and Recognition Ranges
- Fully Integrated Design Supports OEM as Well as Commercial Camera Customers & Applications
- New Digital Data Enhancement (DDE) Sharpening Filter Brings out Detail in Image Data

No Thermo-Electric Cooler (TEC) Required

Photon employs a singular combination of on-focal-plane circuitry and non-uniformity compensation (NUC) processing to eliminate the TEC. The unique approach to TEC-less operation enables the camera to operate over a wide temperature range while maintaining excellent dynamic range and image uniformity. Two significant benefits are realized from TEC-less operation: Reduced power consumption and a near "instant-on" capability.

Photon OEM Camera

Detector	Uncooled Microbolometer	Vanadium Oxide (VOx)
Array Format: Block 2	320x240	160x120 "zoom" mode available
Block 1	320x120	
Pixel Size	38 µm	
Spectral Response	7.5 to 13.5 µm	Longwave Infrared (LWIR)
Video Output	NTSC	PAL Optional
Digital Data	8-bit Serial LVDS or 14-bit Serial LVDS*	Real-time, corrected bad pixel replaced (*pre-AGC)
Frame Rate	30 Hz (320x240) 60 Hz (320x120)	25 Hz PAL 50 Hz PAL
NEdT (subject to export license restriction)	< 85 mK @ f/1.6	Equivalent to 35 mK at f/1.0
Normalization Source	Internal Shutter (Offset Only)	0.7 sec video freeze during shutter wink
Time to Image	< 2 sec.	No Thermoelectric Cooler (TEC)

Extensive Video Processing Capabilities

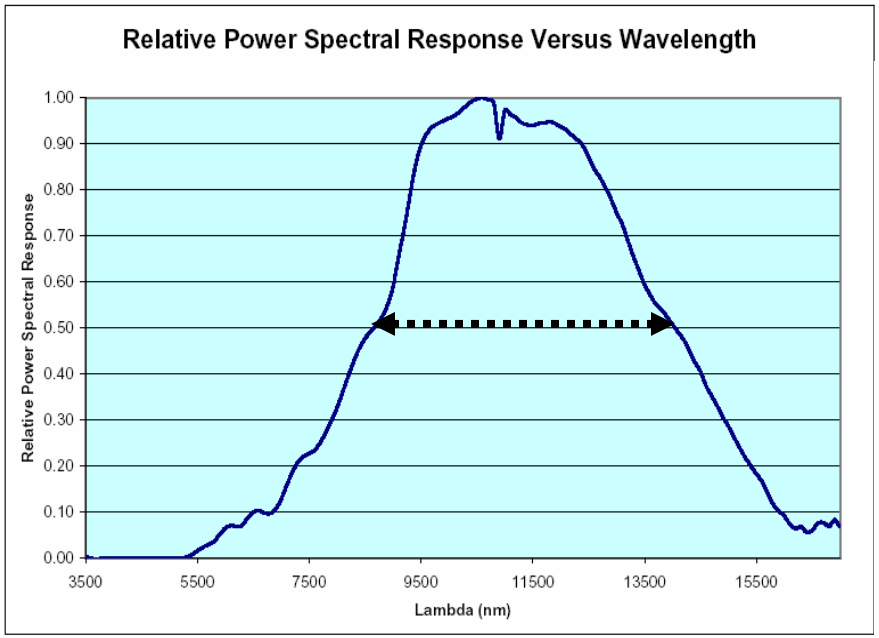
Photon supplies NTSC analog video at 30 fps as a standard. PAL video (25 fps) is available as an option. A choice of 8- or 14-bit digital video is output simultaneously with the analog format. The digital data protocol is serial LVDS.

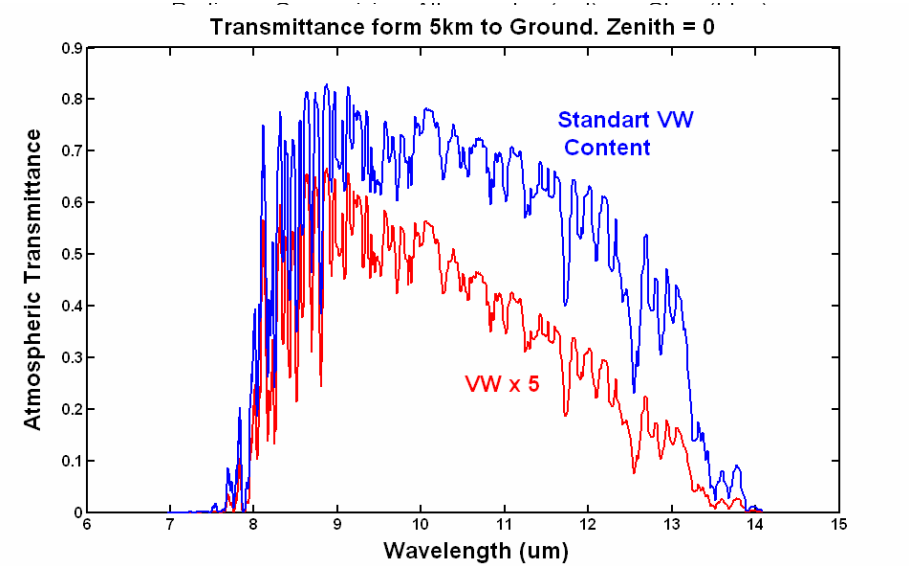
Video processing features include multiple automatic, dynamic image optimization algorithms, as well as polarity control (white-hot/black-hot), image-orientation control (invert / revert), and freeze-frame capability. New to Photon is a 2X digital zoom feature, whereby the center 160x120 of the FPA is upsampled to the full 320x240 image resolution. Color look-up tables are also supported.

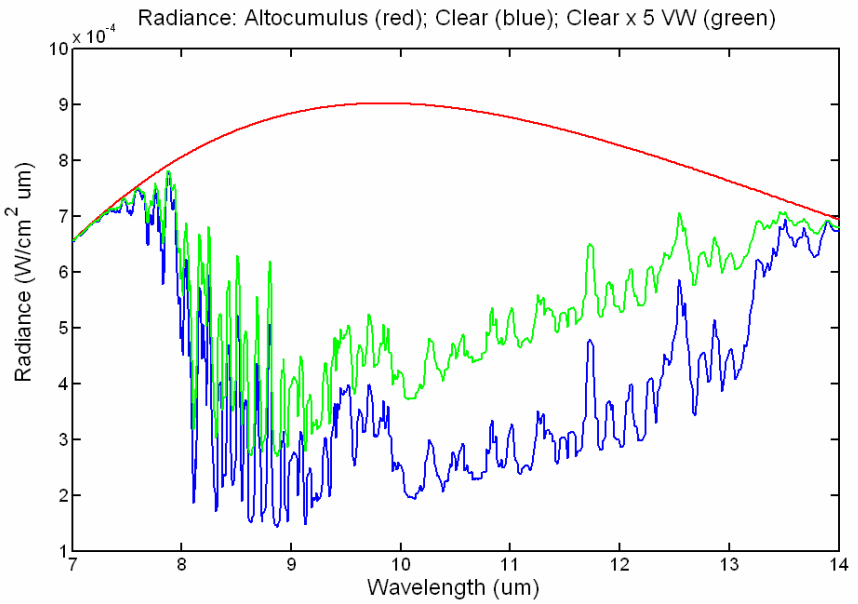
Future options:
Ethernet digital out protocol, to facilitate remote programming and retrieving of the images via internet.

PHOTON OEM Spectral Response

The PHOTON OEM spectral response matches perfectly the atmospheric window



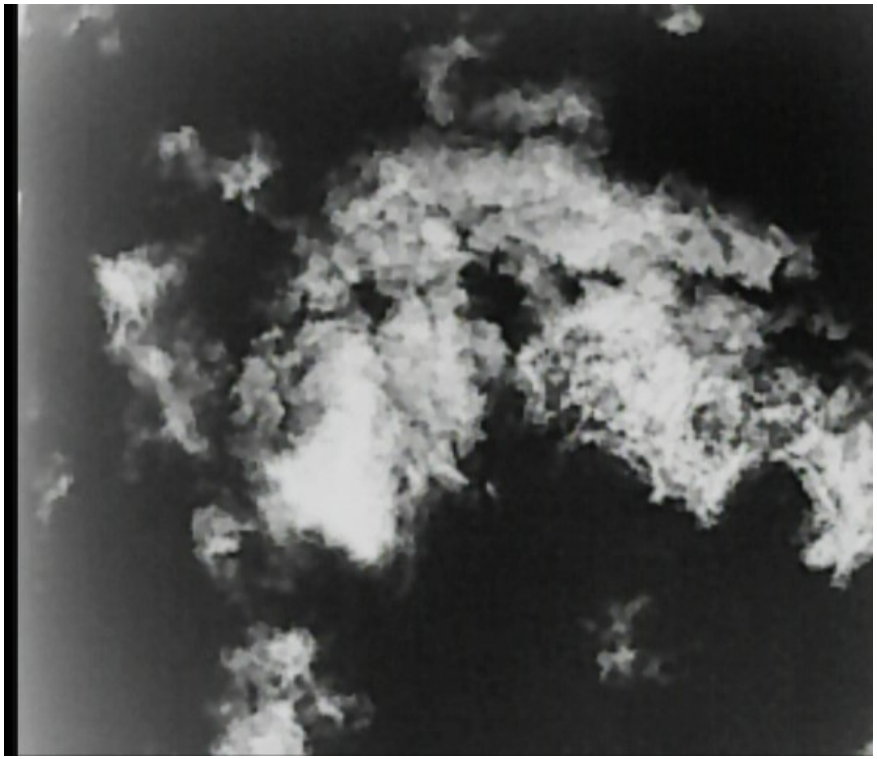


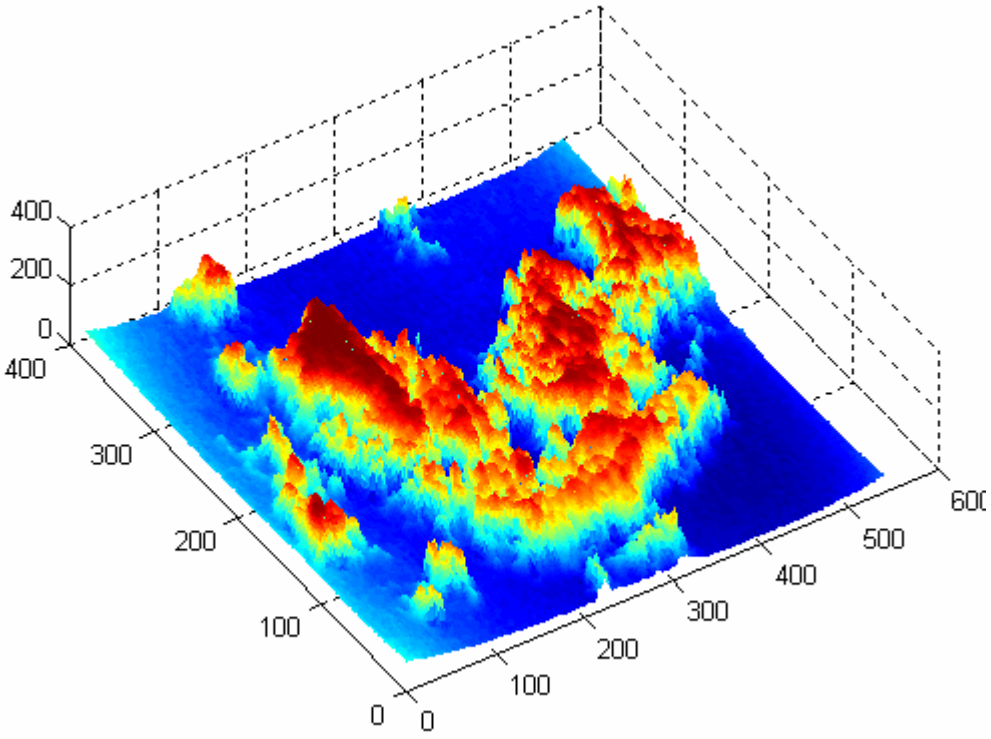


Thermal Infrared Monitoring Program at TMF

- Ordered Photon OEM with 50 Degree FOV optics.
- Collaboration with University of Montana (Professor Joseph Shaw) for the Calibration and software that controls the processing of the digital data.
- June 2006 will be deployed at TMF for first data collection
- The data will be compared with another all sky camera existing at TMF (visible range).
  - Knowledge of the atmospheric water vapor will increase the accuracy of the measurements.
- Future Programs:
- To expand the optics towards larger FOV (~ 100 Degree or more)
- Cloud Prediction Algorithm.
  - To predict the cloud pattern along an hypothetical line of sight.
- Cloud structure determination
  - From the study of the cloud emission to determine cloud structure and heights.
- An Instantaneous by product: AIR TRAFFIC CONTROL
- Possible deployment at DSN location?

PHOTOM OEM 8 Bits Output: 3 PM at JPL



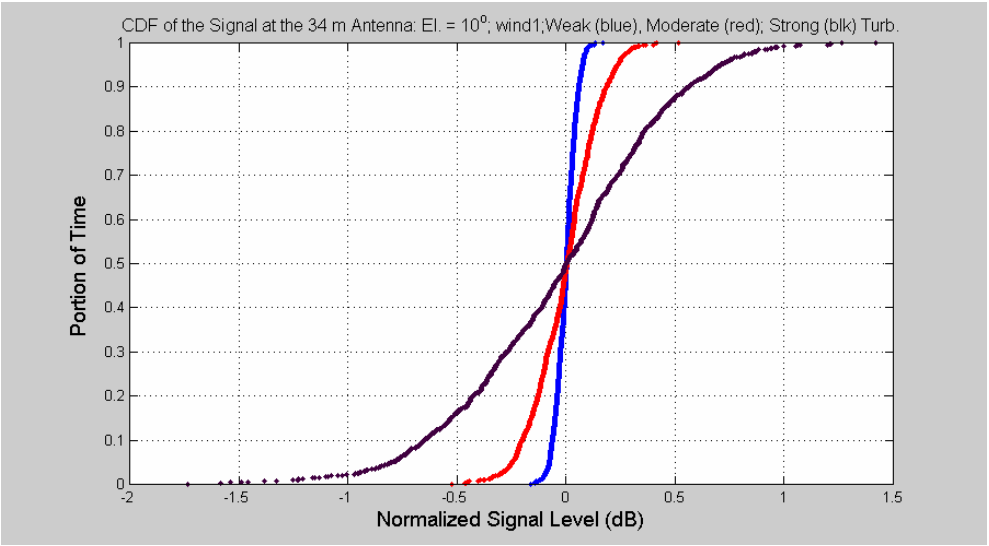


Conclusions

- Low cost, uncooled microbolometer cameras can be an effective sensor for the for the radiometric measurements of the sky.
- JPL Optical Comm is collaborating with University of Montana to deploy an uncooled microbolomet at TMF for to characterize cloud coverage of the sky using low cost thermal infrared camera.
- Among the expected results: real time characterization of the cloud coverage, cloud prediction, cloud coverage statistics, and cloud nature estimation.
- The sensor will be remotely running 24/7 and will provide real time information.

Fading Statistics: Downlink for a 34 m Antenna at 38Ghz

El. 10^{o}; w(0)= 5.5 m/s



El. 20^{o}; w(0)= 5.5 m/s