AMVs from ATSR2-AATSR and MISRlite (Multi-angle Infrared Stereo Radiometer) constellation for ESA Earth Explorer call

Jan-Peter Muller, Dave Walton, Daniel Fisher*

**jpm@mssl.ucl.ac.uk*

Head, Imaging Group
Director UK NASA RPIF
Professor of Image Understanding and Remote Sensing
HRSC Science Team Member (ESA Mars Express 2003)
Stereo Panoramic Camera Science Team Member (ESA EXOMARS)
MODIS & MISR Science Team Member (NASA EOS Project)
TerraSAR-X and TANDEM-X science team member (DLR-Astrium)
Point-of-Contact, GEOSS Task DA-07-01 and DA-09-03d
Chair, ISPRS WG IV/6 on "Global DEM Interoperability" (2006-2010)
Chair, CEOS-WGCV "Terrain mapping from satellites" sub-group (2001-)
Chair, UK JISC Geospatial Working Group (2002-2010)
Chair, STFC AURORA Advisory Committee (2010-2013)

Overview

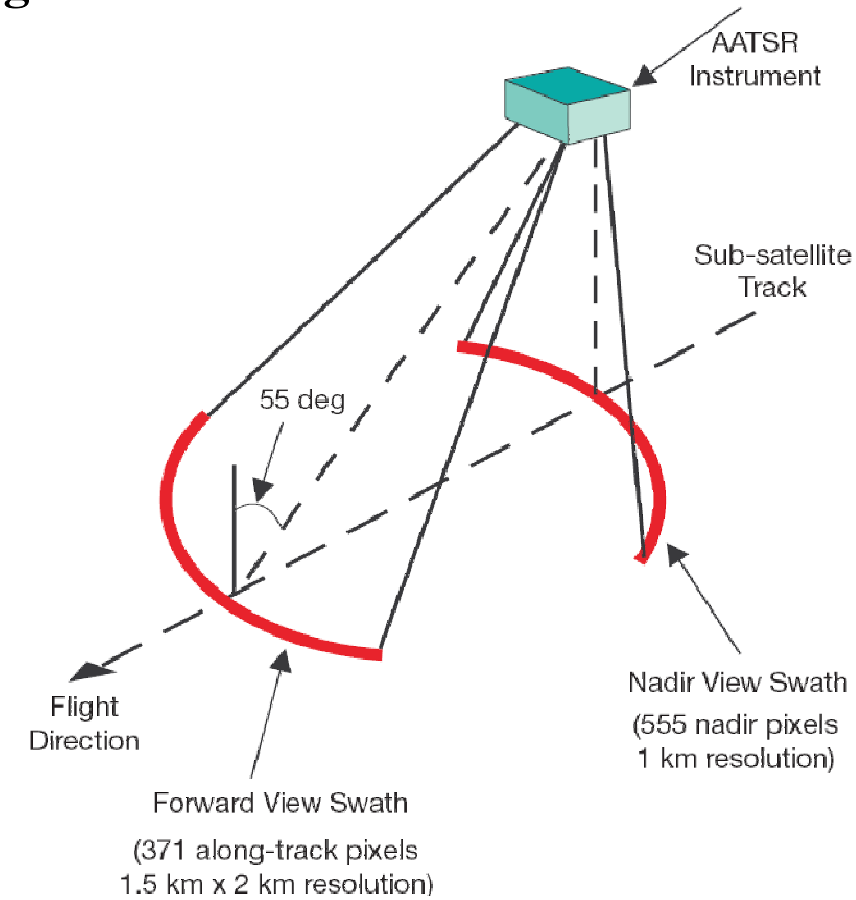
- **Why stereo?**
- **(A)ATSR(2) cloud-top heights**
- **ATSR2-AATSR tandem for AMVs**
- **MISR CTH and AMVs**
- **MISRlite for WINDS for the ESA EEO8 Call**
- **WINDS/MISRlite for EEO8 - support requested**

Why stereo retrievals?

- **Does not rely on external data such as objective analysis T-P profiles**
- **Or assumptions on cloud emissivity**
- **Or accurate thermal radiometric calibration**
- **Technique entirely geometric, relies on accurate pointing information and a robust pattern recognition technique to find corresponding features**
- **Is there a catch?**
- **Need to derive cloud-top winds, preferably using data from the same instrument**
- **Need very accurate information on pointing vector for the imaging instrument**

Heritage: Along-track Scanning Radiometer (ATSR)

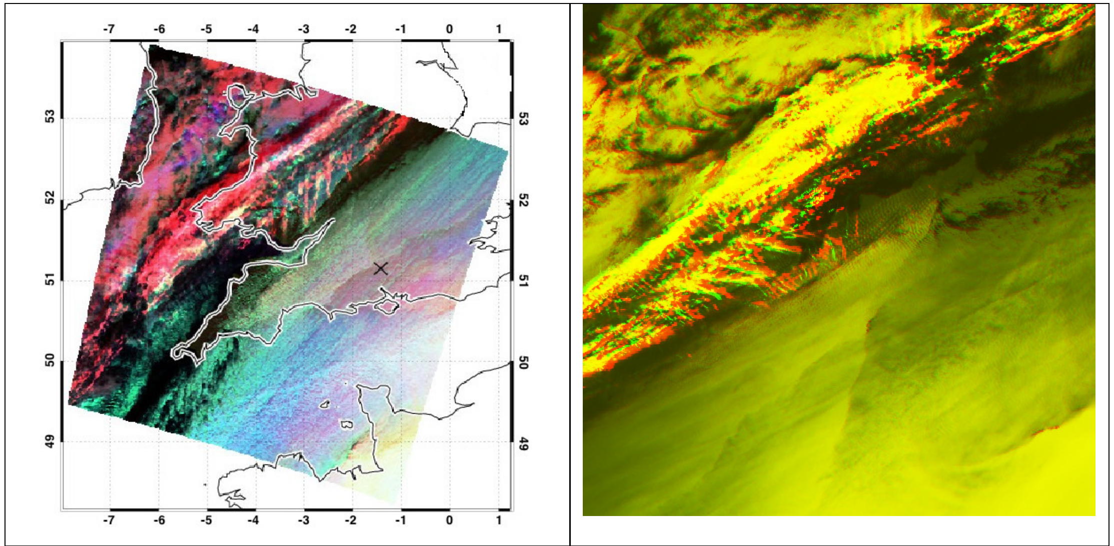
- **Monitoring and detecting climate change**
  - **Sea and Land Surface Temperatures**
  - **Vegetation**
  - **Fire Monitoring**
- **On-board (thermal) calibration**
- **Conical scanner with dual view**
  - **Nadir 0-22°, Forward 55-52°**
  - **500km swath**
- **Seven channels**
  - **Thermal: 11, 12µm**
  - **SW/NIR: 3.7, 1.6µm**
  - **Visible (since ATSR-2): 0.55, 0.65, 0.87µm**
- **512km swath, 1/1.5km pixel size**
- **Continuous record since 1991**
  - **ATSR-1 1991-2000**
  - **ATSR-2 launched 2009**
  - **AATSR launched 2002-present day**
- **Stereoscopic height retrieval**
  - **M4 stereo matcher (Muller et al., 2006)**



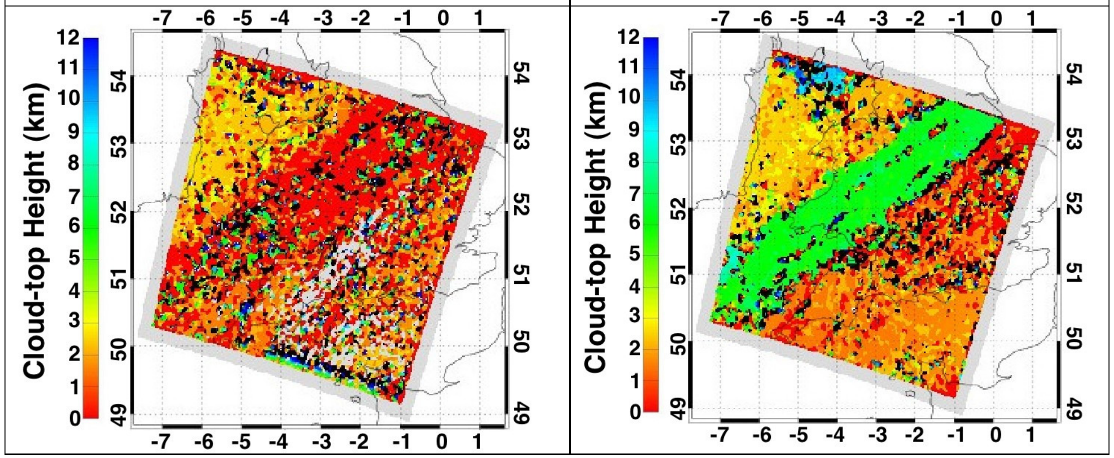
ATSR2-AATSR tandem (30 minutes apart) for 2002/3

Example of (A)ATSR(2) Multispectral Stereo to sample thin high Ci over dense StCu

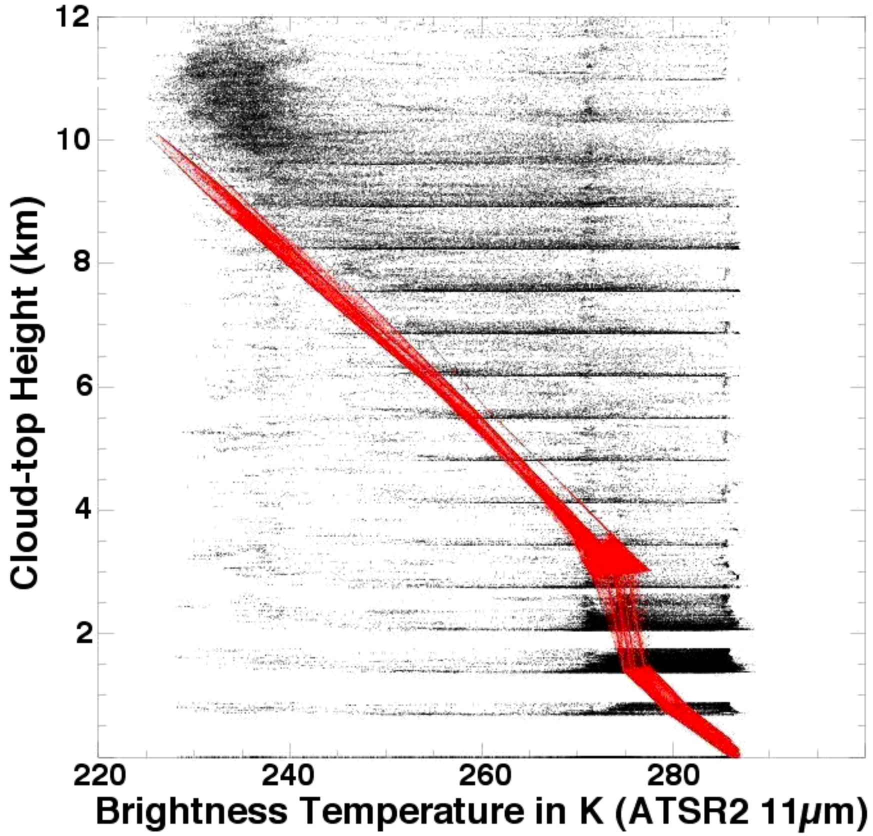
False Colour Composite of 11µm, 1.6µm, 0.68µm (left)
Red/Green stereo anaglyph (right)

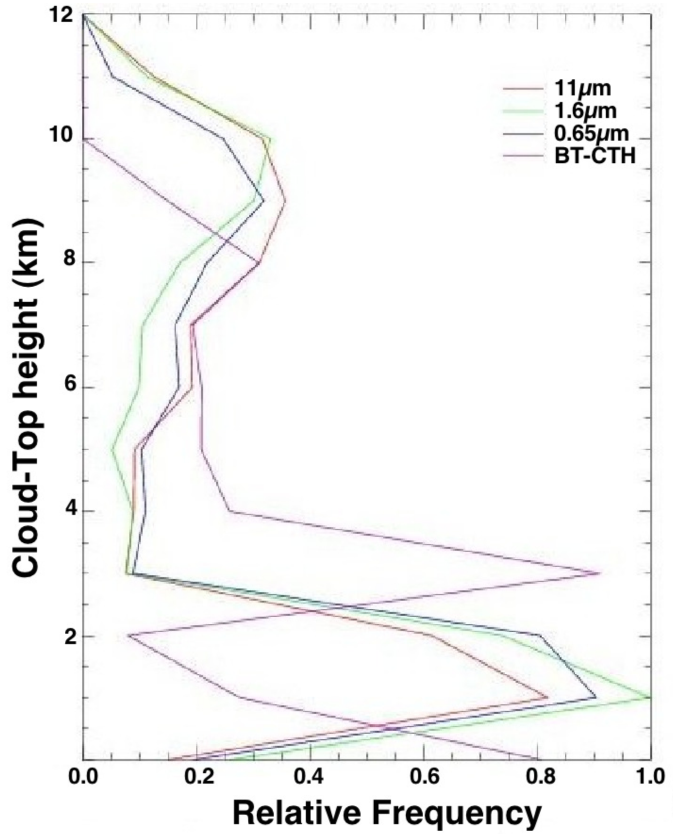


ATSR2 Stereo CTH retrieval at 1.6µm (left) and 11µm (right)

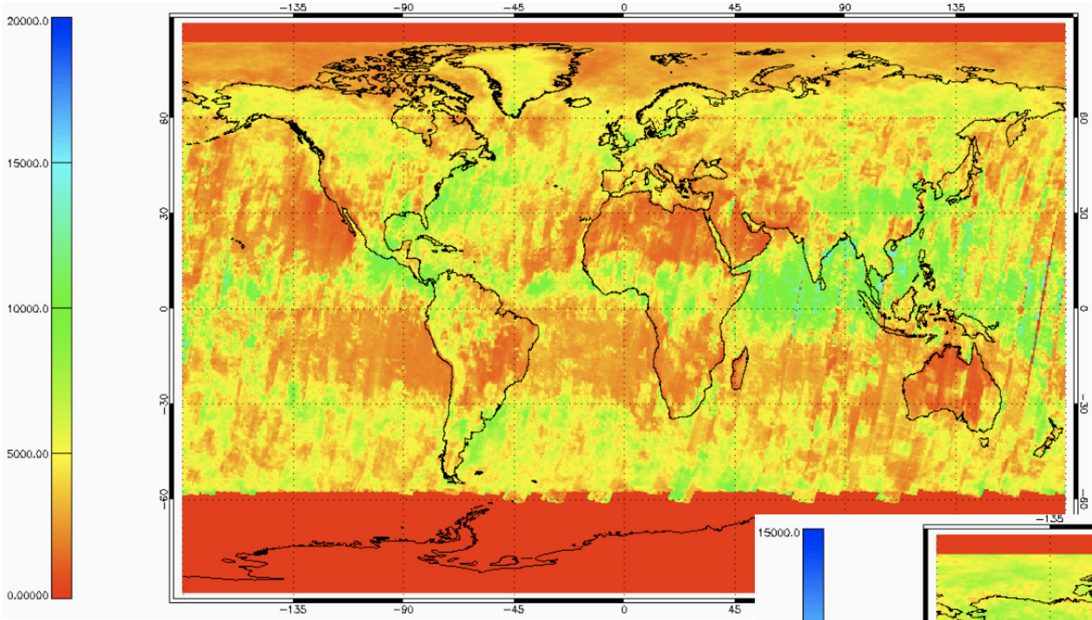


Intercomparison of CTHs from stereo cf. Brightness Temperatures

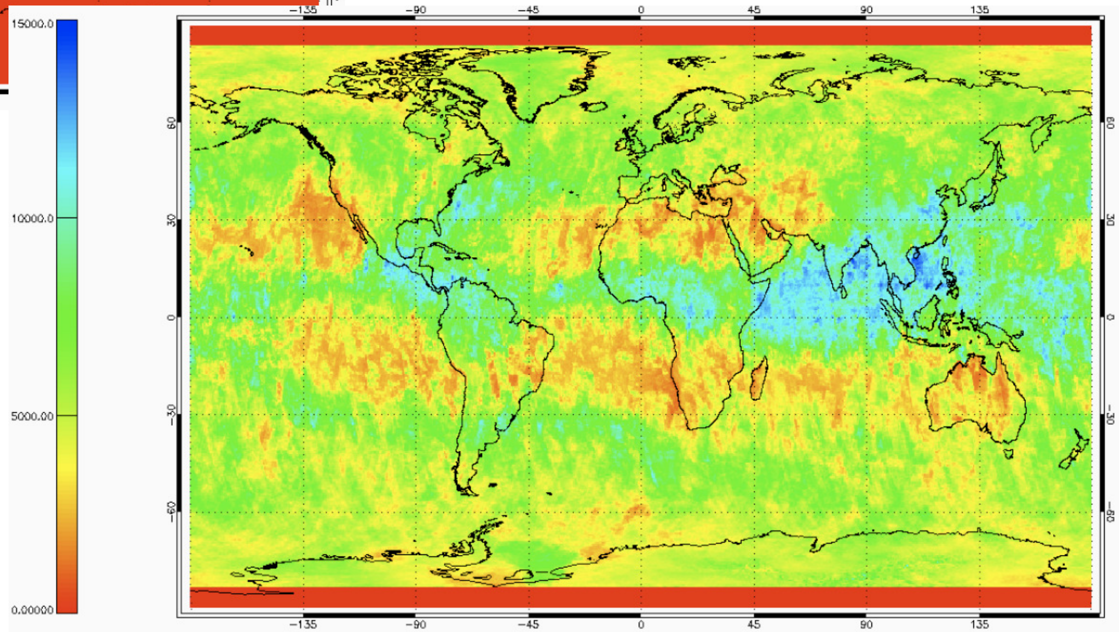




AATSR MONTHLY Cloud Climatologies



0.87μm June 2003

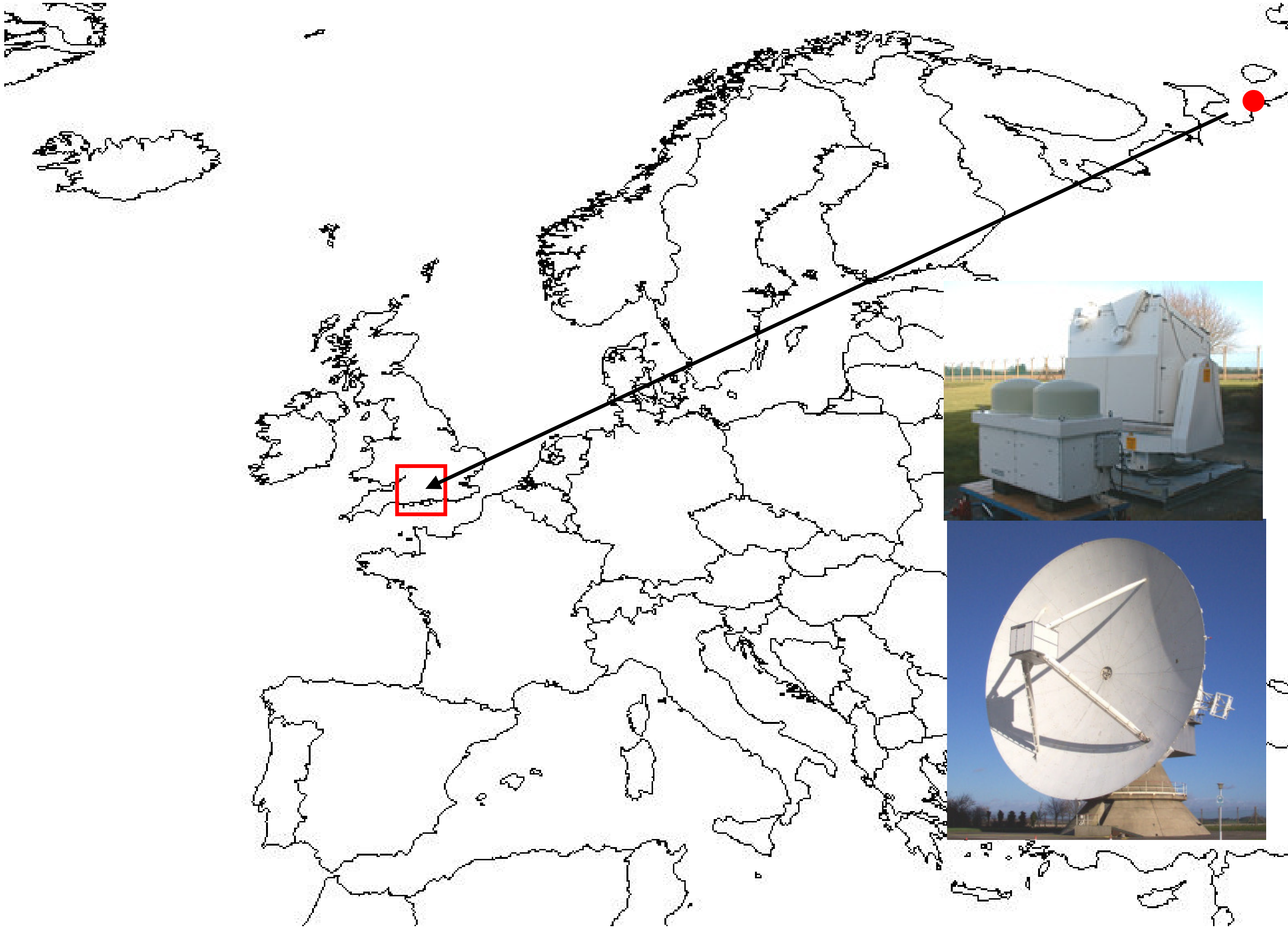


11μm June 2003
Picks up high tropical clouds
Sampling patterns visible

ATSR2 stereo heights validation

- **Stereo heights calculated at 11, 1.6 and 0.65μm using M4 matcher processing chain and Mannstein camera model**
- **Wind correction using ECMWF Objective Analysis wind profiles and method proposed by Seiz & Baltsavias (2000)**
- **Comparison with radar and ECP (Enhanced Cloud Product) CTH at ARM-SGP and CFARR**
- **Use of Version 1 for analysis reported here**

Locations and ground-based instruments (1)



CFARR: Chilbolton, Hampshire, UK (51.15N; 1.43W)
- 94Ghz radar processed with Clothiaux et al (2000) algorithm, continuous cloud mask with clutter flag
- 3GHz radar, not continuous operations, UCL processing of cloud top heights (low clouds only)

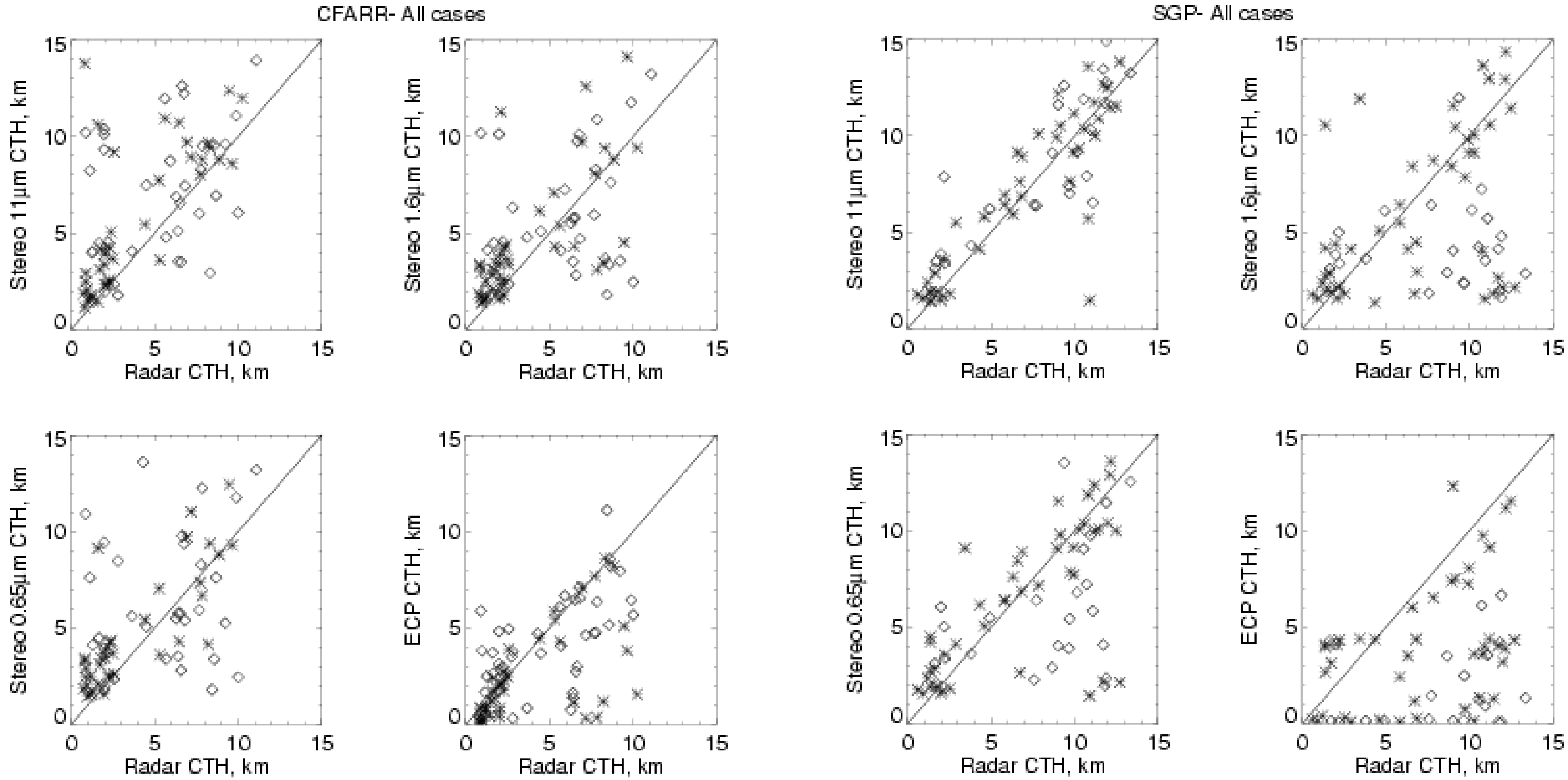
Locations and ground-based instruments (2)

- **SGP: ARM Southern Great Plains, Oklahoma (36.6N; 97.5W), 35Ghz radar processed with Clothiaux et al. (2000) algorithm, continuous cloud mask + clutter flag**

Comparison between ATSR2 stereo and ECP CTHs with radar CTH (1)

	CFARR	SGP
Total number of cases	194	115
ATSR2 Stereo CTHs		
Number of cases with both stereo 11µm and radar cloudy	77	68
Difference Radar-stereo 11µm	-2.1±3.7km	-0.3±2.2km
Number of cases with both radar and stereo 1.6µm	77	70
Difference Radar-stereo 1.6µm	-0.7±3.2km	1.7±4.6km
Number of cases with both stereo 0.65µm and radar cloudy	73	70
Difference Radar-stereo 0.65µm	-1.5±4.1km	0.6±4.2km
ATSR2 ECP CTHs		
Number of cases with both ECP and radar cloudy	87	64
Difference Radar-ECP	0.8±2.6km	4.2±4.2km
Single-level cloud cases		
Difference radar-stereo 11µm	40 cases -1.9±2.7km	43 cases -0.2±2.1km
Difference radar-stereo 1.6µm	41 cases -0.8±2.5km	45 cases 0.8±4.2km
Difference radar-stereo 0.65µm	36 cases -1.0±1.9km	44 cases 0.3±3.1km
Difference radar-ECP	45 cases 1.1±2.7km	43 cases 3.2±3.9km
Multi-layer cloud cases		
Difference radar-stereo 11µm	35 cases -1.8±3.7km	24 cases -0.4±2.3km
Difference radar-stereo 1.6µm	35 cases -0.2±3.7km	24 cases 3.9±4.4km
Difference radar-stereo 0.65µm	34 cases -0.8±4.1km	24 cases 2.3±3.9km
Difference radar-ECP	42 cases 0.5±2.6km	21 cases 6.3±4.1km

Comparison between ATSR2 stereo and ECP CTHs with radar CTH (2)

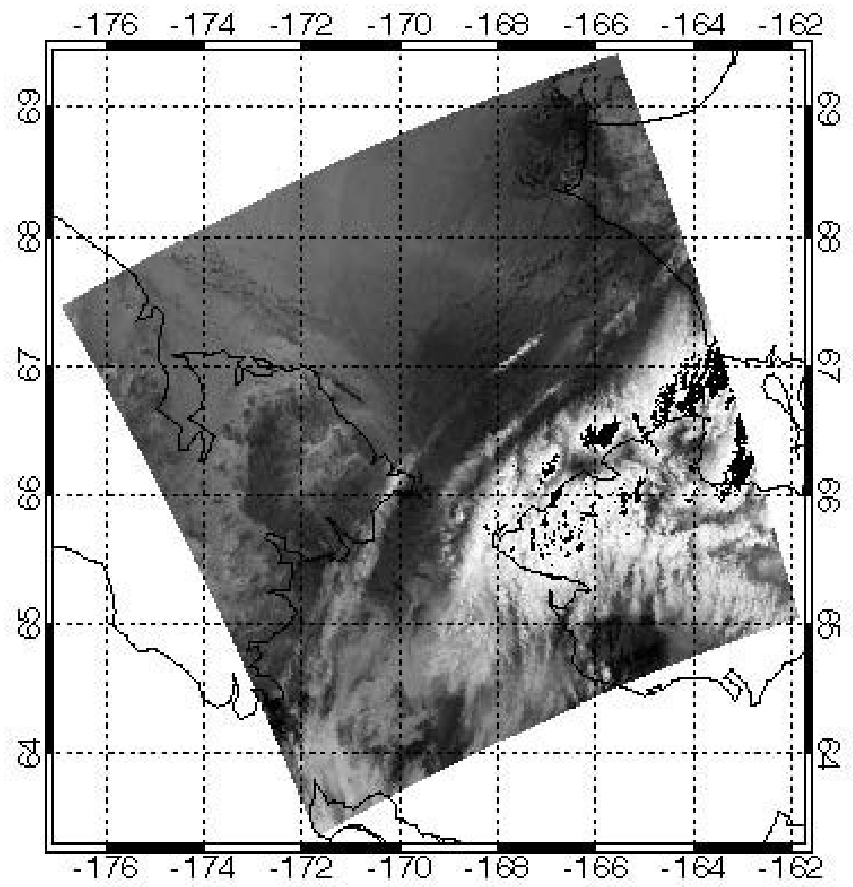


Naud, Muller, Clothiaux, RSE (2006)

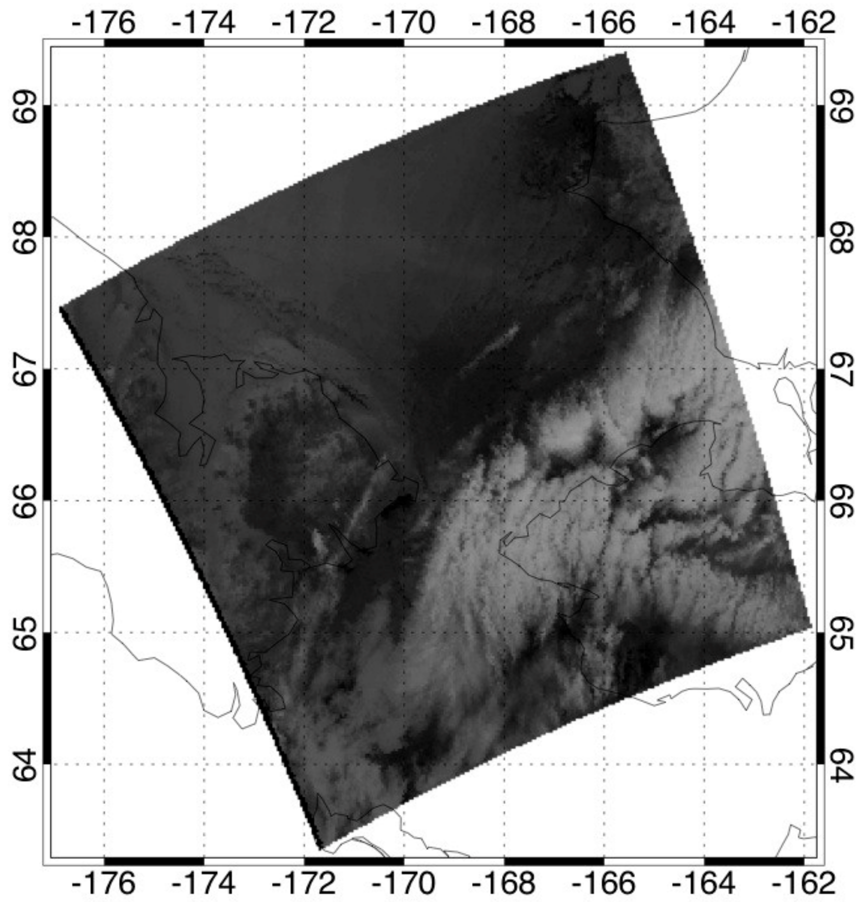
*=single-level clouds; ◊=multi-level clouds

ASTR2-AATSR tandem -example inputs

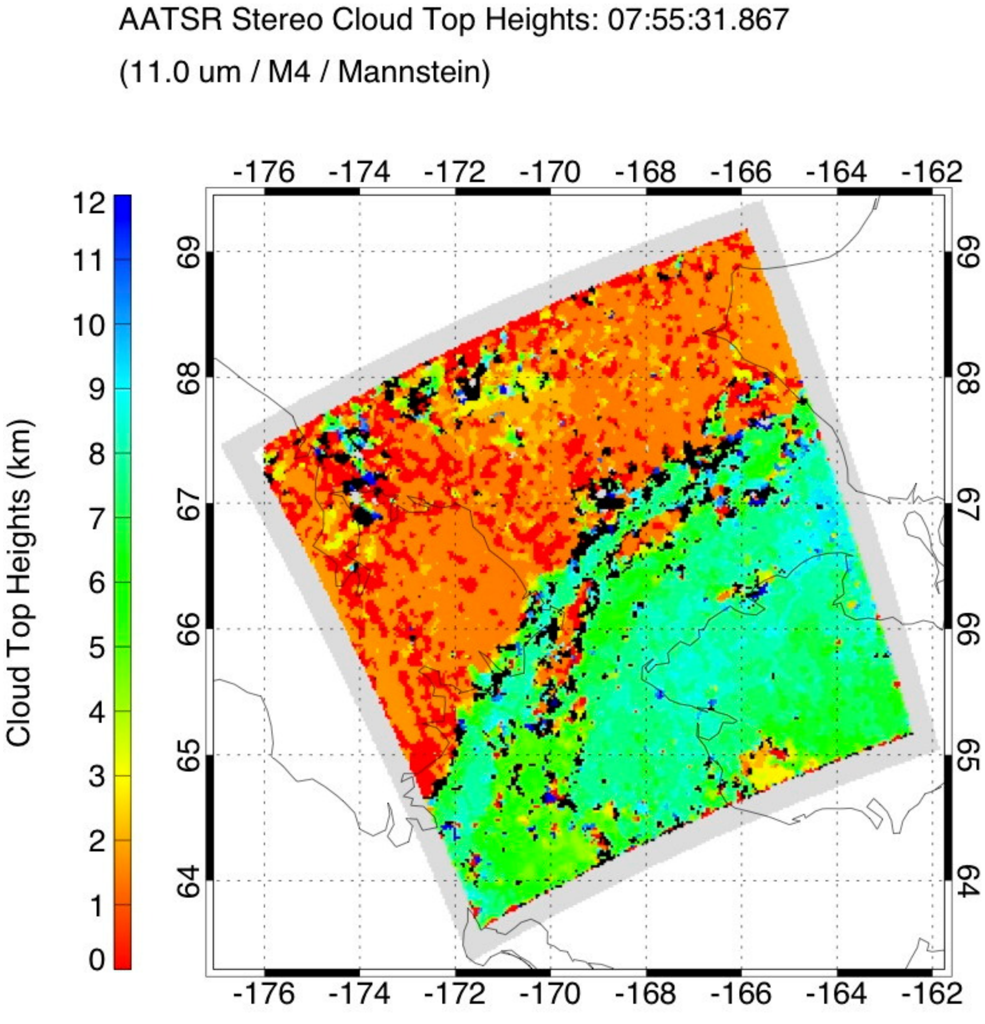
AATSR Nadir Gridded Brightness Temperature : 11.0 um
07:55:31.867

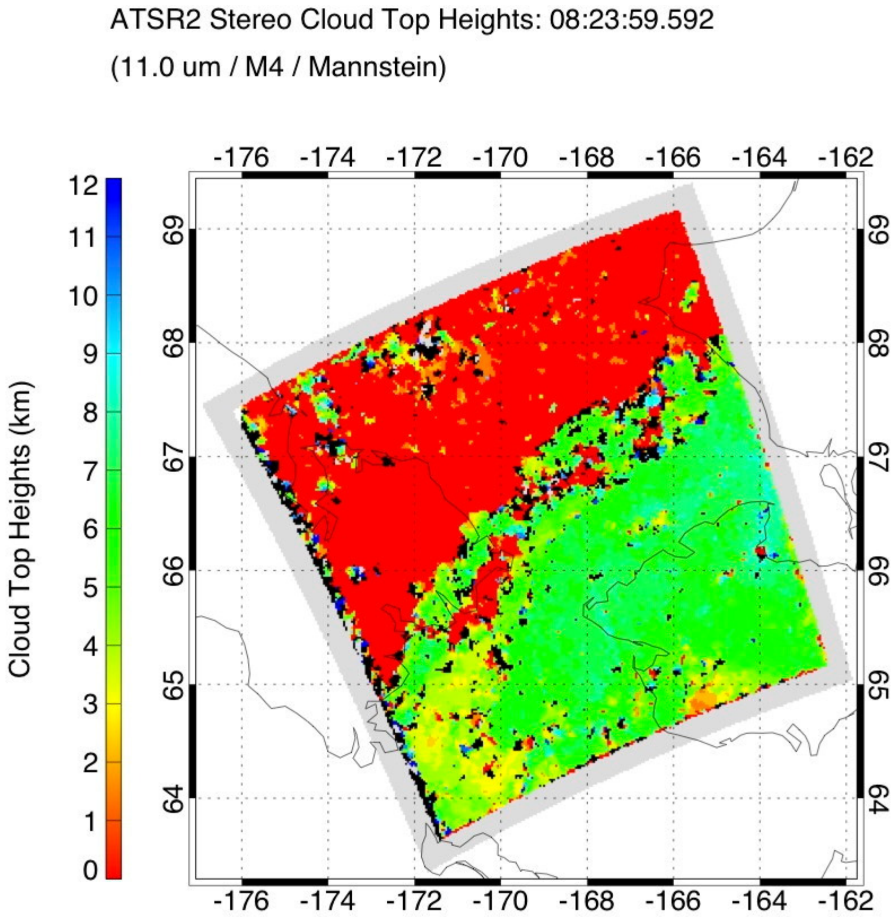


ATSR2 Nadir Gridded Brightness Temperature : 11.0 um
08:23:59.592

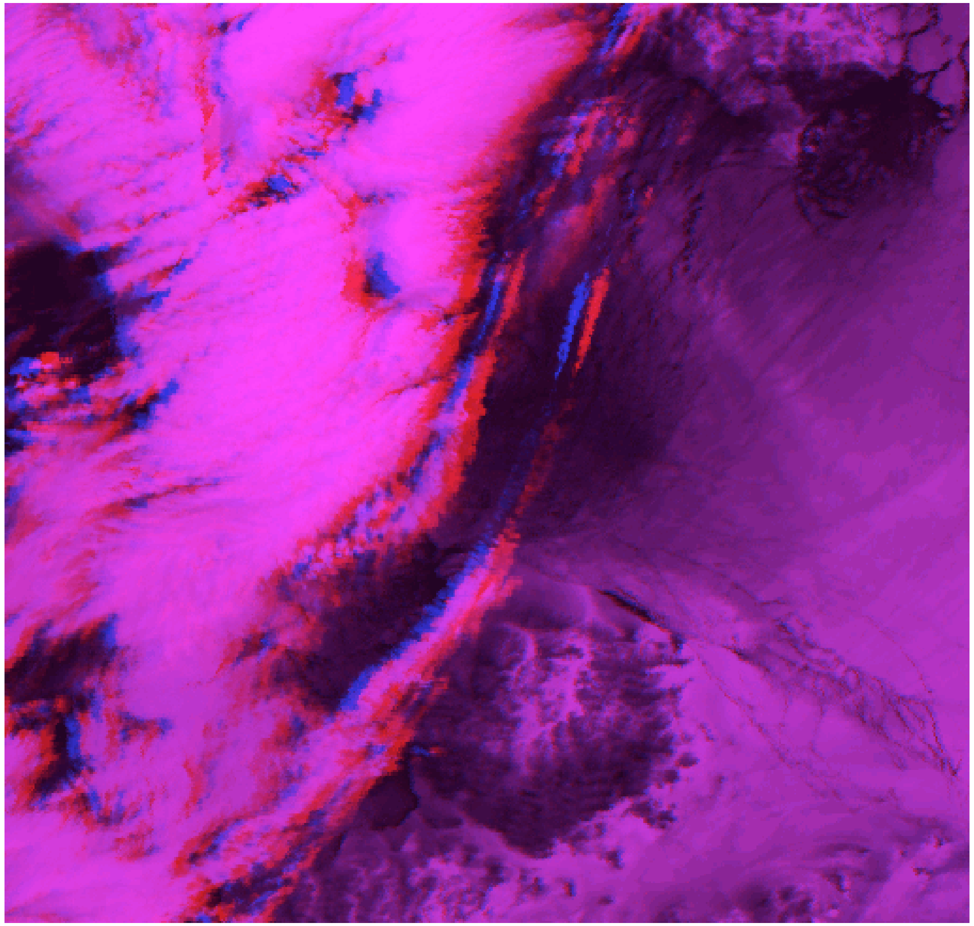


ASTR2-AATSR tandem - CTH fields





ATSR2-AATSR tandem - motion fields

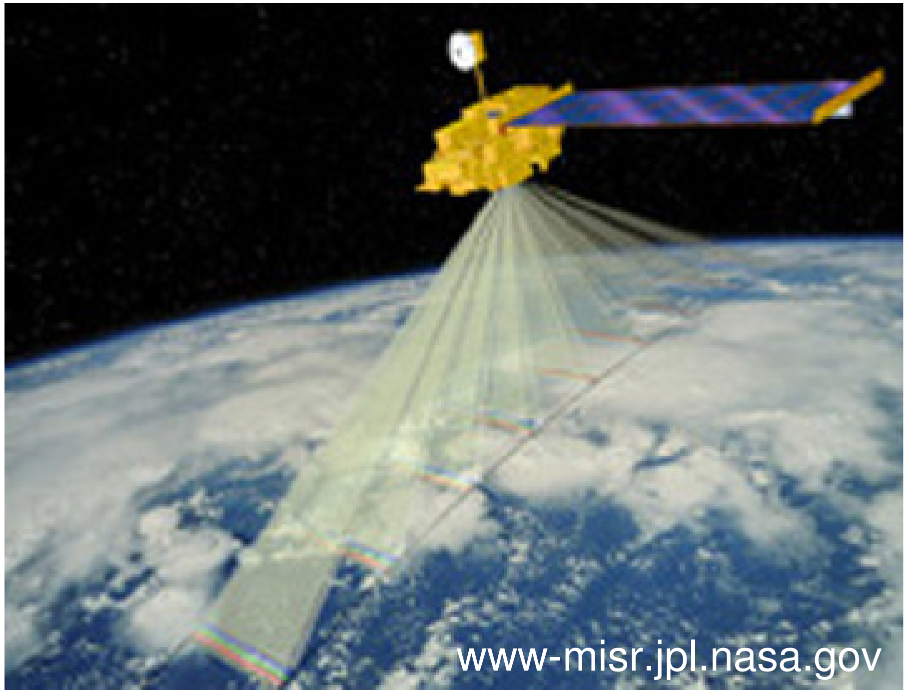


AATSR 07:55:31 20030118

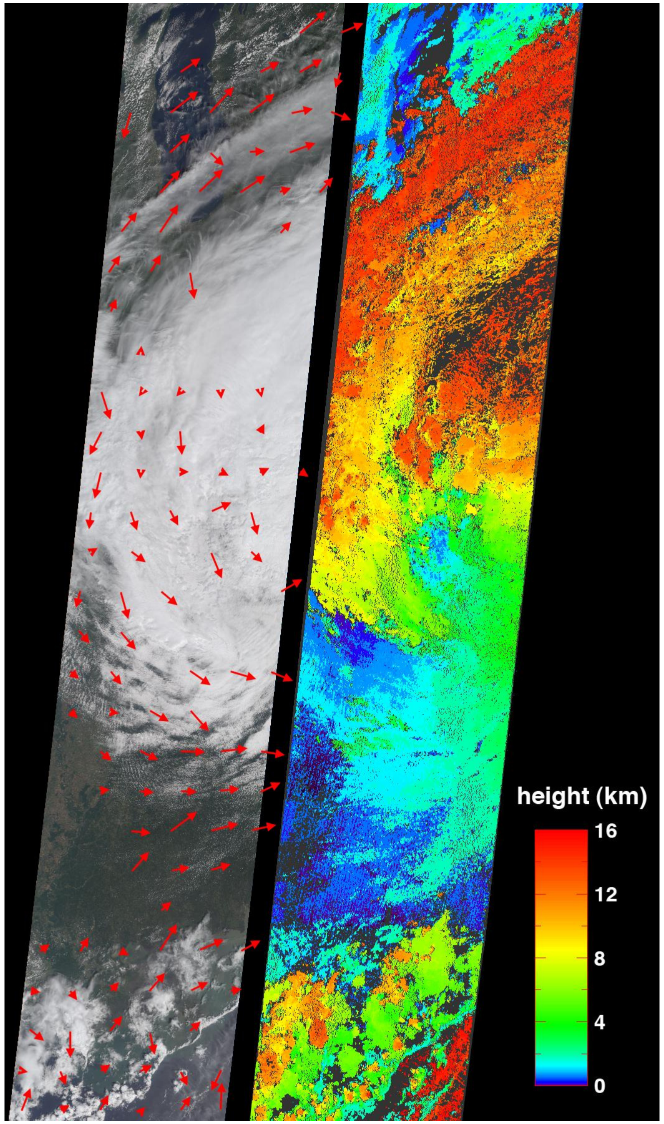
N.B. work still in progress to quantify the motion fields

Heritage: Multiangle Imaging Spectro-Radiometer (MISR)

- **Monitoring clouds, aerosols and vegetation**
- **Pushbroom scanner at nine angles**
  - **Nadir**
  - **Forward at 26.1, 45.6, 60.0, 70.5°**
  - **Aft at 26.1, 45.6, 60.0, 70.5°**
- **Four bands**
  - **Three visible (0.44, 0.55, 0.65µm)**
  - **NIR (0.87µm)**
- **360km swath, 275m pixel size**
- **2-3% radiometric calibration required**
- **Launched 1999, began ops in 3/00**
- **UNIQUE simultaneous retrieval of cloud-top heights and winds (Horvath & Davies, 2001)**
- **Operational stereoscopic cloud-top height (CTH) retrieval**
  - **M2/M3 stereo-matchers (Muller et al. 2002)**
- **CTHs produced at 2.2km and cloud-top winds (AMVs) at 70.4km**
- **Mass 148kg, 117W power, 3.3 Mbps, cost $128M**

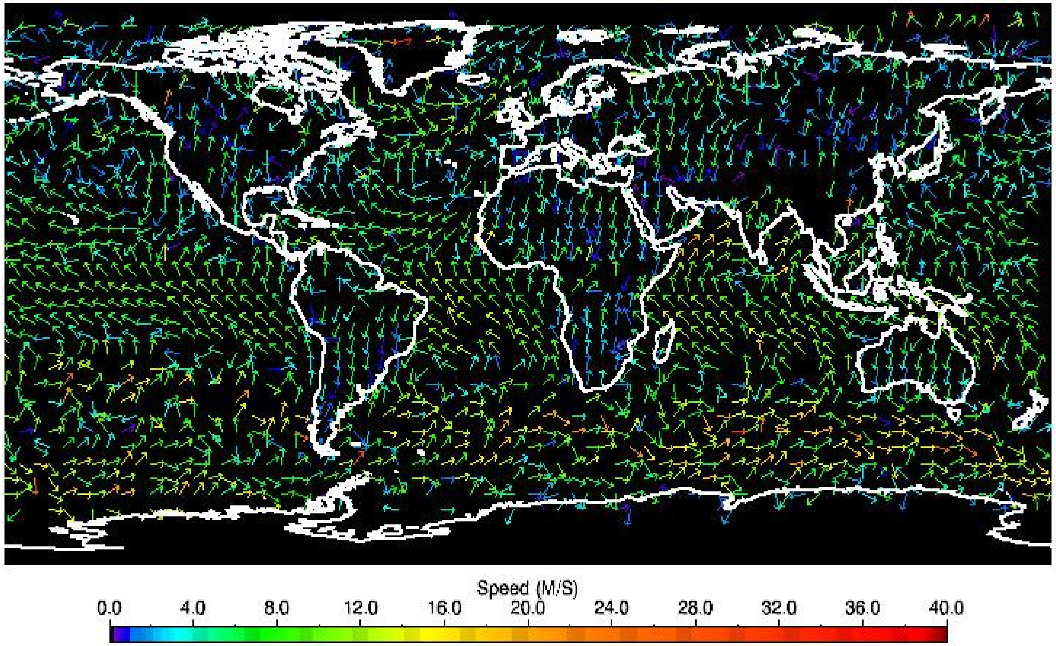


Cloud heights and height-resolved cloud motion winds



Hurricane Katrina 8/30/05

Monthly mean winds August 2005 (0.5-1 km altitude)

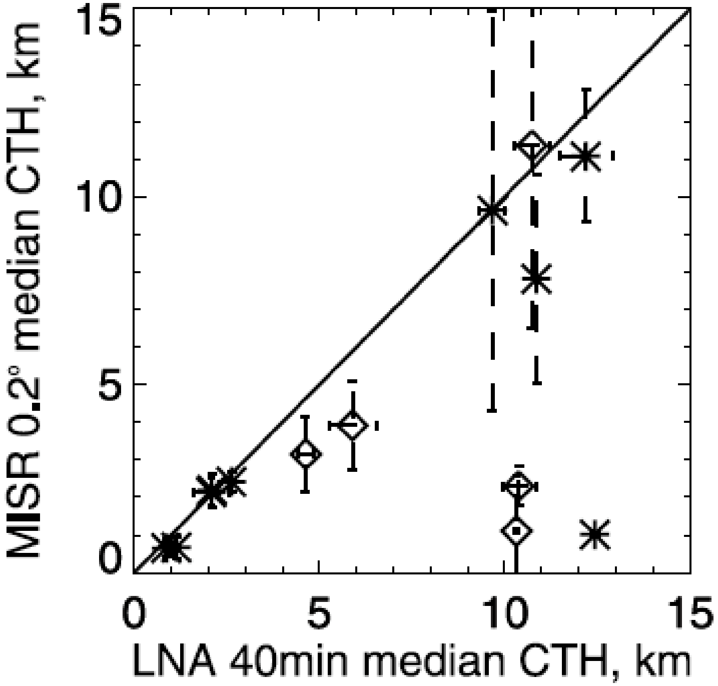


Wind attributes

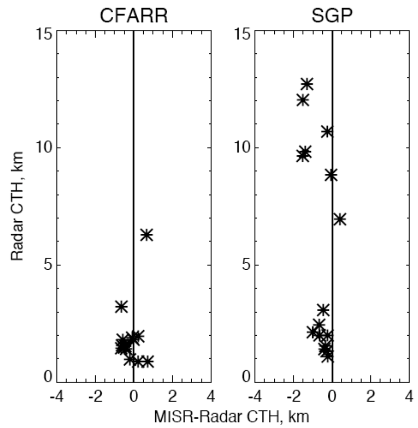
- derived from purely geometric approach
- completely automated, globally
- instantaneous wind accuracies of 1-3 m/sec
- validated against radiosondes and Doppler radar
- can be applied to severe weather systems

MISR Cloud-top height validation using radar/lidar and lidar alone

Palaiseau

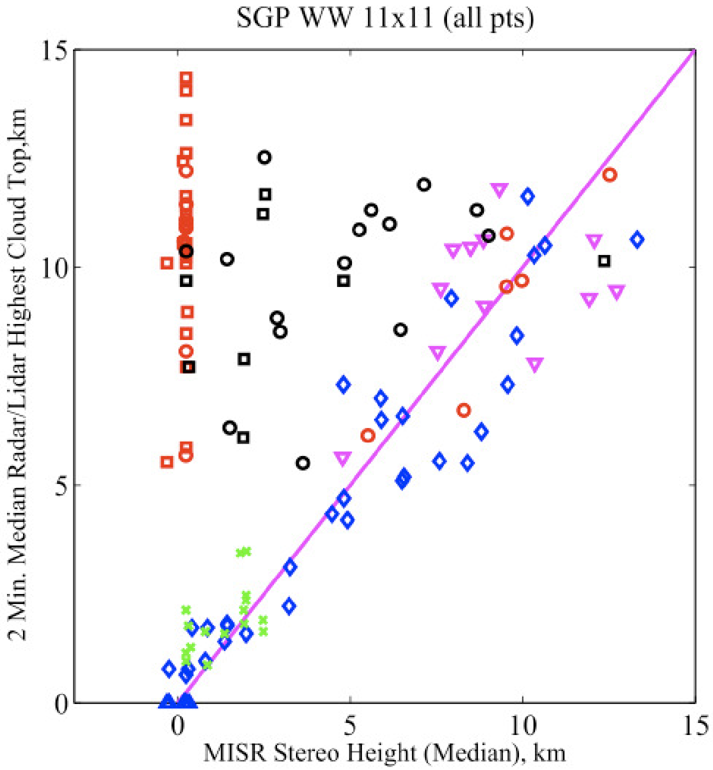


Naud, Muller et al., GRL (2004)
Limiting optical depth>0.01



Naud, Muller et al., Ann. Geophys. (2005)

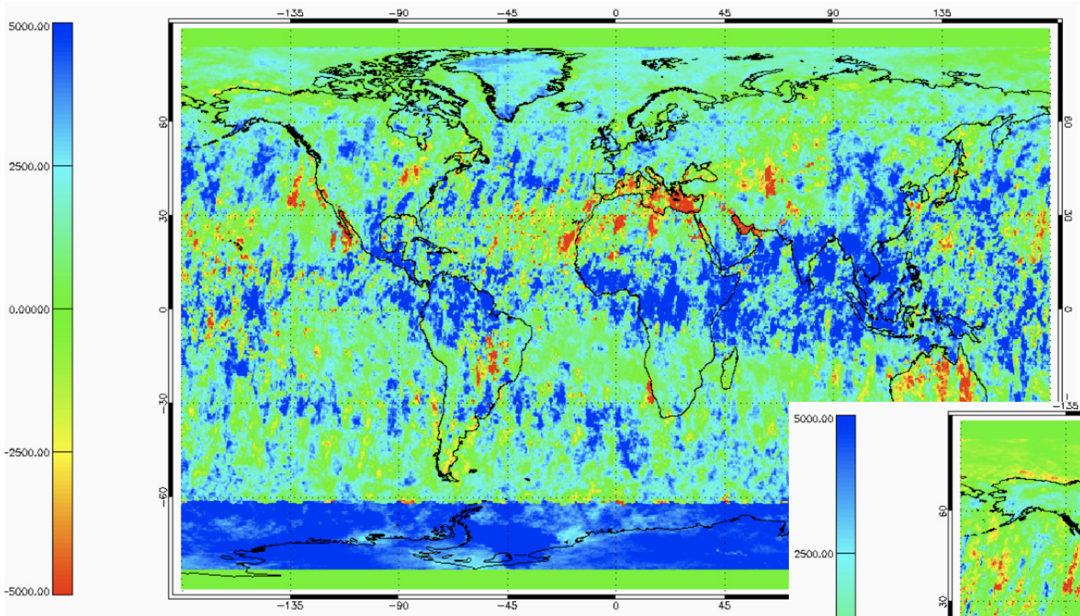
0.05±0.62km



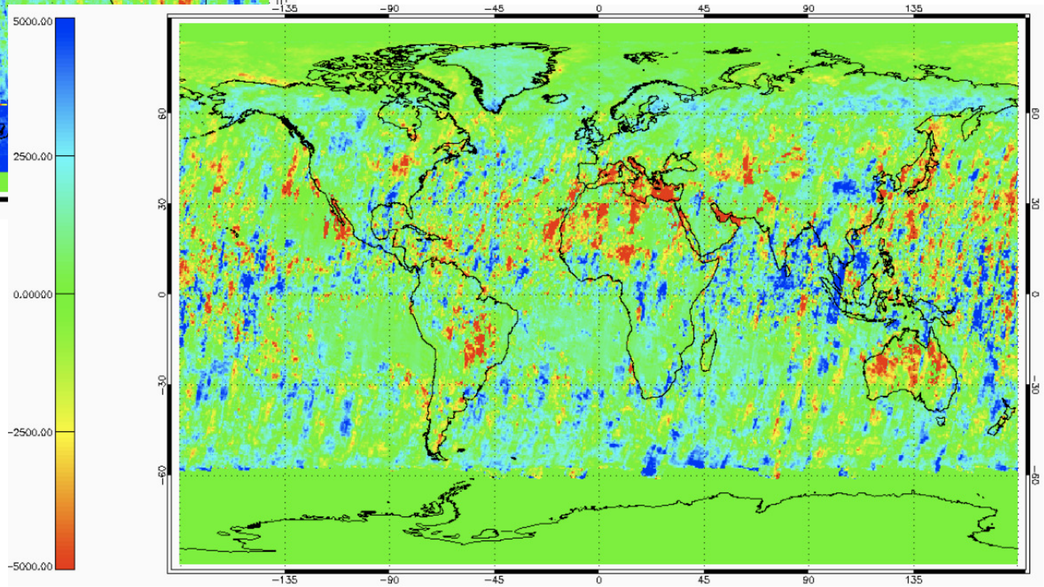
Marchand et al. JGR (2007)

N.B. Radar/lidar cf. radiosondes for CTH show 0.35±0.73km.
Naud, Muller, Clothiaux J.Geophys. Res. (2003)

Intercomparison of AATSR and MISR MONTHLY Cloud-top heights (June 03)

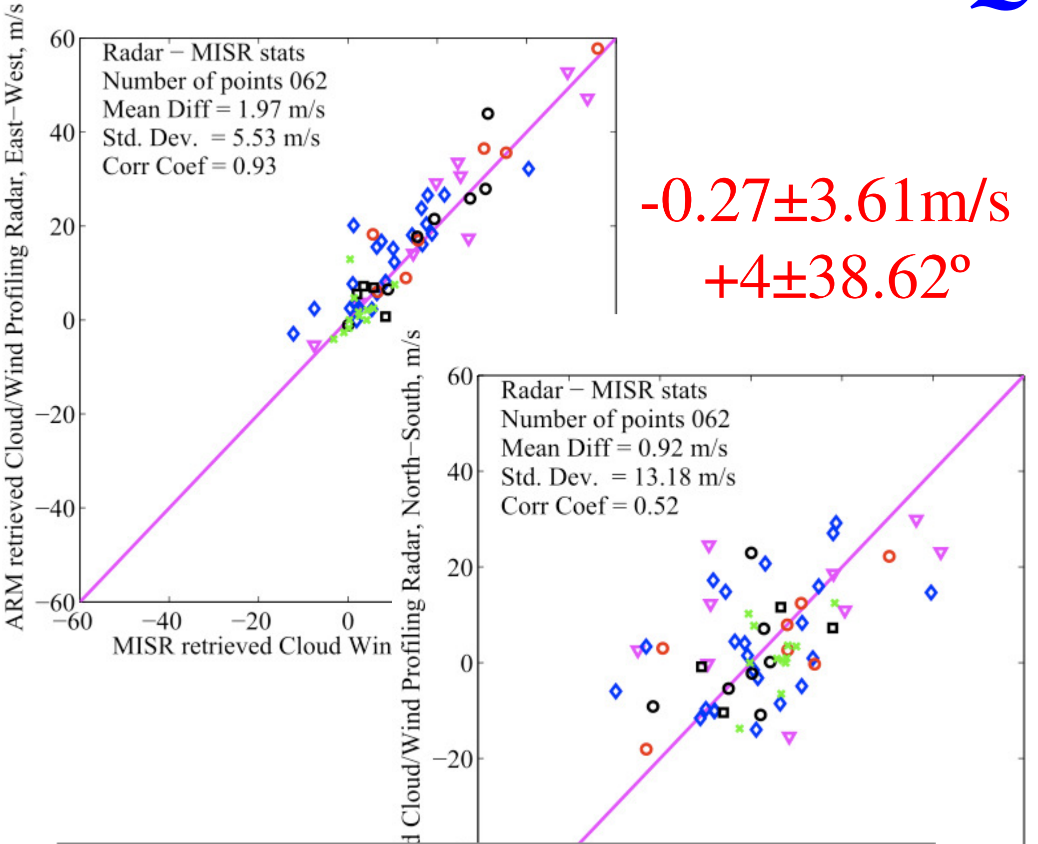


AATSR (12μm)-MISR
Differences due to CTH sampling



AATSR (0.67μm)-MISR
Differences due to time sampling

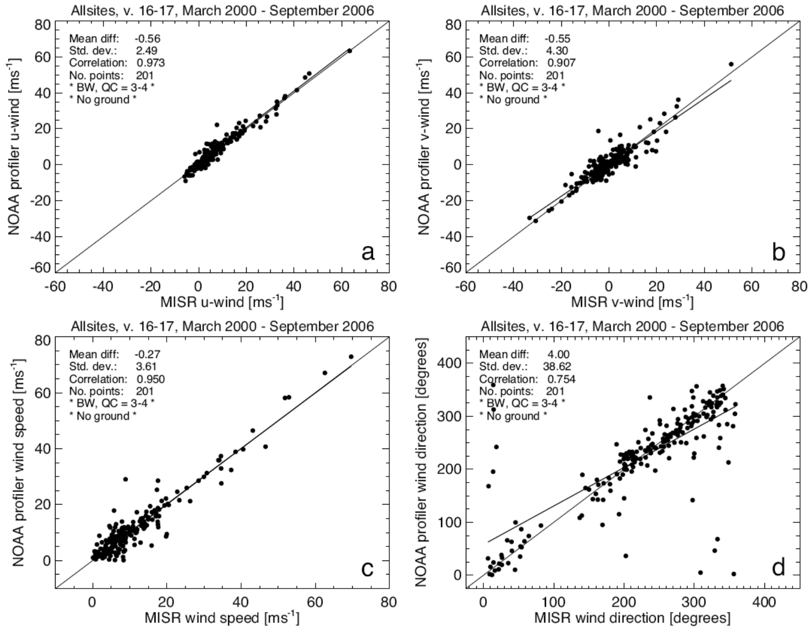
MISR Best wind Quality Assessment

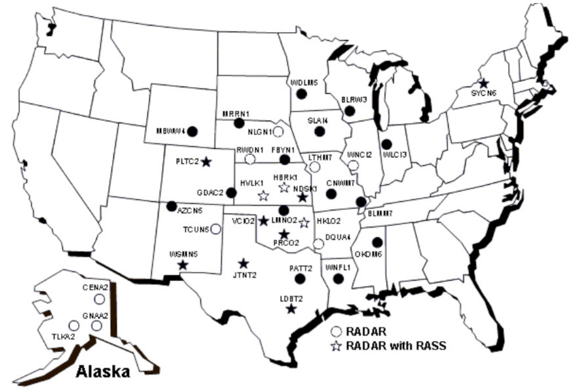


Symbol	Description
Blue triangle	Clear-sky (retrieved height should be at ground level).
Green crosses	Broken boundary layer clouds.
Blue diamonds	Opaque clouds with well defined structure visible at cloud top. One cannot see surface or lower clouds. If a boundary layer cloud, the cloud must be stratiform.
Red symbols	Thin cloud over surface. Squares mean NO hint of a cloud is visible in nadir imagery. Circles mean one can see some cloud "whitening" in nadir imagery, but also clearly make out the surface (or other lower cloud decks).
Black symbols	Thin cloud over other clouds.
Magenta symbols	Opaque to mostly opaque clouds with diffuse clouds top. One can at best marginally identify underlying surface features or lower clouds and there are no well defined structures visible at cloud top in nadir imagery.

-0.27±3.61m/s
+4±38.62°

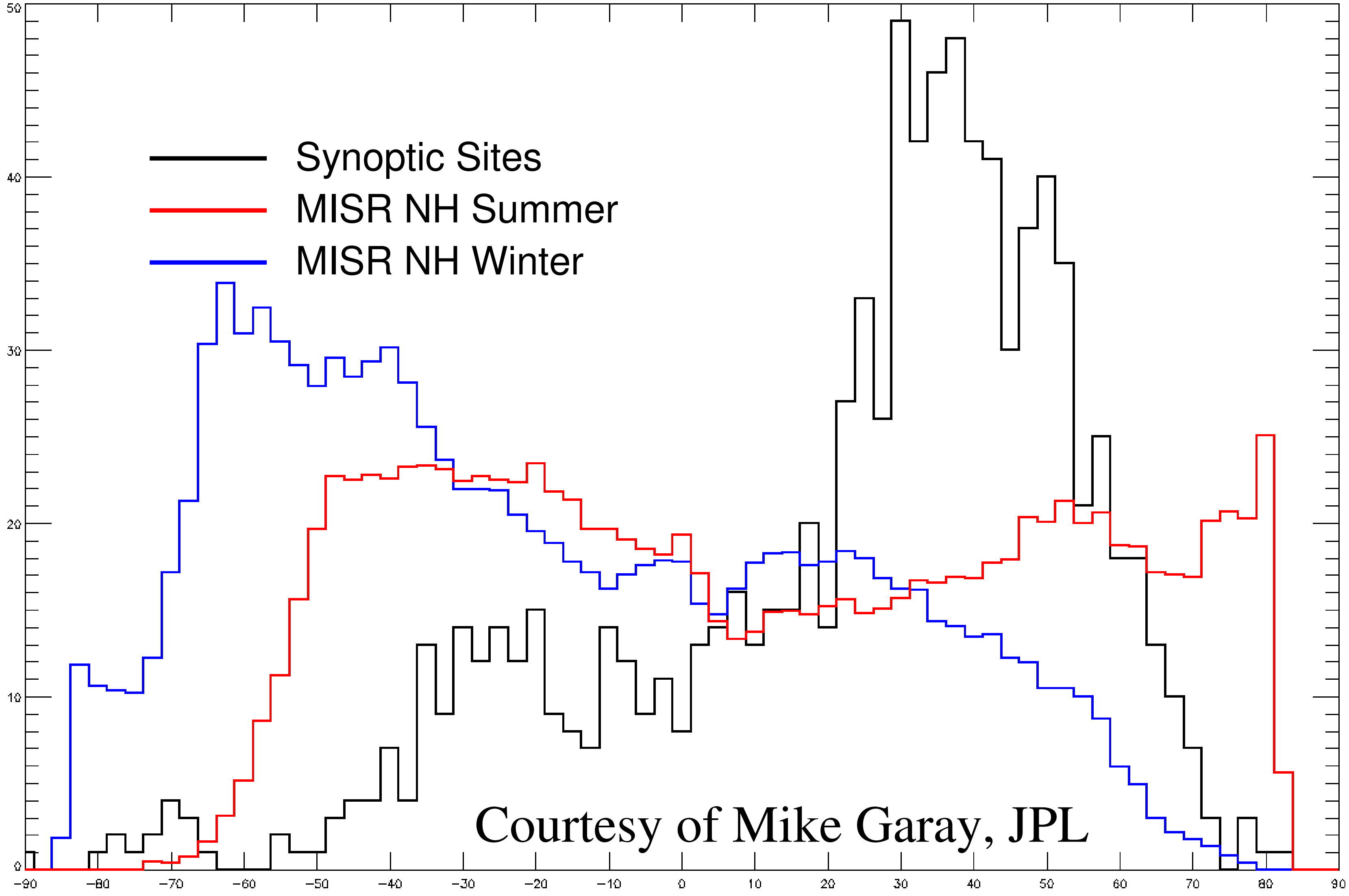
Marchand, Ackermann, Moroney, JGR (2007)

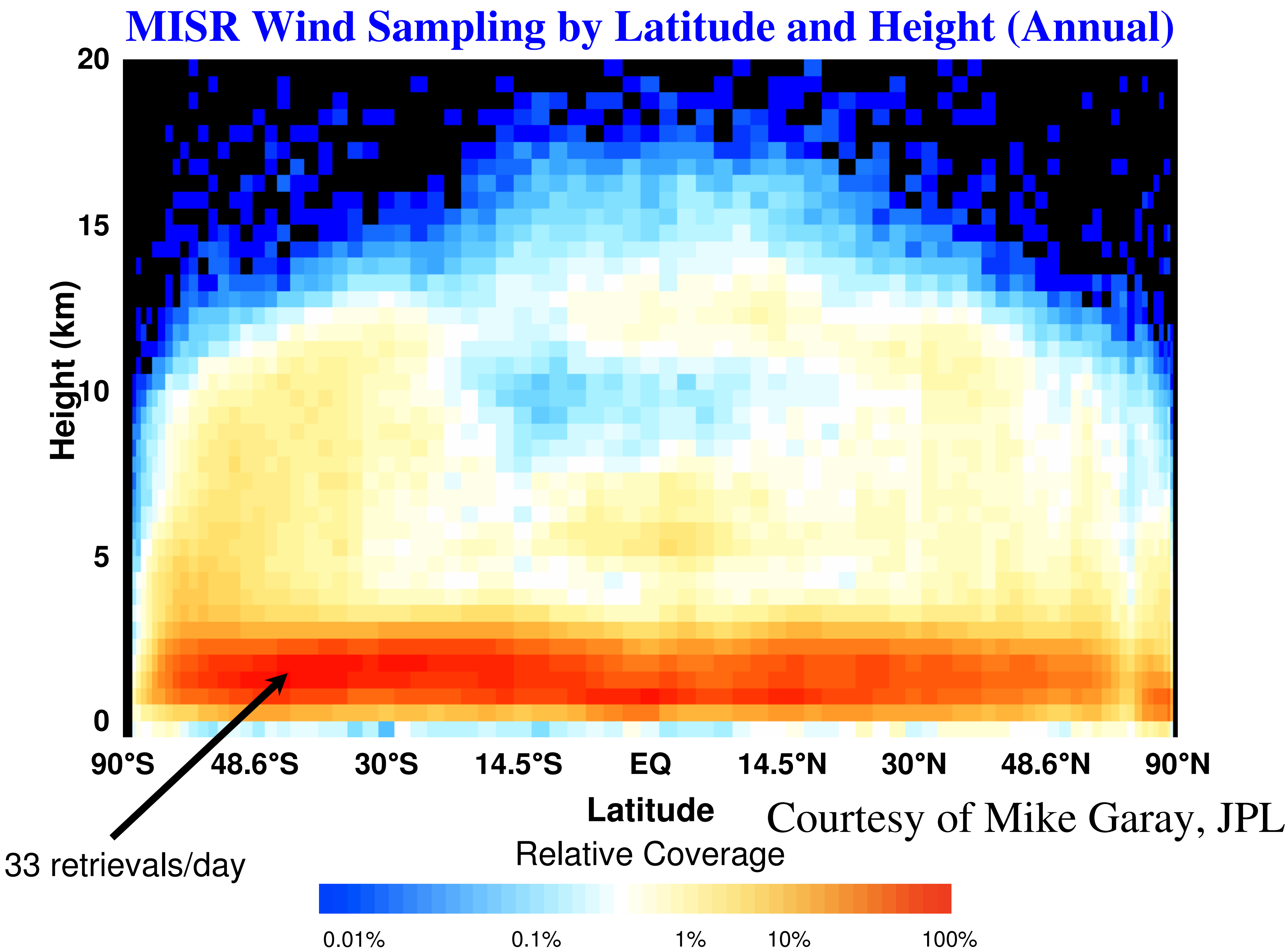




Hinkelman, Marchand, Ackerman, JGR (2009)

Comparison of Synoptic and MISR Wind Sampling by Latitude and Season




MISR Wind Sampling by Latitude and Height (Annual)
Height (km)
20
15
10
5
0
90°S
48.6°S
30°S
14.5°S
EQ
14.5°N
30°N
48.6°N
90°N
Latitude
Courtesy of Mike Garay, JPL
33 retrievals/day
Relative Coverage
0.01%
0.1%
1%
10%
100%

Scientific and Societal Benefit Drivers for objective cloud-top heights and wind effects using the stereo-photogrammetric measurement approach

●Weather

– Improve the forecasting skill of numerical weather prediction models by retrieving cloud-motion vector winds in traditionally <u>data-sparse areas</u>: mid-oceans and high latitudes

– Improve model simulations of intense storms by providing maps of geometric cloud height and vector winds, independent of cloud emissivities or temperature profiles, especially in polar "daytime"

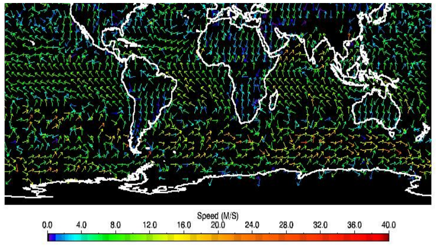
●Climate variability and change

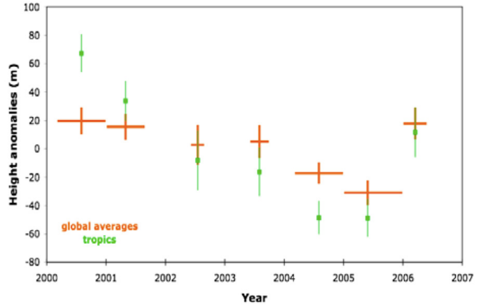
– Establish long-term records of cloud-top height and cloud-motion winds with sensitivities capable of detecting atmospheric response to climate forcings as well as measuring inter-annual variability inc. polar stratospheric winds

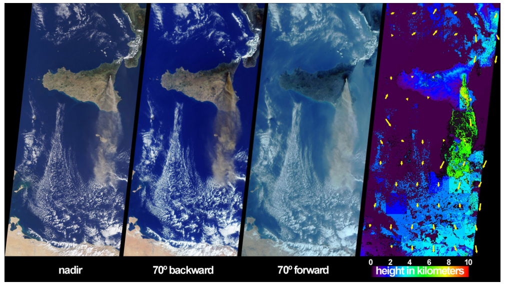
●Human health & Safety

– Improve extreme weather forecast warning times

Monthly mean winds August 2005 (0.5-1 km altitude)

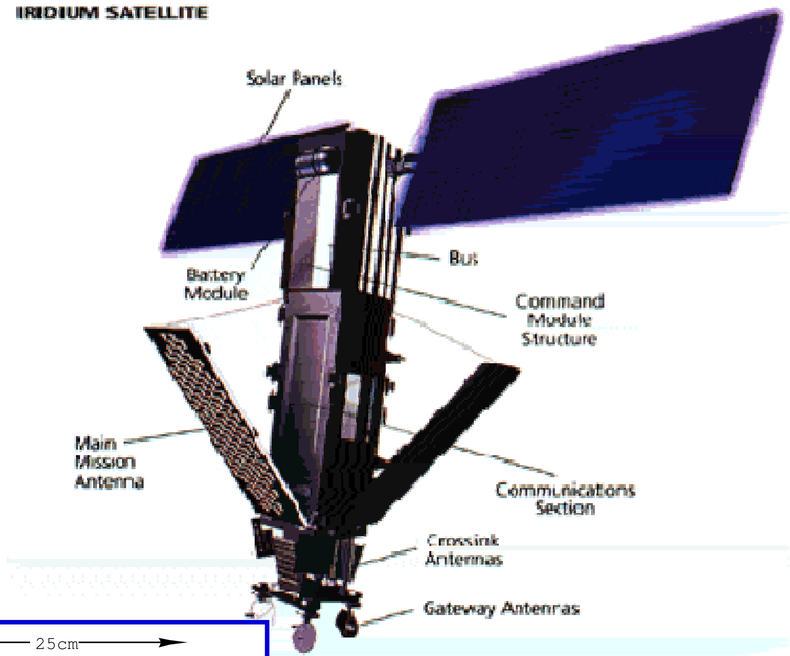


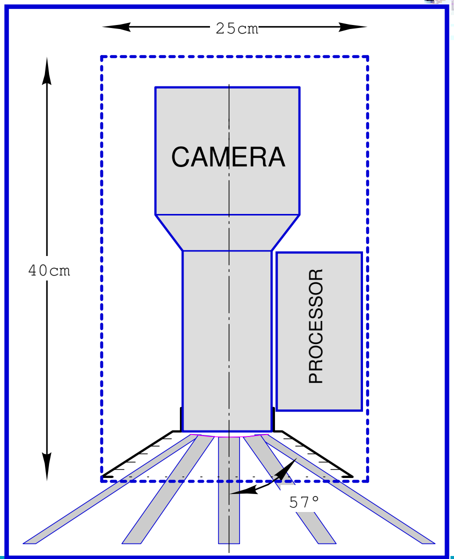




Platform #1: WindCAM and Iridium NEXT

- NASA-JPL study results
- need for a constellation
  - A single WindCAM (1000km swath) in LEO provides 3-day global (dayside) coverage
  - Red band only, no need for in orbit radcal
  - ±32º FoV (X-track) & ±57º (Al-track)
  - 300m IFoV, 1000km swath, product reported at 72km (but could be generated at 2.4km)
  - For NWP models with forecasts every 3-6 hours requires multiple WindCAMs
  - Multiple, phased orbits provide repeat daily coverage over many different times of day
- ideal number of sensors
  - WindCAM with 1000km swath has ~13 orbits/day so would require
    - 3 for daily coverage
    - 12 for 6-hour repeat coverage
    - 24 for 3-hour repeat daily coverage
  - Cost ~$5-6M each
  - Lifetime ~10-15 years
- Not going forward at present





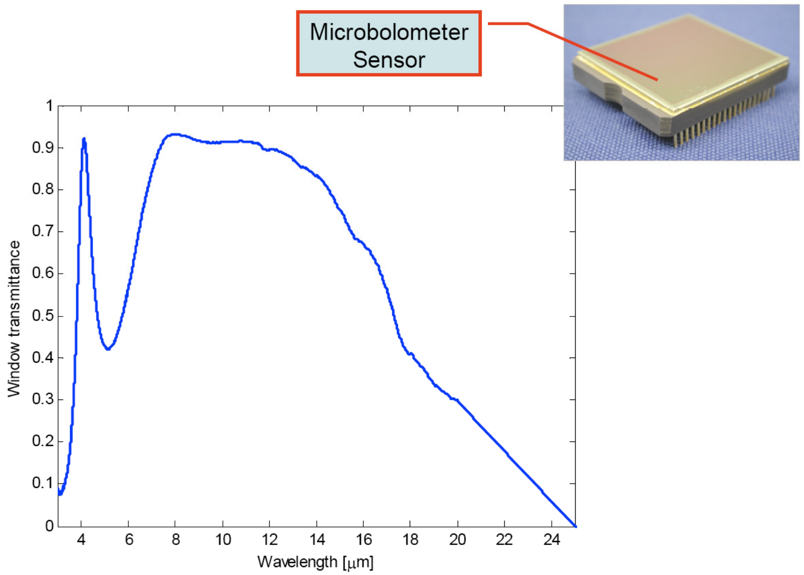
Power	21 W
Mass	10 kg
Data rate	2 Mbps
Volume	25 x 20 x 40 cm
Spectral	Red, no radcal
Extori	30m, 4 arc-secs

WINDS mission with the primary payload of MISRlite (Multi-angle Infrared Stereo Radiometer): Objectives

- **Cloud-top Heights and Winds globally**
  - **Every 3, 6 or 12 hours, day and night,**
  - **Height accuracy ≤300m, wind accuracy ≤ 3m/sec**
- **IR technology**
  - **Thermal IR**
  - **Uncooled technology (NE∂T≤30mK)**
- **Using Non-ITAR, off-the-shelf components (from Canada)**
- **Low mass (<10kg), low power (<20W), low bandwidth (<2Mbps)**
- **Low cost for production model (<1M€)**
- **Complementary to Doppler Lidar technology using heritage data processing chain at very low cost**
- **Fly in constellations/swarms on microsats**
- **Combine with off-the-shelf simple lidars (for height-wind trade-offs) and Oxygen A-band for improved low cloud and aerosols in daylight**
- **Pre-Phase A study underway for ESA technology demonstrator but looking for platform partner**

How achievable?

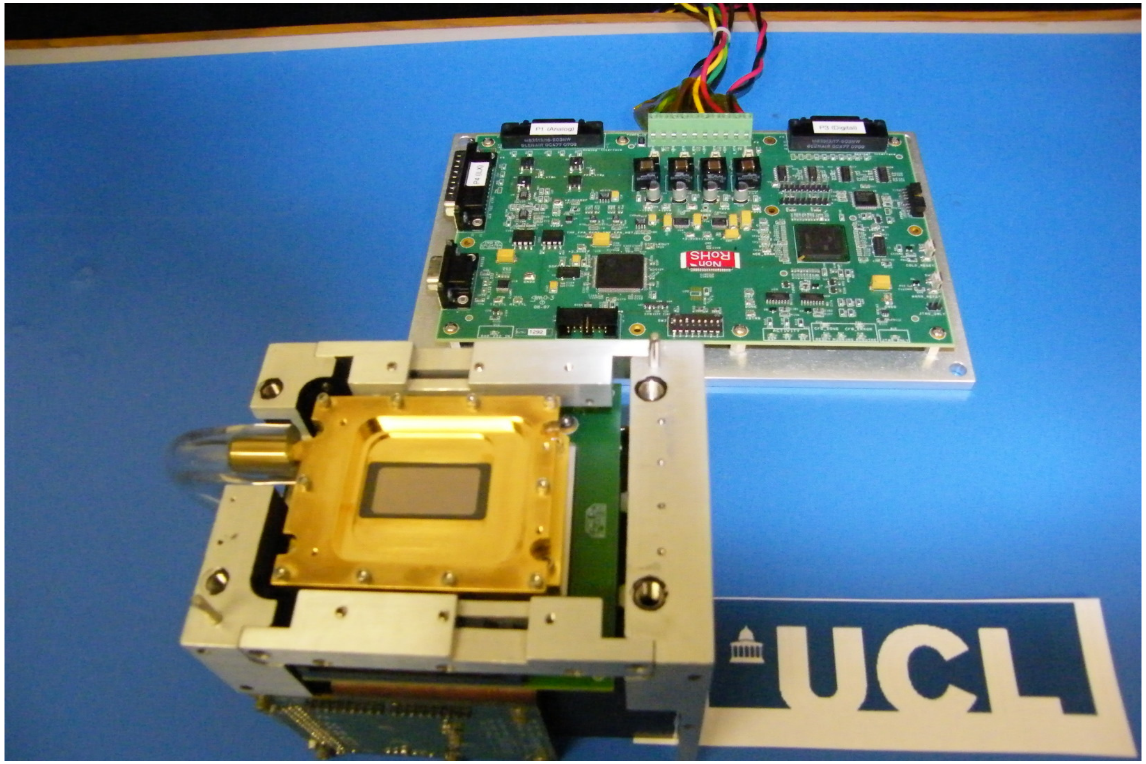
- **Use of TIR wavelengths to achieve day/night coverage**
- **Experience with (A)ATSR(2) shows TIR has sufficient contrast to retrieve good CTHs <u>at all altitudes</u>**
- **Use of non-ITAR uncooled CMOS technology (microbolometer)**
  - **Uncooled systems have heritage on Earth Radiation Budget missions as well as for CALIPSO imager**
  - **To fly on Argentinian-Canadian fire sensor**
- **Use of linear array technology**
- **Use of multi-angle/stereo photogrammetry**
- **300m IFoV, 1200km swath, <0.5º NE∂T**
- **ATC Edinburgh design of single focal plane optics with 5-look sensors meet mass specification**
- **Technology heritage: THEMIS onboard the NASA Mars Odyssey**



©INO, Québec, CA 2008

INO Microbolometer (non-ITAR)

- **Only manufacturer worldwide currently of linear pushbroom arrays**
- **INO building a 2500-pixel uncooled linear array**

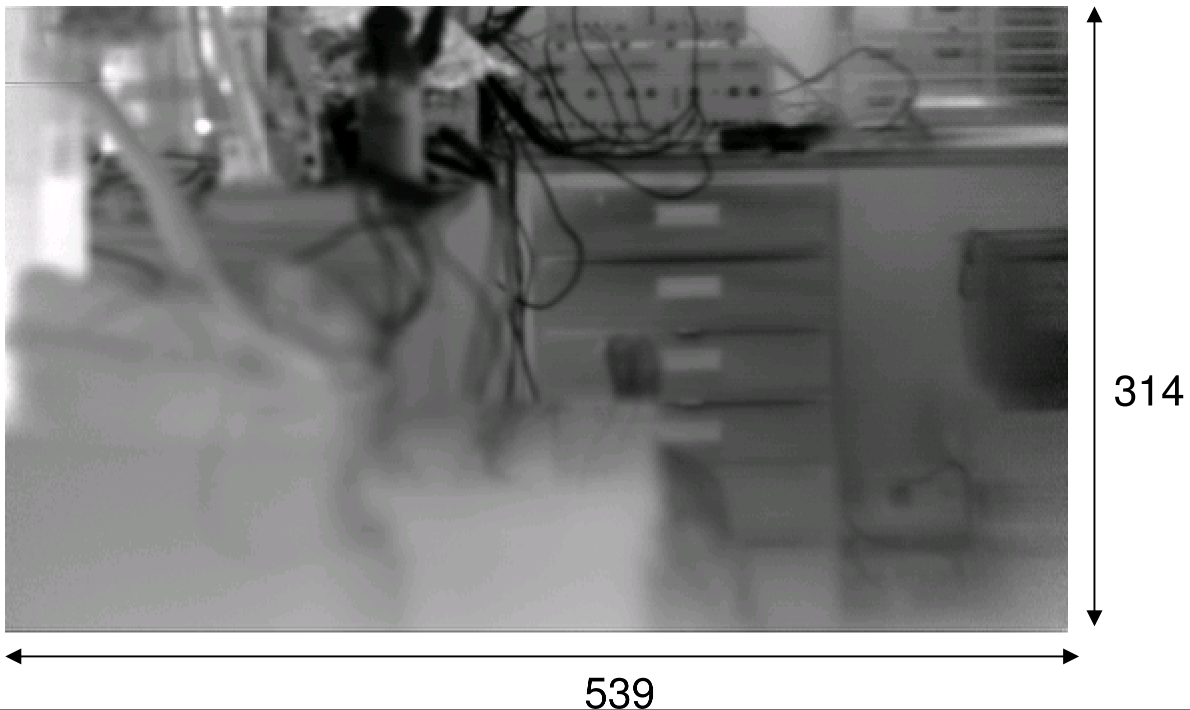


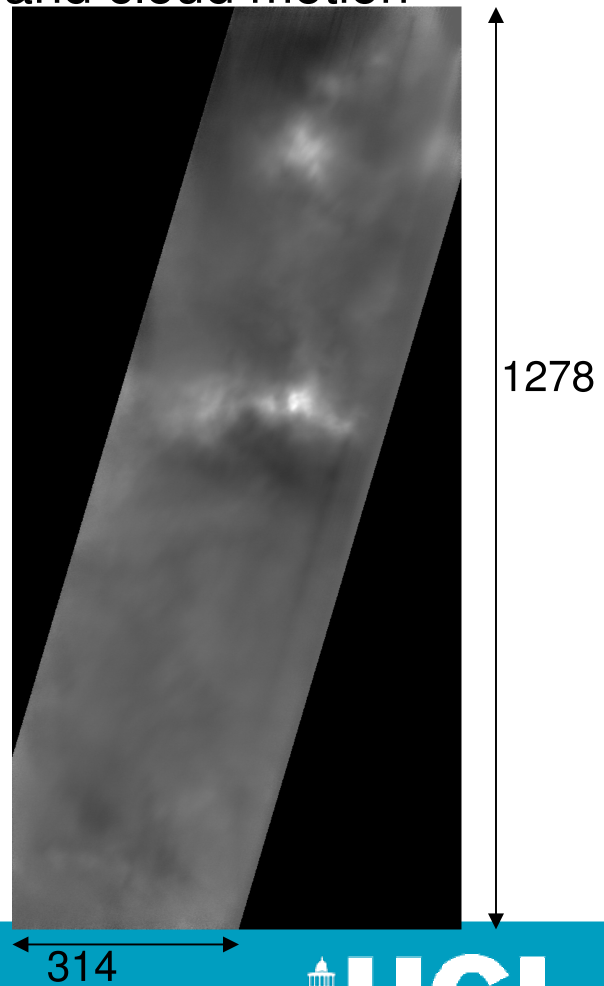
Parameter	Specification
Number of Lines	3
Pixels per Line	512
Pixel Pitch	39 µm
Detector Technology	VOx µbolometer
Combined NETD*	< 0.25 K for: 8.3-9.4 µm 10.4-11.3 µm 11.4-12.3 µm
Spectral Response	Deviation from Ideal Flat Response, < 10 %
Dynamic Range Scene Temperature*	180 K - 350 K
Absolute Temperature Measurement Accuracy	1 K @ 300 K
Response Time	< 8 ms
Integration Time	40 – 140 ms
Outputs	1 digital / line

* per band at 300 K, f/1, τ=0.6, 140 ms integration time

Laboratory Testing of optical IR system

• Integrated Hardware. Test images obtained using low quality PalmIR ferro-electric 320 x 240 pixel TIR camera
• Laboratory scene: Static, corrected for scan motion
• Cloud scene: Dynamic: corrected for scan motion and cloud motion





WINDS/MISRlite for EEO8 - support

- **ESA Earth Explorer no.8 call with 1 June 2010 deadline for a 3 microsat system for technology demonstration to lead to a constellation to provide global data every 3 hours everywhere all the time**
- **UK Met Office, KNMI and MétéoSwiss partners, seeking further operational partners to join the bid team**
- **Freie Universität Berlin and MPI Hamburg as academic partners**
- **Need detailed user requirements for operational system**
- **Need support to develop an OSSE for WINDS and study the complementarity of WINDS and ADM-AEOLUS and future DWLs**
- **Need strong support from this workshop and GCMS to ensure that ESA take the proposal seriously**