Cloud-top property retrievals using (A)ATSR(2), MISR and MODIS

Jan-Peter Muller, Ludwig Brinckmann, Catherine Naud, Marie-Ange Denis*
jpm@mssl.ucl.ac.uk
**Head, Imaging Group*
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)
Chair, CEOS-WGCV TMSG; Point of Contact, GEO Task DA-09-03d

Overview

- **Context - clouds in climate, where are they?**
- **ISCCP - is this still useful for climate studies?**
- **EO systems for cloud-top properties:**
  - **(A)ATSR(2), MISR and MODIS basics**
- **Summary of error characteristics from validation**
- **Sampling issues for Global cloud climatologies**
- **Conclusions**

Context: Level of understanding of radiative forcing sources in the climate system

N.B. IPCC
Clouds ignored even though they are as important as CO2.
High clouds==> Increase warming
Low clouds==> Reduce warming

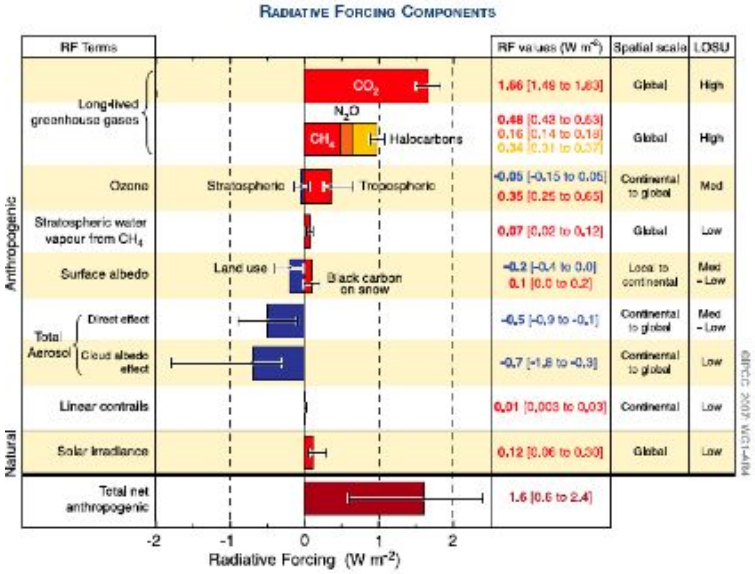
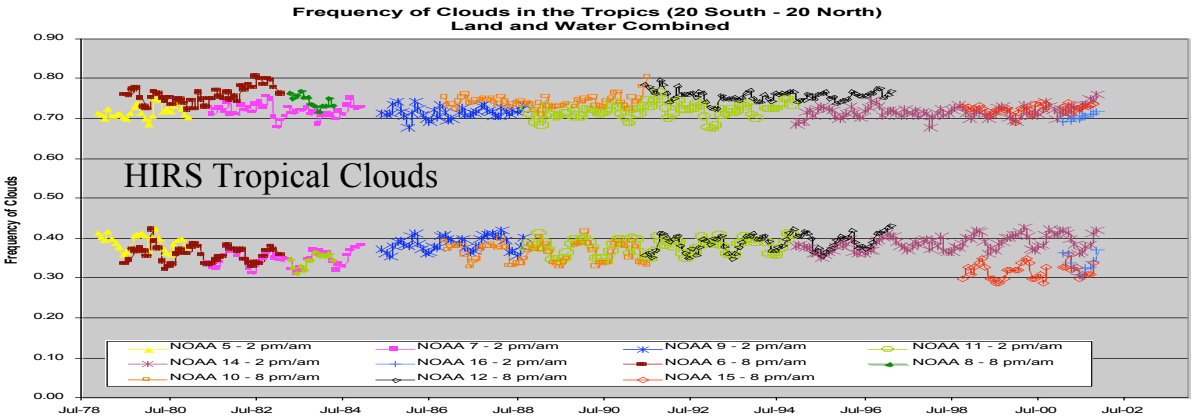
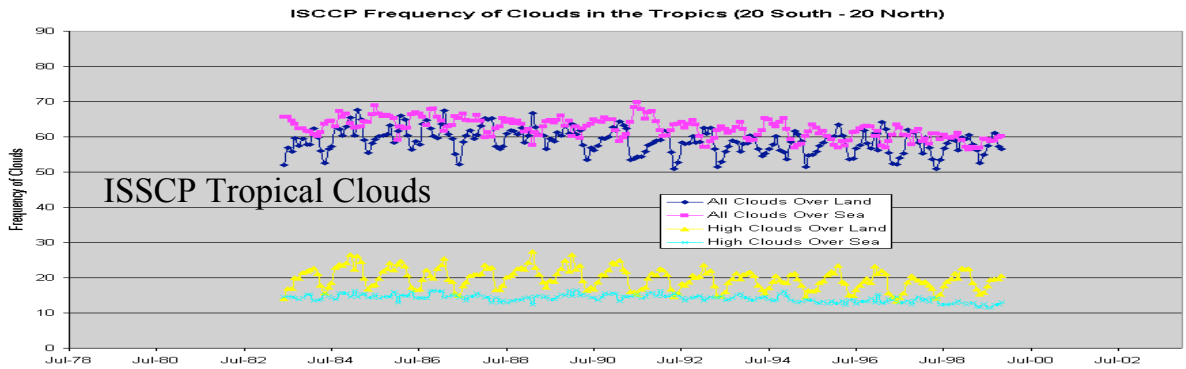


Figure SPM.2. Global average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). The net anthropogenic radiative forcing and its range are also shown. These require summing asymmetric uncertainty estimates from the component terms, and cannot be obtained by simple addition. Additional forcing factors not included here are considered to have a very low LOSU. Volcanic aerosols contribute an additional natural forcing but are not included in this figure due to their episodic nature. The range for linear contrails does not include other possible effects of aviation on cloudiness. (2.9, Figure 2.20)





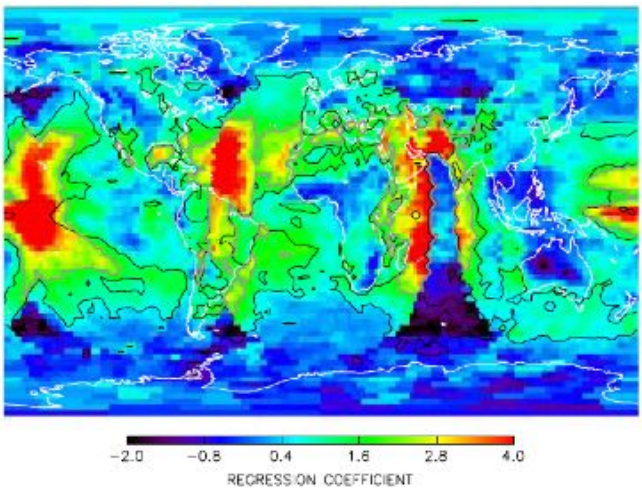
Conclusions from ISSCP Comparisons

•ISSCP finds fewer 10% high and all clouds

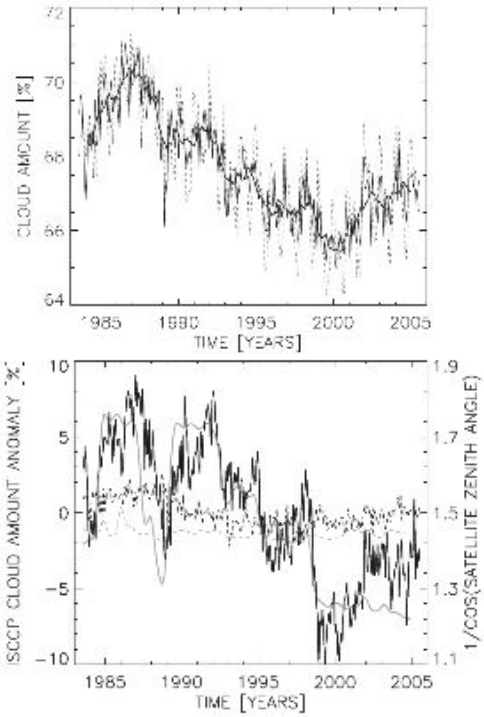
*** ISSCP shows gradual decrease in all clouds**

Courtesy of Paul Menzel

Results undermines use of ISCCP data for cloud trend analysis

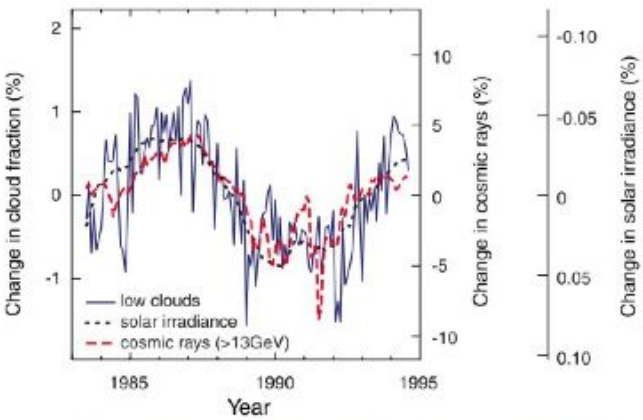


Evan, A. T., A. K. Heidinger, and D. J. Vimont (2007), Arguments against a physical long-term trend in global ISCCP cloud amounts, Geophys. Res. Lett., 34, L04701, doi:10.1029/2006GL028083

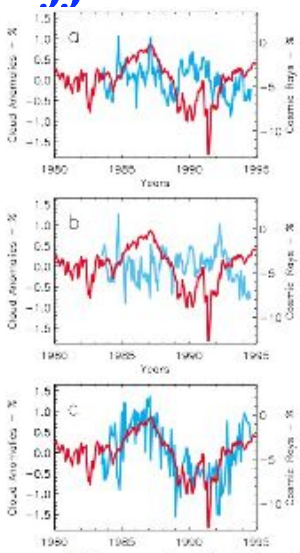


Solar-Earth Climate interactions : are these due to ISCCP sampling effects?

- **Low clouds are correlated with with solar and auroral activity**
- **Low clouds REFLECT sunlight and COOL the atmosphere**



Variation of low-altitude cloud cover, cosmic rays, and total solar irradiance between 1984 and 1994. The cosmic ray intensity is from Huancayo observatory, Hawaii. Carslow et al., Science (2002)



Global average of monthly cloud anomalies for (a) high (<440 hPa), (b) middle (440–680 hPa), and (c) low (>680 hPa) cloud cover (blue). To compute the monthly cloud anomalies the annual cycle is removed by subtracting the climatic monthly average (July 1983–June 1994) from each month on an equal area grid before averaging over the globe. The global average of the annual cycle over this period for high, middle, and low IR detected clouds is 13.5%, 19.9%, and 28.7%, respectively. The cosmic rays (red) represent neutron counts observed at Huancayo (cutoff rigidity 12.91 GeV) and normalized to October 1965.

Marsh and Svensmark, Phys. Rev. Lett. (2000)

EO systems for cloud-top properties

Stereo-photogrammetry
CO2 slicing

What Cloud Data Products?

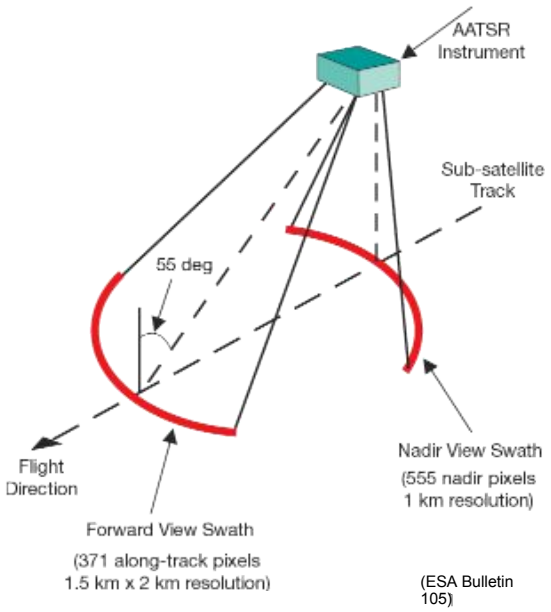
- **Macroscopic**
  - **Cloud detection and fraction**
  - **Cloud boundary and thickness heights (stereo)**
  - **Cloud boundary winds**
  - **Multi-layer cloud detection (multispectral stereo)**
  - **Cloud phase and cloud type**
  - **Cloud BRDF and albedo**
- **Microscopic**
  - **Cloud optical depth (water droplet and ice crystal)**
  - **Cloud effective drop radius**
  - **Cloud emissivity**
  - **Cloud number concentration**

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 correct for cloud-top winds, preferably using data from the same instrument

Along-track Scanning Radiometer (ATSR)

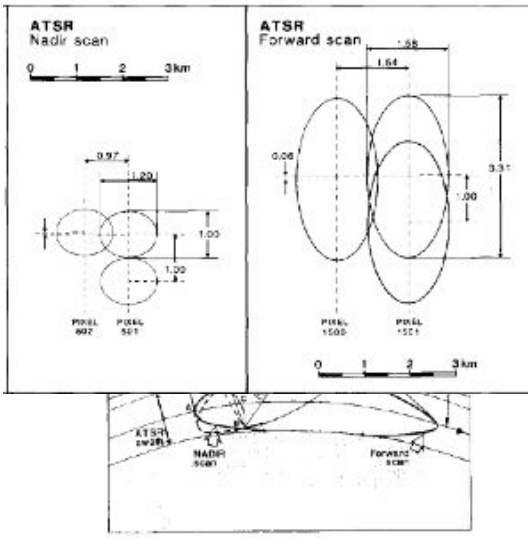
- Monitoring and detecting climate change
  - Sea and Land Surface Temperatures
  - Vegetation
  - Fire Monitoring
- On-board (thermal) calibration
- Conical scanner with dual view
  - Nadir 0-22°, Forward 55-52°
  - 500km swath
- Seven channels
  - Thermal: 11, 12µm
  - SW/NIR: 3.7, 1.6µm
  - Visible (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 1995-present day
  - AATSR launched 2002-present day
- Stereoscopic height retrieval
  - M4 stereo matcher (Muller et al., 2006) => 3km
  - CTHs processed for 5 years (1995-2000) for Europe+Atlantic, global -selected months only



(ESA Bulletin 105)

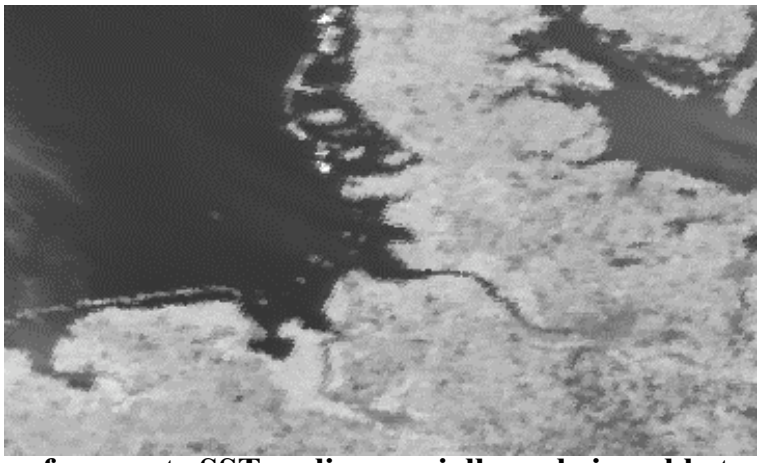
ATSR Image Preparation

- ATSR Viewing Geometry
  - 2000 pixels in one scan
    - » Pixel size increases with distance
    - » 555 nadir, 371 forward
    - » Increasing overlap
- Image rectification
  - Most applications require a 'normal image'
  - Conical scan with differently sized pixels forced into rectangular grid with square pixels
  - Gridded Brightness Temperature Product
  - 512 pixels swath width, 1km x 1km pixel
  - Parallel epipolar lines
  - Co-registration of nadir and forward view
- Envisat Format
  - Common format for ATSR, ATSR-2, AATSR
  - Continuous orbit
    - » Implications for edge effects and scene selection



Prata & Turner 1990

ATSR Co-registration Error

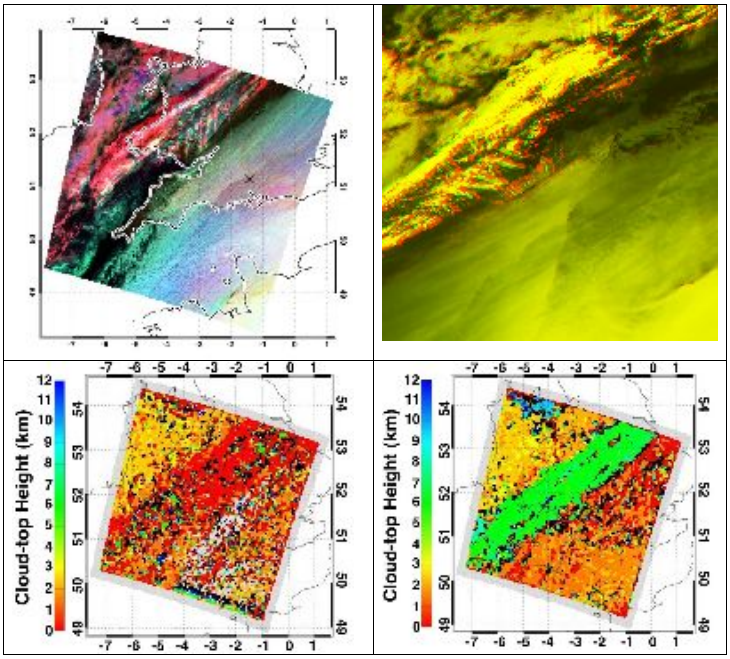


- 'Derivation of accurate SSTs relies crucially on being able to co-locate the dual-angle views.' (Prata 1990)
- Possible Reasons for mis-registration
  - Dynamic Pointing Errors
  - Topographic Errors
  - Static Pointing Errors
  - Band Misalignment
    - » Jovanovic (2002)

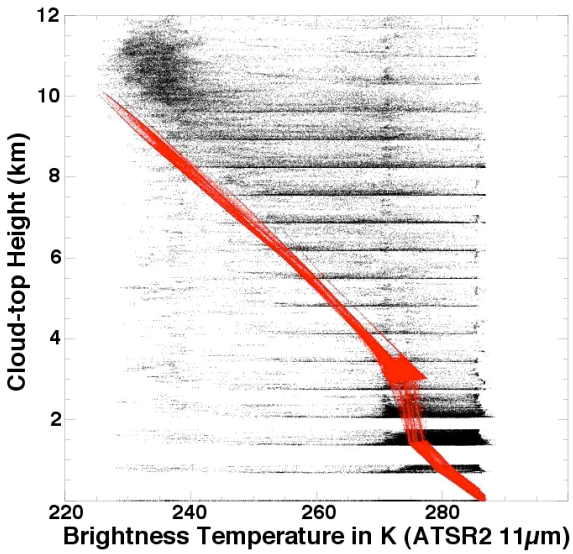
Example of ATSR2 Multispectral capability to sample thin high Ci over dense StCu

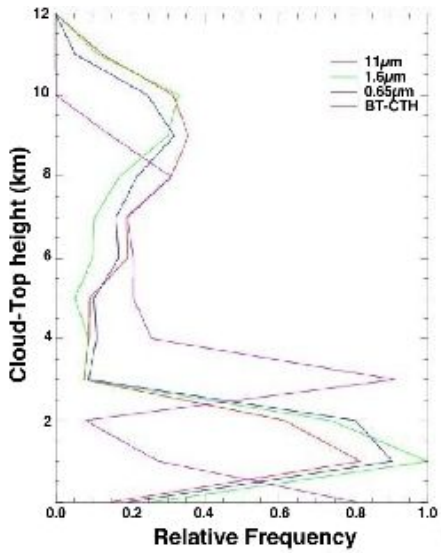
False Colour Composite of 11µm, 1.6µm, 0.68µm (left)
Red/Green stereo anaglyph (right)

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

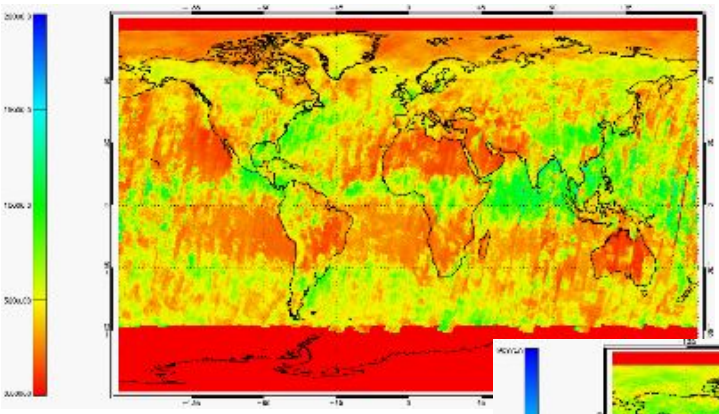


Intercomparison of CTHs from stereo cf. Brightness Temperatures

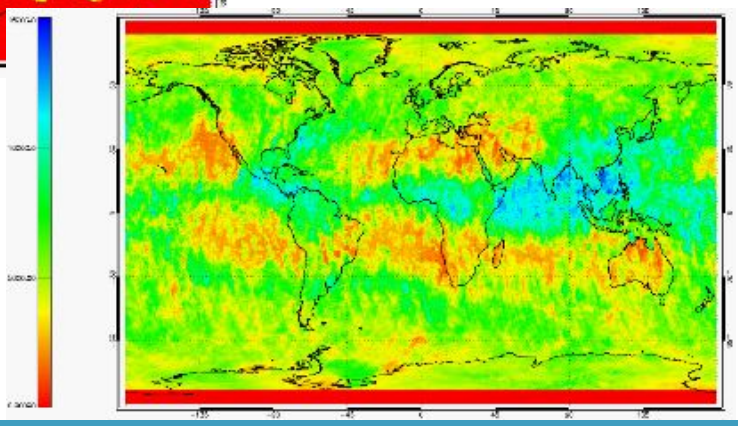




AATSR MONTHLY Cloud Climatologies



0.87µm June 2003

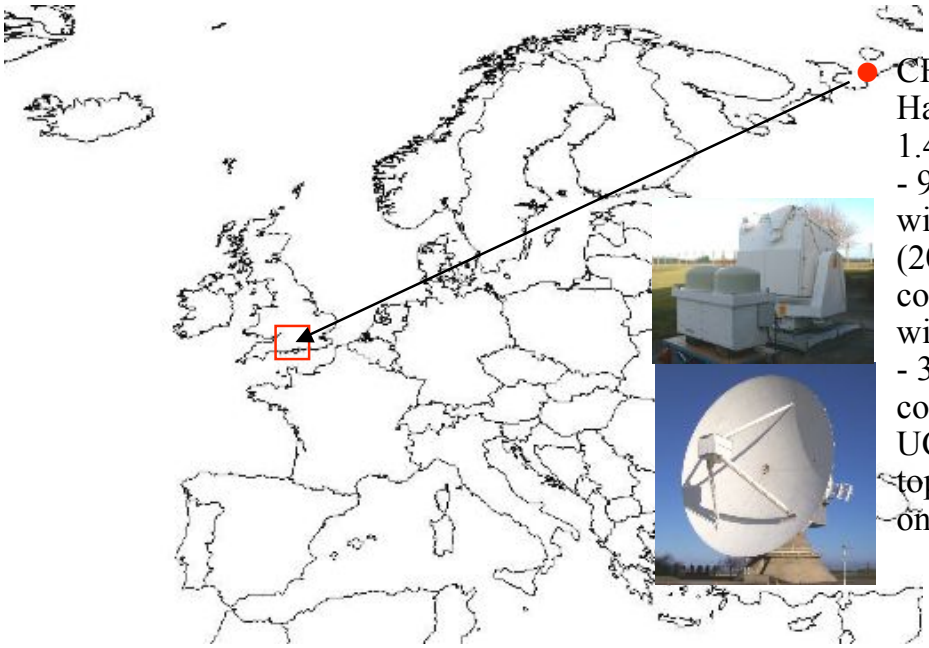


11µm June 2003
Picks up high tropical clouds
Sampling patterns visible

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, see Caroline Poulsen talk tomorrow) 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)

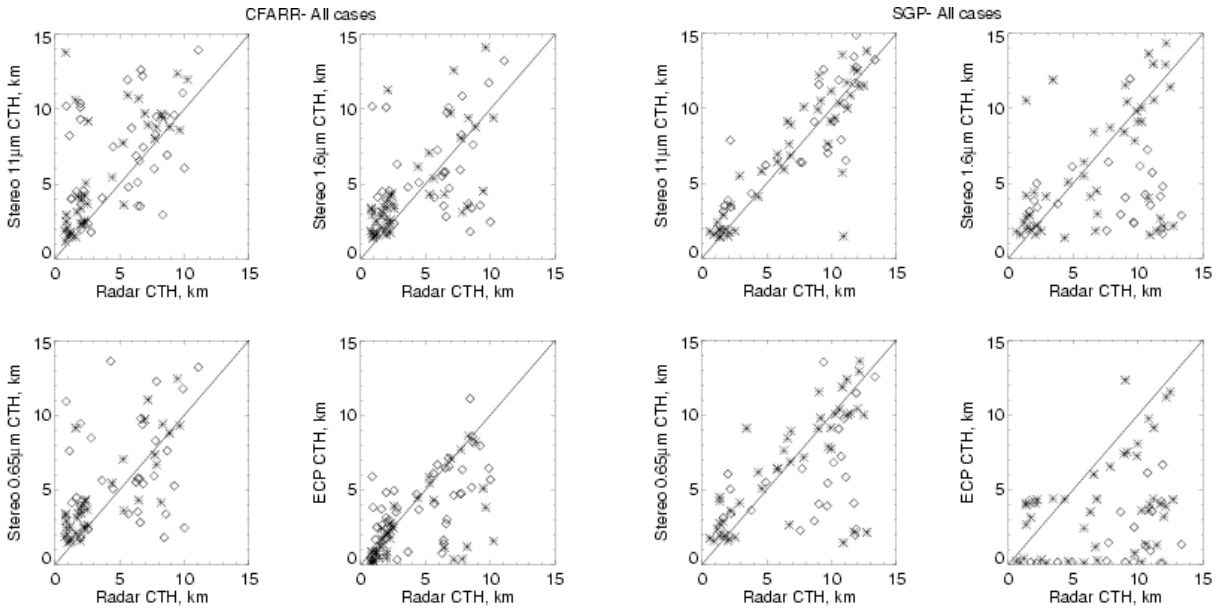
Locations and ground-based instruments (2)

- **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

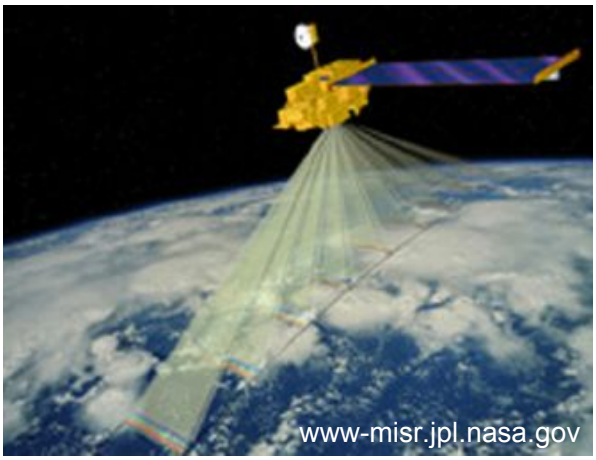
ATSR2 stereo heights validation: conclusions

- **11µm ATSR2 stereo cloud top heights: high bias, best for SGP with a difference of -0.3±2.2km for all cases, single (-0.2±2.1km) or multi-level clouds (-0.4±2.3km) do not affect results. CFARR: overall difference= –2.1±3.7km, single level clouds= –1.9± 2.7km, multi-level clouds= –1.8±3.7km.**

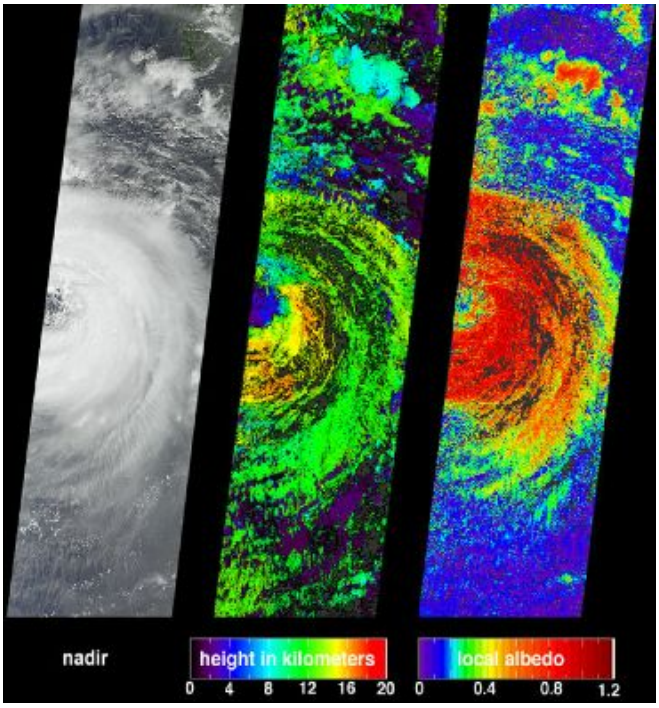
  ATSR2 11µm CTHs detect broken high clouds that are detected by the radar but for a shorter period than for a lower cloud layer.
- **1.6µm ATSR2 stereo cloud top heights: fairly good agreement with the radar CTHs: single level cloud cases at CFARR with a slight high bias. Not as good for SGP, especially when there is cloud overlap. For single and low-level clouds: –0.8±2.5km.**
- **0.65µm ATSR2 stereo cloud top heights: good agreement with radar CTHs for single cloud layers, better at CFARR (lower clouds) than at SGP. better agreement with the radar for single level clouds than for 1.6µm channel, single and low-level clouds: –1.0± 1.9km.**
- **ECP ATSR2 cloud top heights: better agreement at CFARR than at SGP, better for low and single-level clouds: 1.1±2.7km.**

Multiangle Imaging Spectro-Radiometer (MISR)

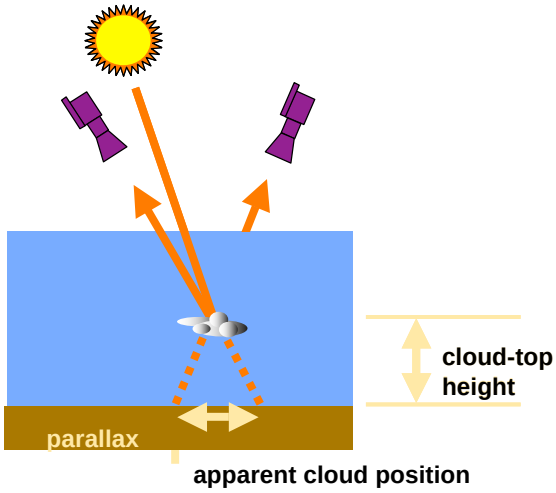
- **Monitoring clouds, aerosols and vegetation**
- **Pushbroom scanner at nine angles**
  - **Nadir**
  - **Forward at 26.1, 45.6, 60.0, 70.5°**
  - **Aft at 26.1, 45.6, 60.0, 70.5°**
- **Four bands**
  - **Three visible (0.44, 0.55, 0.65µm)**
  - **NIR (0.87µm)**
- **360km swath, 275m pixel size**
- **Launched 1999, began ops in 3/00**
- **Operational stereoscopic cloud-top height retrieval**
  - **M2/M3 stereo-matchers (Muller et al. 2002)**
- **CTHs produced at 2.2km and cloud-top winds at 70.4km**



MISR cloud-top heights and albedos : Heritage



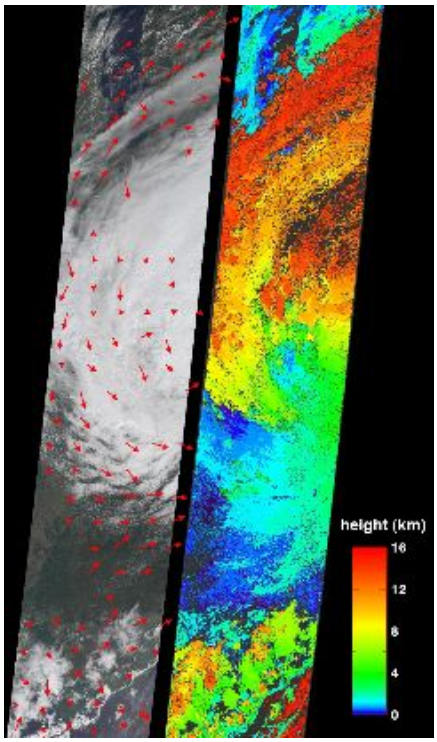
Typhoon Sinlaku, 5 September 2002



Height attributes

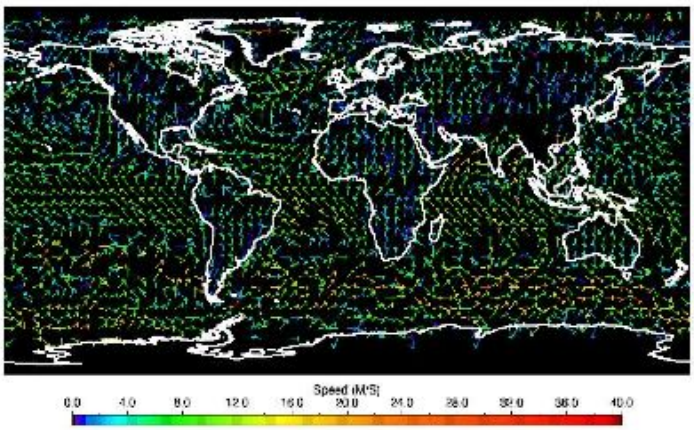
- derived from purely geometric approach
- completely automated, globally
- independent of radiometric calibration, atmospheric temperature profiles, and cloud emissivity
- instantaneous height accuracies of 500 m - 1 km, validated against ground-based radar/lidar

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

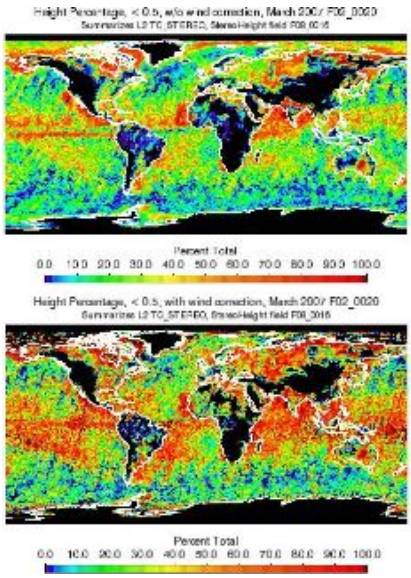
- derived from purely geometric approach
- completely automated, globally
- instantaneous wind accuracies of 1-3 m/sec
- validated against radiosondes and Doppler radar
- can be applied to severe weather systems

NASA-GMAO evaluation of MISR winds

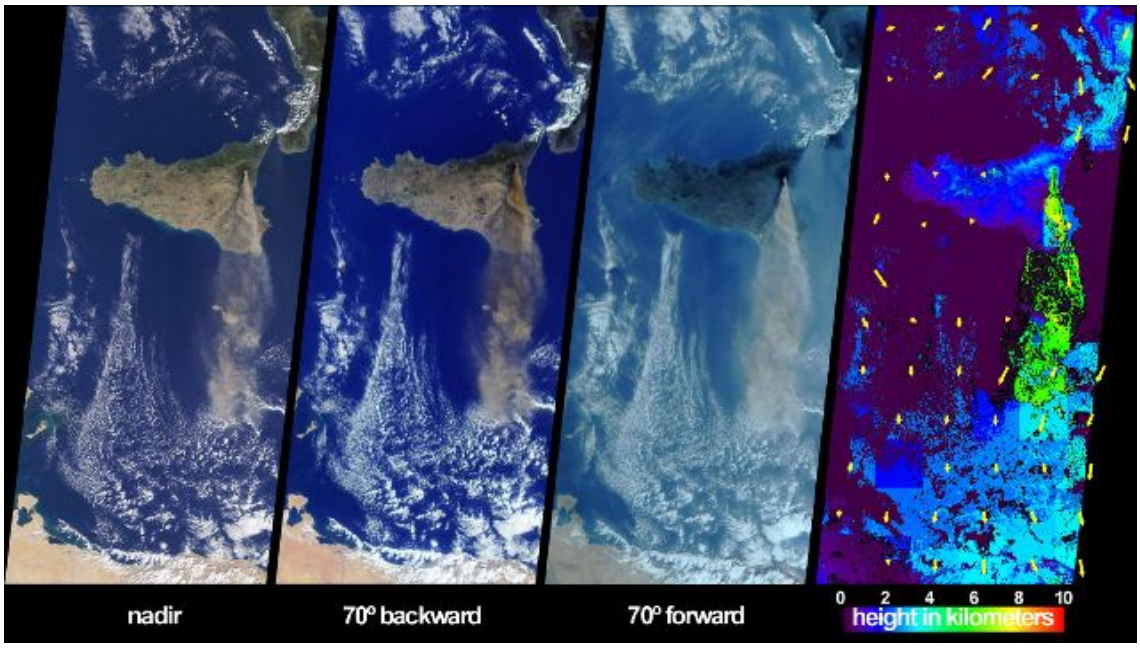
- Analysis performed for period 9/1/03 to 10/15/03
- MISR height-resolved winds were compared against GMAO 6 hr forecast
- Findings:
  - negligible (<1 m/s) bias differences
  - 5.1 m/s RMS differences for low level winds, increasing to 10.5 m/s for high level winds
  - forecast wind errors increase with wind speed (i.e., height), but their absolute accuracy is unknown
- BUT, comparisons of independent retrievals from MISR forward and backward camera triplets show:
  - minor increase in error with height
  - ! 0 bias
  - ! 1-3 m/s RMS consistency, depending on quality assessment threshholds
- It is possible that a significant component of the RMS differences between MISR and GMAO winds are random errors in the forecast winds (of the order 4-9 m/s, increasing with height)

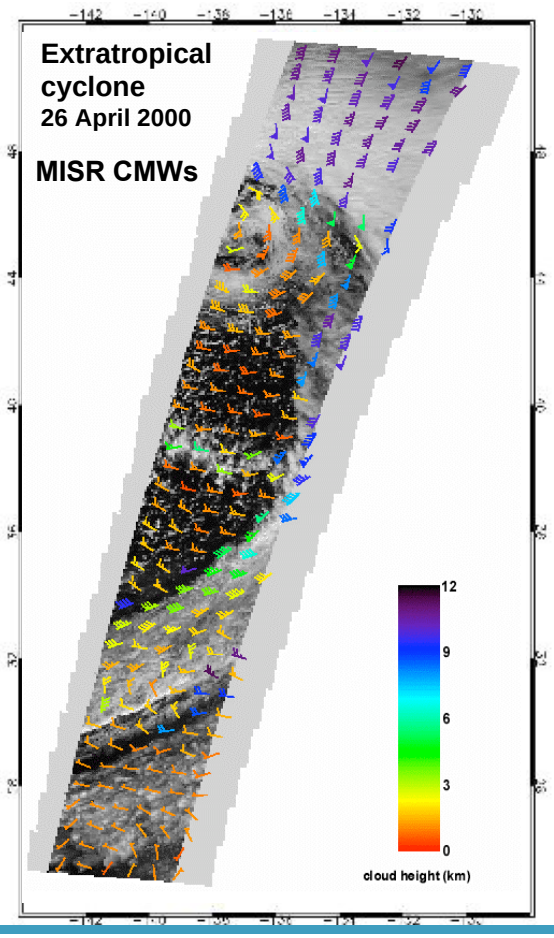
Existing MISR 2TC scheme shortcomings

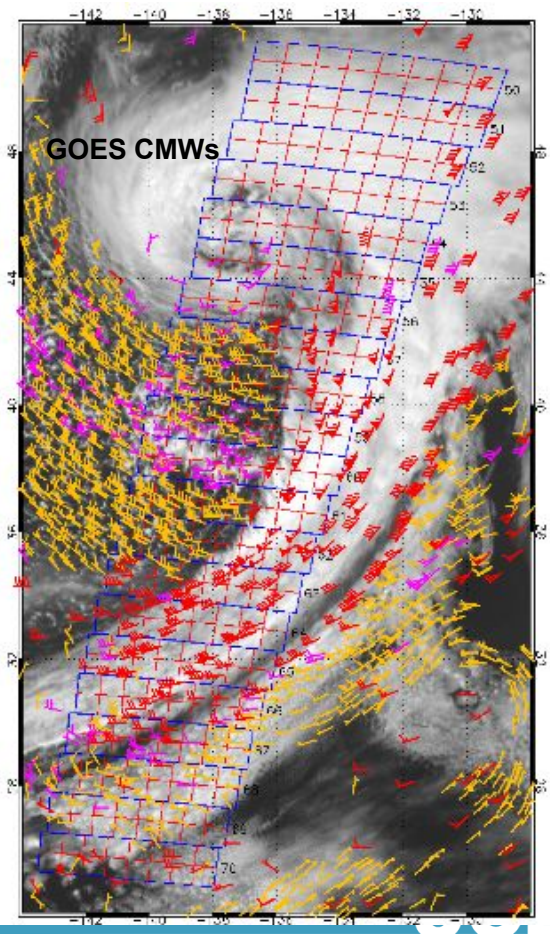
- **Drastic reduction (≈70%) of the number of valid cloud-top heights due to the current schemes used for wind detection**
- **Only 3 innermost MISR cameras employed so misses high thin Ci overlying optically thick clouds resulting in biases in the statistics**
- **Only operates during daylight even though CTH and winds excellent over polar regions during daylight**
- **Narrow swath (380km) so little use in NWP (YET)**
- **Sampling patterns evident for monthly means**



MISR aerosol-top heights and winds

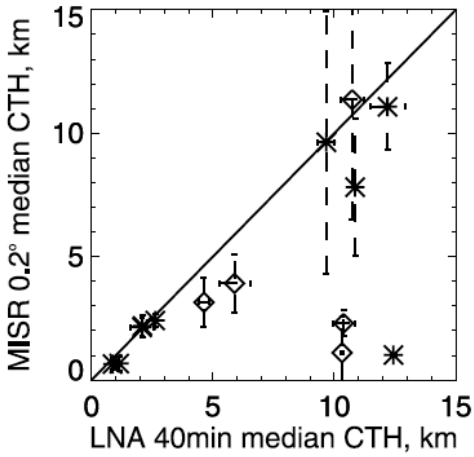


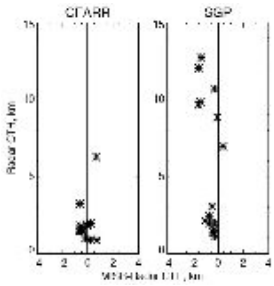




MISR Cloud-top height validation using radar/lidar and lidar alone

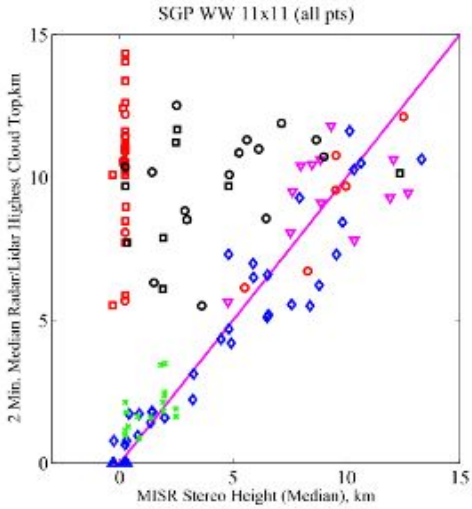
Palaiseau





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

0.05±0.62km

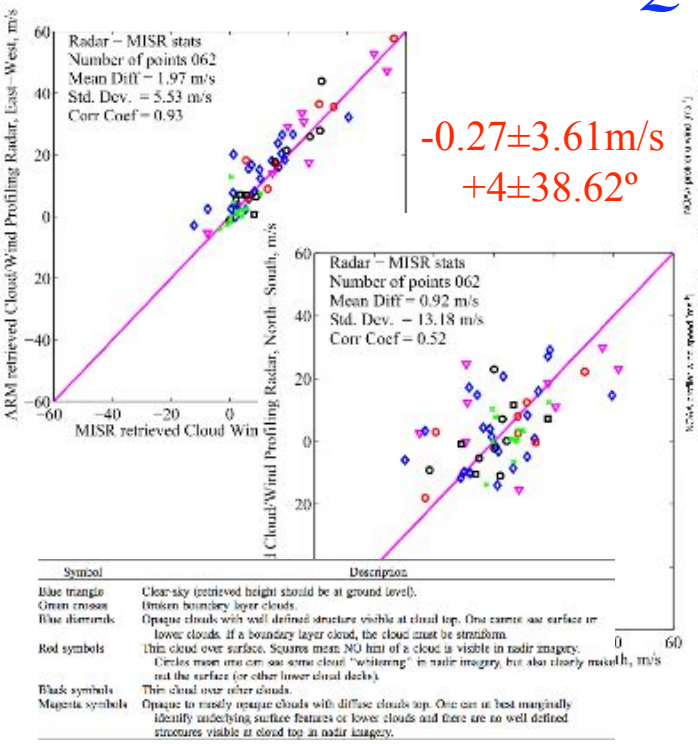


Naud, Muller et al., GRL (2004)
Limiting optical depth>0.01

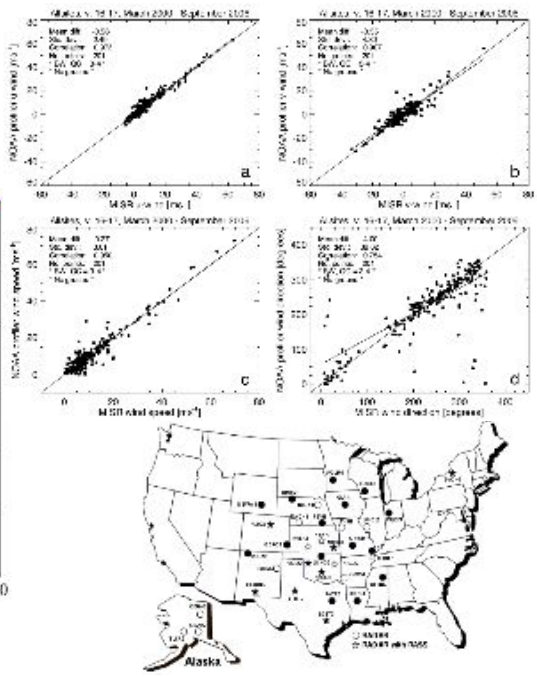
Marchand et al. JGR (2007)

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

MISR Best wind Quality Assessment



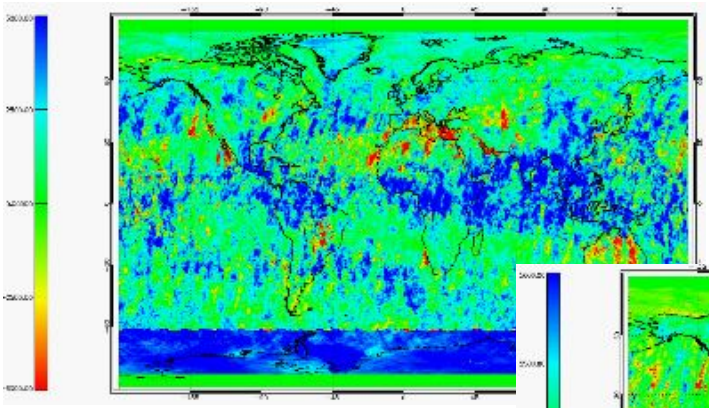
-0.27±3.61m/s
+4±38.62º



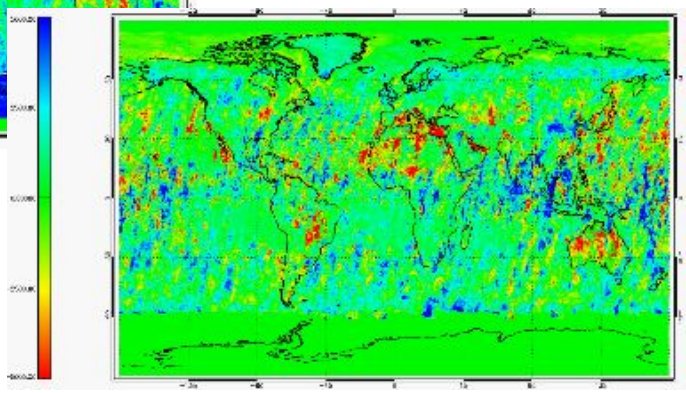
Marchand, Ackermann, Moroney, JGR (2007)

Hinkelman, Marchand, Ackerman, JGR (in press)

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



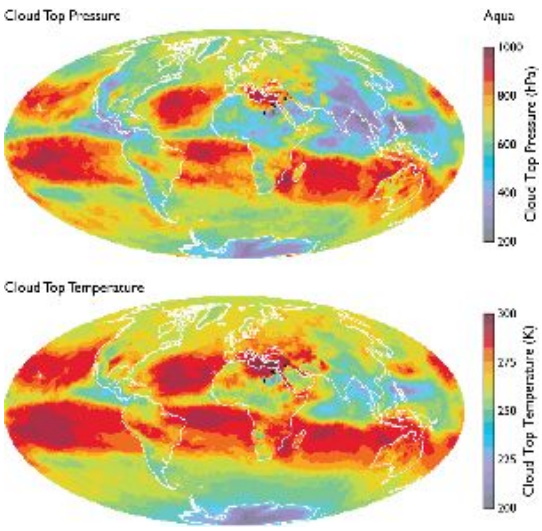
AATSR (12µm)-MISR



AATSR (0.67µm)-MISR

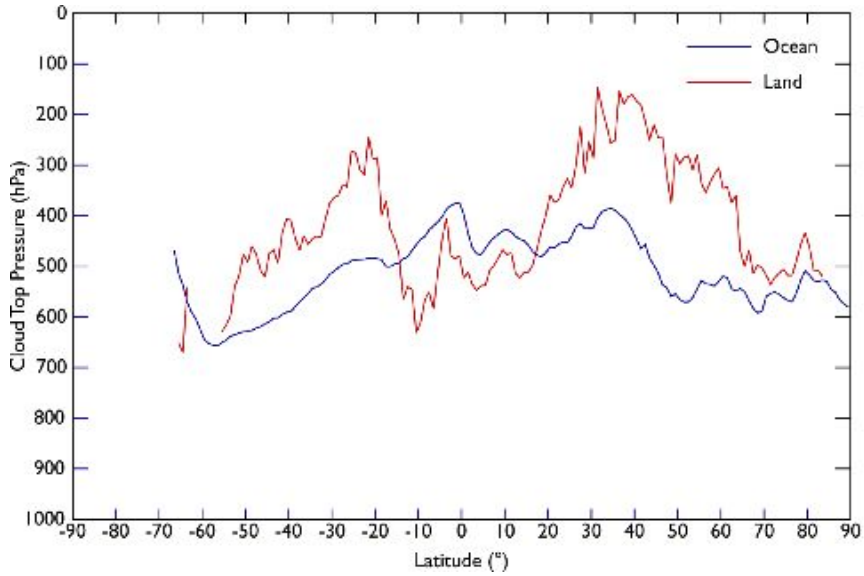
MODerate resolution Imaging Spectrometer MODIS

- **5km product due to noise in TIR channel**
- **1km cloud mask**
- **Relies on complex logic for cloud detection, especially over land**
- **Cloud-top pressure best for optically thick clouds**
- **Worst for low level clouds due to use of brightness temperature rather than CO2 slicing**
- **CTP often located within the cloud rather than at the actual cloud-top**

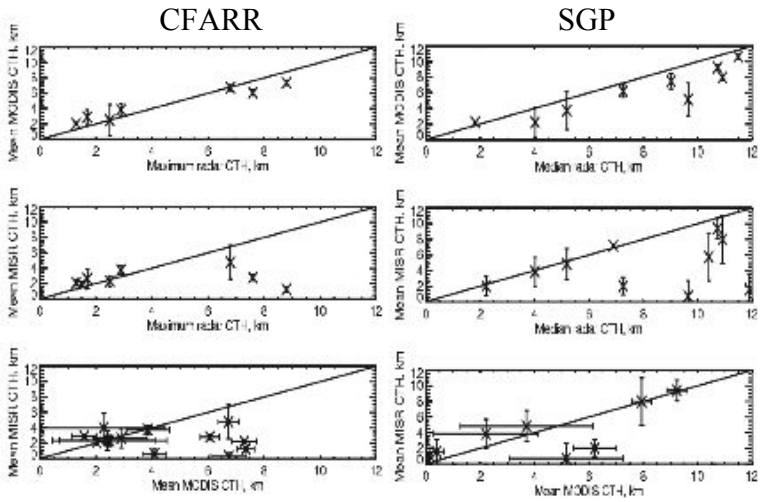


July 2006. Menzel, Frey et al. (Uwisc)

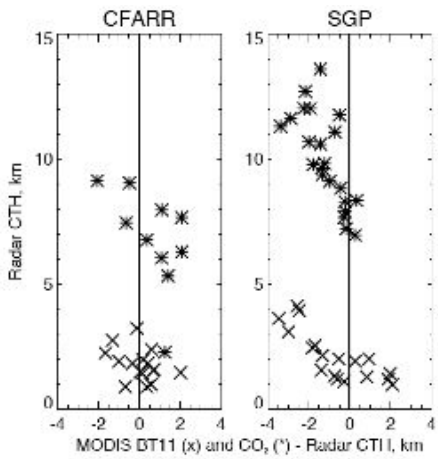
Zonal profiles of MODIS Cloud-Top Pressure over land and ocean



MODIS, MISR and Radar/Lidar CTH assessments



Naud, Muller, Clothiaux, GRL (2002)

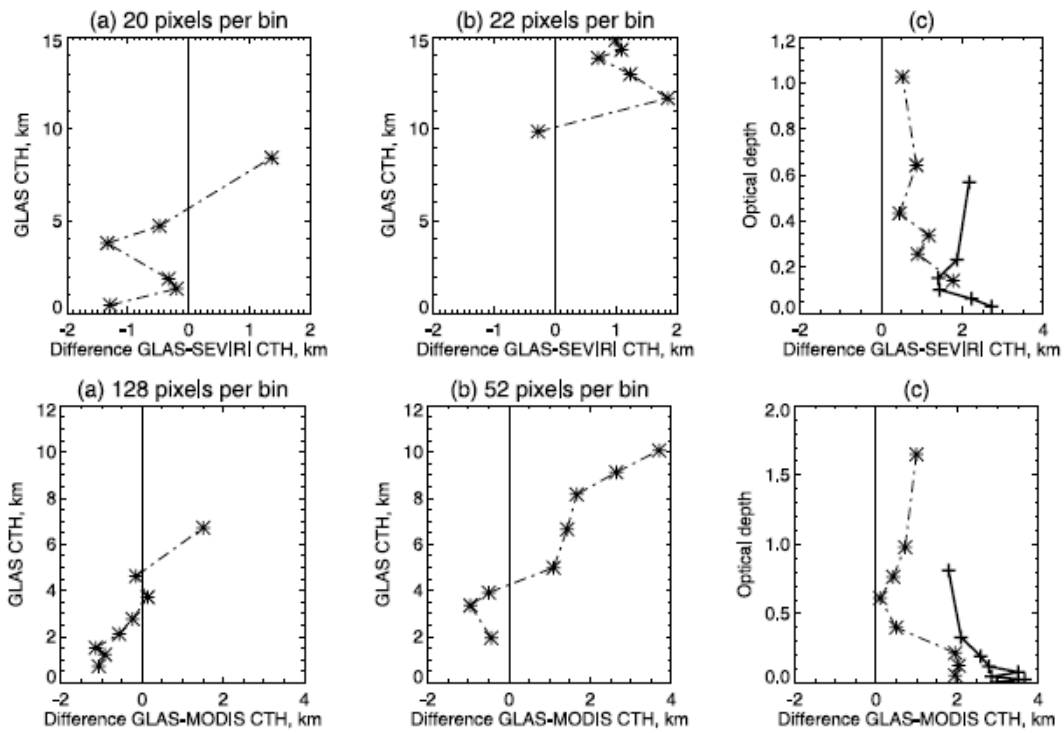


Naud, Muller et al., Ann. Geophys. (2005)

MODIS-radar:-1.2±1km (SGP); 0.6±1.3km (CFARR)

Limiting optical depth>0.13 (Naud et al., GRL (2004)

And how does ICESAT compare to SEVIRI?



MODIS: -0.3±1.5km; SEVIRI: -0.4±2.1km; Naud, Muller et al., GRL (2005)

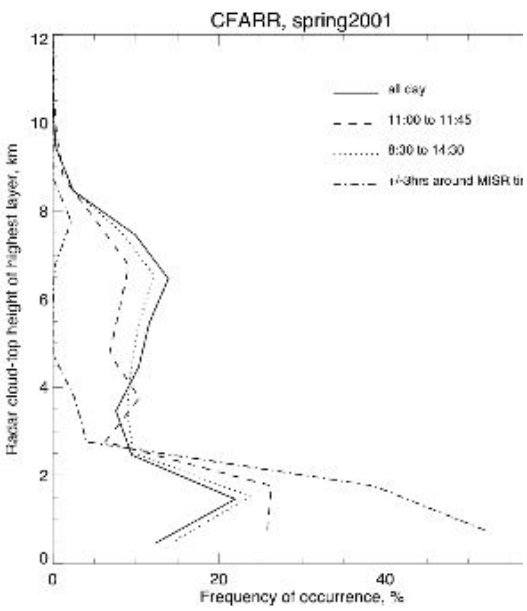
How does polar-orbiting sampling affect representativeness over different sites

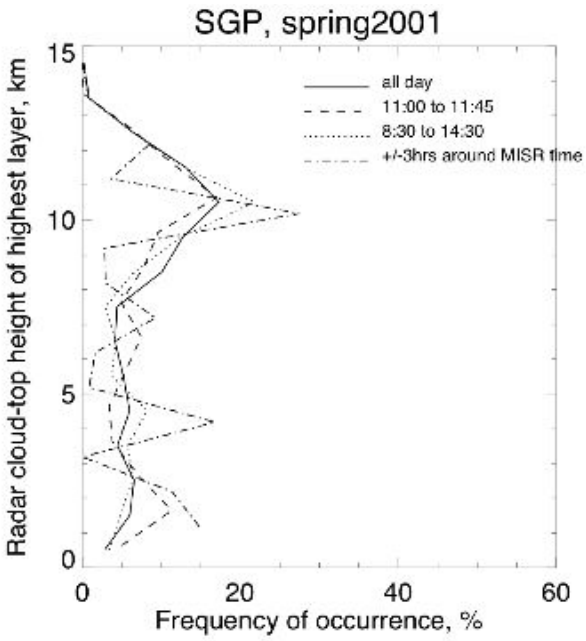
Use CFARR & SGP radar/lidar data and compare sampling using full diurnal cycles cf. polar orbiter sampling

Fusion of MISR and MODIS CTH

- **Fusion has been proposed in the US at the data product level but we need to first address the issue of..**
- **How representative is MISR (and MODIS) with limited spatio-temporal coverage?**
- **Use radar CTHs for the same time of day and for the same dates as MISR/MODIS to investigate sampling issues**
- **Spring 2001 (March-April-May), at CFARR and SGP, radar CTH statistics for 1 season**
- **Comparison with MISR/MODIS CTHs**

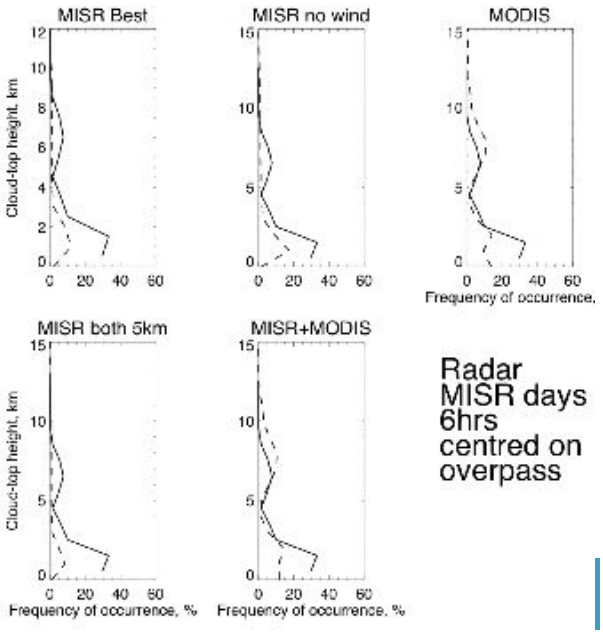
CTH distributions for different time sampling periods using Radar data only





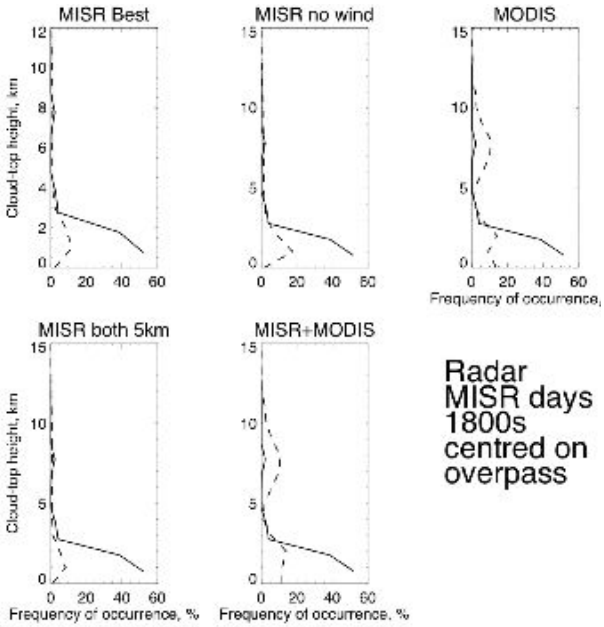
Comparison for same days: CFARR radar sampled over 6hrs or 30min

2.5°



Radar
MISR days
6hrs
centred on
overpass

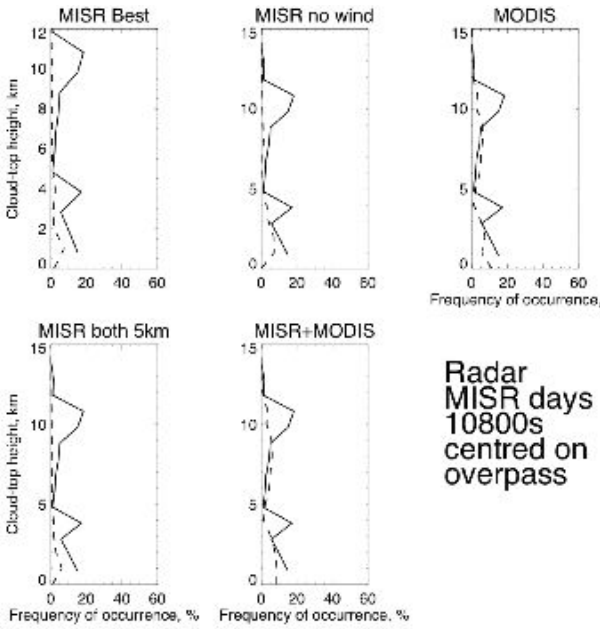
2.5°



Radar
MISR days
1800s
centred on
overpass

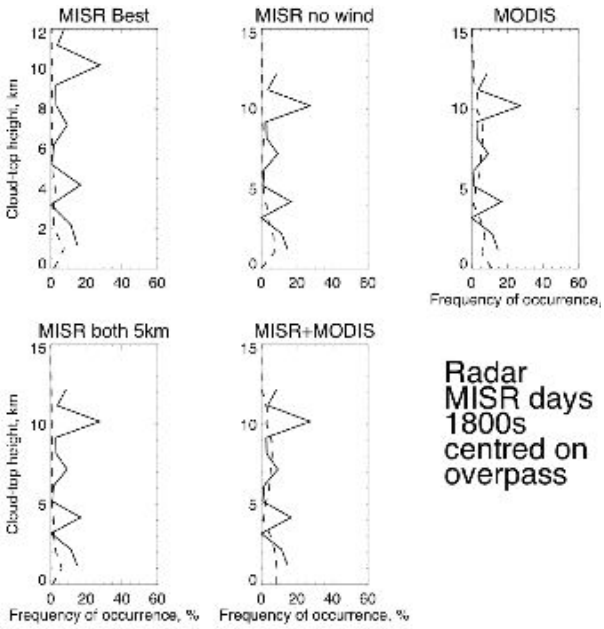
Comparison for same days: SGP radar sampled over 6hrs or 30min

2.5°



Radar
MISR days
10800s
centred on
overpass

2.5°



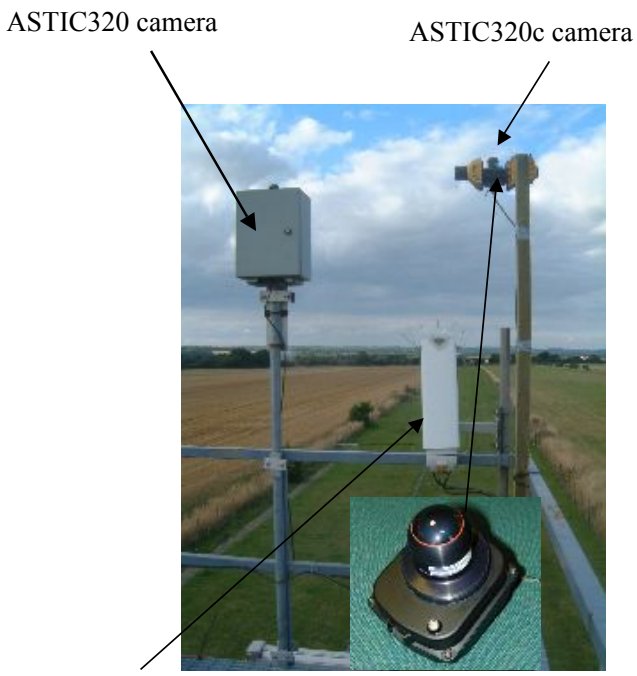
Radar
MISR days
1800s
centred on
overpass

Tentative conclusions

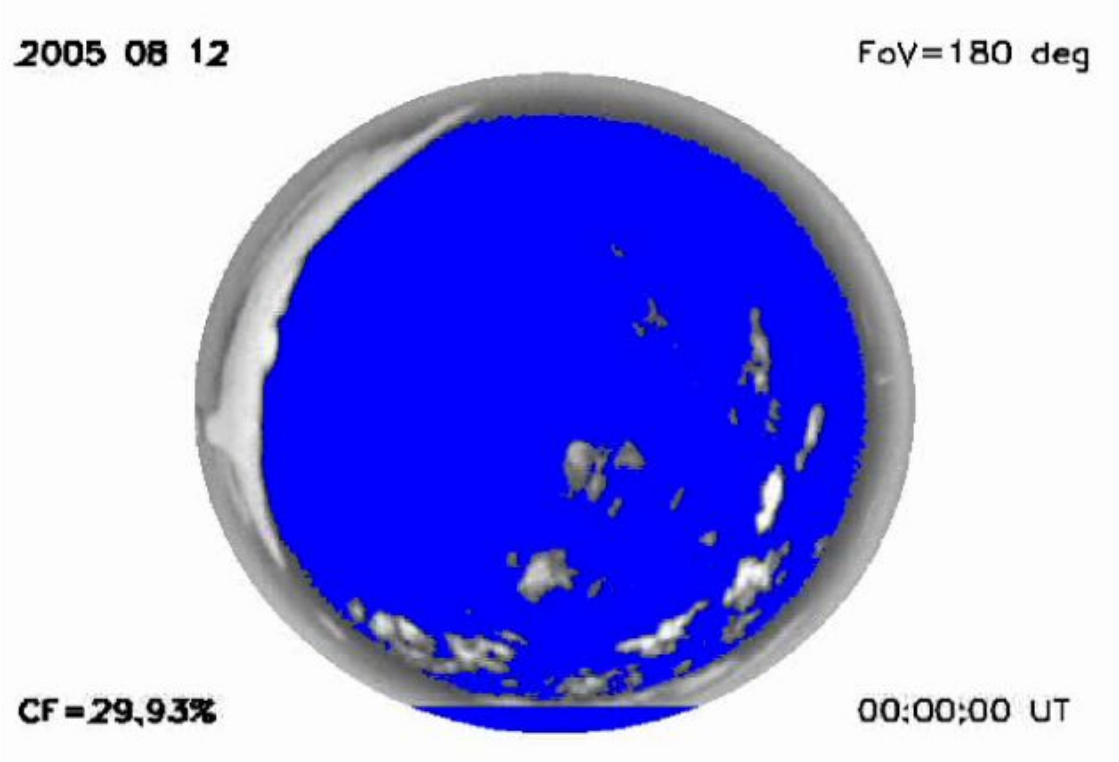
- **Surprising result that daily sampling of (radar) CTHs around time of Terra overpass matches seasonal CTH distribution from continuous sampling**
- **At CFARR, radar CTH distributions for TERRA overpass days matches combined MISR/MODIS CTH but not at SGP**
- **Comparison of CTH distributions for daily radar against MISR+MODIS CTH show missing mid-level clouds in satellite data at CFARR and large disagreements at SGP for all CTHs**
- **Should we increase sample area size? Include orbits at edges?**

Cloud cover fraction assessments at Chilbolton

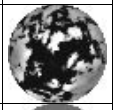
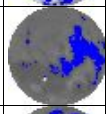
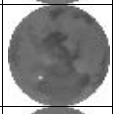
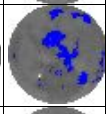
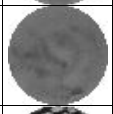
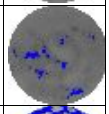
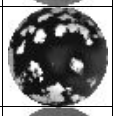
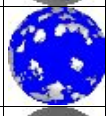
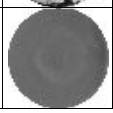
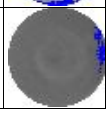
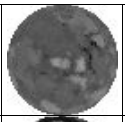
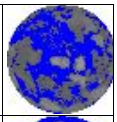
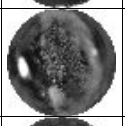
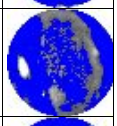
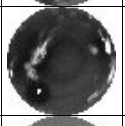
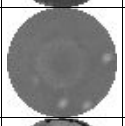
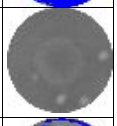
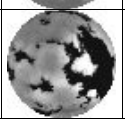
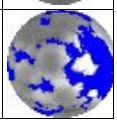
- **Uncooled ferroelectric sensor resistant to direct sun**
- **Operates day and night**
- **Original ASTIC320 camera housed in weatherproof enclosure**
- **New model uses clamp**
- **Sun position used to provide camera geometric calibration**
- **Very few data outages due to insects, birds, dew and precipitation**
- **Two different data acquisition modes:**
  - **1st generation (every 30 minutes except from 11-12UT every 1 minute)**
  - **2nd generation (every 1 minute 24/7)**
- **Continuous measurements from 6/03-6/06 every 1 minute**
- **Daily MPEG animations available from http://cloudmap.org**
- **ASTIC320c installed from August-October 05 and from August 06-November 08 with every 30 second imaging capability**
- **Initial assessment of cloud cover for Aug-Oct 06**
- **ASTIC320c installed at ARM-SGP site since 2006 but not operated continuously**



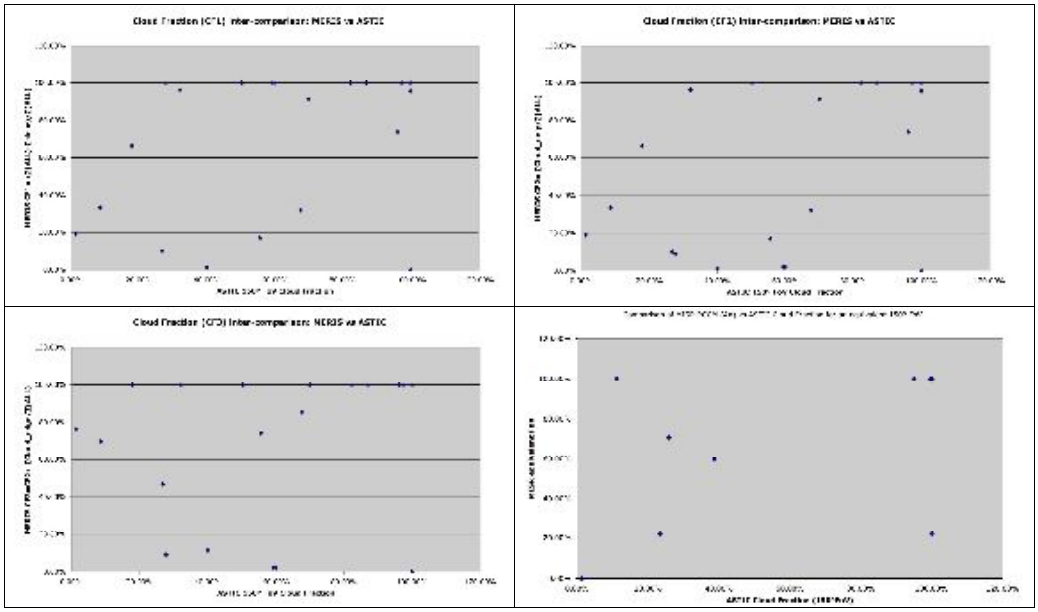
ASTIC320c every 30 seconds for 24 hours



Example ASTIC images for MERIS overpass times

Date	UT	ASTIC -CF	IFoV at zenith	IFoV at 75°	Image captured	Masked image
12/08/05	10:44:59	50.30%	17.80	265.70		
14/08/05	11:21:48	60.00 %	15.85	236.56		
15/08/05	10:50:39	40.00 %	19.74	294.68		
16/08/05	10:19:22	96.20%	13.55	202.35		
18/08/05	10:56:18	26.80%	19.60	292.63		
19/08/05	10:25:03	97.40%	30.78	459.56		
27/08/05	11:13:18	100%	28.86	430.88		
28/08/05	10:42:07	27.77%	9.92	148.06		
09/09/05	11:04:48	32.10%	22.70	338.86		
13/09/05	10:39:17	8.60%	108.73	1623.21		
15/09/05	11:16:07	100%#	1.78	26.58		
16/09/05	10:44:57	69.99%	17.56	262.18		

Assessment of Cloud Fraction for MERIS and for MISR (lower right)



N.B. Little correlation shown for either MERIS or MISR. Many instances of errors of commission. Many examples of 100% satellite cloud cover cf 20-100% ASTIC320c measurements

Conclusions

- **Ground-based radar/lidar the only effective method of long-term validation of spaceborne cloud-top properties**
- **MISR (and (A)ATSR(2)) are very good at detecting thin clouds and clouds at all altitudes,**
- **MODIS better for mid and high-level optically thick clouds, poor for low-level clouds**
- **(A)ATSR(2) can be used for BOTH stereo AND Optimal Estimation but this fusion has yet to be realised**
- **MISR CTHs the most accurate (3-6 times better) with comparable accuracy between (A)ATSR(2) and MODIS**
- **MISR CT winds show zero bias in speed but a large standard deviation in direction**
- **MISR and MERIS CF frequently overly conservative. Is this a general issue?**
- **Polar-orbiting sampling for CFARR and SGP show similar properties as the whole day but this does not take account of synoptic weather systems**
- **Need for concerted continuing effort and extensions to ICEsat, CloudSat, CALIPSO. Limited to MODIS except for polar regions**