The role of CFARR in the EU-CLOUDMAP2 Project

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Overview

- CLOUDMAP2 project: brief description
- Satellite sensor description
- Ground-based instrument description
- CFARR role and achievements
  - MISR, MODIS cloud top height assessment
  - ATSR2 stereo heights assessment
  - MISR, MODIS cloud fraction
  - MERIS water vapour
- Future work

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CLOUDMAP2: Project Overview

- Duration: February 2001 - January 2004, EU-FP5 funded, 8 partners (UCL(inc. PML, PSU), RAL, DLR, FUB, KNMI, SMHI, ETH, MCH).
- Underlying raison d'être
  - Stimulate operational applications of new cloud products from polar-orbiting sensors
  - Contribute towards a deeper understanding of sub-gridscale parameterisation of clouds within NWP and climate models
- Production of cloud parameters (e.g. cloud top height, phase, amount…) for database and near real-time products over Europe & North Atlantic area with web-based interface for dissemination to MetOs
- Assess, qualitatively and quantitatively, how this cloud database could be used to improve the veracity and/or validation of Numerical Weather Prediction models
- Assess the potential of satellite-derived cloud and water vapour products for data assimilation within NWP/climate models

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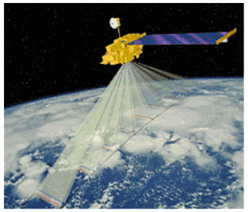
www.cloudmap.org

Satellite instruments and products (1)
NASA: MISR and MODIS



Both onboard TERRA, launched December 1999, MODIS onboard AQUA as well

MISR:

- 9 push-broom cameras at : 0°, ±26.1°, ± 45.6°, ± 60° and ± 70.5°
- 4 wavelengths: 3 visible (0.446µm, 0.558 µm, 0.672 µm) and 1 NIR (0.867 µm), 275m
- 360km swath and same orbit every 16 days, so one site observed up to 6 times per month only
- Stereo cloud-top heights retrieved operationally at 1.1km resolution with 0.672µm channel using algorithm developed at UCL + corrected for wind advection (BestWind)
- Advantages: purely geometrical method, no external climatological information needed
- Limitations: problem when no features with contrast in scene and when there is more than 1 cloud layer
  - Expected to experience problems with multi-layer situations
  - Problems of spurious unrealistic heights or blunders
  - Problems if wind not properly retrieved: no correction

MODIS:

- 36 channels from 0.4 to 14.4 µm, from 250m to 1km resolution
- 2330km swath means that one site can be observed at least once every day
- Cloud top pressures retrieved operationally using CO_2-slicing method at 5km resolution down to 3km and 11 µm brightness temperature below 3km
- Advantages: good performance for high clouds, well tested
- Limitations: depends on externally provided atmospheric temperature and pressure profiles and surface temperature, cannot retrieve accurate cloud top pressure below 3km
- Other cloud products (MOD06): effective emissivity, cloud fraction, cloud phase, cloud top temperature (5km) + optical depth, water path and effective radius (1km)
- Also water vapour (MOD05) in cloud-free areas and above clouds

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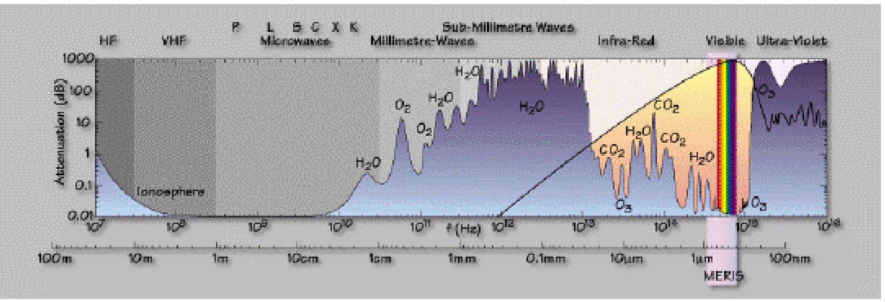
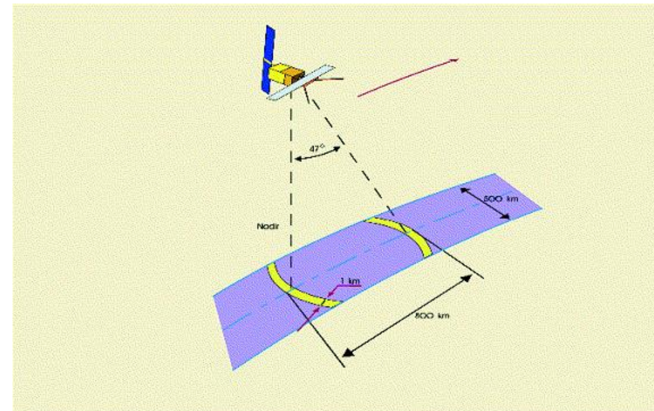
Satellite instruments and products (2)
ESA: MERIS on ENVISAT and ATSR2 on ERS-2



MERIS:

- 15 channels from 0.39μm to 1.04μm at 300m Nadir resolution with 1150km swath, onboard ESA ENVISAT (launched March 2002)
- Cloud top pressure: produced operationally with neural network approach using O_2-A bands (0.753 μm and 0.760 μm), surface albedo and solar angles
- Advantages: good performance for opaque clouds
- Limitations: no retrieval for thin clouds with optical depth less than 5, and dependent on surface albedo, expected to experience problems in multi-layer situations
- Other products: cloud optical depth, water vapour
- Note: ENVISAT 30 minutes earlier than TERRA over SGP



ATSR2:

- Onboard ERS-2, launched Apr 1995, geolocation problems in 2001 and reception cut-off in 2003
- Conical scanner, 2 views (0°, 55°), 7 channels (0.55, 0.65, 0.87, 1.6, 3.7, 11, 12μm), 512km swath, 1km resolution, 8-days repeat time
- Stereo heights derived using stereo-photogrammetry, with matcher M4 developed at UCL, corrected for wind advection using ECMWF Objective Analysis profiles, CTHs derived at 11, 1.6 and 0.65μm

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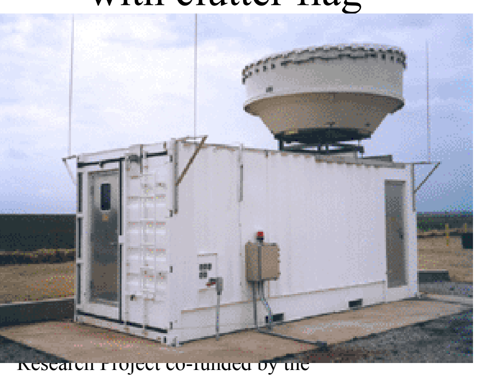
Ground-based instruments (1)
SGP and CFARR

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



- **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)
  - ASTIC320 (Blue Sky Imaging) all sky thermal IR camera, 1 minute observations, day/night

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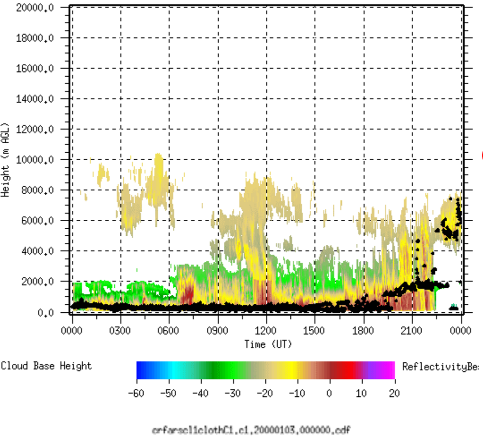
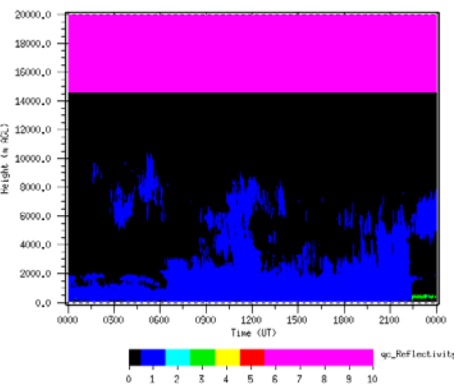
Ground-based instruments (2)
Radar Characteristics and Intercomparison sampling methods





CFARR, 2000-01-03

- Radar: 94GHz at CFARR and 35GHz at SGP, processed with same algorithm (Clothiaux) that produces a cloud mask as a function of time (10s) and altitude (75m). Includes flag for clutter contamination. Cloud base sensitive to drizzle and precipitating hydrometeors, cloud top sensitive to particle size. Accurate to within ≈150m
- Issue: time series vs spatial instantaneous view CTHs sampled over 5, 10, 20 and 40 minute intervals centred on MODIS start time for TERRA and MERIS start time for ENVISAT, Median CTH across time period used
- MISR, MODIS and MERIS sampled in latitude-longitude box centred on ground site, of size ±0.02°, ±0.05°, ±0.1° and ±0.2°, median CTH used for different spatial bin-sizes
- Best agreement usually occurs for largest box and longest time period (overcomes broken cloud situation problem)

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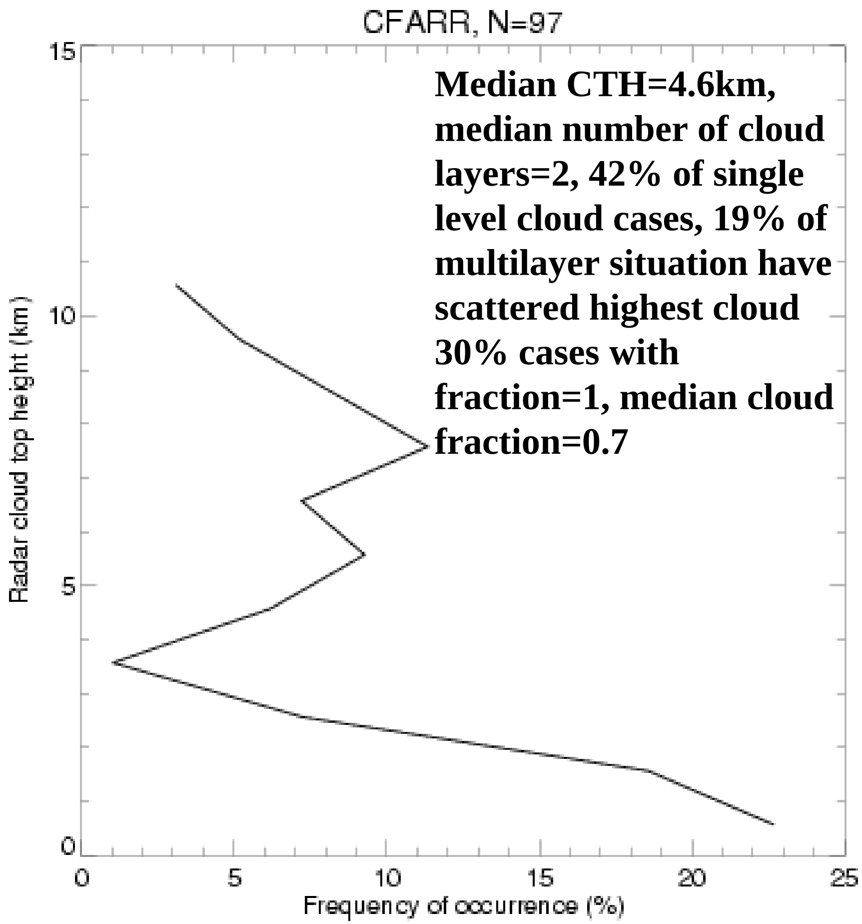
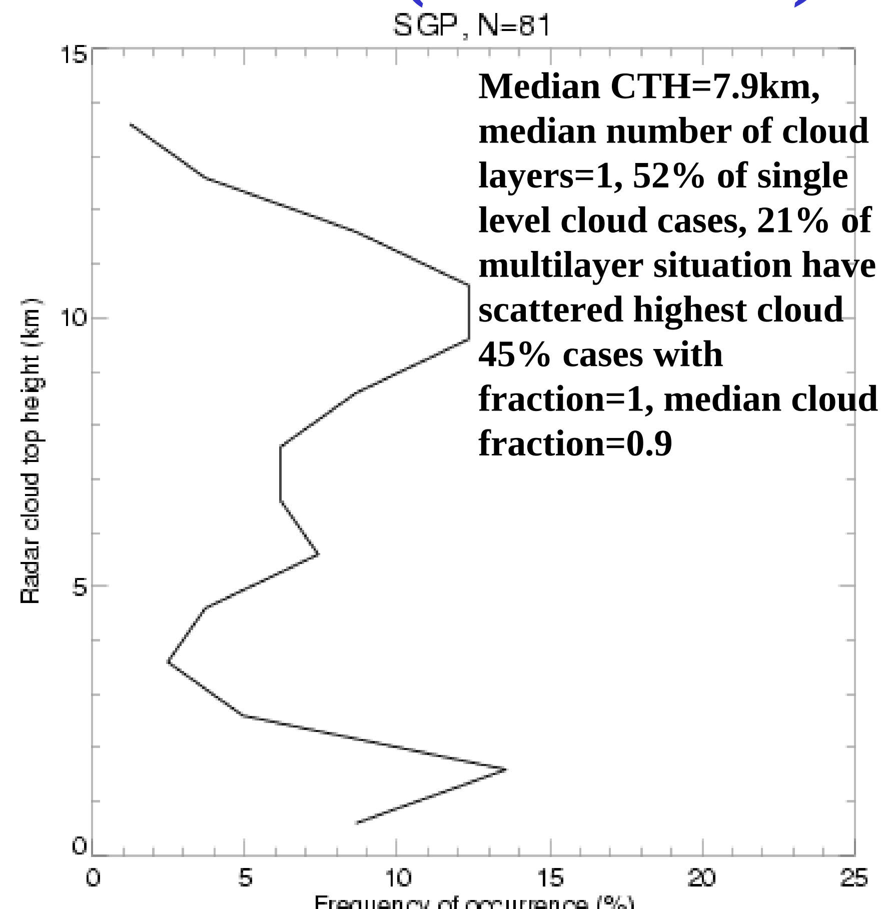
Ground-based instruments (3)
Radar CTH at CFARR and SGP (1997-2000)





N.B. Clouds at SGP are higher and less broken than at CFARR.

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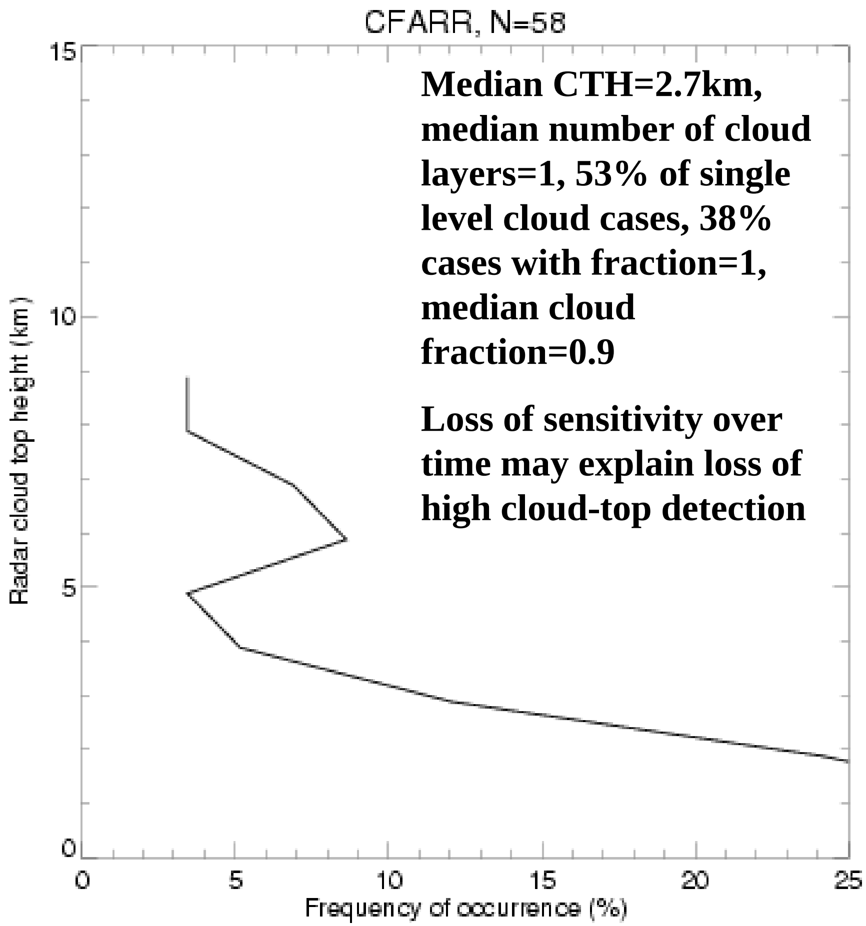
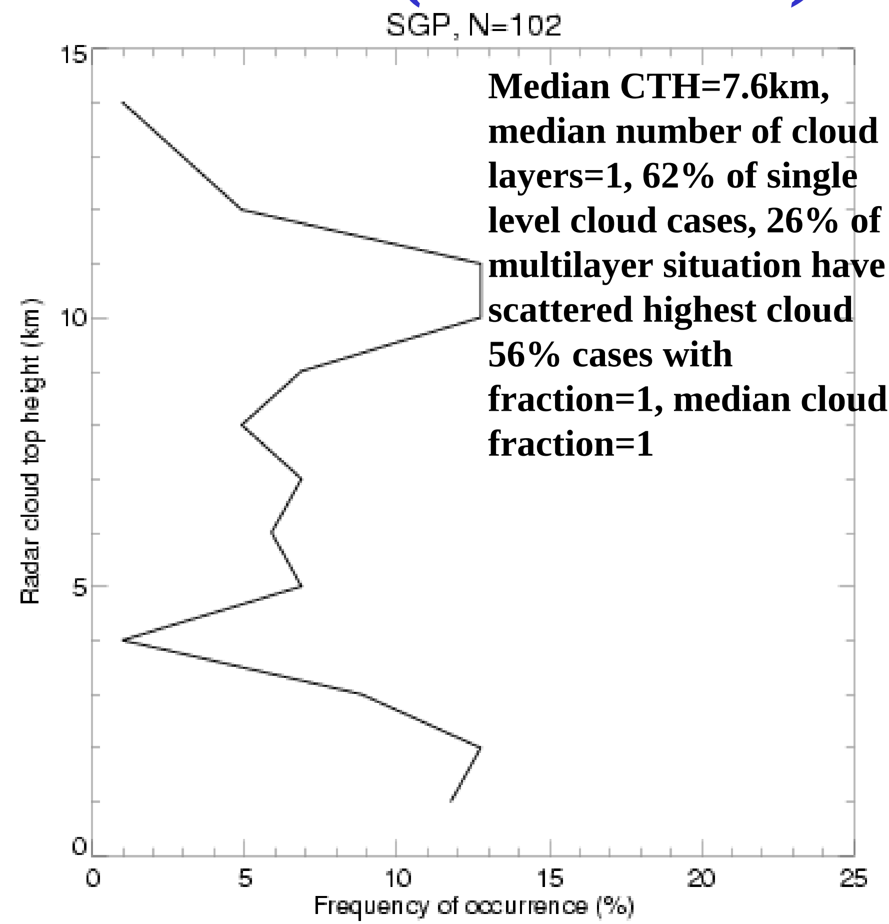
Ground-based instruments (4)
Radar CTH at CFARR and SGP (2000-2003)





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MODIS optical depth available for:
58 cases at CFARR, median=1.27
91 cases at SGP, median=0.49

Comparison between MISR-MODIS-MERIS and MMCR radar at CFARR and SGP (1)

Cloud situation	Date and location	MERIS and Radar CTH (km)			MISR, MODIS and Radar CTH (km)			
		Time of overpass (UT)	MERIS	Radar	Time of overpass (UT)	MISR	MODIS	Radar
Low continuous	2003-02-15, SGP	16:58	1.9	2.0	17:30	2.2	0.8	2.1
Low broken	2003-05-11, CFARR	10:42	CTHs too variable		11:10	1.0	0.6	1.1
	2003-06-12, CFARR	10:35	1.7	1.6	11:10	1.5	0.9	2.0
Low multi-layer	2003-05-27, CFARR	10:37	1.2	2.5/1.4*	11:10	1.2	2.3	2.5/1.4*
Mid-level continuous	2003-06-07, SGP	16:39	4.3	4.6	17:30	4.5	6.1	4.7
Mid-level broken	2003-06-09, SGP	17:15	4.9	6.2	17:15	5.4	7.1	6.2
High multi-layer	2003-05-15, SGP	17:01	5.0	11.7	17:25	9.0	10.6	11.6
	2003-05-31, SGP	16:58	5.5	12.4	17:25	9.0/5.3#	10.6	11.8

All cases per cloud situation: good agreement between MISR, radar and MERIS for single level (non-broken) clouds (#: large box indicates high cloud whilst smaller boxes indicate mid-level cloud)

Naud et al, *Proc. MERIS workshop*, ESA Frascati, Nov 10-14 2003.

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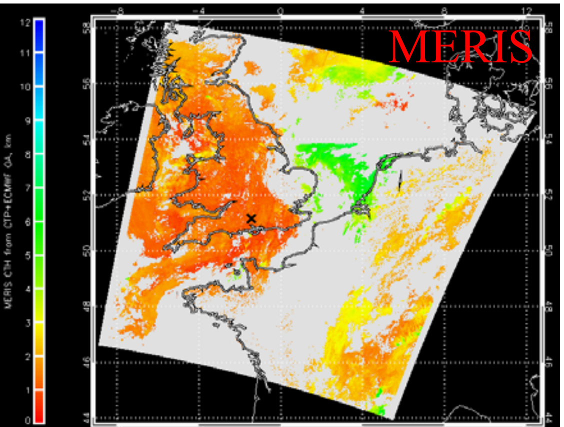
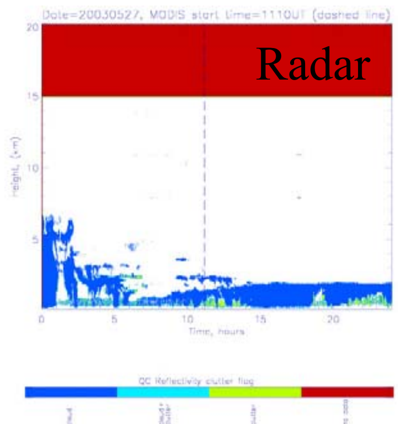
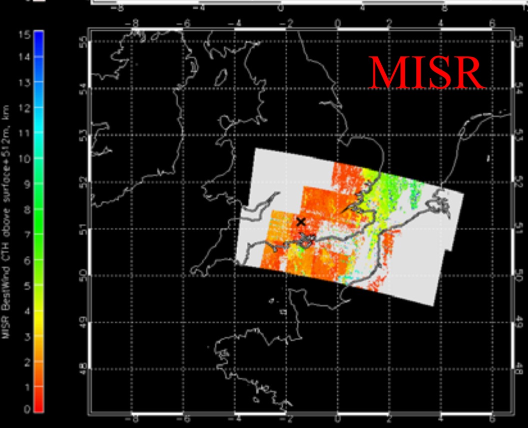
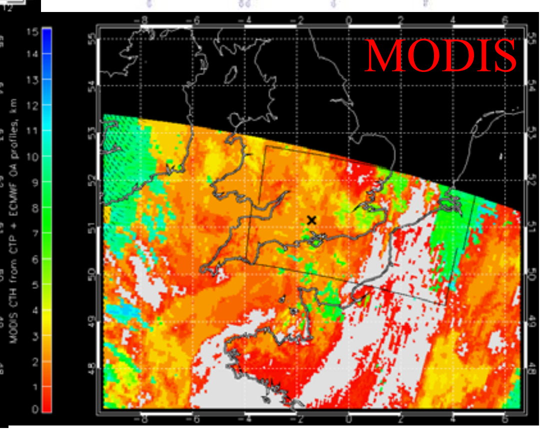
Comparison between MISR-MODIS-MERIS and MMCR radar at CFARR and SGP (2)

2003-05-27, CFARR, MERIS at 10:37UT, MISR/MODIS at 11:10UT









2 low level clouds
Radar CTH:
layer (1)=1.3/1.5km
layer (2)=2.4km
MERIS CTH= 1.2km
MISR CTH= 1.2km
MODIS CTH=2.3km
MERIS and MISR sensitive to multi-layer situations

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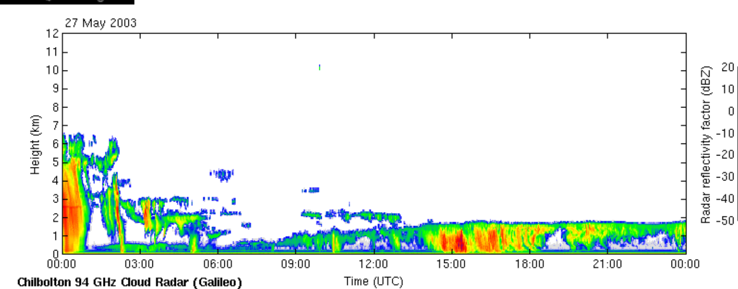
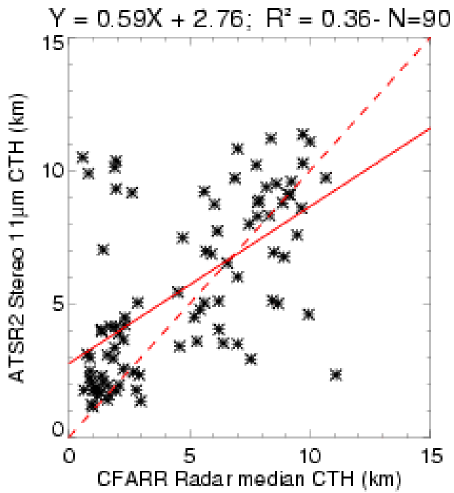
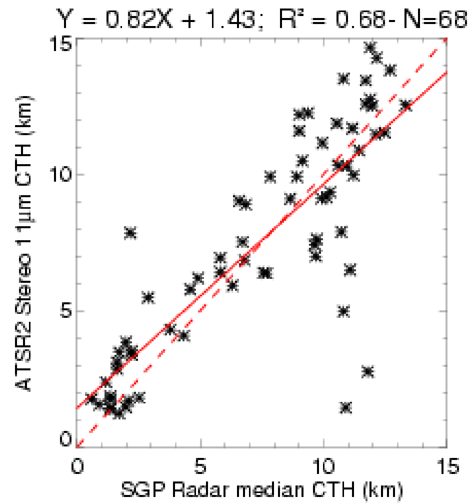


ATSR2 11µm stereo vs radar CTH at CFARR and SGP (1997-2000) (1)



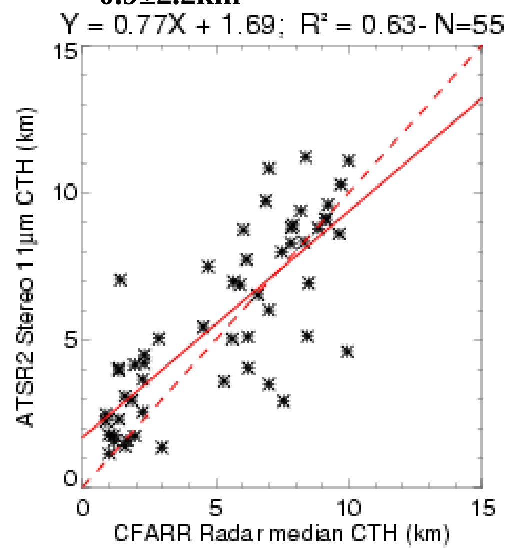


All cases

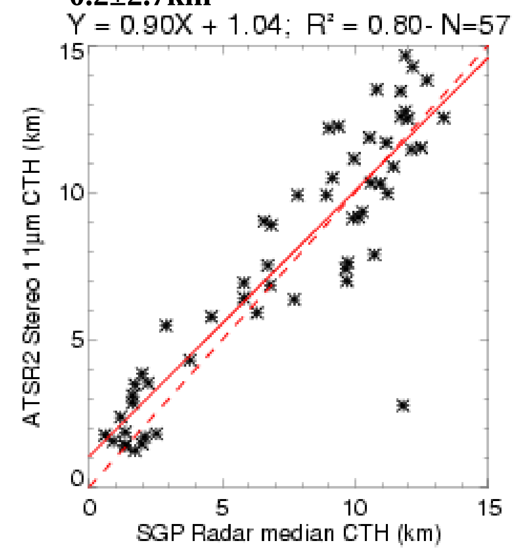
Difference radar-stereo 11µm=
CFARR: -0.84±2.87km
SGP: -0.13±2.42km

Filtered cases where:
- difference Max radar CTH-median>3km
- standard deviation radar CTH>2km
- radar cloud fraction<0.1

Difference radar-stereo 11µm= -0.9±2.2km



Difference radar-stereo 11µm= 0.2±2.7km



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Cloud-Top Height Validation: Conclusions

- MISR: good performance for single level clouds but accuracy depends on the cloud level of largest contrast/brightness, 0.5km for low clouds, 1.5-2km for high single level clouds with optical depth >0.3
- MODIS: good performance for mid/high clouds but accuracy depends on cloud optical depth, similar to MISR, but no problem with multilayer situations
- MERIS: good performance for thick clouds but accuracy depends on optical depth and number of cloud layers, 0.5km for low clouds
- 11μm ATSR2 stereo cloud top heights: high bias, best for SGP with a difference of –0.32±1.86km, CFARR: overall difference= –0.49±1.96km when broken clouds removed.
- 1.6μm and 0.65μm ATSR2 stereo cloud top heights (not shown): strongly dependent on multi-layer situations, investigating if this could be used for automated multilayer detection
- CLOUDMAP2 web-site shows browse images for each individual case

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Conclusions from Inter-comparison/validation work in CLOUDMAP2 for cloud-top height

There is no single satellite technique which works in all weather situations:

- **Stereo works best for single-level clouds unless 11µm channel used**
- **CO_2 slicing works best for optically thick mid to high-level clouds**
- **O_2 works best for single layer thick low-level clouds**

In the case of broken clouds:

- **Collocation of data is an issue**

In the case of multi-layer clouds:

- **Satellite sensor may miss cloud parameter of highest cloud or lower cloud**
- **Cloud top parameter of highest cloud may not be significant in ground based signal**

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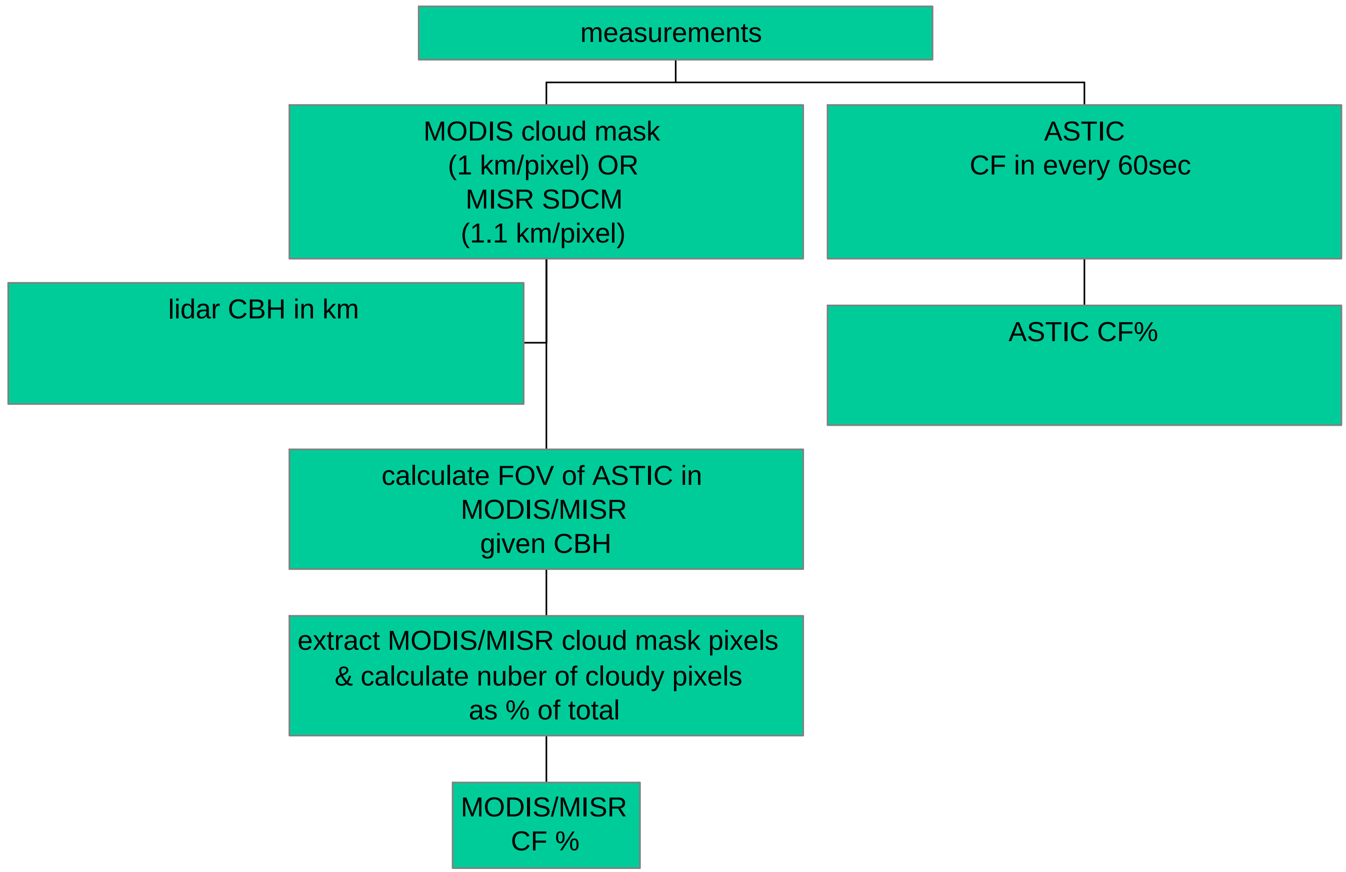
Intercomparison of MODIS cloud mask, MISR stereo derived cloud mask, lidar and ASTIC (below cloud) cloud fraction



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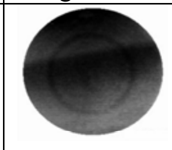
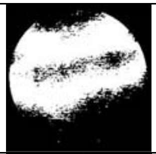
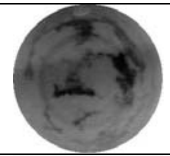
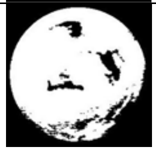
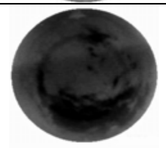
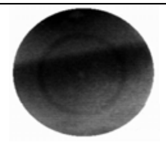
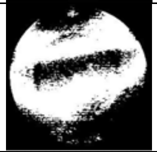
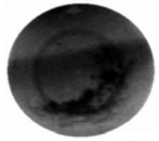
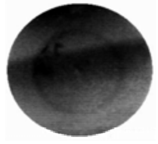
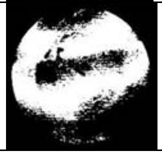
Intercomparison: Results (1)
Assessment of the automated cloud mask from ASTIC

DATE	Time (UT)	ASTIC CF (%)/manual	ASTIC image	ASTIC Cloud mask	Comments
19 June 2003	11:14:06	60.8/100			
26 June 2003	11:12:35	86.0			
03 July 2003	11:22:06	80.3			
05 July 2003	11:14:06	61.1/100			
06 July 2003	11:51:06	71.8/92			
07 July 2003	11:56:06	72.9			
08 July 2003	11:44:06	58.1/100			

N.B. Where the ASTIC FoV is completely cloud covered, the automated cloud mask detects the low SNR chopper diagonal artifact

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Intercomparison: Results (2)
ASTIC, lidar, MODIS and MISR cloud fractions

DATE	Time (UT)	ASTIC CF (%) /manual	Lidar CC% [15min CF%]	MODIS CF (%) [single pixel CC]	CBH, m	LWP, g/m^2	MISR CF (%) [single pixel CC]	Single or multi-layered
19 June 2003	11:14:06	60.8/100	100 [100]	95.0 [cloudy]	851	225	No data	single layered
26 June 2003	11:12:35	86.0	100 [100]	92.7 [cloudy]	1069	131	78.9	single layered
03 July 2003	11:22:06	80.3	100 [100]	76.1 [cloudy]	1740	65	No data	multi-layered (3)
05 July 2003	11:14:06	61.1/100	100 [100]	100 [cloudy]	1327	168	98.8	single layered
06 July 2003	11:51:06	71.8/92	100 [100]	98.9 [cloudy]	1665	126	No data	single layered
07 July 2003	11:56:06	72.9	100 [100]	100 [cloudy]	1369	83	No data	multi-layered (2)
08 July 2003	11:44:06	58.1/100	100 [100]	100 [cloudy]	784	230	No data	multi-layered (2)

N.B. Good agreement between ASTIC derived cloud fraction and MODIS and MISR as well as zenith lidar and MODIS cloudiness. Lidar CC% kindly provided by E. O'Connor and A. Illingworth

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Introduction to CWAVE'03

- **Joint EU-CLOUDMAP2 and CLOUDNET project for intercomparison of instruments and Cloud Resolving Models: CWAVE03 (Clouds, Water Vapour Experiment 2003)**
- **Period:**
  14 June to 11 July 2003
- **Instruments used here:**
  - **3 GPS receivers**
  - **1 Microwave Radiometer (MWR)**

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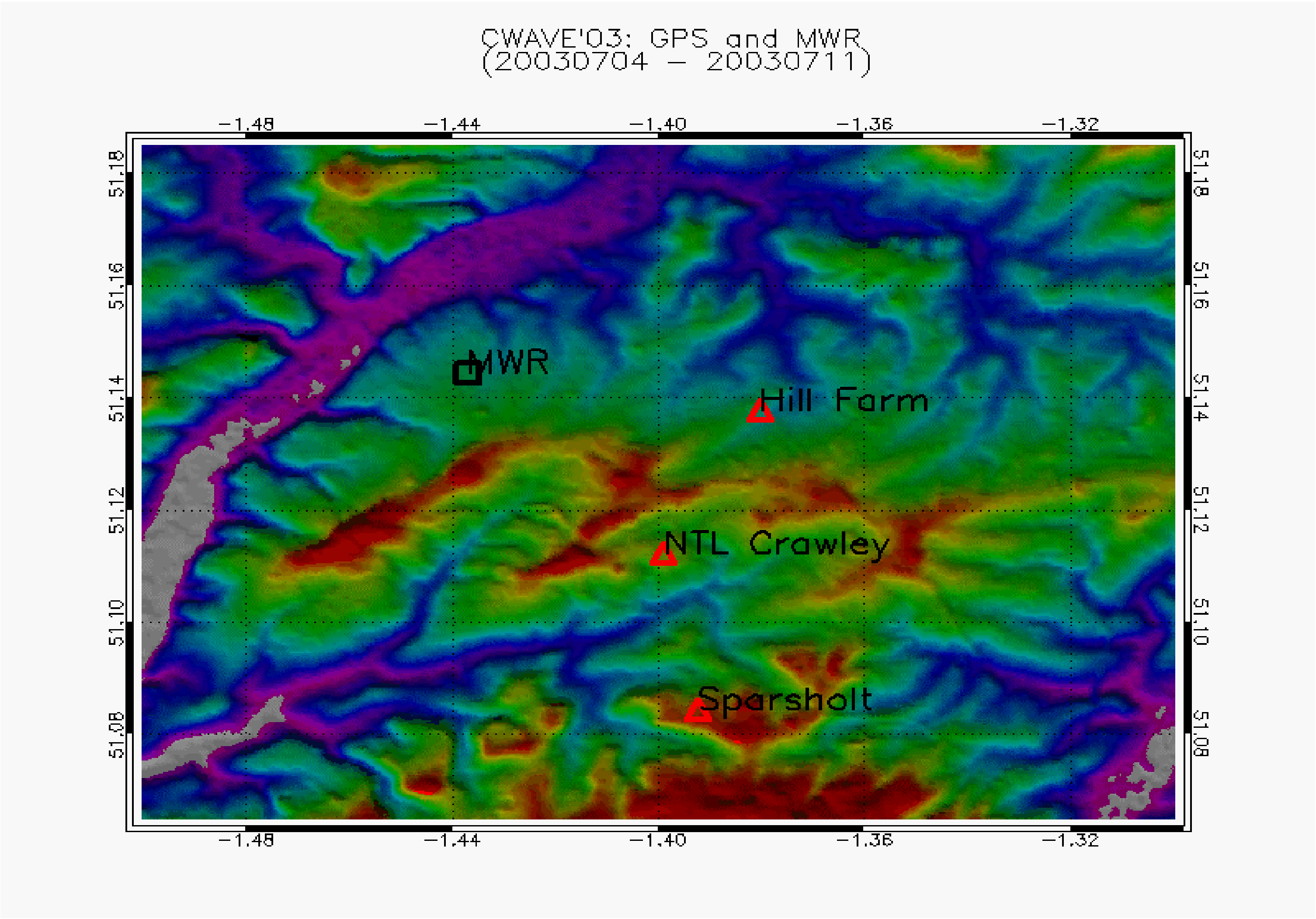
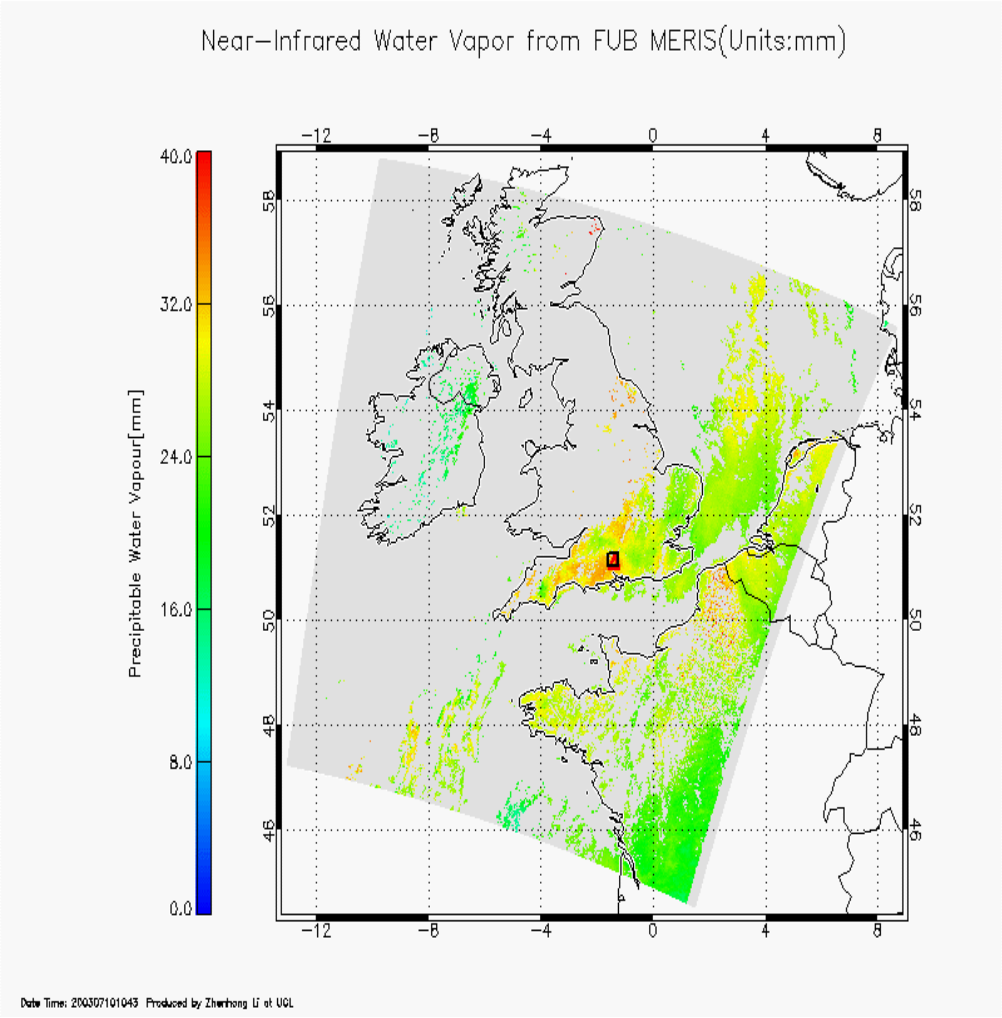
CWAVE'03: GPS and MWR displayed on SRTM DEM



N.B. Triangles show GPS locations whilst square shows location of MWR

Intercomparison of MERIS, MWR and GPS PWVs (CWAVE'03, 10 July 2003)



	GPS(Δ)	MERIS
HILL	30.4	31.9
NTL	29.3	32.8
SPAR	30.4	32.1
	MWR (■)	MERIS
Chilbolton	32.0	33.3

N.B. Unit: mm

Conclusions

- CFARR has proven to be an excellent site for the validation of satellite-derived cloud products
- The availability of CONTINUOUS measurements is the key as well as DERIVED PRODUCTS
- Hopefully the measurement set can be extended in future to include:
  - Cloud microphysical properties
  - Radiation measurements
  - Aerosol measurements
  - Vertical temperature and RH profiles
  - 3D wind-field up to tropopause

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