ATSR Algorithm, Cloud cover, height and temperature

ORAC Oxford/RAL retrieval of aerosol and clouds

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3. *UO/RAL*

Science & Technology Facilities Council

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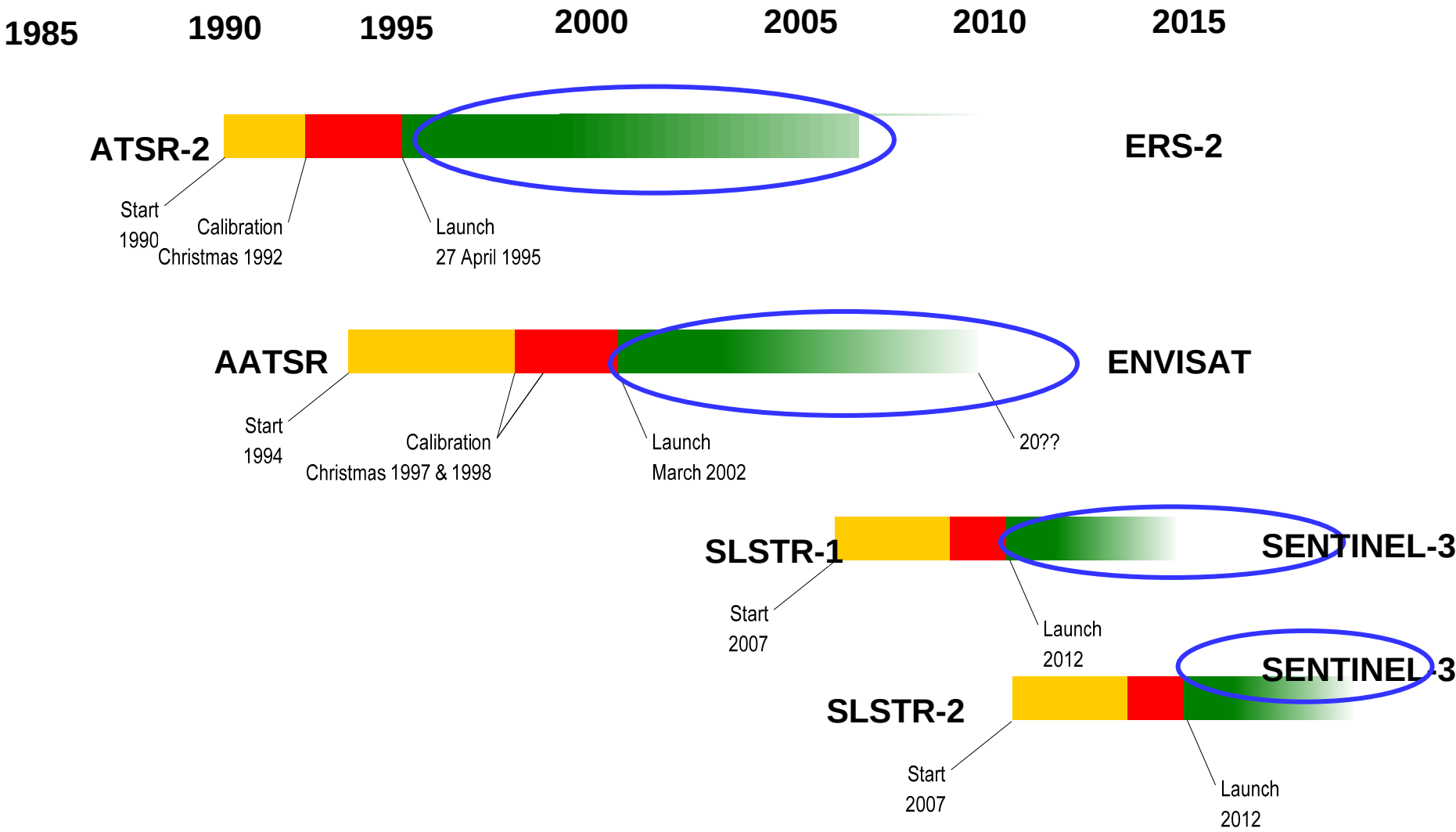
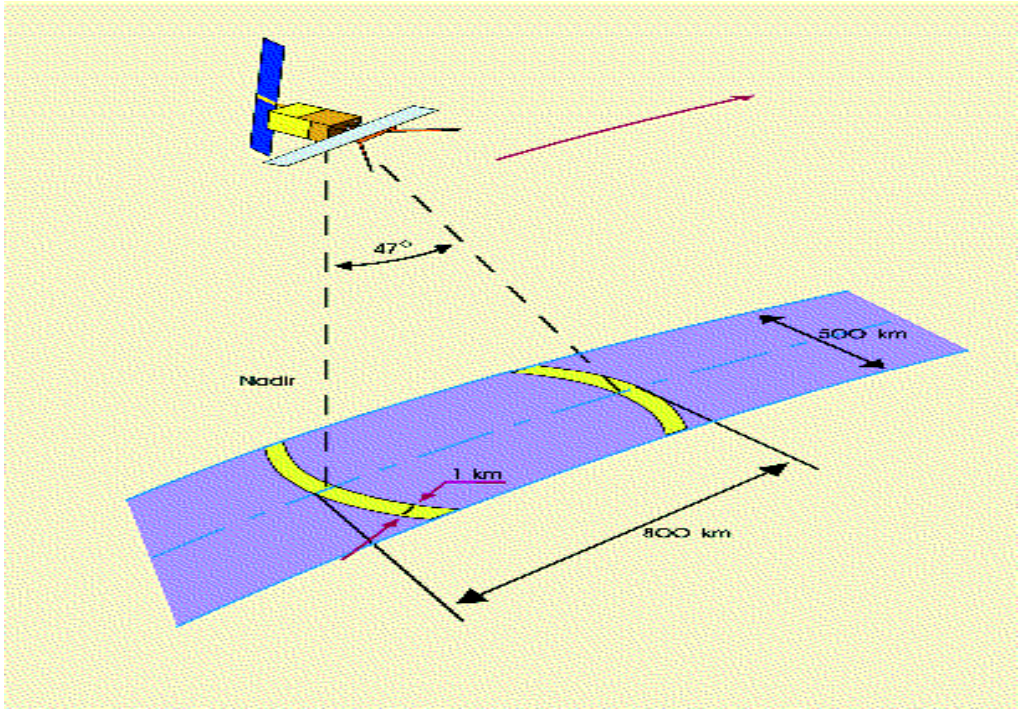
Time line of ATSR (vis/nir and IR) instruments



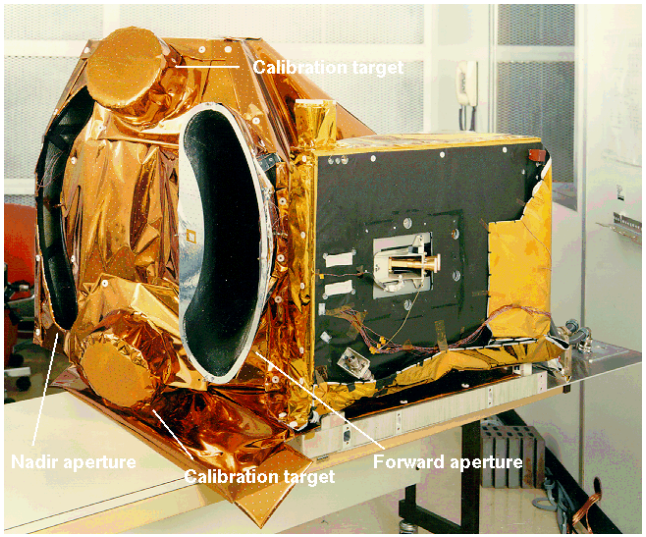
ATSR Scan Geometry and Channels

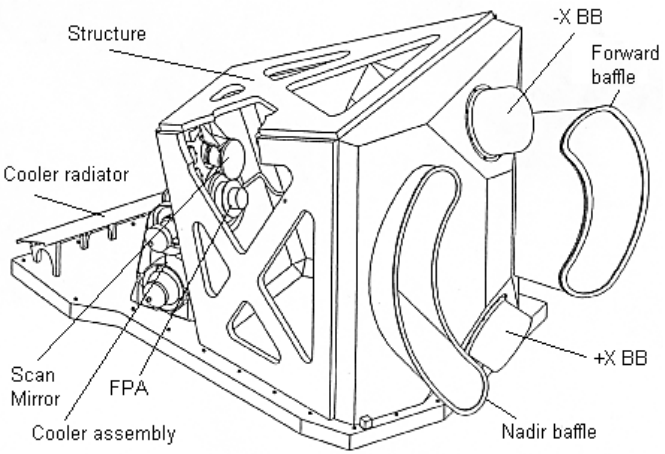
- Dual-viewing visible & IR radiometers
  - Nadir 0º-22º, forward 53º-56º, 100 seconds difference
  - 550 nm, 660 nm, 870 nm, 1.6 µm, 3.7 µm, 10.8 µm, 12 µm (1.38,2.25)



The ATSR scan geometry (courtesy ESA).

ATSR-2/AATSR/SLSTR





ATSR-2

1km resolution

512km swath over land

300km swath over sea

LTDN 10:30

AATSR

1km resolution

512km swath over land

512km swath over sea

LTDN 10:00

SLSTR

0.5-1km resolution

Nadir swath 1300 - 1800 km

Dual view swath 750 km

LTDN 10:00

SOME NOMENCLATURE

- **ORAC**: Oxford – Rutherford Appleton Laboratory (RAL) Aerosol & Cloud retrieval scheme

- **GRAPE**: Global Retrieval of ATSR Cloud Parameters & Evaluation
  - Project in which ORAC first applied to generate a global cloud dataset, 1995 onwards
  - Cloud-free scenes processed with simple aerosol retrieval
  - Available from http://badc.nerc.ac.uk/data/grape/

OPTIMAL ESTIMATION: BASICS

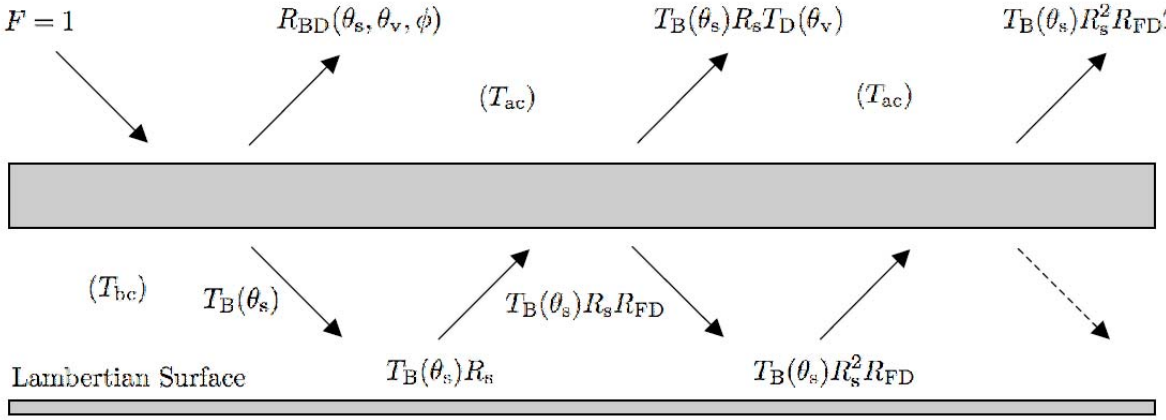
- Find most probable state **x** given:
  - Measurements **y** with covariance $\mathbf{S_y}$
  - Any *a priori* information $\mathbf{x_a}$ with covariance $\mathbf{S_a}$
- Simultaneous fit of all cloud properties to observations in all spectral channels
  - Physically consistent between different spectral domains
- Robust error propagation
  - Measurement, forward model, *a priori*
  - Goodness-of-fit ('cost') statistic on each retrieval
  - Uncertainty estimates $\mathbf{S_x}$ on retrieved state variables
- Can extend easily to different sensors or combinations of sensors, provided uncertainties can be characterised

ORAC CLOUDS: OVERVIEW

- Algorithm: Poulsen *et al.*, (in prep 2010, P. Watts et al 1997 EUMETSAT report)
- Validation:Sayer et al. (in prep)
- Separate solar/thermal forward models
  - 660 nm, 870 nm, 1.6 µm
  - 10.8 µm, 12 µm
  - Consistent ice (Baran) & water properties propagated through
- Single cloud layer
- Simple split between cloudy/clear portions

Retrieved in state vector	Derived
Cloud optical depth at 550 nm	Liquid/ice water path
Cloud effective radius	
(Phase)	
Cloud-top pressure	Cloud-top height
	Cloud-top temperature
Surface temperature	

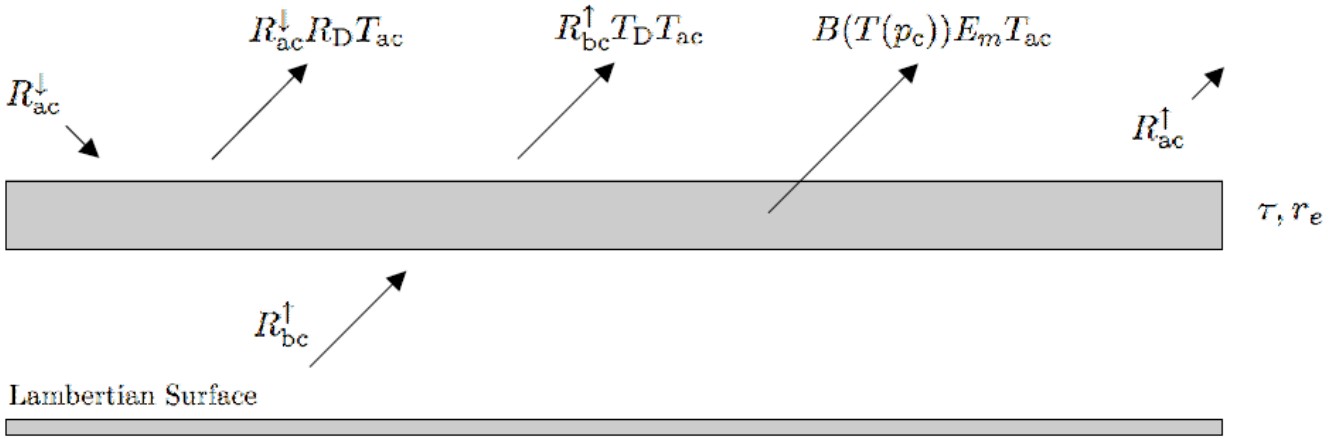
SOLAR FORWARD MODEL: CLOUDS



$$R = R_{BD} + \frac{T_B T_D R_S}{1 - R_s R_{FD}}$$

- Lookup tables (LUTs) of atmospheric transmittance, reflectance (*T*,*R*)
  - DISORT radiative transfer model
  - MODTRAN gas absorption
- Lambertian surface albedo R_S
  - MODIS albedo product for 2002 over land
  - Cox & Munk (1954) glint over sea, ECMWF 10 m winds
- Rayleigh scattering/gas absorption above & below cloud layer
  - ECMWF *p*/*T*/H_20 profiles

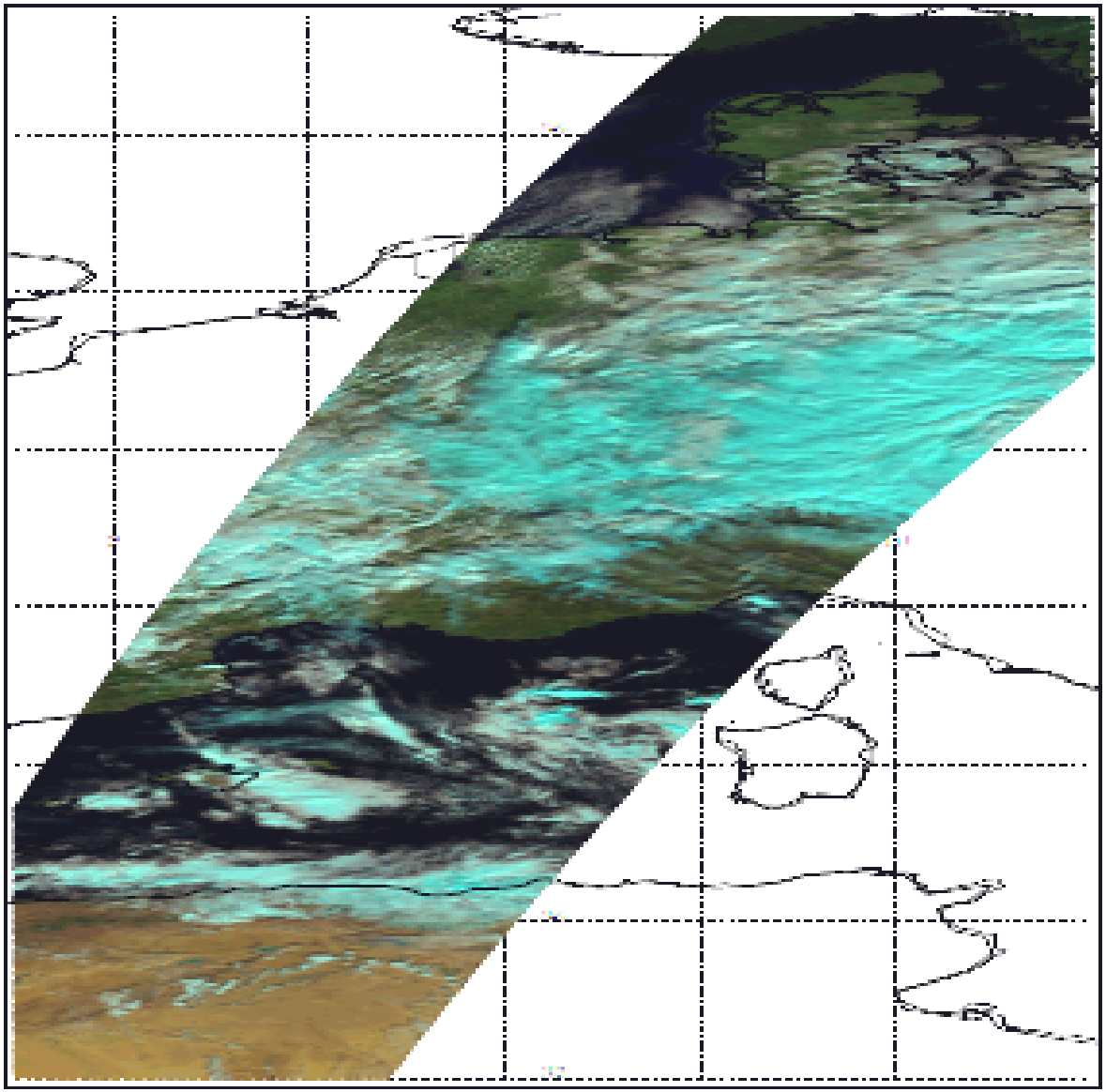
THERMAL FORWARD MODEL: CLOUDS



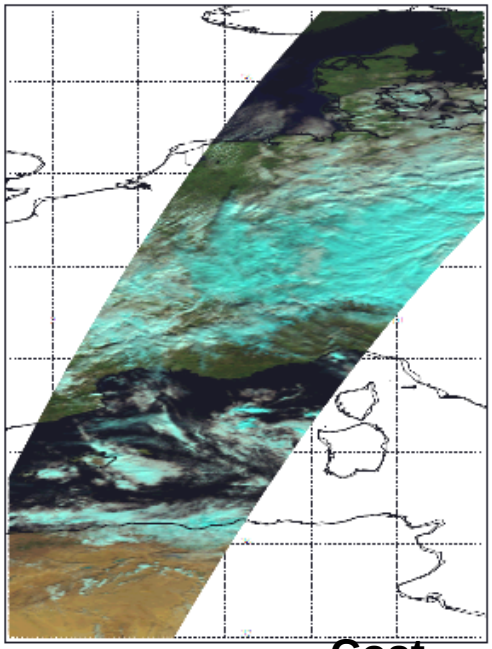
$$R = R^{\uparrow}_{ac} + R^{\downarrow}_{ac}R_DT_{ac} + R^{\uparrow}_{bc}T_DT_{ac} + B\left(T\left(p_c\right)\right)E_mT_{ac}$$

- Similar in principle to solar forward model
  - ECMWF *p*/*T*/H_20 profiles & surface temperature
  - RTTOV radiative transfer model

EXAMPLE SCENE

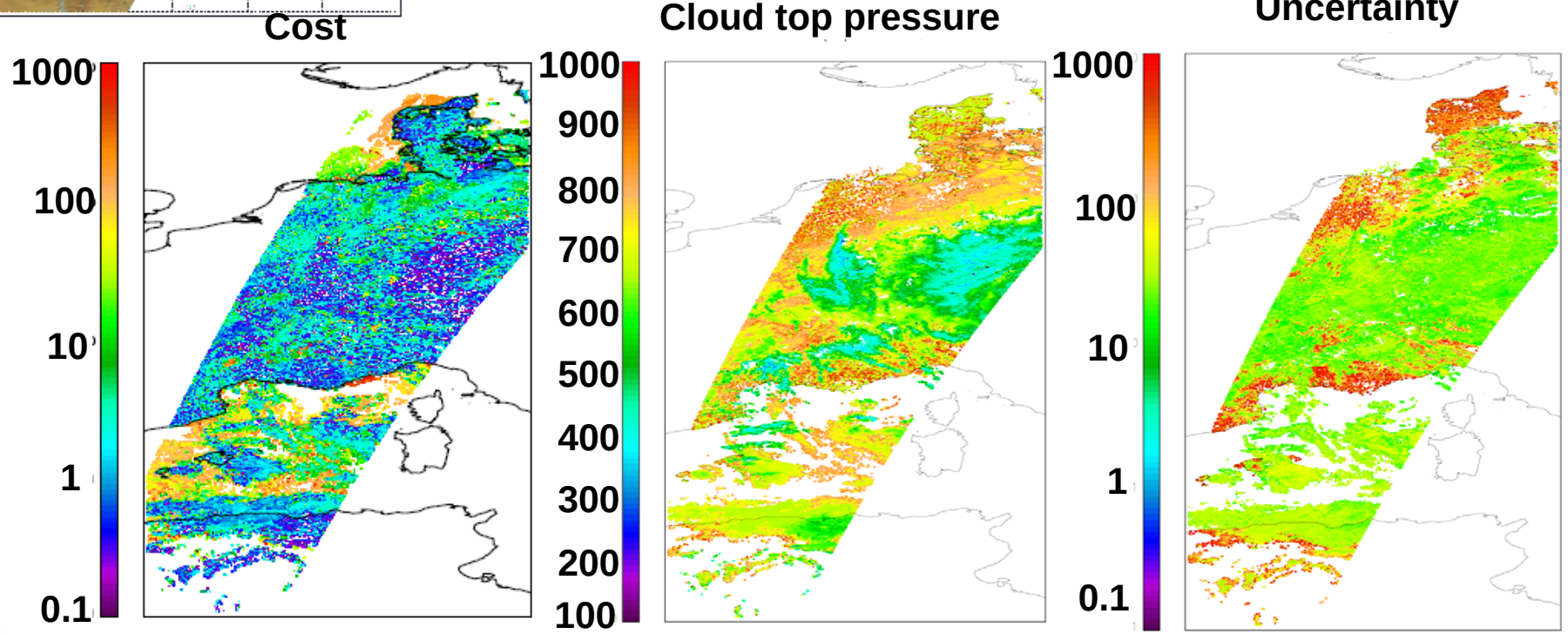


EXAMPLE SCENE

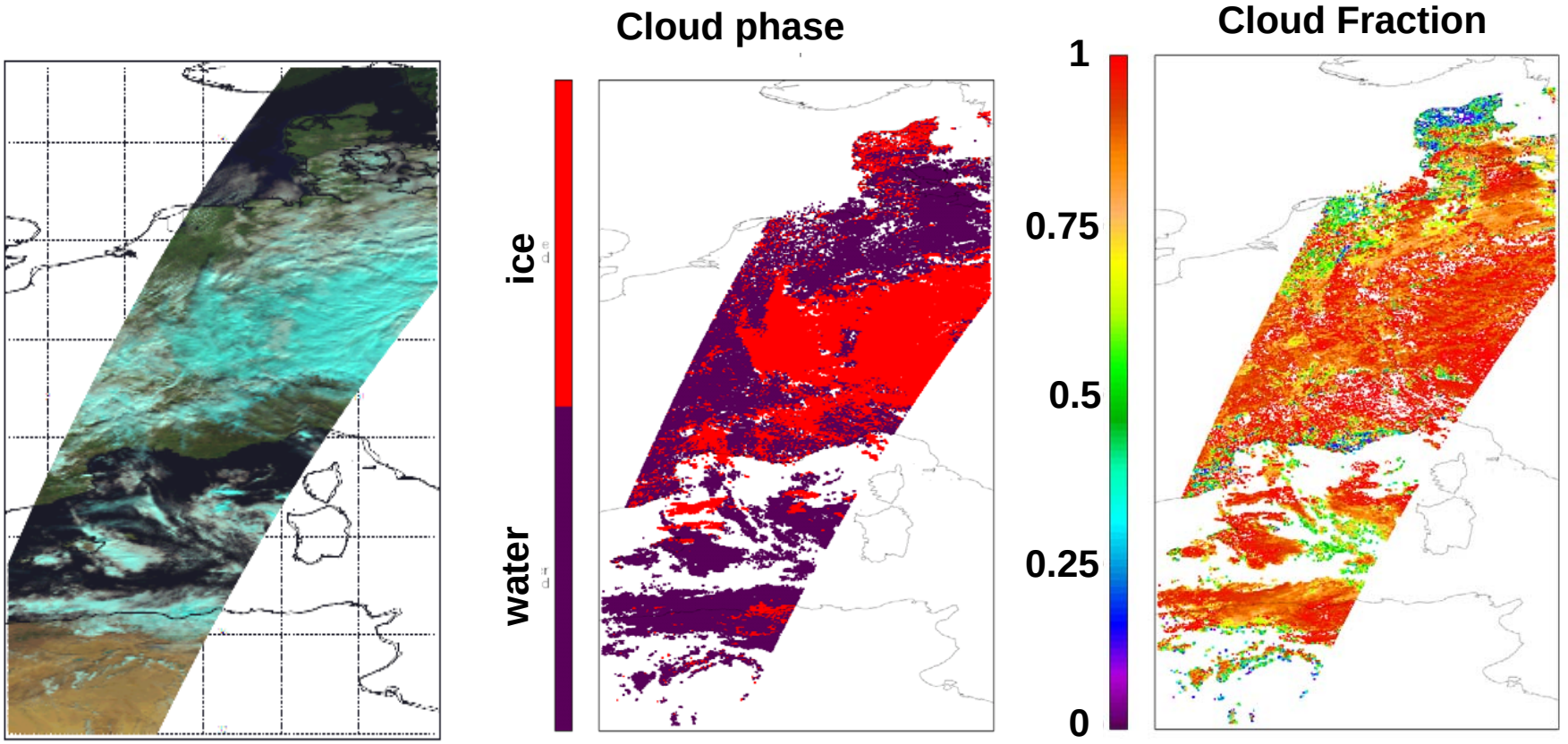


Images from Poulsen *et al.*, 2010

- Cost indicator of where model not consistent with observations
- Errors on cloud-top pressure increase as clouds get thinner.

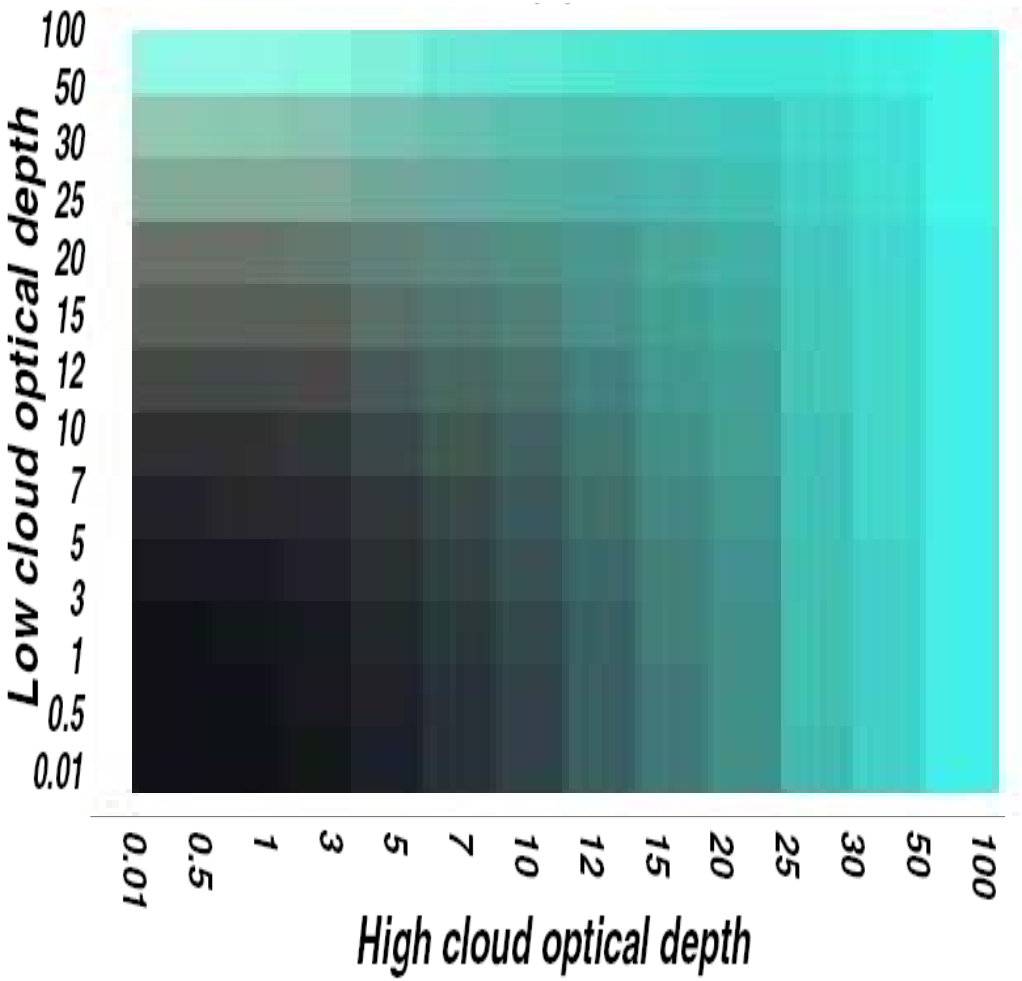


EXAMPLE SCENE



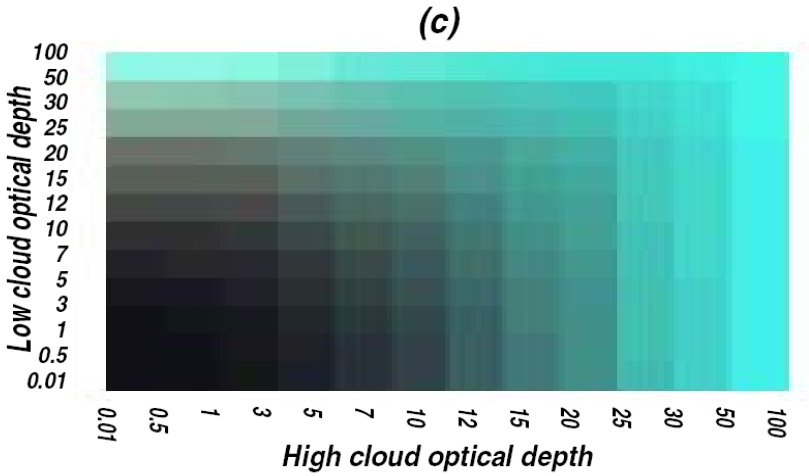
- Phase corresponds to what expected from false-colour image
- Cloud fraction largely determined by ATSR cloud mask
  - On 3x4 km scale, most cloudy scenes fully overcast

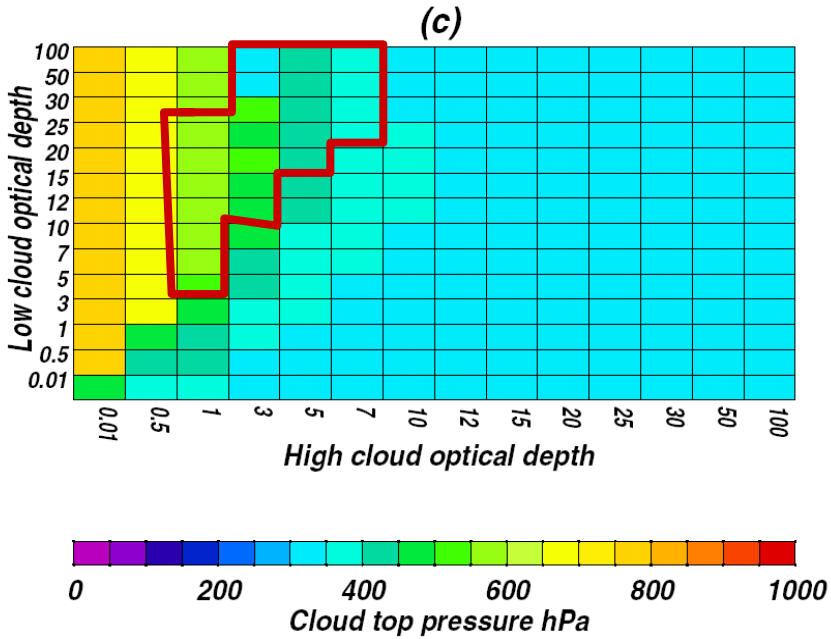
Multi-layer Simulations



Non Linear retrieval simulations of multi layer clouds using the ORAC cloud model.

Low cloud is at 780hPa and high cloud is at 320hPa, optical depth of cloud layers is varied.

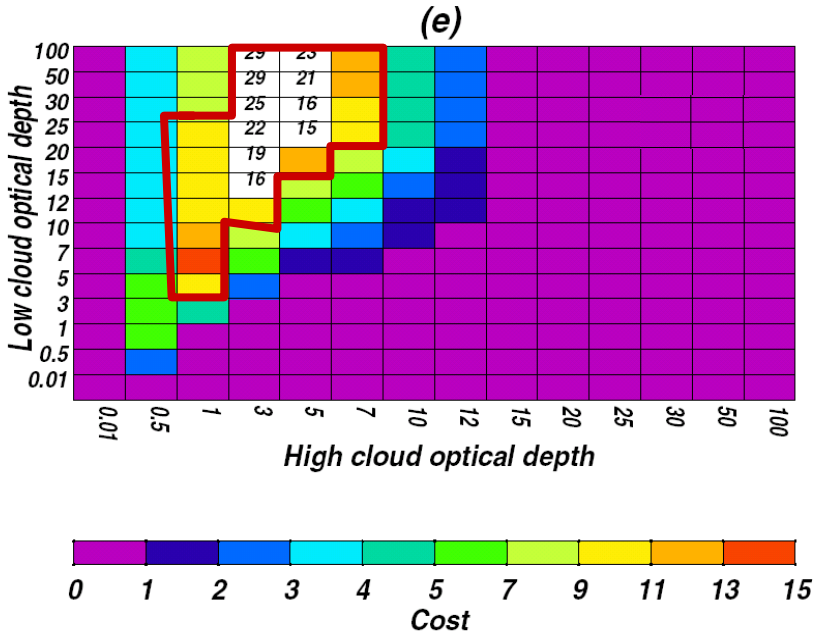




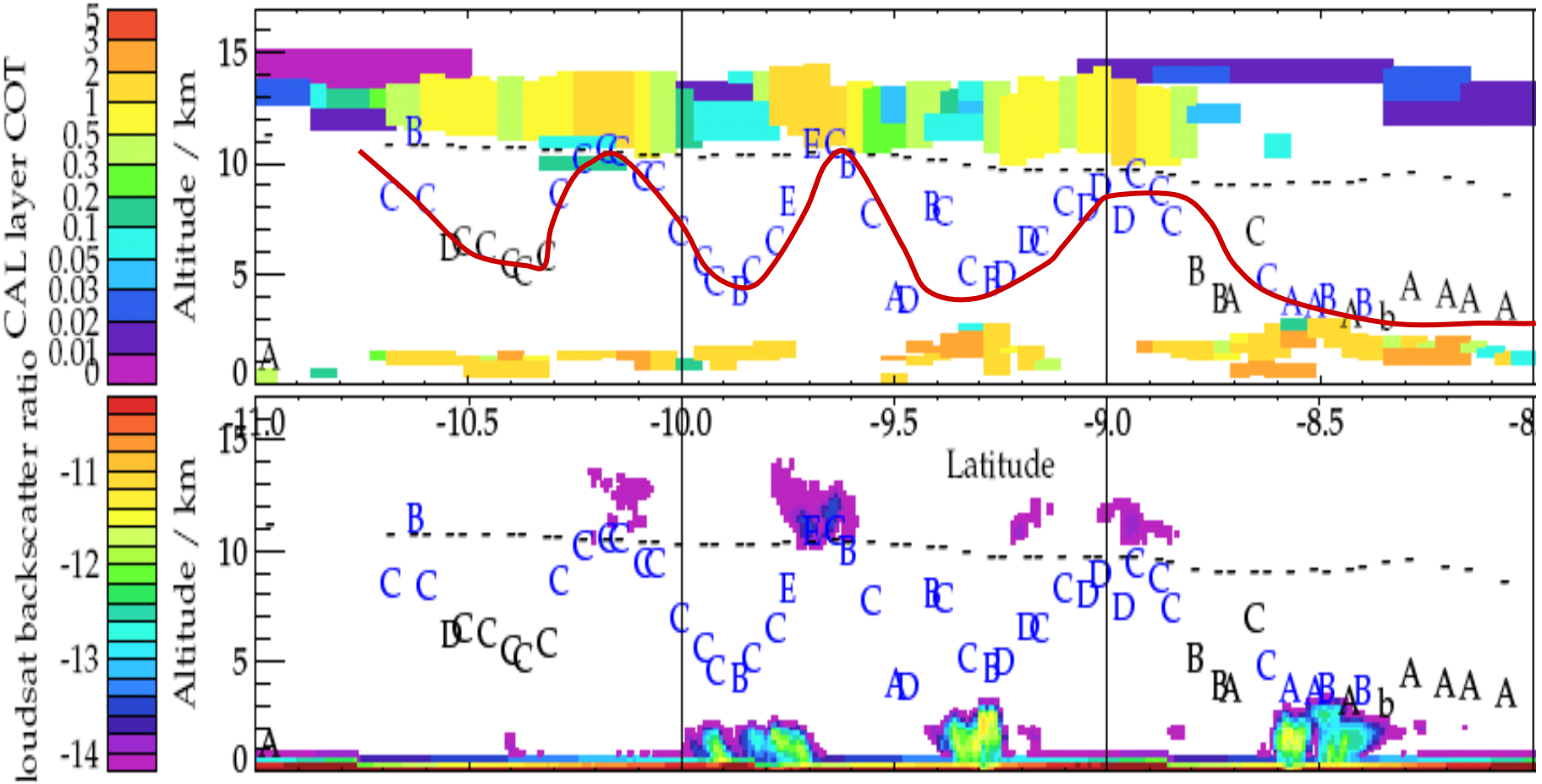
Non Linear retrieval simulations of multi layer clouds using the ORAC cloud model.

Quality control applied to GEWEX files is cost <10

Identifies many multi-layer cloud conditions but not all – some heights still radiative average of 2 layers

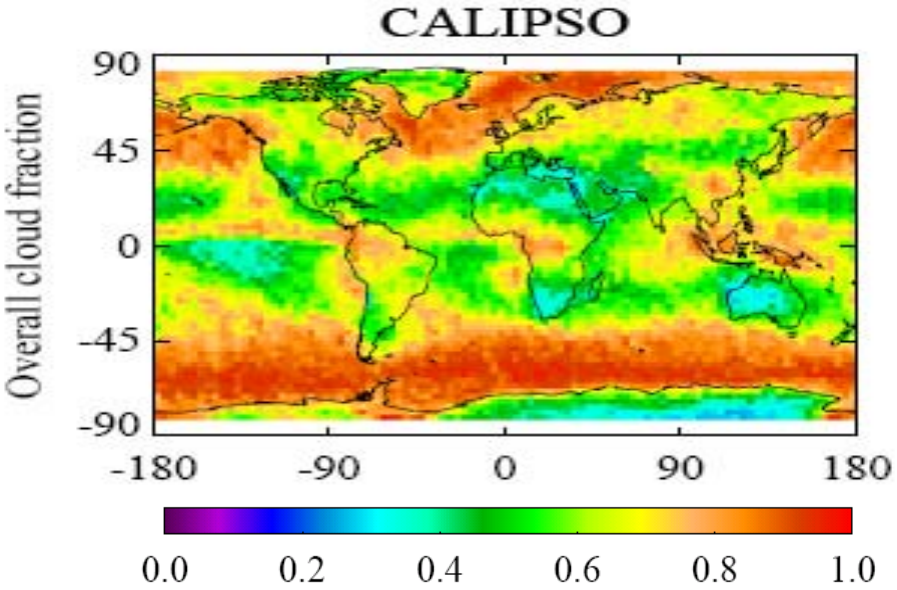


Example Retrieval of multi layer cloud

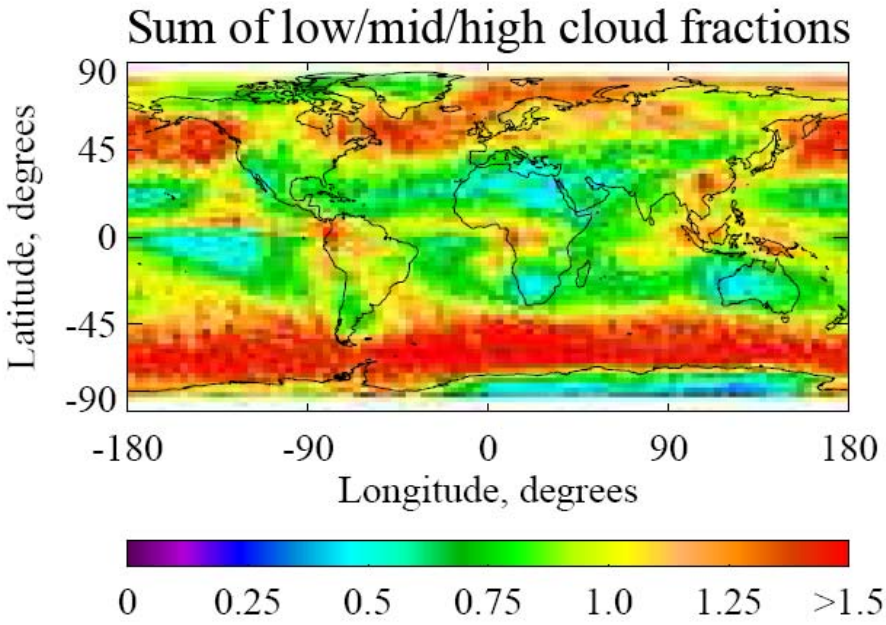


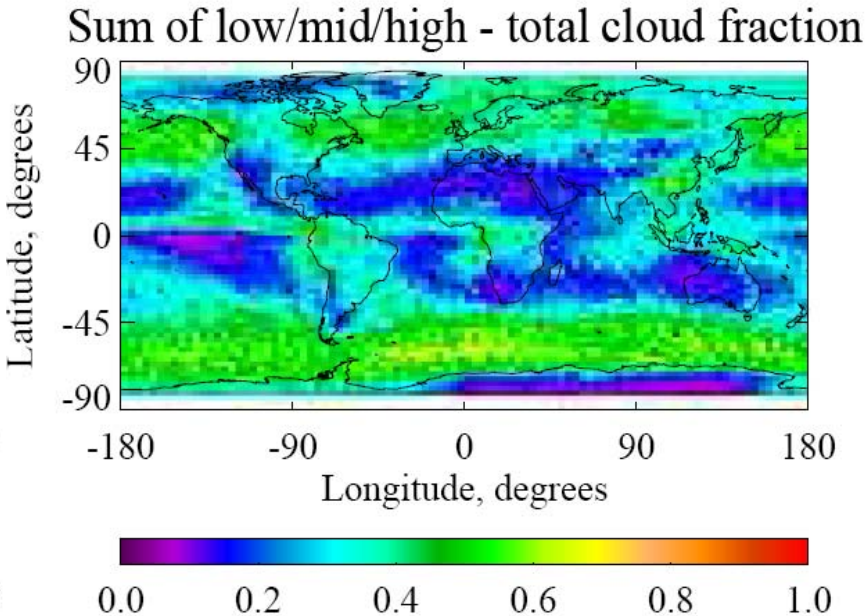
Example of OCA algorithm applied to SEVIRI data and compared with collocated Calipso and Cloud sat data
-IR channels have a penetration depth of approx 1 optical depth
-CTP has a negative bias.

Global location of multi layered cloud



High values indicate the presence of multi layered cloud

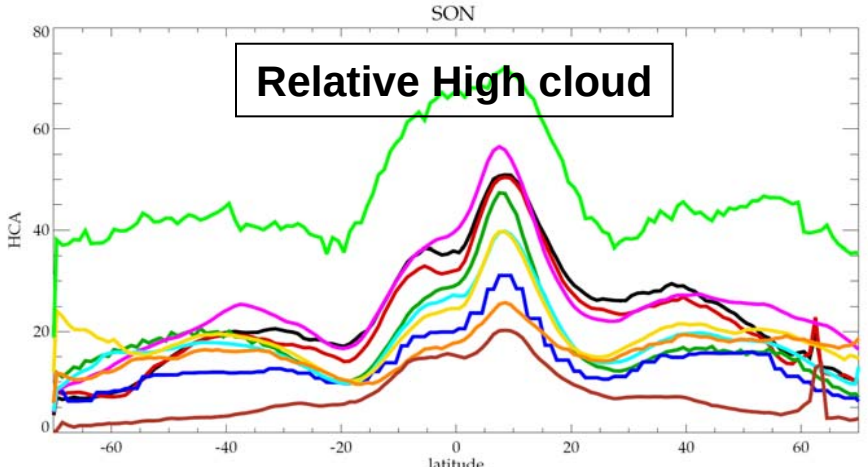


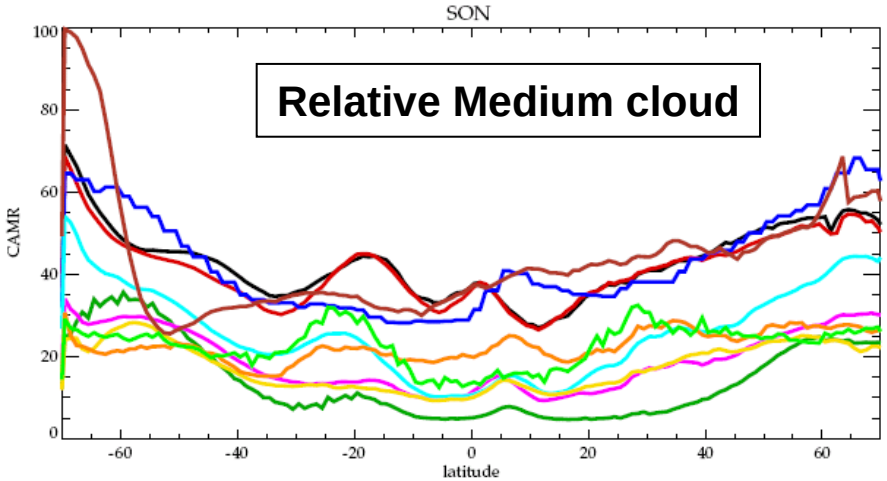


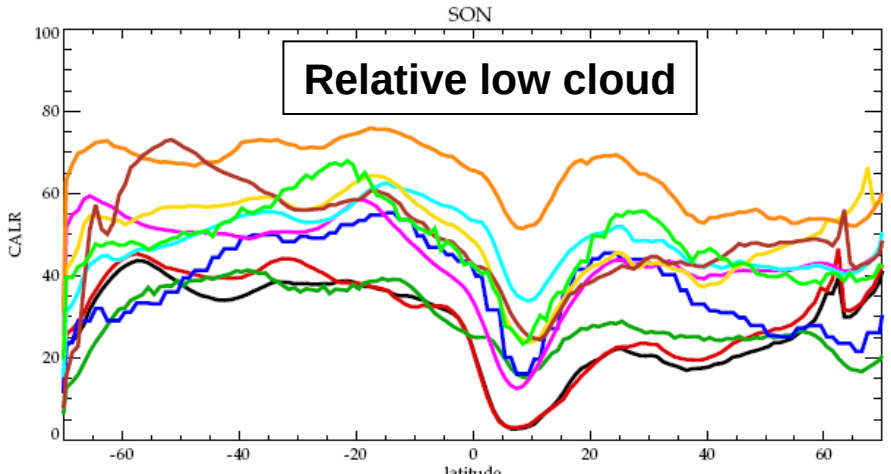
Relative cloud amounts: Comparison with other satellites

ATSR2
AATSR
PATMOSX
ISCCP
AIRS
MODIS-STT
MODIS-CET
MISR
POLDER
CALIPSO

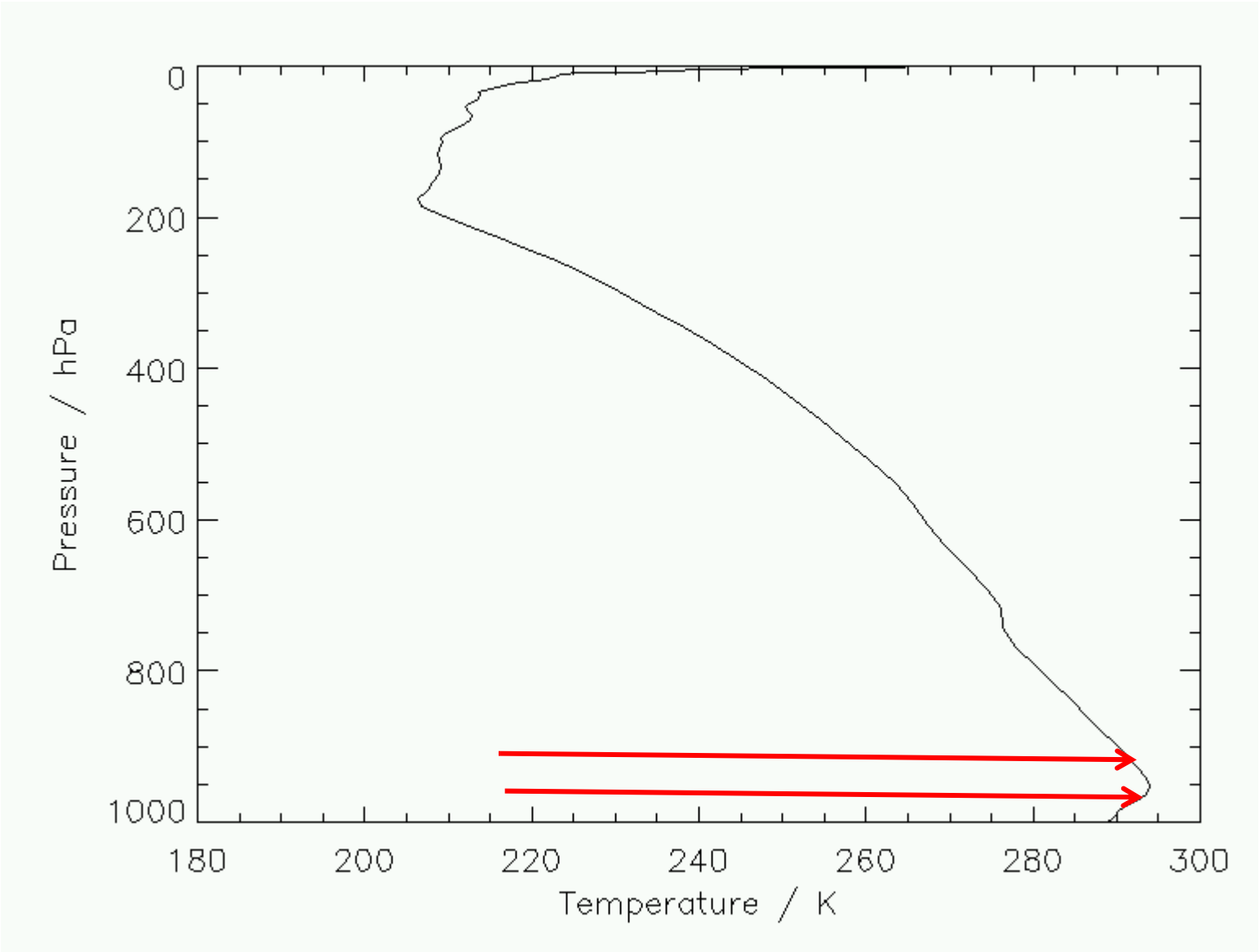
NB. Satellites are collocated with ATSR





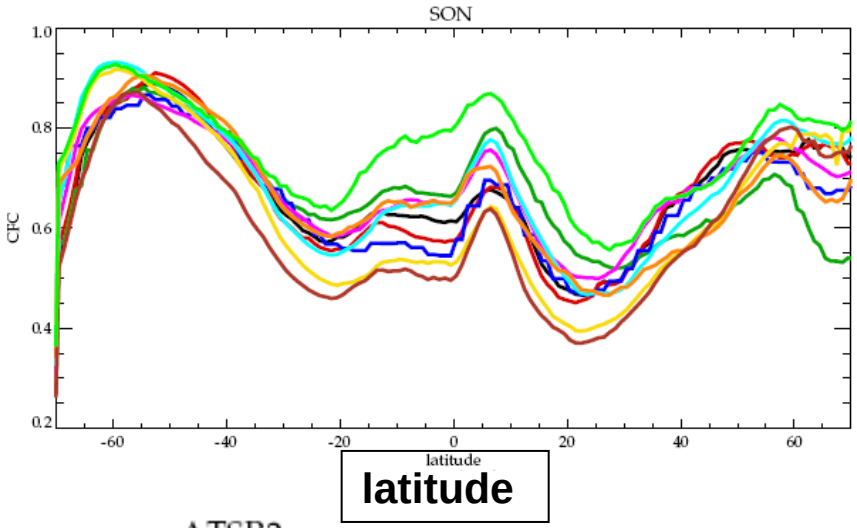


Temperature inversion problem



Cloud fraction: Comparison with other satellites

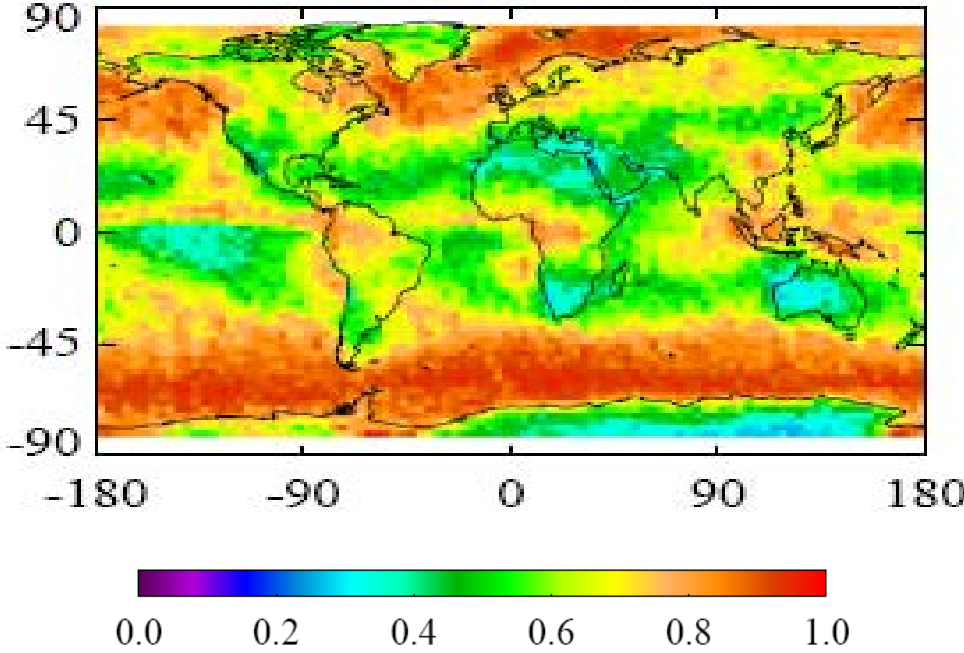
Total cloud fraction: SON



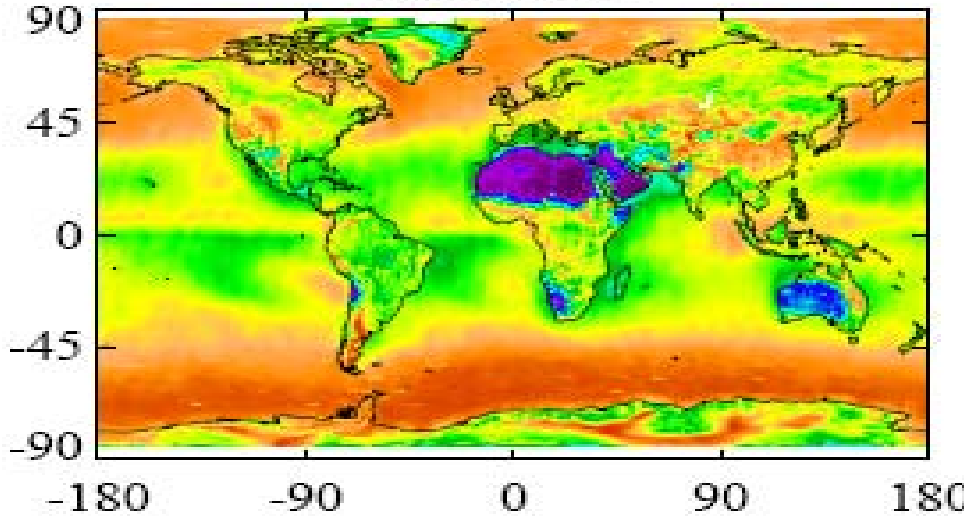
latitude

NB. Satellites are collocated with ATSR

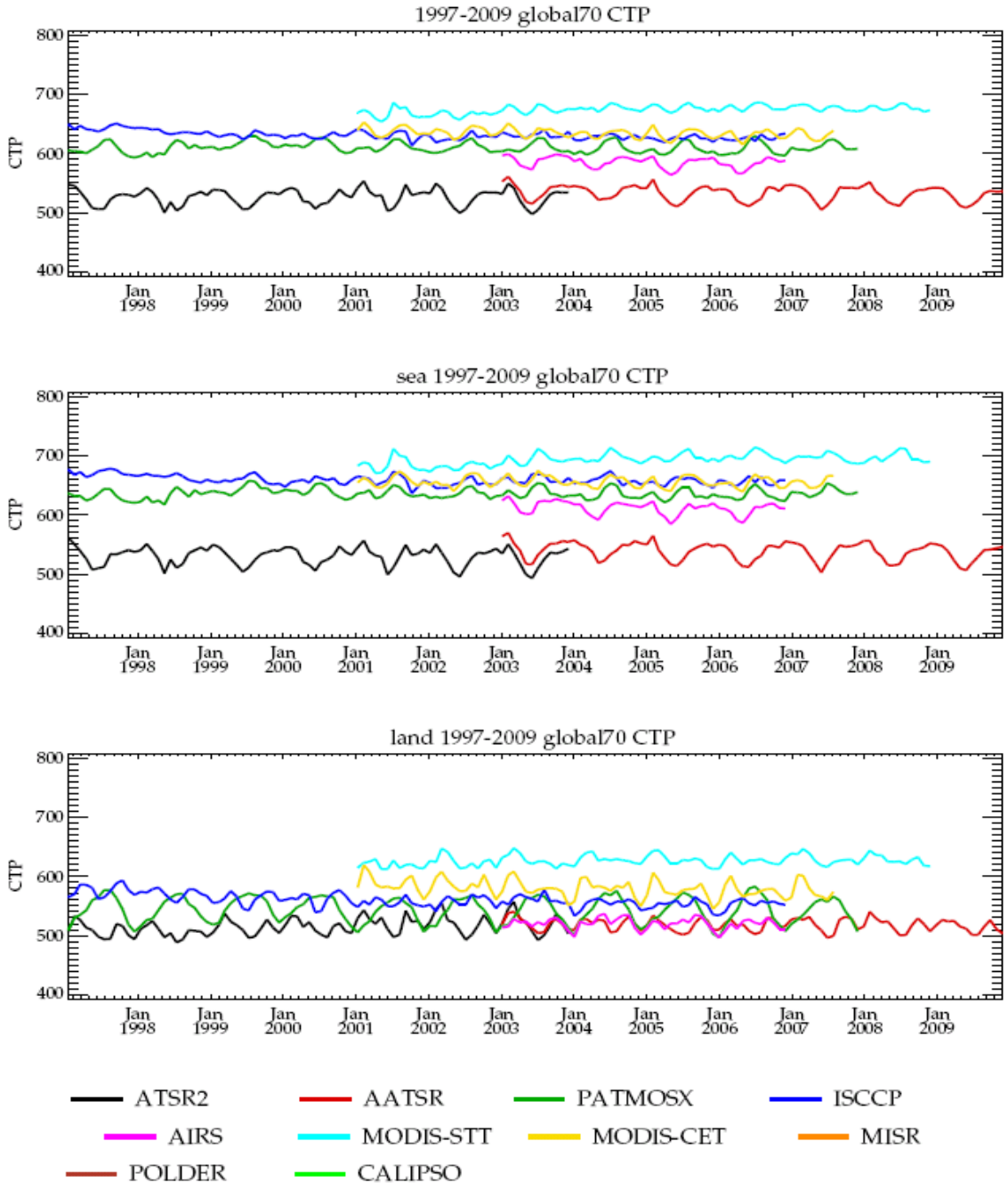
CALIPSO -GOCCP

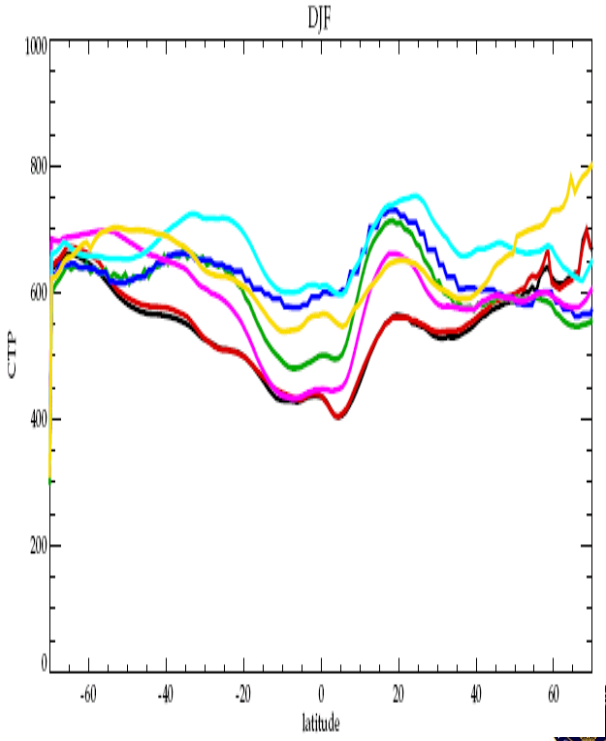


ATSR-2

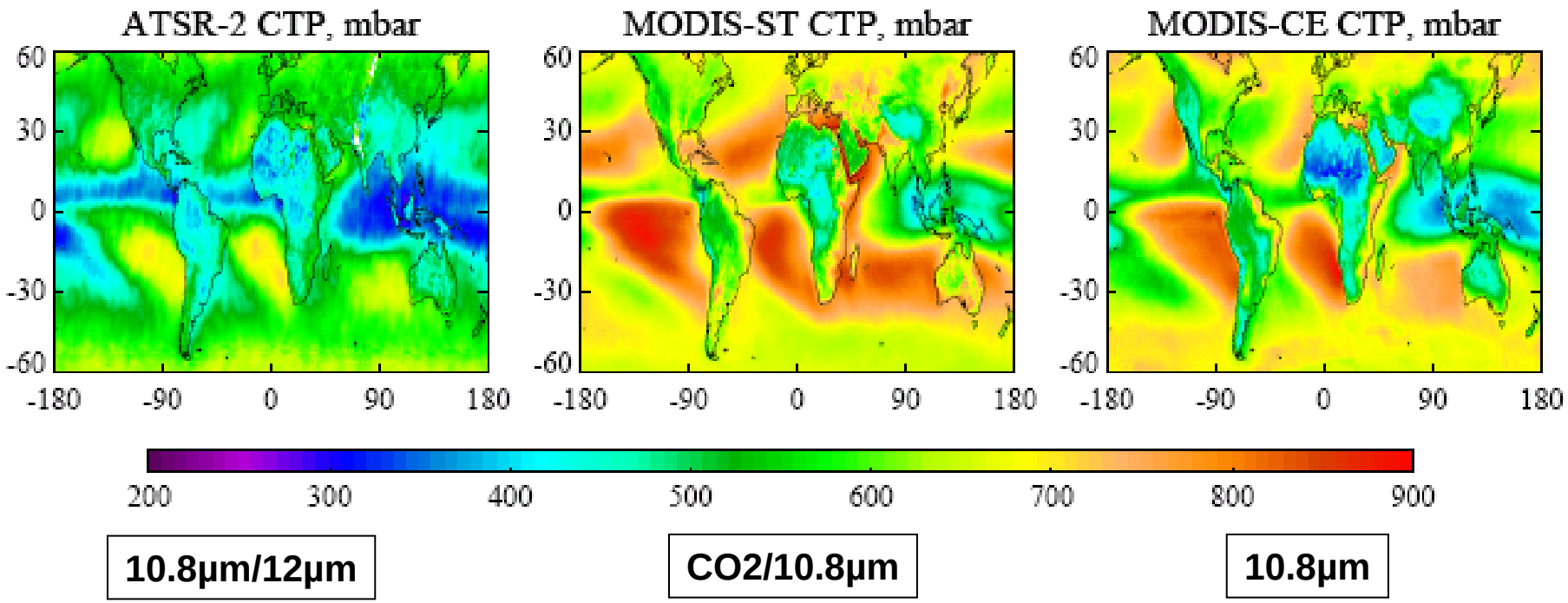


Comparison of ATSR cloud top pressure with other satellite sensors

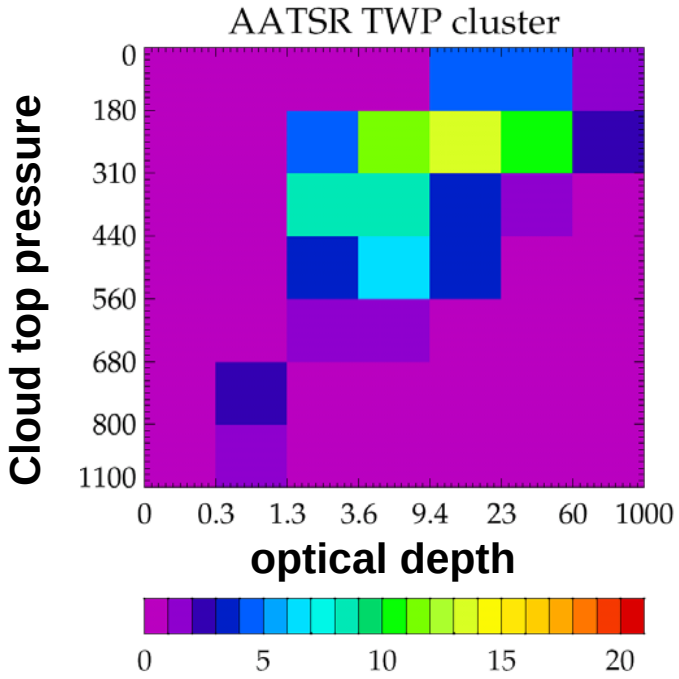


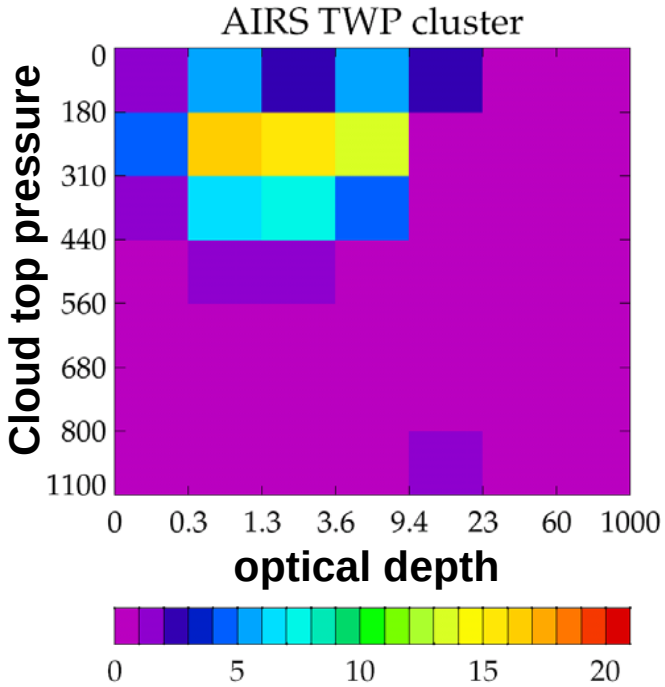


Multi annual mean CTP comparison

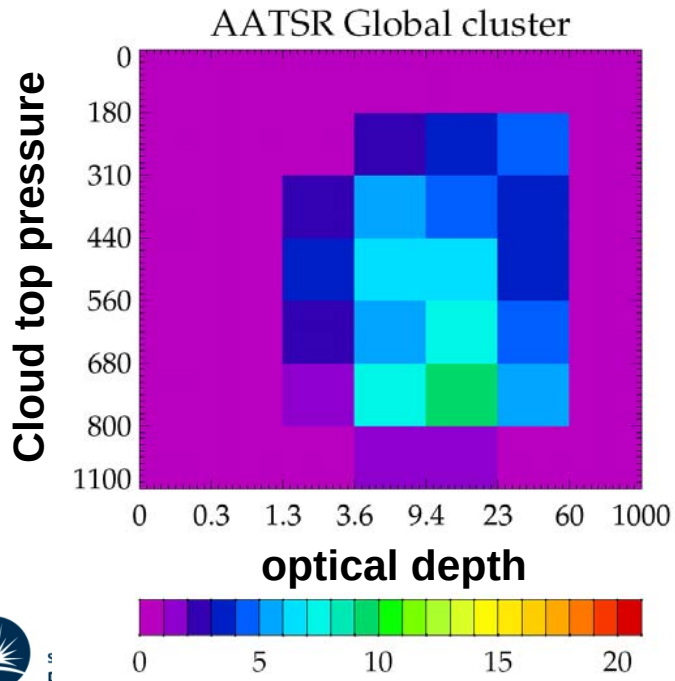


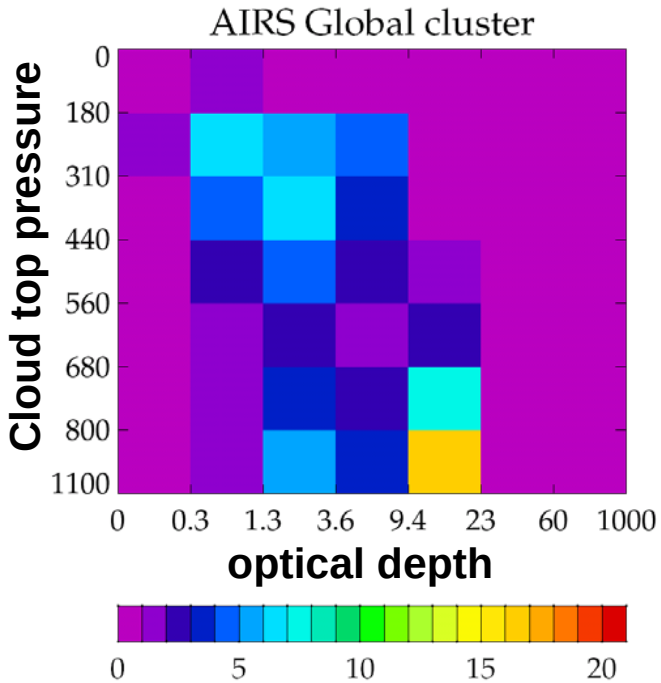
- **Problems with the boundary layer inversions**
- **Underestimation of altitude in the tropics due to IR penetration**
- **Problems with multi layer cloud**
- **Sampling is different**





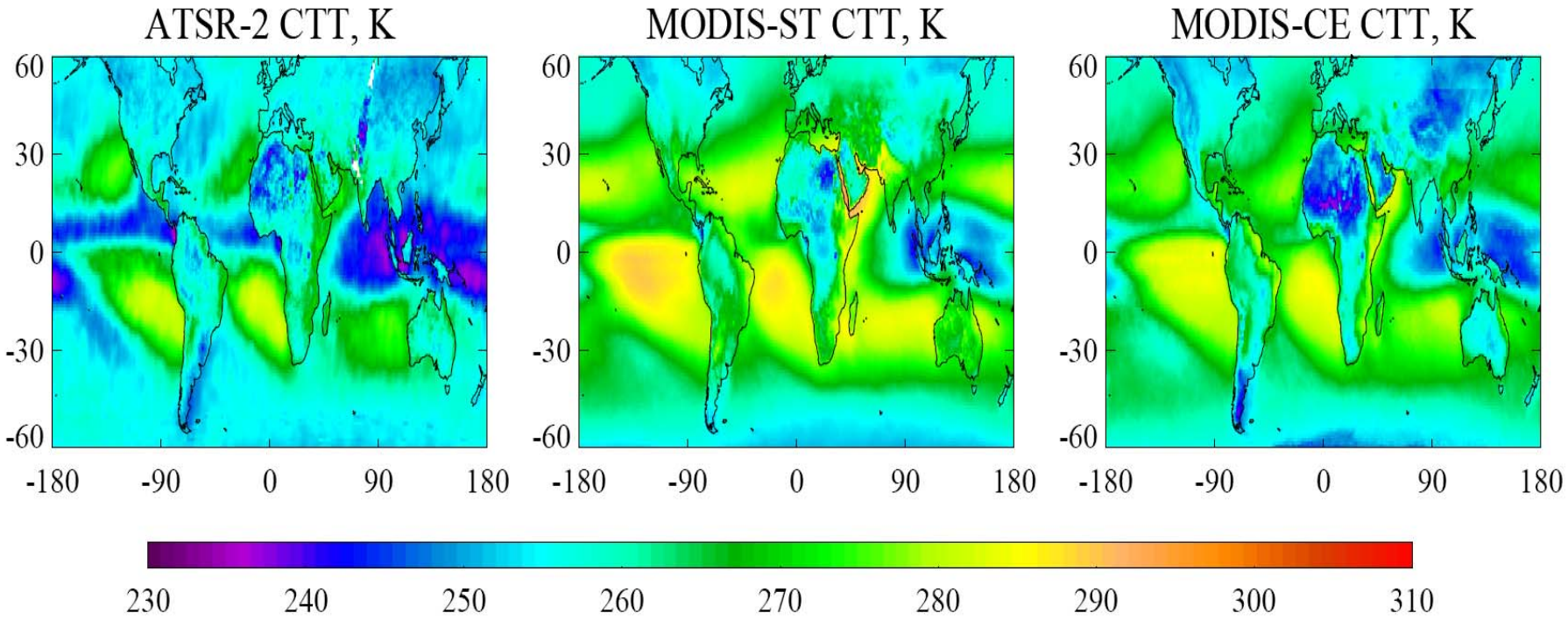
AATSR detects thicker high cloud





AATSR misses thin cloud

Cloud top temperature

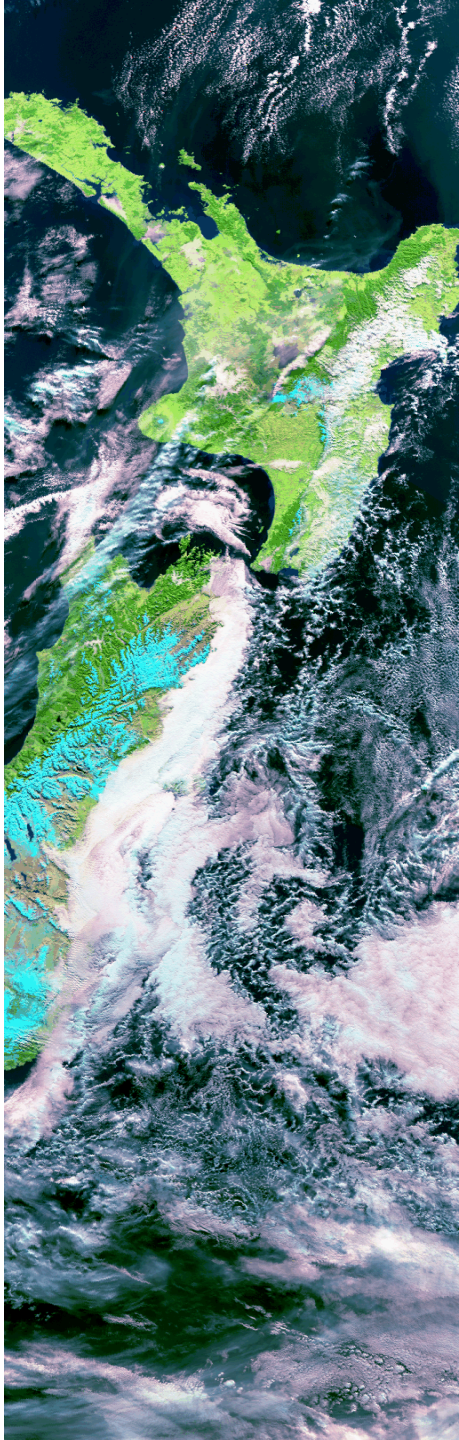


ATSR CTT 3.6K cooler than MODIS-CE
ATSR CTT 6.4K cooler than MODIS-ST

Spread in CTT is smaller than in CTP (about 1km compared to 3km in CTP)
- **Although CTH may be too high, e.g temperature inversions, CTT may be correct.**
- **Sampling likely to be a large contributing factor to differences**

Conclusions

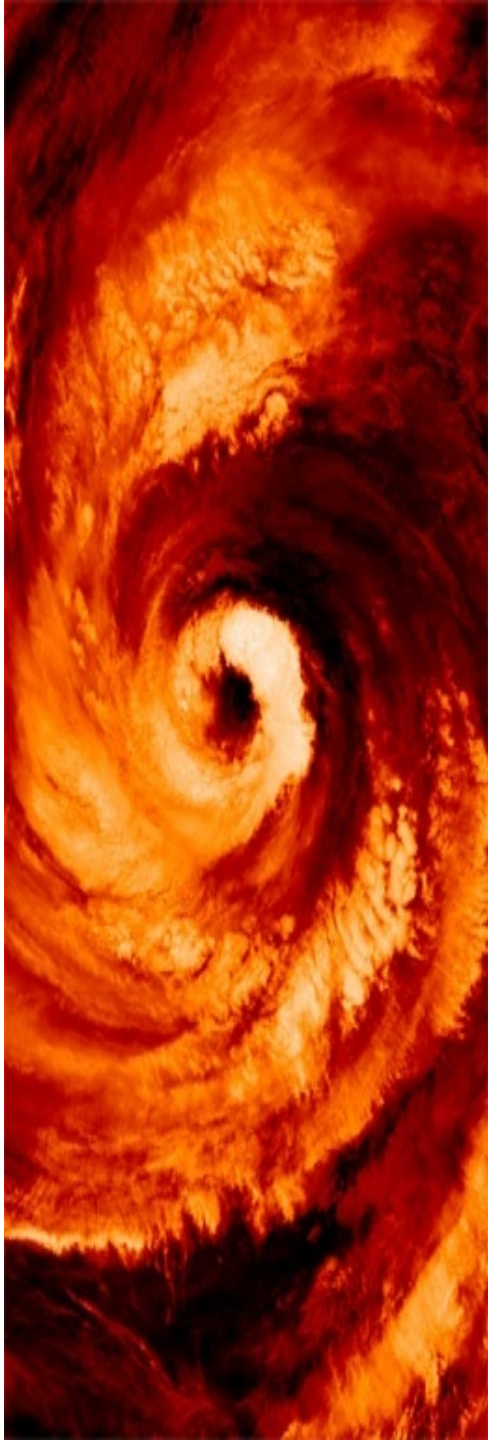
- ATSR detects cloud well over sea, cloud detection over land could be improved.
- Negative bias in cloud top height is expected when observing multi layered cloud, this cloud is often identified using the cost threshold.
  - ATSR detects too much mid level cloud
  - Problem with temperature inversion
    - To be corrected in next processing
    - Could apply quick fix to existing data
- Differences in cloud top height are often a function of the penetration depth or IR compared with active sensors
- CTT shows less discrepancy than CTP
- Sampling effects could be another factor affecting comparisons (NB use of cost to remove some multi-layer)



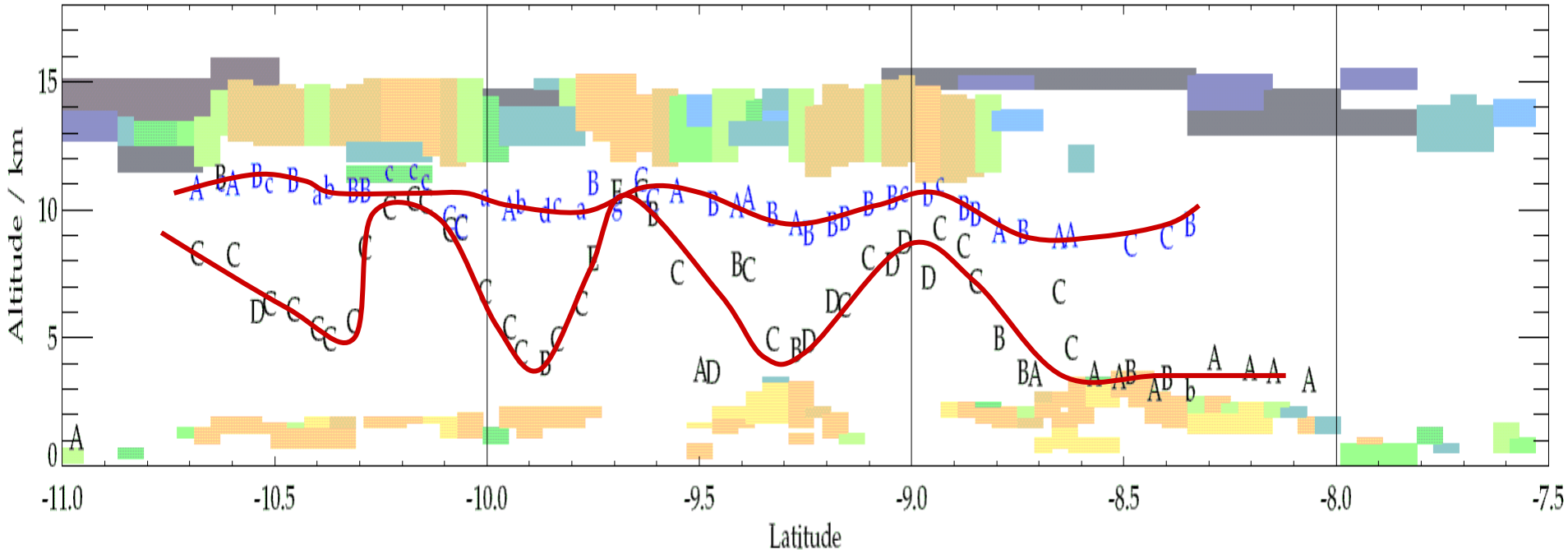
FUTURE PLANS

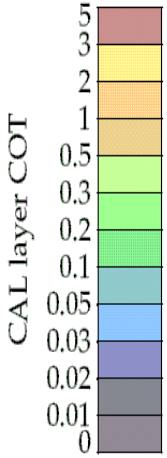
(of particular relevance to fraction and height retrievals)

- More unified aerosol/cloud retrieval scheme
- Improved land surface model
- Move away from simple use of cloud flag, i.e. retrieve all scenes and decide post-hoc if cloud/aerosol using cost of each model + other information (e.g. spatial coherence)
- ATSR forward view in cloud retrieval (PhDs at Oxford and UCL-Stereo retrieval)
- Improved treatment of boundary layer inversions
- Improved treatment of multi-layer systems
  - Recent EUMetSat study
- Synergy between different instruments (AATSR/MERIS, SLSTR/OLCI)- with FUB



Modelling multi layer cloud





Cost

A < 2
B < 4
C < 10
D < 20
E < 40
F < 100
G < 100000

- OCA-Optimal Cloud Analysis code for SEVIRI cloud retrievals used to test multi layer cloud model
- Validated with Cloud sat and Calipso data
- R. Siddans et al 2009. EUMETSAT report

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OPTIMAL ESTIMATION: APPROACH

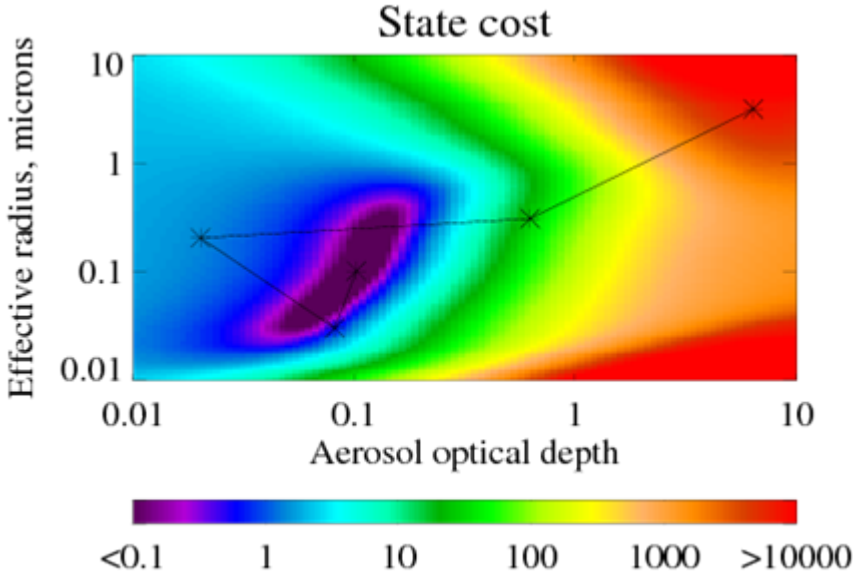
- Minimise cost function, *J*

$$J = (\mathbf{y}_x - \mathbf{y})\mathbf{S}_y^{-1}(\mathbf{y}_x - \mathbf{y})^T + (\mathbf{x} - \mathbf{x}_a)\mathbf{S}_a^{-1}(\mathbf{x} - \mathbf{x}_a)^T$$

- Linearise forward model

$$\mathbf{y}_x = \mathbf{F}\mathbf{x} \qquad \delta\mathbf{y}_x = \mathbf{K}\delta\mathbf{x}$$

- Iterative steps weighted between gradient of *J* and Newtonian descent
  - Stop when change in cost small
- Error estimate on retrieved state



$$J' = \mathbf{K}^T\mathbf{S}_y^{-1}(\mathbf{y}_x - \mathbf{y}) + \mathbf{S}_x^{-1}(\mathbf{x} - \mathbf{x}_a)$$

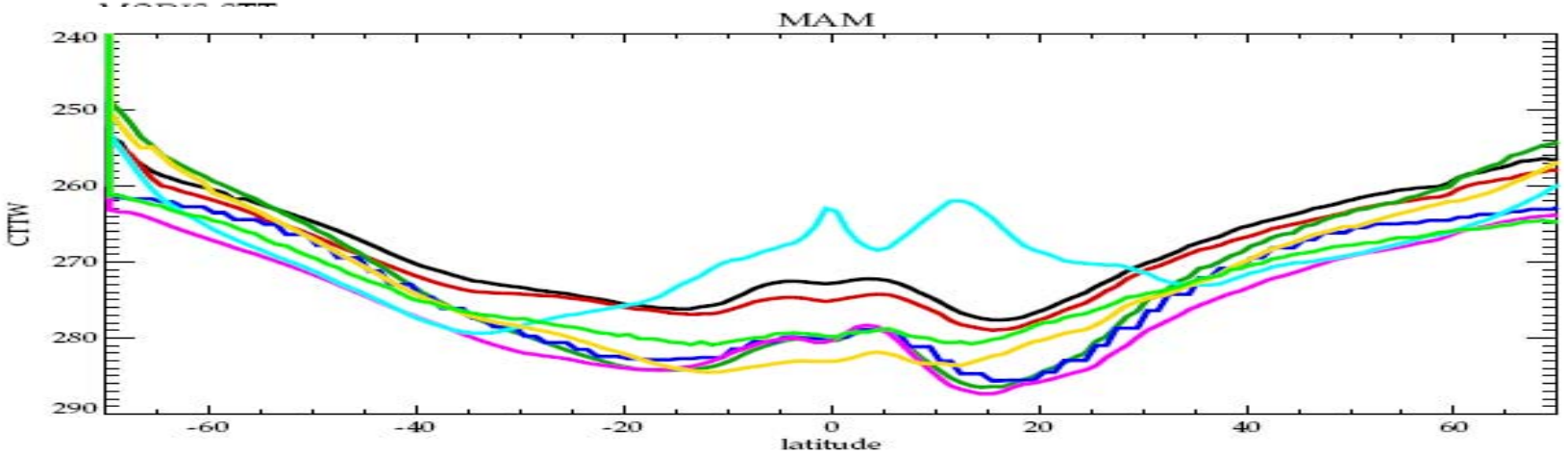
$$\mathbf{S}_x = \left(\mathbf{S}_a^{-1} + \mathbf{K}^T\mathbf{S}_y^{-1}\mathbf{K}^{-1}\right)^{-1}$$

Cloud Top Temperature

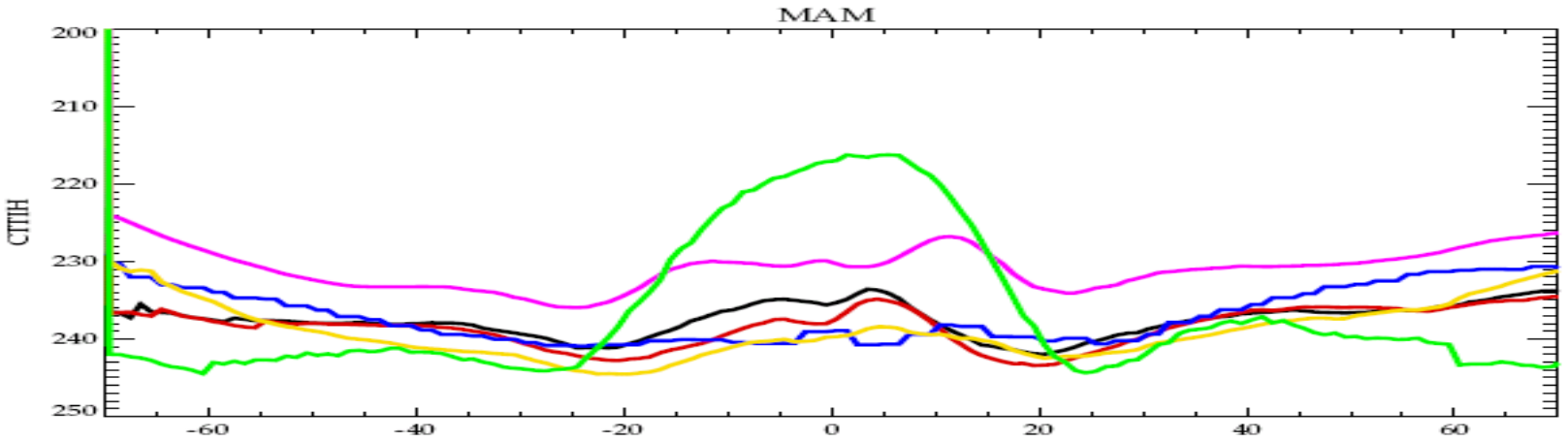
ATSR2
AATSR
PATMOSX
ISCCP
AIRS

MODIS-STT
MODIS-CET
MISR
POLDER
CALIPSO

Water CTT



High Ice CTT



latitude

- End