Climate records and Cloud CCI

Caroline Poulsen, the Cloud CCI team and many others who I have borrowed slides from!

Outline

- What can cloud satellite retrievals tell us about the climate?
- Climate trends
- Process studies
- The Cloud CCI

RAL Space

IPCC AR5

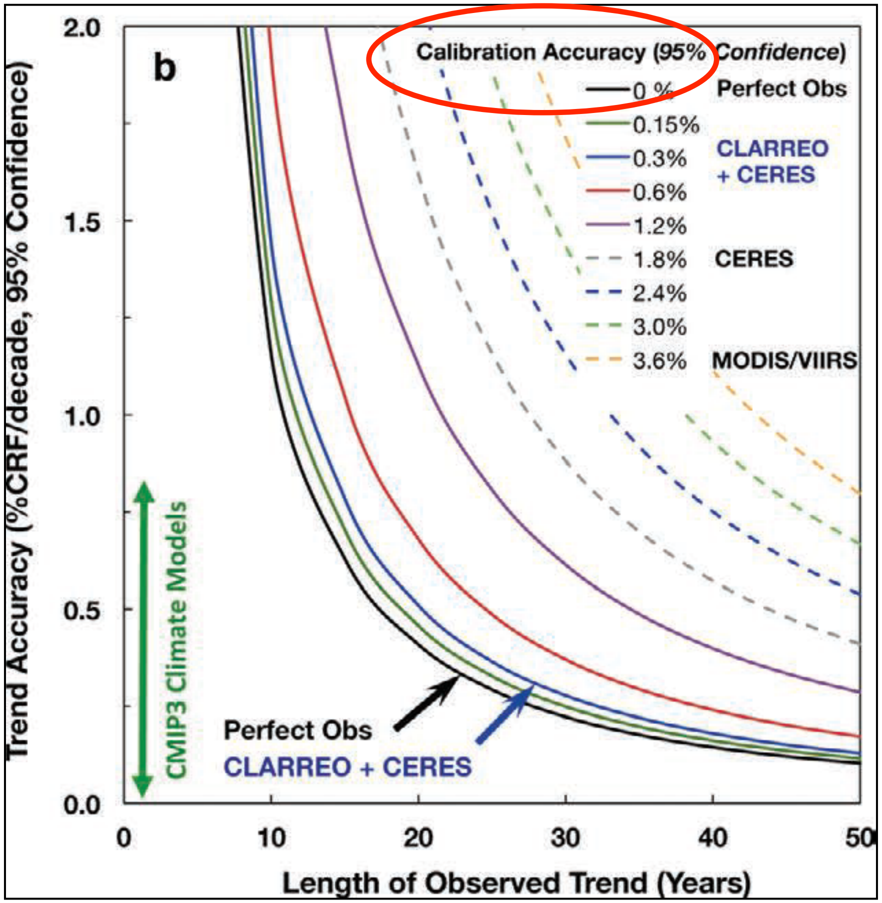
"In summary, surface-based observations show region- and height-specific variations and trends in cloudiness but there remains substantial ambiguity regarding global-scale cloud variations and trends, especially from satellite observations. Although trends of cloud cover are consistent between independent data sets in certain regions, substantial ambiguity and therefore low confidence remains in the observations of global-scale cloud variability and trends."

RAL Space

Observing clouds and climate change

- Observing climate change is hard!
  - No current observing system is perfect
- Need:
  - Stable observing system
  - Accurate observing systems

Wielicki et al. 2013, Bulletin of the American Meteorological Society



Existing global Cloud climatologies Analysed as part of GEWEX

Longterm cloud climatologies:

ISCCP ***GEWEX cloud dataset*** ***1983-2006*** *(Rossow et al. 1999)*

PATMOS-x ***AVHRR*** ***1981-2006*** *(NESDIS/ORA; Heidinger et al.)*

HIRS-NOAA ***13h30/1h30*** ***1985-2001*** *(Wylie et al. 2005)*

TOVS Path-B ***7h30/19h30*** ***1987-1995*** *(Stubenrauch et al. 2006)*

SAGE ***limb solar occultation*** ***1984-1991,1993-2005*** *(Wang et al. 1996, 2001)*

SOBS (Surface Observations): ***1952-1996(sea), 1971-1996(land)*** *(Hahn & Warren 1999; 2003)*

EOS cloud climatologies *(since 2000, 2002)*:

MODIS-ST *(Ackerman et al.)* **MODIS-CE** *(Minnis et al.)*

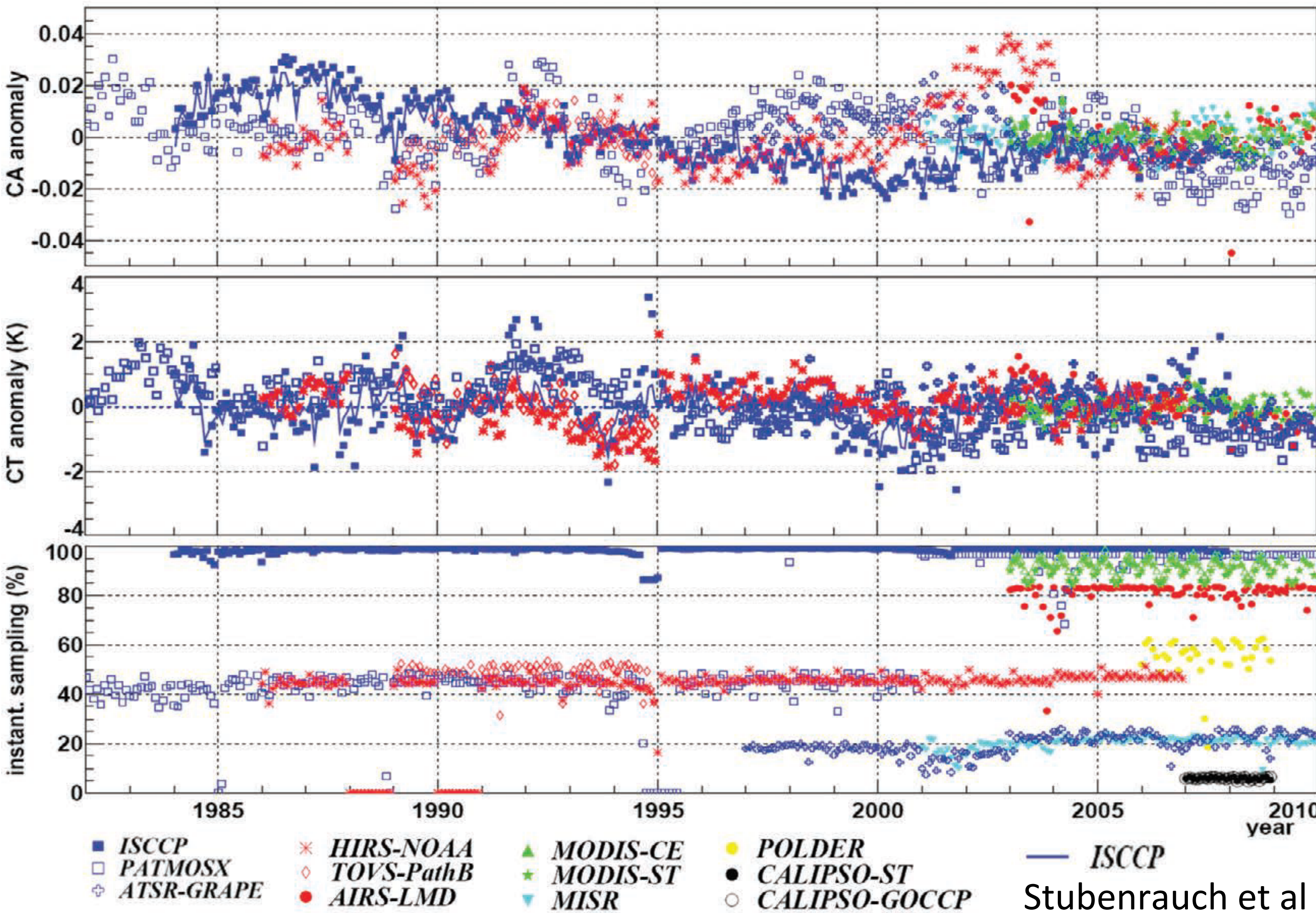
AIRS-LMD *(Stubenrauch et al. 2008)*

+ A-Train *(since 2006)*:

CALIPSO L2 data (V2) *(Winker et al. 2007)* ***active lidar***

CloudSat *(Mace)* **POLDER** *(Riedi)* **MISR** *(DiGirolamo)* ***(since 1995):*** **ATSR** *(Poulsen)*

GEWEX cloud assessment



Stubenrauch et al 2013

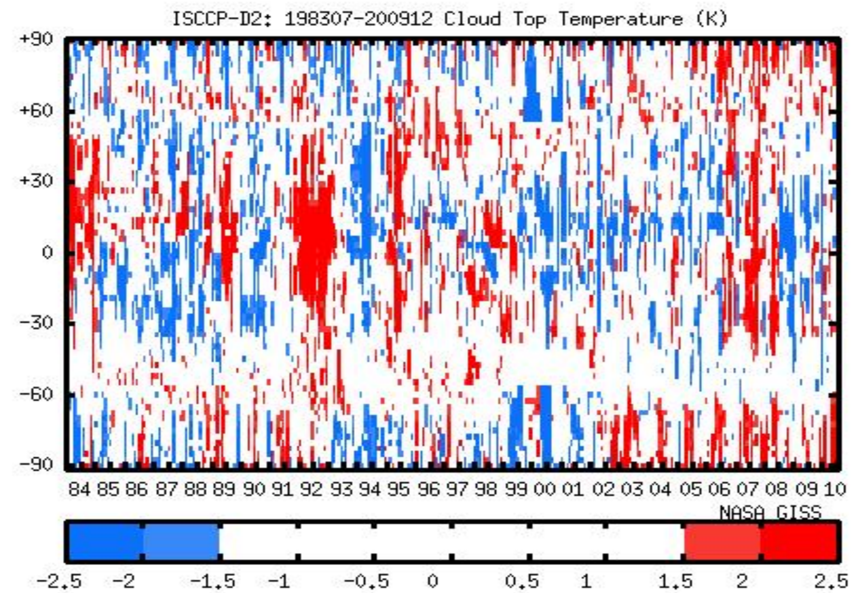
Detection of long term trends

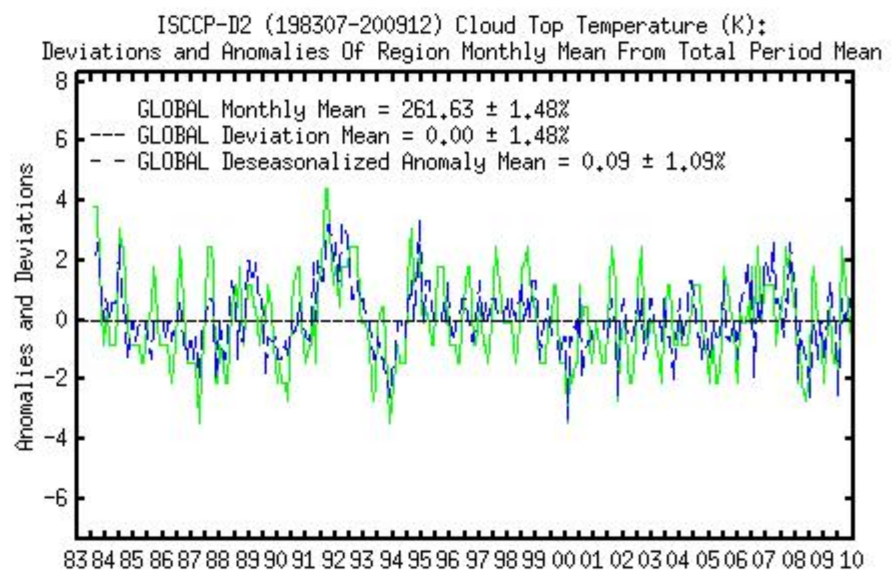
- Limited by:
  - Size of the trend to be detected
  - Time span of available data
  - Magnitude of variability
  - correlation of the noise in the data (ϕ)
  - Sudden changes in the data
- Some locations will be easier to detect trends than others
- Some trends will be easier to predict

Natural variability

ISCCP CTT anomalies
ISCCP web site

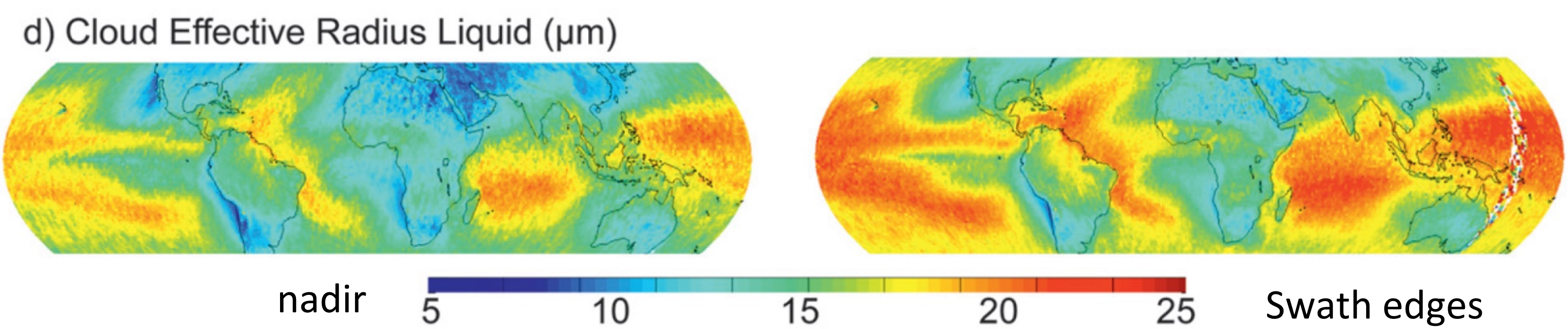
- Large scale natural variability
  - E.g. El Nino ENSO volcanoes
  - can try to reduce this noise
- Small scale
  - Synoptic scale variability





Other sources of uncertainty

- Algorithm uncertainty
  - View angle dependence
  - Phase determination- super cooled cloud
  - Bayesian detection probabilities
- Instrument Calibration uncertainty
- Diurnal sampling



nadir   Swath edges

Maddux et al. 2010 MODIS C5

International Satellite Cloud Climatology Project (ISCCP)

- 3 decades long!
- The ISCCP data set utilizes radiance information from geostationary satellites
  - The data is extended by utilizing Advanced Very High Resolution Radiometer (AVHRR) data from polar orbiting satellite roughly at latitudes above and below 60N and 60S
- A nominal resolution of 8km at nadir
- 3-hourly maps of cloudiness and other associated products.

- Rossow, W. B. and R. A. Schiffer (1991), International Satellite Cloud Climatology Project (ISCCP) cloud data products, *Bull. Amer. Meteor. Soc., 72,2-20*

ISCCP

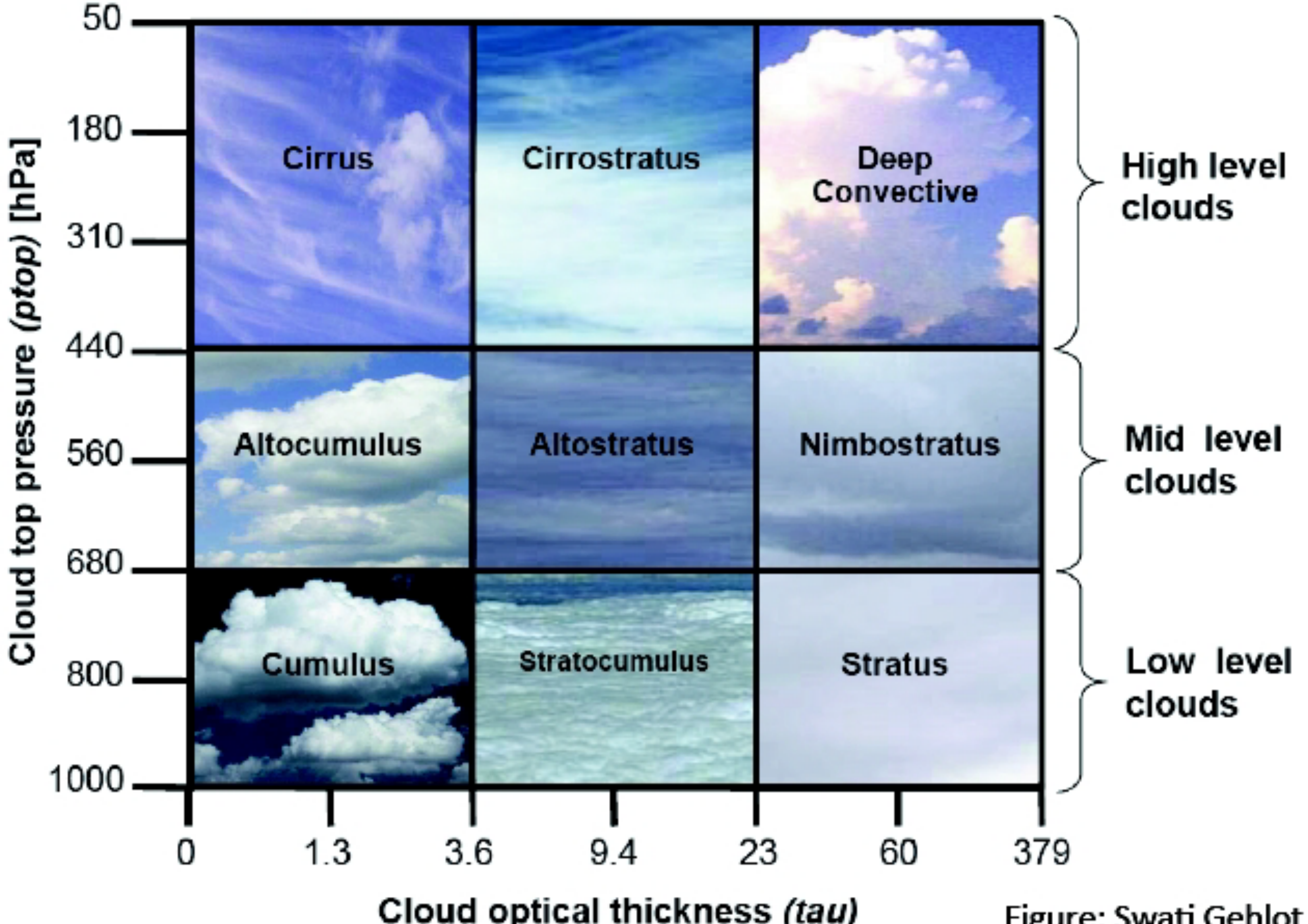


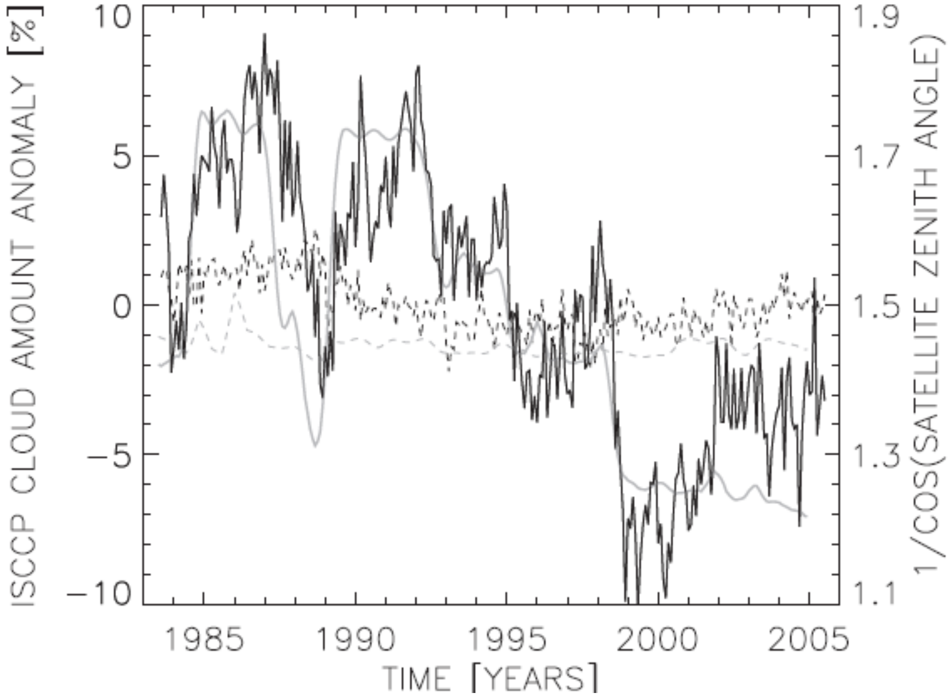
Figure: Swati Gehlot

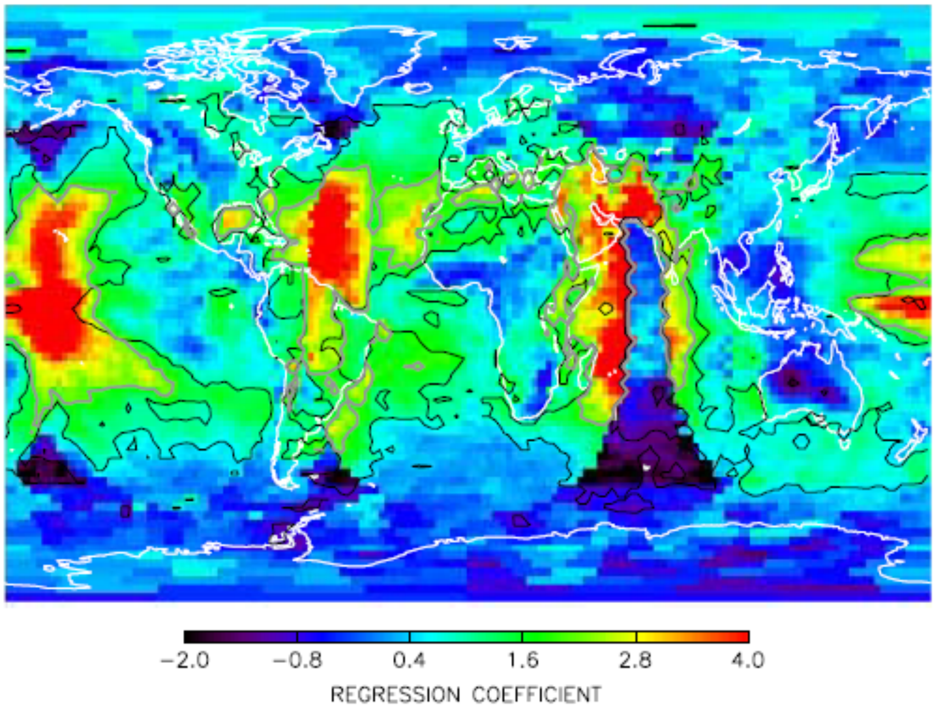
http://isccp.giss.nasa.gov/climanal2.html

ISCCP trends??

- “We have demonstrated that the long-term global trends in cloudiness from the ISCCP record are influenced by artefacts associated with satellite viewing geometry.”

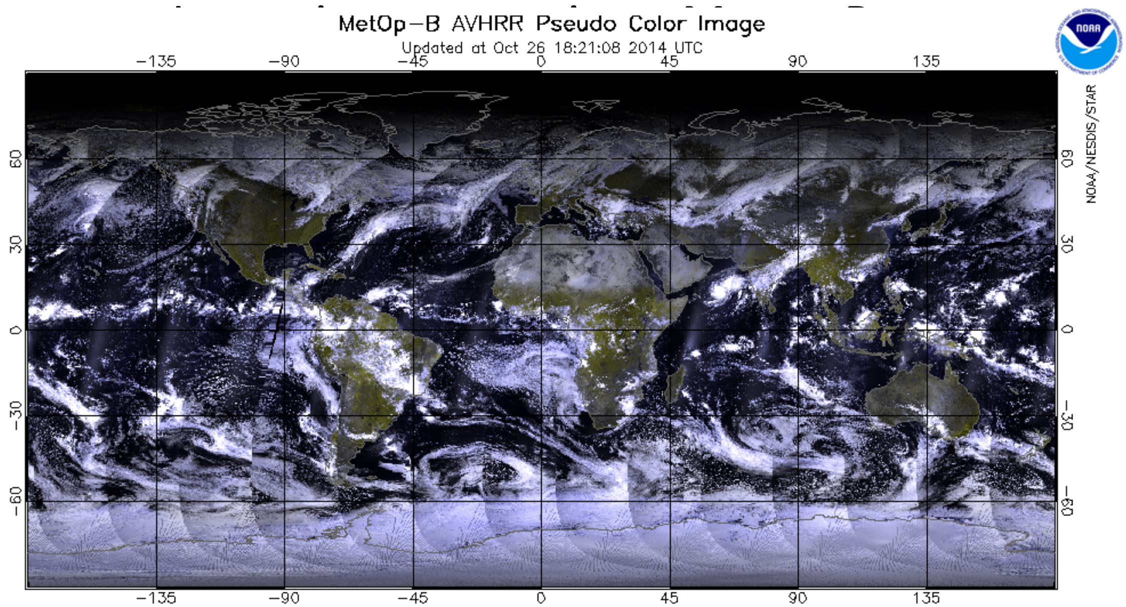
Evans et al. GRL, 2007





PATMOS-X

- **Advanced Very High Resolution Radiometer – AVHRR**
- 1978: The first AVHRR was a 4-channel radiometer, first carried on TIROS-N (launched October 1978).
- 1981:This was subsequently improved to a 5-channel instrument (AVHRR/2) that was initially carried on NOAA-7
- 1998: he latest instrument version is AVHRR/3, with 6 channels, first carried on NOAA-15 .



Trends in cloud climatology

- Paper: Foster and Heidinger ,Patmos-X: results from a diurnally corrected 30 yr satellite Cloud Climatology, Journal of Climate, 2012, V26, p414

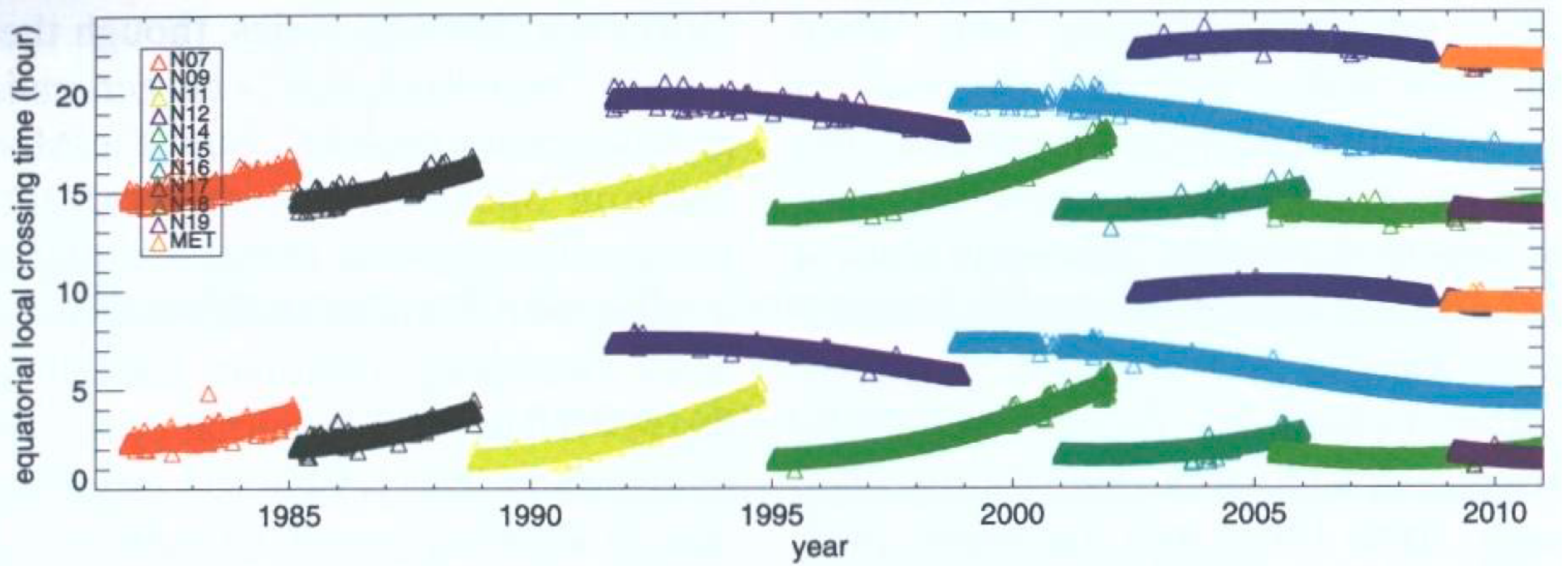
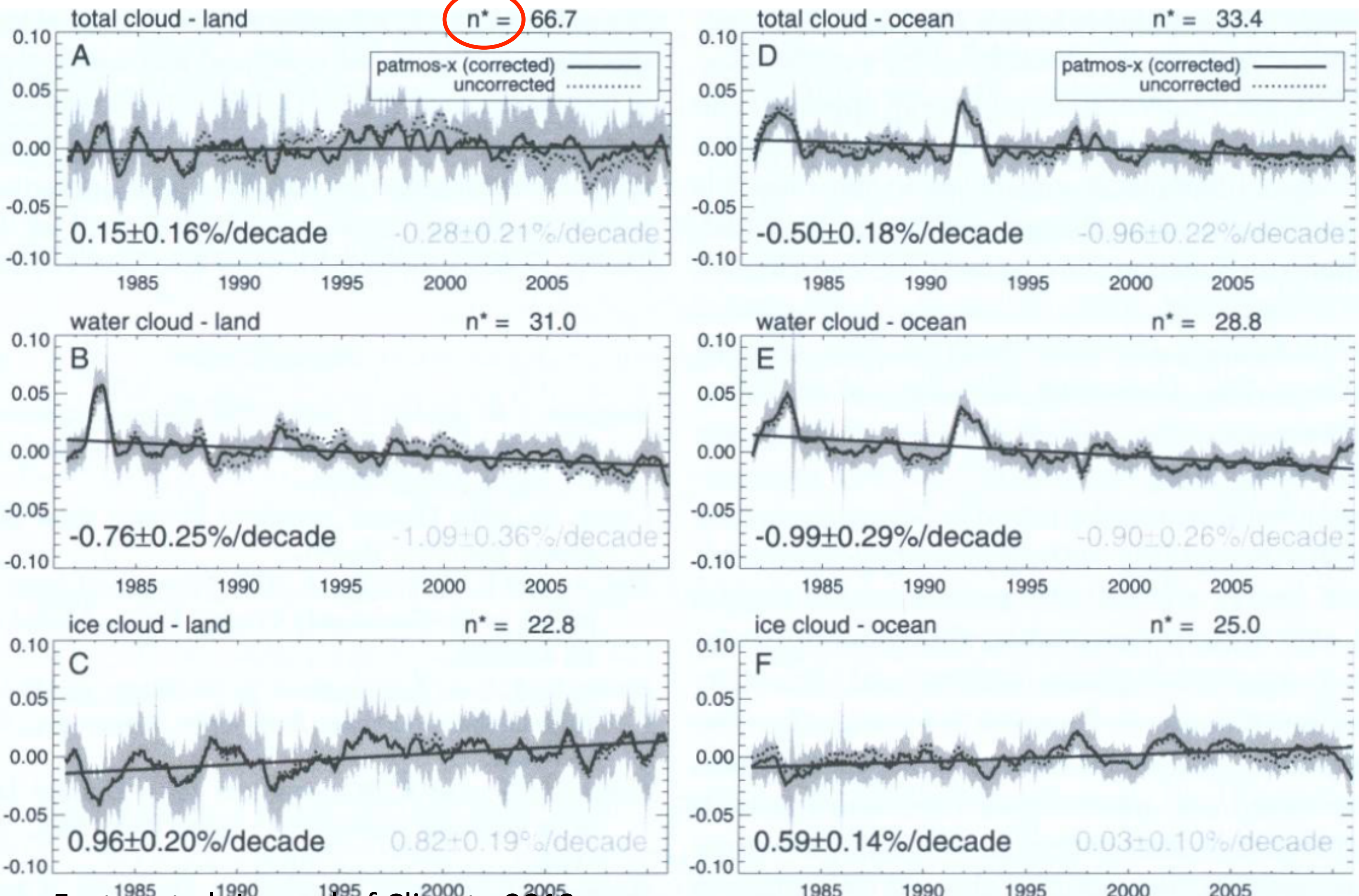


FIG. 1. Equatorial crossing time of the NOAA and MetOp polar-orbiting satellite series spanning 1981–2010.

Can use Geostationary observations to correct for diurnal cycle

PATMOS-X Trend detection (tropics)



Foster et al. Journal of Climate 2013

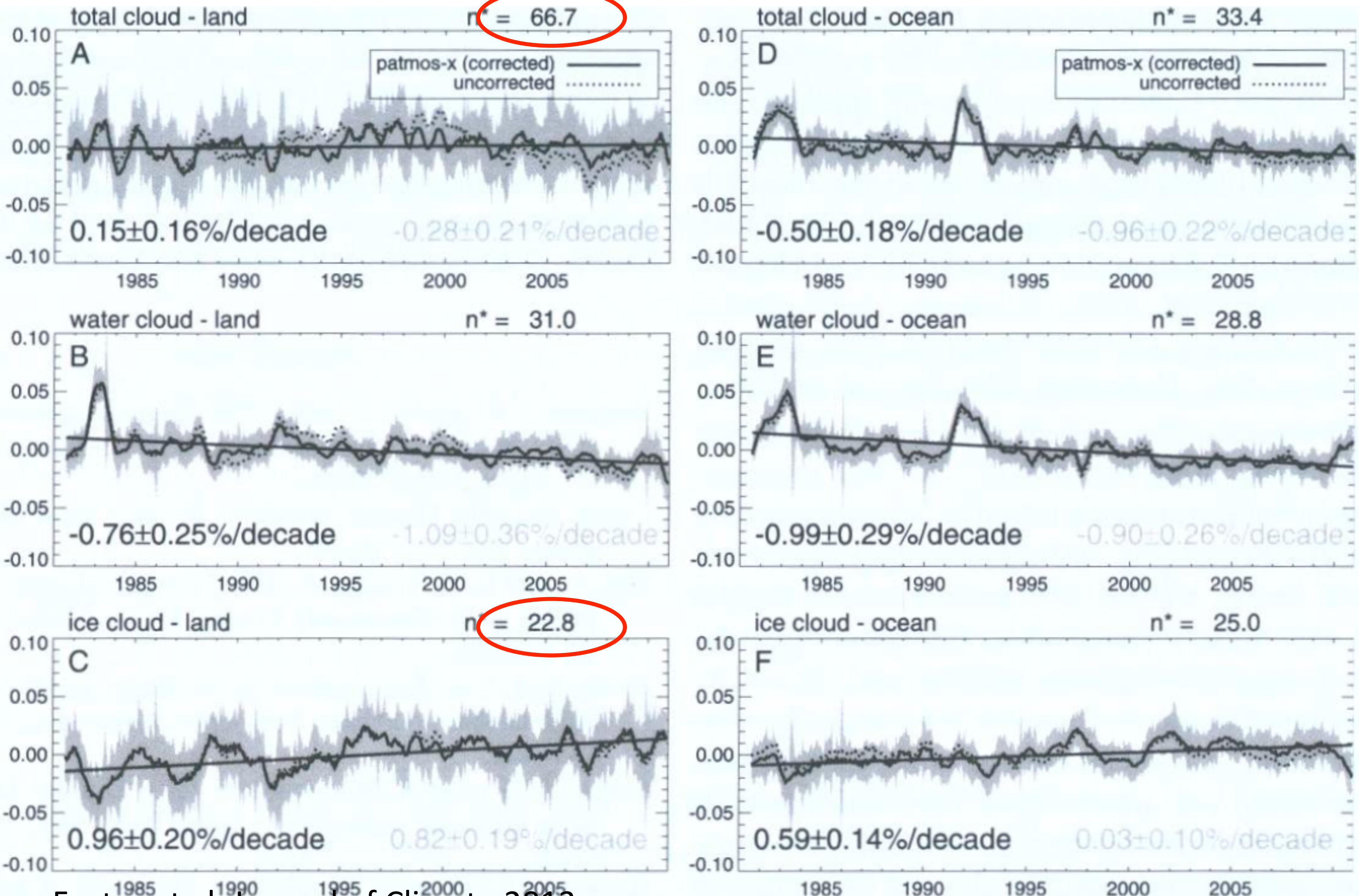
Quantifying factors affecting long term trends

$$n^* \approx \left[\frac{3.3\sigma_\varepsilon}{|\omega|(1-\phi)}\right]^{2/3} = \left(\frac{3.3\sigma_N}{|\omega|}\sqrt{\frac{1+\phi}{1-\phi}}\right)^{2/3},$$

- n^* = number of years to detect the trend
- ω = trend
- σ_N = stdev of noise (N) of the time series (i.e. not explained by ω or seasonal signal)
- Φ = autocorrelation of N
- σ_ε = stdev. of white noise ε

Good paper: Weatherhead et al. Factors affecting the detection of trends: Statistical consideration and application to environmental data. JGR Vol 103, D14, 1998

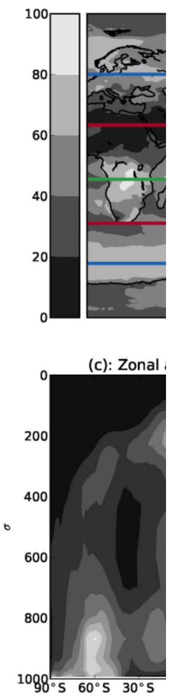
PATMOS-X Trend detection



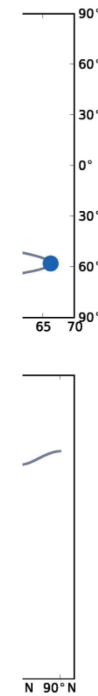
Foster et al. Journal of Climate 2013

Searching for cloud trends using Multivariate techniques

- How are the ***locations*** of max/min cloud fraction changing?
  → Latitude (**L**) Indicator
- How is the ***total cloud fraction*** changing at these locations?
  → Cloudiness (**C**) Indicator
- How is the ***high cloud top pressu*** changing at these locations?
  → Height (**H**) Indicator



- Looking for robust cloud changes
- Tracks features
  - 15 element matrix
  - Can track all at the same time
    →Multivariate
- performed for:
  - model runs
  - satellite data sets



Zelinka/Marvel talk at Climate symposium Darmstadt 2014

What can satellite climate records tell us so far

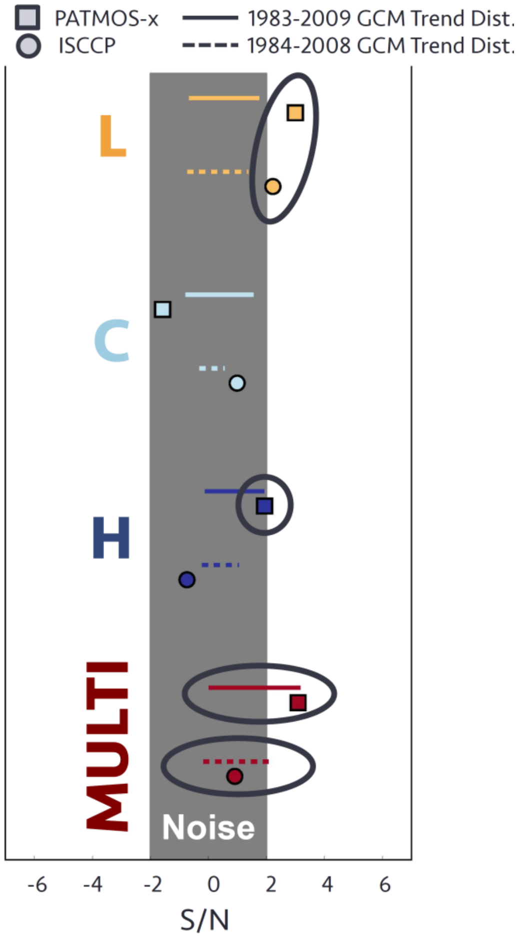
L signal detected,
but is incompatible with
model forced trends

Observed trends in C and H
disagree in sign…
They fall within noise.

H signal is on the cusp of
detectability in PATMOS-x

Multivariate signals positive &
consistent with model forced trends

The only signal that the models say we should detect over this period, we do indeed detect.



Should be treated with caution!

If > 1.96 than 95% confident

From Zelinka et al 2014

LWP trends

- **MAC-LWP**
  - **26 years 1988-2013**
  - **Combined multi satellite SSMI/AMSRE**
  - **Diurnal cycle correction**

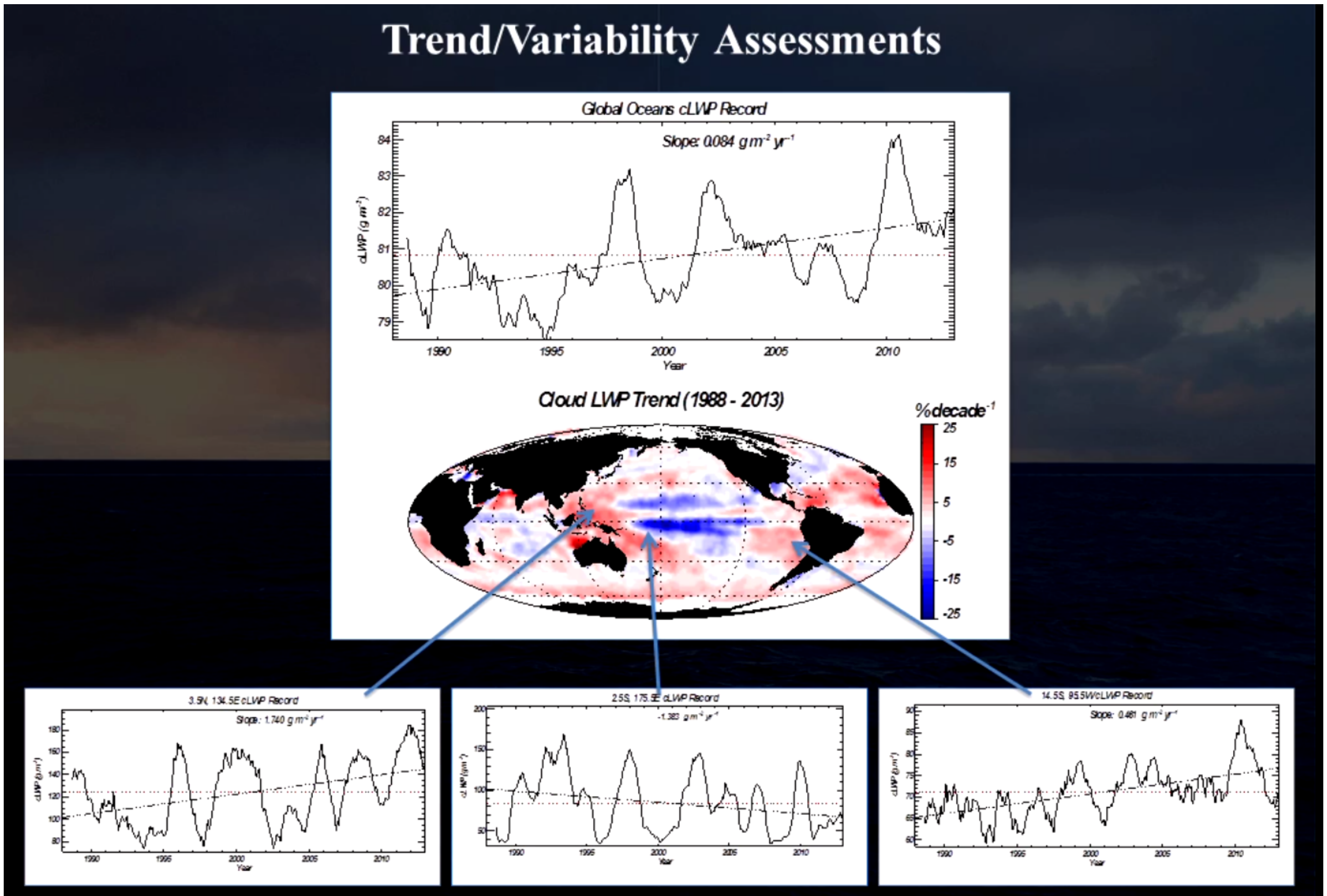
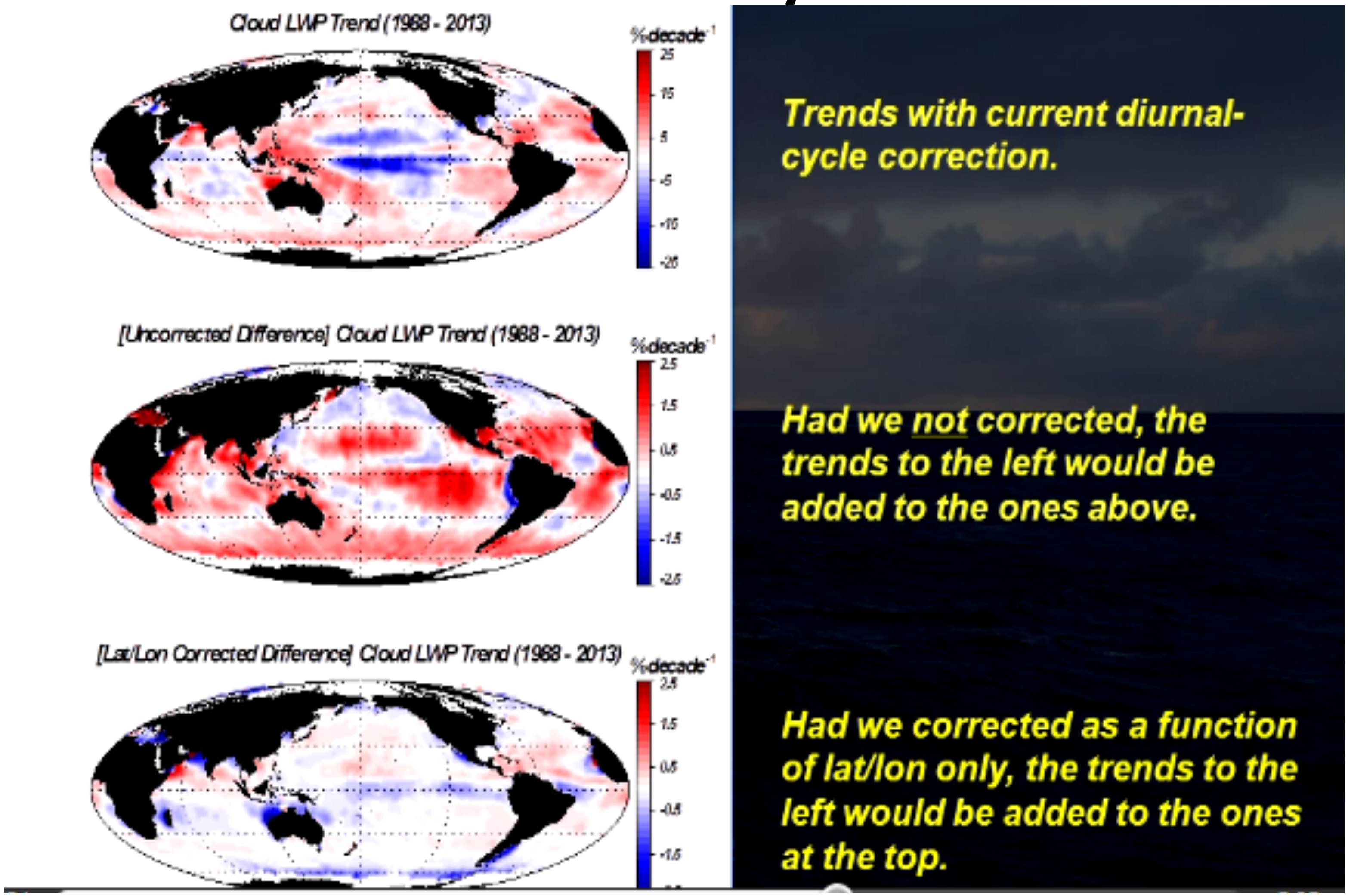


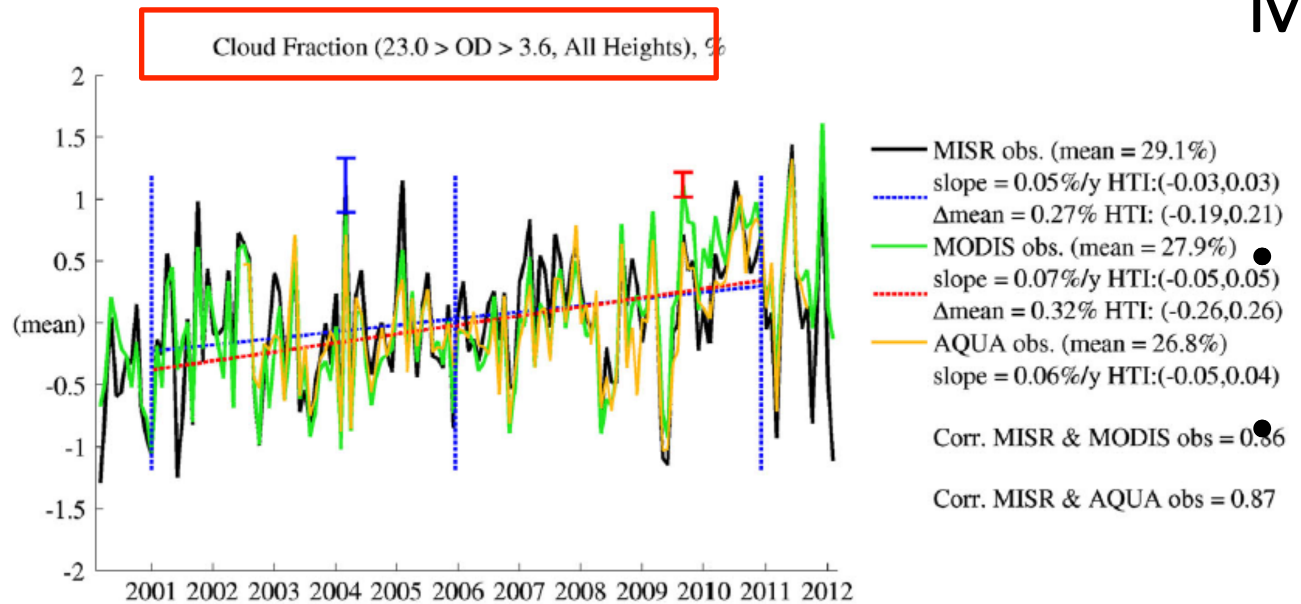
Figure from AMS **Gregory Elsaesser talk** conference 2014

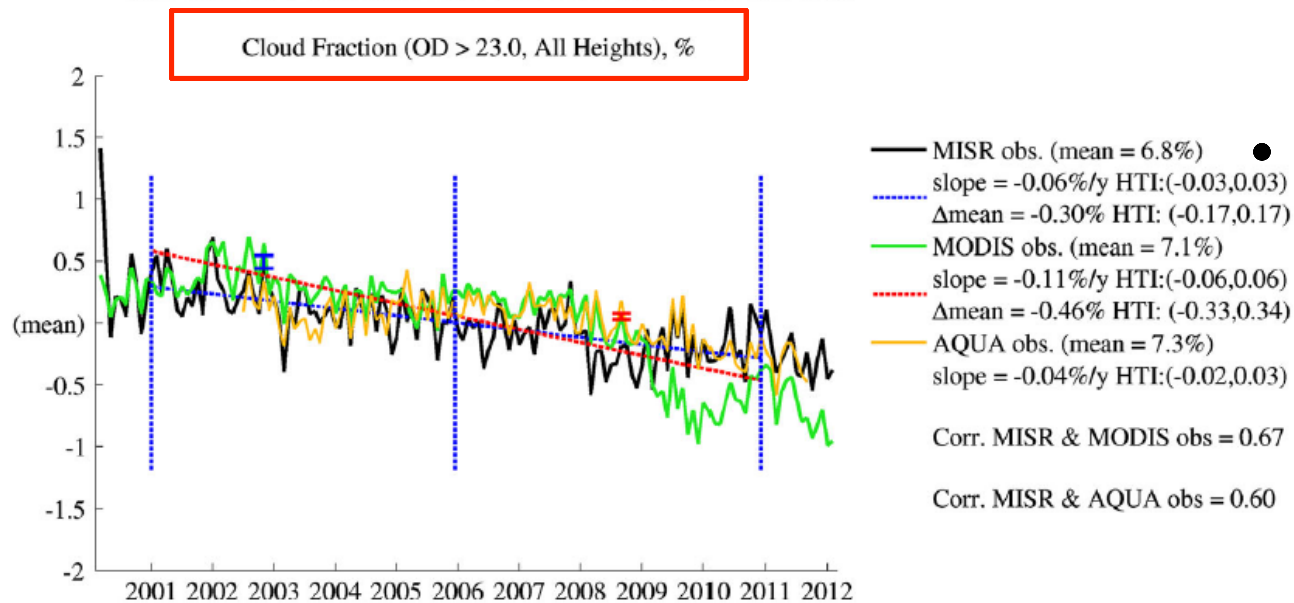
Effect of diurnal cycle correction



- **Gregory Elsaesser**, Colorado State University, Fort Collins, CO; and C. O'Dell, R. Bennartz, and F. J. Wentz

MODIS/MISR Trends



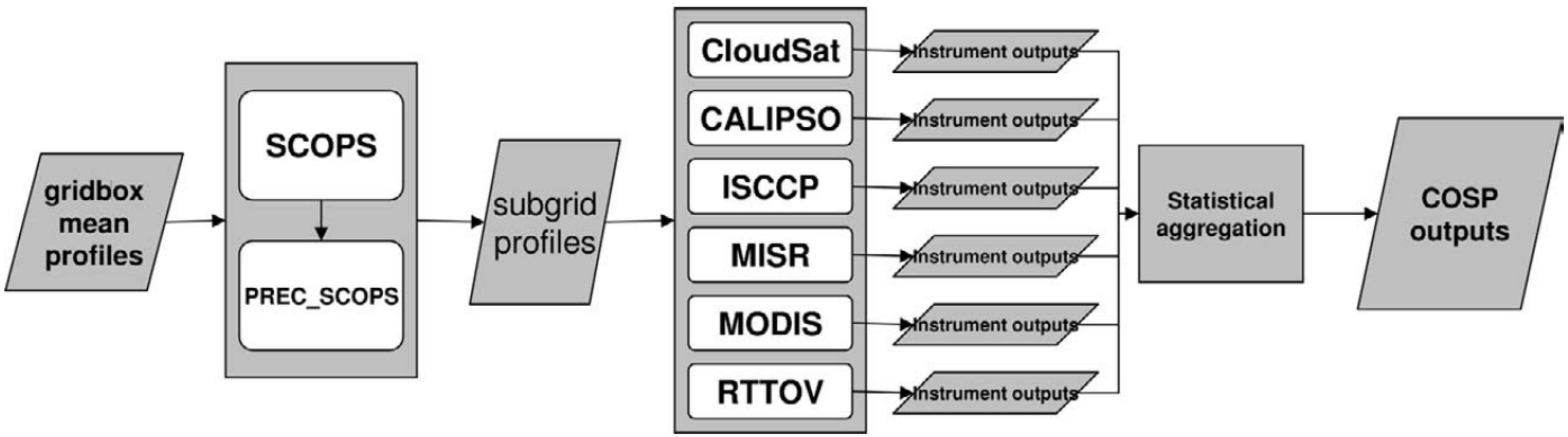


- No trends in global cloud fraction
- But trends in individual CTH/τ histograms from MISR and MODIS-
- Arising from mid latitude storm tracks that have narrowed and shifted northwards??

Marchand, JGR, 2013

The CFMIP (Cloud Feedback Model Intercomparison Project) **Observation Simulator Package (COSP)**

By simulating the observations of multiple satellite instruments, COSP enables quantitative evaluation of clouds, humidity, and precipitation processes in diverse numerical models.



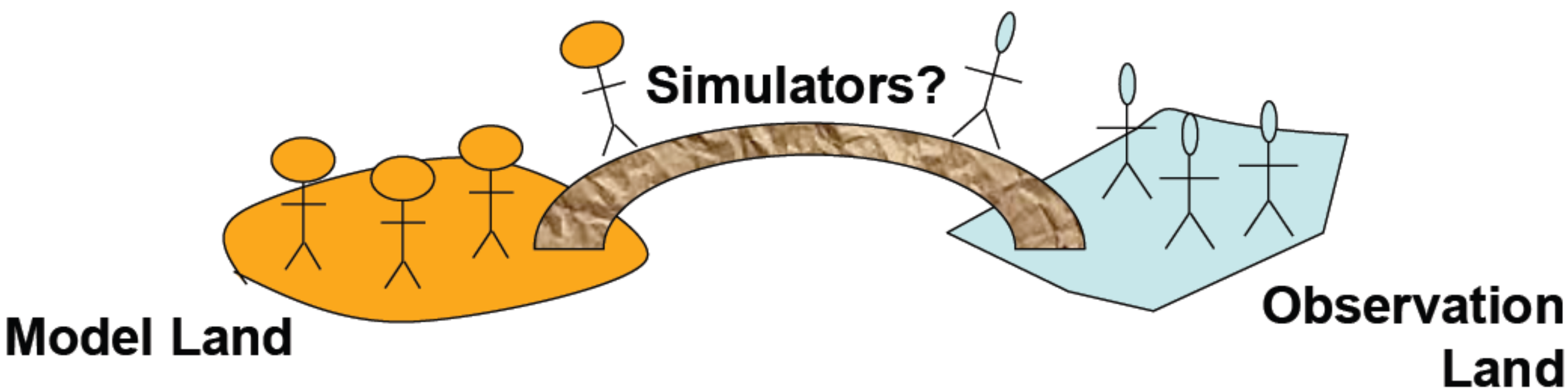
Software to simulate satellite data from models

And build statistics to compare with similar from observations

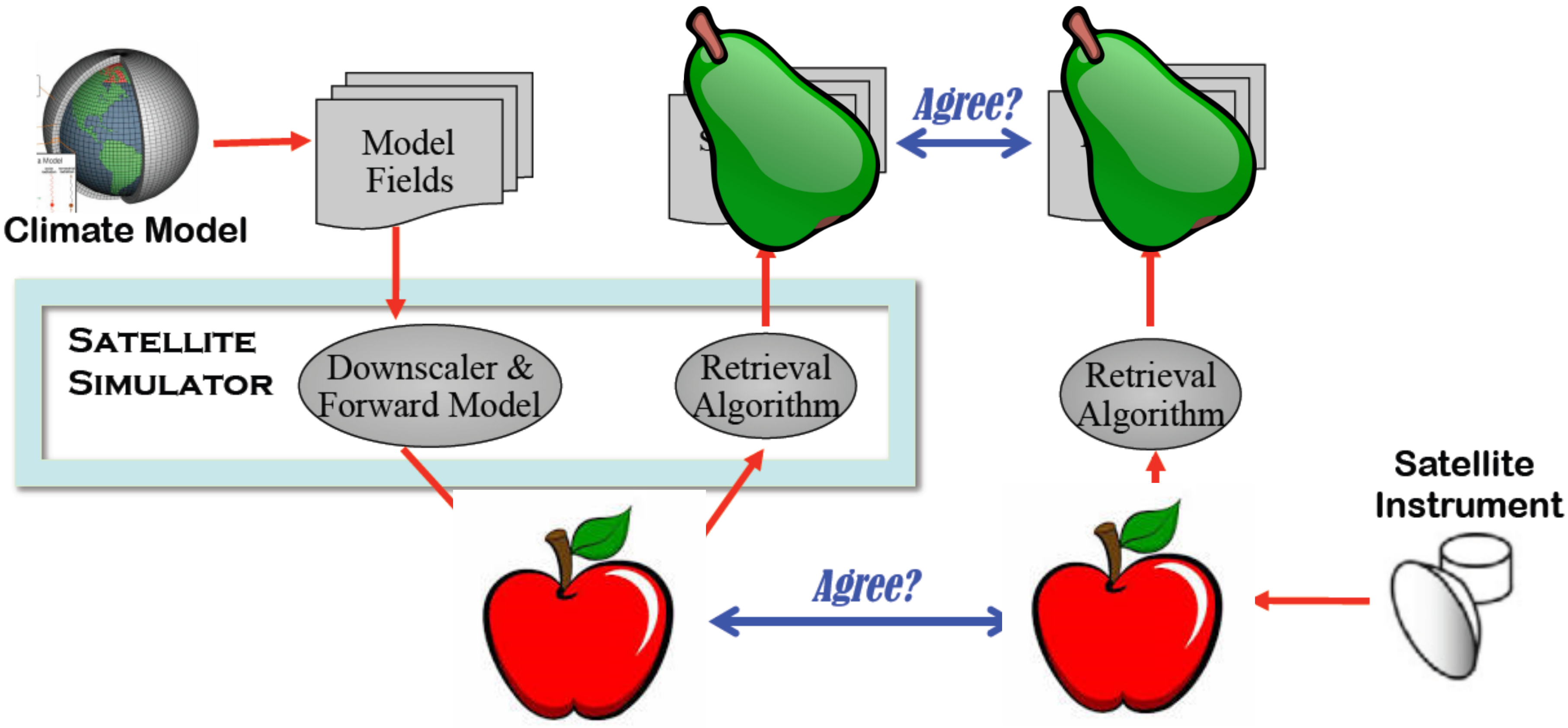
http://cfmip.metoffice.com/COSP.html

Simulators- Why?

- Modelled quantities are not the same as observed quantities (e.g. clouds)
- Sensitivity depends on the instrument
- Measurement footprints are substantially different from model grids
- Numerous assumptions are made in retrievals (and models)
- Passive measurements have limited information on the vertical structure of clouds



How does a simulator work?



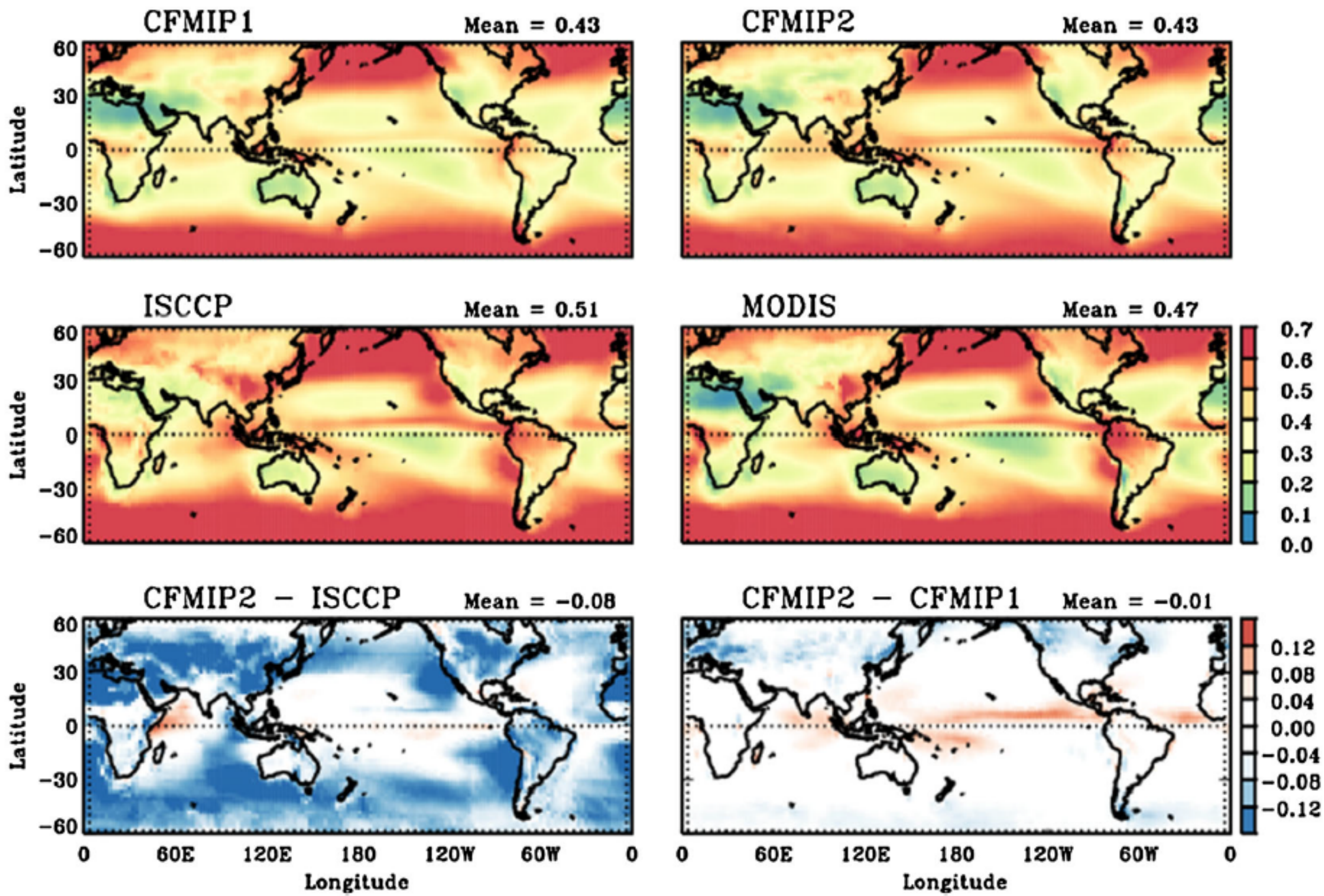
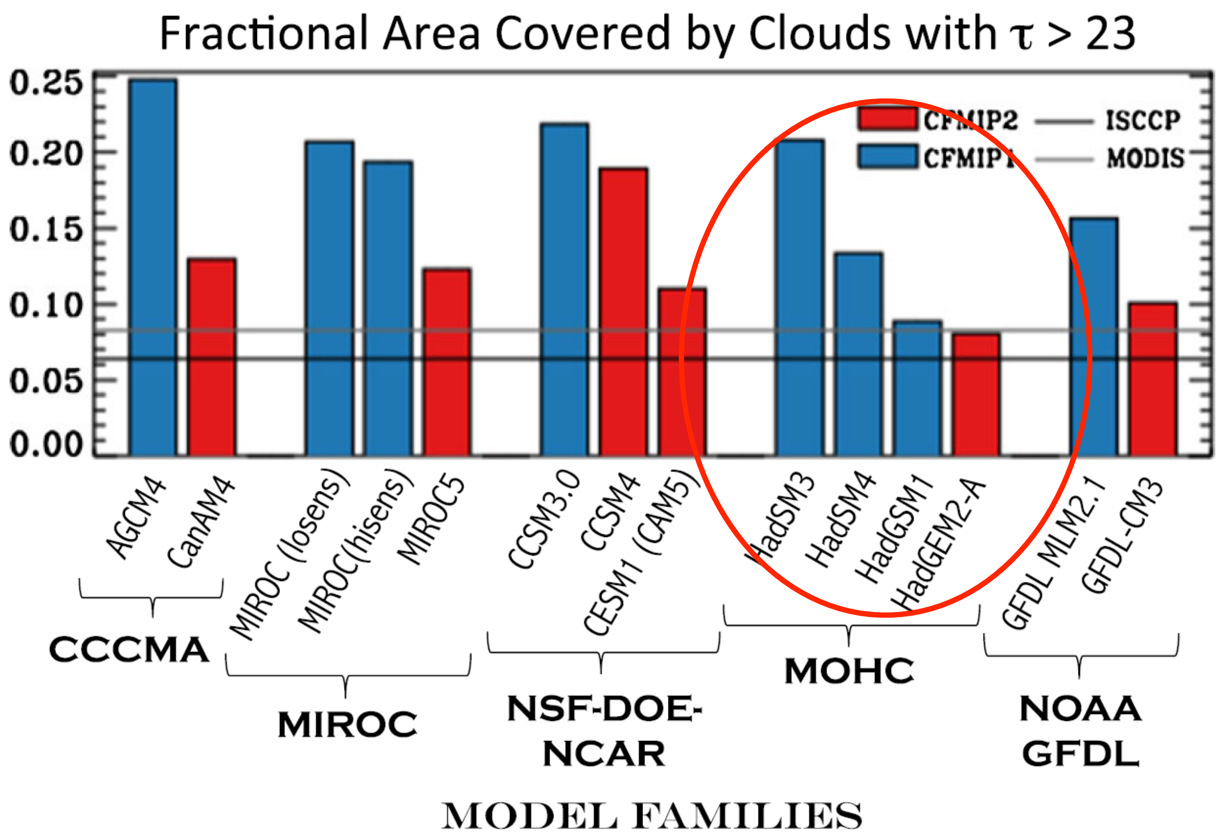


Figure 1. Total cloud amount ($\tau > 1.3$) from CFMIP1 and CFMIP2 multimodel means, ISCCP and MODIS observations, and the difference of CFMIP2 multimodel mean to the ISCCP and CFMIP1 multimodel mean. The ensemble-mean distribution of total cloud amount is only slightly closer to observations in CFMIP2 than in CFMIP1, despite substantial improvement in some models.

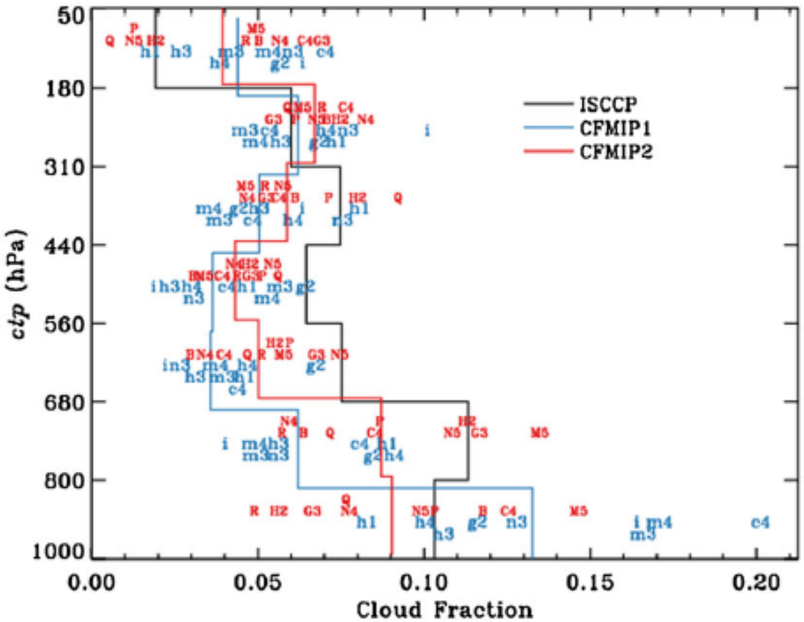
Klein et al JGR 2013

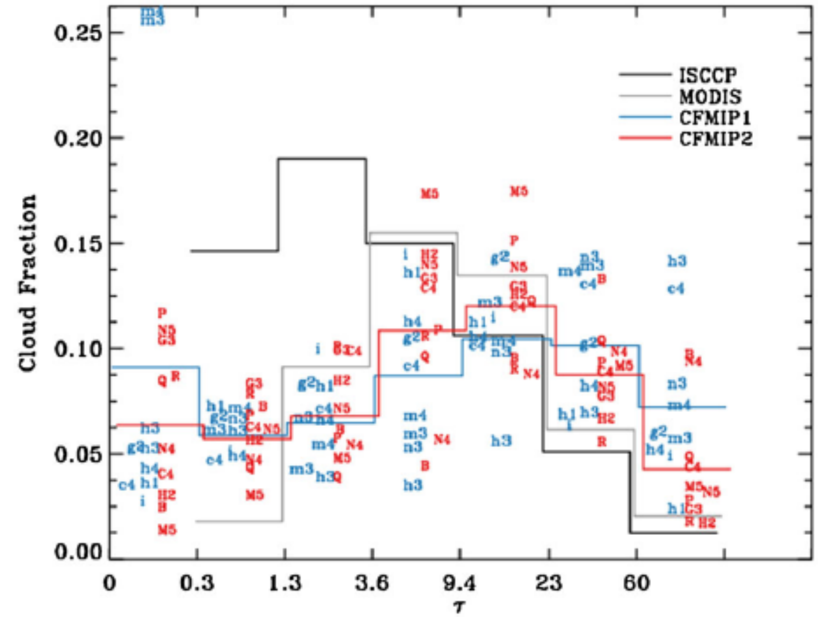
How ISCCP has been used to improve models

- First and widely used simulator



Klein et al JGR 2013





Fraction of area 60S-60N covered by clouds as a function of CTP for models and satellites

Fraction of area 60S-60N covered by clouds as a function of optical thickness for models and satellites

Must be careful with interpretation of satellite and models

Klein et al JGR 2013

Global - DJF 2006

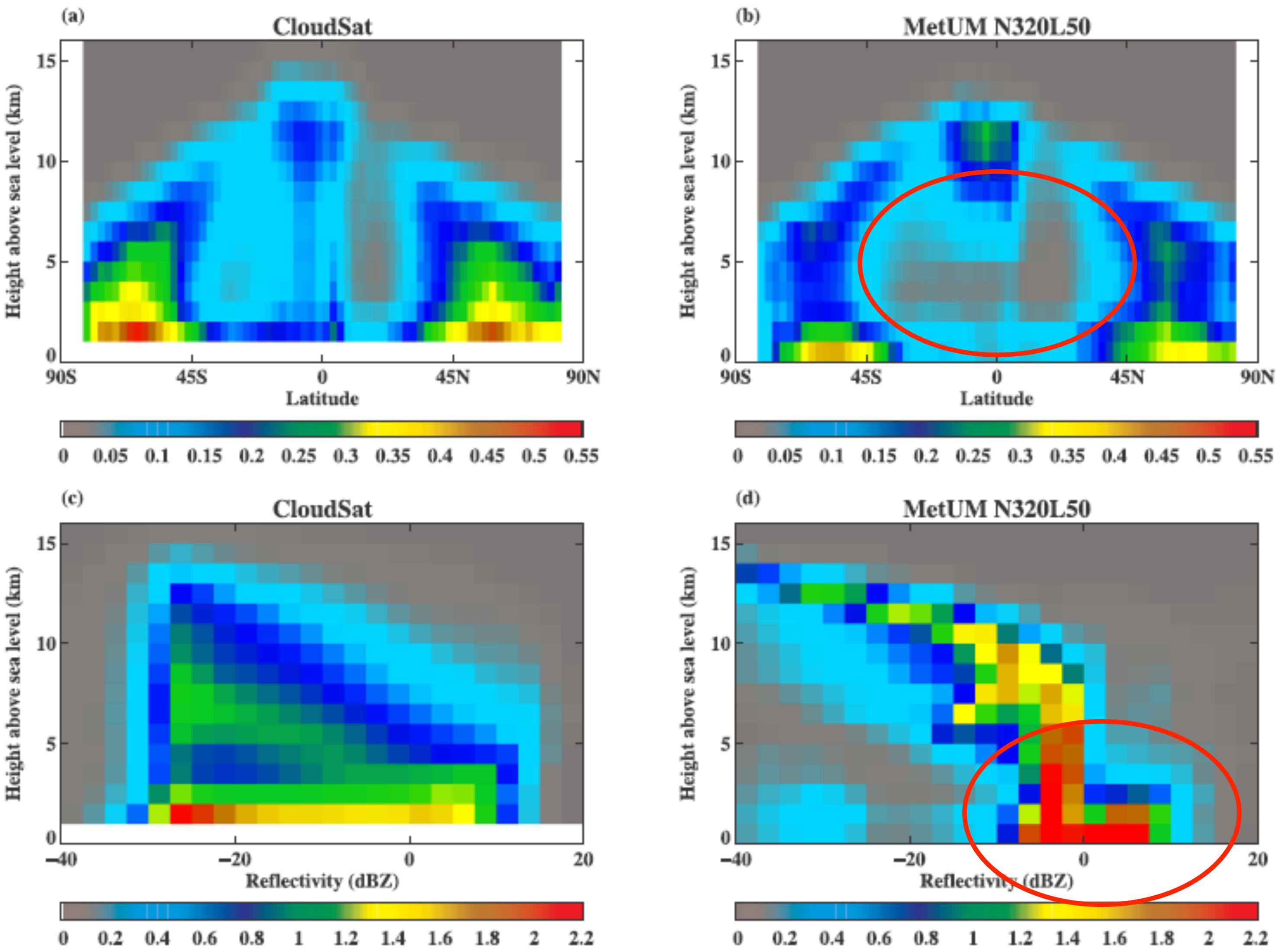


Figure 2. Comparison of DJF 2006 statistics for the whole globe: (a) zonal mean cross section of hydrometeor occurrence as observed by CloudSat and (b) simulated by the MetUM model; (c) joint height-reflectivity hydrometeor frequency of occurrence as observed by CloudSat and (d) simulated by the MetUM global forecast model. The frequency in the height-reflectivity histograms is expressed as a percentage (%).

Bodas Salcedo et al, JGR, 2008

Consortium: Cloud cci

Deutscher Wetterdienst (DWD), Lead
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Free University of Berlin – Institute for Space Sciences (FUB) – Institute for Space Sciences (FUB)
Swedish Meteorological and Hydrological Institute (SMHI)
Koninklijk Nederlands Meteorologisch Instituut (KNMI)
Laboratoire Météorologie Dynamique (LMD)
German Aerospace Centre (DLR)
ETH (Switzerland)

Cloud_cci Phase 2 requirements

Global **C**limate **O**bserving **S**ystem **Target Requirements:**
Cloud **E**ssential **C**limate **V**ariables (2011 update)

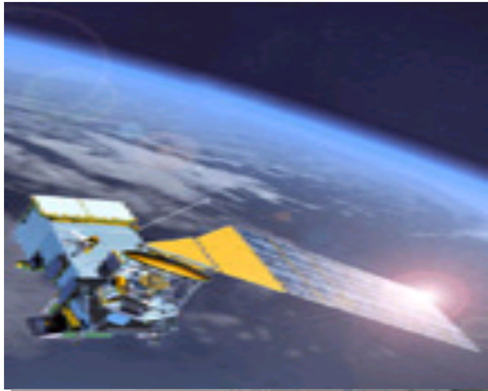
Variable	Horizontal Res	Vertical Res	Temporal Res	Accuracy	Stability (/decade)
CA	50km	N/A	3hr	0.01 – 0.05	0.003 – 0.03
CP	50km	NA	3hr	15hPa – 50hPa	3hPa -15hPa
CT	50km	NA	3hr	1K – 5K	0.2K – 1K
CWP	50km	NA	3hr	25%	5%
CRE	50km	NA	3hr	5-10%	1-2%

assuming cloud feedback similar to rad forcing of 0.3Wm^{-2} (~ 20% of current GHG forcing)
radiative forcing depends on CAE (and not CA)
=> target ranges (opt thick/ low clouds - opt thin Ci (CEM=0.2))

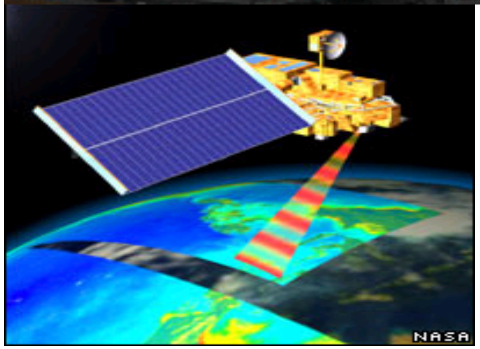
based on NISTIR 7047 report (March 2004)

Achieved uncertainties & accuracies ?

Cloud CCI instruments



- Heritage Algorithm
  - AVHRR 1982-2014 (Cloud)
  - AATSR (1991)1995-2012 (Cloud and Aerosol) SLSTR
  - MODIS 2000-2014 (Cloud)
  - Combined product.
- Synergy Algorithm
  - MERIS/AATSR 2002-2012

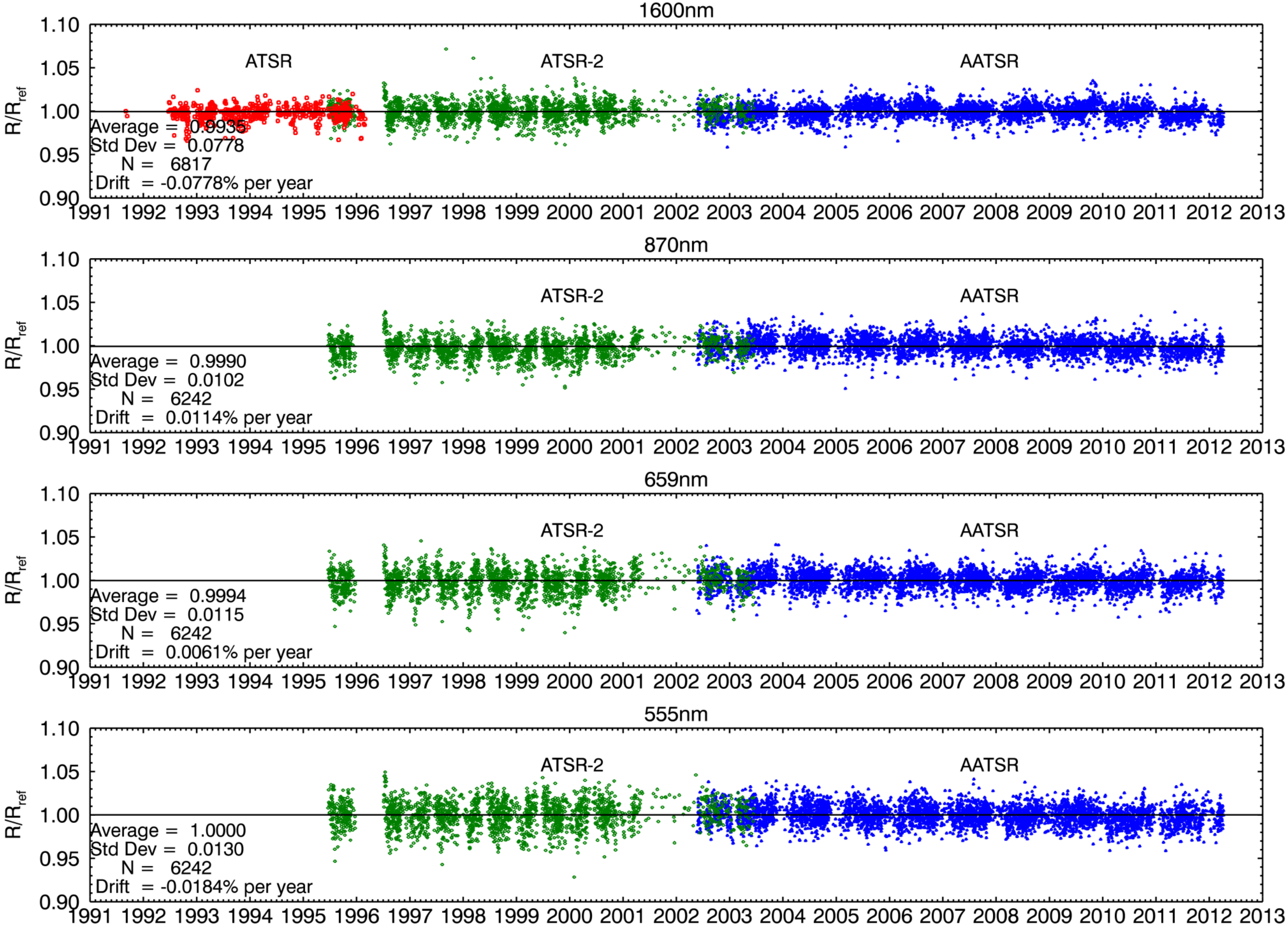


RAL Space

What's new about the Cloud CCI products?

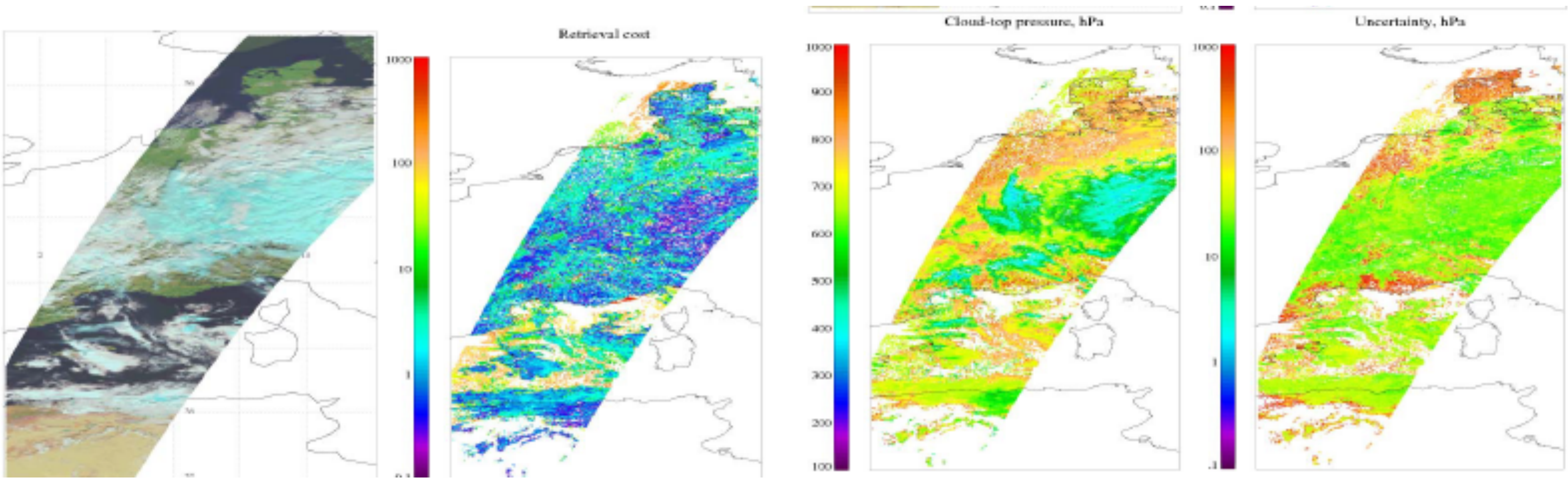
- New instruments
  - *Increased temporal and spatial resolution*
- Multiple channel retrievals
- Consistent optimal estimation algorithm
  - *Attention to uncertainty in L2 and L3 products*
  - http://proj.badc.rl.ac.uk/orac - open source
- Radiative consistent products
  - *All surface-atmosphere properties determined from a satellite instrument are consistent with the TOA radiance field from visible to mid IR*
- Product consistency
  - *Improved consistency with Aerosol CCI products*
- Detailed attention to achieving the best calibration
- Correction of diurnal cycle in AVHRR products
- Demonstrate usefulness of merged cloud datasets
- Model comparison tools

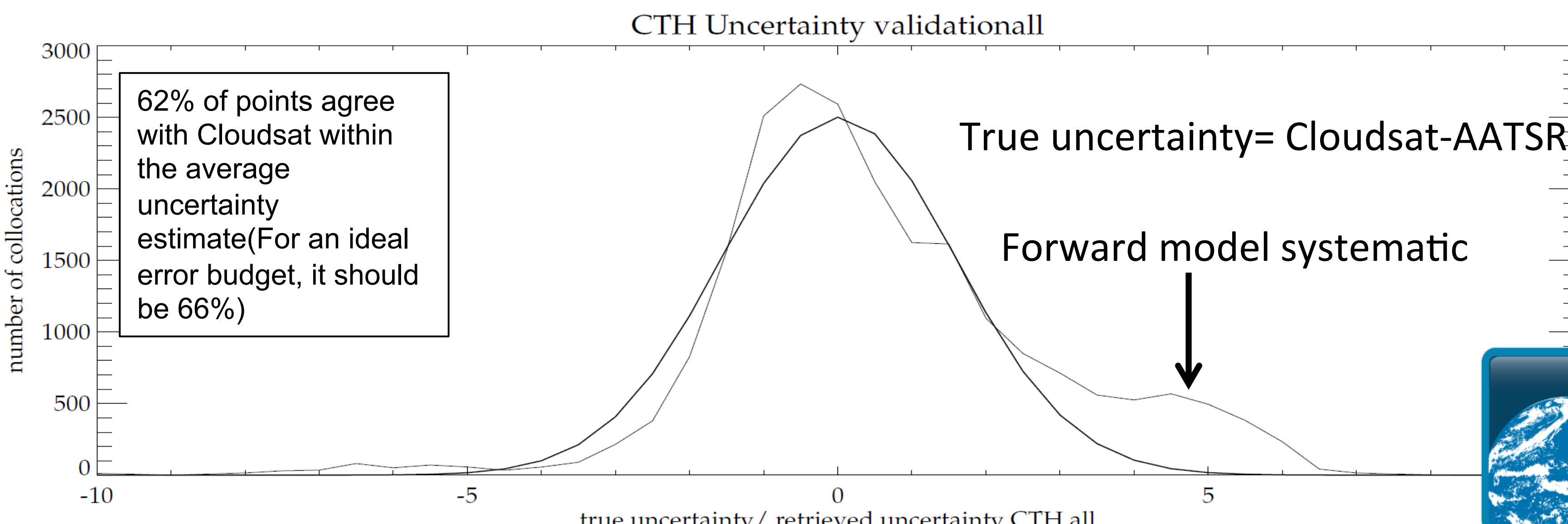
Calibration

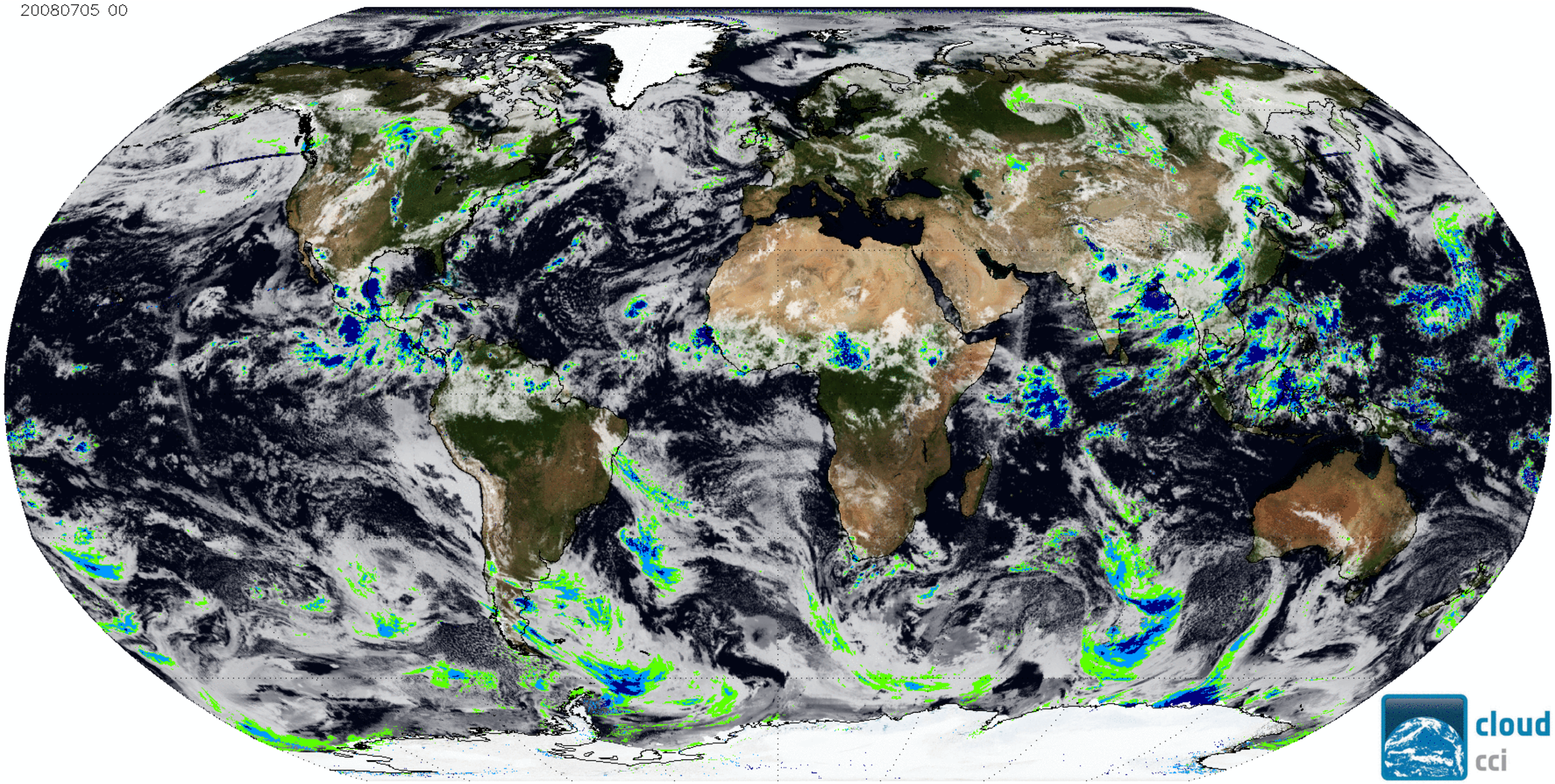


ATSR stability, slides courtesy Dave Smith

Uncertainty in CCI products

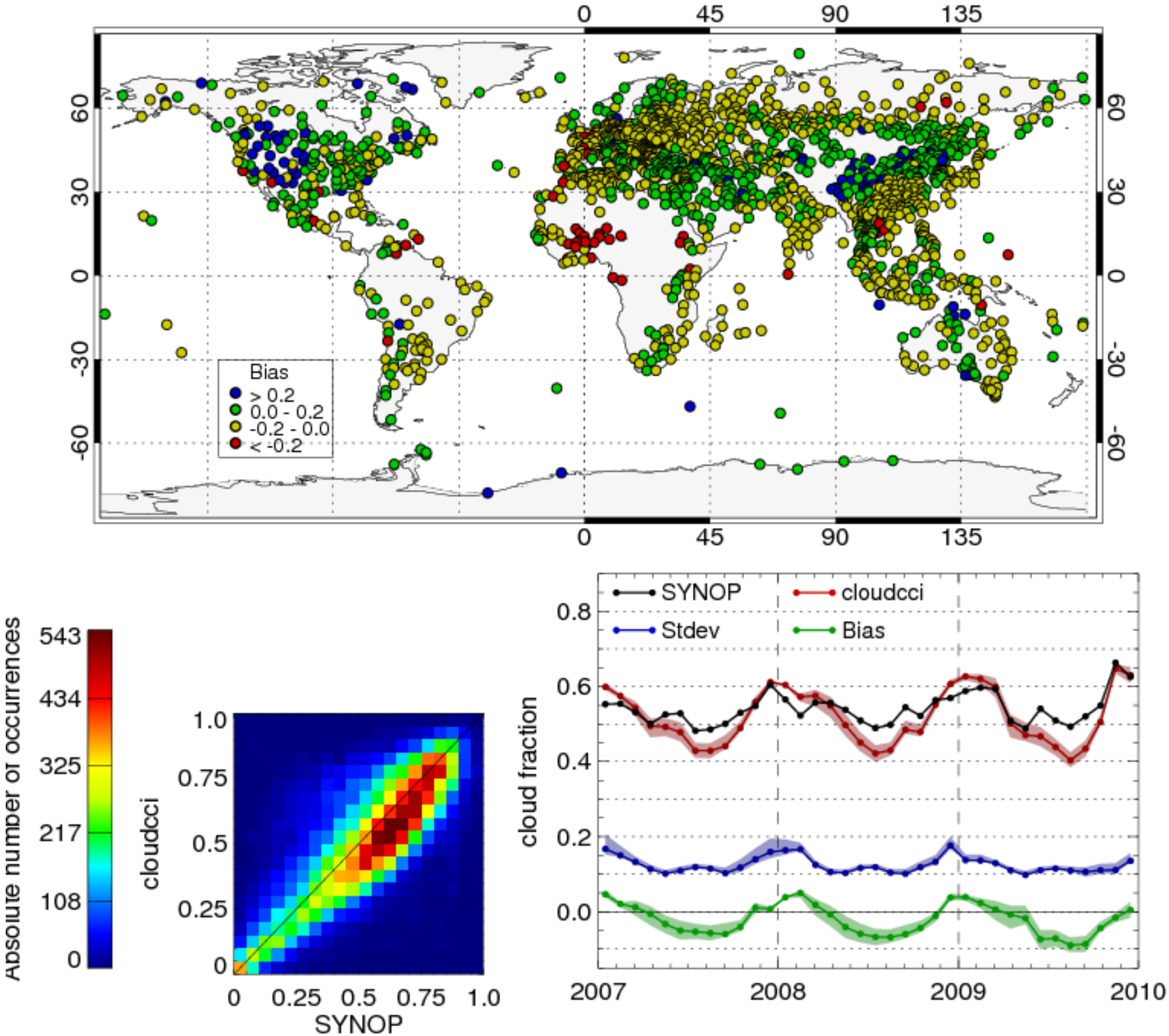






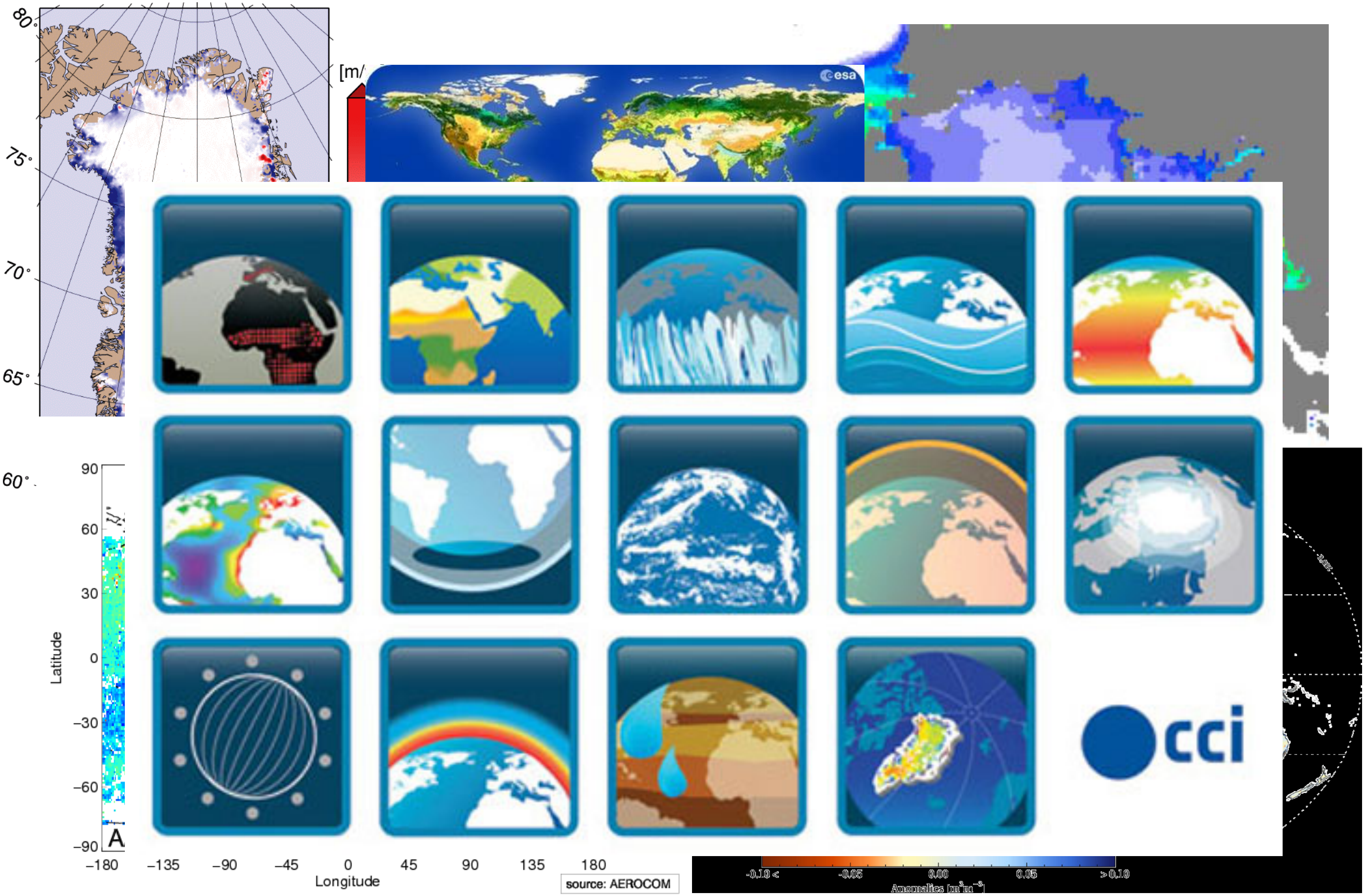
- “ESA Cloud_cci cloud detection. Blue shading: Cold clouds with Cloud_cci CTT < 240K. Data shown is a composite for 06 July 2008 in a time window 9-15 UTC, using AVHRRs of NOAA 15/16/17/18. Background: NASA’ s Earth Observatory Blue Marble ”

Cloud fraction bias L3 - 20070101-20091231



Summary

- Satellite cloud data sets have been evolving rapidly
- Many are on the cusp of providing information on climates trends
- Scientists have to be very careful about the sources of uncertainty in the data sets
- Models and satellites are successfully confronting each other
- The Cloud CCI is going to provide a new and exciting data sets to analyse.



- To extract maximum information on clouds and climate will need to combine satellite records e.g aerosol, cloud, water vapour, SST +++

Extra slides

Simulator example (ISCCP)