Numerical Weather Prediction
Parametrization of sub-grid physical processes

Clouds (4)
Cloud Scheme Validation

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(with thanks to Adrian Tompkins and Christian Jakob)

Outline

Today's lecture will discuss:

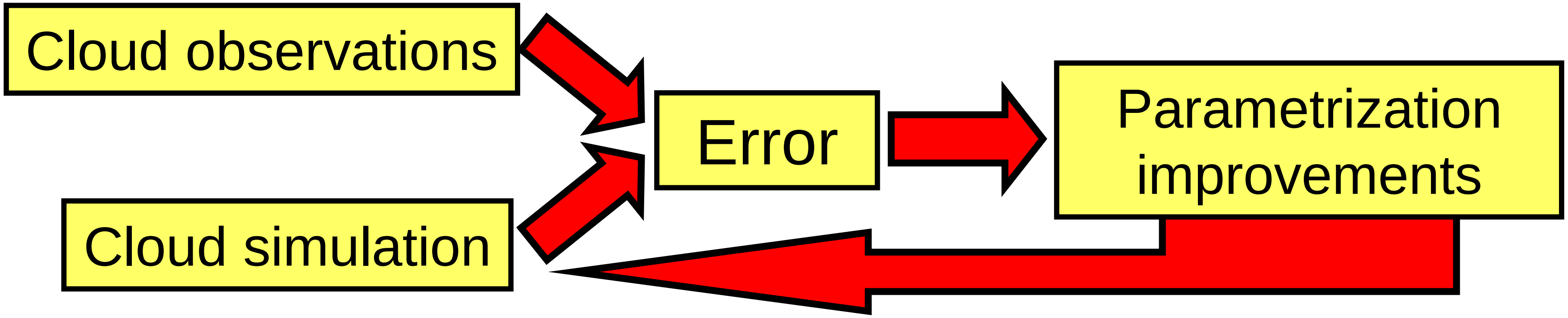
- Different observation types for model cloud evaluation
- Different evaluation methodologies to inform parametrization development
- Limitations of model evaluation due to uncertainties and differences in observed and modelled quantities

Two parts:

1. Methodologies for diagnosing model errors
2. Evaluation uncertainties and limitations

Cloud Validation: The issues

- AIM: To perfectly simulate one aspect of nature: CLOUDS
- APPROACH: Validate the model generated clouds against observations, and use the information concerning apparent errors to improve the model physics, and subsequently the cloud simulation.



Cloud observations

Cloud simulation

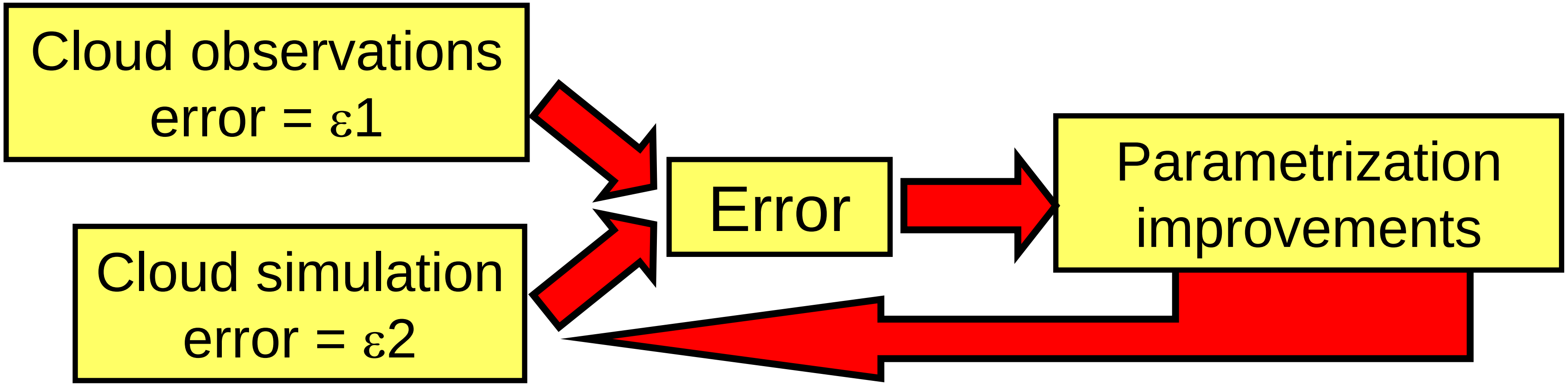
Error

Parametrization improvements

Sounds easy?

Cloud Validation: The problems

- How much of the ‘error’ derives from observations?



Cloud observations
error = ε1

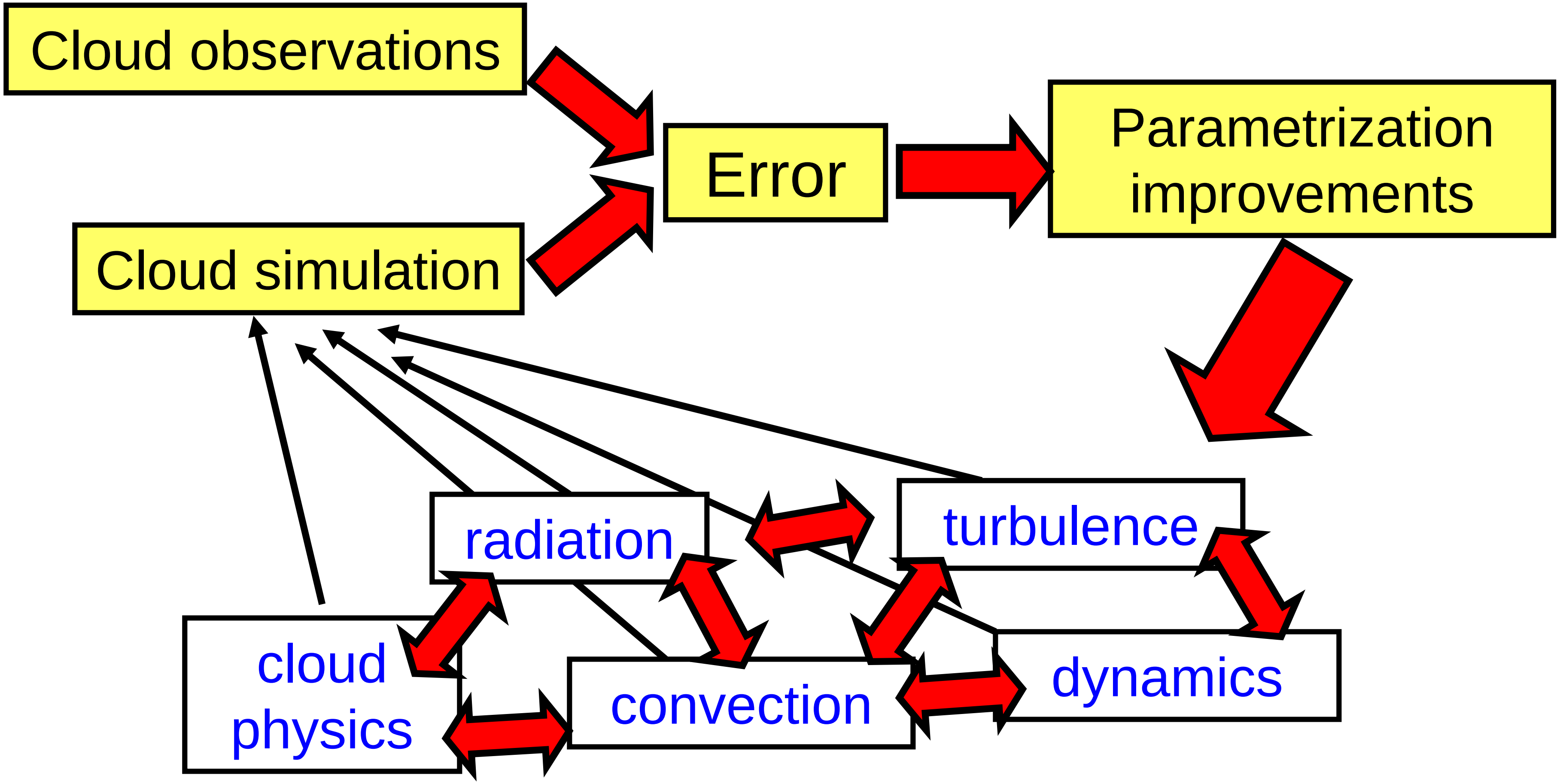
Cloud simulation
error = ε2

Error

Parametrization improvements

Cloud Validation: The problems

- Which Physics is responsible for the error?



Cloud observations

Cloud simulation

Error

Parametrization improvements

radiation

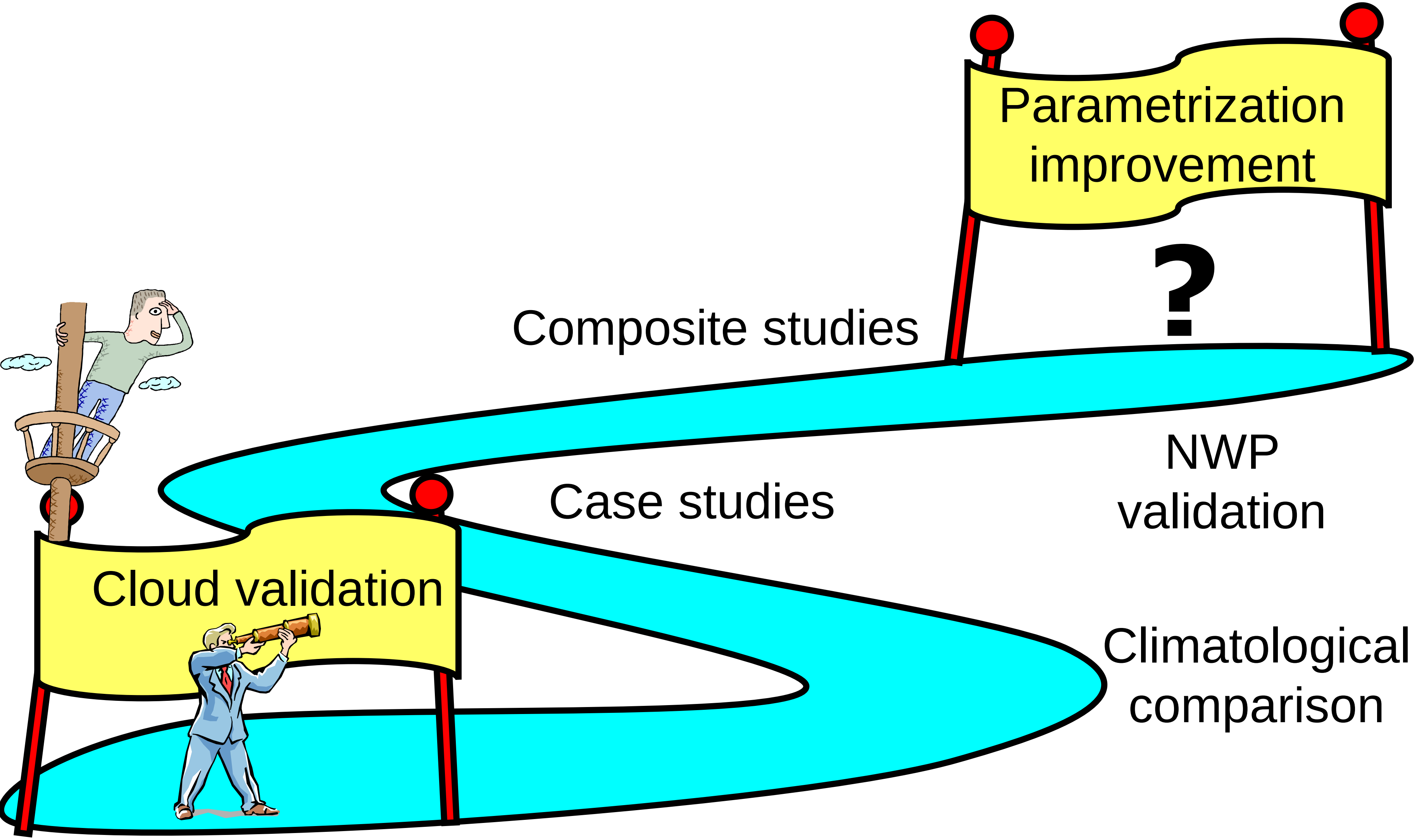
turbulence

cloud physics

convection

dynamics

The path to improved cloud parametrization…



Parametrization improvement

?

Composite studies

NWP validation

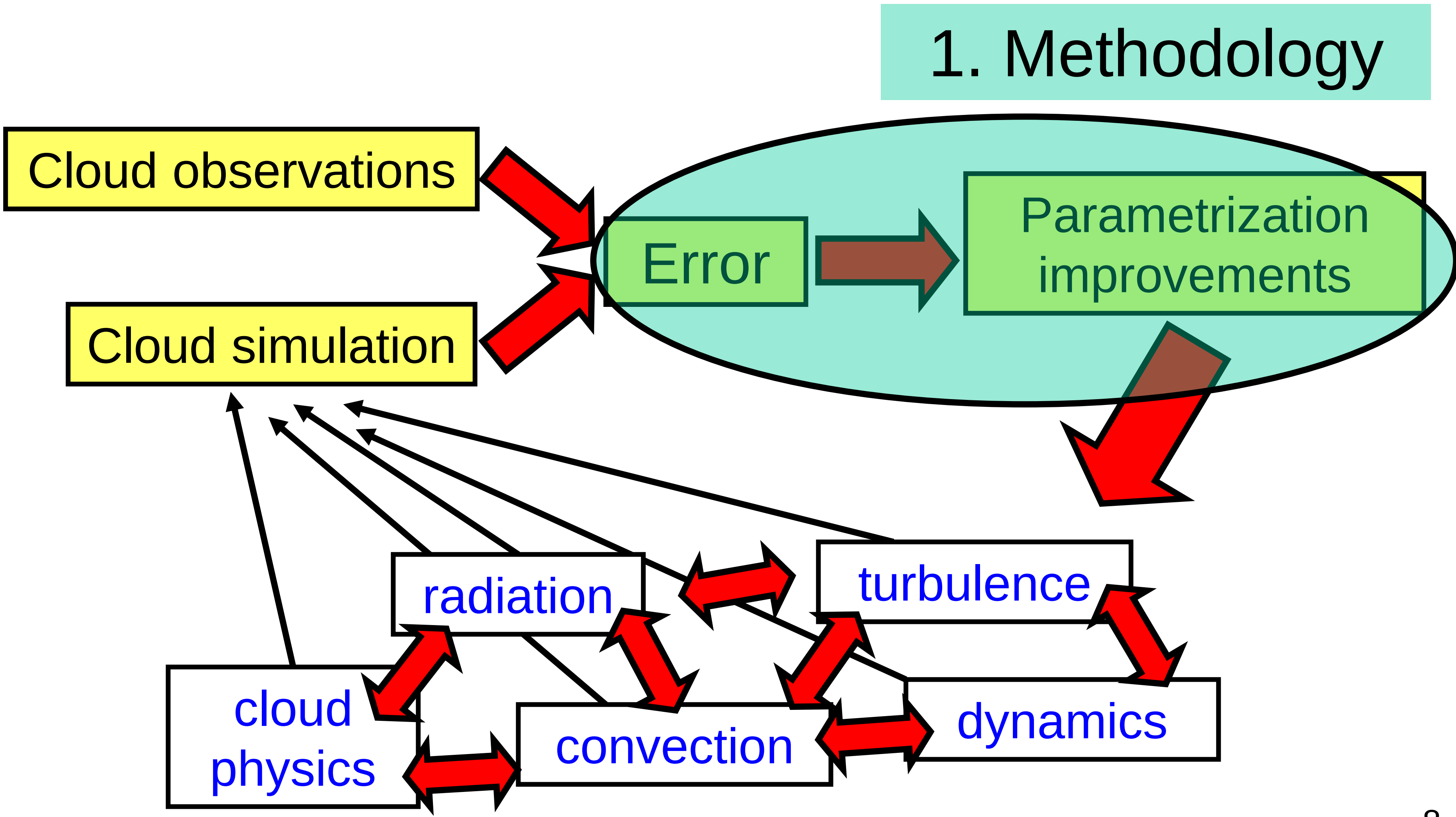
Case studies

Climatological comparison

Cloud validation

1. Methodology for diagnosing errors and improving parametrizations

Cloud Validation: The problems



1. Methodology

Cloud observations

Cloud simulation

Error

Parametrization improvements

radiation

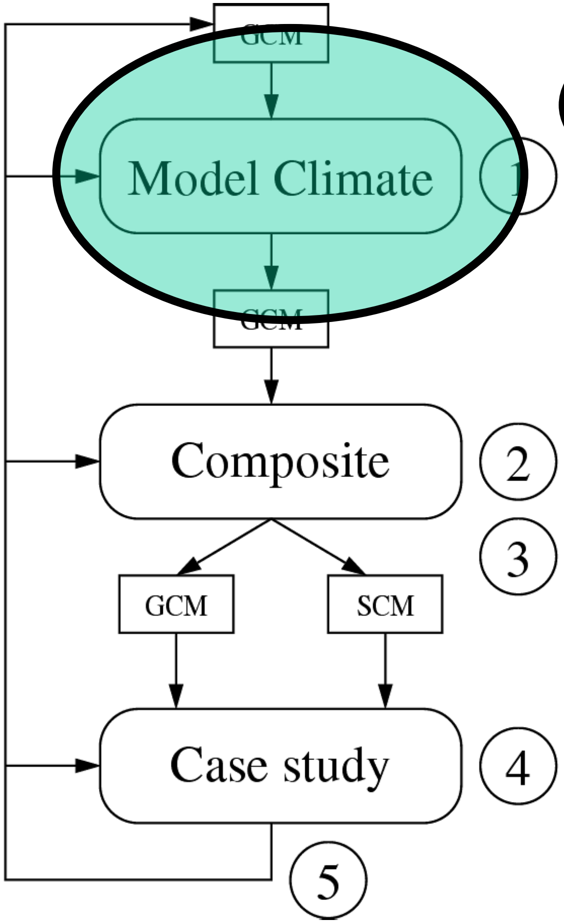
turbulence

cloud physics

convection

dynamics

A strategy for cloud parametrization evaluation



Step 1 : identify major problem areas

Step 2 : identify major problem regimes

Step 3 : identify typical case

Step 4 : identify detailed problems

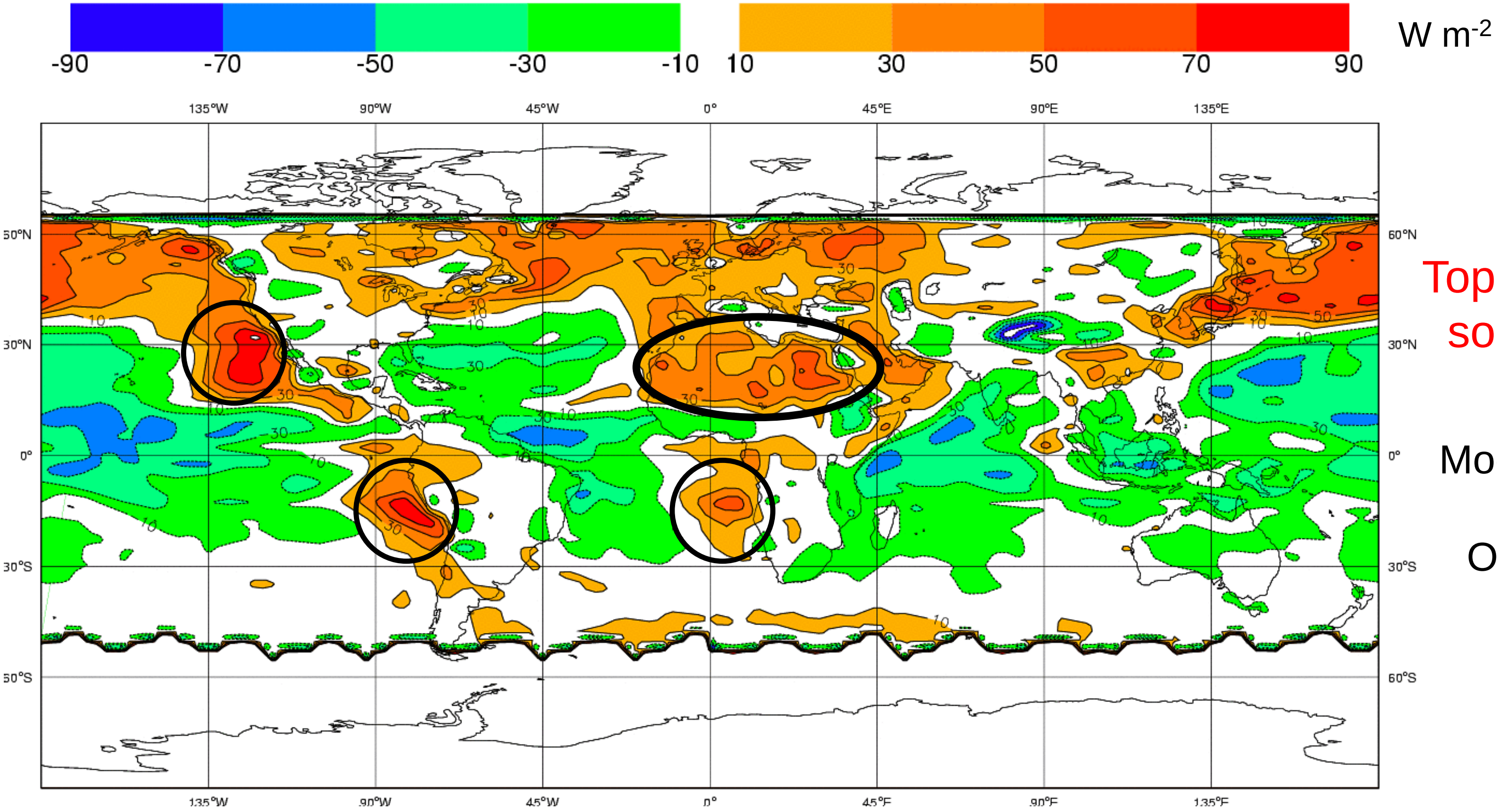
Step 5 : improve parametrization

- For example, systematic errors in radiation, cloud cover, precipitation…
- Use long timeseries of observational data (satellite, ground-based profile, NWP verification)
- Statistical evaluation (mean, PDFs)
- Short-range forecasts or model climate (multi-year simulations)

From C.Jakob

Model climate: Broadband radiative fluxes

Can compare Top of Atmosphere (TOA) radiative fluxes with satellite observations: e.g. Example of TOA Shortwave radiation (TSR) from **an old version** of the model (operational in 1998!)



JJA 87

Top of atmos net solar radiation

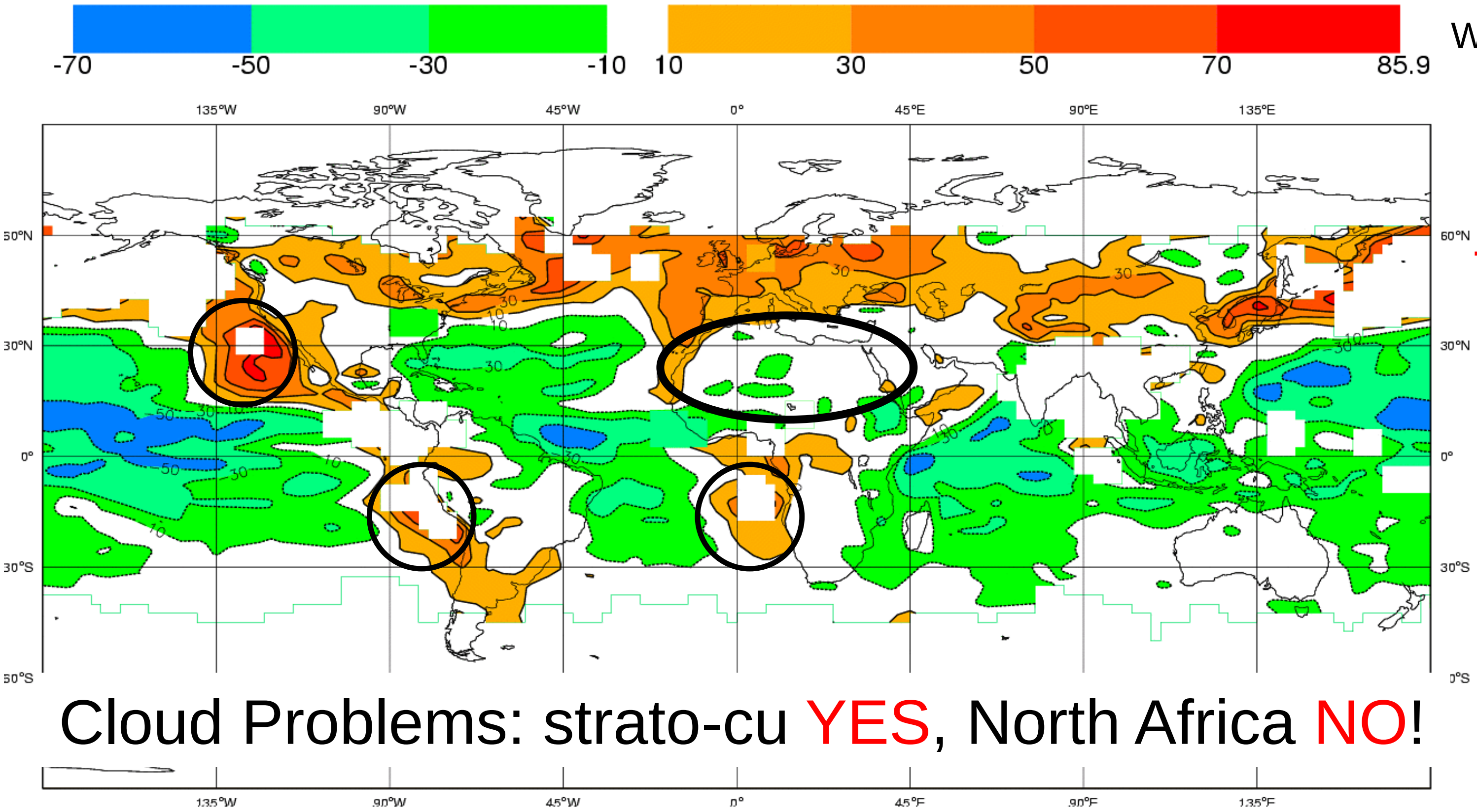
Model (Cy18r6)
minus
Obs (ERBE)

Stratocumulus regions bad - also North Africa (**old cycle!**)

Model climate:
Cloud radiative "forcing"

- Problem: Can we associate these "errors" with clouds?
- We can look at "cloud radiative forcing"

  (calculate radiative impact of cloud by comparing cloudy points with clear sky points)



JJA 87

TOA SW cloud radiative forcing

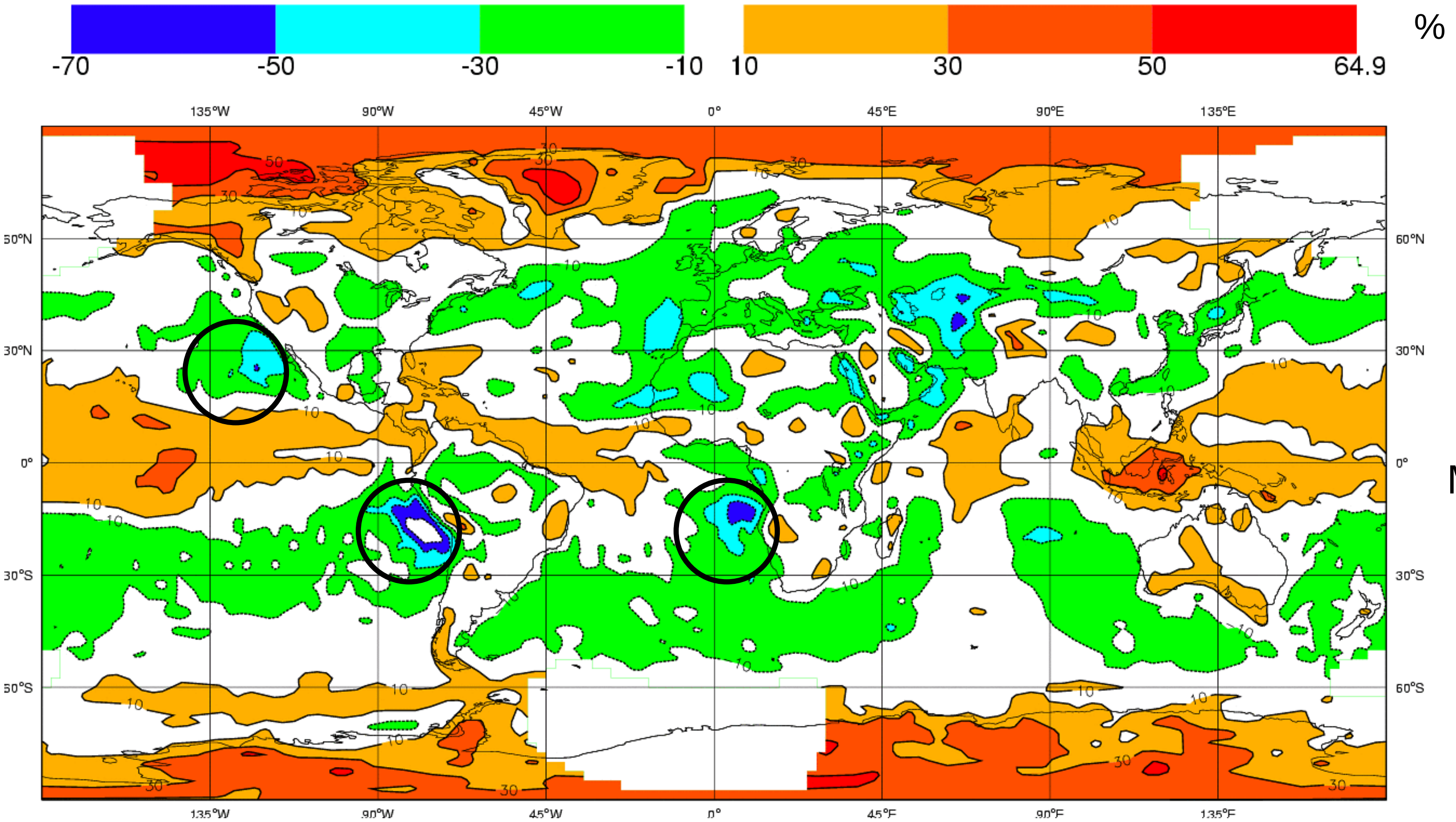
Model (Cy18r6)
minus
Obs (ERBE)

Cloud Problems: strato-cu YES, North Africa NO!

Note: blanked out areas are where there are not enough clear sky points in the obs

Model climate
"Cloud fraction" or "Total cloud cover"

Can also compare other variables to derived products: CC



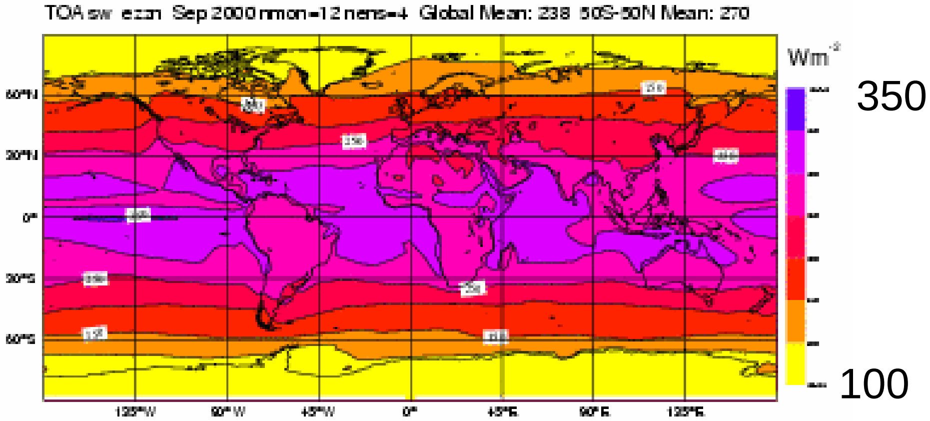
JJA 87

TCC

Model (Cy18r6)
minus
Obs (ISCCP)

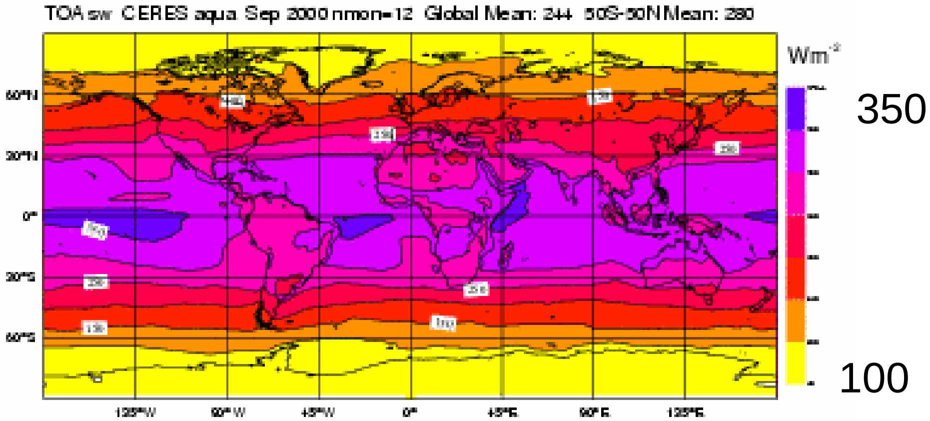
References: ISCCP - Rossow and Schiffer, Bull Am Met Soc. 91,
ERBE - Ramanathan et al. Science 89

Model climate mean differences


TOA sw ezzn Sep 2000 nmon=12 nens=4 Global Mean: 238 50S-50N Mean: 270

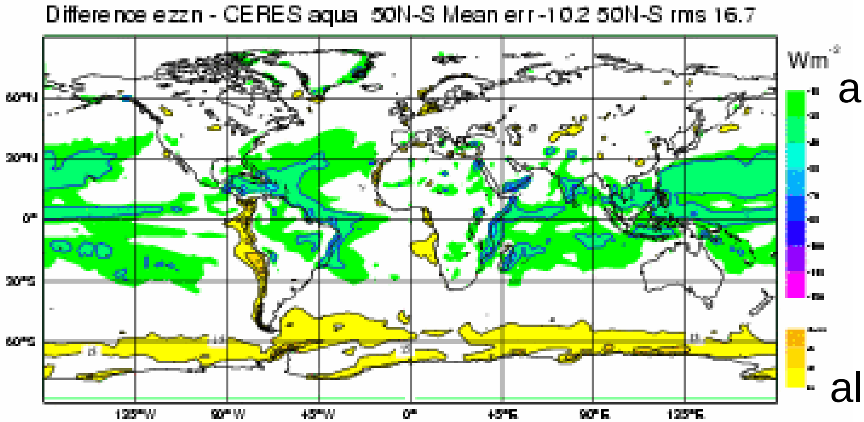
Model
T159
L91

More recent cycle!


TOA sw CERES aqua Sep 2000 nmon=12 Global Mean: 244 50S-50N Mean: 280

CERES
satellite
obs

Top-of-atmos net
SW radiation
1-year average


Difference ezzn - CERES aqua 50N-S Mean err -10.2 50N-S rms 16.7

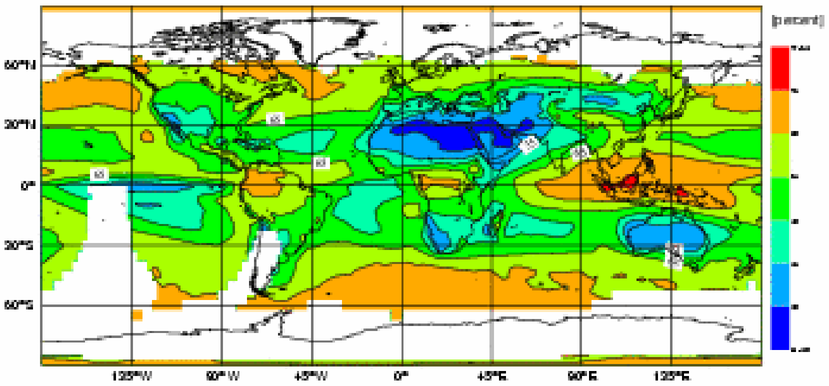
albedo high

Difference

albedo low

Model climate mean differences

Total Cloud Cover ezzn Sep 2000 nmon=12 nens=4 Global Mean: 63.1 50N-S Mean: 61.1

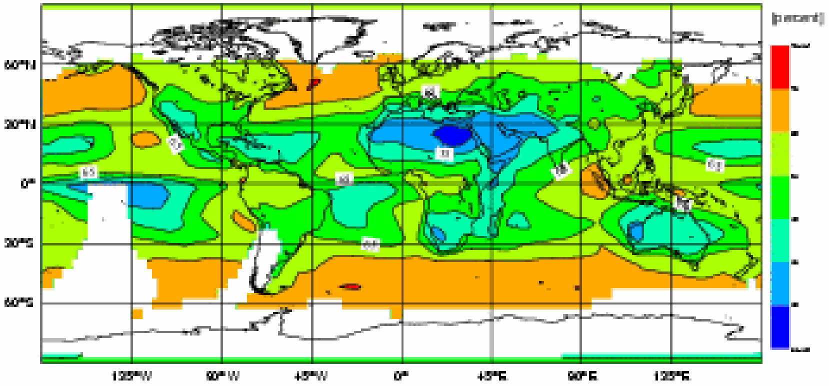


80

Model
T159
L91

10

Total Cloud Cover ISCCP Sep 2000 nmon=12 50N-S Mean: 62.2



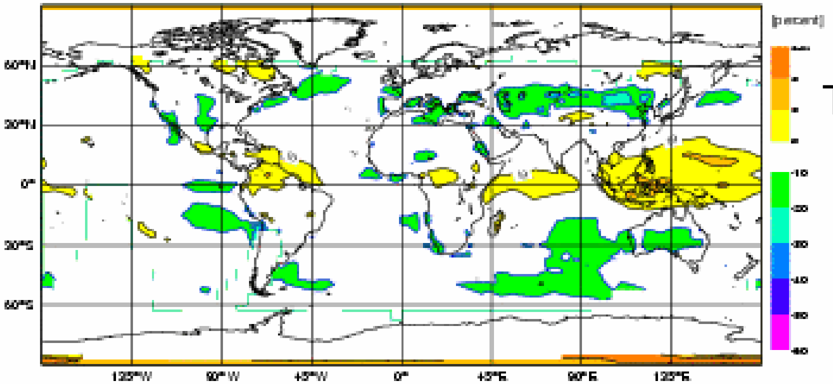
80

ISCCP
satellite
obs

10

Total Cloud Cover (TCC)
1-year average

Difference ezzn - ISCCP 50N-S Mean err -1.1 50N-S rms 8.5



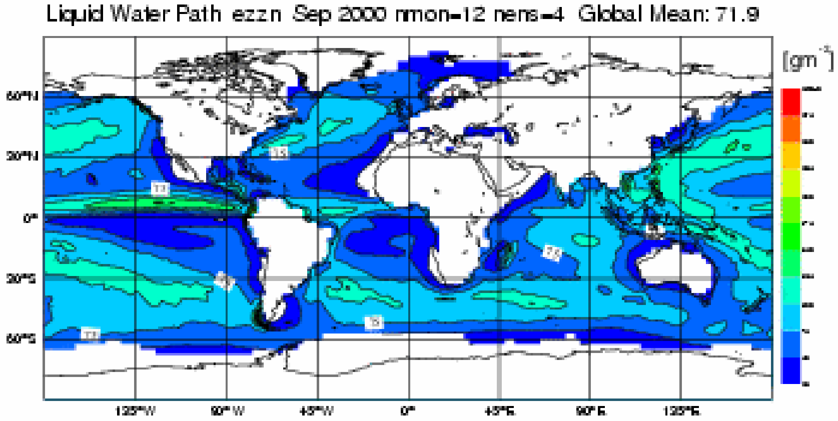
TCC high

Difference

TCC low

Model climate mean differences

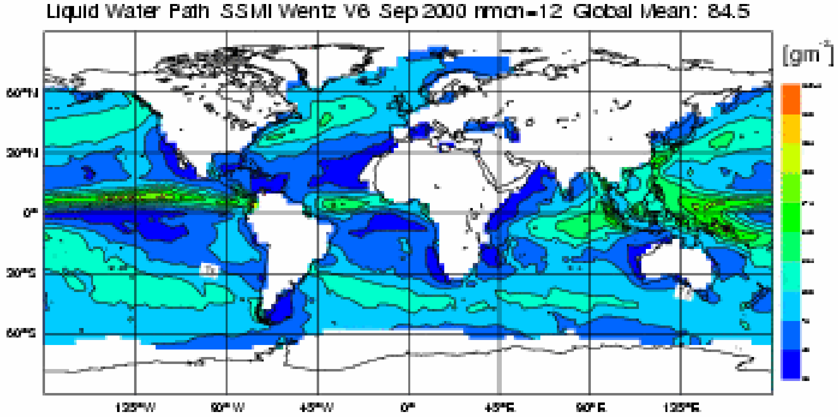
Total Column Liquid Water (TCLW)
1-year average


Liquid Water Path ezzn Sep 2000 nmon=12 nens=4 Global Mean: 71.9

250

25

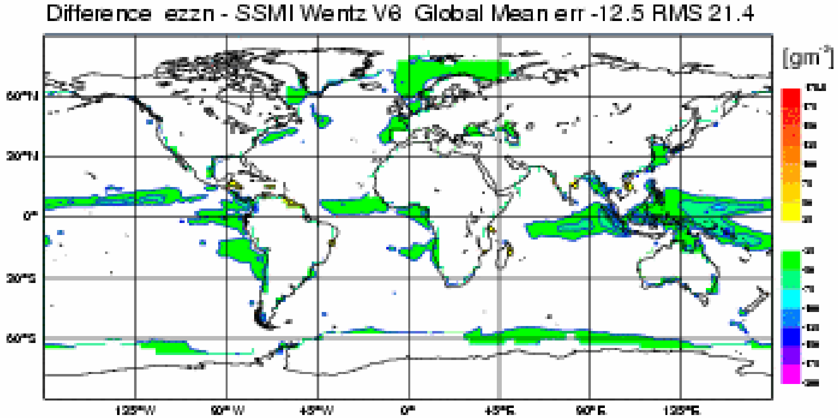
Model
T159
L91


Liquid Water Path SSMI Wentz V6 Sep 2000 nmon=12 Global Mean: 84.5

250

25

SSMI
satellite
obs


Difference ezzn - SSMI Wentz V6 Global Mean err -12.5 RMS 21.4

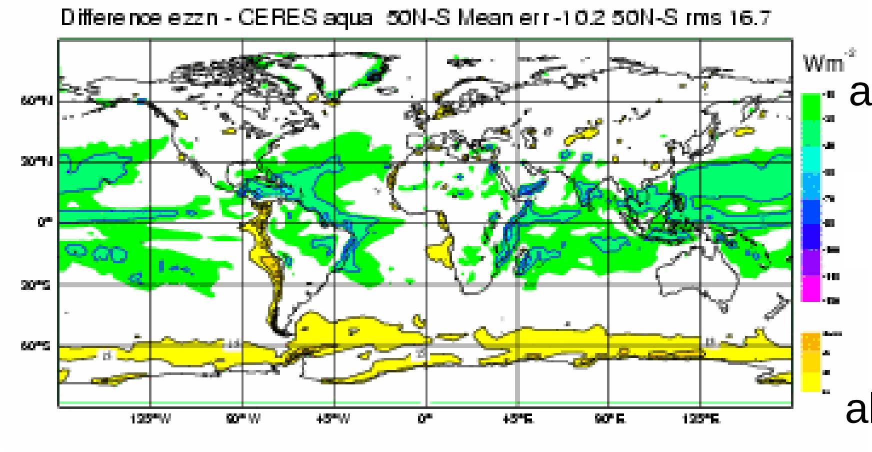
high

low

Difference

Model climate mean differences

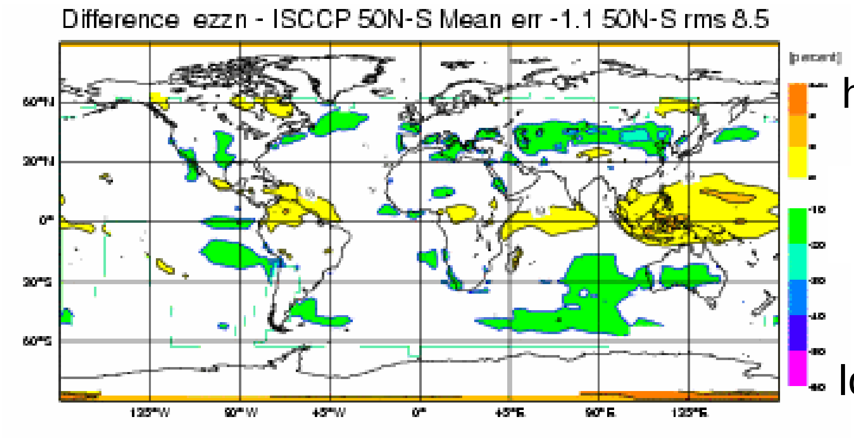
T159 IFS – Obs differences
1-year average


Difference ezzn - CERES aqua 50N-S Mean err -10.2 50N-S rms 16.7

albedo high

net TOA SW

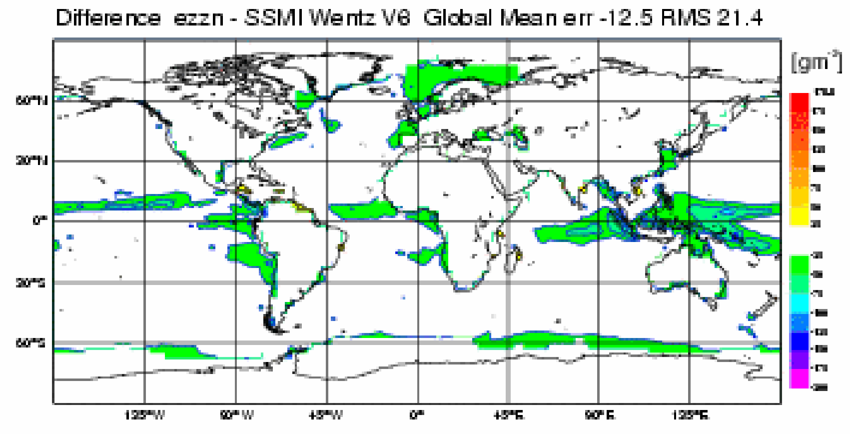
albedo low


Difference ezzn - ISCCP 50N-S Mean err -1.1 50N-S rms 8.5

high

Cloud cover

low


Difference ezzn - SSMI Wentz V6 Global Mean err -12.5 RMS 21.4

high

Liquid water path

low

Correlations not always so clear! Need additional info to understand systematic errors

Statistical evaluation:
Long term ground-based observations

European observation sites

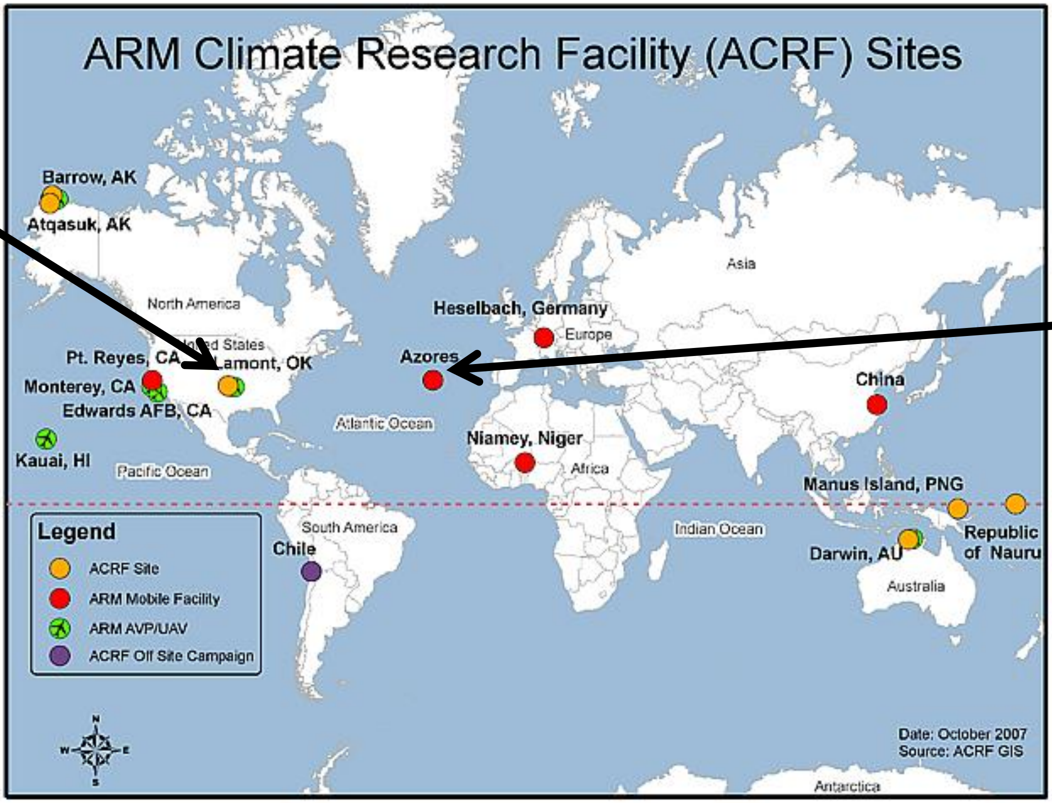

Chilbolton, UK
51.1445 North 1.4370 West
Operated by RCRU, RAL.


SIRTA, Palaiseau (Paris), France
48.713 North 2.204 Est
Operated by CNRS/IPSL


Cabauw, The Netherlands
51.971 North 4.927 Est
Operated by KNMI

- Network of stations providing profile data for multi-year period
- “CloudNet” project (www.cloud-net.org) “ACTRIS” is follow-on: European multi-site data processing using identical algorithms for model evaluation.
- “FASTER” project (faster.arm.gov) processing for global observation sites from the ARM programme (currently active).

Statistical evaluation:
Long term ground-based observations



Global ARM observation sites

- “Permanent” ARM sites and movable “ARM mobile facilities” for observational campaigns (www.arm.gov)

Note for 2015: Azores now fixed site, Tropical fixed sites now closed

Cloud fraction

Chilbolton
Observations

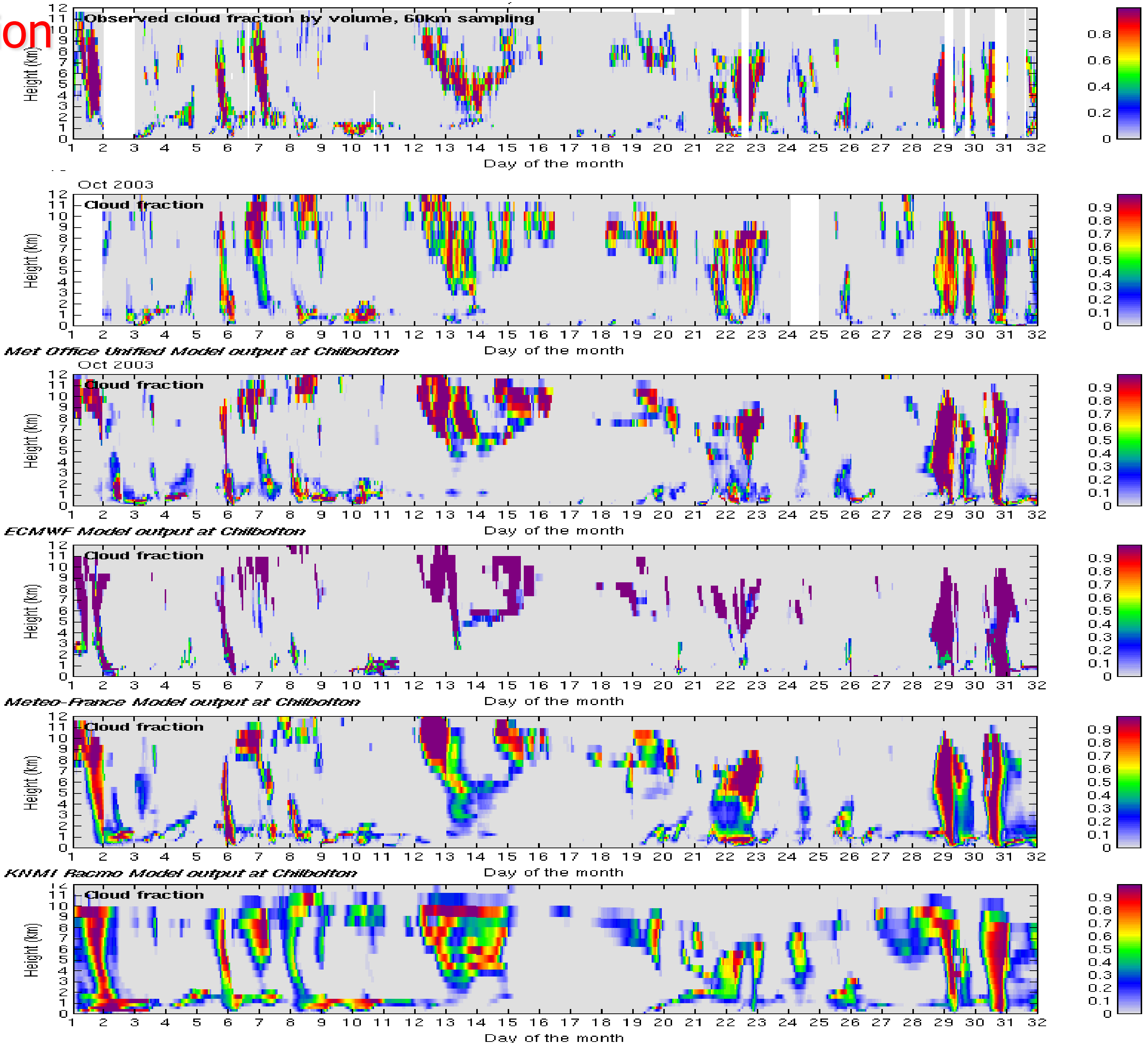
Met Office
Mesoscale
Model

ECMWF
Global Model

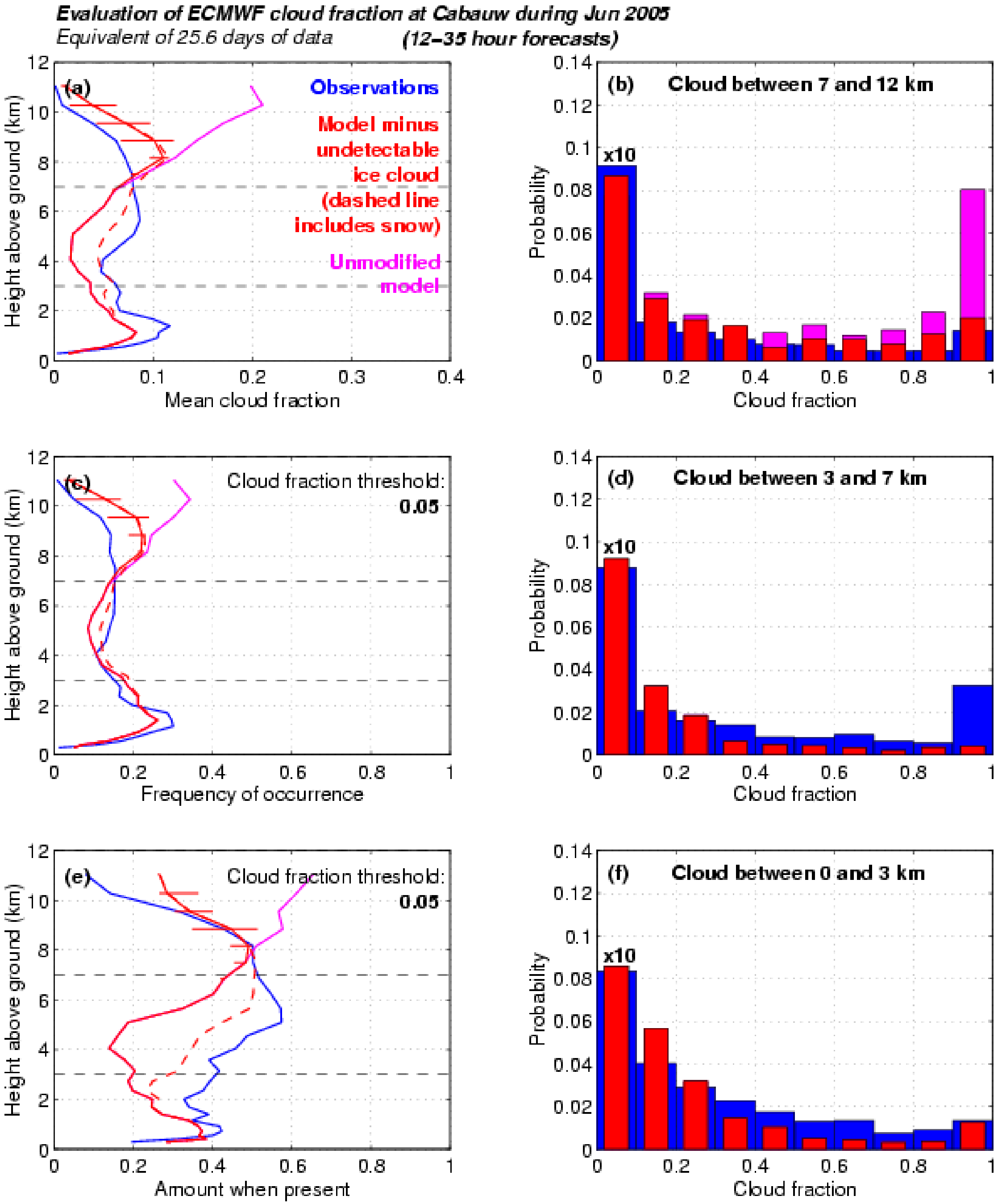
Meteo-France
ARPEGE Model

KNMI
RACMO Model

Swedish RCA
model



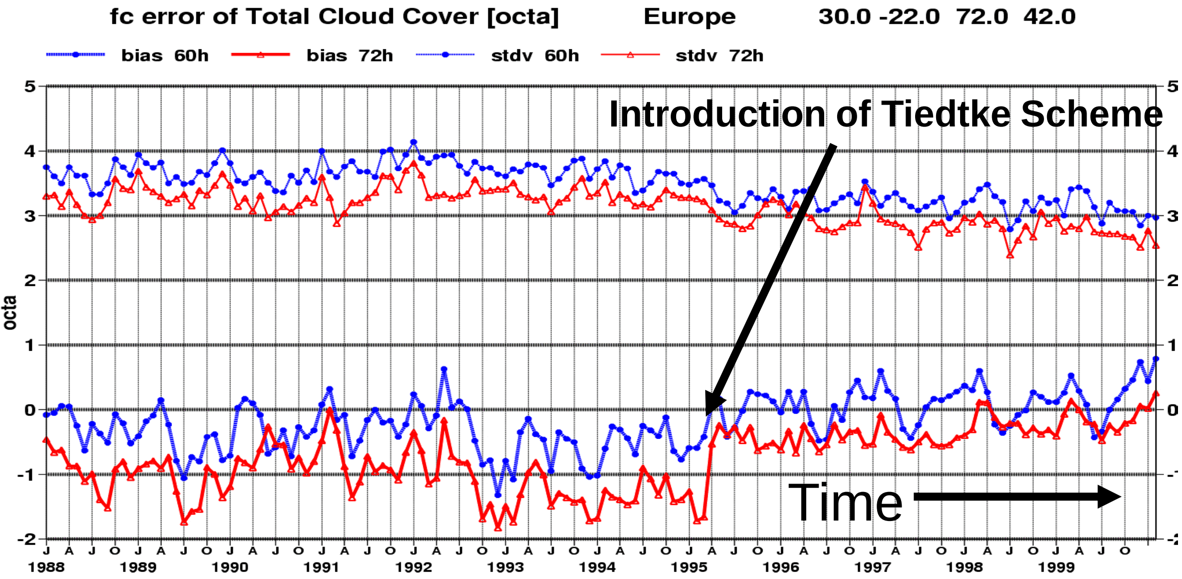
Statistical evaluation:
CloudNet Example



- In addition to standard quicklooks, longer-term statistics are available.
- This example is for ECMWF cloud cover during June 2005.
- Includes pre-processing to account for radar attenuation and snow.
- See www.cloud-net.org for more details and examples!

Statistical evaluation:
Short-range NWP versus long-range “climate”

- Differences in longer simulations may not be the direct result of the cloud scheme:
  - Interaction with radiation, dynamics etc.
  - E.g: poor stratocumulus regions
- Using short-term NWP or analysis restricts this and allows one to concentrate on the cloud scheme

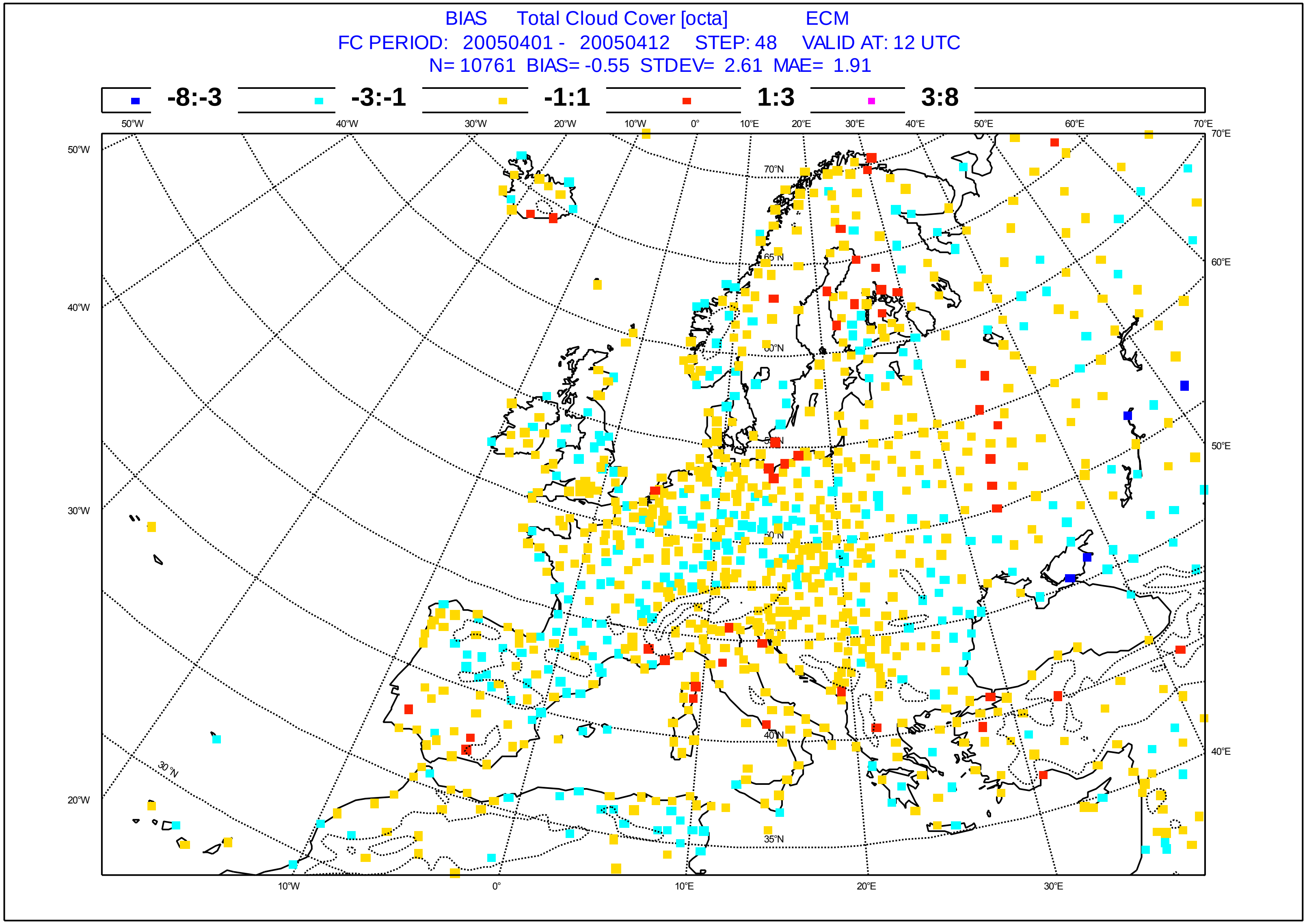


Introduction of Tiedtke Scheme

Time

Cloud cover bias vs Synops

Example over Europe
Bias of 48 hour forecast cloud cover vs Synop



BIAS Total Cloud Cover [octa] ECM

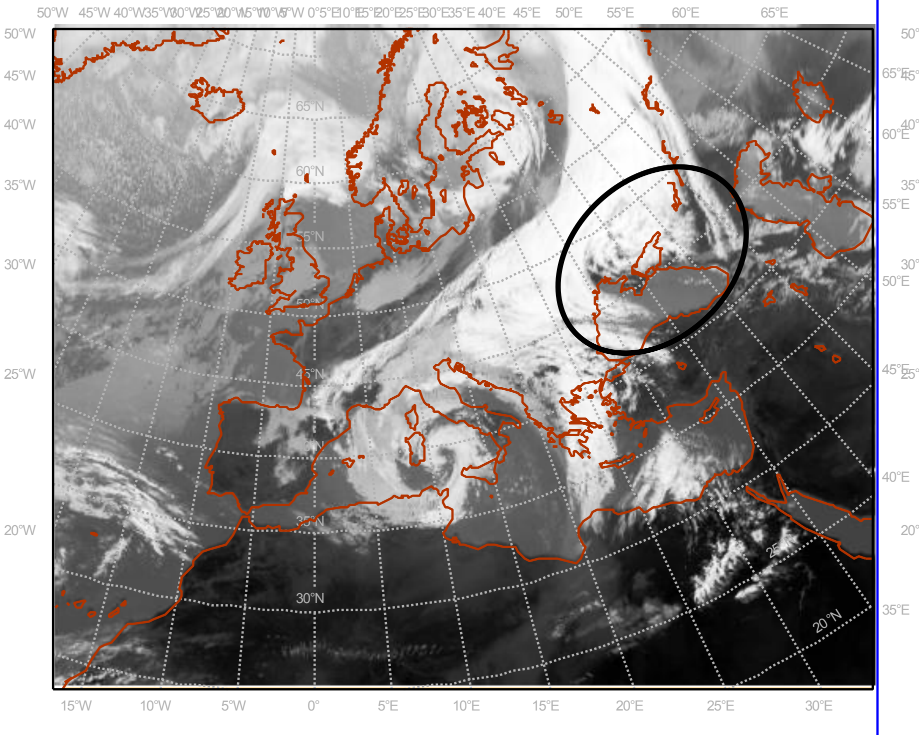
FC PERIOD: 20050401 - 20050412 STEP: 48 VALID AT: 12 UTC

N= 10761 BIAS= -0.55 STDEV= 2.61 MAE= 1.91

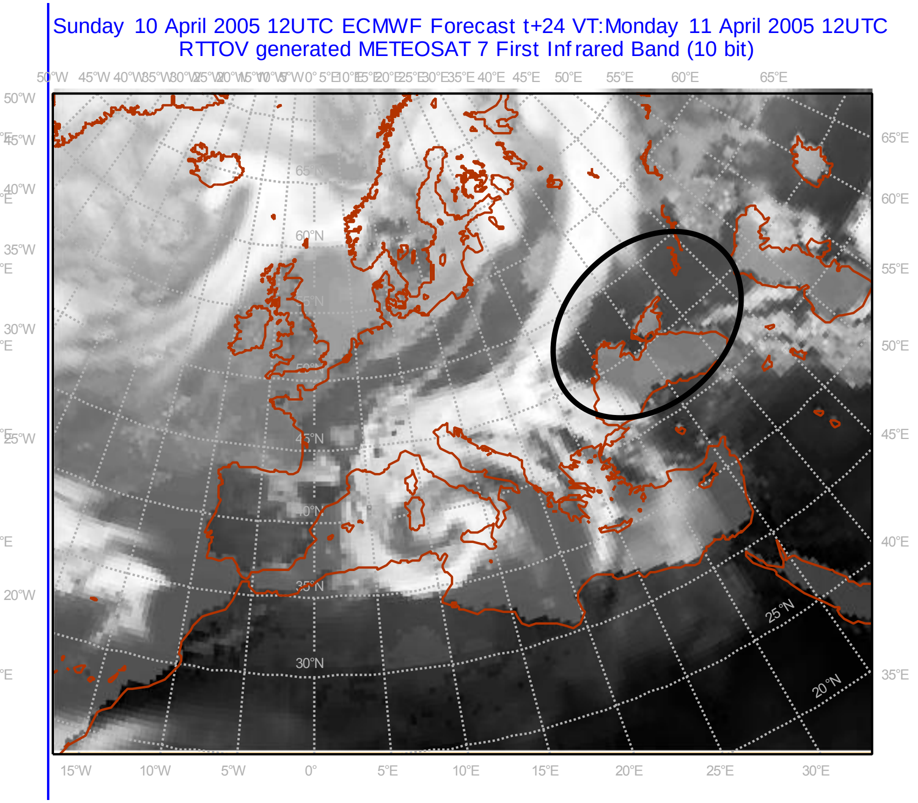
NWP Forecast Evaluation
Identifying the cause of cloud errors?

Daily Report 11th April 2005
Meteosat and simulated IR example

METEOSAT 7 First Infrared Band Monday 11 April 2005 1200UTC



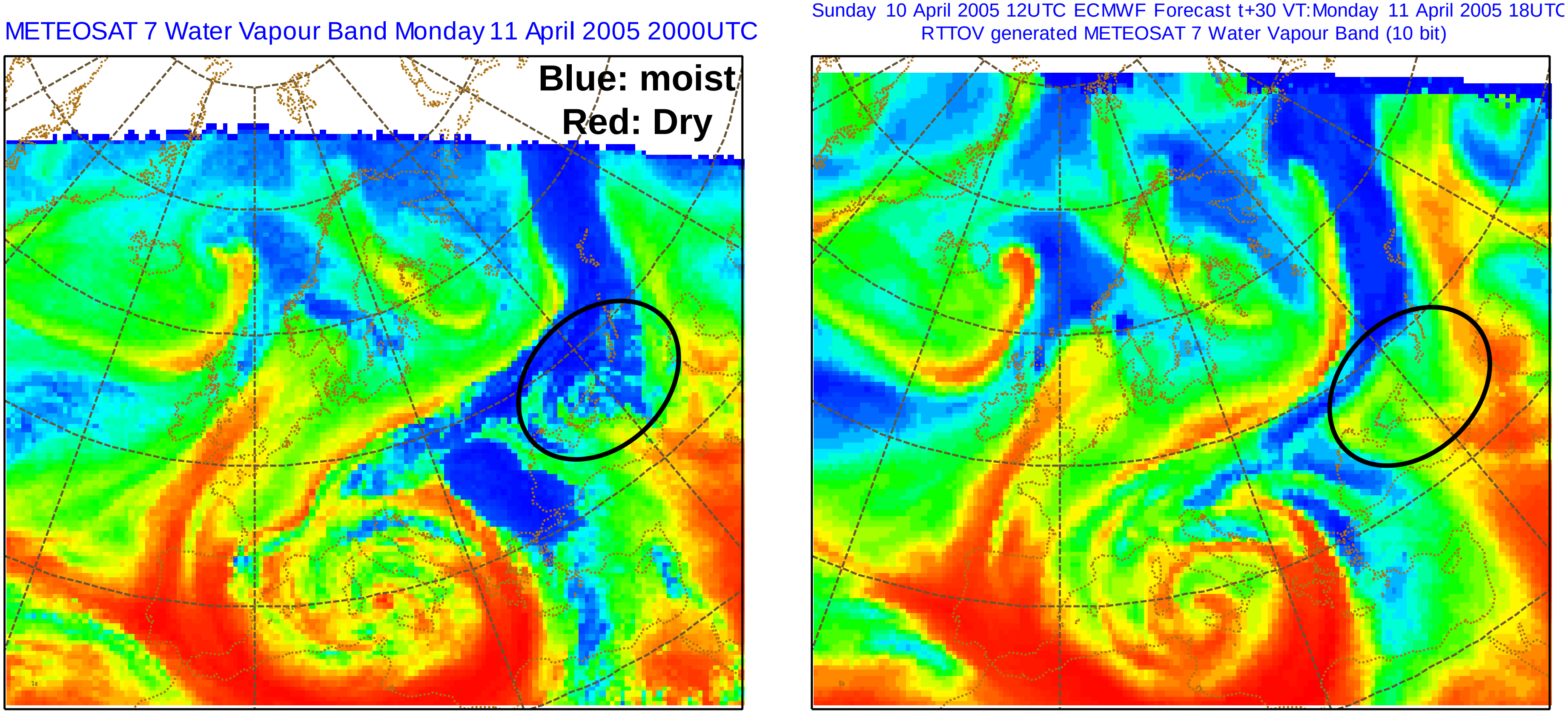
Sunday 10 April 2005 12UTC ECMWF Forecast t+24 VT:Monday 11 April 2005 12UTC
RTTOV generated METEOSAT 7 First Infrared Band (10 bit)



"Going more into details of the cyclone, it can be seen that the model was able to reproduce the very peculiar spiral structure in the clouds bands. However large differences can be noticed further east, in the warm sector of the frontal system attached to the cyclone, where the model largely underpredicts the typical high-cloud shield. Look for example in the two maps above where a clear deficiency of cloud cover is evident in the model generated satellite images north of the Black Sea. In this case this was systematic over different forecasts." – Quote from ECMWF daily report 11th April 2005

NWP Forecast Evaluation
Identifying the cause of cloud errors?

Daily Report 11th April 2005
Meteosat and simulated WV example


METEOSAT 7 Water Vapour Band Monday 11 April 2005 2000UTC

Sunday 10 April 2005 12UTC ECMWF Forecast t+30 VT:Monday 11 April 2005 18UTC
RTTOV generated METEOSAT 7 Water Vapour Band (10 bit)

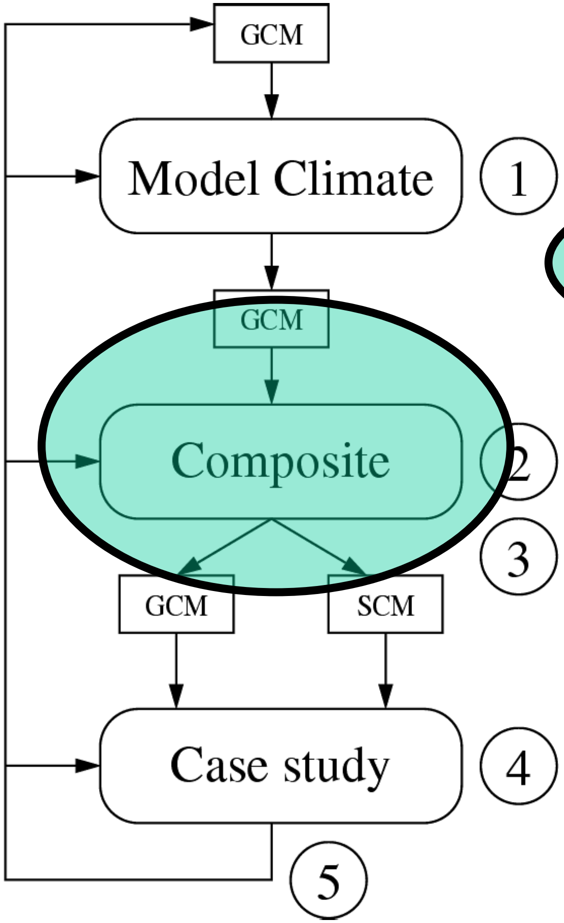
Blue: moist
Red: Dry

30 hr forecast too dry in front region.
So maybe another cause, not the cloud scheme itself.

Identifying major problem areas

- Need to evaluate the model from many different view points to identify which problems are associated with cloud.
- Evaluate the statistics of the model (mean, pdf,…)
  - long timeseries of data.
- Use of long forecasts (climate) and short forecasts (to avoid climate interactions and feedbacks).
- Use of data assimilation increments, initial tendencies.

A strategy for cloud parametrization evaluation: Composites



Step 1 : identify major problem areas

Step 2 : identify major problem regimes

Step 3 : identify typical case

Step 4 : identify detailed problems

Step 5 : improve parametrization

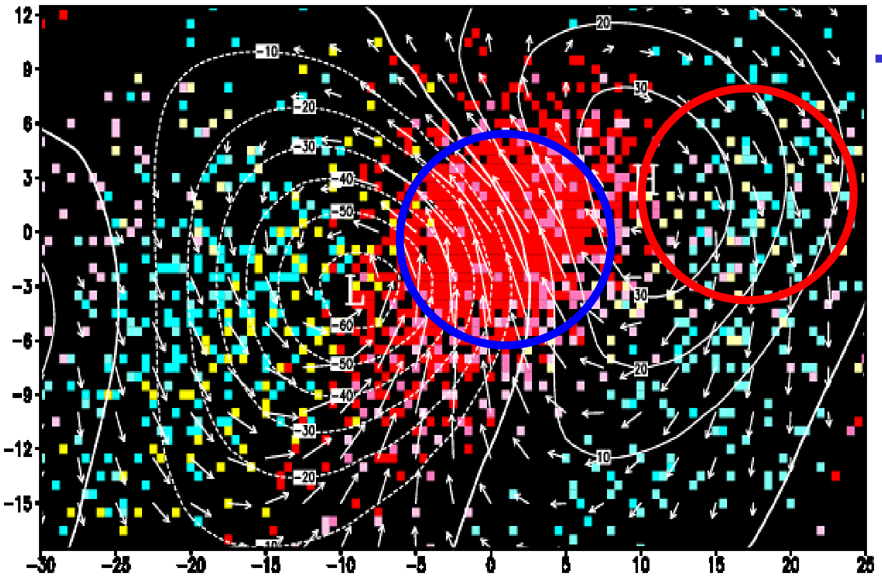
C.Jakob

Isolating the source of error

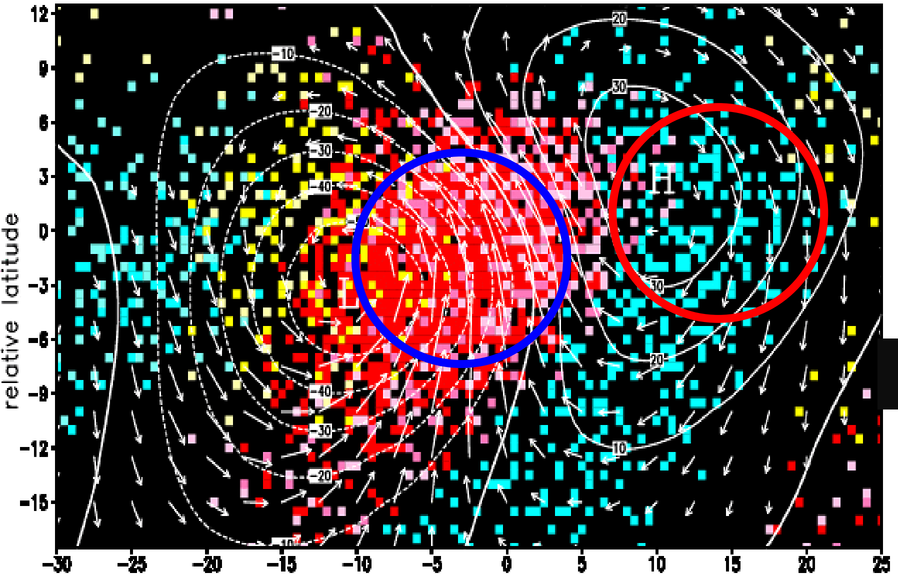
- We want to isolate the sources of error. Focus on particular phenomena/regimes, e.g.
  - Extra tropical cyclones
  - Stratocumulus regions
- An individual case may not be conclusive: Is it typical?
- On the other hand general statistics may swamp this kind of system.
- Can use compositing technique (e.g. extra-tropical cyclones).
- Focus on distinct regimes if can isolate (e.g. Stratocumulus, Trade Cumulus).

Composites – Extra-tropical cyclones

ISCCP clouds



ECMWF clouds



Overlay about 1000 cyclones, defined about a location of maximum optical thickness

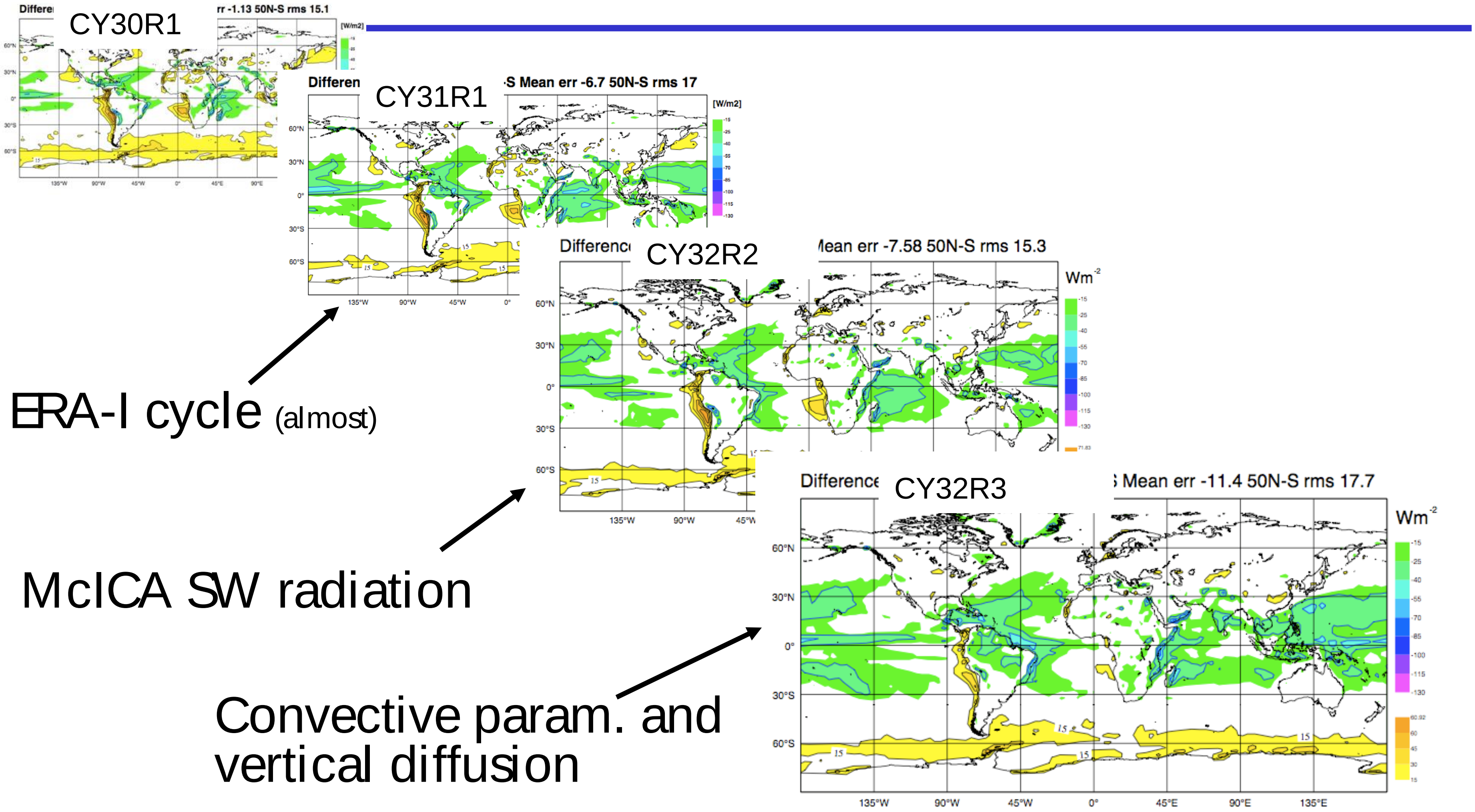
Plot predominant cloud types by looking at anomalies from 5-day average

- High Clouds too thin
- Low clouds too thick

High tops=Red, Mid tops=Yellow, Low tops=Blue

Klein and Jakob, 1999, MWR

Model Climate: Regime dependent error?



ERA-I cycle (almost)

McICA SW radiation

Convective param. and vertical diffusion

TOA net SW radiation vs. CERES:
Too much reflectance from TCu, not enough from Sc

Maike Ahlgrimm

Does the model have "correct" trade cumulus cloudiness?

Three aspects:

Cloud amount
when present
(AWP)

helps identify
cloud type

Cloud frequency
of occurrence
(FOO)

with amount when
present (AWP) gives
total cloud cover

Radiative
properties

radiative balance
ultimately drives
the system

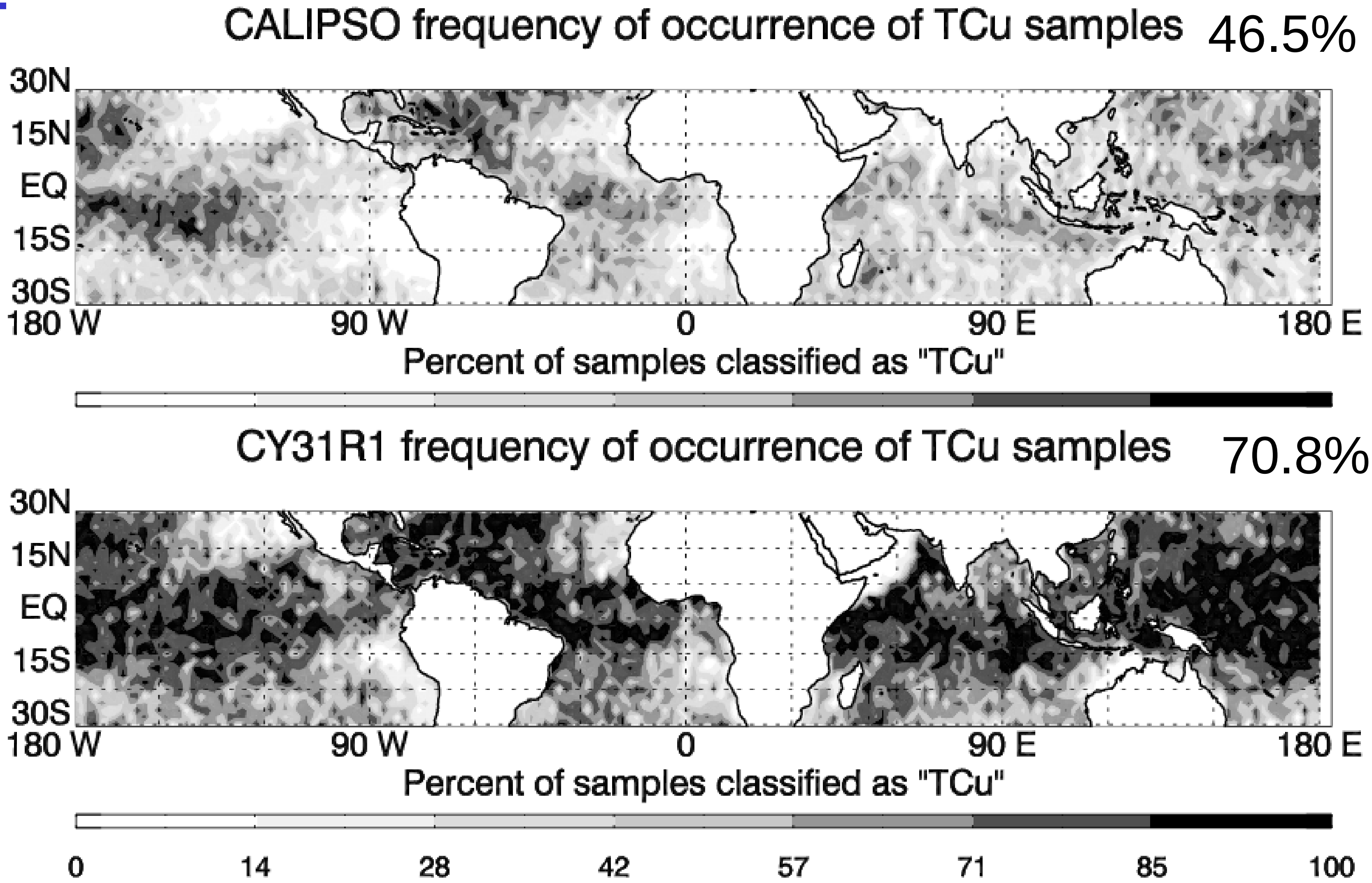
Maike Ahlgrimm

Isolating the Trade Cu Regime

Identify cloud samples as:

- with less than 50% cloud fraction
- cloud top below 4km
- over ocean
- between 30S and 30N

TCu frequency of occurrence (FOO)



46.5%

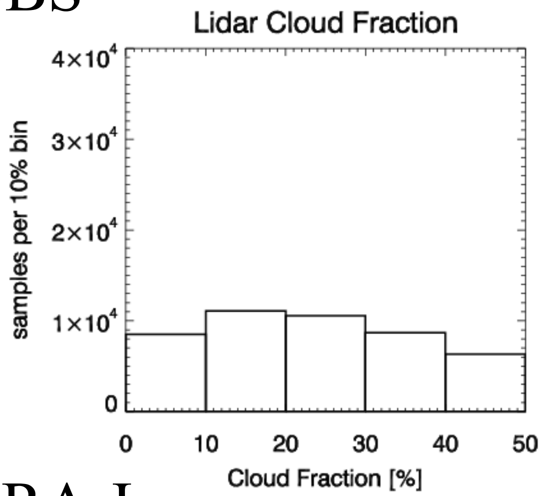
70.8%

Model has TCu more frequently than observed

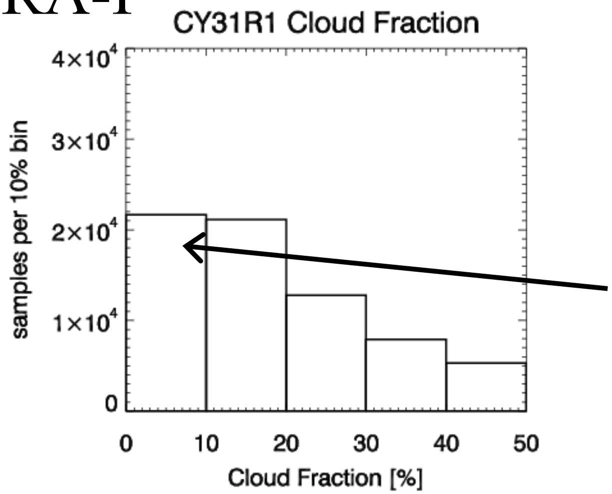
Ahlgrimm and Köhler,
MWR 2010

Cloud amount when present (AWP)

OBS



ERA-I



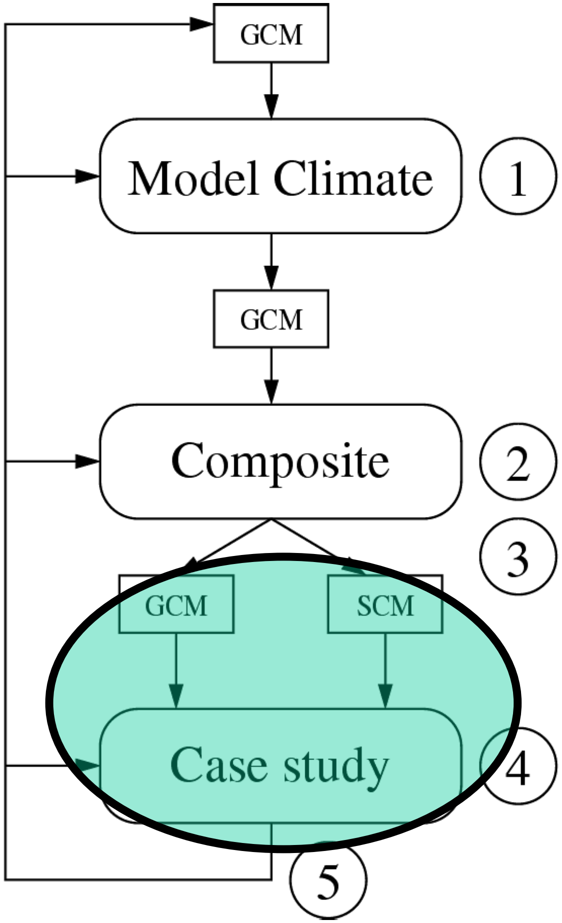
Smaller cloud fractions partially compensate for the overprediction of frequency of cloud occurrence, but still overall cloud fraction from trade cumulus is too large – too reflecting – short wave bias?

↑

Most of the additional TCu samples have very small cloud fractions

Ahlgrimm and Köhler,
MWR 2010

A strategy for cloud parametrization evaluation



Step 1 : identify major problem areas

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C.Jakob

Case Studies

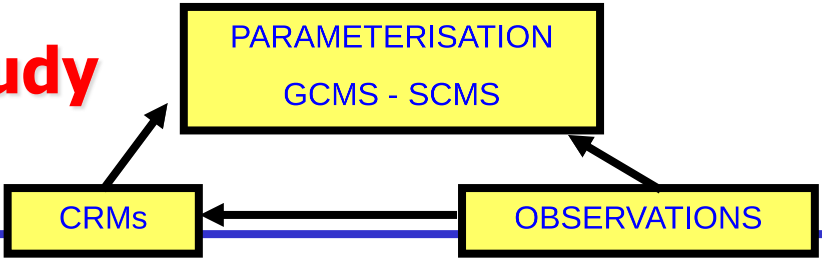
- Can concentrate on a particular location and/or time period in more detail, for which specific observational data is collected:

CASE STUDY

- Examples:
  - GATE, CEPEX, TOGA-COARE, ARM, TWP-ICE, ASCOS, M-PACE,…

GEWEX Cloud System Study
(now GASS, gewex.org)

(Moncrieff et al. Bull. AMS 97)


PARAMETERISATION

GCMS - SCMS

CRMs

OBSERVATIONS

Step 1

Use observations to evaluate parameterizations of subgrid-scale processes in a CRM

Step 2

Evaluate CRM results against observational datasets

Step 3

Use CRM to simulate precipitating cloud systems forced by large-scale observations

Step 4

Evaluate and improve SCMs by comparing to observations and CRM diagnostics

GCSS: Comparison of many SCMs with a CRM

Bechtold et al QJRMS 2000 SQUALL LINE SIMULATIONS

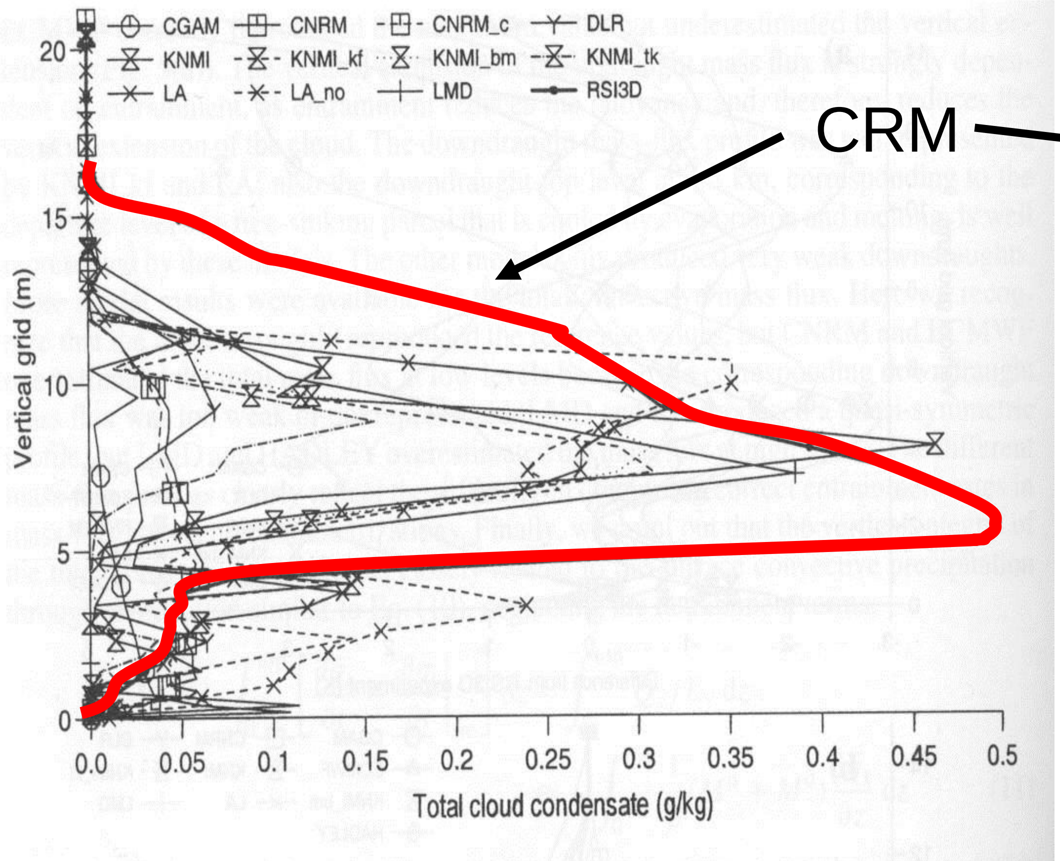
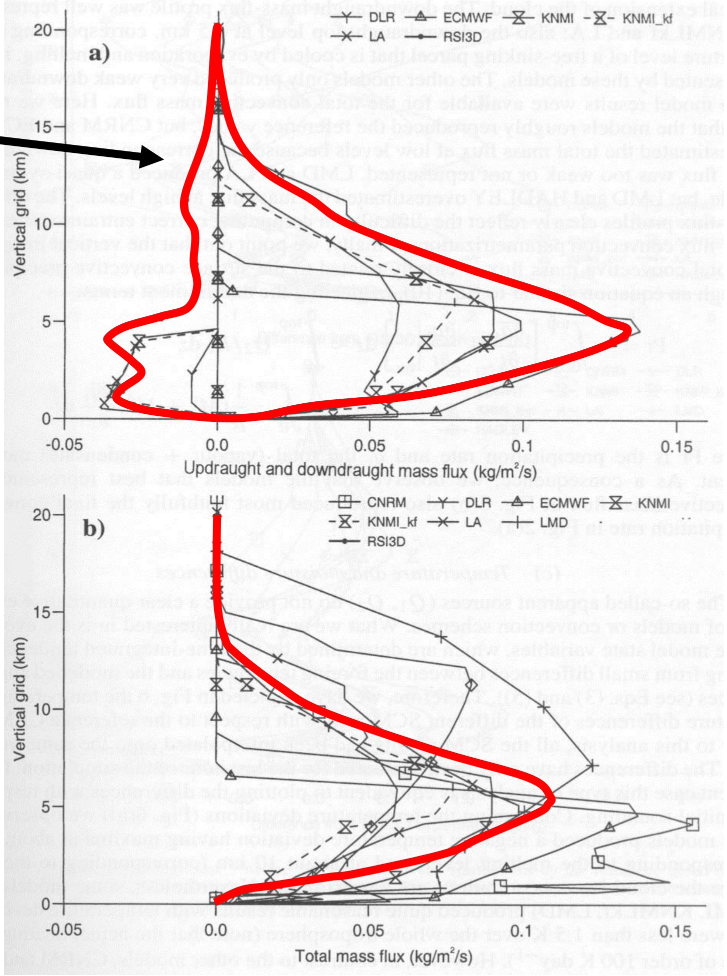


Figure 7. Vertical profiles of the total cloud condensate (liquid + solid) for simulations by different single-column models (see Tables 1 and 2 for explanations of the acronyms).



Summary

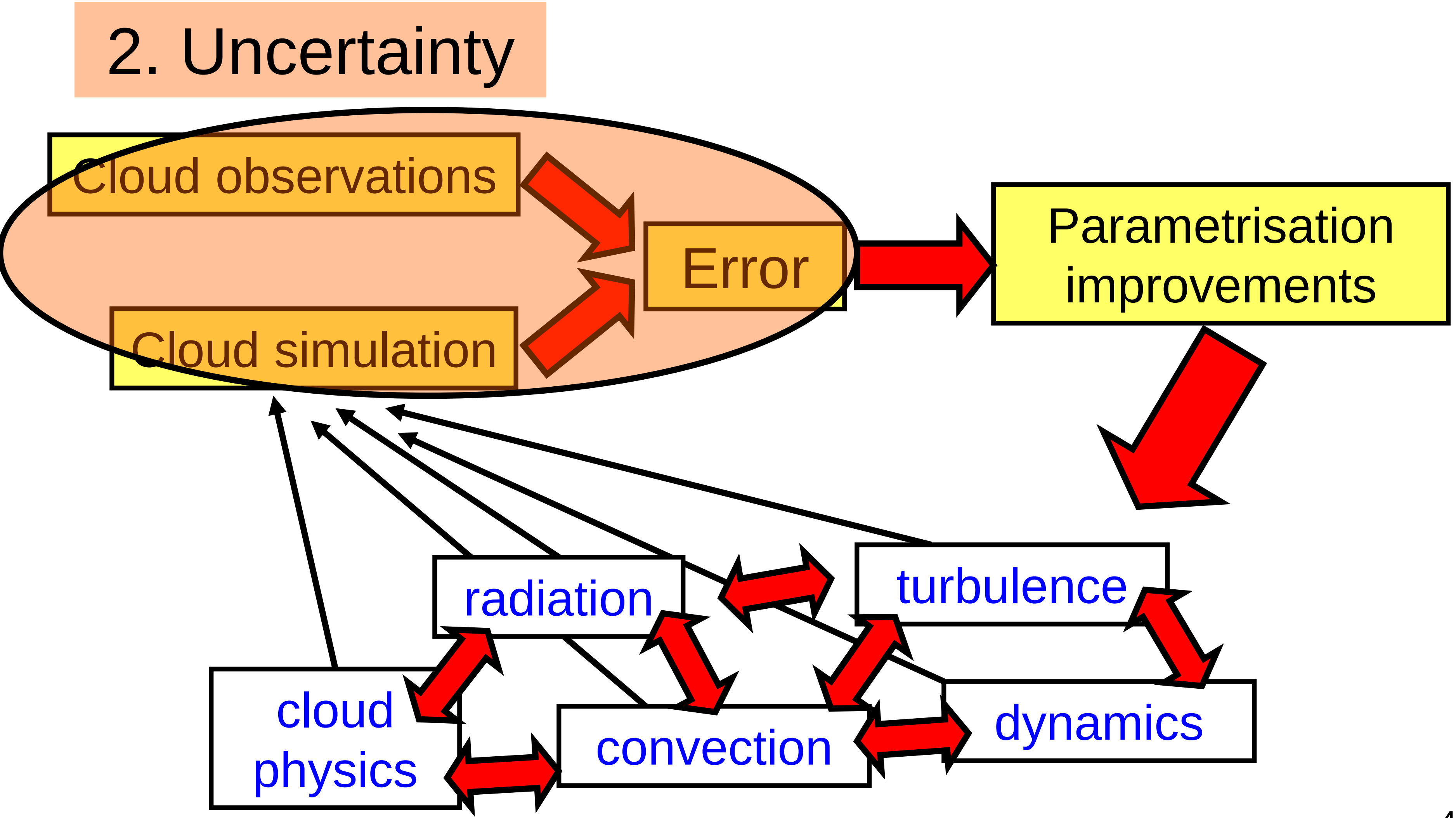
- Long term statistics:
  - Climate systematic errors – we want to improve the basic state/climatology of the model
  - But which physics is responsible for the errors? Non-linear interactions.
  - Long term response vs. transient response.

- Isolating regimes:
  - Composites and focus on geographical regions.

- Case studies
  - Detailed studies with Single Column Models, Cloud Resolving Models, NWP models
  - Easier to explore parameter space.
  - Are they representative? Do changes translate into global skill?

2. Comparing model and obs: Uncertainty and limitations

Cloud Validation: The problems



What is a cloud ?

What is a cloud ?

- Different observational instruments will detect different characteristics of clouds.
- A cloud from observations may be different to the representation in models

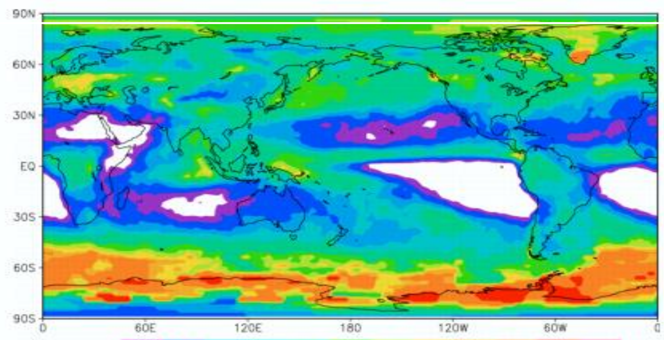
- ➢ Understanding the limitations of different instruments
- ➢ Benefit of observations from different sources
- ➢ Comparing like-with-like (physical quantity, resolution)

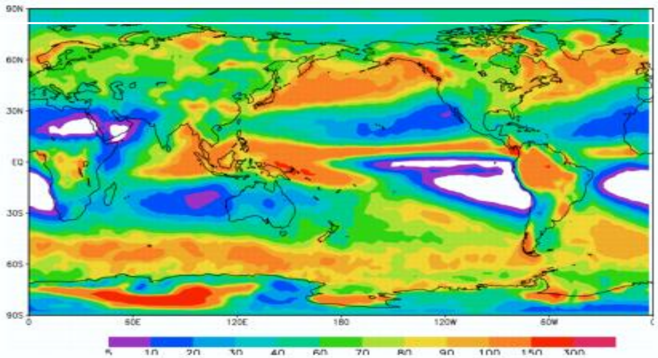
Verification

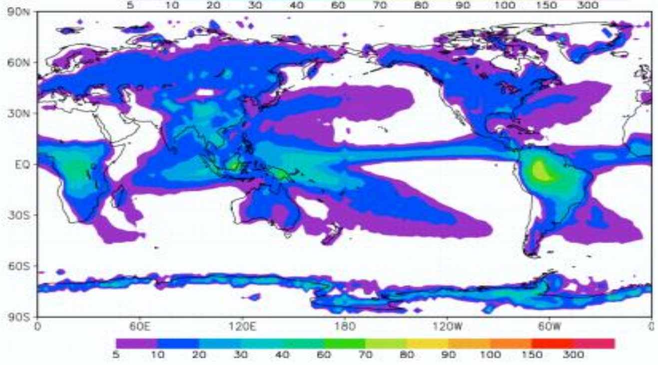
Uncertainty in quantities derived from observations…

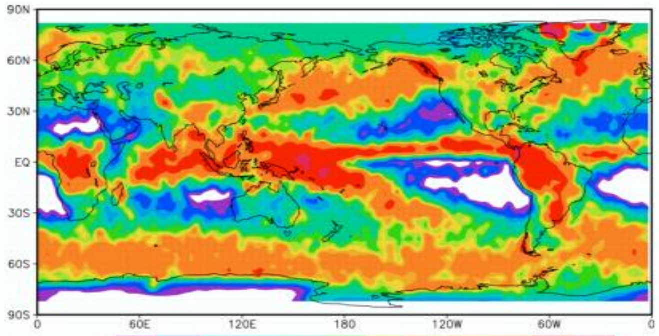
Widely varying estimates of IWP from different satellite datasets!

From
Waliser
et al.
(2009),
JGR

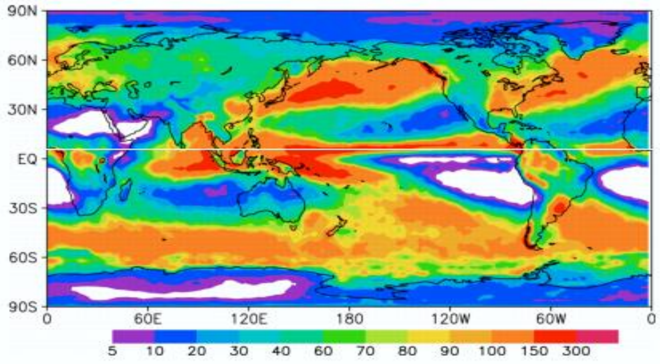








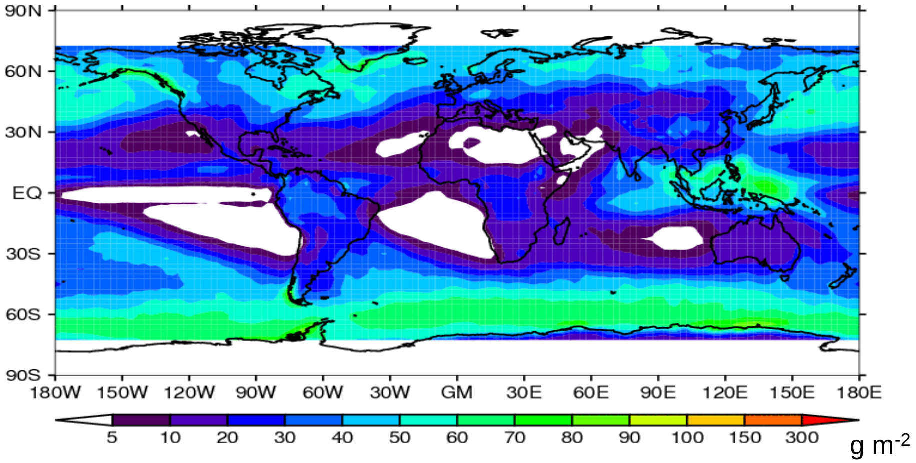
Cloud
Sat
(From
Waliser et
al 2009)



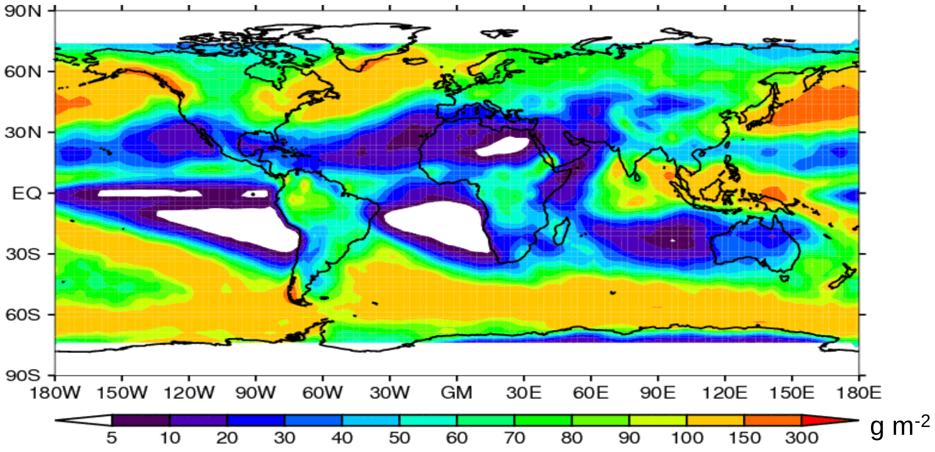
What is being compared?
Cloud ice vs. snow – comparing like-with like

Model Ice Water Path (IWP) (1 year climate)

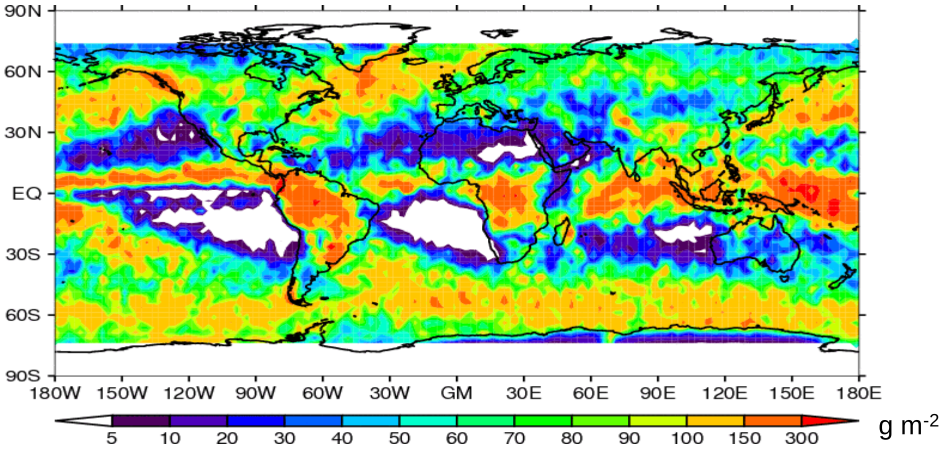
IWP from prognostic cloud ice variable

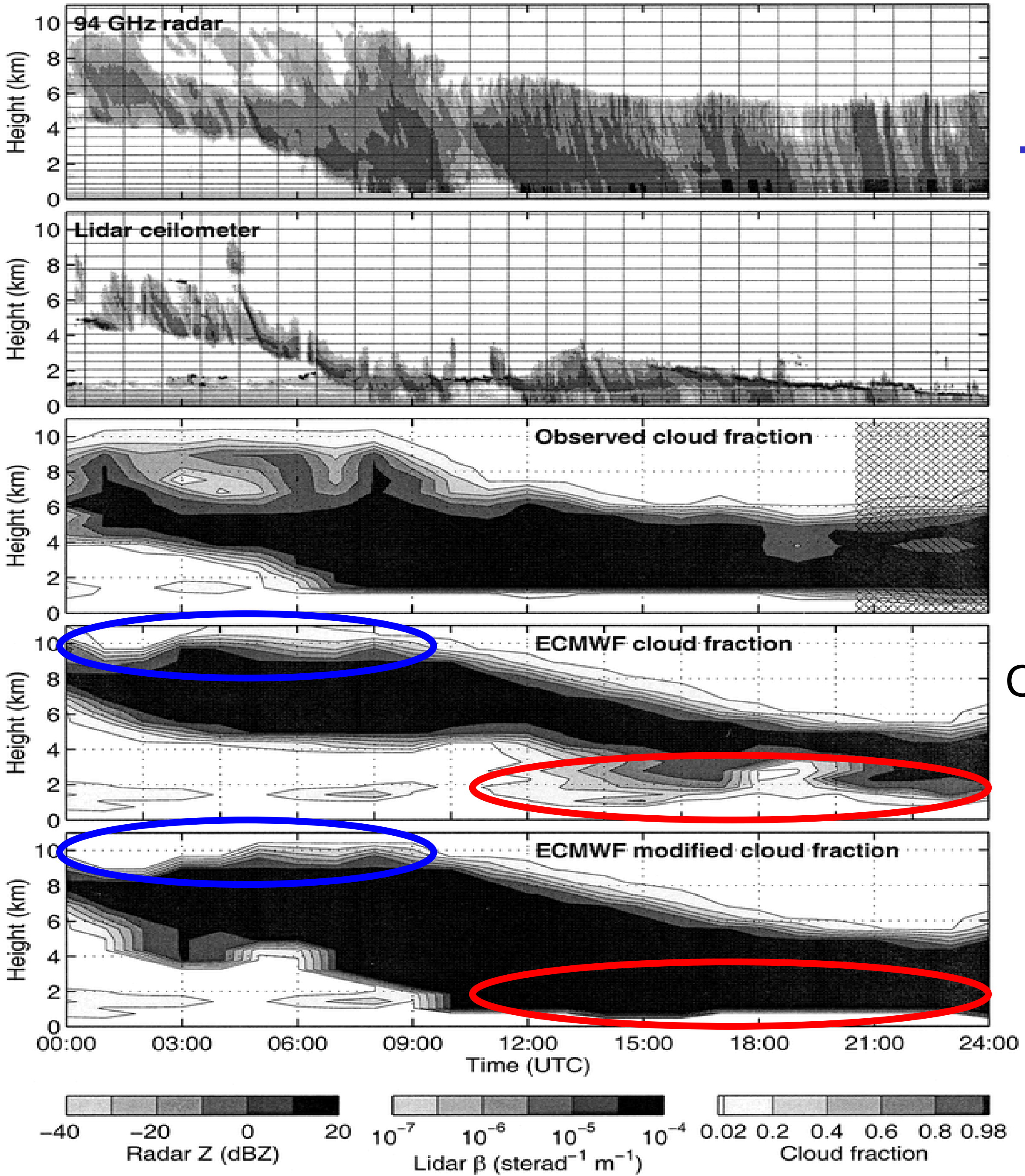


IWP from cloud ice + precipitating snow



Observed Ice Water Path (IWP)
CloudSat 1 year climatology





Hogan et al. (2001)

Comparison improved when:

(a) snow was included,

(b) cloud below the sensitivity of the instruments was removed.

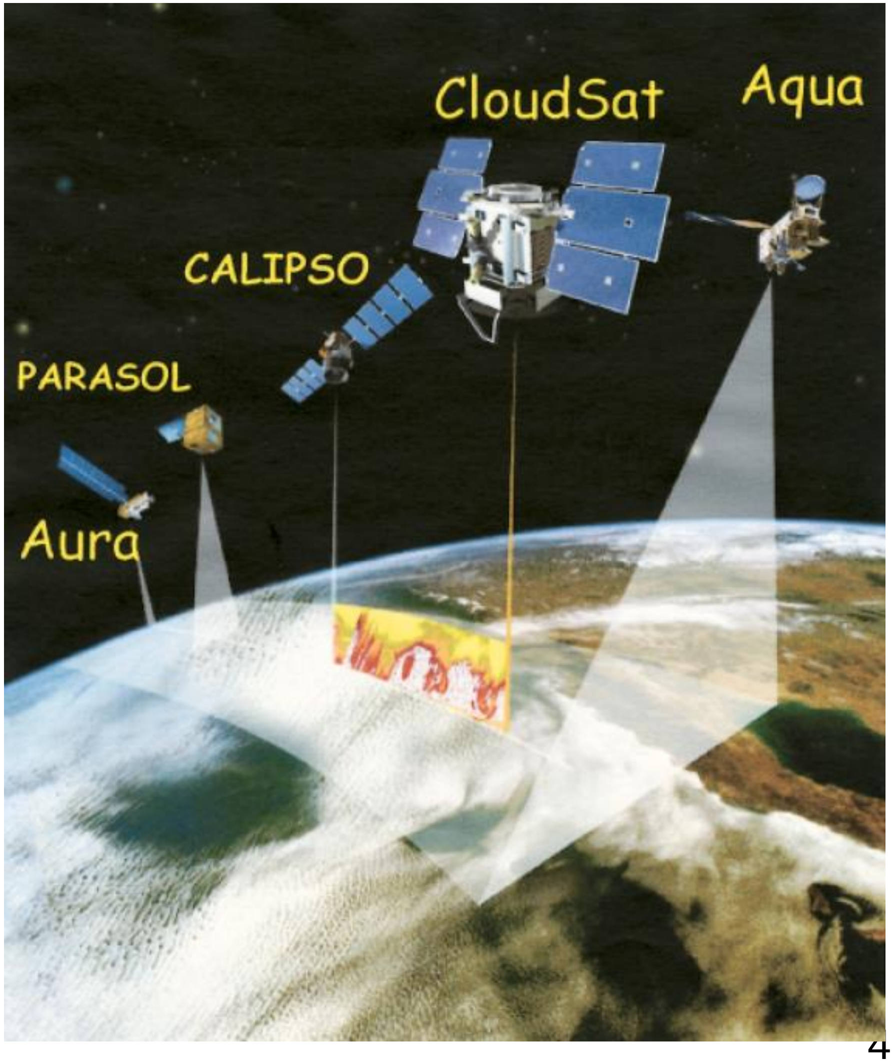
Space-borne active remote sensing
A-Train

- CloudSat and CALIPSO have active radar and lidar to provide information on the vertical profile of clouds and precipitation.
  (Launched 28th April 2006)

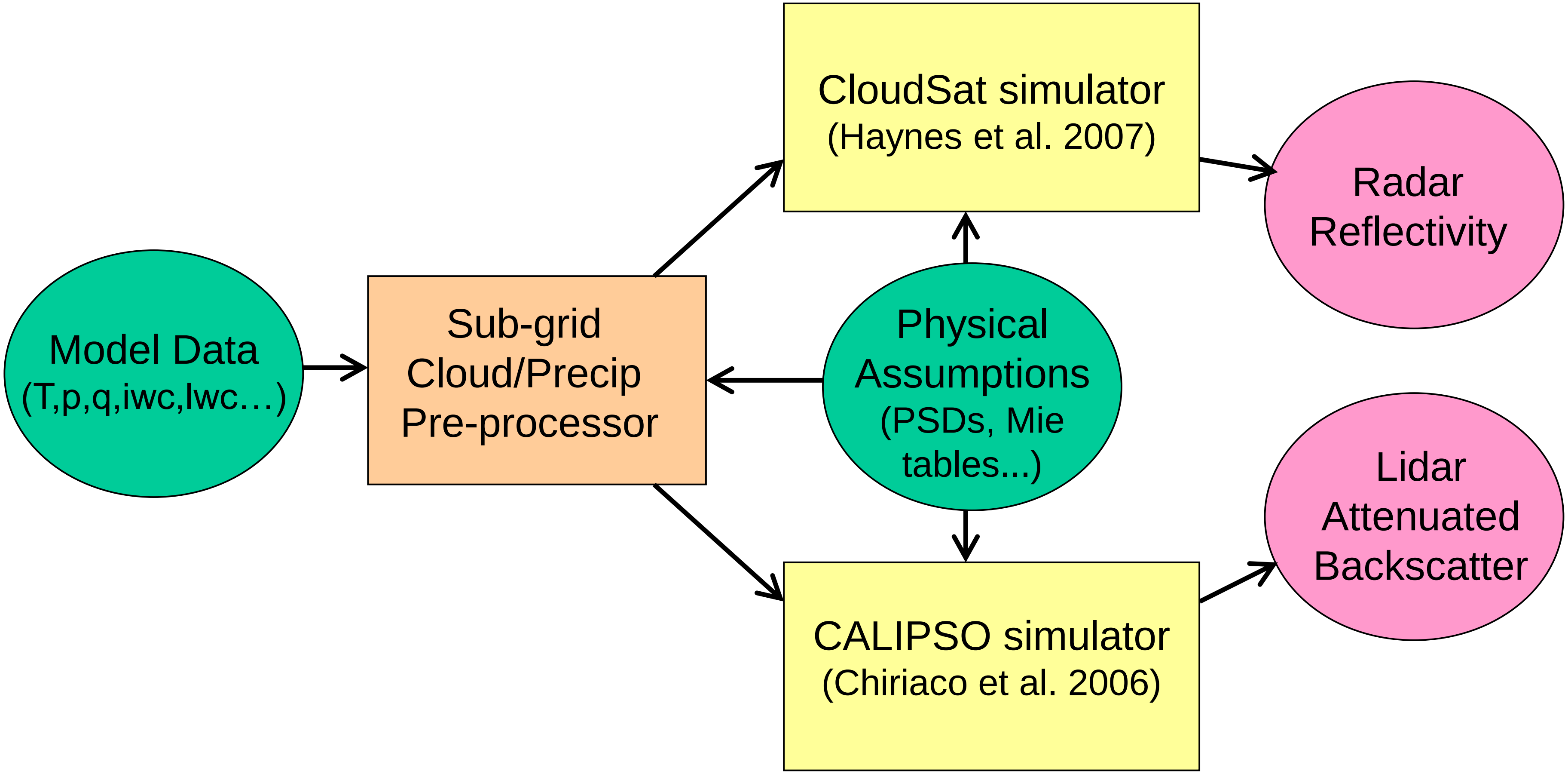
- Approaches to model validation:

  Model → Obs parameters
  Obs → Model parameters

- Spatial/temporal mismatch



Simulating Observations
CFMIP COSP radar/lidar simulator



CloudSat simulator
(Haynes et al. 2007)

Radar Reflectivity

Model Data
(T,p,q,iwc,lwc…)

Sub-grid Cloud/Precip Pre-processor

Physical Assumptions
(PSDs, Mie tables...)

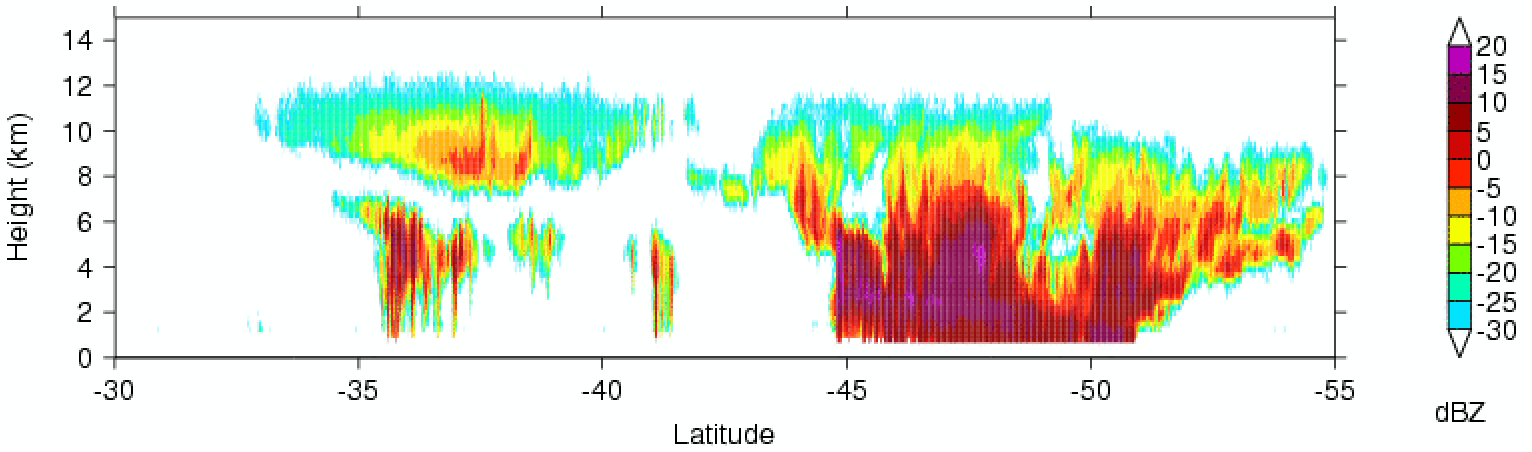
Lidar Attenuated Backscatter

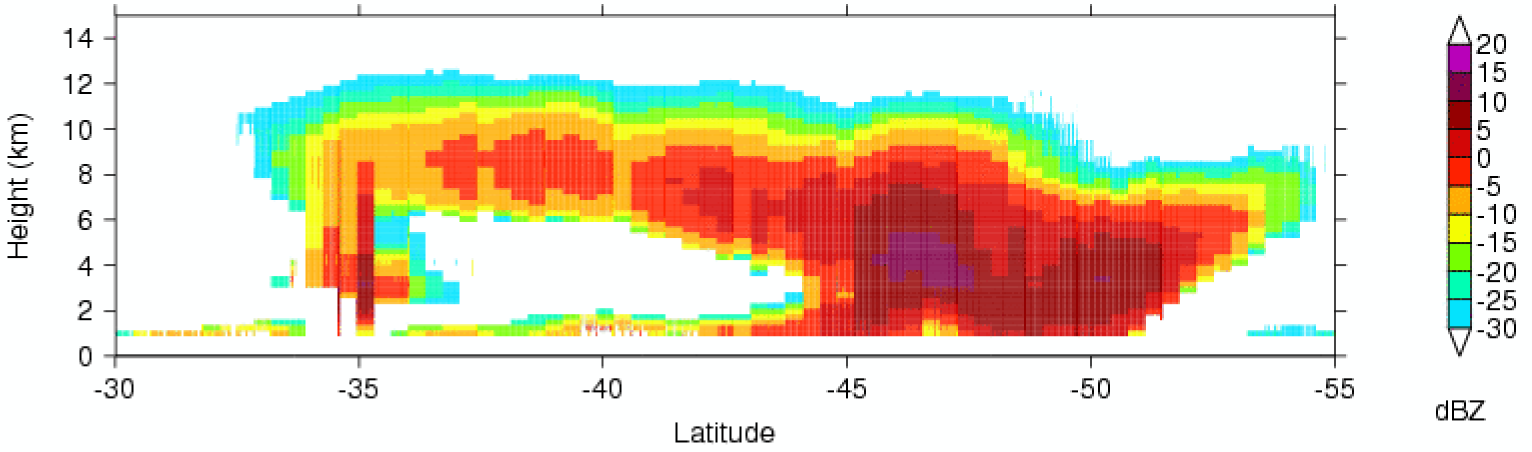
CALIPSO simulator
(Chiriaco et al. 2006)

http://cfmip.metoffice.com

Note: COSP now has many more satellite simulators

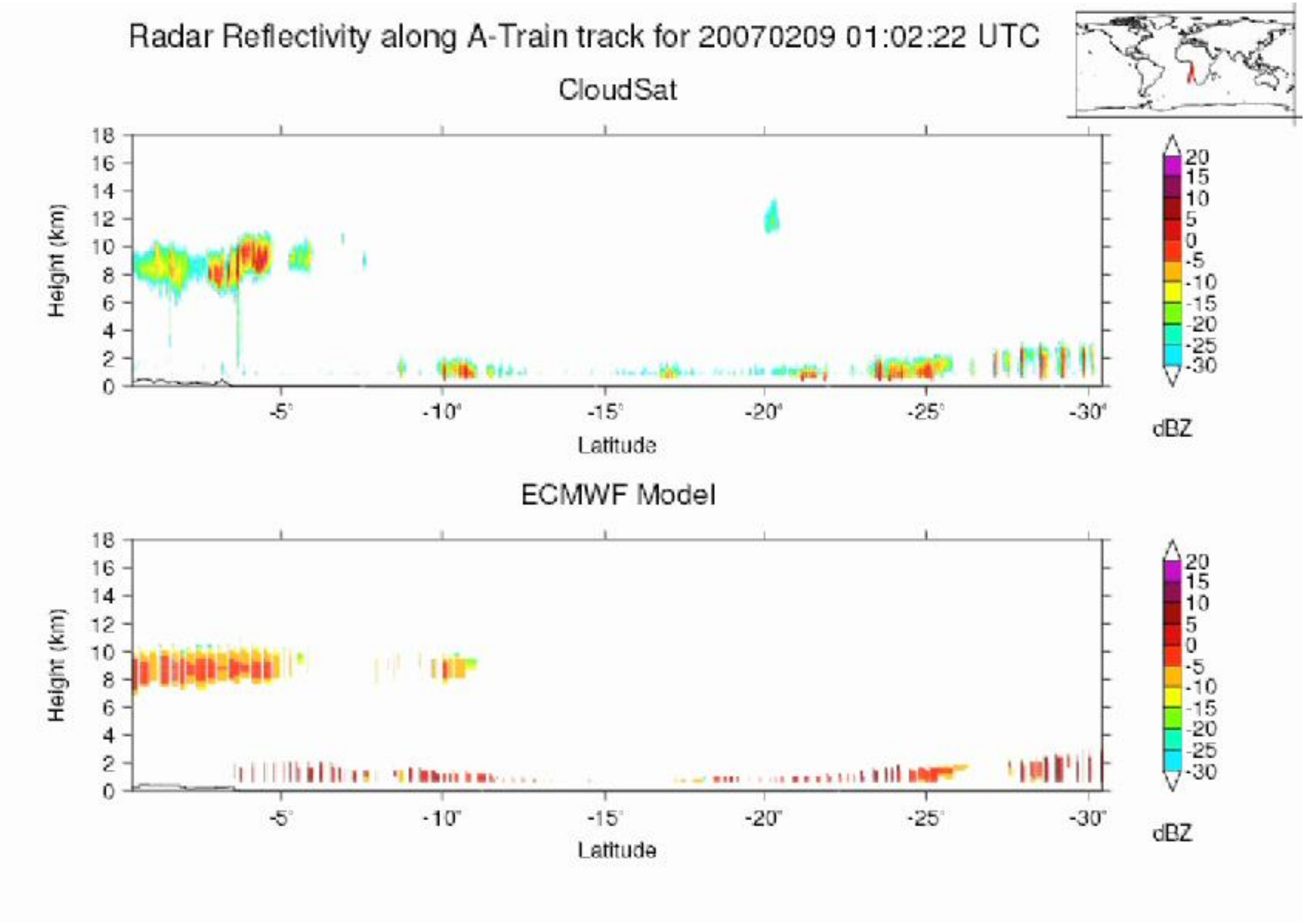
Example cross-section through a front
Model vs CloudSat radar reflectivity


CloudSat Effective Radar Reflectivity


IFS Along-track Effective Radar Reflectivity

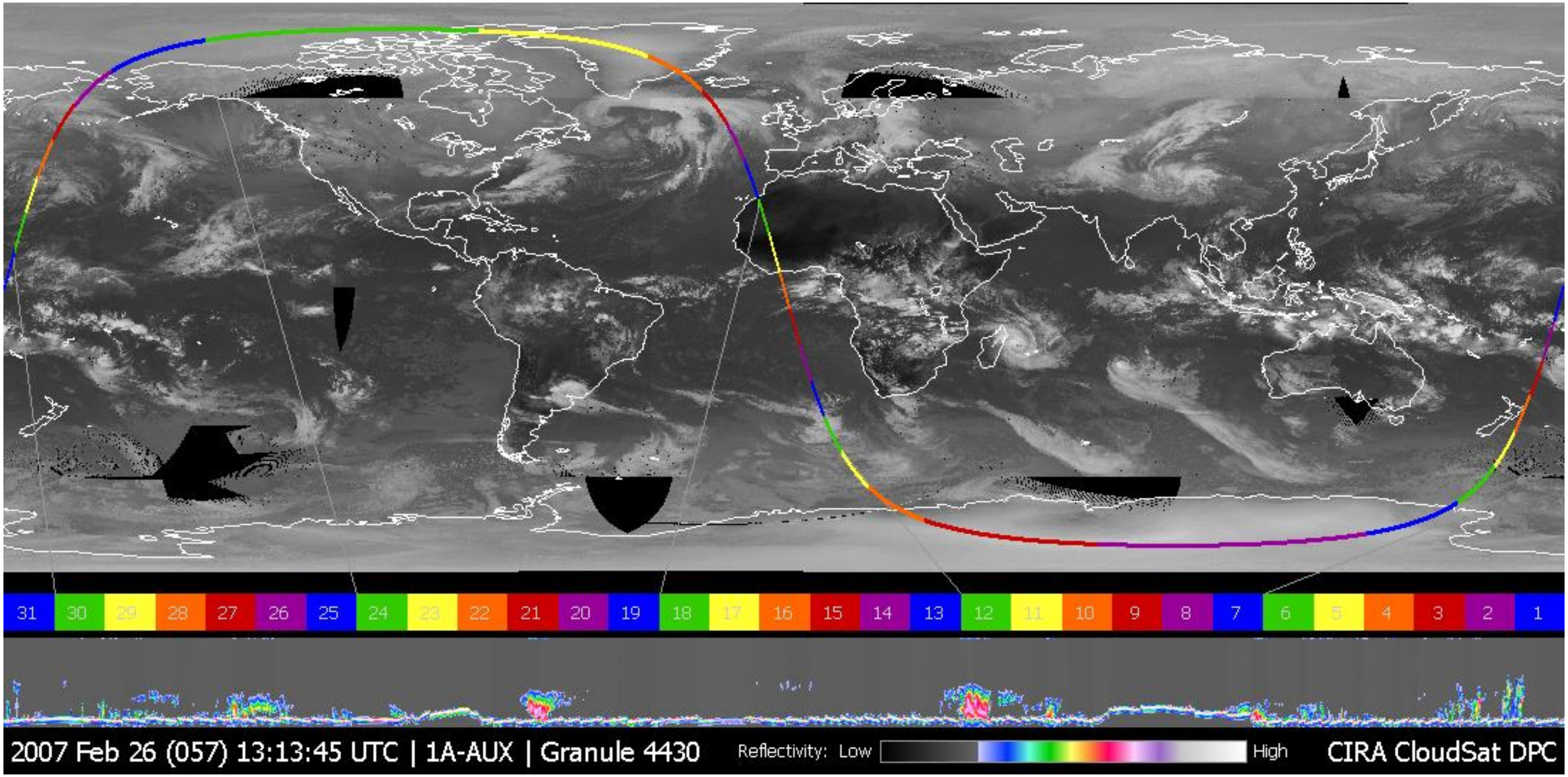
Radar Reflectivity

Along-track model vs. CloudSat animation

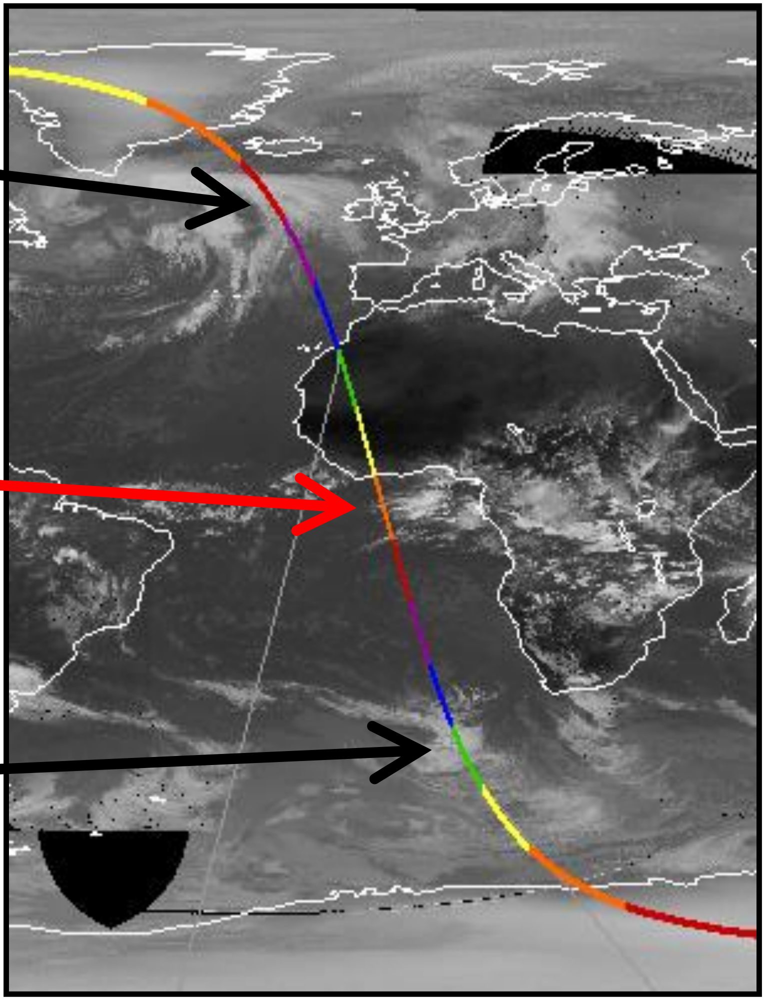


Example CloudSat orbit “quicklook”

http://www.cloudsat.cira.colostate.edu/dpcstatusQL.php



Example section of a CloudSat orbit 26th February 2006 15 UTC



Mid-latitude cyclone

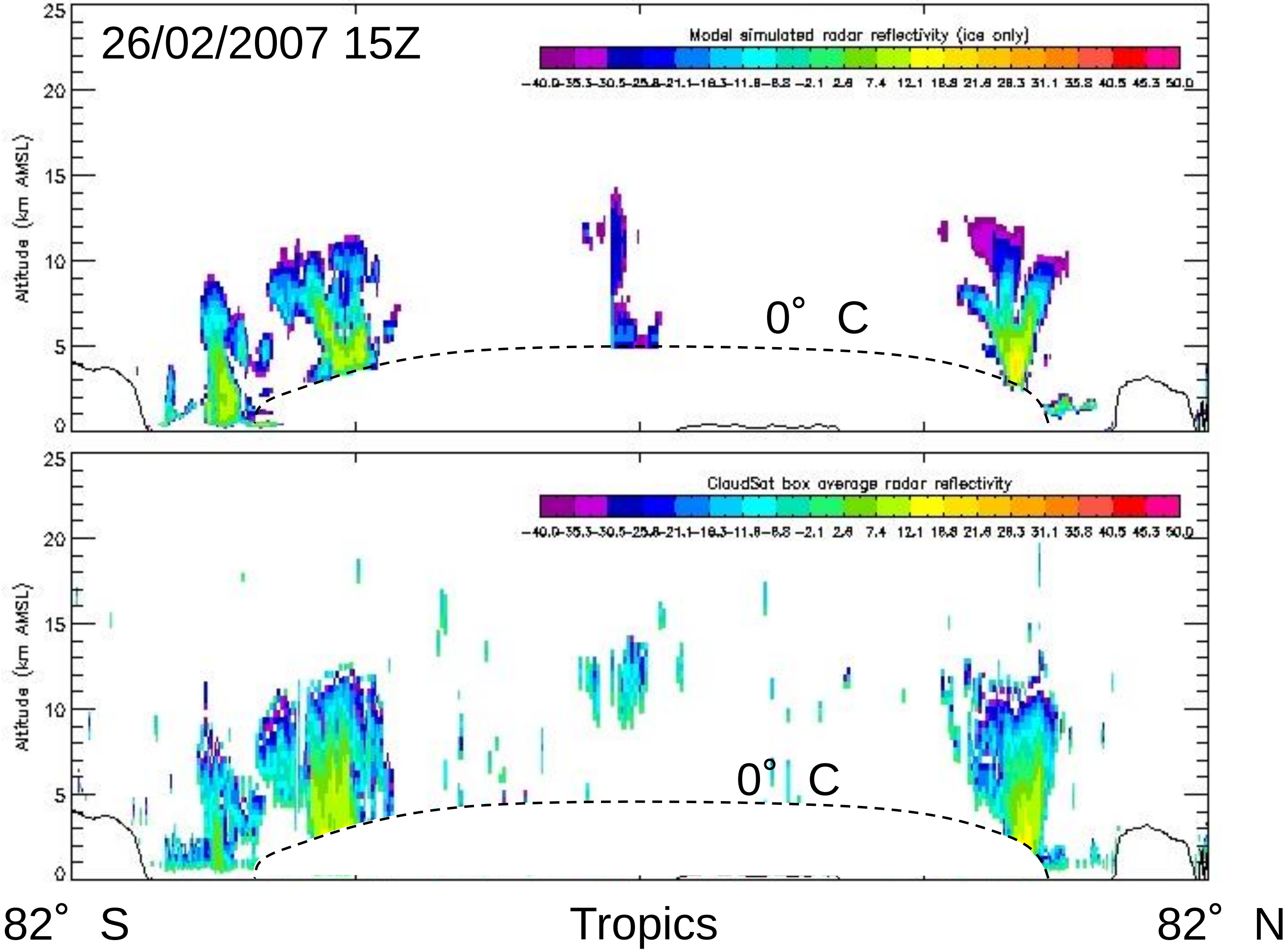
High tropical cirrus

Mid-latitude cyclone

Compare model with observed parameters: Radar reflectivity

Simulated radar reflectivity from the model for ice only (< 0° C)

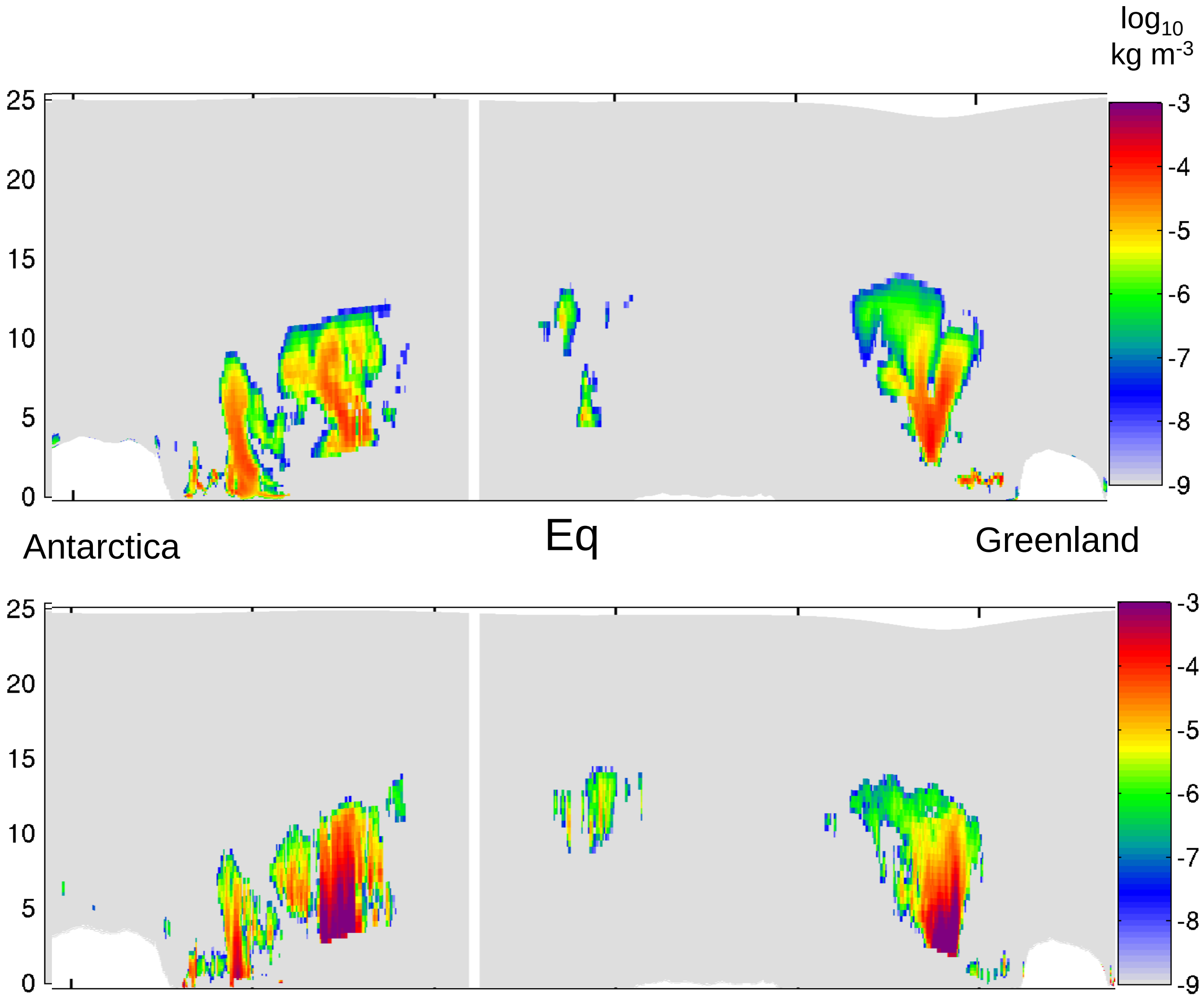
Observed radar reflectivity from CloudSat
(ice + rain)


26/02/2007 15Z

Compare model parameters with equivalent derived from observations: Ice Amount

Model ice water content (*excluding precipitating snow*).

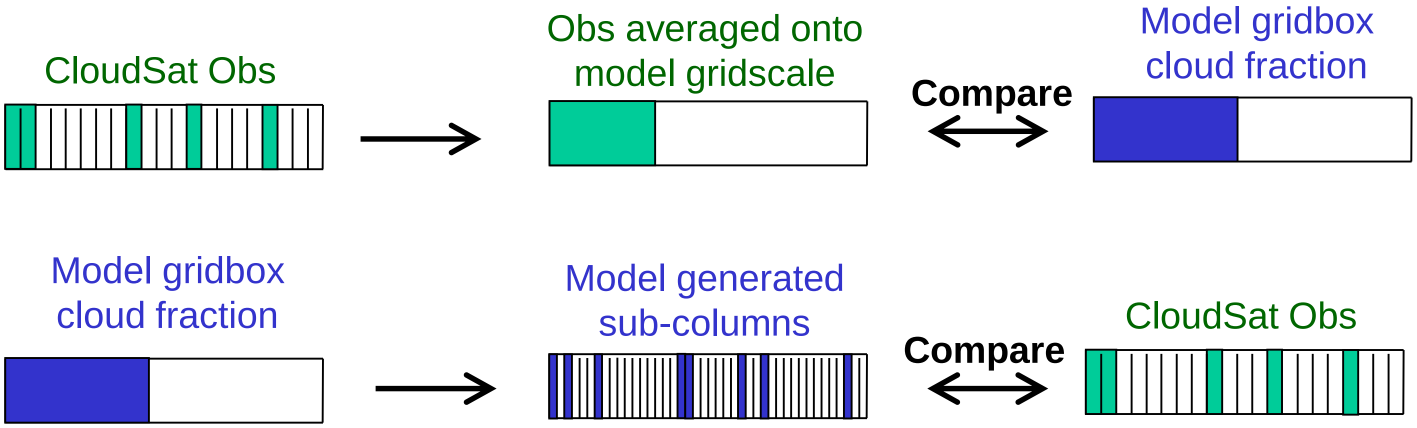
Ice water content derived from a 1DVAR retrieval of CloudSat/ CALIPSO/Aqua



(Delanöe and Hogan (2007), Reading Univ., UK)

Spatial resolution mis-match

- Need to address mismatch in spatial scales in model (50 km) and obs (1 km)
- Sub-grid variability is predicted by the IFS model in terms of a cloud fraction and assumes a vertical overlap.
- Either:
  - (1) Average obs to model representative spatial scale
  - (2) Statistically represent model sub-gridscale variability using a Monte-Carlo multi-independent column approach.



CloudSat Obs

Obs averaged onto model gridscale

Compare

Model gridbox cloud fraction

Model gridbox cloud fraction

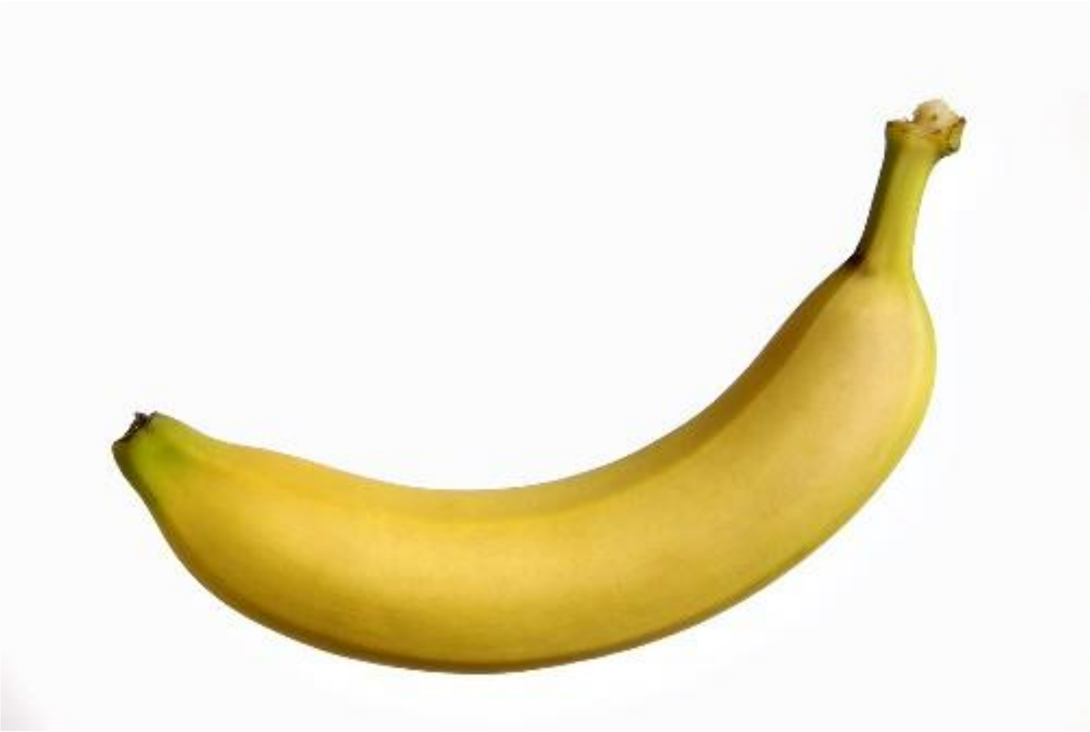
Model generated sub-columns

Compare

CloudSat Obs

🟦 Model Cloudy
🟩 Obs Cloudy
⬜ Cloud-free

When comparing a model with observations, we need to compare like-with-like



Model validation

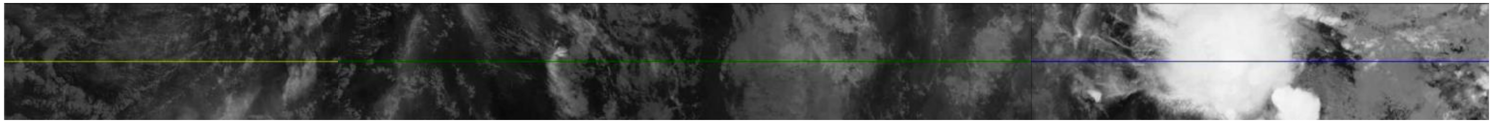
Making the most of instrument synergy

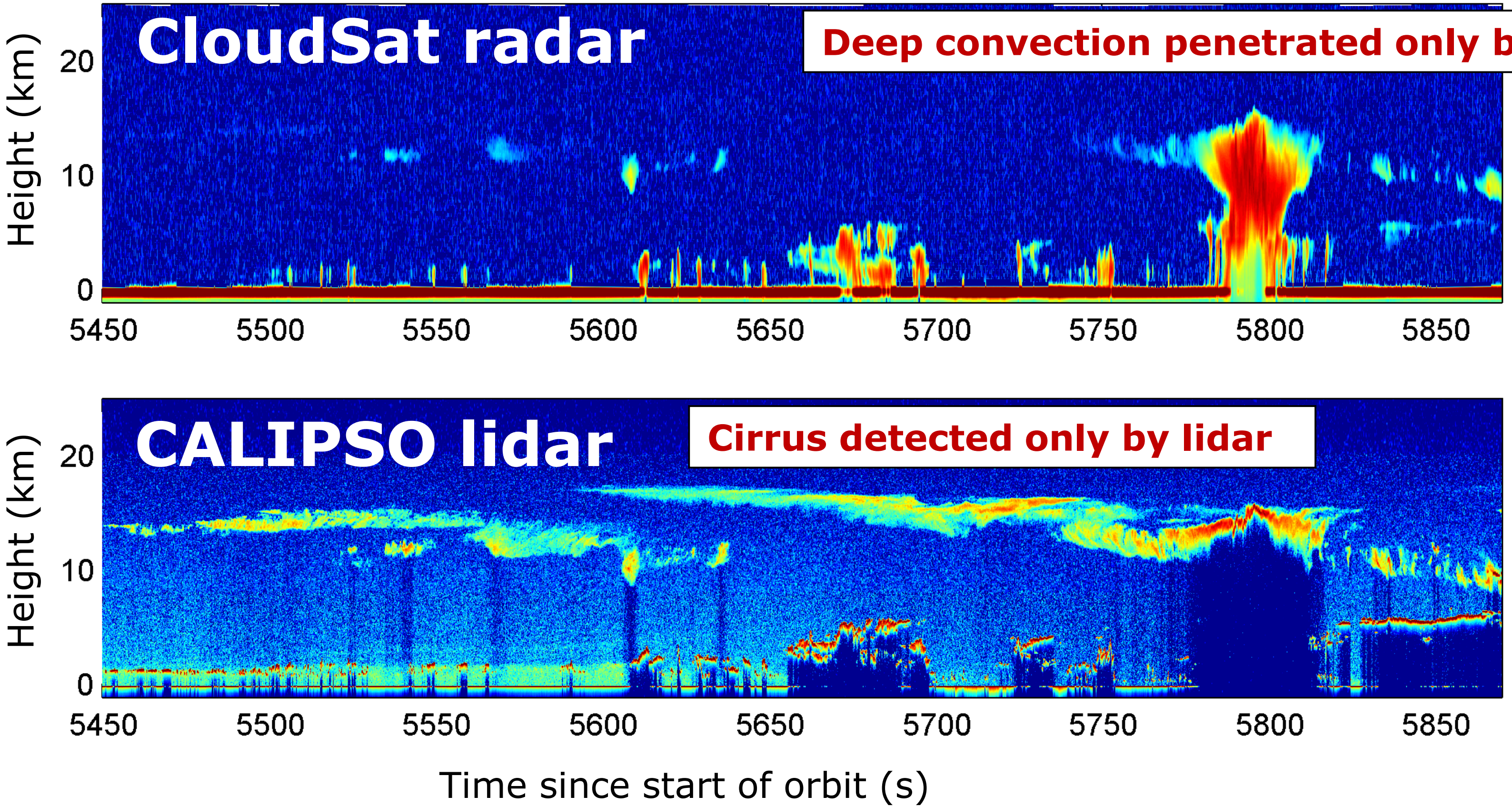
- Observational instruments measure one aspect of the atmosphere.
- Often, combining information from different instruments can provide complementary information (particularly for remote sensing)
- For example, radars at different wavelengths, lidar, radiometers.
- *CloudSat/CALIPSO*

Radar, lidar and radiometer instruments at Chilbolton, UK (*www.chilbolton.rl.ac.uk*)

Example of mid-Pacific convection

MODIS 11 micron channel





Deep convection penetrated only by radar

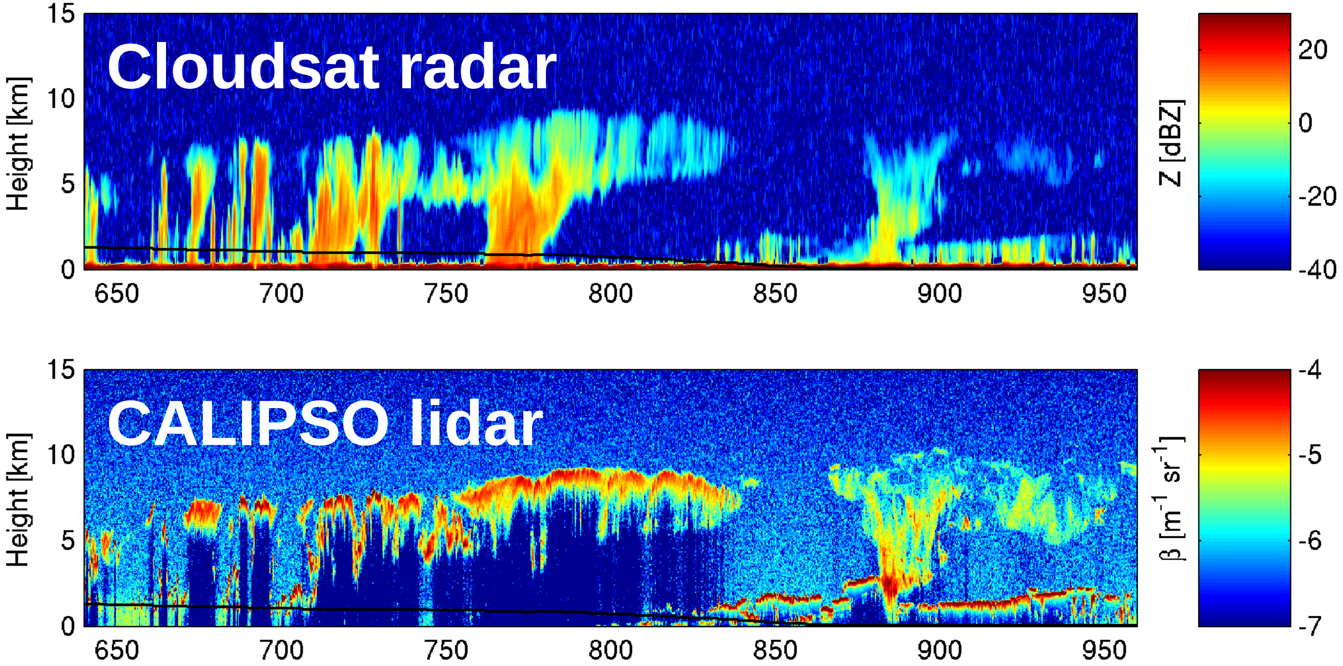
Cirrus detected only by lidar

Mid-level liquid clouds

Julien Delanoë/Robin Hogan

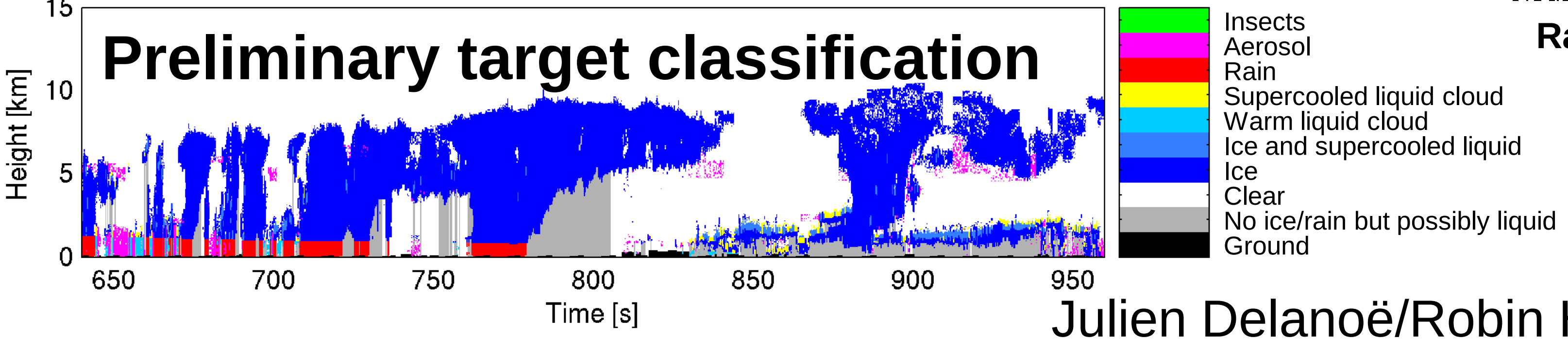
Combining radar and lidar…

using a variational technique (Delanoë and Hogan 2010)



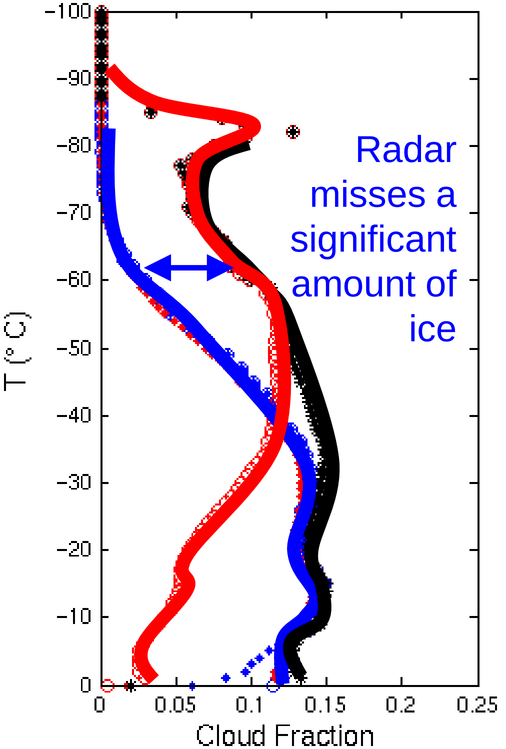
Cloudsat radar

CALIPSO lidar



Preliminary target classification

Global-mean cloud fraction



Radar misses a significant amount of ice

Radar and lidar
Radar only
Lidar only

Julien Delanoë/Robin Hogan

Summary

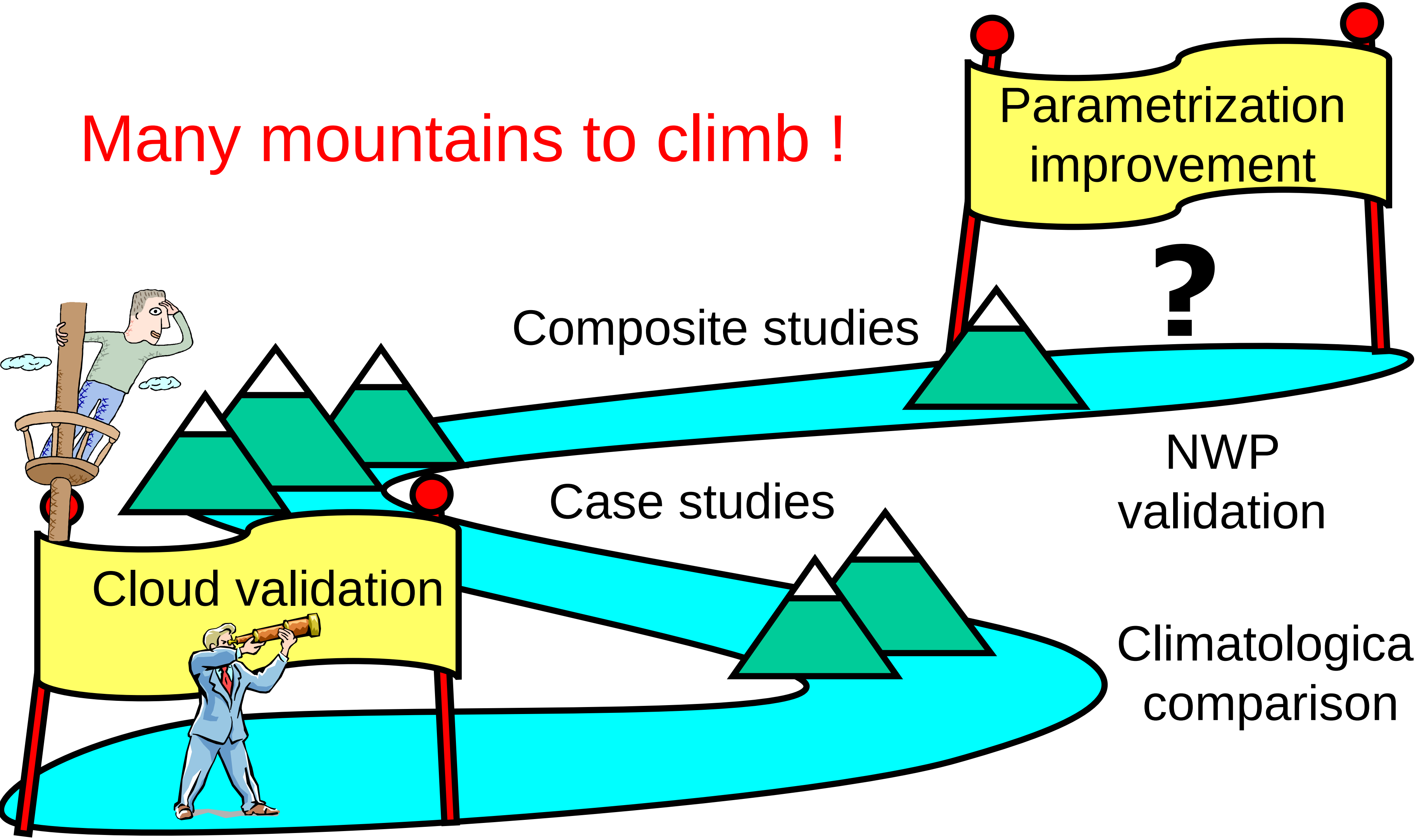
- **Different approaches** to verification (climate statistics, case studies, composites), different techniques (model-to-obs, obs-to-model) and a **range of observations** are required to validate and improve cloud parametrizations.

- Need to **understand the limitations** of observational data.
  Ensure we are **comparing like with like**.
  Use complementary observations - **synergy.**

- The model developer **needs to understand physical processes** to improve the model. Requires, theory and modelling and novel techniques for extracting information from observations.

The path to improved cloud parametrization…

Many mountains to climb !



Parametrization improvement

?

Composite studies

NWP validation

Case studies

Climatological comparison

Cloud validation