A multi-variables statistical description of clouds over the tropical ocean using daytime A-train high spatial resolution observations to assess cloud processes parameterization in climate model

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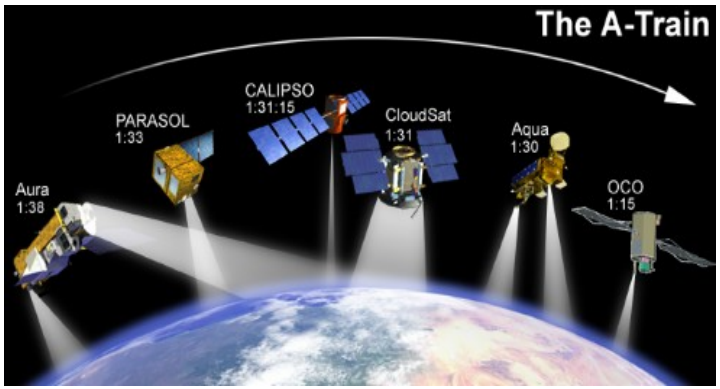
Evaluation of clouds in climate models

Observations



Data processing (starting from level1) :

Lidar CALIPSO (Cloud cover: 330m,Vertical structure: 30m)

Radiometer PARASOL (reflectance: 6km)

Radiometer MODIS (reflectance: 250m-500m-1km)

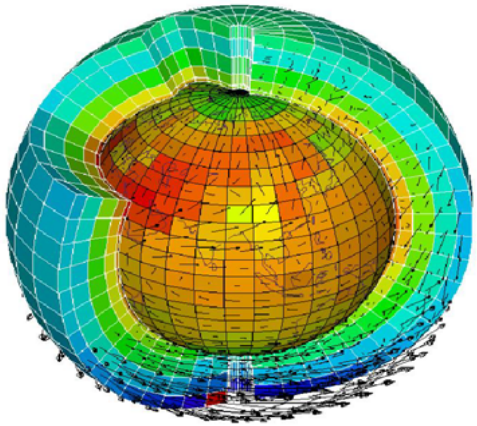
CFMIP-OBS: observational datasets consistent with the simulator

CALIPSO – GOCCP

PARASOL- reflectance in 1constant direction (θv=30°, φv=320°)

consistency

Climate Models



LMDZ5

LMDZ-New Physics

COSP Simulator:

- Subgrid cloud simulator-SCOPS
- Lidar simulator
- PARASOL simulator

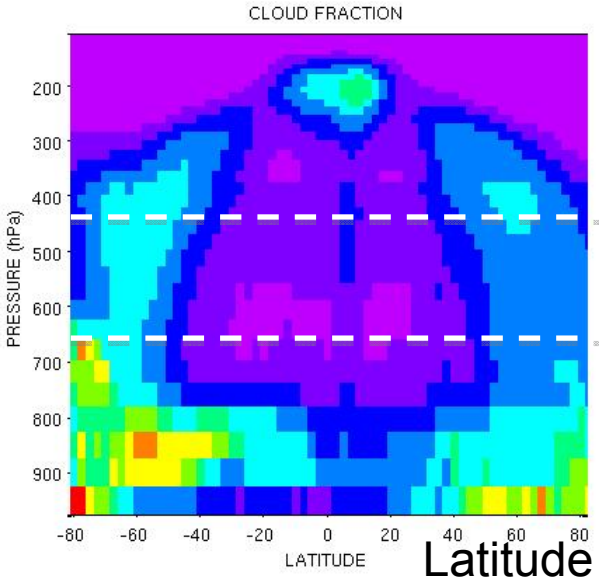
Simulated Datasets

CALIPSO-like

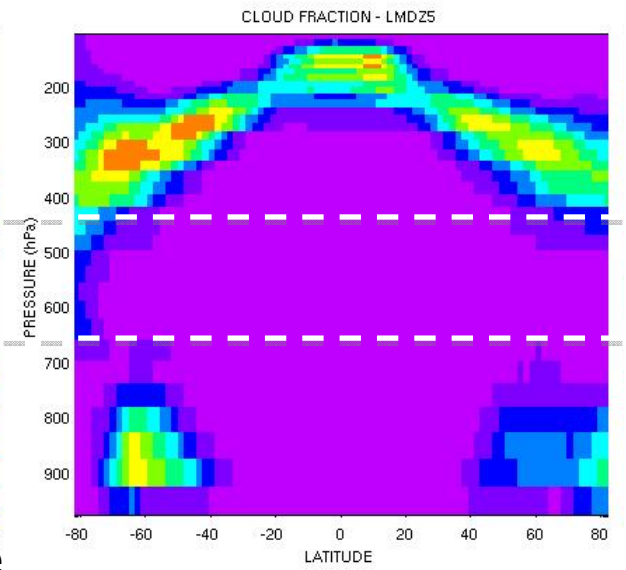
PARASOL-like

Zonal Mean Cloud Fraction – monthly mean

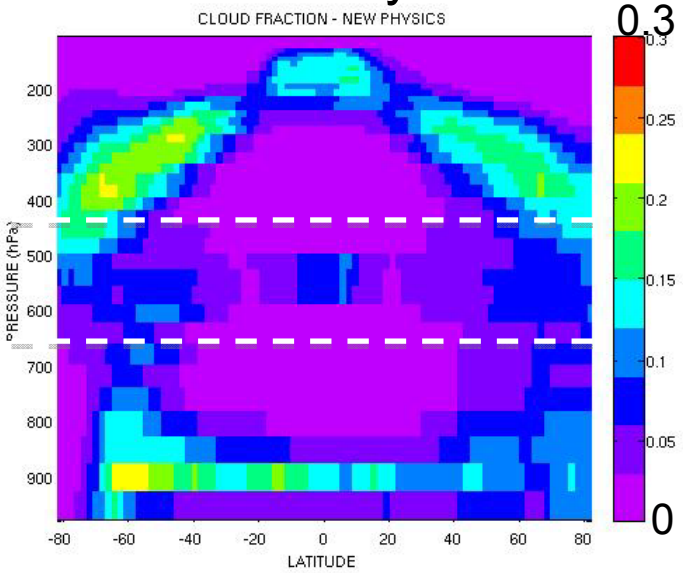
CALIPSO-GOCCP OBS



LMDZ5+SIM



LMDZ New Physics +SIM



LMDZ5

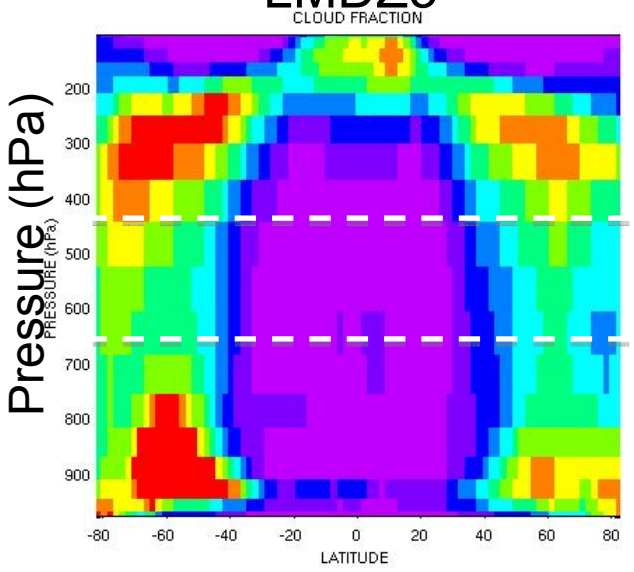
Overestimate:
- High clouds

Underestimate:
- Tropical low/mid clouds
- Congestus
- Mid level mid lat

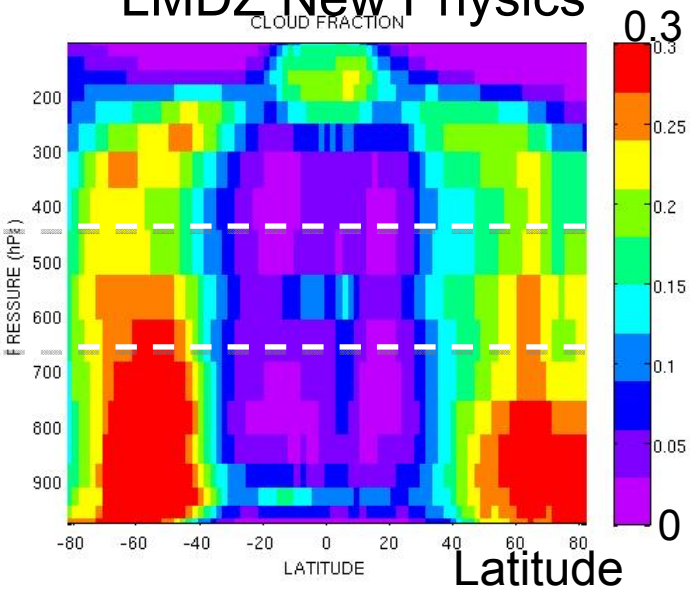
LMDZ New Physics

Better representation of clouds

LMDZ5



LMDZ New Physics



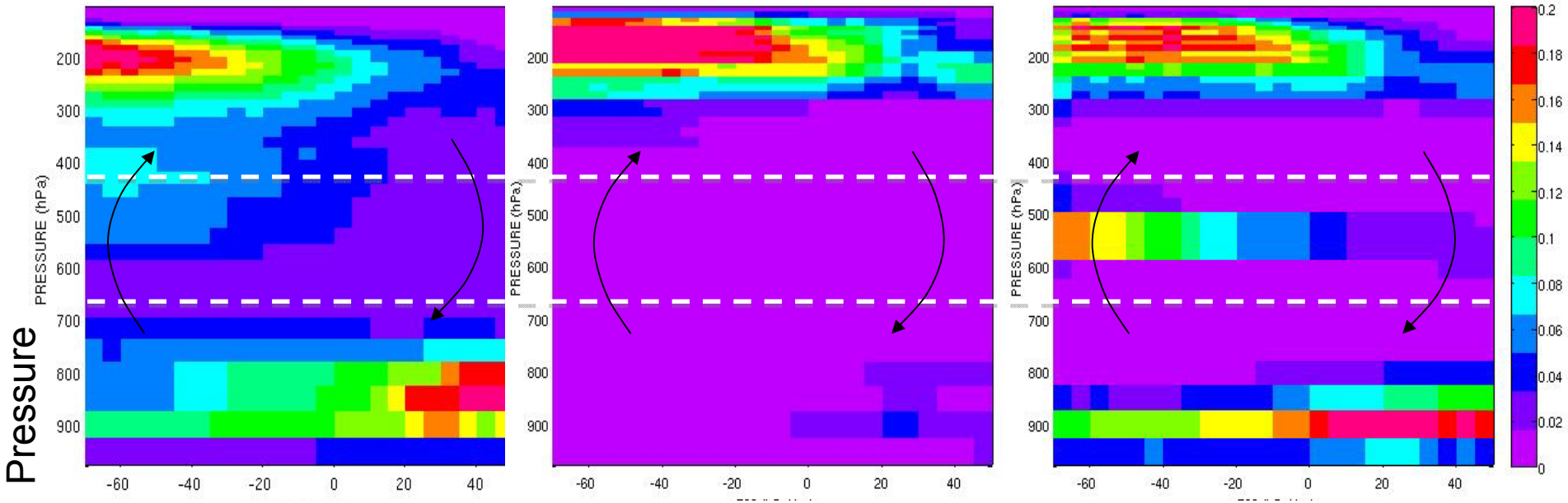
Cloud Cover and Cloud Vertical Distribution in circulation regimes - Monthly mean

Tropical ocean

CF CALIPSO-GOCCP

CF LMDZ5+SIM

CF LMDZ new+SIM



OBSERVATIONS:

- Subsidence regimes → Strong presence of low stratiform clouds
- Convective regimes → clouds at high troposphere + mid level clouds

LMDZ5:

-underestimation of low level clouds
-no mid level clouds
-overestimation of high convective clouds

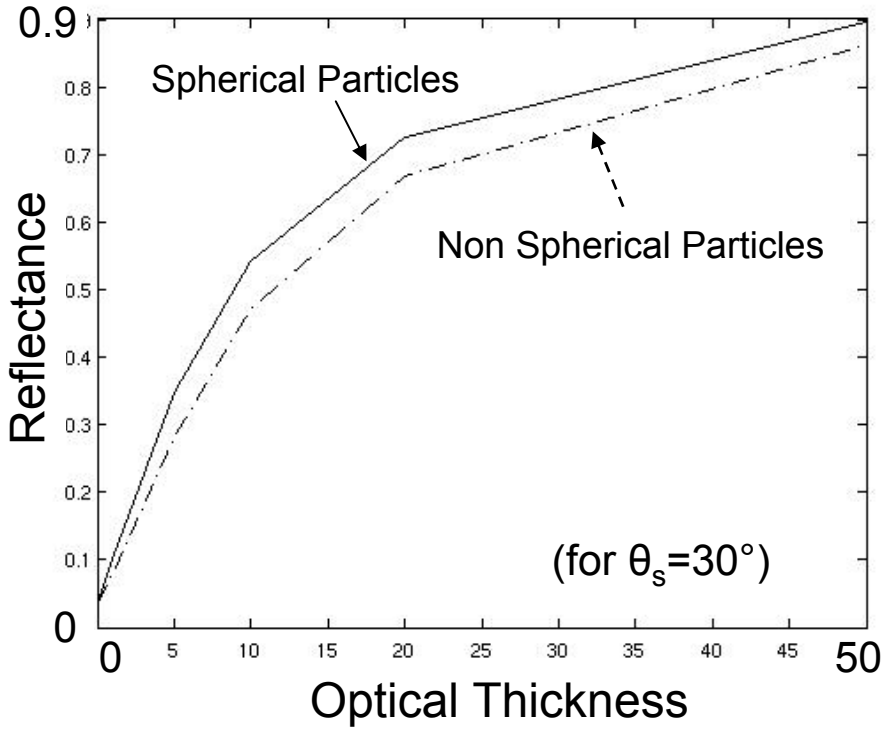
LMDZ New Physics:

-representation of boundary layer clouds in all regimes
-overestimation of mid level clouds in one single layer
-fewer high clouds

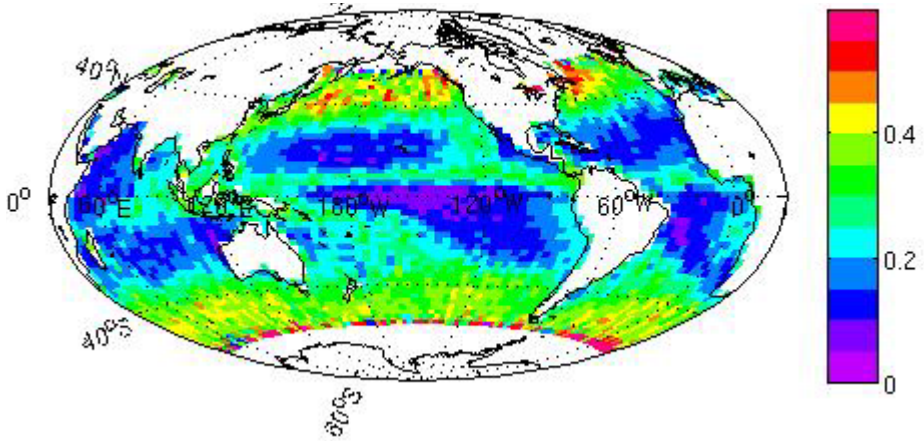
Clouds Optical depth (or Reflectance)

Radiometer PARASOL: directional reflectances, selection of one constant single direction (θ_v=30°, φ_s- φ_v=320°)

↳Reflectance is a proxy of optical thickness



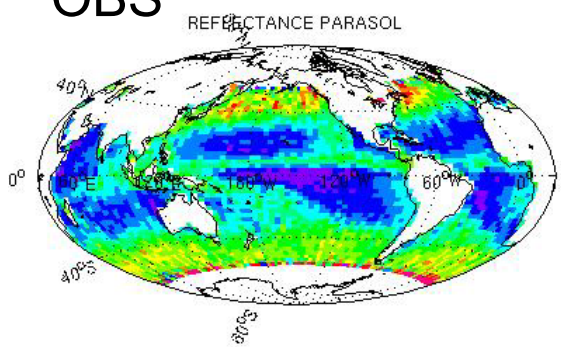
PARASOL
Reflectance 1constant direction



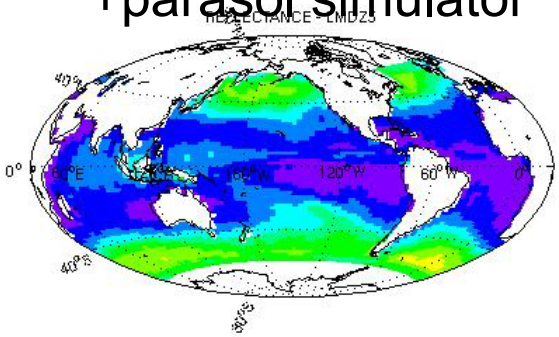
Cloud Cover and All Sky Reflectance – monthly mean

ALL SKY REFLECTANCE

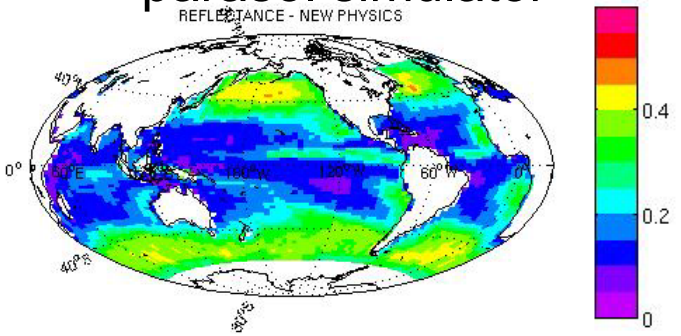
PARASOL 1con.dir. OBS



LMDZ5 +parasol simulator

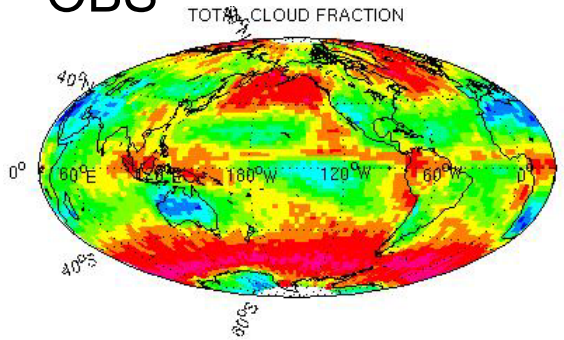


LMDZ New Physics +parasol simulator

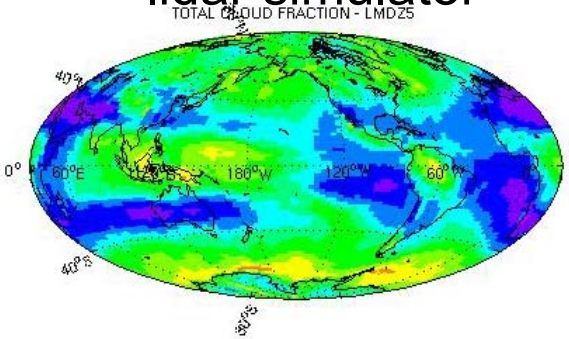


CLOUD FRACTION

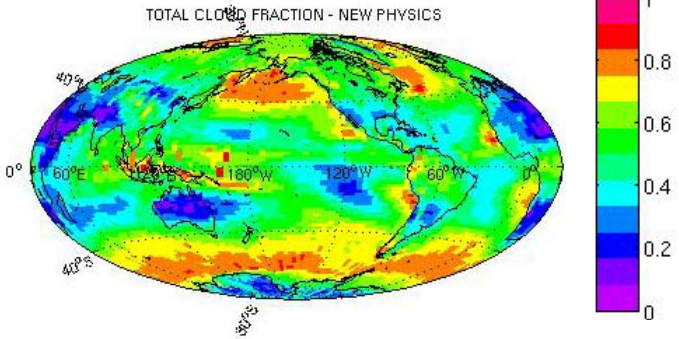
CALIPSO-GOCCP OBS



LMDZ5 +lidar simulator



LMDZ New Physics +lidar simulator



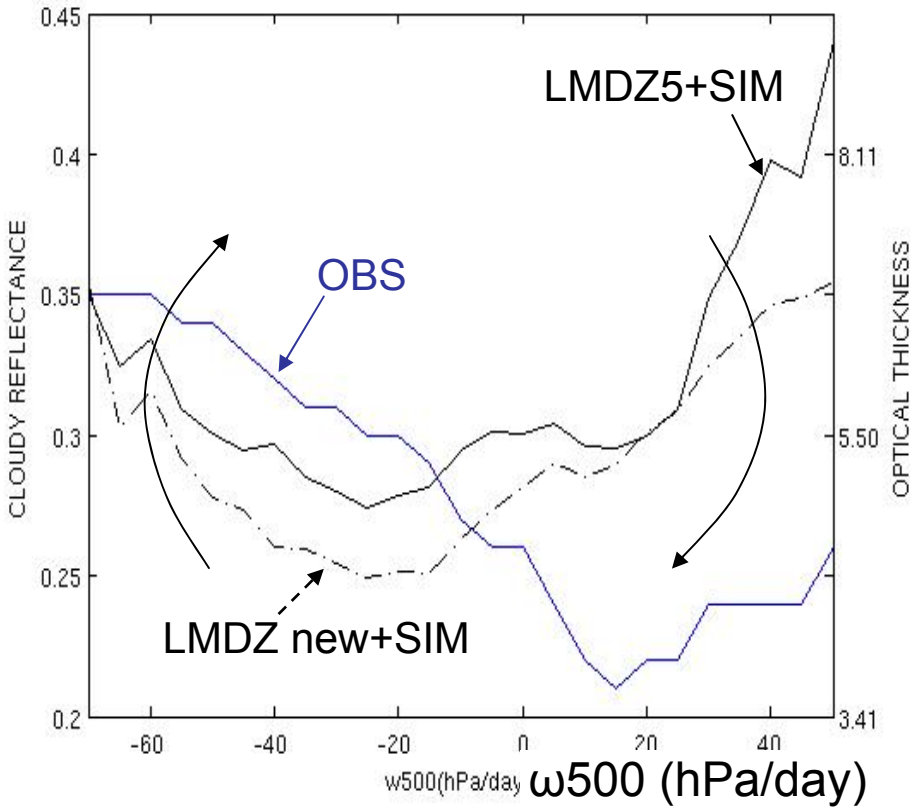
Error compensations between Total Cloud Cover and Optical depth (vertically integrated value within the lat x lon grid box)

→ Need to evaluate the cloud parameterizations in climate models

Cloud Cover and Cloud Optical Depth in circulation regimes - Monthly mean

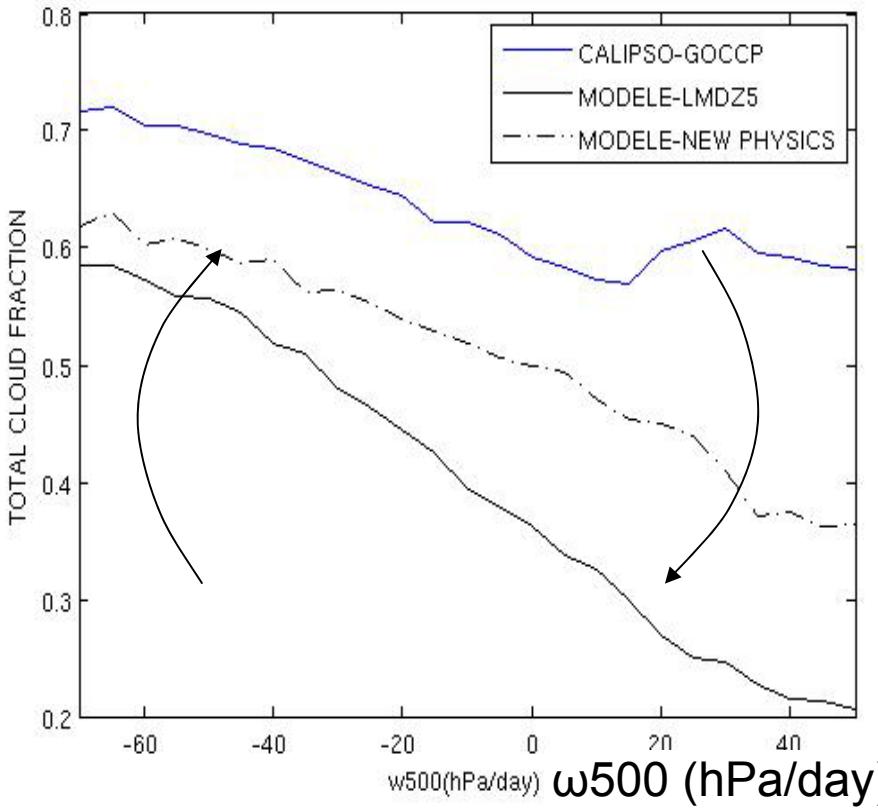
Tropical ocean

CLOUDY REFLECTANCE



ω500 (hPa/day)

CLOUD FRACTION



ω500 (hPa/day)

-Subsidence regimes:
strong underestimation of cloud fraction but strong overestimation of cloud optical depth (less from LMDZ New Physics)
-Convective regimes:
underestimation of cloud cover and cloud optical depth

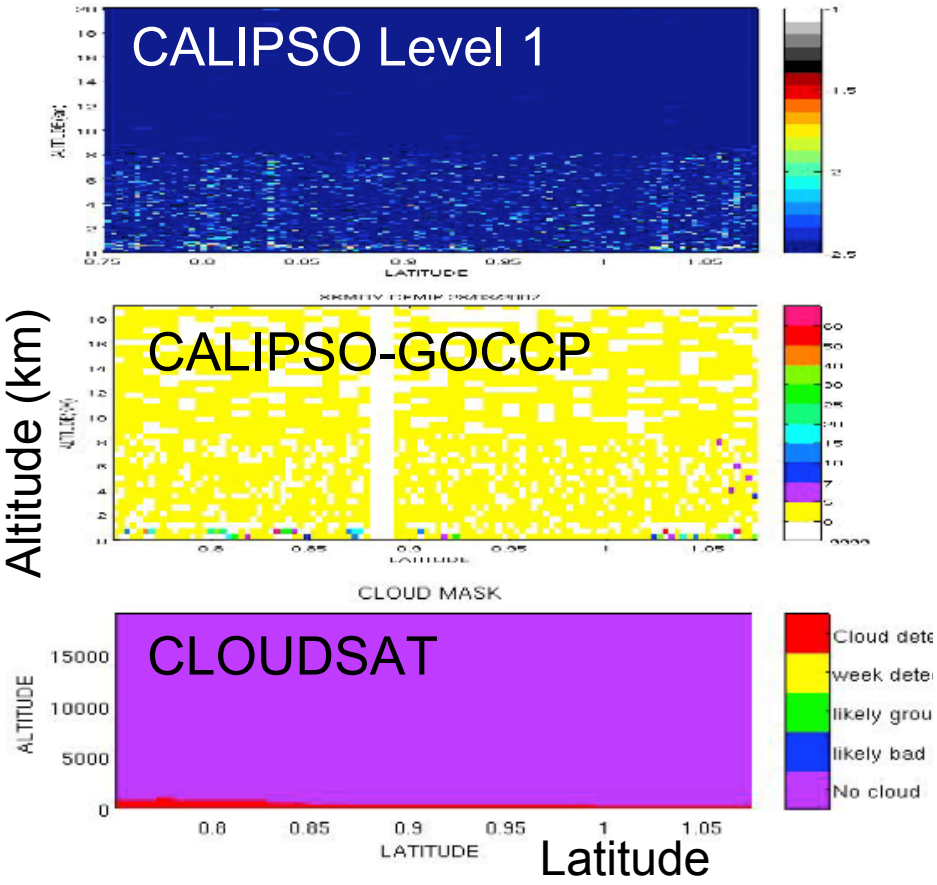
→ Need to evaluate the cloud parameterizations in climate models

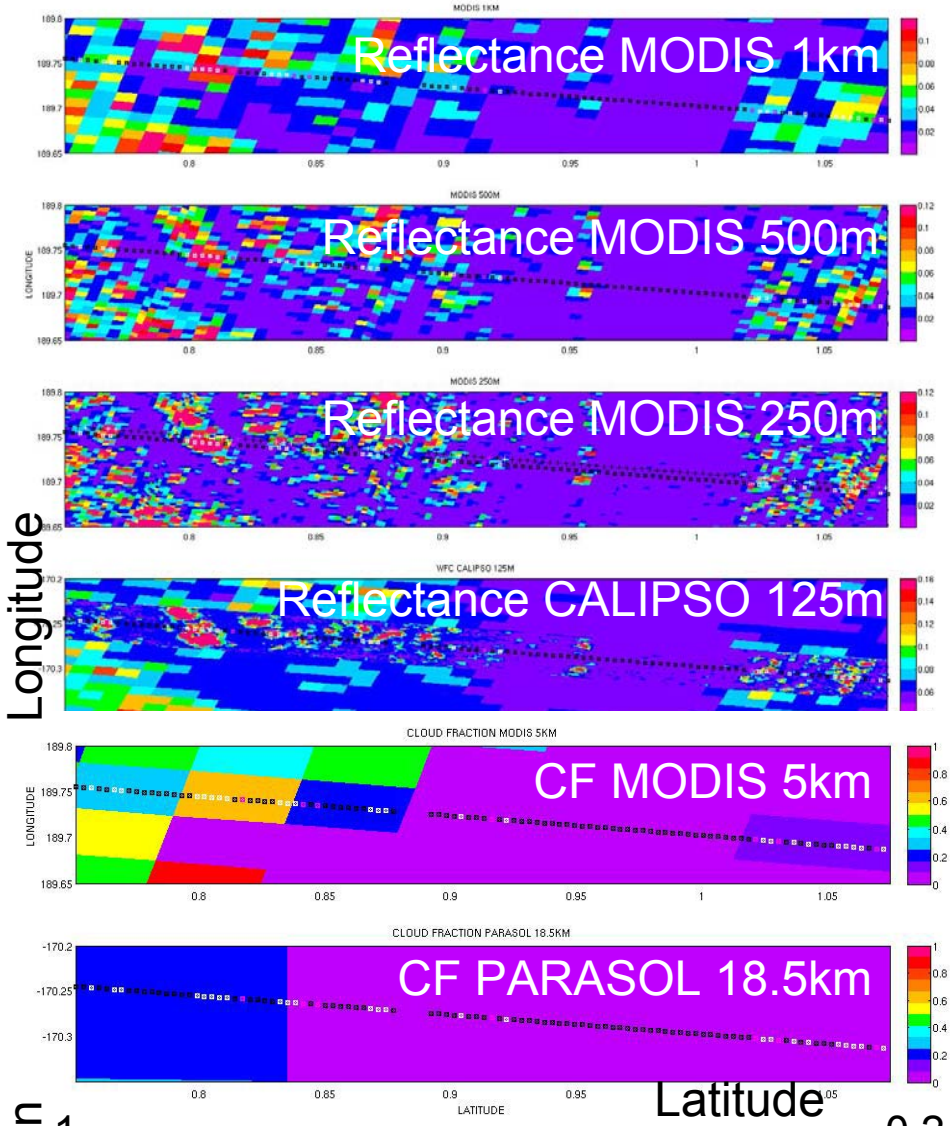
- To evaluate the cloud parameterizations in climate models:

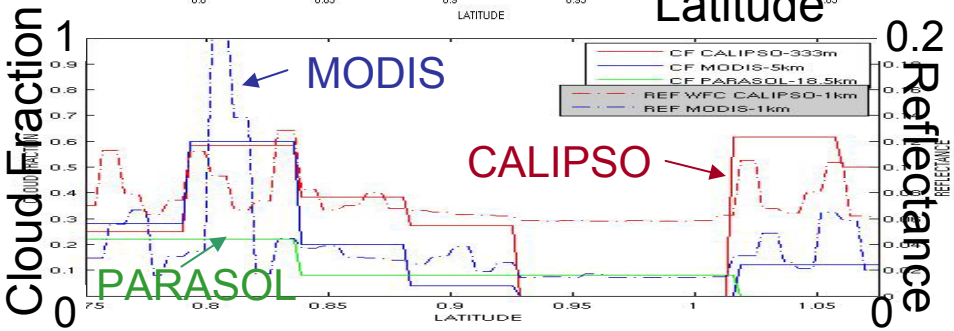
  Monthly mean observations are not sufficient

  We need to use high resolution (spatial and temporal) observations

A case study: low tropical boundary layer clouds - high resolution obs -

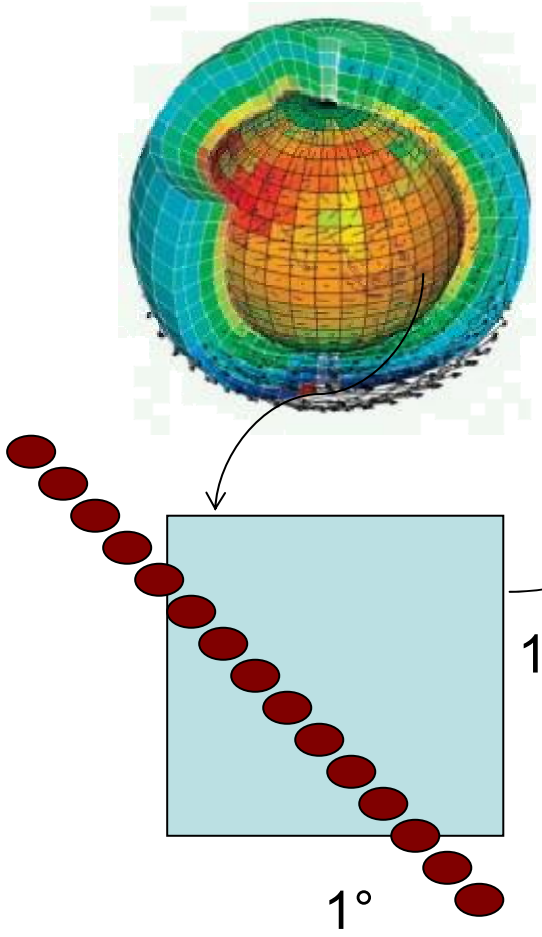






Impact of the spatial resolution of the sensors
Need a clean separation clear/cloudy
Need colocated and simultaneous observations

A methodology: from the case study to global statistics using high spatial resolution data



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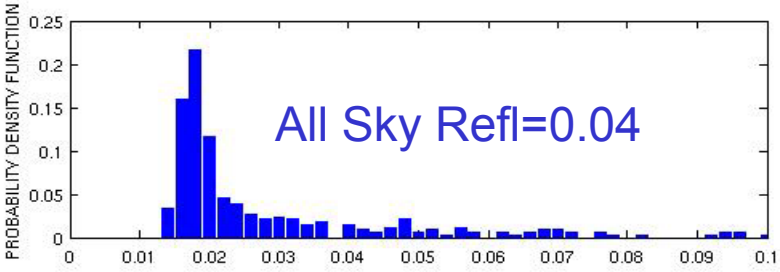
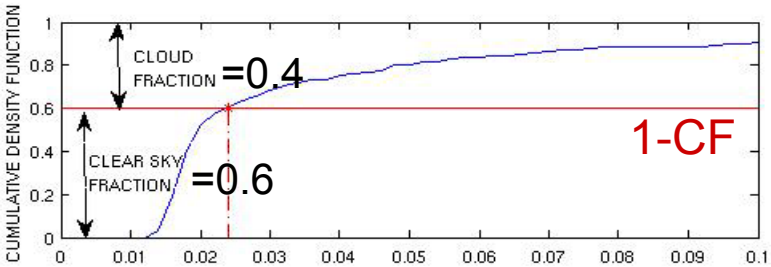
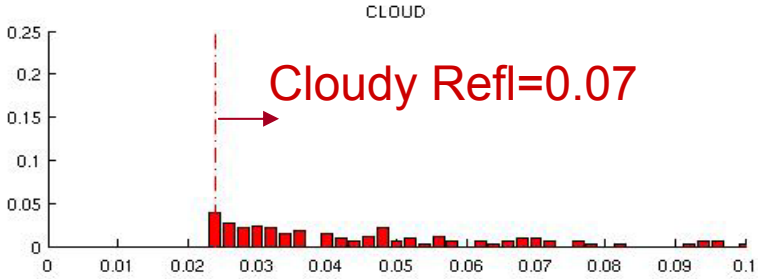
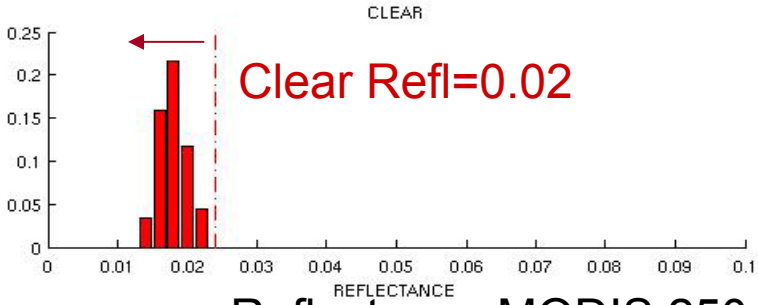


CDF







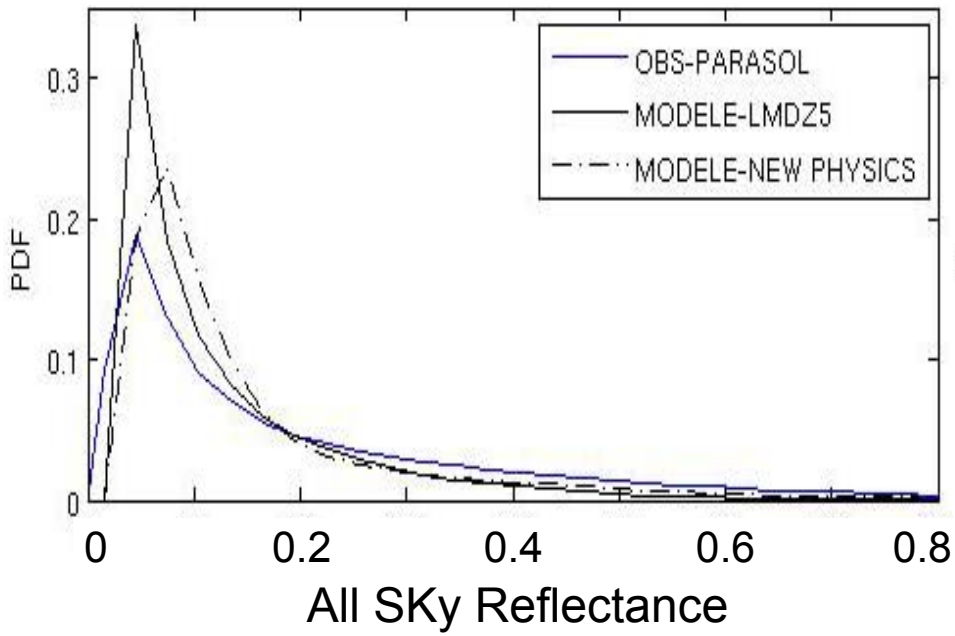
Reflectance MODIS 250m

Same methodology for simulator's outputs
⇒In each grid box (obs/mod):
Cloud Fraction and Cloudy Refl

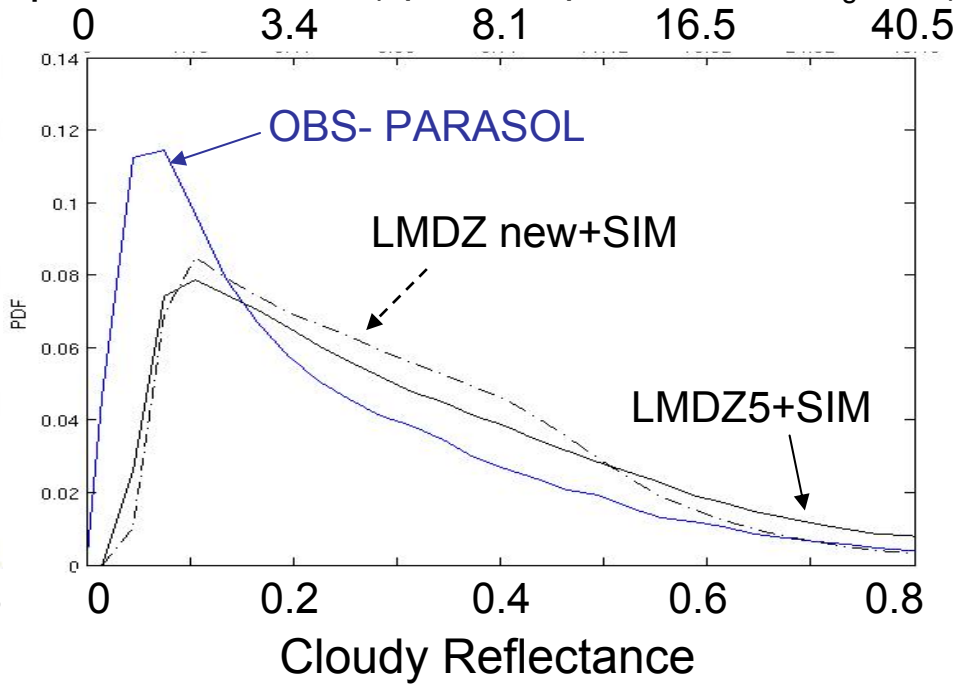
Cloud Optical Depth
Evaluation of the model at high resolution

Tropical ocean

PDF



Optical thickness (spherical particles and θ_s=30°)



→ Overestimation of low values of All-Sky Reflectance and underestimation of high values.

BUT for cloudy reflectance (no clear sky contribution):

→ More optically thick clouds and less optically thin clouds simulated.

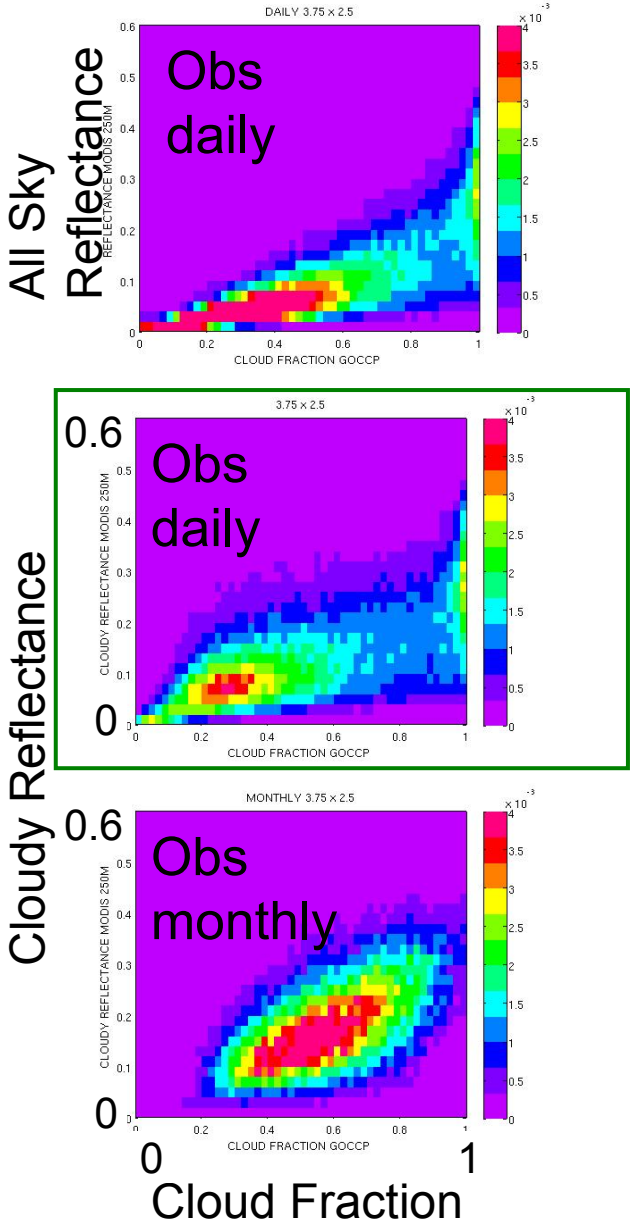
Corresponding CDF: 50% of the cloud:

Obs optical depth = 2.6

Models cloud optical depth = 4.8

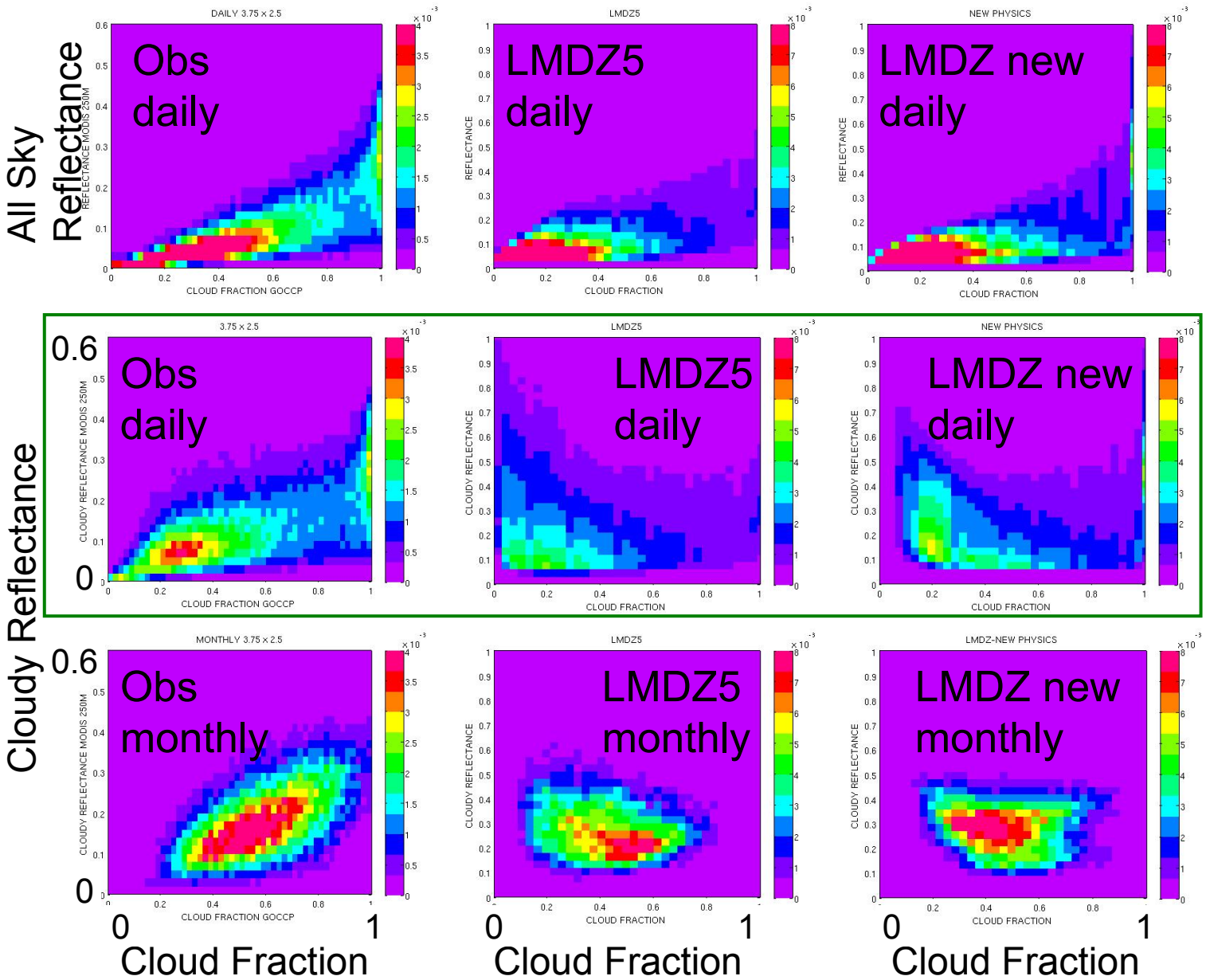
Relationship between Cloud Cover and Cloud Optical Depth

OBSERVATIONS Tropical ocean



→ The relation between optical depth and Cloud Fraction changes with the scale of averaging changes in time (monthly.vs. daily) and in space (all sky .vs. cloudy)

Relationship between Cloud Cover and Cloud Optical Depth



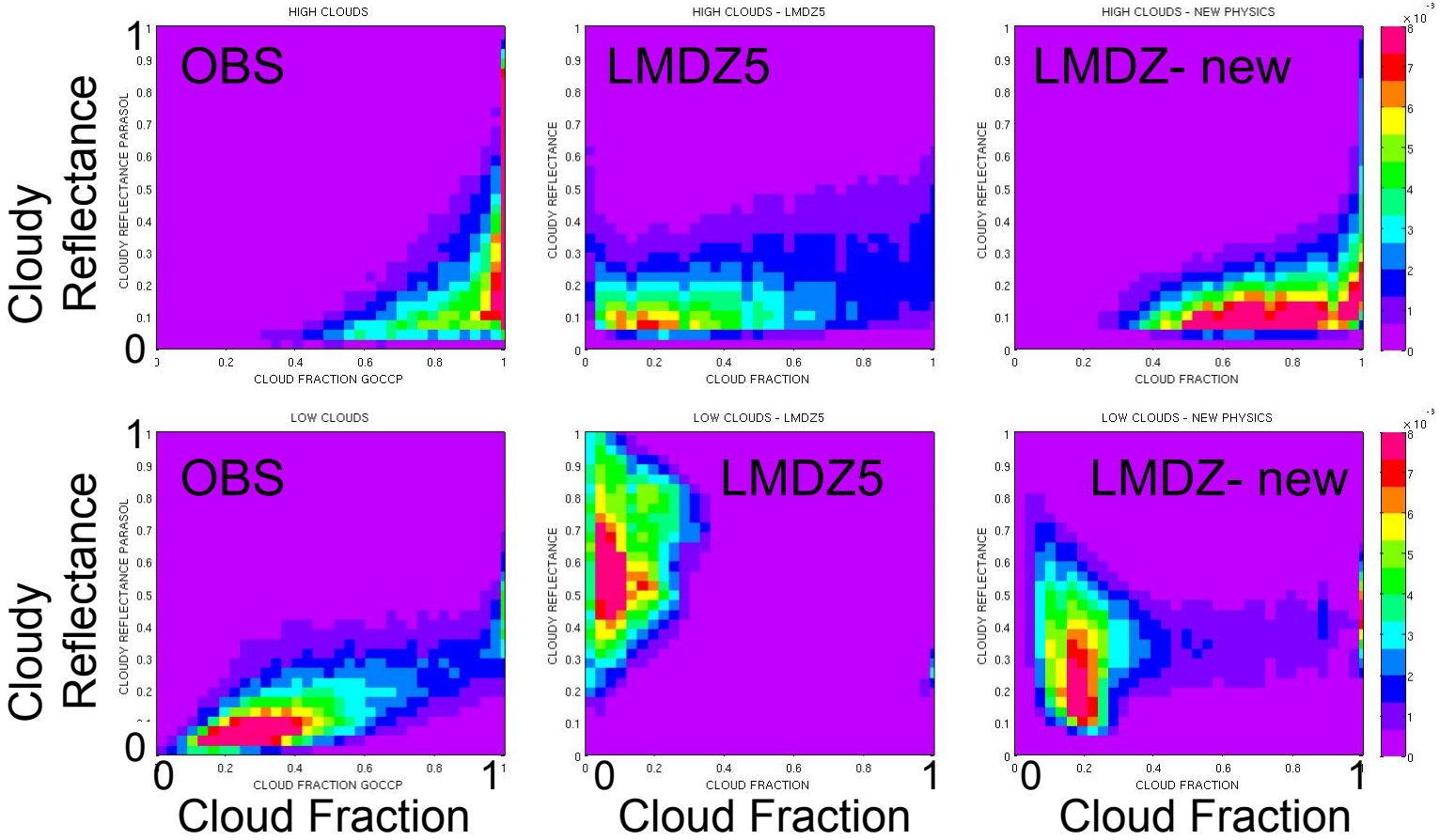
Tropical ocean

→ Model has difficulties to reproduce the 'instantaneous' relationship

=> Here after, we use « High Resolution » : Cloudy Refl, Daily

Relationship between Cloud Cover and Cloud Optical Depth for high and low tropical oceanic clouds

Tropical ocean

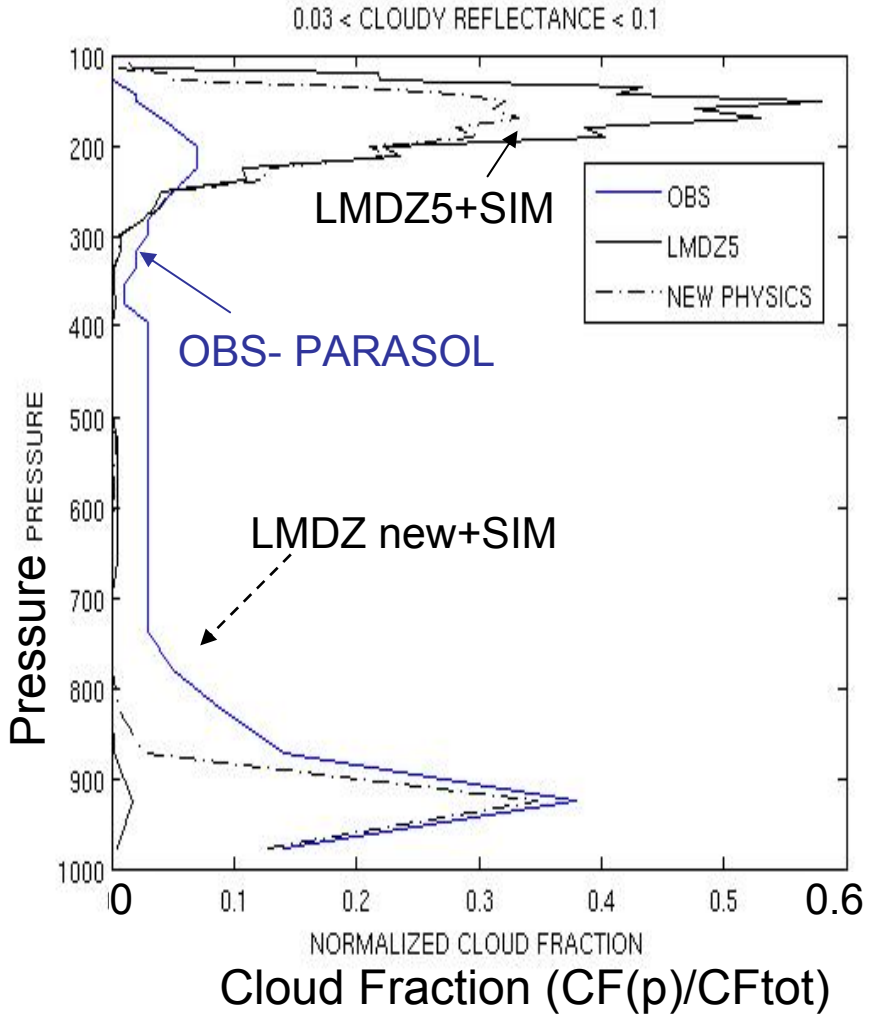


- Error compensation between optically thin high clouds and very thick boundary layer clouds
- Underestimation of the Cloud Fraction

Cloud Cover versus Vertical distribution versus Cloud Reflectance

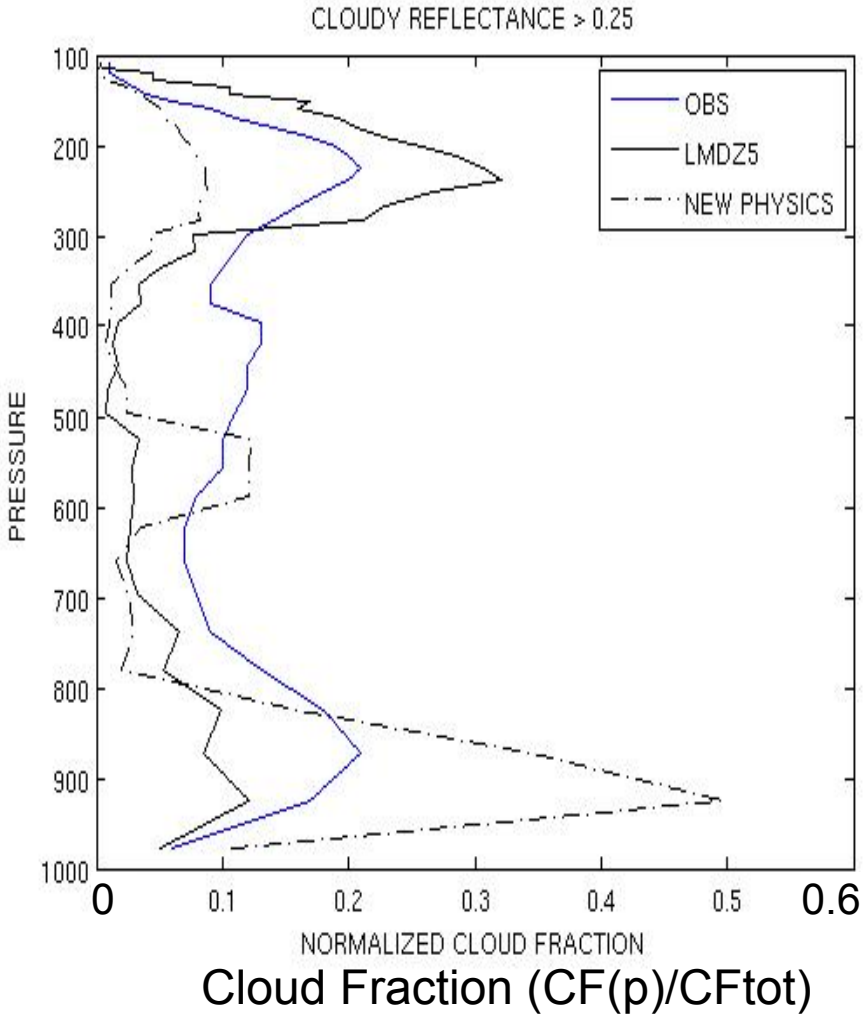
Tropical ocean

OPTICALLY THIN CLOUDS



Cloud Fraction (CF(p)/CFtot)

OPTICALLY THICK CLOUDS



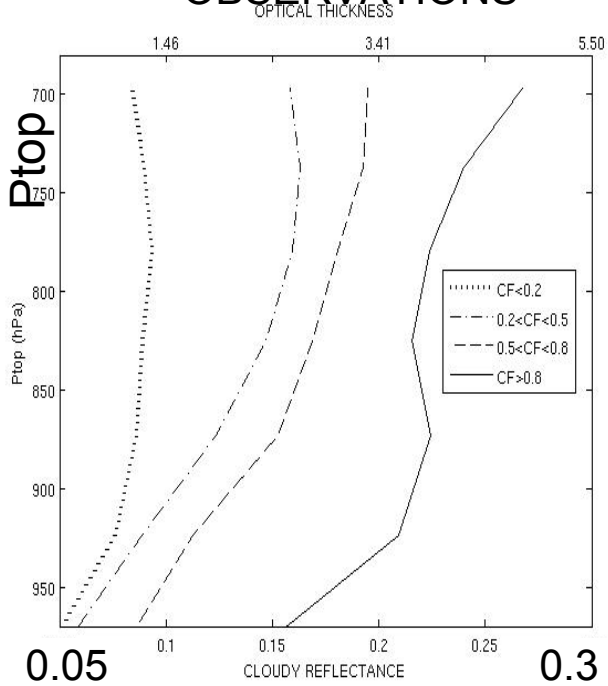
Cloud Fraction (CF(p)/CFtot)

Focus on low level boundary layer clouds:

Relationship between the Cloud Top Pressure and the Cloudy Reflectance

Tropical ocean

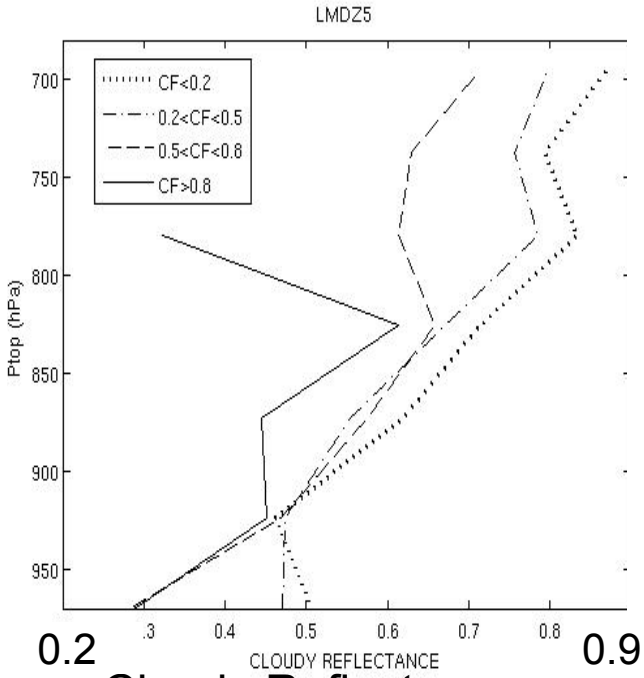
OBSERVATIONS



Cloudy Reflectance

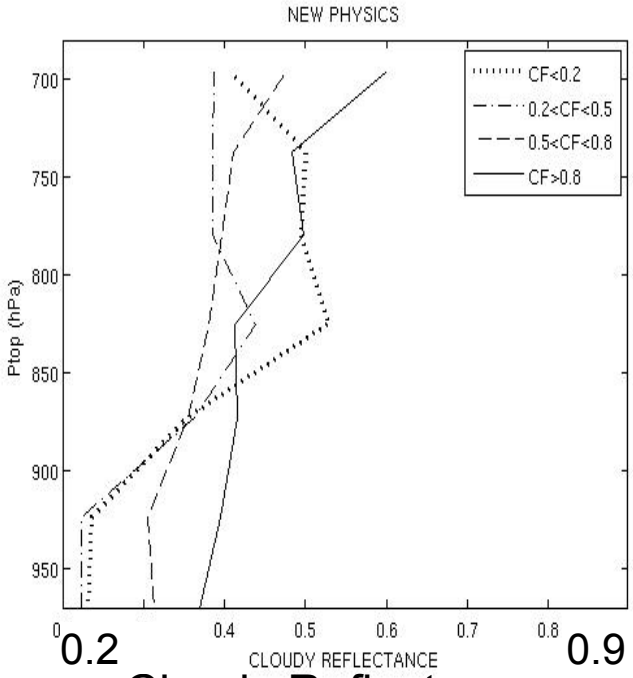
Or Optical depth

LMDZ5+SIM



Cloudy Reflectance

LMDZ new+SIM



Cloudy Reflectance

- OBS: The cloud optical depth increases with the cloud top altitude (and with the cloud cover) → the cloud grows vertically (and horizontally)

- Difficulties of the model to reproduce the relationship

Conclusions

A statistical view of clouds with A-train observations:

- simultaneous and independent observations of multiple cloud parameters at **high resolution**→ assess cloud process parameterization in climate models
- the spatial resolution of different sensors and the temporal resolution of the statistical analysis are critical
- study of cloud properties **only** (excluding 'Clear sky' contribution)
- link between Cloud Cover, Vertical Structure and Cloud Optical Depth
- low clouds: cloudy reflectance increase with the cloud top altitude

LMDZ model evaluation:

- Error's compensations between
  - underestimation of low tropical clouds/ few medium clouds and overestimation of high clouds
  - underestimation of the total Cloud Cover and overestimation of the Cloud Optical Depth (mainly in regions of subsidence)
  - Optically thinner high clouds and optically thicker boundary layer clouds
- Better representation of clouds from LMDZ New Physics

Perspectives:

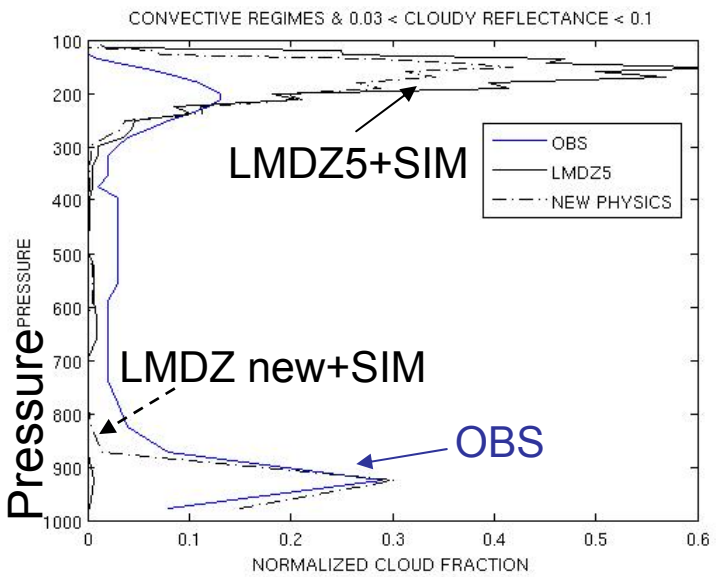
- Similar analysis based on "high resolution" A-train observations to evaluate other climate models
- Analysis of the subgrid variability (observations and models)

Thank you!

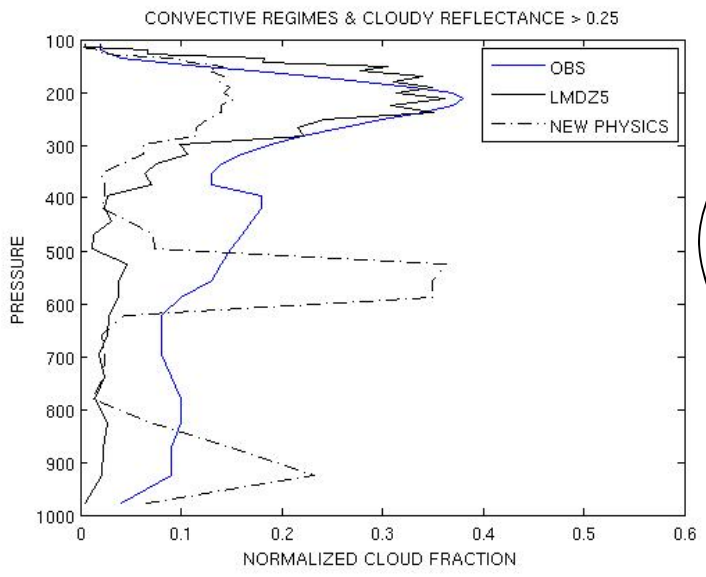
Cloud Cover - Cloud Vertical Distribution – Cloud Optical Depth in circulation regimes

Tropical ocean

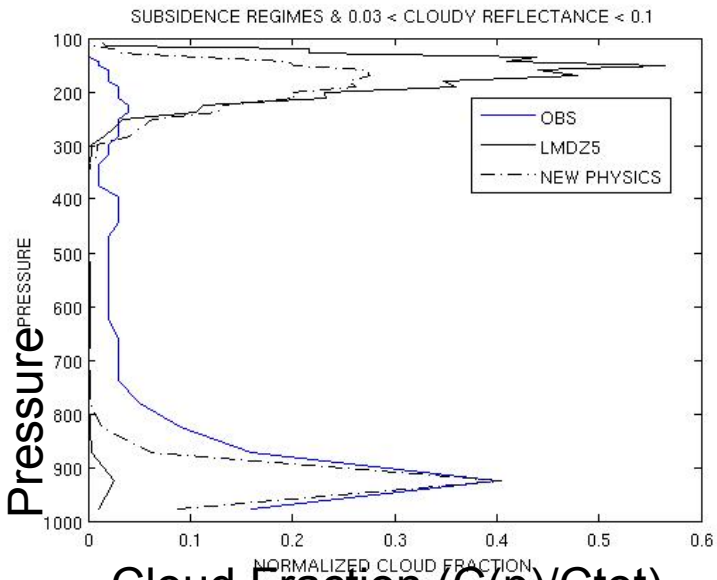
OPTICALLY THIN CLOUDS



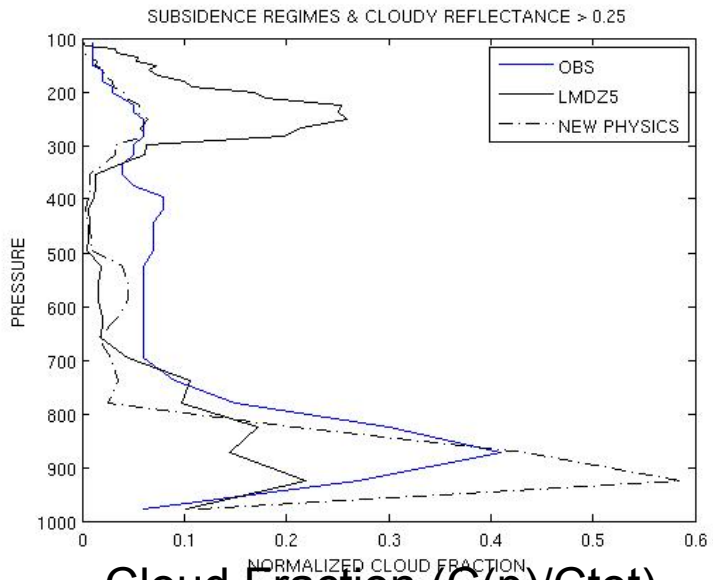
OPTICALLY THICK CLOUDS



CONVECTIVE REGIONS



Cloud Fraction (C(p)/Ctot)



Cloud Fraction (C(p)/Ctot)

REGIONS OF SUBSIDENCE