Evaluation of NCEP GFS clouds using A-train and ARM observations

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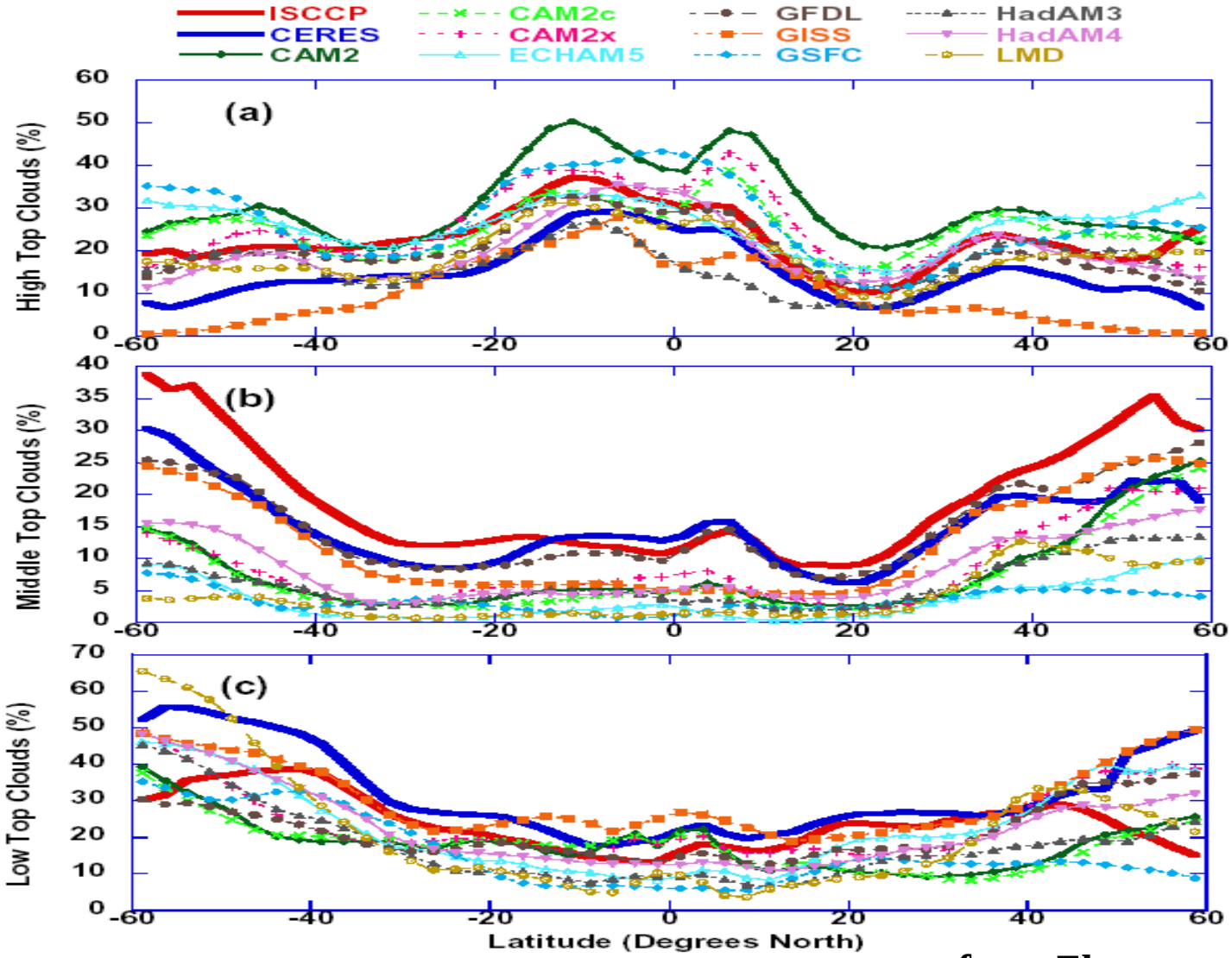
Introduction

- Problems in representation of clouds



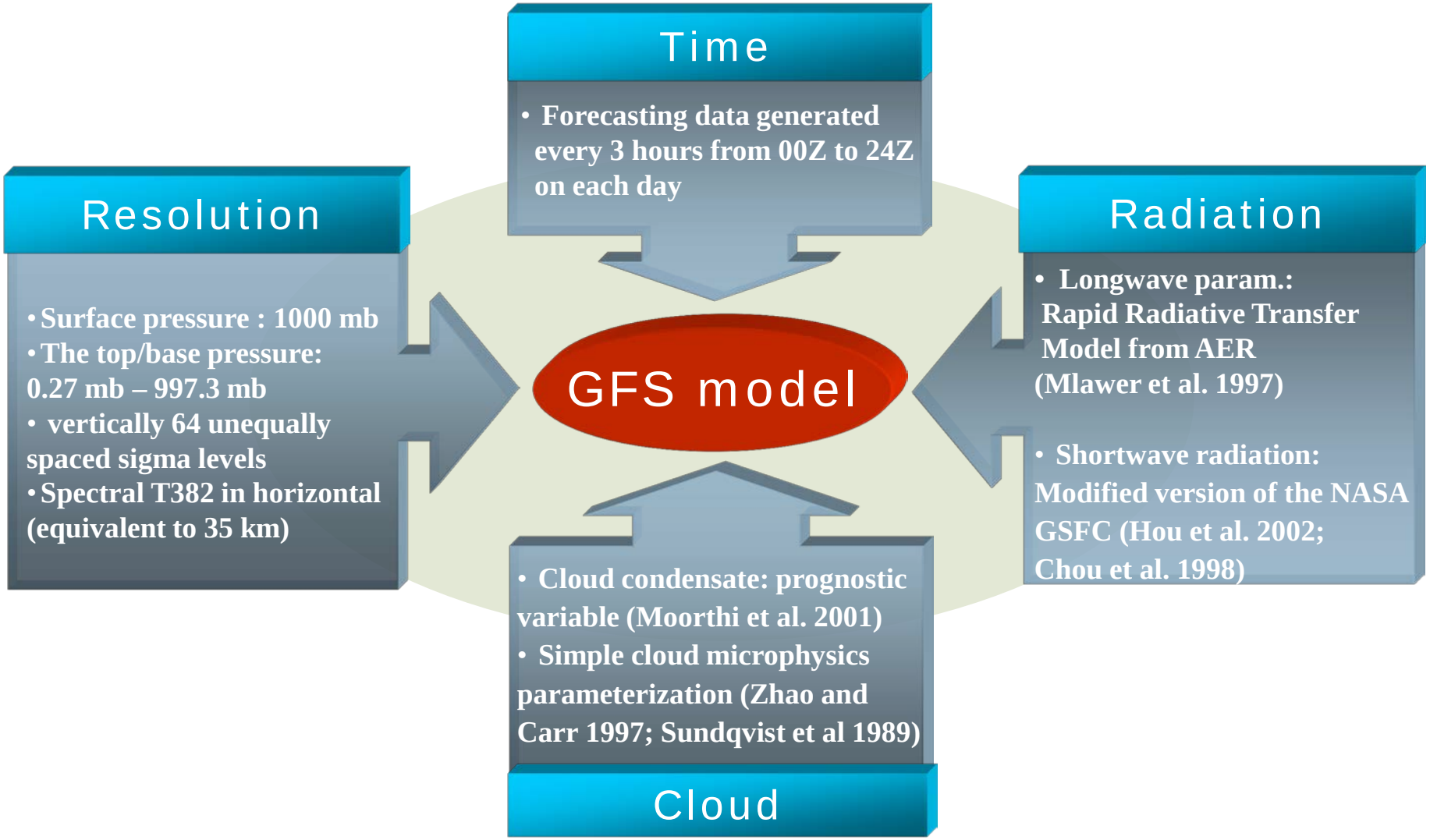
from Zhang et al. 2005

Overview of the talk

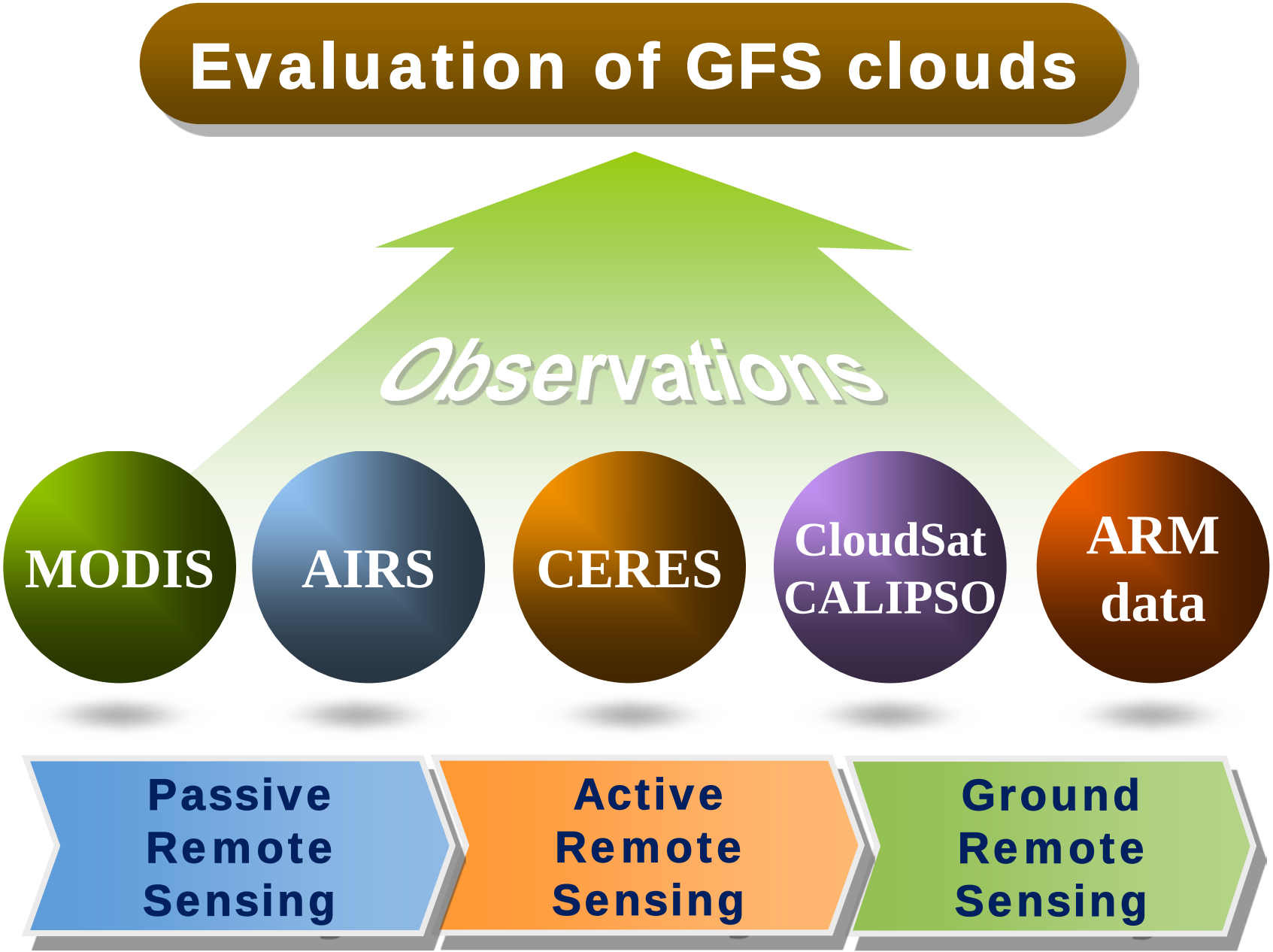
1	**Diagnosis**	● Diagnosis of the state of GFS model parameterization of cloud variables such as cloud fraction, cloud optical depth, liquid & ice water path
2	**Analysis**	● Assessment of atmospheric meteorological variables (e.g. RH, T) leading to cloud formation in the GFS model against observational data
3	**Application**	● Testing of Cloud fraction Scheme & Cloud Overlap Scheme ● Findings of aerosol climate effects and implications for weather & climate modeling

Data & approach

- GFS model: Global Forecast System model run by NOAA



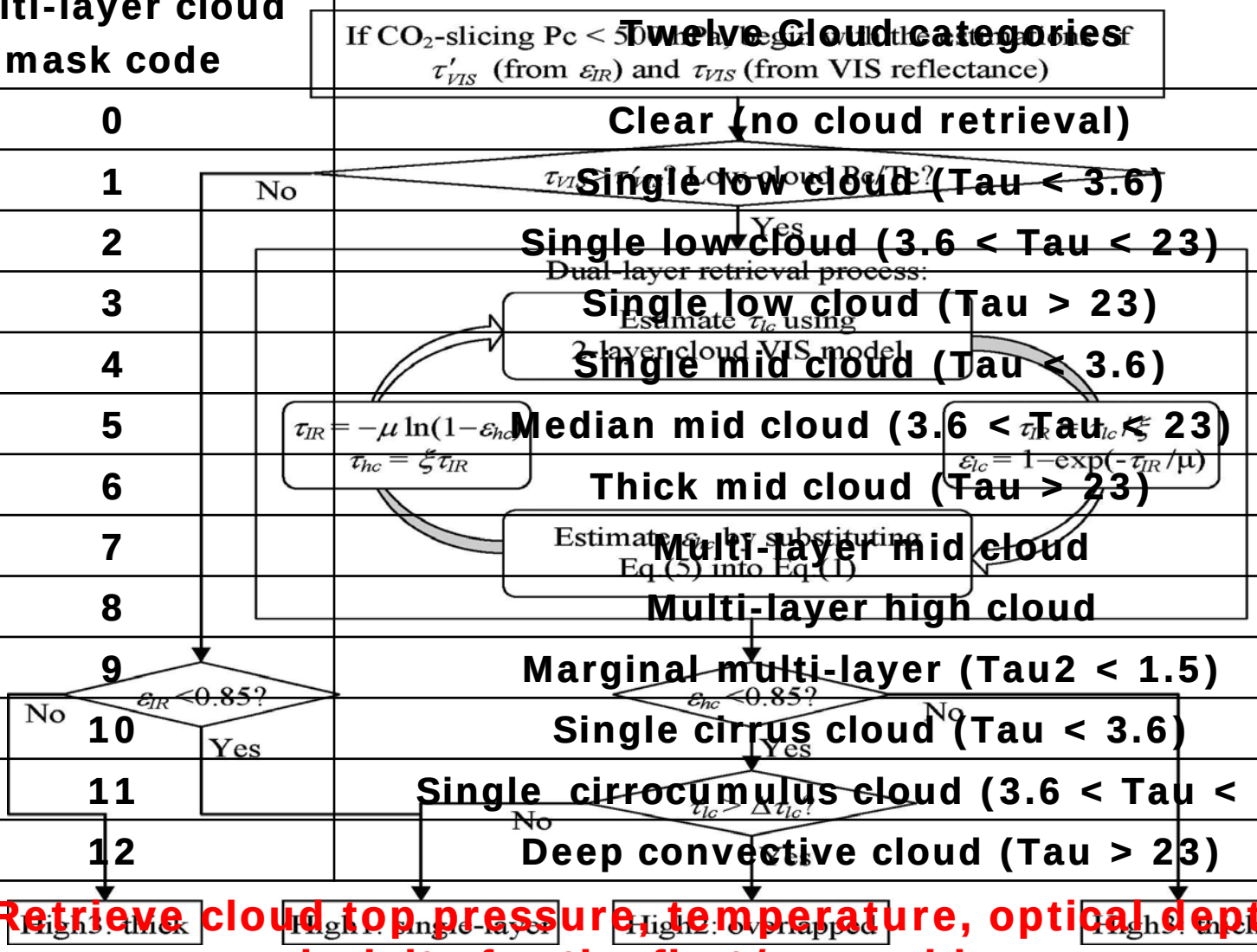
Data & approach



Satellite-retrieval algorithm

Chang-Li algorithm (JAS & JCL, 2005)

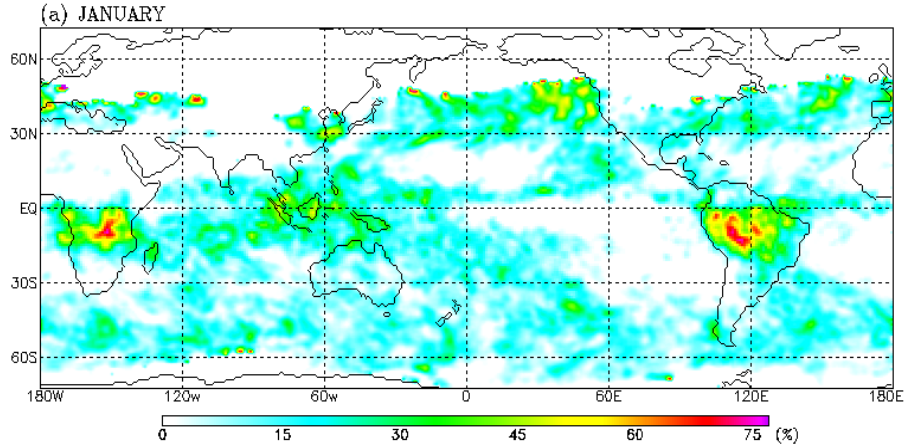
Multi-layer cloud mask code	Twelve Cloud categories
0	Clear (no cloud retrieval)
1	Single low cloud (Tau < 3.6)
2	Single low cloud (3.6 < Tau < 23)
3	Single low cloud (Tau > 23)
4	Single mid cloud (Tau < 3.6)
5	Median mid cloud (3.6 < Tau < 23)
6	Thick mid cloud (Tau > 23)
7	Multi-layer mid cloud
8	Multi-layer high cloud
9	Marginal multi-layer (Tau2 < 1.5)
10	Single cirrus cloud (Tau < 3.6)
11	Single cirrocumulus cloud (3.6 < Tau < 23)
12	Deep convective cloud (Tau > 23)



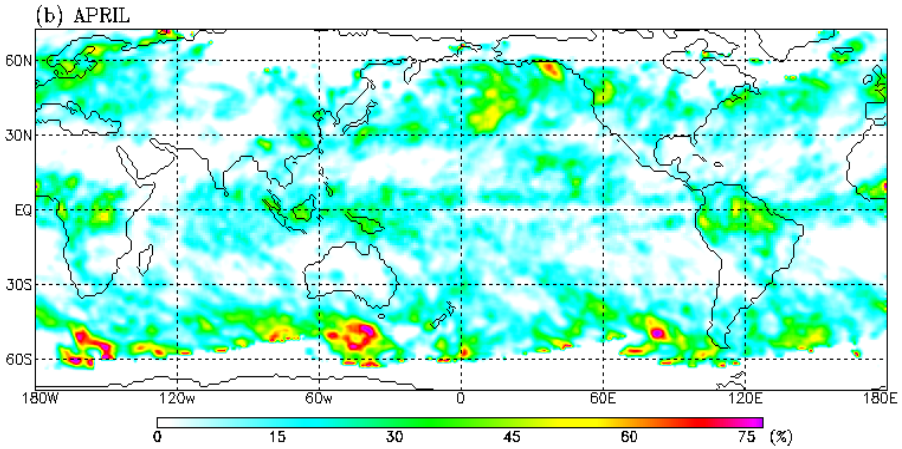
Retrieve cloud top pressure, temperature, optical depth, emissivity for the first/second layer

Cirrus-Overlapping-Low Cloud Amount (High/Low)

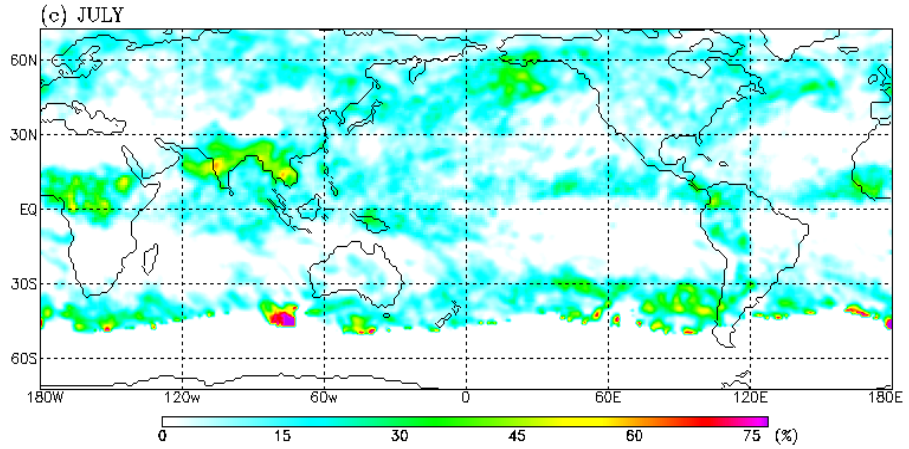
January 2001



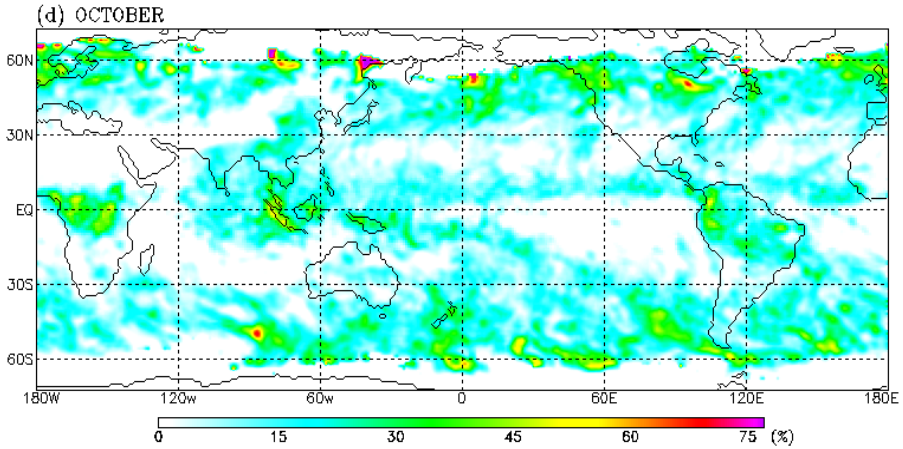
April 2001



July 2001



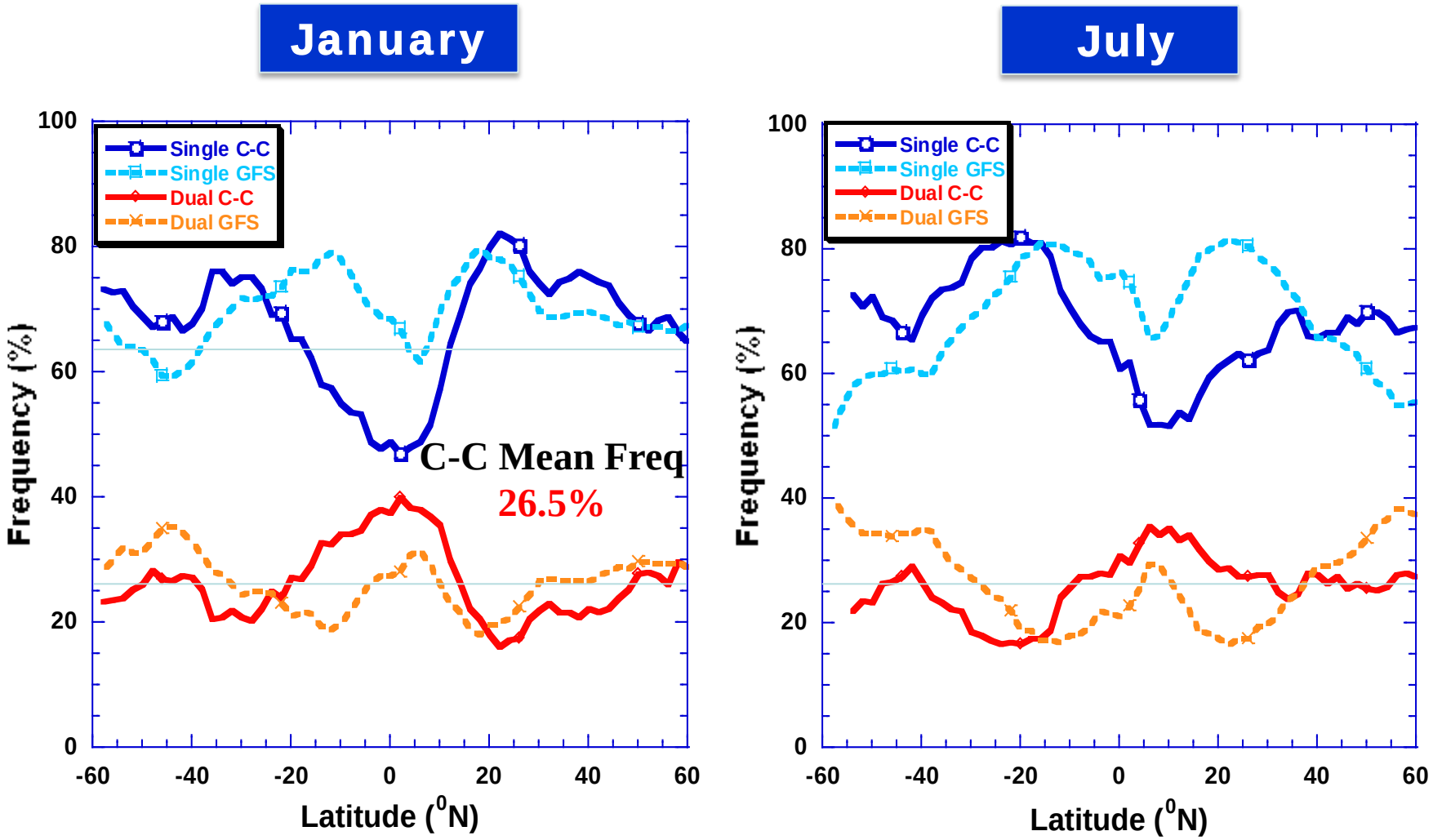
October 2001



Annual mean: 27%

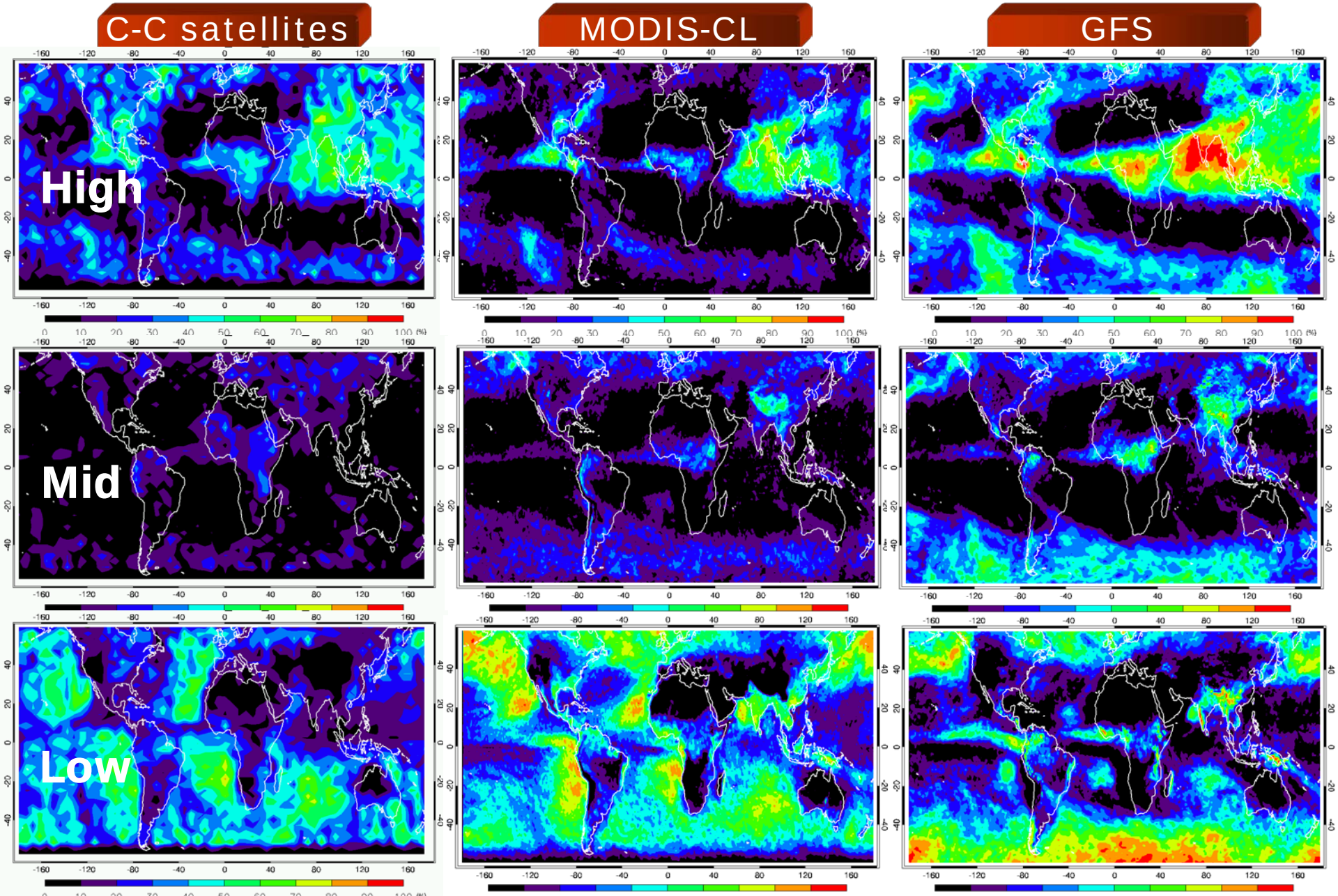
Chang and Li (2005, JCL)

Overlap cloud occurrence

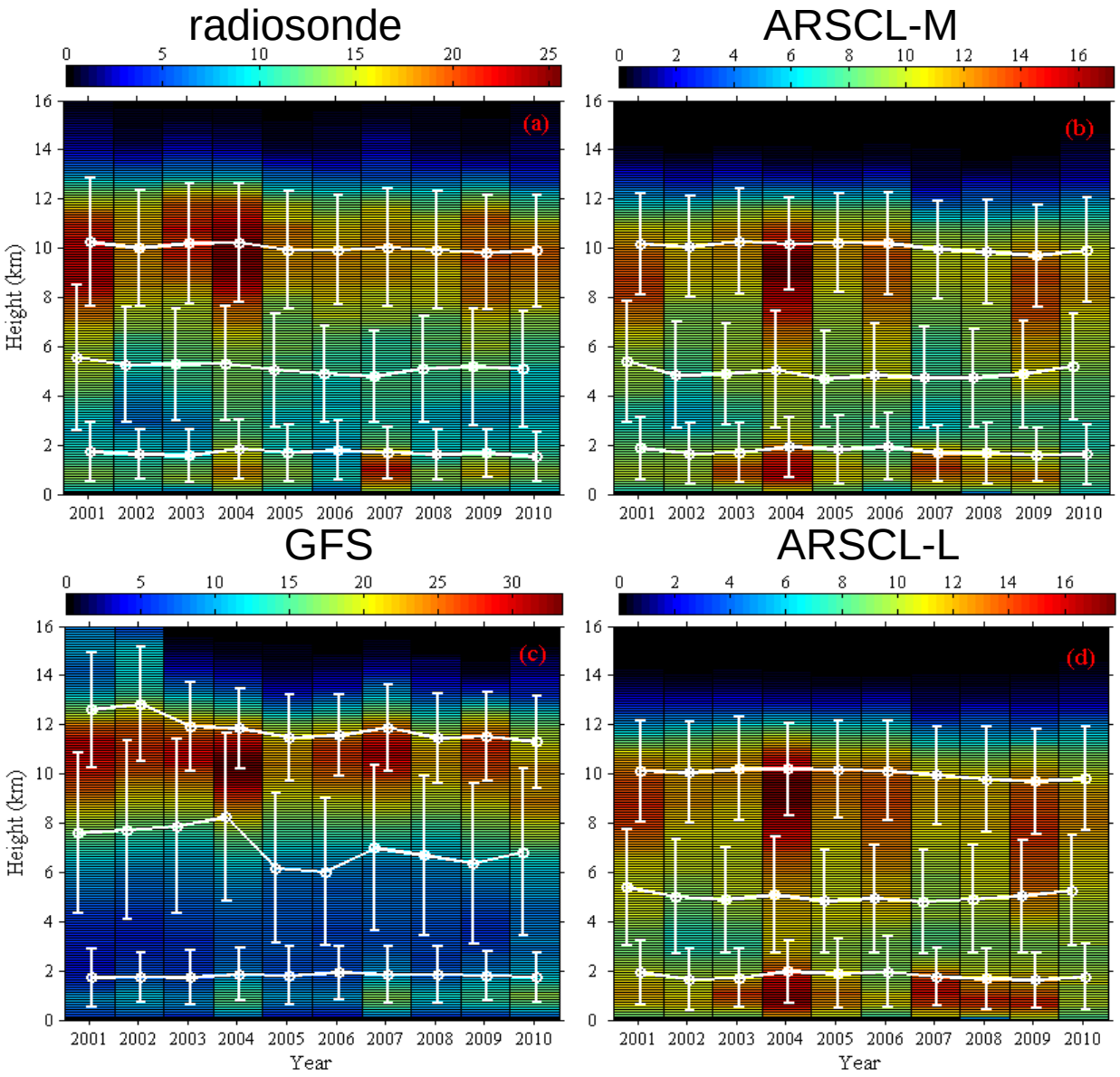


Latitudinal variations of the frequencies of cloud occurrence from the C-C satellites and the GFS model for single and dual-layer clouds in January (left) and July (right) of 2007.

Comparison Cloud Fraction - July

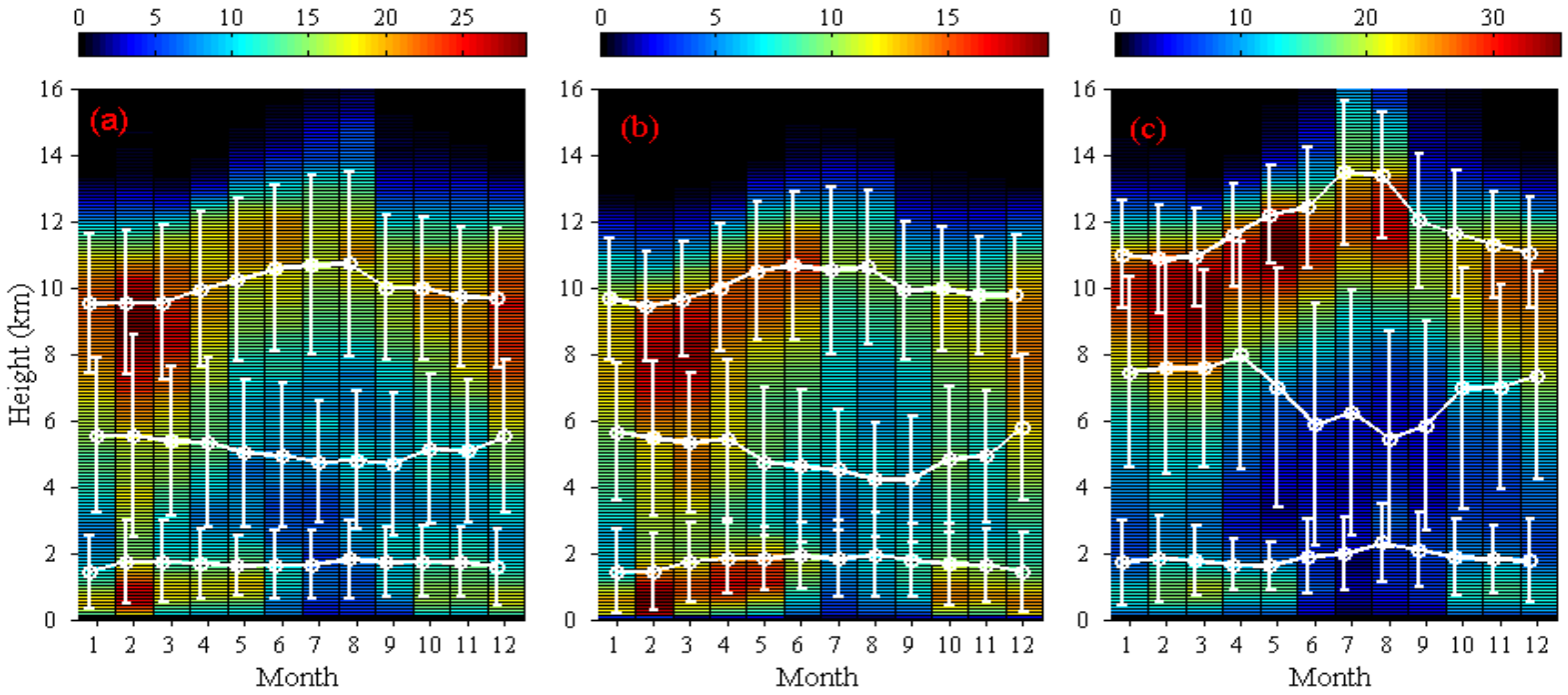


Comparison of clouds from radiosonde, radar and GFS



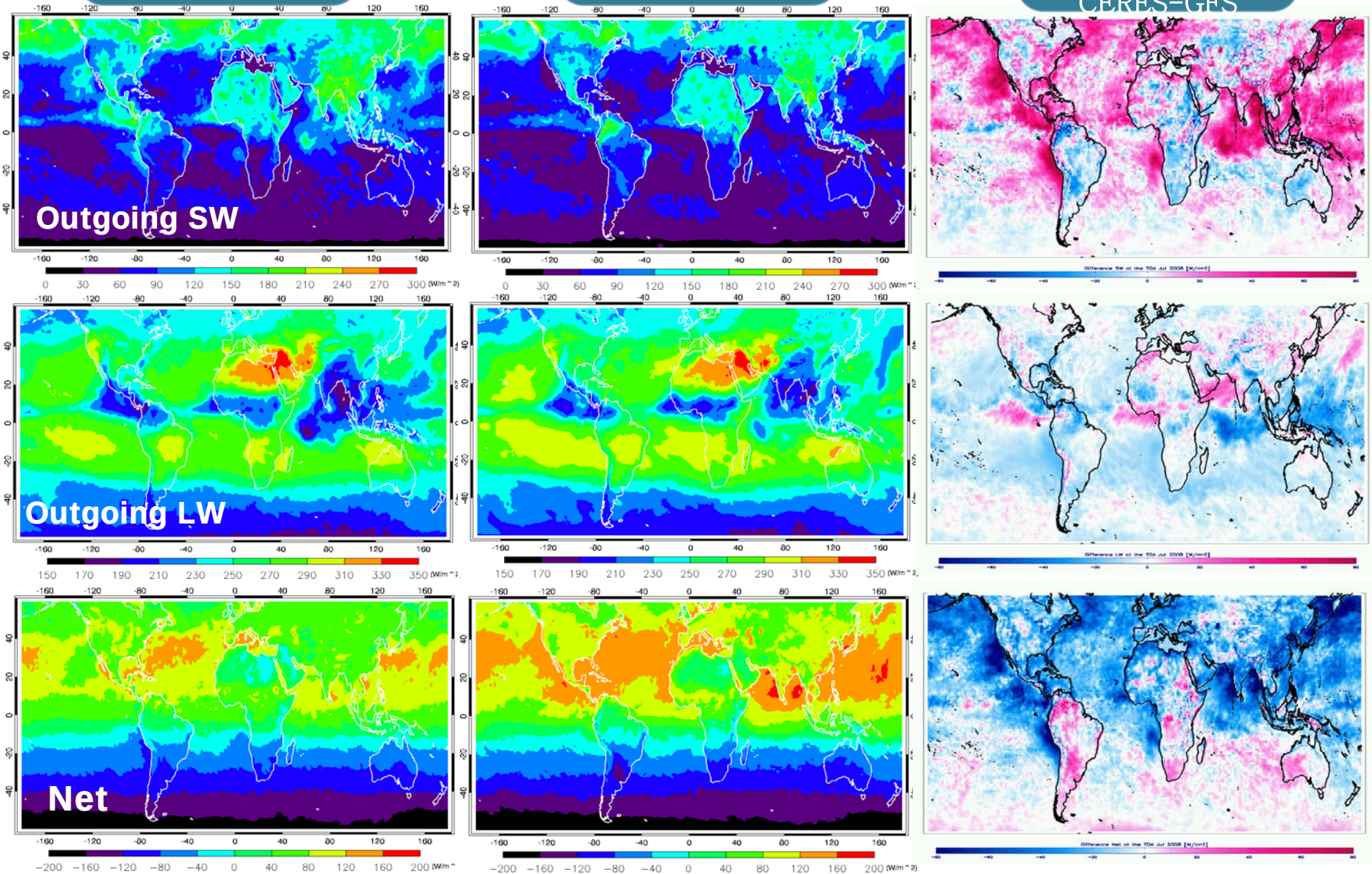
Seasonal Variations of Clouds from Radiosonde, Radar and GFS

Radiosonde | Ground Radar | GFS Model



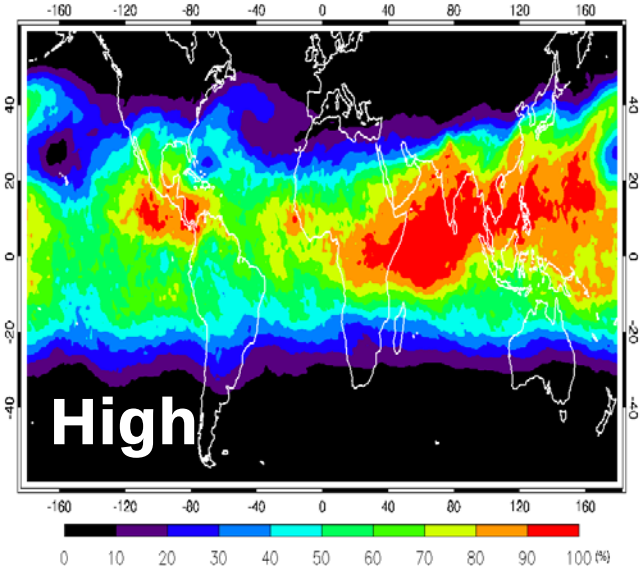
Comparison of radiation at the TOA

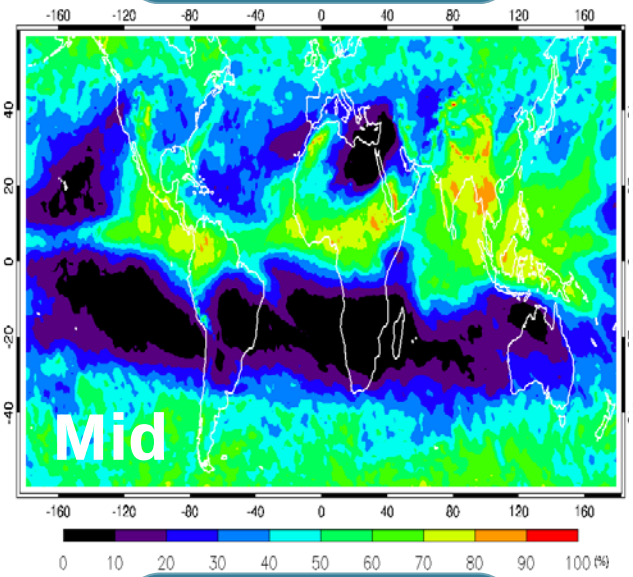
CERES | GFS | Difference CERES–GFS

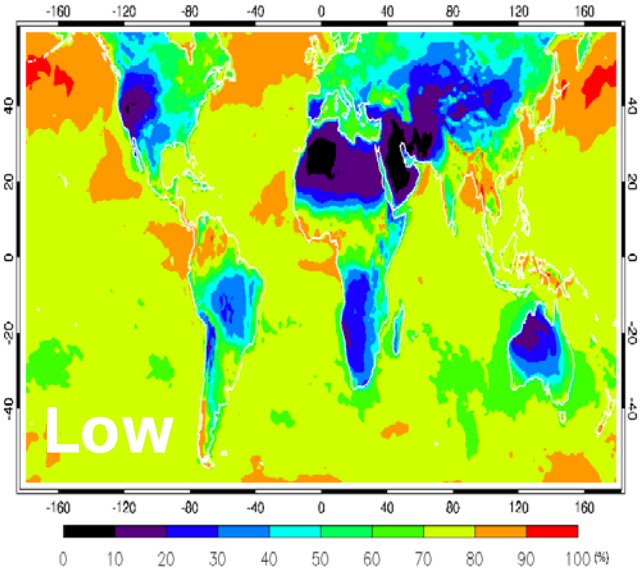


Comparison of RH Fields

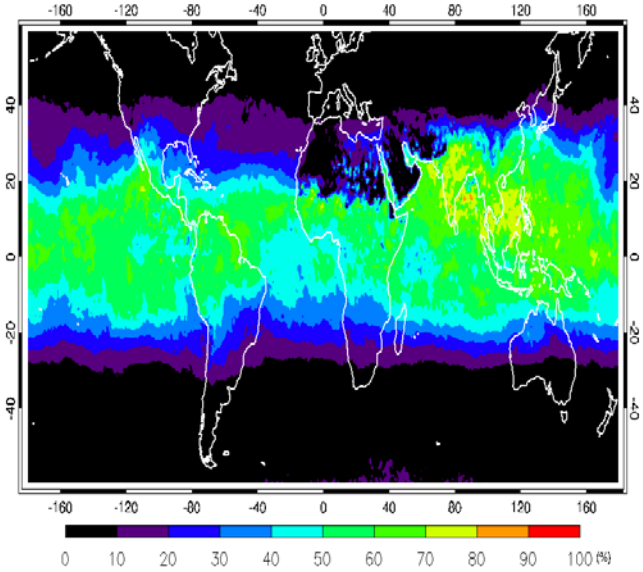
GFS

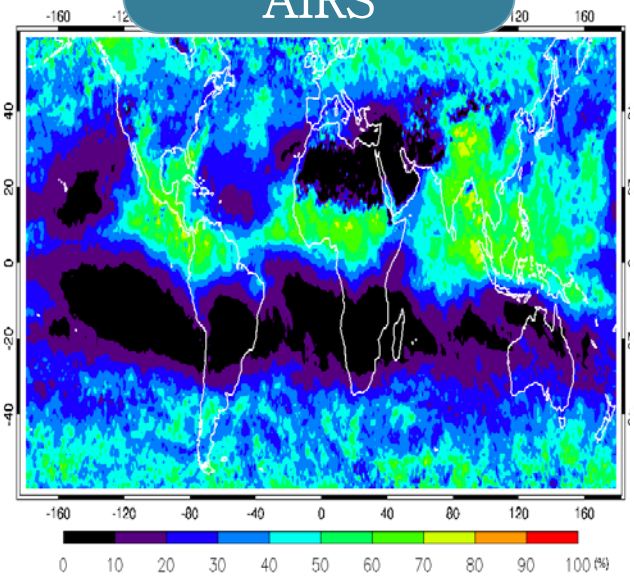


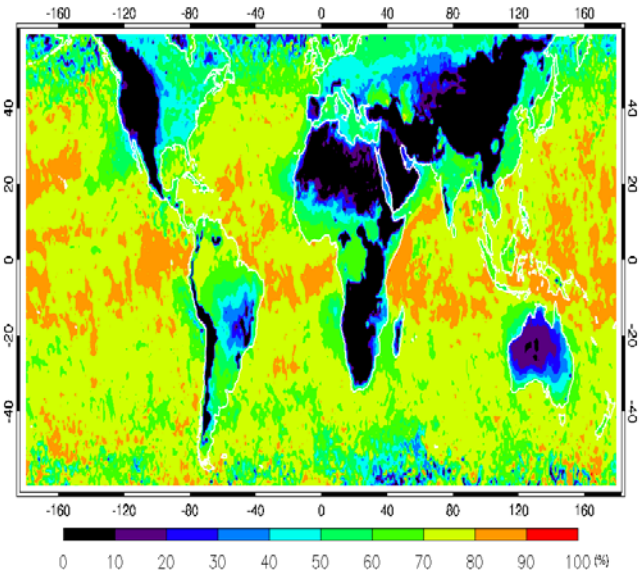




AIRS

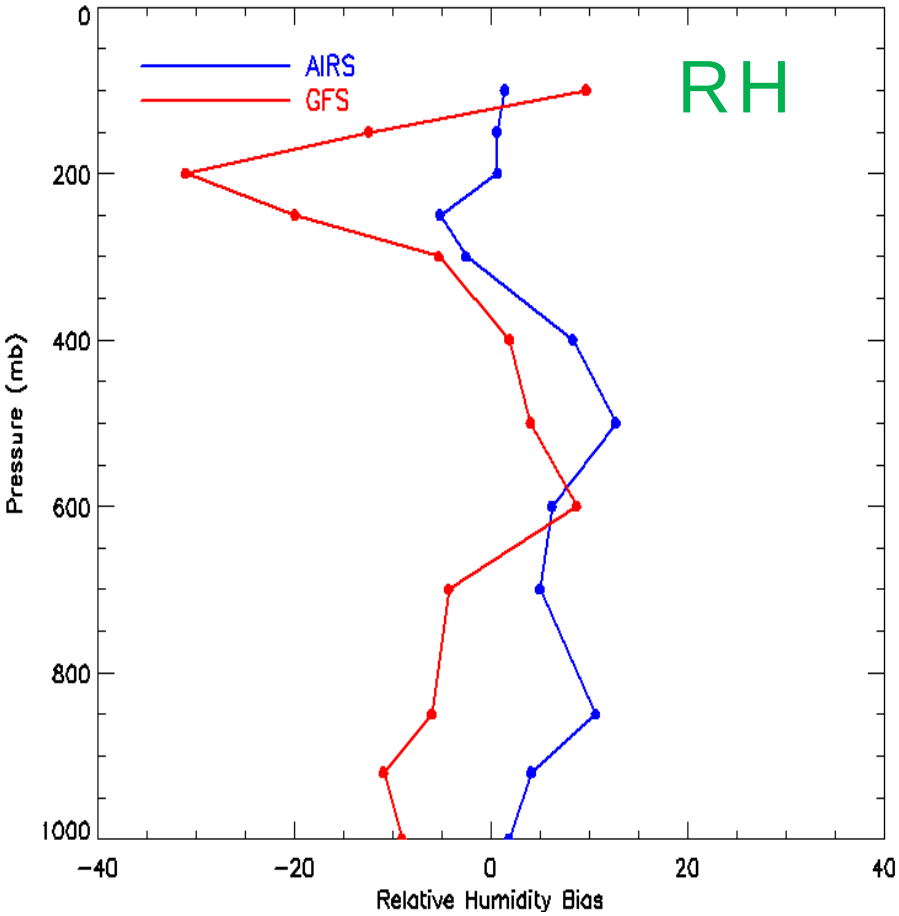


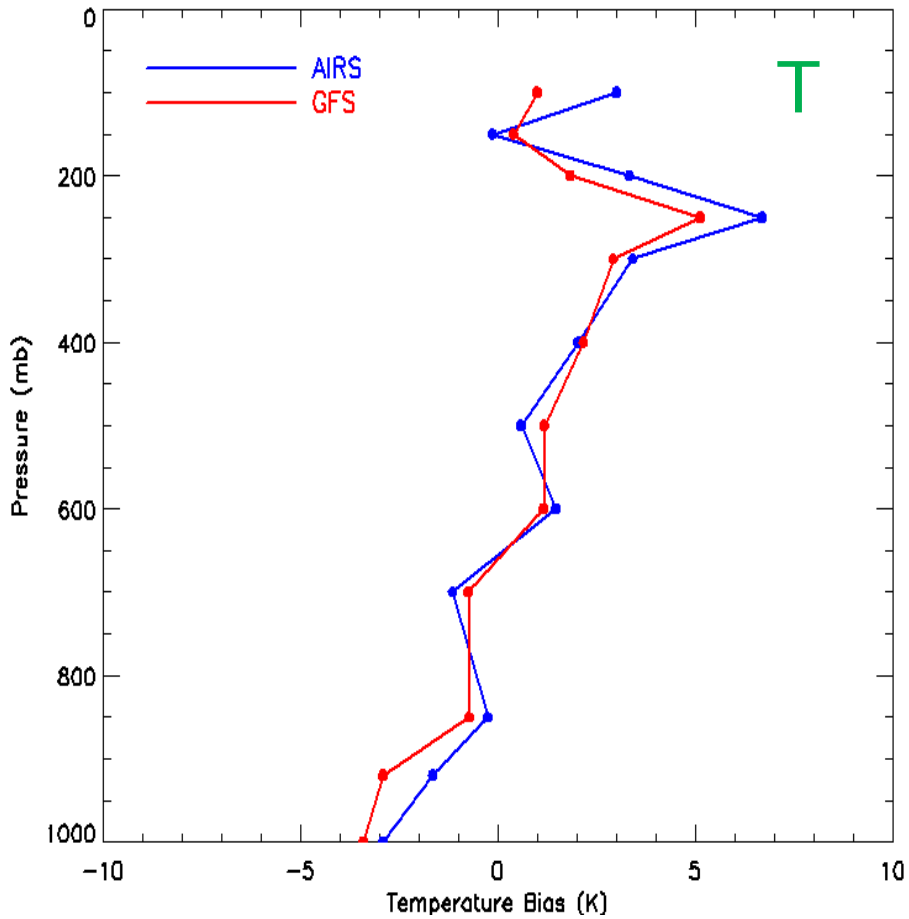




Analysis

- ARM data at SGP site

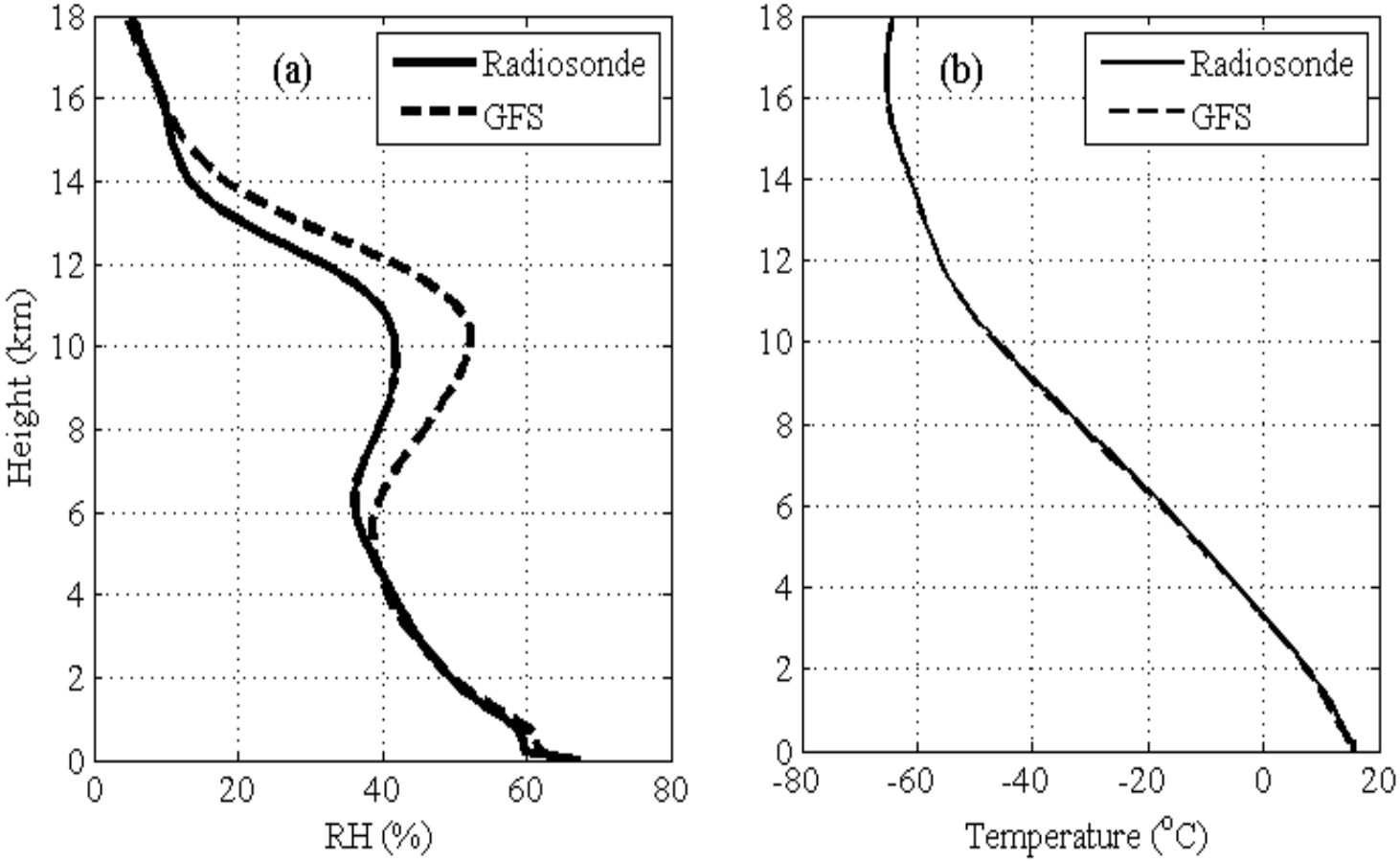




Relative humidity (left panel) and temperature (right panel) biases during July 2008: AERI versus AIRS, blue line; AERI versus GFS, red line.

Bias = AERI measurements – AIRS or GFS

Comparison of the Profiles of Relative Humidity & Temperature from Radiosonde, and GFS



Comparison of two schemes

GFS scheme		SG scheme
Xu and Randall (1996)	Scheme	Slingo (1987) Gordon (1992)
An equation is from empirical formula	Similar	Many of constants are based on observations
Only one equation determines CFR	Differ	Several equations determine CFR
T, RH, and Cloud mixing ratio	Variables	RH, convective cfr, vertical velo, lapse rate
Maximum-Random overlap	Overlap	Maximum overlap

Comparison of two schemes

1 GFS cloud scheme

High, middle, low cloud fraction

$$\text{cloud fraction} = R^{0.25}\left(1-\exp\left(-\frac{2000*(q_c - q_{c\min})}{\min[\max([(1-R)q^*]^{0.25}, 0.0001), 1.0]}\right)\right)$$

2 SG cloud scheme

High cloud fraction:

Default setting of RHc = 0.80 for p < 750.0 hPa

$$\begin{bmatrix} 0.0 \\ (RH - RHc)^2 / (1.0 - RHc)^2 \\ 1.0 \end{bmatrix} \text{ if } \begin{bmatrix} RH < RHc \\ RHc \le RH \le 1.0 \\ RH > 1.0 \end{bmatrix}$$

Mid cloud fraction:

Default setting of RHc = 0.80 for p < 750.0 hPa

RHe : RH*(1.0 – Ncnv), Ncnv: convective cfr

$$\begin{bmatrix} 0.0 \\ (RHe - RHc)^2 / (1.0 - RHc)^2 \\ 1.0 \end{bmatrix} \text{ if } \begin{bmatrix} RHe < RHc \\ RHc \le RHe \le 1.0 \\ RHe > 1.0 \end{bmatrix}$$

Comparison of two schemes

SG cloud scheme: Low cloud fraction

2

- synoptic subclass of stratiform clouds

$$Nsl = A(RHe) * B(\omega)$$

$$\mathbf{A(RHe)=}\begin{bmatrix} 0.0 \\ (RHe - RHc)^2 / (1.0 - RHc)^2 \\ 1.0 \end{bmatrix} \textbf{ if } \begin{bmatrix} RHe < RHc \\ RHc \le RHe \le 1.0 \\ RHe > 1.0 \end{bmatrix}$$

$$\mathbf{B(\omega)=}\begin{bmatrix} 1 \\ (\omega - \omega_0) / (\omega_1 - \omega_0) \\ 0 \end{bmatrix} \textbf{ if } \begin{bmatrix} \omega < \omega_1 \\ \omega_1 \le \omega \le \omega_0 \\ \omega > \omega_0 \end{bmatrix}$$

- marine stratocumulus clouds

$$Nmcl = S\left(-\frac{\partial\theta}{\partial p}\right) * B(RH)$$

$$S\left(-\frac{\partial\theta}{\partial p}\right) = \begin{bmatrix} 1.0 \\ \alpha\left(-\frac{\partial\theta}{\partial p}\right) + \beta \\ 0.0 \end{bmatrix} \textbf{ if } \begin{bmatrix} \left(-\frac{\partial\theta}{\partial p}\right) > 0.10 \\ 0.05 \le \left(-\frac{\partial\theta}{\partial p}\right) \le 0.10 \\ \left(-\frac{\partial\theta}{\partial p}\right) < 0.05 \end{bmatrix}$$

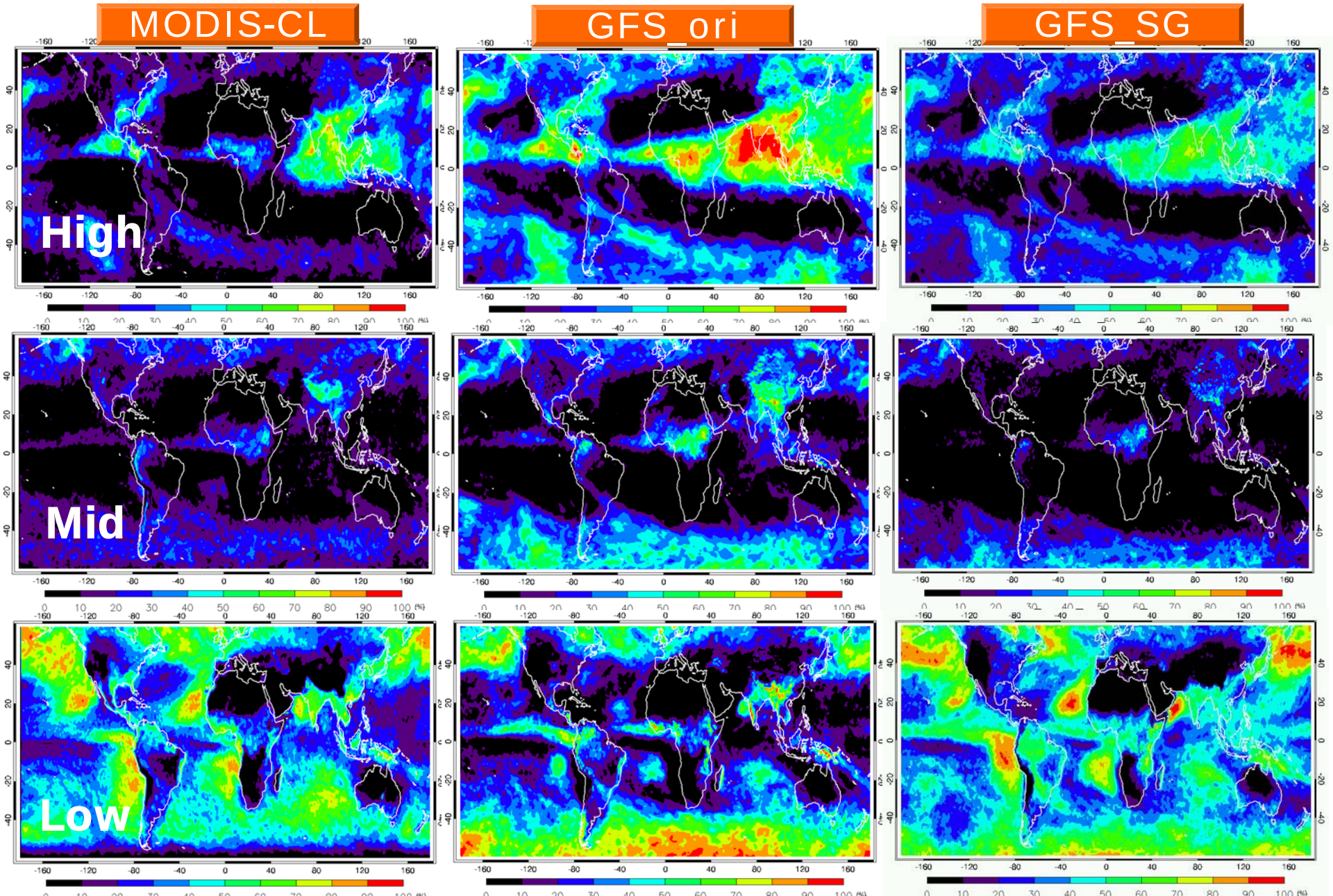
$$B(RH) = \begin{bmatrix} 1 \\ (RH - RH_{min}) / (RH_{max} - RH_{min}) \\ 0 \end{bmatrix} \textbf{ if } \begin{bmatrix} RH > RH_{max} \\ RH_{min} \le RH \le RH_{max} \\ RH < RH_{min} \end{bmatrix}$$

- shallow convective clouds

$$Nshl = 0.2 * A_{max}(RHe)$$

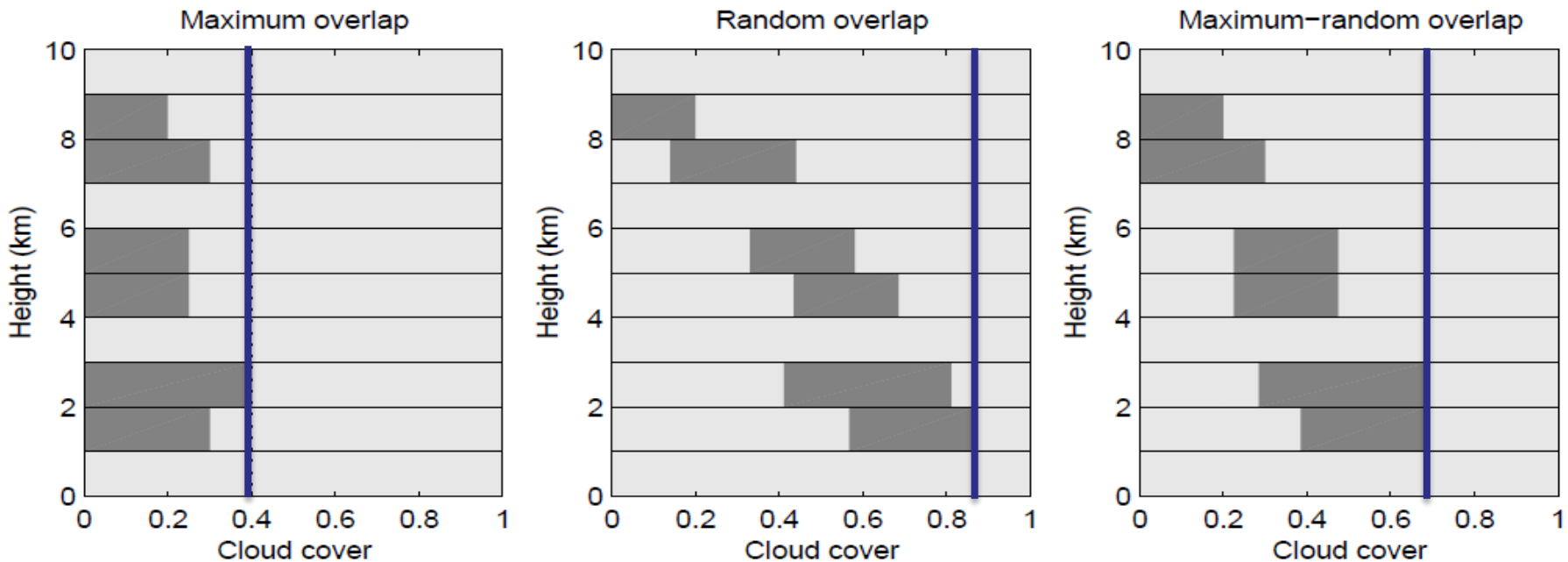
$A_{max}(RHe)$ is the maximum value of RHe

Comparisons of cld fraction



Cloud Overlapping Scheme

Overlap assumption



A schematic illustrating the three overlap assumptions (from Hogan and Illingworth, 2000)

Geleyn and Hollingsworth 1979

Random overlap: noncontiguous layers, Maximum overlap: contiguous layers
Most widely used cloud overlap approximation in modern GCMs

$C_{max} = Max(C1, C2)$

$C_{ran} = C1+C2-C1*C2$

Cloud Overlapping Scheme

Previous studies

$$C_{true} = a*C_{max} + (1-a)*C_{ran}, \text{where } a(\Delta z) = \exp(-\Delta z / L_{cf})$$

EXPONENTIAL RANDOM

Hogan and Illingworth (2000)

- For vertically continuous cloud, the degree of correlation between the cloud positions decreased with vertical separation of the layers

Lcf : 4 km

Mace and Benson-Troth (2002)

- Using MMCR Radar data from 4 ARM sites :SGP, TWP, Manus, Nauru

Lcf : 3.9 km at SGP, 4 km at Manus, 4.6 km at Nauru

Pincus et al. (2005)

- Using CRM simulation, Stratiform and convective clouds have different overlap.

St: Random, Con: Max

Naud et al. (2008)

- Using cloud radar data from ARM with NCEP reanalysis data

Lcf : 2 km at SGP, 2.3 km at Manus, 1.8 km at Nauru

Barker (2008)

- Using CloudSat and CALIPSO data

Lcf : median value of 2 km for global scales

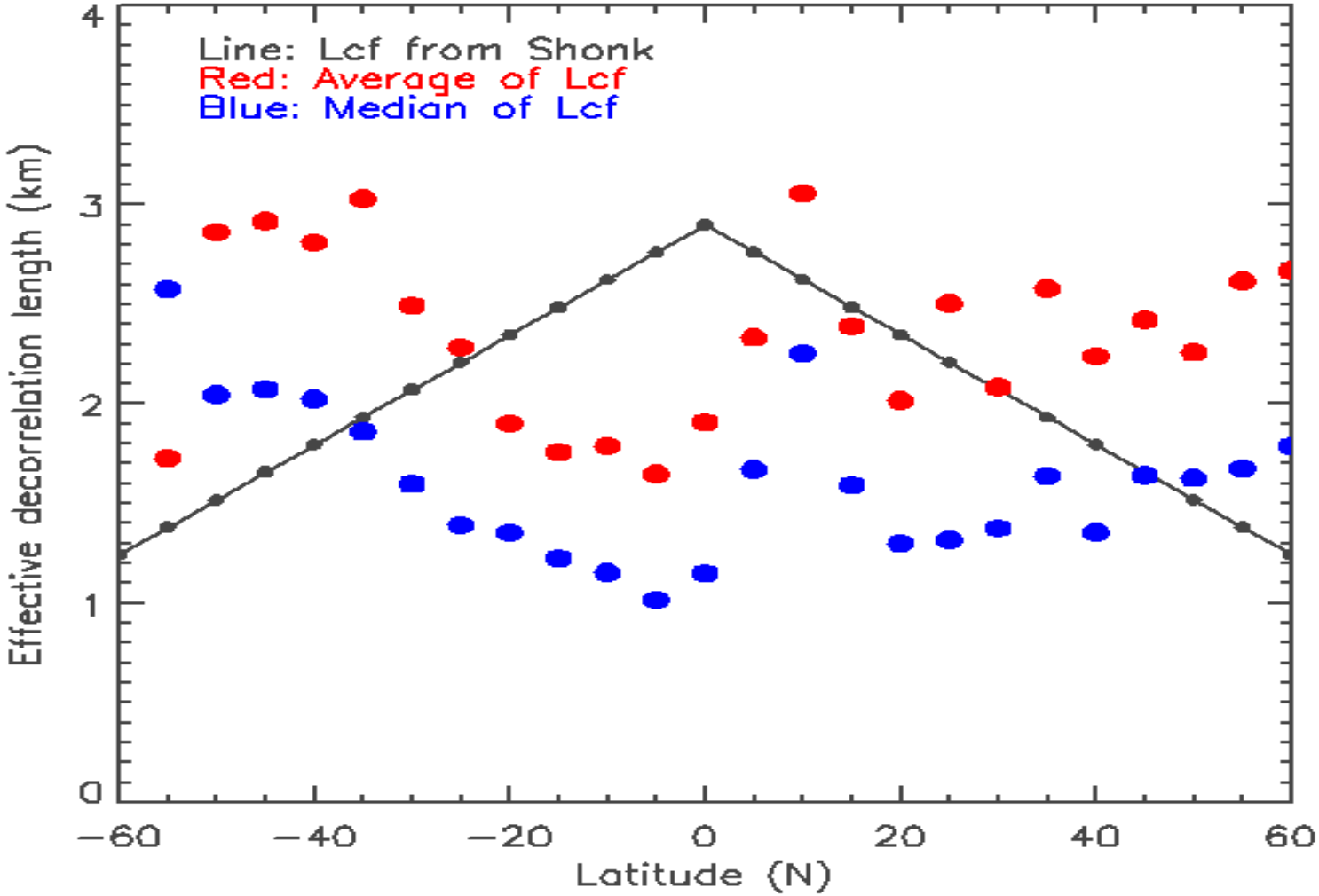
Shonk et al. (2010)

- Based on two studies, they suggest a simple linear fit

Lcf : dependent on only latitudes

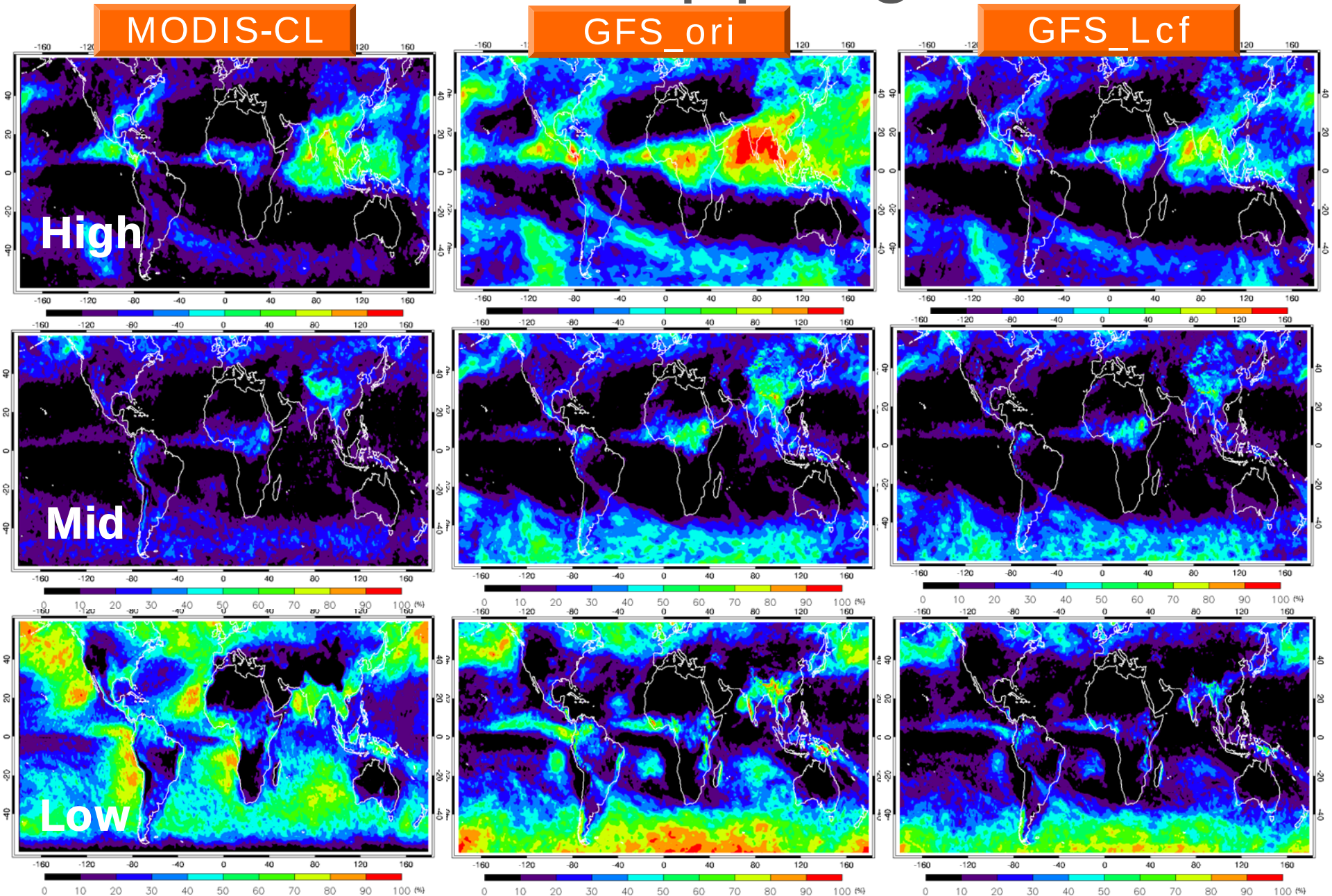
Cloud Overlapping Scheme

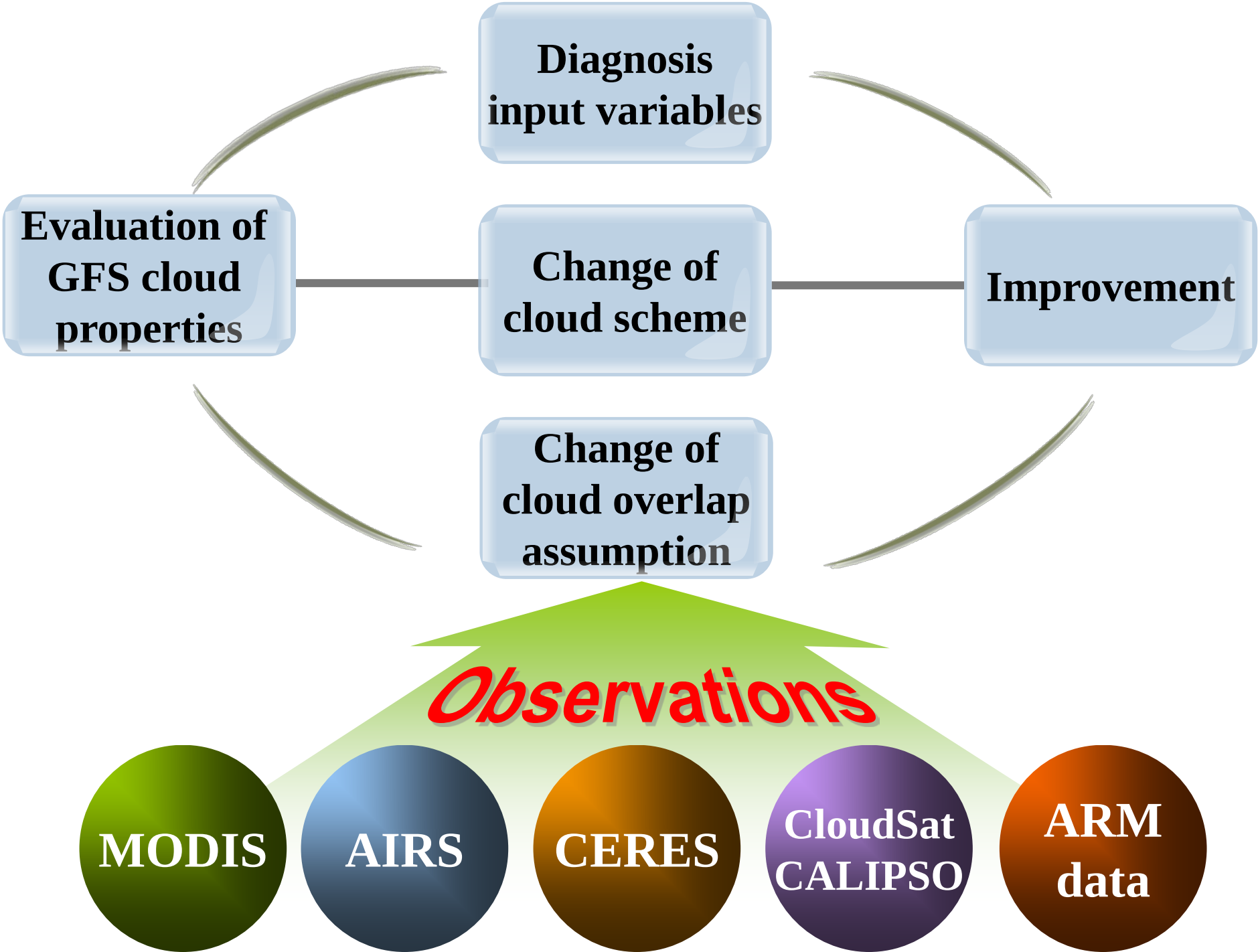
Comparisons of Lcf



Lcf values as a function of latitude for July 2007. The black solid line is a simple linear fit suggested by Shonk et al. (2010) and the red and blue dots show mean and median values of Lcf, respectively.

Cloud Overlapping Scheme




Diagnosis input variables
Evaluation of GFS cloud properties
Change of cloud scheme
Improvement
Change of cloud overlap assumption
Observations
MODIS
AIRS
CERES
CloudSat CALIPSO
ARM data

Publications

Yoo, H., Z. Li, Y.-T. You, S.Lord, F. Weng, and H. W. Barker, 2013: Diagnosis and testing of low-level cloud parameterizations for the NCEP/GFS model satellite and ground-based measurements, *Climat e Dynamic*, doi:10.1007/s00382-013-1884-8.

Yoo, H., and Z. Li, (2012), Evaluation of cloud properties in the NO AA/NCEP Global Forecaster System using multiple satellite produt, *Climate Dynamics*, 10.1007/s00382-012-1430-0.

Zhang, J., Z. Li, H. Chen, M. Cribb, H. Yoo, 2013, Evaluation of Cl oud Structure Simulated by NECP GFS using Ground-based Remot e Sensing and Radiosonde Products at the ARM SGP site, *Climate Dynamics*, under revision.

Summary

Findings

Diagnosis of clouds

- The GFS model captures well the spatial distributions of hydrometeors compared to satellite retrievals, although large differences exist in the magnitudes.
- The GFS model generates more high and mid-level clouds, but less low-level clouds than do satellite retrievals and tends to miss low-level marine stratocumulus clouds.
- An underestimation of low clouds leads to more outgoing LW radiation and less SW radiation at the TOA.
- The GFS temperature field agrees well with observations, the GFS RH simulations both in the lower and upper troposphere tend to be overestimated than observations.

Aerosol on rain

- For thin clouds, rainfall occurrence is suppressed by aerosols (30%)
- For thick clouds, rainfall frequency is increased by aerosols (50%)

Aerosol on cloud height

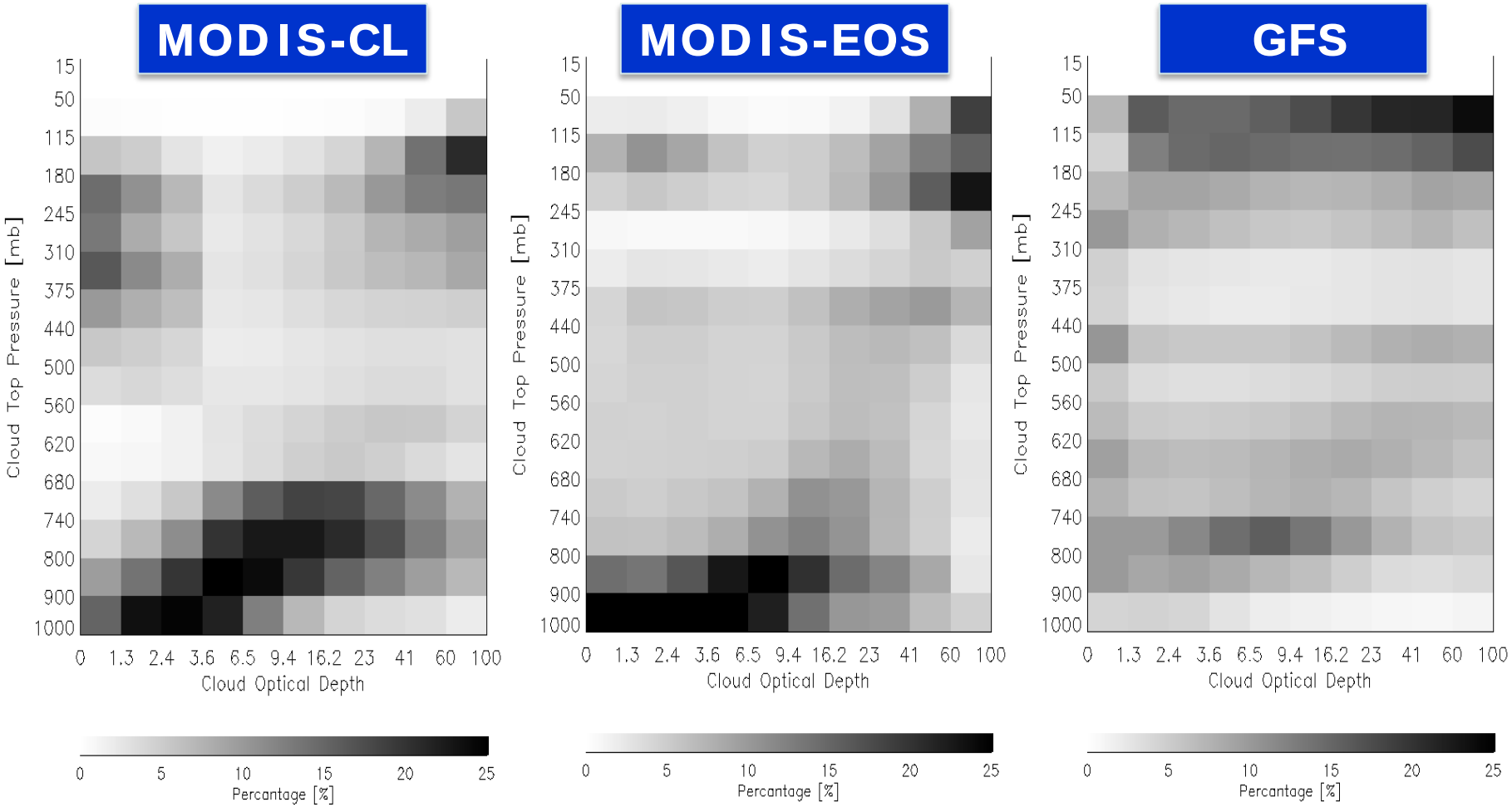
- For mixed-phase clouds of low cloud base, cloud top (also thickness) increases with aerosol number concentration
- For warm clouds, cloud top height (thickness) is not affected.

Aerosol on cloud phase

- As CN increases, high clouds occurred more frequently, but low clouds occurred less frequently.

Diagnosis

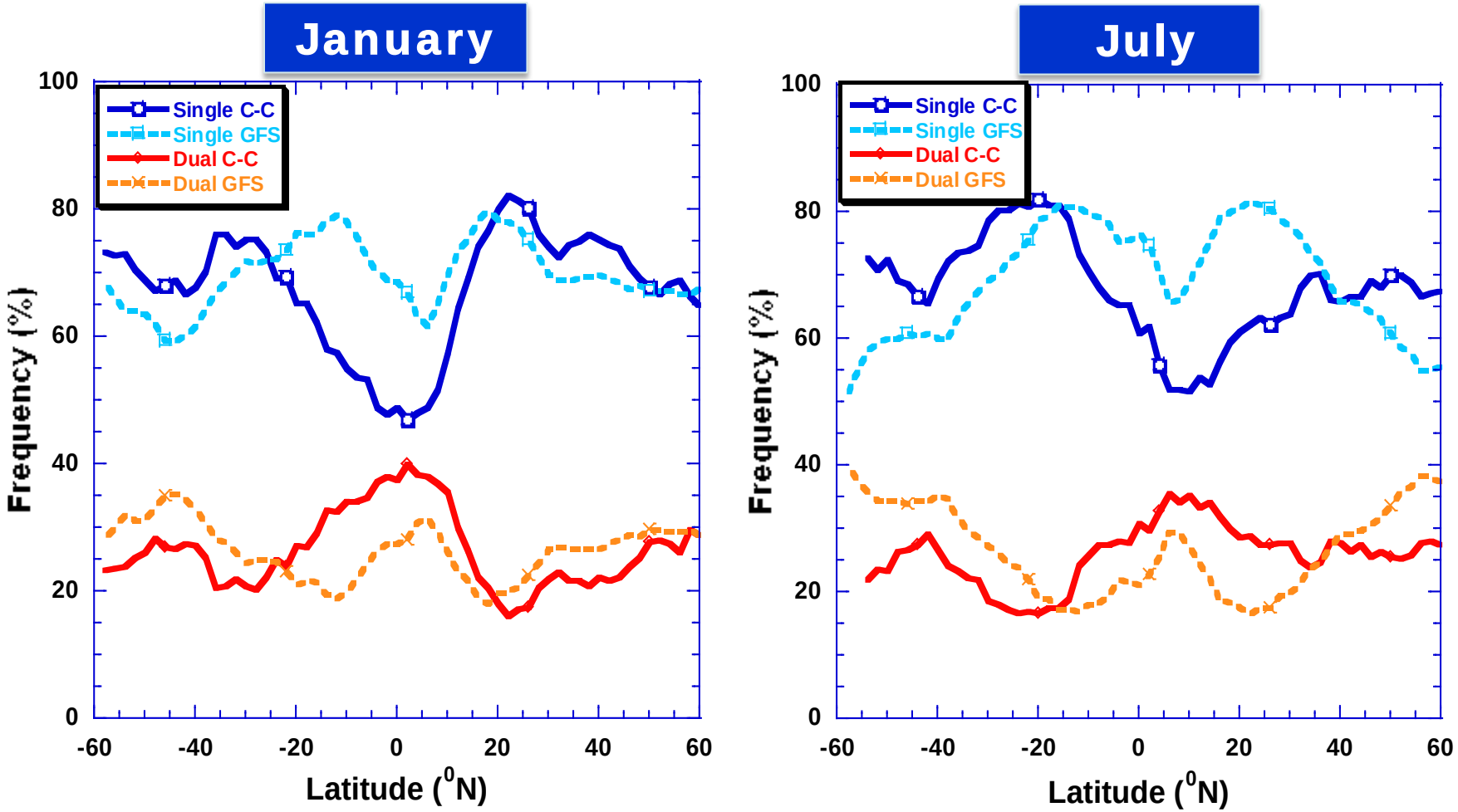
Cloud top pressure and cloud optical depth



Joint histograms of CTP and COD derived from retrievals by applying the C-L algorithm (left), the MODIS-EOS products (middle), and the GFS model (right) in July 2007.

Diagnosis

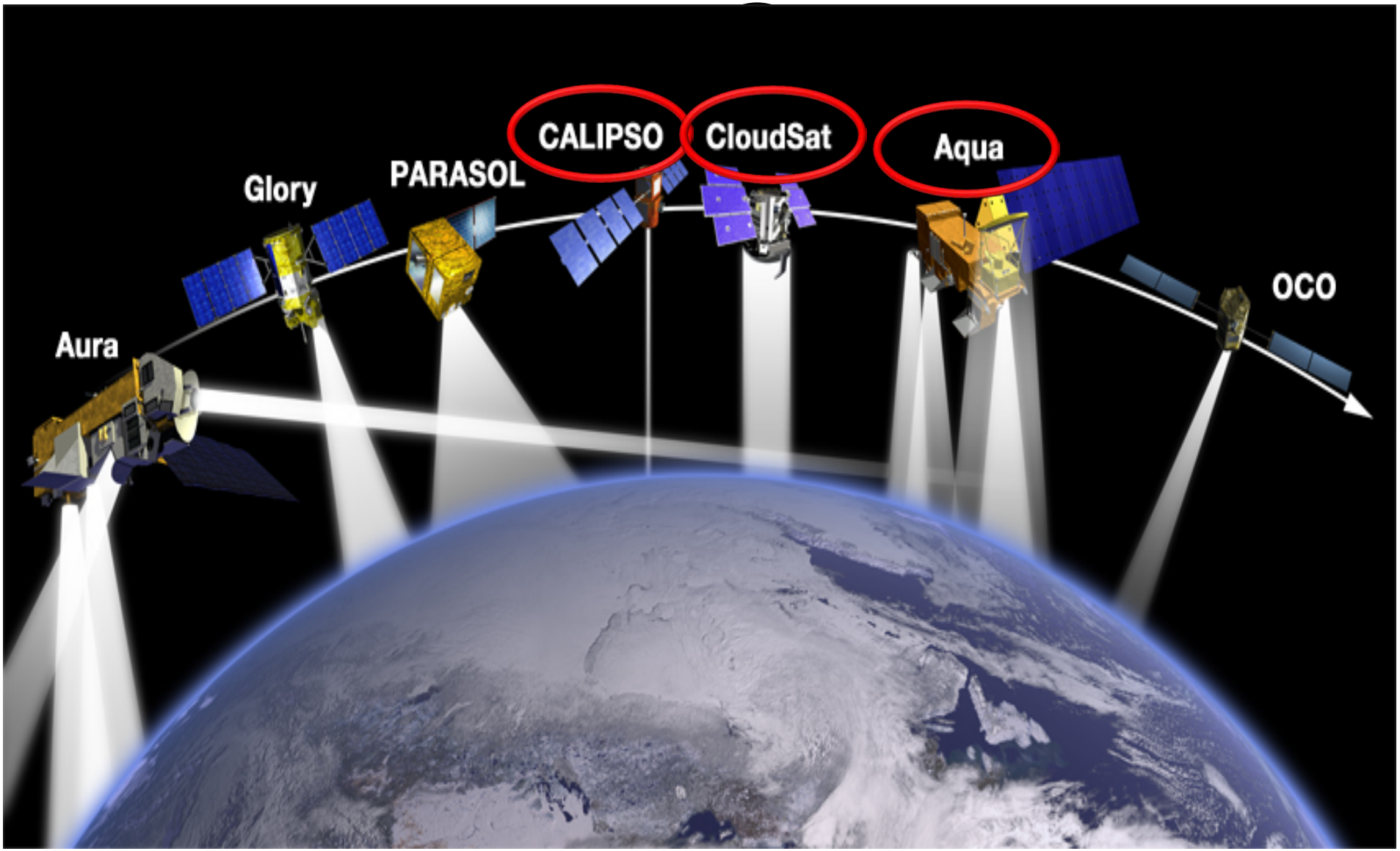
Multi-layered cloud occurrence



Latitudinal variations of the frequencies of cloud occurrence from the C-C satellites and the GFS model for single and dual-layer clouds in January (left) and July (right) of 2007.

Data & approach

Satellites



from NASA site