云、气溶胶气候效应观测与模拟研究
Observation and Modeling Studies of Cloud, Aerosol and Climate Effects

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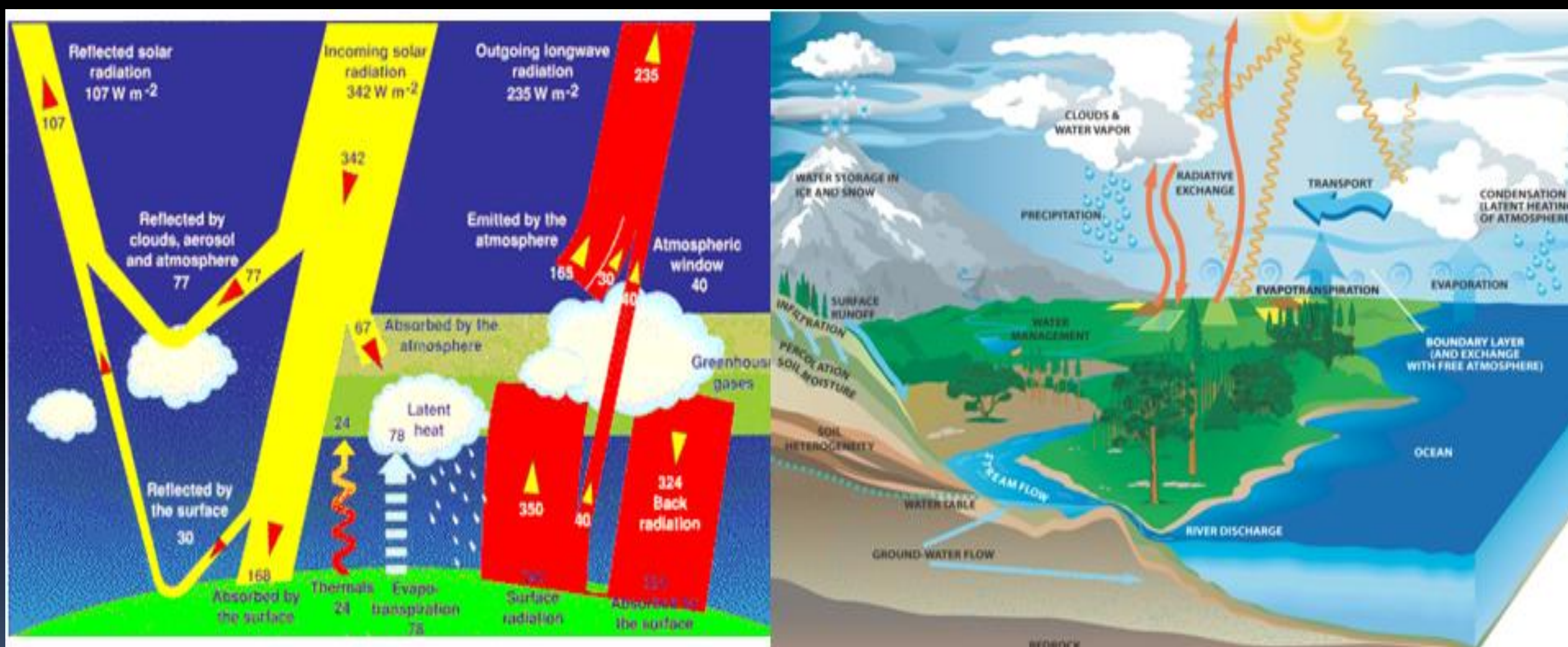
Water and Energy Cycles Driven by Clouds and Aerosols

1. 地球气候由两个循环所决定：能量和水
   - 云是影响地球能量平衡和水循环的最主要因素



Most Uncertainties Originated From Treatments of Clouds

气候模式对CO2加倍所产生的温度变化预测的差异，主要来源于不同云和气溶胶参数化

- 云和气溶胶一直是气候研究的焦点和难点

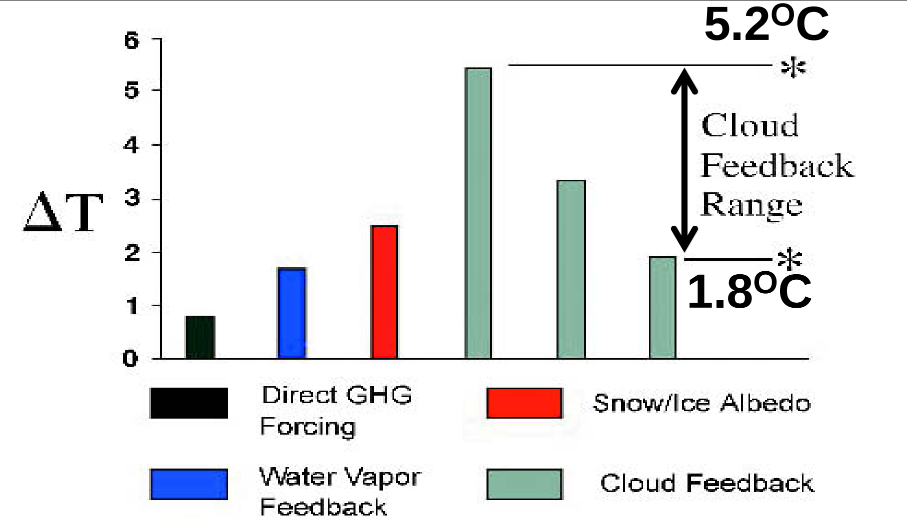


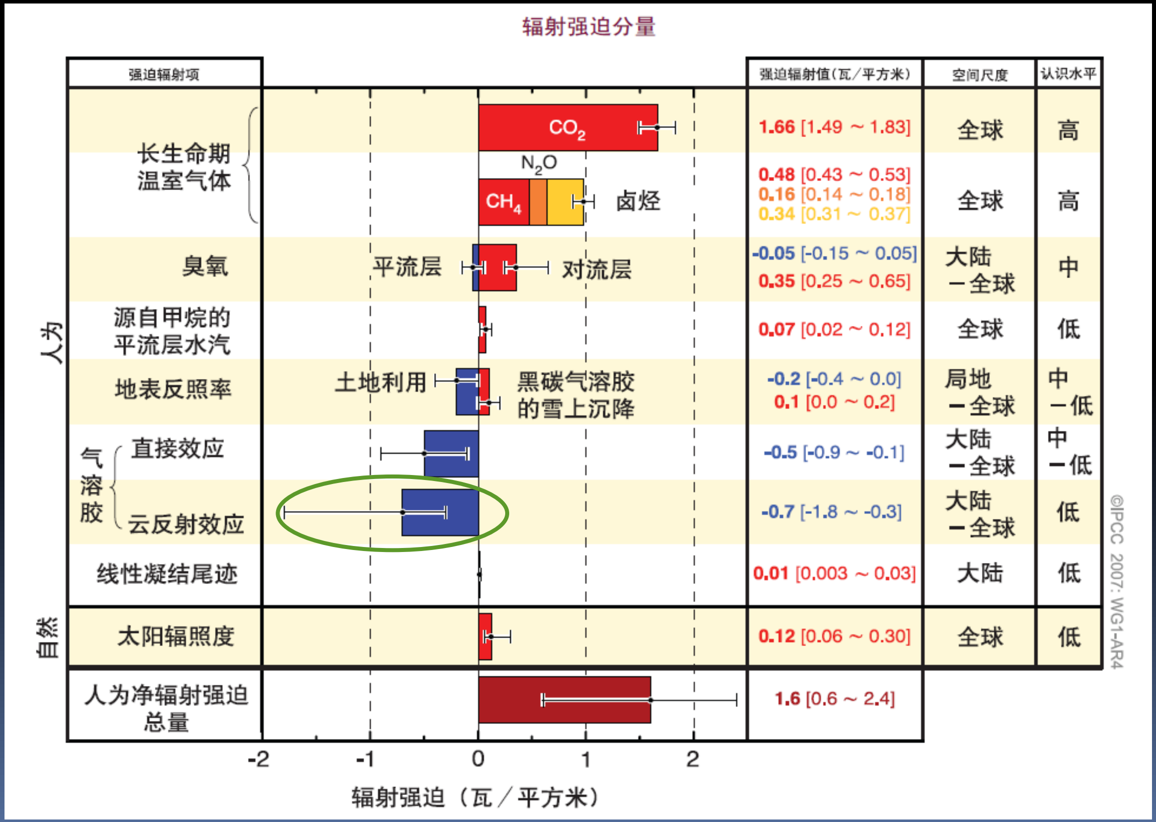
FIG. 13. The response of a single climate model to an imposed doubling of CO_2 as different feedbacks are systematically added in the model (adapted from Senior and Mitchell 1993). Different treatments of cloud processes in the model produce a large spread in predicted surface temperature due to CO_2 doubling.

Stephens, 2005

同一模式，不同参数化

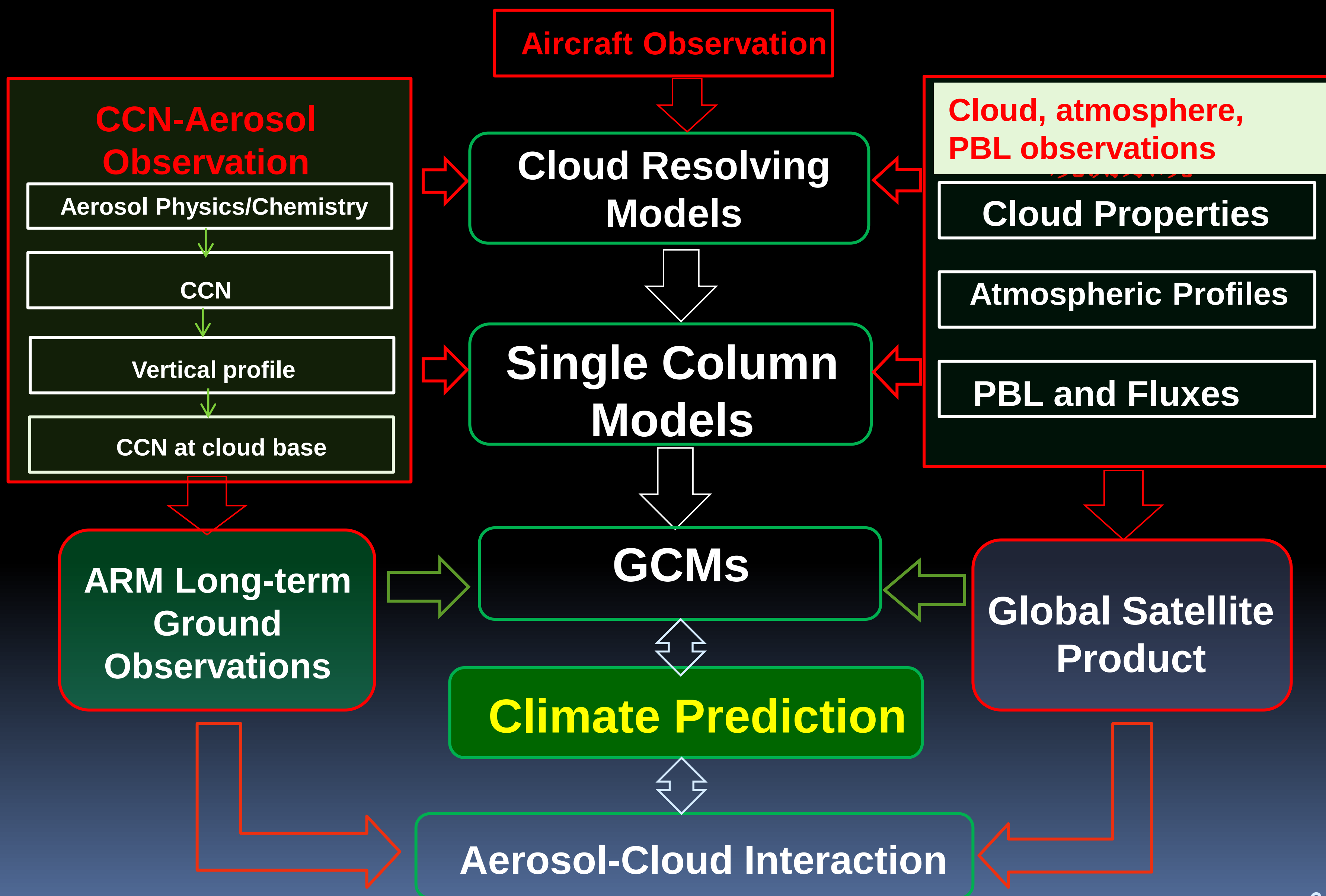
Aerosol: Earth's Most Uncertain Forcing Agent

2. 气候变化的核心是地球系统对外部强迫(扰动)而进行的状态调整
   - 气溶胶在所有外部强迫中不确定性最大

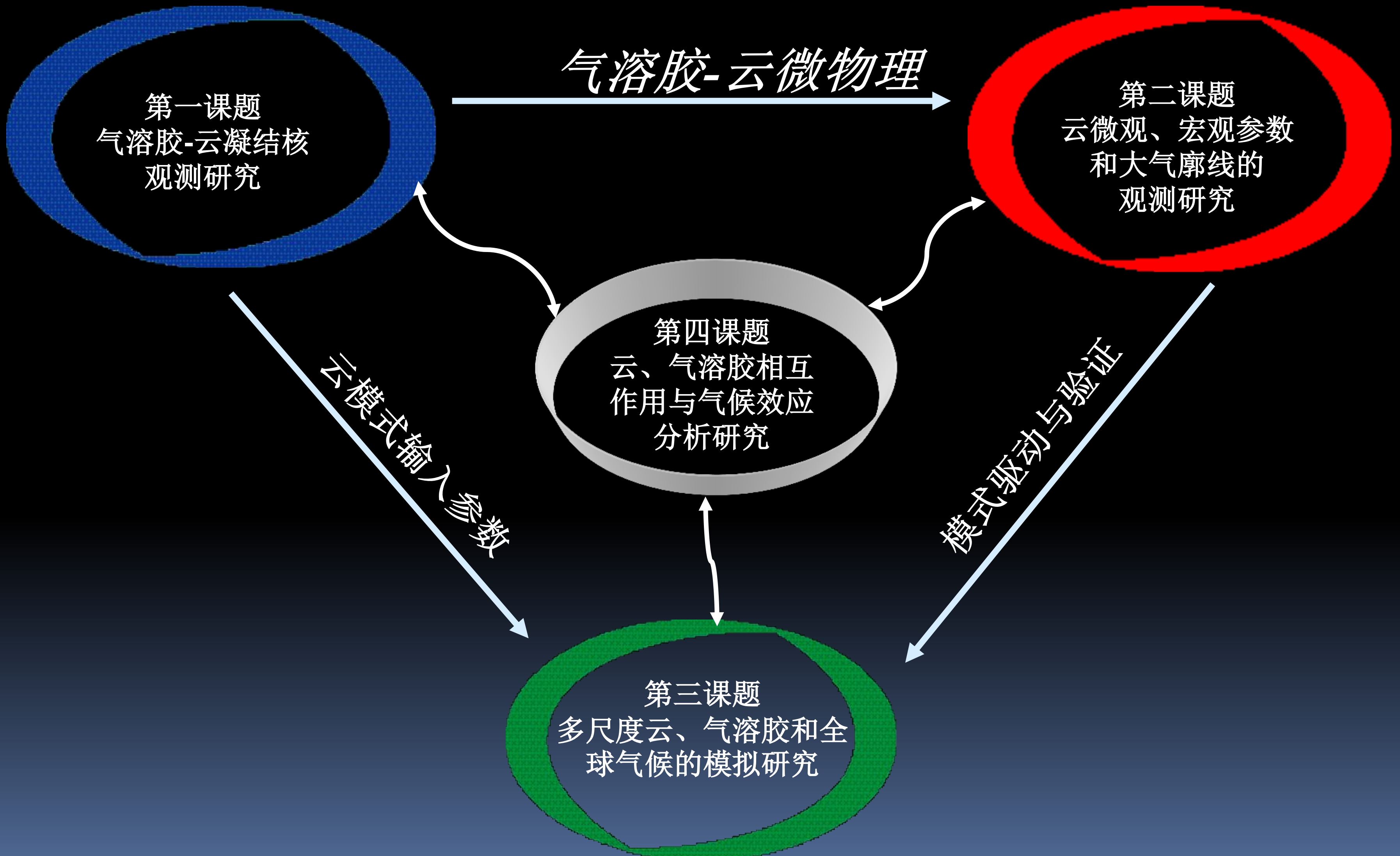


1. 大气气溶胶物理-化学特性对云过程的影响
2. 云宏、微观特性及其与大气环境的关系
3. 云-气溶胶-降水相互作用过程机理模拟，发展气候系统模式中云物理参数化方案
4. 云、气溶胶对我国气候变化（温度、降水、环流等）的影响。

Road Map of Our Approach



课题设置和之间的关系



气溶胶-云微物理
第一课题
气溶胶-云凝结核
观测研究
第二课题
云微观、宏观参数
和大气廓线的
观测研究
第四课题
云、气溶胶相互
作用与气候效应
分析研究
云模式输入参数
模式驱动与验证
第三课题
多尺度云、气溶胶和全
球气候的模拟研究

子课题研究内容与负责人

云、气溶胶及其气候效应的观测与模拟研究

1. 气溶胶，云凝（冻）结核，冰核综合观测研究 （王普才，中科院大气所）

■选择气候地表性观测站点，开展气溶胶和云凝结核谱分布的同时观测
■气溶胶粒子的活化率谱，给出气溶胶谱分布和云凝结核谱的参数化方案
■利用3波段激光雷达，反演气溶胶谱分布的高度分布，在假定气溶胶化学成成份垂直均匀分布的条件下，得到云底处凝结核谱分布拉曼散射激光雷达
■实验室研究气溶胶微观、辐射和核化特性及其之间的关系

2. 云宏观、微观参数和大气廓线综合观测研究（王英剑，中科院安光所)

■综合利用和开发多种地基遥感技术；获得云、气溶胶参数及其垂直分布
■卫星反演全球气溶胶和云参数；
■飞机观测。利用人影的优势，在常规的业务飞行中加上研究所需仪器
■利用多种地面遥感方法连续观测大气风场和温、湿度廓线

3. 气溶胶、云、降水过程模拟及其在参数化研究 （薛惠文，北京大学)

■ 不同云系对云-气溶胶关系的影响及气溶胶与对流云的关系
■ 检验改进模式中云-气溶胶及其相互作用的参数化
■使用全球卫星资料评估中国主要气候模式云、气溶胶模拟效果
■在模式中气溶胶与云微物理过程间接气候效应

4. 气溶胶、云、降水过程及其相互作用的机理分析研究（李占清,北京师范大学）

■综合分析各种观测资料，研究气溶胶-云－降水的时空变化规律
■气溶胶对云和降水的影响并估算气溶胶的间接气候效应
■云和降水对气溶胶的影响-它们之间的反馈
■中美气溶胶、云、降水特性的对比分析及其与气候和环境的关系

观测研究不同气候区
气溶胶、云、降水及其相互作用的差异

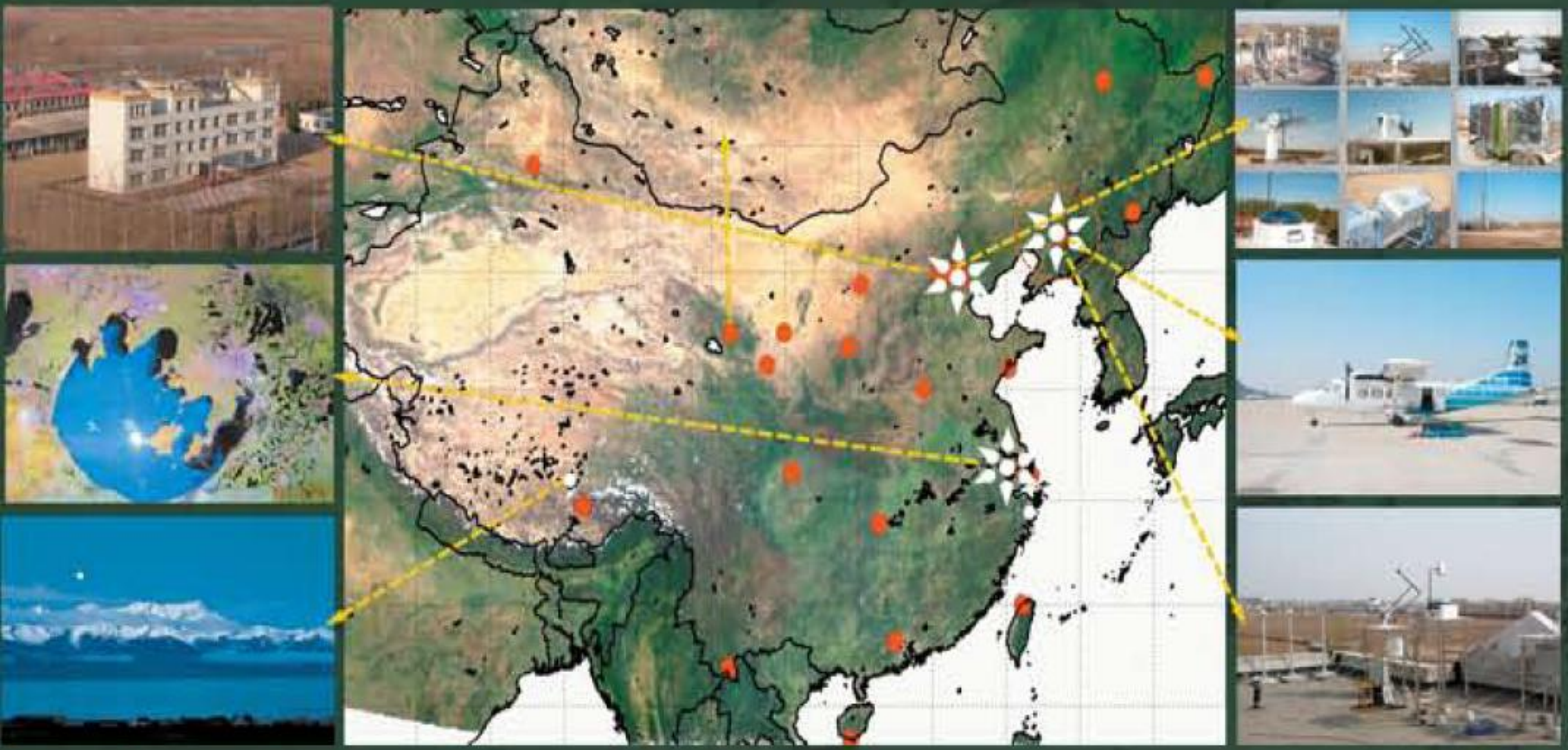
统一标准、统一算法的长期连续产品

East Asian Study of Tropospheric Aerosols:

JGR Special Issue
2007 (20 articles)

An International Regional Experiment (EAST-AIRE)

东亚对流层气溶胶区域试验（2004-2007，首席：李占清）



East Asian Study of Tropospheric Aerosols and Impact on Regional Climate (EAST-AIRC)

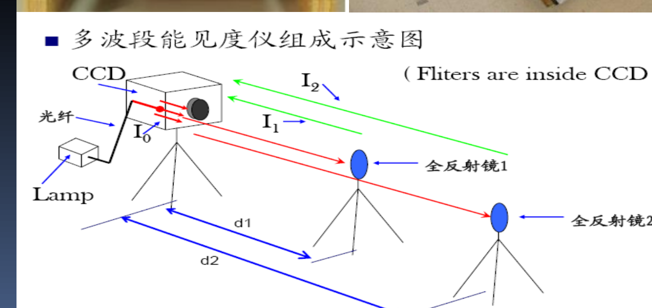
东亚对流层气溶胶对区域气候影响（首席李占清）

JGR Special Issue
30 articles (2010-present)

云底处云凝结核确定的新方法

目前开展的气溶胶和云凝结核观测大多是静态和近地面的，不反映云中的实际情况。

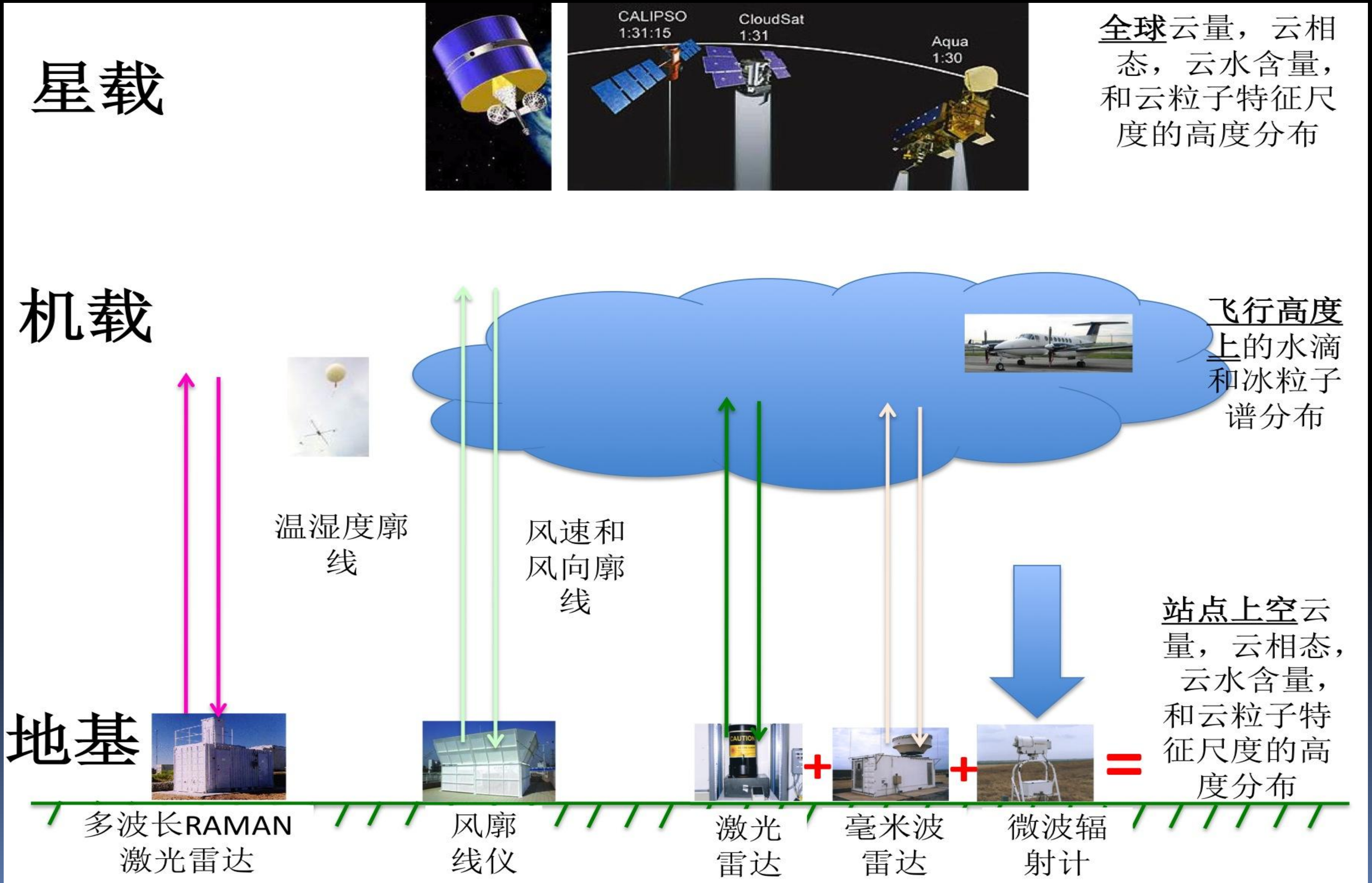
1) 地面干气溶胶的谱和组份
2) 气溶胶的分粒径吸湿增长
3) 云凝结核分粒径活化特性
4) 气溶胶粒子谱随高度变化
5) 云底云滴的浓度及其尺度



综合反演技术

主被动遥感结合；多观测平台结合；多仪器联合反演

发展、改进、优化一系列综合反演算法！

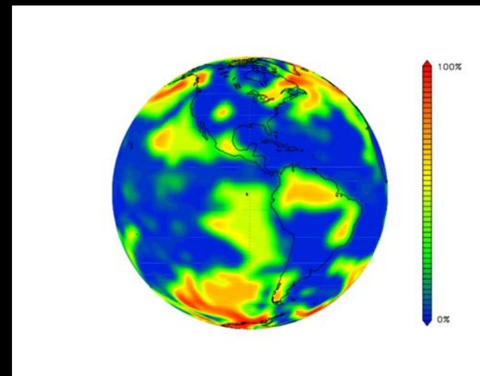


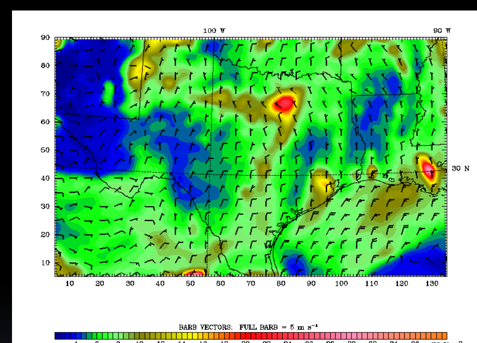
多尺度模式模拟研究

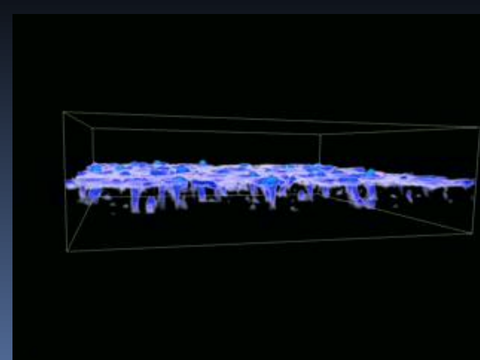
全球气候模式
单柱模式

中尺度模式
区域模式

云分辨模式
大涡模拟模式







气溶胶和云对
全球气候的影响

气溶胶和云对
区域气候的影响

气溶胶、云、降水
的物理过程

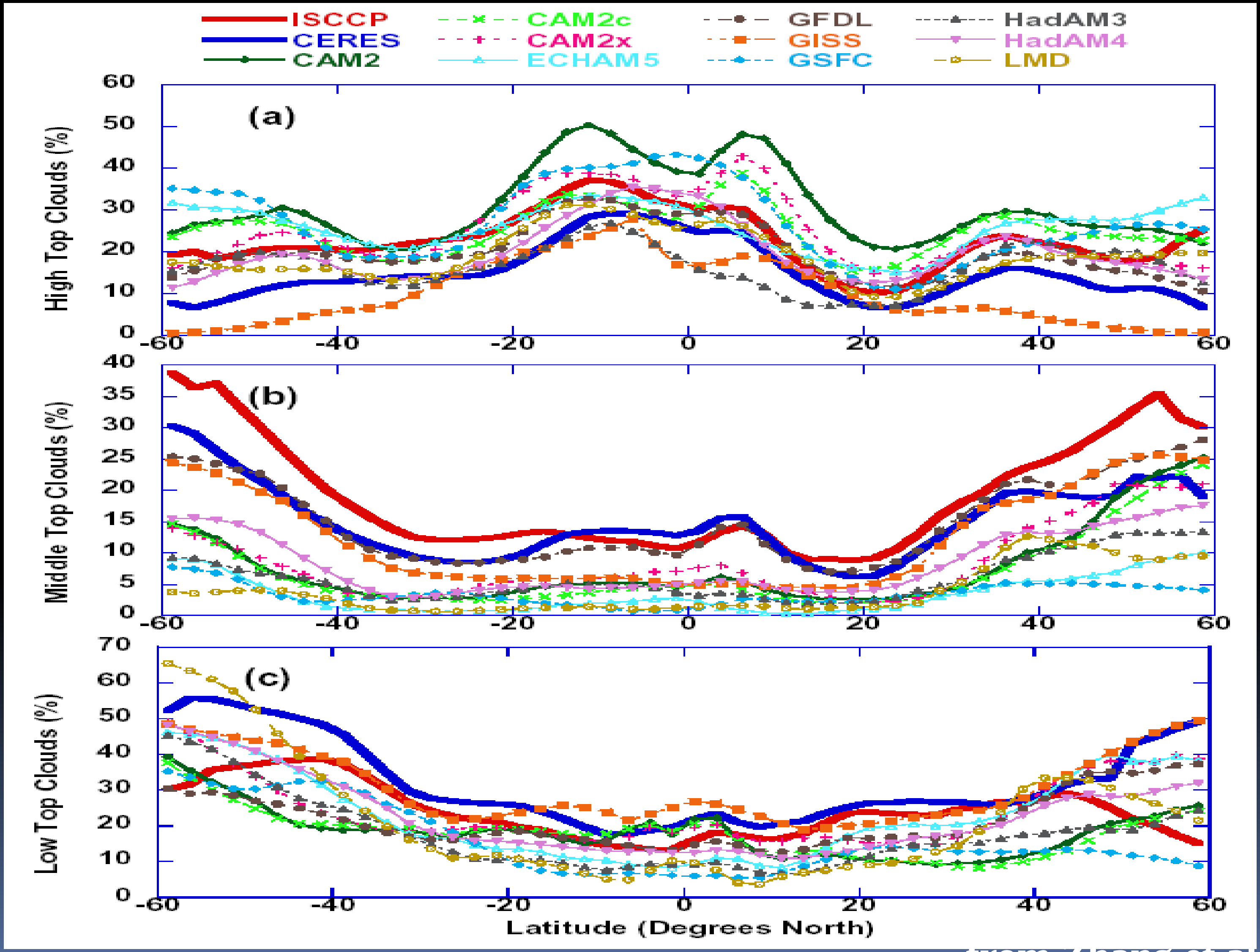
Evaluation of NCEP GFS clouds using A-train observations

Yoo, H., and Z. Li, 2012a: Evaluation of cloud properties in the NOAA/NCEP global forecast system using multiple satellite products, Clim. Dyn., doi:10.1007/s00382-012-1430-0

Yoo, H., and Z. Li, 2012b: Diagnosis and improvement of low level warm cloud simulation in the NOAA/GFS, Climate Dynmics, under revision.

Comparison of cloud products

Problems in representation of clouds



from Zhang et al. 2005

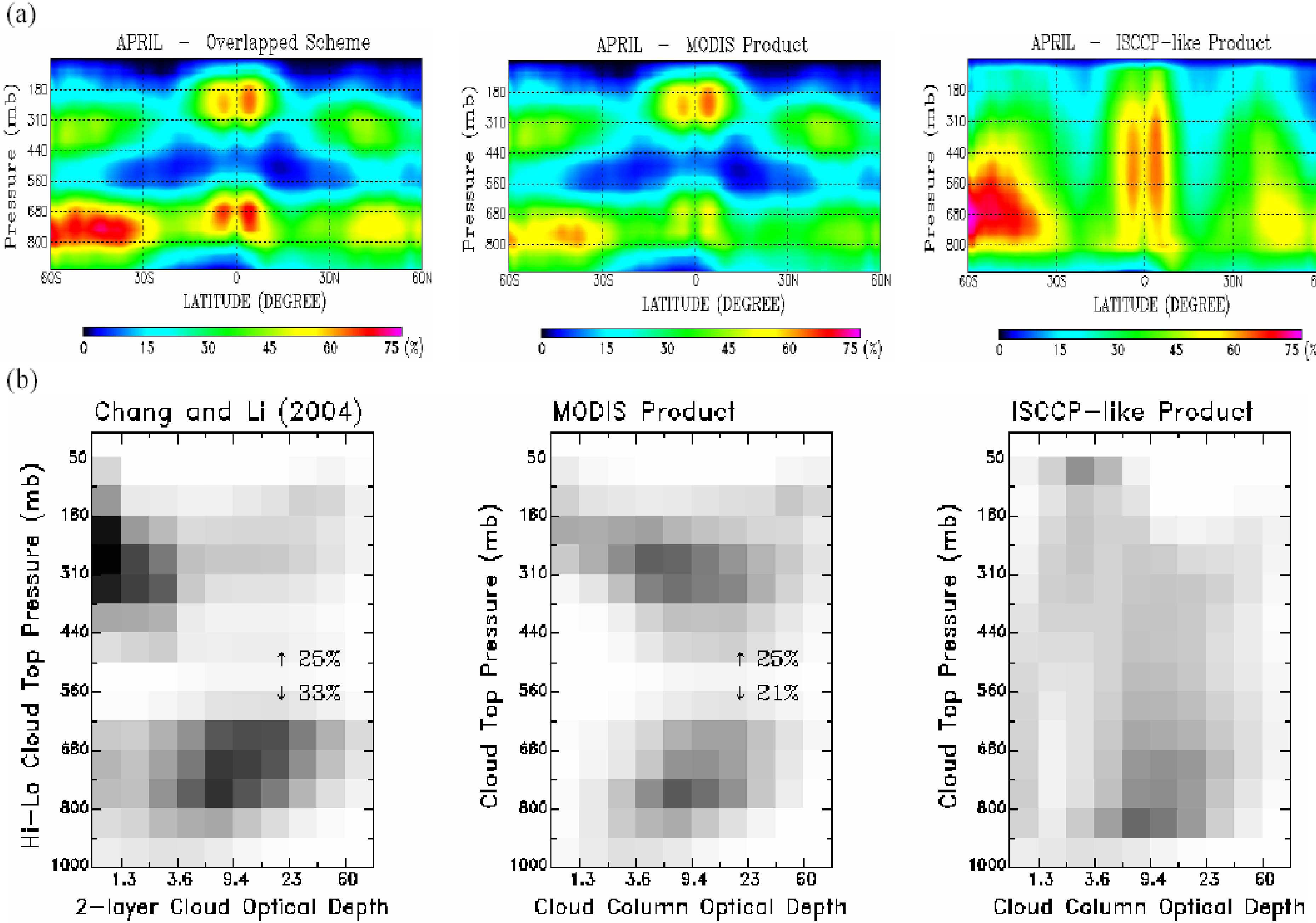
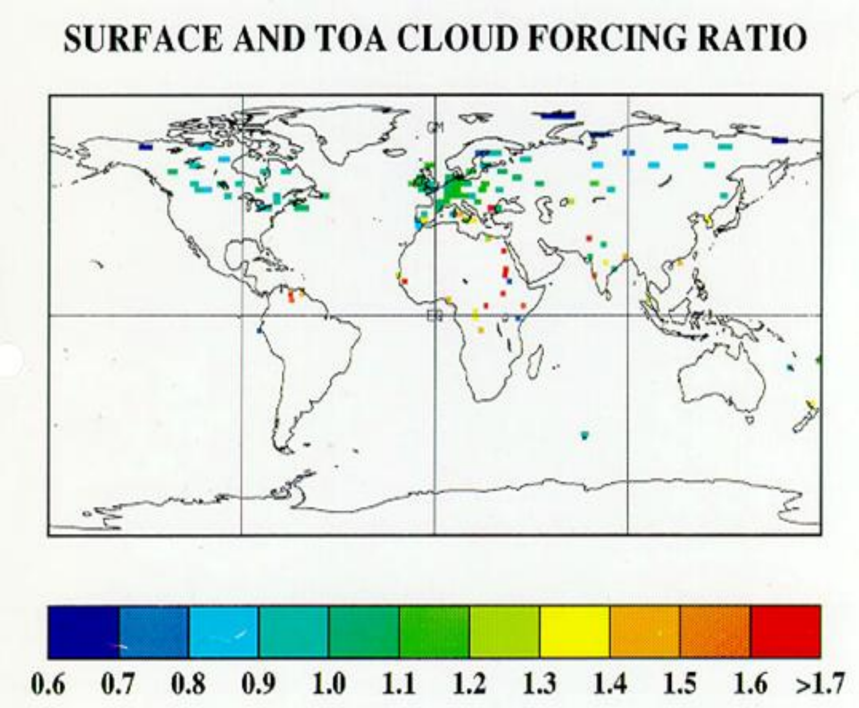
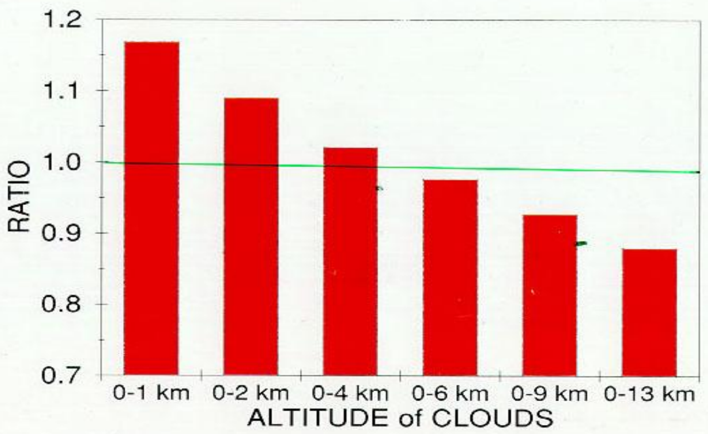


Fig. 6 a) Probabilities of cloud occurrence and b) joined-probabilities of Pc and τ_{VIS} derived from three different satellite inversion algorithms applied to the MODIS pixel data.

Impact of cloud macro- & micro-physics on Total column atmospheric absorption



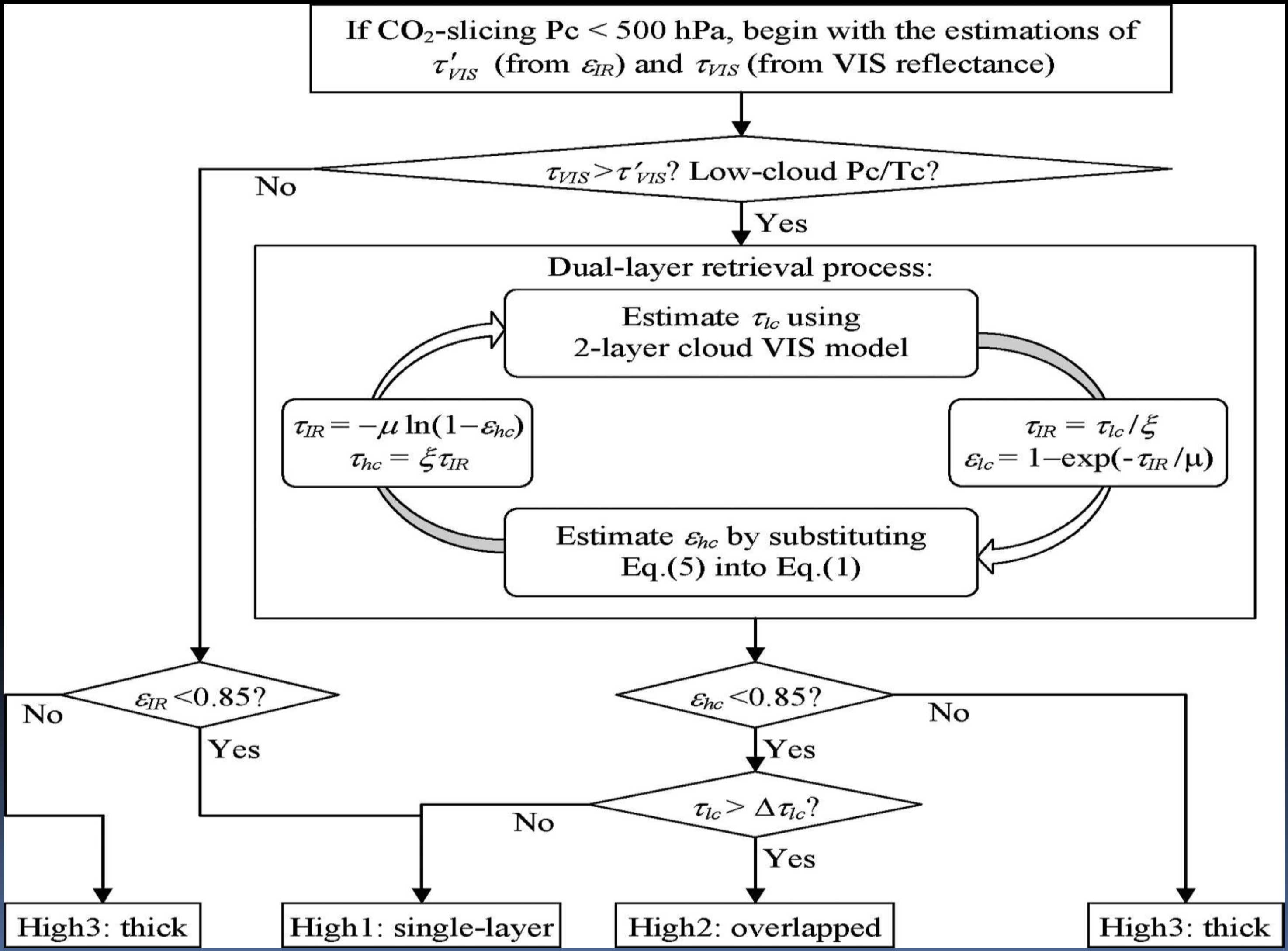


Li et al. (Nature, 1995)

Li and Moreau (JAM, 1996)

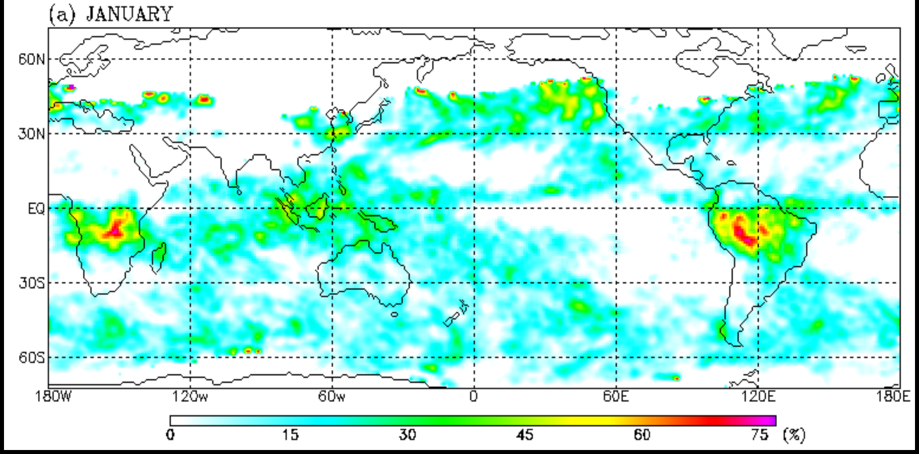
Satellite-retrieval algorithm

- Chang-Li algorithm (JAS & JCL, 2005)

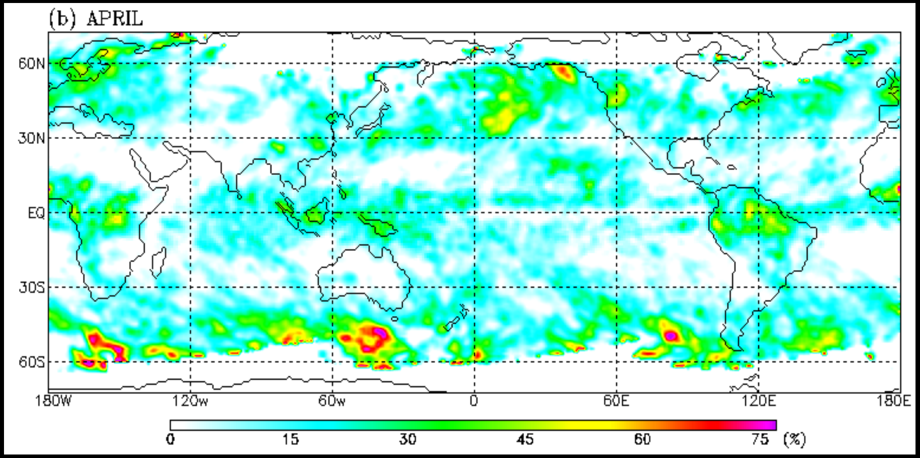


Cirrus-Overlapping-Low Cloud Amount (High/Low)

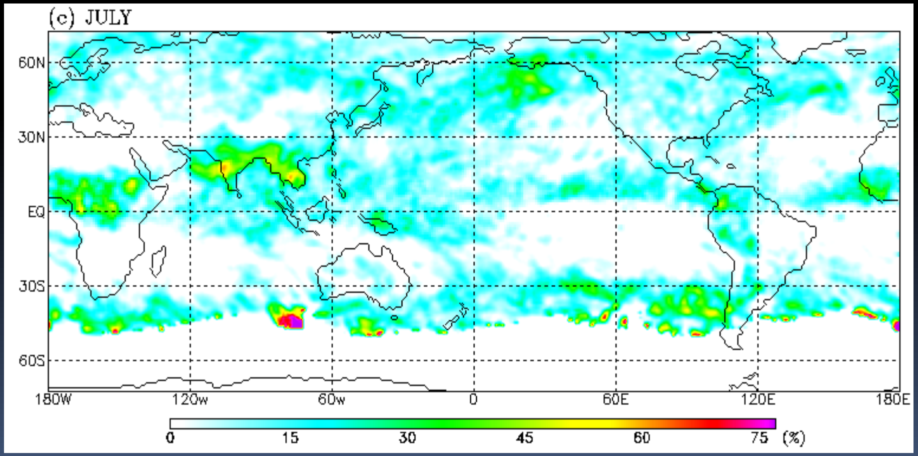
January 2001



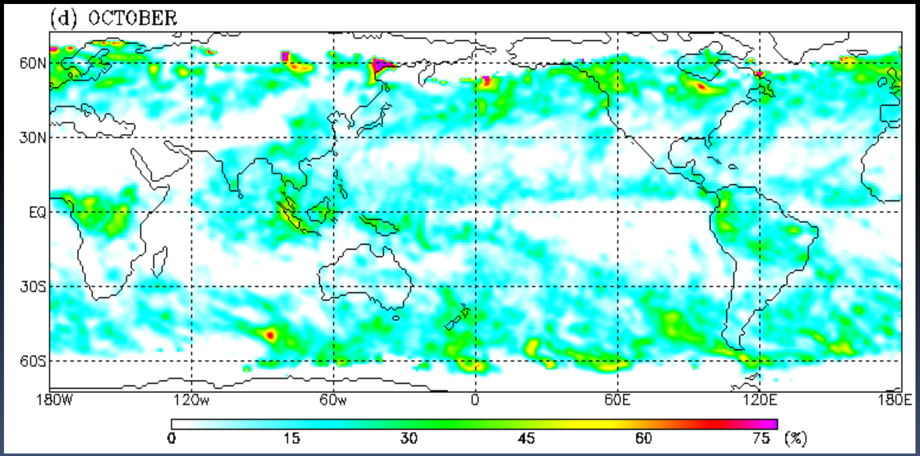
April 2001



July 2001

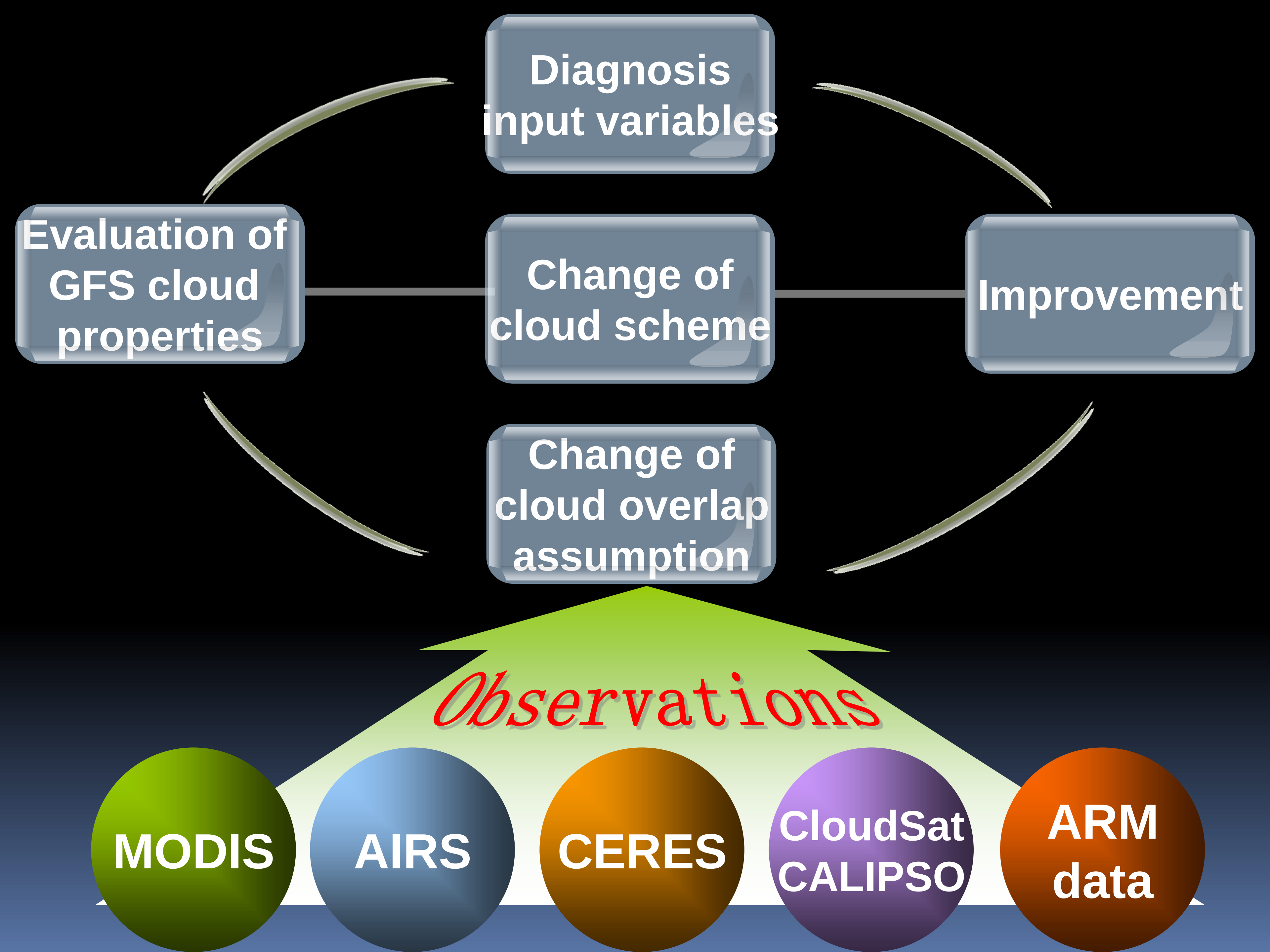


October 2001

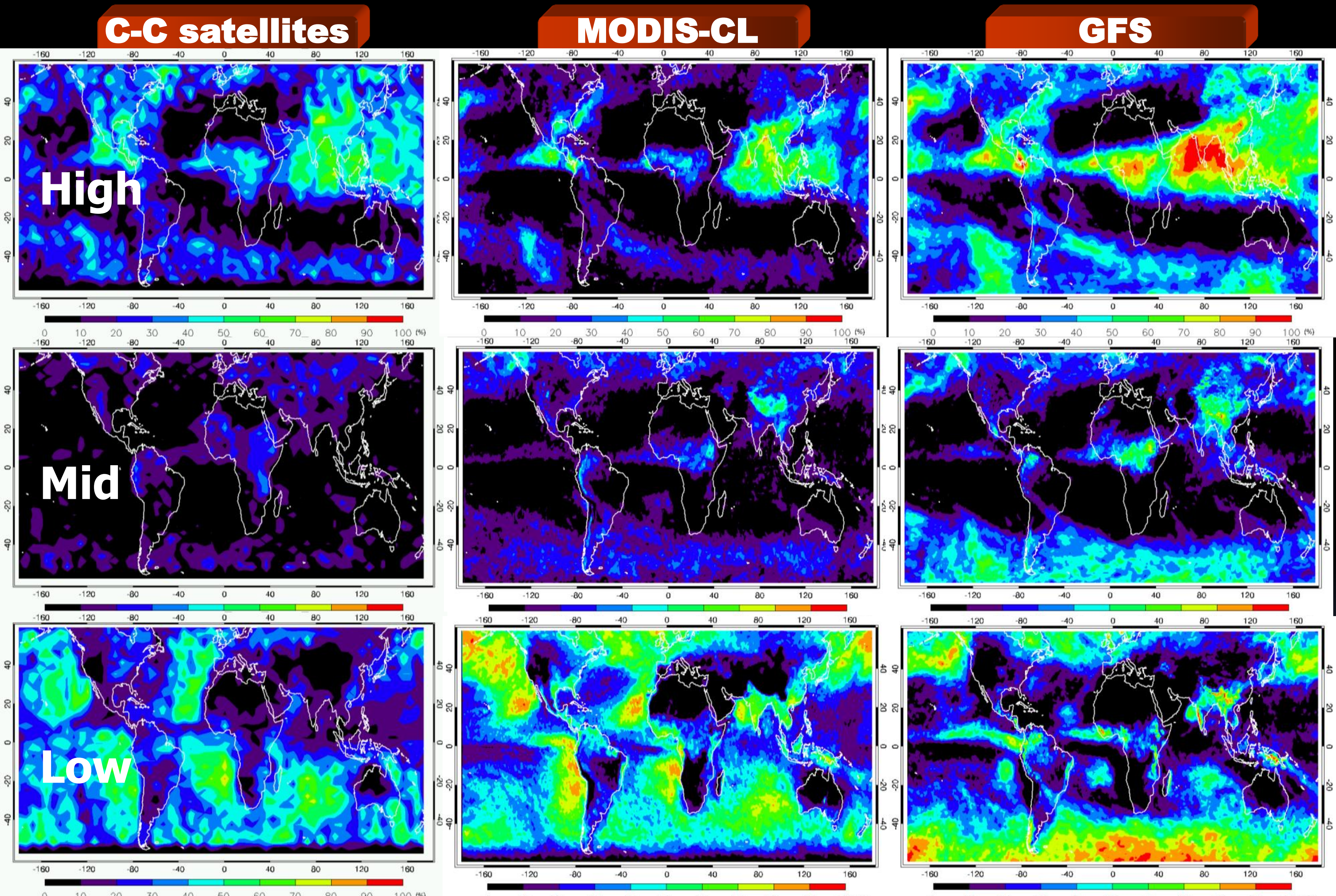


Annual mean: 27%

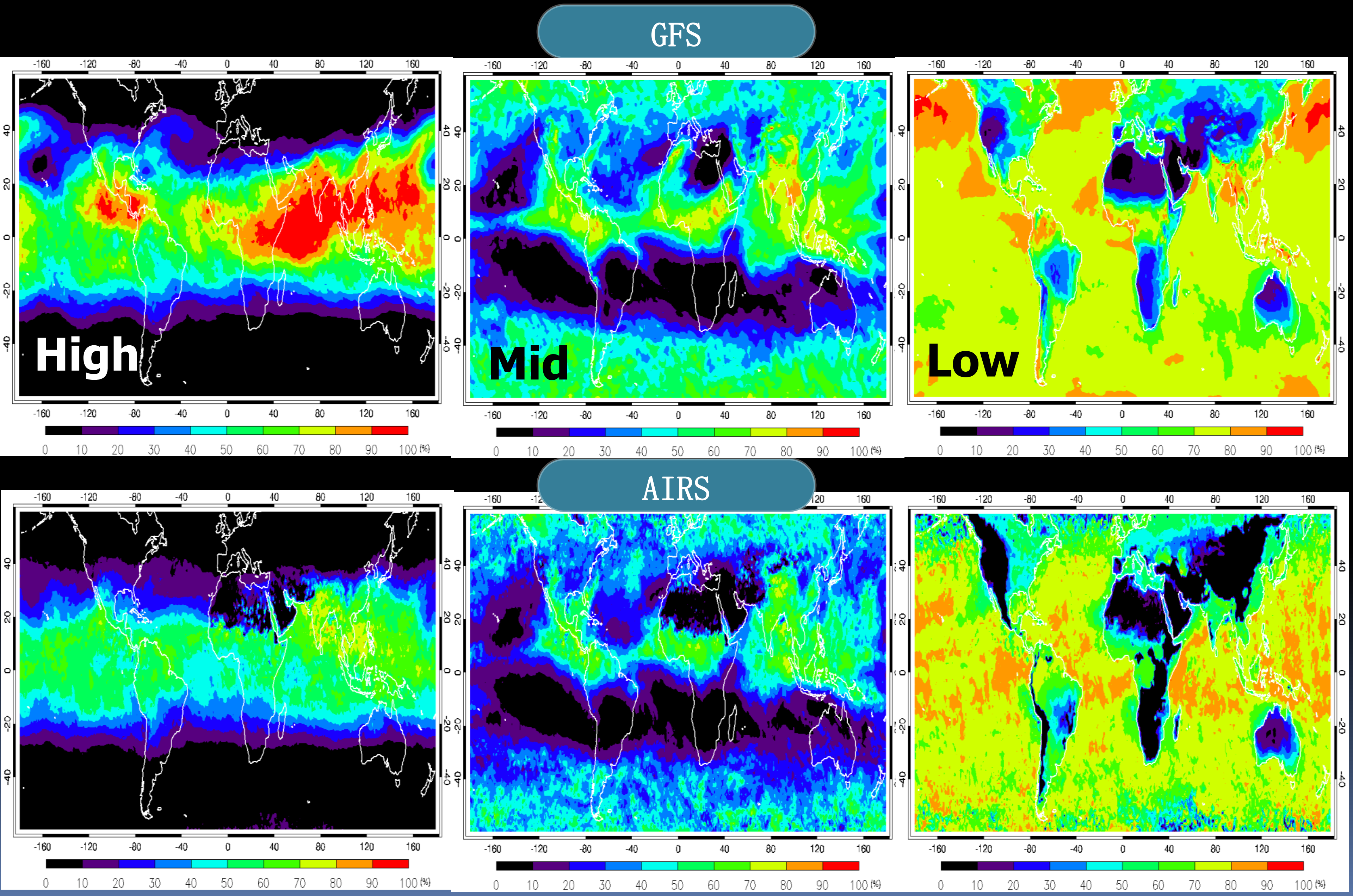
Chang and Li (2005, JCL)


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

Comparison of Original Cloud Fraction

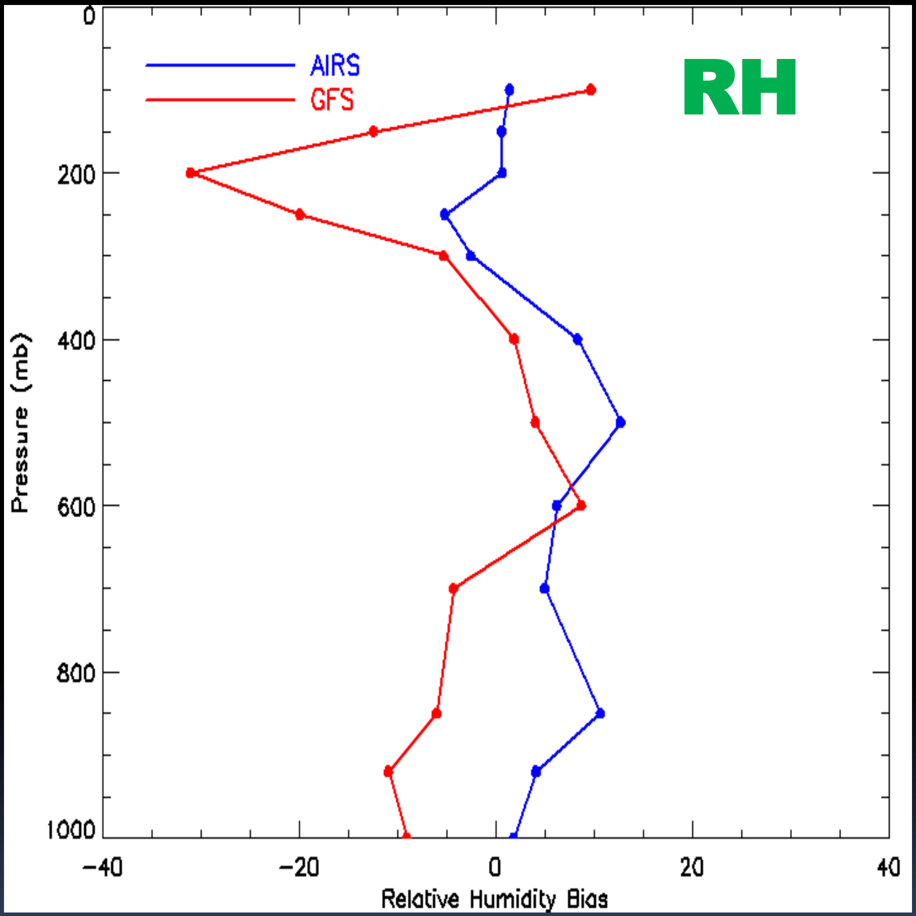


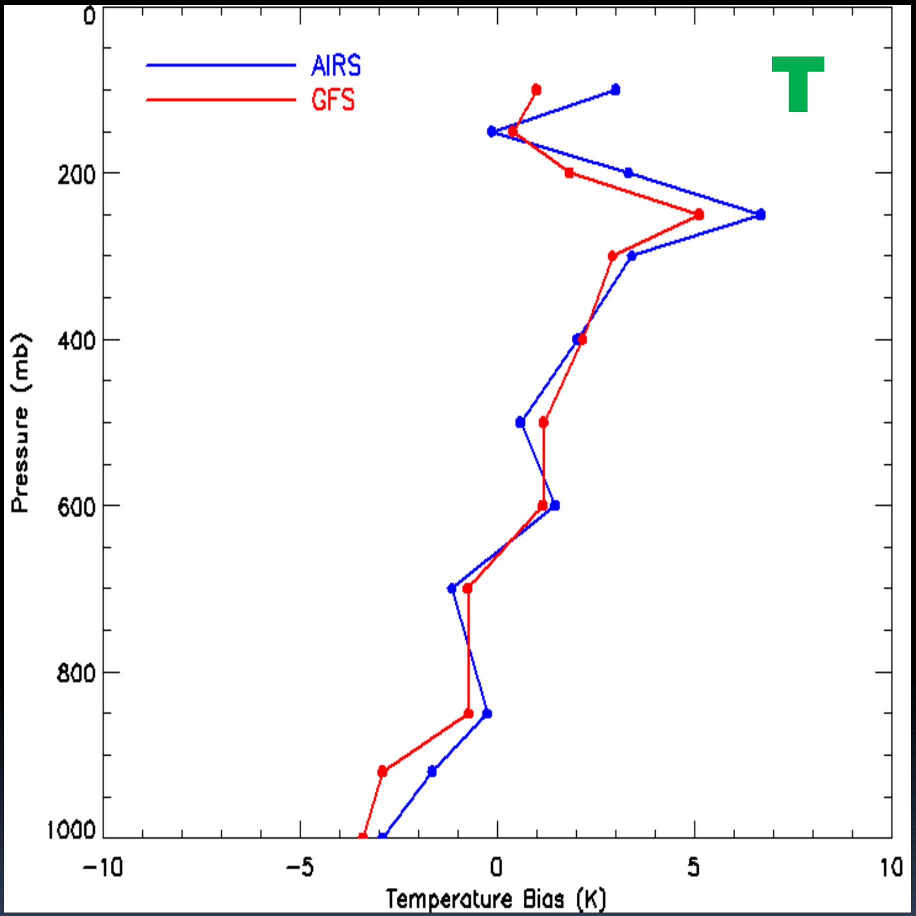
Comparison of RH Fields



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 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

cloud fraction =

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

SG cloud scheme 2

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(ω)

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

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

- marine stratocumulus clouds

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

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

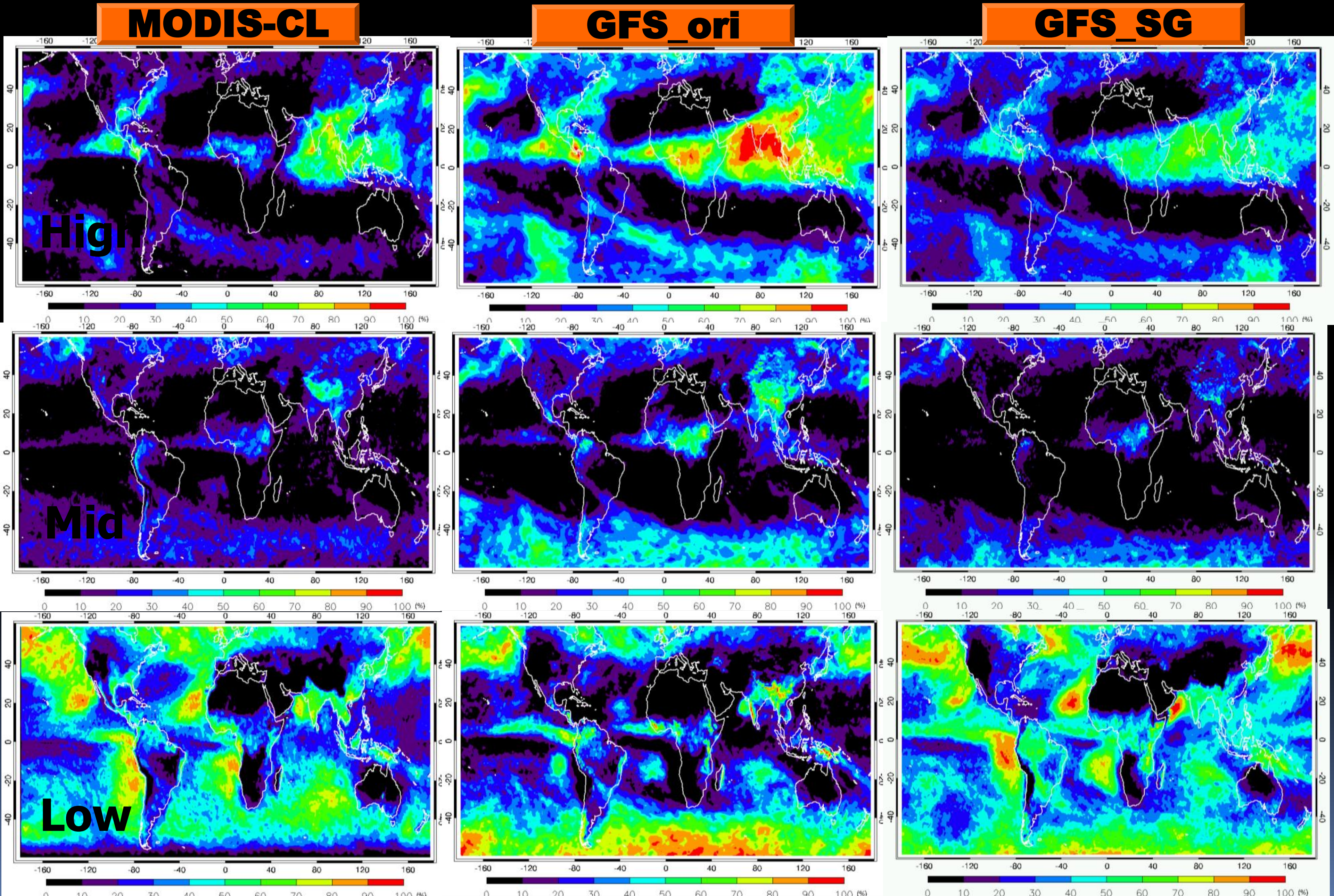
$$B(RH)=\begin{bmatrix} 1 \\ (RH-RH_{min})/(RH_{max}-RH_{min}) \\ 0 \end{bmatrix} \text{ if } \begin{bmatrix} RH > RH_{max} \\ RH_{min} \le RH \le RH_{max} \\ RH < RH_{min} \end{bmatrix}$$

- shallow convective clouds

Nshl = 0.2*A_{max}(RHe)

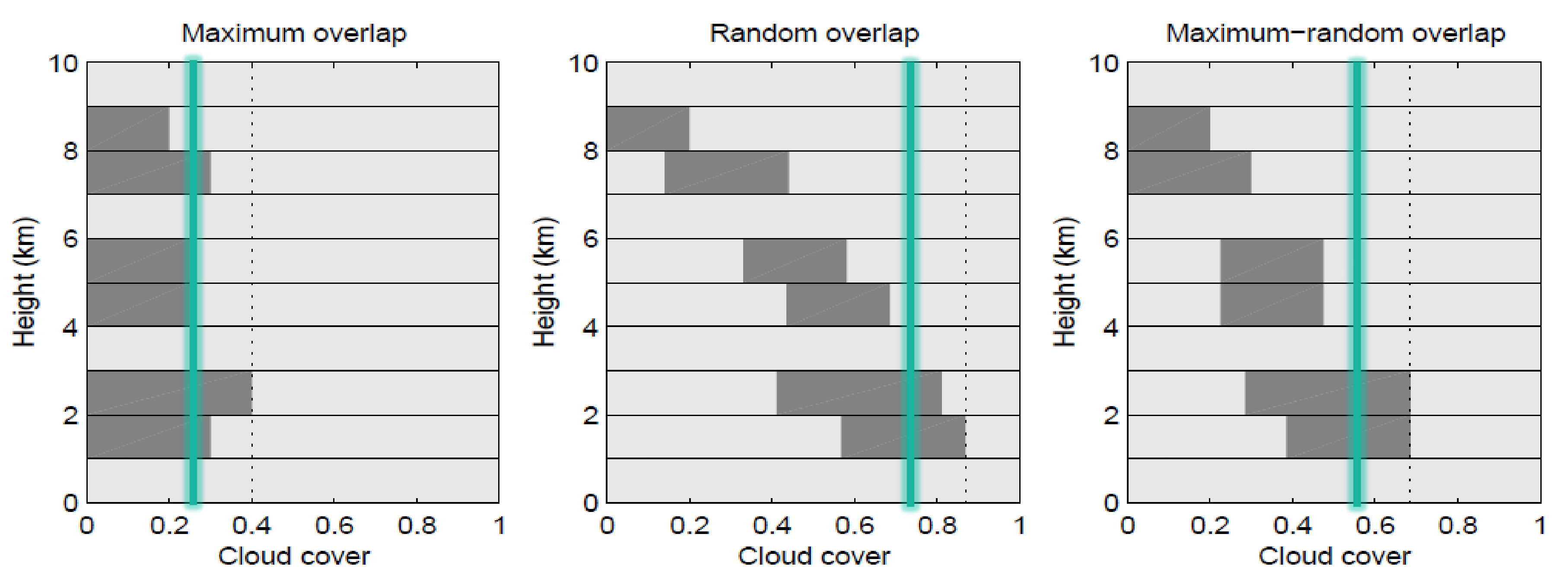
A_{max}(RHe) is the maximum value of RHe

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

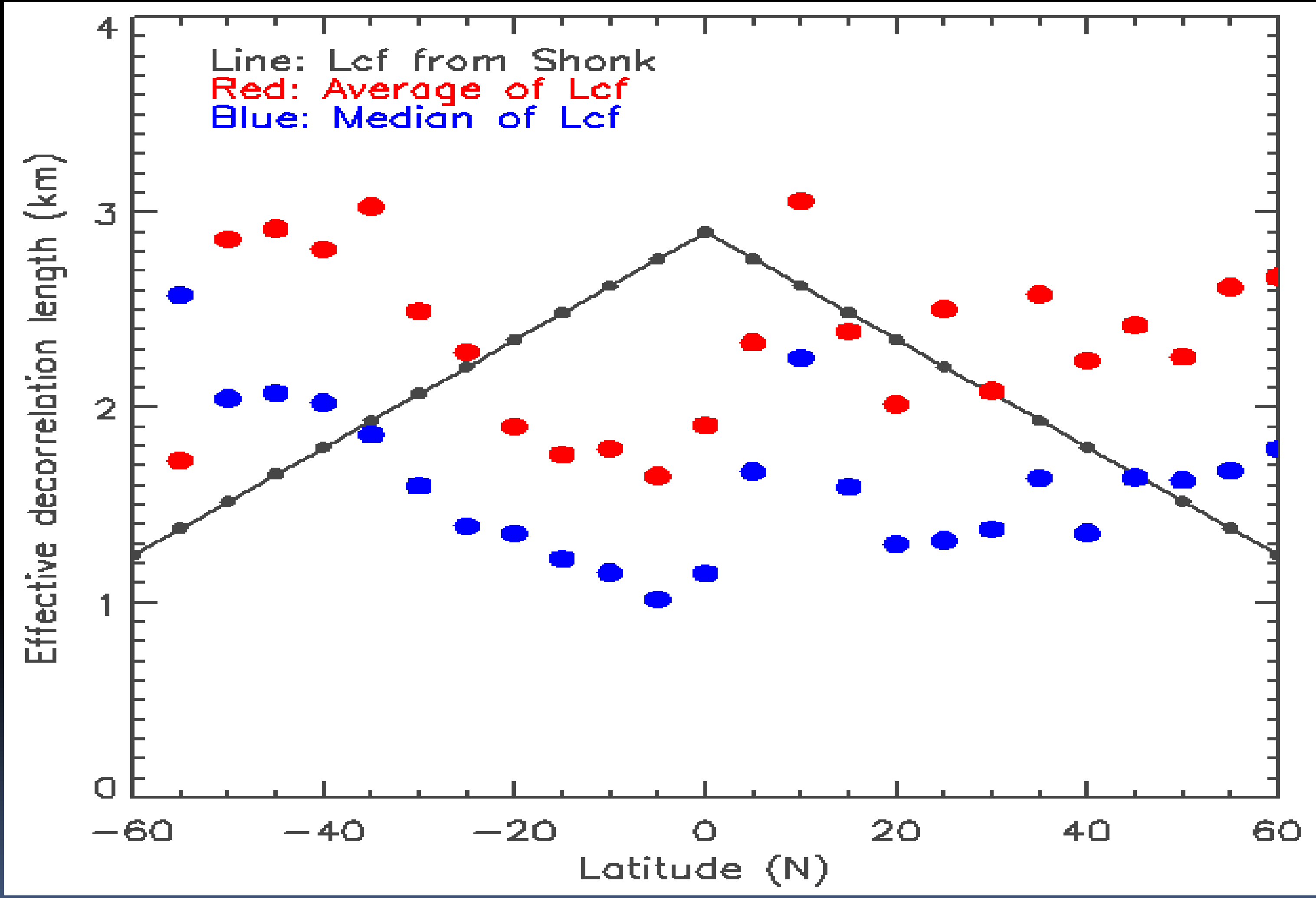
▶ Shonk et al. — 2010

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

Lcf : dependent on only latitudes

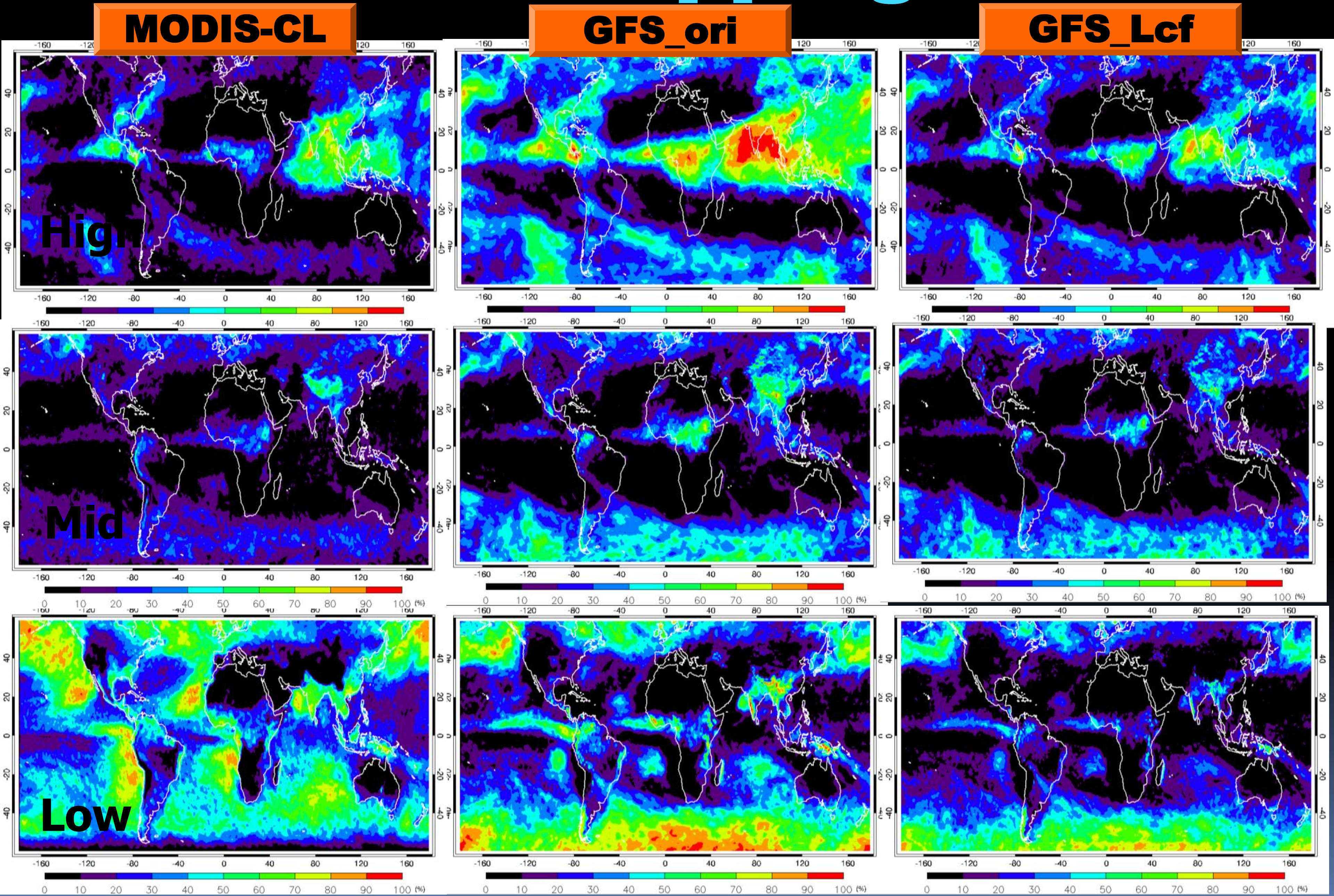
Cloud Overlapping Scheme

Comparisons of Lcf

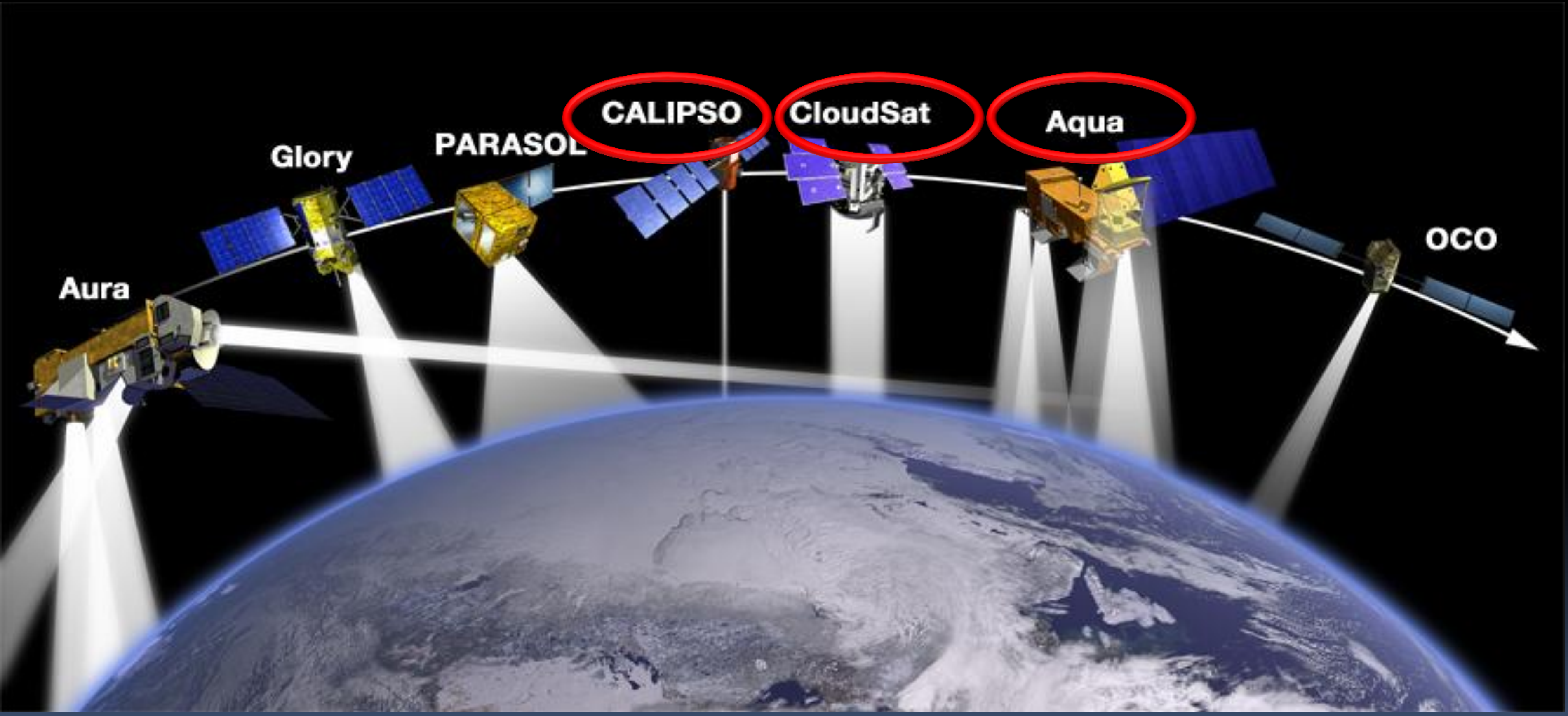


Lcf values as a function of latitude for July 2007. The black solid line is a simple linear fit suggested by Shonk et al. (2010) and the red and blue dots show mean and median values of Lcf, respectively.

Cloud Overlapping Scheme

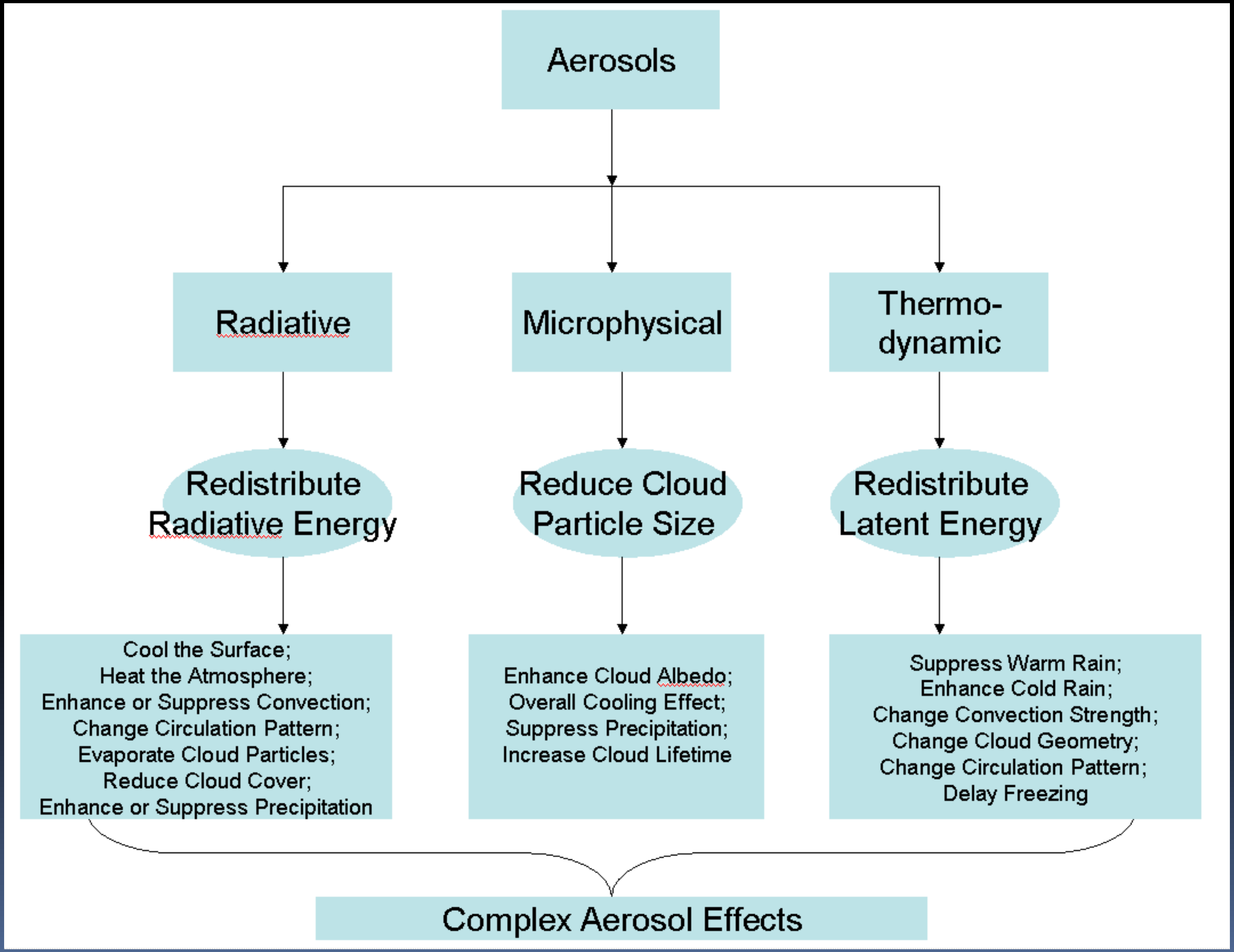


Use of A-Train Satellite Data to Study the Impact of Aerosols on Cloud, Precipitation & Radiation Budget

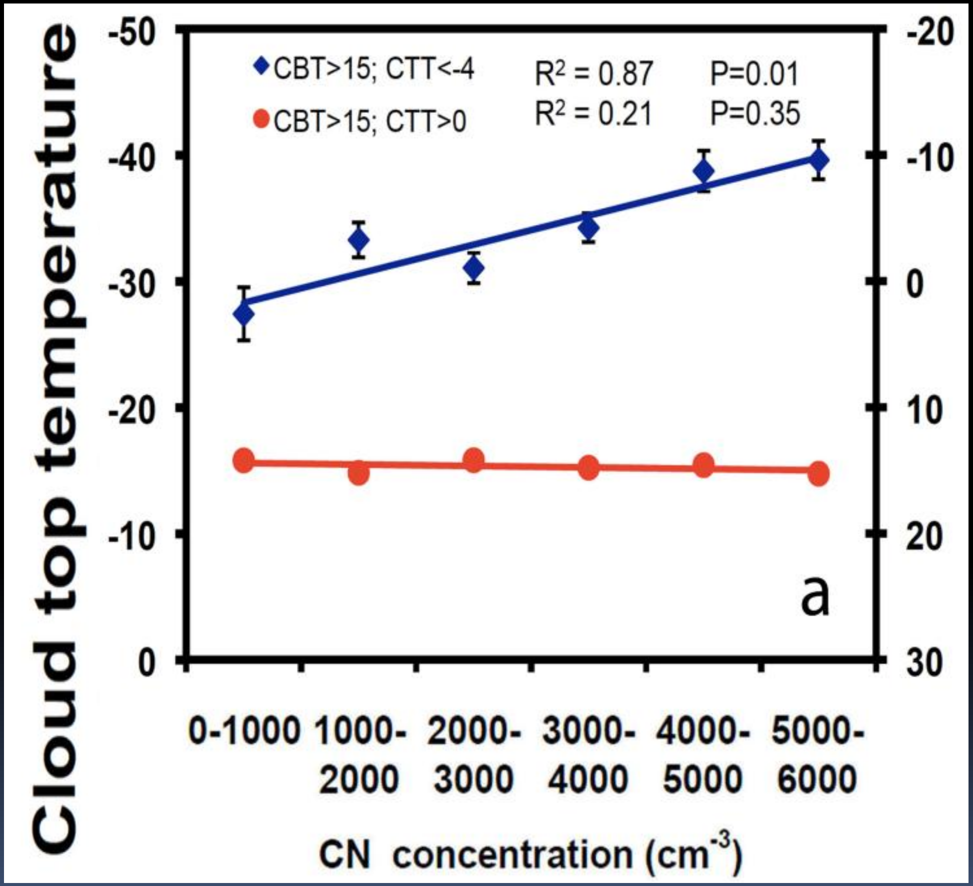


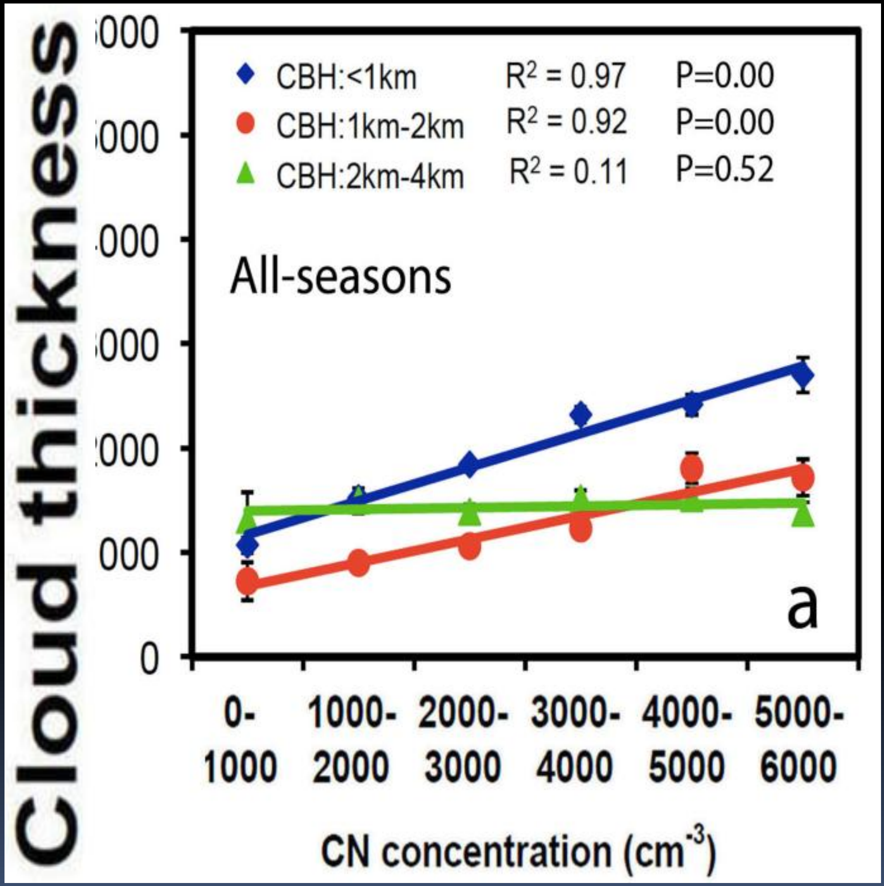
Niu, F., and Z. Li, 2012: Systematic variations of cloud top temperature and precipitation rate with aerosols over the global tropics, Atmos. Chem. Phys., 12, 8491-8498.

Three Pathways by Which Aerosols Influence Climate



Long-term Impact of Aerosols on Cloud Geometry

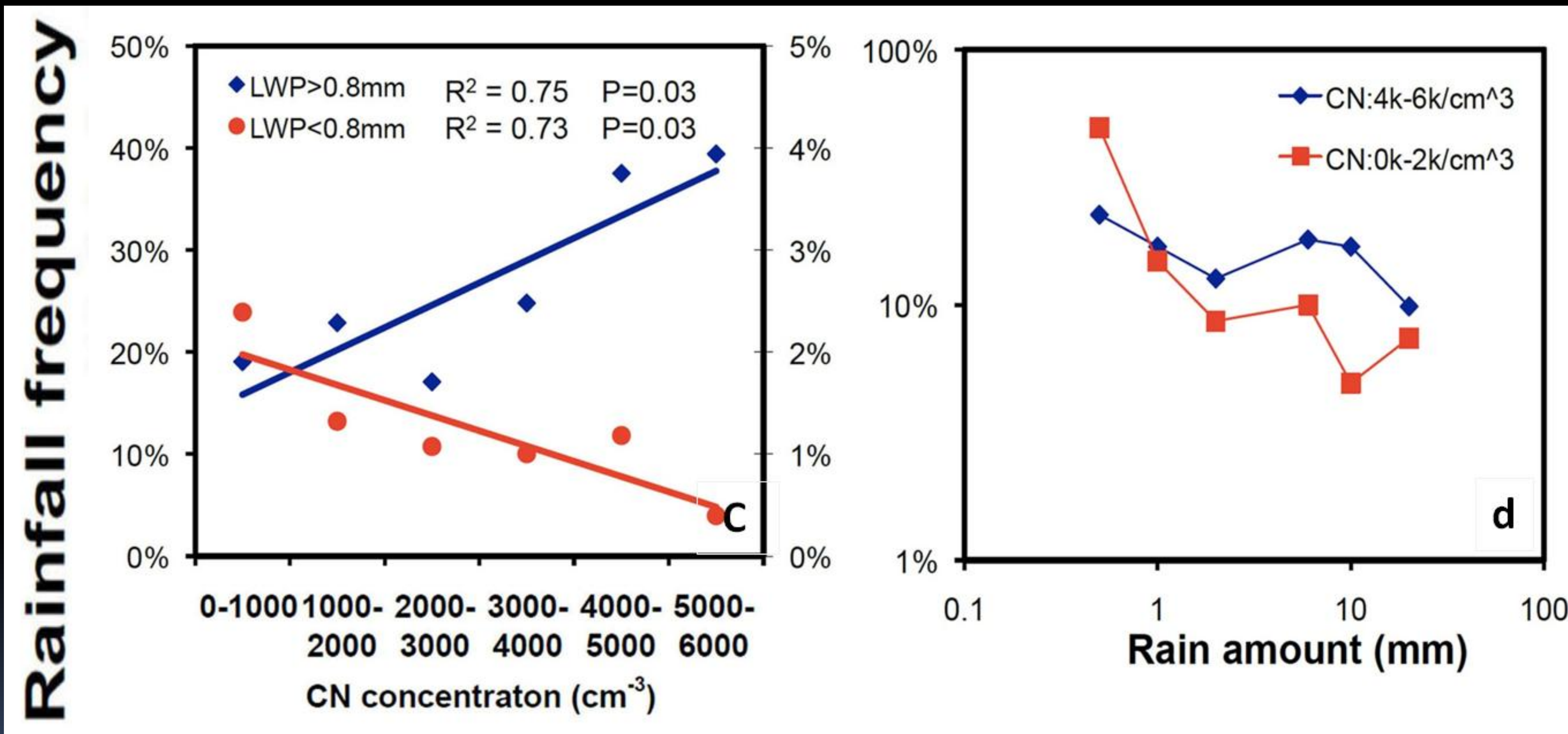




CBT: cloud base temp. **CBH: cloud base height**

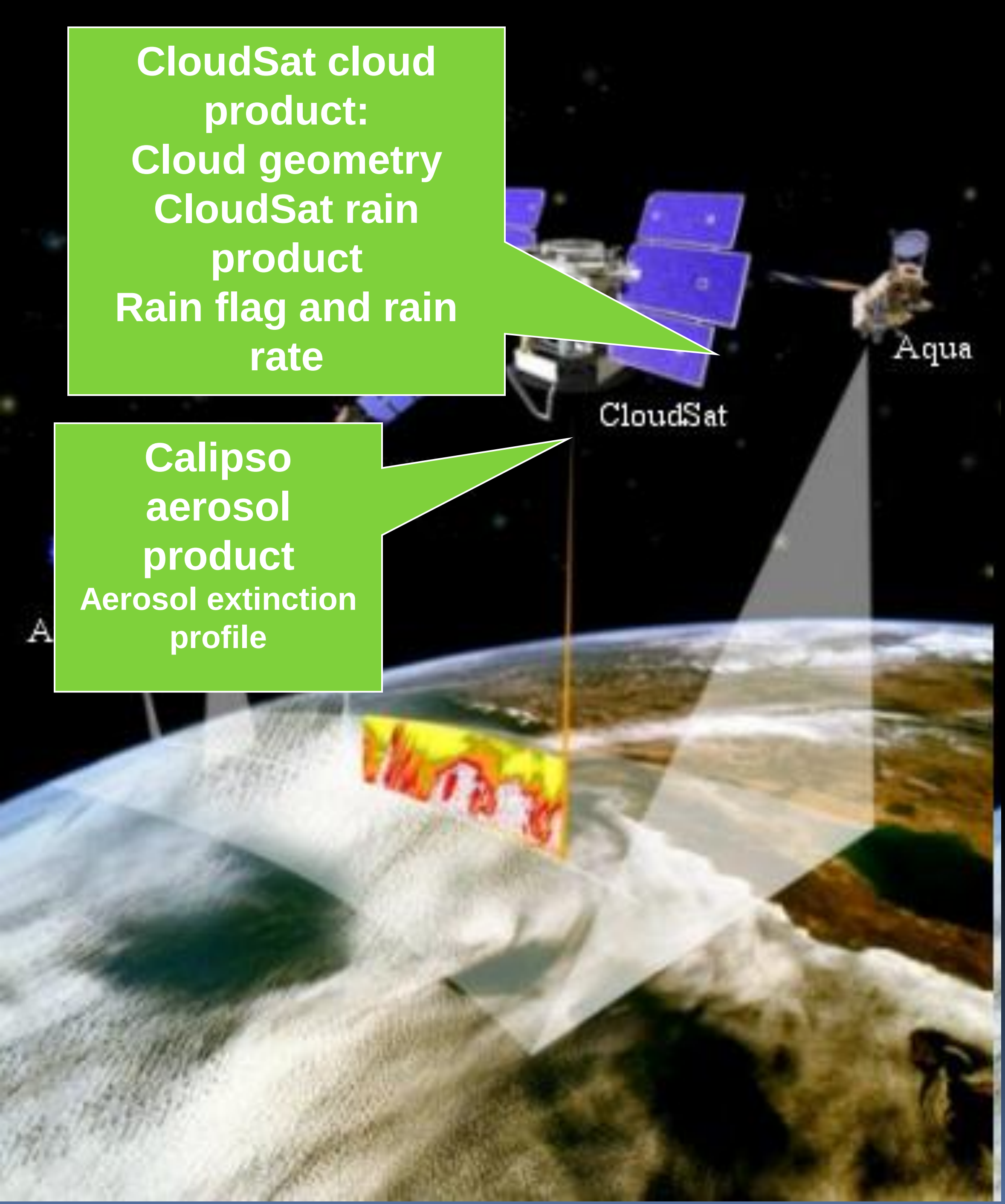
Li et al. (Nature-Geosci., 2011)

Long-term Impact of Aerosols on Precipitation



LWP: liquid water path, CN: condensation nuclei

Li et al. (Nature-Geosci., 2011)



CloudSat cloud product:
Cloud geometry
CloudSat rain product
Rain flag and rain rate

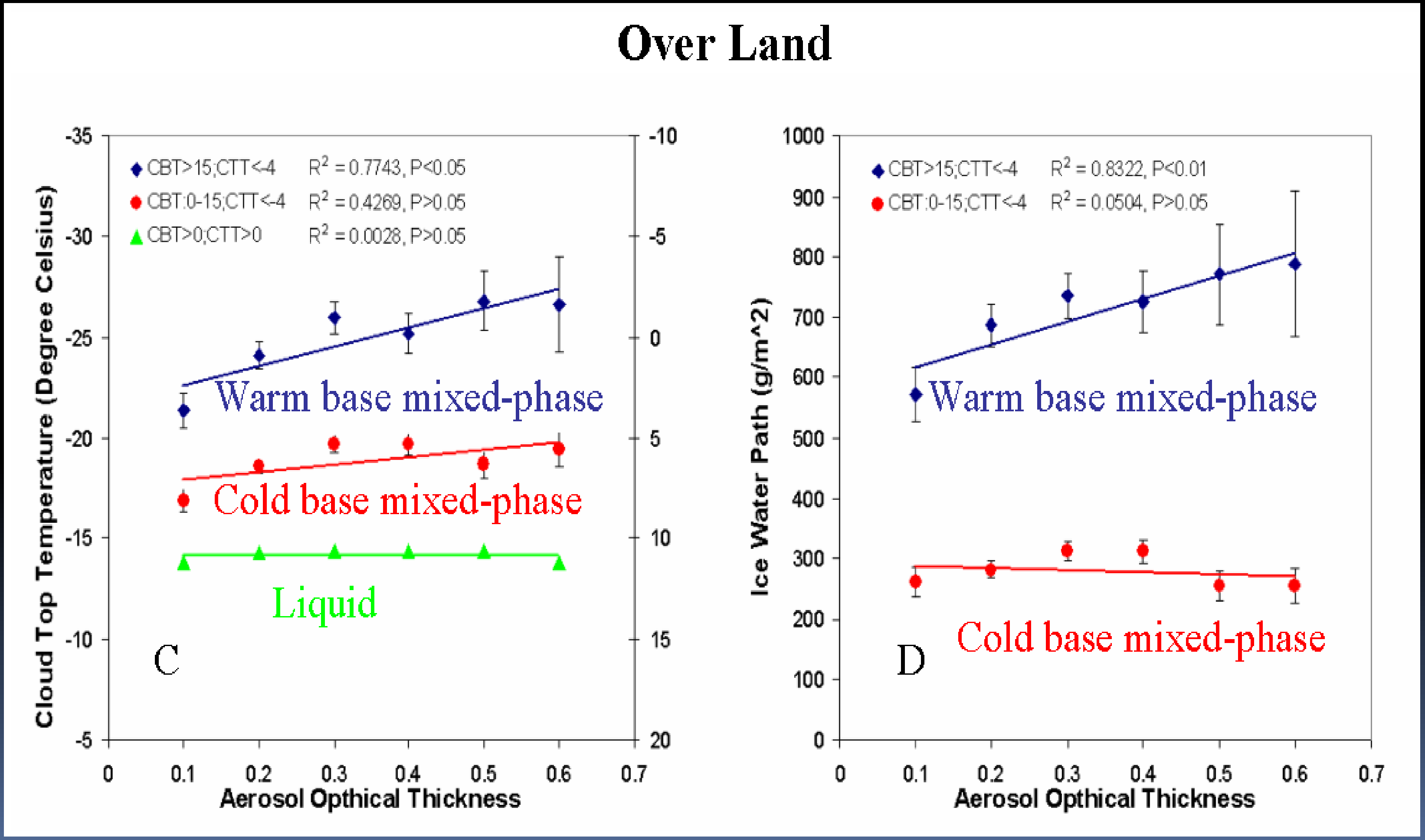
Calipso aerosol product
Aerosol extinction profile

MODIS aerosol product:
AOT over ocean
AOT over land

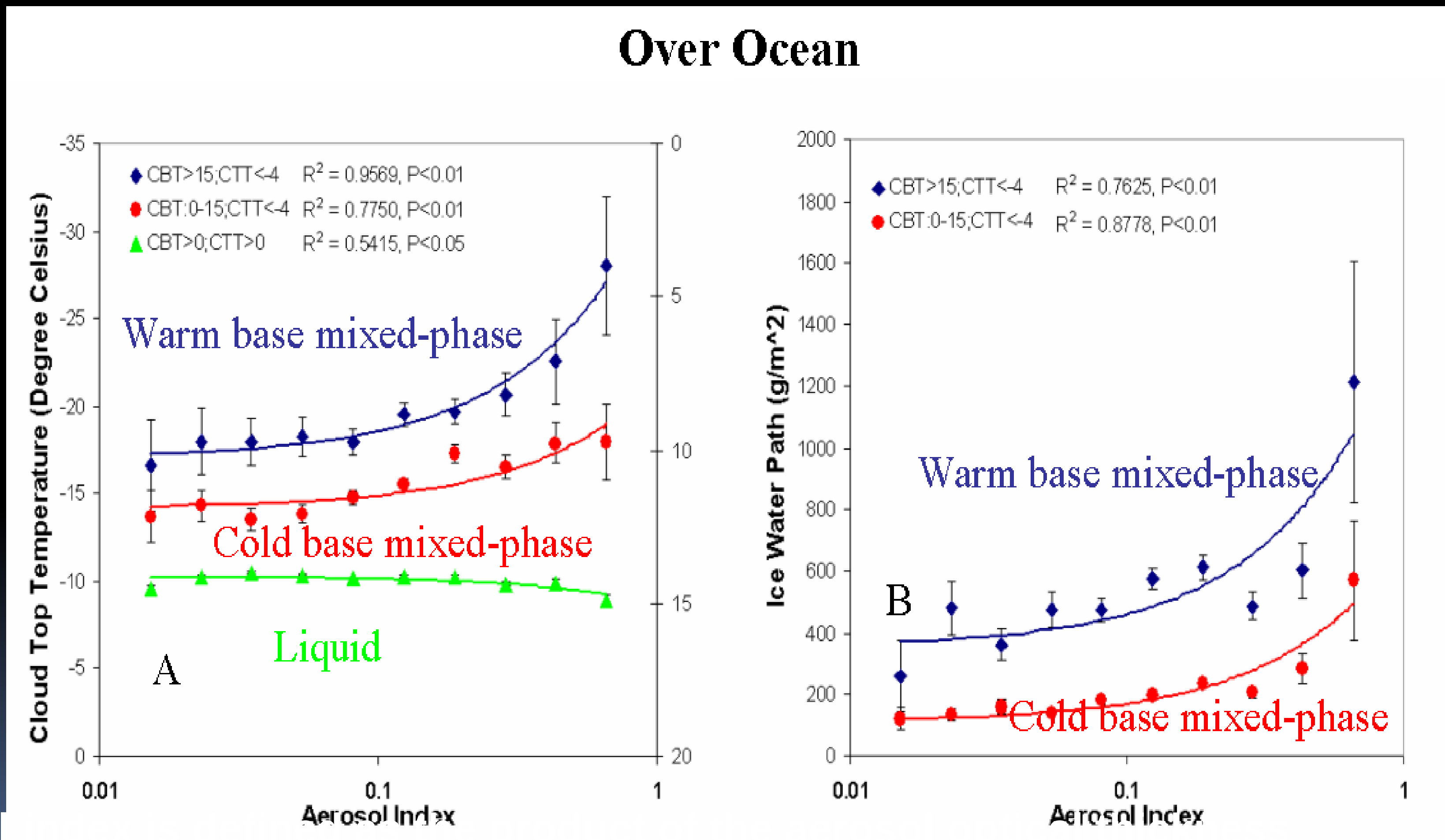
MODIS cloud product:
Cloud effective radius
Cloud optical depth

AMSR-E cloud product:
Cloud liquid water
Column water vapor

Cloud Top Temperature and Ice Water Path Vary Systematically with Aerosol Loading for Deep Clouds but Little Change for Shallow Warm Clouds

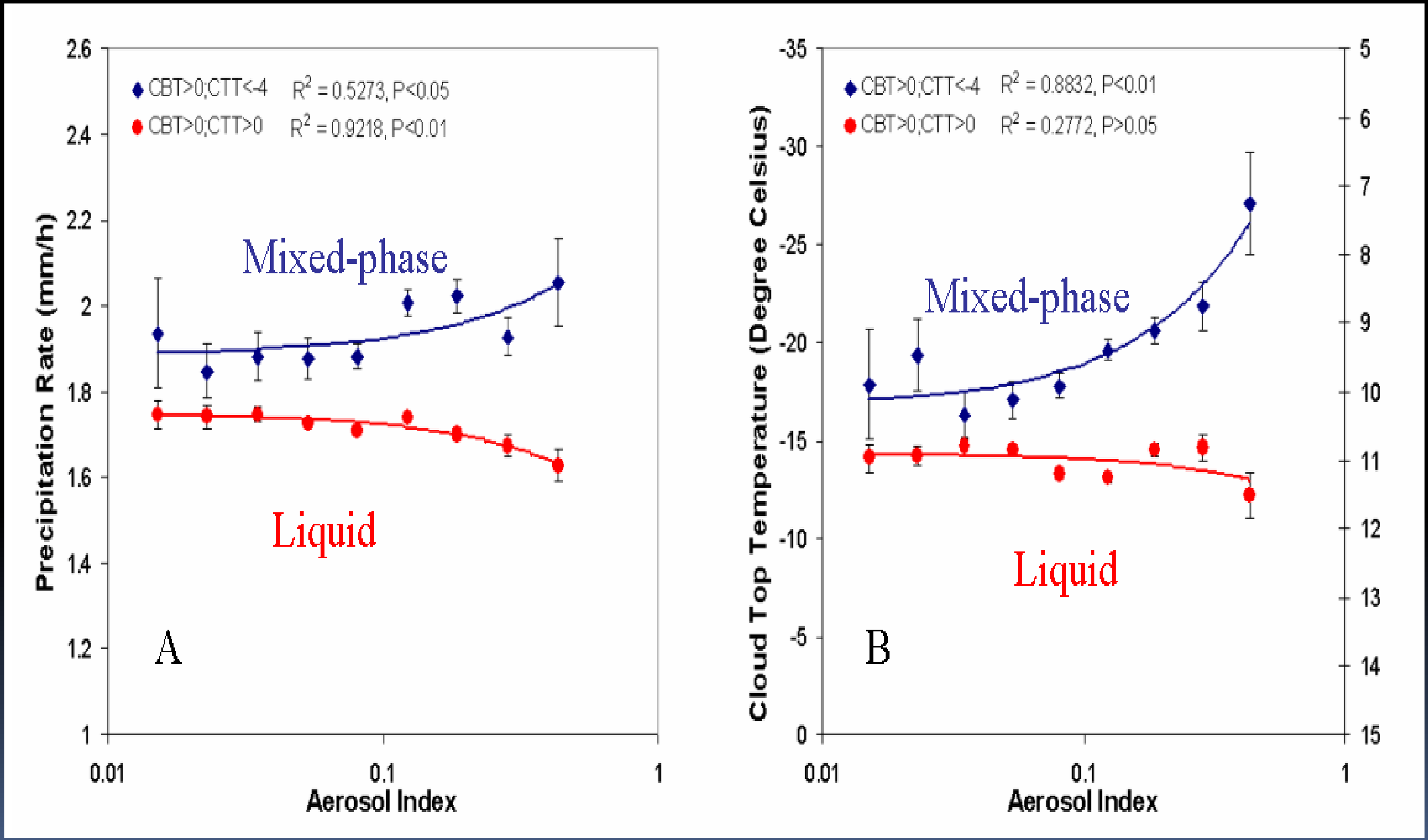


Cloud Top Temperature and Ice Water Path Vary Systematically with Aerosol Loading for Deep Clouds but Little Change for Shallow Warm Clouds

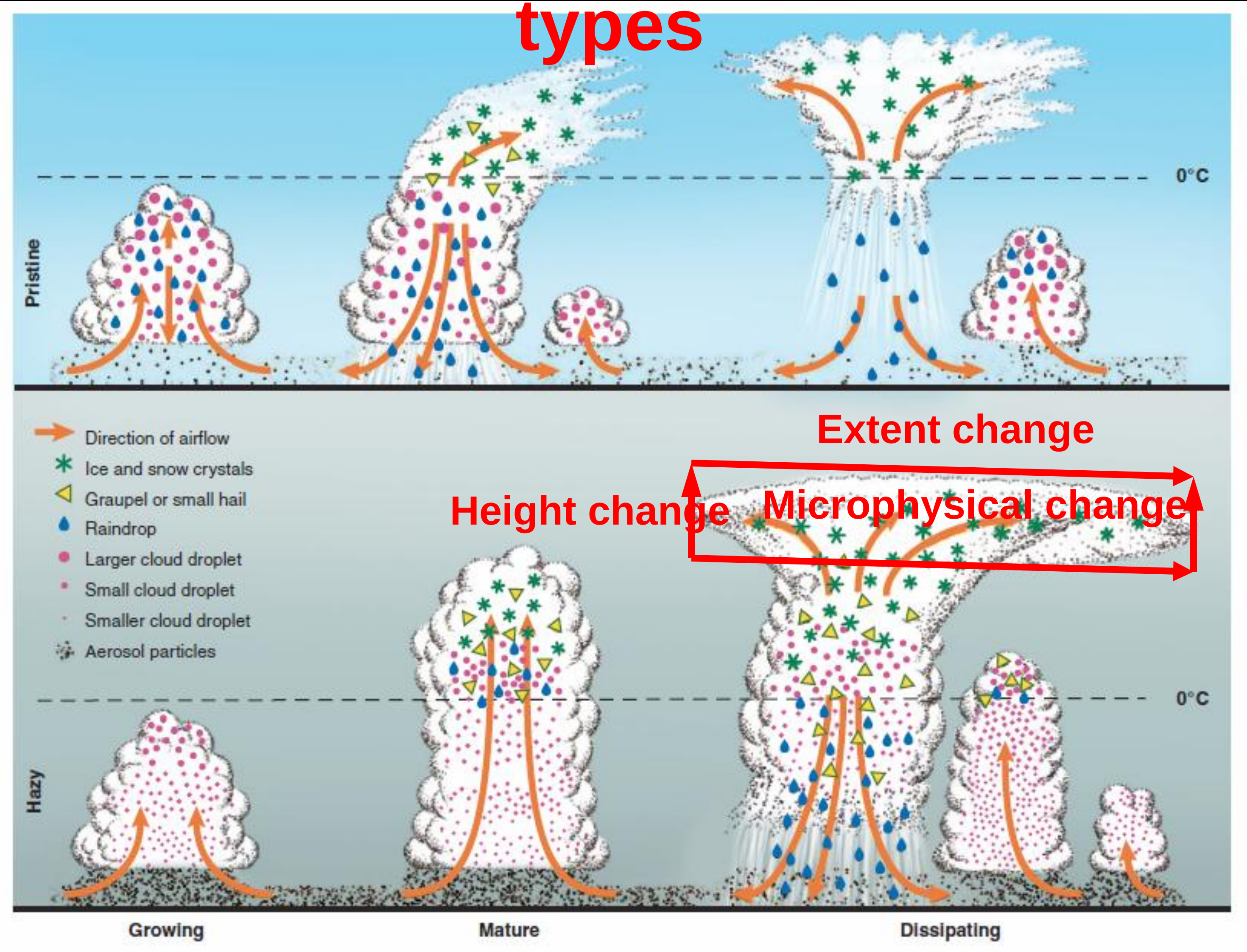


Aerosol
and Angstrom exponent.

Precipitation Rate Increases with Aerosol for Mix-phase Clouds but Decreases for Liquid Clouds



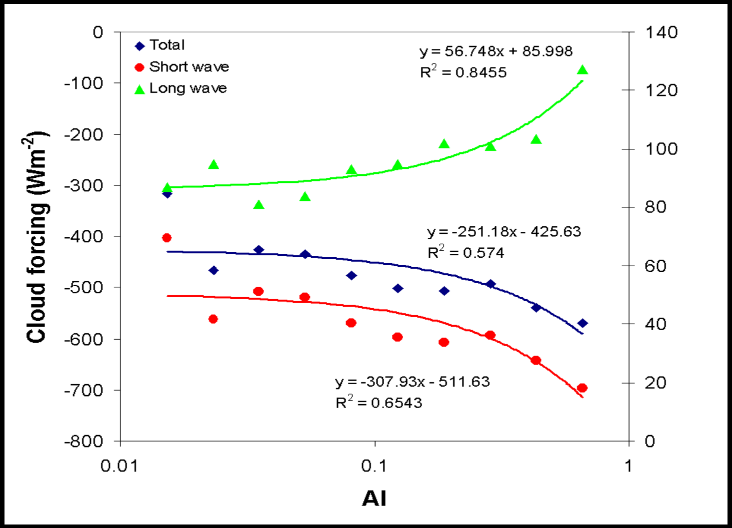
Impact of aerosol invigoration effect on cloud radiative forcing: 3 types



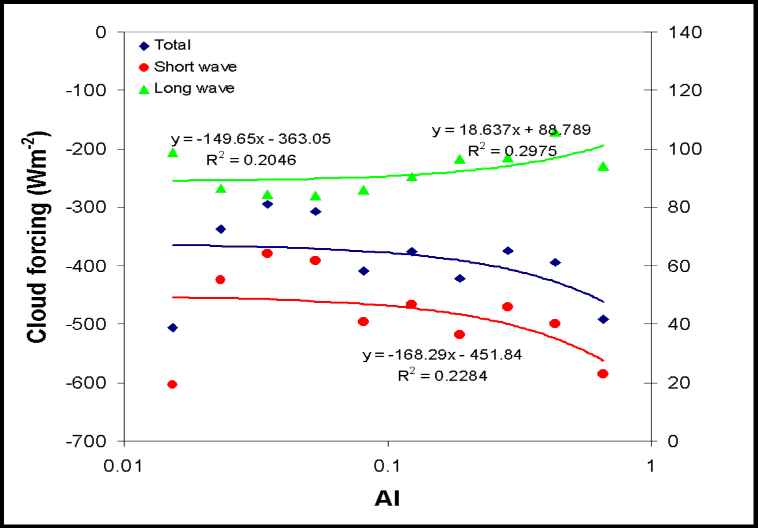
Rosenfeld et al (2008, Science)

Impact on aerosol radiative forcing due to The macro- and micro-physcial changes by Aerosols A missing term in the climate forcing estimation

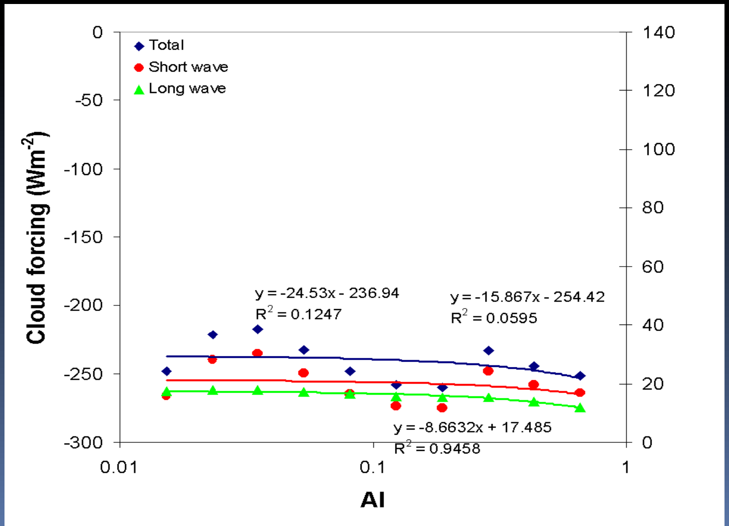
Warm base mixed-phase



Cold base mixed-phase



Only the microphysical effect is accounted for in the current estimates



Liquid clouds – Microphysical effe

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.

谢谢各位！

Thank you!