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Satellite observations, cloudy boundary layers and the representation of subgrid scale processes in climate models

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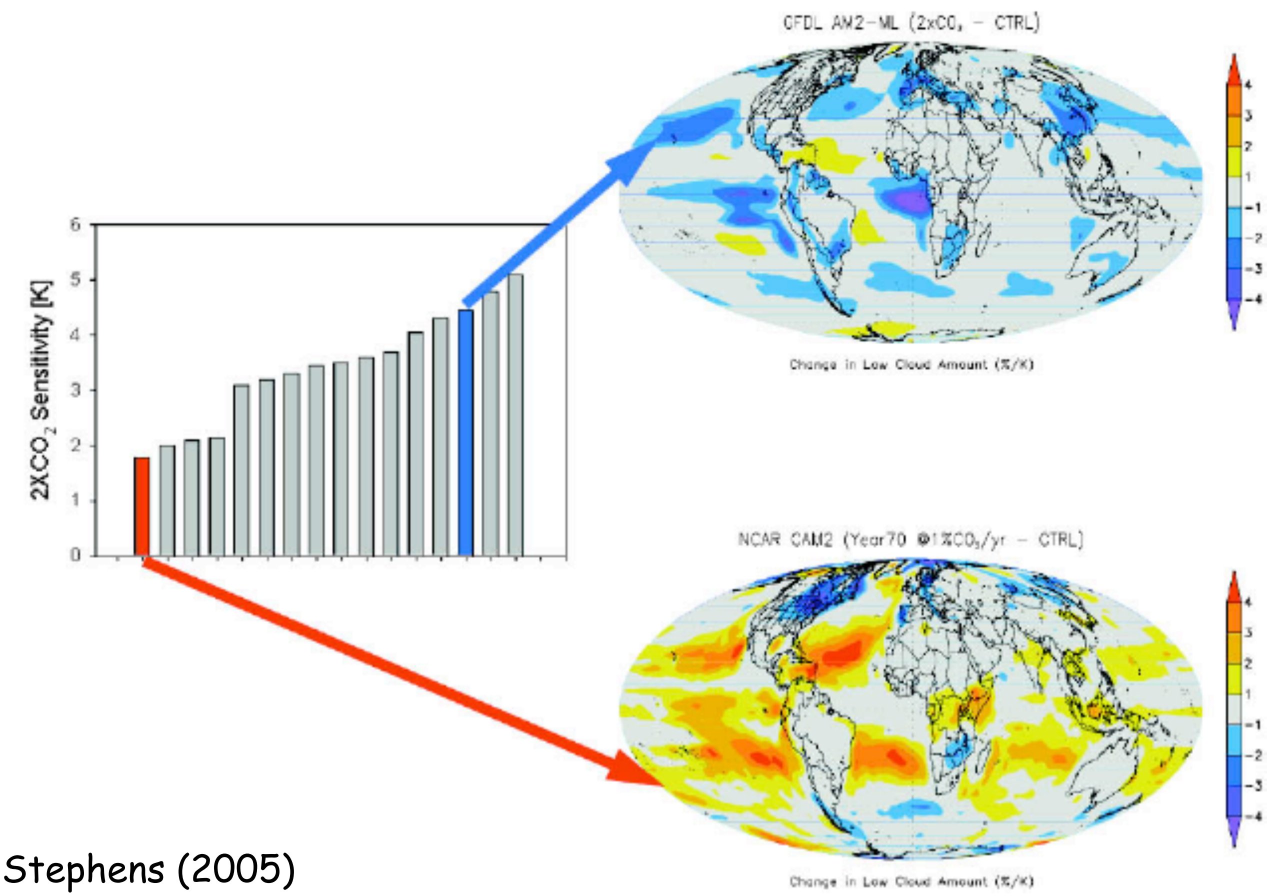
Climate is changing … YET there is large uncertainty in climate prediction

IPCC 2007: "Cloud feedbacks remain the largest source of uncertainty"



Stephens (2005)

Doubling CO_2 → less low clouds in GFDL → 4 K global warming

Doubling CO_2 → more low clouds in NCAR → 2 K global warming

We do not know if low clouds are going to increase or decrease – Why?

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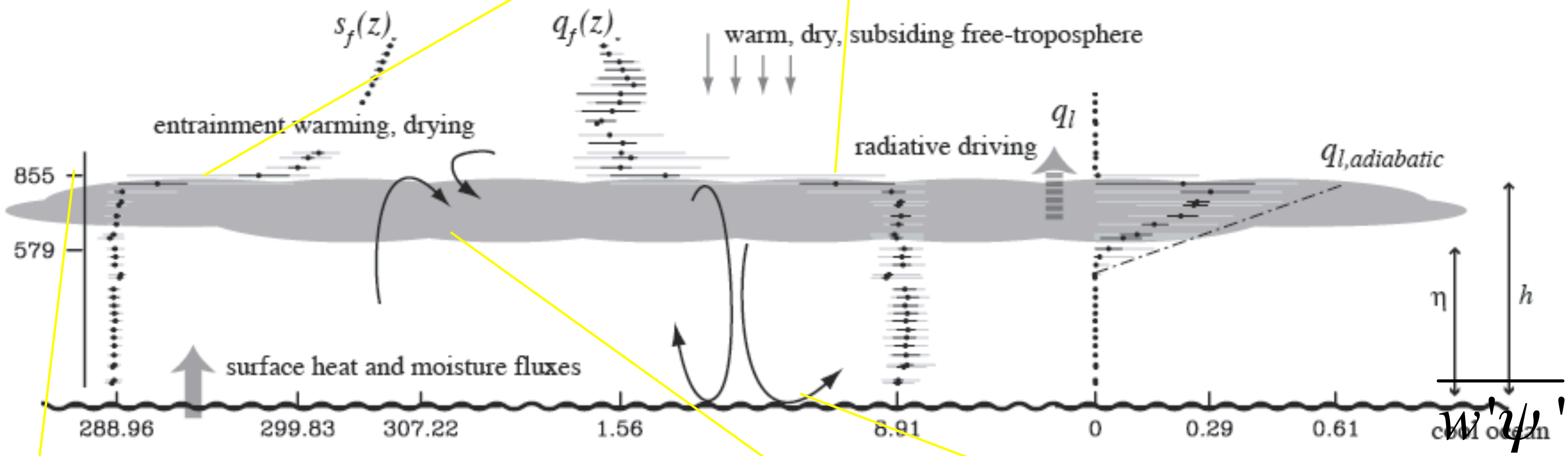
Cloudy boundary layer: the main challenges

Strong gradients of temperature and water vapor

DYCOMS II composite

Courtesy: B. Stevens



Even just detecting accurately the height of the gradient is essential

Small-scale turbulent mixing

<u>Main Observation and Modeling Problems:</u>

a) Strong vertical gradients;
b) Small-scale turbulent mixing.

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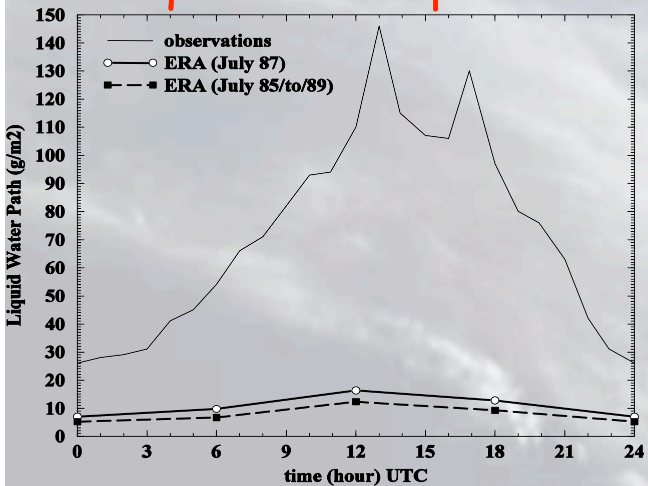
How well are stratocumulus represented? Observations versus ECMWF Re-Analysis (ERA)

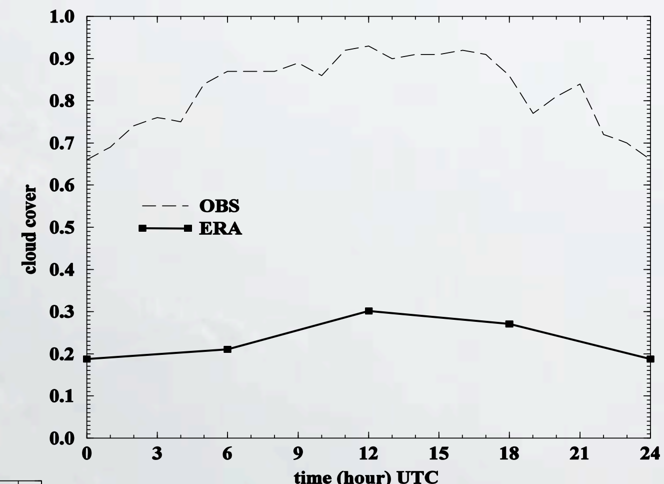
July 1987, San Nicolas island, California

Liquid water path

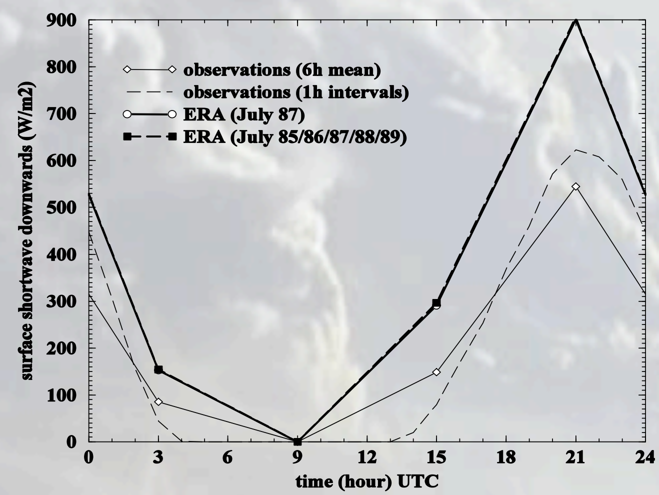


Severe underestimation of clouds

Cloud cover



Surface shortwave



Duynkerke and Teixeira, JCLI, 2001

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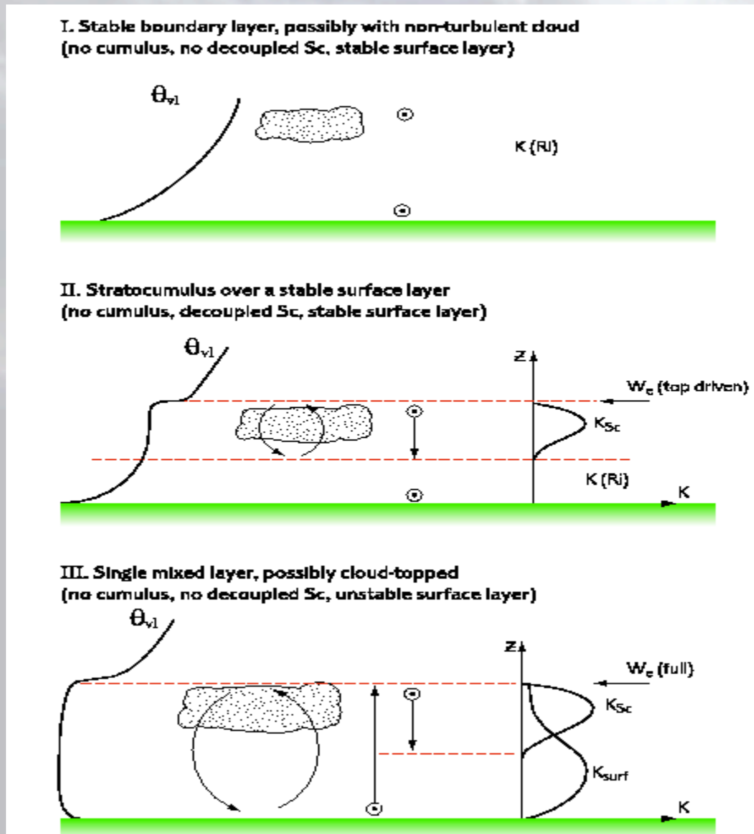
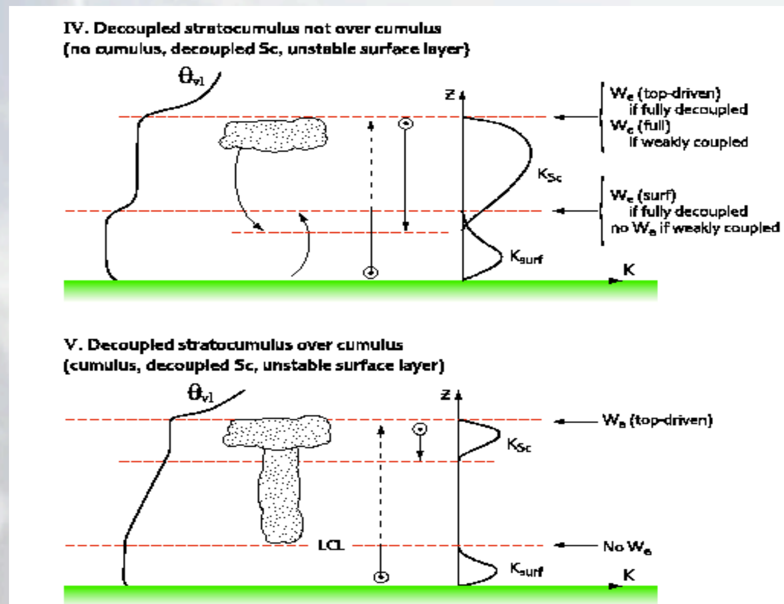
Cloudy boundary layer: Nature organizes itself in different "regimes"

These regimes may have similar cloud properties observed from space –

BUT have very different T and q structures





Courtesy: A. Lock

Boundary layer T , q structures is key to understand low cloud feedbacks

Ability to observe different vertical structures from space is essential!

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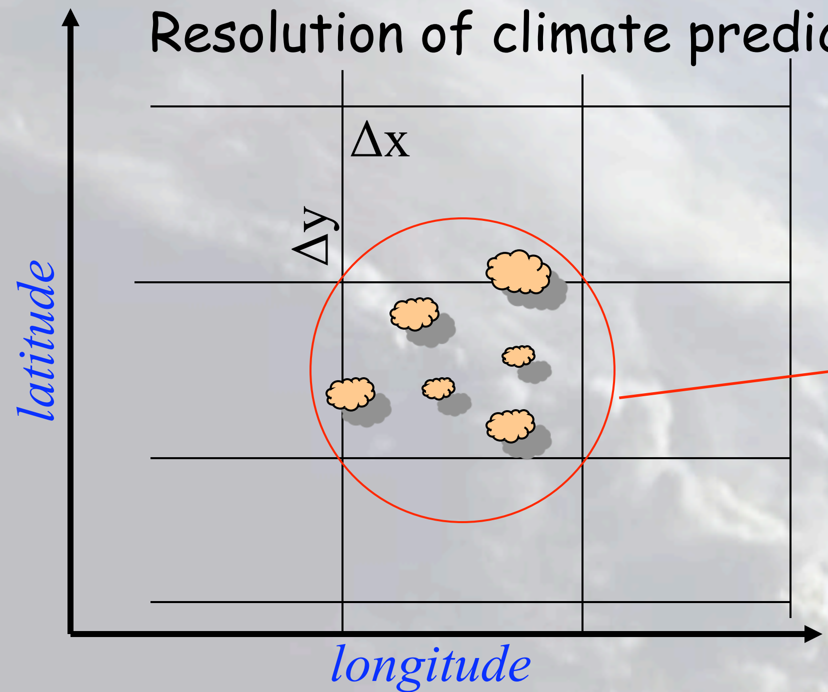
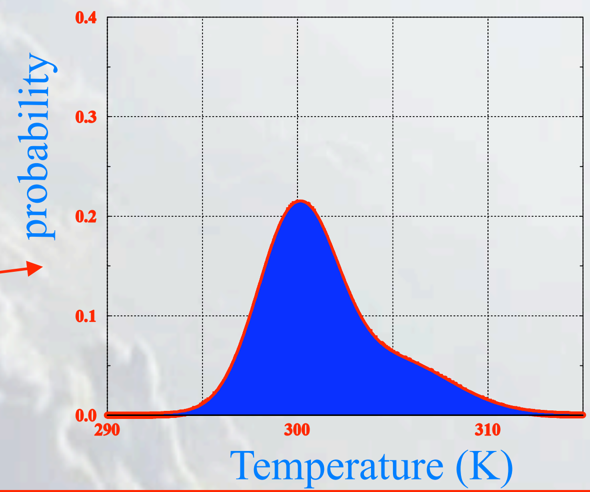
What is the physical parameterization problem in Climate models?

It is related to the classic problem of turbulence (e.g. Von Karman) with additional complexity: buoyancy, phase-transitions, radiation, precipitation, gravity waves, wide range of scales (from 10^{-3} to 10^{6} m)

Resolution of climate prediction models: $\Delta x = \Delta y \sim 100$ km





PDF of temperature in model grid-box

Essence of parameterization problem is the estimation of PDFs of climate model variables (u, v, T, q)

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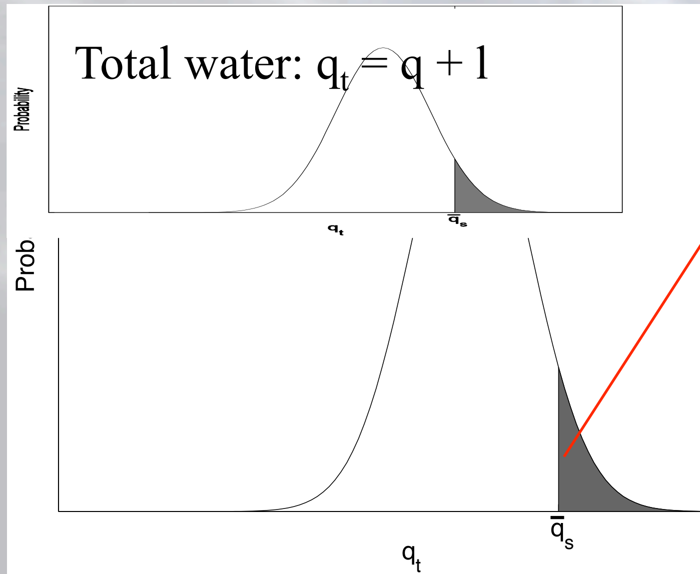
PDF-based Cloud Parameterizations

PDF-based cloud parameterizations are based on the pdf of q_t (in this simple example) or on the joint pdf of q_t and θ_l



Values larger than saturation are cloudy

$$a = \int_{q_s}^{+\infty} p(q_t)\,dq_t$$

$$\overline{l} = \int_{q_s}^{+\infty} (q_t - \overline{q_s})\,p(q_t)\,dq_t$$

With Gaussian distribution we obtain cloud fraction and liquid water as a function of Q:

$$a = \frac{1}{2} + \frac{1}{2}\,erf\left(\frac{Q}{\sqrt{2}}\right)$$

$$\frac{l}{\sigma} = aQ + \frac{1}{\sqrt{2\pi}} e^{-Q^2/2}$$

$$Q = \frac{q_t - q_s}{\sigma}$$

Characterizing the variance of thermodynamic properties is essential for cloud parameterization development

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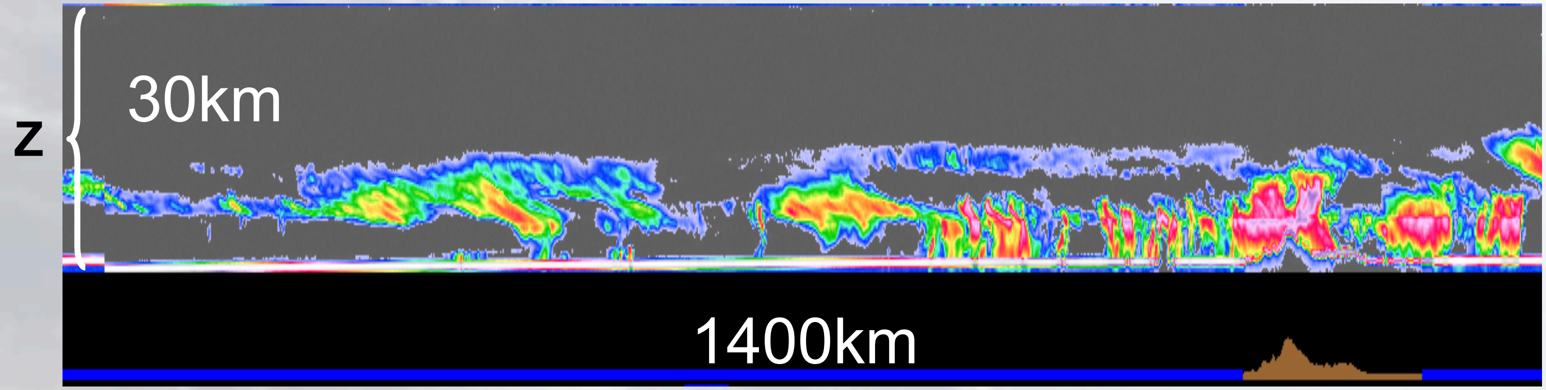
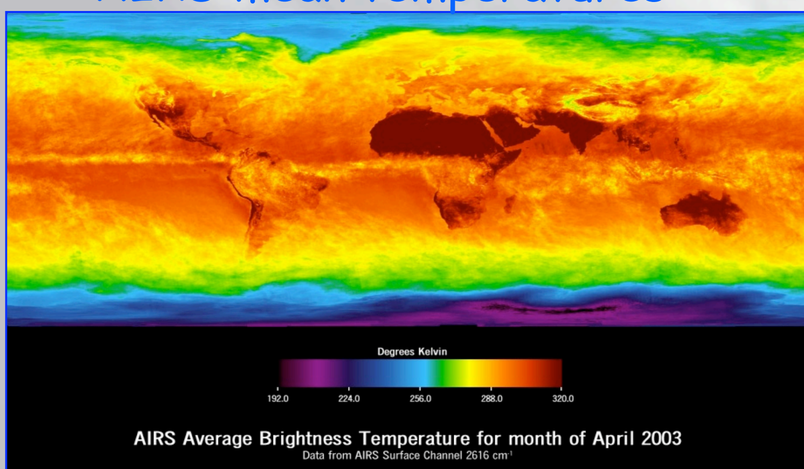
New satellite observations of 3D cloud and thermodynamic structure of atmosphere

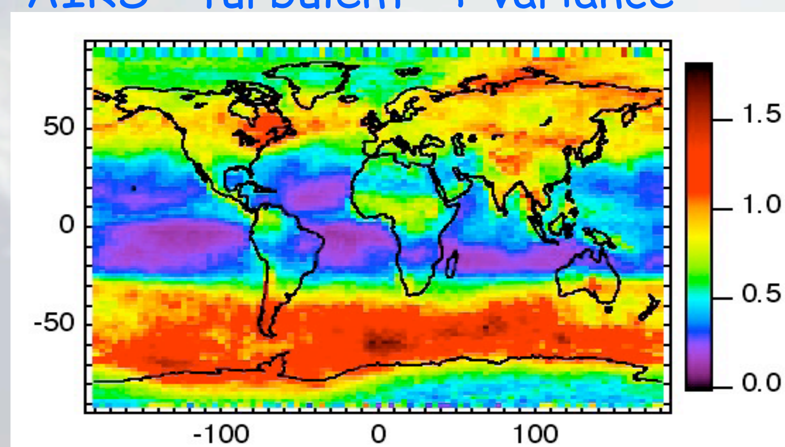
Vertical structure of clouds from CloudSat



AIRS mean temperatures



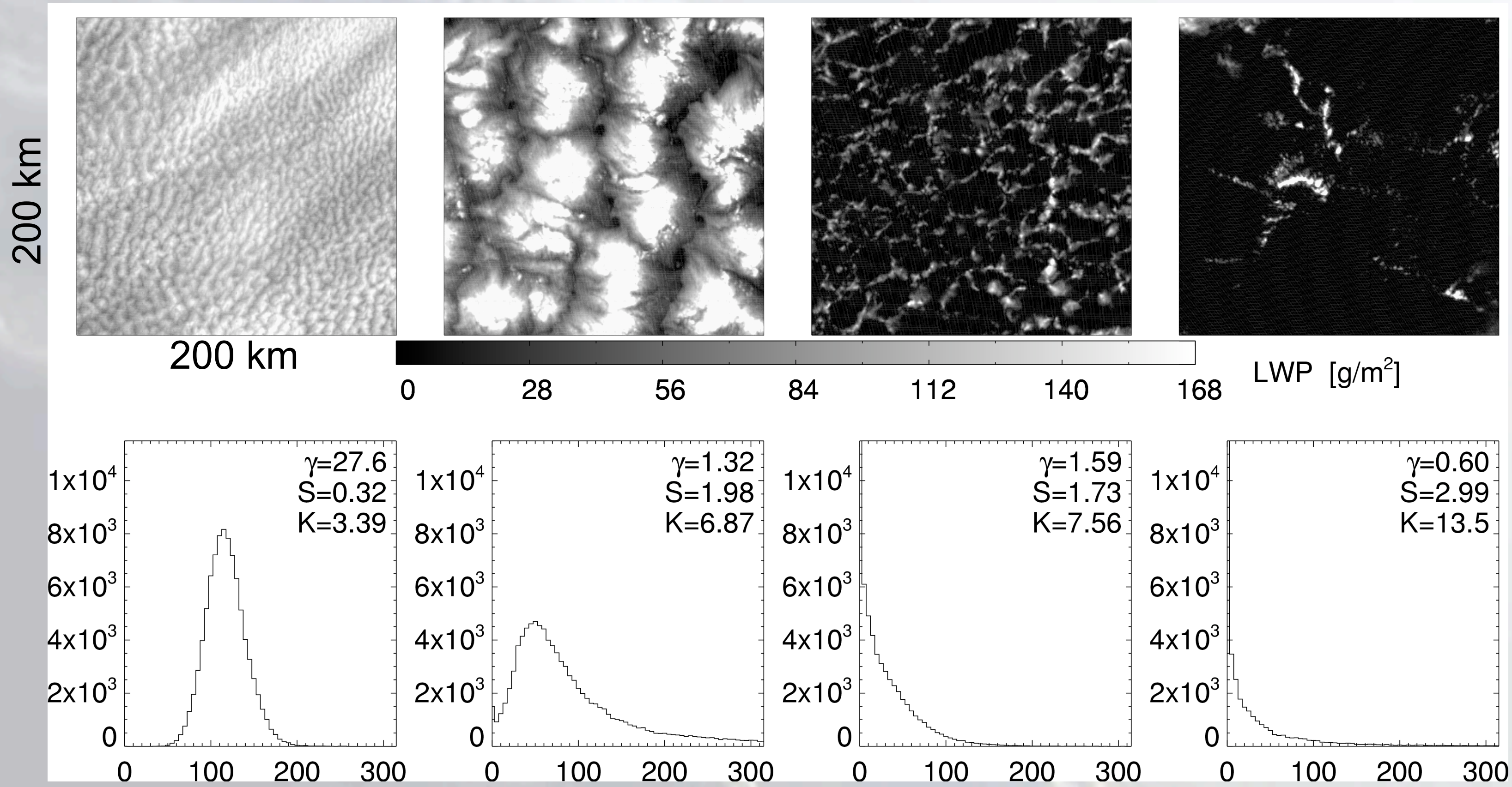
AIRS "turbulent" T variance



2 lat X 4 lon grid-boxes

3D Global High-resolution satellite observations can be used for cloud parameterization improvements in climate models

Liquid Water Path PDFs from GOES for different types of boundary layer clouds



From Gaussian stratocumulus to skewed cumulus regimes

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Summary and the Future

- Climate is changing YET there is large uncertainty in Climate prediction
- Low cloud-climate feedback is a major cause of uncertainty
- Global observations from space of boundary layer T, q structure are essential for better understanding and prediction of low clouds
- Key problem is representation of small-scales (e.g. turbulence, clouds)
- Traditionally we use local high-resolution models -> NO global picture
- High resolution satellite data can be directly used for parameterization

Future: What else do we need to solve the parameterization problem?

- Global high-resolution models – Global Turbulence from the computer
- New high resolution satellite data sets – Turbulence from space