From the ISCCP Simulator to COSP

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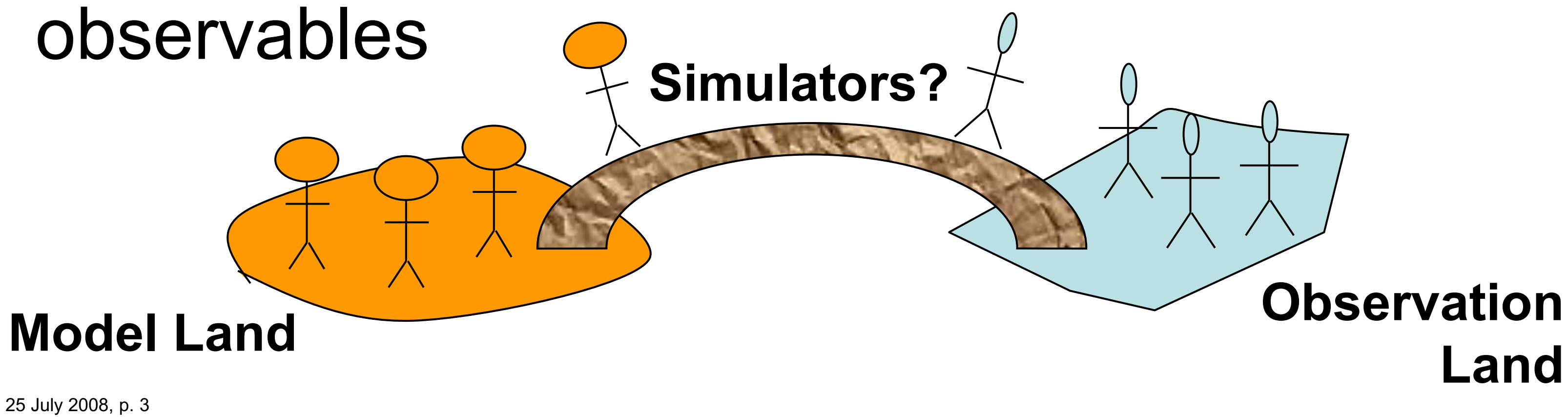
Outline

- Why simulators?
- The ISCCP Simulator (1997 – present)
  - What is it?
  - Results
  - Simulator Evaluation
- The CFMIP Observation Simulator Package (COSP) (2006 – present)
  - What is it?
  - Early Results
  - Future Plans
- Final Remarks

Simulators for models

- How to bridge the divide between observations and models?
  - Inverting of observations into model variables can be ambiguous
  - Converting model variables to observations, although more straightforward in principle, also requires forward modeling assumptions and it may be difficult to relate to observables



Simulators for models

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- The simulators discussed here convert model data into forms that can immediately be compared to high-level data products (e.g. Level 3) based on observations
- While these simulators may use forward models, they may also use portions of the inversion models which convert observations into high-level data products

Why create a simulator?

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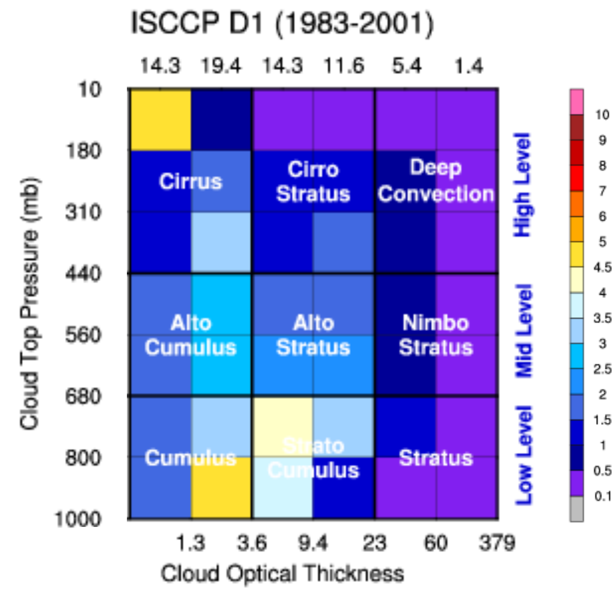
- Facilitate the use of data by the modeling community
- Get a truer comparison of models to observations by accounting for limitations or features of the observing process
- Facilitate the intercomparison of models which is difficult because the cloud variables defined in each model can be significantly different in important ways

The ISCCP Simulator: What is it?

- The primary ISCCP data product is the joint-histogram of the cloud-top pressure of the highest cloud in a column and the total optical thickness of all clouds in a column



ISCCP's 'pc-tau' diagram

- *These are not model variables!*
- Model variables include the level-by-level cloud fraction, optical thickness, and longwave emissivity for stratiform and convective clouds

The ISCCP Simulator: What is it?

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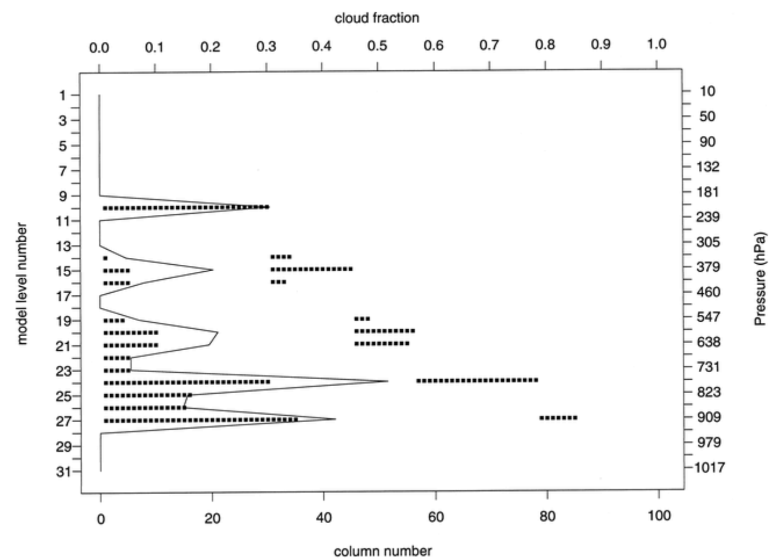
- The ISCCP simulator has two parts:
  - The Subgrid Cloud Overlap Profile Sampler (SCOPS)
  - The ISCCP Clouds and Radiances Using SCOPS (ICARUS)
- SCOPS generates an ensemble of sub-columns that are clear or cloudy at each level and consistent with the model's grid-box mean cloud fraction and cloud overlap assumption



Klein and Jakob (1999): An example of SCOPS

The ISCCP Simulator: What is it?

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- From this ensemble, one can determine the cloud-top pressure of the highest cloud and the total cloud optical thickness of all the clouds in each sub-column. The sub-columns become the statistical base from which the joint histogram of cloud top pressure and cloud optical thickness is calculated.
- These sub-columns can be used directly in a climate model to calculate cloudy-sky radiative transfer via the Monte Carlo Independent Column Approximation *(McICA, Pincus, Barker and Morcrette et al. 2003)*

The ISCCP Simulator: What is it?

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- ICARUS accounts for difficulties in retrieving cloud-top pressure from the infrared and visible radiances by
  - calculating an infrared brightness temperature for each sub-column
  - deriving a cloud-top temperature from this brightness temperature by using the visible optical thickness to account for non-opaque clouds
  - assigning the cloud-top pressure to the model level with a temperature closest to the radiance-derived cloud-top temperature

The ISCCP Simulator: What is it?

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- The most common difficulty that this accounts for is the tendency for ISCCP to retrieve a cloud-top pressure in the middle troposphere when there is a high thin cloud above lower level clouds
- The ISCCP simulator does not try to reproduce any difficulties ISCCP might have in retrieving the column cloud optical thickness

The ISCCP Simulator: Widely Used

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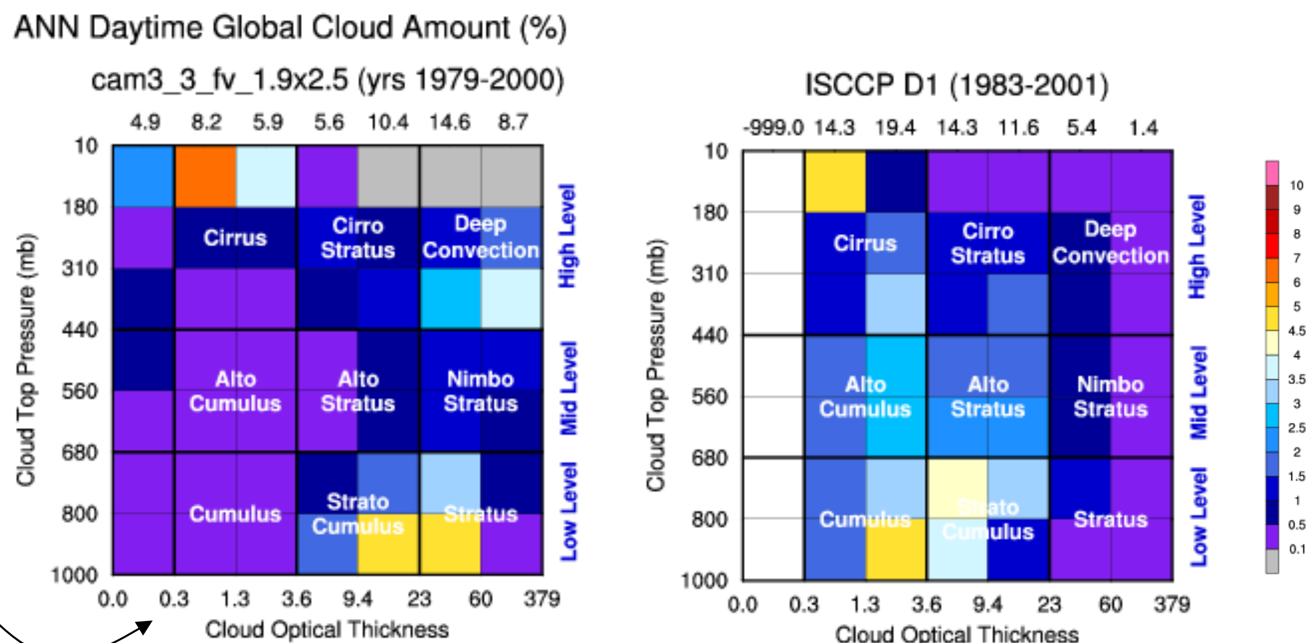
- The ISCCP simulator was created by Mark Webb and myself *(Klein and Jakob 1999, Webb et al. 2001)*
- Virtually every major climate model has used the ISCCP simulator, including the Multiscale Modeling Framework (a. k. a. “super-parameterization”) and the Japanese global cloud resolving model
- The simulator has generally been embedded into model codes facilitating its use

The ISCCP Simulator: An Example

- The United States's Community Atmosphere Model has embedded the ISCCP simulator into its routine (or automatic) diagnostic package.
- An example automatic diagnostic figure is:

The simulator tracks the number of clouds with tau < 0.3. Beneath this value, it is assumed that ISCCP cannot detect the cloud



The ISCCP Simulator: Results

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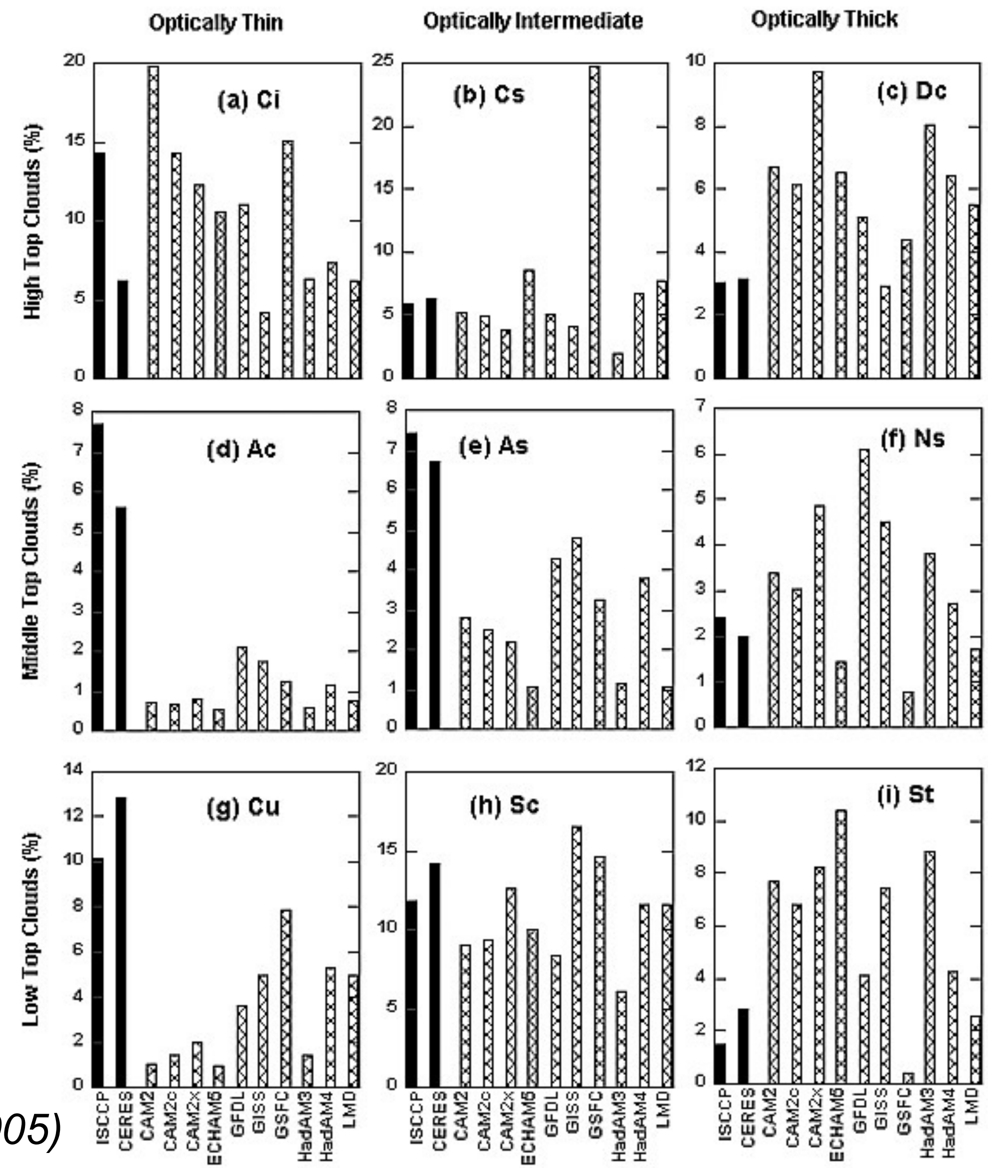
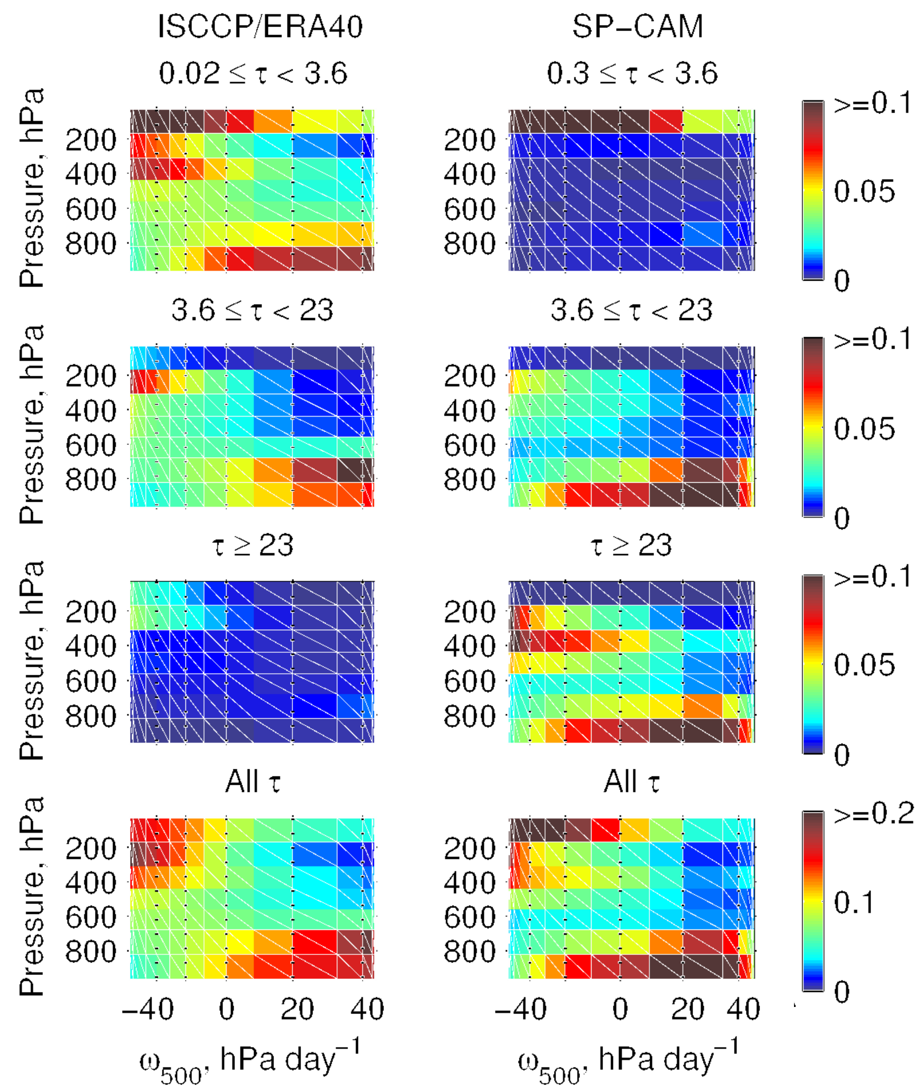
- The problem of model clouds with too great an optical depth and too few middle-level topped thin model clouds is very common



Zhang et al. (2005)

The ISCCP Simulator: Results

- These biases are also apparent in the Multiscale Modeling Framework model, which has a cloud-resolving model in each grid-box
- Too many optically thick clouds
- Better middle level clouds



Wyant et al. (2006): Tropical clouds sorted by 500 hPa vertical velocity

The ISCCP Simulator: Results

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- These biases are also apparent in the NICAM Global Cloud Resolving Model (delta-x ~ 7 – 14 km)
- Too many optically thick clouds
- A lot of very thin cirrus (tau < 0.3)

NICAM (July)

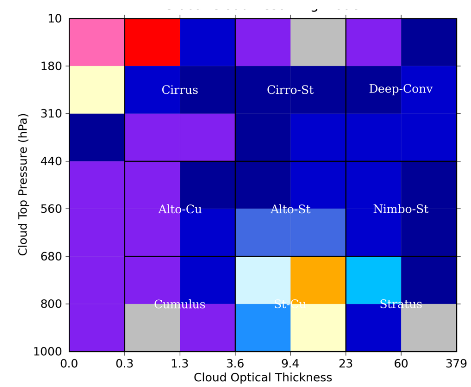
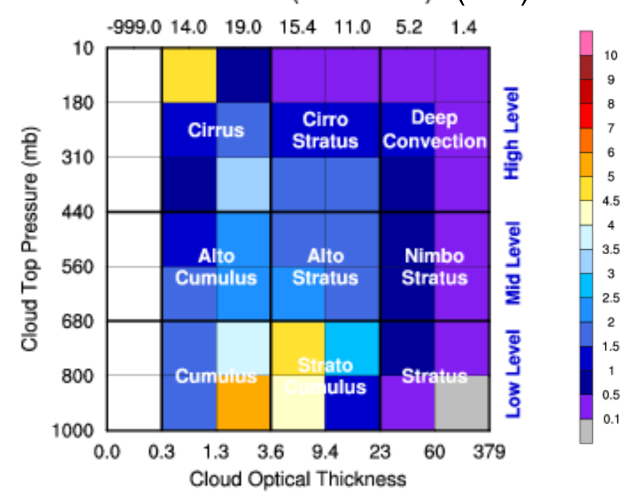


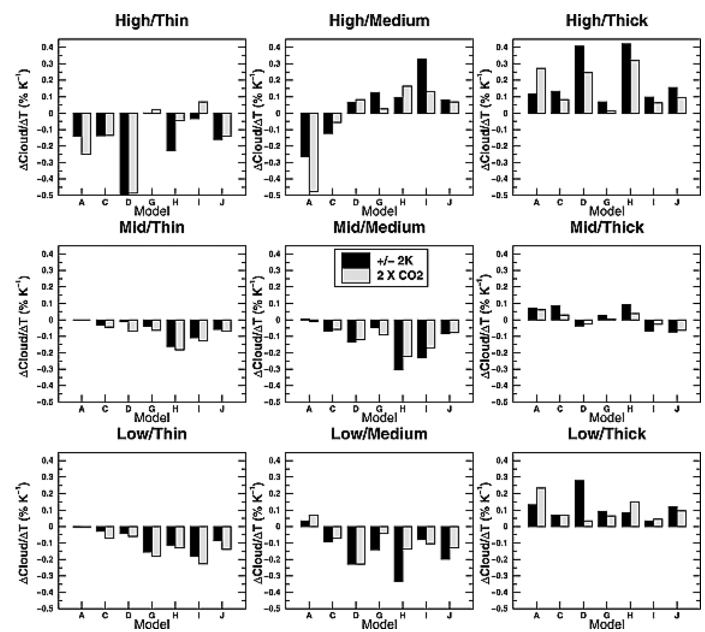
Figure courtesy of Yoko Tsushima

ISCCP D1 (1983-2001) (JJA)



The ISCCP Simulator: CFMIP

- The ISCCP simulator is a central tool of the Cloud Feedback Model Intercomparison Project (www.cfmip.net), led by Mark Webb and Sandrine Bony, which studies cloud feedbacks in climate models
- A common climate change response is for low and high thick clouds to increase and for thin clouds and low and middle level medium optical thickness clouds to decrease



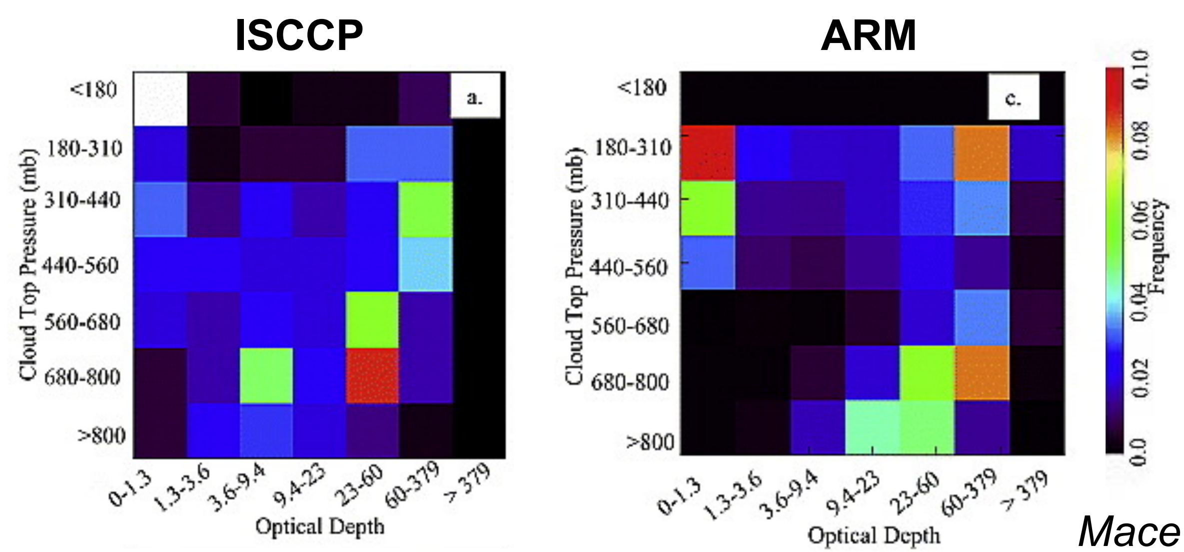
Ringer et al. (2006)

The ISCCP Simulator: Evaluation

- Primary model – ISCCP differences are:
  1. Greater model cloud optical thickness
  2. Fewer model middle level-topped clouds
  3. Lower model total cloudiness
- Differences #1 and #3 compensate and permit models to simulate a balanced radiation budget
- *Are these differences model errors?*
- Could these differences reflect ISCCP retrieval errors (which haven't yet been built into the simulator)?

The ISCCP Simulator: Evaluation

- Mace et al. (2006) compare the cloud-top pressure and optical thickness of radar-retrieved clouds over the ARM Oklahoma site to ISCCP observations



Mace et al. (2006)

- ARM clouds have greater optical thickness
- ARM has fewer middle and low level thin clouds

The ISCCP Simulator: Evaluation

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- ARM cloud optical thickness, calculated from retrievals of ice & liquid water path and effective radii, agree well with cloud optical those derived from another ground-based instrument and unbiased radiative closure is obtained with ARM cloud radiative properties
- The amount of optically thin clouds in ISCCP retrievals agree well with other satellite retrievals such as Minnis’s MODIS cloud retrievals
- Could there be a significant ‘beam-filling’ problem in satellite retrievals for thin clouds with sizes less than 1 km (e.g. small cumulus)?

The ISCCP Simulator: Evaluation

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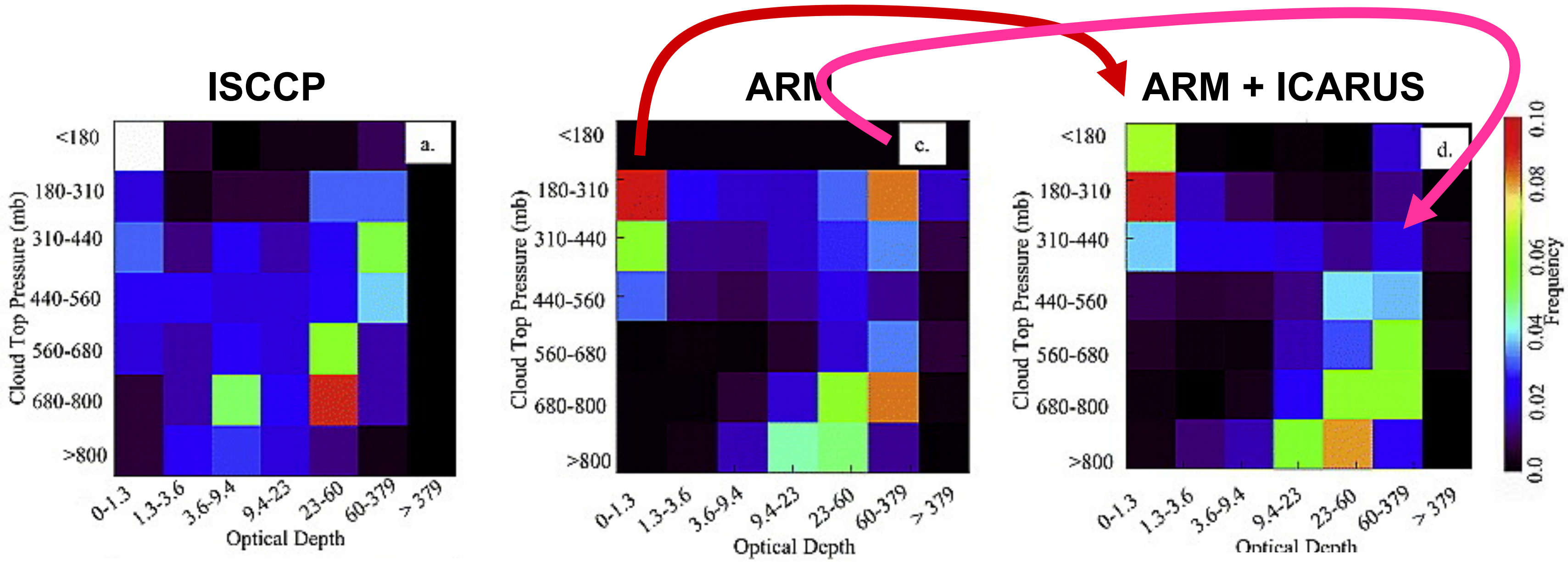
- To understand differences in cloud-top pressure, Mace applied the ICARUS code from the ISCCP simulator to ARM clouds

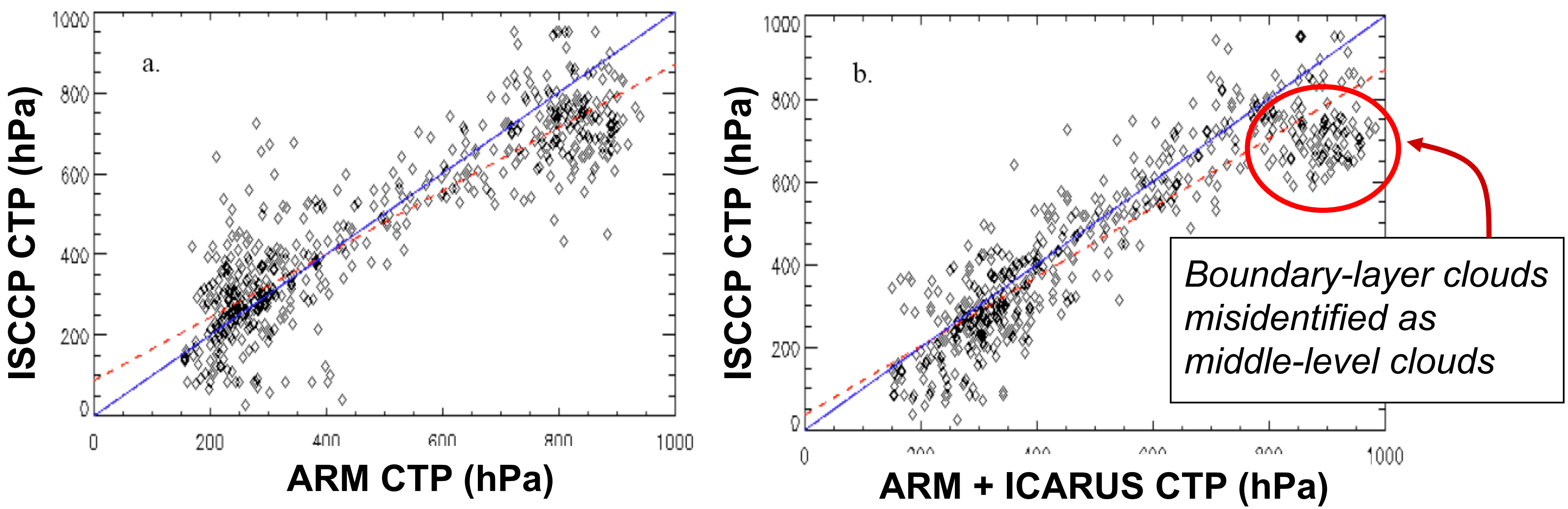


Mace et al. (2006)

- ICARUS improves agreement of cloud-top pressure for high clouds, but not thin middle level clouds

The ISCCP Simulator: Evaluation

- ICARUS does not account for boundary layer cloud that is placed too high because of the difficulty of locating clouds under an inversion
- An addition to ICARUS to mimic this problem is being tested



Houser and Mace (2008) unpublished

The ISCCP Simulator: Evaluation

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- I conclude that while ISCCP is overall doing very well, there remain uncertainties with respect to ISCCP retrievals of optical depth (particularly for thin broken cloud fields) and the amount of middle level topped clouds
- But is ISCCP trustworthy enough to use pc-tau diagrams as climate model metrics? *(Williams and Webb 2008)*
- I also believe that these model – ISCCP differences do in part reflect true model errors, partly for reasons to be shown herewith and from the experience in other contexts

COSP: What is it?

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- The CFMIP Observation Simulator Package includes simulators for comparing to ISCCP, CloudSat, and Calipso
- For comparison to CloudSat, COSP employs a forward model for radar reflectivity called "Quickbeam" *(Haynes, Stephens et al. 2008)*
- CloudSat limitations which the simulator accounts for include:
  - Minimum radar reflectivity of -30 dBZ
  - Difficulty of separating cloud from precipitation
  - Attenuation of radar signal in heavy precipitation

COSP: What is it?

- For comparison to Calipso, COSP employs a forward model of attenuated backscatter at the lidar frequency *(Chepfer et al. 2008)*
- Calipso limitations which the simulator accounts for include:
  - Attenuation at column cloud optical thickness of ~ 3
  - Cloud detection backscattering thresholds
- The choice of simulating the instrument signals preserves the flexibility to mimic whatever higher level data products are produced from CloudSat and Calipso

COSP: What is it?

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- Simulator limitations include:
  - Sensitive to the assumed shape of the particle size distribution
  - Must generate a sub-column distribution of precipitation, both large-scale & convective
- COSP contributors include:
  - Alejandro Bodas-Salcedo and Mark Webb *(UKMO)*
  - Helene Chepfer and Sandrine Bony *(LMD/IPSL)*
  - Yuying Zhang and Steve Klein *(LLNL)*
  - Roger Marchand *(U. Washginton)*
  - John Haynes and Graeme Stephens *(CSU)*

Flowchart of CloudSat/CALIPSO Simulator for GCMs

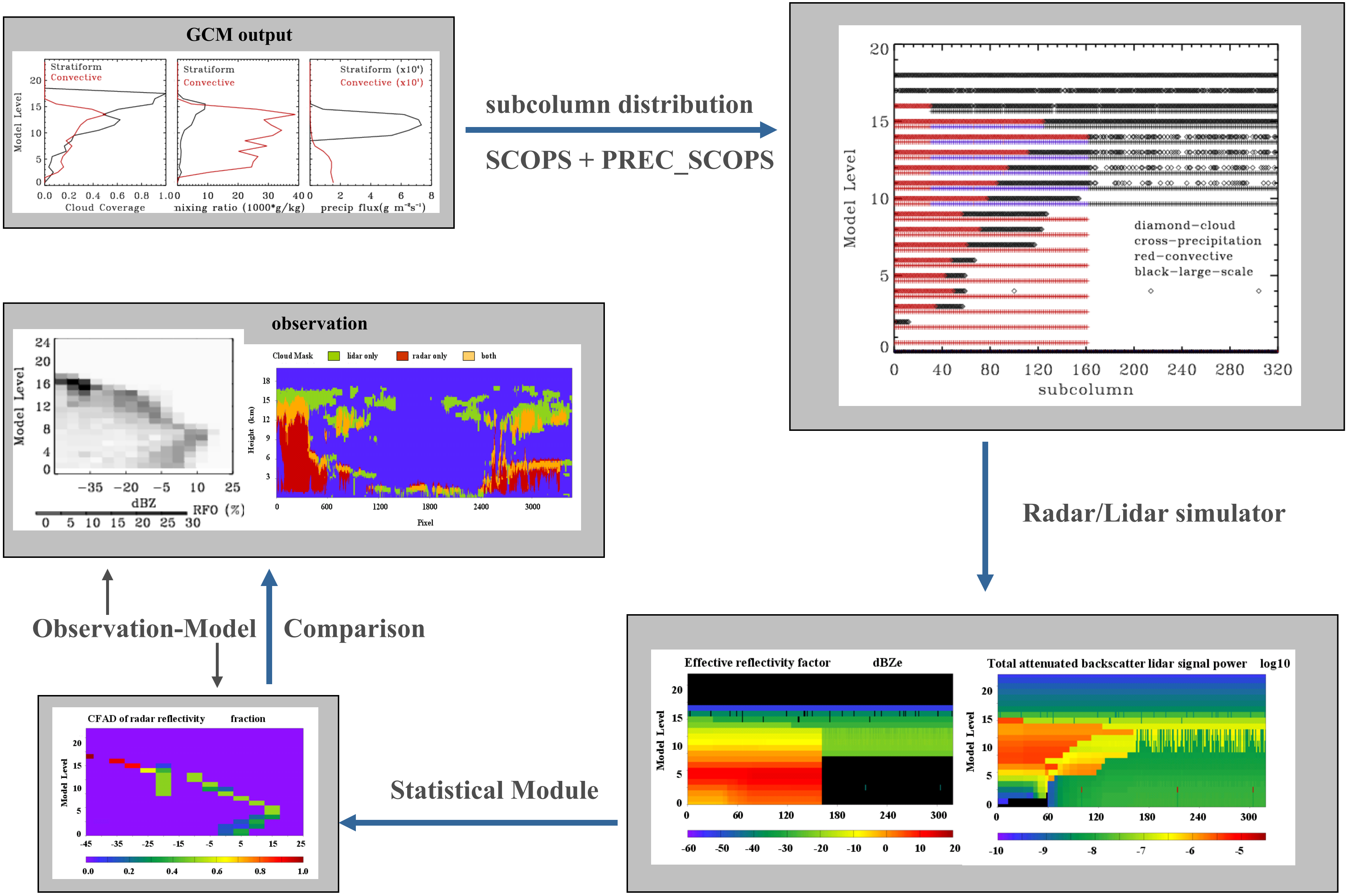
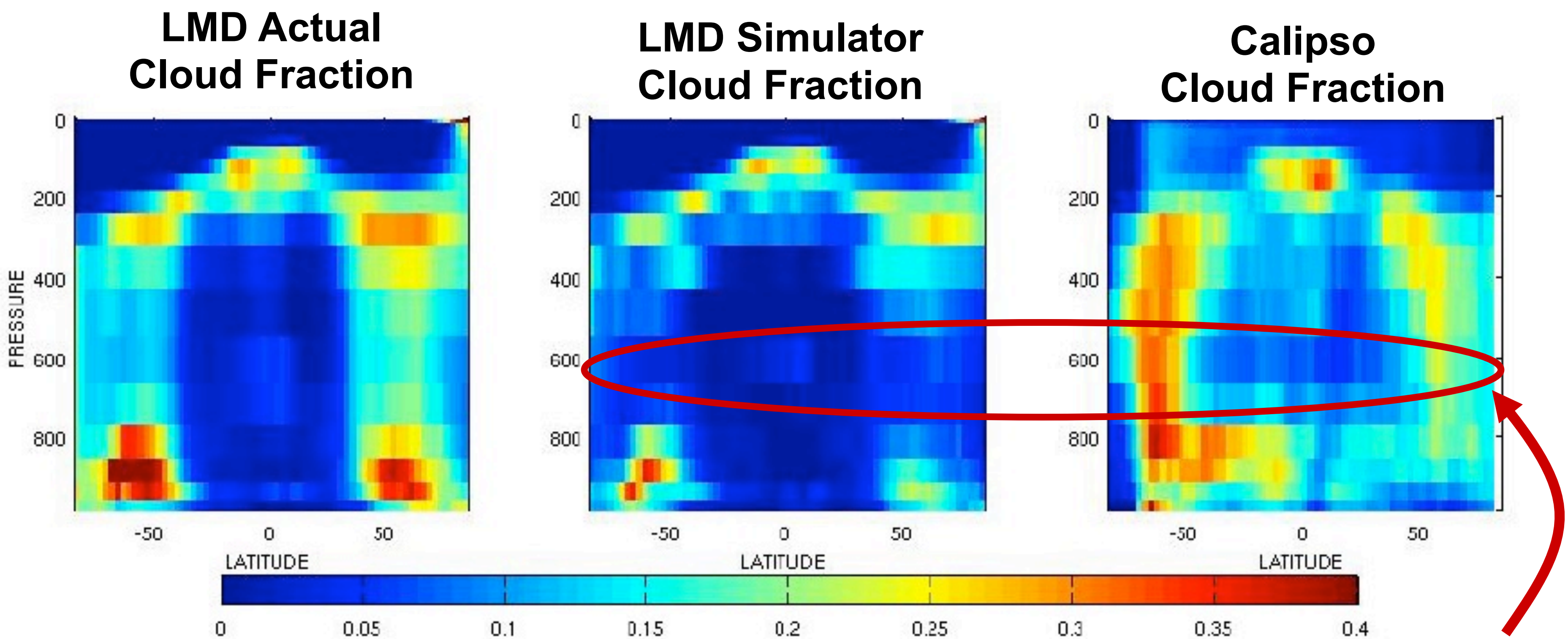


Figure courtesy of Yuying Zhang and Steve Klein (LLNL)

COSP: Early Results

- Comparison of LMD climate model to Calipso-only cloud occurrence



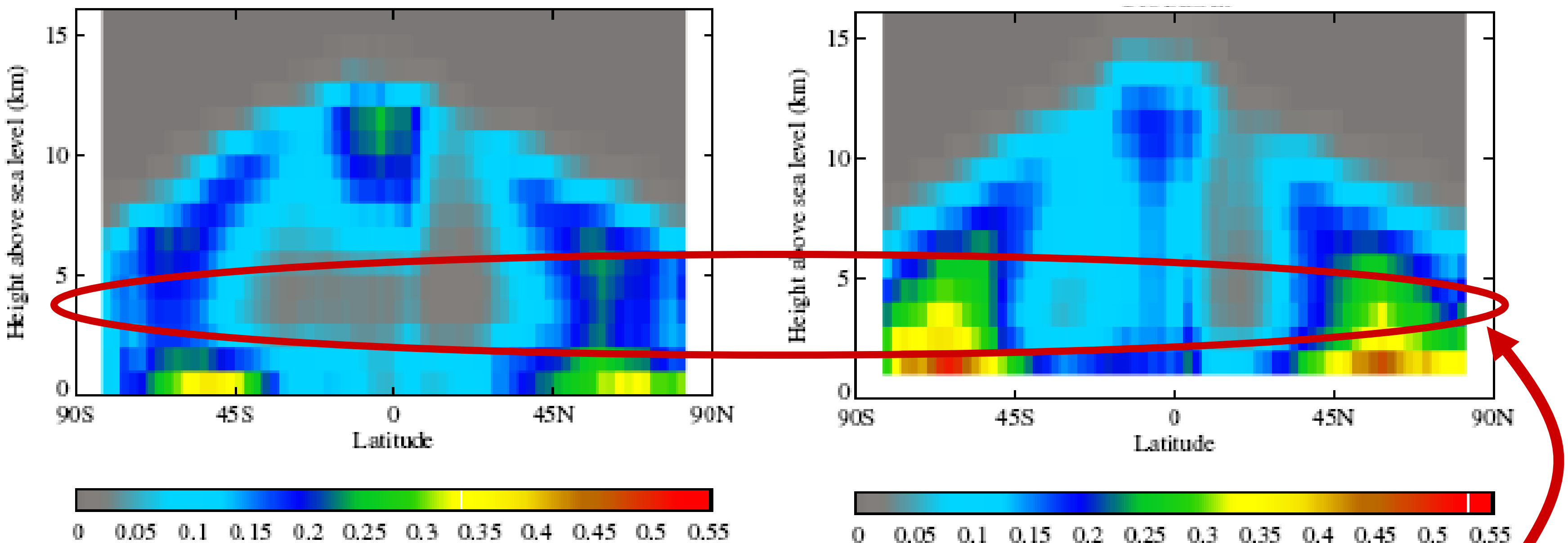
Model lacks middle level clouds – but not because high level clouds attenuate the simulated lidar signal

Chepfer et al. (2008): Latitude-pressure zonal mean cloud fraction

COSP: Early Results

- Comparison of UKMO weather forecast model to Cloudsat-only cloud (or precipitation) occurrence

UKMO Simulator Cloud Fraction | **CloudSat Cloud Fraction**



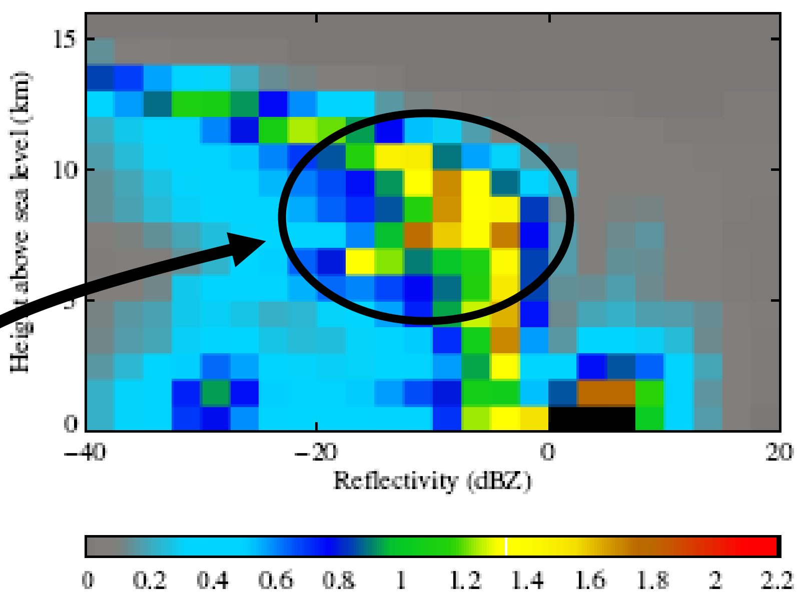
Bodas-Salcedo et al. (2008): Latitude-height zonal mean cloud fraction

Again the model lacks middle level cloud

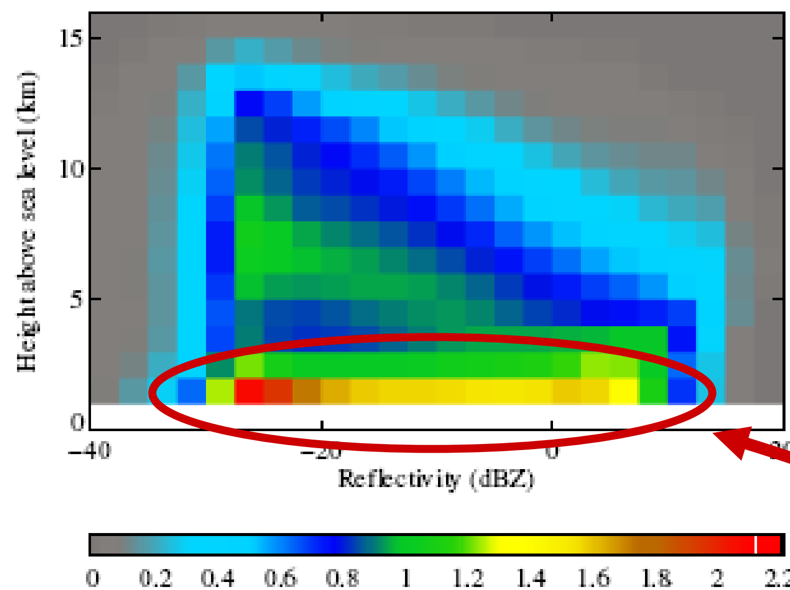
COSP: Early Results

- Comparison of reflectivity – height joint histogram (a loose analog to the ISCCP pc-tau diagram)

UKMO Simulator



CloudSat



Model ice-snow is too reflective and dBZ distribution too narrow

Bodas-Salcedo et al. (2008): Global mean reflectivity-height histogram

Continuous distribution between cloud (< -15 dBZ) and drizzle or rain (> -15 dBZ) unlike model

COSP: Early Results

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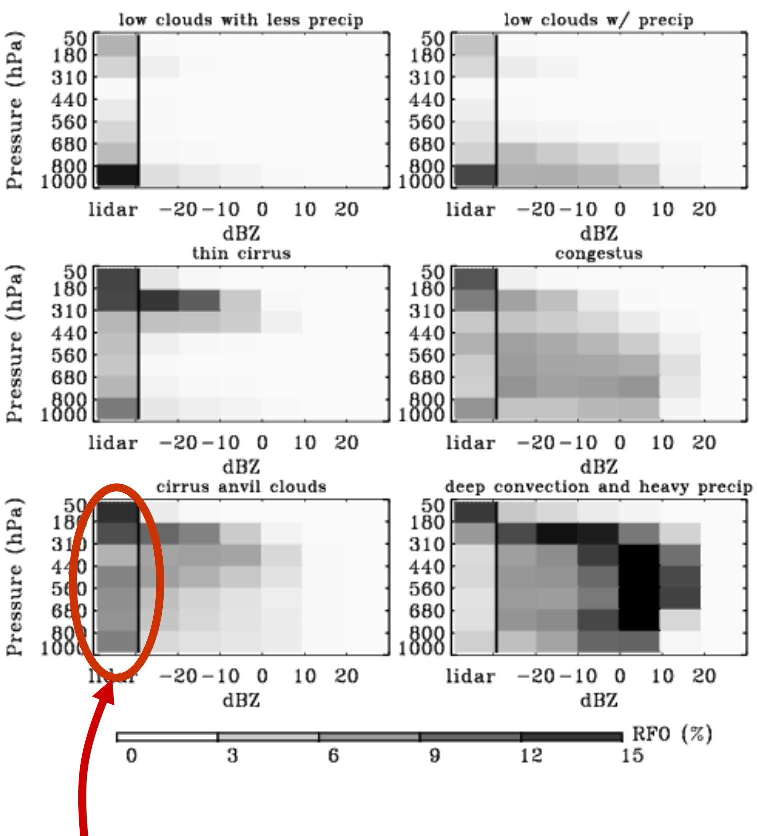
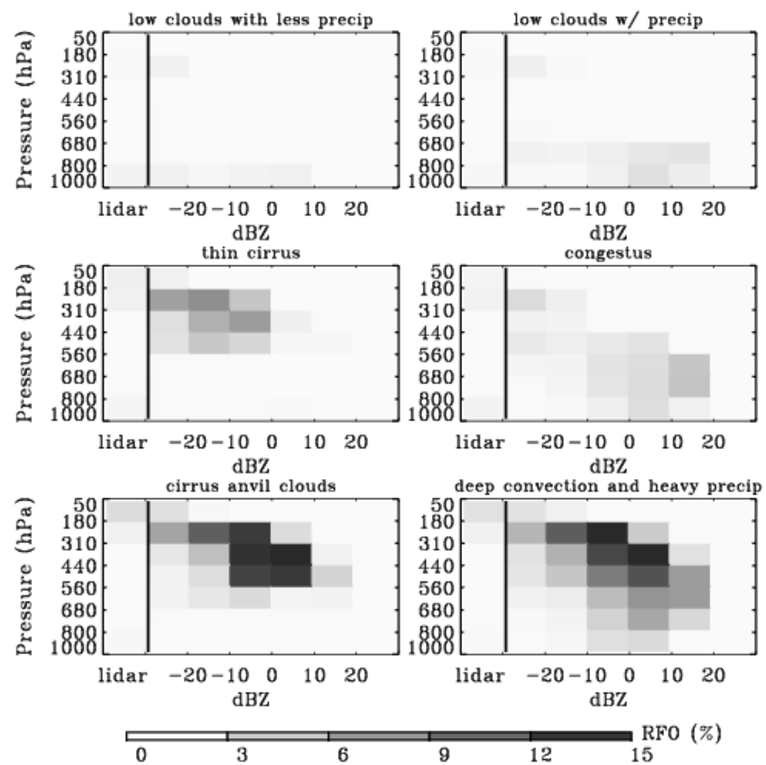
- Comparison of Community Atmosphere Model to CloudSat + Calipso tropical cloud clusters

CloudSat + Calipso



CAM3.5



Zhang et al. (2008): Tropical H-dBZ cloud clusters

This column is the frequency of clouds which are detected by Calipso but not by CloudSat

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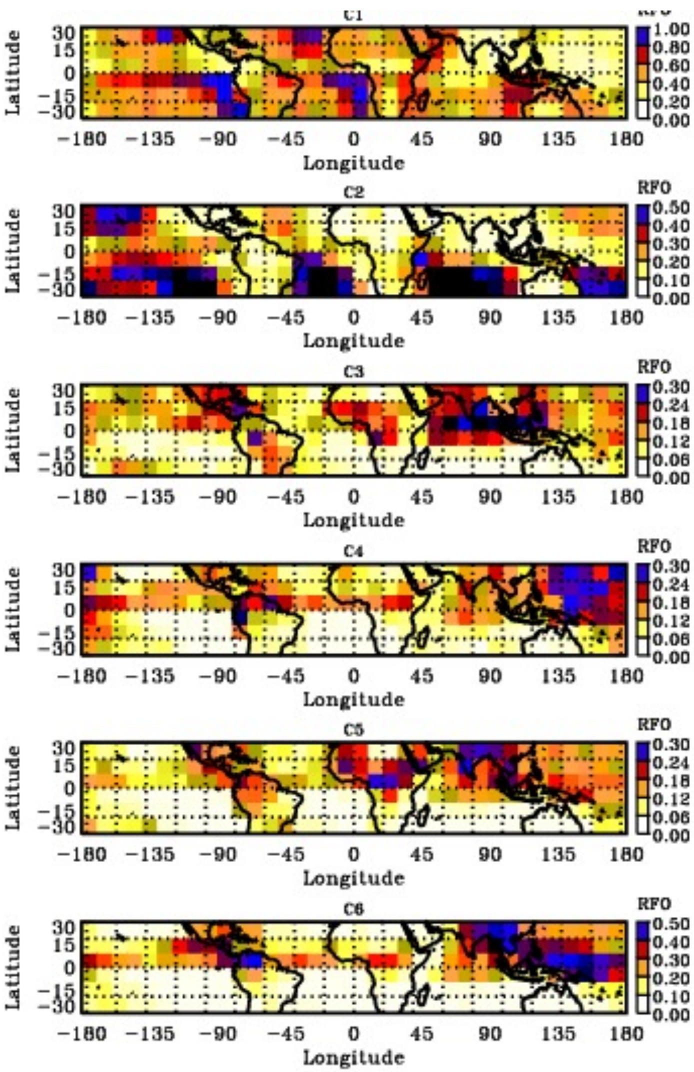
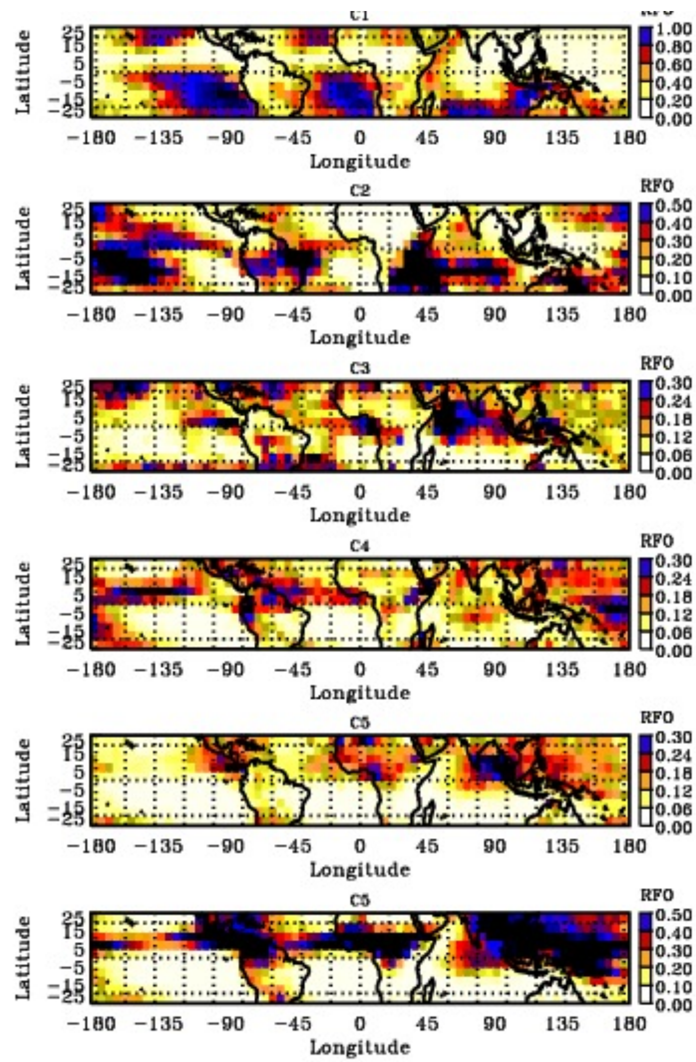
COSP: Early Results

CloudSat + Calipso



CAM3.5



Low clouds with less precip

Low clouds with precip

Thin cirrus

Congestus

Anvil clouds

Deep conv & heavy precip

Zhang et al. (2008): Frequency of occurrence of cloud clusters

COSP: Future Plans

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- Being a simulator package, it is envisioned that others will contribute other simulators (and diagnostics!). Simulators or diagnostics which might be added include:
  - MISR *(Marchand)* & MODIS *(Pincus)*
  - Passive Microwave *(?)*
  - Precipitation vs. Cloud Top Height *(Stephens)*
- COSP is a central element of the second phase of CFMIP and we are working hard to have it ready for the soon-to-begin climate model simulations in support of the next IPCC assessment

Final Remarks

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- Experience with the ISCCP simulator has demonstrated that a community software tool that facilitates comparison of climate model simulations with valuable satellite observations can be a powerful aide in bridging the model – data world divide
- Comparison with ISCCP raises questions for the observational community to examine:
  - Are there so many optically thin clouds?
  - Are there so many middle-level clouds?
- The COSP is continuing in this tradition for CloudSat and Calipso

Why too few middle level clouds?

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- Potential reasons include:
  - Convection parameterizations do not detrain enough at middle-levels
  - Many middle-level clouds are very thin (100 – 300 m) yet model resolution in the middle troposphere is much coarser (500 – 1000 m)
  - Many middle-level clouds consist of supercooled water which is difficult for models to simulate because their conversion of liquid to ice (the Bergeron process) is too efficient
  - Unresolved gravity waves may be responsible for the formation of some middle level clouds

Why too large optical thicknesses?

- Potential reasons include:
  - Too coarse vertical resolution
  - Inability to simulate cloud formation and dissipation stages properly
  - Inability to simulate weak forcing which might accompany optically thin clouds
  - Inability of parameterizations to recognize that frontal or mesoscale ascent is concentrated in only a portion of a grid box

The End

Extra Slides

CAM diagnostic figures

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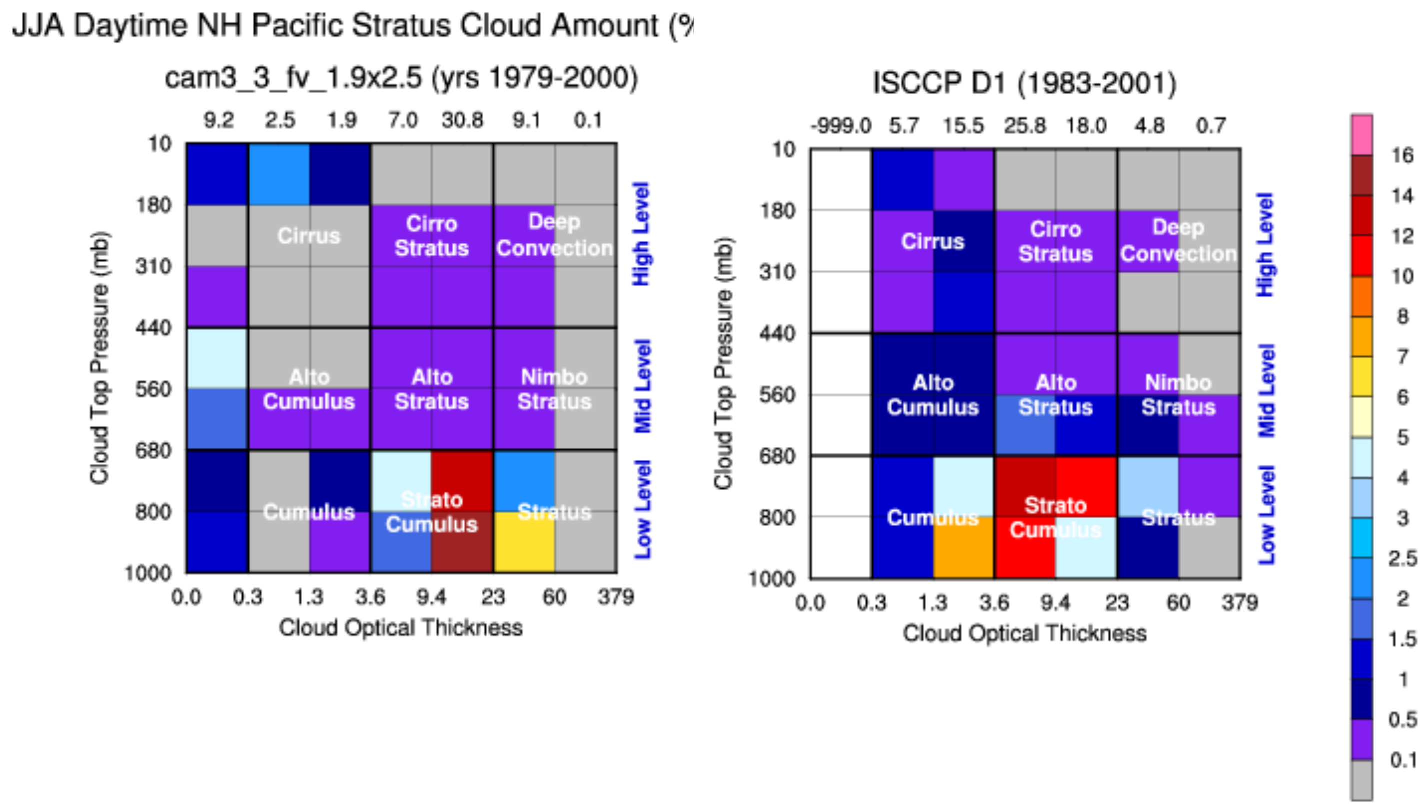

Mace Method

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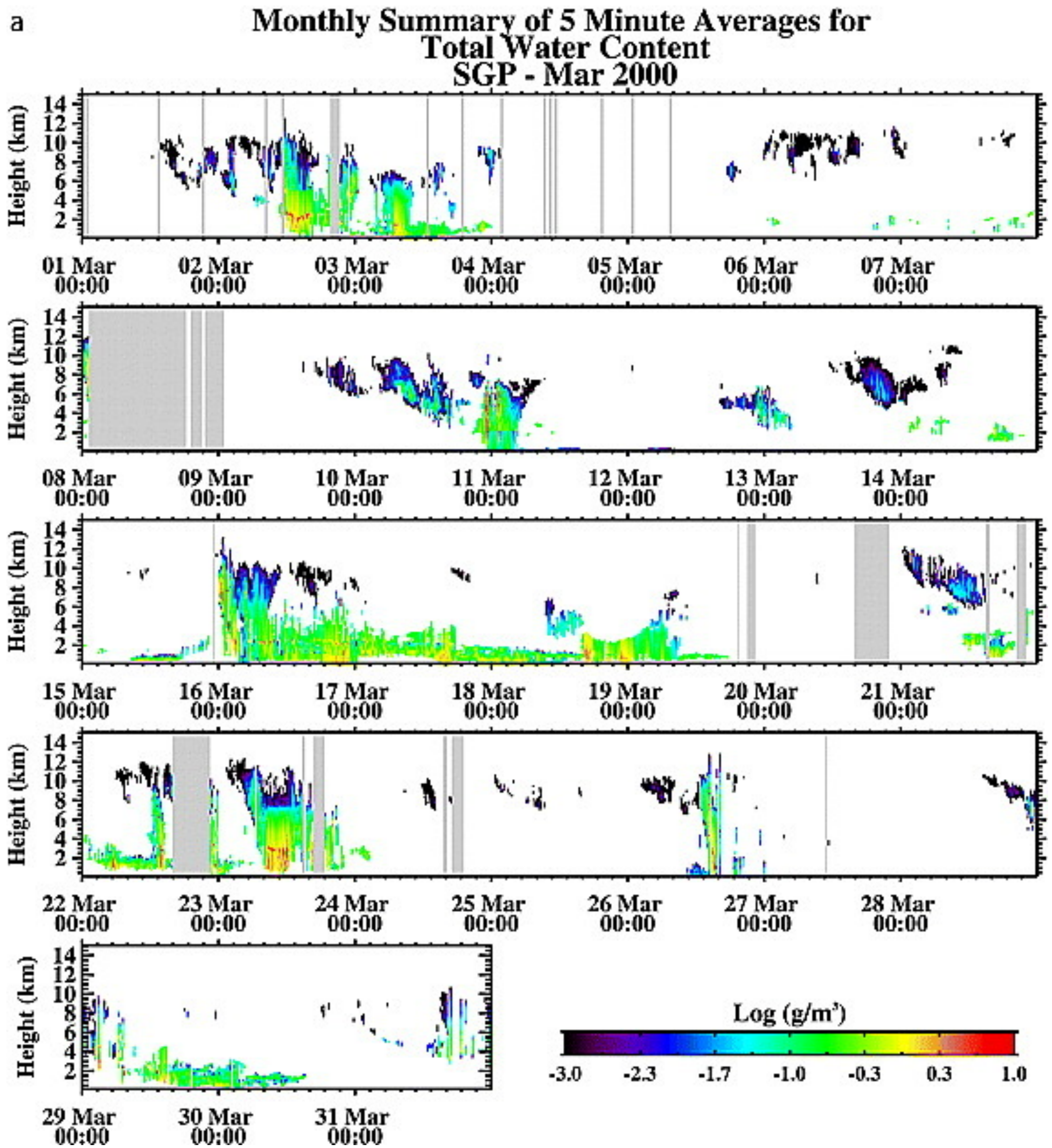
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Monthly Summary of 5 Minute Averages for Total Water Content SGP - Mar 2000
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