Observational Needs for Evaluating Climate Model Processes/Parameterizations

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Acknowledgments

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Outline

- Why evaluate climate model parameterizations?

  Example: Clouds

- How to identify ***observational priorities?***

  Example: *Field observations*

- What ***tools can be used*** to evaluate parameterizations?

  Example: Evaluating Arctic clouds in climate models

Why evaluate climate model *parameterizations?*

- We rely heavily on model projections of climate change, but large uncertainties persist

- Much of this uncertainty is thought to be due to differences in *model clouds* and their interactions with *other processes*

- Clouds and most other climate processes are fundamentally subgrid-scale phenomena, and must be *parameterized* in terms of *model-resolved* state variables (T,q, p, …)

→A necessary step to improve climate simulation is to evaluate *model parameterizations* using *suitable* observations

Clouds as 'leitmotiv' parameterization

- Clouds are central to both radiative and hydrological aspects of the climate system
- Clouds also manifest or mediate other important climate processes (e.g. boundary layer fluxes, shallow/deep convection, transport of aerosols and chemical constituents, etc.)

→ Types of data needed for evaluating cloud parameterizations imply *observational priorities* for many climate processes

Identifying observational priorities

Evaluation of cloud parameterizations demands a case-study approach:

Simultaneous measurements of *different aspects* of clouds (microphysical, radiative, hydrological, etc.) as these evolve in space/time

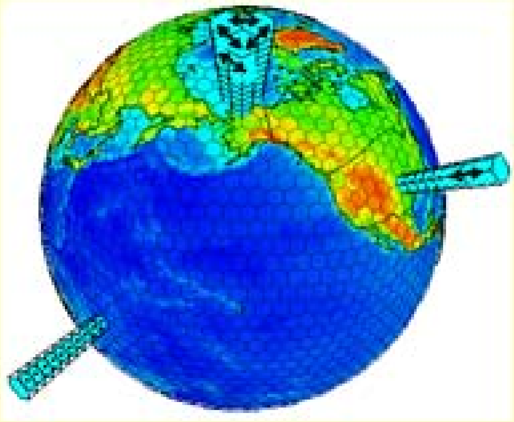
Spatial Criteria

Obs at relevant locations--where the cloud process of interest *operates strongly*

Temporal Criteria

Obs sampled *continuously* and at *high-frequency*

Priority observations for evaluating *cloud* parameterizations



Key variables needed in the *vertical column at model grid-box scale*:

- Profiles of cloud properties (horizontal extent/vertical distribution, CCN number & size, water content, liquid/ice mixing ratio, etc.)
- Profiles of atmospheric moisture, temperature (derive relative humidity)
- Precipitation, surface turbulent fluxes
- Surface & TOA radiative fluxes
- Column forcings: vertical motion, advective tendencies of heat & moisture

Example: Atmospheric Radiation Measurement (ARM) Data

- *High-frequency* (3-hourly and higher) and *continuous* observations (relevant for process studies, but also for long-term climate monitoring)

- Observations at 3 sites representative of very different climatic regimes:

North Slope of Alaska (NSA)

U.S. Southern Great Plains (SGP)

Tropical West Pacific (TWP)

…and ARM Mobile Facility (AMF)--
currently in Niger for the 'AMMA' African Monsoon Field Experiment

Field Experiments *supplement* "routine" ARM observations by employing dedicated radiosonde *networks*, aircraft, etc. *intensively* for a selected period

Example: The Mixed-Phase Arctic Cloud Experiment (M-PACE)

October 5-22, 2004

ARM NSA sites near Barrow, Alaska

Figure 1 Experimental layout. The two ARM sites are located at Barrow and Atqasuk; the two supplementalsites will be at Oliktok Point and the NSF Toolik Lake Field Station.

Measurements/Instruments

Cloud Microphysical Properties

- Millimeter-wavelength cloud radar
- Micropulse Lidars
- Laser Ceilometers
- Aircraft
- Microwave Radiometers

Surface Radiation

- Radiometric Instrument Systems

TOA Radiation

- NASA-Terra and NOAA-15,-16 Satellites

Using field data to evaluate parameterizations: Tools

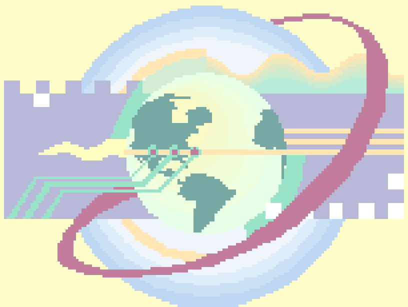
1) Cloud-resolving models (CRMs)

2) Single-column models (SCMs)

→ *require complete* forcings from field experiments

→ 3) Climate models run in weather-forecasting (NWP) mode

Using field data to evaluate parameterizations: Tools



Use a global climate model to *forecast the weather*, and *available field data* to infer parameterization performance:

1) Initialize climate model state variables ***realistically*** (global weather at 'day 1') (use reanalyses in place of a data assimilation system)

2) Make a series of short (~3-day) weather forecasts, map to field experiment site, and compare model forecasts with field observations

3) Identify local forecast errors and infer shortcomings in process parameterization

Example: The CCPP-ARM Parameterization Testbed (CAPT)

U.S. Department of Energy
Climate Change Prediction Program
CCPP

ARM Atmospheric Radiation Measurement Program

BAMS, December 2004 (Reprints Available)

EVALUATING PARAMETERIZATIONS IN GENERAL CIRCULATION MODELS:

Climate Simulation Meets Weather Prediction

BY THOMAS J. PHILLIPS, GERALD L. POTTER, DAVID L. WILLIAMSON, RICHARD T. CEDERWALL, JAMES S. BOYLE, MICHAEL FIORINO, JUSTIN J. HNILO, JERRY G. OLSON, SHAOCHENG XIE, AND J. JOHN YIO

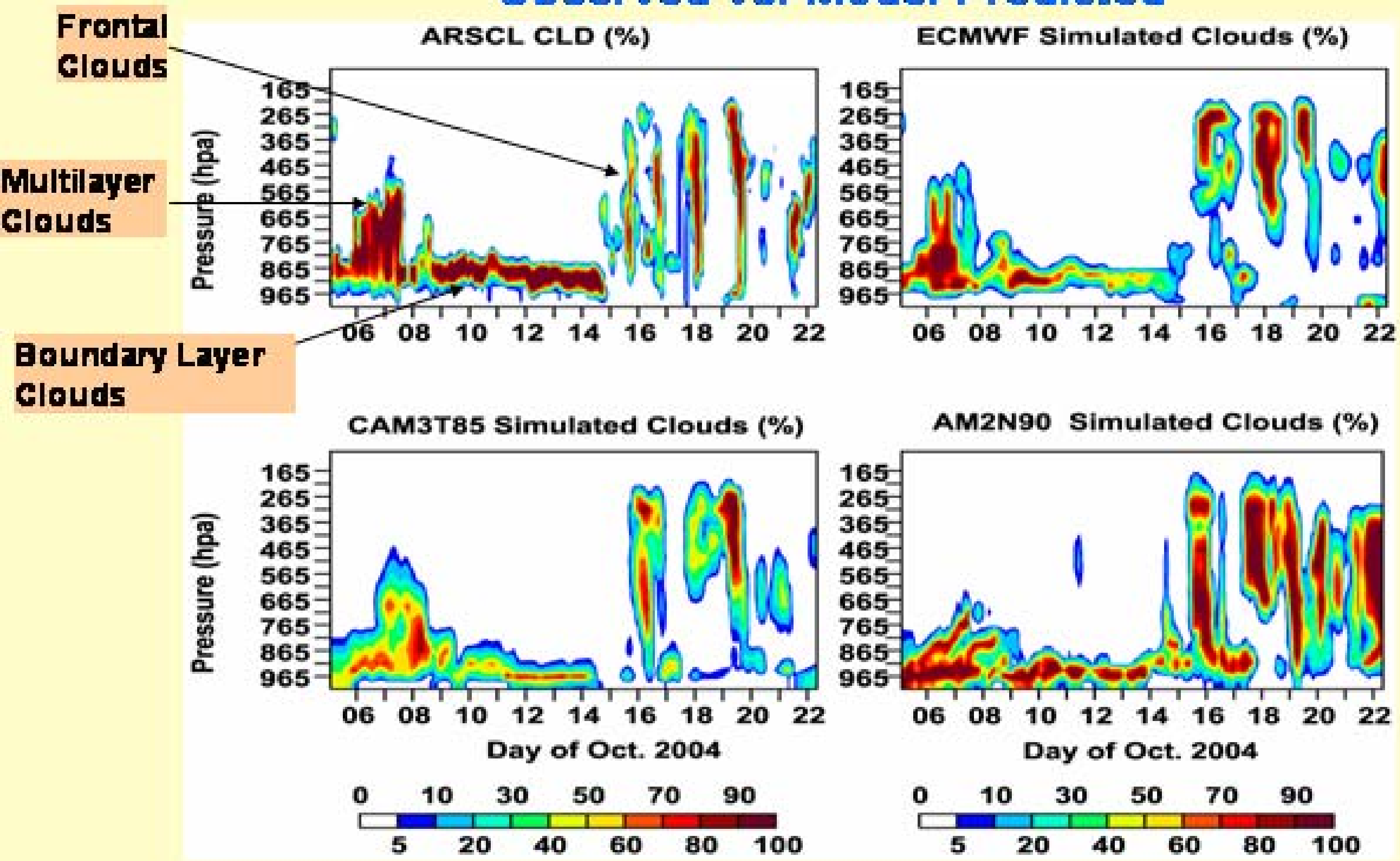
Numerical weather prediction methods show promise for improving parameterizations in climate GCMs.

Example: CAPT evaluation of model cloud predictions for M-PACE
(Acknowledgments: S. Xie et al. 2006)

Models Evaluated

- NCAR CAM3 T85 L26
- GFDL AM2 2.0 x 2.5 L24
- ECMWF T511L60 Weather Forecast Model

Time Sequence of M-PACE Cloud Amount/Distribution: Observed vs. Model-Predicted



All models are able to predict time sequences of cloud amount & distribution that are *qualitatively* similar to observations, but that show *quantitative* disparities.

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Summary

- Evaluating parameterizations is necessary to advance climate modeling
- High-frequency, continuous field observations in key locations are needed
- We have tools (e.g. CRMs, SCMs, NWP techniques) for productively using field obs to evaluate climate model parameterizations

Extra Slides

Using field data to evaluate parameterizations: Tools

Cloud-resolving models (CRMs)

- predict microphysical properties at *cloud-scale* (~1 km resolution)
- supply details for developing *new cloud parameterizations*
- *require* the "complete" forcings provided by field experiments

Single-column models (SCMs)

- test *existing* cloud parameterizations *at model grid-box scale* (~ 100 km)
- *also require* "complete" forcings

In CRMs/SCMs, specifying "correct" dynamics/forcings allows a "clean" test of a cloud scheme…

… but their application is limited to sites where "complete" forcings from field experiments are available

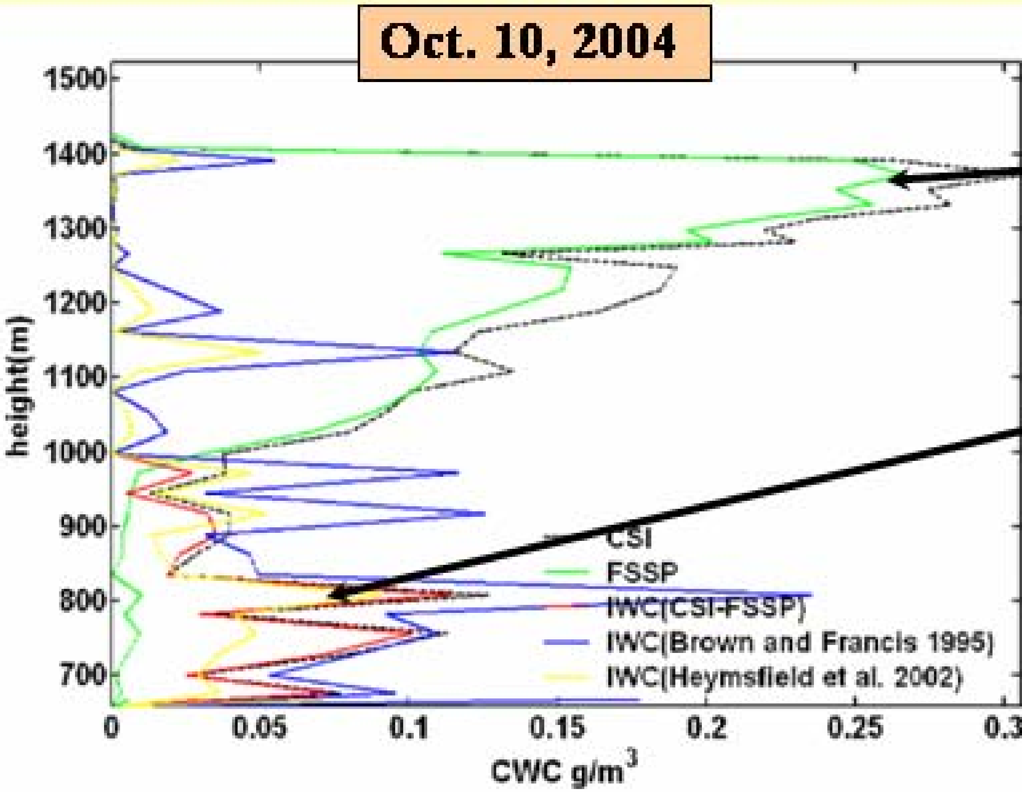
CAPT case studies of NCAR CAM3 and GFDL AM2 models:

Model errors in moist physics (humidity, clouds, precipitation) identified for

- U.S. Southern Great Plains (ARM IOPs) : Spring/Summer 1997, 2000
- Tropical West Pacific (TOGA-COARE Experiment): Winter 1992/93
- Subtropical Pacific (GCSS Cross-Section Intercomparison): Summer 1998

→ North Slope of Alaska (M-PACE Experiment): Autumn 2004

Aircraft-Measured Cloud Water Content



A strong liquid layer occurred near cloud top at 1300 m

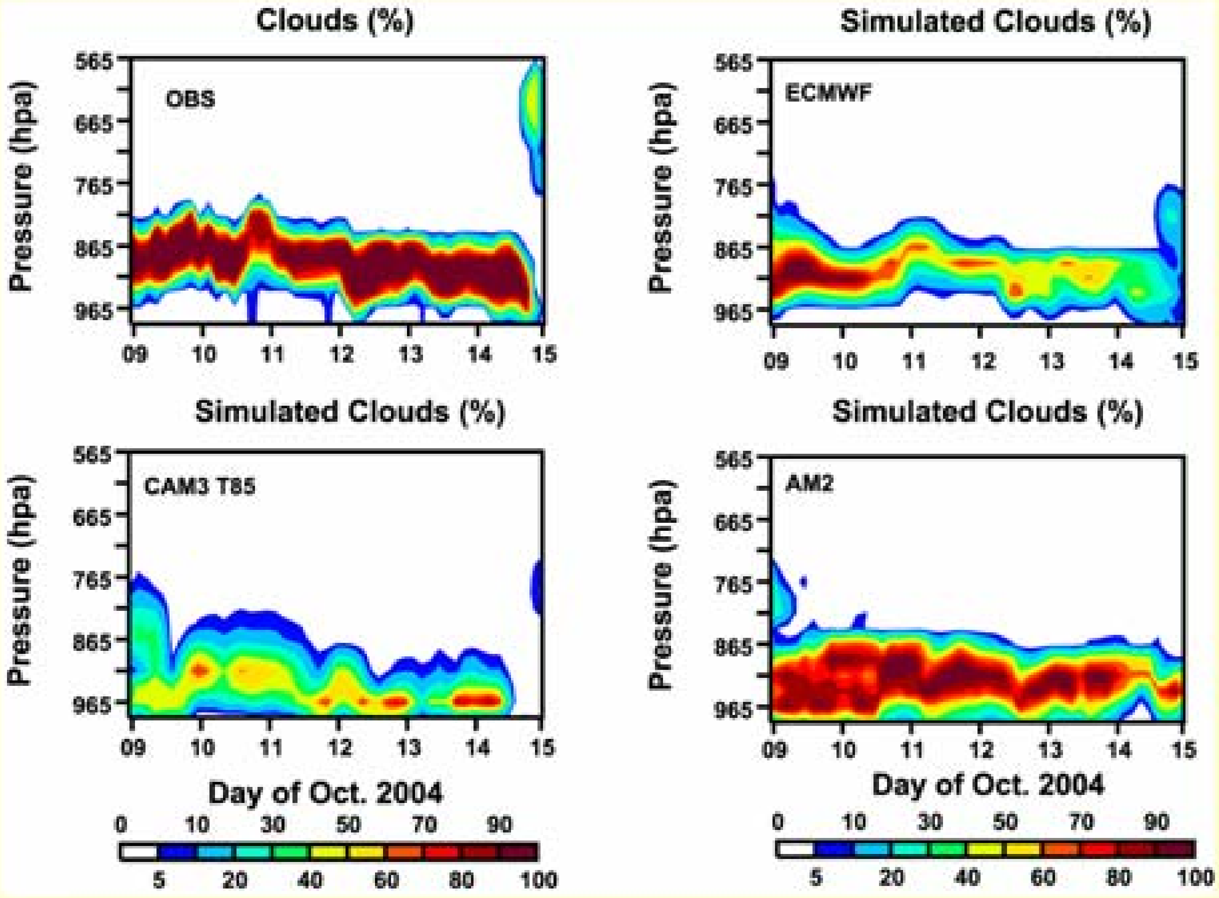
Ice crystals in the liquid cloud layer and precipitating ice crystals beneath

Figure 6 Comparison of bulk measurements of IWC (CSI-FSSP) against IWC estimated from 2DC using variety of habit identification and mass calculation techniques

(From G. McFarquhar et al. 2005)

- CSI: Cloud Spectrometer and Impactor probe
- FSSP: Forward scattering spectrometer probe
- 2DC: two dimensional cloud probe

M-PACE Mixed-Phase Boundary-Layer Cloud Fractions



- All models are able to produce BL clouds
- Cloud bases are too low in CAM3 and AM2
- Cloud amounts are largely underestimated by ECMWF and CAM3

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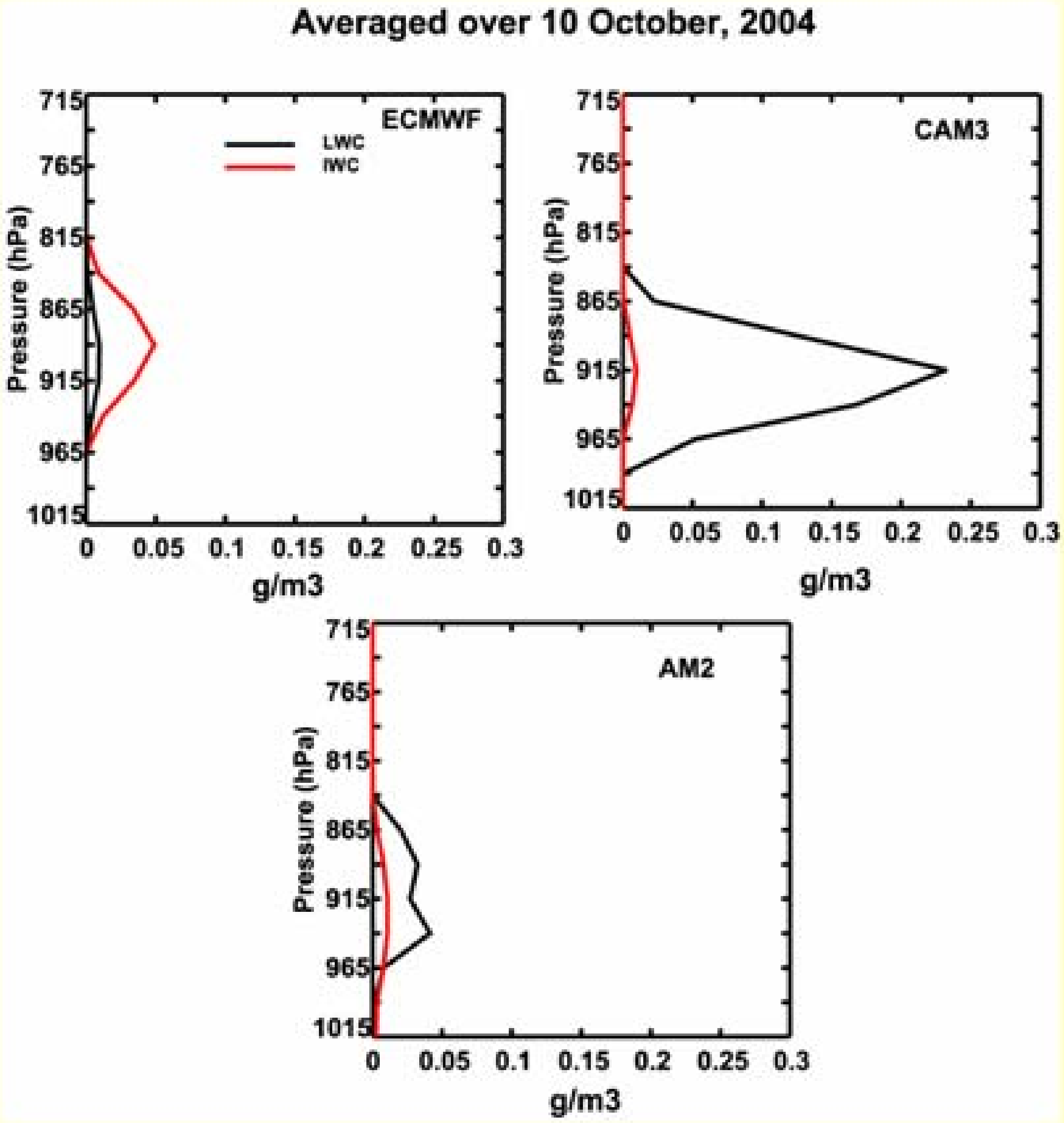
Simulated liquid- and ice-water concentrations (LWC and IWC)



- Substantial differences in the cloud physical properties among models
- The vertical distributions of LWC and IWC are significantly different from the observations

- **ECMWF and CAM3**:

Cloud phase dependent on T

- **AM2**: separate prognostic equations for liquid and ice