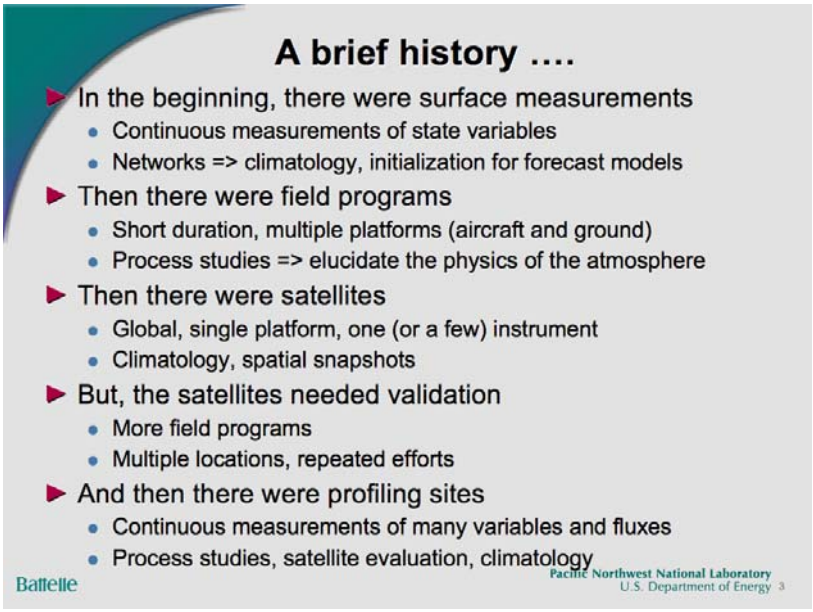
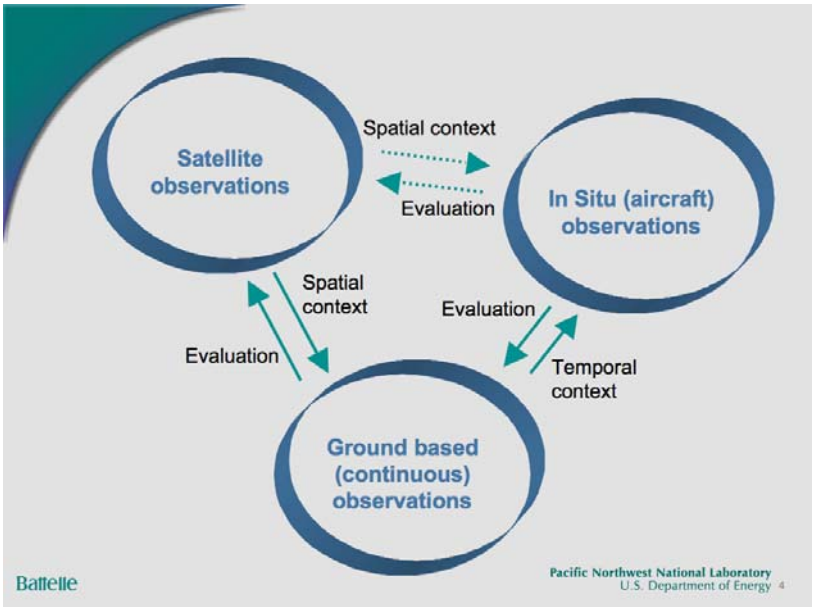
Using Validation Sites and Field Campaigns to Evaluate Observational and Model Bias

Tom Ackerman

DOE Atmospheric Radiation Measurement Program
Pacific Northwest National Laboratory, Richland, WA USA
Ackerman@pnl.gov





Types of Ground-based sites

- Standard meteorology – radiosondes
- Special networks: Baseline Surface Radiation Network (BSRN) or Aerosol Robotic Network (AERONET)
- Cloud and Aerosol Profiling (CAP) Sites

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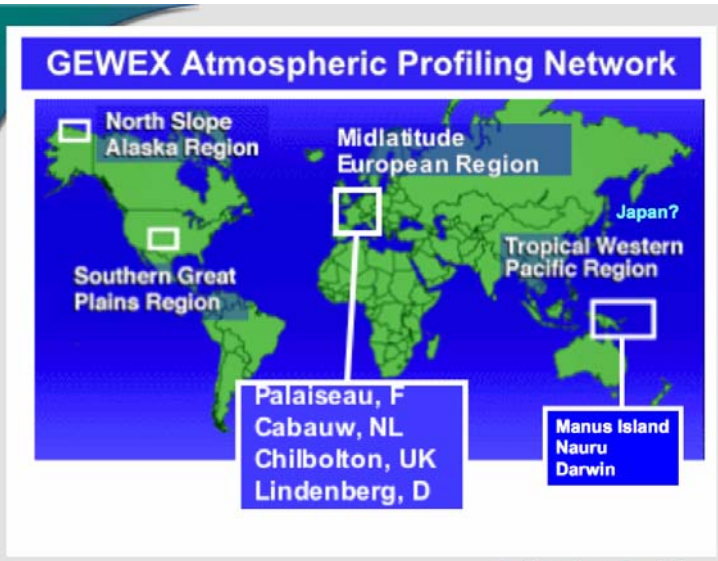
GEWEX Atmospheric Profiling Network



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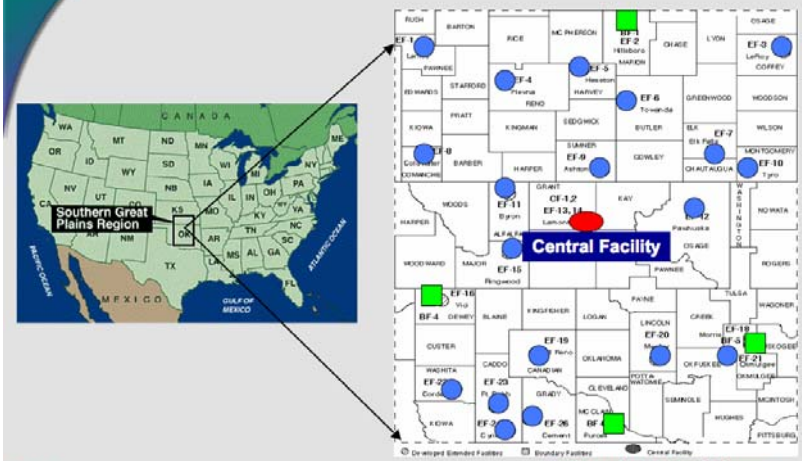
ARM Southern Great Plains



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Bias errors in measurements

- Most difficult errors to diagnose
  - By definition, if we know about a bias error, we remove it
- How do we find them?
  - Instrument to instrument comparison (water vapor)

    But, often have only one instrument or we cannot sort out source of inconsistency
  - Instrument to model comparison (diffuse flux, MPACE)

    But, which do we trust? (instrument, of course!)
  - Consistency among multiple measurements (single-scatter albedo, aerosol closure experiments)

    But, can we reduce solution to bias in only one instrument?

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Story #1: Water vapor

- ARM has invested more effort and money in the study of water vapor measurements than any other quantity
- Multiple instrumentation
- FIVE intensive campaigns
- Many science team research projects
- Countless hours of debate

Revercomb et al., 2003, BAMS (and a host of references)

Soden et al., 2005, JGR and references therein

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TABLE 2. Operational water vapor instrumentation at the ARM SGP Central Facility. (Additional information about the instruments listed may be found online at www.arm.gov/docs/instruments.html.)

Instrument	Primary quantity observed and typical resolutions	References
AERI retrievals	Water vapor mixing ratio profiles: 10 min, 100-m resolution, 24 h day^{-1}	Feltz et al. (1998); Turner et al. (2000)
Cimel sun photometer (CE-318)	Total precipitable water vapor: every quarter air mass for air masses greater than 2, and every 15 min for airmasses less than 2	Holben et al. (1998); Schmid et al. (2001)
GPS at Lamont, OK	Total precipitable water vapor: 30-min resolution, 24 h day^{-1}	Wolfe and Gutman (2000); King and Bock (1996); Rotacher (1992)
In situ probes (Vaisala HMP35D*)	Water vapor mixing ratio: at surface, 25 m, and 60 m; 1-min resolution	Richardson and Tobin (1998); Richardson et al. (2000)
MFRSR	Total precipitable water vapor: 1-min resolution during daytime	Harrison et al. (1994); Schmid et al. (2001)
MWR (Radiometrics WVR-1100)	Total precipitable water vapor: 20-s resolution, 24 h day^{-1}	Liljegren and Lesht (1996); Liljegren (1999)
Radiosonde (Vaisala RS-80H)	Relative humidity profiles: 10-m resolution, eight launches per day	Turner et al. (2003); Lesht (1998)
Raman lidar (CARL)	Water vapor mixing ratio profiles: 10 min, 78-m resolution, 24 h day^{-1}	Goldsmith et al. (1998); Turner and Goldsmith (1999)
RSS	Total precipitable water vapor: 1-min resolution during daytime (installed after the 1996 WVIOP)	Harrison et al. (1999); Schmid et al. (2001)

*Installed after the 1996 WVIOP, replacing the original Qualimetrics 5120-E and 5134-E sensors.

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TABLE 3. Additional instrumentation brought to the ARM SGP central facility for the 1996 and 1997 WVIOPs.

Instrument	Primary quantity observed and typical resolutions	References
AATS-6	Total precipitable water vapor: 12-s resolution during daytime (during 1997 WVIOP only)	Matsumoto et al. (1987); Schmid et al. (2001)
Chilled mirrors (Meteor AG) on kite and tethersonde	Relative humidity profiles: 2-s data during most evenings	Porch et al. (1998); Turner and Goldsmith (1999)
Chilled mirrors on tower (General Eastern D2/M4)	Dewpoint temperature: 1-min resolution, 24 h day^{-1}*	Richardson and Tobin (1998); Richardson et al. (2000)
GPS receiver at SGP Central Facility	Total precipitable water vapor: 30-min data, 24 h day^{-1}	Wolfe and Gutman (2000)
MPI-DIAL	Water vapor density profiles: 30 s, 75-m resolution during multiple 12-h periods (operations restricted by FAA)*	Wulfmeyer and Bösenberg (1998); Linné et al. (2001)
NOAA ETL 20.6/31.65-GHz microwave radiometer (ETL 1)	Atmospheric brightness temperatures and total precipitable water vapor:‡ 30-s resolution, 24 h day^{-1}	Hogg et al. (1983); Han and Westwater (2000)
NOAA ETL 23.87/31.65-GHz microwave radiometer (ETL 2)	Atmospheric brightness temperatures and total precipitable water vapor: 30-s resolution, 24 h day^{-1} (during 1997 WVIOP only)	Hogg et al. (1983); Han and Westwater (2000)
Scanning AERI in trailer	Downwelling infrared radiance: 8 min, 1-wavenumber resolution, 24 h day^{-1}	Feltz et al. (1998)
SRL	Water vapor mixing ratio profiles: 1 min, 75-m resolution primarily at night	Whiteman and Melfi (1999); Whiteman et al. (2001)

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Microwave Radiometer vs. Vaisala Radiosonde

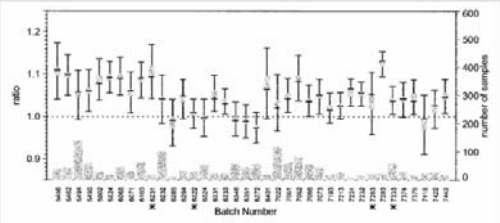

FIG. 6. Analysis of the ratio of the PWV observed by the MWR to the radiosonde as a function of radiosonde calibration batch. The quasi-box-plot indicates the spread (±1 standard deviation about the mean by the error bars and ±1 standard error of the mean by the gray box), the mean value (center of the gray box), and the median ratio (intermediate horizontal black line). The histogram at the bottom indicates the number of radiosondes analyzed in each batch. The standard deviation of the PWV ratio for the 1670 MWR–radiosonde observations, where the mean value for the corresponding batch is removed first, is 0.060. This is almost twice as large as the standard deviation of the mean batch values (0.038 for the 38 batches). Radiosondes launched during the 1996 WVIOP were from batches 6231 and 6322, while radiosondes launched during the 1997 WVIOP were from batches 7263 and 7333. These batches are indicated by the asterisks in the plot.

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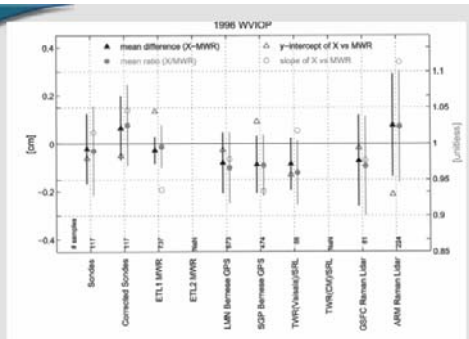

FIG. 10. Comparisons of various techniques that derive PWV with the ARM MWR for the 1996 WVIOP. Data have been averaged to 30-min values before comparison. The mean bias (solid triangles, left axis) and mean ratio (solid circle, right axis), as well as the slope (open circle, right axis) and y intercept (open triangle, left axis) of the fitted regression line, are shown. Error bars represent ±1 standard deviation. The number of points used in each intercomparison is indicated along the base of the figure: NaN for the number of samples indicates that no comparisons for this instrument are available, corrected sonde refers to the radiosondes that have been corrected using the Vaisala correction to account for the chemical contamination of the sensor, and TWR(x)/SRL stands for the SRL calibrated to the x sensor on the 60-m tower, where x is either the chilled mirror (CM) or Vaisala capacitive element probe. The two GPS results are from the station at Lamont, OK (LMN), or the one at the SGP Central Facility (SGP).

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Comparison of Upper Tropospheric Humidity (UTH) from GOES 6.7 m channel with radiosondes and Raman lidar

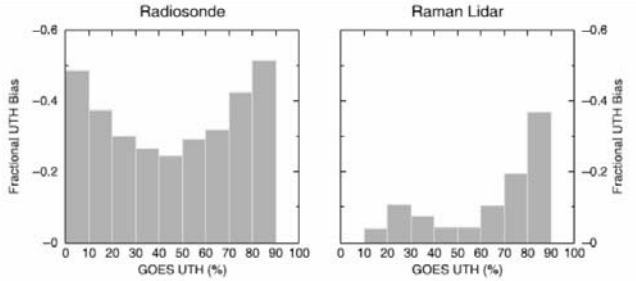

Figure 5. Fractional UTH bias relative to GOES plotted as a function of UTH for the Vaisala RS80-H radiosonde observations (left) and Raman lidar observations (right). The results are averages from all four IOPs.

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Lessons learned

- We can measure water vapor to better than 2% in the column and better than 5% in upper troposphere
- Radiosondes have to be corrected to get close to this accuracy
- We have schemes to do that for Vaisala sondes and they seem to work pretty well (we can quantify this)
- This information does not seem to be penetrating the operational side of the field (case in point: we cannot get the US Weather Service to switch to Vaisala sondes at Barrow despite our identification of gross errors in the current sondes; Reason: climate record!)

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Sidebar (courtesy of A. Tomkins)

- Fact: we can measure PWV continuously (every 20 seconds) with a MWR to a column error < 2%
- MWR measurements are accurate over land (and water)
- Cost of MWR (bulk discount) is ~$100,000
- Cost of SSM/I is ? (but let's estimate $20,000,000)
- So for the cost of 1 SSM/I, I can deploy 200 operational MWRs at land sites
- If you have $20M, which would you prefer?

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Story #2: Solar diffuse flux

- Started with identification of a discrepancy between measured and calculated clear-sky diffuse flux at the SGP
- Resulted in a large number of model investigations
- Spawned one aircraft IOP and two later ground-based IOPs
- Identified problem with thermal correction in solar broad-band radiometers
- Calculated a correction factor that is now standard across all thermal-pile radiometers

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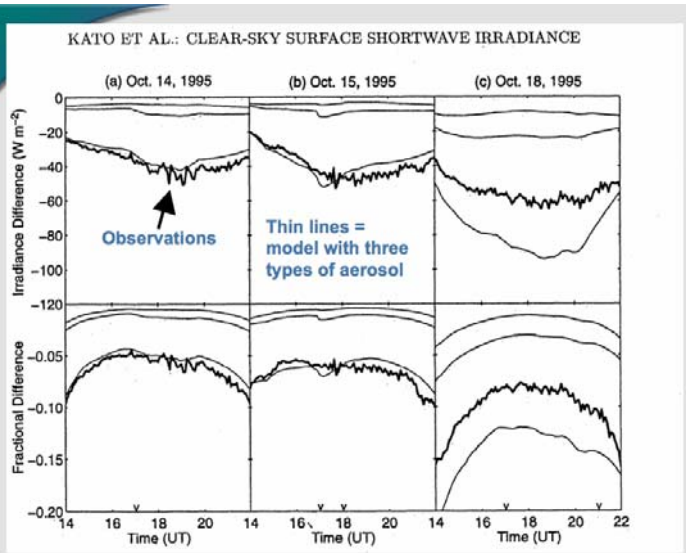

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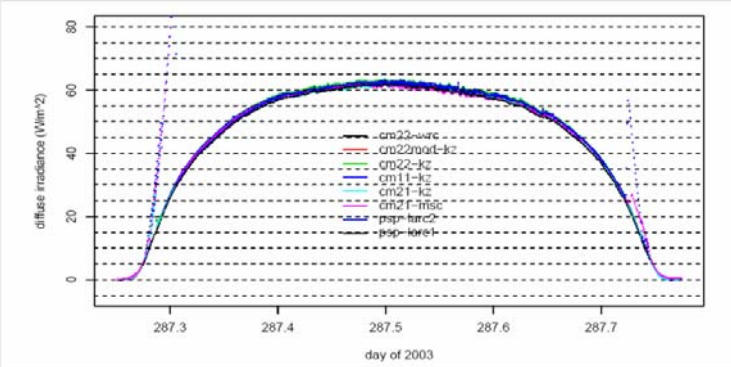
Michalsky et al.: Diffuse Irradiance IOP in 2003 Comparison of 8 BB radiometers



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Lessons learned

- Sometimes it ISN'T the model
- Continuous, well-calibrated measurements can produce new problems
- Well-designed experiments can identify the errors and correct them
- Why do you care? If you are removing the bias in your model (adding aerosol?) when it is a bias in the instrument ….

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Story #3: Arctic clouds

An Assessment of ECMWF Model Analyses and Forecasts over the North Slope of Alaska Using Observations from the ARM Mixed-Phase Arctic Cloud Experiment

Shaocheng Xie, Stephen A. Klein, John J. Yio, Anton C. M. Beljaars, Charles N. Long, and Minghua Zhang

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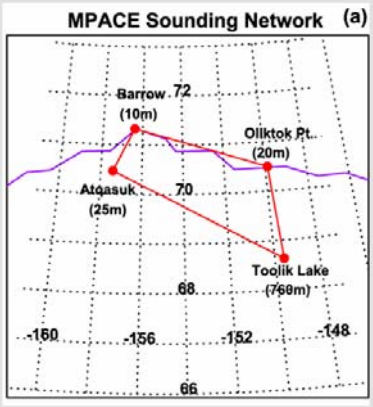
Mixed-Phase Arctic Cloud Experiment

- Start with MPACE domain
- Create domain-average values
  - Variational analysis
  - Time and space averaging
  - 3-hourly values
- Compare with ECMWF analysis (6 hourly values)



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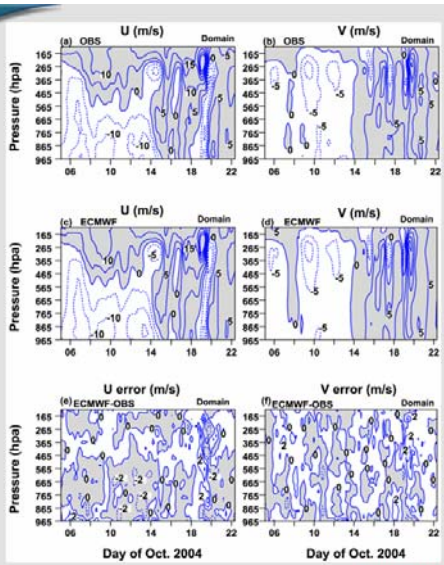

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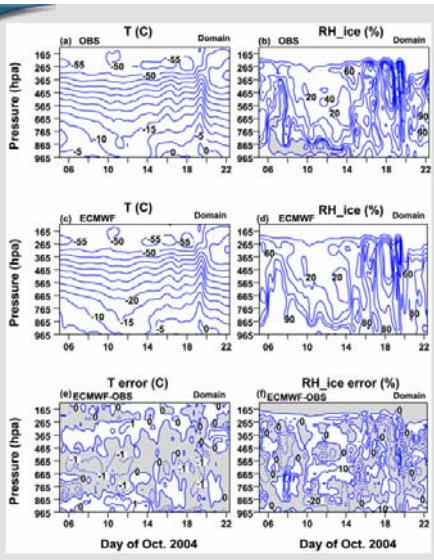

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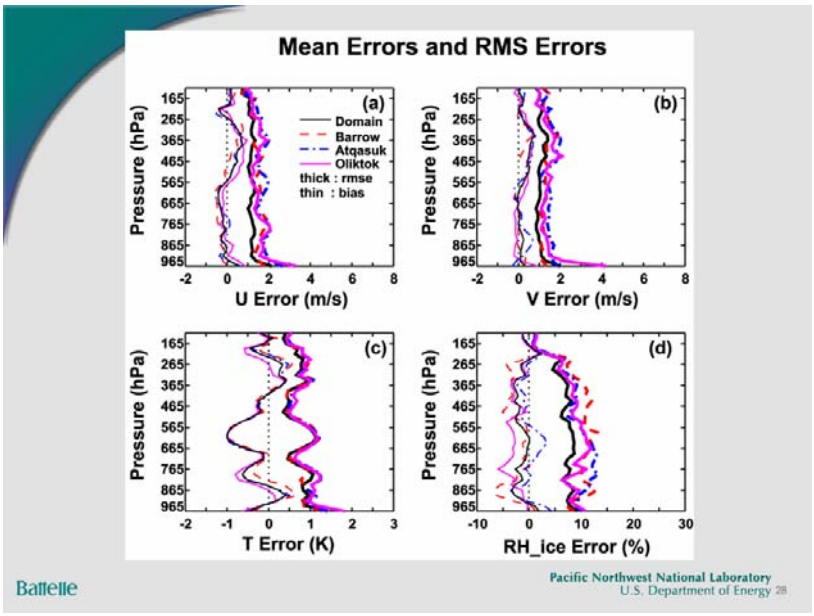
Mean Errors and RMS Errors
(a)
Domain
Barrow
Atqasuk
Oliktok
thick : rmse
thin : bias
Pressure (hPa)
U Error (m/s)
(b)
V Error (m/s)
(c)
T Error (K)
(d)
RH_ice Error (%)
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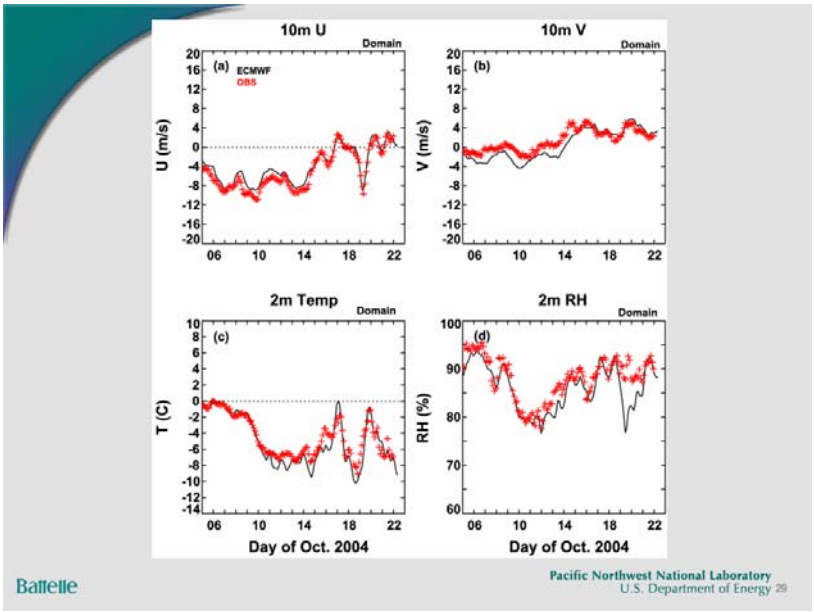
10m U
Domain
(a)
ECMWF
OBS
U (m/s)
10m V
(b)
V (m/s)
2m Temp
(c)
T (C)
2m RH
(d)
RH (%)
Day of Oct. 2004
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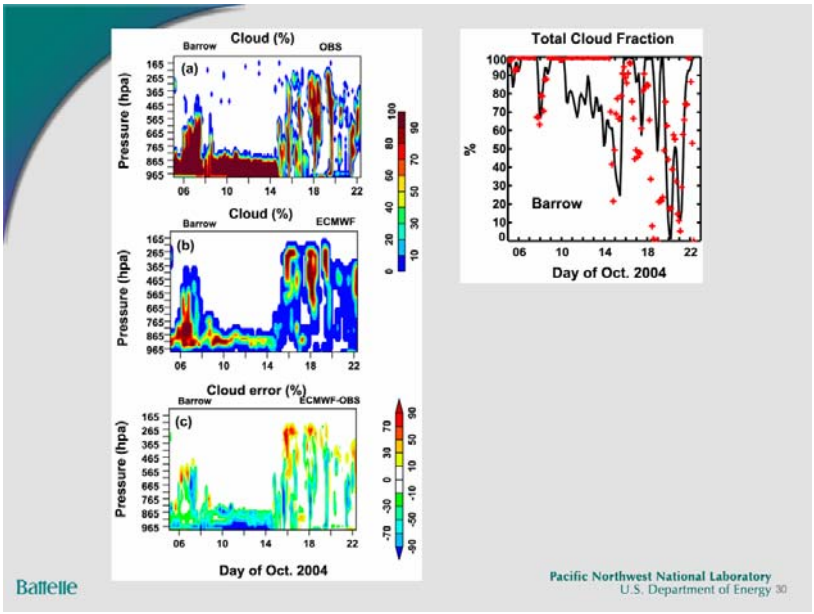
Cloud (%)
Barrow
OBS
(a)
Pressure (hpa)
Cloud (%)
ECMWF
(b)
Cloud error (%)
ECMWF-OBS
(c)
Day of Oct. 2004
Total Cloud Fraction
%
Barrow
Day of Oct. 2004
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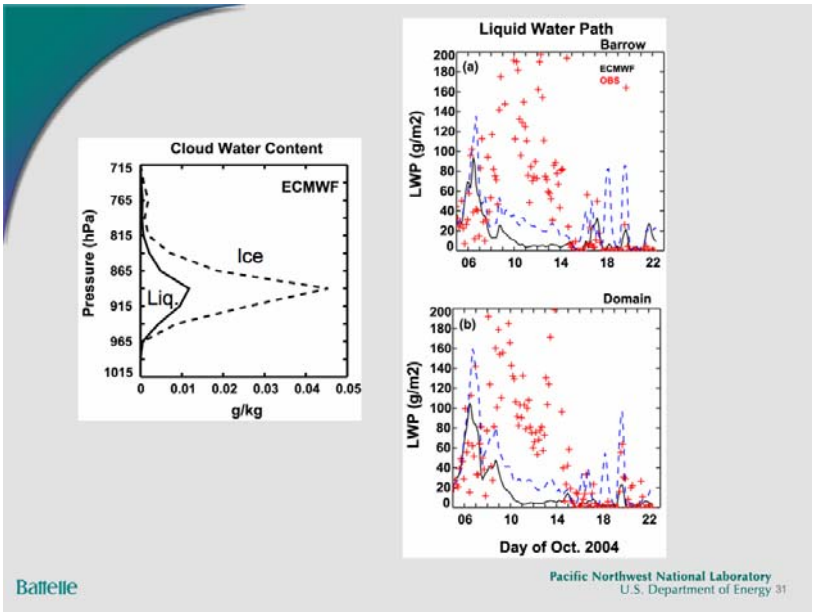
Cloud Water Content
ECMWF
Ice
Liq.
Pressure (hPa)
715
765
815
865
915
965
1015
0
0.01
0.02
0.03
0.04
0.05
g/kg
Liquid Water Path
Barrow
(a)
ECMWF
OBS
LWP (g/m2)
Domain
(b)
Day of Oct. 2004
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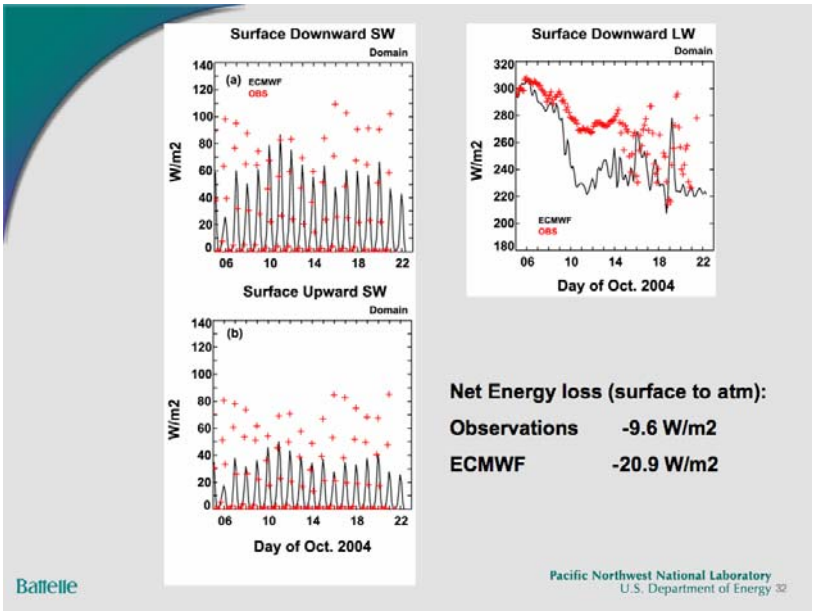
Surface Downward SW
Domain
(a)
ECMWF
OBS
W/m2
Surface Upward SW
(b)
Day of Oct. 2004
Surface Downward LW
Net Energy loss (surface to atm):
Observations -9.6 W/m2
ECMWF -20.9 W/m2
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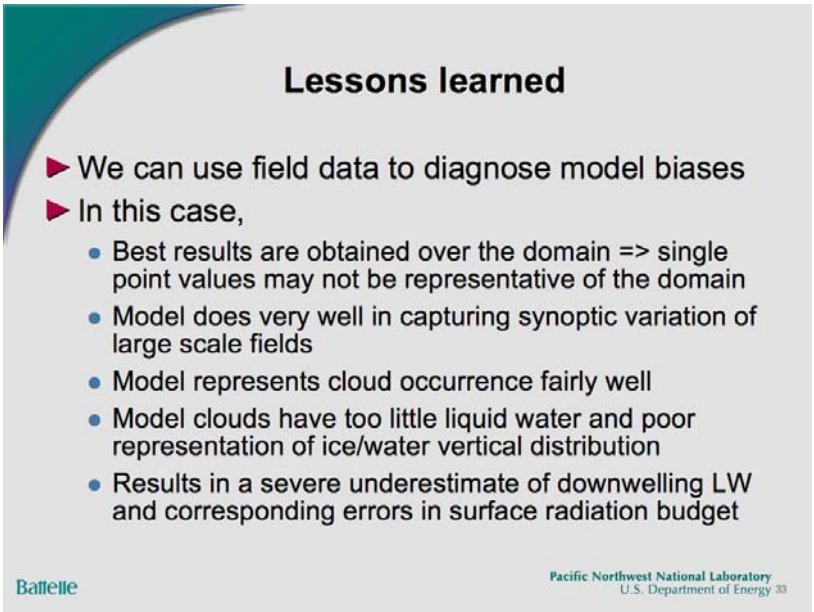
Lessons learned
We can use field data to diagnose model biases
In this case,
Best results are obtained over the domain => single point values may not be representative of the domain
Model does very well in capturing synoptic variation of large scale fields
Model represents cloud occurrence fairly well
Model clouds have too little liquid water and poor representation of ice/water vertical distribution
Results in a severe underestimate of downwelling LW and corresponding errors in surface radiation budget
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Story #4: Operational comparison

- CloudNet project
- PI: Prof. Anthony Illingworth, U. Reading
- Comparison of data from 3 European sites (Cabauw, Chilbolton, Palaiseau) with forecast model output
- Brilliant webpage
- Being extended to Lindenberg and ARM sites

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Story #5: Heating Rate Profiles

Acknowledgements to:
Sally McFarlane, Jim Mather, Roger Marchand

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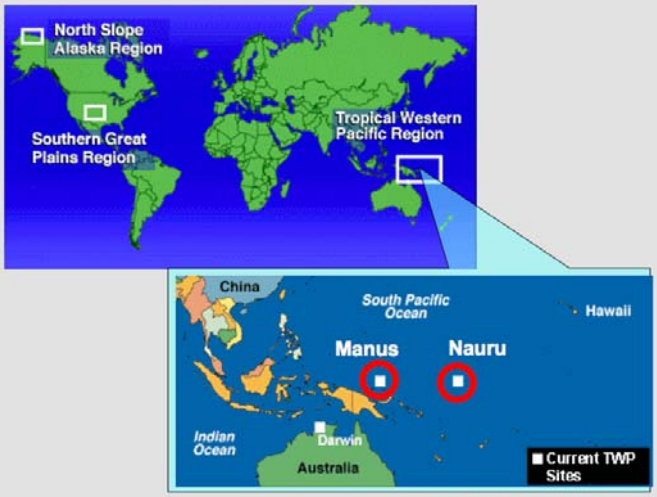
ARM Tropical Western Pacific Sites



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ARM Data Processing

- Heating Rate Profiles
  - Temperature and water vapor profiles from radiosondes, scaled to microwave radiometer precipitable water and surface temperature
  - Vertical profiles of cloud microphysical properties calculated from ARM millimeter wave radar data (data has 10-second temporal and 45 m vertical resolution)
  - Sample the cloud properties every 5 minutes and perform radiative transfer only on the sampled profiles.
  - Calculate broadband fluxes and vertical profile of heating rates.

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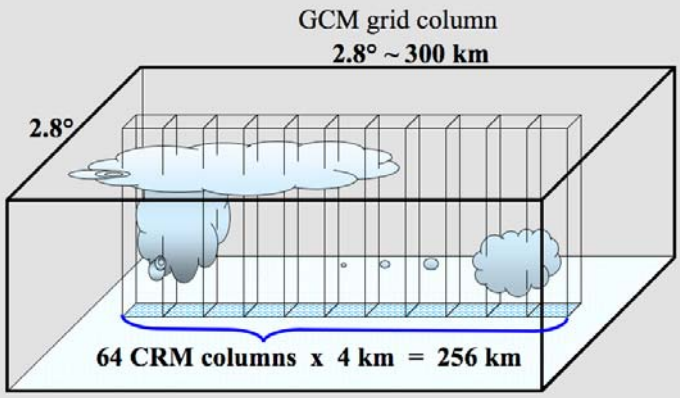
MMF Schematic



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Simulations

- MMF simulations with CSU model *
  - Run with observed SST values
  - Start in January 1998 and run into 2001
  - Second run for 2000 started from different initial conditions
- CAM simulations
  - Run with observed SST values for same period
- For the CAM-only runs, we examine output from the gridbox containing the ARM site
- For MMF runs, we examine the average over the 64 CRM columns within the gridbox containing the ARM site

** Model output available to any interested scientists*

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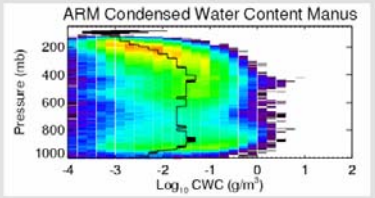
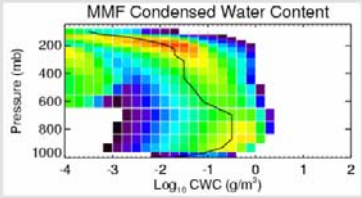
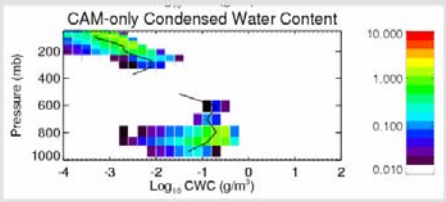
Condensed Water Frequency Distributions - Manus







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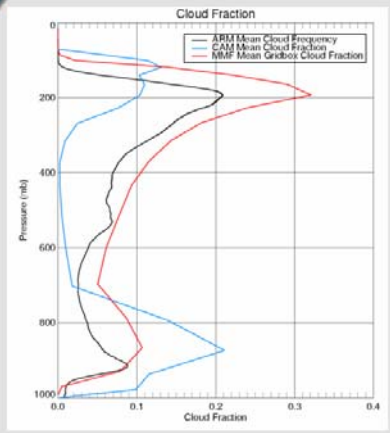
Cloud Fraction



- ARM cloud frequency is percent of time reflectivity is greater than -40 dBZ at given level
- CAM cloud fraction is mean gridbox cloud fraction from cloud parameterization
- MMF cloud fraction is number of cloudy CRM columns within CAM gridbox

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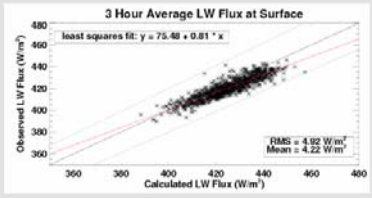
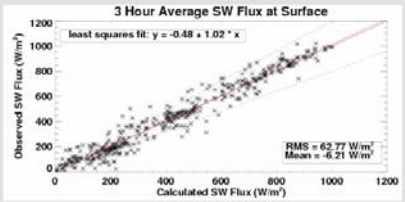
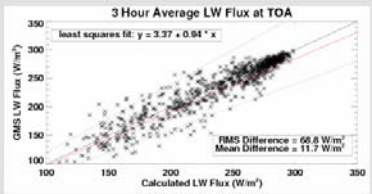
Surface and TOA Flux Comparisons (RT model and Data)

- SW surface comparisons show strong correlation, little bias
- LW surface comparisons are biased towards model overestimate of LW flux under cloudy conditions
- LW TOA comparisons show large scatter under cloudy conditions







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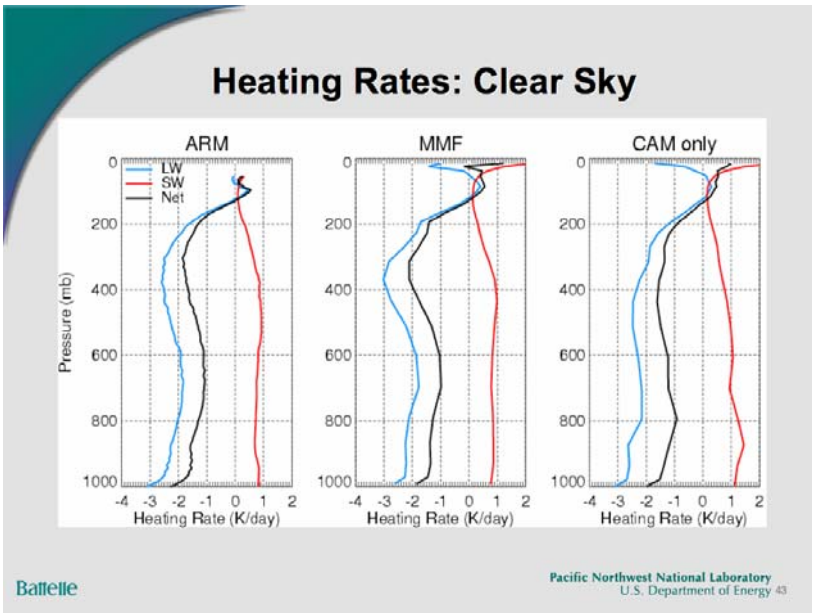
Heating Rates: Clear Sky
ARM
MMF
CAM only
LW
SW
Net
Pressure (mb)
Heating Rate (K/day)
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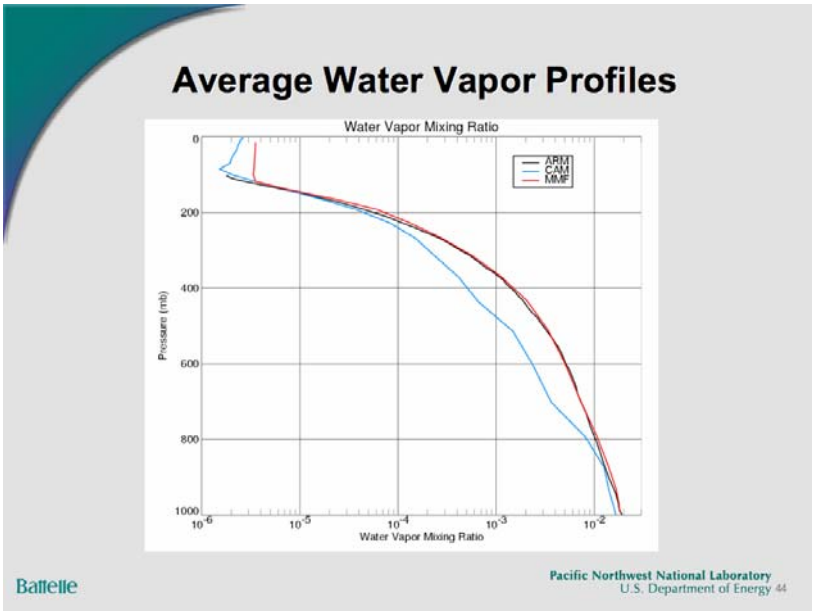
Average Water Vapor Profiles
Water Vapor Mixing Ratio
ARM
CAM
MMF
Pressure (mb)
Water Vapor Mixing Ratio
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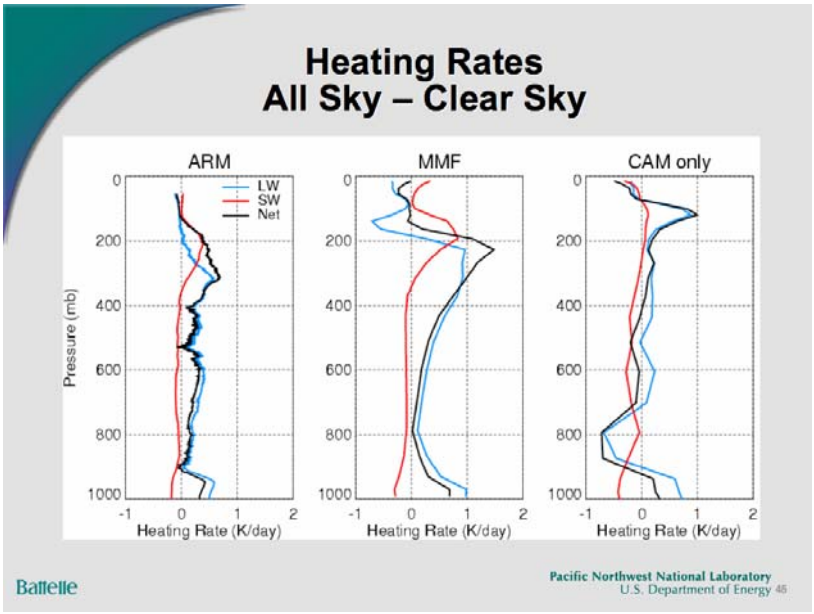
Heating Rates
All Sky – Clear Sky
ARM
MMF
CAM only
LW
SW
Net
Pressure (mb)
Heating Rate (K/day)
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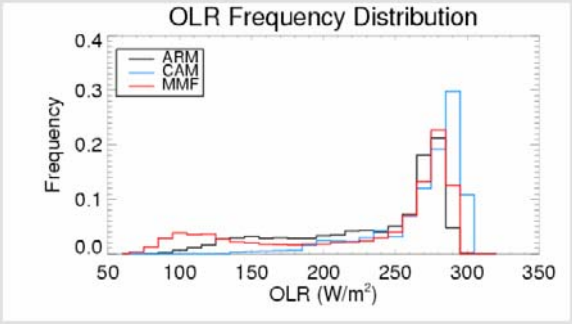

- CAM has no OLR values below 175 W/m²; larger frequency of very high OLR
- MMF/ARM frequency distributions similar; MMF has more very low OLR values

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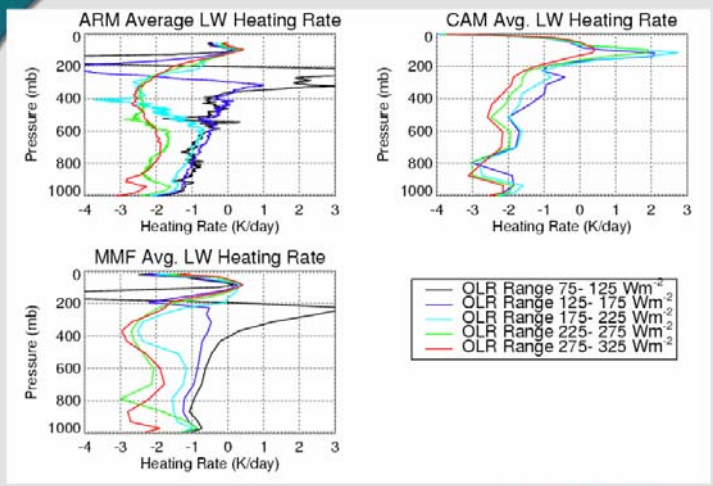
Heating Rates for Various OLR Ranges



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Lessons learned

- We can use routine CAP data to carry out statistical comparisons to identify model biases
- Results from this study
  - MMF reproduces observed water vapor profile and clear sky heating rates better than CAM
  - Both models have problems with clouds, but CAM are more severe
  - Heating rates errors can be directly tied to deficiencies in cloud properties
  - Classification is a very helpful diagnostic

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Summary

- Extensive networks (limited instrumentation)
  - Continuous well-calibrated observations of a few important variables
  - Provide constraint on model bias
- CAP sites (heavily instrumented, few in number)
  - Continuous, well-calibrated observations of many variables
  - Testing ground for fundamental physics and chemistry
  - Development framework for process models
  - Evaluation facility for satellite measurements
  - Evaluation facility for model performance

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Summary

- Best way (currently) to evaluate model bias
  - Continuous comparison with CAP site data => multiple measurements of variables where possible
  - Identify discrepancies
  - Target field campaigns at one or more sites to study processes and assign cause to discrepancy
  - Correct
  - Continue

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Issues

- Are we making the “right” measurements?
- Are there simple data streams that we could generate that would be useful?
- Do we know the absolute accuracy of the measurements?
- How good is the data quality assessment?
- How much measurement detail do we have to communicate to the user (NWP) community in order to make the measurements useful?

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