

# Sensitivities of Cloud Resolving Model Simulations of KWAJEX

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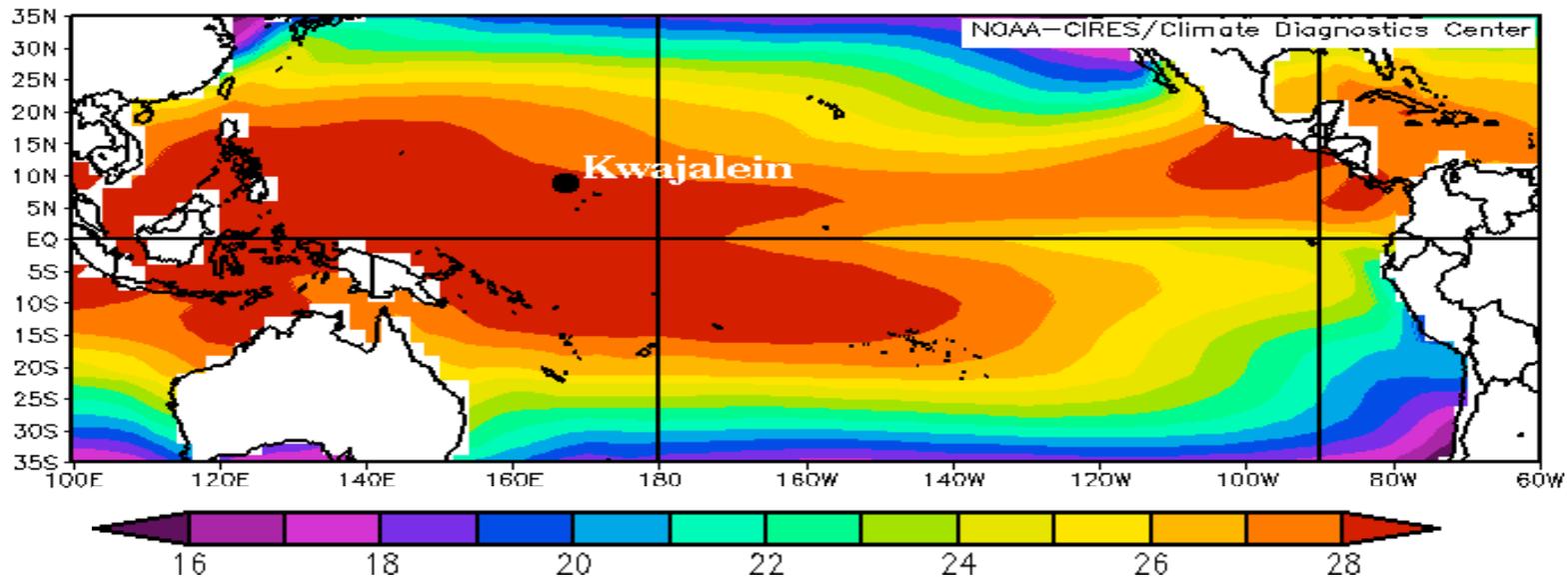
Thanks to Marat Khairoutdinov (CSU), Jasmine Cetrone (UW) and Steve Krueger (Utah).

# Outline

- Introduction/Motivation
- Forcings/Simulation Design
- Results (Temperature, Moisture, Radiation, ISCCP, Microphysics, Radar)
- Compare/contrast with results from 120 day simulations of TOGA-COARE
- Summary

# Kwajalein Experiment (KWAJEX)

- Part of TRMM ground validation program
- Centered on Kwajalein Atoll in Marshall Islands.
- From 23 July to 15 September 1999.
- Extensive data collection effort including five sounding sites, three aircraft, one ship and a ground-based S-band radar.



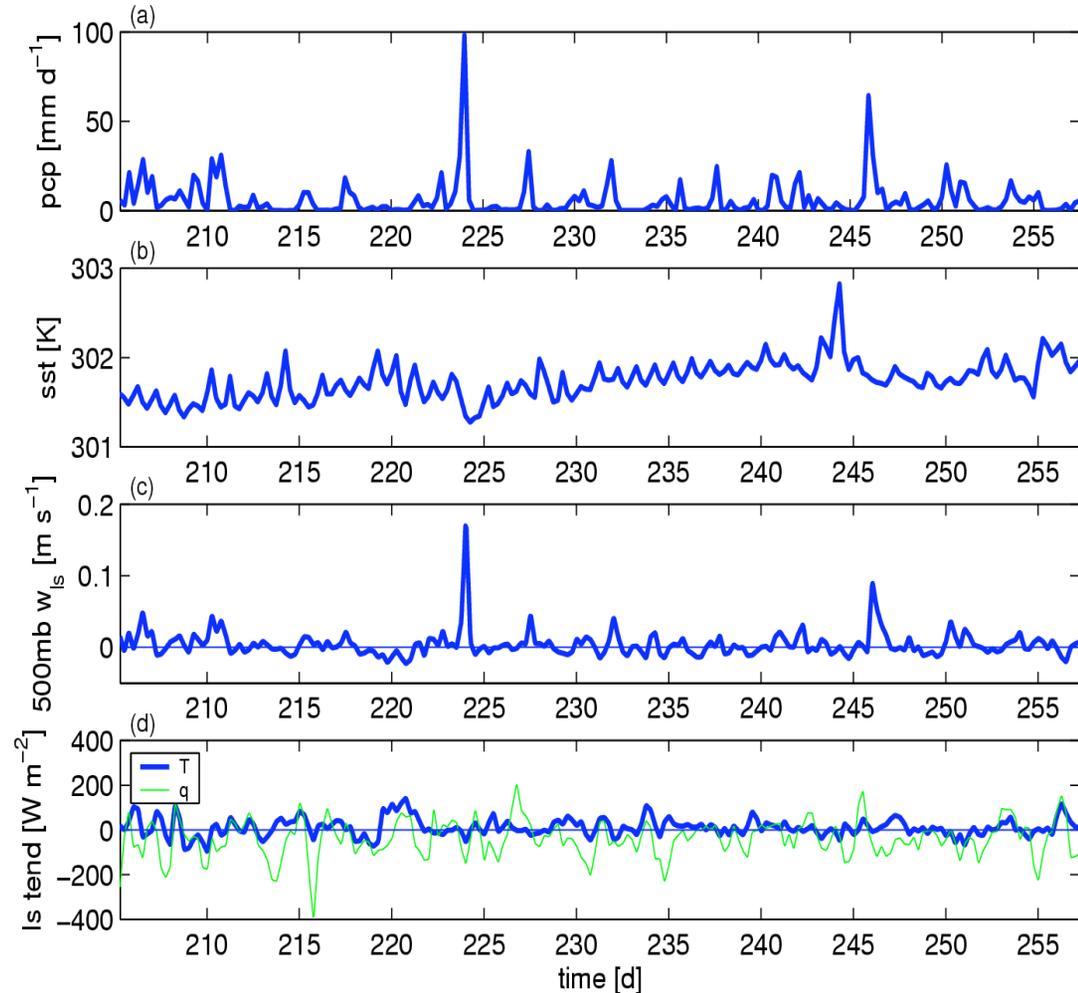
NOAA SST Climatology (Jan-Sep) 1971-2000

# Motivation

- Validate CRM and understand its sensitivities
- Use long term (52 day) simulations to separate persistent and transient biases.
- KWAJEX is attractive case for:
  - extensive observational dataset and
  - research-quality radar that constrains precipitation/latent heating.

# Forcings

- Supplied by Minghua Zhang (Stony Brook) based on variational analysis
- Provide large-scale horizontal advection and vertical velocity.
- SST drawn from *in situ* measurements.



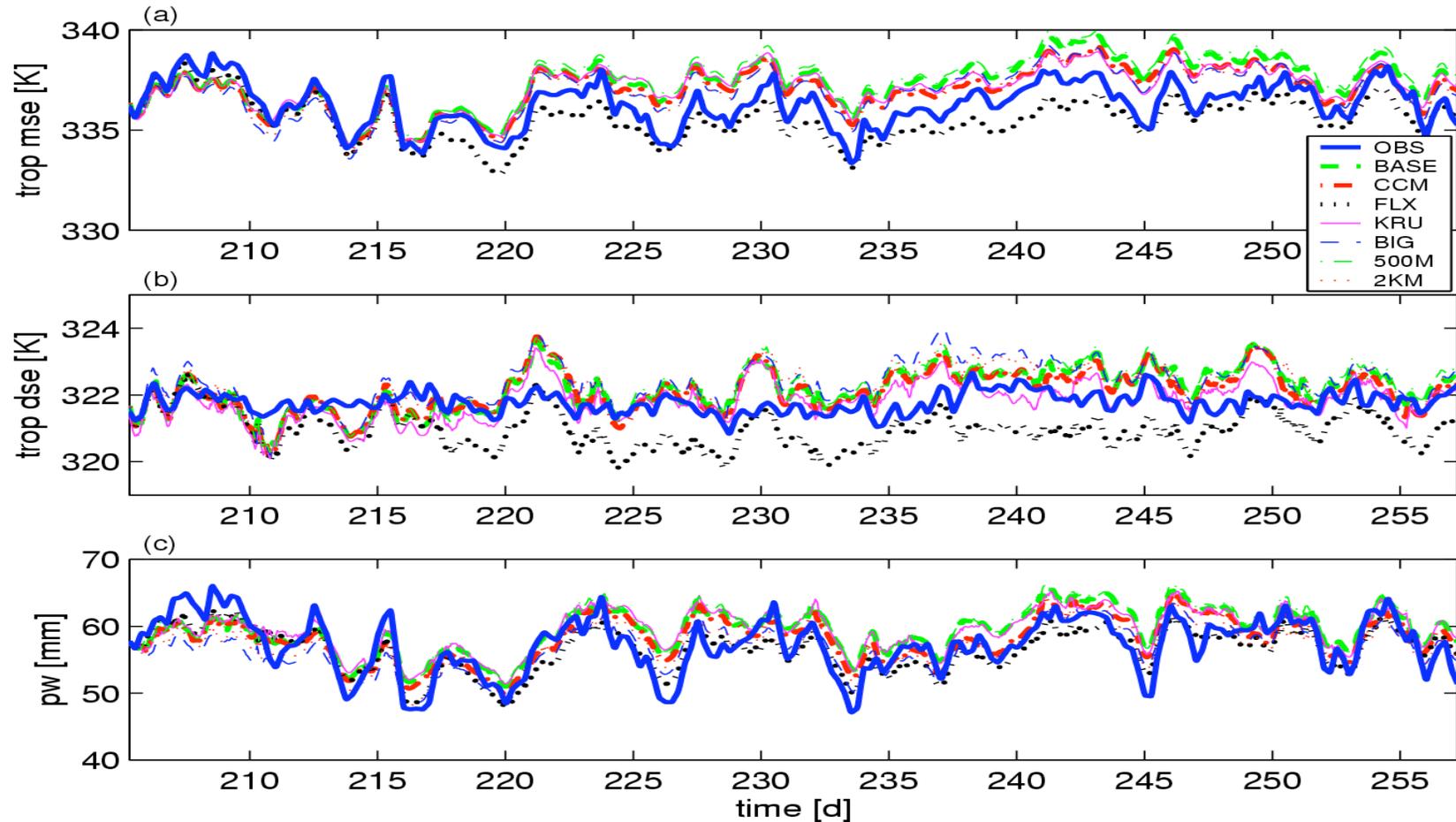
# BASE Simulation Setup

- System for Atmospheric Modeling (SAM), version 6.3.
- Bulk microphysics -- total non-precipitating and precipitating water advected. Phases diagnosed from temperature.
- Interactive radiation (CAM3.0).
- Domain: 64x64x29 km,  $\Delta x = \Delta y = 1\text{km}$ ,  $\Delta z = 75\text{-}400\text{m}$  (to 1km in sponge: 20-29 km)
- Forced by LS horizontal advection, LS vertical velocity and SST.
- Winds nudged on 2 hour timescale.
- No thermodynamic nudging.

# Legend/Sensitivity Studies

-  OBS Observations
-  BASE  $(64\text{km})^2$  domain,  $\Delta x=1\text{km}$
-  CCM CCM3.6 radiation
-  FLX Forced by LHF/SHF (NCEP/obs)
-  KRU Krueger microphysics (six class)
-  BIG  $(256\text{ km})^2$  domain with  $\Delta x=1\text{km}$ .
-  500M  $(64\text{ km})^2$  domain with  $\Delta x=500\text{m}$ .
-  2KM  $(128\text{ km})^2$  domain with  $\Delta x=2\text{km}$ .

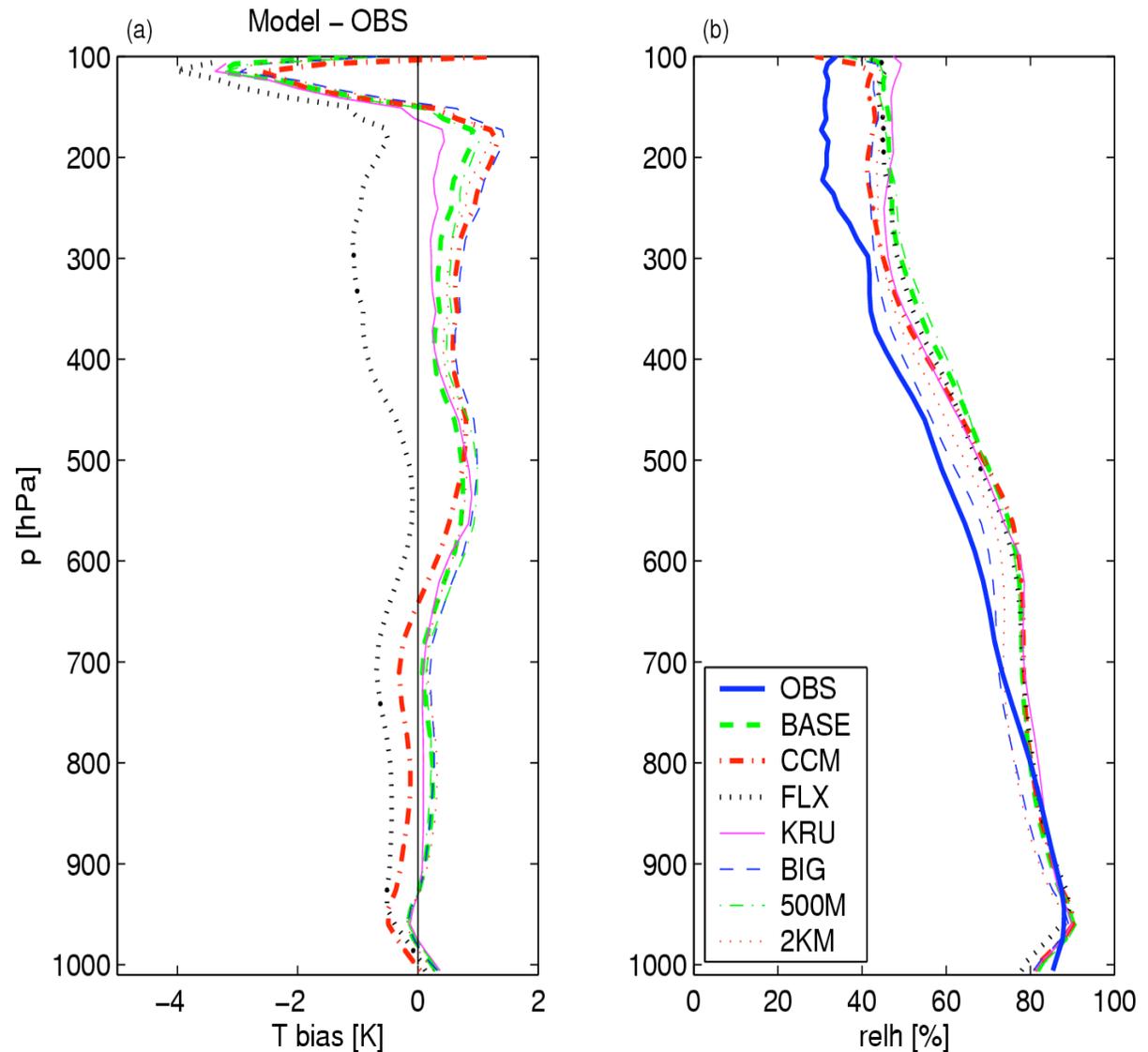
# Column-integrated Biases



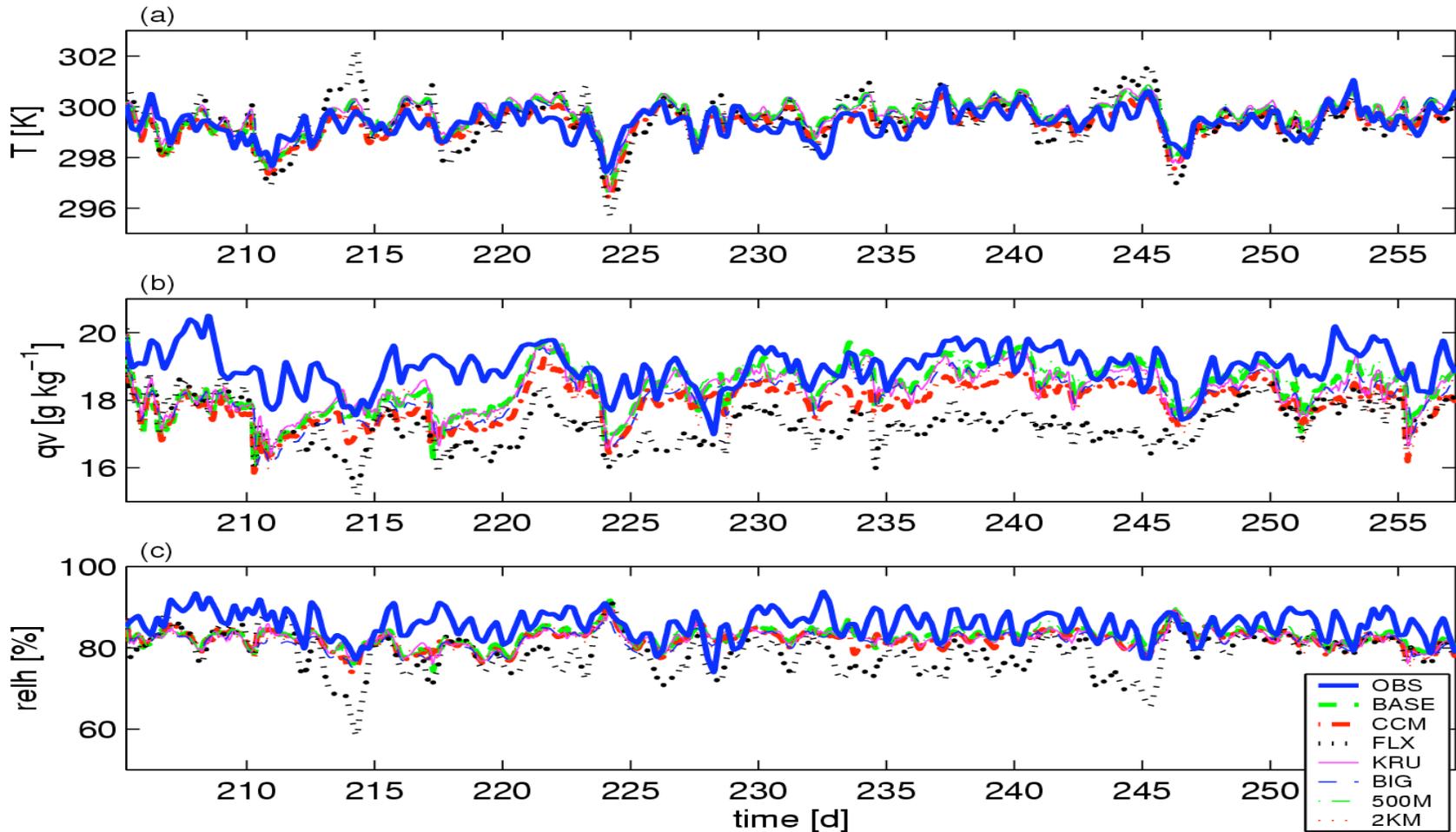
- SST-forced runs behave similarly, with slight warm bias.
- Runs show more variability than OBS in DSE, less in PW.

# Time-avg. Temperature/Moisture Biases

- T bias < 1K through most of troposphere.
- SST-forced runs more stable than OBS.
- All runs moister than OBS above ~700 hPa.
- Moist bias decreases with domain size (e.g. BIG/2KM).

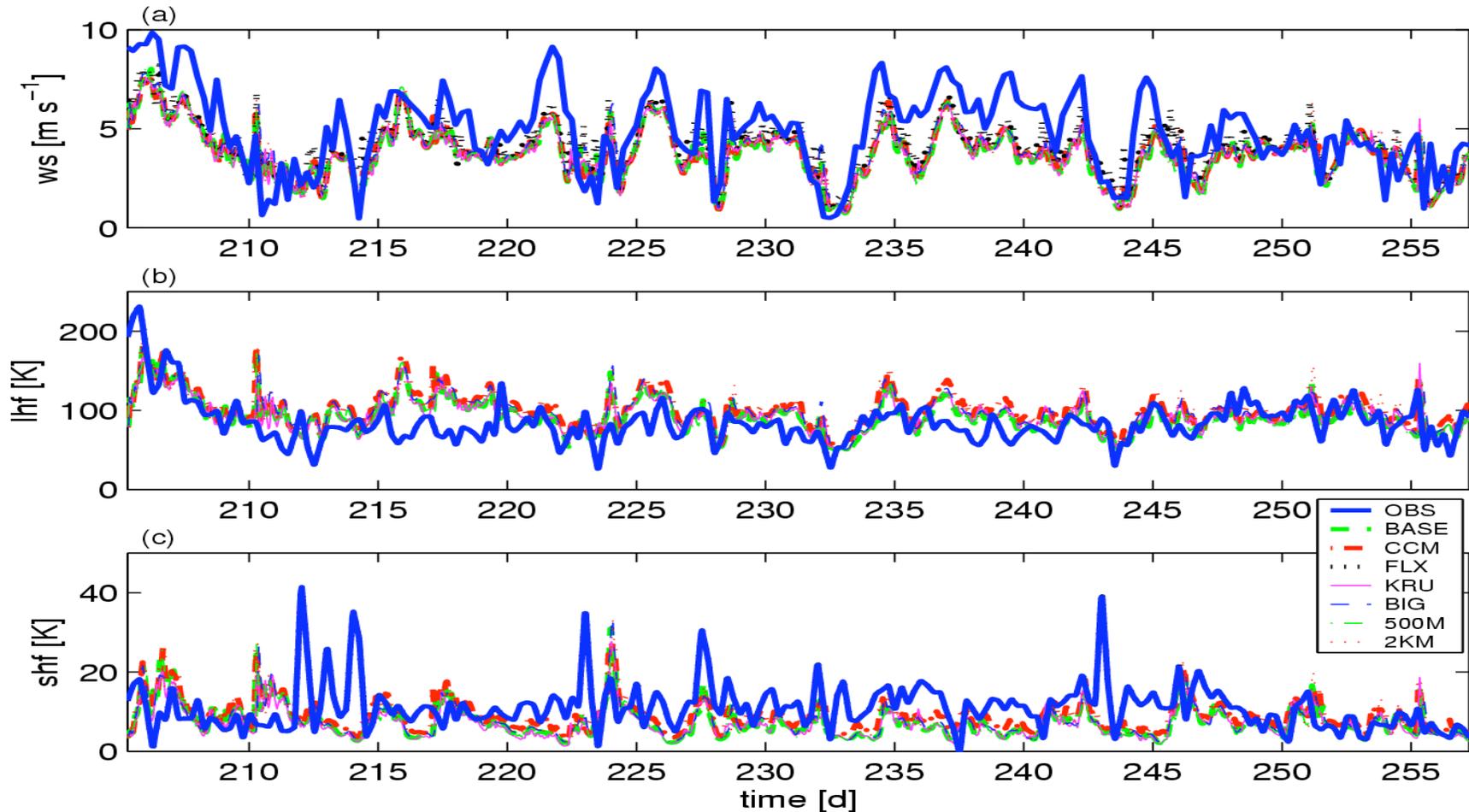


# 1000hPa Temperature/Moisture



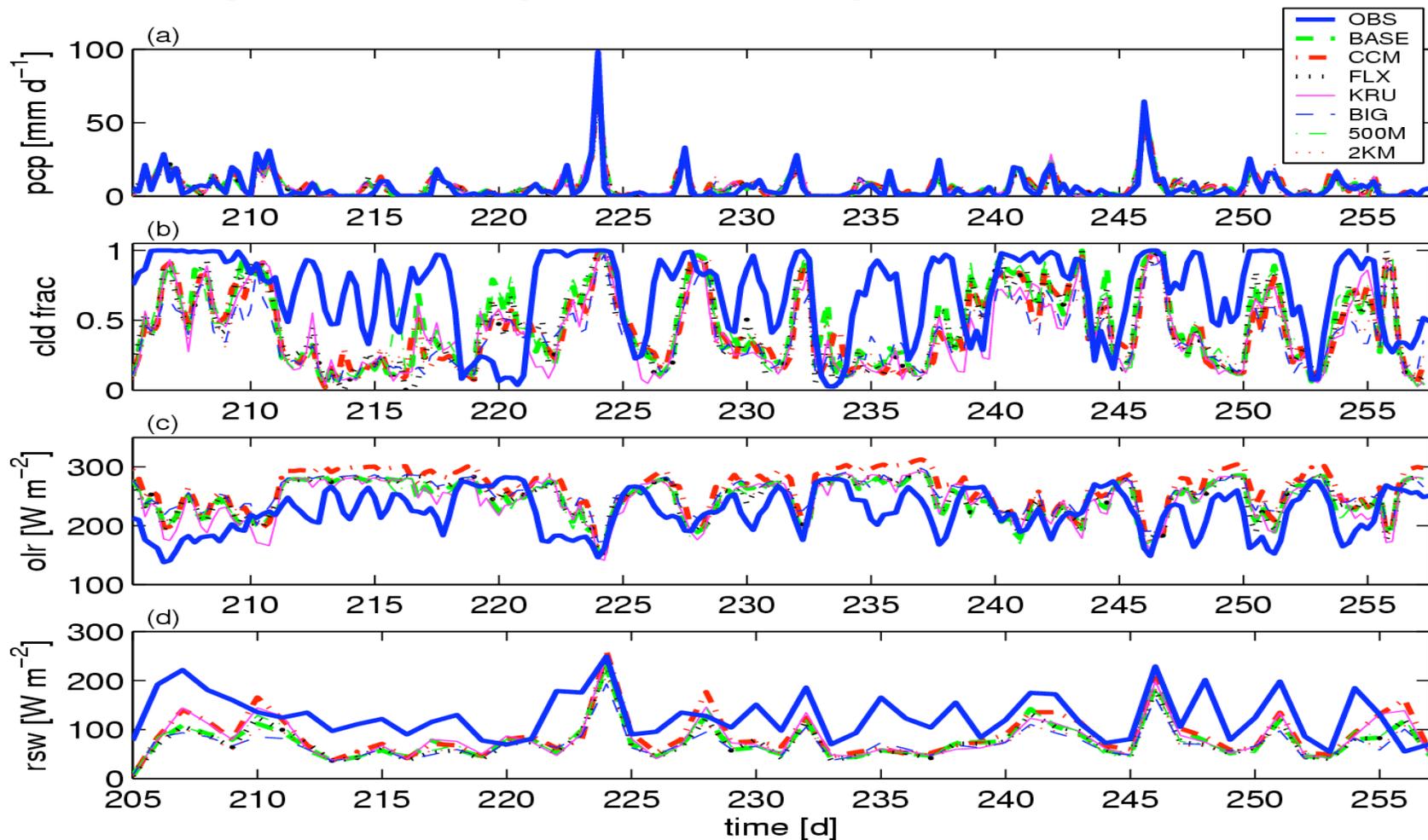
- SST-forced have little bias in 1000hPa temperature.
- All runs dry near surface w/less variability in RH than OBS.

# Surface Wind Speed/Fluxes



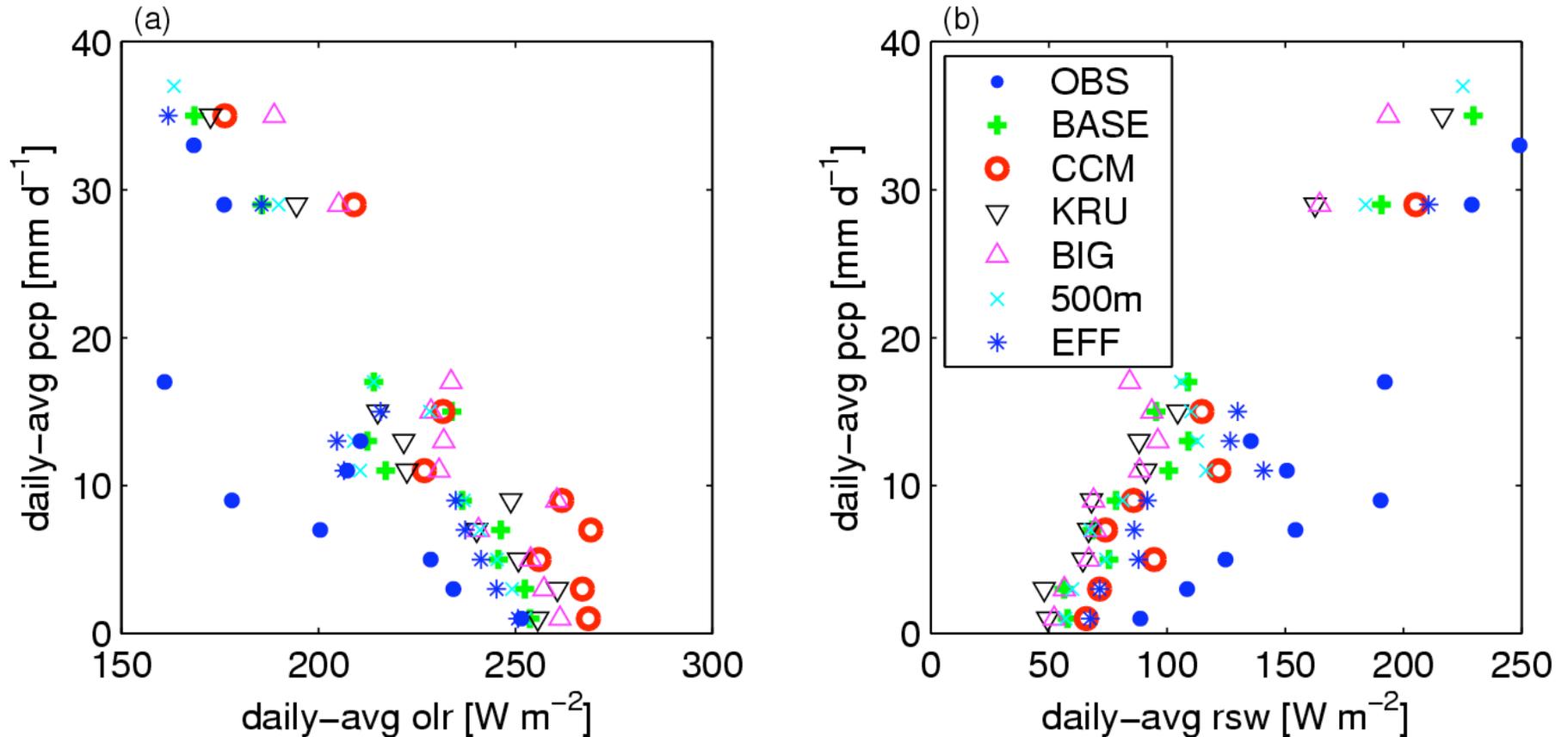
- OBS: wind (soundings/Meck Island), fluxes (NCEP/Meck).
- Nudged winds give reasonable surface wind speed/fluxes.

# Precipitation, Clouds, TOA Radiation



- Precip match not surprising, since  $w_{ls}$  derived from it.
- Insufficient cloud, albedo during periods of weak precip.
- TOA radiation reproduces OBS during most intense precip.

# TOA Radiation binned by Precip



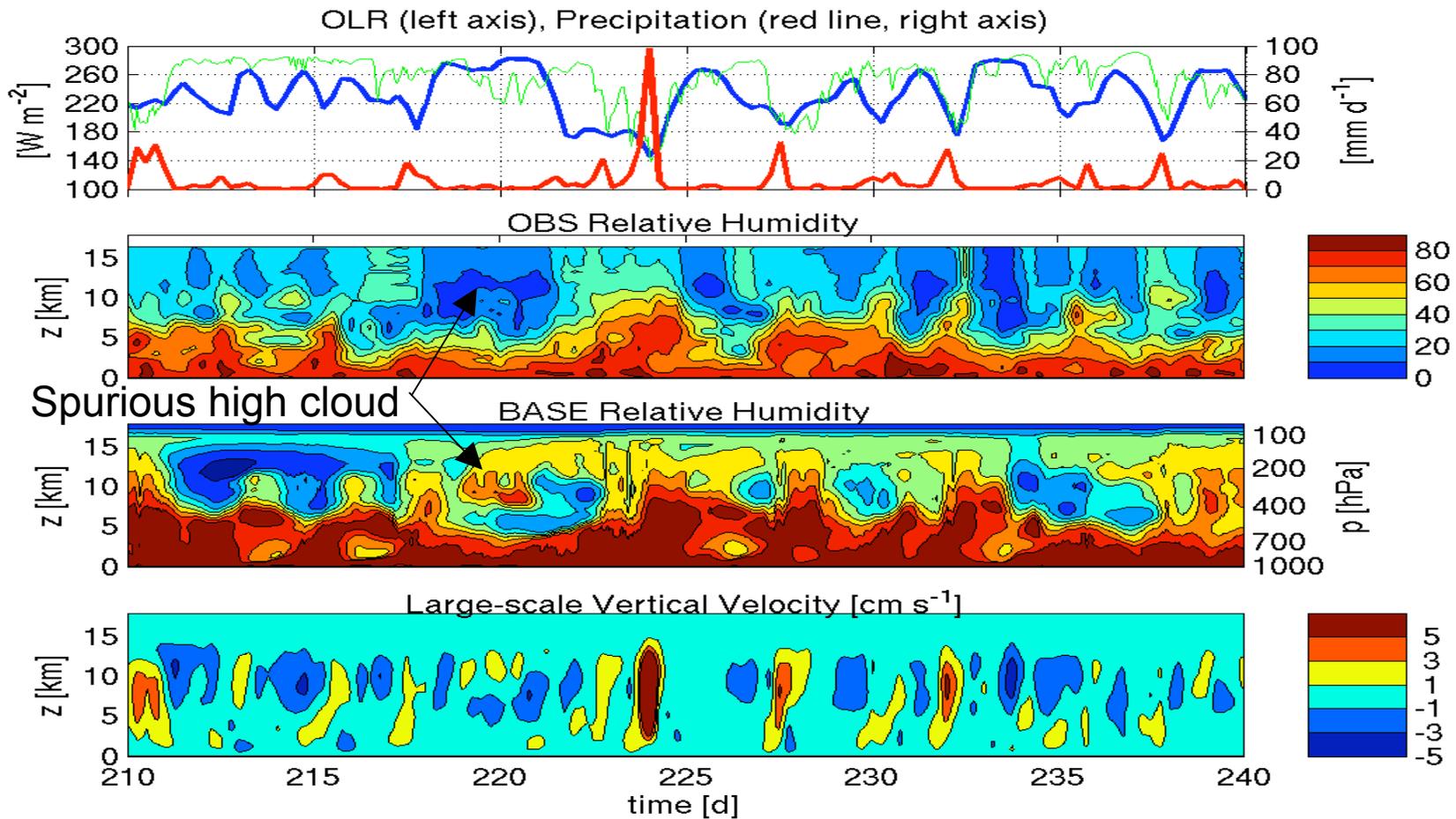
- Daily-avg. TOA radiation averaged into bins by precipitation.
- Model biases strongest during periods of weak/moderate precip
- Biases not eliminated by changing effective radius assumptions (EFF,  $r_{ei}=10\mu\text{m}$ ,  $r_{ei}=25\mu\text{m}$ ,  $r_{es}=75\mu\text{m}$  -- also used in KRU)

# ISCCP simulator results

Opt. depth $p_{\text{top}}$	Thin ( $0.3 < t < 3.6$ )	Med ( $3.6 < t < 23$ )	Thick ( $23 < t$ )
High ( $p_{\text{top}} < 440\text{hPa}$ )	25.4 25.8	13.2 8.2	8.6 4.2
Med ( $p_{\text{top}} > 440\text{hPa}$ )	9.1 0.8	5.5 1.7	0.7 1.4
Low ( $p_{\text{top}} > 680\text{hPa}$ )	4.8 1.6	2.4 1.9	0.1 1.0

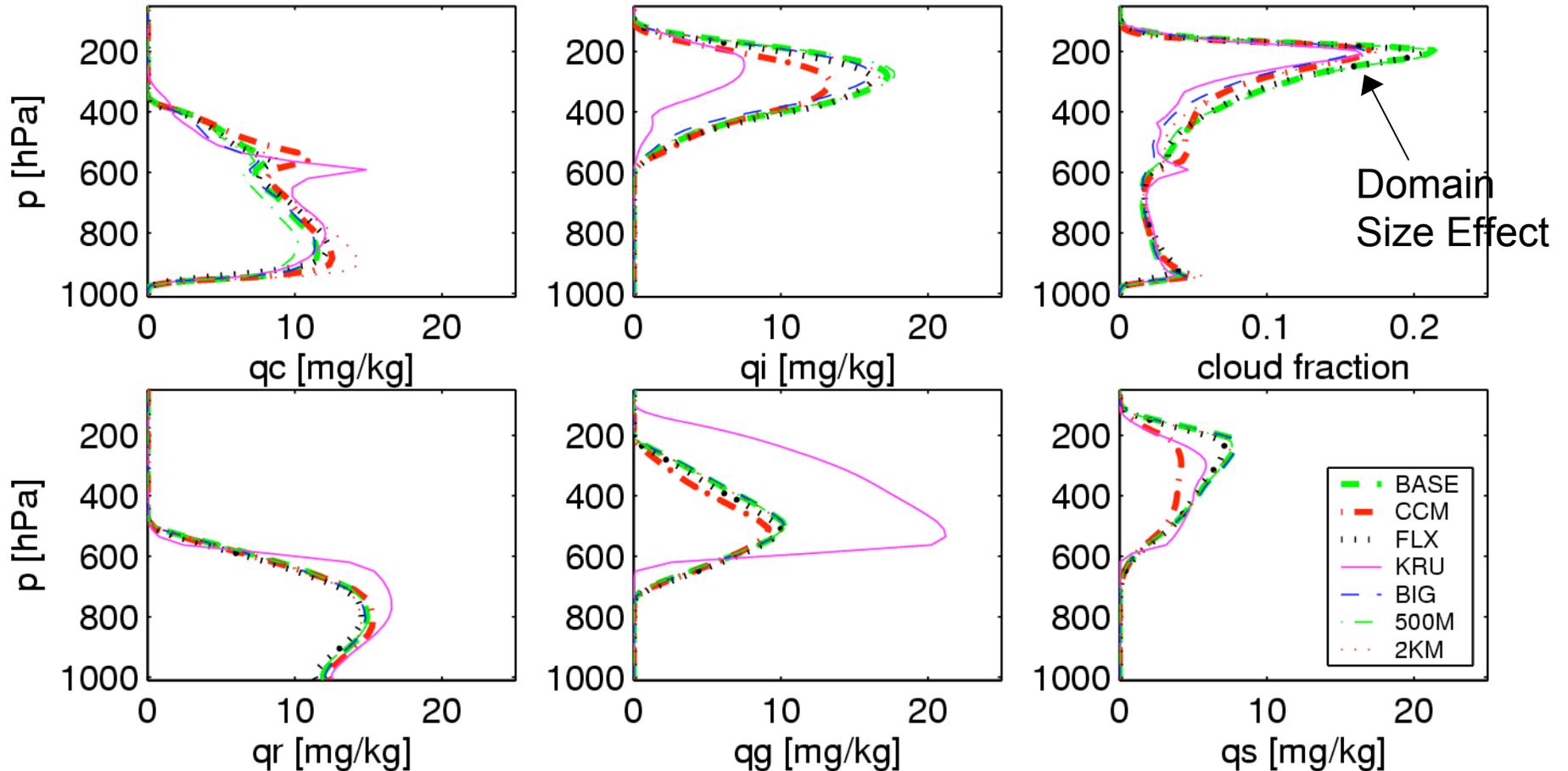
- Thin high cloud in **BASE** matches **ISCCP**.
- Insufficient medium and thick high cloud.

# Role of Forcing in Biases?



- Only obvious forcing problem generates spurious high cloud.
- Advected condensate (neglected in forcings) could be present.

# Time-avg. Microphysical Fields



- Krueger microphysics: much more graupel, less snow/cloud ice, sharper transition at melting layer.
- Slight sensitivity of cloud fraction, ice/snow to radiation scheme.

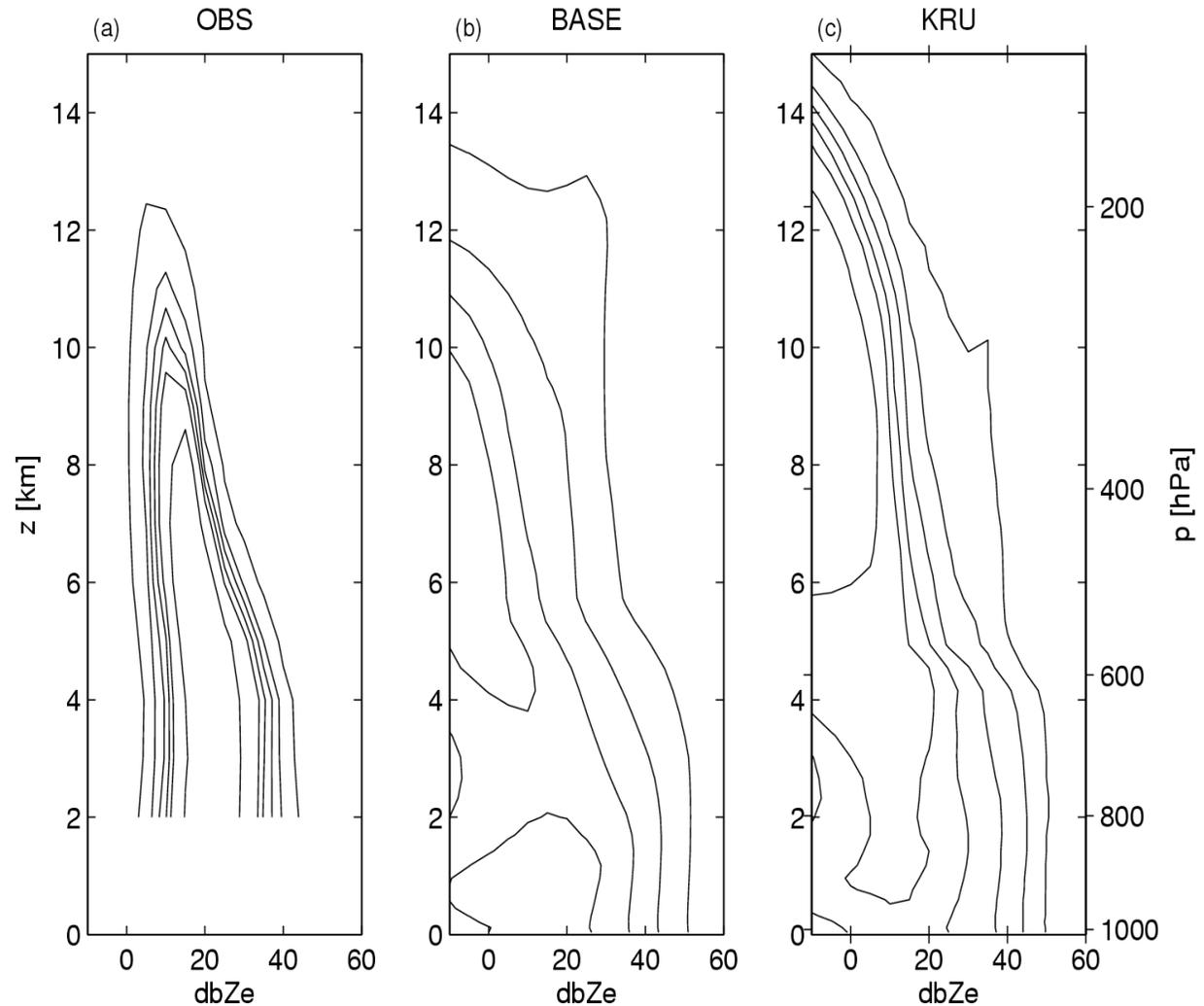
# Simulated Radar Reflectivity

- Construct approximate radar reflectivities from SAM's microphysical assumptions:
  - exponential size distribution w/fixed  $N_0$
  - fixed hydrometeor density
- Ice relations from Heymsfield et al (2002).

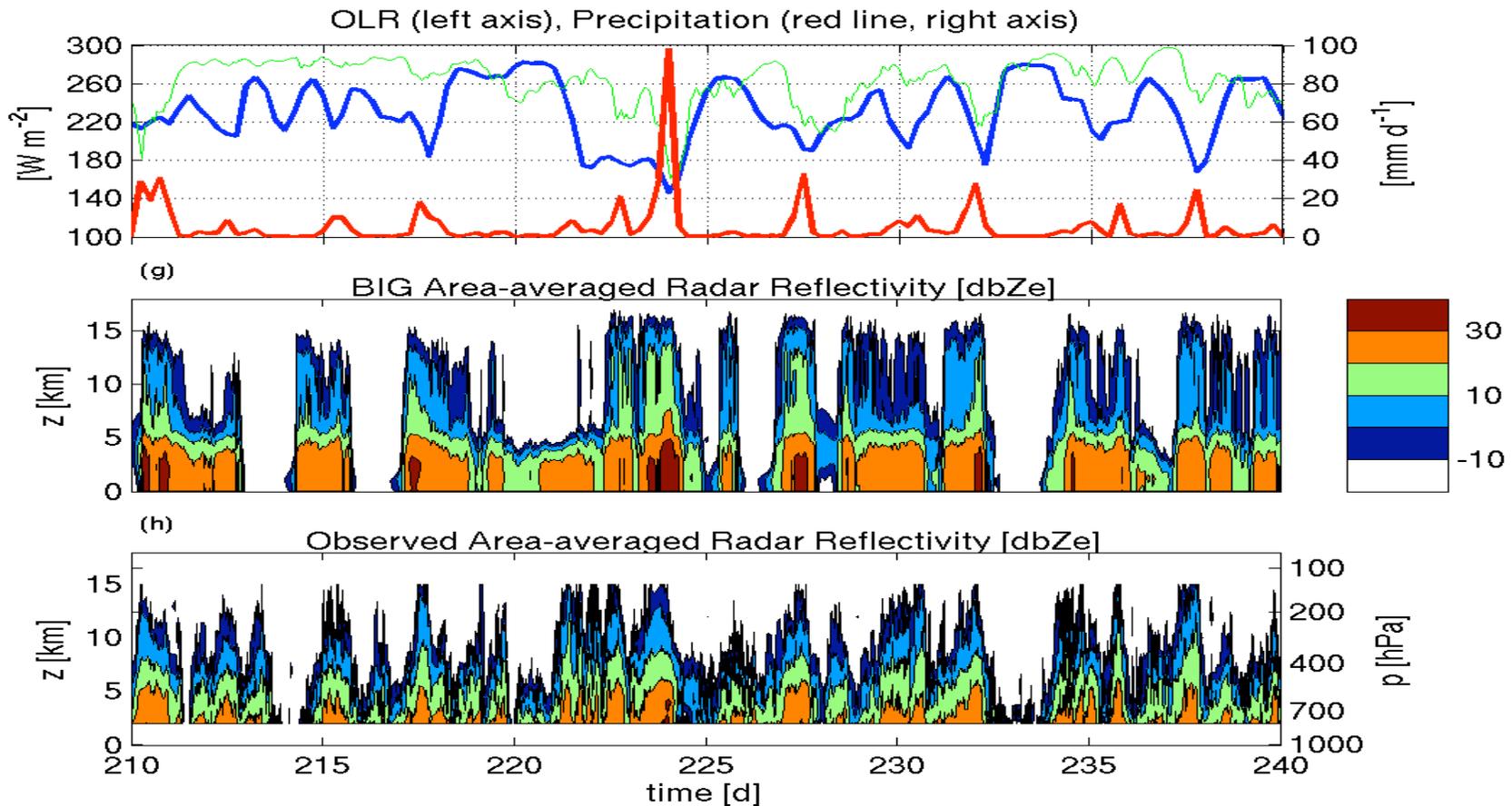
$$Z_e = 2 \cdot 10^4 (\rho q_r)^{1.75} + \frac{0.197}{0.93} (6 \cdot 10^3 (\rho q_s)^{1.72} + 4.9 \cdot 10^3 (\rho q_g)^{1.72})$$

# Radar Reflectivity PDFs

- PDFs integrate to area fraction of precipitation at each height.
- Broader distribution in BASE/KRU than in OBS.
- OBS peak at  $\sim 20 \text{ dBZ}_e$
- Excess of convective precip in model.



# Area-Avg. Radar Reflectivity



- Computed as  $\text{dB}\langle Z_e \rangle$  where  $\langle . \rangle$  is an horizontal average.
- Simulations (here BIG) show higher  $Z_e$  both below and above freezing level and echo heights higher than observed.

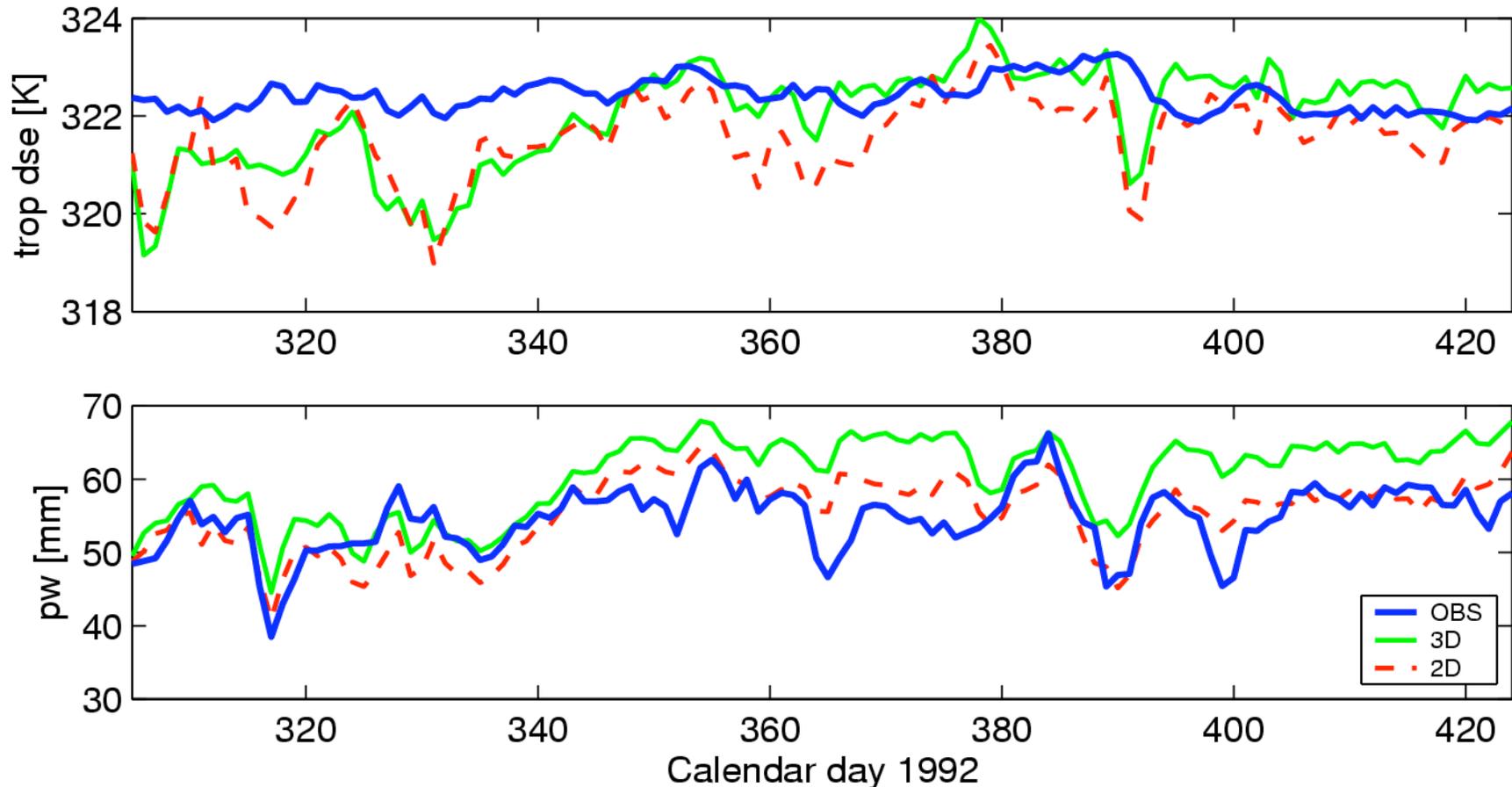
# Summary of KWAJEX Simulations

- Model tracks observed thermodynamic conditions without nudging.
- Insufficient cloud and albedo during periods of weak precipitation.
- Model produces correct amount of precip, but has too much convective precipitation.
- Model doesn't produce enough ice cloud under weak/moderate forcing.

# TOGA COARE Simulations

- Same setup as for KWAJEX, except:
  - CSU v2.1 IFA-averaged forcings, comparison fields, SST.
  - 96 vertical levels,  $Dz=50-250m$ .
  - Two runs (120 days each):
    - + 3D:  $Lx=Ly=64$  km domain,  $Dx=1km$ .
    - + 2D:  $Lx=256km$  domain,  $Dx=500m$ .
- 3D run takes  $\sim 3$  days on 8x2 node cluster.

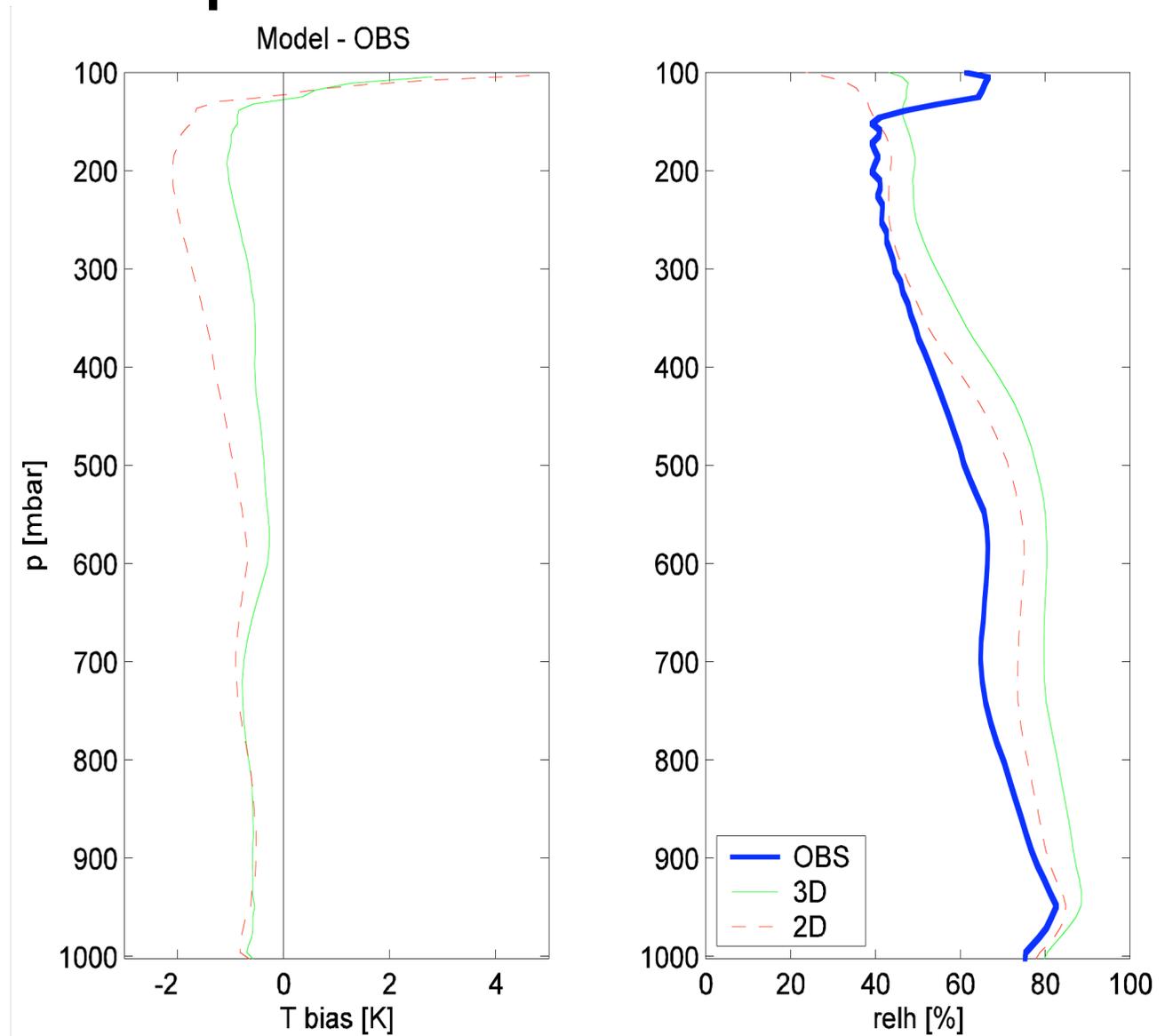
# Column-integrated Biases



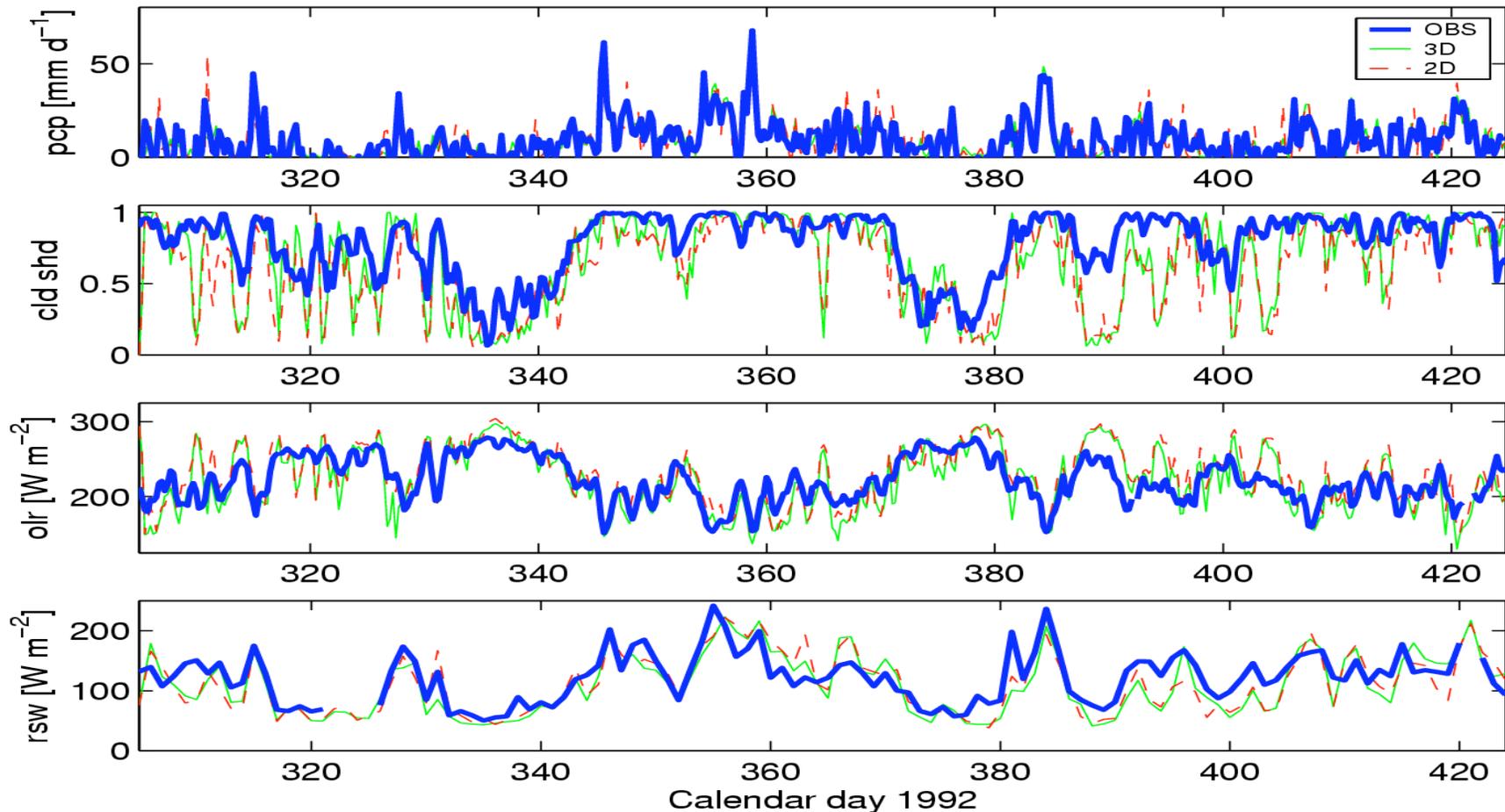
- Drift in  $\langle s/c_p \rangle$  could involve forcing or model errors.
- Moist bias in precipitating periods in 3D run.

# Time-avg. Temperature/Moisture Bias

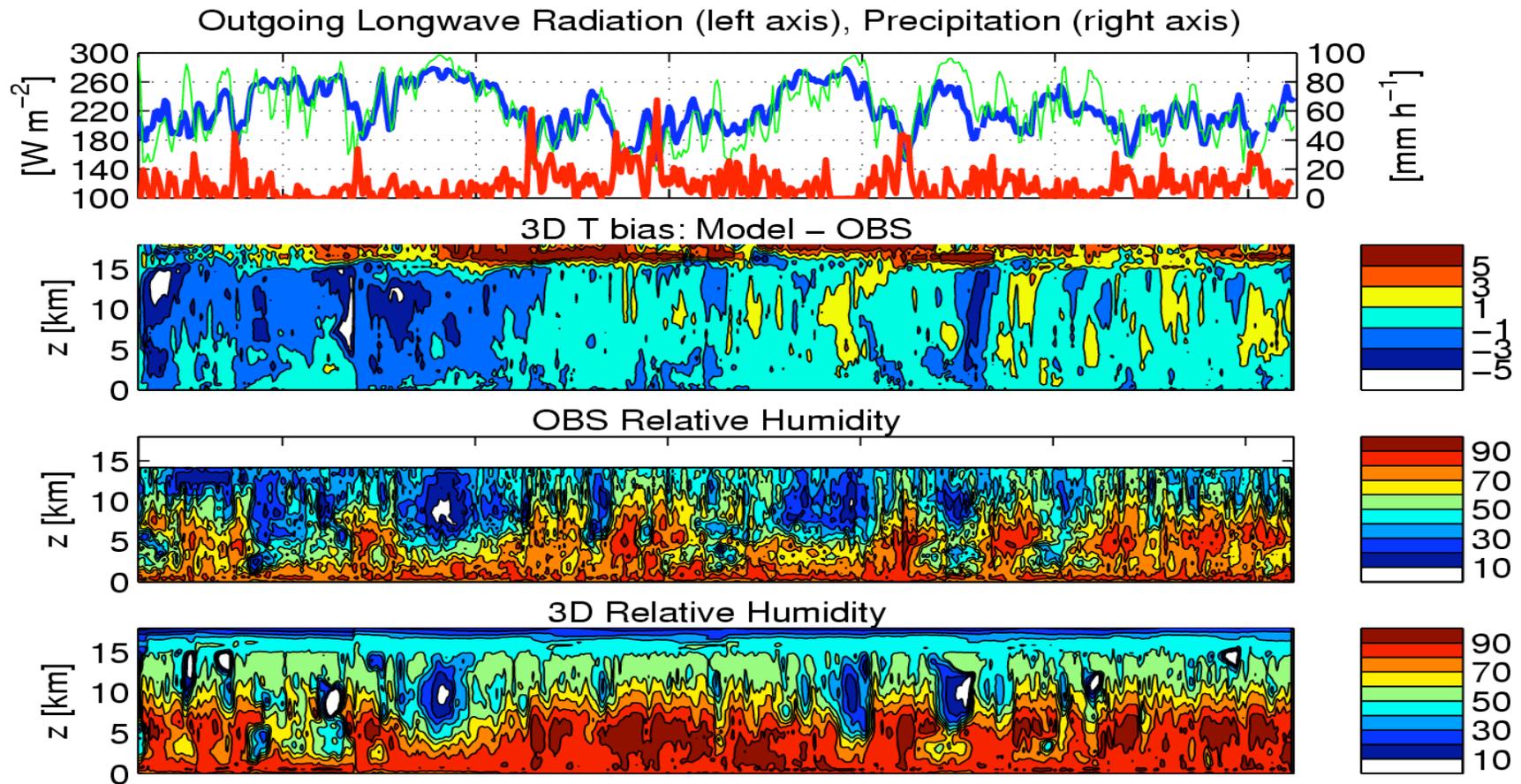
- 3D T bias small.
- Moist bias; 3D would likely dry out above boundary layer in a larger domain.



# Precipitation, Clouds, TOA Radiation



- Model tracks cloud cover/TOA radiative fluxes well.
- OBS from CSU forcings (precip), ISCCP (IR cloud amount) and Minnis (TOA radiative fluxes).



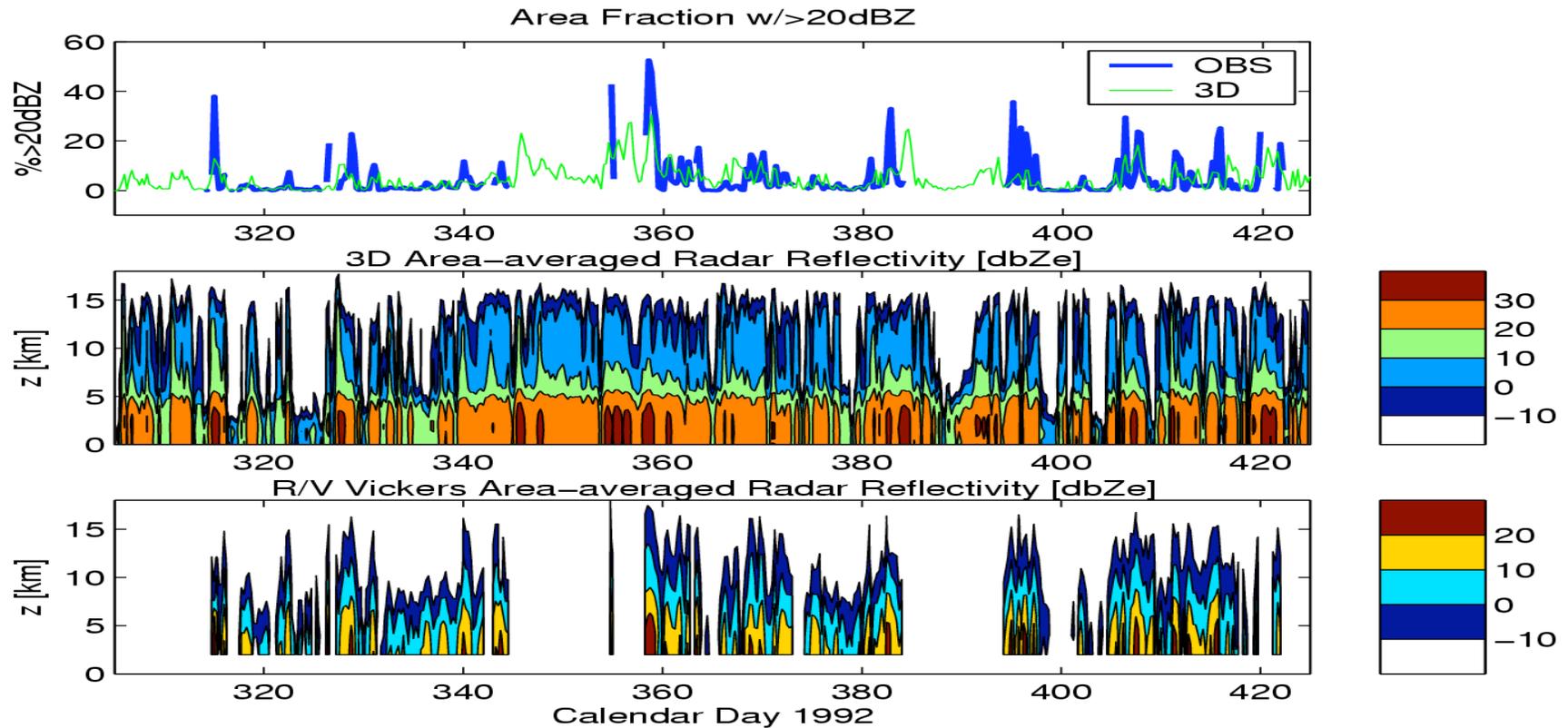
- Main relative humidity features well simulated.
- Periods of strong cold bias/low RH, especially in upper troposphere.

# ISCCP simulator results

Opt. depth $p_{top}$	Thin ( $0.3 < t < 3.6$ )	Med ( $3.6 < t < 23$ )	Thick ( $23 < t$ )
High ( $p_{top} < 440\text{hPa}$ )	39.8 28.5 24.0	14.1 18.4 15.3	7.1 10.1 10.7
Med ( $p_{top} > 440\text{hPa}$ )	7.1 1.1 1.0	4.1 2.7 4.1	0.6 1.8 3.6
Low ( $p_{top} > 680\text{hPa}$ )	3.2 1.1 0.9	2.3 1.5 1.6	0.0 0.7 0.9

Better agreement between ISCCP and 3D/2D CRM than for KWAJEX.

# Radar Comparison

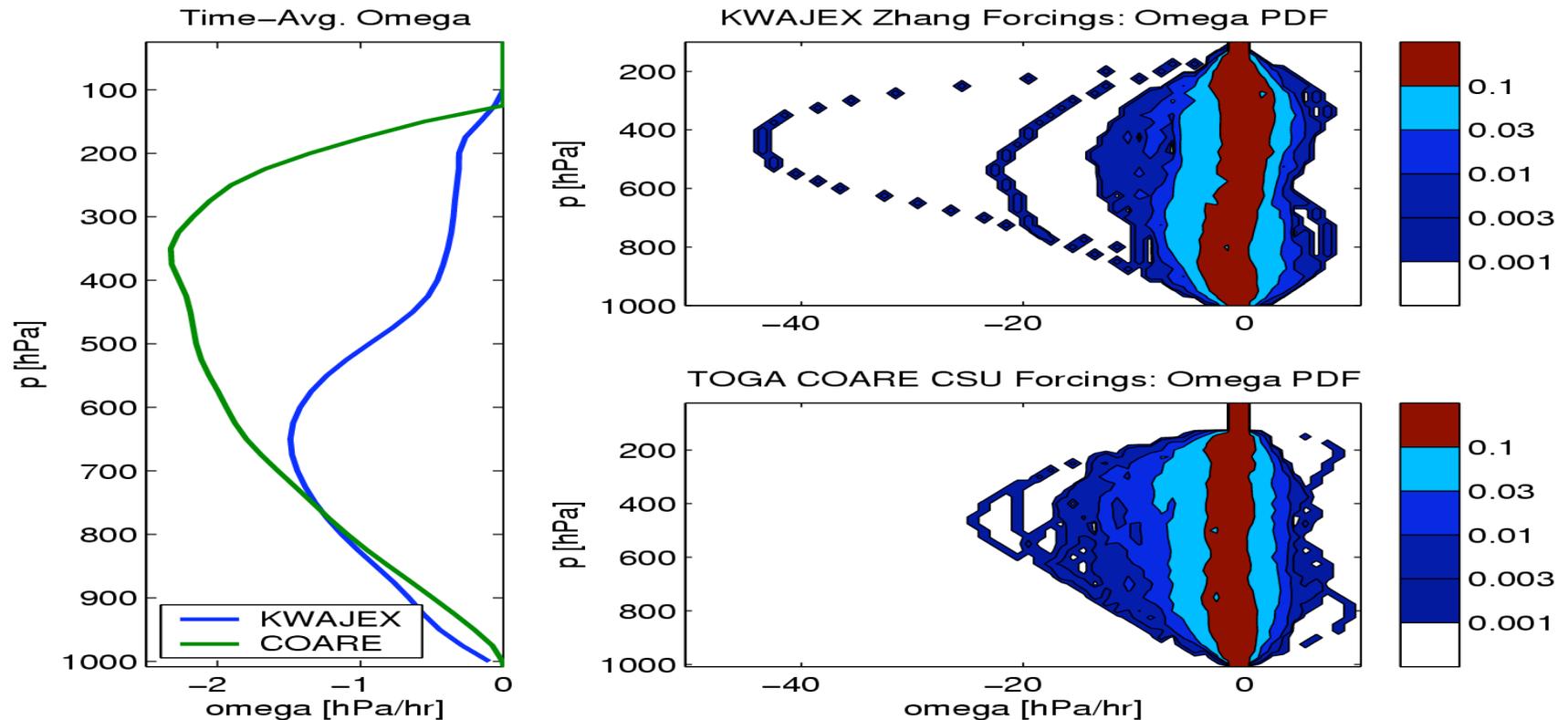


- Radar data from R/V Vickers (courtesy of Sandy Yuter, UW/NCSU).
- Model has stronger  $\text{dB}\langle Z_e \rangle$  than observed.

# **Possible causes for differences in model performance between KWAJEX & TOGA COARE:**

- Regime-dependent model biases.
- Forcings:
  - Large-scale vertical motion profiles.
  - Advected condensate/moisture less likely to be important in COARE.
- Similar high cloud according to ISCCP:  
(KW: 25.4, 13.2, 8.6/ TC: 39.8, 14.1, 7.1).

# Comparison of Forcings (Omega)



- Upward motion in KWAJEX is focused in lower and middle troposphere.
- Upper tropospheric subsidence more prominent in KWAJEX, may affect maintenance of high cloud.

# Summary

- Both 2D and 3D 120 day un-nudged COARE CRM simulations reproduced the observations.
- TOGA COARE simulations have larger thermodynamic biases than KWAJEX, but smaller radiation/cloud biases.
- Both show an excess of convective precip.
- Modifications to microphysics might help (e.g. different distributions --  $N_{0s}(T)$ ?, consistency between microphysics & radiation, extra moments for precipitate and condensate, simplified scheme w/explicit phase changes)