Comparison of ship-following large-eddy simulations with cloud and boundary layer structure observed in MAGIC

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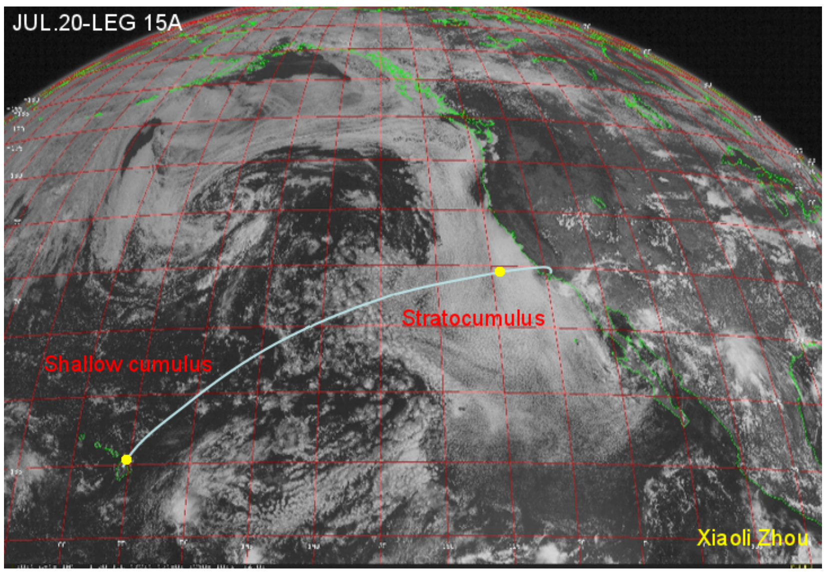

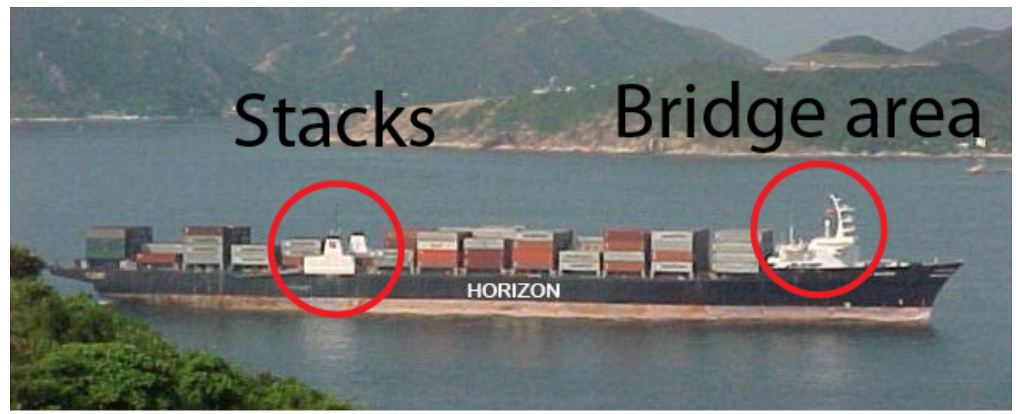

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Goal: Compare LES initialized with MAGIC soundings with observations at later times

1) Can a Large Eddy Simulation (LES) capture the observed cloud variability during MAGIC?

2) Implications for credibility of LES for simulating PBL cloud response to climate perturbations?

Motivation

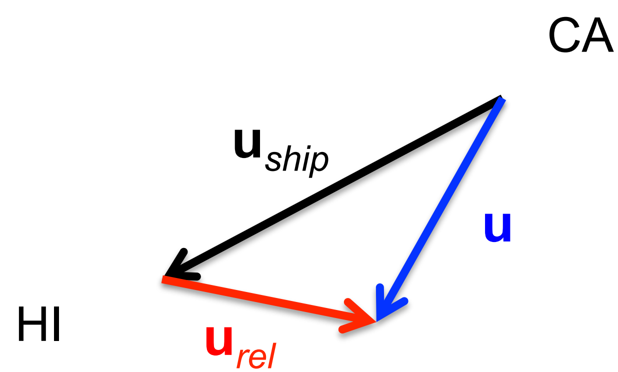
- Cloud feedbacks are currently the largest source of uncertainty in climate sensitivity of GCMs
- This is partly due to inadequate observational constraints on cloud parameterizations
- LES can help improve cloud parameterizations, but should we quantitatively believe LES in challenging cloud regimes?
- The MAGIC dataset provides a test of how well LES can simulate NE Pacific PBL cloud properties across a range of SSTs, seasons, and synoptic conditions.

Model Configuration

- LES: System for Atmospheric Modeling (SAM6.10)
- 128x128 (6.4x6.4 km) doubly-periodic domain, 460 levels to 25.1km
- dx = 50 m, dz = 15 m at surface, 5 m from 0.6 - 2.1 km, stretching to about 50 m at 3 km and 1000 m at model top
- UM5 advection scheme (Yamaguchi et. al., 2011)
- Double-moment microphysics (Morrison et al. 2005), no ice
- RRTMG radiative transfer; insolation at moving ship lat/lon.

Ship-relative advective forcings

- Critical innovation for comparing LES with multiday ship observations
- One multiday LES per cruise leg.
- Horizontal advection computed with ship-relative wind $\mathbf{u}_{rel} = \mathbf{u} - \mathbf{u}_{ship}$
- Works well if $\mathbf{u}_{rel}$ is not too large, i. e. on outbound legs only.

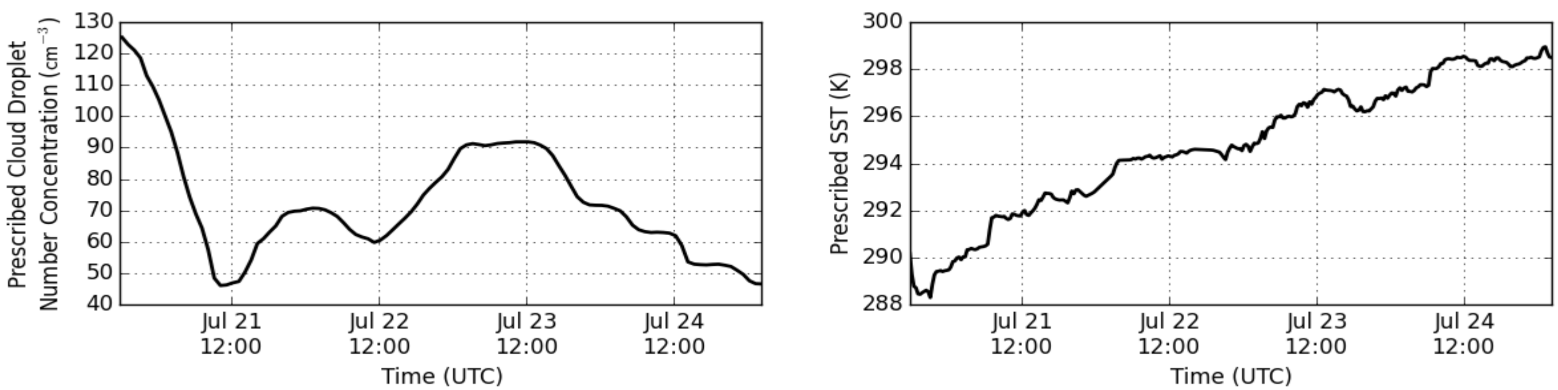


- Ship-following horizontal advective forcings, mean vertical motion, pressure gradients specified using ECMWF MAGIC data set.
- Vertical velocity adjusted to nudge temperature profile toward sondes on 1-day timescale. Humidity also nudged with 2 day timescale. Stronger nudging above 3 km.

Model forcing and boundary conditions

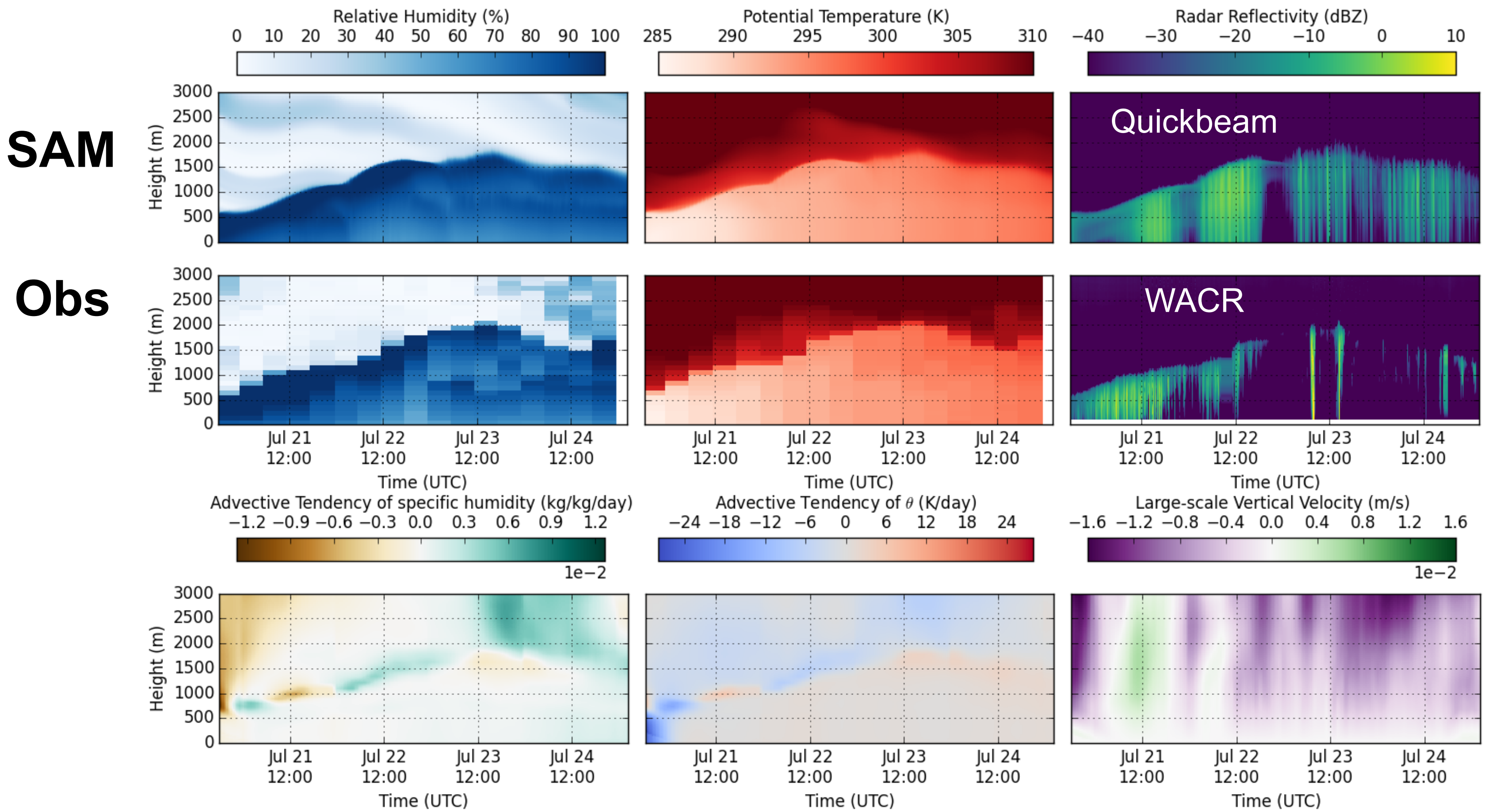
- Initial thermodynamic profiles from first balloon sounding of leg (balloon soundings nominally occur every 6 hours)
- SST prescribed from ship observations
- Time-varying cloud droplet number concentration prescribed from linear fit of hourly median ship-observed CCN concentration to GOES cloud droplet number concentration

Leg 15A N_d and SST



Leg 15A Case Study

A successful simulation of a Sc-Cu transition

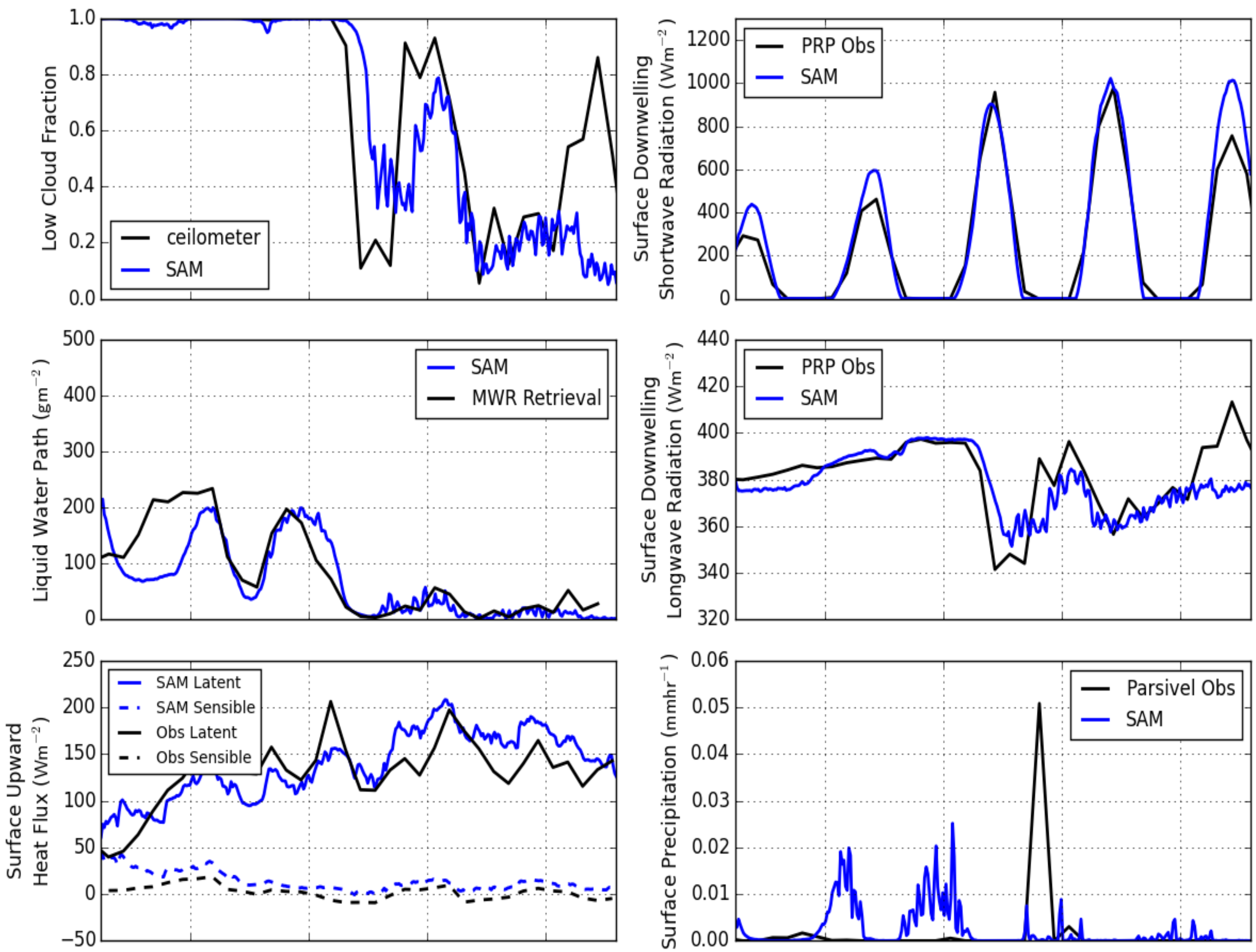


Decoupling and Sc-Cu transition occur near 00 UTC Jul 23 in SAM and observations

Horizontal advective forcings include ship-relative advection of inversion height gradients

Leg 15A Case Study

Comparison of 3h-mean observed quantities with horizontal mean SAM quantities.



Cloud fraction, LWP, surface fluxes all well simulated.

Little surface precip.

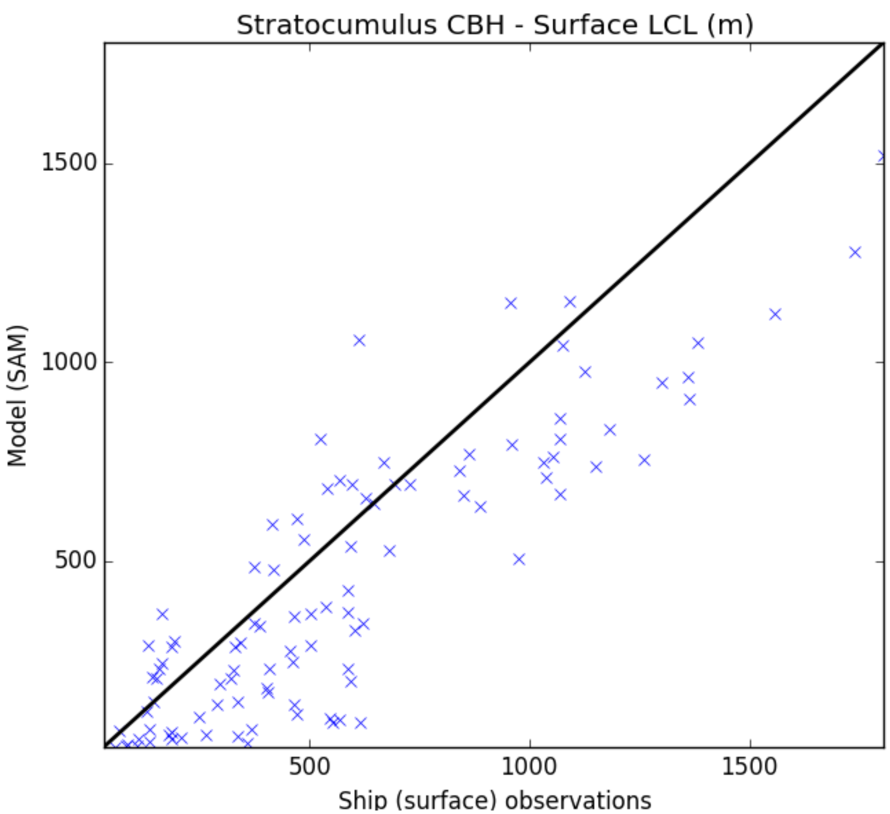
Analysis of all legs

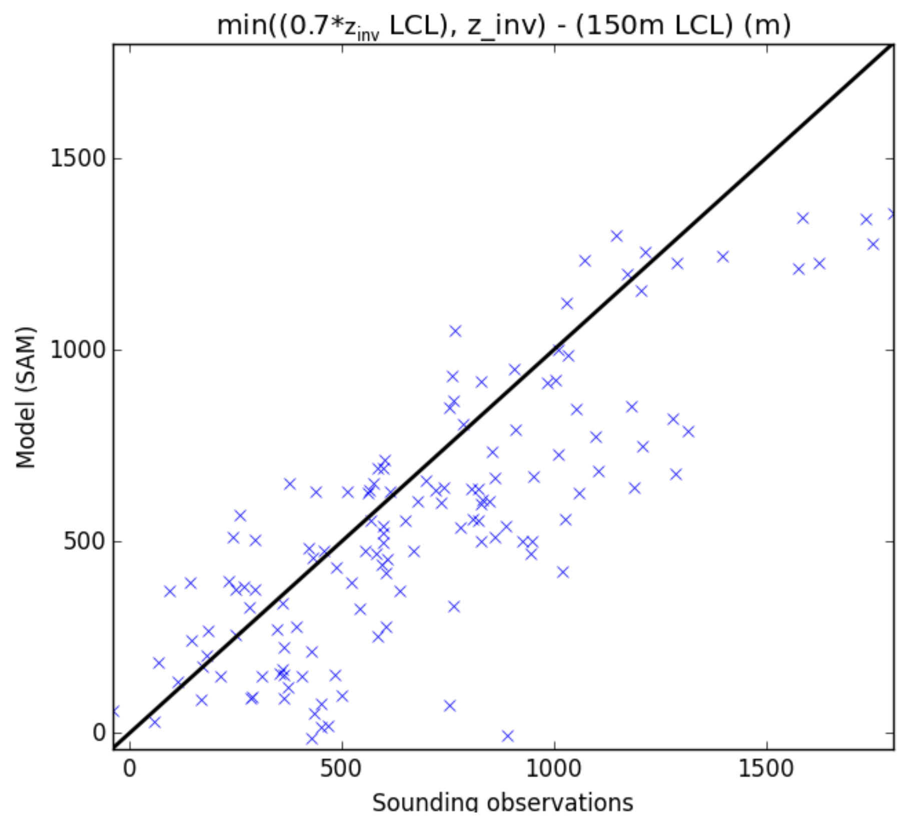
- A total of 14 transects from Los Angeles, CA to Honolulu, HI were run.
- The first 6h of each run was discarded as spin-up time.
- Next 48h of Leg 19A and all of Leg 13A discarded due to <2 soundings/day.
- 1h analysis bins. Hours with no obs or $|z_{i,SAM} - z_{i,sonde}|$>400 m (28%) discarded. Mean of remaining hours taken over each UTC day.

Quantity	Instrument	R^2 of daily mean	SAM Bias
Low Cloud Fraction	Ceilometer	0.51	0.02 (3.2%)
Surface Longwave Radiation	Portable Radiation Package	0.41	2.35 W/m^2 upward
Surface Shortwave Radiation (fraction of TOA)	Portable Radiation Package	0.16	0.05 downward (10%)
Precipitable Water Vapor	Microwave Radiometer (MWR) Retrieval	0.72	-0.89 kg/m^2 (-3.7%)
Liquid Water Path	MWR Retrieval	0.53	1.9 g/m^2 (3.2%)
Latent Heat Flux	COARE-3 Bulk Fluxes	0.53	13 W/m^2 upward (13%)

All-leg statistical analysis of decoupling in LES vs. obs

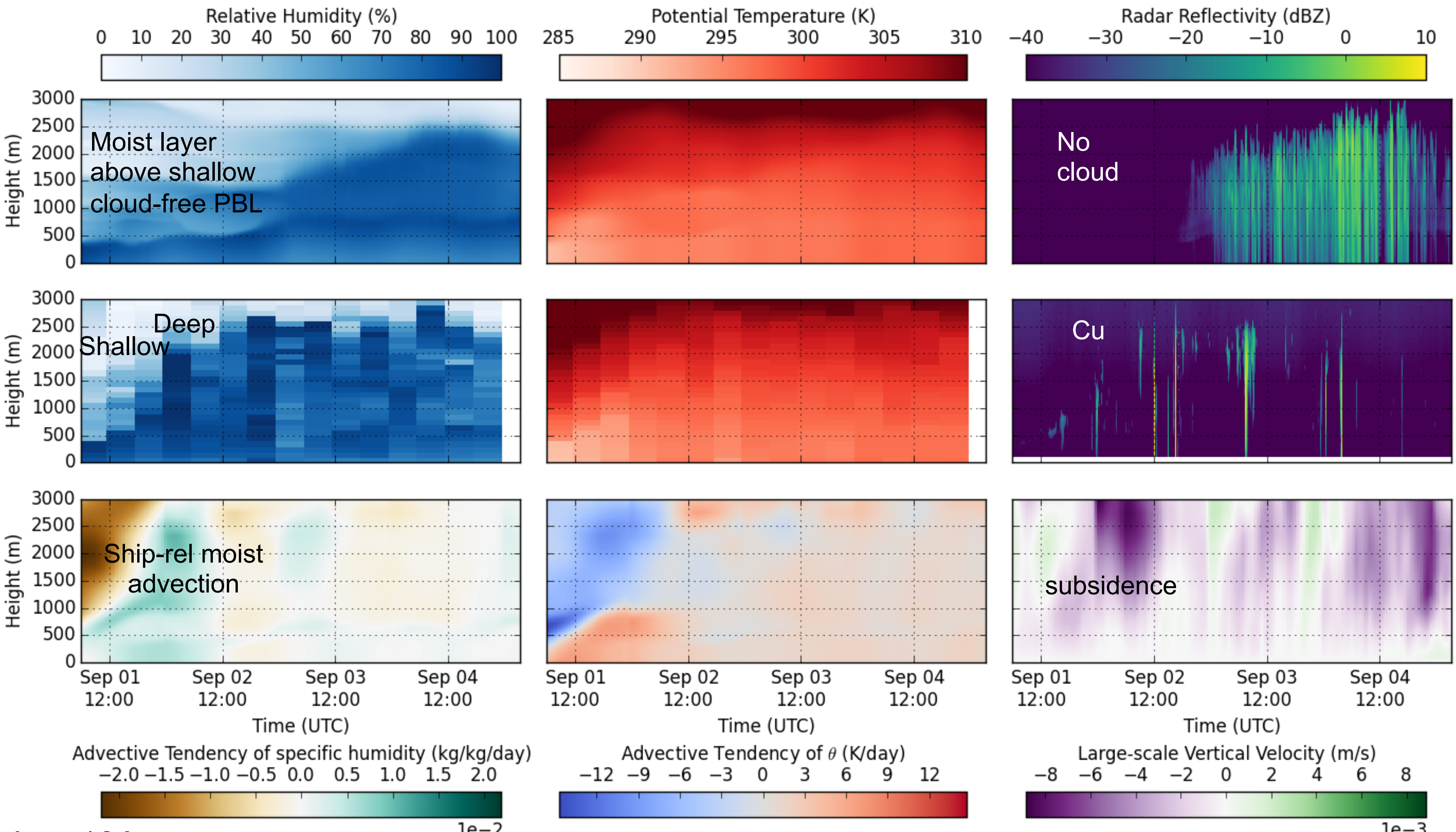
- Decoupling is measured from surface obs. as the difference between the stratocumulus cloud base (cloud frac > 50%) and the surface LCL.
- Decoupling is measured from soundings as the difference between the LCL at 70% of the inversion height and the LCL at 150m. The LCL at $0.7z_{inv}$ matches the Sc base well and generalizes to soundings without Sc.
- As for the daily mean analysis, times where SAM did not track the sounding inversion height were discarded.
- SAM and obs. correlate well in both surface and sonde-based decoupling metrics





Problematic situations for LES-obs comparison

If initial sounding near the coast is too different than offshore conditions, simulated z_{inv} can't keep up. Infrequent soundings with noisy z_{inv} can be unrepresentative and jerk LES around.



Leg 18A

Summary

SAM shows significant skill in reproducing day-to-day variability in cloud properties and decoupling across the MAGIC cruises

Discussion

- When simulated inversion height is not too far from observed, LES reproduces cloud structure and radiative properties well.
- No mean bias in cloud cover or cloud thickness!
- Significant positive correlation of daily-mean LES vs. obs cloud parameters implies LES skillfully represents SST/seasonal/ synoptic variability of NE Pacific PBL clouds.
- Case-by-case inspection of model timeseries show Sc-Cu transition and boundary layer decoupling often well-represented.
- Insufficient sounding frequency degrades model comparison
- High bias in downwelling shortwave radiation – clouds or aerosol?