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

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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 25.1 km
- \( dx = 50 \) 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 $u_{rel} = u - u_{ship}$
- Works well if $u_{rel}$ 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
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 \(|z_{i,\text{SAM}} - z_{i,\text{sonde}}| > 400 \text{ m}\) (28%) discarded. Mean of remaining hours taken over each UTC day.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Instrument</th>
<th>$R^2$ of daily mean</th>
<th>SAM Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Cloud Fraction</td>
<td>Ceilometer</td>
<td>0.51</td>
<td>0.02 (3.2%)</td>
</tr>
<tr>
<td>Surface Longwave Radiation</td>
<td>Portable Radiation Package</td>
<td>0.41</td>
<td>2.35 W/m$^2$ upward</td>
</tr>
<tr>
<td>Surface Shortwave Radiation (fraction of TOA)</td>
<td>Portable Radiation Package</td>
<td>0.16</td>
<td>0.05 downward (10%)</td>
</tr>
<tr>
<td>Precipitable Water Vapor</td>
<td>Microwave Radiometer (MWR) Retrieval</td>
<td>0.72</td>
<td>-0.89 kg/m$^2$ (-3.7%)</td>
</tr>
<tr>
<td>Liquid Water Path</td>
<td>MWR Retrieval</td>
<td>0.53</td>
<td>1.9 g/m$^2$ (3.2%)</td>
</tr>
<tr>
<td>Latent Heat Flux</td>
<td>COARE-3 Bulk Fluxes</td>
<td>0.53</td>
<td>13 W/m$^2$ upward (13%)</td>
</tr>
</tbody>
</table>
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 $0.7z_{\text{inv}}$ 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?