Atmospheric Sciences
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Skill of ship-following large-eddy simulations in reproducing MAGIC observations

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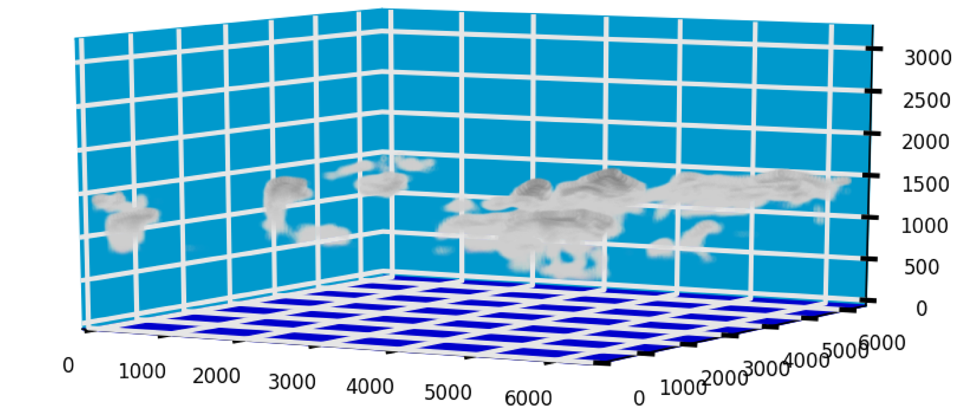


3D snapshot of model cloud water in cumulus regime

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?

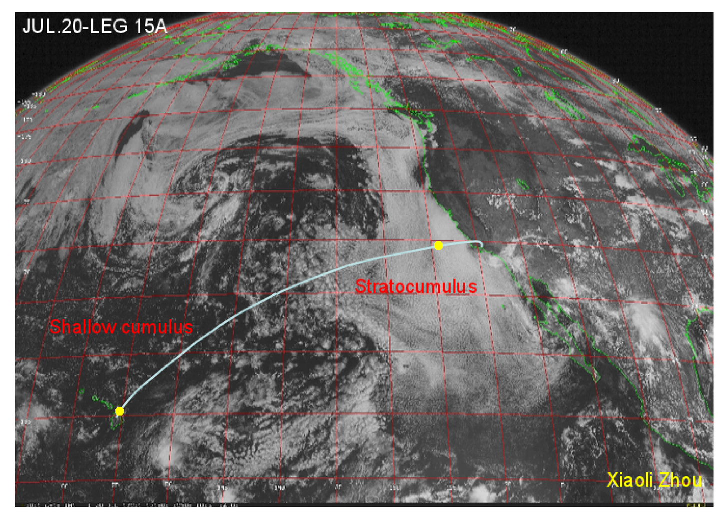
(2) Can this test the credibility of LES for simulating PBL cloud response to climate perturbations?

Motivation

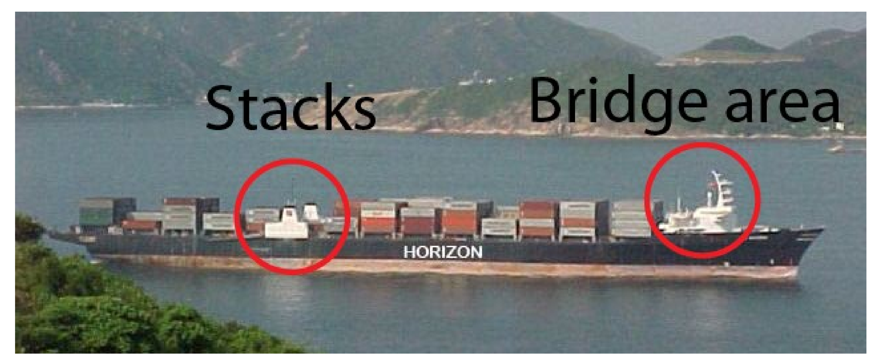
- Cloud feedbacks are currently the largest source of uncertainty in climate sensitivity of GCMs
- This is partly due to inadequate observational constraints on cloud parameterizations
- We can compare cloud parameterizations to LES, but this requires the results of LES to be credible
- The MAGIC dataset may provide a good test of how well LES can simulate cloud properties in the stratocumulus to trade cumulus transition

Model Configuration

- LES used was System for Atmospheric Modeling (SAM)
- Prescribed time-varying cloud droplet number concentration based on linear fit of hourly median ship CCN measurements to GOES cloud droplet number concentration
- 3D model with 128x128 horizontal grid, 460 vertical levels. Horizontal domain of 6.4km by 6.4km, vertical domain of 25.1km
- Horizontal grid spacing of 50m, variable vertical grid spacing of 15m at surface, 5m from 0.6 to 2.1km, increasing to about 50m at 3km and to a maximum of 1000m at model top
- RRTMG radiative transfer with translating domain position, double-moment microphysics (Morrison et al. 2005) with ice microphysics disabled, 5th-order ULTIMATE_MACHO (Yamaguchi et. al., 2011) advection scheme for non-uniform vertical grid
- Initial profile of temperature and moisture determined by first balloon sounding of leg (balloon soundings nominally occur every 6 hours)
- Thermodynamic profile nudged weakly (2 day timescale for moisture, 1 day for temperature) to sounding profiles below 3000m, and strongly above 3000m, to ensure inversion height stays in agreement with sounding profiles
- Forcings used were in a Lagrangian (ship-following) frame, using ship-relative winds, eg.
- Advective tendencies of q and T, large scale vertical velocity, and geostrophic winds were determined from ECMWF MAGIC dataset. Dataset has horizontal resolution of 0.5 degrees, and was smoothed in the horizontal with a Gaussian kernel of standard deviation 2 degrees prior to calculating forcings.
- 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



Schematic of ship path for Leg 15A with ship position at start and end of simulation



The Horizon *Spirit*

Leg 15A Case Study

- Model accurately reproduces peaks of LWP near start of run (Fig 2a)
- Boundary layer decouples and transitions into cumulus regime at correct times (Fig 1a-f, Fig 2b)
- Advective forcings mainly represent ship-relative advection of changes in inversion height (Fig 1g-i)
- Bulk surface fluxes are reasonable (Fig 2e)

Analysis

A total of 13 transects from Los Angeles, CA to Honolulu, HI were run. The first 6h of each run was discarded as spin-up time. In addition, the next 60h of Leg 13A was discarded due to low sounding availability (less than 2 per day).

Each run was then divided into 1h bins. Hours with no observations were discarded, as were hours where the sounding inversion height and model inversion height were more than 400m apart (this test was failed for 28% of soundings). Then a mean was taken over the UTC day.

Linear fits of these daily mean model values to observations were then performed, with the results in Table 1. All correlation coefficients were positive, and all fits were statistically significant.

Quantity	Observation source	Linear fit R^2	Bias in SAM mean
Low Cloud Fraction	Ceilometer	0.51*	+0.082* (13%)
Liquid Water Path	MWR Retrieval	0.55*	+1.2 g/m² (1.8%)
"Albedo" Proxy $1 - Sw_{dn}^{sfc} / SW_{dn}^{TOA}$	Portable Radiation Package	0.52*	-0.016 (-3.1%)
30m Relative Humidity	Surface Meteorological Instrumentation	0.66*	-0.5% (-0.7%)
30m Temperature	Surface Meteorological Instrumentation	0.96*	-0.61 K
500m "rain" fraction (>5dBZ)	WACR (cloud radar)	0.01	-40%
Latent Heat Flux	COARE-3 Bulk Fluxes	0.50*	3.0 W/m² upward (0.1%)

Table 1: Squared correlation coefficients and mean biases for daily mean values between SAM and observations. See Analysis for details. All correlation coefficients were positive. * denotes statistically significant value

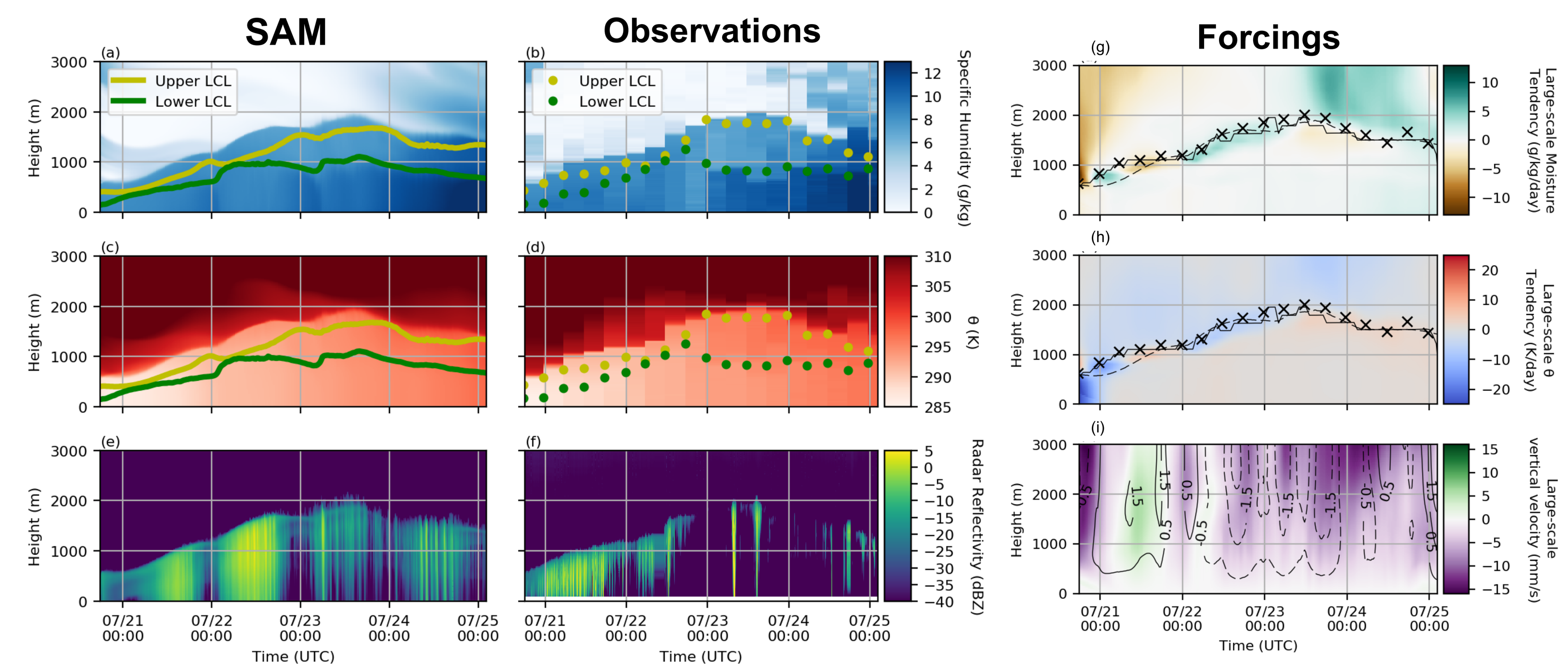


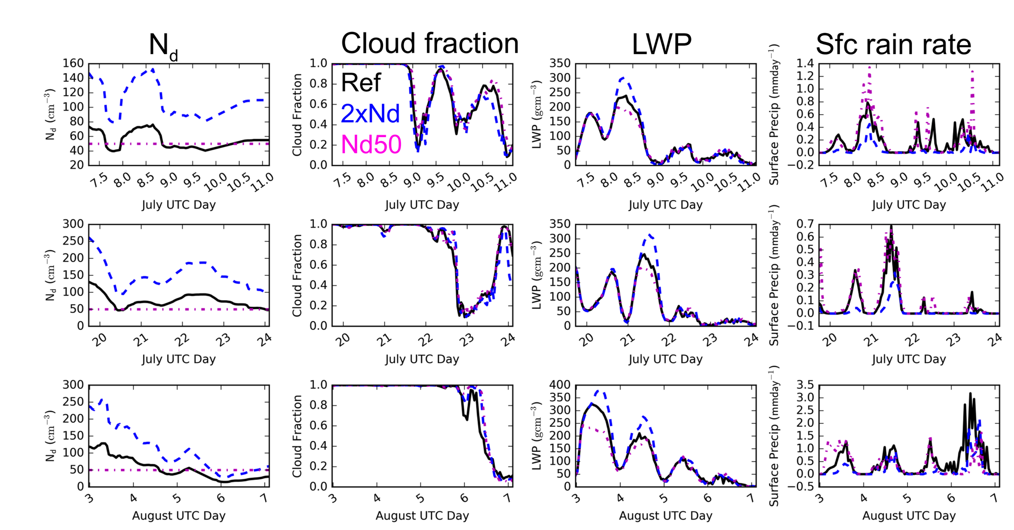
Figure 1: Thermodynamic profiles and large-scale forcings of Leg 15A ship-following run. Panels a-b: specific humidity overlaid with LCL calculated from 30m, and from 70% of the inversion height. c-d: potential temperature overlaid with LCL as in a-b. e-f: Modeled and observed radar reflectivity, where model value is domain mean, and observed value is 5-minute mean. g-i: Ship-relative advective tendencies of specific humidity and potential temperature, and vertical velocity derived from 2-degree smoothed ECMWF analysis and prescribed as forcing conditions in SAM.

Aerosol Sensitivity

- Sensitivity simulations were performed for legs 14A, 15A, and 16A with doubled cloud droplet number concentration (N_d) and with a constant value of N_d = 50cm^{-3}. Each of these simulations contains a stratocumulus to cumulus transition.
- Sensitivity runs of three legs with doubled N_d showed downwelling shortwave radiation was slightly but consistently reduced. LWP (but not cloud fraction) was increased, contributing about one-third as much to the cloud albedo increase as the Twomey effect (Table 2 and Figure 3).
- Surface precipitation was reduced by more than 60% with doubled N_d (Table 2 and Figure 3).
- Simulated cloud properties match observations almost as well with a constant N_d = 50 cm^{-3} as with time-varying number concentration.

Quantity	Reference Mean	14A	15A	16A
Low Cloud Fraction	0.79	0.97	0.98	1.02
Liquid Water Path	86.7 g m^{-2}	1.10	1.10	1.16
Surface Shortwave	262 W m^{-2}	0.96	0.96	0.93
Surface Precipitation	0.24 mm day^{-1}	0.26	0.32	0.41
Latent Heat Flux	137 W m^{-2}	1.01	1.01	0.99

Table 2: Comparison of simulation-mean quantities for three legs between reference simulations and runs with doubled N_d. The reference mean is calculated among all three legs. Values for each leg are the ratio of the mean value in the doubled N_d simulation to the mean value in the reference simulation.



	N_d	Cloud fraction	LWP	Sfc rain rate
3-leg mean	61 cm^{-3}	0.79	87	0.24 mm d^{-1}
	122 = 200%	99%	112%	33%
	50 = 82%	103%	93%	88%

Figure 3: Time series from aerosol sensitivity runs for legs 14A, 15A, and 16A. Values from the reference simulations are in solid black line, doubled N_d simulations in blue dashed line, and N_d = 50 cm^{-3} simulations in purple dot-dashed line.

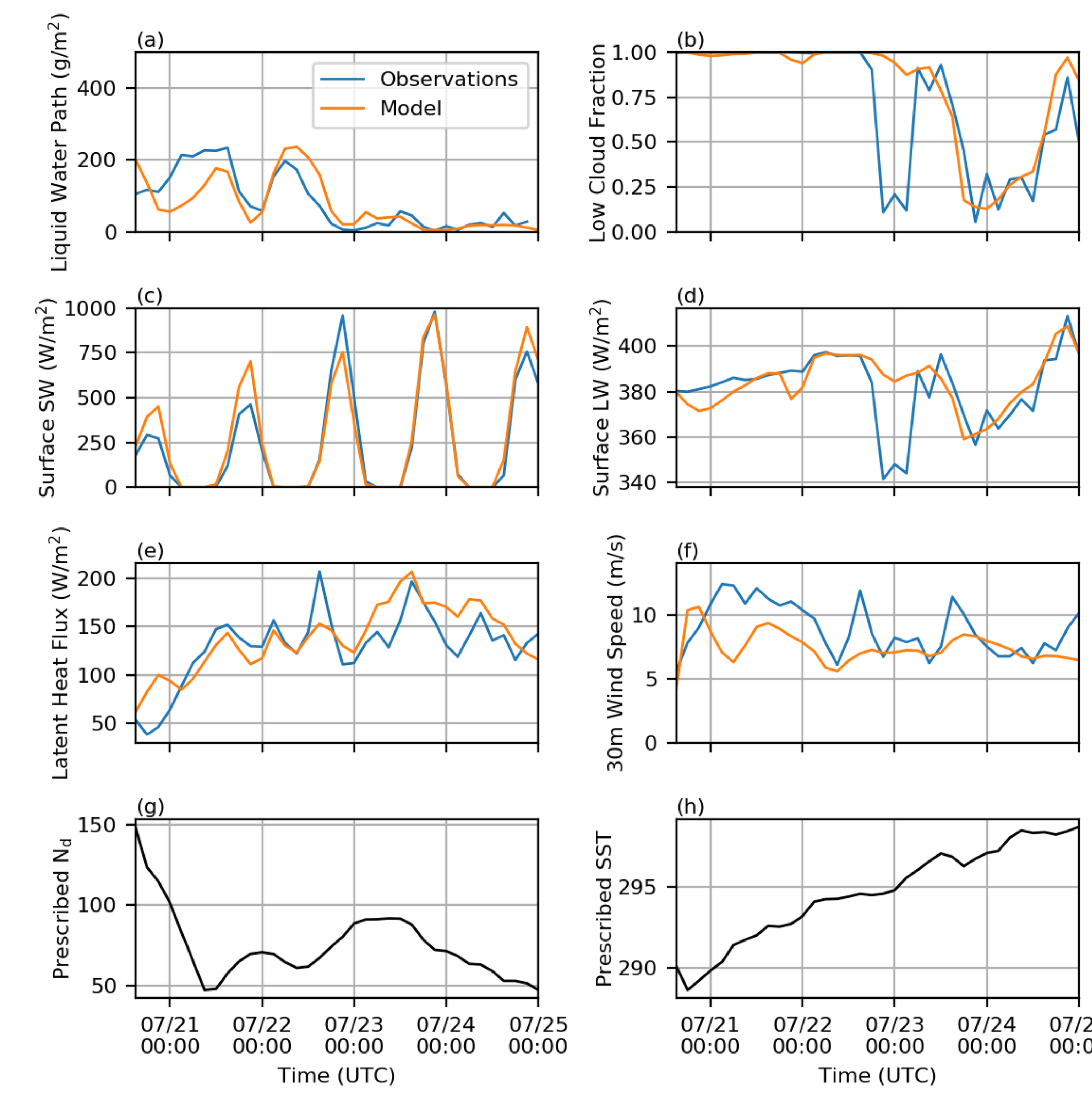


Figure 2: Time-varying quantities for Leg 15A ship-following run. Panels a-f: Comparison of 3h-mean observed quantities with horizontal mean SAM quantities. PRP, MWR, SHF and LHF refer to Portable Radiation Package, Microwave Radiometer, sensible heat flux, and latent heat flux, respectively. Panels g-h: Prescribed cloud droplet number concentration and sea-surface temperatures. Cloud droplet number concentration determined from linear fit of hourly-median ship CCN measurements with GOES cloud droplet number concentration.

Discussion

- When inversion height is constrained to match observations, model reproduces cloud structure and radiative properties
- Statistically significant positive correlation of all cloud parameters, other than 500m radar-derived rain fraction
- No observed bias in cloud cover or cloud thickness
- Visual analysis of model timeseries and analysis of decoupling parameters show the stratocumulus to trade cumulus transition and boundary layer decoupling are well-represented
- Sensitivity studies suggest that specified aerosol increases would raise the albedo of NE Pacific cloud regimes mainly via the Twomey effect, with slight additional contribution from enhanced LWP

Conclusion

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

For more information:

McGibbon and Bretherton (2017), Skill of ship-following large-eddy simulations in reproducing MAGIC observations across the Northeast Pacific stratocumulus to cumulus transition region, JAMES, accepted subject to minor revision

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