Aerosol sensitivity in large-eddy simulations of subtropical boundary layer clouds observed in MAGIC

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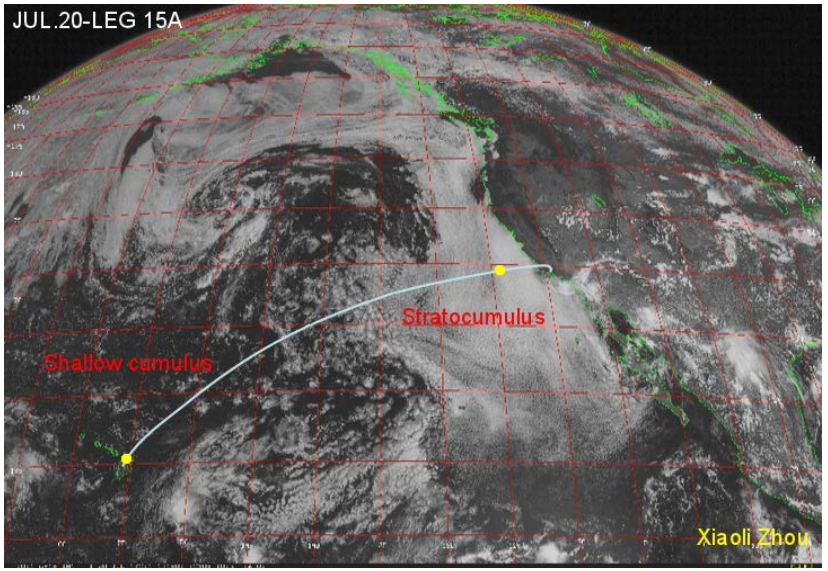
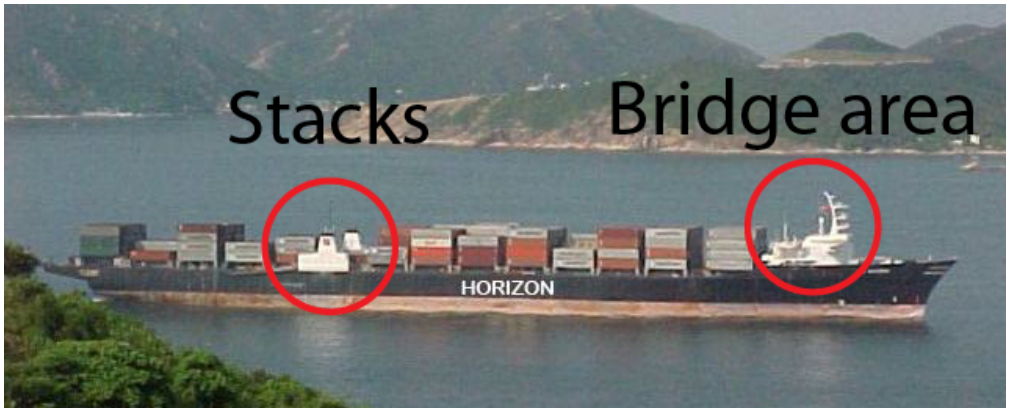




MAGIC: ARM Mobile Faciliity deployment on a container ship (CA-HI) for Oct. 2011-Sept. 2012

Thanks: ASR DE-SC0011602 for funding
Marat Khairoutdinov and Peter Blossey for SAM
Maike Almgrimm for the ECMWF MAGIC dataset
Maria Cadeddu for the MWR retrievals (and other instrument mentors)
Ernie Lewis for leadership of MAGIC

Aerosol sensitivity study is part of a broader LES comparison with extensive MAGIC observations

MAGIC comprehensively sampled across the NE Pacific Sc-Cu transitions in multiple seasons and weather regimes.

MAGIC instrumentation

- Cloud radar/lidar/microwave radiometer
- Radiosondes (2-4x daily)
- Surface meteorology/radiative fluxes/SST
- Surface aerosols (UHSAS, CCN)

1) Can a LES capture observed cloud variability during MAGIC?

2) Is LES credible for simulating PBL cloud response to climate (including aerosol) perturbations?

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)
- Aerosol-aware double-moment microphysics (Morrison et al. 2005)
- RRTMG radiative transfer; insolation at moving ship lat/lon.
- Initial thermodynamic profiles from first balloon sounding of leg
- Forcings (along moving path of ship):

ECMWF w, $\mathbf{v}_g$, **ship-relative** hor. adv. of T, q (200 km Gauss smooth)

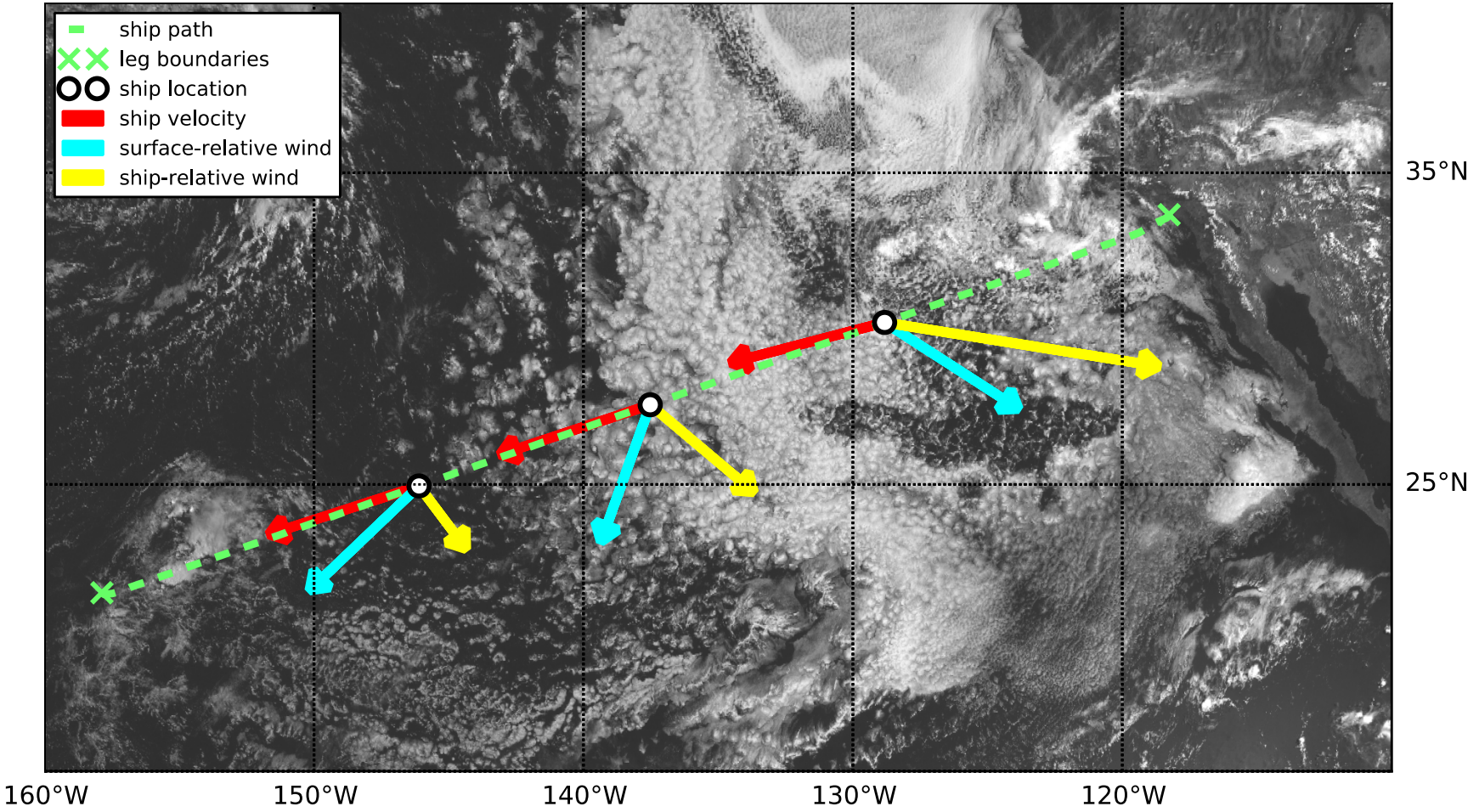
- works well if $\mathbf{u}_{rel}$ not too large, i. e. on **CA to HI legs only**.

SST from ship

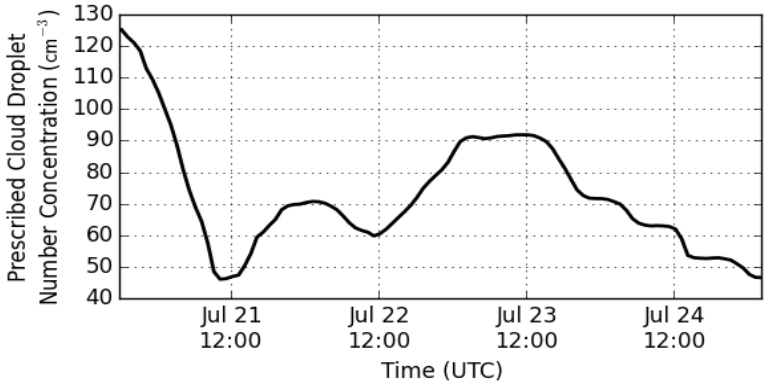
CDNC from UHSAS + regression to GOES-derived CDNC

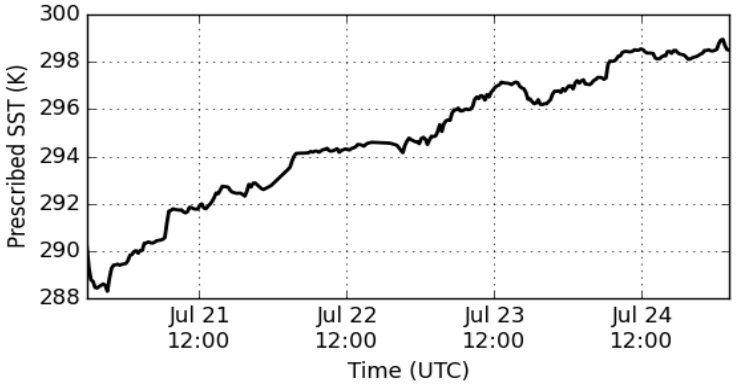
Inversion height and mean soundings weakly relaxed toward sondes

Leg 15A Case Study

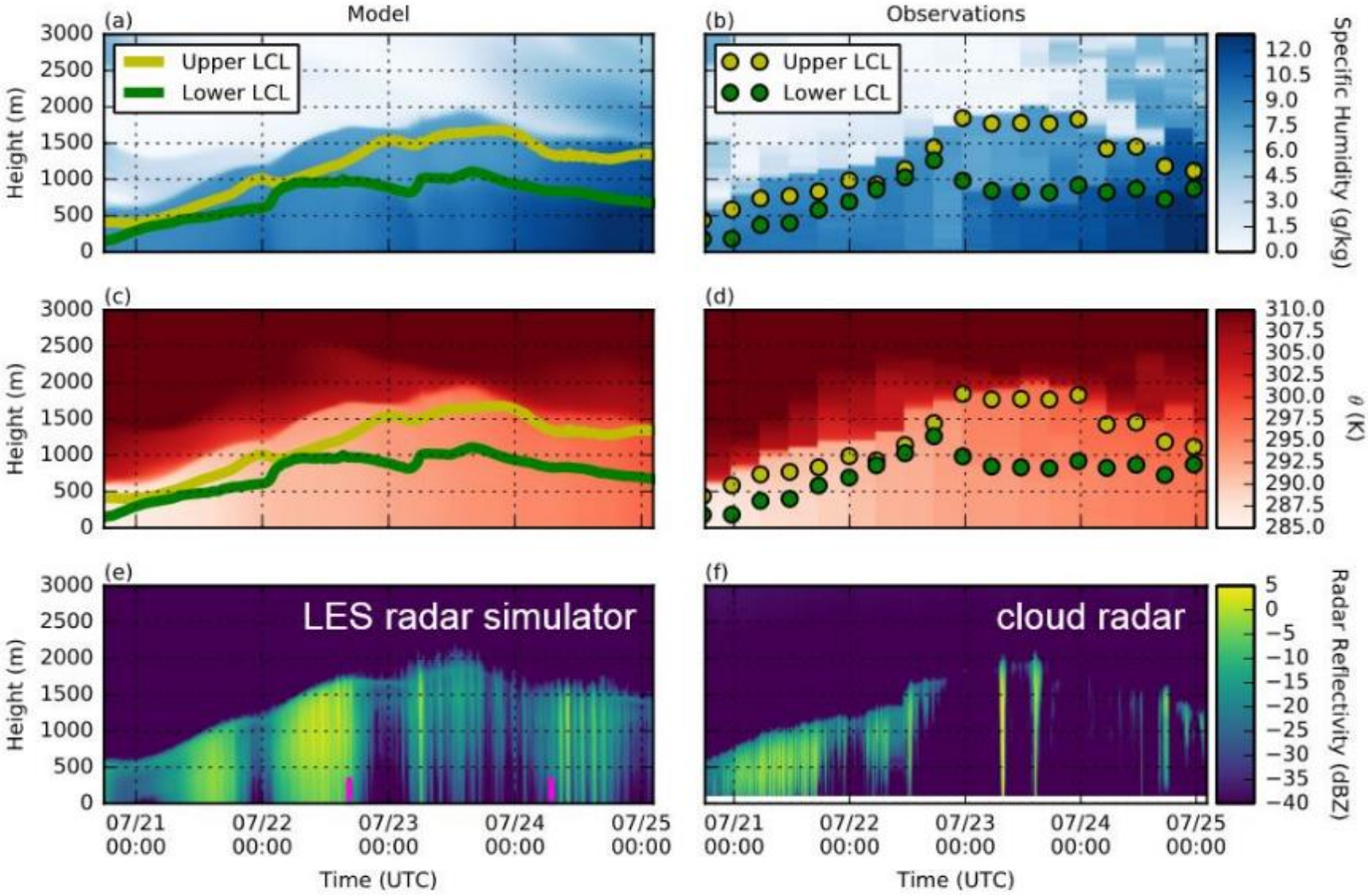


Leg 15A N_d and SST



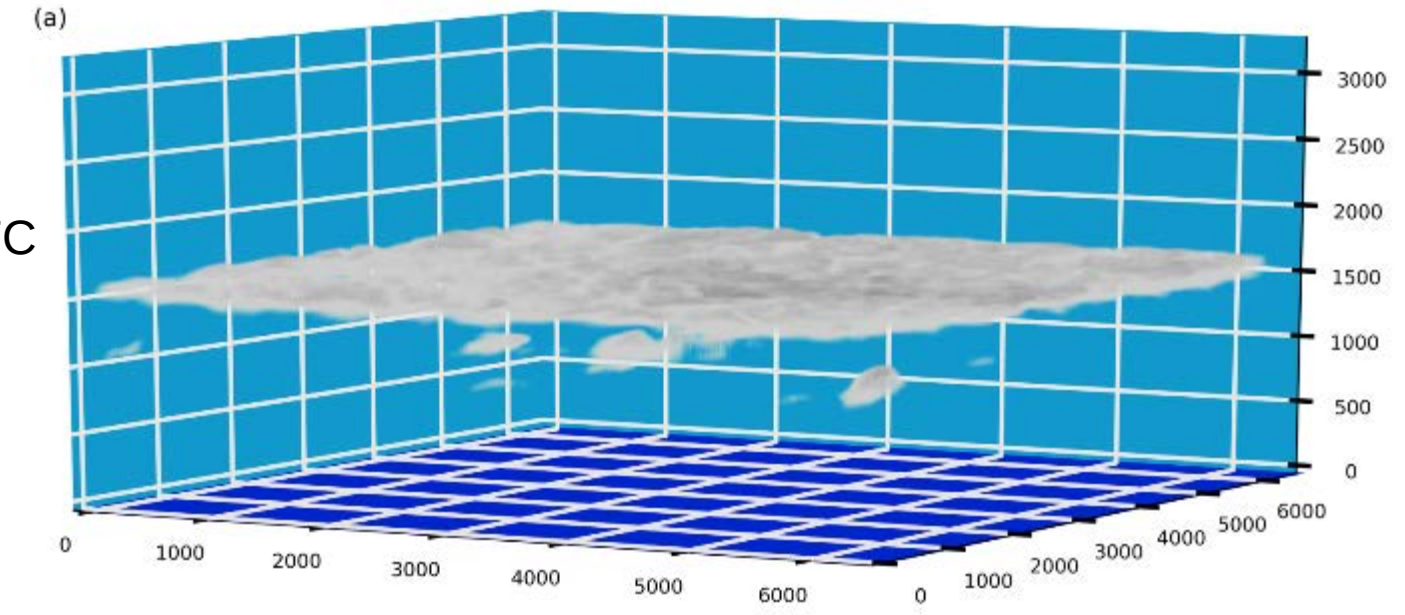


Leg 15A: successful simulation of a Sc-Cu transition

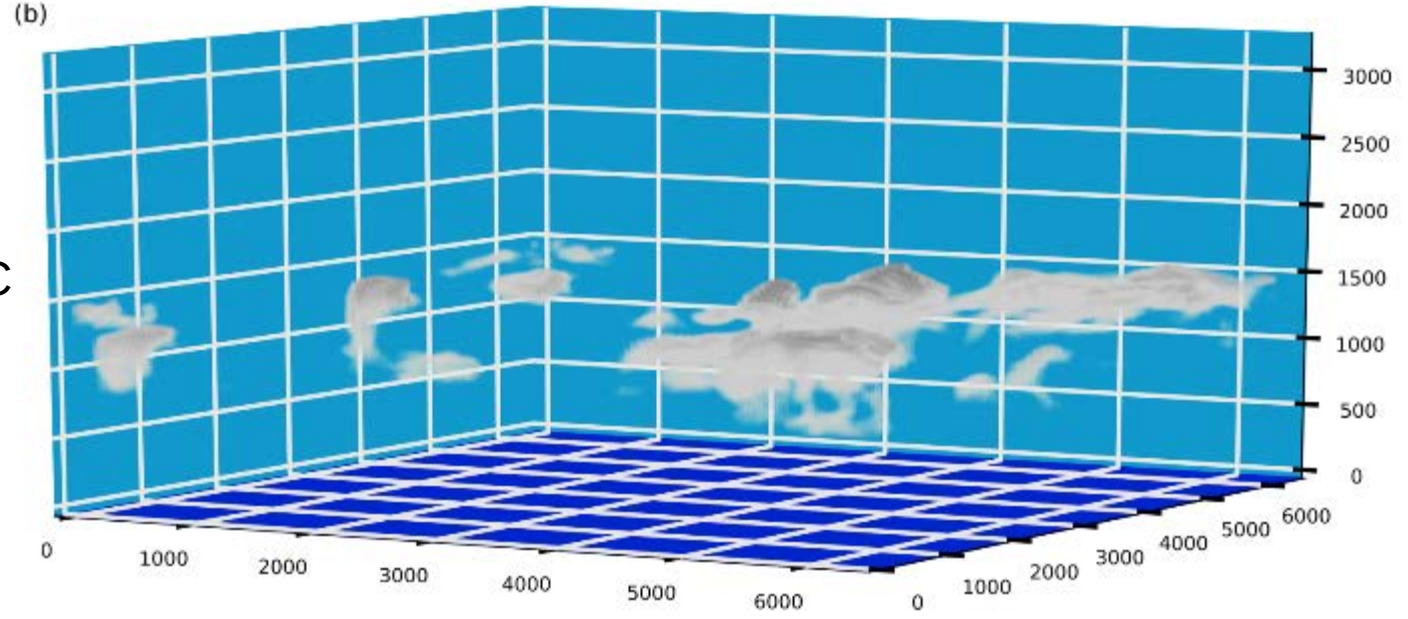


Decoupling and Sc-Cu transition occur near 00 UTC Jul 23 in SAM and observations

7/22 1945 UTC
Cu under Sc

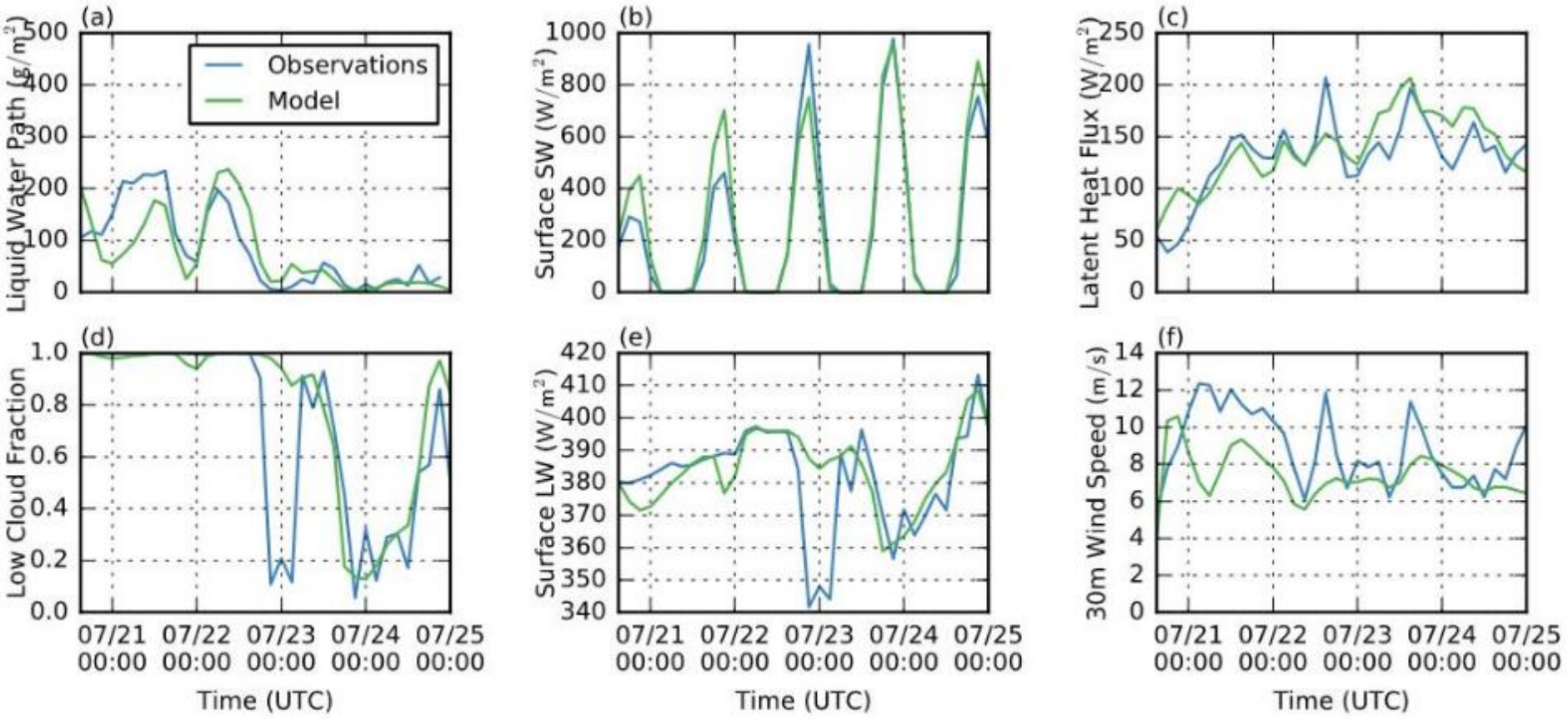


7/24 0845 UTC
Mainly Cu



Leg 15A Case Study

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



Cloud fraction, LWP, surface fluxes all well simulated.

Analysis of all 14 CA-HI legs

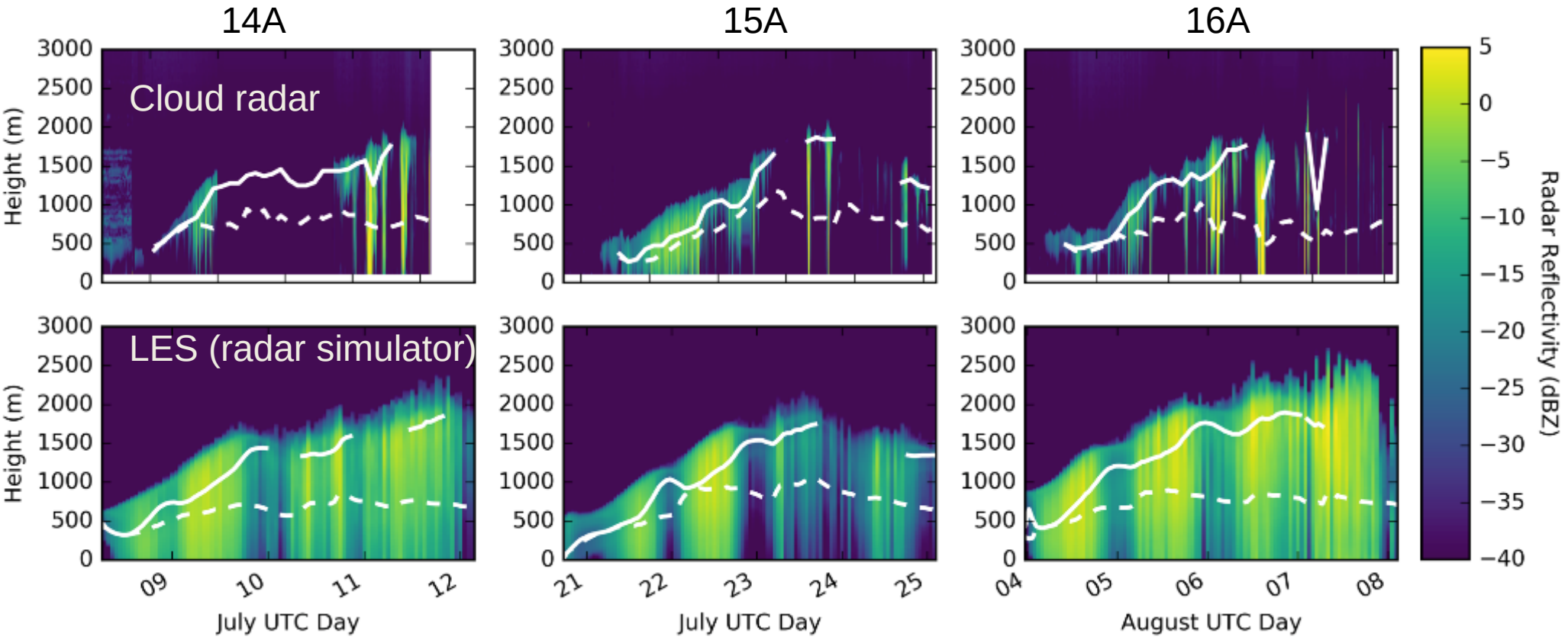
Quantity	**Instrument**	**Observed mean**	**R^2 of daily mean**	**LES Bias**
Low Cloud Fraction	Ceilometer	0.62	0.51*	12%
Liquid Water Path	MWR Retrieval	65 g m^{-2}	0.55*	2%
'Albedo' proxy $1 - SW_{dn}^{sfc}/SW_{dn}^{TOA}$	Portable Radiation Package	0.51	0.52*	-3%
500 m 'rain' fraction (>5dBZ)	K-band cloud radar	0.06	0.01	-40%
Latent Heat Flux	COARE-3 Bulk	122 W m^{-2}	0.53*	3%

LES skillful & unbiased on cloud/radiation; precip harder

- = Significant at 95% confidence

Estimated hourly CDNC ranged from less than 20 to over 200 cm^{-3}

Legs 14A-16A (July-Aug 2012)



Obs and LES of all three legs have Sc-Cu transition, precipitating clouds

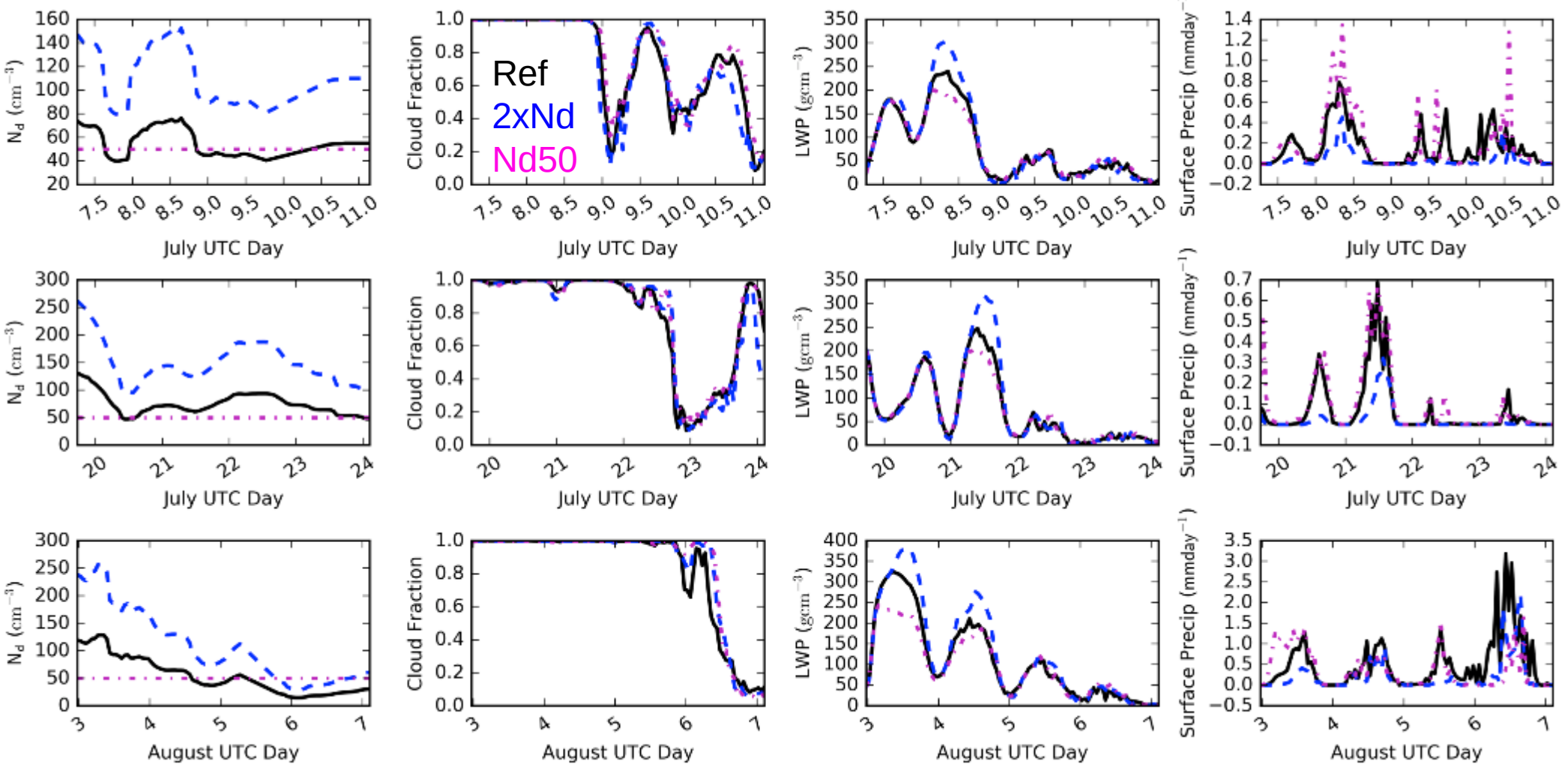
Use these legs for representative LES aerosol sensitivity study

2xNd: CDNC doubled from reference run

Nd50: CDNC fixed at 50 cm^{-3}, as in ECMWF forecast model

Time series from aerosol sensitivity runs

Aerosol is mostly a minor perturbation to the cloud evolution, so CDNC = 50 cm^{-3} works OK



	N_d	Cloud fraction	LWP	Surface 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%

Twomey-Platnick albedo susceptibility analysis

For a plane-parallel cloud of albedo *a*:

$$\Delta a = a(1-a)\left(\frac{1}{3}\Delta \ln N_s + \frac{5}{6}\Delta \ln LWP\right)$$

For 2xNd:

- Daytime albedo increases from 0.31 to 0.36
- 75% due to Twomey effect
- 25% due to 10% LWP increase
- Negligible cloud fraction change

Conclusions

- SAM LES with 5 m vertical resolution simulates diverse NE Pacific boundary-layer clouds and radiation skillfully and without substantial bias

- Aerosol-doubling sensitivity of 3 representative MAGIC legs suggests:
  - Large precipitation decrease
  - Modest LWP increase
  - Twomey effect dominates albedo change
  - Little cloud fraction change

- LES suggests that sampled variability of cloud fraction/LWP is mostly not due to aerosol variability, so a weather forecast model with fixed CDNC can still have high skill in predicting clouds.