[Toward] Improvements to Warm Microphysics and Shallow Cumulus Parameterizations in regional models

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Third scientific workshop on ONR DRI "Unified Parameterization for Seasonal Prediction"

Ongoing collaborations with Yefim Kogan, Simon de Szoeke, Sandra Yuter, Kevin Nelson, Carly Fish

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Monterey, CA
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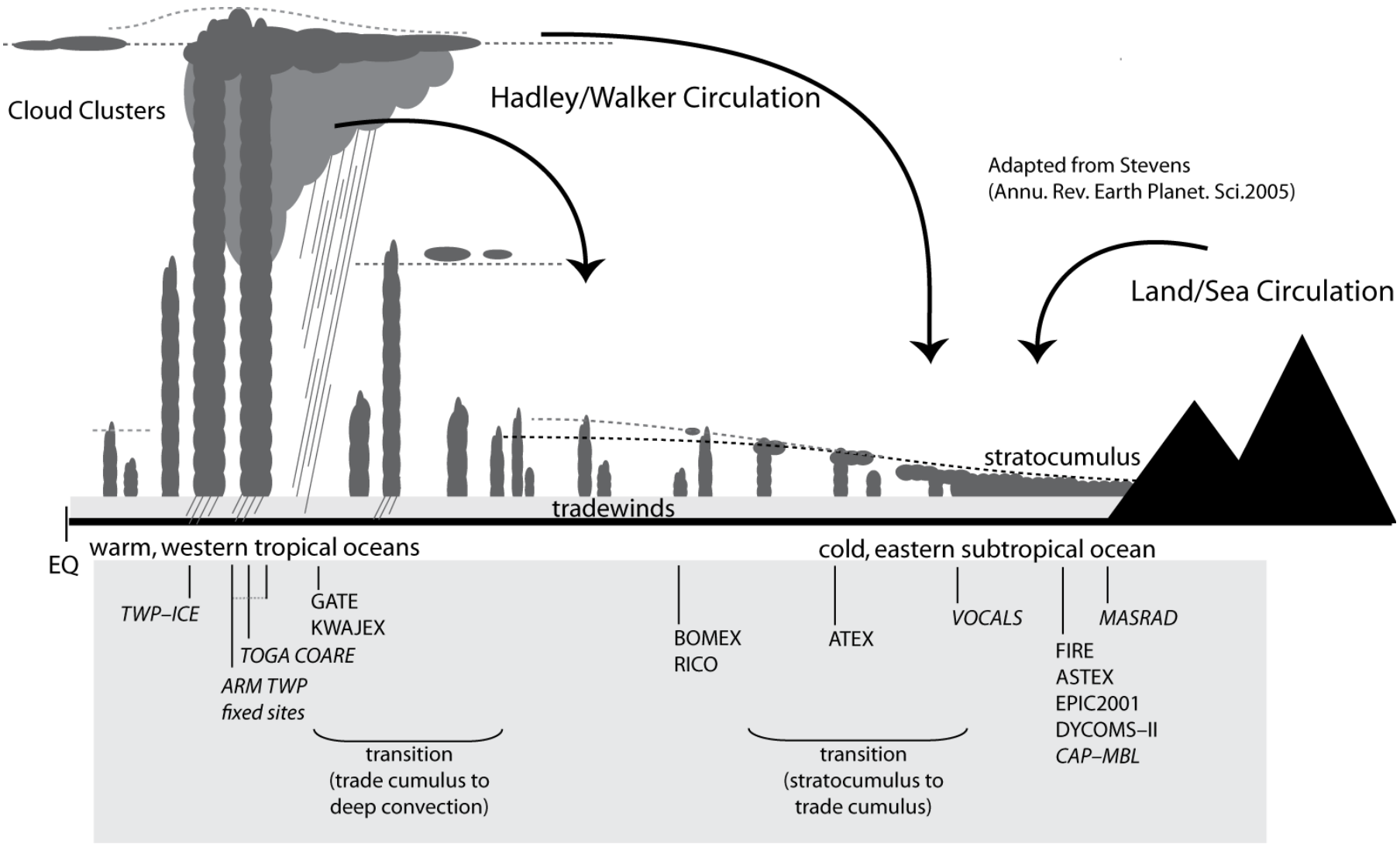
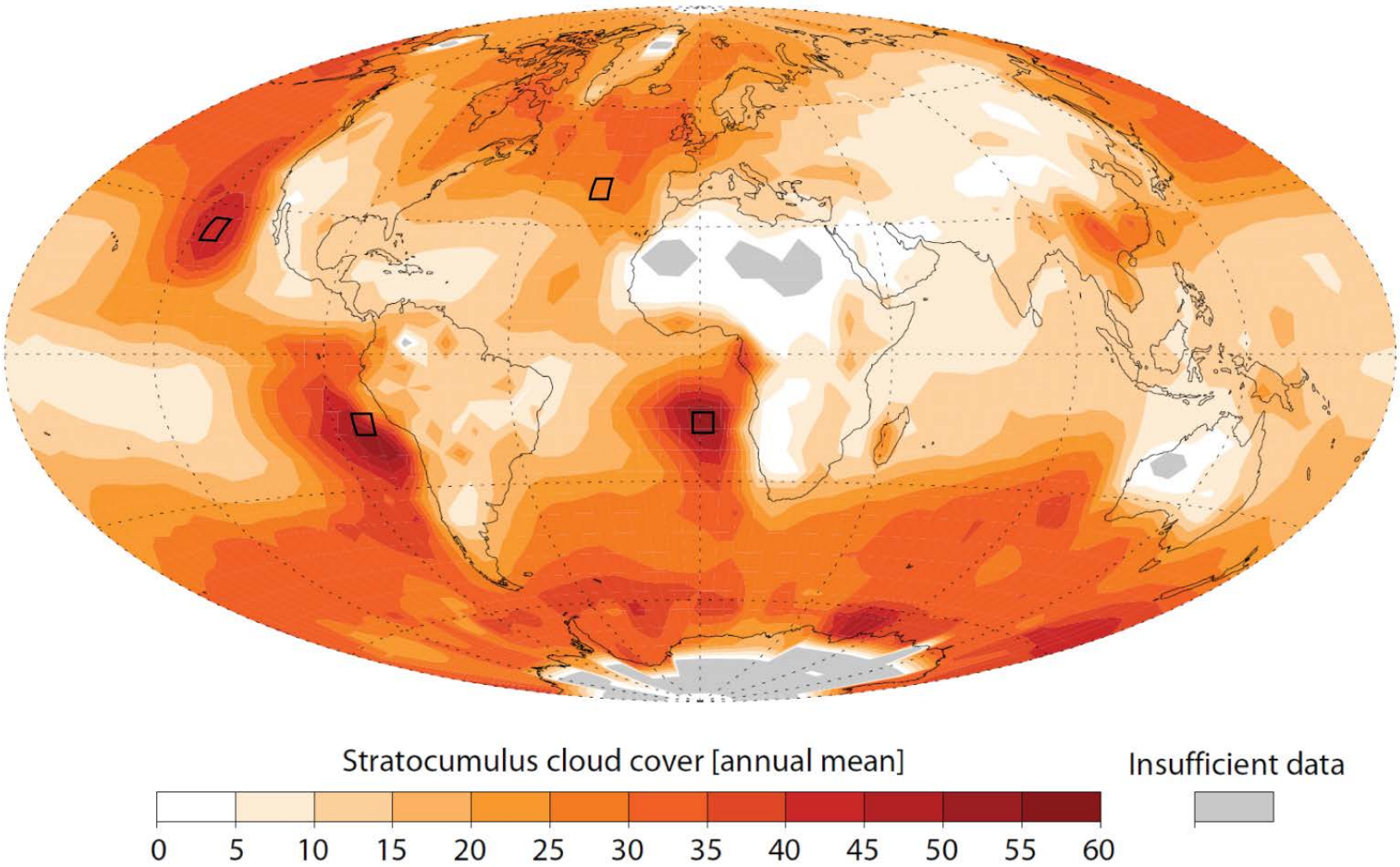
Cloud regime transitions

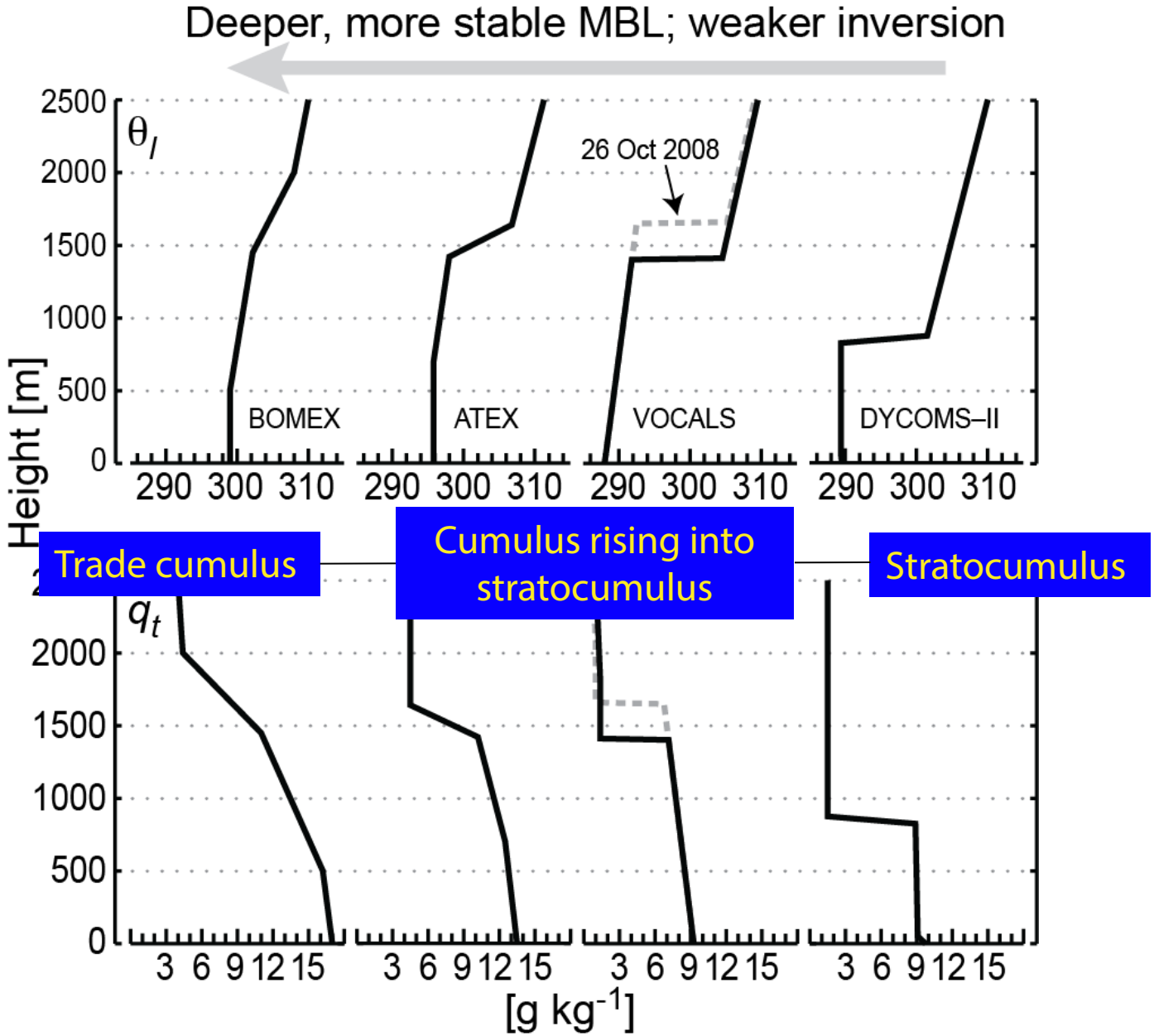


Stratocumulus clouds

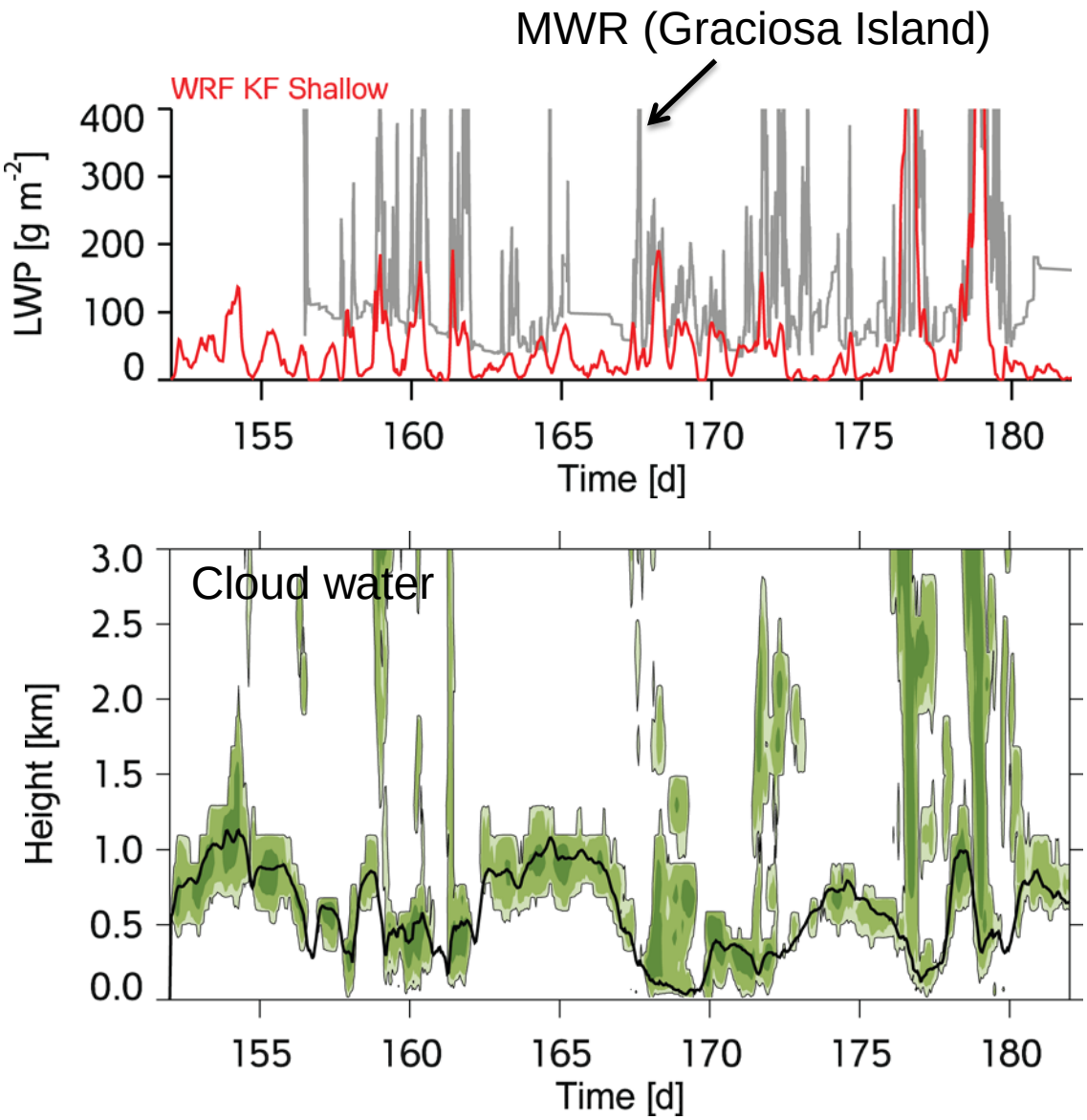


Marine boundary layer cloud regimes

Mechem et al. (2012)



Scrutinizing mesoscale cloud predictions over the northeast Atlantic (NEA) with long-term observations



The Azores region of the NEA is an ideal laboratory for studying cloud-system variability:

- It constitutes a transition zone between stratocumulus and trade cumulus, which varies by season.
- The region is frequently affected by the passage of mid-latitude synoptic waves

The rich variability in cloud properties over the NEA constitutes an acid test for the statistical behavior of mesoscale models.

We are working toward improving mesoscale prediction of cloud and MBL properties in this region of substantial variability.

Motivation

- Current parameterizations do not handle clouds other than pure undrizzling Sc very well. This leaves…

  drizzle-induced MBL decoupling
  Cu rising into Sc
  POCs
  trade cumulus boundary layers
  … congestus, too.

Seasonal forecasts and climate model projections are sensitive to the treatment of shallow clouds, and models need to be able to represent all boundary layer cloud types.

Approach

- Evaluating new warm-rain parameterizations in VOCALS simulations (COAMPS)
- Quantifying the roles of radiatively-driven vs. surface-driven buoyancy in VOCALS stratocumulus simulations (LES)
- Extending upward into the congestus mode

Approach

- Keep “seasonal” in mind
- Evaluate model improvements (microphysical parameterizations and [eventually] shallow cumulus) in light of multi-day to multi-month prediction
- Use LES to better understand boundary-layer cloud processes and lead to improvements in parameterizations
- Previous feedback suggested we move toward using COAMPS for evaluating parameterizations

1 Oct – 1 Dec 2008 VOCALS Regional Experiment

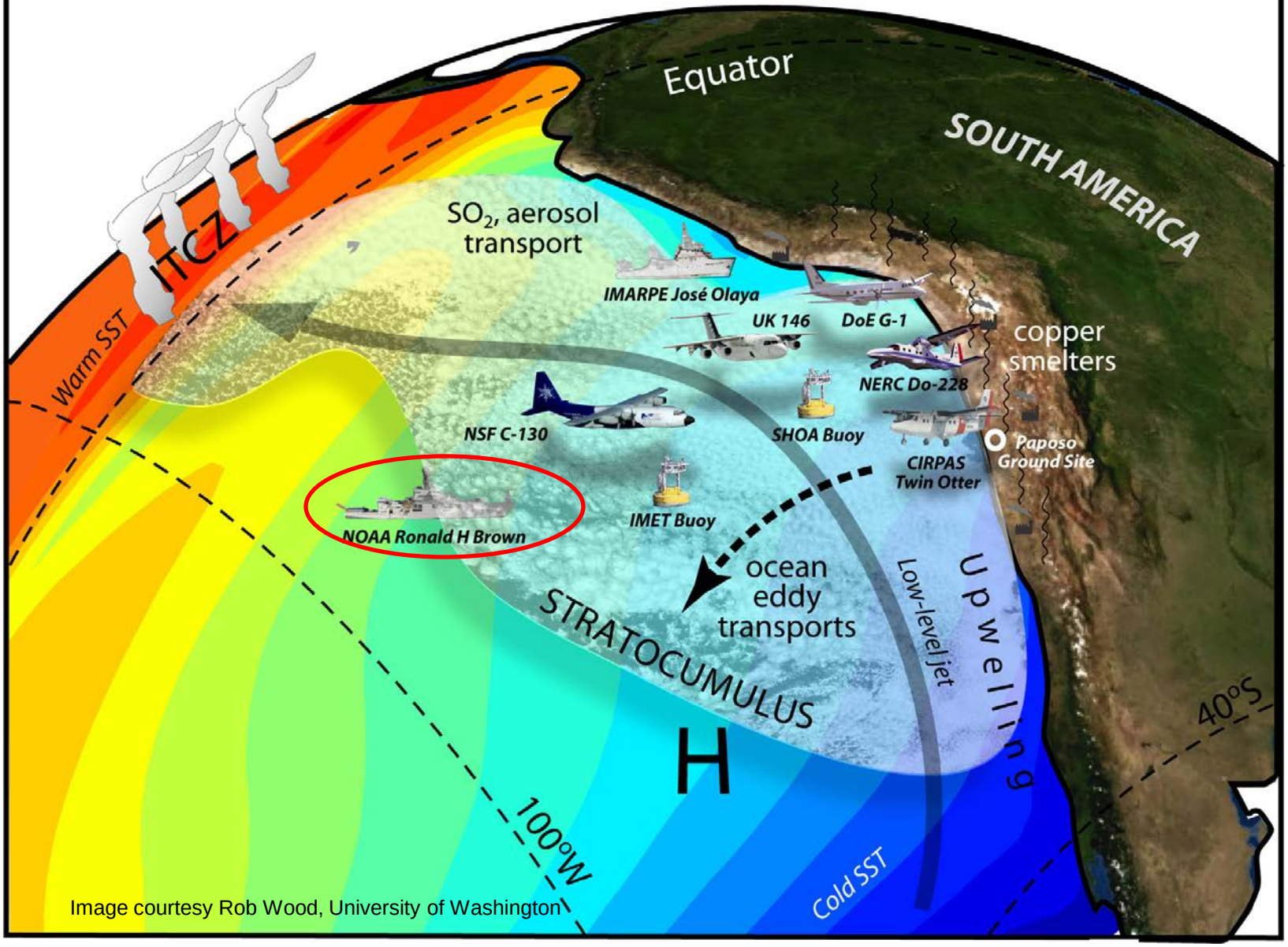
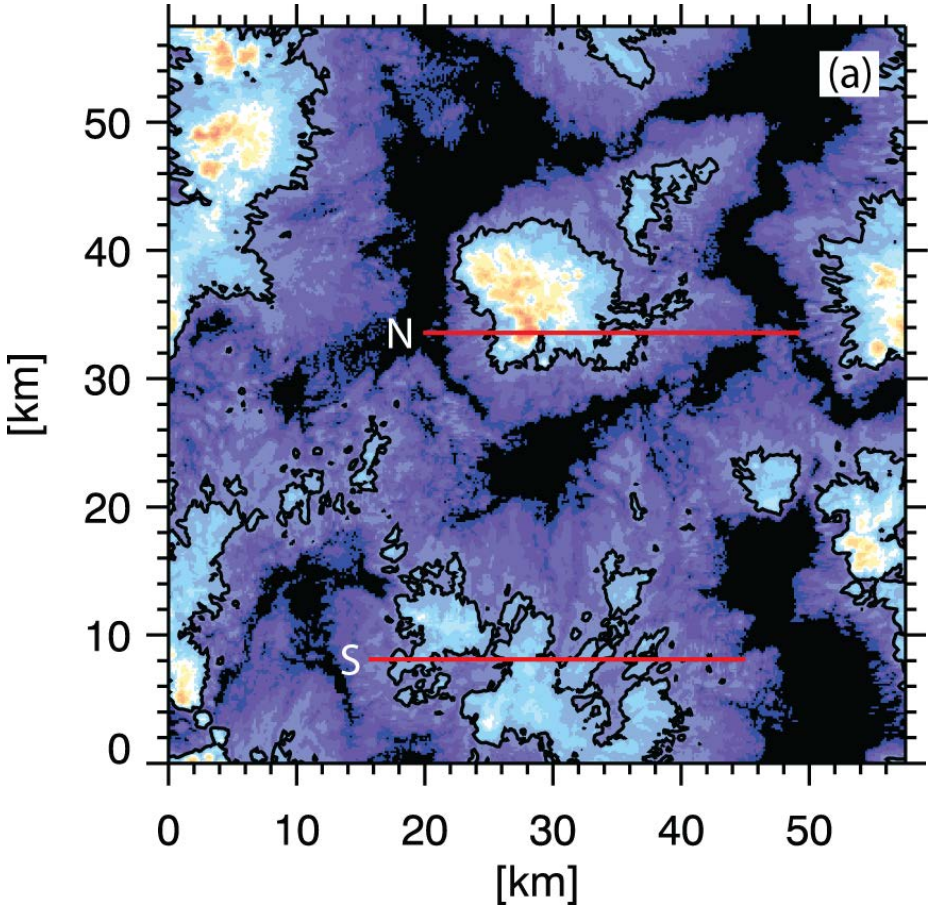
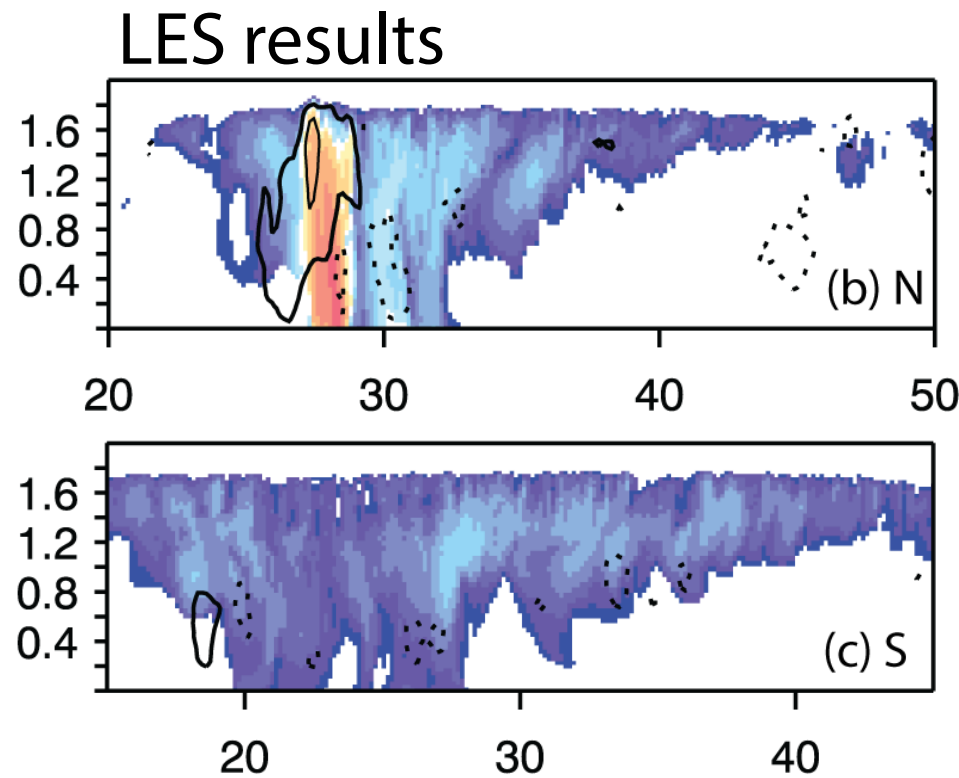


Image courtesy Rob Wood, University of Washington

Sensitivity of mesoscale variability to aerosol/thermodynamics

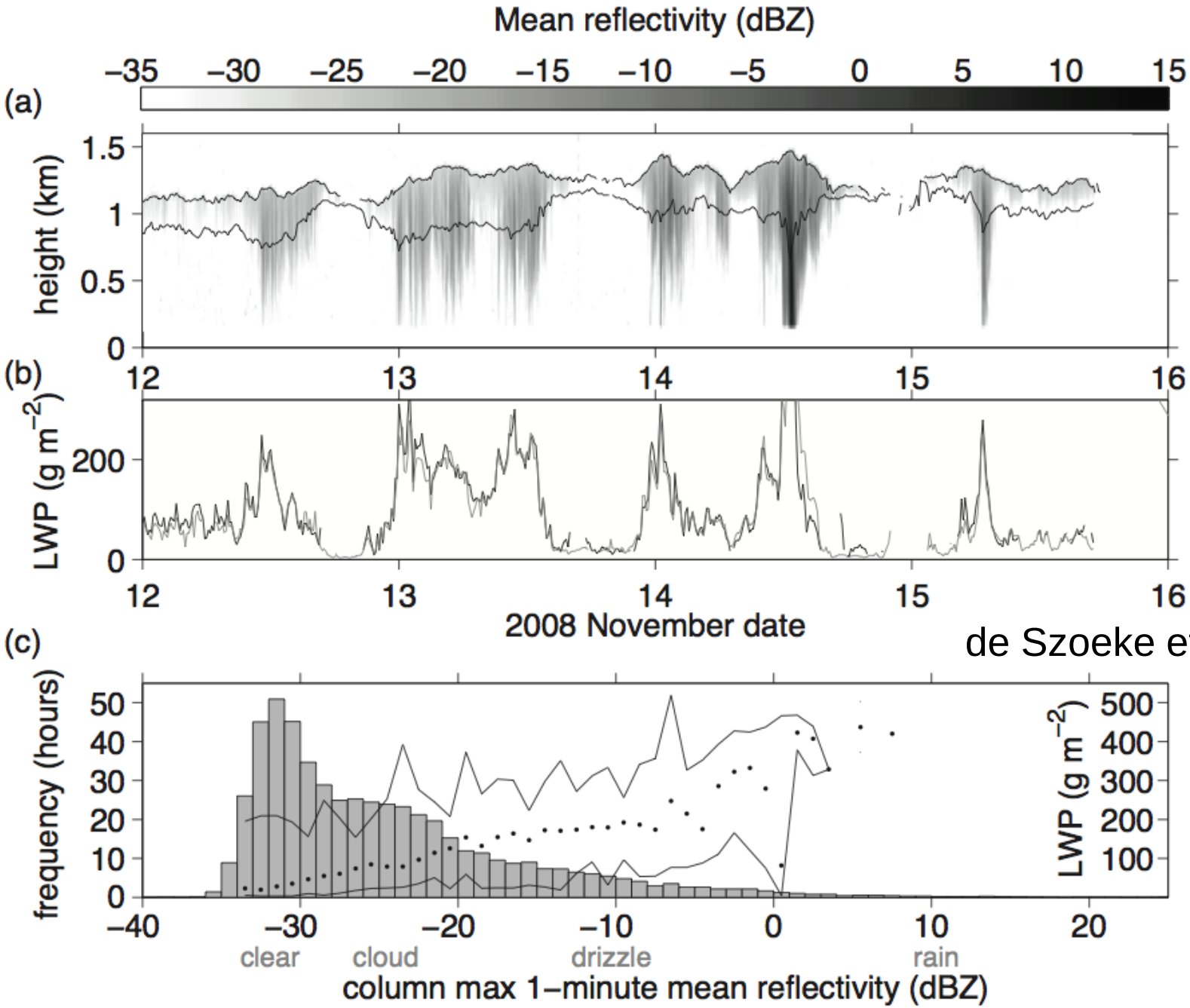




Mechem et al. (2012)

Simulation	R [mm d^{-1}]		w_e [cm s^{-1}]
Deep (control simulation)	0.98		0.76
Shallow	0.44	(–55%)	0.58
Doubled CCN	0.57	(–42%)	0.85
Shallow + Doubled CCN	0.28		0.72

Observations from NOAA R/V Ron Brown (20° S, 75° W)



de Szoeke et al. (2011)

VOCALS COAMPS simulations

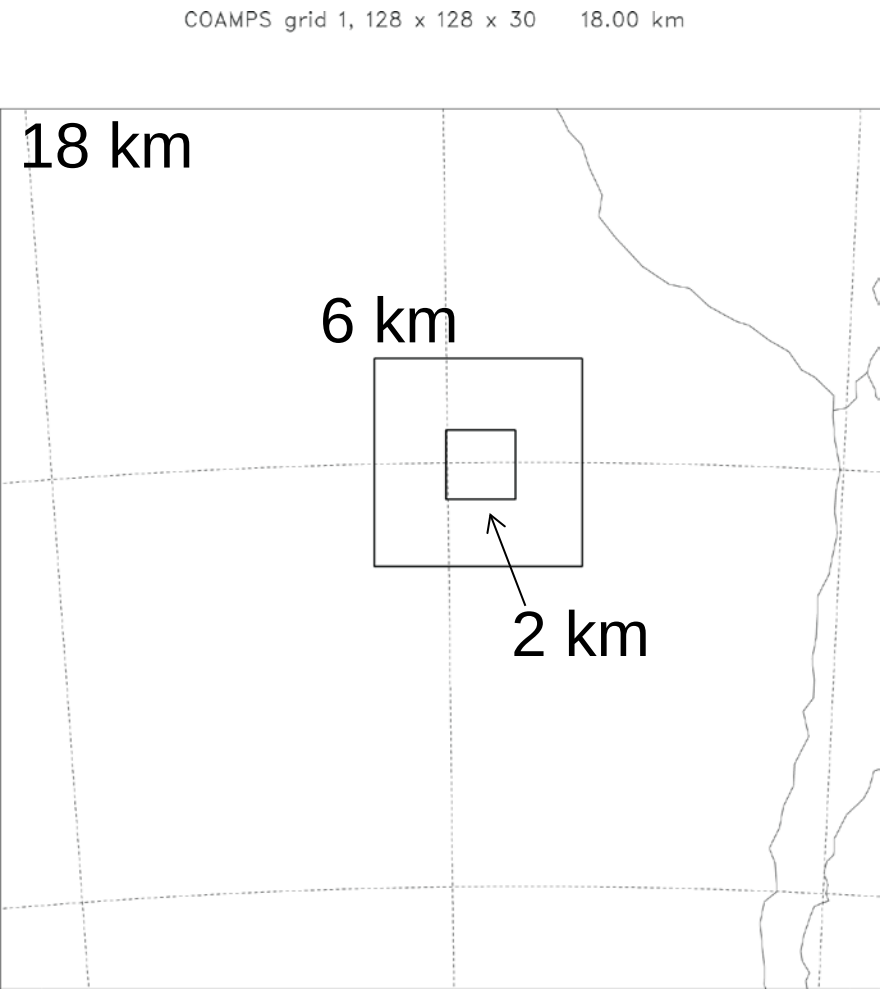
COAMPS 4.2.2

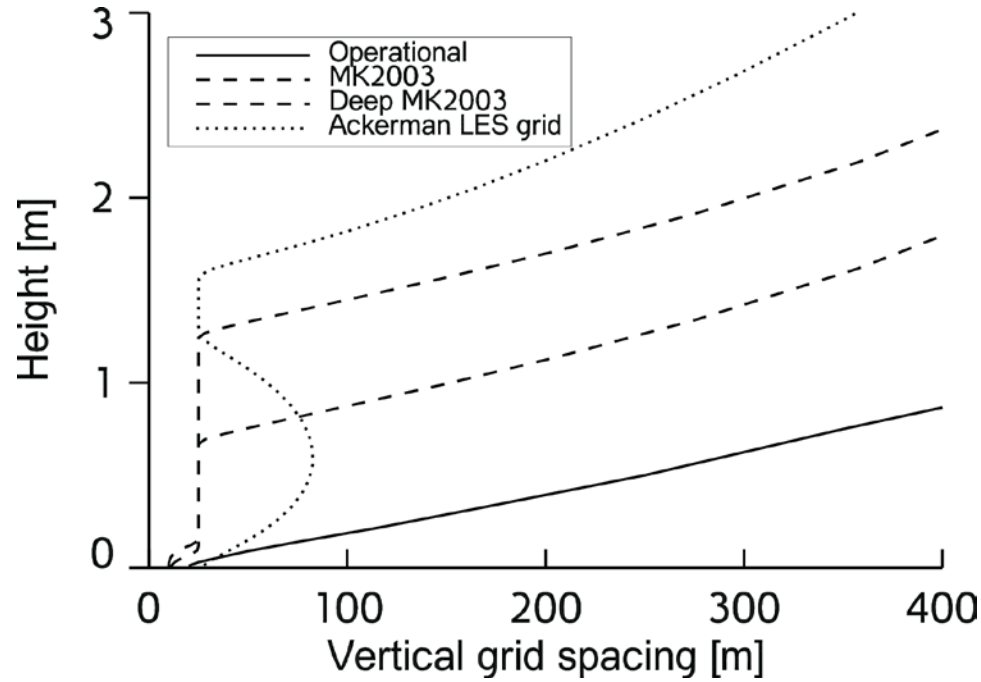
Domain: 2304x2304 km^2

- *dx*=*dy*=18 km
- *dz* stretched:
  - Operational (30 levels)
  - Mechem and Kogan (2003) (62 levels)
  - **Mechem and Kogan (Deep) (82 levels)
  - Ackerman configuration (62 levels)
- ~10 m at $z = 0$; 25 m from $z = 120$ m to 1250 m; 357 m at $z = 2.2$ km
- Grid: 128 × 128 × 82, run for 120 hours
- NOGAPS analysis provides initial conditions
- Combination of NOGAPS analysis and forecasts provide boundary conditions
- NOGAPS only, no observations

See also, Wang, S., L. W. O'Neill, Q. Jiang, S. P. de Szoeke, X. Hong, H. Jin, W. T. Thompson, and X. Zheng, 2011: A regional real-time forecast of marine boundary layers during VOCALS–REx. *Atmos. Chem. Phys.*, **11**, 421–437, doi:10.5194/acp-11-421-2011.

VOCALS simulations — COAMPS grid configuration

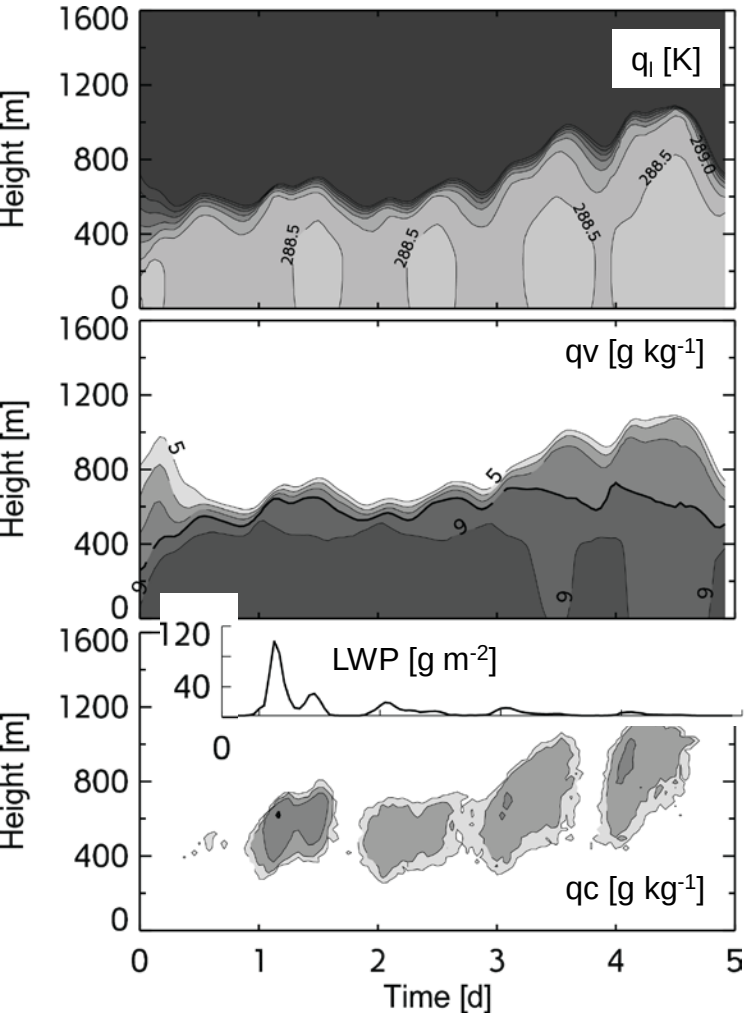


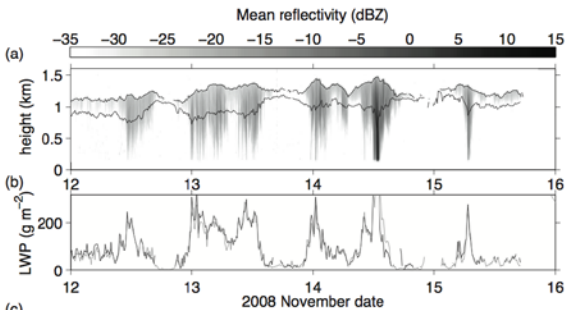


Cloud and precipitation fields can be acutely sensitive to grid spacing

LES studies (e.g., Bretherton et al. 1999) show ~5 m vertical grid spacing required to capture entrainment rate.

COAMPS simulations of VOCALS (12–16 Nov 2008)





The good:

- Inversion is nicely maintained
- Evidence of a diurnal cycle

The bad:

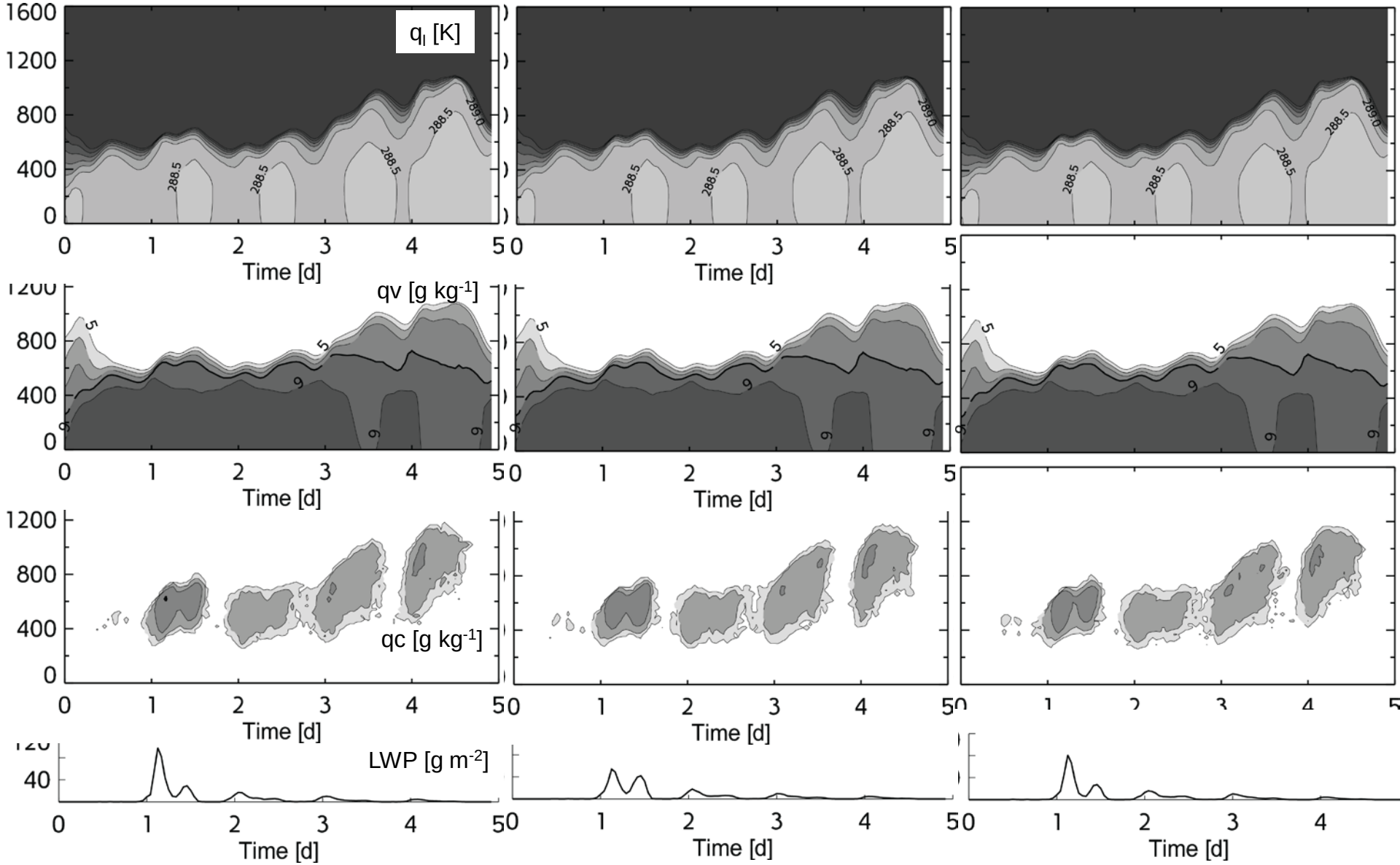
- Early on, inversion is too shallow— (blame NOGAPS?)
- Cloud LWP too small

The ugly:

- Spin-up issues?
- A multi-day mean forcing we could run for many days (e.g., McCaa and Bretherton 2004) might be preferable.

VOCALS simulations — a unified autoconversion?

Kessler (operational)	KK2000 (stratocumulus)	Kogan 2013 (shallow cu)
$\alpha(q_c - q_{c0})H(q_c - q_{c0})$	$1350\ q_c^{2.47} N_c^{-1.79}$	$7.98 \times 10^{10} \times q_c^{4.22} N_c^{-3.01}$



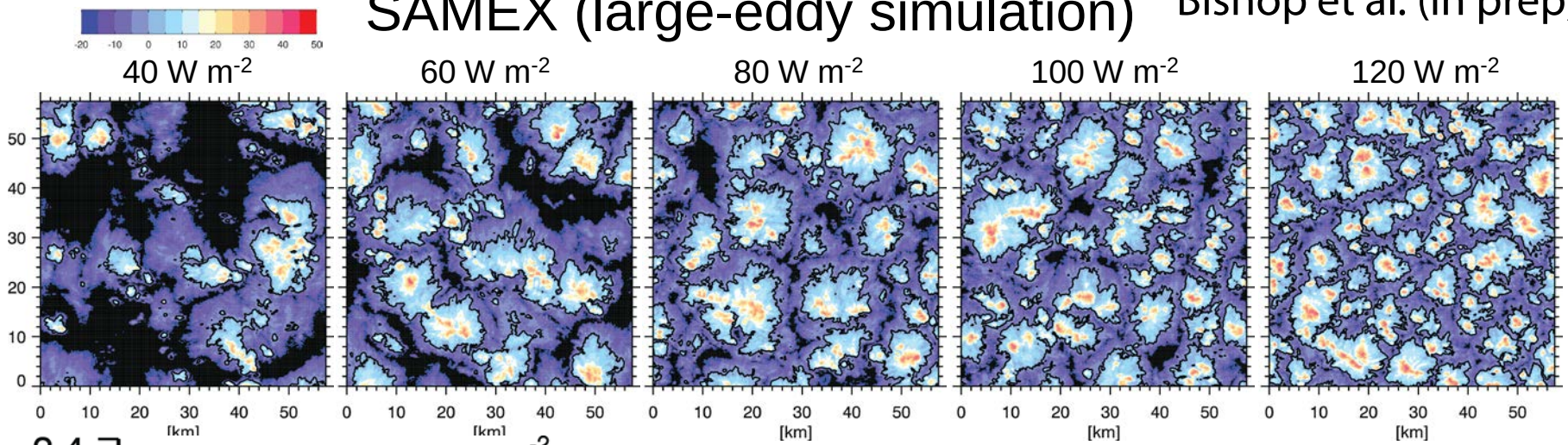
What role does shallow convection play in stratocumulus?

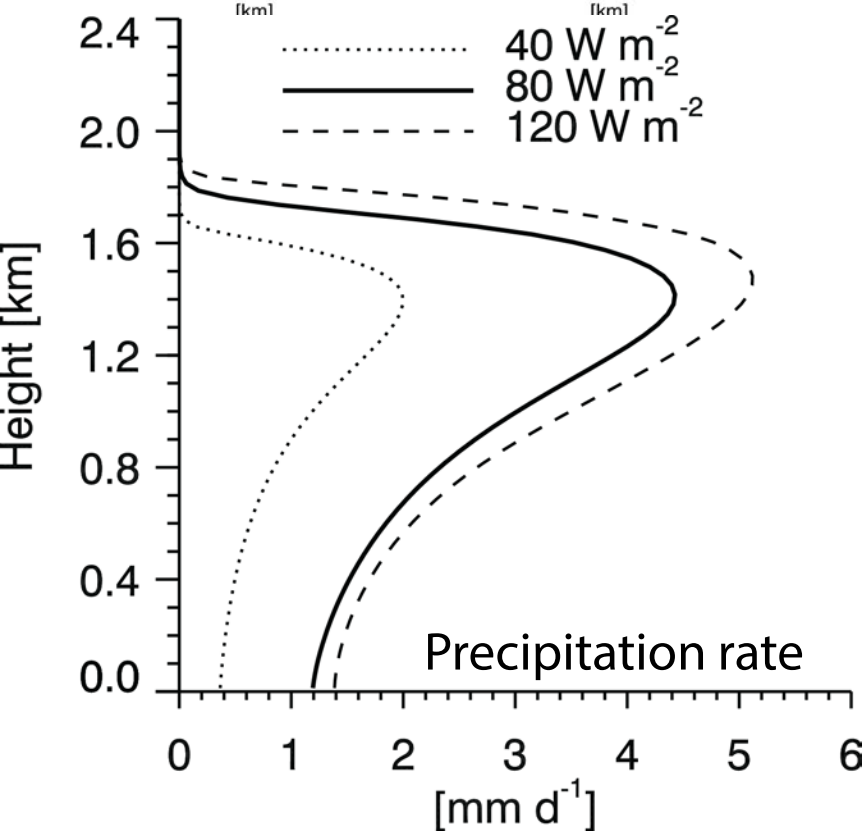
- The deeper, decoupled MBL away from the coast exhibits cumulus rising into a stratocumulus layer.
- Turbulence forced by surface-based buoyancy, yet the solid cloud deck means cloud-top cooling is active, too.
- What are the relative roles of top-down, radiatively-driven buoyancy vs. surface-based (cumulus) buoyancy?

Sensitivity of mesoscale organization to longwave forcing

SAMEX (large-eddy simulation)

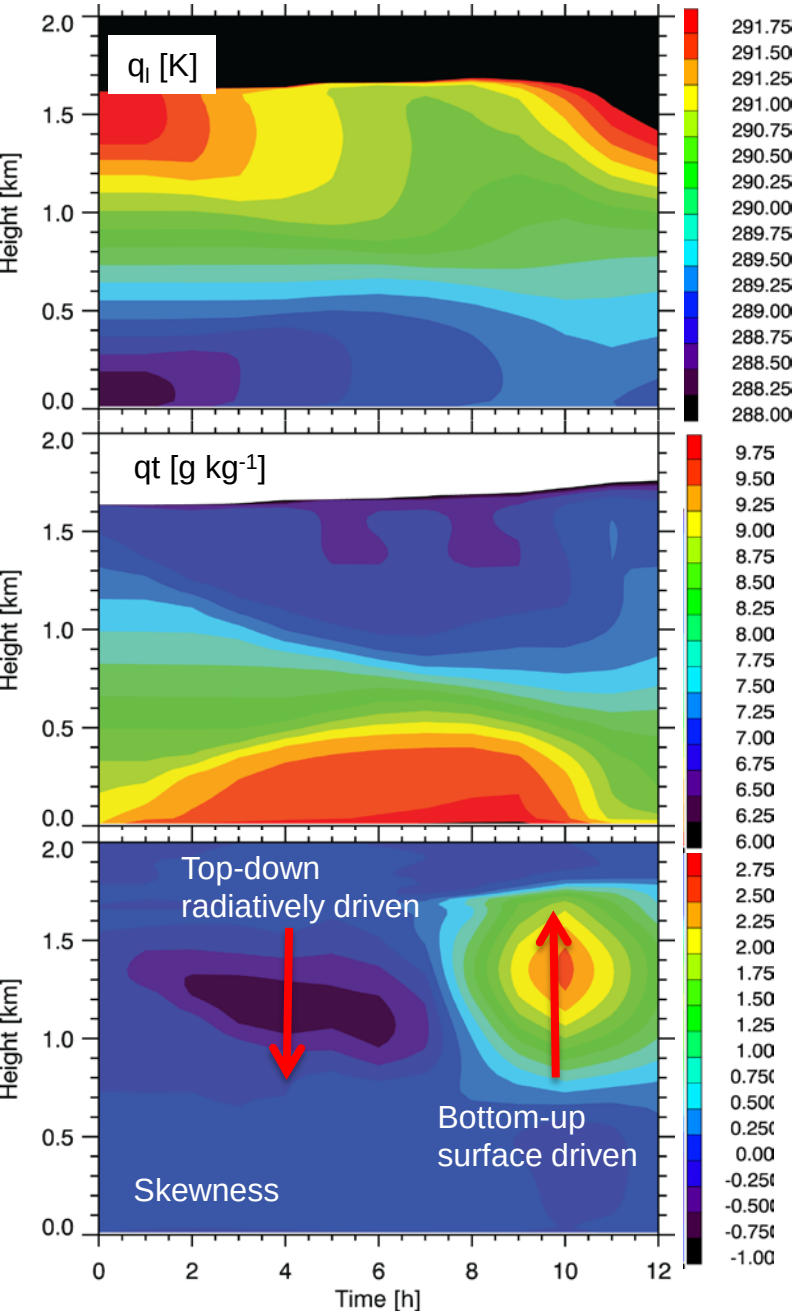
Bishop et al. (in prep)

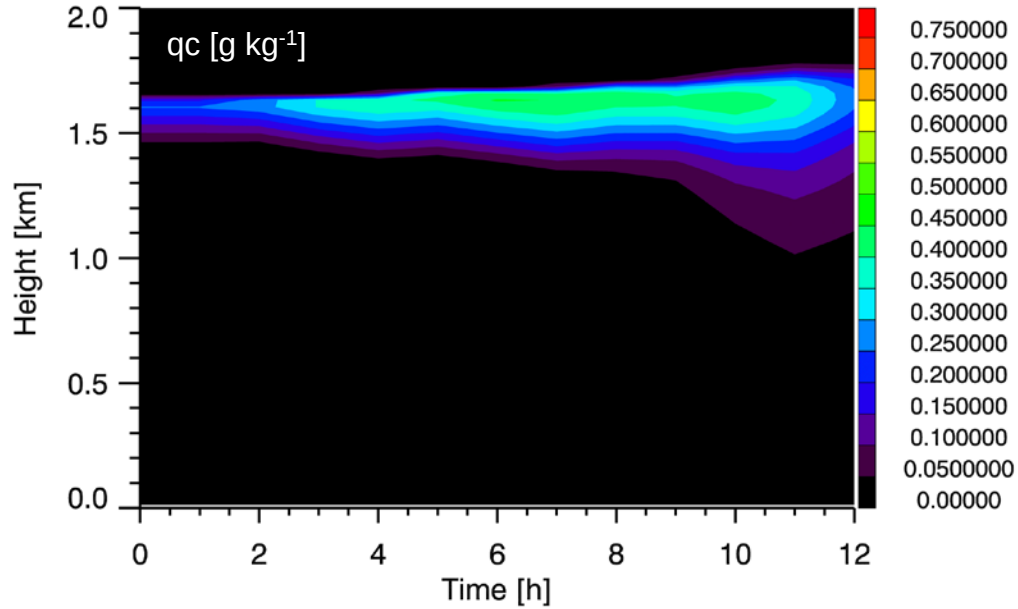




- Stronger LW forcing leads to more precipitation and stronger MBL turbulence
- Stronger mean turbulence is not a result of greater updraft buoyancy
- Stronger LW forcing results in greater updraft area fraction

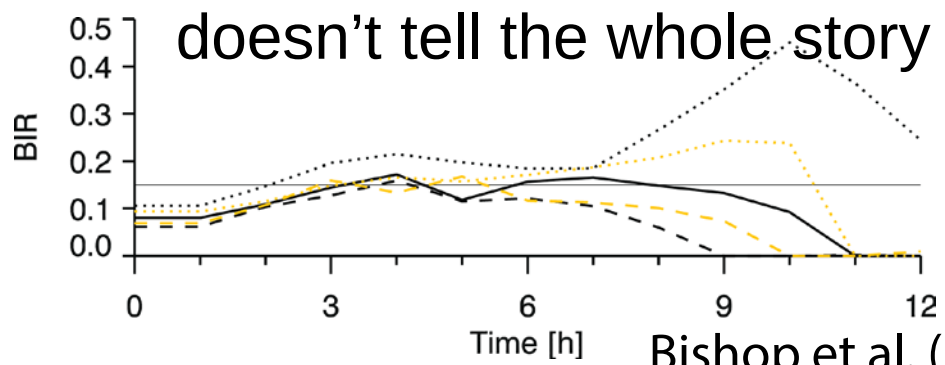
What role does shallow convection play in stratocumulus?





But you don't notice this transition by looking just at the liquid water field!

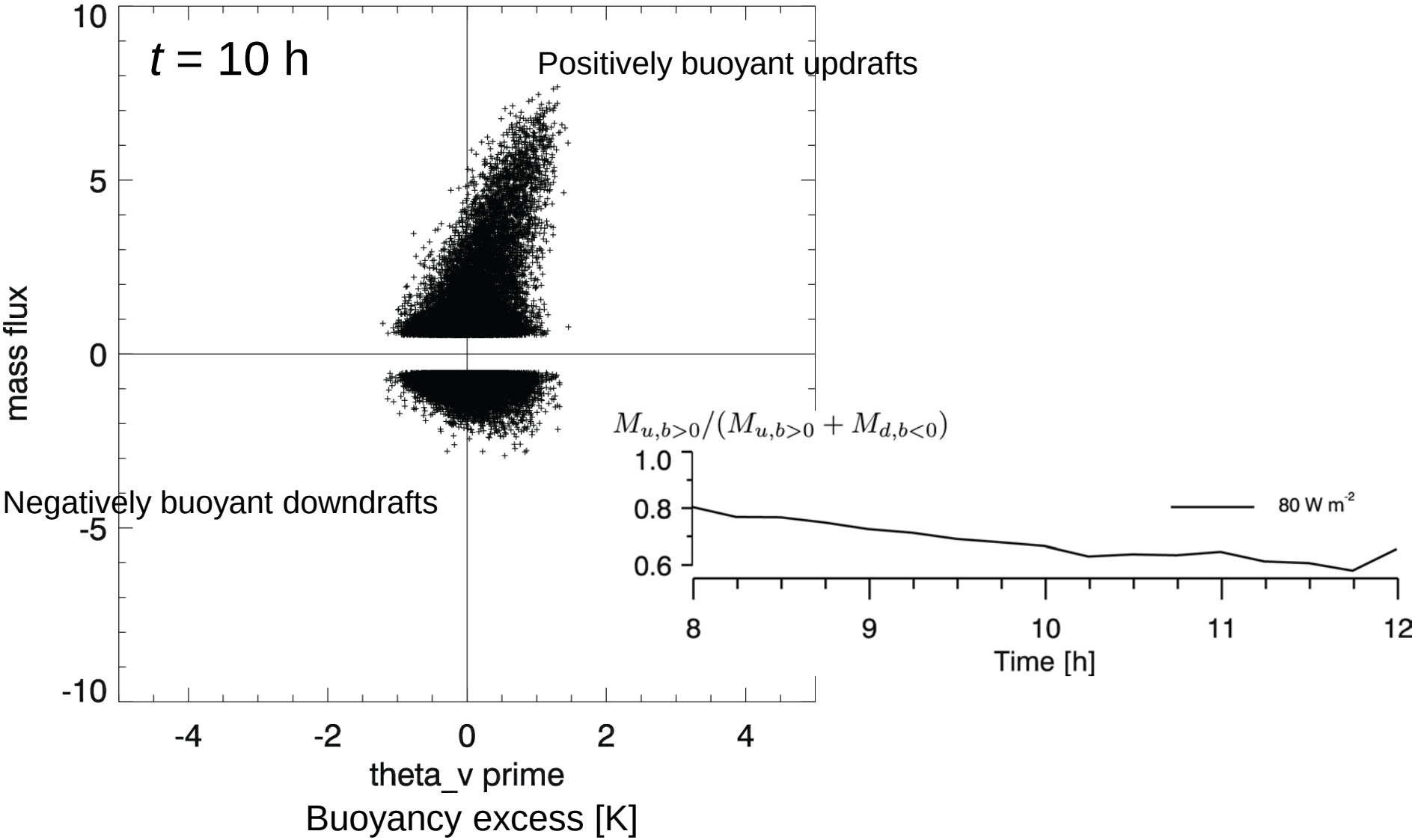
Buoyancy integral ratio (BIR) doesn't tell the whole story either



Bishop et al. (in prep)

What role does shallow convection play in stratocumulus?

SAMEX VOCALS simulations



Cumulus congestus in the tropics

Classically, the cloud distribution in the tropics has been considered bimodal:

- Shallow, trade cumulus mode (tops from 1-3 km)
- Mid-depth, cumulus congestus (tops from 4-6 km)
- Deep convective mode (tops from 9 km upward)

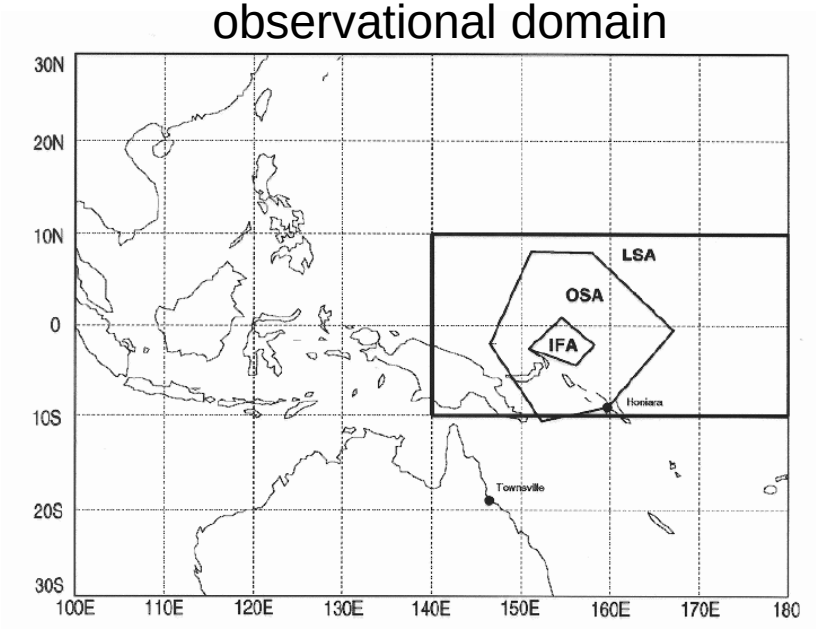
RICO cumulus (Bjorn Steve

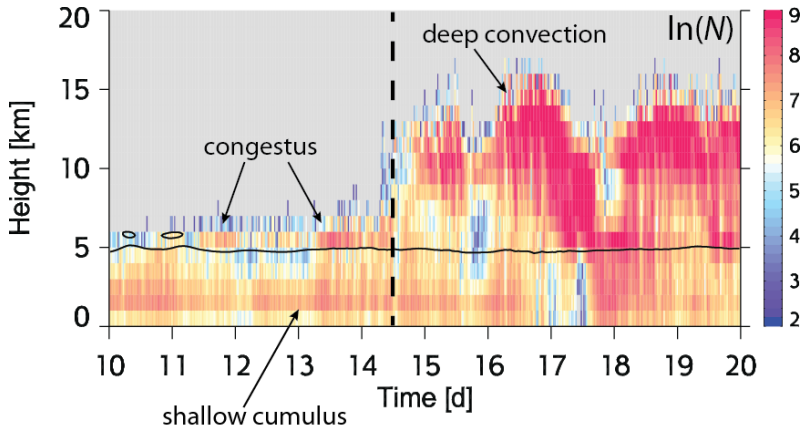
Cumulus congestus (G. Stephens 2004)

nasa.gov/view_rec.php?id=16086

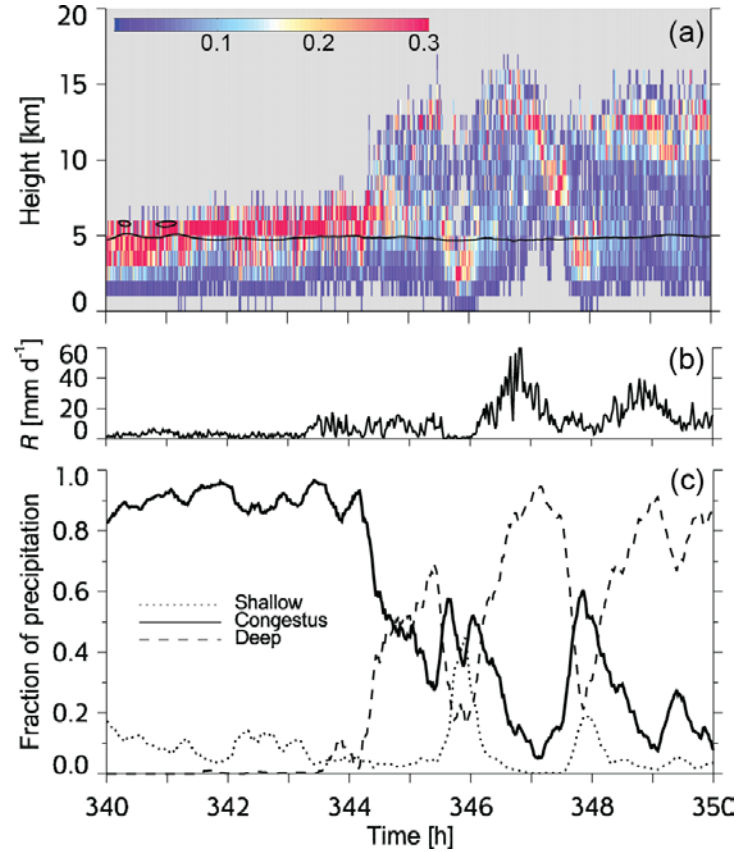
Numerical simulation (LES) of cumulus congestus in the tropics

TOGA COARE observational domain





Simulation beginning at 26 November 1992; analysis from 6-16 December 1992.

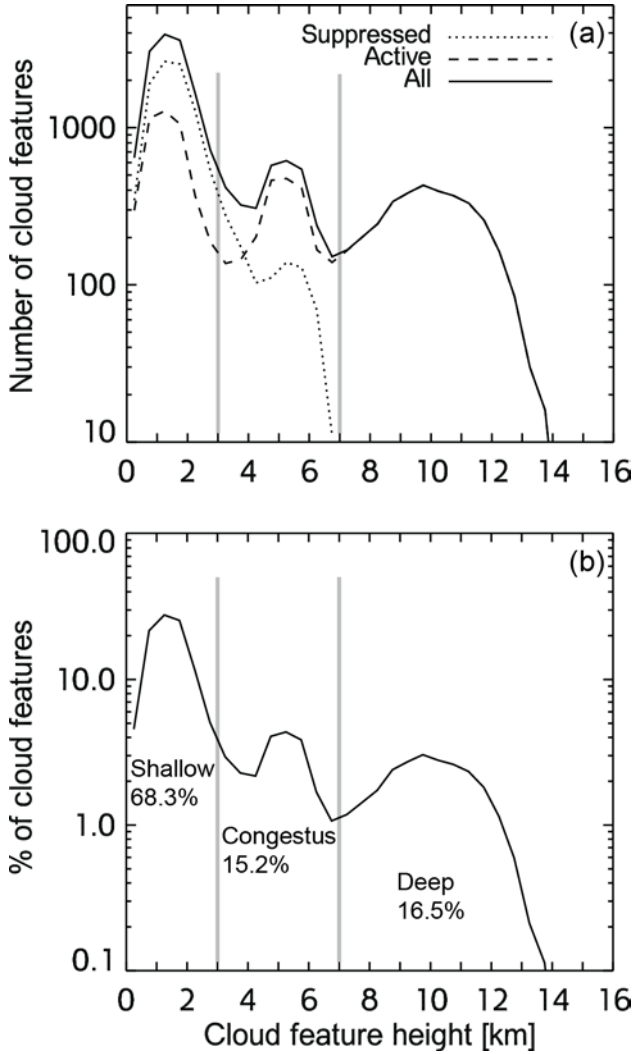


Precipitation contributions:
4% from shallow cumulus
34% from congestus
62% from deep convection

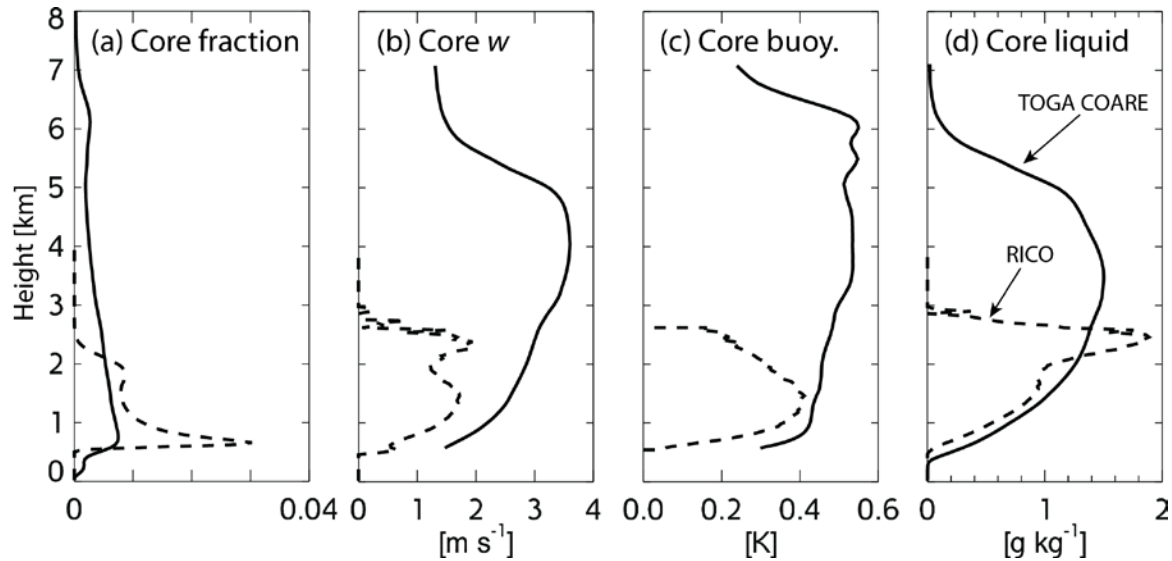
Mechem and Oberthaler (JAMES, in press)

Congestus — shallow (trade) cumulus on steroids?

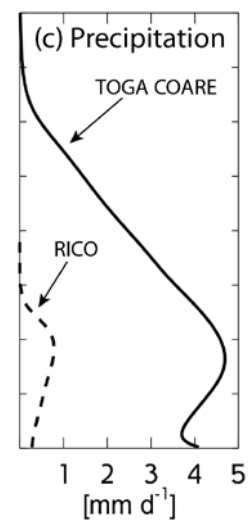
Congestus are common



Comparison of cloudy cores — trade cumulus and congestus



Bigger, greater buoyancy, stronger vertical motion, more precipitation (Bigger! Stronger! Faster!)



Conclusions, discussion points, ongoing and future work

- Decomposition of buoyancy mechanisms from LES results can serve as a diagnostic to evaluate the performance of shallow cumulus and/or EDMF
- A unified parameterization should be able to represent traditional shallow (trade cumulus), but also shallow convection in high cloud fraction regimes
- Congestus as overgrown trade cumulus
- Still getting (re)aquainted with COAMPS
- Need for a simulation testbed to evaluate parameterizations (VOCALS and Azores)
- Implementing shallow cumulus (UW) scheme from WRF into COAMPS (redundant to NRL effort?)