Warm Cloud Modeling Session

CLWG/CAPI/ALWG

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Warm Clouds

- No ice
- Within the boundary layer—certainly below 5-km
- Marine and continental
- Seasonal

Suppressed environments favorable for low clouds

significant (but not overwhelming) subsidence ($1 \rightarrow 3\ \mu bar\ s^{-1}$)
adequate BL water vapor
source of BL TKE
saturation beneath inversion

MARINE BOUNDARY LAYER

Bulletin of the American Meteorological Society: CAP-MBL

Clouds, Aerosol, and Precipitation in the Marine Boundary Layer: An ARM Mobile Facility Deployment

Capsule: A 21-month deployment to Graciosa Island in the northeastern Atlantic Ocean is providing an unprecedented record of the clouds, aerosols and meteorology in a poorly-sampled remote marine environment

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MESOSCALE CELLULAR CONVECTION

Pockets of Open Cells
POCS

Case I: Closed cell Case II: Open cell

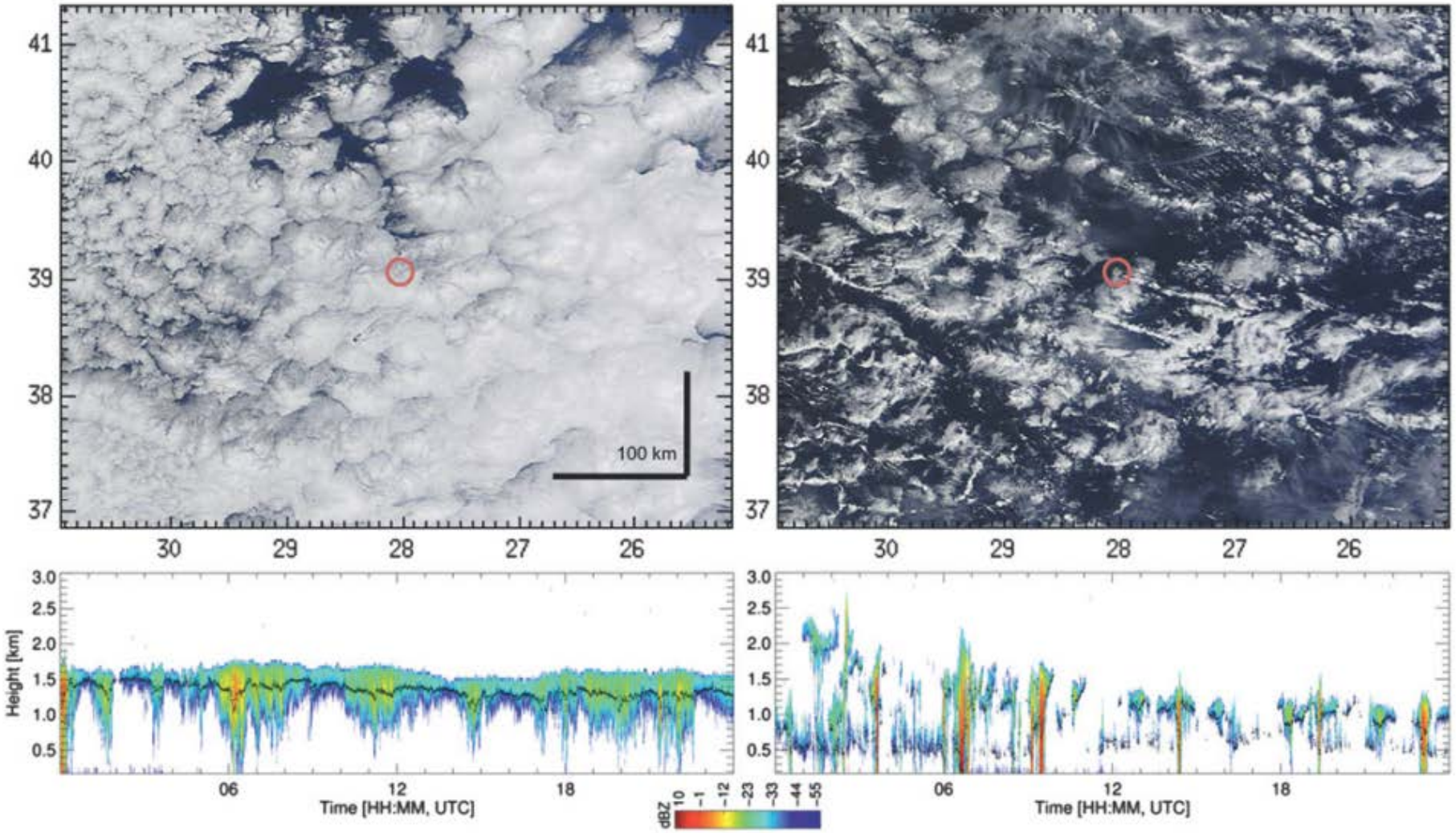


FIG. 2. (top) True color images from MODIS onboard *Terra* taken around 1315 UTC and spanning about 500 km in both dimensions centered at the location of Graciosa Island (shown in red circle). (left) A stratocumulus cloud case (22 Nov 2009) and (right) a broken cumulus (0300–0600 UTC) and cumulus with stratocumulus (1800–2400 UTC) cases (30 Aug 2010). (bottom) The corresponding daily WACR time–height reflectivity observations with the first ceilometer cloud base shown as black dots.

Rémillard et al., 2012, *J. Climate*

Wang and Feingold, 2009, JAS

Albedo

WRF LES 300 m horizontal, 30 m vertical

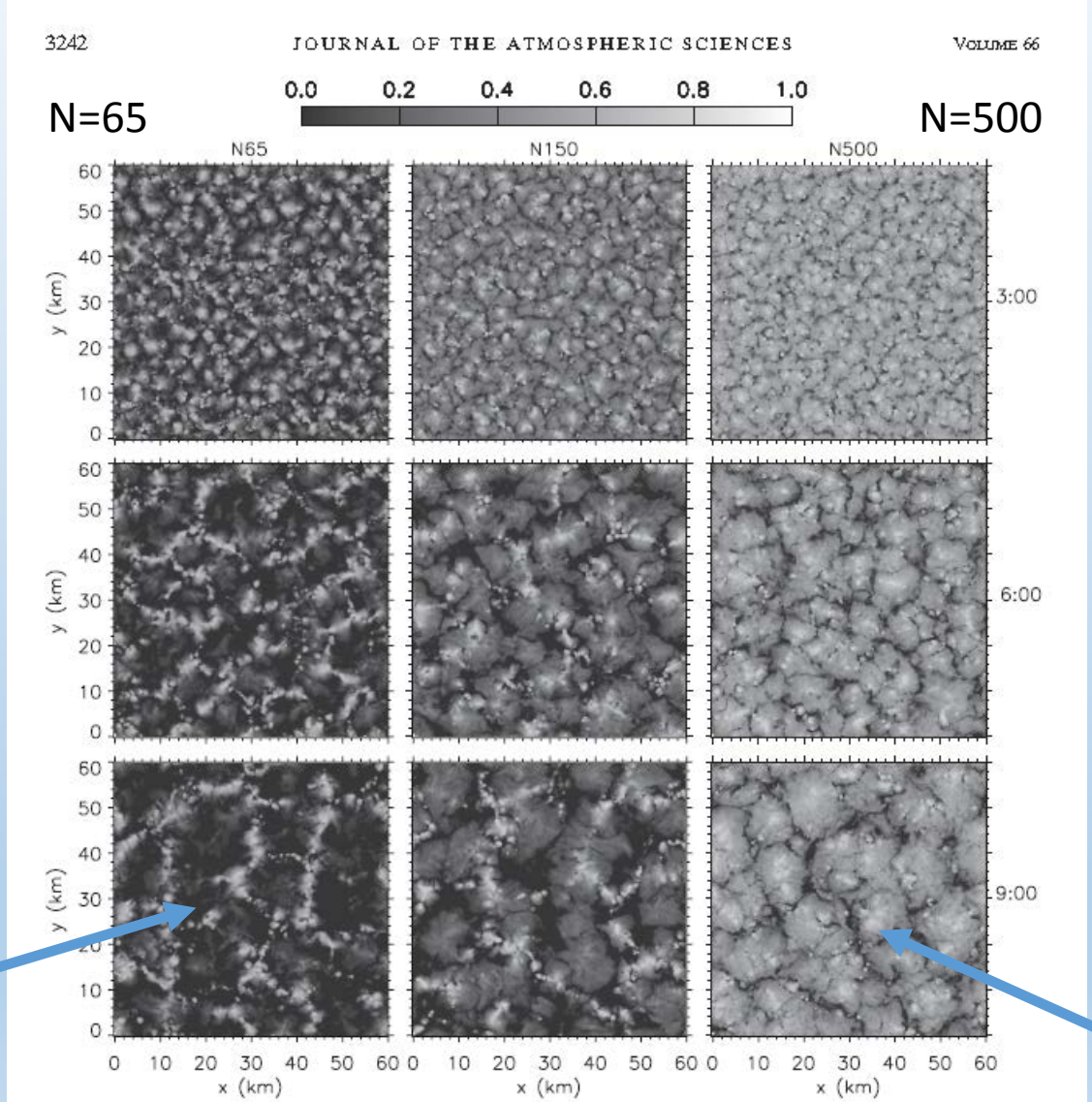


FIG. 2. Snapshots of cloud albedo fields at t = 3, 6, and 9 h (corresponding to each of the three rows) during the life cycle of the stratocumulus deck for experiments N65, N150, and N500 (corresponding to each of the three columns, with initial CCN concentrations of 65, 150, and 500 mg^{-3} respectively).

3 hours

6 hours

9 hours

Open Cell

Closed Cell

Wang and Feingold, 2009, JAS

200 m Vertical Velocity

WRF LES 300 m horizontal, 30 m vertical

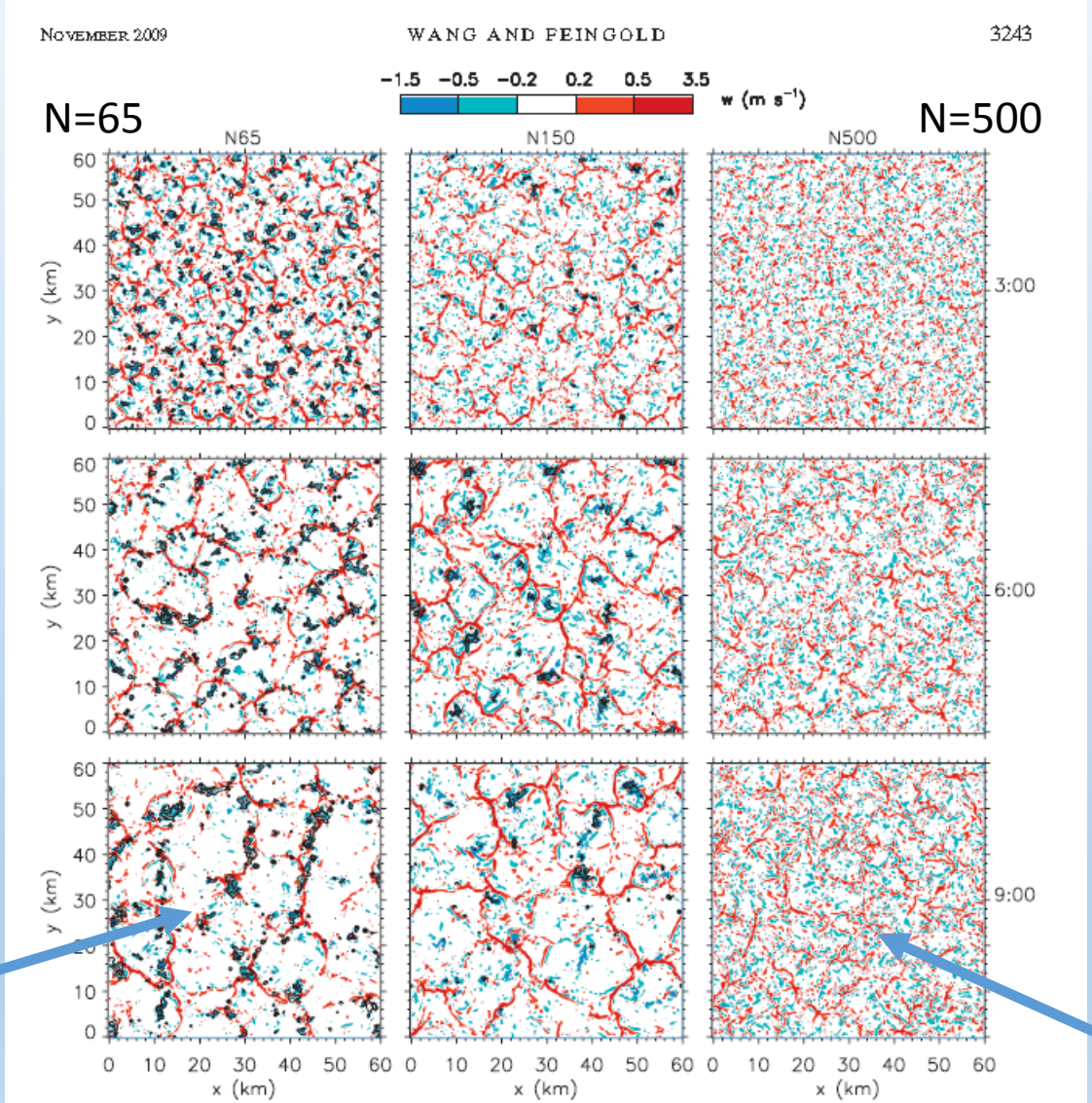


FIG. 3. Snapshots of 200-m level vertical velocity fields at $t = 3$, 6, and 9 h with contours of rain rate (0.5, 5, and 20 mm day^{-2}) superimposed. Plots are arranged in the same way as in Fig. 2.

Dark areas= rainfall rate

Open Cell

Closed Cell

3 hours

6 hours

9 hours

Role in Guiding ASR Warm Low Cloud Science

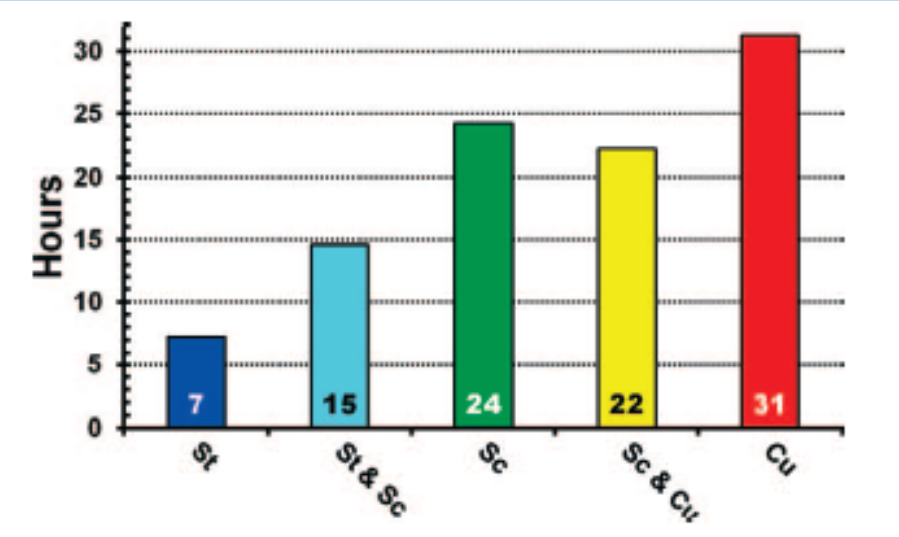
- CAP-MBL Case Studies: stimulate further modeling efforts with the goals of:
  - Comparing structural features of the open and closed cell mesoscale cellular convection
  - Refining LES-observation interface
  - Interpreting idealized LES studies
    - Example: Wang and Feingold, 2009
      - Aerosol at open-closed cell boundary cause gradients in precipitation
      - Circulation promotes precipitation in the polluted closed cells
      - Circulation strength depends on the contrast in precipitation under the clean and polluted conditions at the boundary
  - Stimulating specific LES studies on these cases

RACORO EXTENDED-TERM AIRCRAFT OBSERVATIONS OF BOUNDARY LAYER CLOUDS

BY ANDREW M. VOGELMANN, GREG M. MCFARQUHAR, JOHN A. OGREN, DAVID D. TURNER, JENNIFER M. COMSTOCK, GRAHAM FEINGOLD, CHARLES N. LONG, HAFLIDI H. JONSSON, ANTHONY BUCHOLTZ, DON R. COLLINS, GLENN S. DISKIN, HERMANN GERBER, R. PAUL LAWSON, ROY K. WOODS, ELISABETH ANDREWS, HEE-JUNG YANG, J. CHRISTINE CHIU, DANIEL HARTSOCK, JOHN M. HUBBE, CHAOMEI LO, ALEXANDER MARSHAK, JUSTIN W. MONROE, SALLY A. MCFARLANE, BEAT SCHMID, JASON M. TOMLINSON, AND TAMI TOTO

A campaign involving 260 flight hours over more than 5 months provides the first extended-term aircraft dataset of a wide range of continental boundary layer clouds, and aerosol properties for climate studies.

FIG. 2. RACORO flight hour distributions per objective. Total flight hours are plotted per primary objective: cloud sampling, boundary layer turbulence characterization, aerosol characterization, surface albedo mapping, and radiometer tilt-correction characterization. The ferry time to and from the study site is provided, which also was used to scout the conditions in preparation for the on-site patterns (e.g., determine cloud altitudes, boundary layer height, and wind direction). The primary objective dictated the flight pattern used; however, a given flight pattern could serve the sampling needs of other objectives. At the base of each bar, the time is expressed as a percentage of the total 260 h flown.



Session Goals

- Brief descriptions of CAP-MBL and RACORO studies
- Are warm low cloud observation and modeling efforts sufficiently coordinated across working groups?
- Do we have the necessary tools?
- How do we proceed beyond these case studies? What is the long term plan?

Agenda

10:30-10:45 Mark Miller: Overview of the cases and objectives for the session

10:45-11:00 Xiquan Dong: Short surveys of the characteristics of the ENA cases

11:00-11:15 Andy Vogelmann: Results from RACORO observations

11:15-11:30 Wuyin Lin: Results from RACORO modeling

11:30-12:00 Discussion

Outtakes

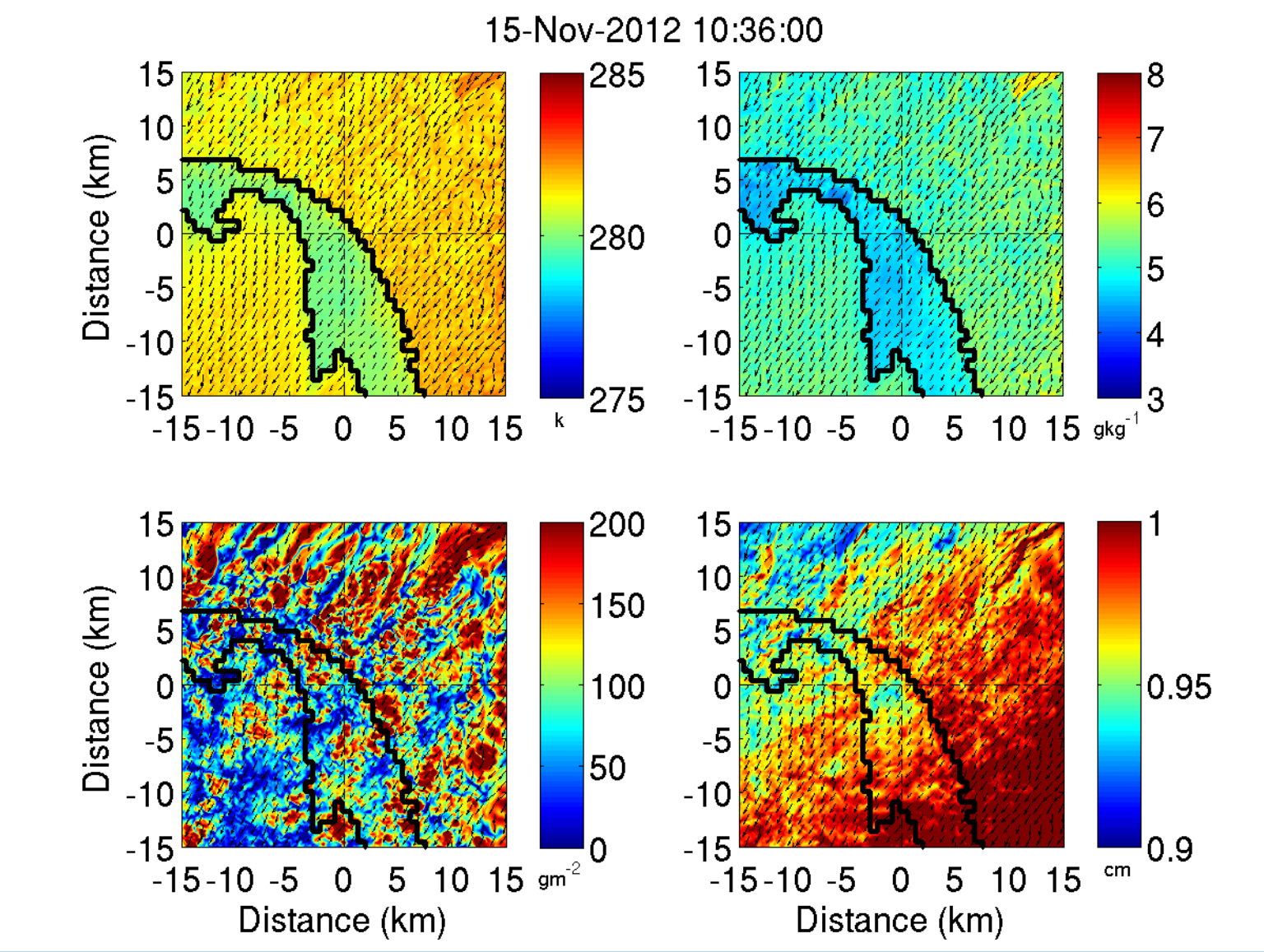
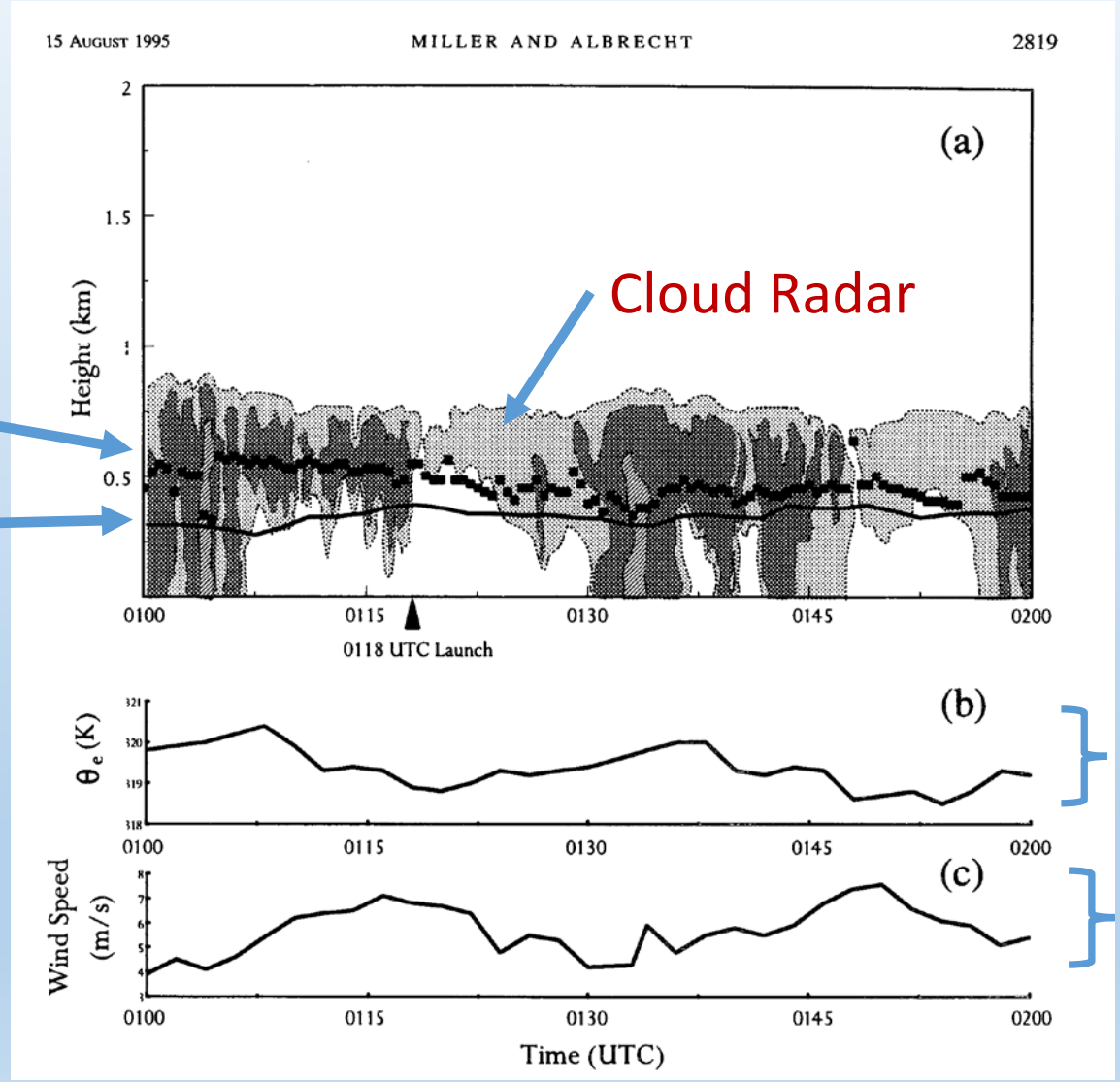


Figure 2. WRF LES simulation of stratocumulus at TCAP AMF#1 site (15 November 2012 at10:36 UTC)

- Observed during ASTEX (Atlantic Stratocumulus Transition Experiment; 1992)

Santa Maria, Azores



Ceilometer

LCL

θ_e

Wind Speed

$\Delta\theta_e$=1-2 K

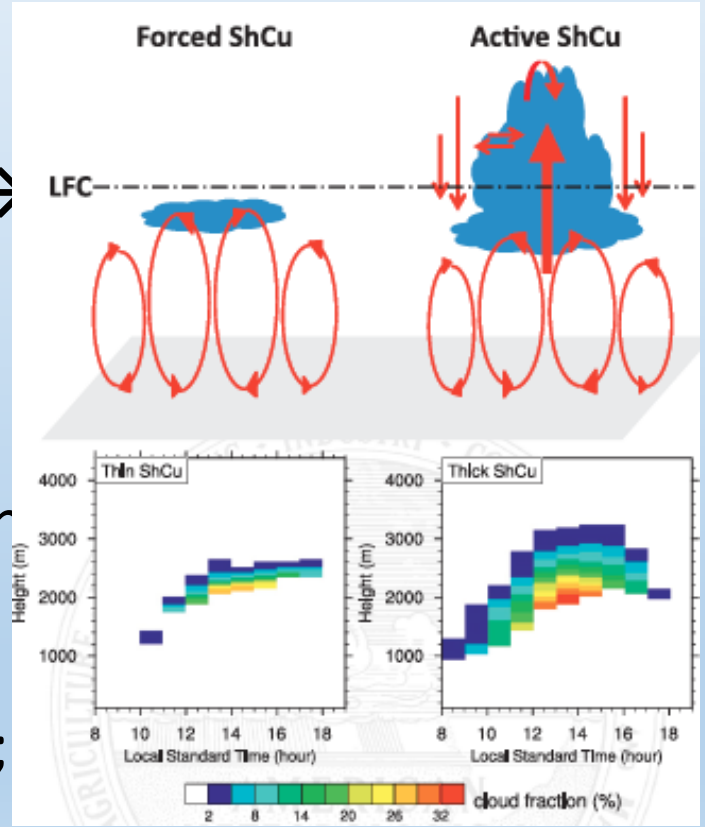
Δu=3 m/s

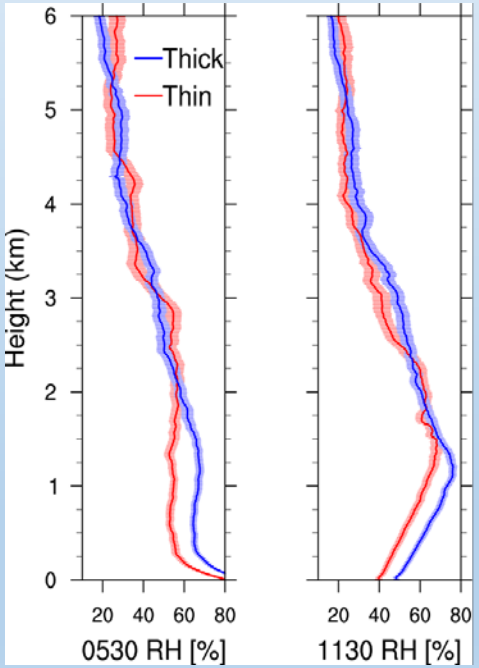
1 Hour

What large-scale controls determine why on some days over land (SGP) there are active cumulus whereas other days do not have only forced cumulus?

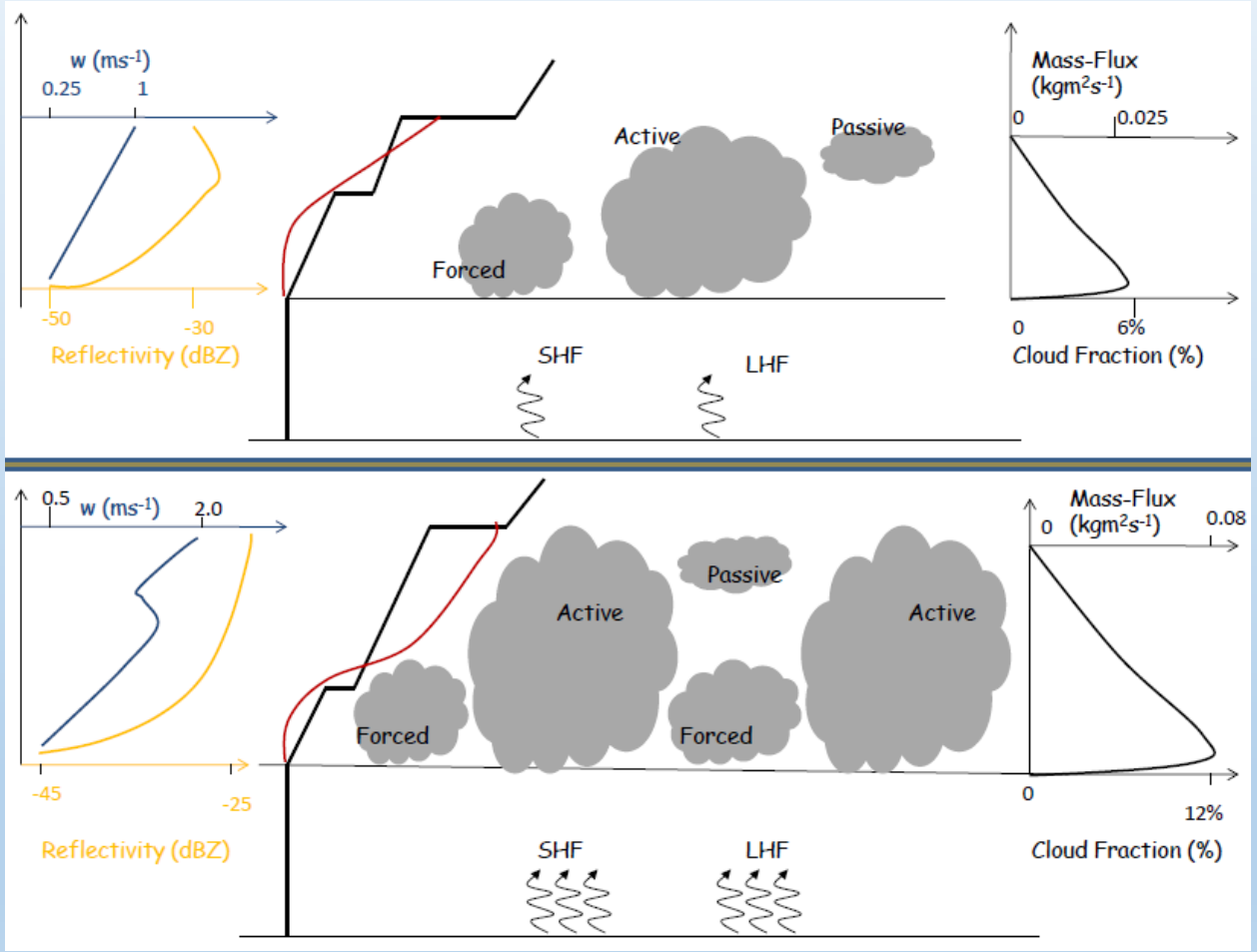
Zhang and Klein, JAS 2013, in press

- Answer: Higher BL Relative humidity at the start of the day. → lower cloud base, → greater in-cloud buoyancy
- Answer: Lower bower ratios and weaker inversions are secondary influences; shear doesn't matter





Based upon composites of SGP observations for 40 days of thin shallow cumulus and 70 days of thick shallow



Fair weather boundary layer structure during low turbulence conditions (top) and high turbulence conditions (bottom)

Ghate and Miller, unpublished

Mesoscale Organization in the Marine Boundary Layer: A Key Scientific Issue

- Hailong Wang and Graham Feingold, 2009: Modeling mesoscale cellular structures and drizzle in marine stratocumulus. part I: impact of drizzle on the formation and evolution of open cells. *J. Atmos. Sci.*,**66**, 3237–3256.
- A new modeling framework is used to investigate aerosol–cloud–precipitation interactions and dynamical feedbacks at the mesoscale. The focus is on simulation of the formation and evolution of cellular structures that are commonly seen in satellite images of marine stratocumulus clouds. Simulations are performed at moderate resolution in a 60 × 60 km^2domain for 16 h to adequately represent the mesoscale organization associated with open cells and precipitation. Results support the emerging understanding that precipitation plays a critical role in the formation and evolution of open cells. Evaporation of raindrops generates a dynamic response that manifests itself in cellular organization of updrafts and downdrafts and promotes and sustains the formation of an open cellular structure in cloud fields. Vertical motion in open-cell centers with thin clouds is minimal. It is shown that a mean surface rain rate as low as 0.02 mm day^{-1} is, for the case considered, sufficient to promote the formation of open cells. The maximum dimension of individual open cells ranges between 5 and 30 km. Individual cells grow at a mean rate of between 5 and 10 km h^{-1}. Irregularity in the shape of open cells is caused by formation of new precipitating regions at the cell walls and interference with neighboring cells, which erode, and eventually eliminate, the old cells. The typical lifetime of large individual open cells is about 2 h, close to that observed by radar, although a collection of open cells as a whole may last for tens of hours.

Mesoscale Organization in the Marine Boundary Layer: A Key Scientific Issue

- Hailong Wang and Graham Feingold, 2009: Modeling mesoscale cellular structures and drizzle in marine stratocumulus. part II: the microphysics and dynamics of the boundary region between open and closed cells. *J. Atmos. Sci.*, **66**, 3257–3275.
- This is the second of two companion papers on modeling of mesoscale cellular structures and drizzle in marinestratocumulus. In the first, aerosol–cloud–precipitation interactions and dynamical feedbacks were investigated to study the formation and evolution of open and closed cellular structures separately. In this paper, coexisting open and closed cells and how they influence one another are examined in a model domain of 180 × 60 × 1.5 km^3. Simulations show that gradients in aerosol at the open–closed-cell boundary cause gradients in precipitation that generate a mesoscalecirculation. The circulation promotes precipitation in the polluted closed cells but suppresses it in open cells by transporting water vapor to the closed-cell regime and carrying drier air and aerosol back to the open cells. The strength of this circulation depends on the contrast in precipitation under clean and polluted conditions at the boundary. Ship plumes emitted into clean, precipitating regions, simulated as a special case of a clean–polluted boundary, develop a similar circulation. Drizzle in the ship track is first suppressed by the increase in aerosol particles but later recovers and becomes even stronger because the local circulation enhances liquid water path owing to the convergence of water vapor from the region adjacent to the track. This circulation modifies the transport and mixing of ship plumes and enhances their dispersal. Finally, results show that whereas ship emissions do increase cloud albedo in regions of open cells, even the addition of very large aerosol concentrations cannot transform an open cellular structure to a closed one, for the case considered.

- **Suppressed environments favorable for low clouds**
  - significant (but not overwhelming) subsidence ($1 \rightarrow 3\ \mu bar\ s^{-1}$)
  - adequate BL water vapor
  - source of BL TKE
  - saturation beneath inversion
  - shallow clouds dominate regardless of time of day

- **Cloud systems**
  - eastern ocean stratocumulus
  - northern ocean and Arctic stratus
  - wintertime continental stratocumulus
  - continental forced cumulus
  - subtropical ocean trade cumulus

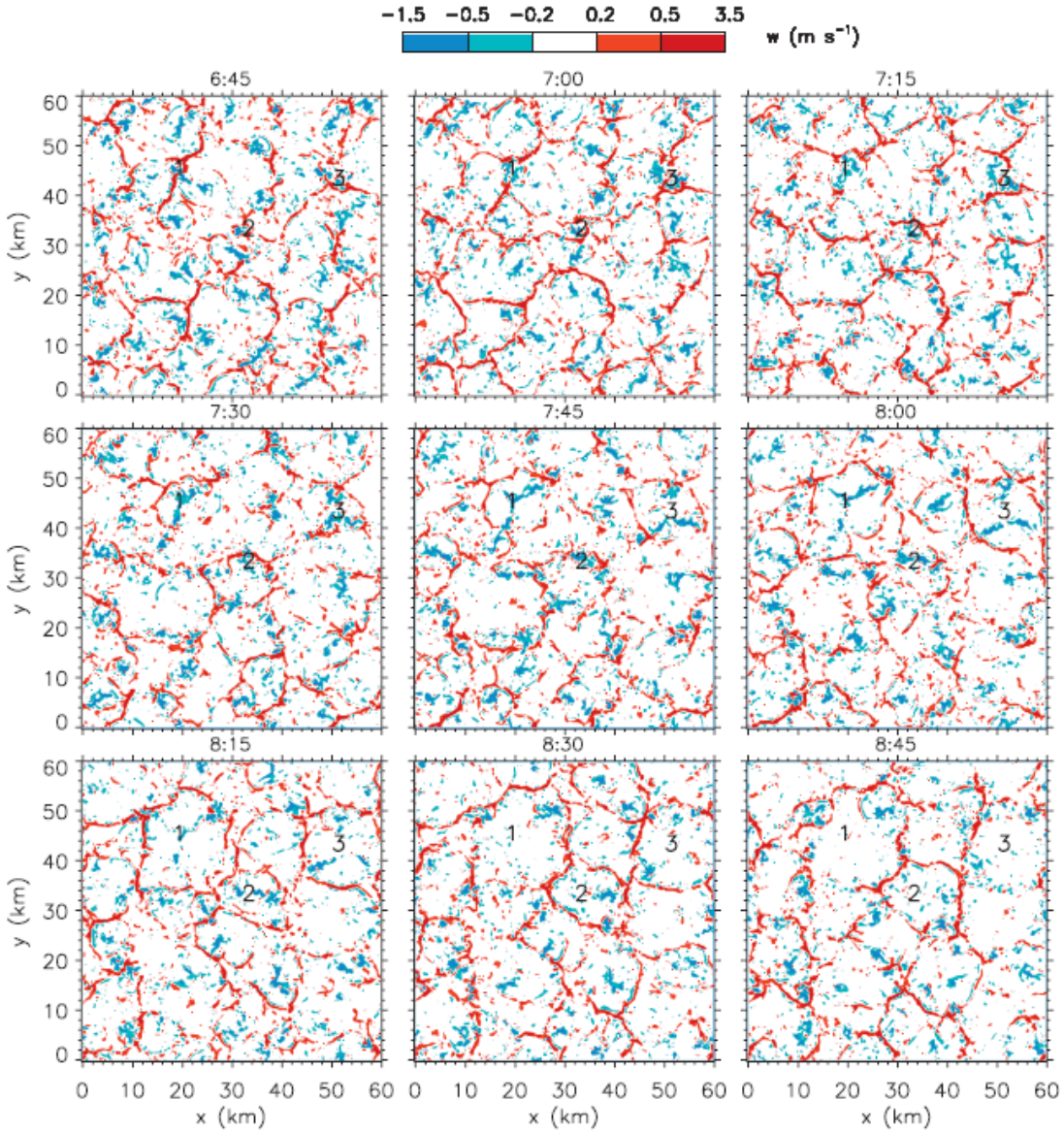


FIG. 8. Snapshots of 200-m-level vertical velocity fields over a 2-h period for experiment N65. Time since model start is indicated above each panel. Three individual updraft cells are labeled 1, 2, and 3 to track their evolution with time.

Cloud Lifecycle Working Group

Warm Low Cloud Science Thematic Group

Fall 2014

ASR Working Group Meeting

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Case Studies

- Tend to galvanize the observation and modeling communities
- Facilitate collaboration between CLWG and CAPI low cloud groups
- High quality warm low cloud data sets from CAP-MBL (marine boundary layer) and RACORO (continental boundary layer)
- We have new experimental capabilities at SGP and at the new Eastern North Atlantic Site
  - Cases may suggest new ways to configure our measurements