Marine Low Clouds Workshop

27-29 January 2016, Brookhaven National Laboratory

Organizers

Jian Wang and Mike Jensen, Brookhaven National Laboratory

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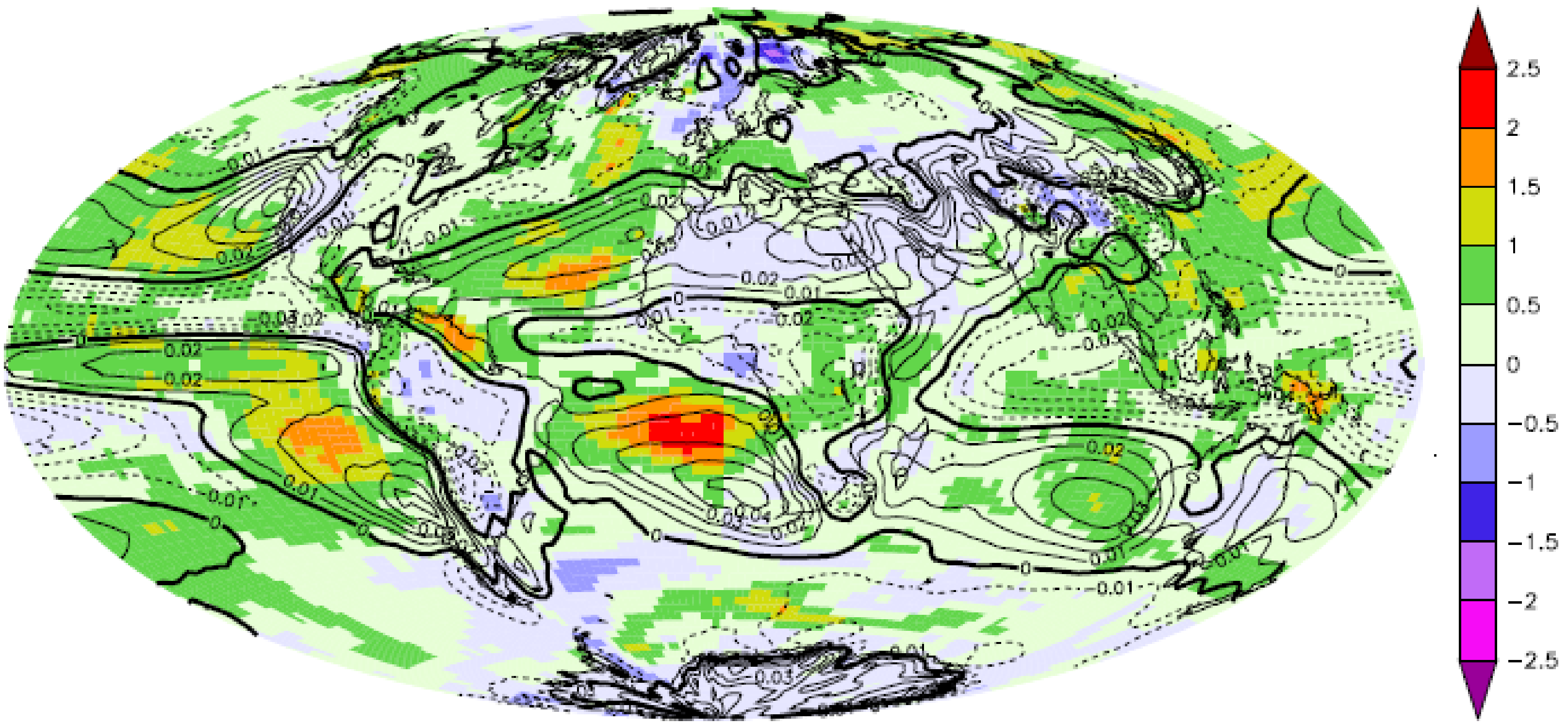
Participants

Robert Wood, Michael P. Jensen, Jian Wang, Christopher S. Bretherton, Susannah M. Burrows, Anthony D. Del Genio, Ann M. Fridlind, Steven J. Ghan, Virendra P. Ghate, Pavlos Kollias, Steven K. Krueger, Robert L. McGraw, Mark A. Miller, David Painemal, Lynn M. Russell, Sandra E. Yuter, and Paquita Zuidema

ARM/ASR Meeting, March 2017, Washington DC

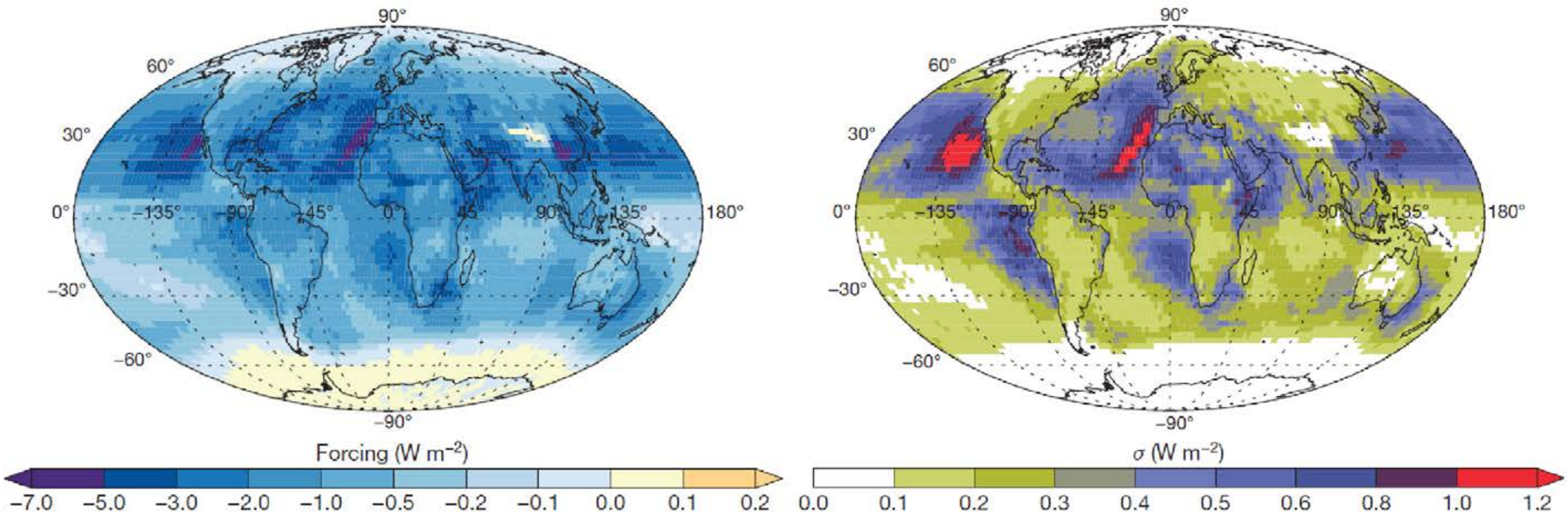
Clouds in subsiding regions of the subtropics/tropics explain intermodel spread in global cloud feedback



Shade: regression local to mean cloud feedback (local per mean)
Contour: mean ω500

Figure courtesy Gabriel Vecchi, data from Soden and Vecchi (*Geophys. Res. Lett.*, 2011)

MBL clouds likely responsible for much of the global aerosol indirect forcing



LEFT: Annual mean aerosol first indirect forcing; RIGHT: uncertainty in simulated first indirect forcing due to uncertainty in model (GLOMAP) parameters. Note the large aerosol indirect forcing and uncertainty in regions of persistent low clouds. Adapted from Carslaw et al. (2013)

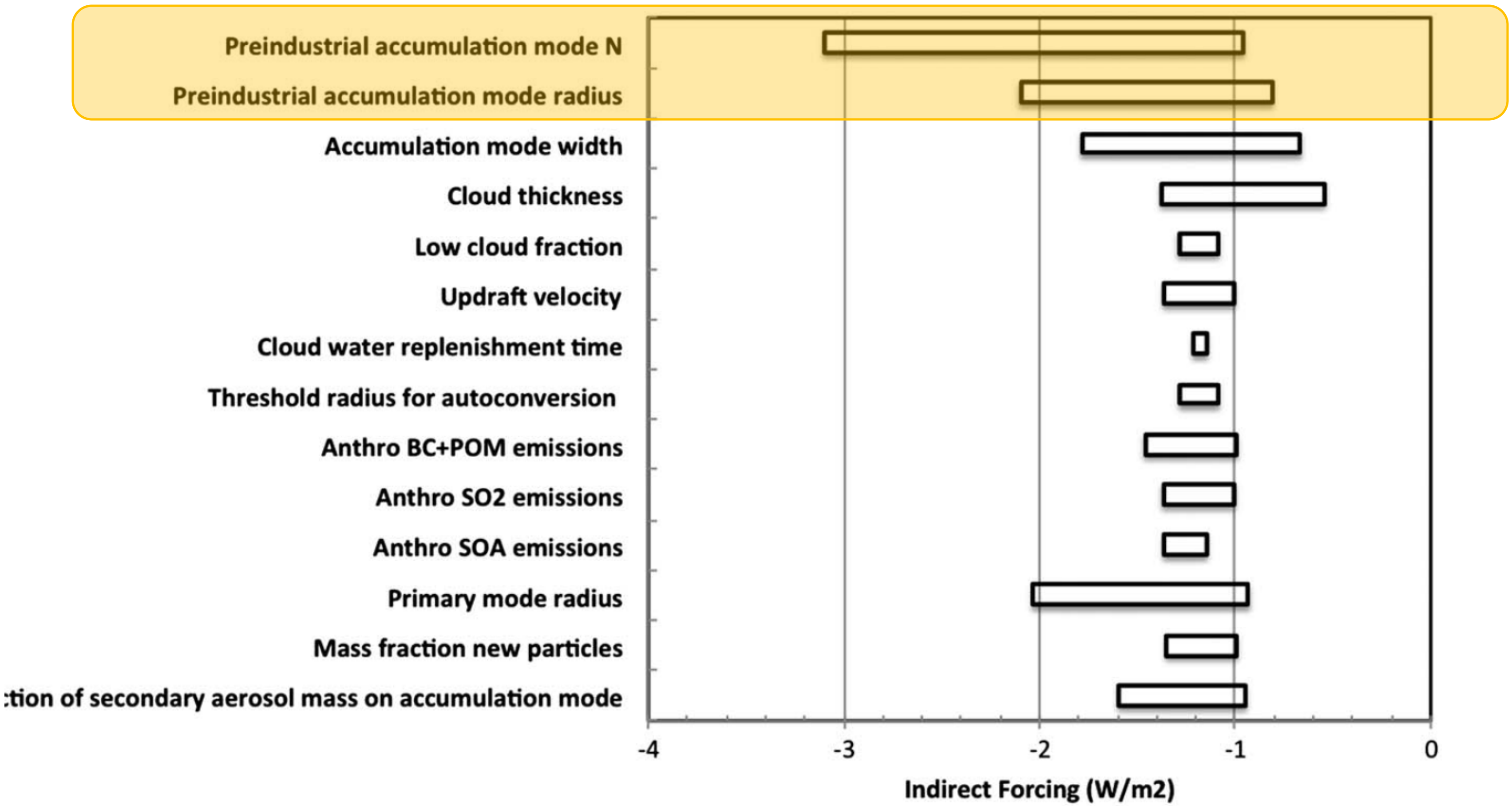
Four theme areas

- Aerosol Indirect Effect and CCN Budget
- Precipitation
- Entrainment
- Mesoscale Organization

Aerosol Indirect Effect and CCN Budget

- Importance of cloud droplet concentration (N_d) for mediating aerosol impacts on clouds
  - Twomey effect, $[d\ln\alpha/d\log N_d]_{LWP}$
  - Precipitation susceptibility, $S = -[d\ln R/d\log N_d]_{LWP}$
- Quantification of aerosol indirect effects necessitates improved understanding of aerosol and cloud properties under pristine conditions.
  - Sensitivity of cloud albedo to increases in CCN is most acute under low CCN conditions
  - Models not well tested under pristine conditions
  - Need focus on drivers of N_d "background". Source (surface and free troposphere) and sink (precipitation) quantification needed.

What factors control the magnitude and uncertainty of the global AIE?



Ghan et al. (*J.Geophys. Res.*, 2013)

…..also Carslaw et al. (Nature, 2013)

CCN Sources in the remote marine PBL

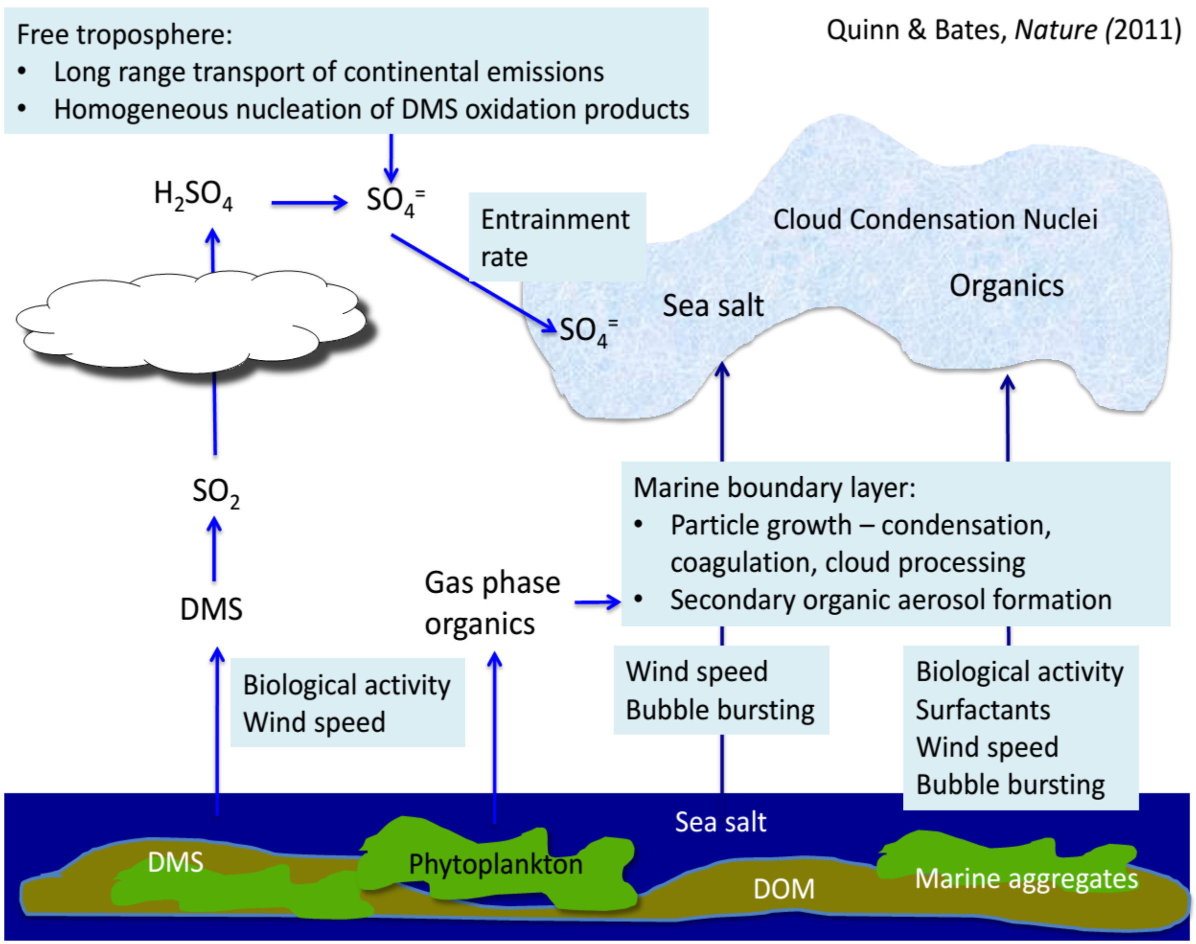


Figure 1: *Major sources of boundary layer CCN in a remote marine environment. Courtesy of Patricia Quinn.*

Precipitation

- Active remote sensing playing critical role in quantifying precipitation in marine low clouds
  - Precipitation evaporation important
  - Drizzle initiation: bridging the gap between cloud droplets and raindrops can be investigated using new combinations of remote sensors (e.g., high resolution Doppler radar and lidar)
  - New retrievals to characterize relationships between cloud and precipitation as a function of cloud dynamics
- Effects of precipitation on marine low clouds
  - Mechanisms by which precipitation impacts transitions from high to low cloud cover need exploration
  - Large-domain LES can be used to examine impacts of precipitation on mesoscale cloud structure

Precipitation susceptibility in marine low clouds from ground based remote sensing, aircraft and LES

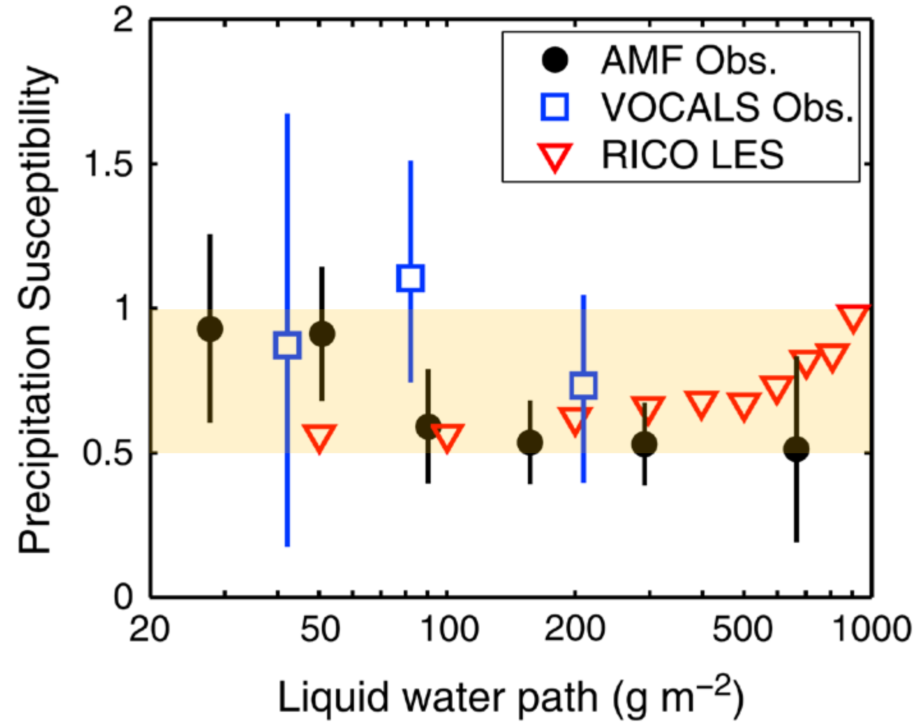


Figure 4. Precipitation susceptibility with respect to CCN number concentration as a function of liquid water path in AMF observations from this study and to cloud droplet number concentration in VOCALS observations averaged over a 5 km length scale (squares) [*Terai et al.*, 2012, Figure 7] and large-eddy simulations (LES, triangles; adapted from *Sorooshian et al.* [2009]) of precipitating cumulus initialized using soundings from the Rain in Cumulus over the Ocean (RICO) field campaign [*Rauber et al.*, 2007]. Error bars in AMF data represent 95% confidence intervals, which take into account the errors associated with R_{cb} in Figure 2.

Mann, J. A. L., J. C. Chiu, R. J. Hogan, E. J. O'Connor, T. S. L'Ecuyer, T. H. M. Stein, and A. Jefferson, 2014: Aerosol Impacts on Drizzle Properties in Warm Clouds from ARM Mobile Facility Maritime and Continental Deployments. *J. Geophys. Res.* 119, 2013JD021339.

Entrainment

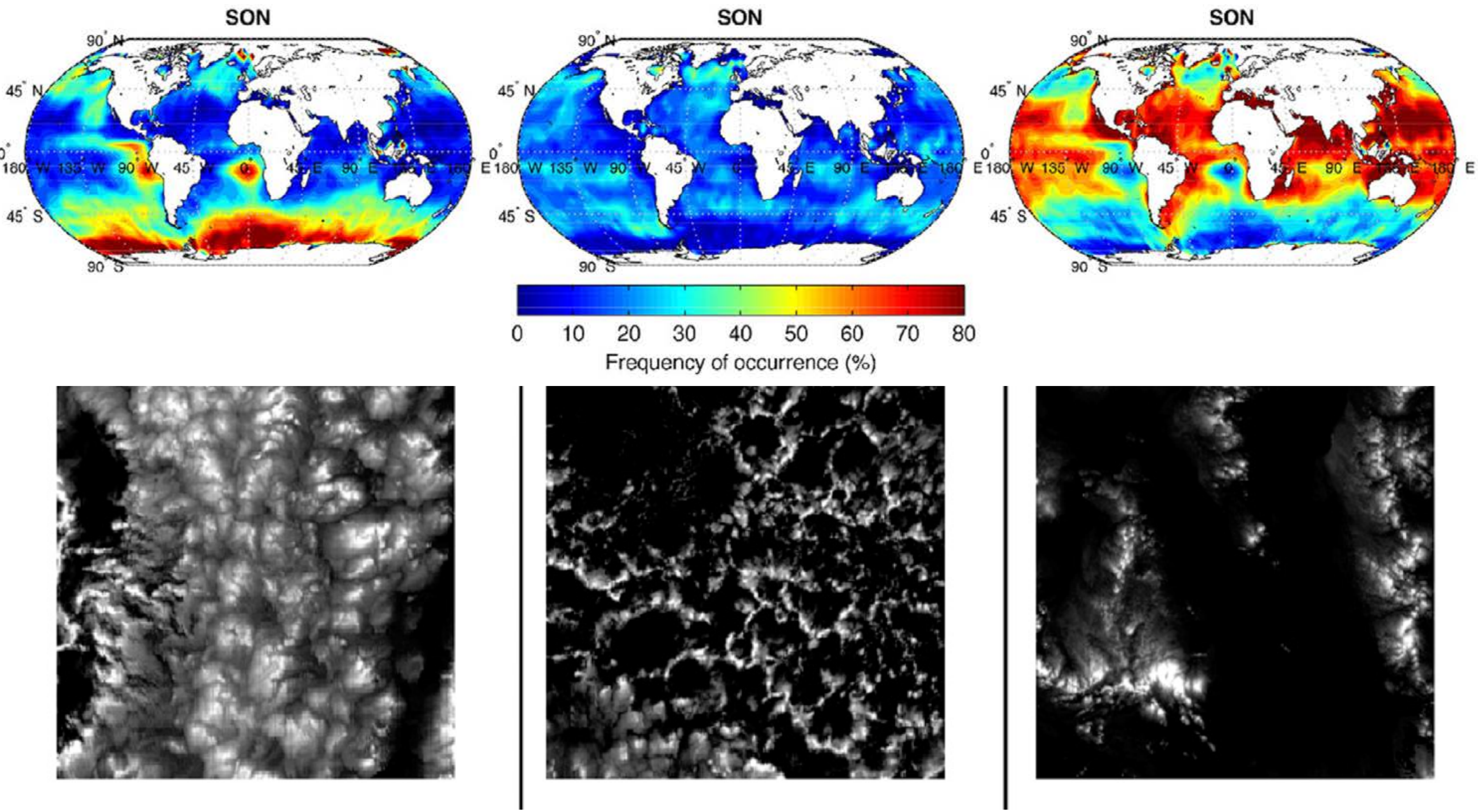
- Relating cloud top and lateral entrainment to vertical and horizontal structure of turbulence in cloudy boundary layers
  - Need to test and refine entrainment closures
  - New remote sensing and in situ aircraft approaches for quantifying fine scale turbulent motions and eddy dissipation rates are being developed
- Impacts of entrainment
  - Entrainment a key process driving PBL and resulting in macroscale cloudiness transitions
  - Effects of entrainment on cloud microphysical processes, and feedback on small scale eddies and turbulence poorly characterized

Mesoscale Organization

- Marine low cloud fields tend to organize on scales of 5-100 km into *mesoscale cellular convection* (MCC)
  - Organizes/concentrates the diabatic forcings on the PBL (e.g., longwave cooling, precipitation)
  - Unaccounted for in climate model parameterizations despite dominance.
- Impacts of mesoscale organization
  - Organized precipitation drives cold pools but unclear if these are essential for cloud breakup
  - Mesoscale organization appears to be strongly correlated with PBL aerosols (e.g., contrasts between closed and open cells) but causality is poorly understood. Open MCC may regulate its own aerosol environment, with resulting questions about possible sensitivity to external aerosol perturbations

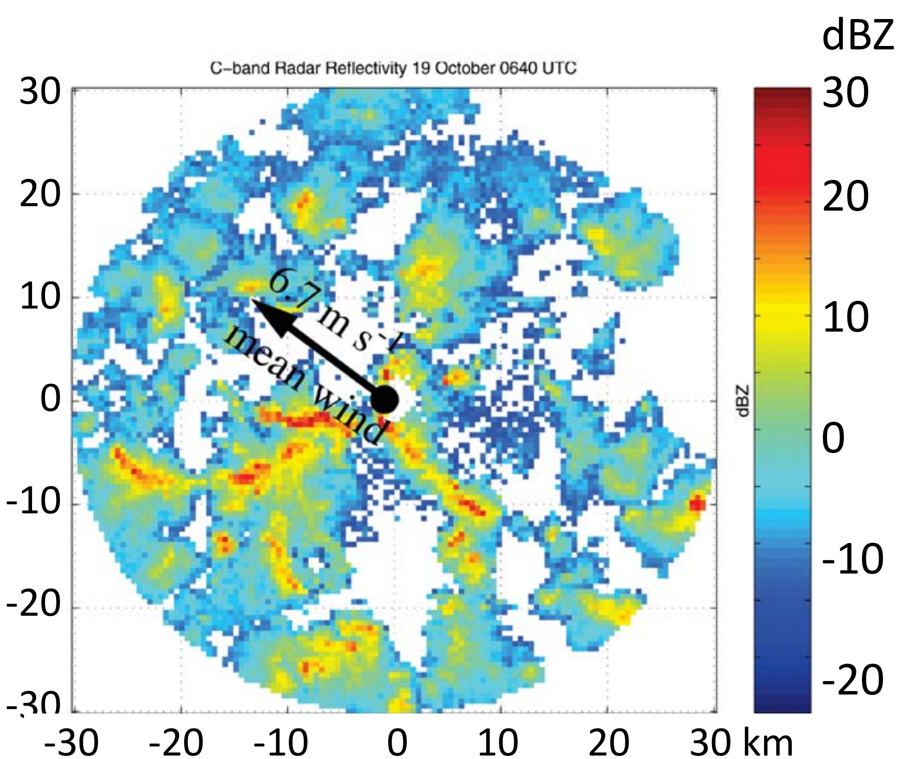
Climatology: mesoscale morphology

CLOSED CELLS | **OPEN CELLS** | **DISORGANIZED CELLS**

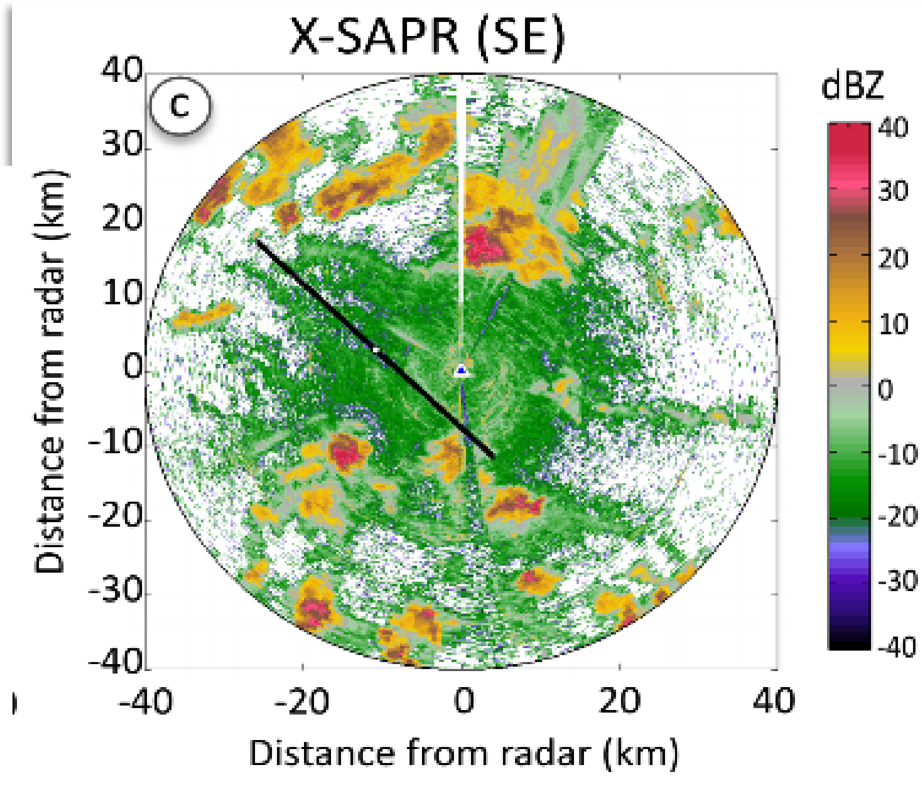


Muhlbauer et al. (ACP, 2014)

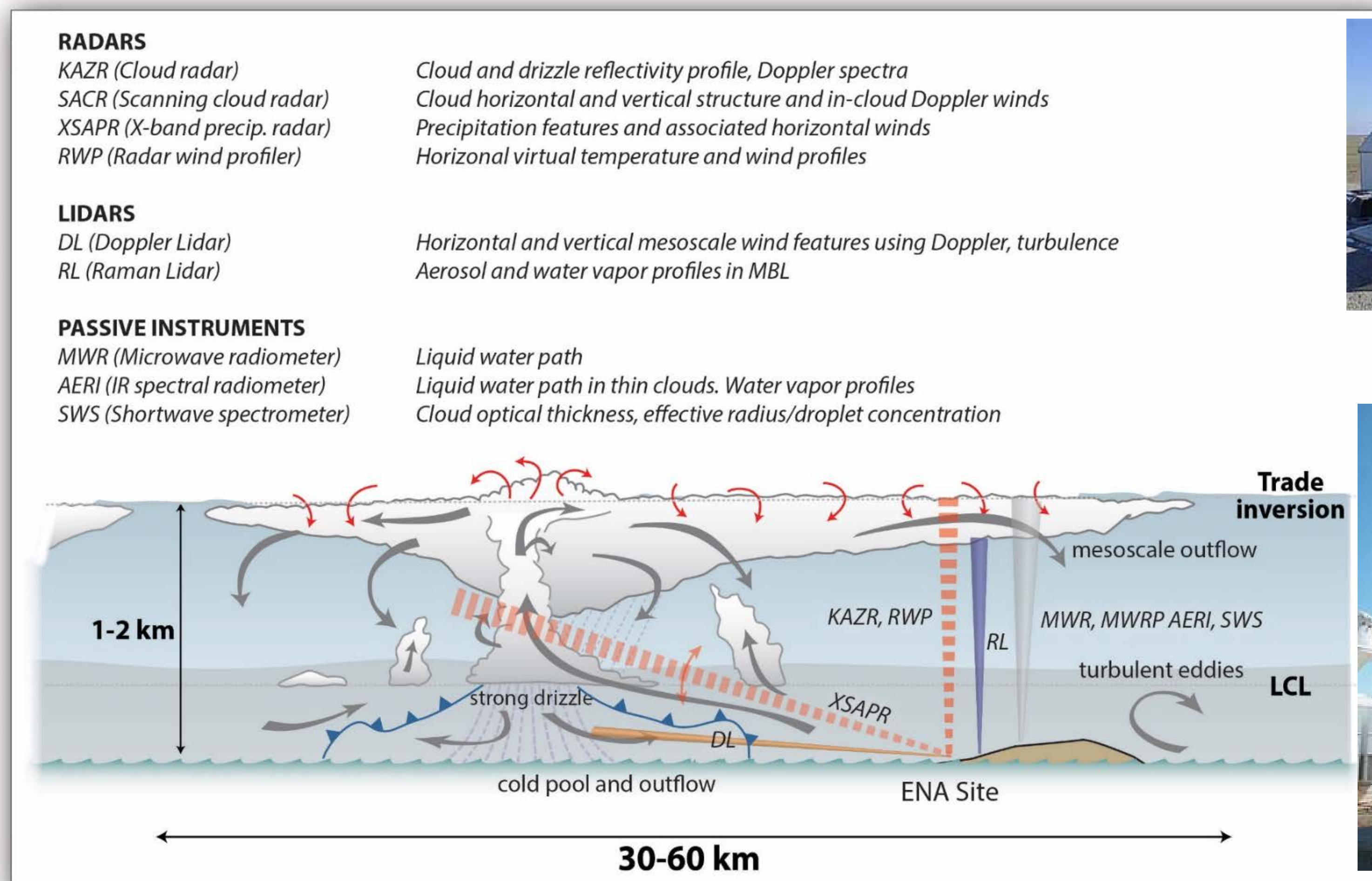
New observations to quantify precipitation and mesoscale organization



C-band of mesoscale cells from SE Pacific
Bretherton et al. (2004)



Surface-based approaches for probing mesoscale organization



Raman lidar

KaW SACR

Planning the next decade of coordinated research to better understand and simulate marine low clouds. Robert Wood, Michael P. Jensen, Jian Wang, Christopher S. Bretherton, Susannah M. Burrows, Anthony D. Del Genio, Ann M. Fridlind, Steven J. Ghan, Virendra P. Ghate, Pavlos Kollias, Steven K. Krueger, Robert L. McGraw, Mark A. Miller, David Painemal, Lynn M. Russell, Sandra E. Yuter, and Paquita Zuidema. *Bull. Amer. Meteor. Soc.,* 97, 1699–1702, doi: 10.1175/BAMS-D-16-0160.1.

PLANNING THE NEXT DECADE OF COORDINATED RESEARCH TO BETTER UNDERSTAND AND SIMULATE MARINE LOW CLOUDS

BY ROBERT WOOD, MICHAEL P. JENSEN, JIAN WANG, CHRISTOPHER S. BRETHERTON, SUSANNAH M. BURROWS, ANTHONY D. DEL GENIO, ANN M. FRIDLIND, STEVEN J. GHAN, VIRENDRA P. GHATE, PAVLOS KOLLIAS, STEVEN K. KRUEGER, ROBERT L. MCGRAW, MARK A. MILLER, DAVID PAINEMAL, LYNN M. RUSSELL, SANDRA E. YUTER, AND PAQUITA ZUIDEMA

Marine Low Clouds Workshop Report, United States Department of Energy Atmospheric System Research Report. Jensen, M., J. Wang, and R. Wood, 2016: DOE/SC-ASR-16-001, June 2016, 13pp.