Dynamics and Thermodynamics of Convection
Shallow Convection

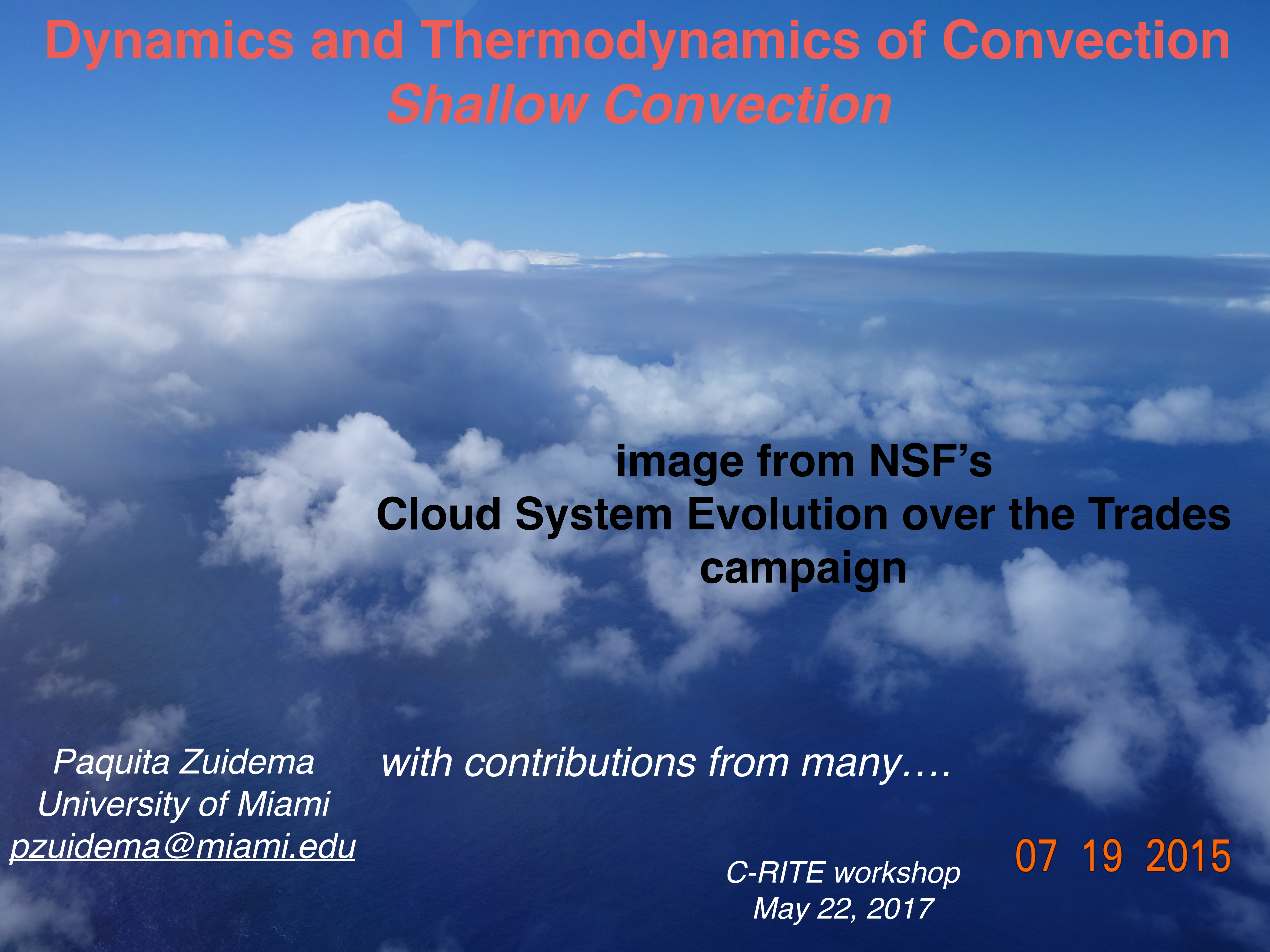


image from NSF's Cloud System Evolution over the Trades campaign

with contributions from many….

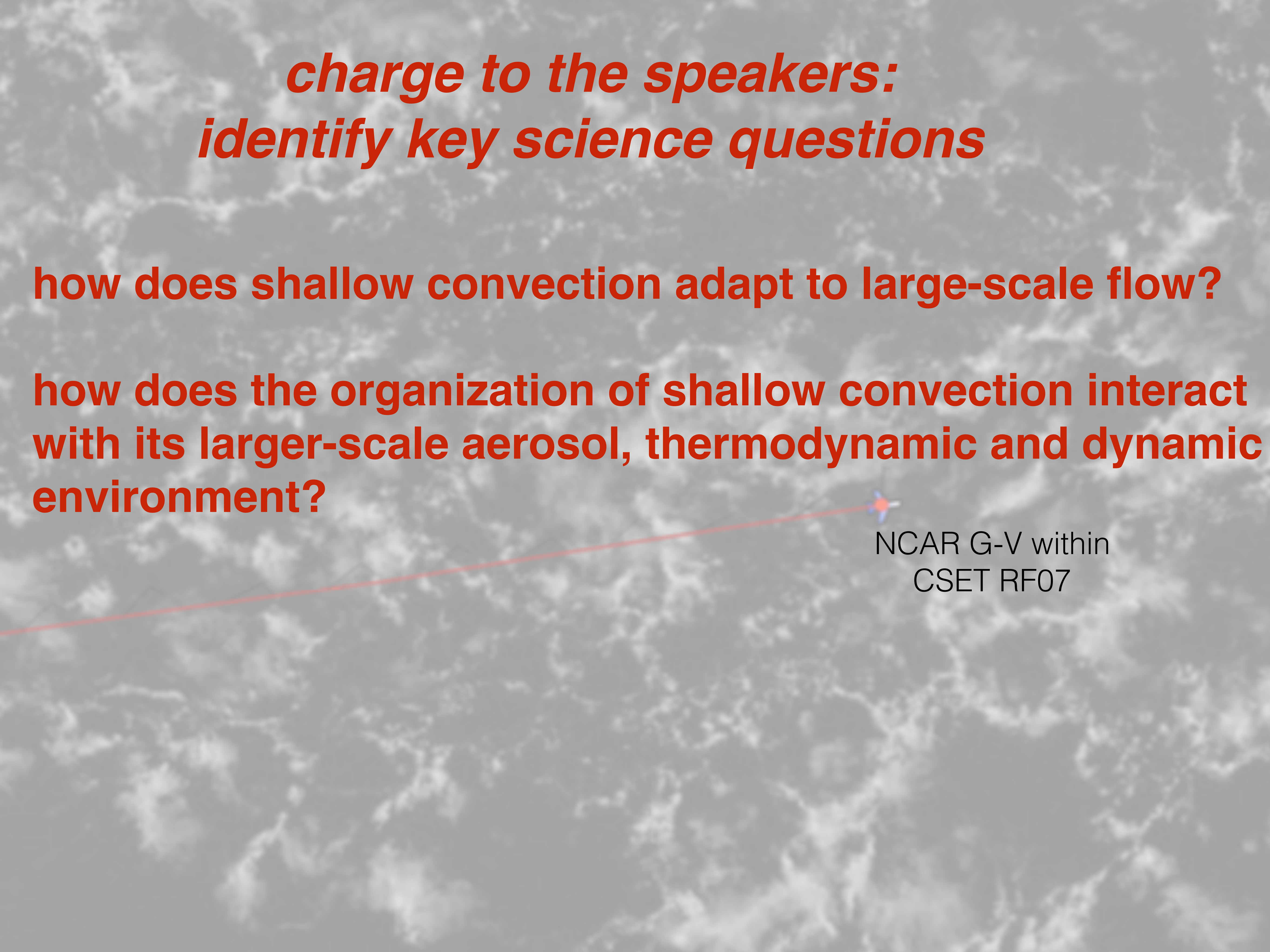
Paquita Zuidema
University of Miami
pzuidema@miami.edu

C-RITE workshop
May 22, 2017

charge to the speakers: identify key science questions

how does shallow convection adapt to large-scale flow?

how does the organization of shallow convection interact with its larger-scale aerosol, thermodynamic and dynamic environment?



more concrete applications (all oceanic):

shallow cloud mesoscale organization:

- what is the role of mesoscale organization (cold pools) in shallow-to-deep convection transition?
- what is the relationship of shallow cloud convection to cloud fraction?

evolution of boundary-layer flow into the ITCZ

- how does the low cloud population evolve within the large-scale flow?
- how do the low cloud micro & macrophysics adapt to the aerosol and moisture environment?

high-latitude mixed-phase clouds

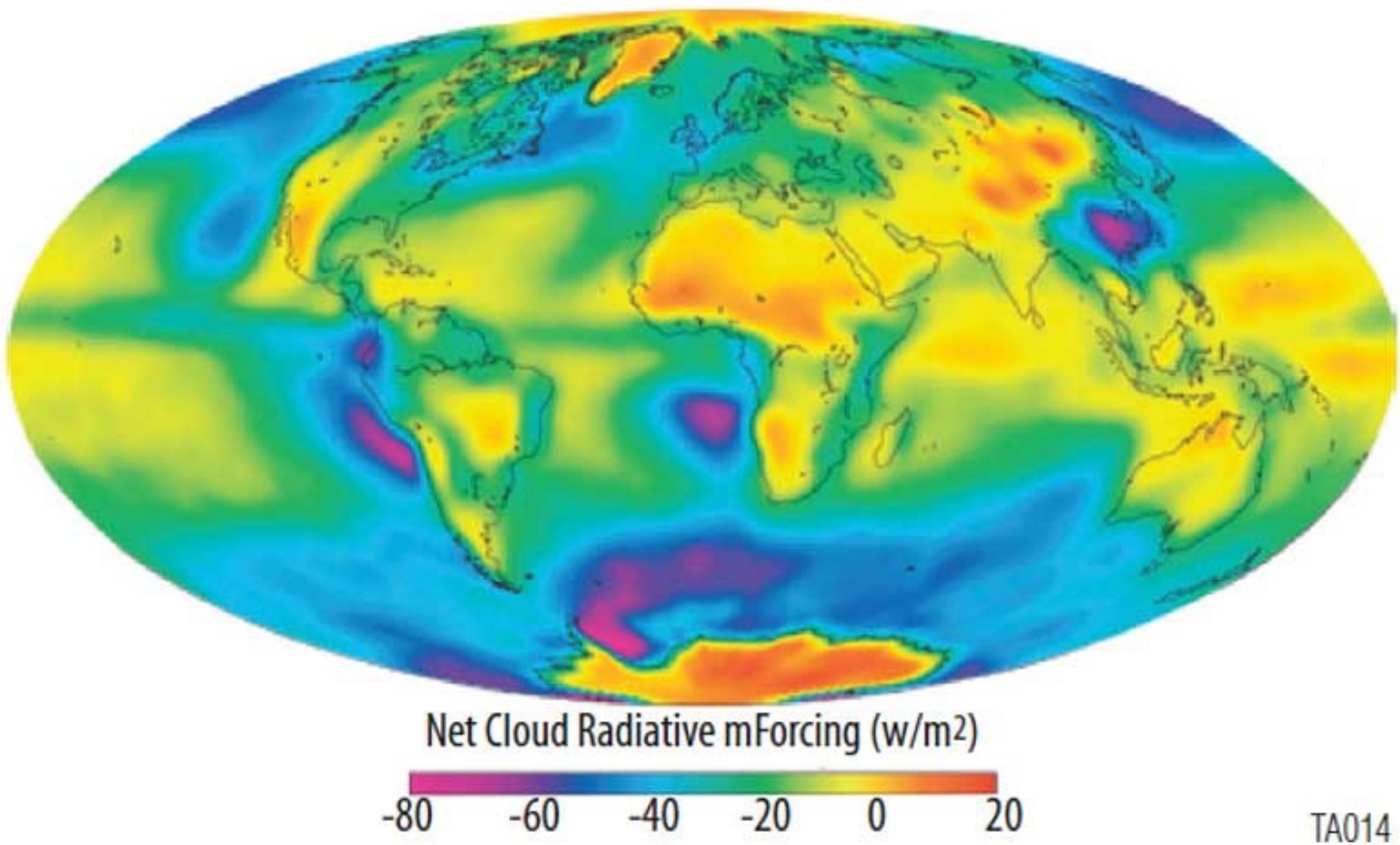
- how do boundary layer clouds interact with changing surface conditions?

answering all these questions requires complementary model simulations. Are we able to constrain them sufficiently?

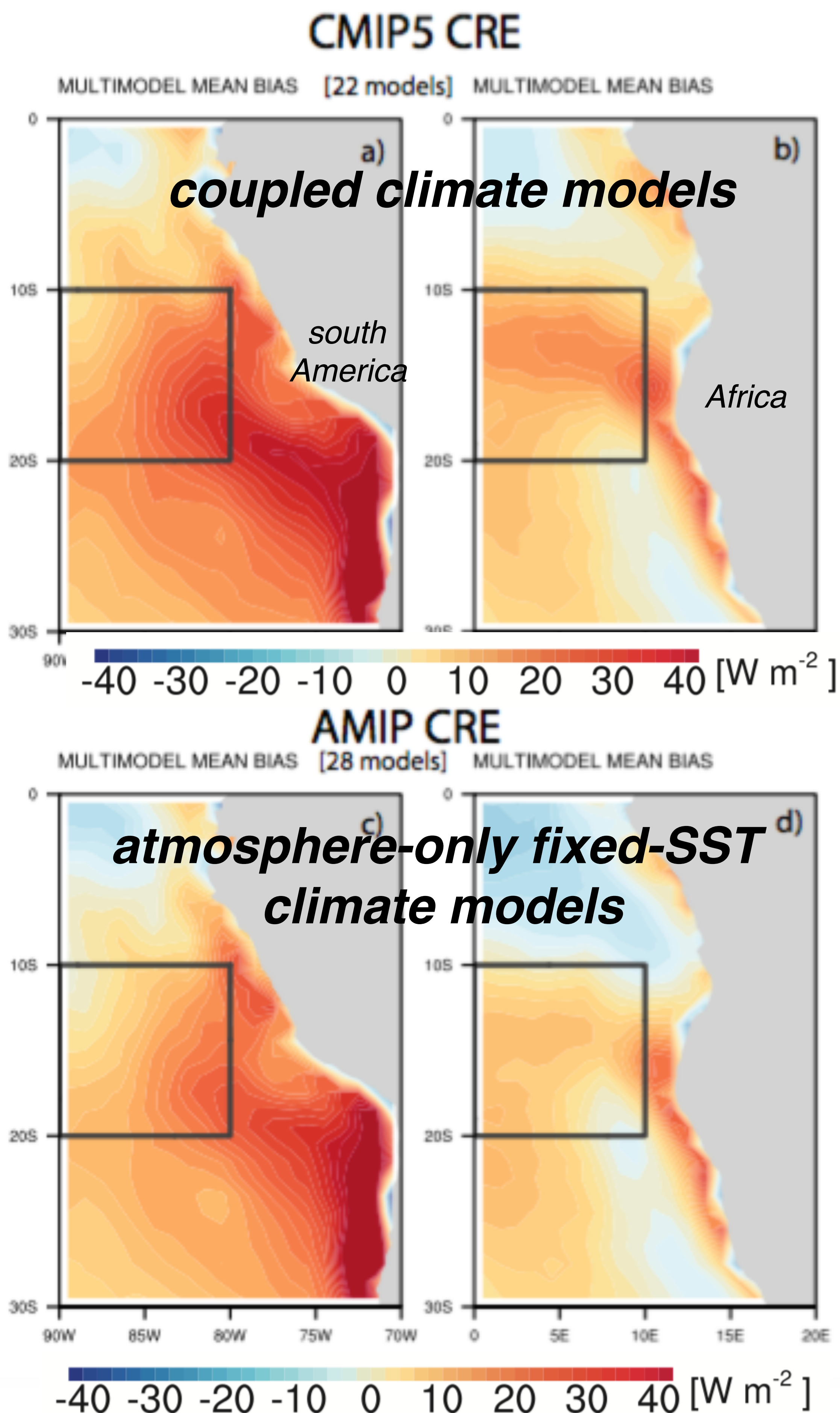
why are these questions important?

distribution of global albedo and how it is evolving with time critically linked to shallow clouds

annual-mean cloud radiative forcing, CERES website



why are these questions important?



our main tool for linking low clouds to changes in the global environment, coupled climate models, struggle with depicting low clouds

figures show a similar bias of up to -40 W m-2 in the cloud radiative effect calculated within both ocean-atmosphere and atmosphere-only climate models. This implies climate model difficulty in capturing low clouds lies in the atmospheric modeling

figure by Brian Medeiros, from Zuidema et al. 2016, BAMS (Dec).

process modeling bridges the gap

- *best if confirmed by observations on a complementary scale*

CGILS=CFMIP/GASS inter comparison of Large eddy and Single column models

RESEARCH ARTICLE
10.1002/2016MS000765

CGILS Phase 2 LES intercomparison of response of subtropical marine low cloud regimes to CO_2 quadrupling and a CMIP3 composite forcing change

Peter N. Blossey[1], Christopher S. Bretherton[1], Anning Cheng[2,3], Satoshi Endo[4], Thijs Heus[5], Adrian P. Lock[6], and Johan J. van der Dussen[7]

[1]Department of Atmospheric Sciences, University of Washington, Seattle, Washington, USA, [2]Science Systems and Applications, Inc., Hampton, Virginia, USA, [3]Climate Science Branch, NASA Langley Research Center, Hampton, Virginia, USA, [4]Brookhaven National Laboratory, Upton, New York, USA, [5]Department of Physics, Cleveland State University, Cleveland, Ohio, USA, [6]Met Office, Exeter, United Kingdom, [7]Delft University of Technology, Delft, The Netherlands

Key Points:
- LES intercomparison: more CO_2 lowers, thins marine subtropical low cloud.
- CMIP3 composite climate change forcing also reduces low cloud in all LESs.
- Cloud responses consistent across stratocumulus and shallow cumulus regimes.

Correspondence to:
P. N. Blossey,
pblossey@uw.edu

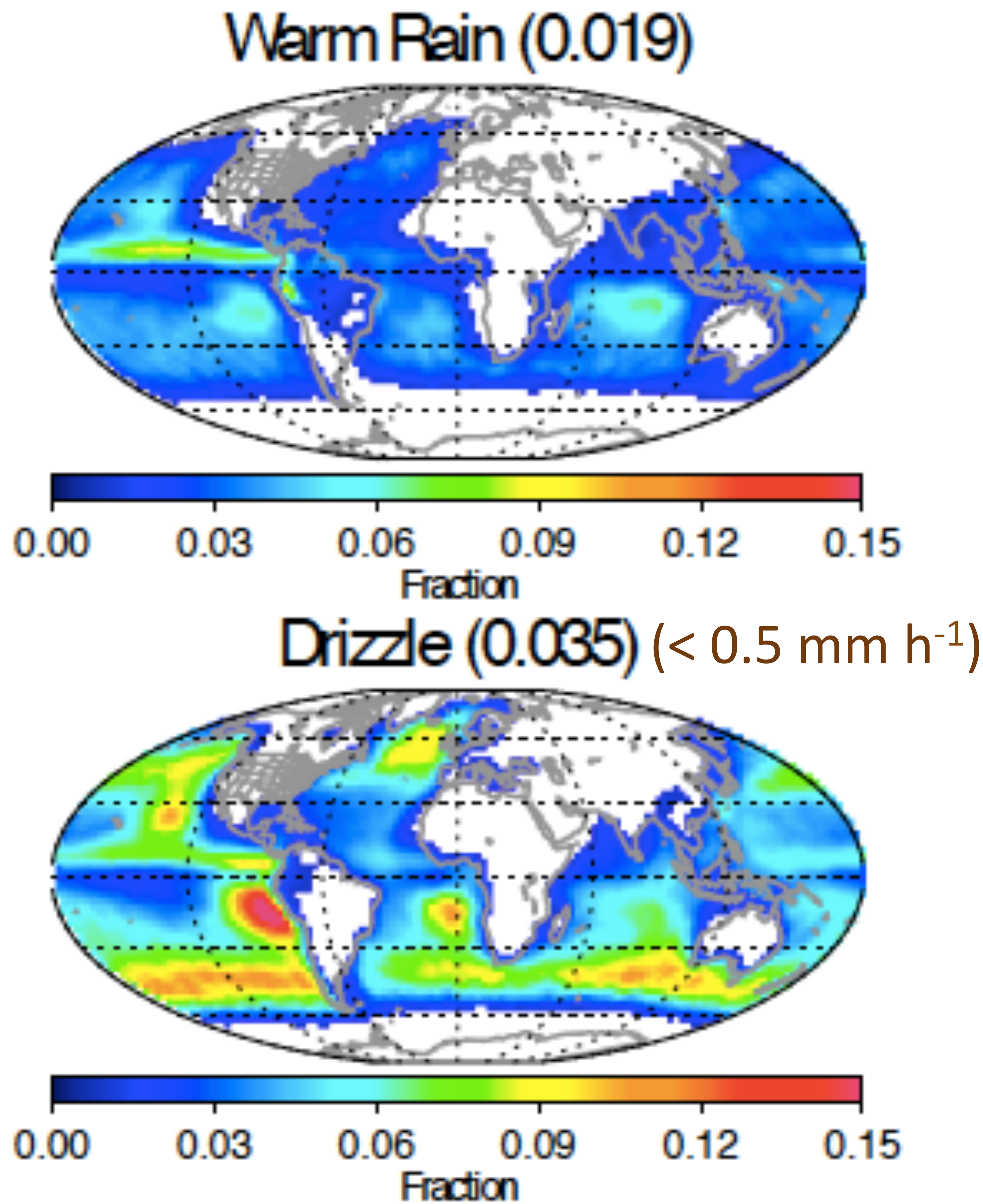
Citation:
Blossey, P. N., C. S. Bretherton, A. Cheng, S. Endo, T. Heus, A. P. Lock, and J. J. van der Dussen (2016), CGILS Phase 2 LES intercomparison of response of subtropical marine low cloud regimes to CO_2 quadrupling and a CMIP3 composite forcing change, *J. Adv. Model. Earth Syst.*, *8*, 1714–1726, doi:10.1002/2016MS000765.

Received 22 JUL 2016
Accepted 2 OCT 2016
Accepted article online 6 OCT 2016
Published online 27 OCT 2016

Abstract Phase 1 of the CGILS large-eddy simulation (LES) intercomparison is extended to understand if subtropical marine boundary-layer clouds respond to idealized climate perturbations consistently in six LES models. Here the responses to quadrupled carbon dioxide ("fast adjustment") and to a composite climate perturbation representative of CMIP3 multimodel mean $2\times CO_2$ near-equilibrium conditions are analyzed. As in Phase 1, the LES is run to equilibrium using specified steady summertime forcings representative of three locations in the Northeast Pacific Ocean in shallow well-mixed stratocumulus, decoupled stratocumulus, and shallow cumulus cloud regimes. The results are generally consistent with a single-LES study of Bretherton et al. (2013) on which this intercomparison was based. Both quadrupled CO_2 and the composite climate perturbation result in less cloud and a shallower boundary layer for all models in well-mixed stratocumulus and for all but a single LES in decoupled stratocumulus and shallow cumulus, corroborating similar findings from global climate models (GCMs). For both perturbations, the amount of cloud reduction varies across the models, but there is less intermodel scatter than in GCMs. The cloud radiative effect changes are much larger in the stratocumulus-capped regimes than in the shallow cumulus regime, for which precipitation buffering may damp the cloud response. In the decoupled stratocumulus and cumulus regimes, both the CO_2 increase and CMIP3 perturbations reduce boundary-layer decoupling, due to the shallowing of inversion height.

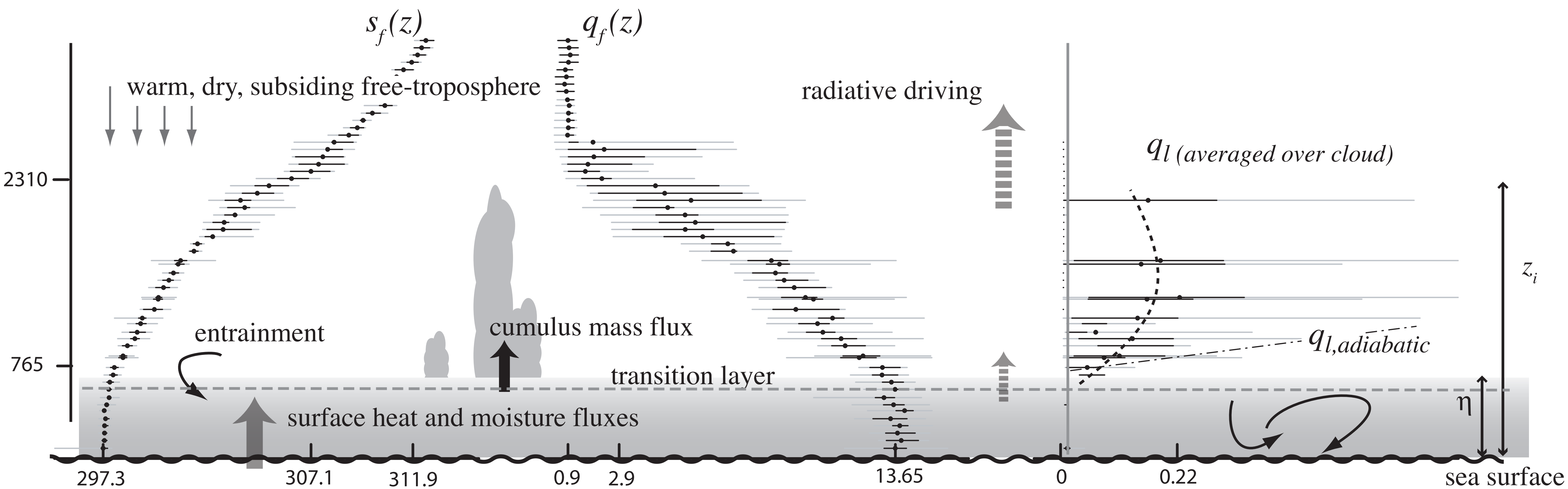
we know in particular models struggle with 'internal' processes

CloudSat-derived shallow convective rains vary significantly by region



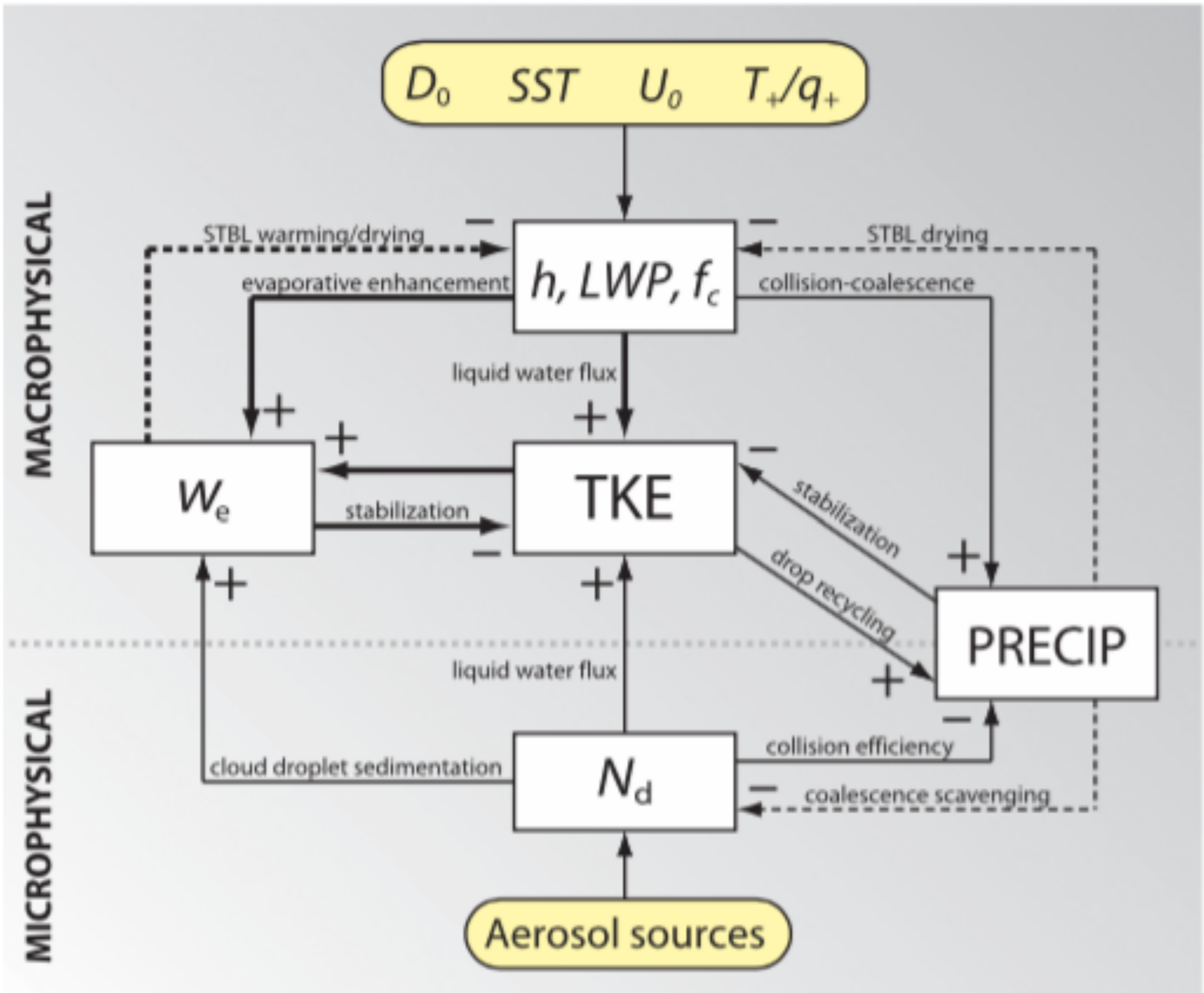
figures provided by Tristan L'Ecuyer

boundary-layer clouds are maintained by a strong coupling with radiation and moisture mediated by mixing



Stevens et al., 2006

both external (yellow) and internal (white) mechanisms influence warm low cloud presence/thickness



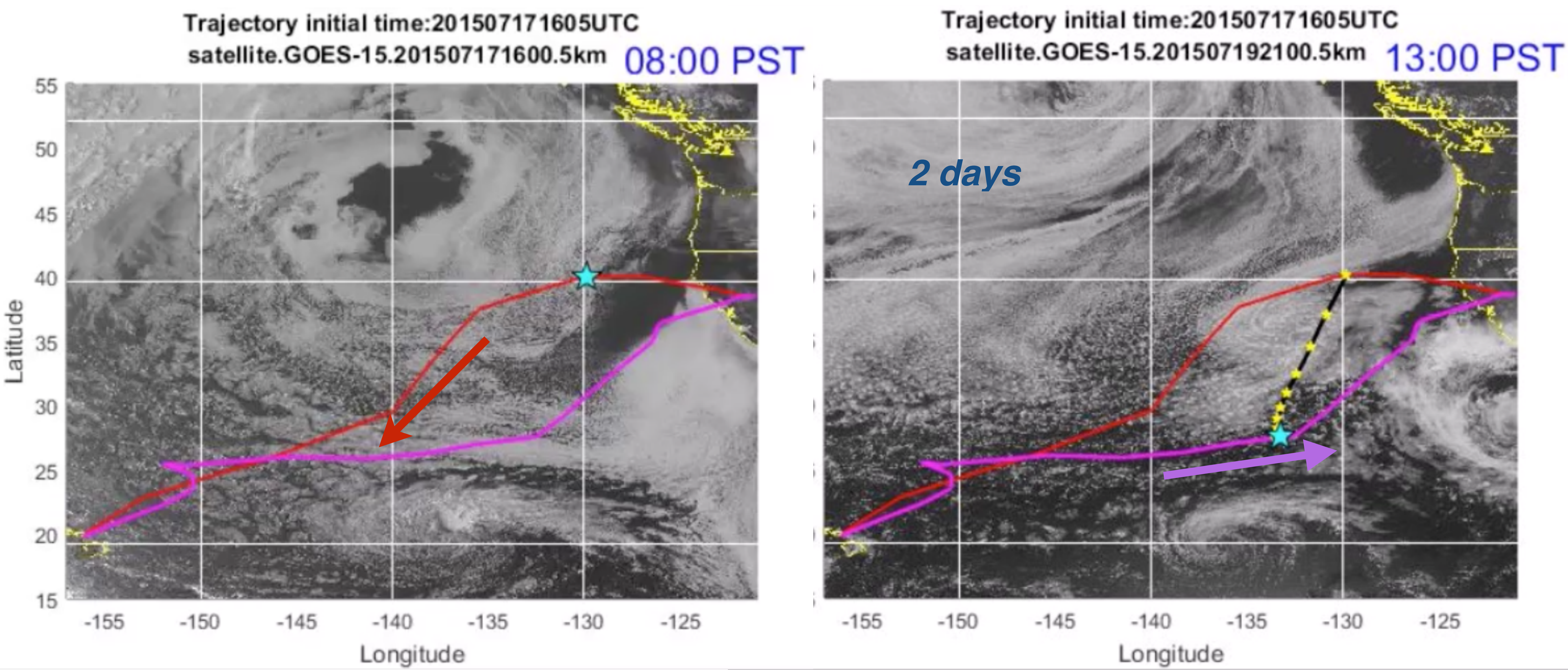
Wood, 2012, MWR

we know oceanic low clouds are not in equilibrium with their environment

to advance our understanding requires a good characterization of the four-dimensional structure of
cloud fundamentals, water vapor, radiation, fluxes -
bringing in dynamics

Cloud System Evolution over the Trades (CSET)

to study cloud and boundary layer evolution along Lagrangian trajectories
within the north Pacific trade-winds using the NCAR GV



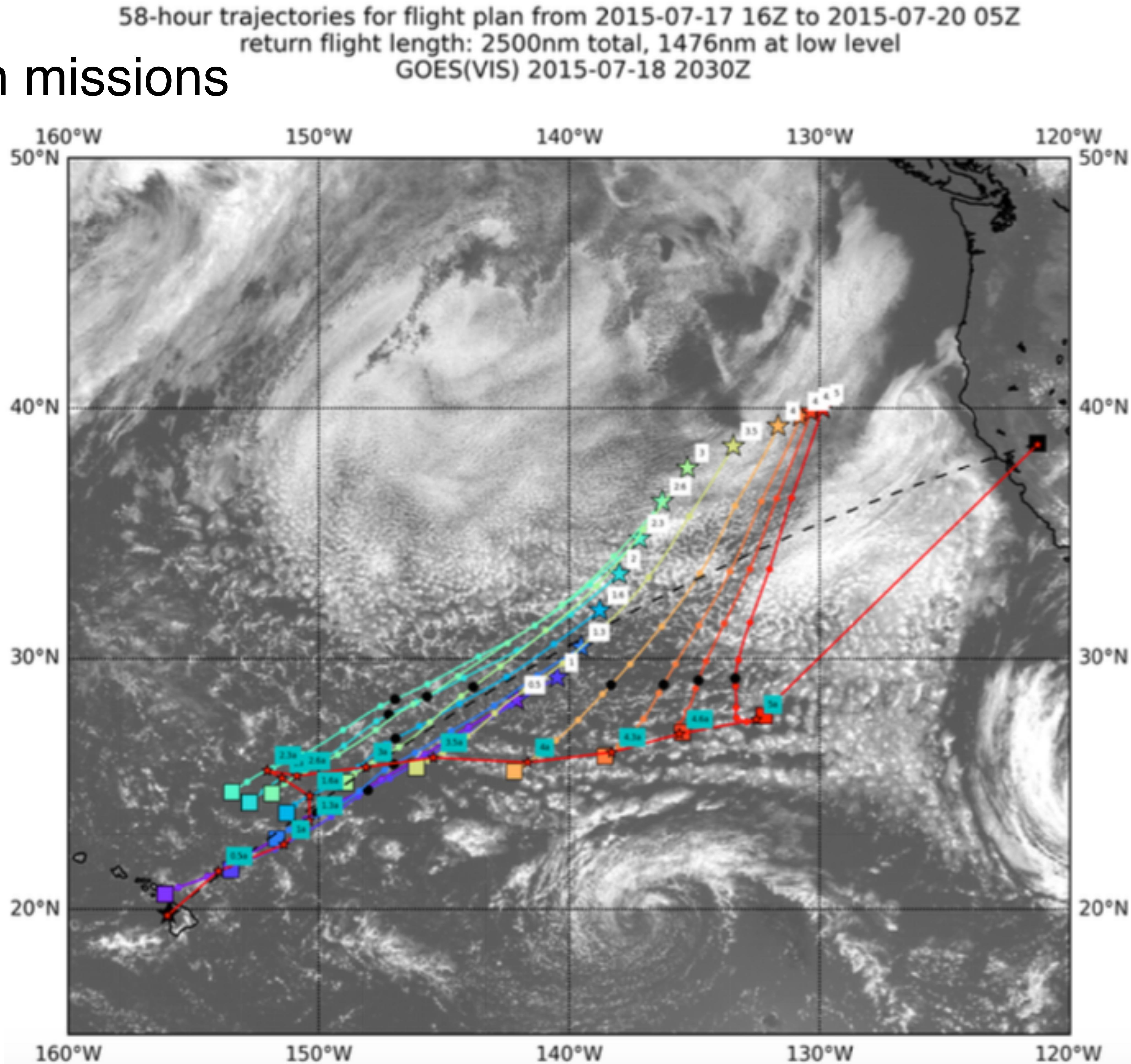
builds on ASTEX, Albrecht et al.,1995

Bruce Albrecht - Principal Investigator
Chris Bretherton, Virendra Ghate, Robert Wood, myself - Investigators

7 Lagrangian missions

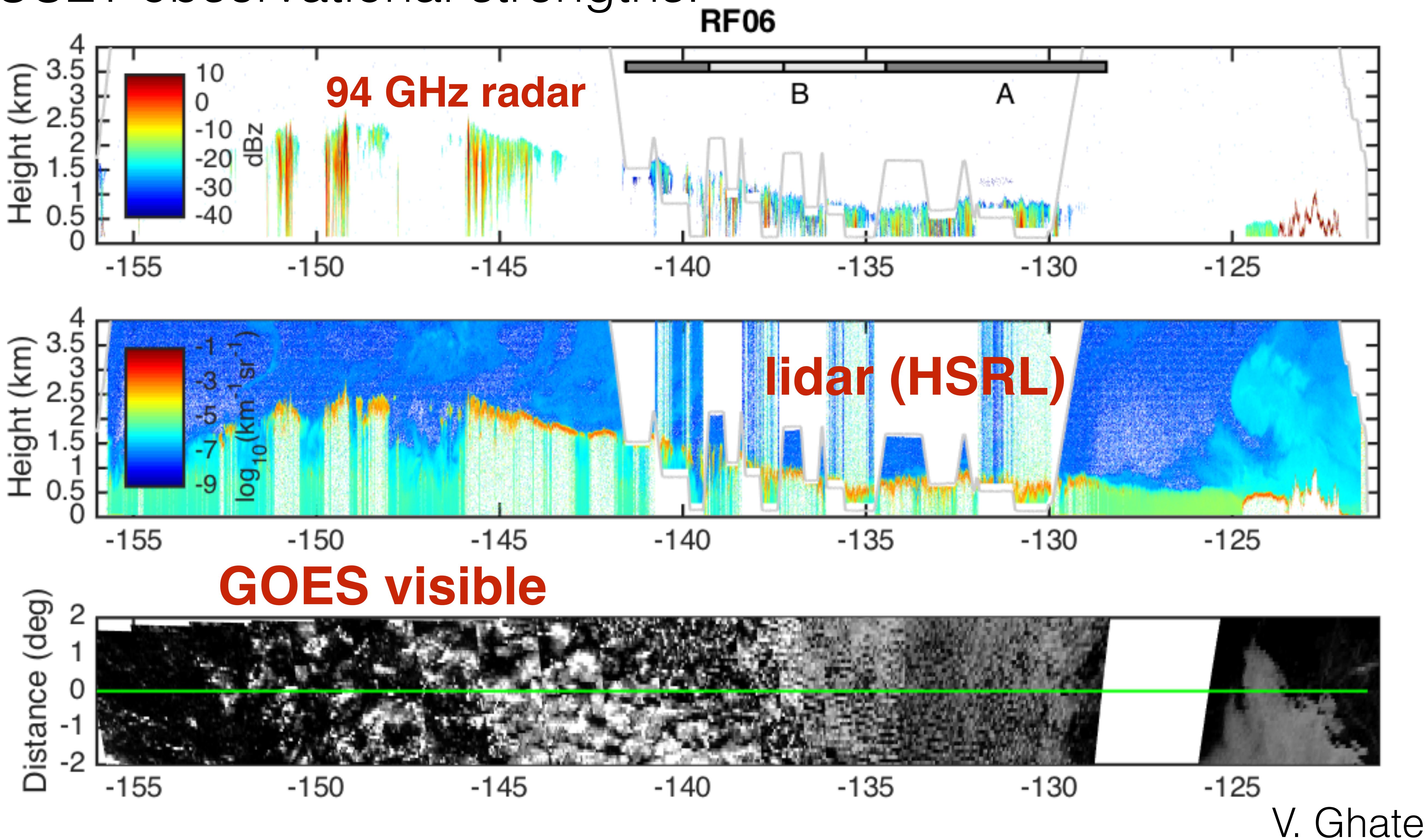
NCAR G-V aircraft

W-band Doppler radar
HSRL (Lidar)
Dropsondes
Meteorology
Microphysics
Turbulence
Radiation
Size-resolved aerosol
(UHSAS)

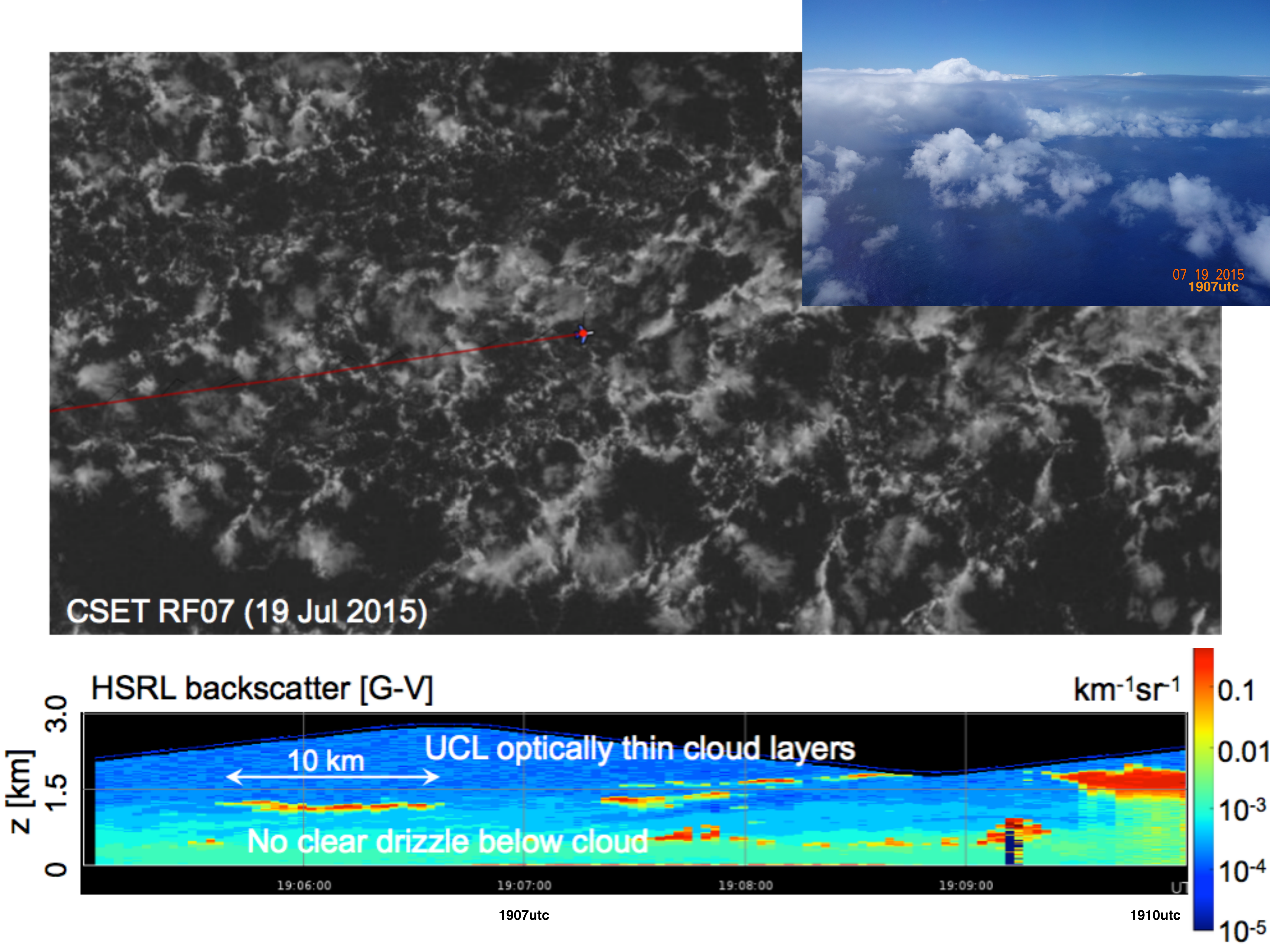


July 17, 2015 California to Hawaii

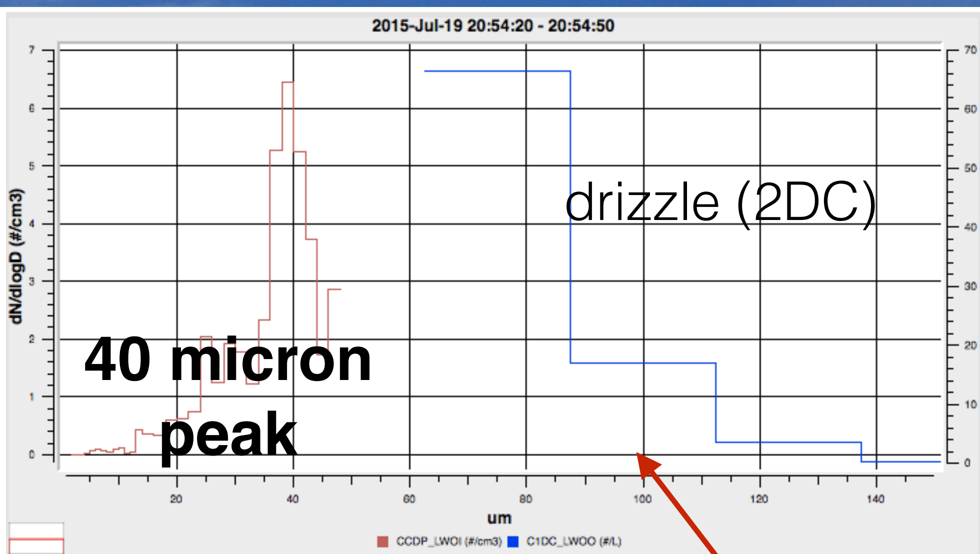
CSET observational strengths:



further desired: LWP as a geophysical constraint on retrievals from microwave radiometer


07 19 2015
1907utc
CSET RF07 (19 Jul 2015)
HSRL backscatter [G-V]
km-1sr-1
z [km]
0
1.5
3.0
10 km
UCL optically thin cloud layers
No clear drizzle below cloud
19:06:00
19:07:00
19:08:00
19:09:00
1907utc
1910utc
0.1
0.01
10-3
10-4
10-5

cumulus towers connected to thin stratiform veils



preliminary budget studies suggest the thin veils are more likely when surface fluxes are weak and subsidence is strong

radiative implications of the thin clouds

- **decreased outgoing long wave radiation**
- **enhanced long wave warming of surface**
- **enhanced shortwave albedo**

all else equal

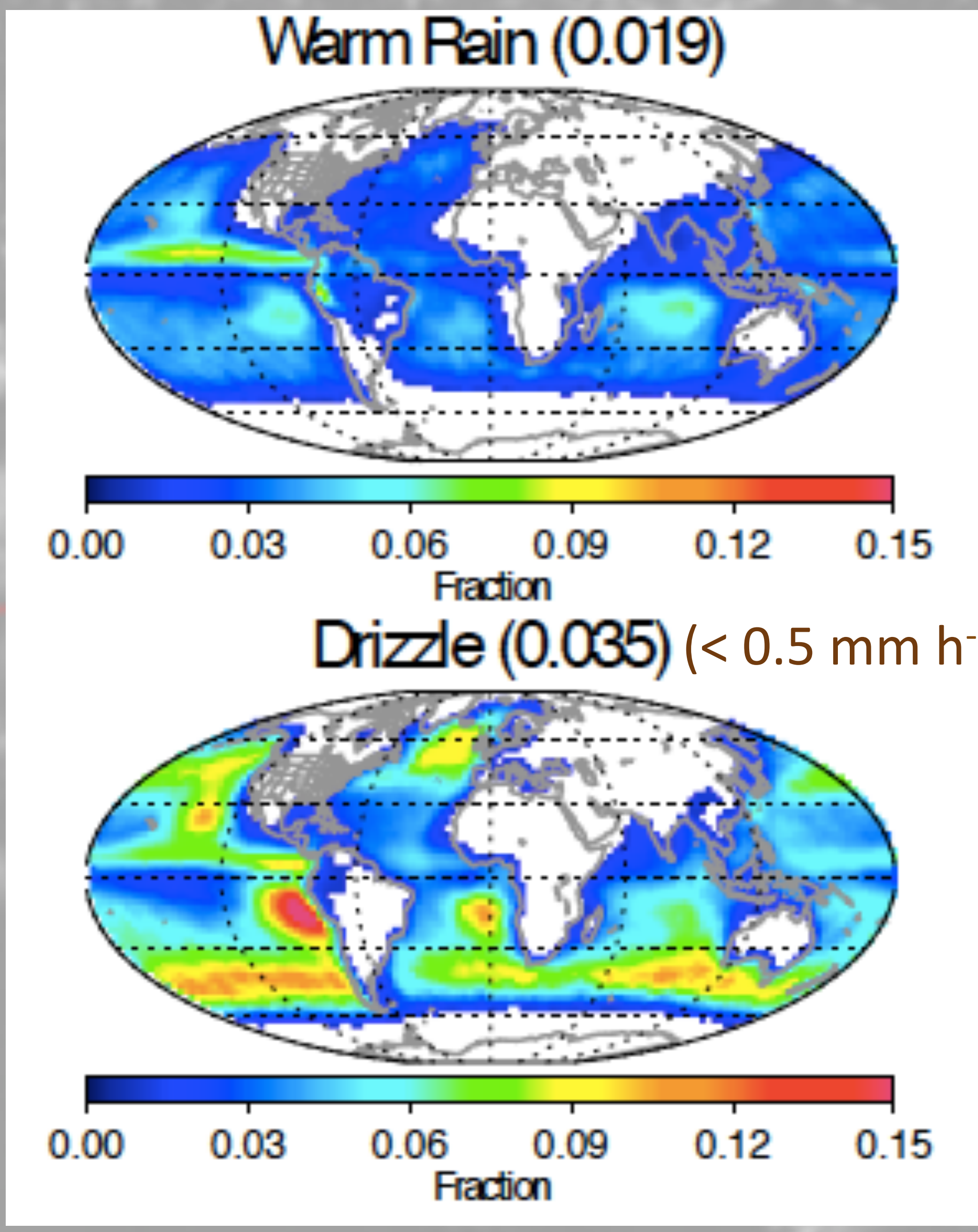
statistically,
dropsize mode 20-40 micron
LWPs of < 10 g/m^2
optical depths<1

desired: better integration of spectral solar flux radiometer (SSFR) analysis with its availability

(EOL field catalog capabilities keep getting better and better…)

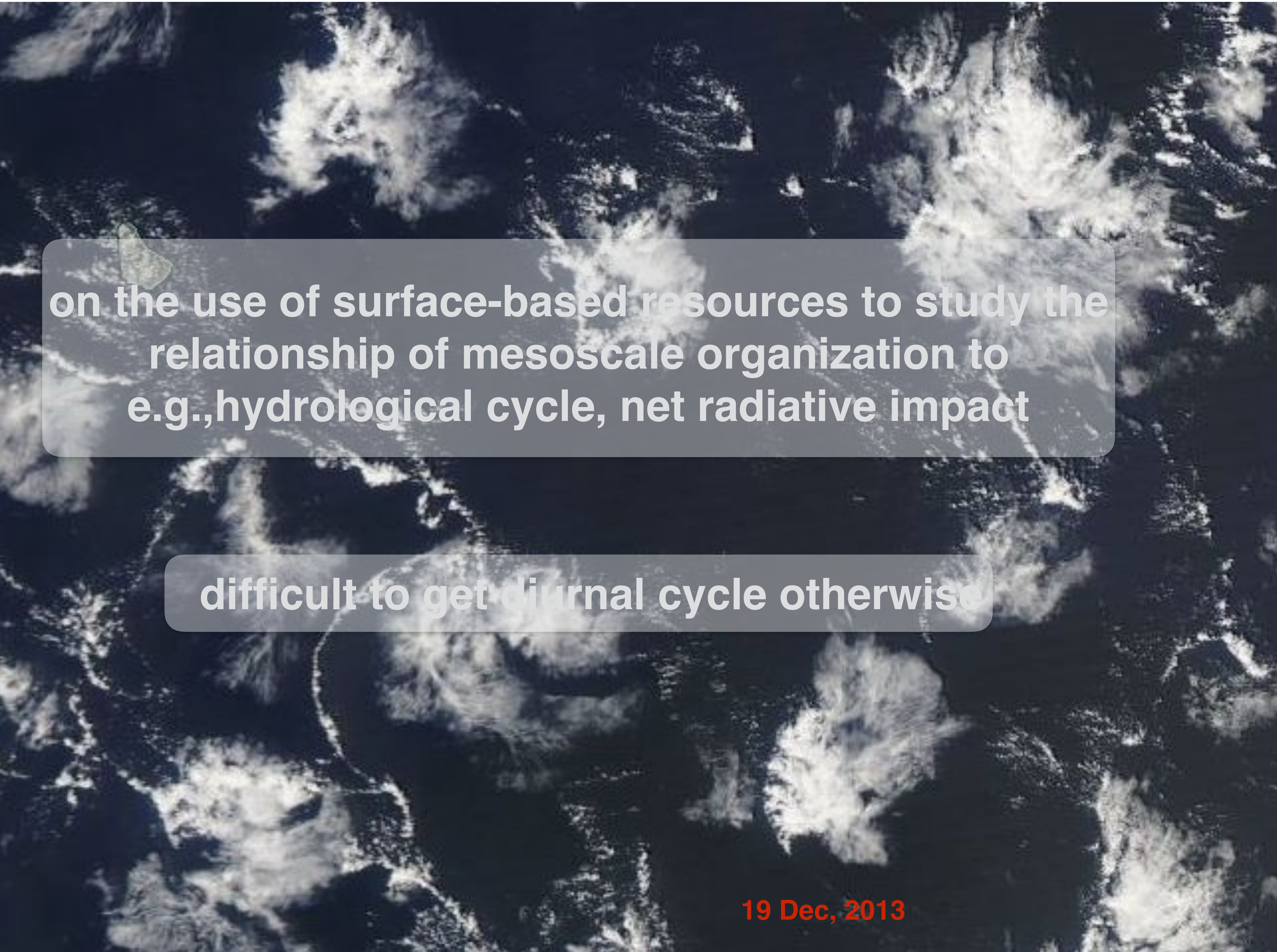
evolution of boundary-layer flow into the ITCZ

- how does the low cloud population evolve within the large-scale flow?
- how do the low cloud micro & macrophysics adapt to the aerosol and moisture environment?



(< 0.5 mm h^{-1})

GV

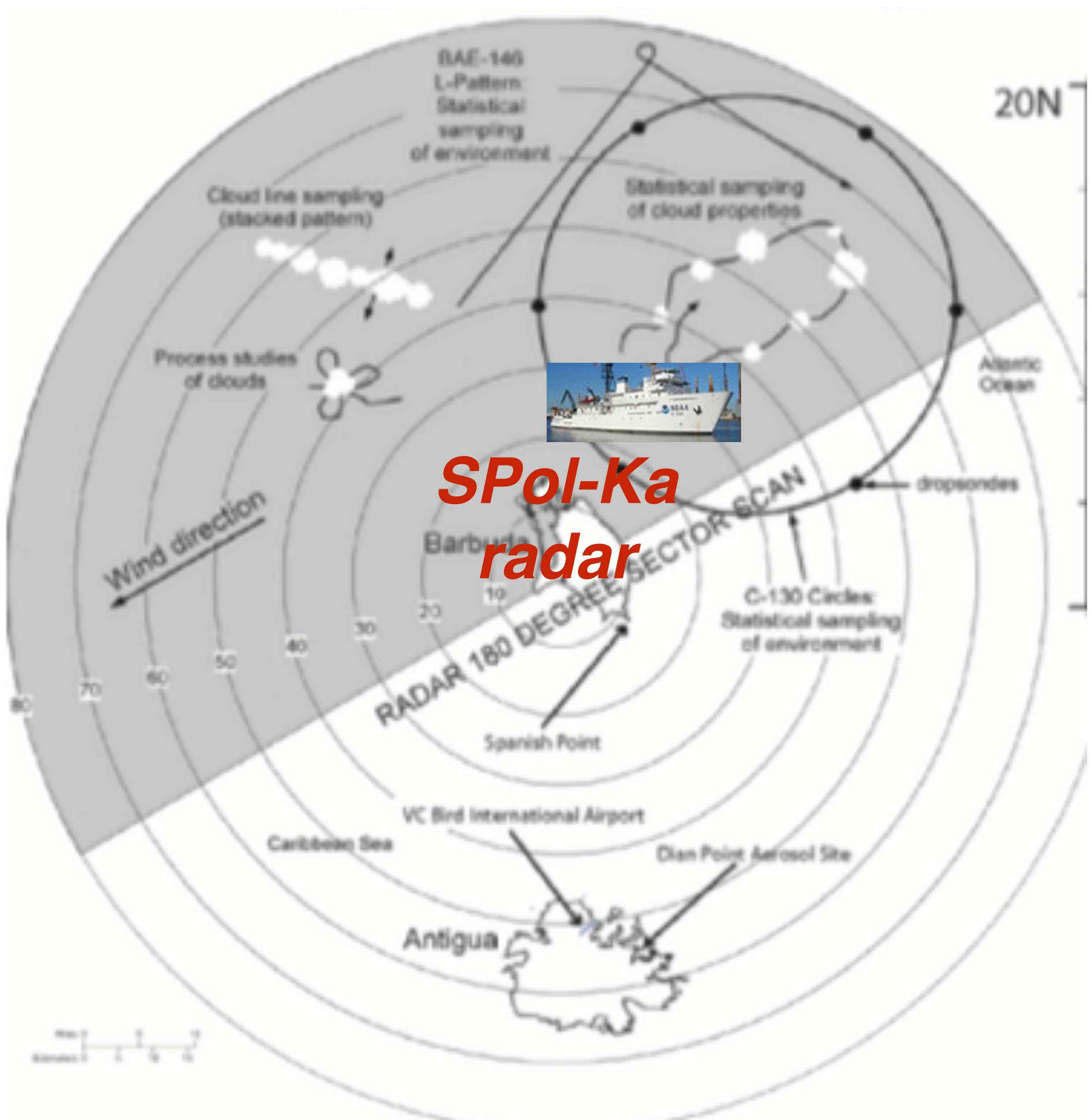


on the use of surface-based resources to study the relationship of mesoscale organization to e.g.,hydrological cycle, net radiative impact

difficult to get diurnal cycle otherwise

19 Dec, 2013

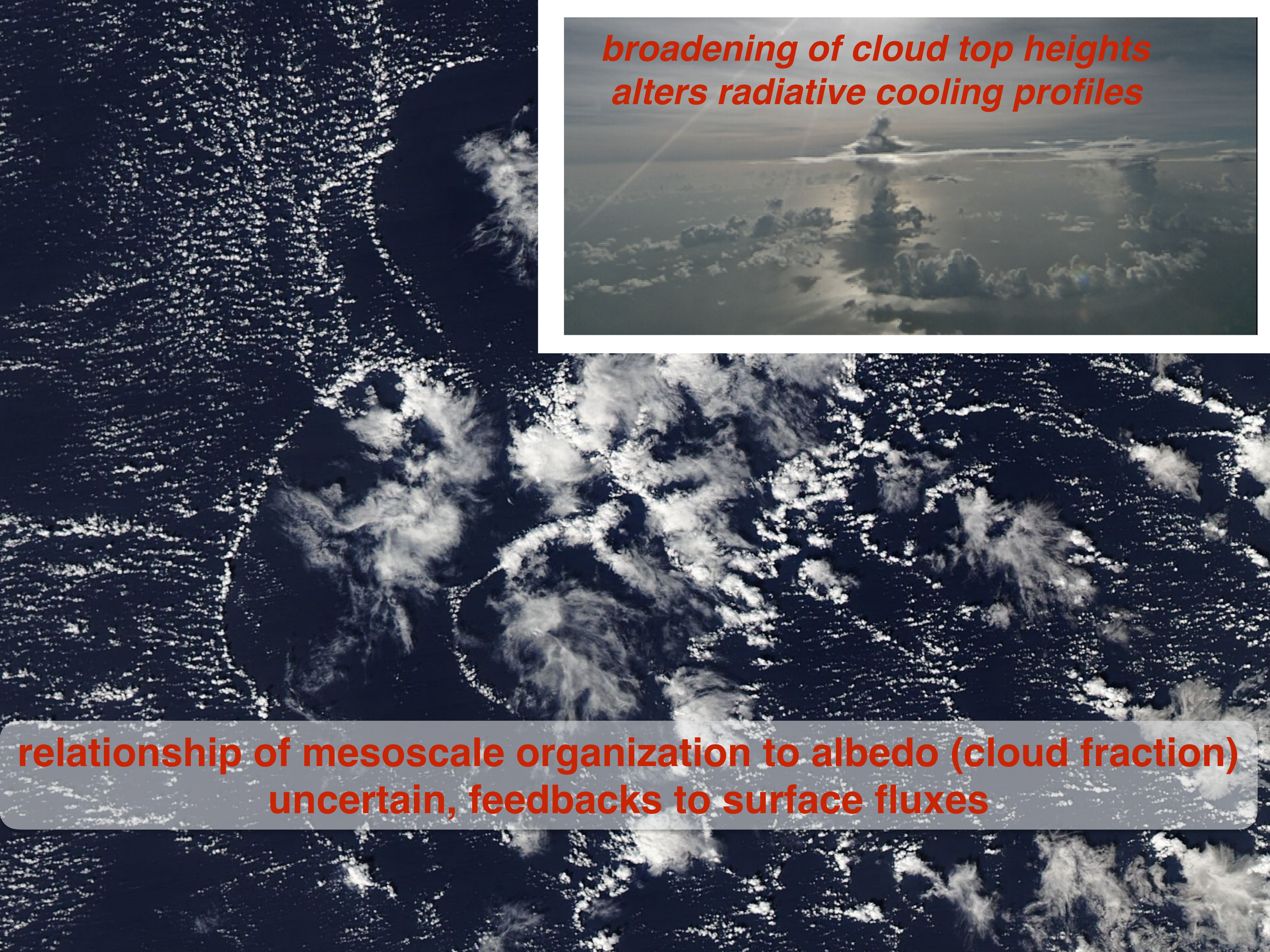
synergy of 3D observations and complementary constrained modeling;

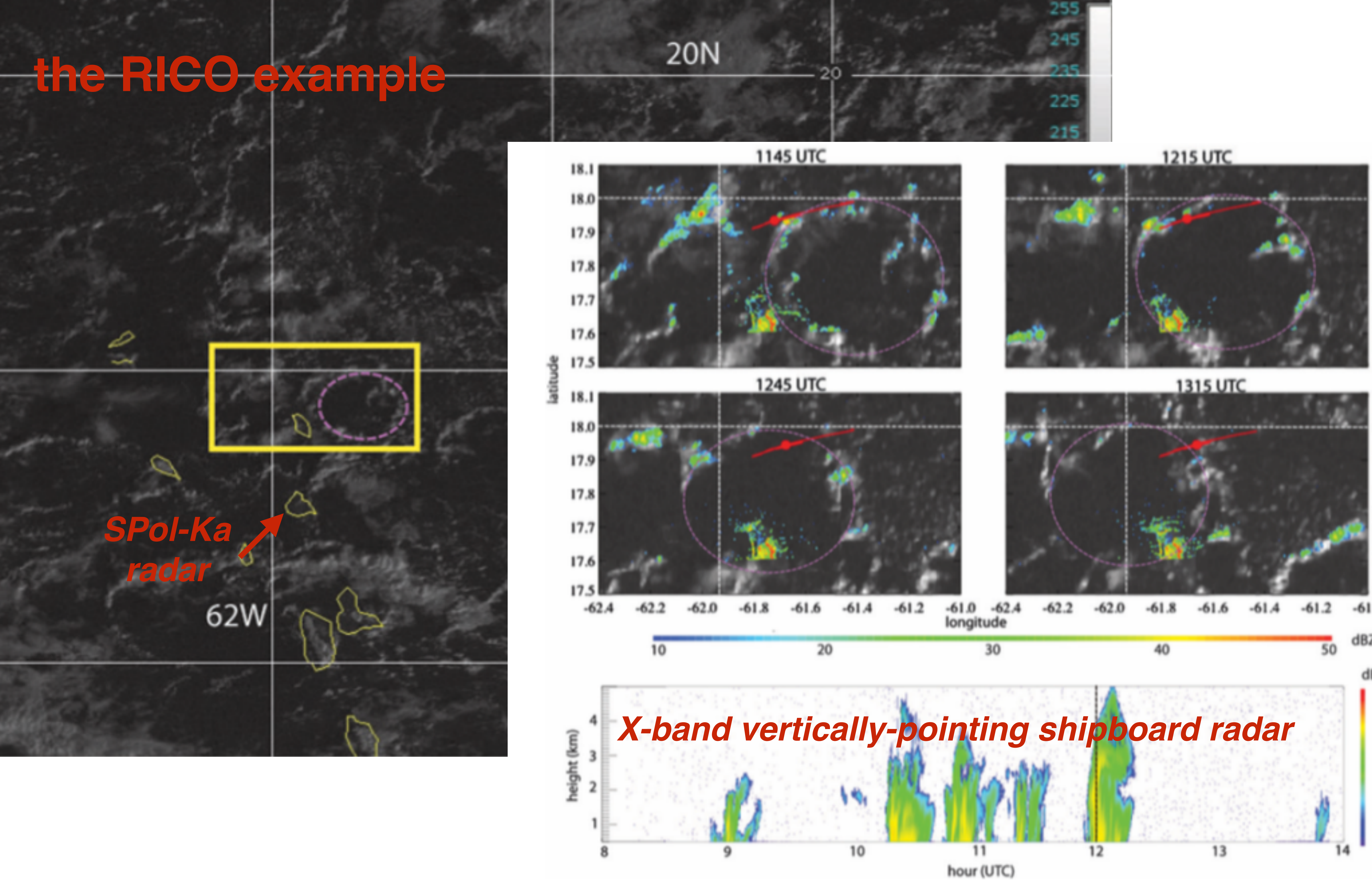


Rauber et al., 2007

Rain in Cumulus over Ocean (RICO) setup:
SPol-Ka radar provided 3D (or 4D) convection, ship profiling &
in situ provided detailed cloud/vertical structure,
radiosondes provide thermodynamic structure

Shallow convection with precipitation > ~ 1 mm/hr only occur ~ 2% of the time (Snodgrass et al., 2009, Neggers et al.,2002), consistent with early BOMEX/ATEX studies (Augstein et al., 1973) but have outsized influence on character of the trade-winds


broadening of cloud top heights
alters radiative cooling profiles
relationship of mesoscale organization to albedo (cloud fraction)
uncertain, feedbacks to surface fluxes

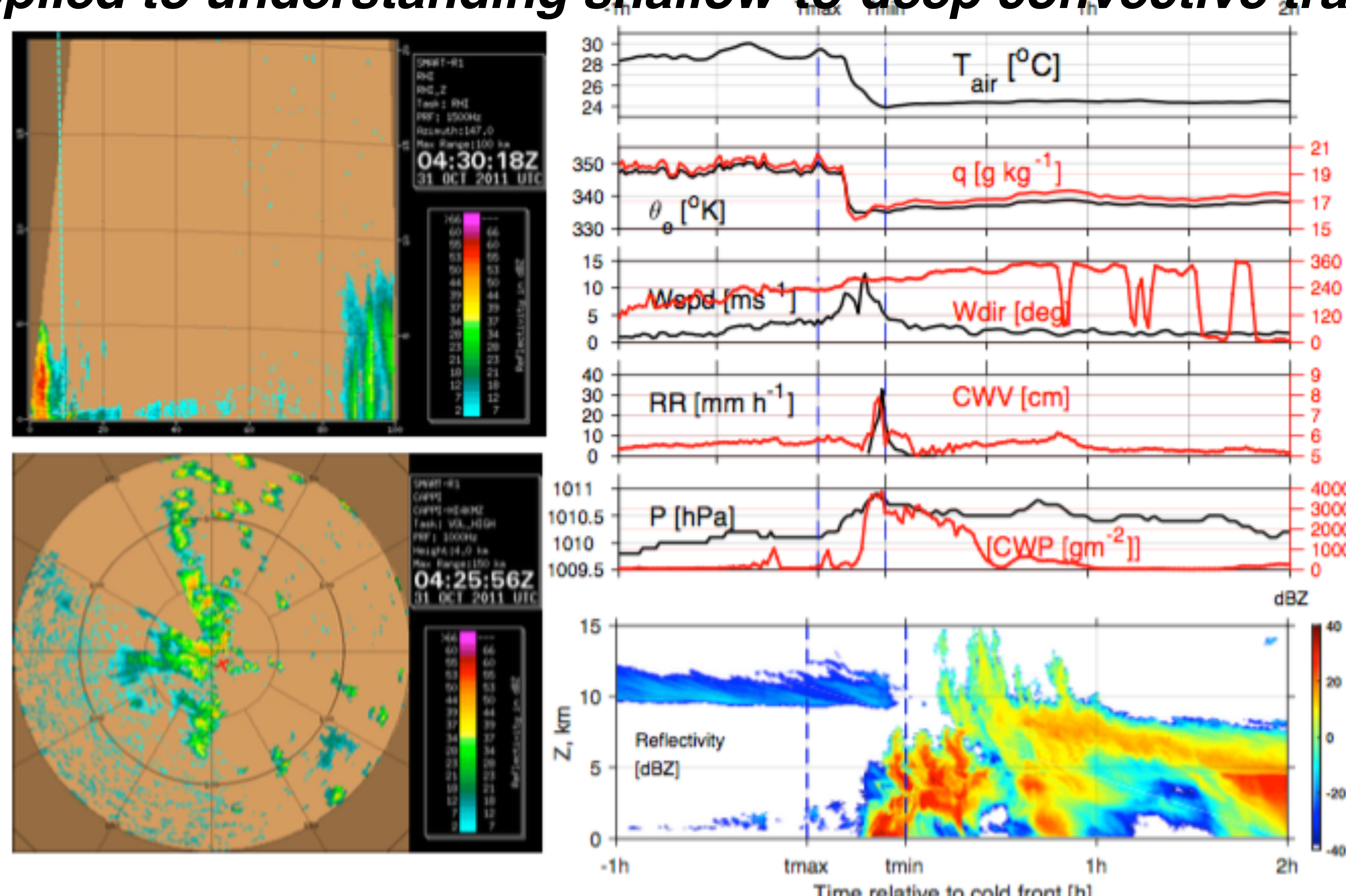


On Trade Wind Cumulus Cold Pools

Paquita Zuidema,[*] Zhujun Li,[*] Reginald J. Hill,[+] Ludovic Bariteau,[+] Bob Rilling,[#] Chris Fairall,[@] W. Alan Brewer,[@] Bruce Albrecht,[*] and Jeff Hare[&]

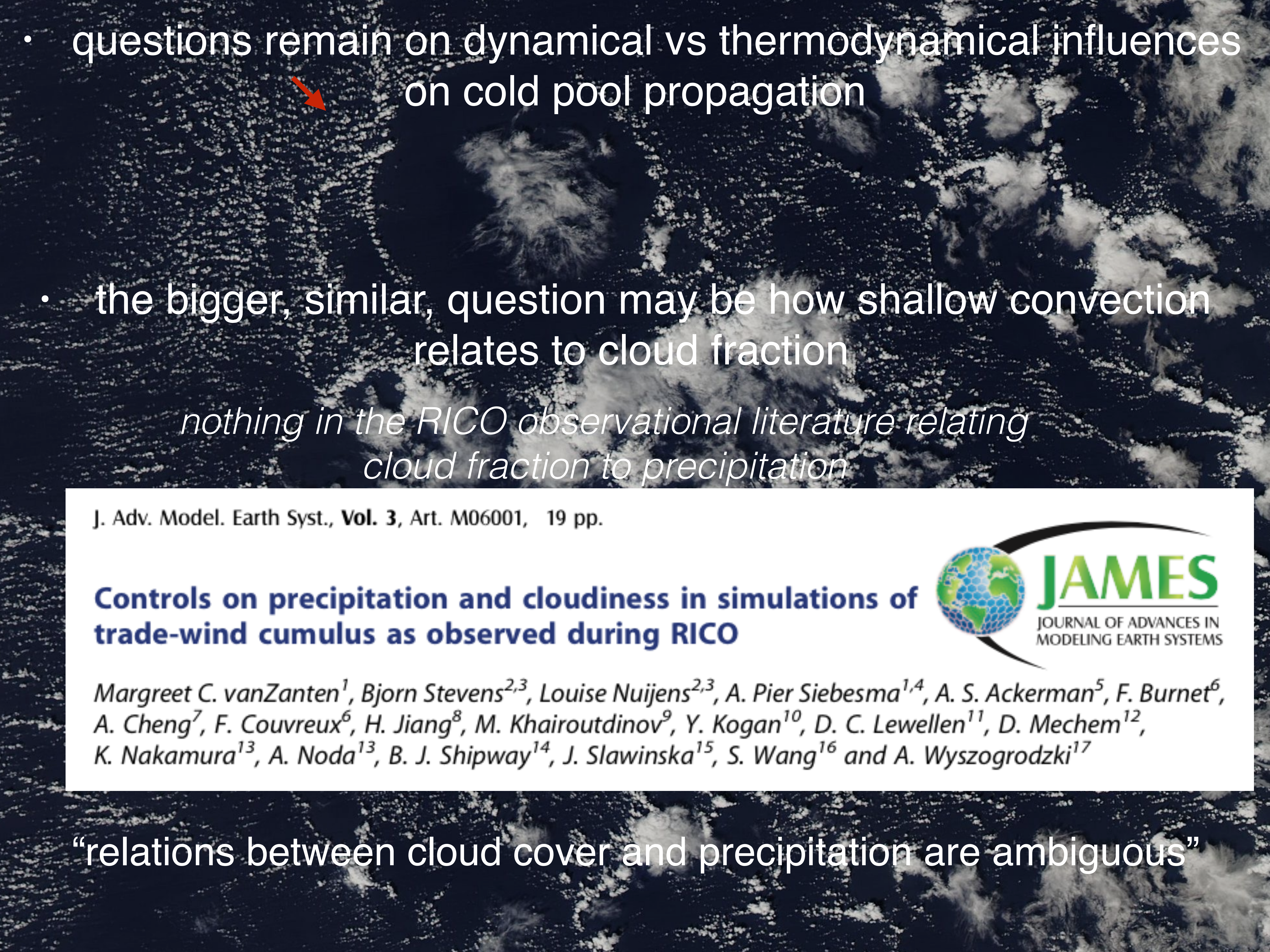
2012, JAS

Similar observational strategy applied within Dynamics of the Madden-Julian Oscillation (DYNAMO): SPol-Ka azimuth scan over an ARM surface site data applied to understanding shallow-to-deep convective transition



Chandra et al., manuscript in preparation, see also Rowe and Houze 2015, Feng et al., 2014

160 **Figure 1.** Example time series of a cold pool passage on Gan island on October 31, 2011, 4:00-8:00 UTC.



- questions remain on dynamical vs thermodynamical influences on cold pool propagation

- the bigger, similar, question may be how shallow convection relates to cloud fraction

nothing in the RICO observational literature relating cloud fraction to precipitation

J. Adv. Model. Earth Syst., **Vol. 3**, Art. M06001, 19 pp.

JAMES
JOURNAL OF ADVANCES IN MODELING EARTH SYSTEMS

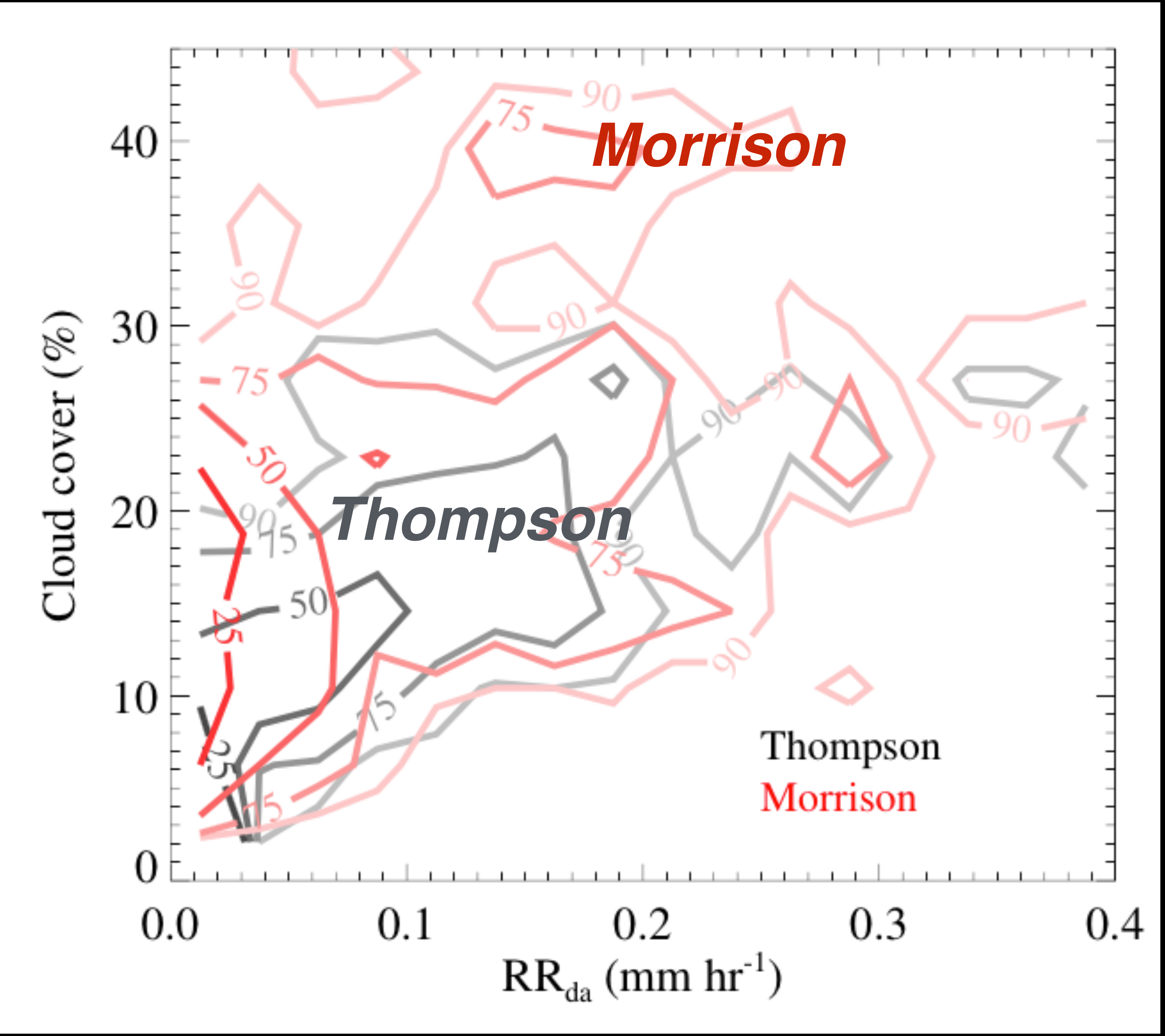
Controls on precipitation and cloudiness in simulations of trade-wind cumulus as observed during RICO

Margreet C. vanZanten[1], Bjorn Stevens[2,3], Louise Nuijens[2,3], A. Pier Siebesma[1,4], A. S. Ackerman[5], F. Burnet[6], A. Cheng[7], F. Couvreux[6], H. Jiang[8], M. Khairoutdinov[9], Y. Kogan[10], D. C. Lewellen[11], D. Mechem[12], K. Nakamura[13], A. Noda[13], B. J. Shipway[14], J. Slawinska[15], S. Wang[16] and A. Wyszogrodzki[17]

“relations between cloud cover and precipitation are ambiguous”

different microphysical schemes can produce quite different low cloud fractions:

e.g., Morrison autoconversion/accretion ratio<Thompson; more low cloud

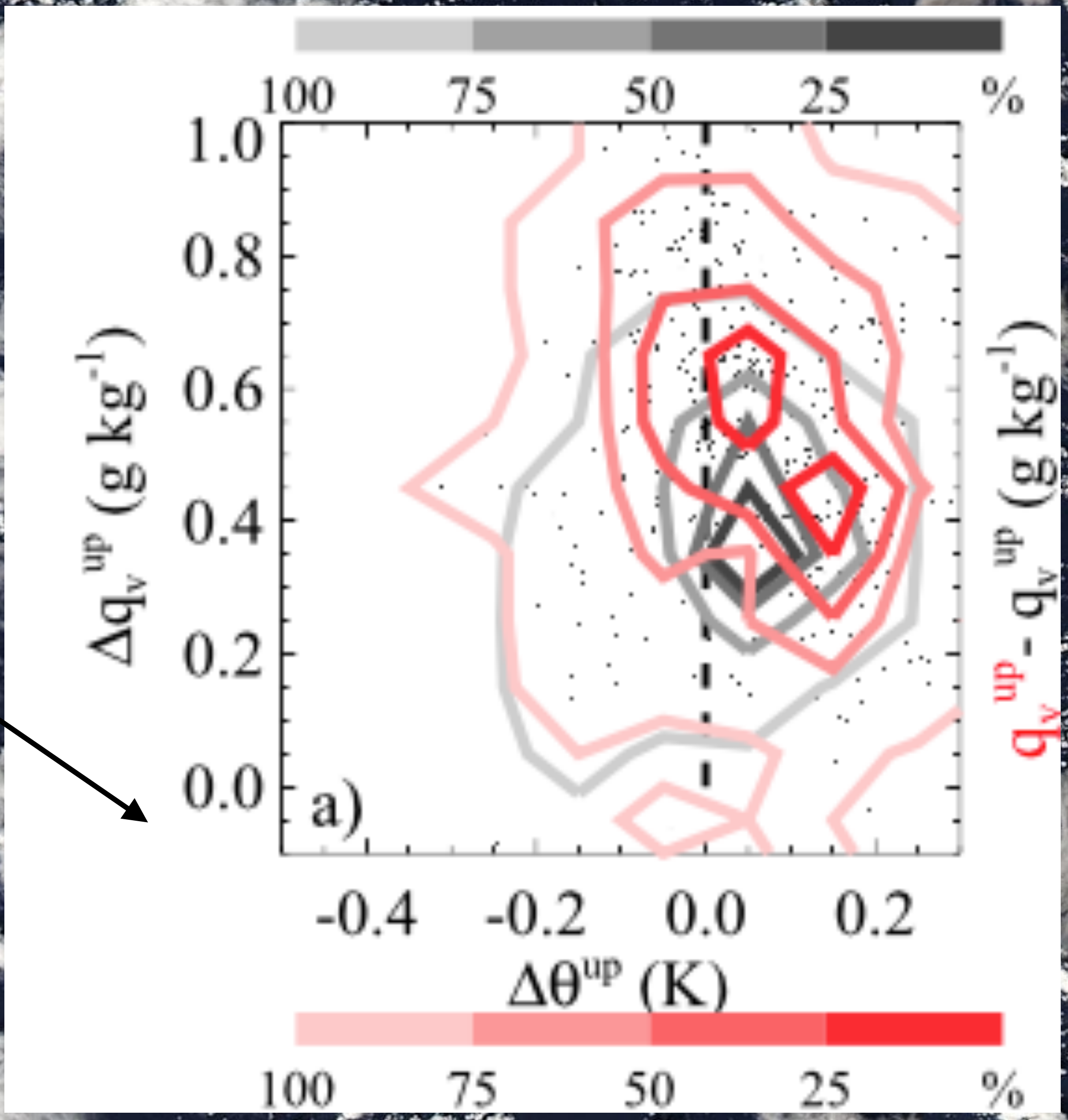


Li, Zuidema, Zhu, Morrison, 2015

contour values indicate percentage of time simulations include a specific rainrate/cloud cover

moisture key to understanding convection: a difficult observable

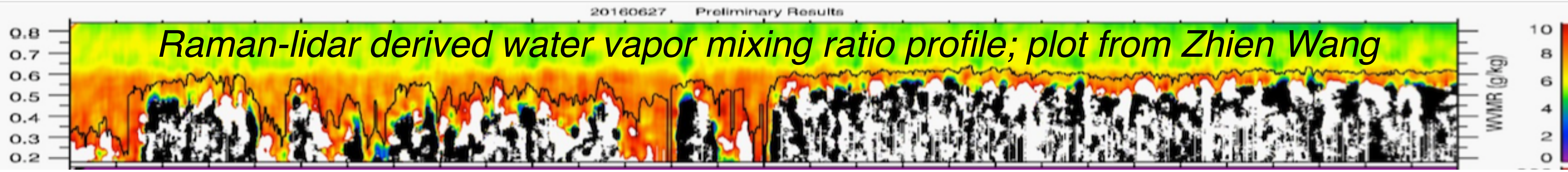
e.g.,more moist updrafts near cold pools (red) are more successful at invigorating secondary convection - in this model



nested-WRF simulations
Li, Zuidema, Zhu, 2014

moisture and its horizontal/vertical structure remains an important observational gap

active remote sensing, from, e.g., Raman or DIAL lidar, provides vertical structure & thereby mixing estimates



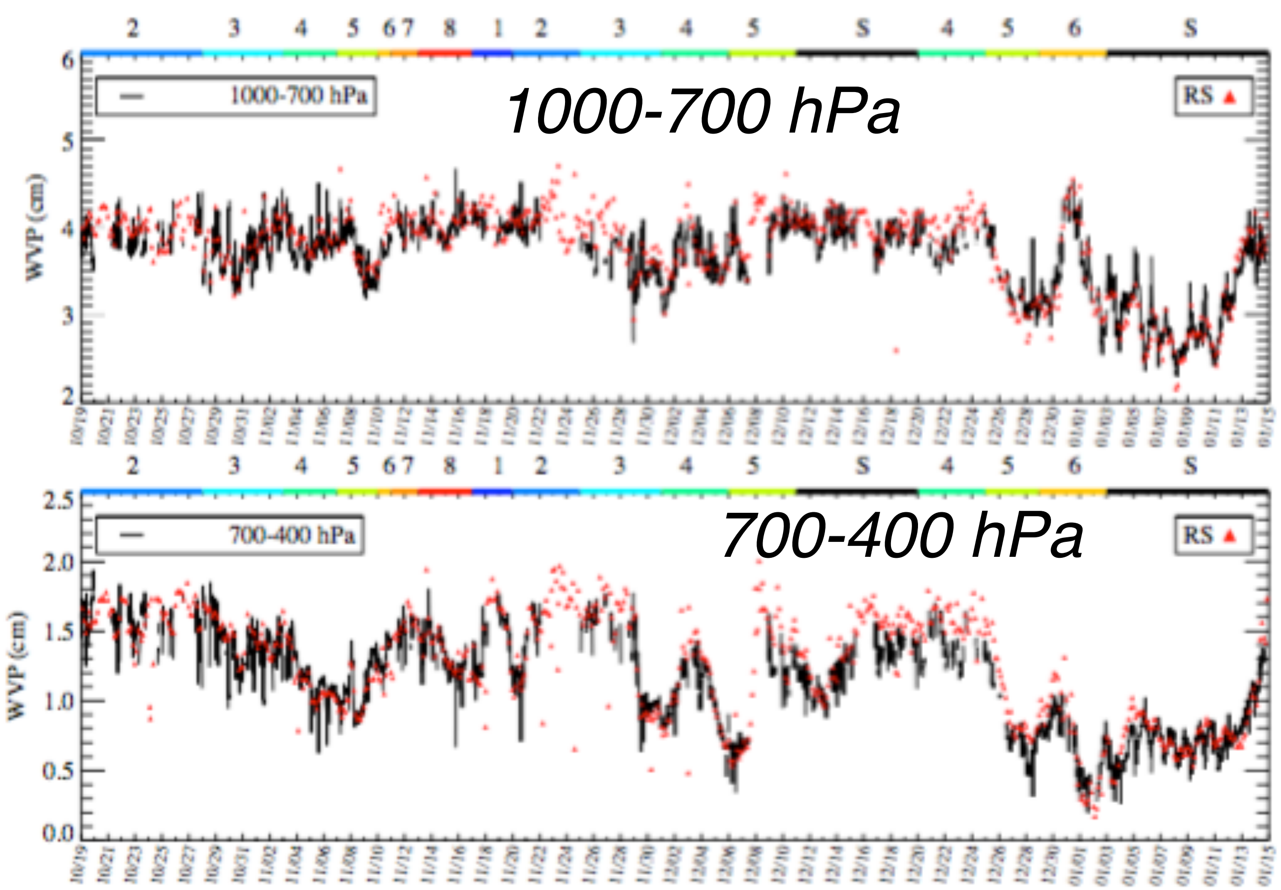


FIG. 8: Layer integrated water vapor path time series as a function of MJO phases during DYNAMO at (a) 1000–700 hPa and (b) 700–400 hPa. CAL-2 Retrievals are at 30-minute resolution. MJO phases are labeled in color, and DOE ARM RS-92 Radiosondes are in red. Gaps within the data are due to non-converging and rain contaminated conditions.

more difficult to get from passively,
layer-integrated vapor from passive sensors can augment radiosonde networks

see also David Turner poster combining passive infrared with DIAL lidar

layer-integrated vapor from passive microwave radiometer and soundings over the equatorial Indian Ocean

Zhang, Zuidema, Turner and Cadeddu, manuscript in preparation

high-latitude mixed-phase clouds: climate change becoming more and more obvious at short time scales

nature geoscience

REVIEW ARTICLE

PUBLISHED ONLINE: 11 DECEMBER 2011 | DOI: 10.1038/NGEO1332

Resilience of persistent Arctic mixed-phase clouds

Hugh Morrison[1]*, Gijs de Boer[2,5], Graham Feingold[3], Jerry Harrington[4], Matthew D. Shupe[5] and Kara Sulia[4]

The Arctic region is particularly sensitive to climate change. Mixed-phase clouds, comprising both ice and supercooled liquid water, have a large impact on radiative fluxes in the Arctic. These clouds occur frequently during all seasons in the region, where they often persist for many days at a time. This persistence is remarkable given the inherent instability of ice-liquid mixtures. In recent years it has emerged that feedbacks between numerous local processes, including the formation and growth of ice and cloud droplets, radiative cooling, turbulence, entrainment and surface fluxes of heat and moisture, interact to create a resilient mixed-phase cloud system. As well as the persistent mixed-phase cloud state there is another distinct Arctic state, characterized by radiatively clear conditions. The occurrence of either state seems to be related, in part, to large-scale environmental conditions. We suggest that shifts in the large-scale environment could alter the prevalence of mixed-phase clouds, potentially affecting surface radiative fluxes and the Arctic energy budget.

Myriad processes affect (mixed-phase) clouds, however observations suggest presence of two preferred states

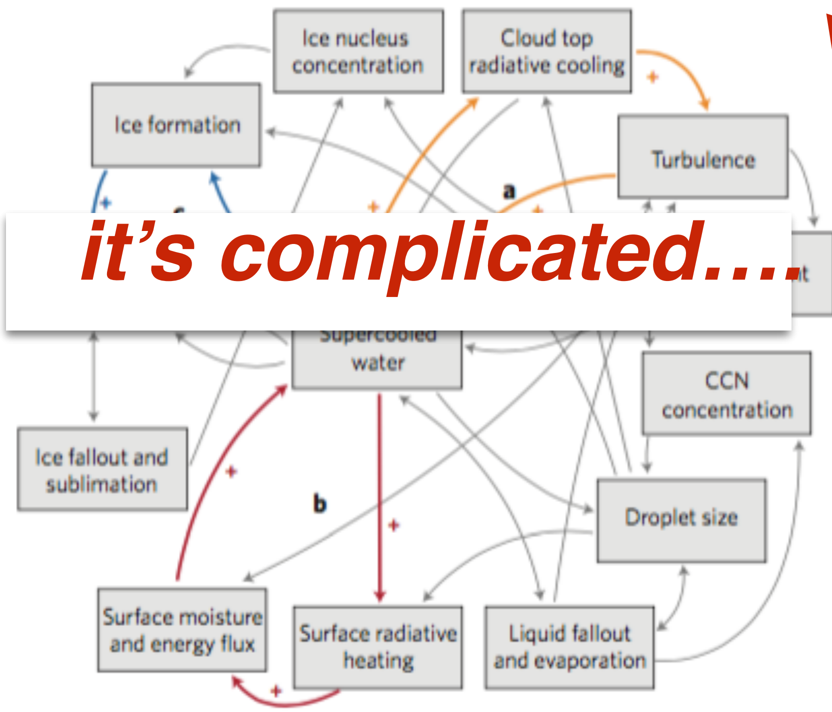
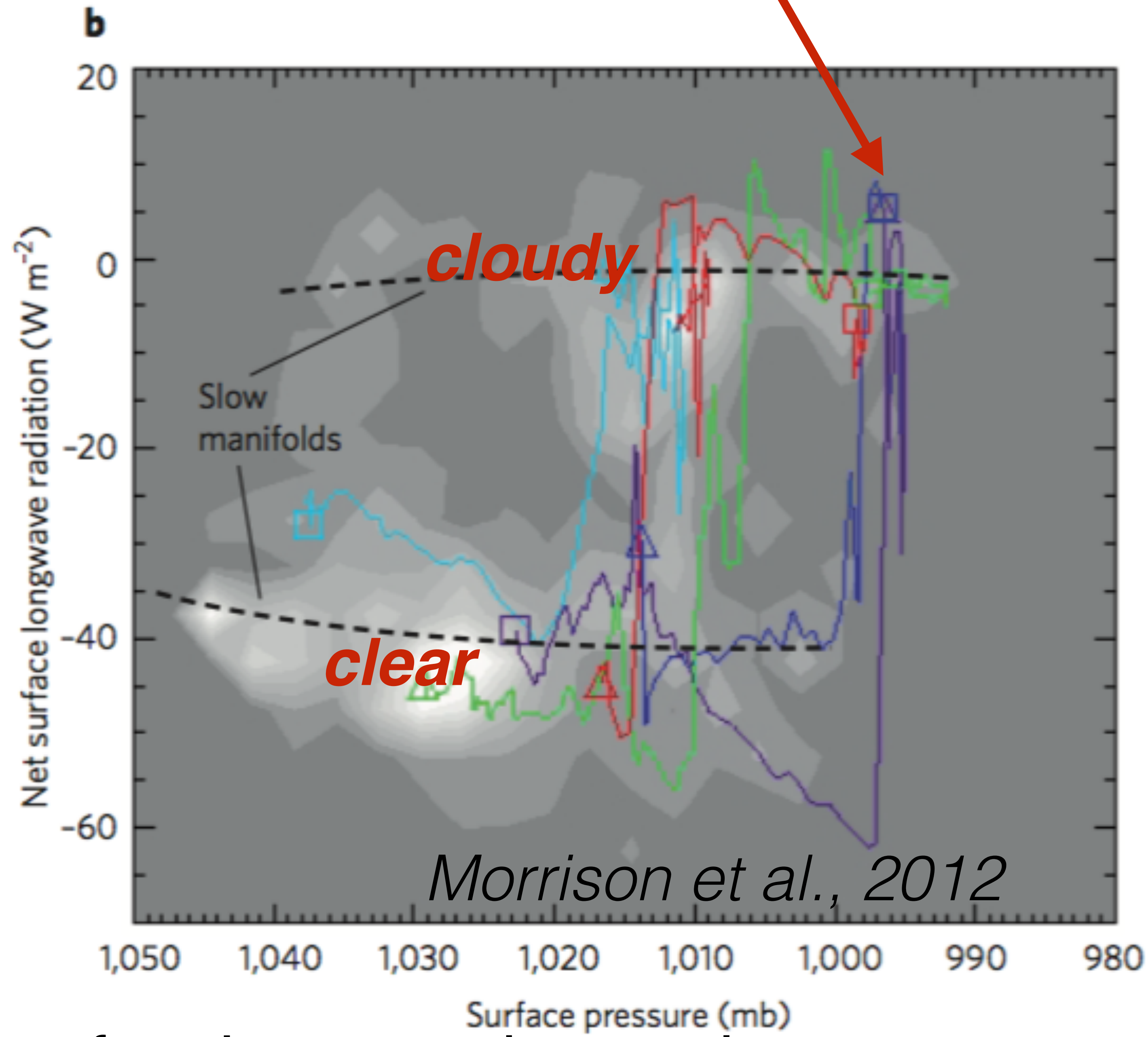


Figure 2 | Processes associated with Arctic mixed-phase clouds are linked through a complex web of interactions and feedbacks. In this diagram, the arrows signify the direction of influence of interactions between various physical quantities and processes. Not all important associations are included. Three specific interaction pathways (labelled a, b and c) are highlighted by coloured arrows and discussed in greater depth in the text. Signs (+ or -) indicate the expected response (increase or decrease) of the receiving element.



fast (internal) processes govern transition between the 2 states

slow processes - advection of moisture and warmth - govern evolution within the 2 states

is this changing as the Arctic changes? i.e through convection?

argues for comprehensive observations/modeling

summary: what is needed to advance shallow convection research?

- comprehensive observations spanning micro-meso-large-scales
- an observational suite that works well to constrain complementary modeling (process&larger-scale)
- intellectually-diverse investigator team

any observational gaps?

- more ways to sense water vapor & its structure, including through winds *(e.g, Sherwood, Roca, Weckwerth,Andronova, 2010)*
- more measurements of mixing (TKE)

- better attention to existing measurements, e.g., strong instrument mentorship/retrieval ownership programs

NCAR workshop, Sept 2014

Recommendations for Improving U.S. NSF-Supported Airborne Microwave Radiometry

BY PAQUITA ZUIDEMA, JULIE HAGGERTY, MARIA CADEDDU, JORGEN JENSEN, EMILIANO ORLANDI, MARIO MECH, J. VIVEKANANDAN, AND ZHIEN WANG

The cloudy, humid atmosphere remains our most important weather and climate forecasting challenge. Airborne remote sensors such as radars and lidars have revolutionized information on aerosol, moisture, cloud, and precipitation (liquid and ice) vertical structure, far increasing the information gathered from in situ measurements alone. In recognition, the National Science Foundation (NSF) has expanded its aircraft deployment resources to the remote sensors listed in Table 1. These also include a profiling microwave radiometer sensitive to the atmospheric temperature structure. However, microwave observations from which integrated water vapor and liquid water paths and free-tropospheric humidity profiles can be retrieved are not yet available. Clouds and water vapor are semitransparent in the micro/millimeter wavelength spectral range, in contrast to infrared. The atmospheric emission can be used to infer atmospheric thermodynamics and cloud information in almost all conditions. The integrated water-phase measurements provide important geophysical constraints on hydrometeor and vapor profiles derived from active sensors, and the profiling and mapping of the atmosphere is more comprehensive than that available from in situ observations. Simultaneously, technological improvements are producing ever more miniaturized, modular, and electronically stable designs that consume less power, allowing micro- and millimeter-wavelength radiometers to fit into standard wing-mounted canisters. The National Aeronautics and Space Administration (NASA) and several European agencies operate profiling radiometers, but, along with the Department of Energy (DOE), lack airborne radiometers capable of sensing integrated vapor and liquid that are compact enough to easily integrate into a synergistic instrumental suite.

These considerations motivated a workshop on airborne radiometry for water vapor and liquid water retrievals held at the National Center for Atmospheric Research (NCAR) on 23–24 September 2014. The workshop provided a critical opportunity to revisit U.S. NSF capabilities, forge a community consensus on scientific requirements, and discuss infrastructure and institutional resources. These discussions culminated in a set of technical and institutional process recommendations.

The science goals were distinguished through

TABLE 1. NSF aircraft deployment pool: active and passive remote sensin

Instrument	Frequency (wavelength)	Platform
Active		
Wyoming Cloud Radar (WCR)	94 GHz (3.2 mm)	King Air, C-130
Wyoming Cloud Lidar (WCL)	(355 nm)	King Air, C-130
HIAPER[1] Cloud Radar (HCR)	94 GHz (3.2 mm)	Gulfstream-V
High Spectral Resolution Lidar (HSRL)	(532 nm)	Gulfstream-V
Multi-function Airborne Raman Lidar (MARLi)[2]	(266, 355 nm)	King Air, C-130
Passive		
Microwave Temperature Profiler (MTP)	56-59 GHZ	Gulfstream-V
HIAPER[1] Airborne Radiation Package	(300-2400 nm)	Gulfstream-V
Kipp and Zonen pyrgeo-, pyranometers	(4.5-40, 0.2-3.6 μm)	C-130, Gulfstream-V

http://journals.ametsoc.org/doi/10.1175/BAMS-D-15-00081.1

extra slides

do we possess the necessary observations with which to constrain the complementary model simulations?

NSF-sponsored field campaigns have/are addressing all 3

water vapor remote sensing
the Arctic hydrological cycle

active-passive

Andersen et al., 2017 ACPD

Kay et al., 2016 review
Morrison nature
Ilen (Tristan's student) paper may not be out yet

something NCAR is really doing right: the EOL flight planning/data archiving capabilities

water vapor remote sensing
the Arctic hydrological cycle

active-passive

Andersen et al., 2017 ACPD

Kay et al., 2016 review
Morrison nature
Ilen (Tristan's student) paper may not be out yet

more concrete applications (all oceanic):

shallow cloud mesoscale organization:

- what is the role of mesoscale organization (cold pools) in shallow-to-deep convection transition?
- what is the relationship of shallow cloud convection to cloud fraction?

evolution of boundary-layer flow into the ITCZ

- how does the low cloud population evolve within the large-scale flow?
- how do the low cloud micro & macrophysics adapt to the aerosol and moisture environment?

high-latitude mixed-phase clouds

- how do boundary layer clouds and changing surface conditions interact?

answering all these questions requires complementary model simulations. Are we able to constrain them sufficiently?