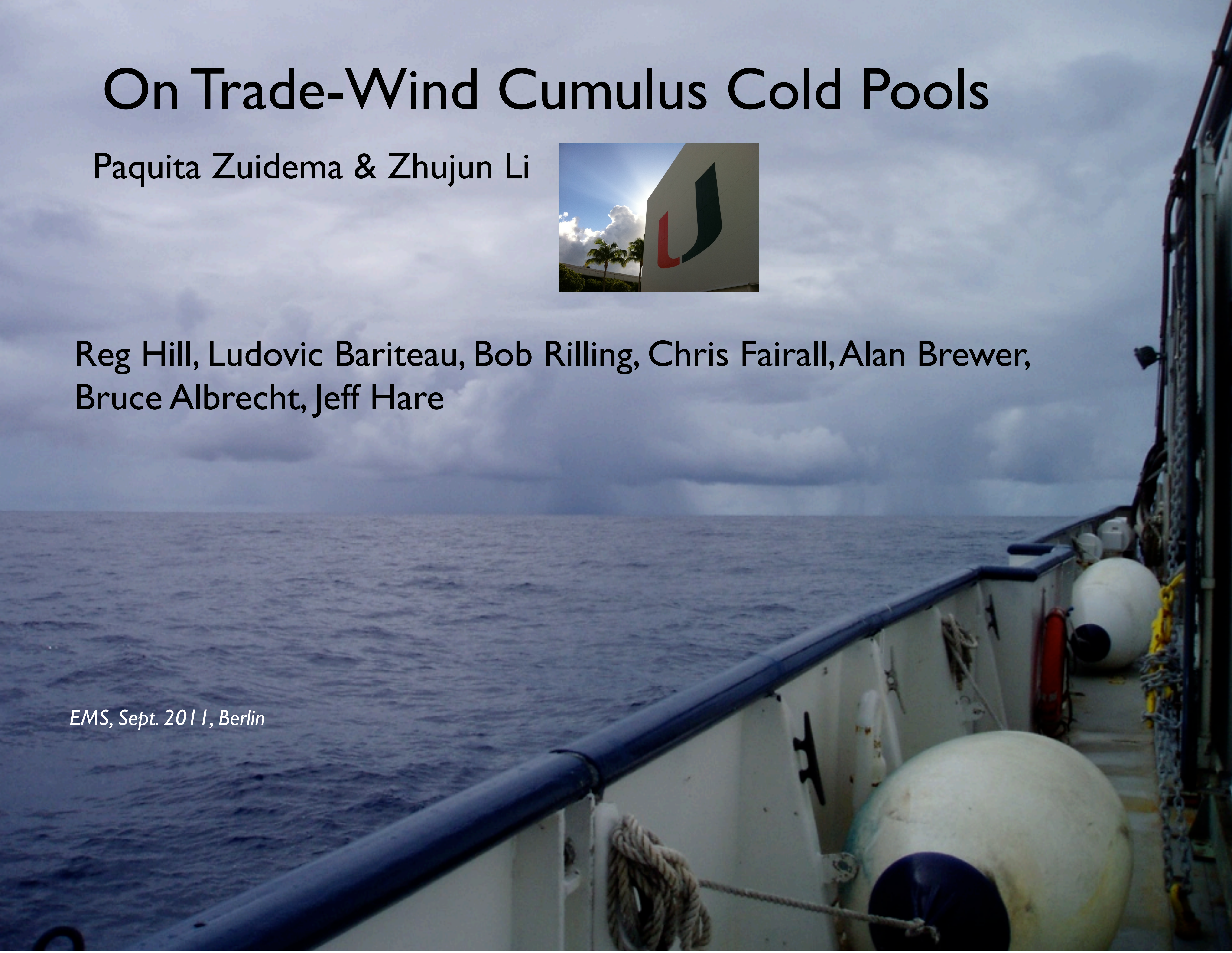
On Trade-Wind Cumulus Cold Pools

Paquita Zuidema & Zhujun Li

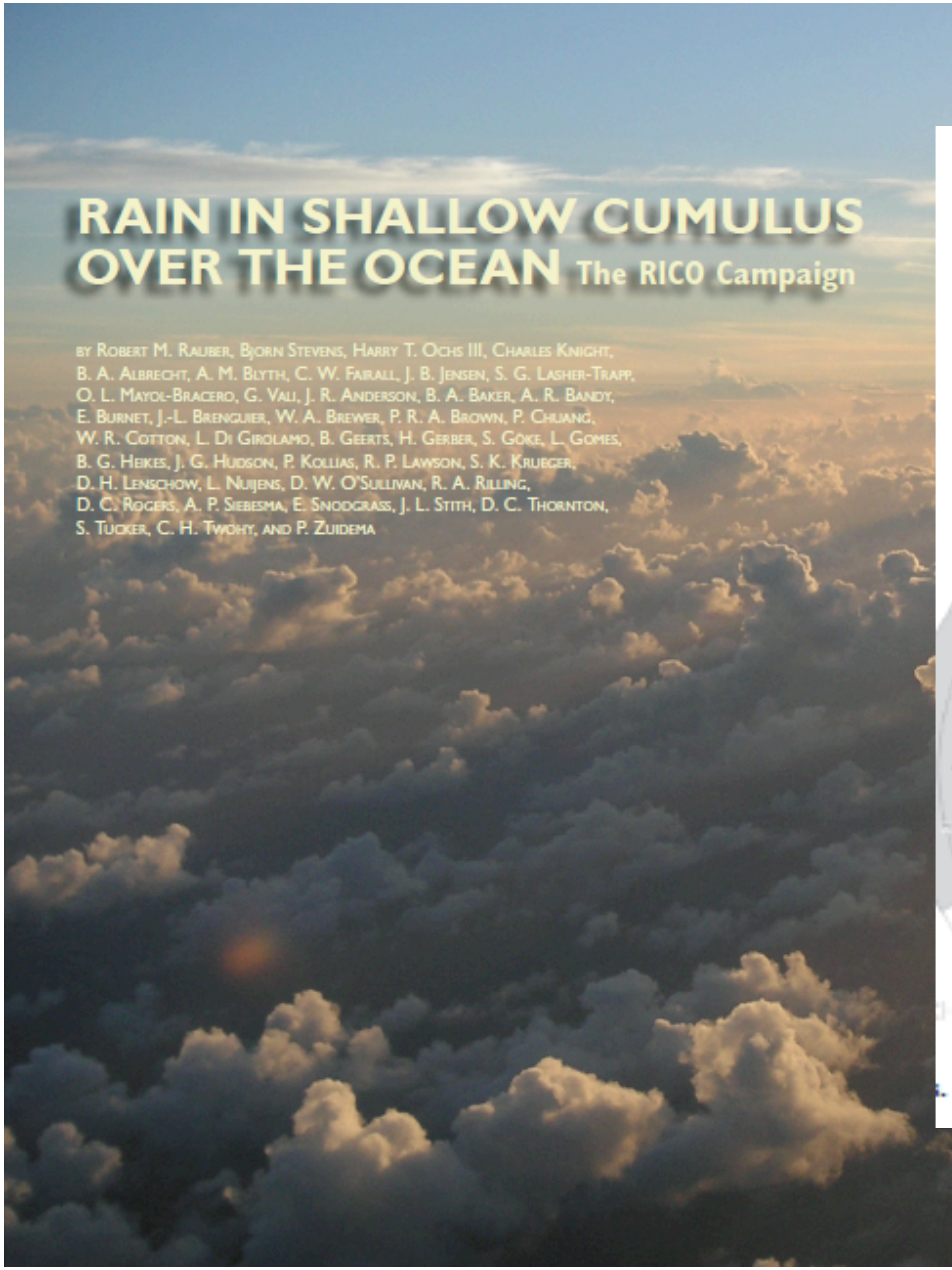
Reg Hill, Ludovic Bariteau, Bob Rilling, Chris Fairall, Alan Brewer,
Bruce Albrecht, Jeff Hare

EMS, Sept. 2011, Berlin



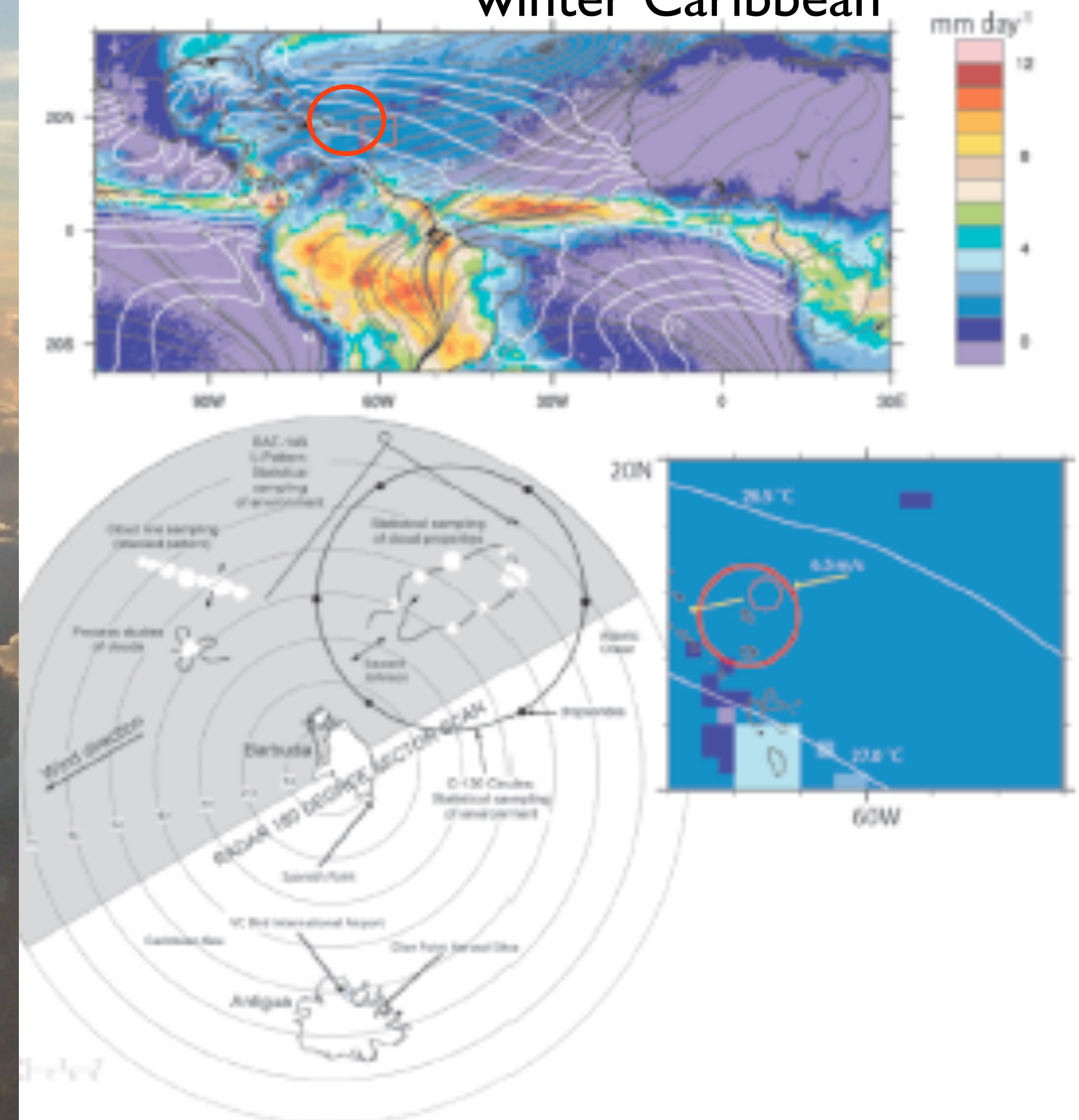
Rauber et al., 2007 BAMS

winter Caribbean



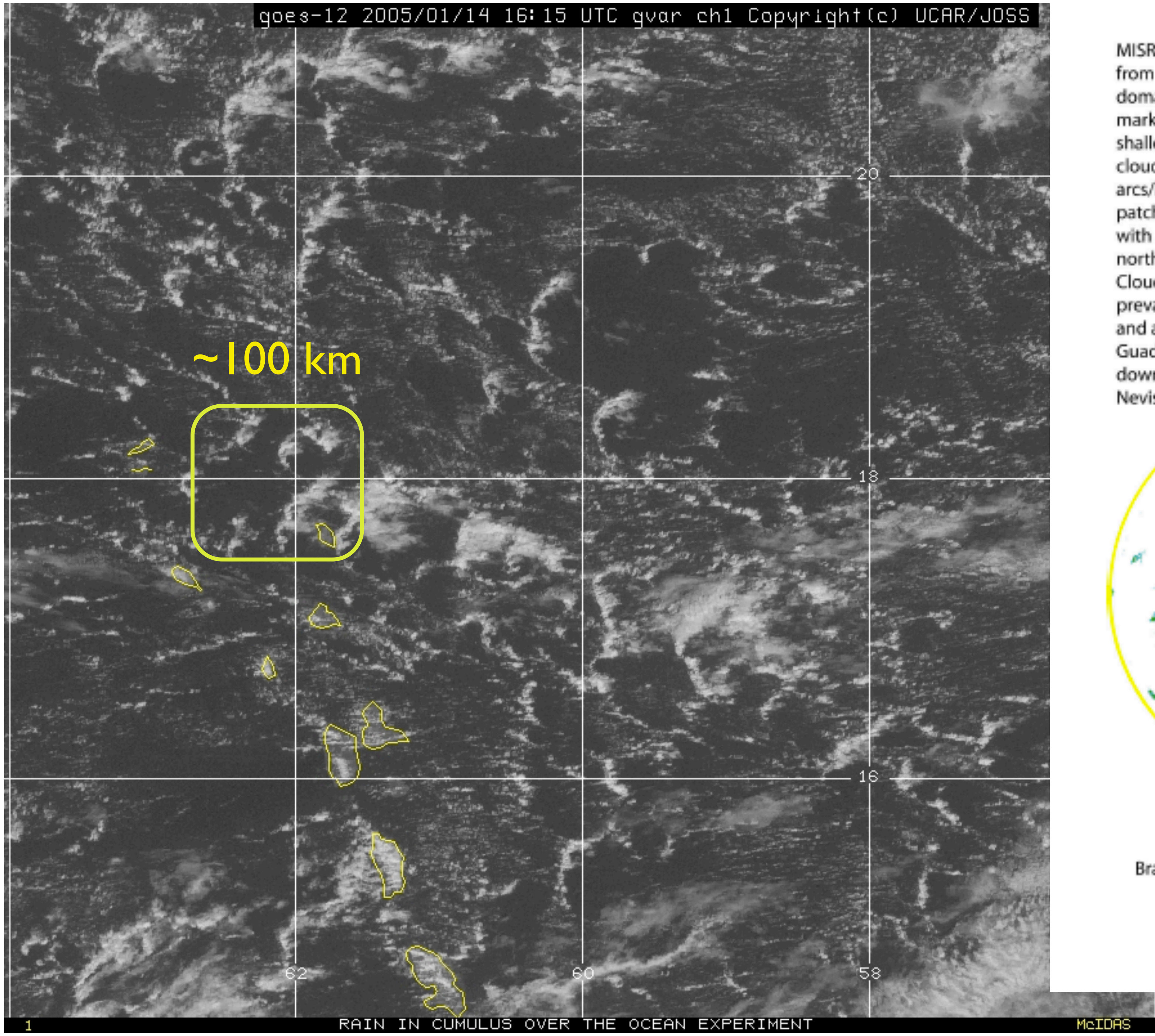
RAIN IN SHALLOW CUMULUS OVER THE OCEAN The RICO Campaign

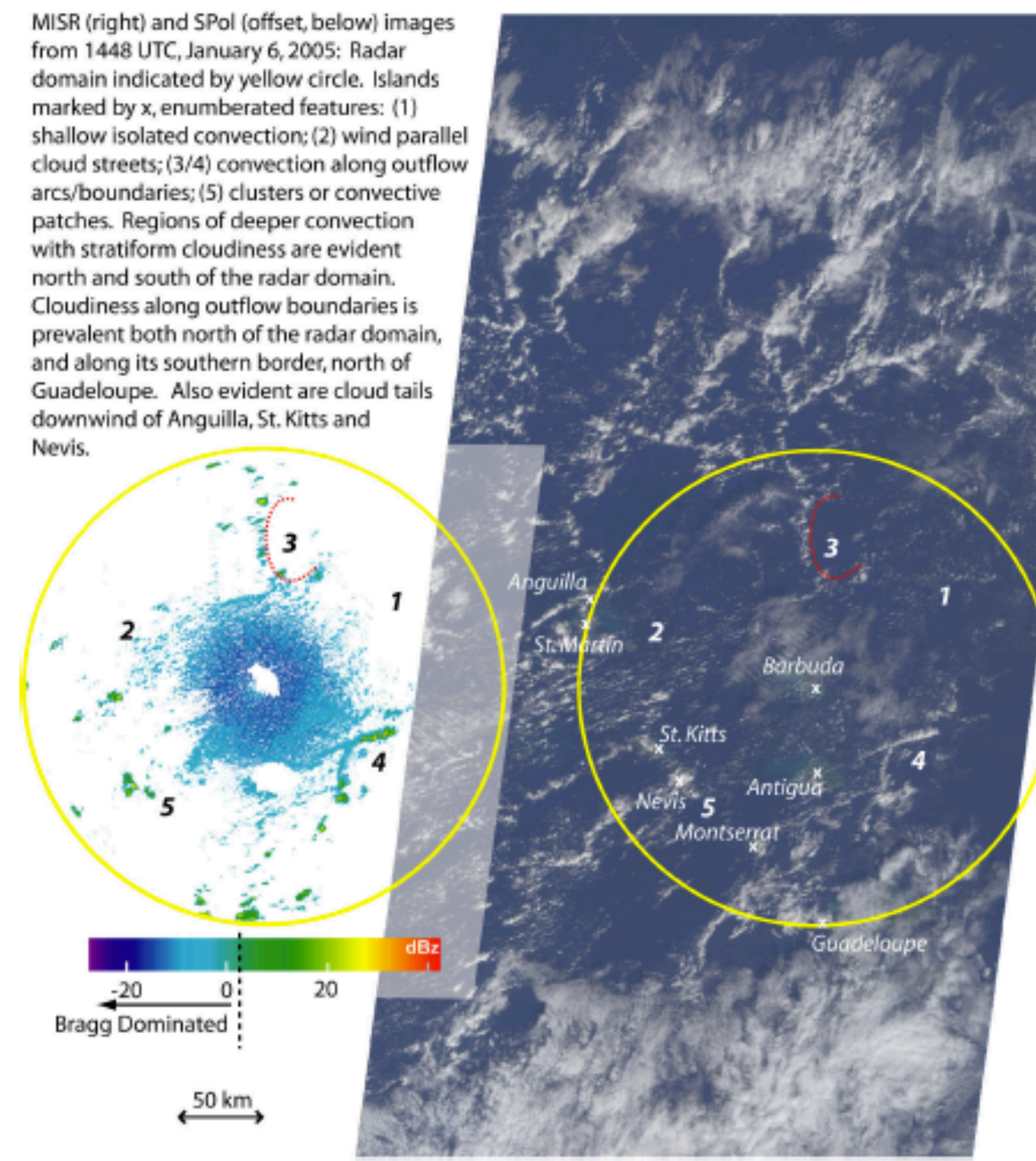
BY ROBERT M. RAUBER, BJORN STEVENS, HARRY T. OCHS III, CHARLES KNIGHT, B. A. ALBRECHT, A. M. BLYTH, C. W. FAIRALL, J. B. JENSEN, S. G. LASHER-TRAPP, O. L. MAYOL-BRACERO, G. VALI, J. R. ANDERSON, B. A. BAKER, A. R. BANDY, E. BURNET, J.-L. BRENGUIER, W. A. BREWER, P. R. A. BROWN, P. CHUANG, W. R. COTTON, L. DI GIROLAMO, B. GEERTS, H. GERBER, S. GÖKE, L. GOMES, B. G. HEIKES, J. G. HUDSON, P. KOLLIAS, R. P. LAWSON, S. K. KRUEGER, D. H. LENSCHOW, L. NUIJENS, D. W. O'SULLIVAN, R. A. RILLING, D. C. ROGERS, A. P. SIEBESMA, E. SNODGRASS, J. L. STITH, D. C. THORNTON, S. TUCKER, C. H. TWOHY, AND P. ZUIDEMA



. 1. RICO experimental area, sampling strategy, and climatology.

key finding from RICO: nearly all cloud producing > 1 mm/hr rainrates associated with arc-shaped formations reminiscent of cold pool outflow boundaries





Rauber et al. 2007

Precipitation Characteristics of Trade Wind Clouds during RICO Derived from Radar, Satellite, and Aircraft Measurements

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ABSTRACT

Precipitation characteristics of trade wind clouds over the Atlantic Ocean near Barbuda are derived from radar and aircraft data and are compared with satellite-observed cloud fields collected during the Rain in Cumulus over the Ocean (RICO) field campaign. S-band reflectivity measurements Z were converted to rainfall rates R using a Z–R relationship derived from aircraft measurements. Daily rainfall rates varied from 0 to 22 mm day^{-1}. The area-averaged rainfall rate for the 62-day period was 2.37 mm day^{-1}. If corrected for evaporation below cloud base, this value is reduced to 2.23 mm day^{-1}, which translates to a latent heat flux to the atmosphere of 63 W m^{-2}. When compared with the wintertime ocean-surface latent heat flux from this region, the average return of water to the ocean through precipitation processes within the trade wind layer during RICO was 31%–39%. A weak diurnal cycle was observed in the area-averaged rainfall rate. The magnitude of the rainfall and the frequency of its occurrence had a maximum in the predawn hours and a minimum in the midmorning to early afternoon on 64% of the days. Radar data were collocated with data from the Multiangle Imaging Spectroradiometer (MISR) to develop relationships between cloud-top height, cloud fraction, 866-nm bidirectional reflectance factor (BRF), and radar-derived precipitation. The collocation took place at the overpass time of ~1045 local time. These relationships revealed that between 5.5% and 10.5% of the cloudy area had rainfall rates that were > 0.1 mm h^{-1}, and between 1.5% and 3.5% of the cloudy area had rainfall rates that were >1 mm h^{-1}. Cloud-top heights between ~3 and 4 km and BRFs between 0.4 and 1.0 contributed ~50% of the total rainfall. For cloudy pixels having detectable rain, average rainfall rates increased from ~1 to 4 mm h^{-1} as cloud-top heights increased from ~1 to 4 km. Rainfall rates were closely tied to the type of mesoscale organization, with much of the rainfall originating from shallow (<5 km) cumulus clusters shaped as arcs associated with cold-pool outflows.

visually determined

open questions:

how does shallow cumulus precipitation relate to the subcloud layer energetics & thermodynamic structure?

can we learn anything about the convective triggering mechanism?

what are the characteristics of the cold pools?


combine ship-based data (flux, radar & lidar;
R/V Seward Johnson, Jan. 9-25, 2005) with satellite imagery &
S-Pol radar data


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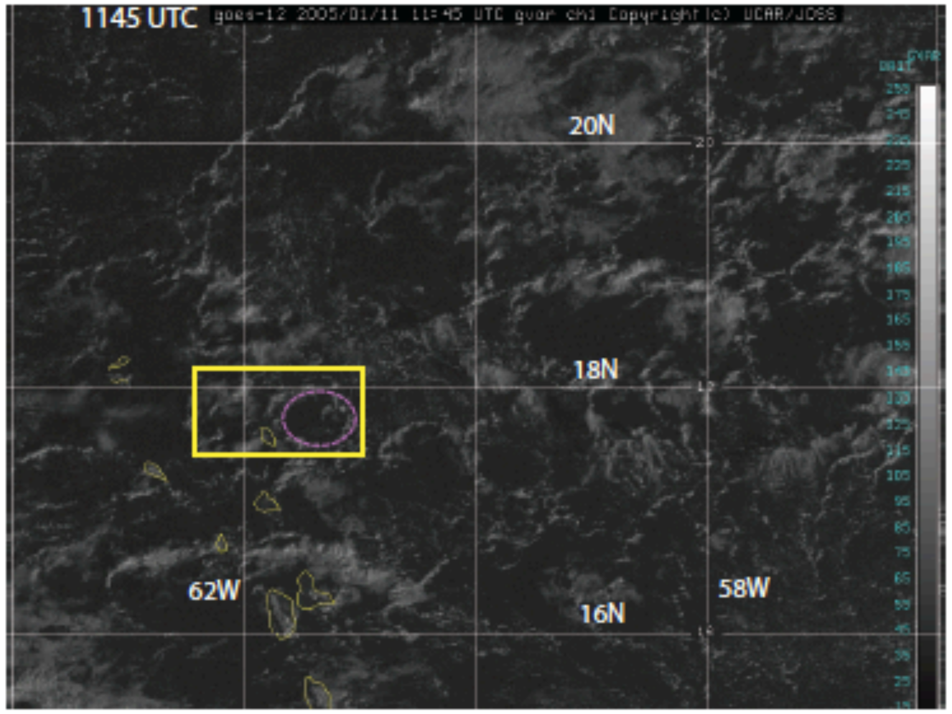
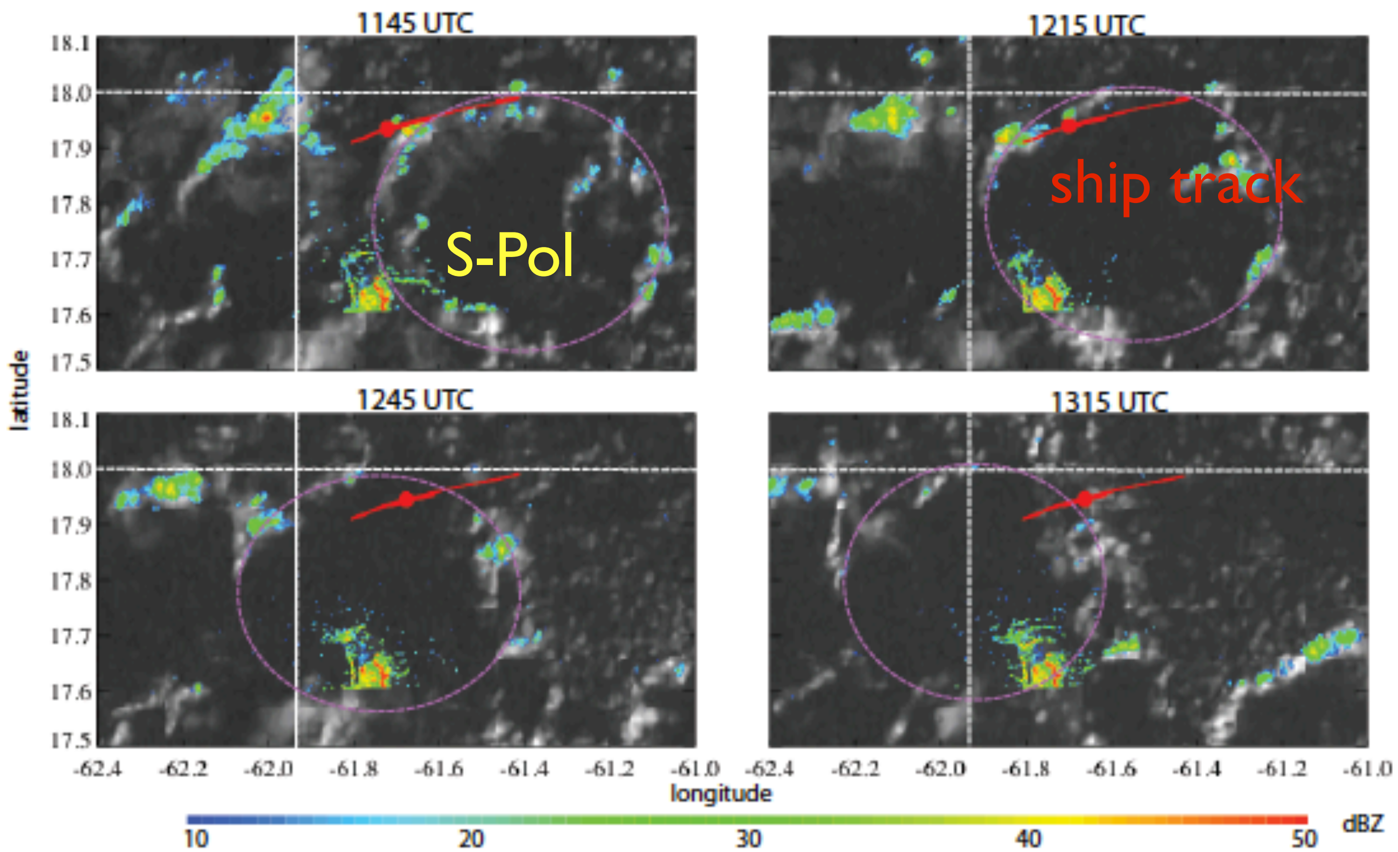
(R/V Seward Johnson, Jan. 9-25, 2005) with satellite imagery &
S-Pol radar data
no a-priori expectations

11 Jan

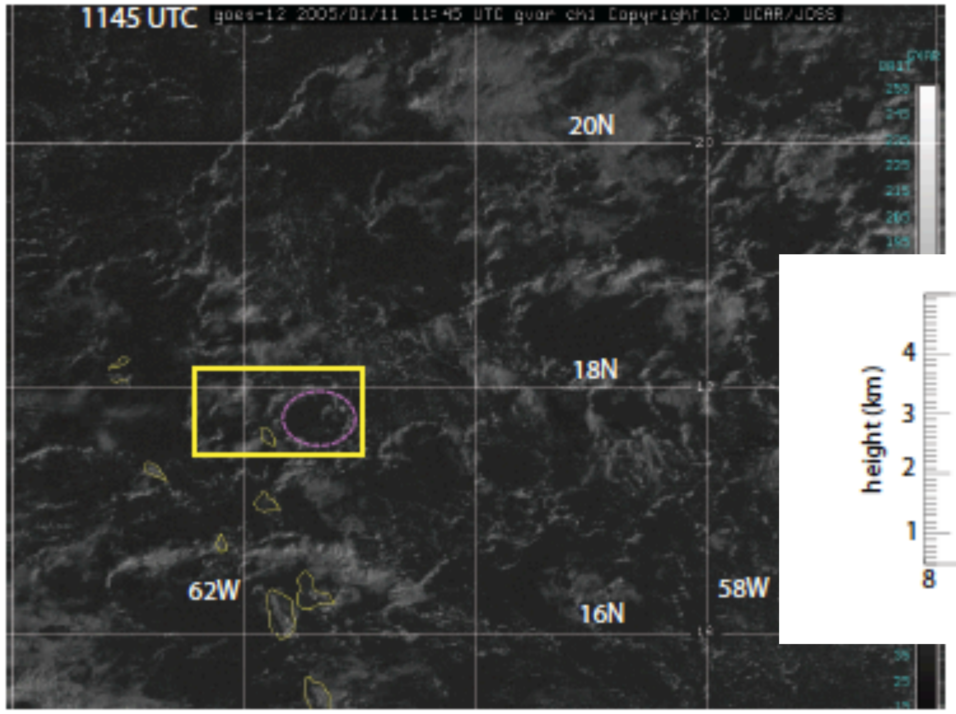


1145 UTC
20N
18N
16N
62W
58W



1145 UTC
1215 UTC
1245 UTC
1315 UTC
S-Pol
ship track
latitude
longitude
dBZ

11 Jan


1145 UTC
20N
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16N
62W
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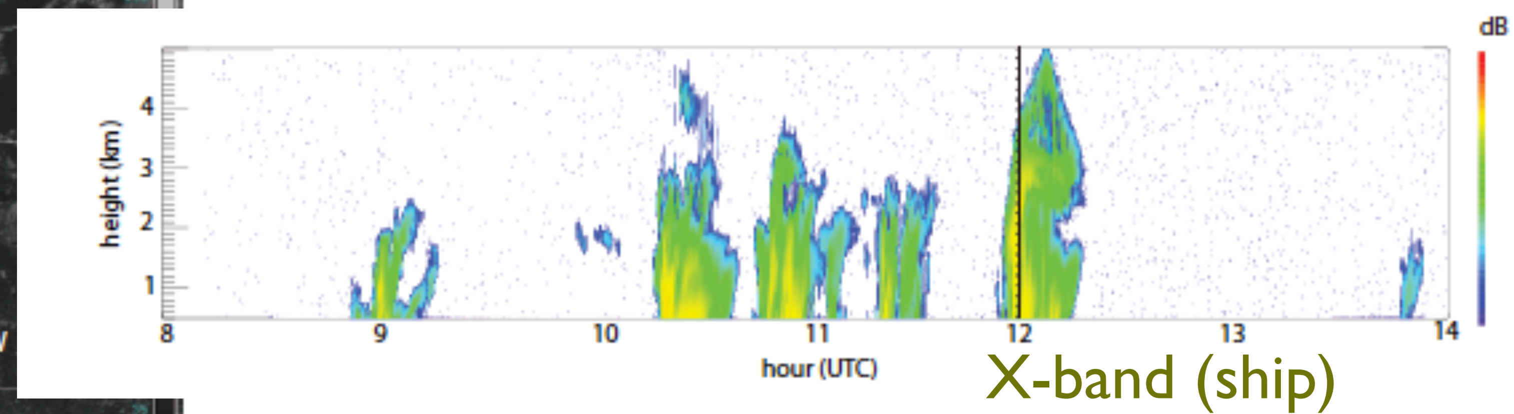
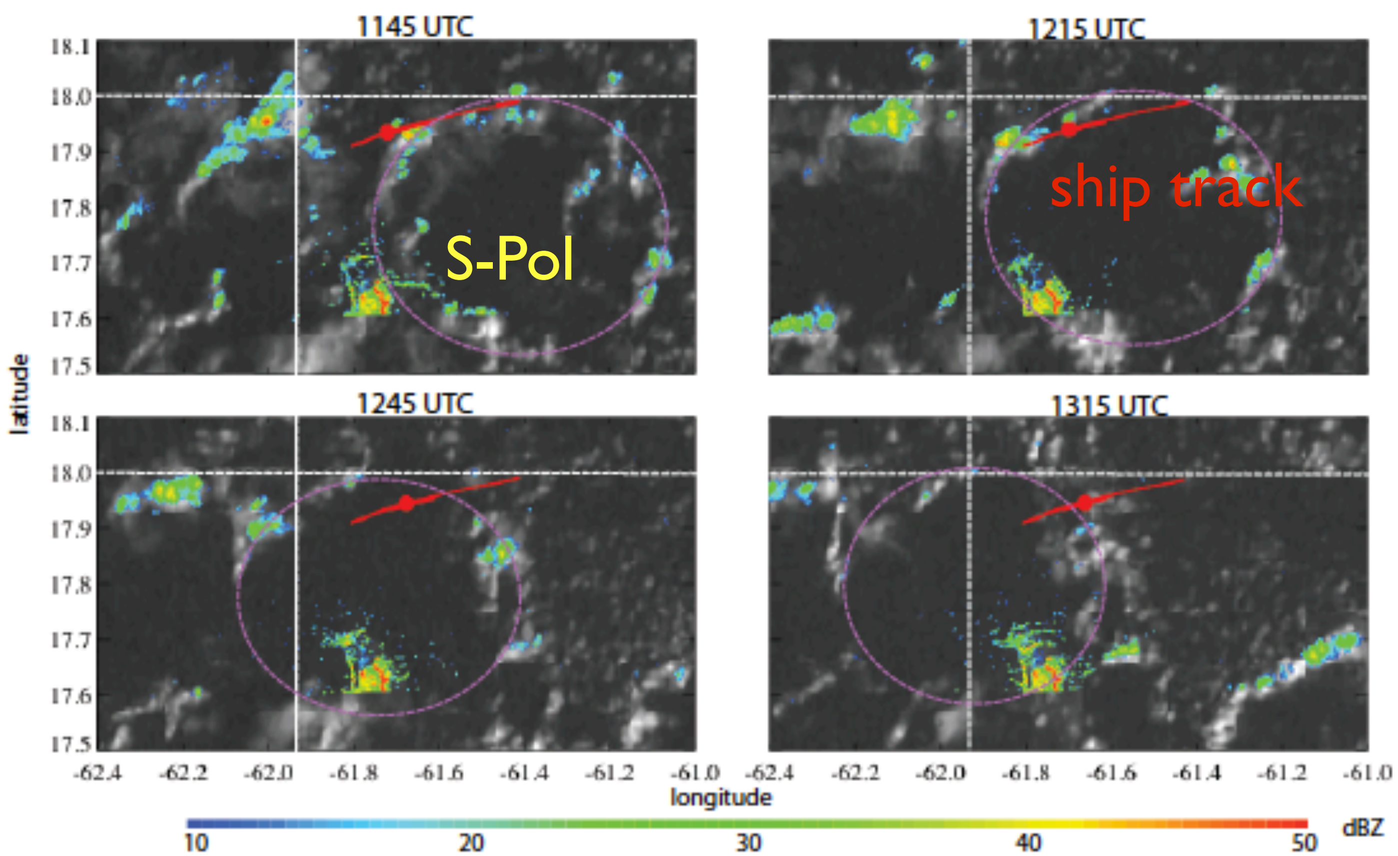

height (km)
hour (UTC)
dB
X-band (ship)


1145 UTC
1215 UTC
1245 UTC
1315 UTC
S-Pol
ship track
latitude
longitude
dBZ

during 9-24 January:

37 recorded surface rain events

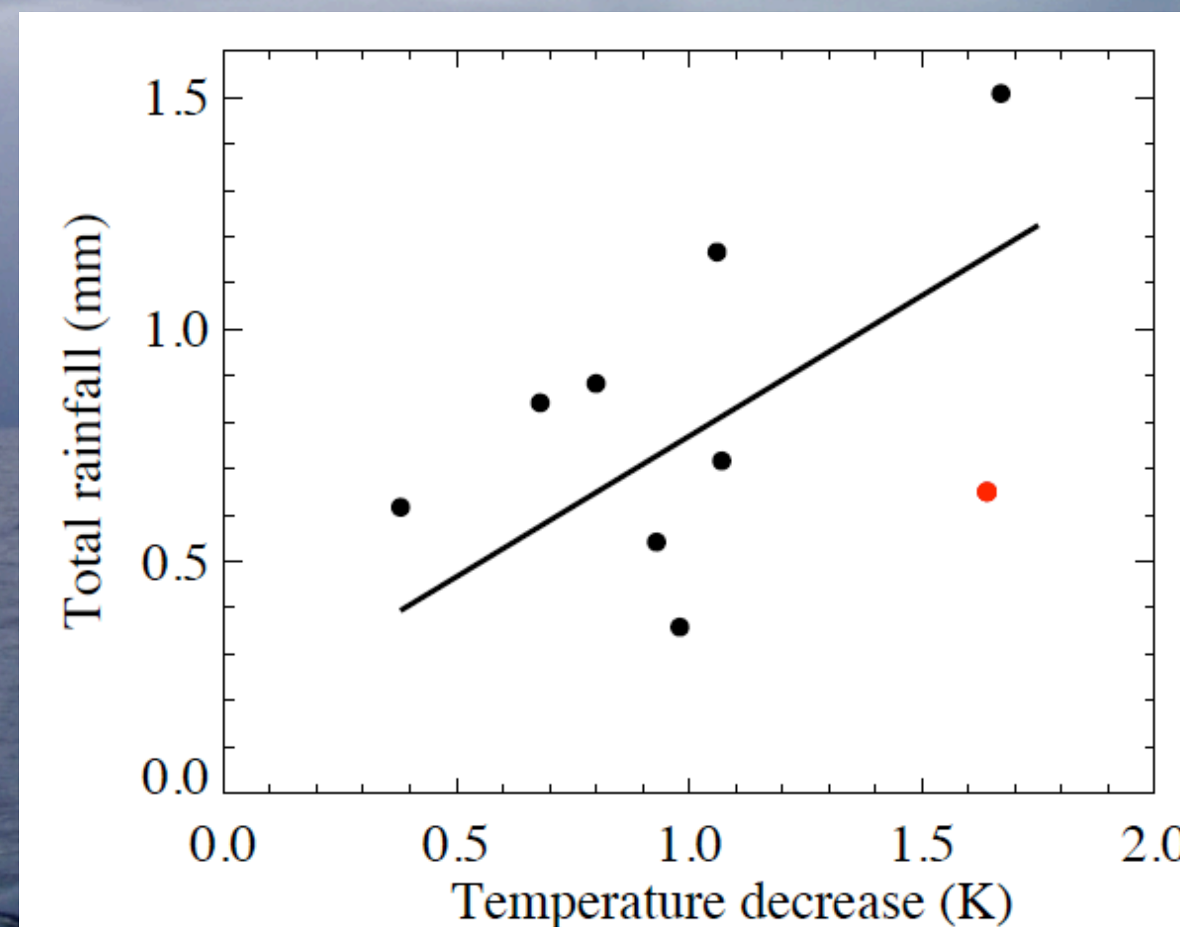
17 on ‘undisturbed’ days *(Nuijens et al., 2009)*

15 clearly associated with mesoscale arcs

10 through convection center

& > 2 mm/hr max. rainrate

> 2km cloud depth (X-band)



pre-rain to rain maximum

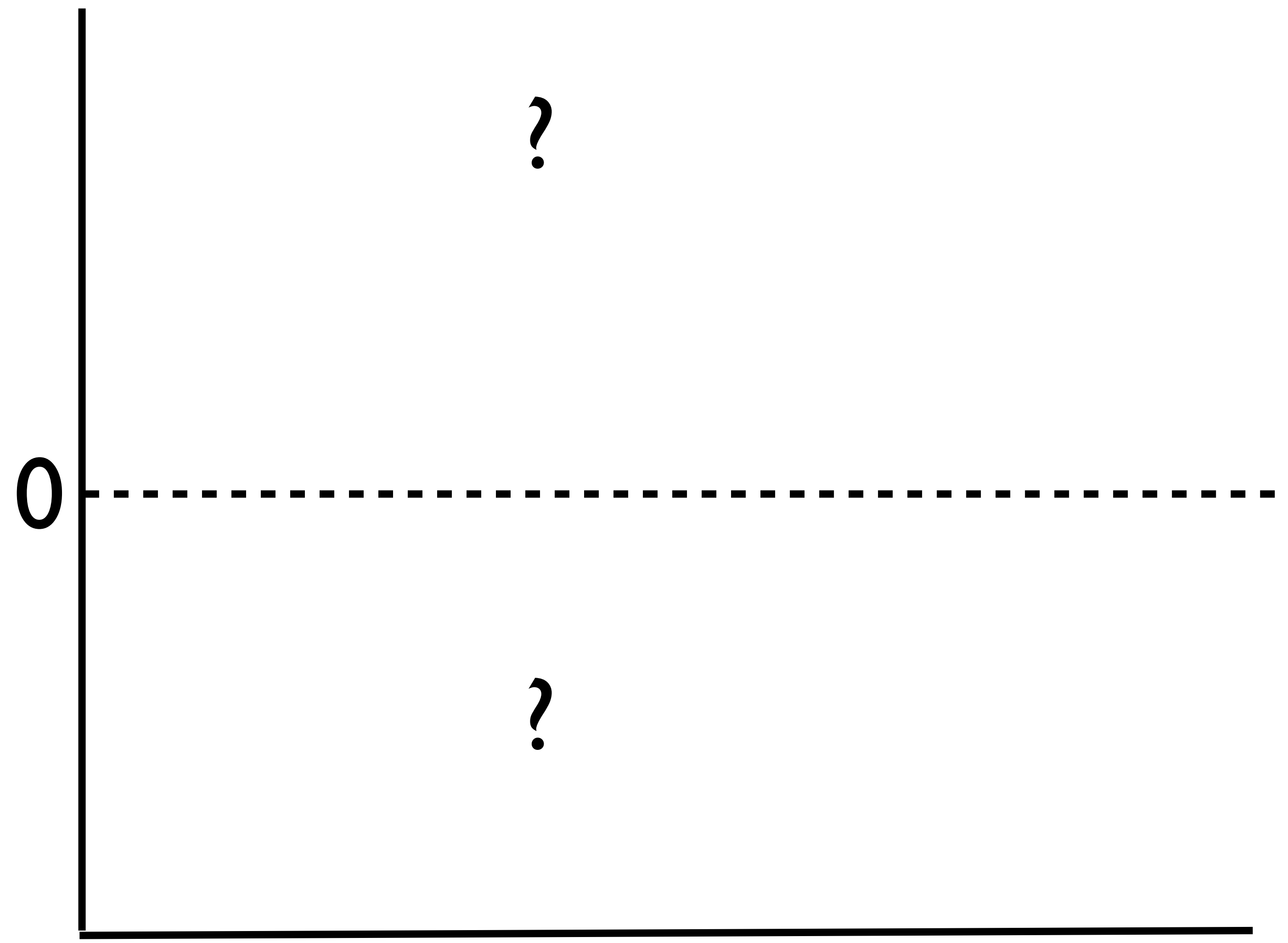
‘cold pool’: a region or ‘pool’ of relatively colder air surrounded by warmer air; any large-scale mass of colder air *(AMS glossary)*

sought an explicit connection to precip:

beginning: > 0 mm/hr

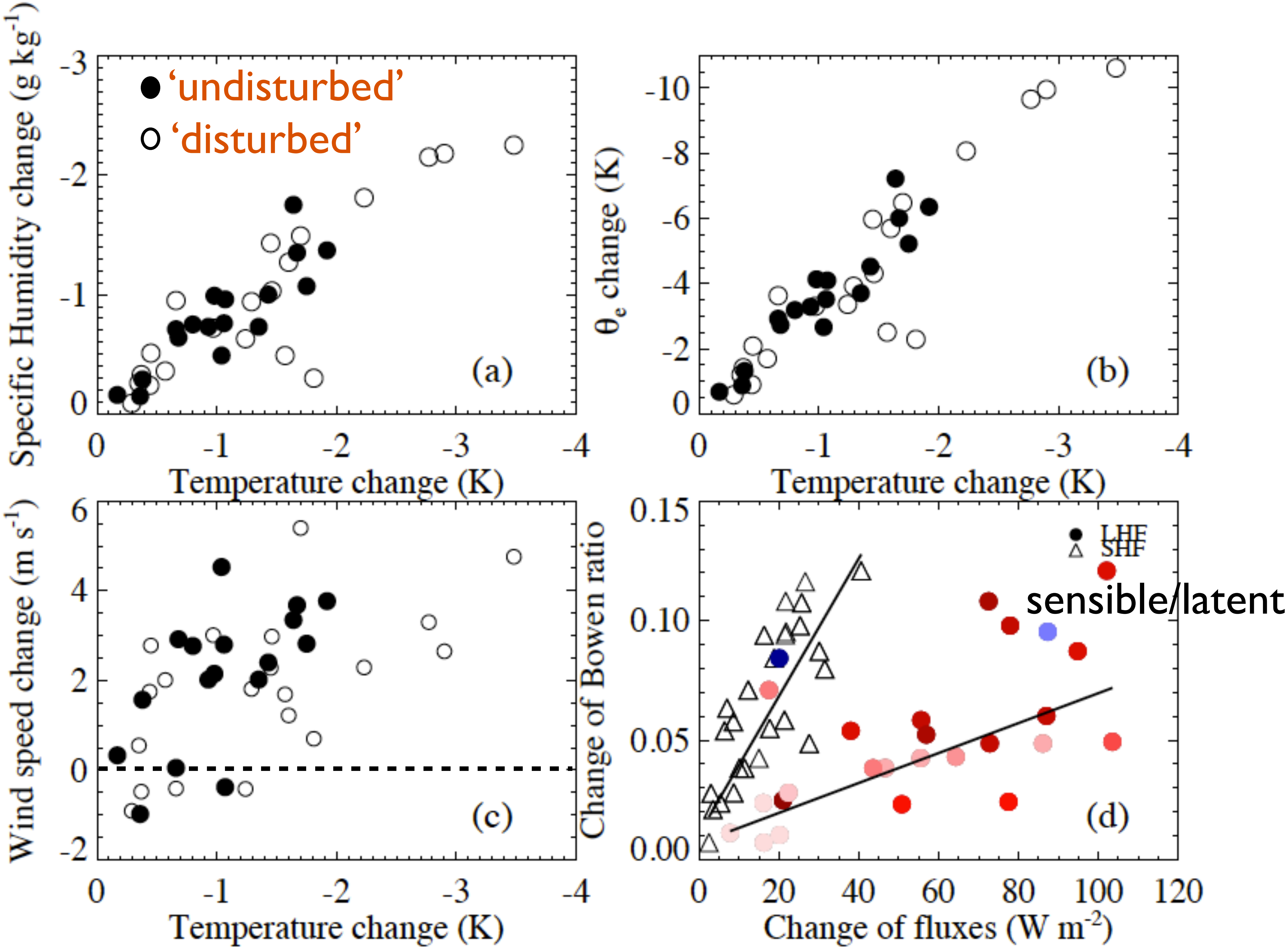
end: T_{air} ~ SST or max T_{air}

q_v, θ_e, u

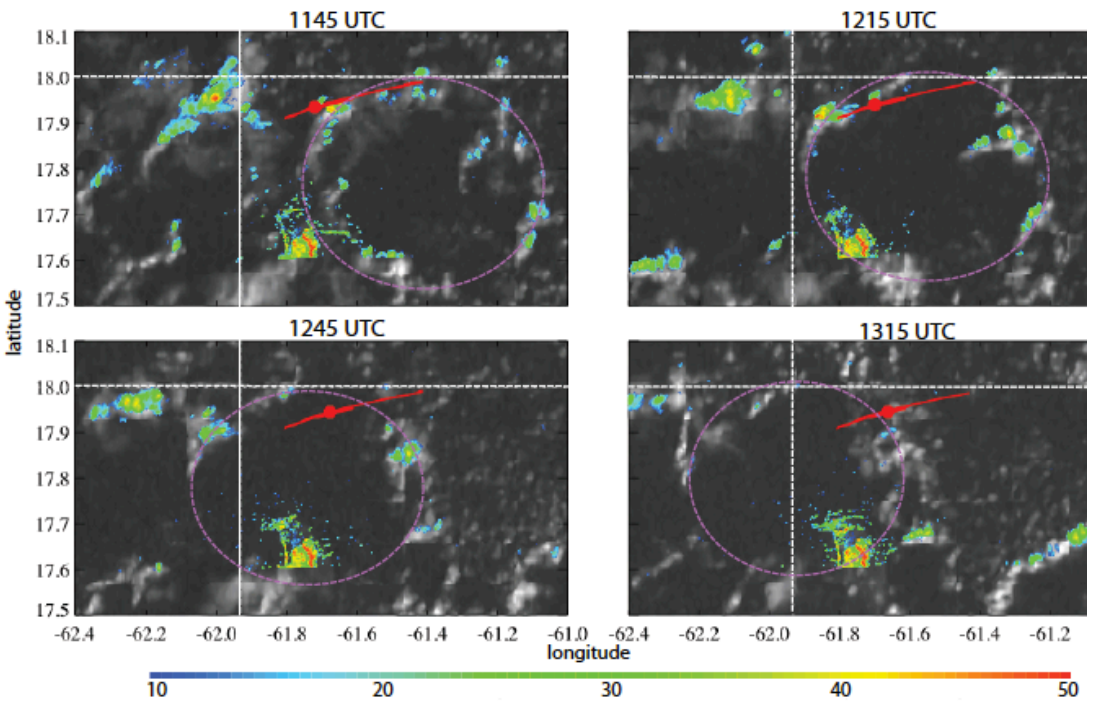


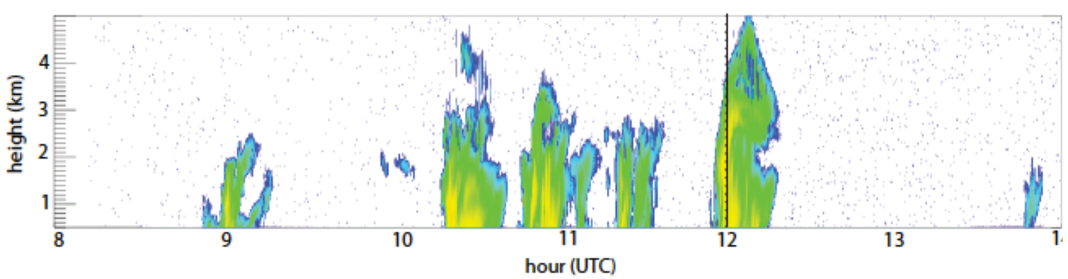
T decrease

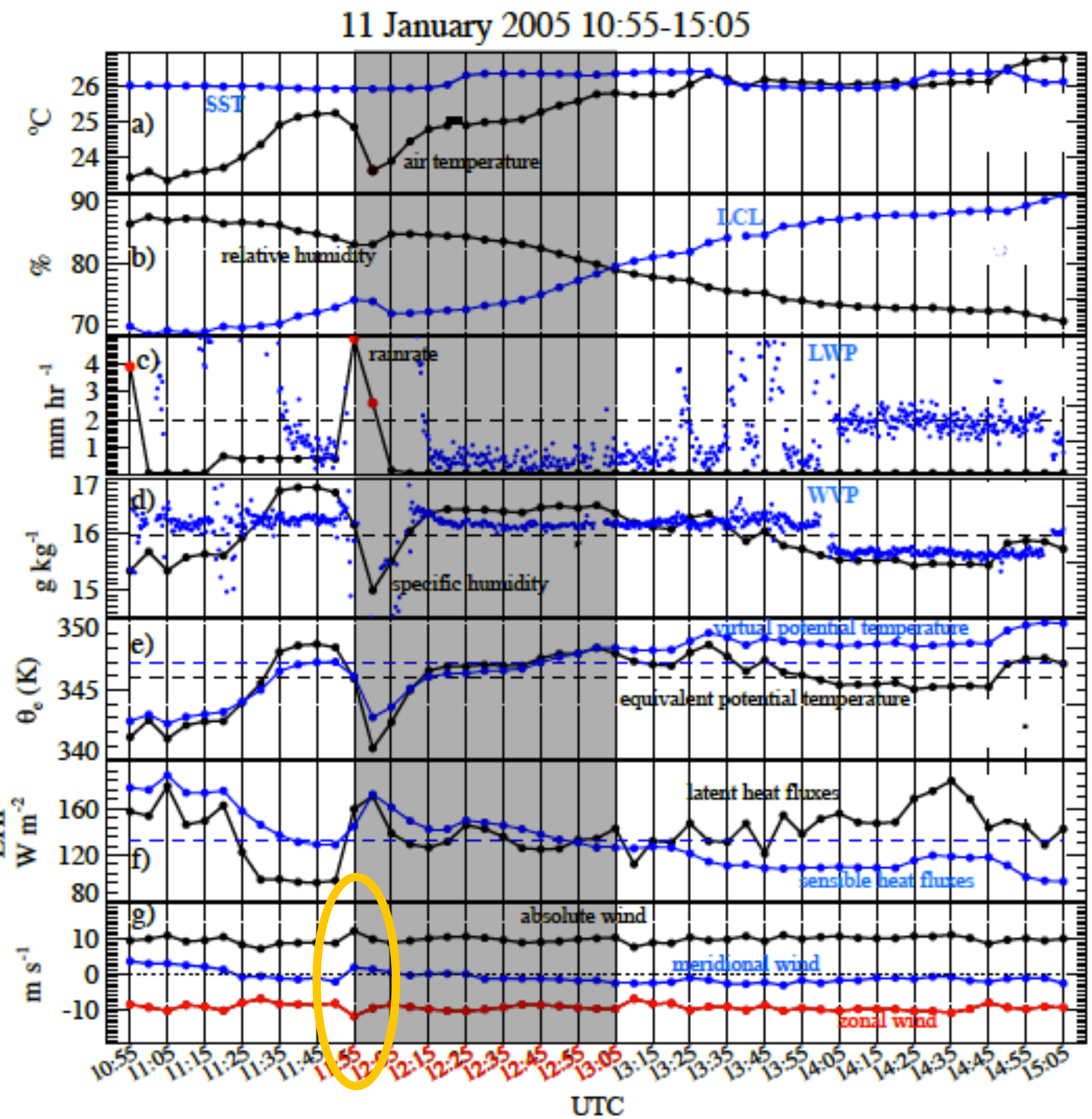
pre-rain to rainrate max.



pre-rain to maximum rainrate


1145 UTC
1215 UTC
1245 UTC
1315 UTC
latitude
longitude


height (km)
hour (UTC)


11 January 2005 10:55-15:05
SST
air temperature
relative humidity
LCL
rainrate
LWP
WVP
specific humidity
virtual potential temperature
equivalent potential temperature
latent heat fluxes
sensible heat fluxes
absolute wind
meridional wind
zonal wind
UTC

our current view

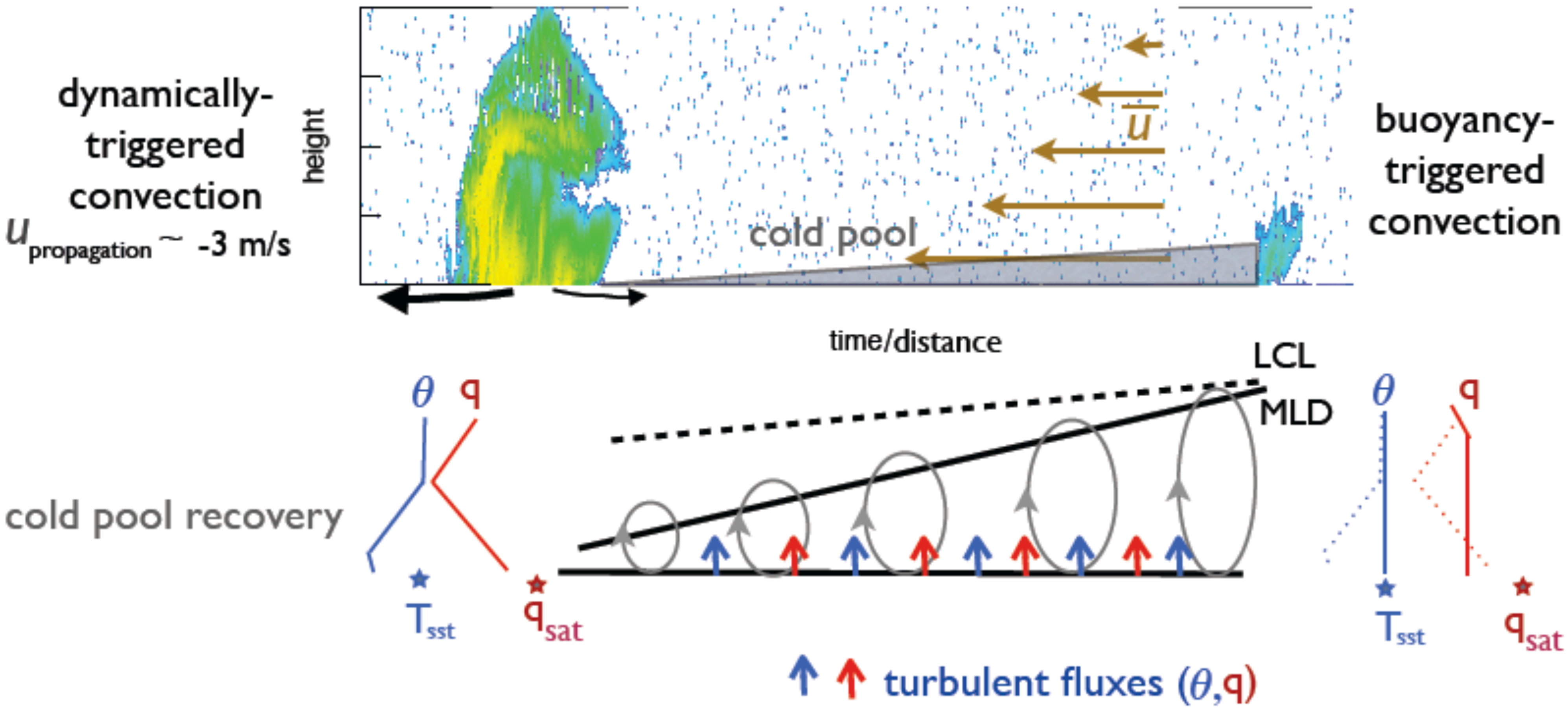


FIG. 21. Schematic of propagating precipitating shallow convection and the cold pool recovery. Radar reflectivity exam
is from January 11, 12-14 UTC. $\bar{u}$ is the mean wind speed, MLD is mixed-layer depth.

just accepted into JAS (not yet on early on-line release)

ABSTRACT

Shallow, precipitating, cumuli within the easterly trades were investigated using ship-board measurements, scanning radar data, and visible satellite imagery from two weeks in January 2005 of the Rain in Cumulus over Ocean experiment. Shipboard rainfall rates of up to 2 mm hr^{-1} were recorded almost daily, if only for 10-30 minutes typically, almost always from clouds within mesoscale arcs. The precipitating cumuli, capable of reaching above 4 km, cooled surface air by 1-2 K, in all cases lowered surface specific humidities by up to 1.5 g kg^{-1}, reduced surface equivalent potential temperatures by up to 6 K, and were often associated with short-lived increases in wind speed. Upper-level downdrafts were inferred to explain double-lobed moisture and temperature sounding profiles, and multiple inversions in wind profiler data. In two cases investigated further, the precipitating convection propagated faster westward than the mean surface wind by $\sim$ 2-3 m s^{-1}, consistent with a density current of depth $\sim$ 200 m. In their cold pool recovery zones, the surface air temperatures equilibrated with time to the sea surface temperatures, but the surface air specific humidities stayed relatively constant after initial quick recoveries. This suggested entrainment of drier air from above fully compensated moistening from surface latent heat fluxes. Recovery zone surface wind speeds and latent heat fluxes were not higher than environmental values. Non-precipitating clouds developed after the surface buoyancy had recovered (barring encroachment of other convection). The mesoscale arcs favored atmospheres with higher water vapor paths. These observations differed from those of stratocumulus and deep tropical cumulus cold pools.


Thank you !
Questions/Comments?