Understanding the low cloud reduction and its diurnal cycle within the smoky boundary layer in the remote SE Atlantic

UNIVERSITY OF MIAMI
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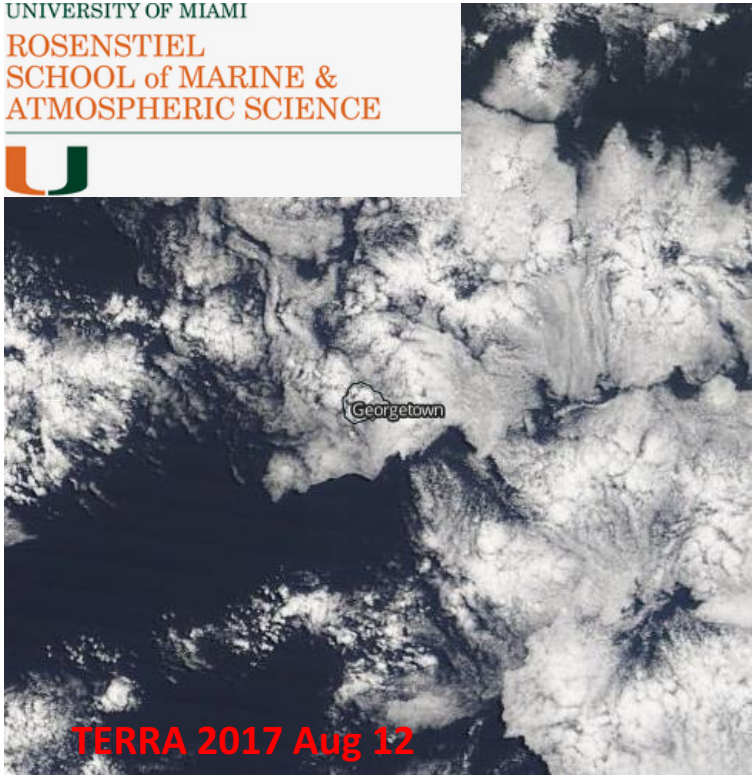
ATMOSPHERIC SCIENCE



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and

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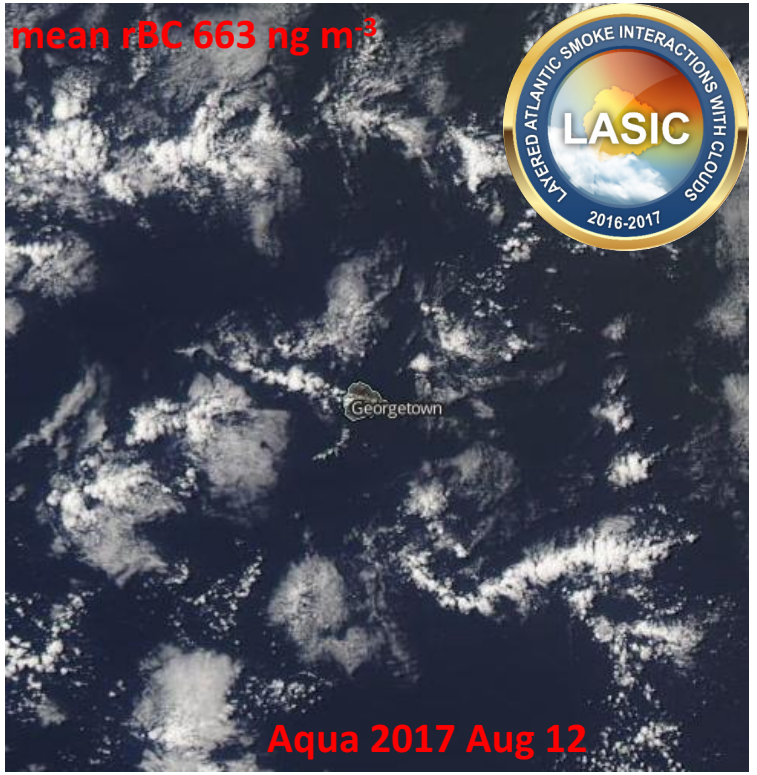

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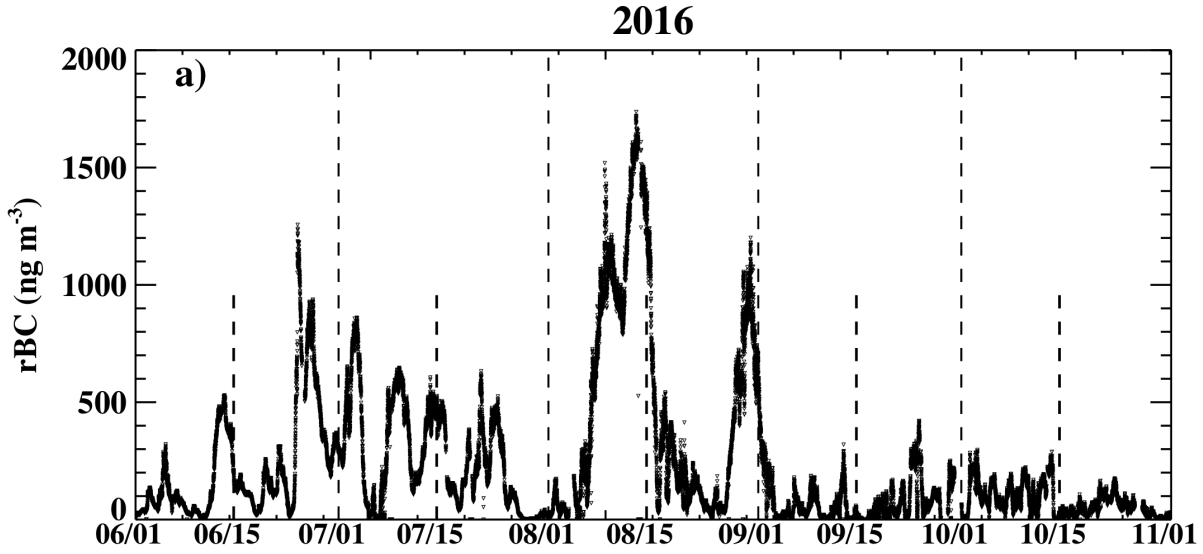
Motivated by stratocumulus thickening by the biomass burning aerosols shown previous in the SE Atlantic

- Previous studies showed **increase in LWP** and **cloudiness** in the SE Atlantic region when smoke plume overlays the stratocumulus. *[Johnson et al. 2004, Wilcox 2010, Adebiyi et al. 2015]*
- New measurements at **Ascension Island** during the DOE AMF1 LASIC campaign reveal high concentration of light absorbing aerosols in the boundary layer during June-August.
- How do clouds respond to presence of aerosol **in the BL**?

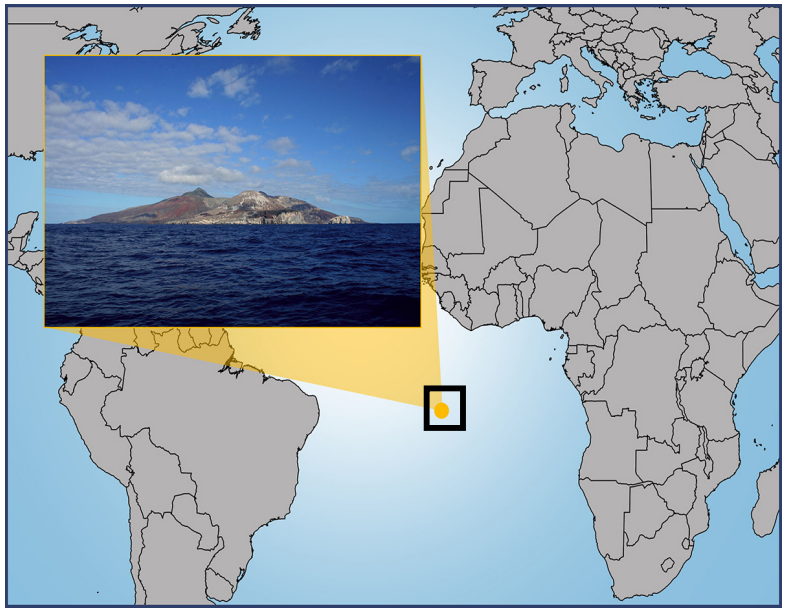


The LASIC Field Campaign at Ascension Island

Layered Atlantic Smoke Interactions with Clouds (LASIC)

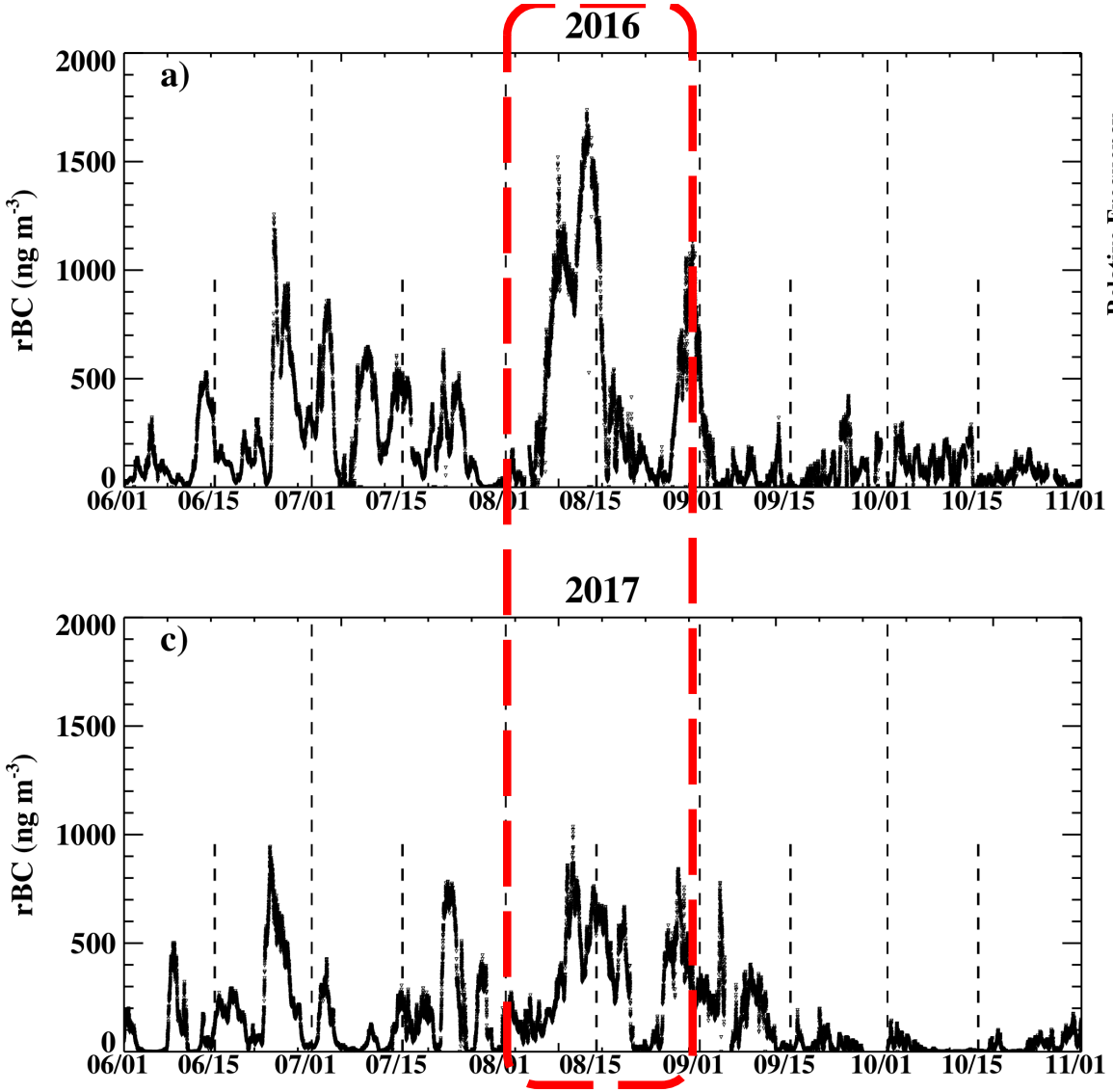
Surface-based observations

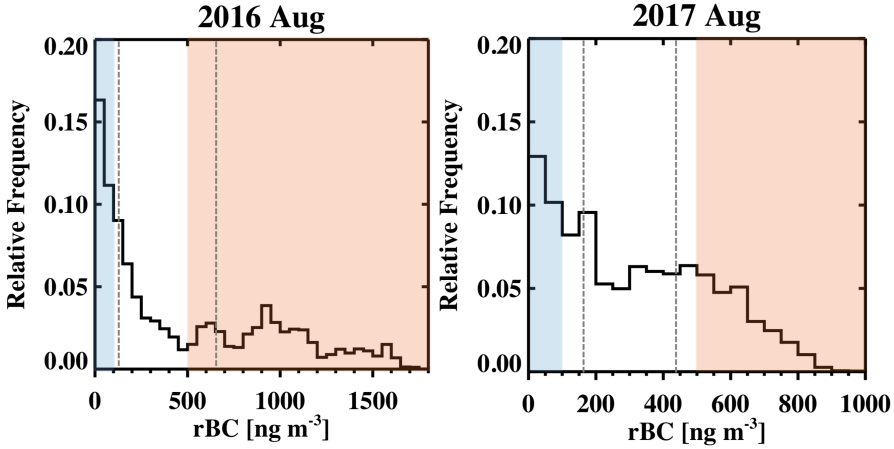
- 17 months, two biomass burning seasons
- 8x or 4x daily **radiosondes**
- DOE ARM Mobile Facility **1** (SP2, MWR, KAZR…)



Satellite Retrievals

- **4º x 4º** centered on slightly east of ASI (6S-10S, 15W-11W)
- **SEVIRI** hourly VISST product (onboard Meteosat10)
- **CERES** (1-degree SYN, daily) from Aqua & Terra



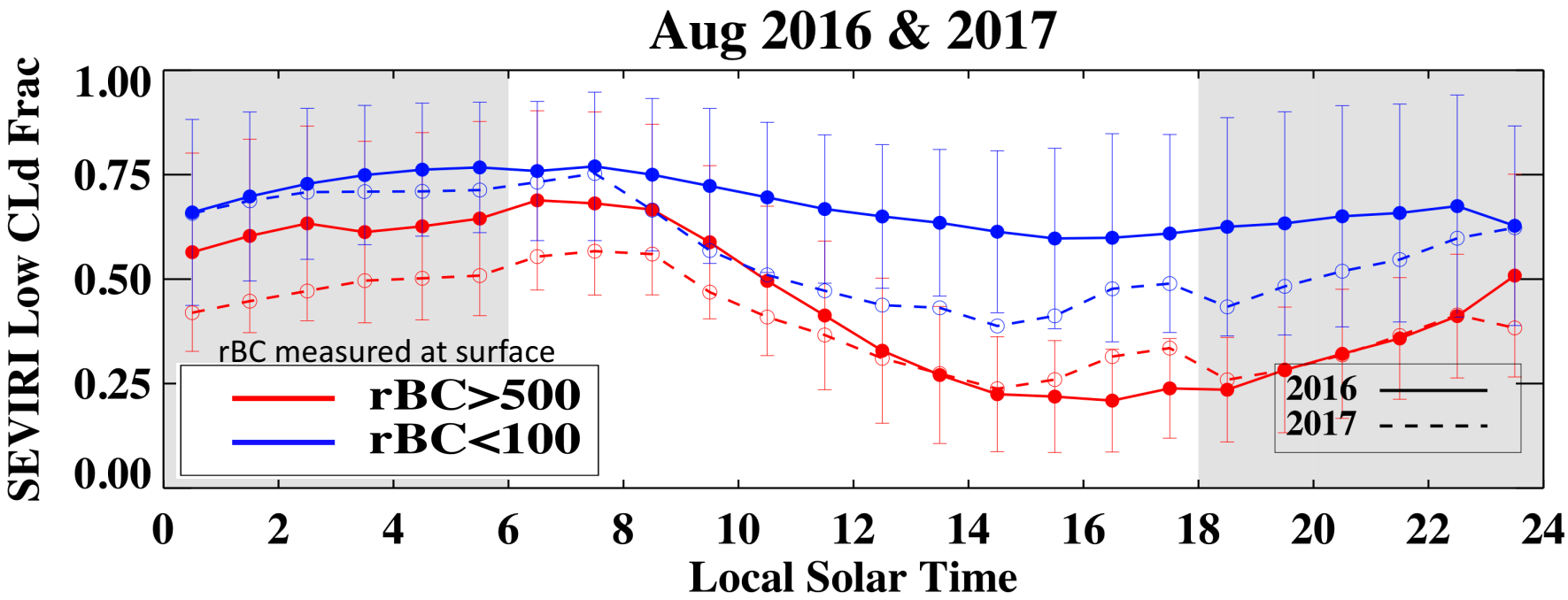


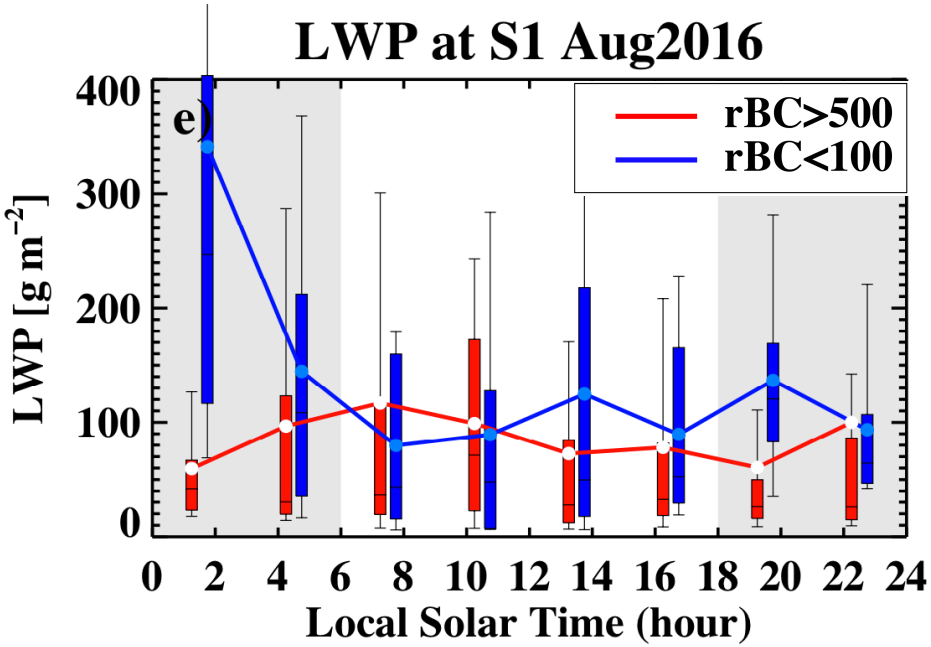
more smoky (rBC > 500)
vs less smoky (rBC < 100)

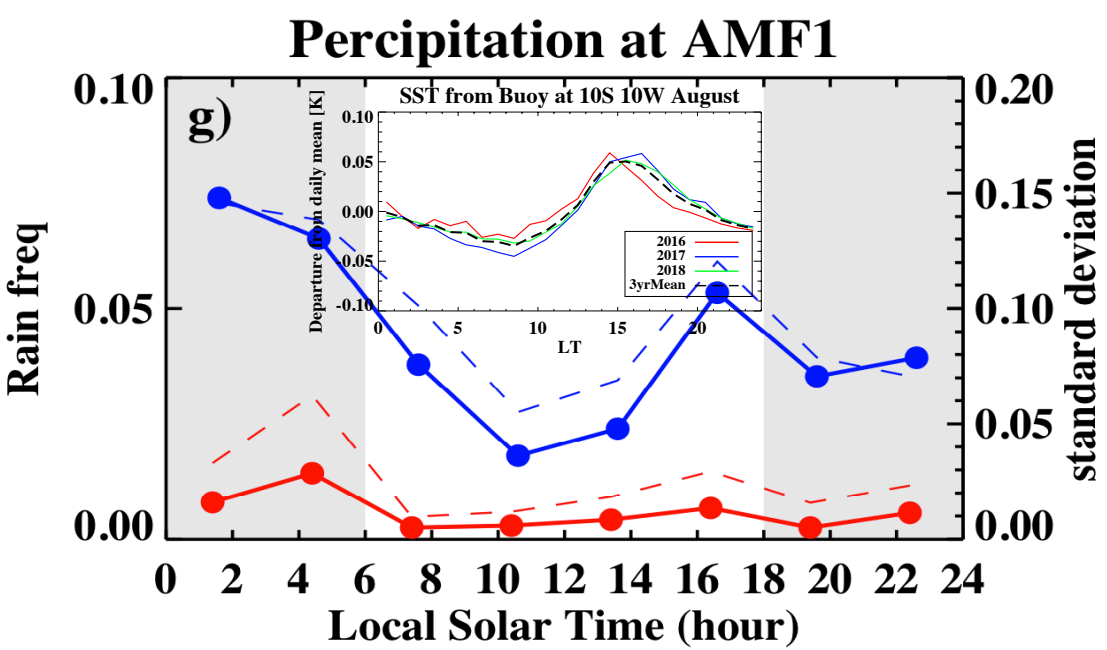
The most black carbon is present within the boundary layer at Ascension in August

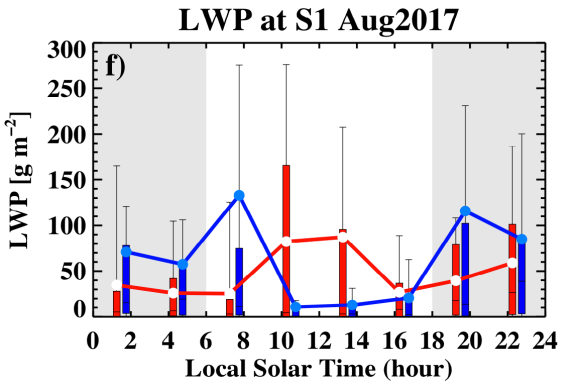
Less low cloud cover when the BL is smokier, in August, most apparent in afternoon

Hourly SEVIRI VISST Satellite Retrievals 4° x 4° centered on east of ASI– done to avoid local orographic effect & be general







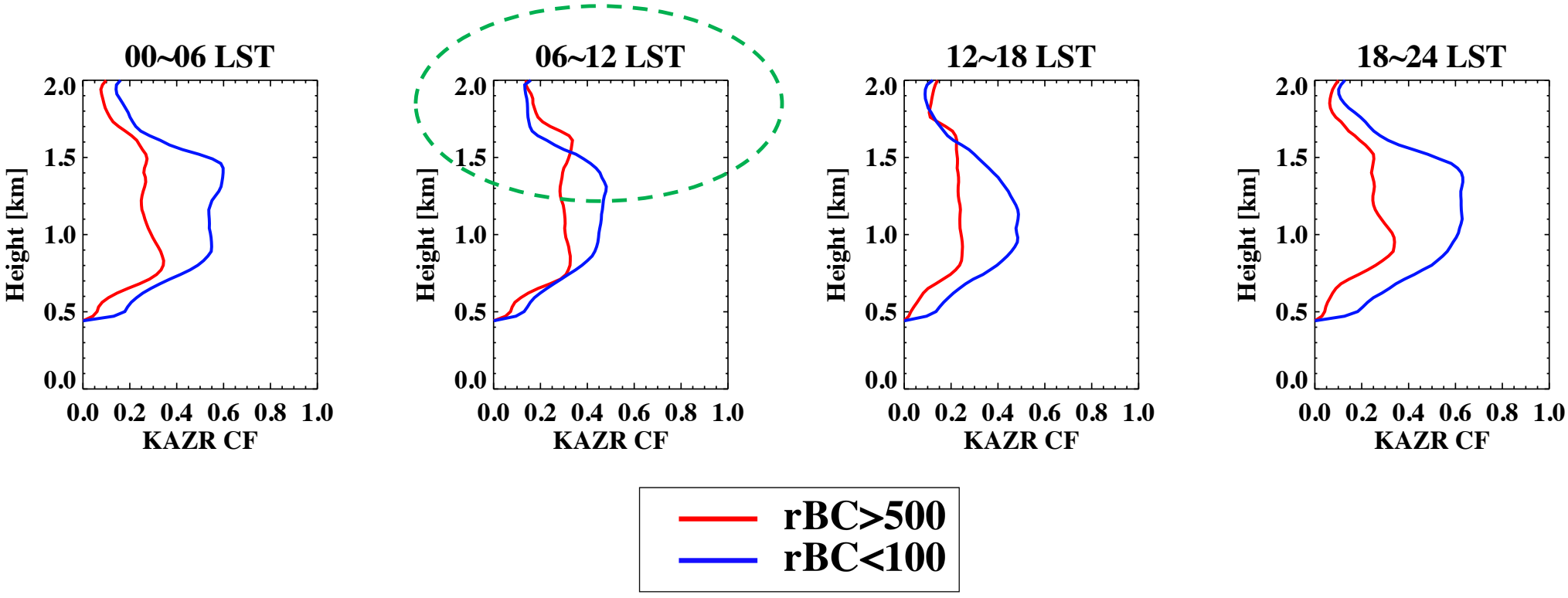


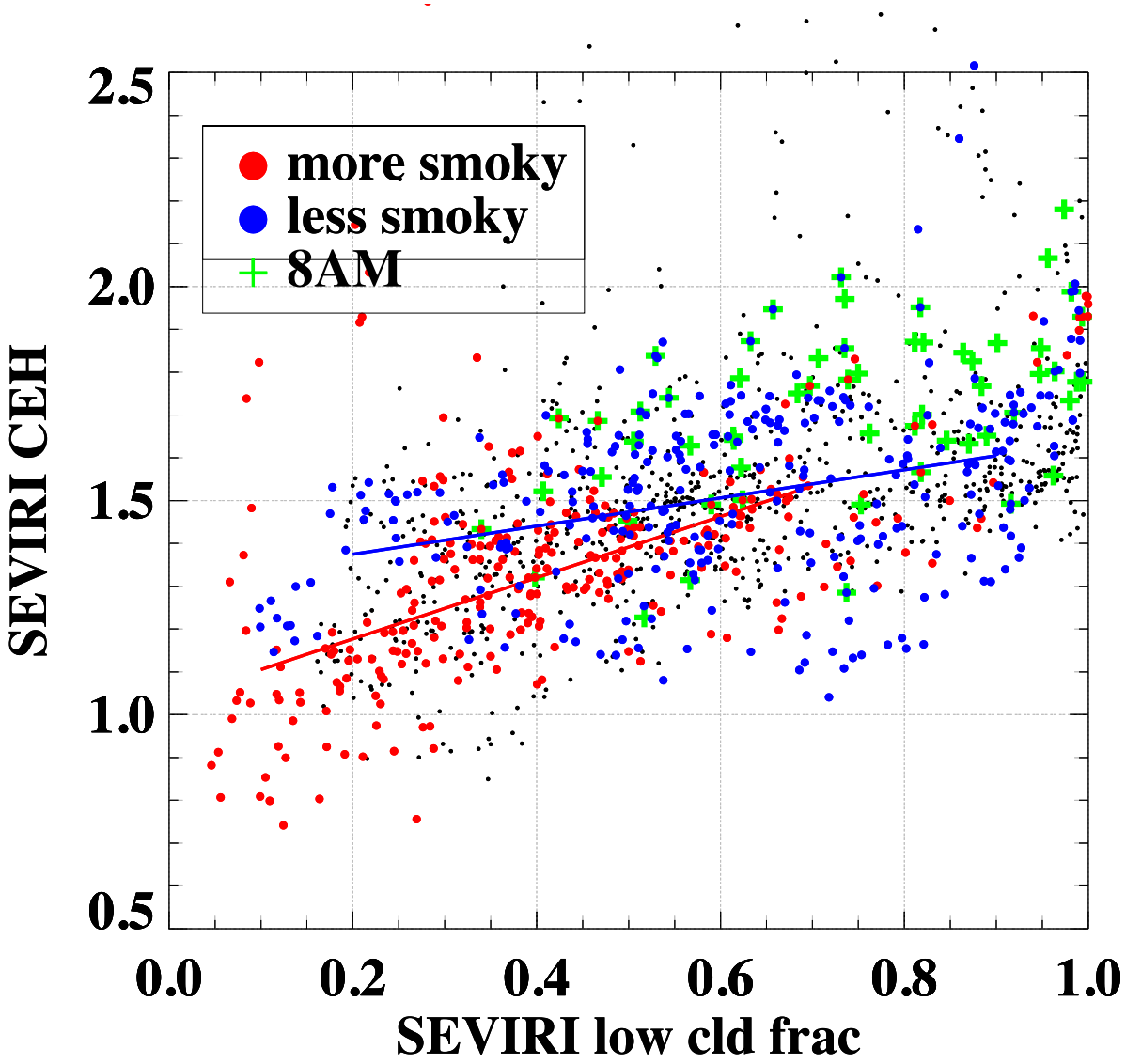
- LWP is lower (thinner clouds) when smoke is present, consistent with less cloud cover
- Early morning clouds are thicker
- LWP is reduced more at night than during the day, in contrast to the cloud cover

- Precipitation diurnal cycle, and its reduction by smoke (not surprising)
- nighttime maximum, when radiation only cools
- A smaller afternoon maximum when cumulus responds to a warmer ocean

Deeper, if fewer, clouds, apparent in radar CFADs after sunrise when BL is smokier

KAZR-derived cld freq (dBz>-35) as a function of altitude



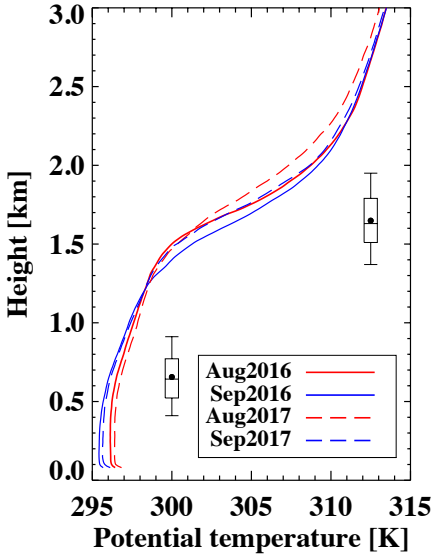


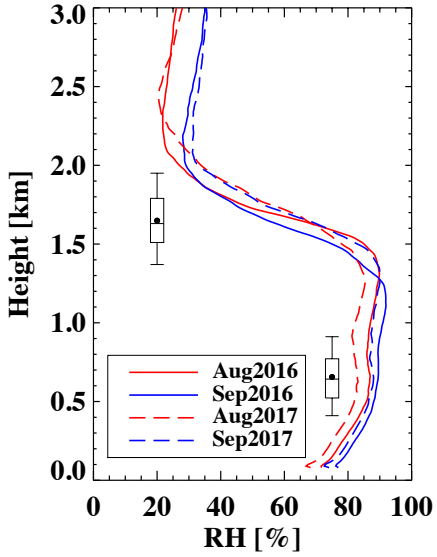
Lower cloud tops when smoky (consistent with thinner clouds), except for early morning

Low cloud reduction by black carbon shown previously by *Ackerman et al., (2000)* "Reduction of tropical cloudiness by soot" (INDOEX)

- This goes counter to how we have been thinking about the dominant semi-direct effect in the southeast Atlantic (StratoCu deck enhanced)

- *Pistone et al. 2016* & *Wilcox et al. 2016* (CARDEX): smoke in the BL suppresses turbulence in the sub-cloud layer, lower PBL and higher LWP



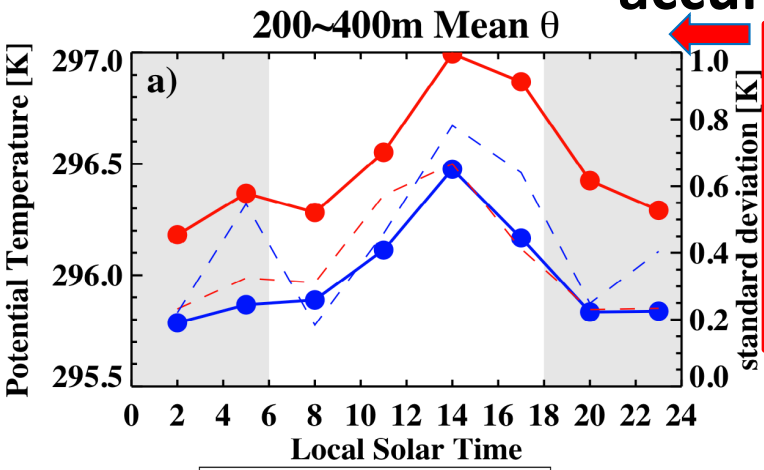


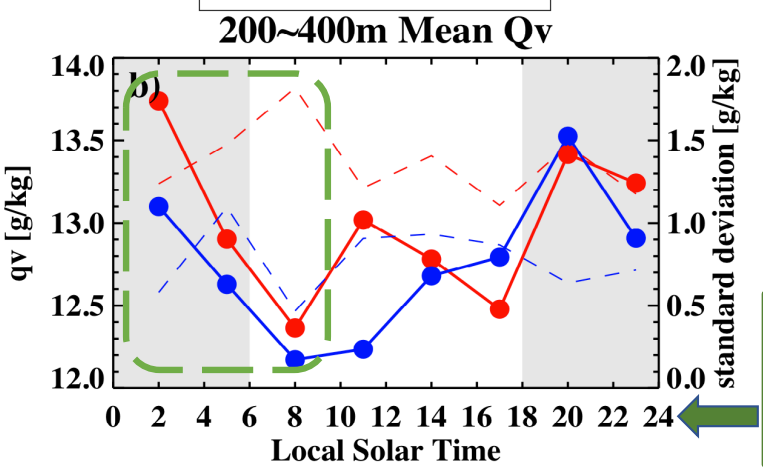
- But meteorology/aerosol vertical structure different over the Indian Ocean than remote SEA.

- BL depth 1.5km ~ 1.8km
- often decoupled
- 2 layers of cloud

- LASIC measurements resolved across the diurnal cycle should provide new process insights. (8x or 4x daily radiosondes)

Sub-cloud layer warms, reducing RH during the day - but moisture accumulates during the night





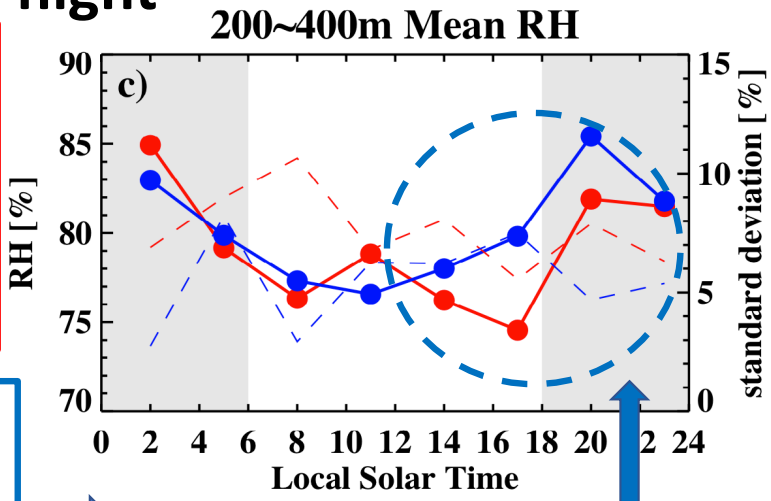
mean value
stddev

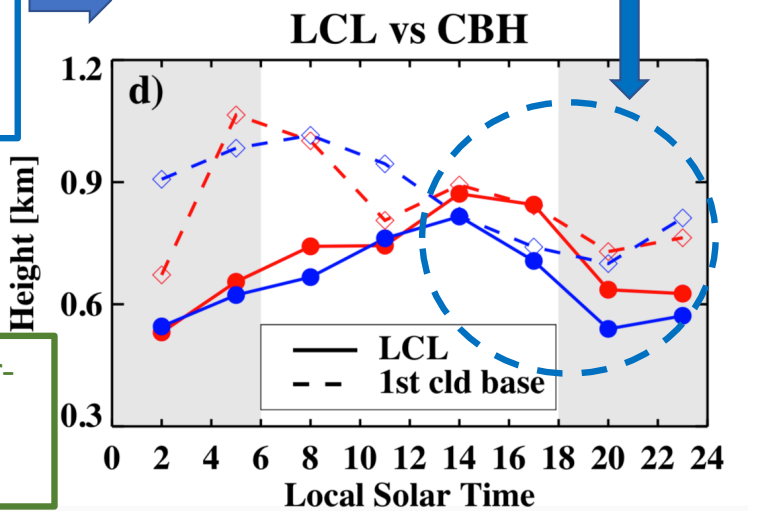
- Diurnal warming of ~0.5K
- Afternoon maximum
- Warming doesn't dissipate away during night

- Lowered near-surface RH raises afternoon LCL
- surface-driven buoyancy plumes less likely to condense

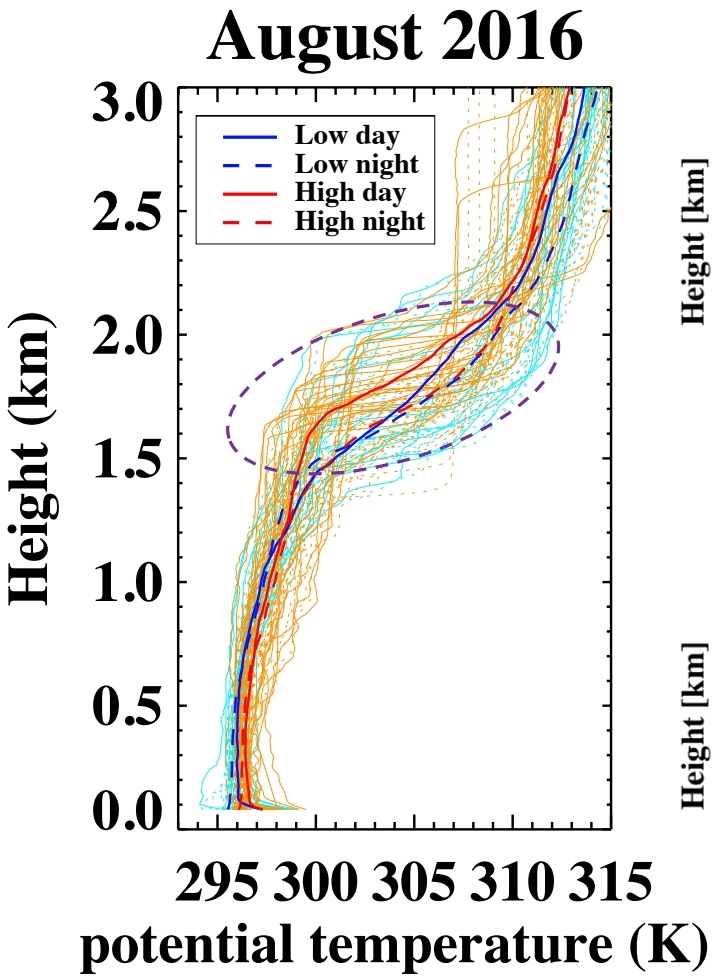
rBC>500
rBC<100

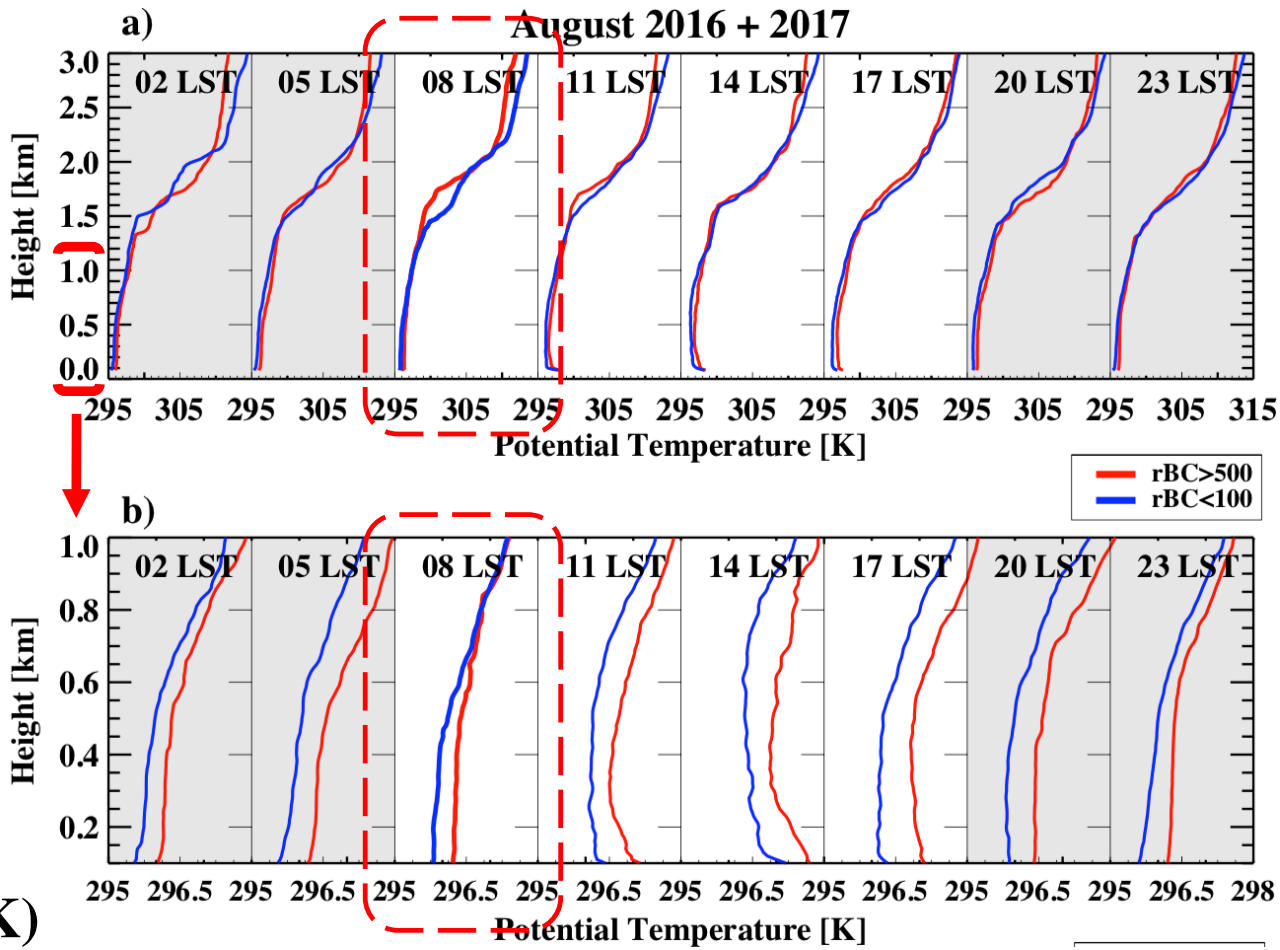
Similar RH at night as near-surface moisture accumulates



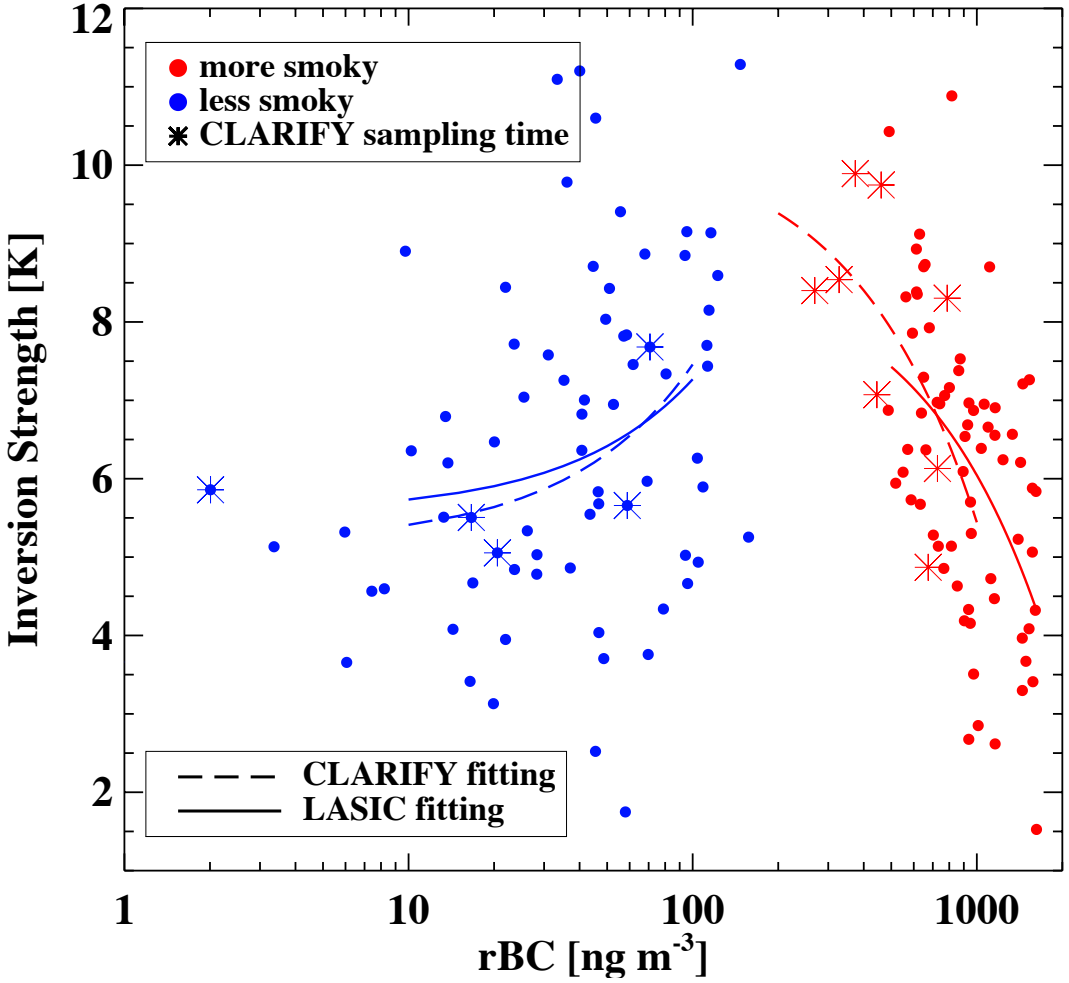


Deepening of BL in the early morning





is there no free-tropospheric semi-direct effect strengthening the cloud-top inversion?

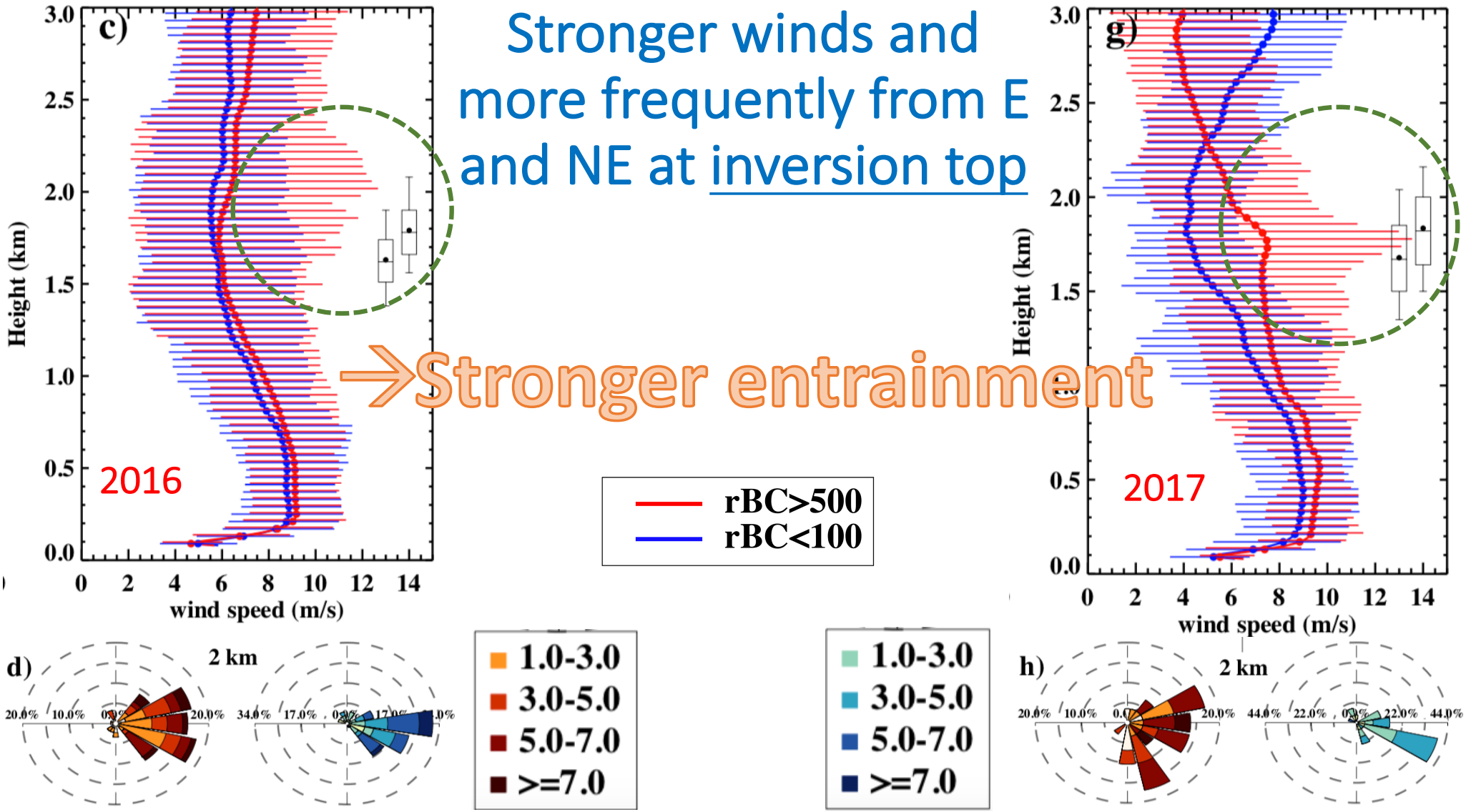


Weaker inversions are found when smoke loading is high

Weaker Inversion

→more entrainment

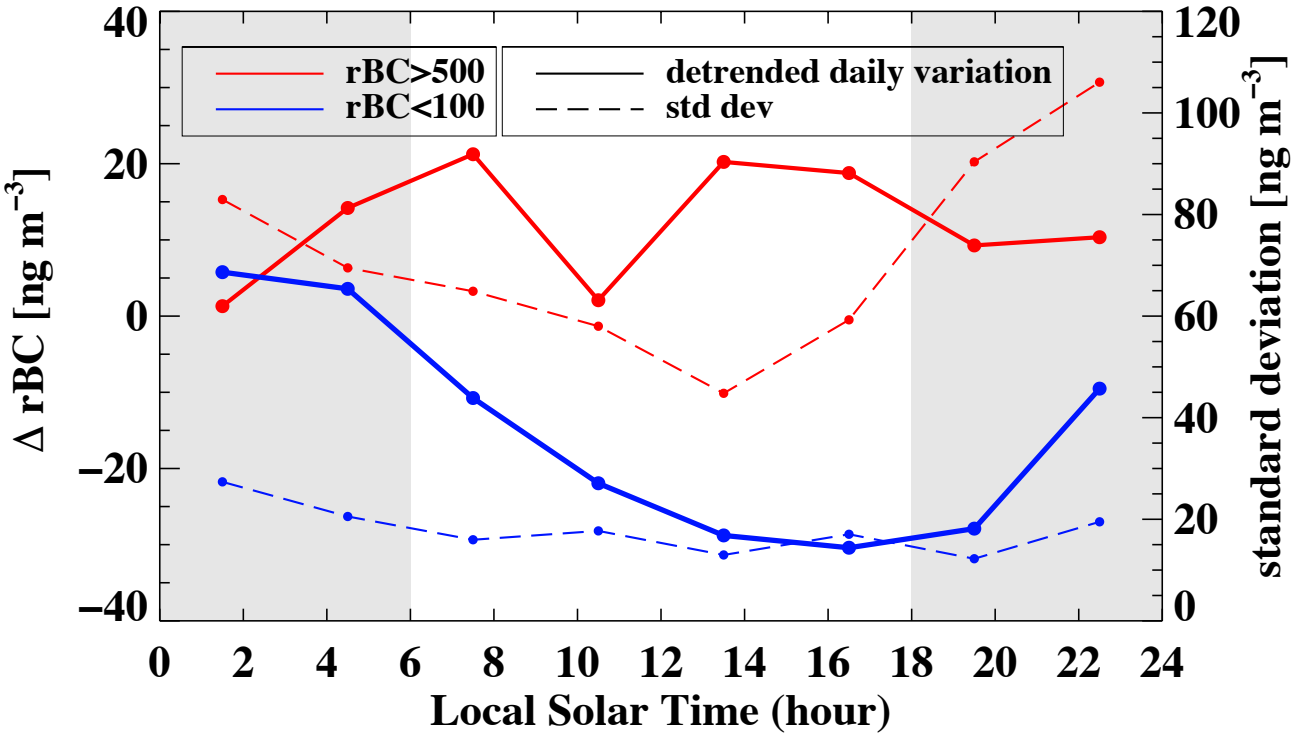
→ Dissipate clouds

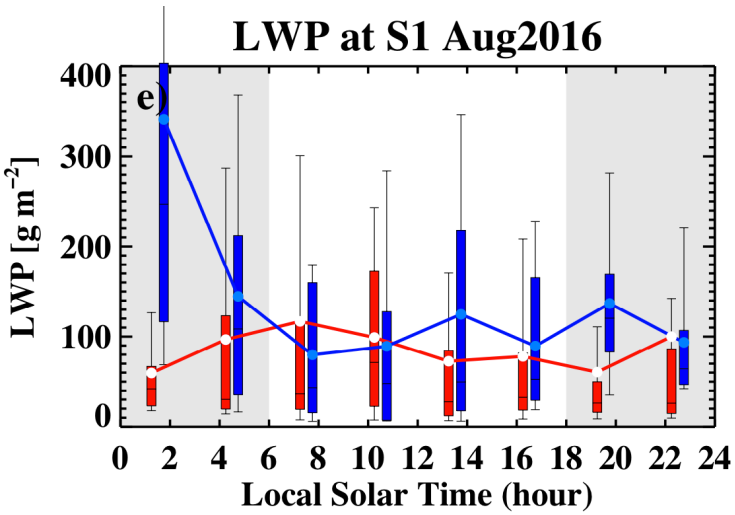

Stronger winds and more frequently from E and NE at inversion top
→Stronger entrainment
c)
g)
2016
2017
Height (km)
wind speed (m/s)
rBC>500
rBC<100
d)
h)
2 km
1.0-3.0
3.0-5.0
5.0-7.0
>=7.0

Diurnal redistribution of BL smoke

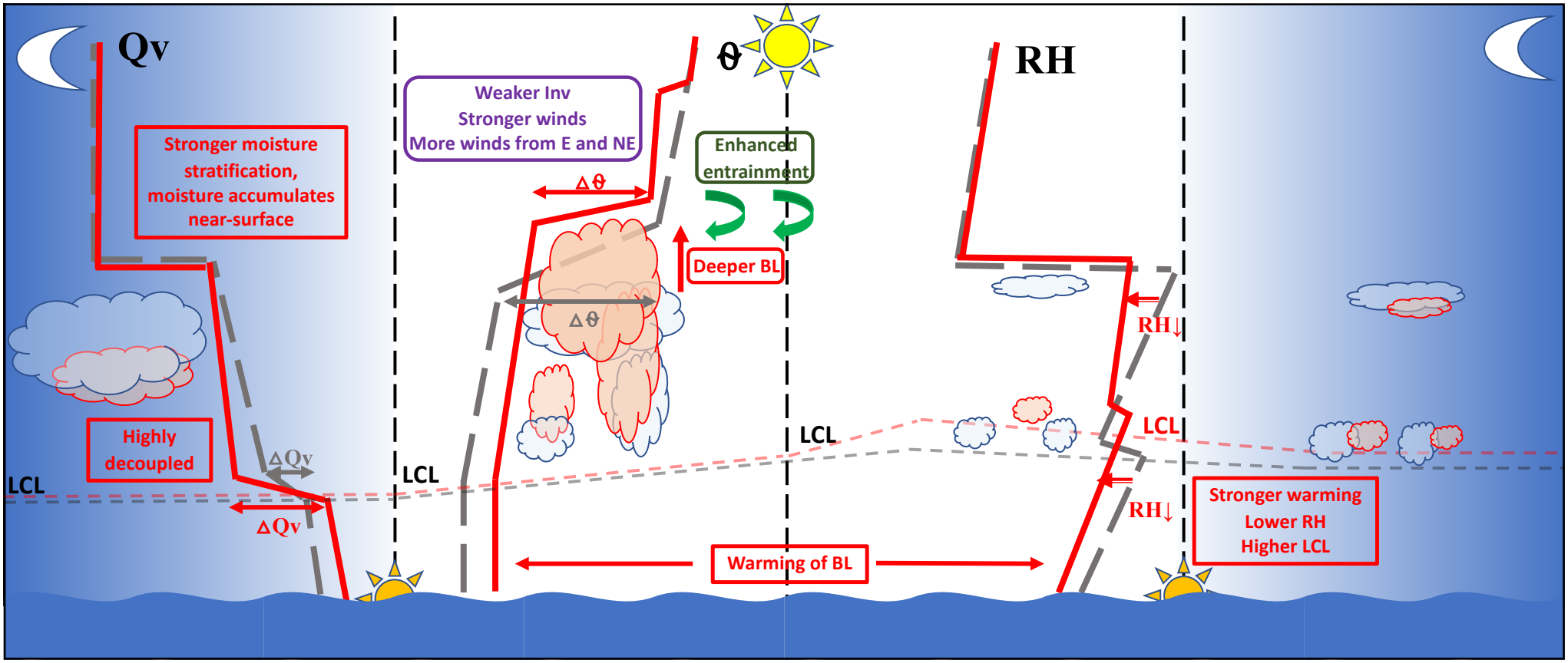
Smokier: weaker inv, enhanced entrainment help the persistence of smoke events

Cleaner: loss of smoke during the day, entrained more as BL recouples during night





Diurnal Cycle

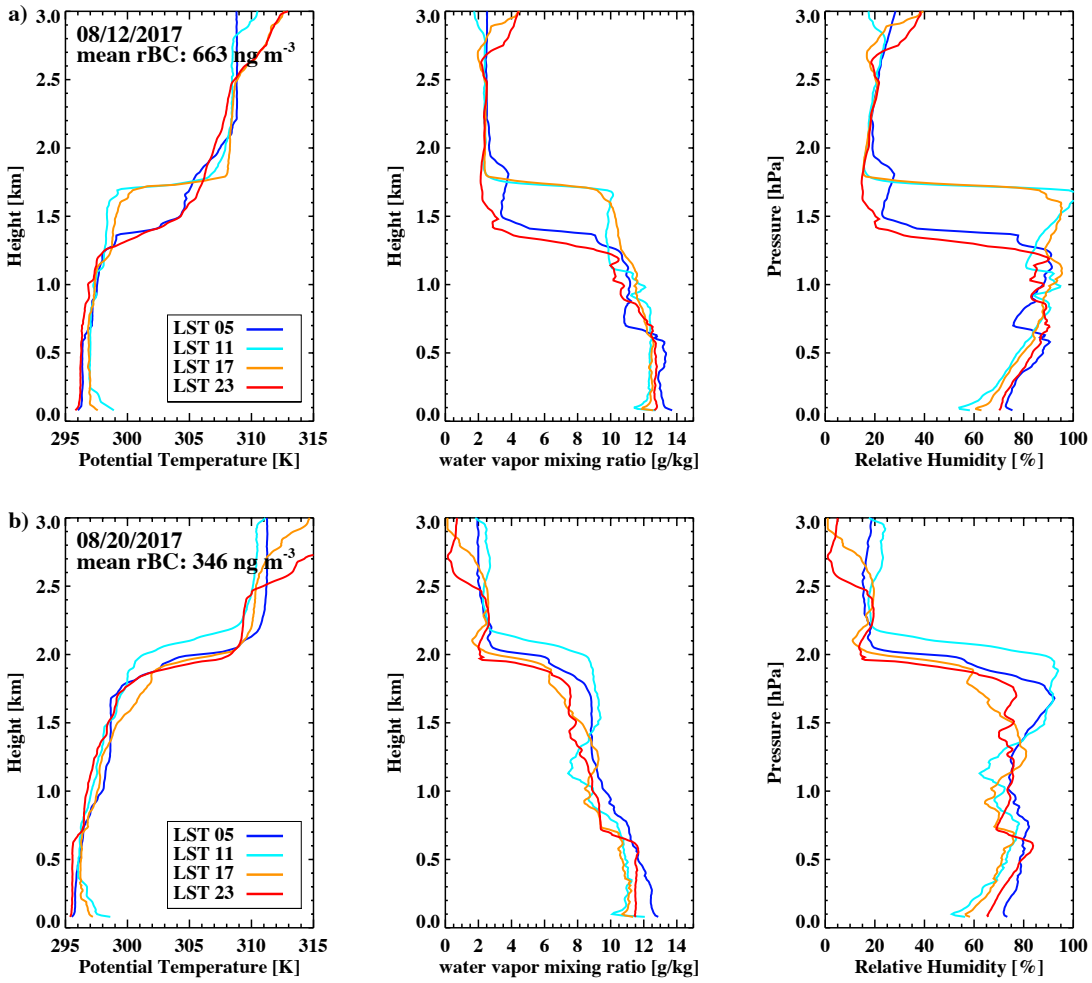


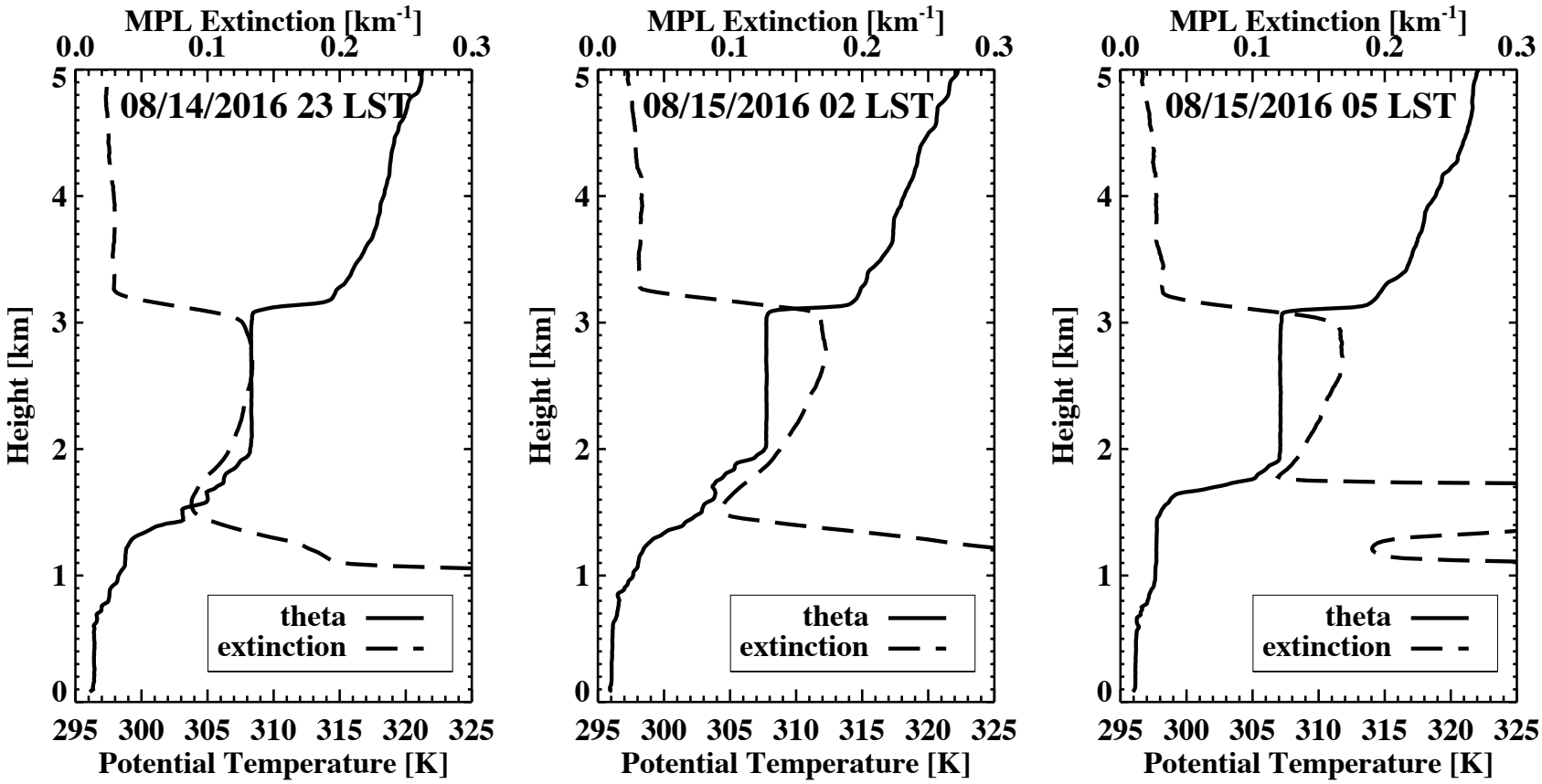
Zhang and Zuidema, ACPD, 2019

Takeaways

- Afternoon cloud reduction is stronger (cloud "burnoff"; Ackerman et al. 2000) in August when smoke presents, and nighttime cloud thinning as moisture stratifies (consistent with turbulence suppression; Pistone/Wilcox et al. 2016).
- The **new observation** being the morning cloud development and BL deepening by ~200m.
  - Both a dynamical and microphysical explanation:
    - **A. Dynamical**: lower BL is fairly well-mixed by sunrise, facilitating vertical ascent
    - **B. Microphysical**: elevated CCN when smoky help deepen the clouds (BL) by reducing precipitation.
- Meteorological influences helps perpetuate episodes with elevated BL smoke loading.

Backup slides


a)
08/12/2017
mean rBC: 663 ng m-3
LST 05
LST 11
LST 17
LST 23
Height [km]
Potential Temperature [K]
water vapor mixing ratio [g/kg]
Pressure [hPa]
Relative Humidity [%]
b)
08/20/2017
mean rBC: 346 ng m-3


MPL Extinction [km-1]
0.0
0.1
0.2
0.3
08/14/2016 23 LST
08/15/2016 02 LST
08/15/2016 05 LST
Height [km]
0
1
2
3
4
5
theta
extinction
295
300
305
310
315
320
325
Potential Temperature [K]

Smoke brightens the scene at a given cloud fraction

CERES all-sky TOA albedo as a function of **CERES low-cloud frac**, composited by **smoke conditions** (rBC at ASI, **August 2016+2017**)

↓

2 linear fitting lines

↓

Pick two low-cloud frac (**0.4 & 0.65**)

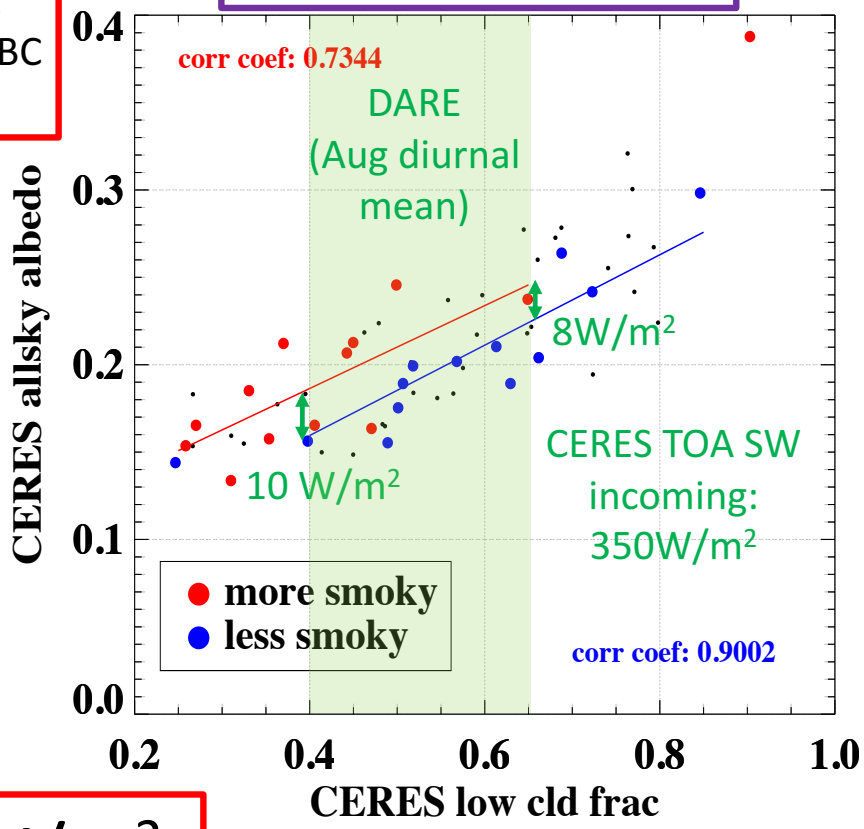
↓

Difference in TOA albedo **multiplied by** CERES TOA incoming SW (350 W/m^2)

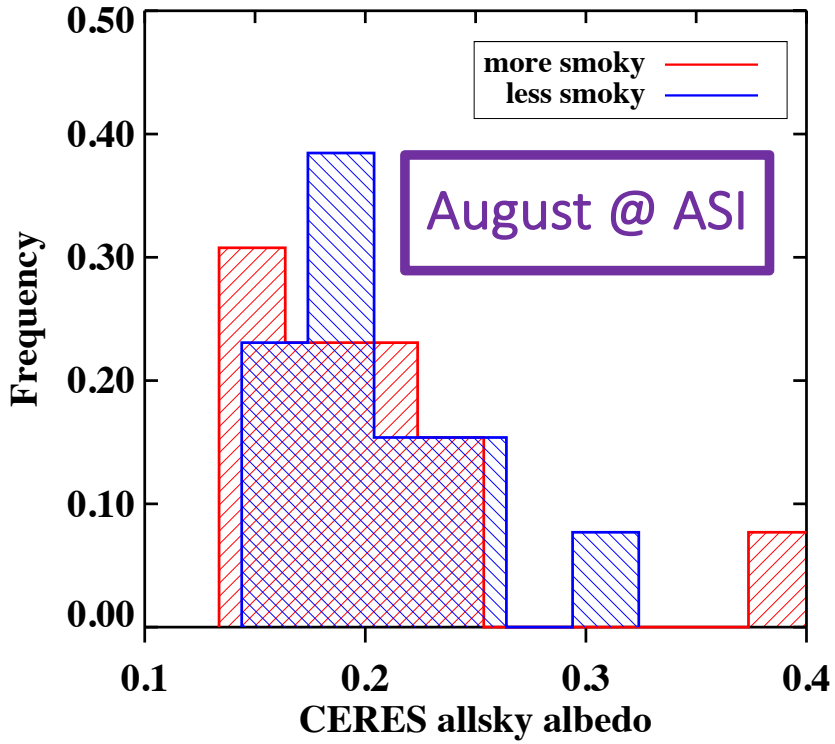
↓

DARE ~ 8 to 10 W/m^2

CERES products averaged over a 4° x 4° box centered on ASI



All-sky TOA albedo is reduced when smoky



Aerosol-cloud radiative Interactions (low clouds burn-off)
dominates
DARE (cooling) in the remote SEA (ASI)

Remarks for ASI

- **Direct ARE** approximately **8 to 10 W/m²** (cooling), which is **biased low** because just comparing more-smoky to less-smoky conditions (not pristine condition).
- **TOA all-sky albedo is reduced** due to reduction in cloudiness.
- Surface rBC follows AeroNet AOD fairly well **during August** (*Zuidema et al. 2018 GRL*), need to look at other products if doing this type of calculation for other months, plan to look at **AeroNet AOD** first.
- Plan to compare this with regional **modeled values** for Ascension (*Pablo and Calvin*).