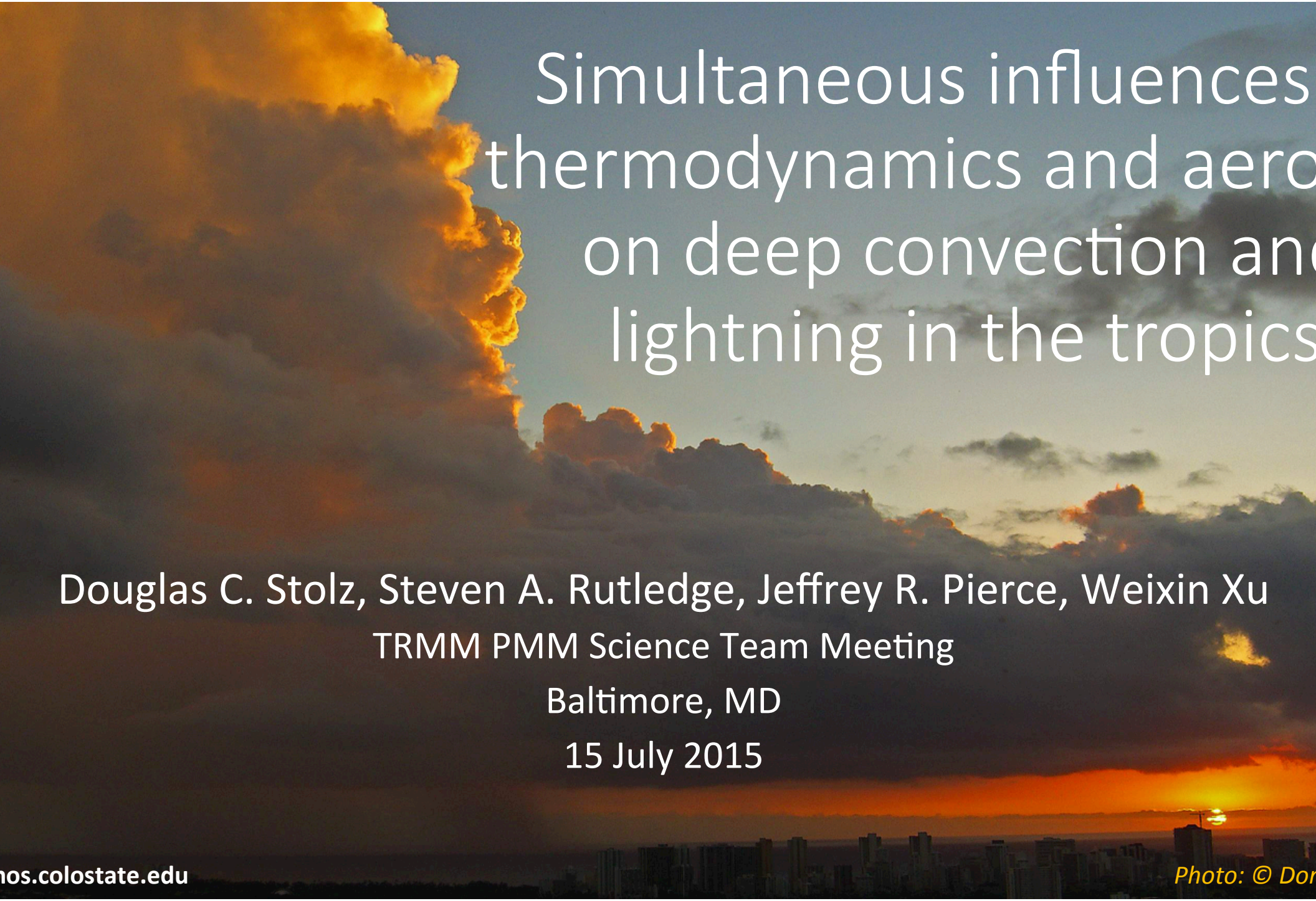


Simultaneous influences thermodynamics and aero on deep convection an lightning in the tropics

Douglas C. Stolz, Steven A. Rutledge, Jeffrey R. Pierce, Weixin Xu

TRMM PMM Science Team Meeting

Baltimore, MD

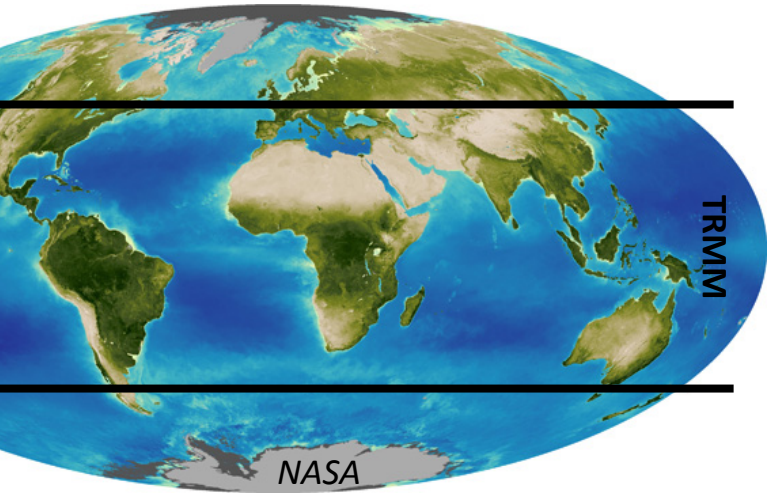
15 July 2015

Photo: © Dor

Outline

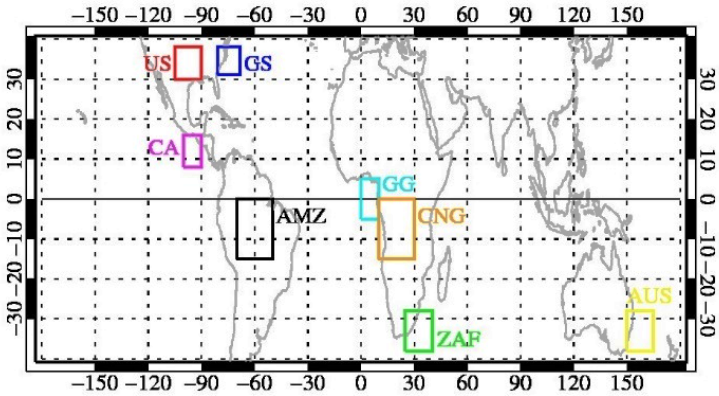
Objective: To determine the relative contribution thermodynamics and aerosols to the variability o convective intensity/lightning in the tropics.

lobal (Continents vs. Oceans)

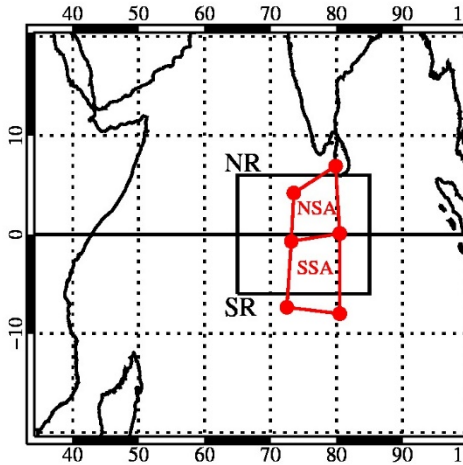


***Research design**: A global perspective nesting down progressively finer space and time scales of interest*

Regional



Basin Scale (CIO) – DYNA



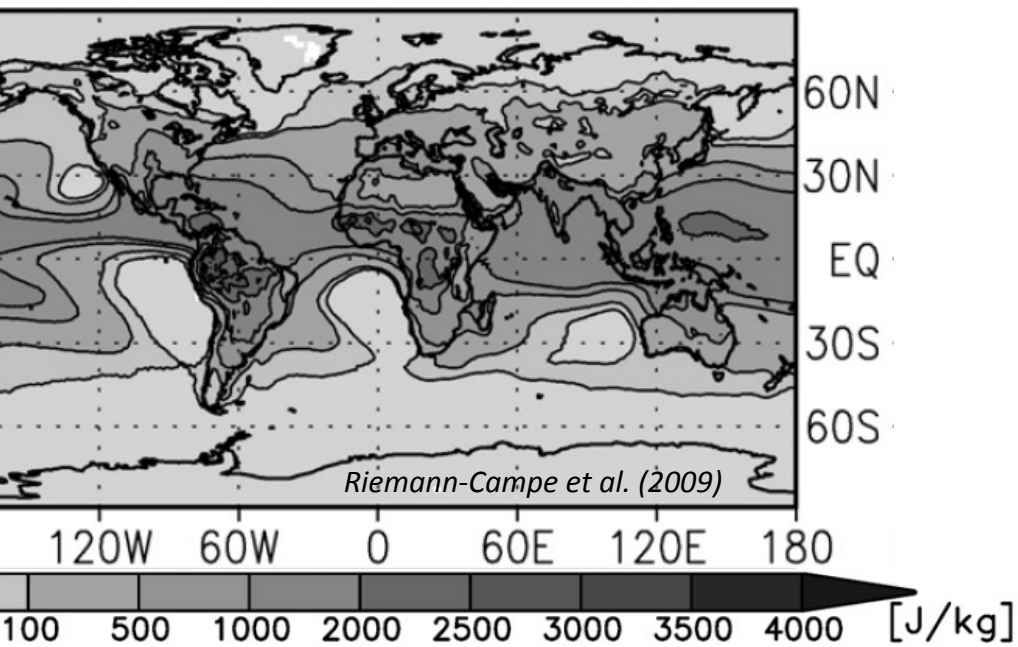
characterization of cloud-aerosol-odynamic interplay.

e-scale MJO feeding onto basin scale.

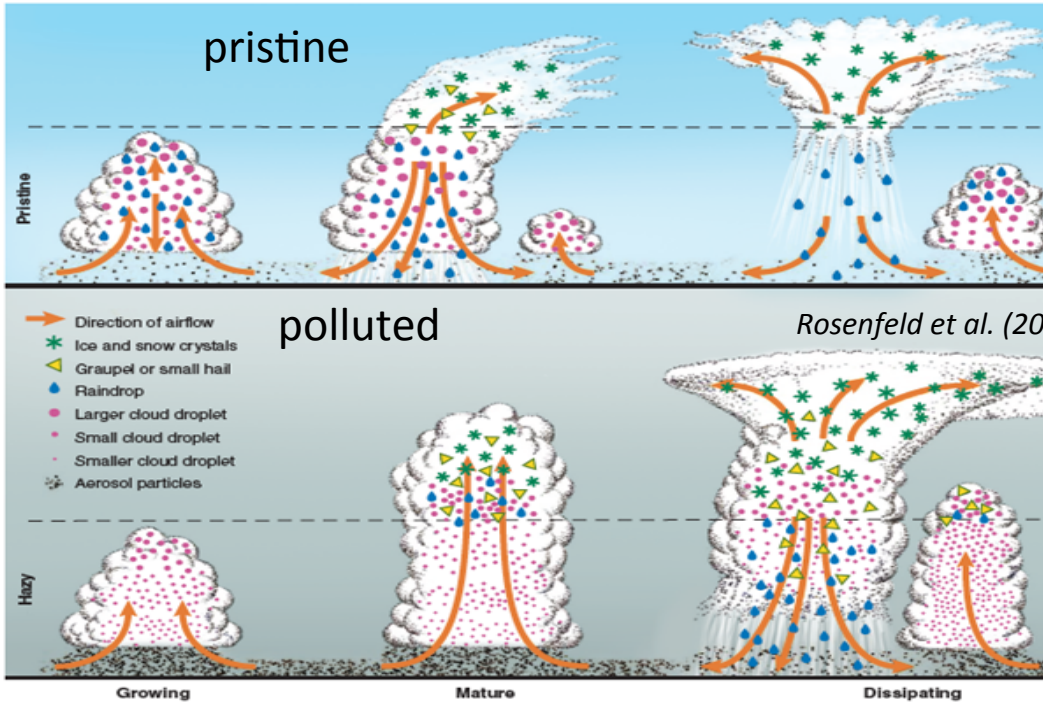
onal-scale variability.

npeting Hypotheses

CAPE



AEROSOLS



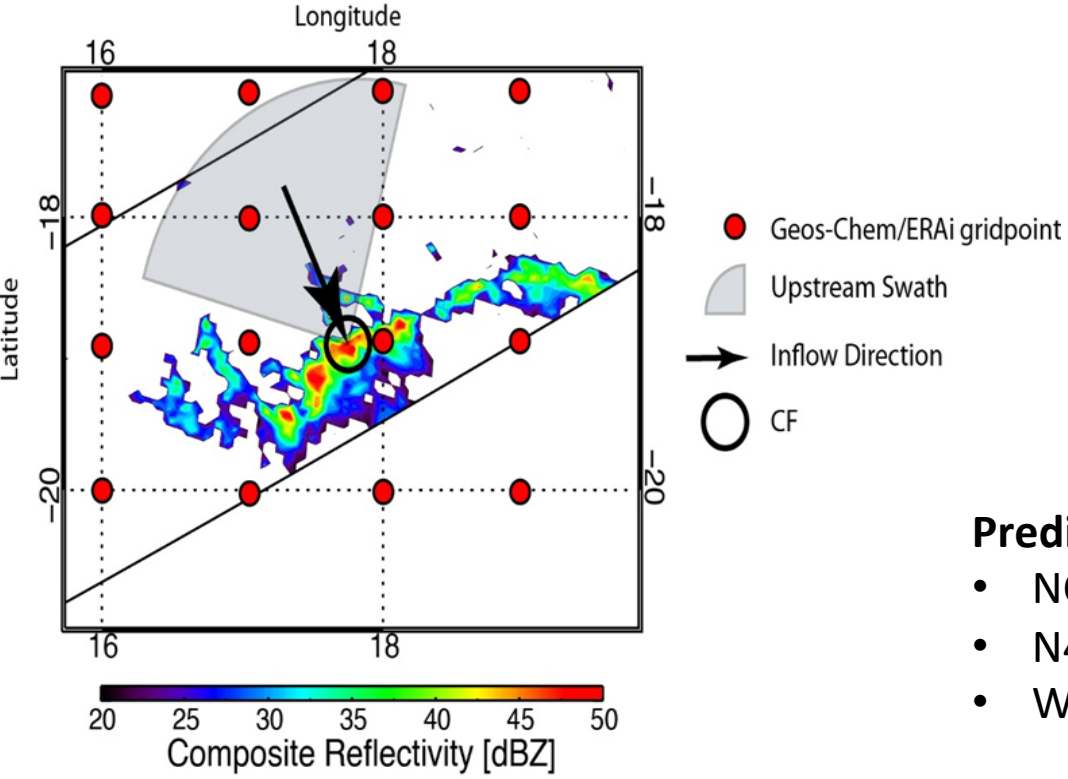
Traditional Thermal: CAPE controlling factor for convective intensity; idealized parcel theory

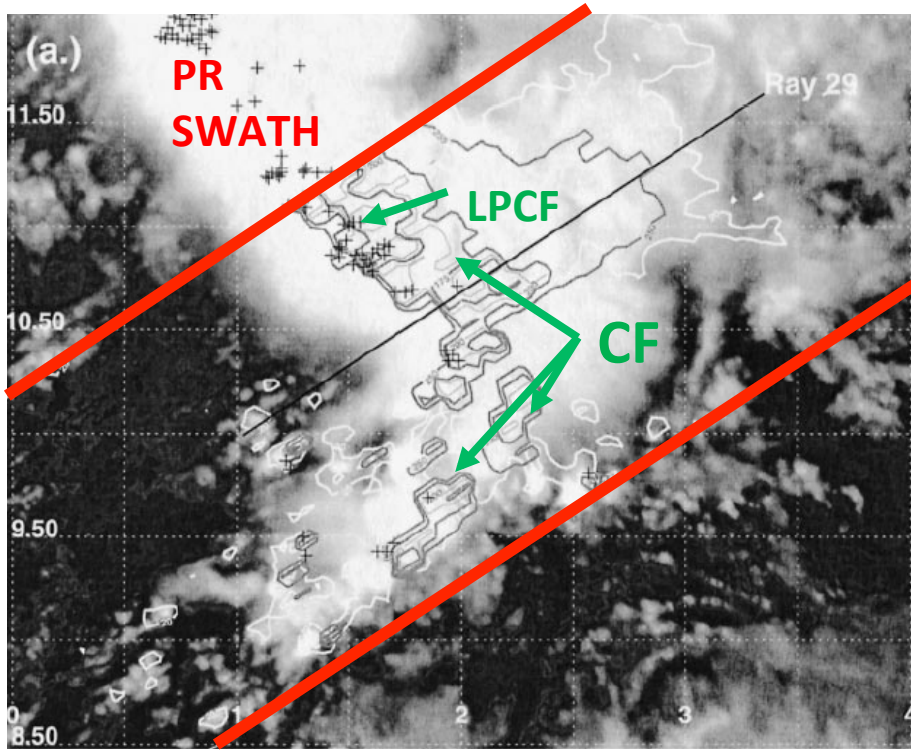
Aerosol: CCN modify size distribution of liquid hydrometeors → impact warm-rain process → subsequently influence riming efficiency/latent heat release above 0°C (transition from shallow Cu to deep Cb)

rminology

ctive Feature (CF) – a contiguous group of dentified as "convective" precipitation by PR.

ng-Producing Convective Feature (LPCF) – a tive feature with lightning flash rates above LIS's minimum detection threshold (~0.7 fl.





Nesbitt et al. (2000)

Predictors have been matched to CFs/LPCFs usi inflow attribution methodology (illustrated schematically at left)

Predictors (temporal interpolation to time of TRMM over

- NCAPE – Normalized CAPE
- N40 – CCN
- WCD – Warm-cloud depth

CF/Predictor climatology

1. Census of CFs and LPCFs[a]

in	CFs	LPCFs	CFs (AVGHT30 >5 km)	LPCFs (AVGHT30 >5 km)
l	12,232,564	503,133	1,457,919	263,378
nents	2,148,492	360,190	388,859	162,593
s	10,084,072	142,943	1,069,060	100,785

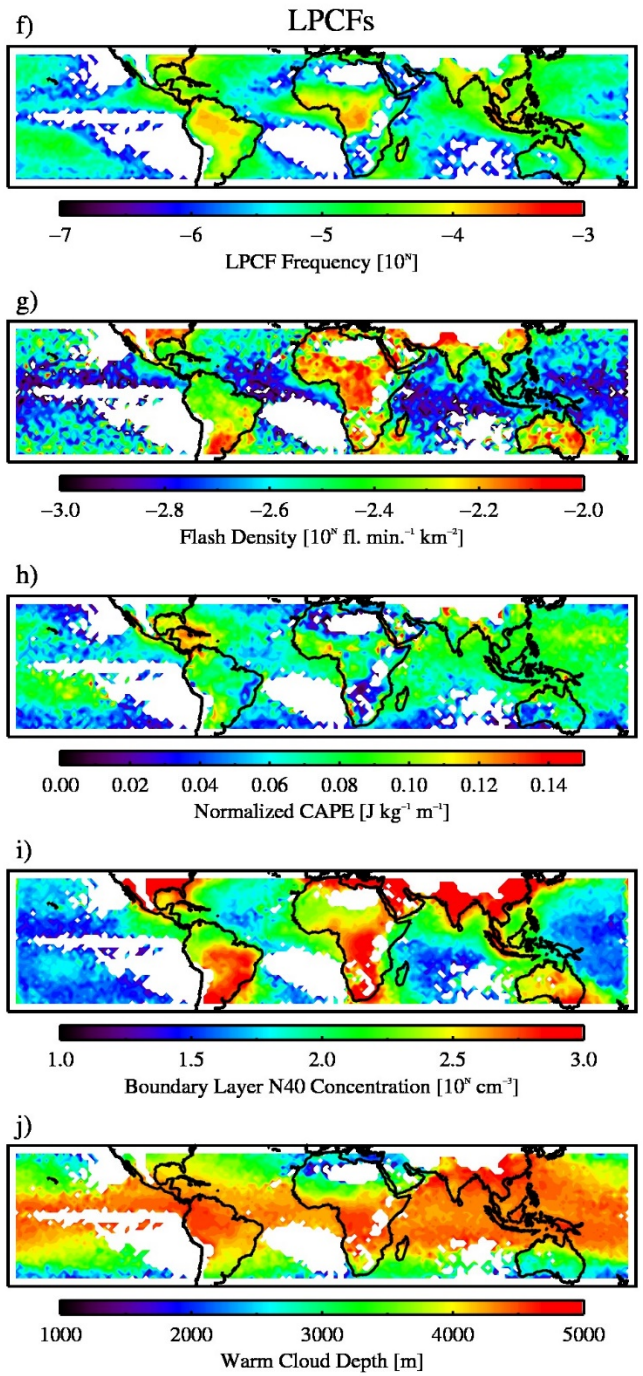
pulations of convective features (CFs) and lightning-producing convective features (LPCFs; i.e., CFs with lightning ates above TRMM LIS's minimum detection threshold) over the TRMM domain for the years 2004–2011. The first olumns represent populations in the original CF/LPCF database, while the latter two columns represent the sample of the data subset for the current analysis.

Stolz et al. (2015)

htning-Producing Convective Features (LPCFs) occur most quently over continents; salient features of general circulation nd out in climatology (e.g., storm tracks, ITCZ/SPCZ, AEJ, and pical chimneys)

al Lightning Density (TLD) is greater over continents compared to ans by a factor of 2-3 (e.g., *Boccippio et al.*, 2000)

na of NCAPE, N40, and WCD are found in association with maxima f TLD – it is plausible that variability in TLD results from some combination of environmental thermodynamic and aerosol characteristics.



O

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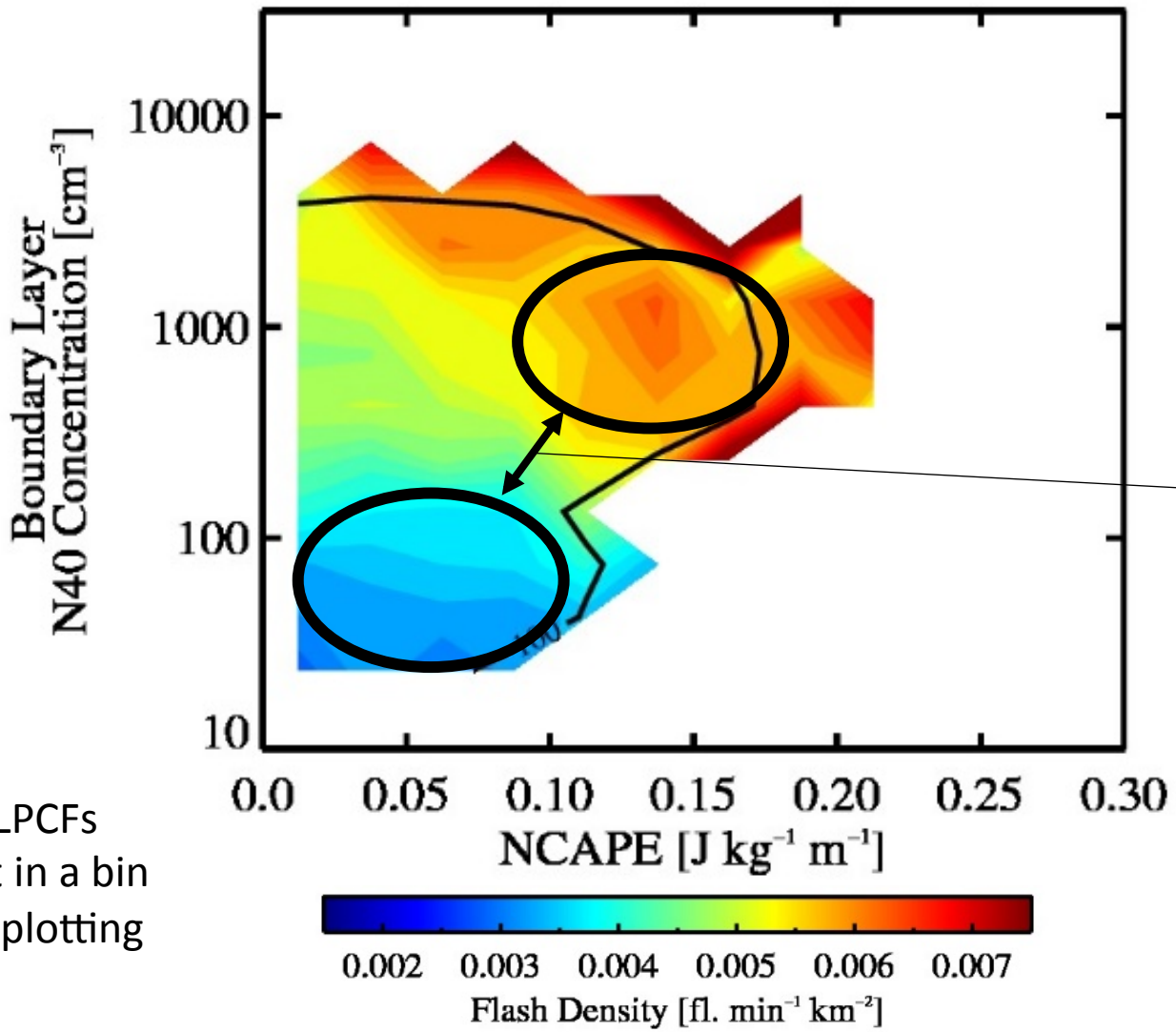
N

C

W

ghtning Density: 2D comparison

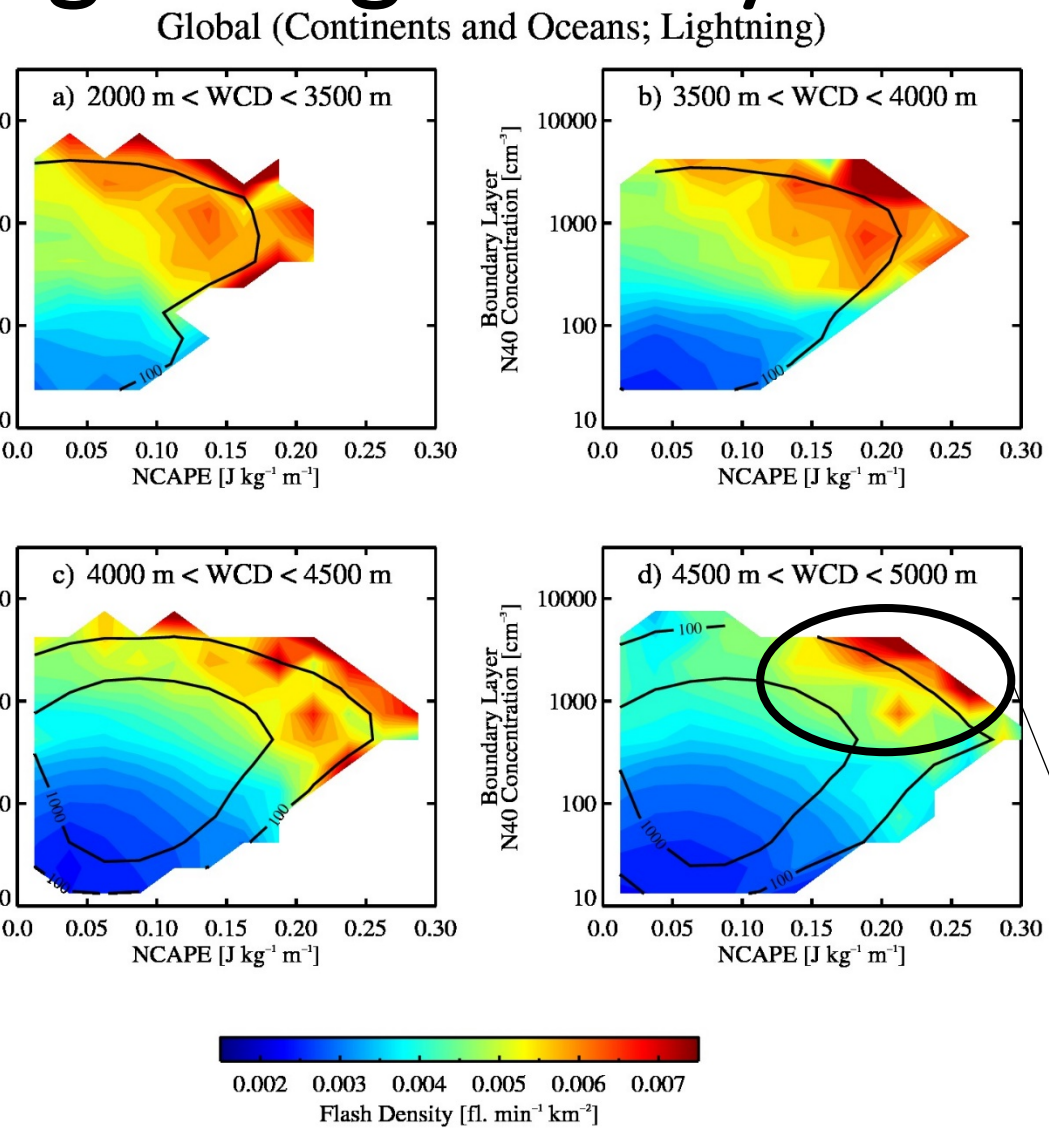


LPCFs
t in a bin
plotting

Two dimensional histogram appr
map the sensitivity of convect
intensity proxies to simultane
changes in thermodynamics (X)
aerosols (Y)

Lightning density is higher for h
CCN and high NCAPE compared
low CCN and low NCAPE

Lightning Density: 2D distribution + WCD



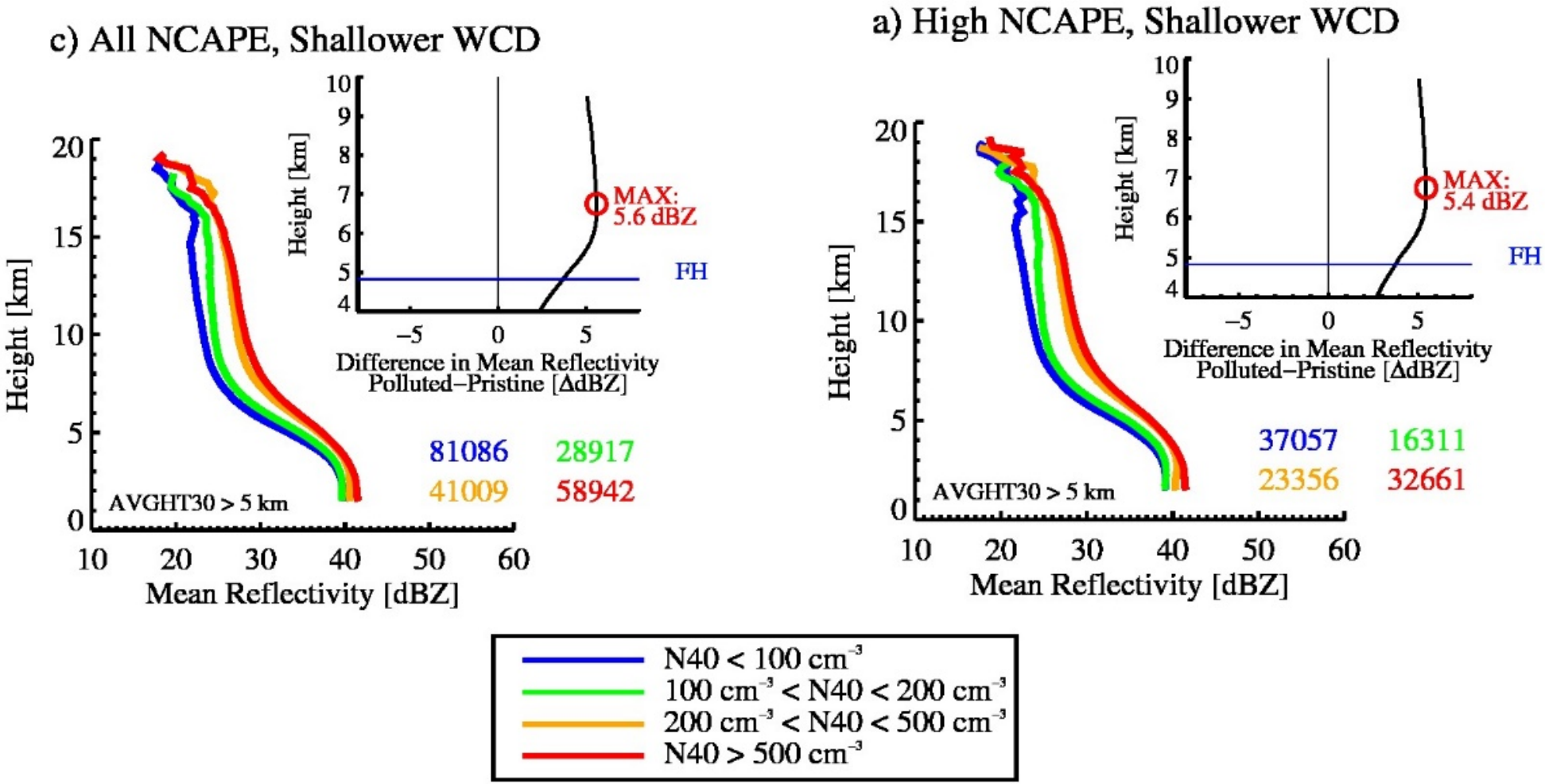
Two dimensional comparison "maps" of lightning d can be created for different stratifications of warm depth (WCD) – a three dimensional compariso

Lightning density is greatest for high NCAPE and hig for all WCD stratifications (all panels)

Lightning density varies by up to ~600% between NCAPE/CCN (lower left) and high NCAPE/CCN (uppe

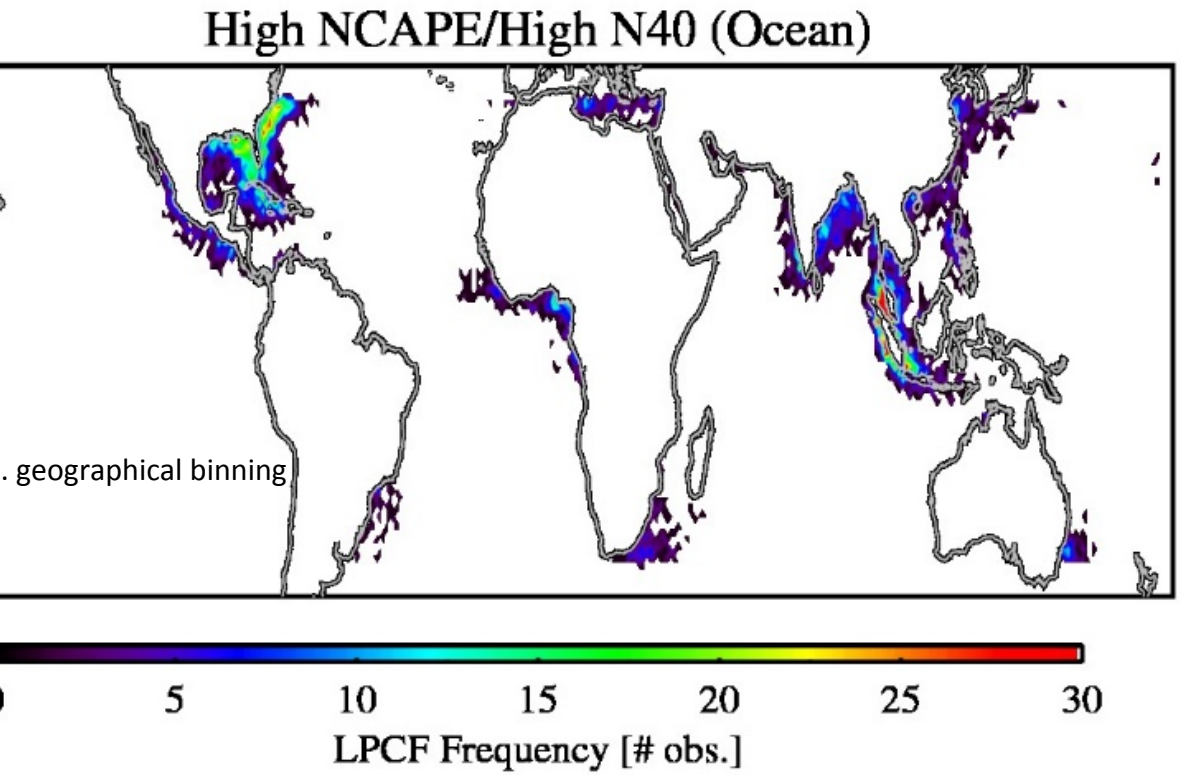
For deeper WCD (panel d), the greatest lightning de restricted to exceedingly high NCAPE/high CCN – V exhibits a non-trivial influence on lightning

rtical Reflectivity Structure

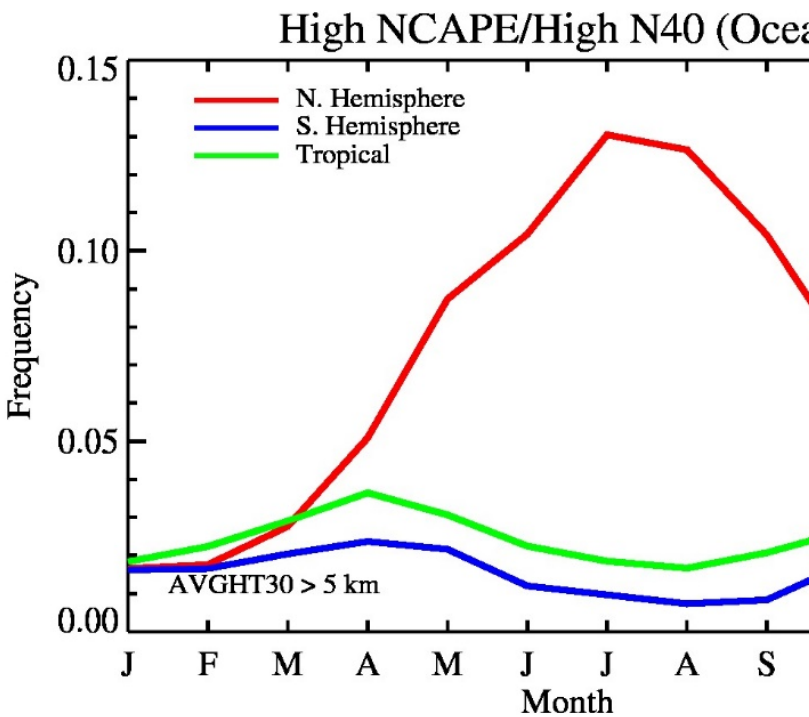


Reflectivity in polluted clouds is up to 5.6 dB larger compared to pristine clouds (in mixed phase)

gional behavior (Ocean)

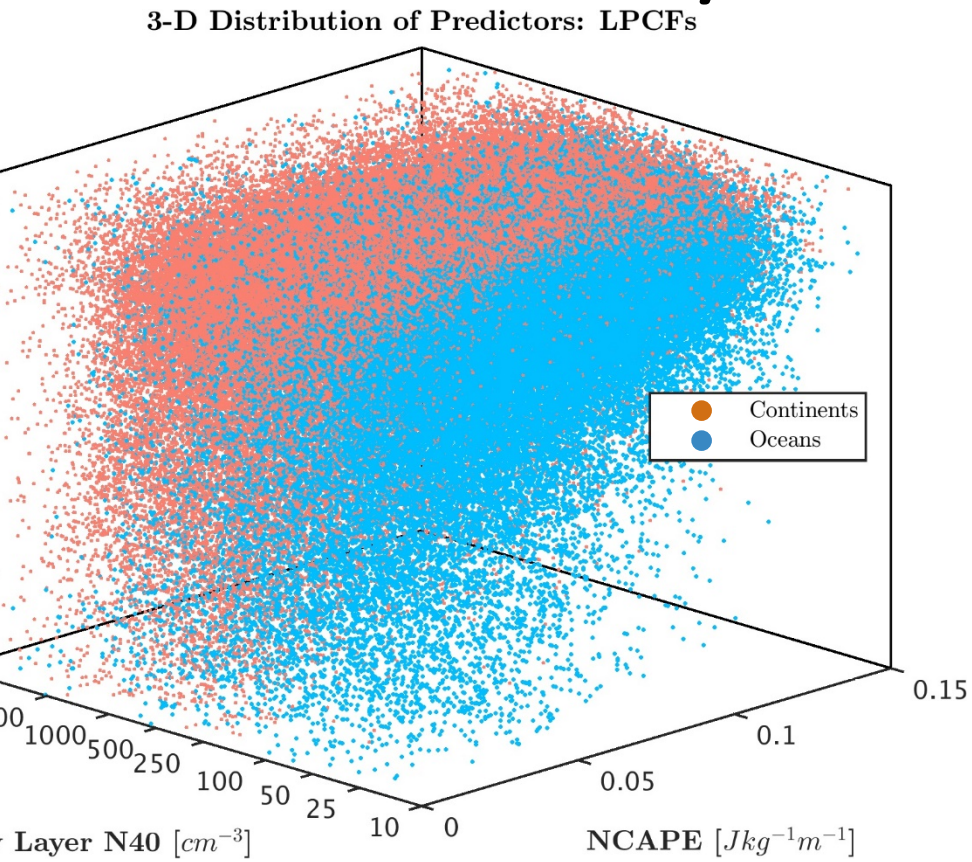


- **Isolate convective features w NCAPE above the median valu and N40 greater than 500 cm**
- **Plot geographical and tempor dependence of these features**



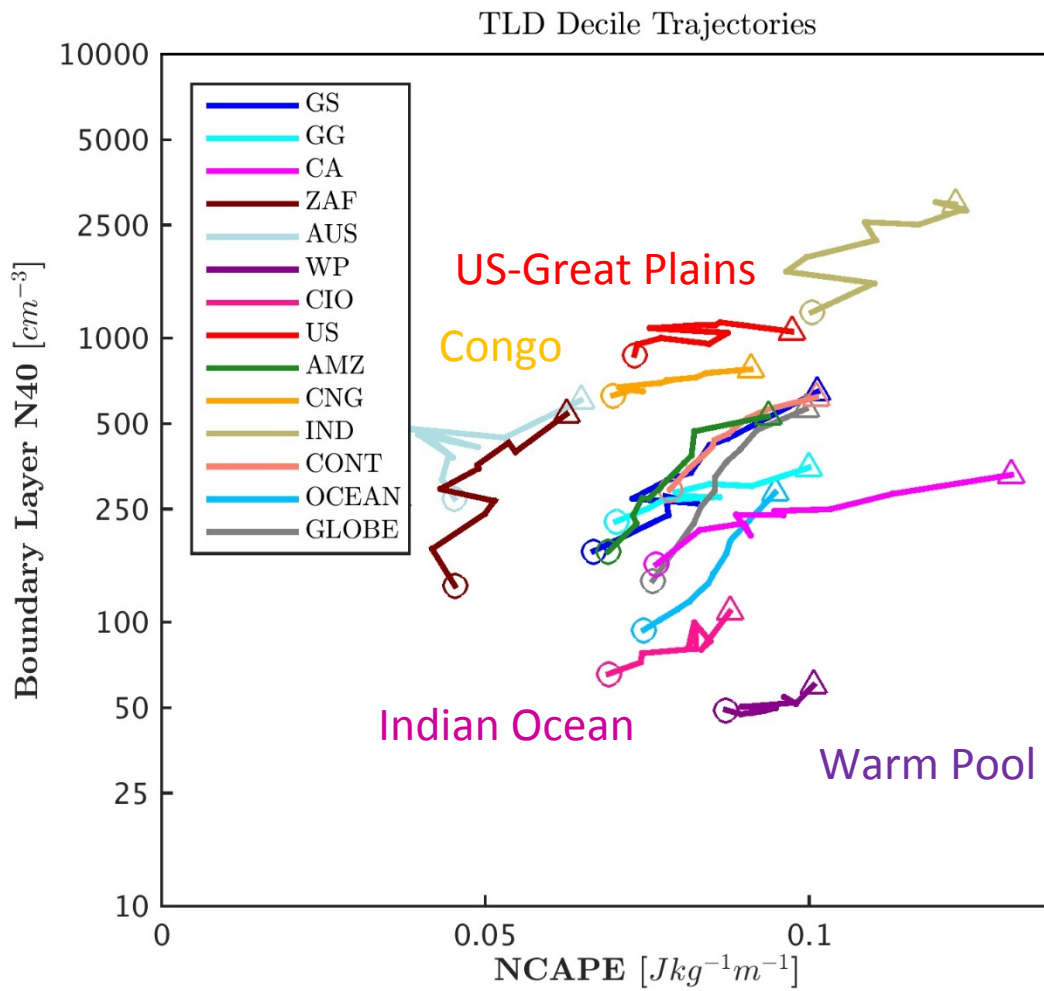
ng oceanic LPCFs that occupy upper right section of the NCAPE-arameter space illustrates these features occur preferentially in coastal regions (e.g., Strait of Malacca, Gulf Stream)
Northern Hemisphere = boreal warm season
Southern Hemisphere = bi-annual, transition seasons

gional Sensitivity: LPCFs



Isolate LPCFs in certain regions of interests (e.g., ntinental, coastal, oceanic) within 3-D "cloud"

2. Compute LIS lightning deciles, map trajecto (low (circles) → high (triangles) flash density) through 3-D parameter space



*Represents projection onto NCAPE-CCN plan

Aerosol-cloud interactions during DYNAMO (2011-2012)

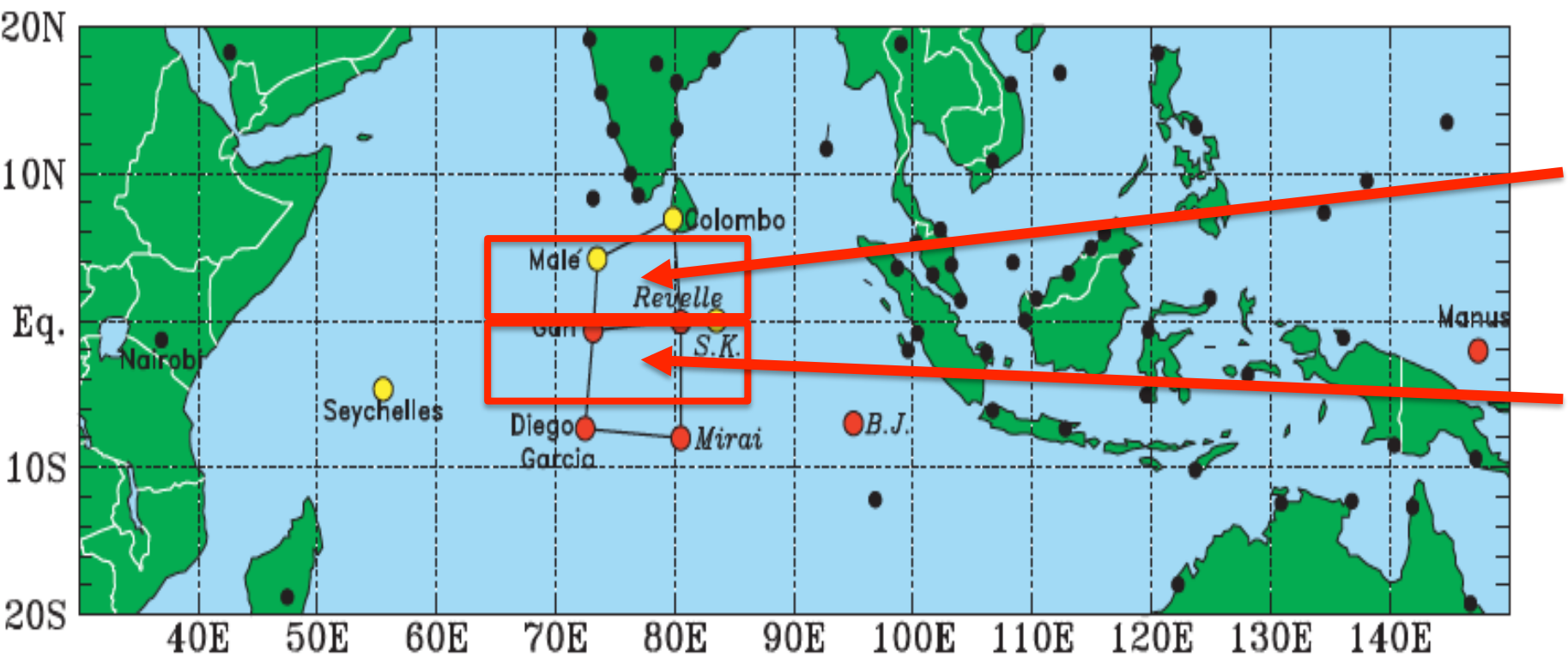
glas Stolz, Steven A. Rutledge, Weixin Xu, Jeffrey R. Pierce (in prep.)

DYNAMICS of the MJO (DYNAMO, Fall 2011- Winter 2012)

ve see CAPE/CCN influences on regional scales, like the MJO for exam

NAMO provided an opportunity for exploring the role of CCN during 3 MJO episodes since we do expect CAPE to vary geographically in the IO basin – a natural laboratory for study.

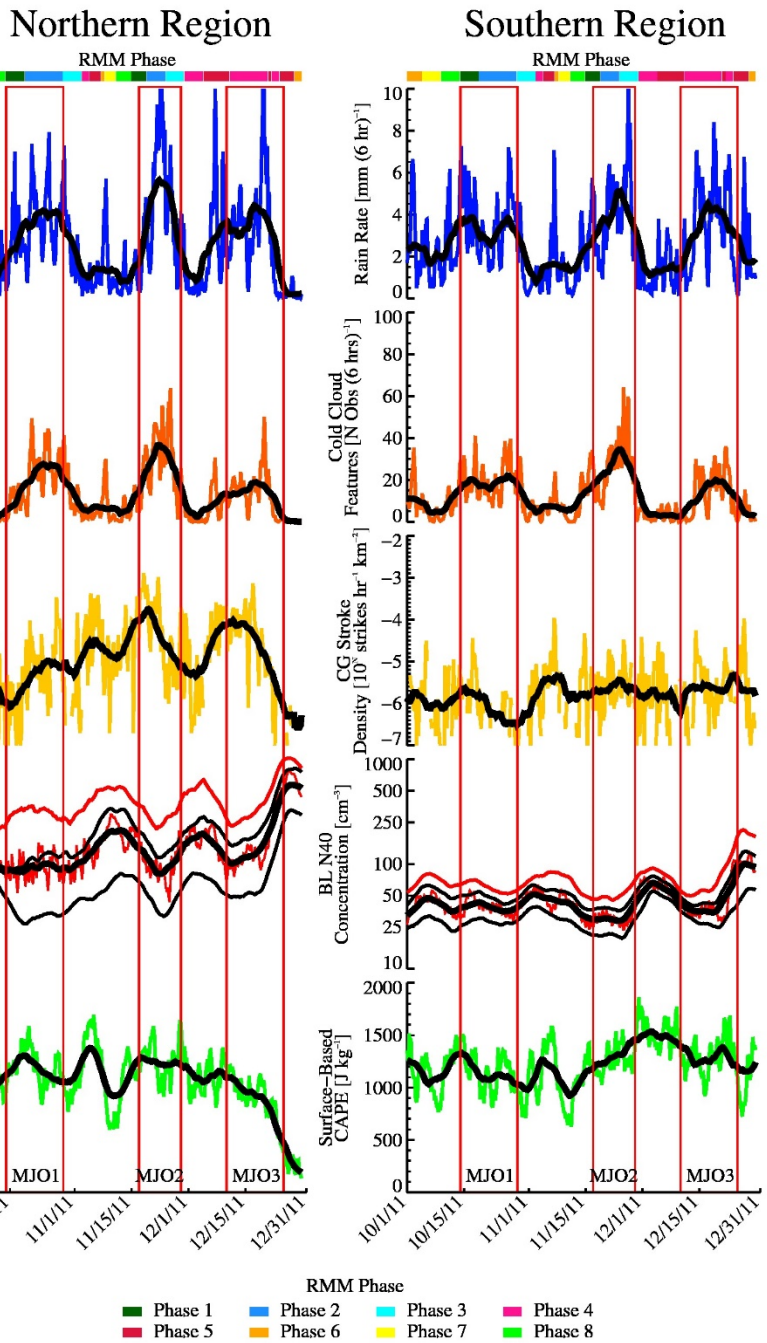
(Courtesy Johnson and Ciesielski 2013)



Northern
(NP

Southern
(SP

NAMO 2011 (1 October – 31 December)



Rain

Cold Cloud

Lightning

Aerosols

CAPE

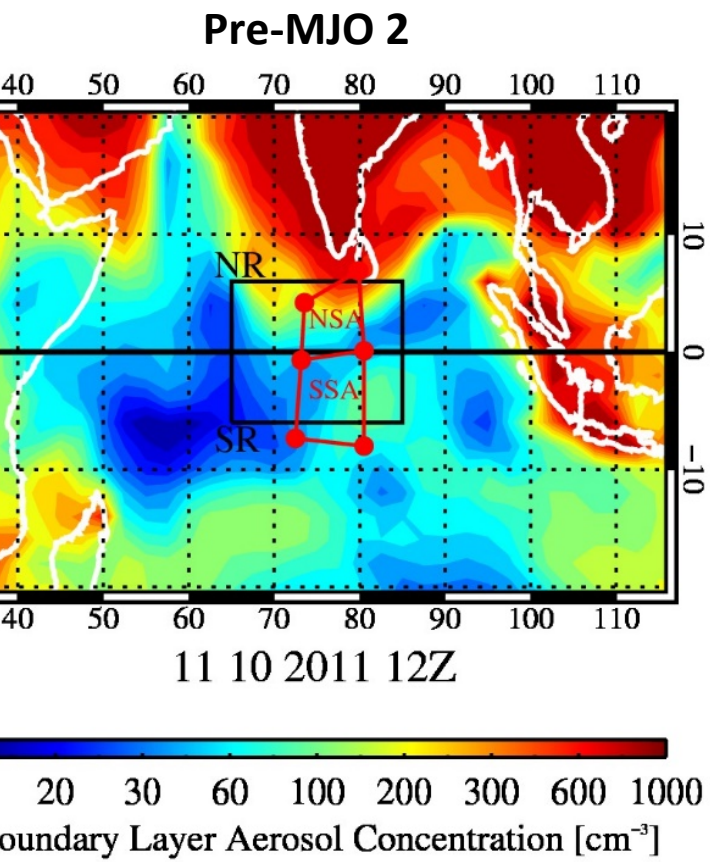
Peaks in rainfall and frequency of Cold Cloud Features coincide with 3 observed MJO episodes

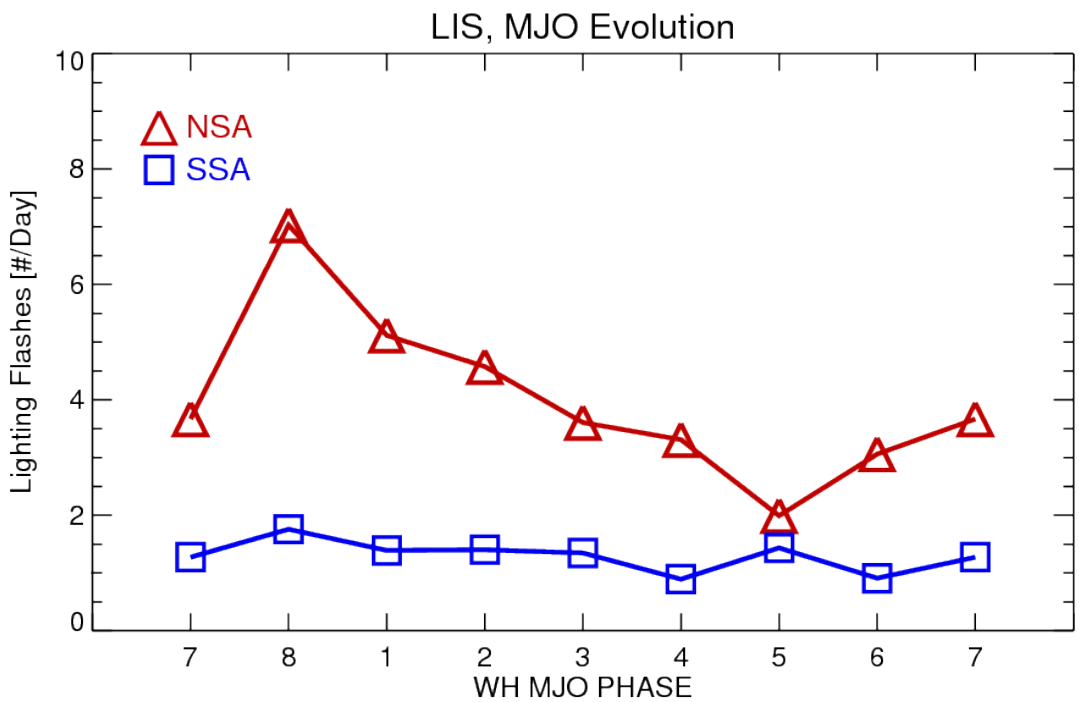
Lightning density is up to an order of magnitude larger in the NR compared to SR.

CCN in NR ~ 150 cm^{-3}
CCN in SR ~ 40 cm^{-3}

CAPE is very nearly the same between NR and SR regions.

MJO Phase Composites: TRMM LIS

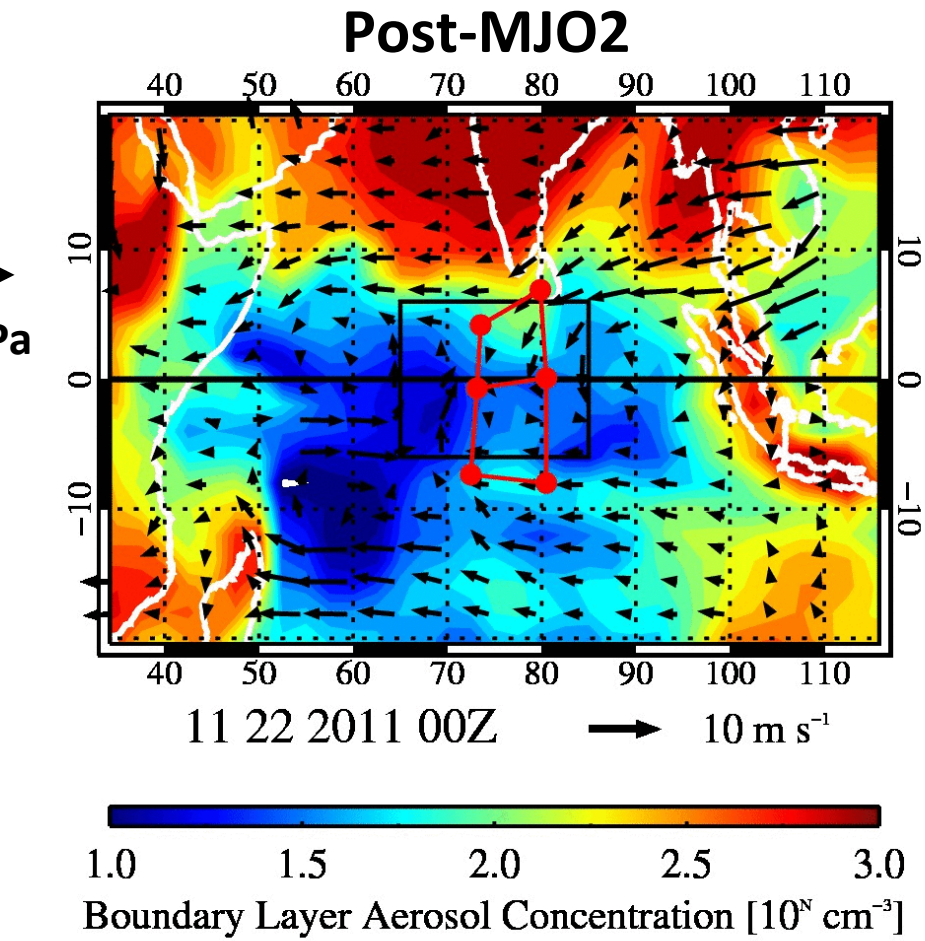


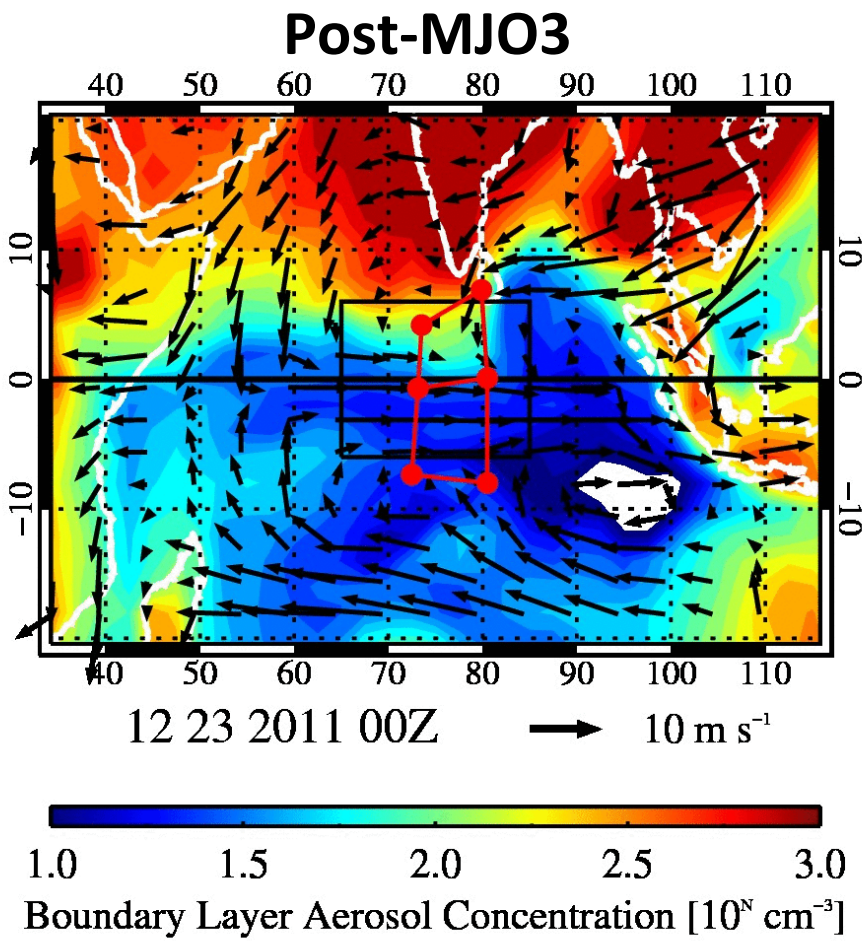


ean distribution of N40 indicative of
dional gradient near the equator (high
oncentrations north of the equator)

Regional differences in total lightning rates over the CIO ar
consistent with aerosol invigoration hypothesis under moder
CCN concentrations during MJO pre-onset phases

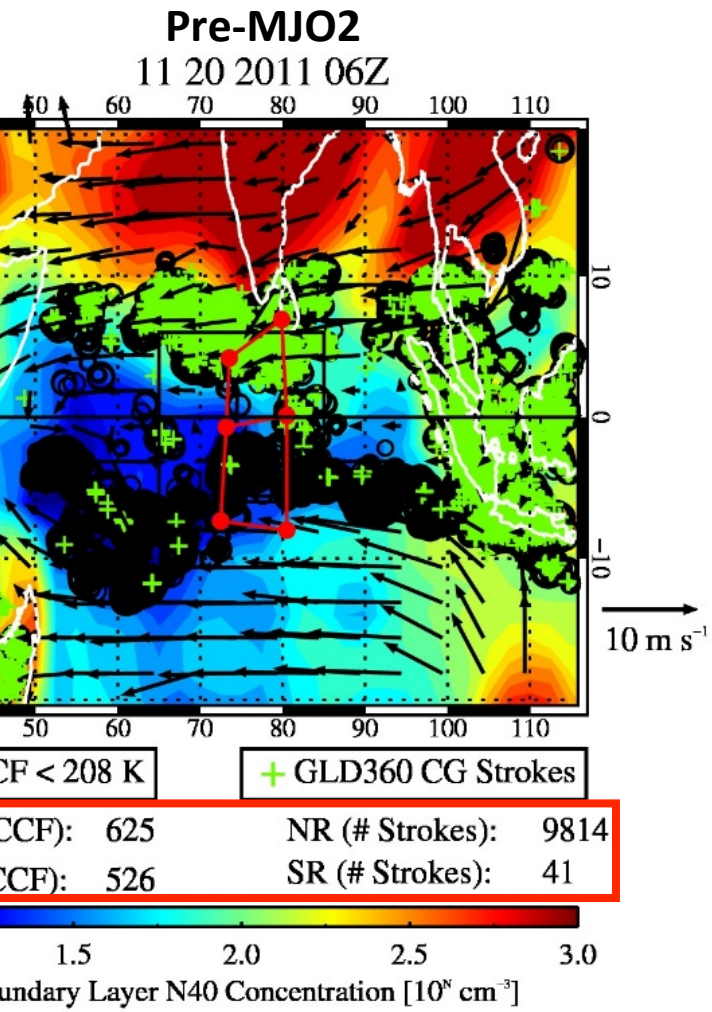
Eddy/Gyre transport

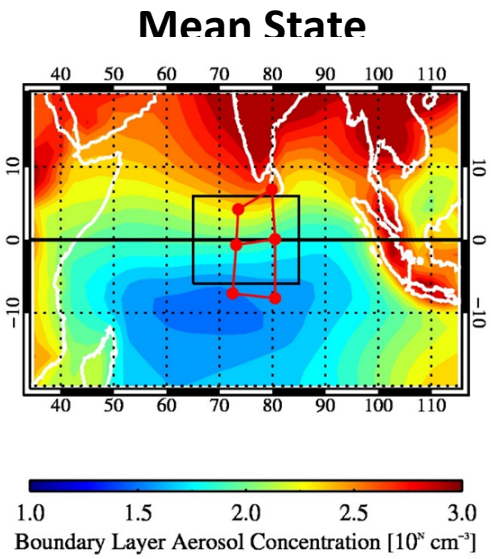




Equatorward transport of high CCN, in association with cyclonic eddies, in northern region

How does convection respo
on the large (basin) scale?

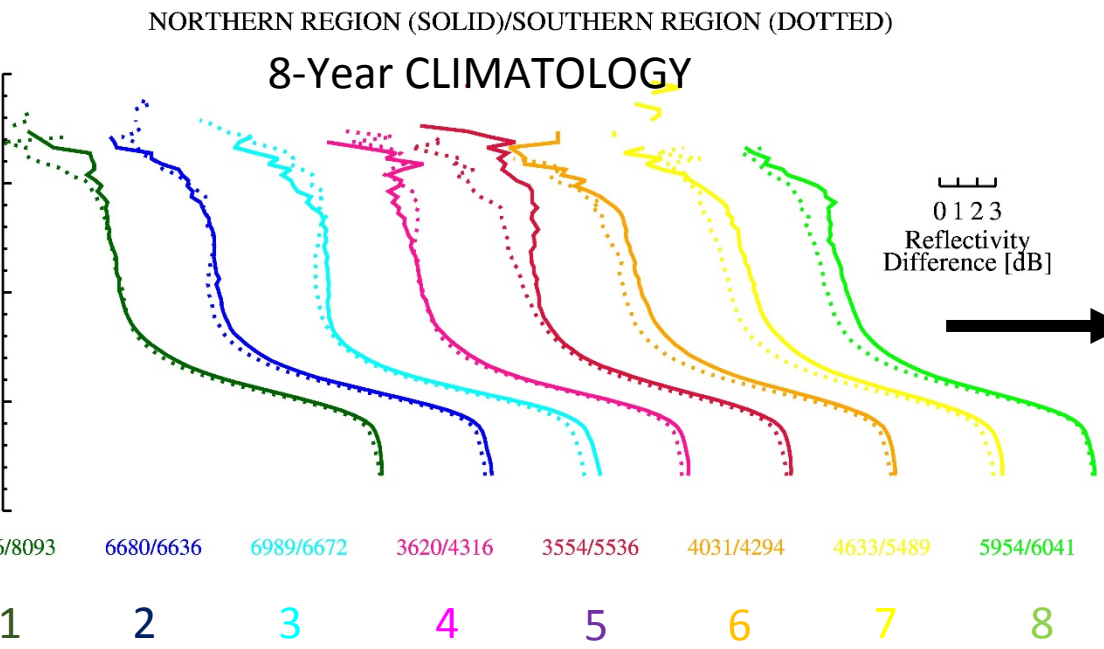




Shading = N40 concentratio
Black Circles = Cold Cloud Featu
Green Plus = CG lightning
Vectors = 925 hPa winds

Despite similar populations of Cold Cloud Fe (i.e., deep convection) lightning appears to preferentially in the northern region, wh aerosol concentrations are highest

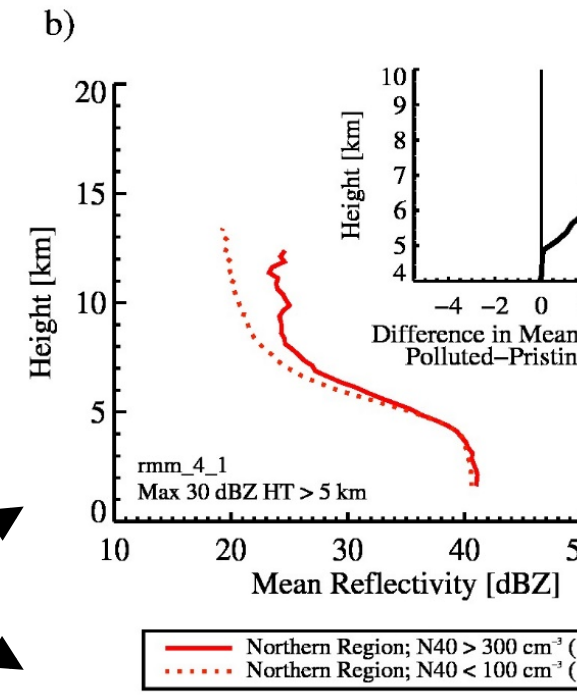
MM PR observations

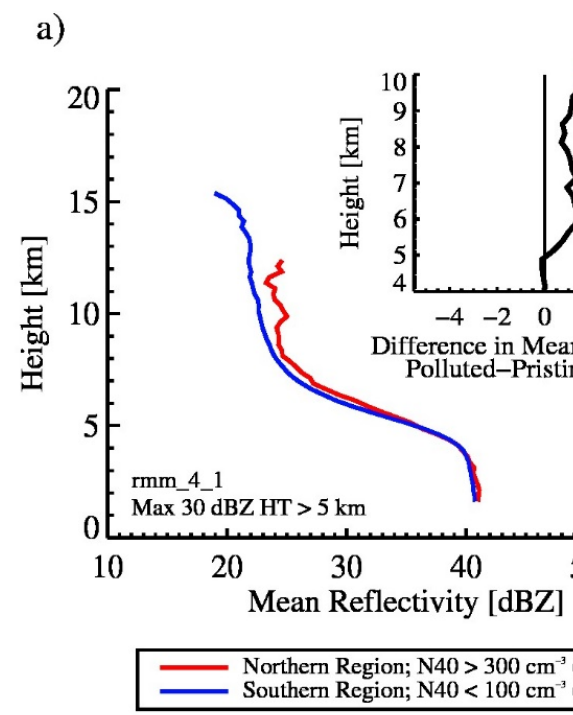


Current research focuses on linking these different precipitation structures to environmental aerosols.

OBS (NR/SR)

rgest differences (1-2 dB) between NR/SR appear in ixed phase region during suppressed MJO periods





ummary

A global investigation focusing on the variability of tropical convection (lightning and radar reflectivity) suggests thermodynamics and aerosols simultaneously invigorate convective clouds.

- Lightning rates and radar reflectivity were higher (greater) for *higher NCAPE*, *higher CCN*, and *shallower WCD*
- Preliminary results from regional analysis illustrate different sensitivity to NCAPE, CCN, and WCD in various geographical regions.

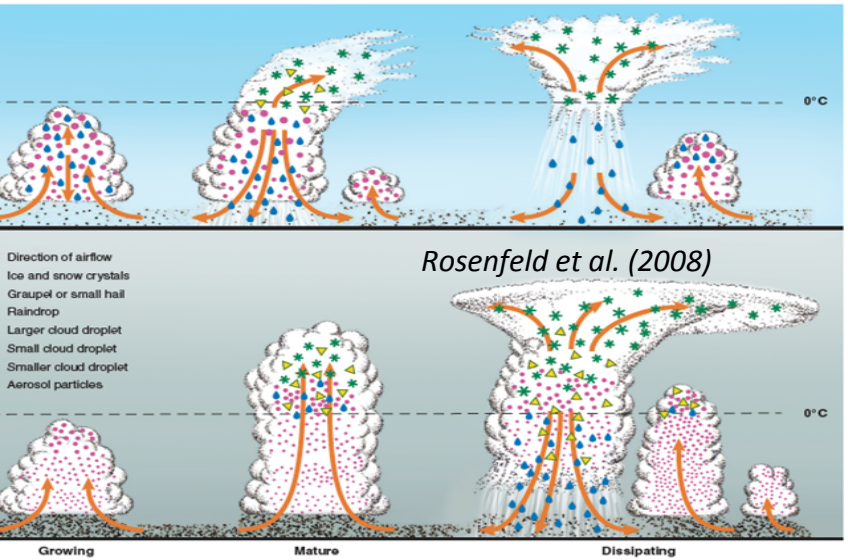
Large-scale wind anomalies associated with the MJO appear to be responsible for modulating lower tropospheric CCN concentrations on intraseasonal timescales over the central Indian Ocean.

Radar and lightning observations from TRMM PR/LIS depict non-trivial changes in convective characteristics during certain phases of the MJO in areas with high CCN concentrations over the central Indian Ocean.

Extra

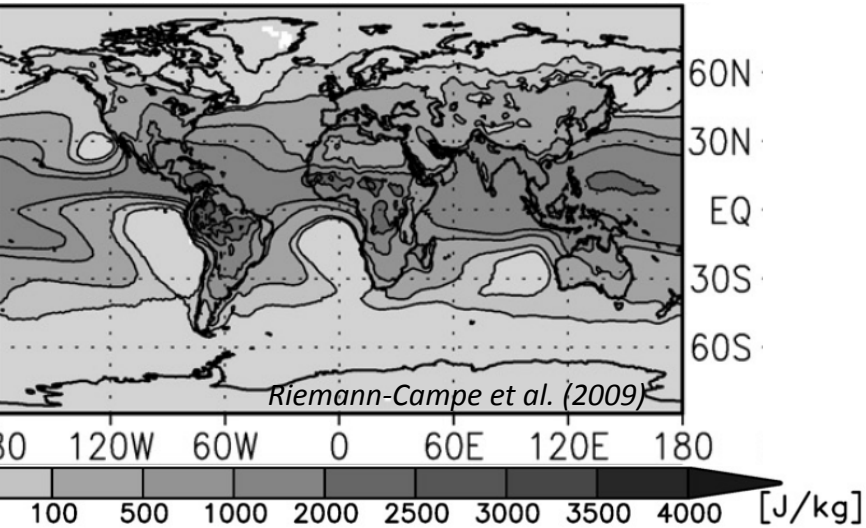
npeting Hypotheses

AEROSOLS



Rosenfeld et al. (2008)

CAPE



Riemann-Campe et al. (2009)

Updraft width

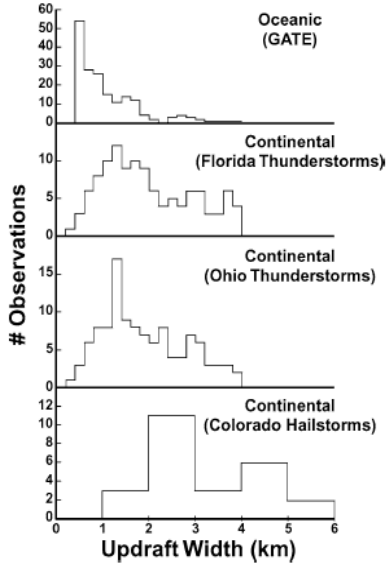


Figure 8. Histograms of observations of updraft width in: (a) oceanic conditions [24]; (b) Florida thunderstorms [23]; (c) Ohio thunderstorms [23]; and (d) large Colorado hailstorms [43].

Updraft strengt

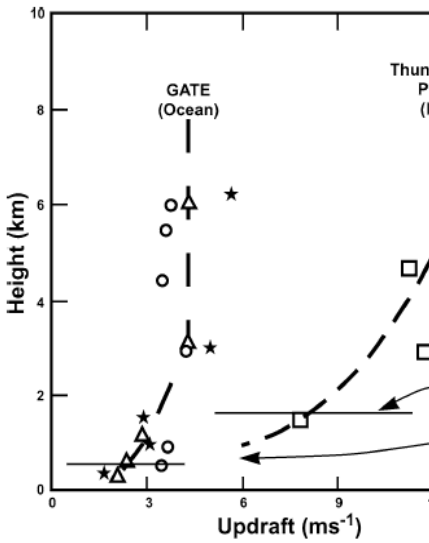


Figure 9. Summary of updraft profiles for o
continental conditions [31]. The contrast in up
exceeds a factor of two even at cloud bas

Byers and Braham (1949); Kyle et al. (1976); LeMone and Zipser (1980); J
LeMone (1989); Williams and Stanfill (2002)

Traditional Thermal: CAPE controlling factor for convective in
Warm-Cloud Depth (WCD): Cloud base height scales with wid
updraft; wider updrafts → efficient conversion of CAPE to upd
kinetic energy (via reduced entrainment)
Aerosol: CCN modify size distribution of liquid hydrometeors
impact warm-rain process → riming/latent heat release above

PDFs for CFs and LPCFs

NCAPE
Fs (CFs
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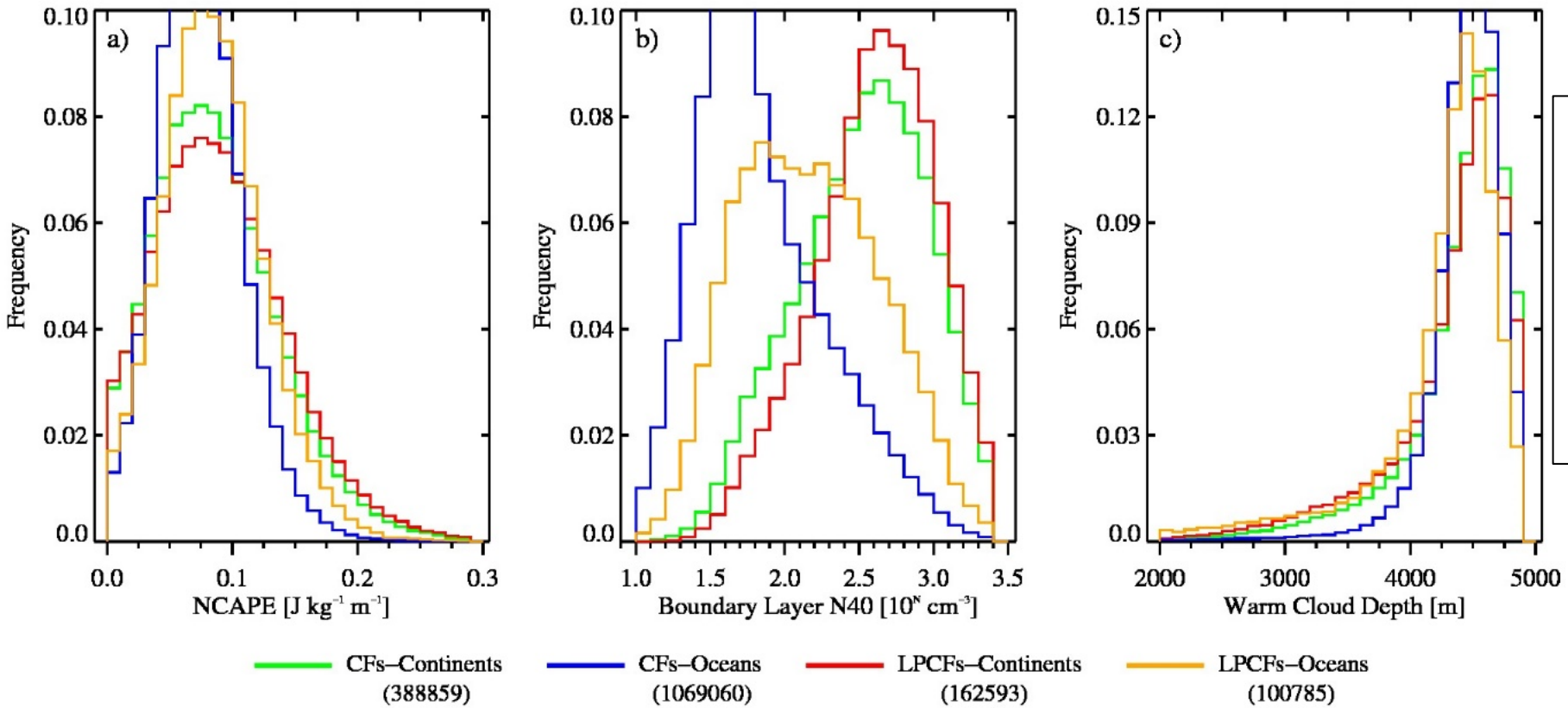

Medi
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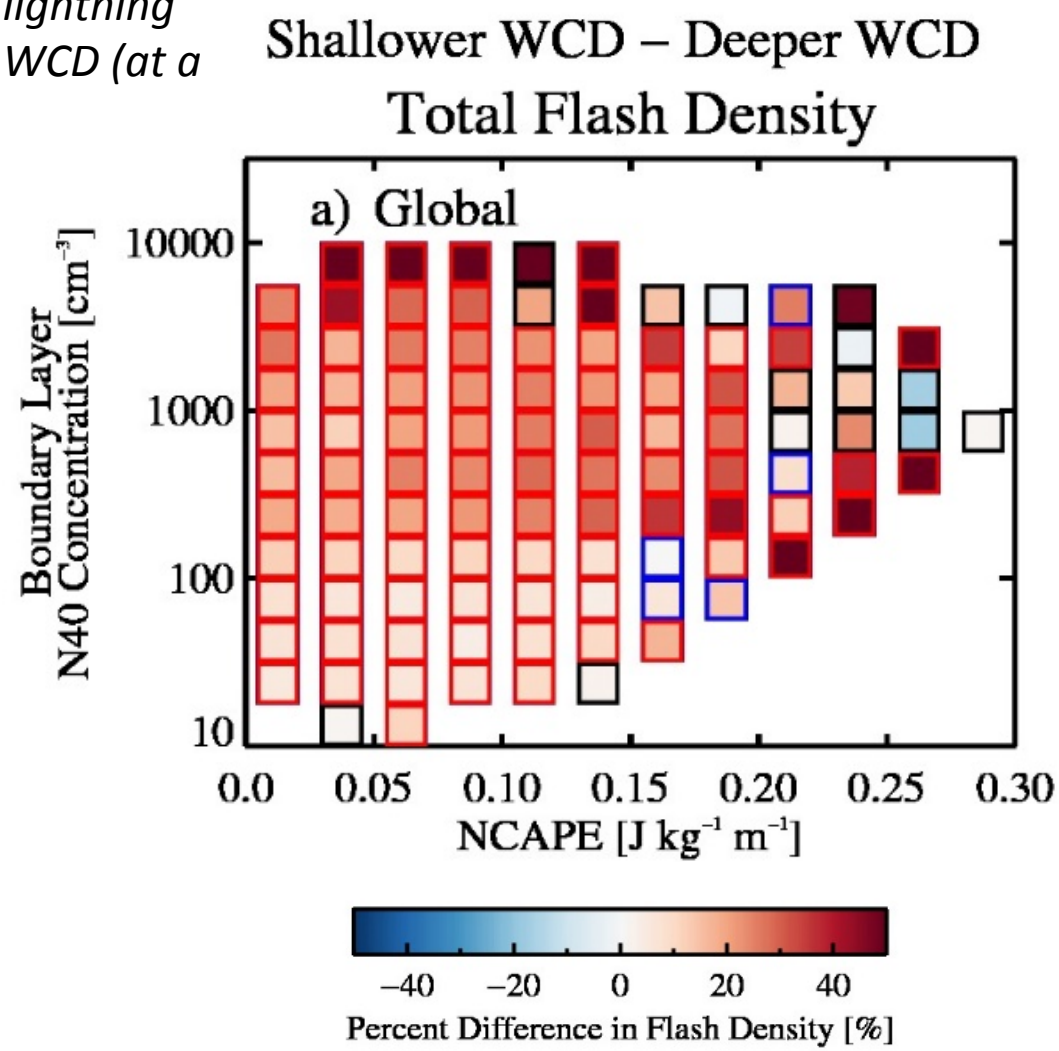
clima
LPCFs
and c
shallo

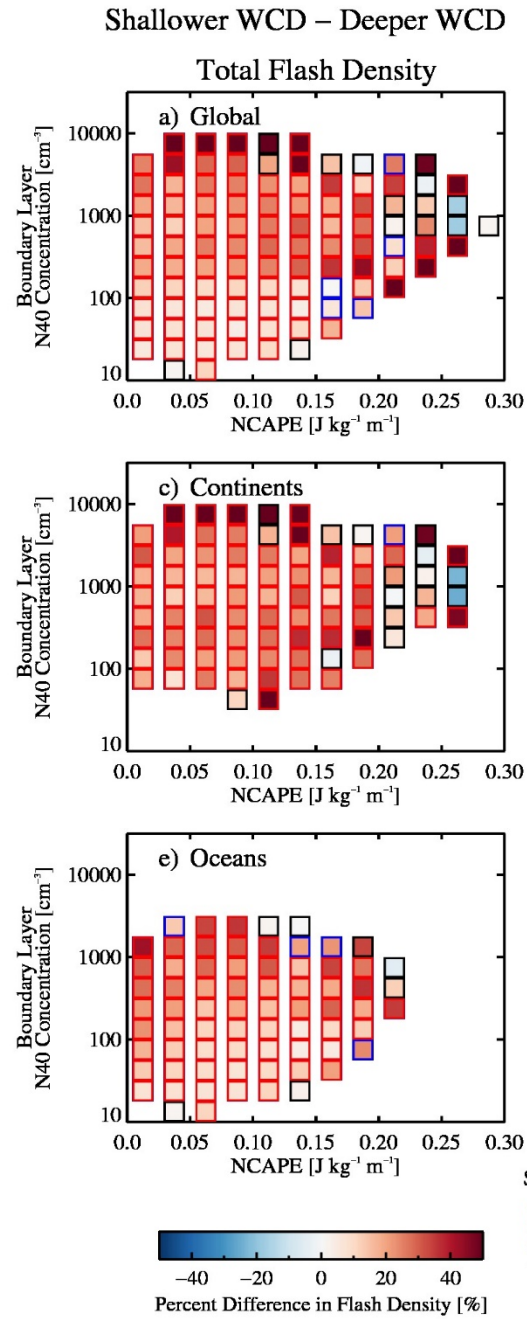
N40 is highest for LPCFs over continents (> 500 cm^{-3}) and N40 is lowest for CFs over oceans (< 100 cm^{-3})

Quantifying the Influence of WCD

essing the difference in lightning shallower and deeper WCD (at a CAPE/N40 point).

any points in the E-N40 parameter ce, the lightning ity is greater for allower WCD pared to deeper WCD



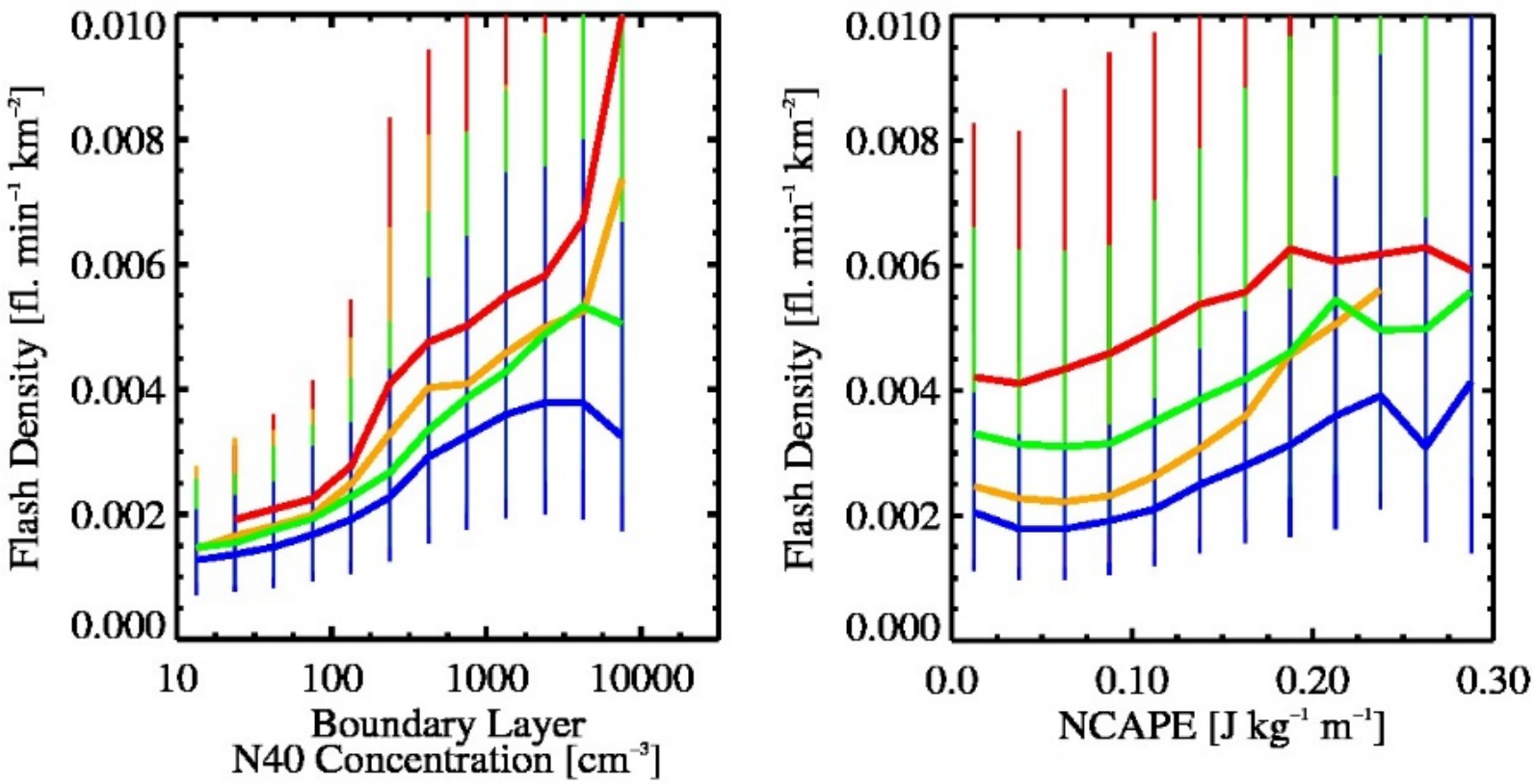


Partial Sensitivity of Lightning Density

ΔLightning/ΔAerosols

ΔLightning/ΔThermodynamics

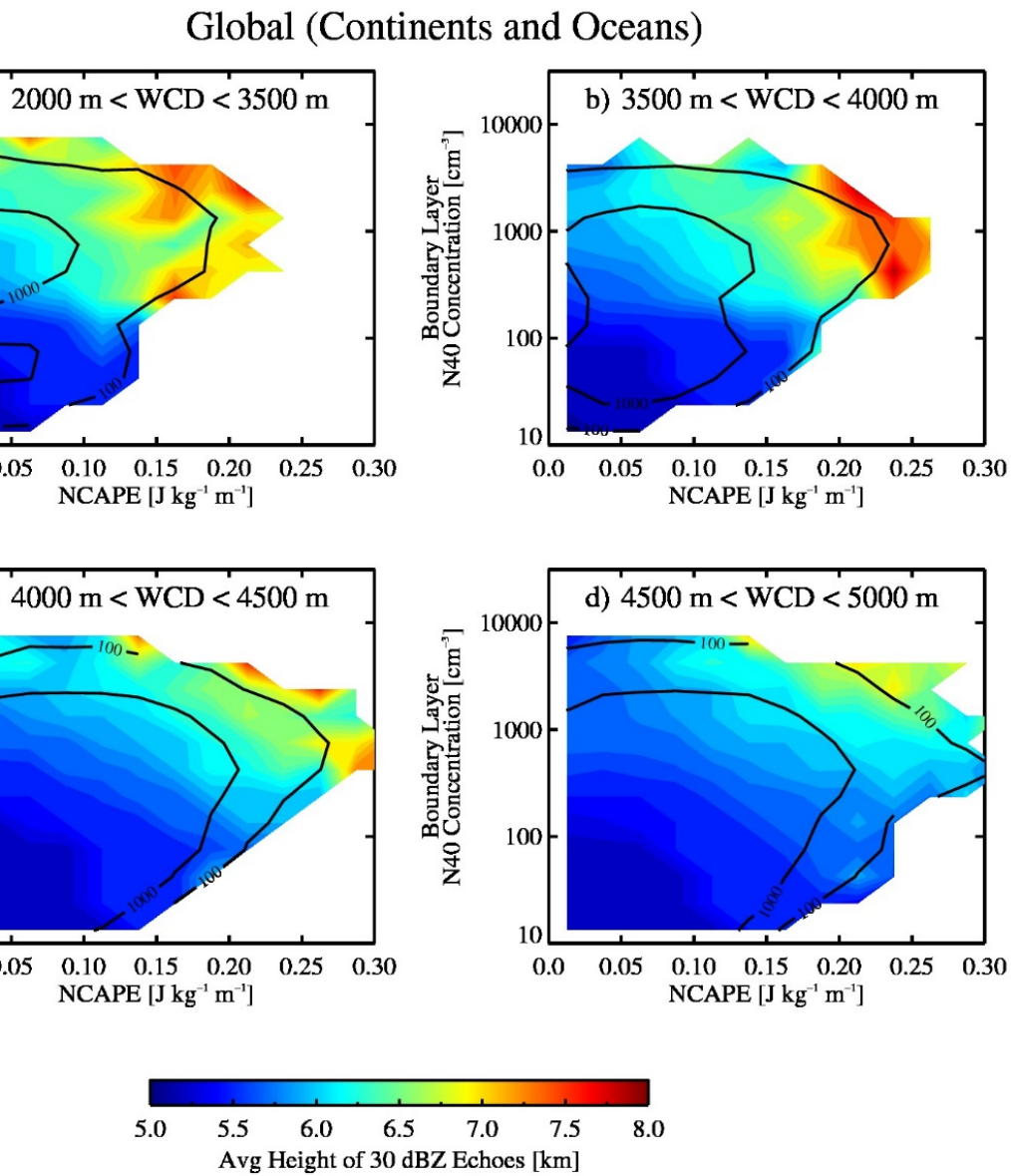
, ↓WCD
, ↓WCD
, ↑WCD
, ↑WCD



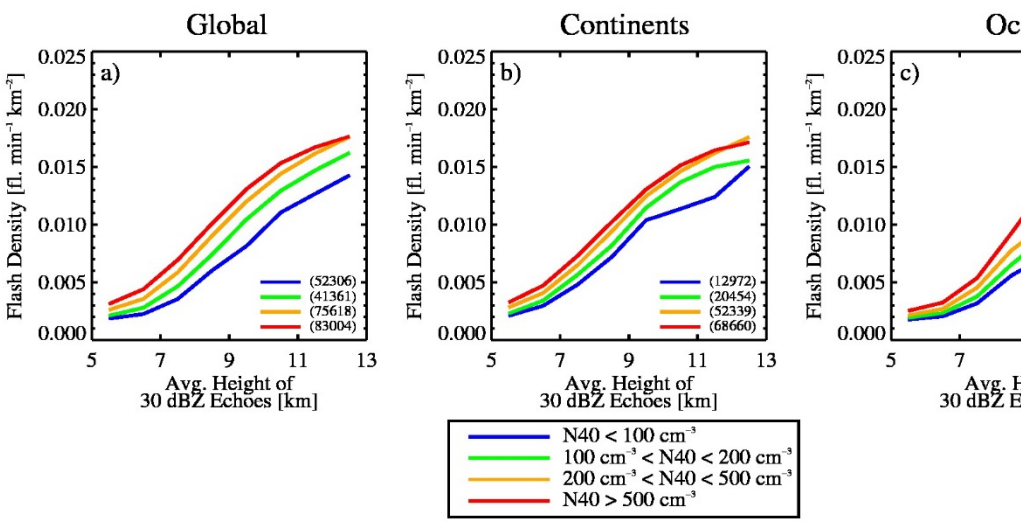
↑N40, ↓W
↓N40, ↓W
↑N40, ↑W
↓N40, ↑W

The range of these relationships is *comparable* (for most separations), but separate dependence on either NCAPE or N40 is not sufficient to account for the full range of observed variability in lightning density.

/GHT30: 2D distribution + WCD

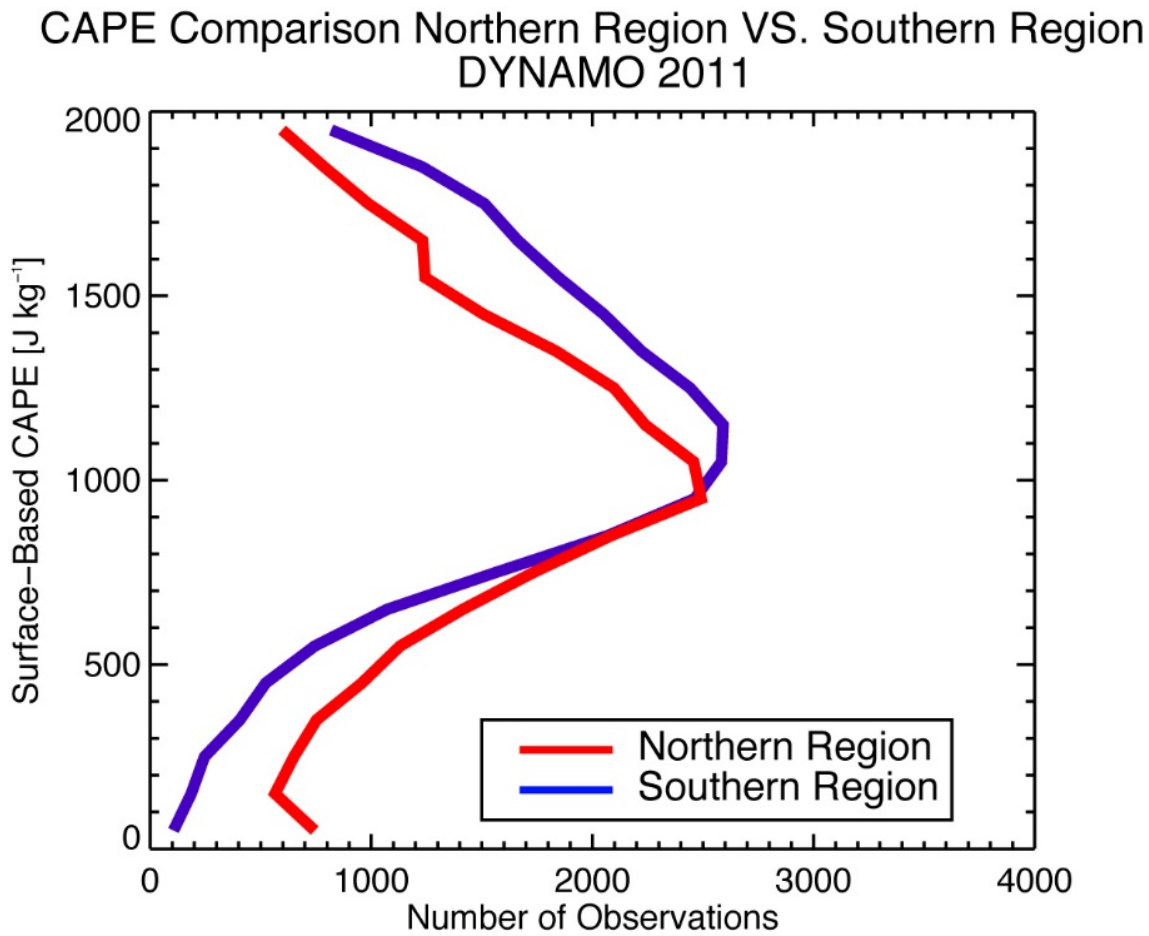


Qualitative agreement in the distributions of A
for combinations of NCAPE, CCN, and WC



Lightning and radar characteristics are stro
correlated (e.g., Liu et al., 2012), but slope var
function of CCN

Homogeneous thermodynamics



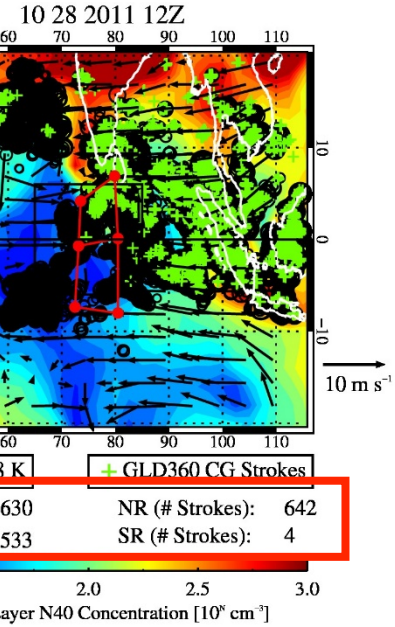
The central Indian Ocean (CIO) represents natural thermodynamic laboratory (e.g., M et al., 2009; 2011) to study aerosol impact deep convection

Similar distributions of CAPE between each region (DYNAMO period, Oct.-Dec. 2011)

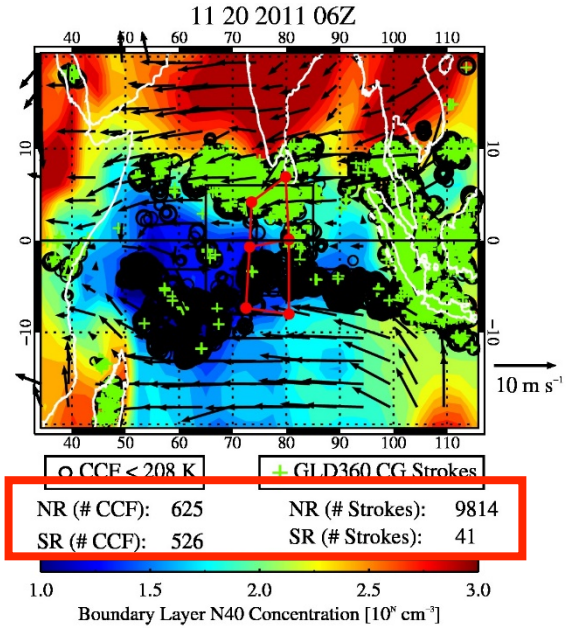
How does convection resp
on the large (basin) scal

Shading = N40 concentration
Black Circles = Cold Cloud Featur
Green Plus = CG lightning
Vectors = 925 hPa winds

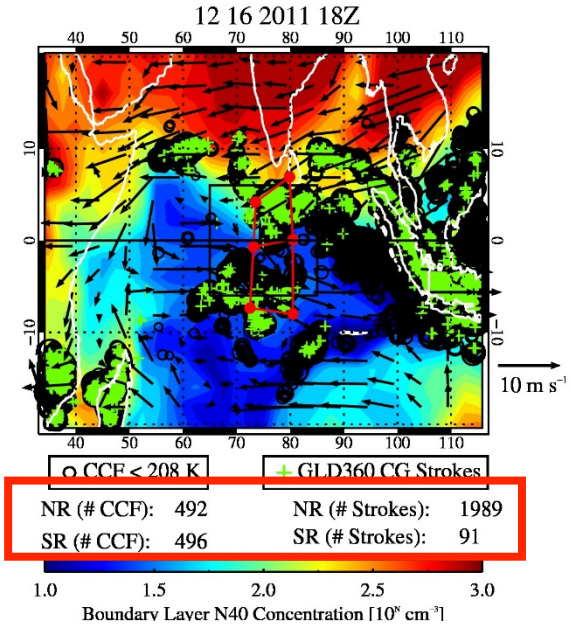
Pre-MJO1



Pre-MJO2

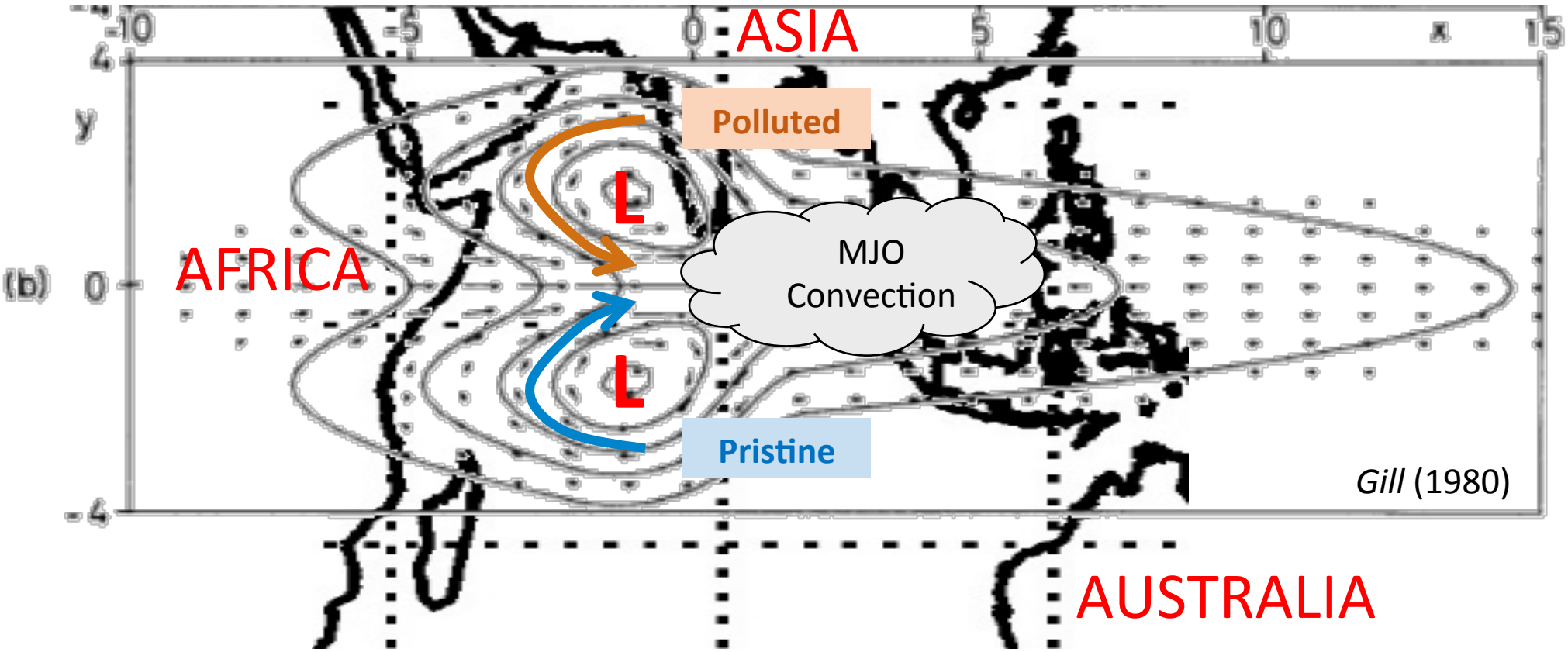


Pre-MJO3



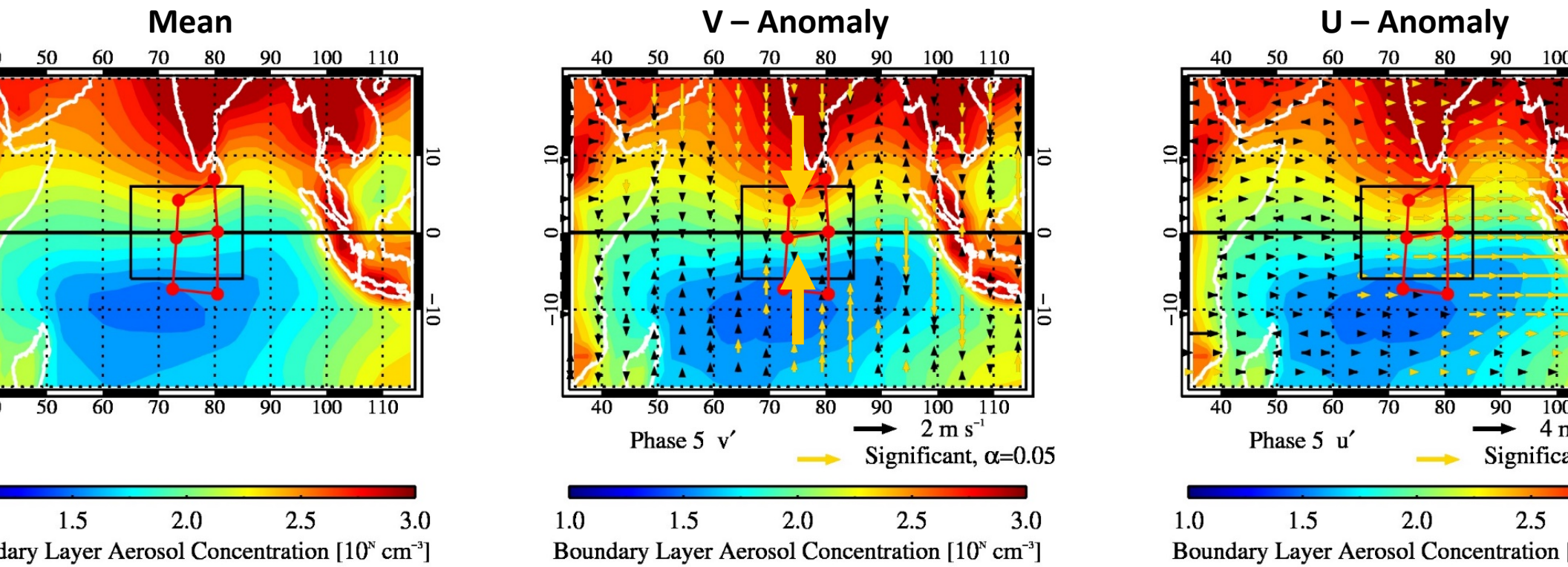
Despite similar populations of Cold Cloud Features (i.e., deep convection) lightning appears to occur preferentially in the northern region, where aerosol concentrations are highest

30-50 day variability in CCN?



Horizontal transport of atmospheric pollutants may occur preferentially in the northern hemisphere in the wake of active MJO convective episodes in association with Rossby Gyres.

Aerosol variance



malous flows acting on background (mean) aerosol gradient (e.g., phase 5) increase aerosol gradient along
equator in the Central Indian Ocean (Rossby Gyre/eddie activity?)