Relevance of Large-Scale Vertical Motions and Cumuliform Buoyancy to MJO Convective Onset

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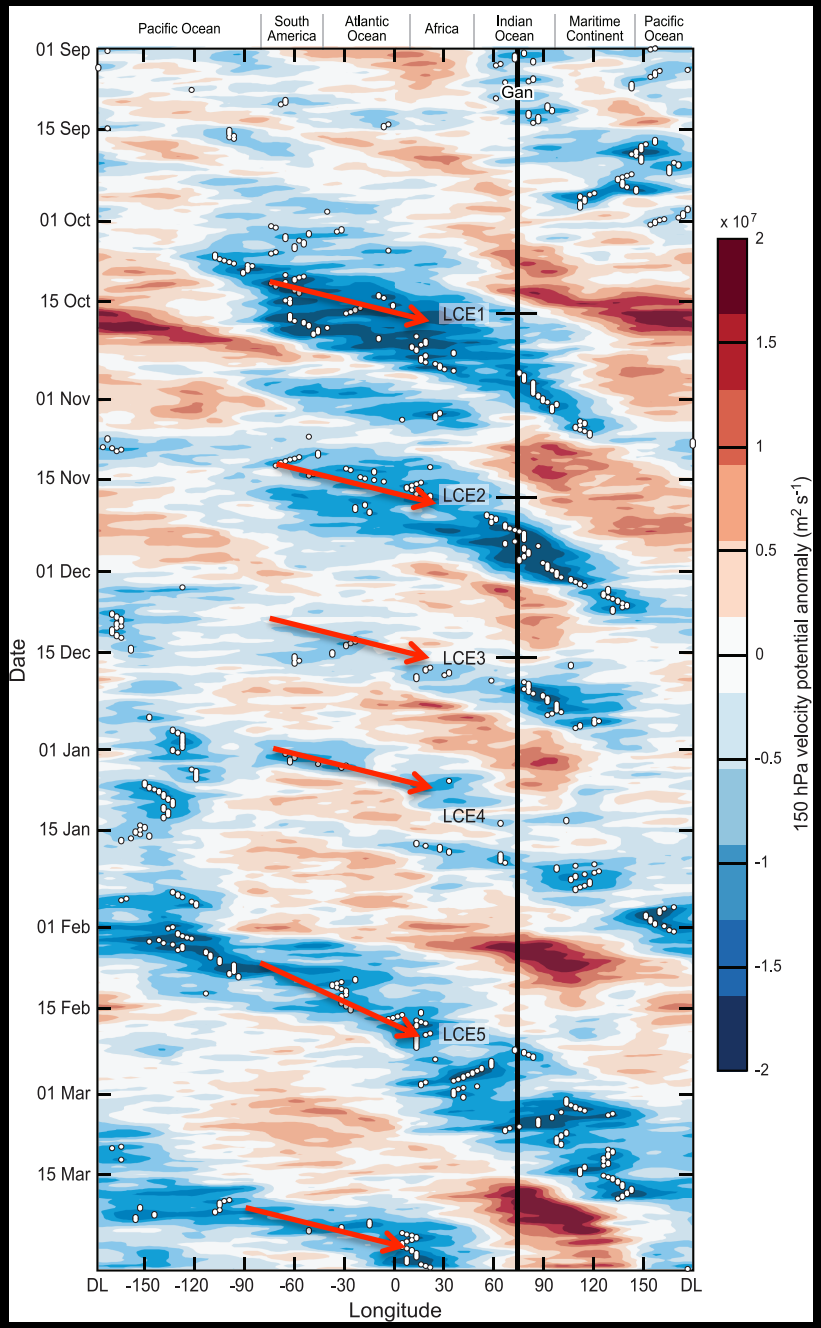
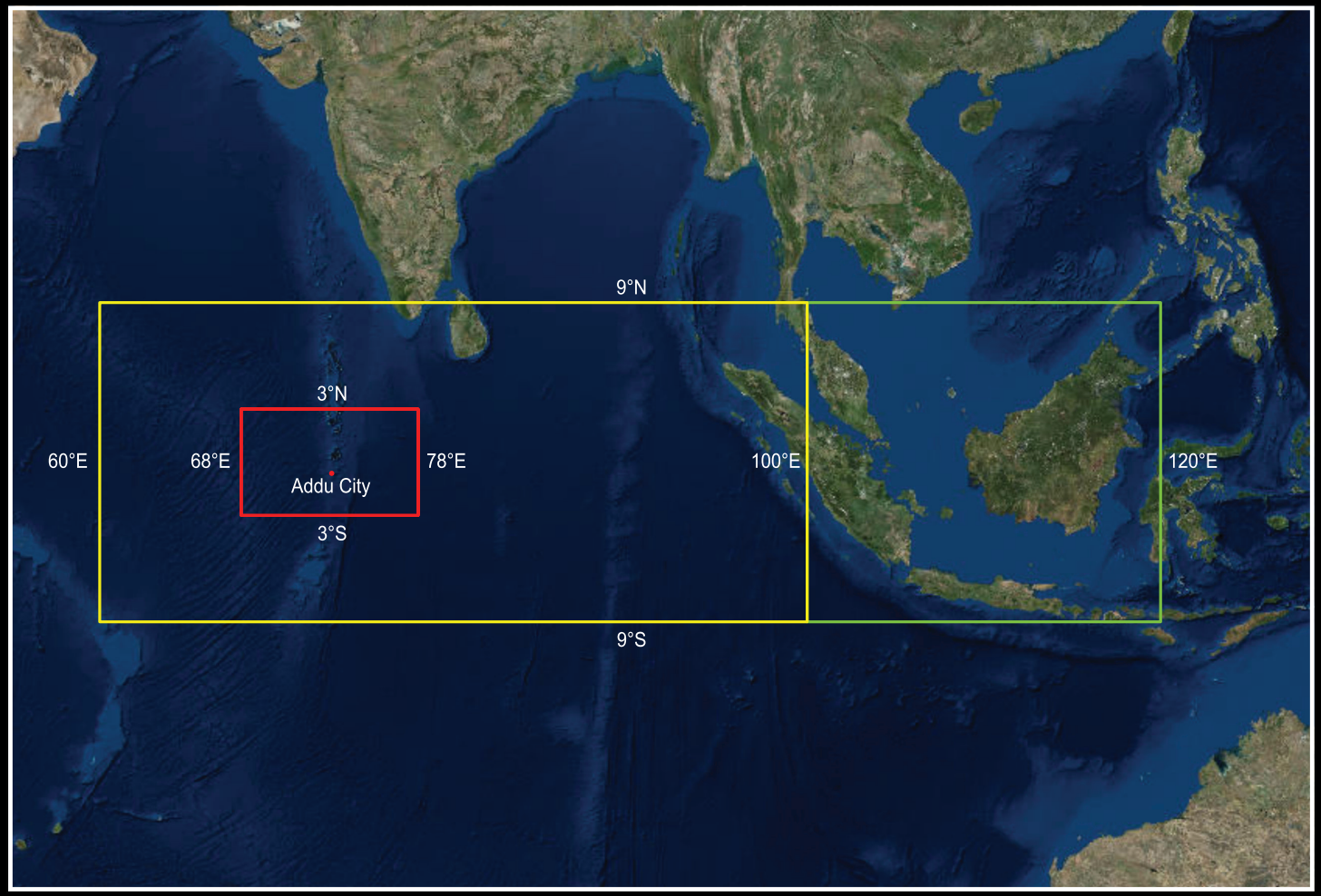
Hypothesis: Convection passively responds to changes in the large-scale environment.



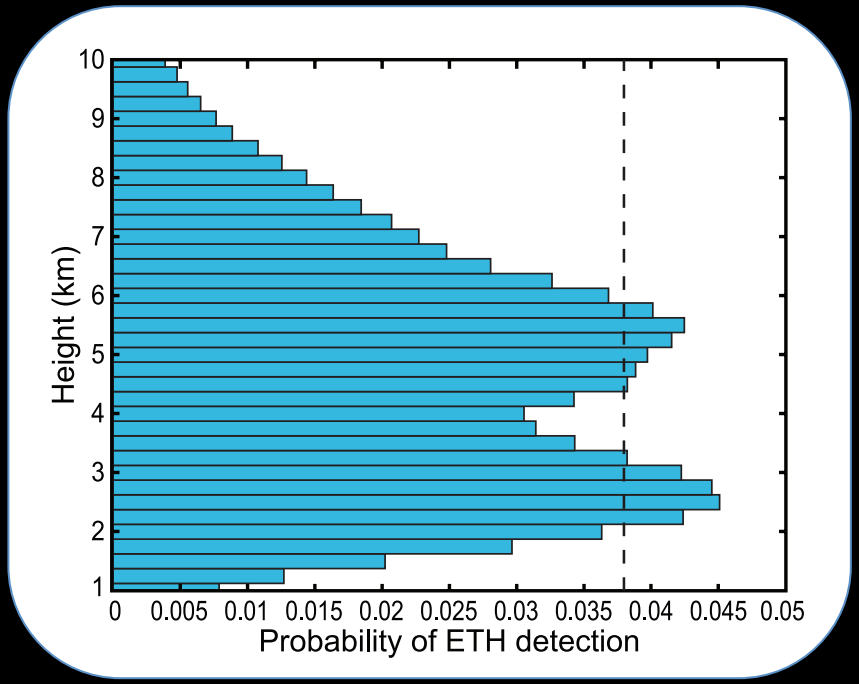
Timescale of MJO Convective Build-up

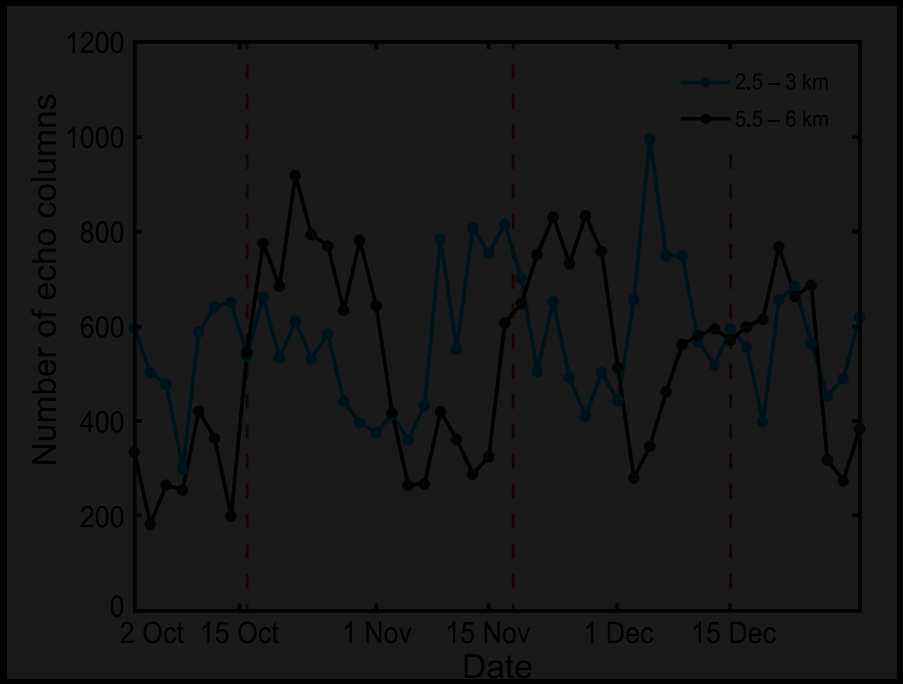
What duration is the transition from suppressed to widespread, deep convection?

Powell and Houze (2013, 2015a) in JGR


9°N
3°N
60°E
68°E
78°E
100°E
120°E
Addu City
3°S
9°S

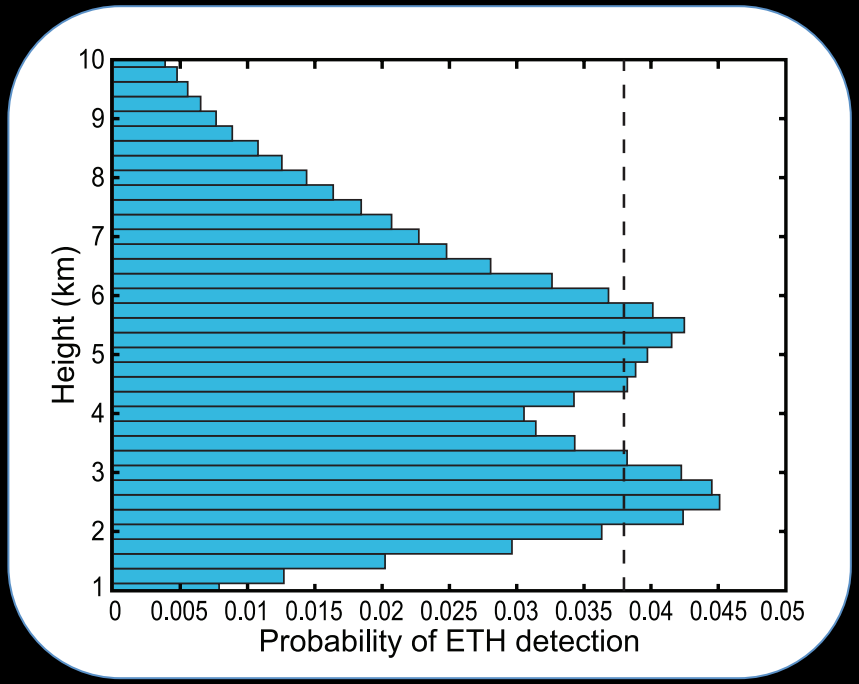
Powell and Houze (2015a)

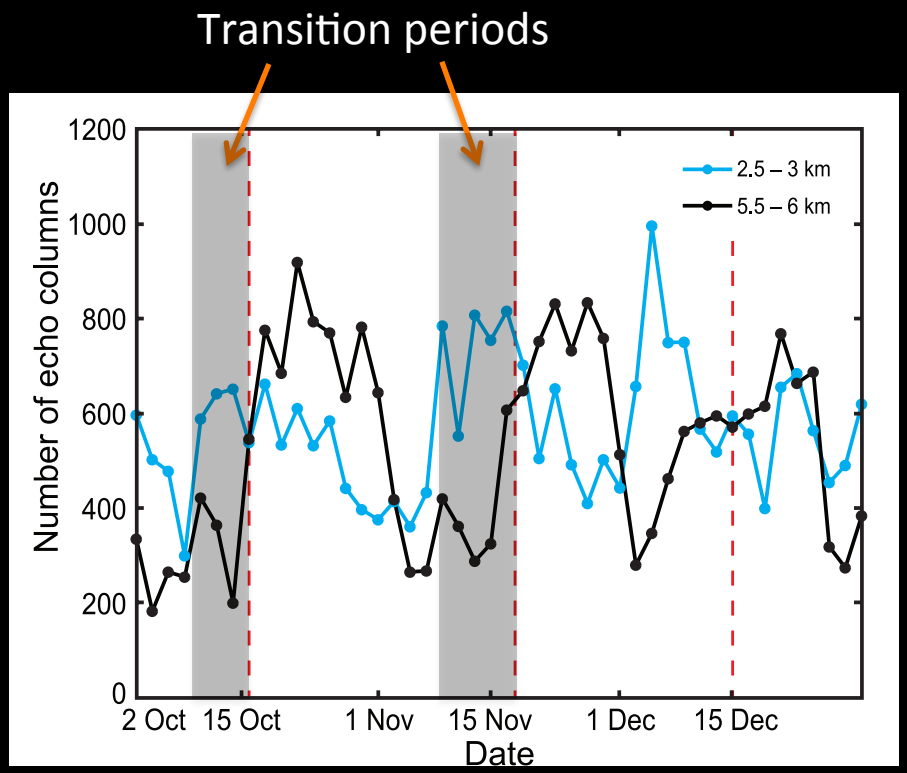




TRMM 20dBZ echo tops: 9N–9S; 60–100E

Powell and Houze (2015a)





TRMM 20dBZ echo tops: 9N–9S; 60–100E

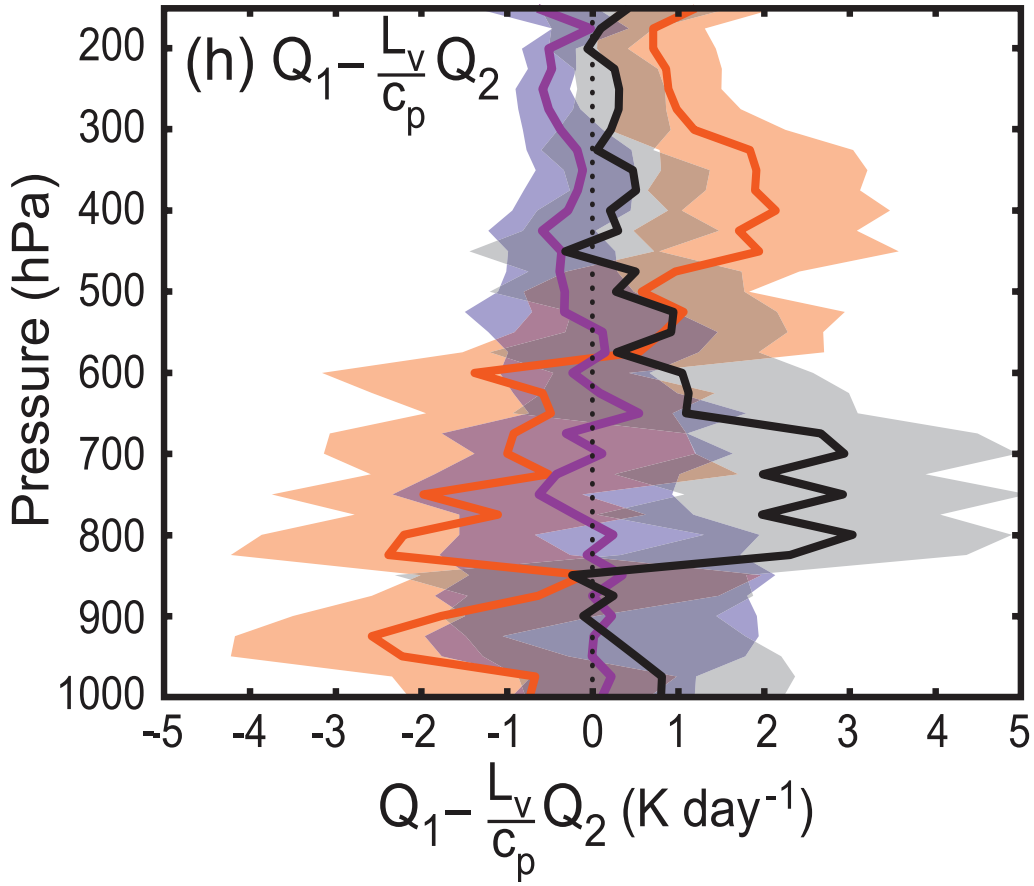
Moistening by Cumulonimbi

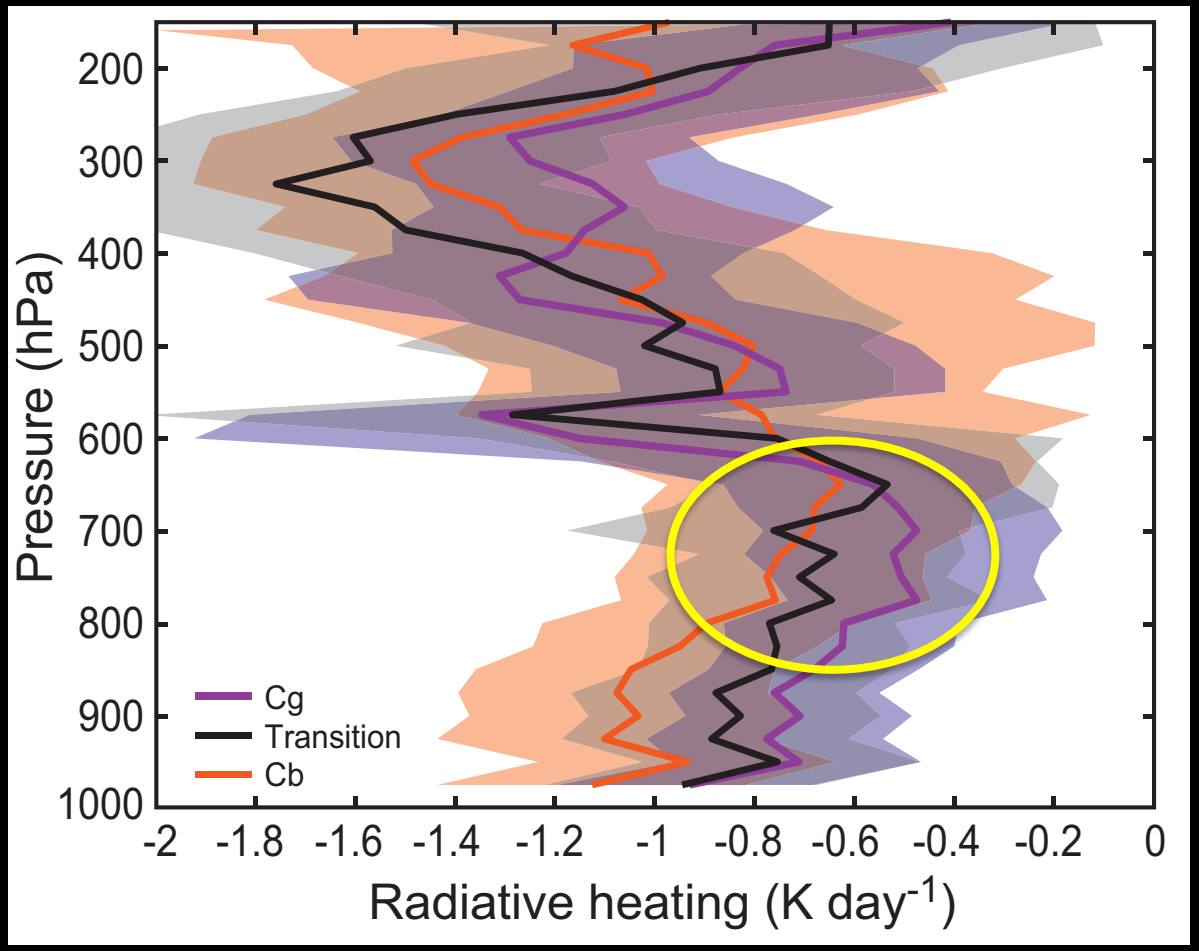
Do moderately deep clouds moisten the troposphere during transition periods, or does moistening permit observed cloud deepening?

Powell and Houze (2015b) in JGR

Purple = Cg
Black = Trans.
Red = Cb

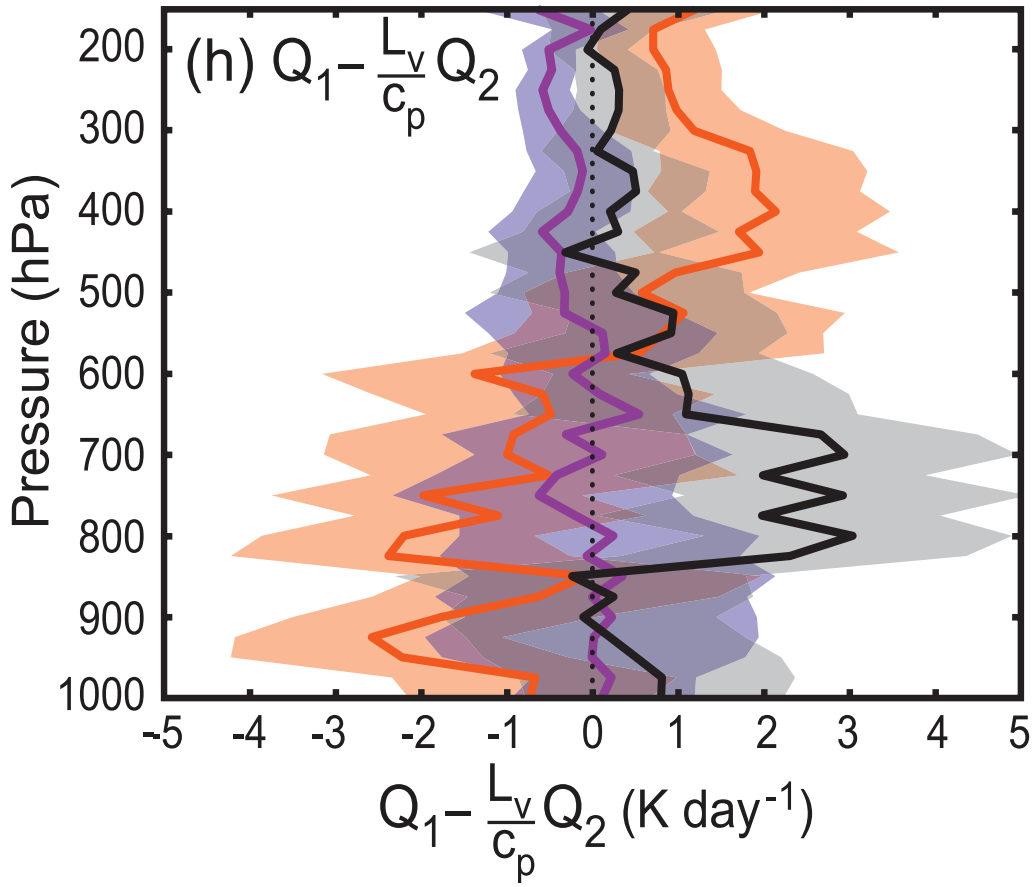
$$Q_1 - \frac{L_v}{c_p} Q_2 = Q_R - \frac{1}{c_p} \frac{\partial}{\partial p} \left(\overline{\omega' h'} \right)$$




Pressure (hPa)
200
300
400
500
600
700
800
900
1000
-2
-1.8
-1.6
-1.4
-1.2
-1
-0.8
-0.6
-0.4
-0.2
0
Radiative heating (K day-1)
Cg
Transition
Cb

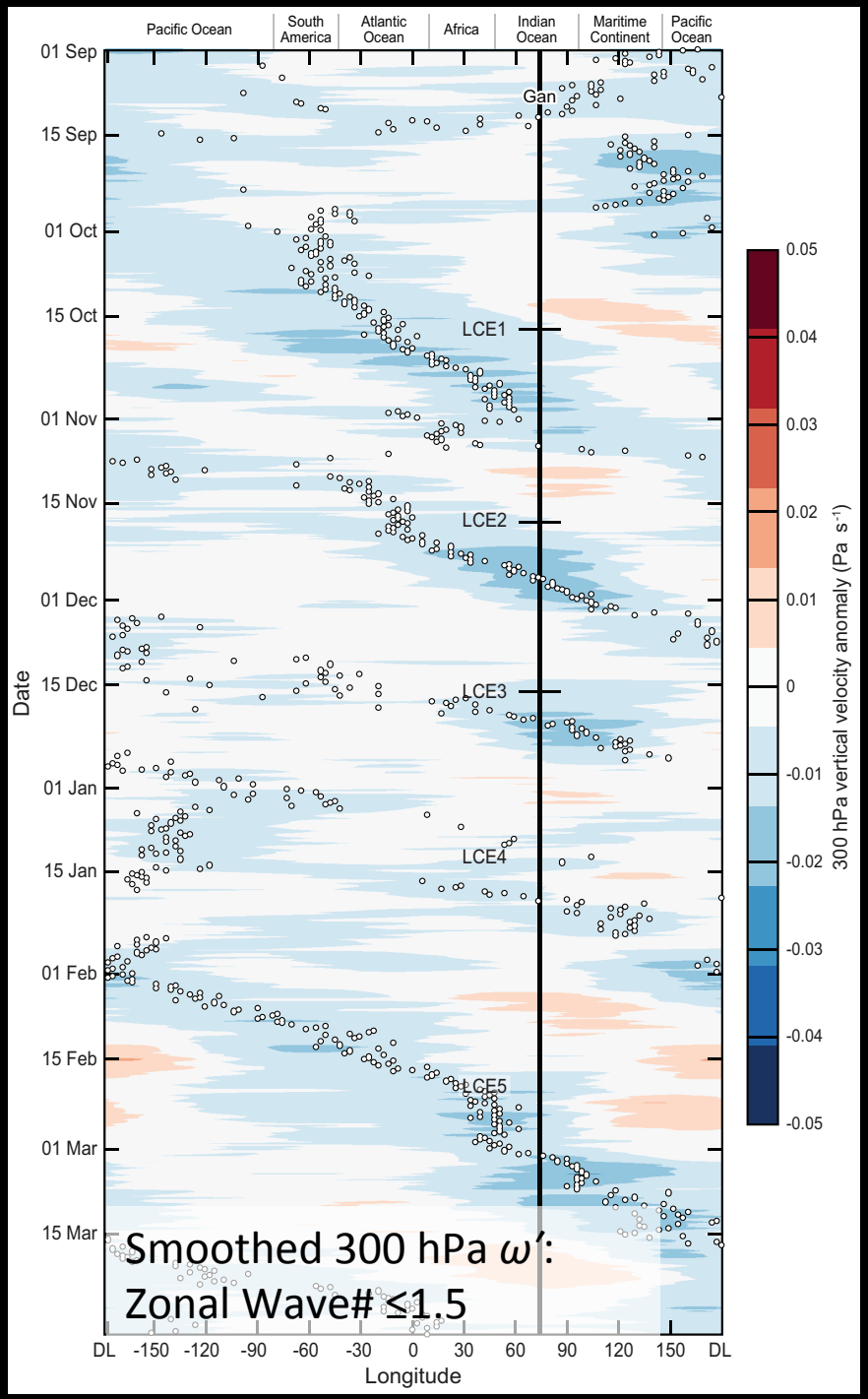
Purple = Cg
Black = Trans.
Red = Cb

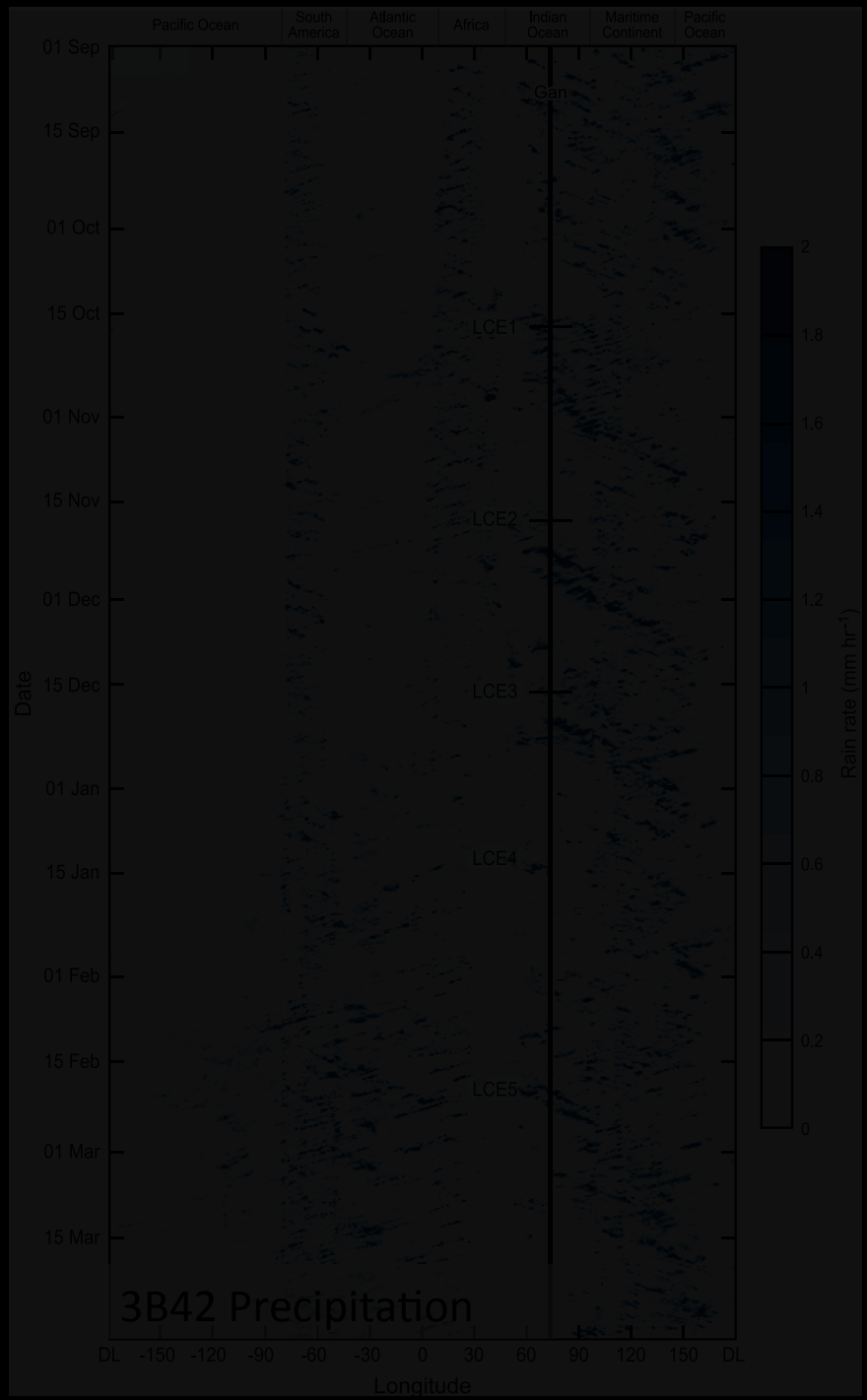
$$Q_1 - \frac{L_v}{c_p} Q_2 = Q_R - \frac{1}{c_p} \frac{\partial}{\partial p} \left(\overline{\omega' h'} \right)$$

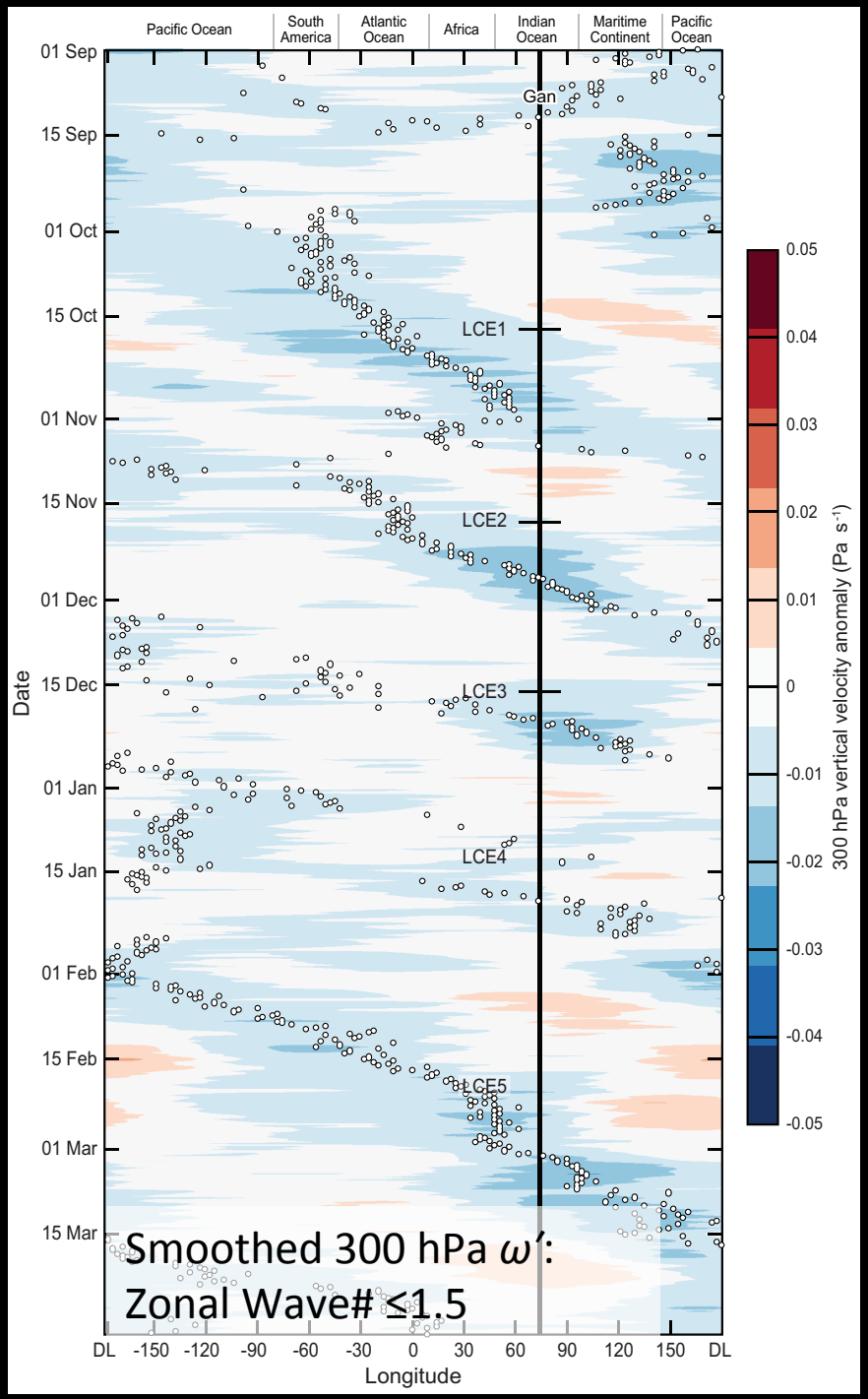


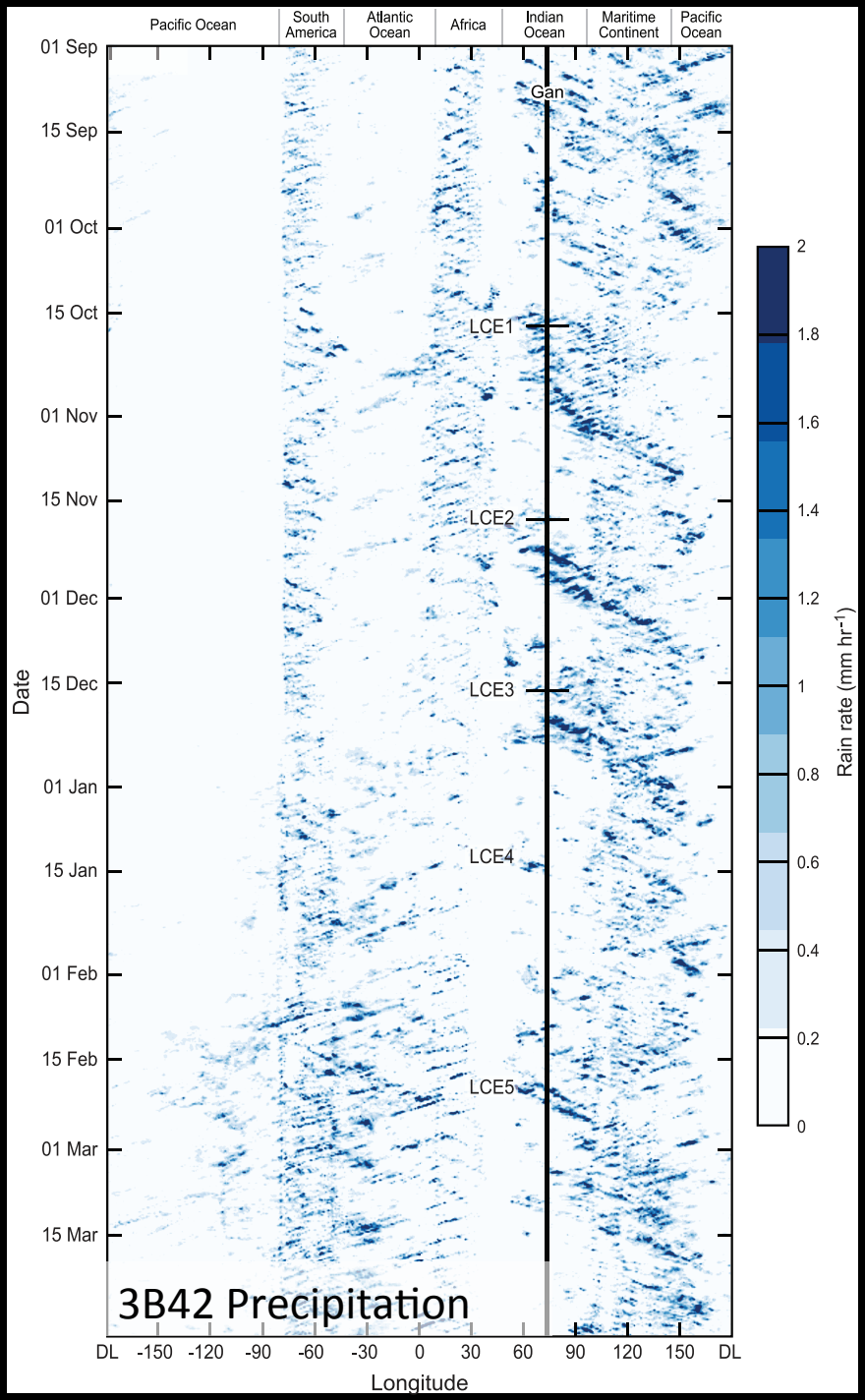
The Circumnavigating MJO (Kelvin wave?)

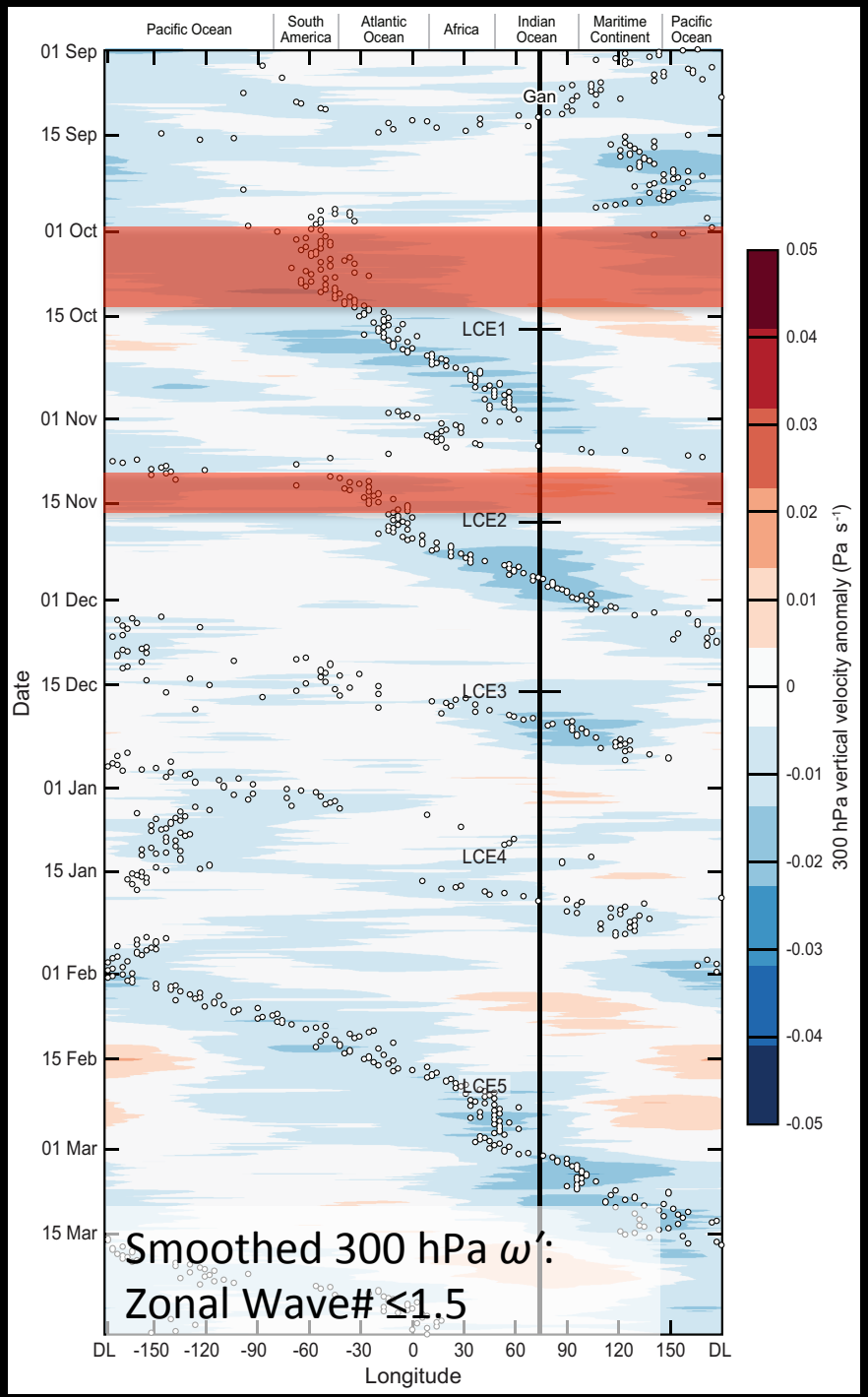
How does LS upper-tropospheric divergence relate to convection rooted in a warm, moist boundary layer?

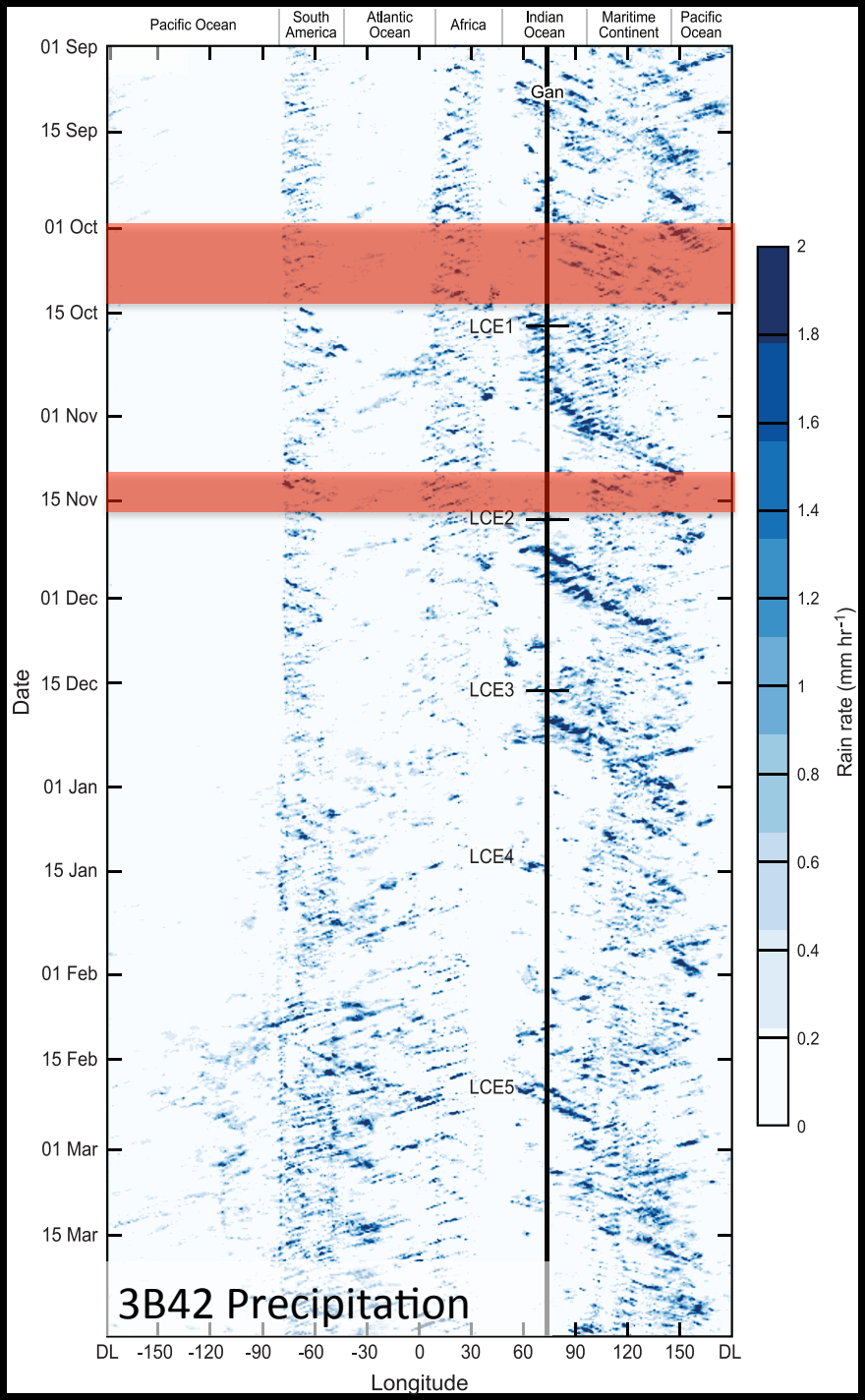

Pacific Ocean
South America
Atlantic Ocean
Africa
Indian Ocean
Maritime Continent
Pacific Ocean
Gan
01 Sep
15 Sep
01 Oct
15 Oct
01 Nov
15 Nov
01 Dec
15 Dec
01 Jan
15 Jan
01 Feb
15 Feb
01 Mar
15 Mar
LCE1
LCE2
LCE3
LCE4
LCE5
Date
DL -150 -120 -90 -60 -30 0 30 60 90 120 150 DL
Longitude
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
300 hPa vertical velocity anomaly (Pa s-1)
Smoothed 300 hPa ω′:
Zonal Wave# ≤1.5


Pacific Ocean
South America
Atlantic Ocean
Africa
Indian Ocean
Maritime Continent
Pacific Ocean
Gan
01 Sep
15 Sep
01 Oct
15 Oct
01 Nov
15 Nov
01 Dec
15 Dec
01 Jan
15 Jan
01 Feb
15 Feb
01 Mar
15 Mar
LCE1
LCE2
LCE3
LCE4
LCE5
Date
DL -150 -120 -90 -60 -30 0 30 60 90 120 150 DL
Longitude
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Rain rate (mm hr-1)
3B42 Precipitation


Pacific Ocean
South America
Atlantic Ocean
Africa
Indian Ocean
Maritime Continent
Pacific Ocean
01 Sep
15 Sep
01 Oct
15 Oct
01 Nov
15 Nov
01 Dec
15 Dec
01 Jan
15 Jan
01 Feb
15 Feb
01 Mar
15 Mar
Date
Gan
LCE1
LCE2
LCE3
LCE4
LCE5
DL -150 -120 -90 -60 -30 0 30 60 90 120 150 DL
Longitude
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
300 hPa vertical velocity anomaly (Pa s-1)
Smoothed 300 hPa ω′:
Zonal Wave# ≤1.5


Pacific Ocean
South America
Atlantic Ocean
Africa
Indian Ocean
Maritime Continent
Pacific Ocean
01 Sep
15 Sep
01 Oct
15 Oct
01 Nov
15 Nov
01 Dec
15 Dec
01 Jan
15 Jan
01 Feb
15 Feb
01 Mar
15 Mar
Date
Gan
LCE1
LCE2
LCE3
LCE4
LCE5
DL -150 -120 -90 -60 -30 0 30 60 90 120 150 DL
Longitude
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Rain rate (mm hr-1)
3B42 Precipitation


Pacific Ocean
South America
Atlantic Ocean
Africa
Indian Ocean
Maritime Continent
Pacific Ocean
01 Sep
15 Sep
01 Oct
15 Oct
01 Nov
15 Nov
01 Dec
15 Dec
01 Jan
15 Jan
01 Feb
15 Feb
01 Mar
15 Mar
Date
Gan
LCE1
LCE2
LCE3
LCE4
LCE5
DL -150 -120 -90 -60 -30 0 30 60 90 120 150 DL
Longitude
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
300 hPa vertical velocity anomaly (Pa s-1)
Smoothed 300 hPa ω′:
Zonal Wave# ≤1.5


Pacific Ocean
South America
Atlantic Ocean
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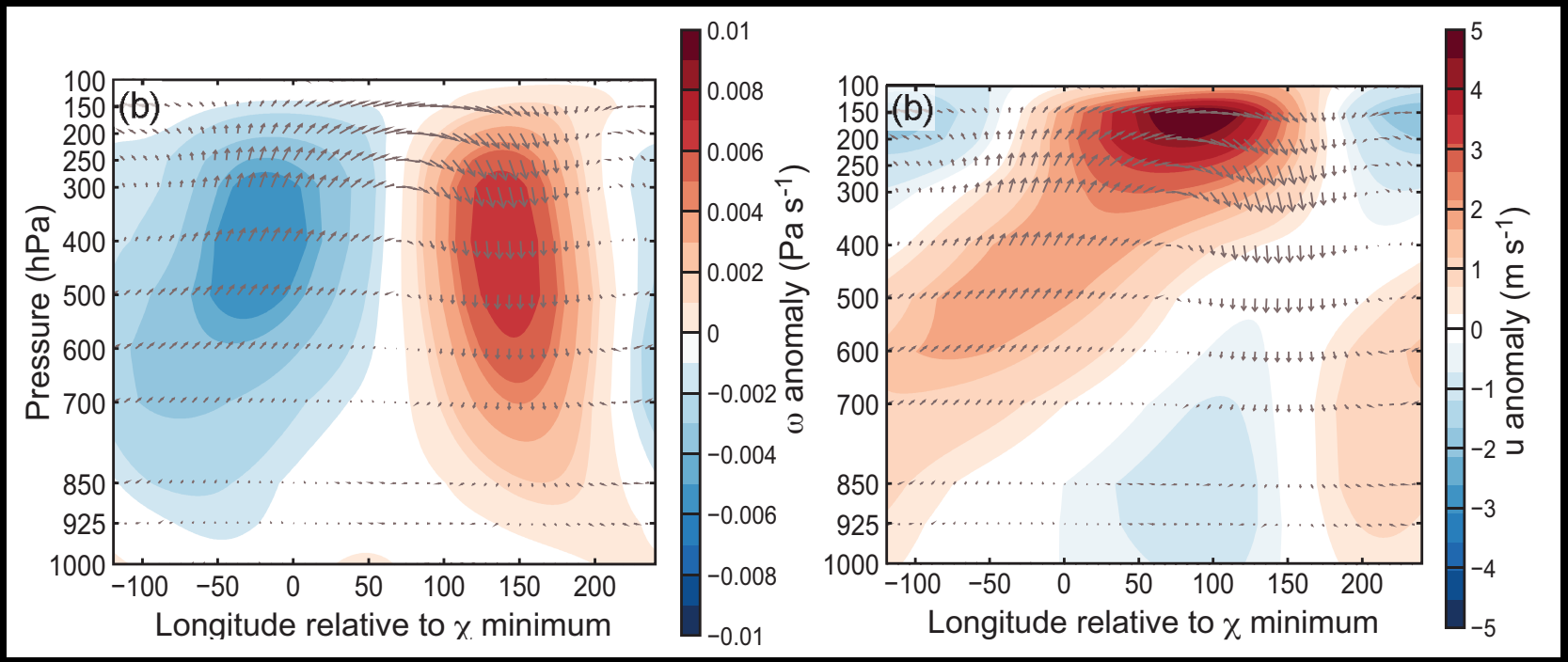
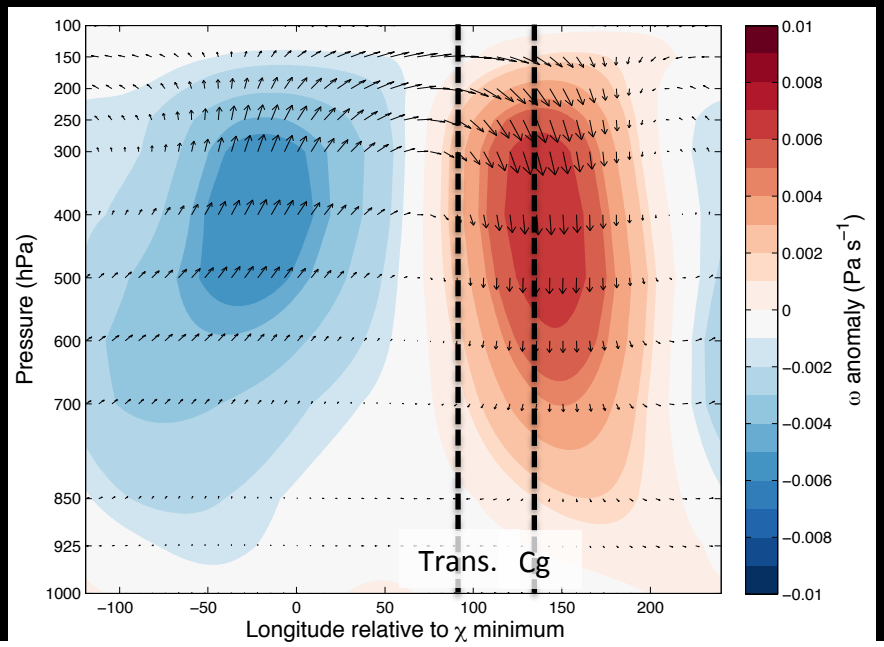
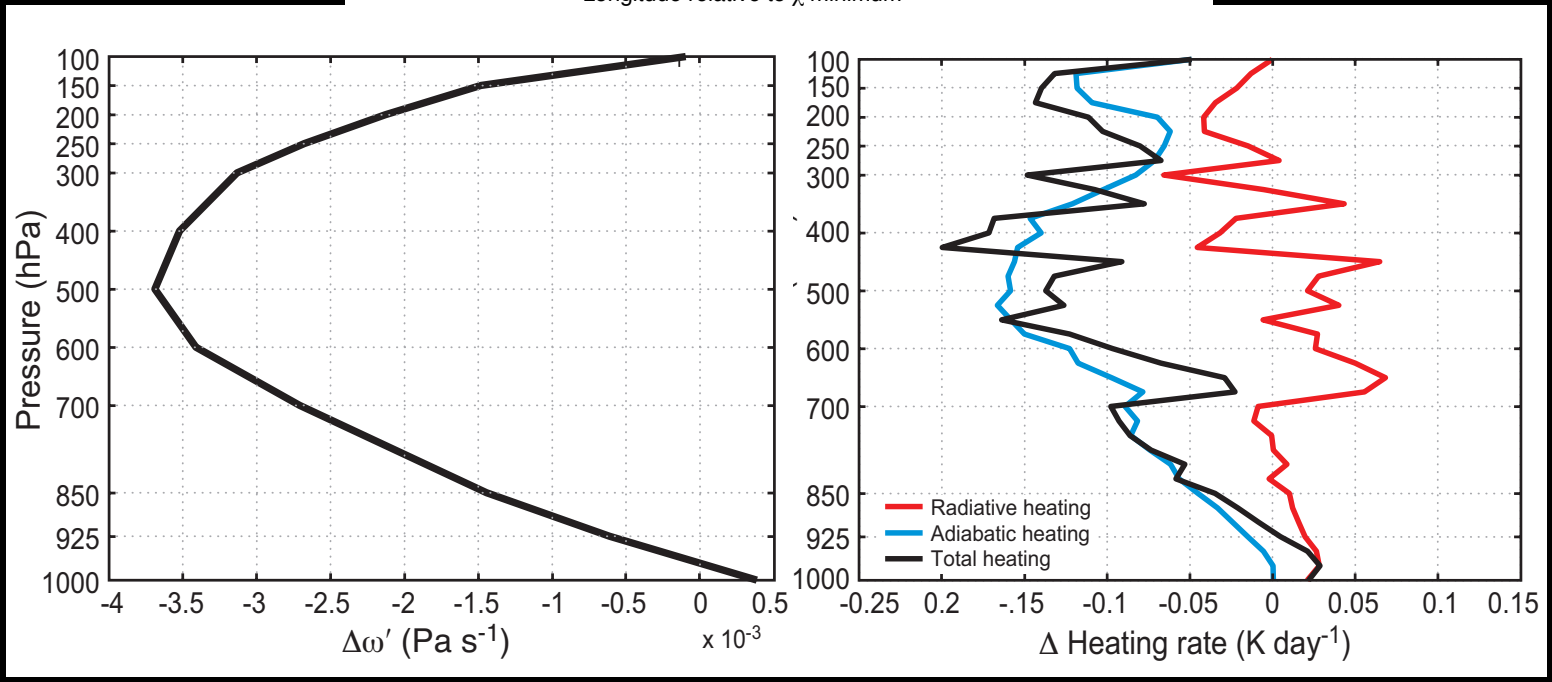
Maritime Continent
Pacific Ocean
01 Sep
15 Sep
01 Oct
15 Oct
01 Nov
15 Nov
01 Dec
15 Dec
01 Jan
15 Jan
01 Feb
15 Feb
01 Mar
15 Mar
Date
Gan
LCE1
LCE2
LCE3
LCE4
LCE5
DL -150 -120 -90 -60 -30 0 30 60 90 120 150 DL
Longitude
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Rain rate (mm hr-1)
3B42 Precipitation

Wave #
≤ 1.5


ω′
u′
(b)
Pressure (hPa)
100
150
200
250
300
400
500
600
700
850
925
1000
−100
−50
0
50
100
150
200
Longitude relative to χ minimum
0.01
0.008
0.006
0.004
0.002
0
−0.002
−0.004
−0.006
−0.008
−0.01
ω anomaly (Pa s^{-1})
5
4
3
2
1
0
−1
−2
−3
−4
−5
u anomaly (m s^{-1})

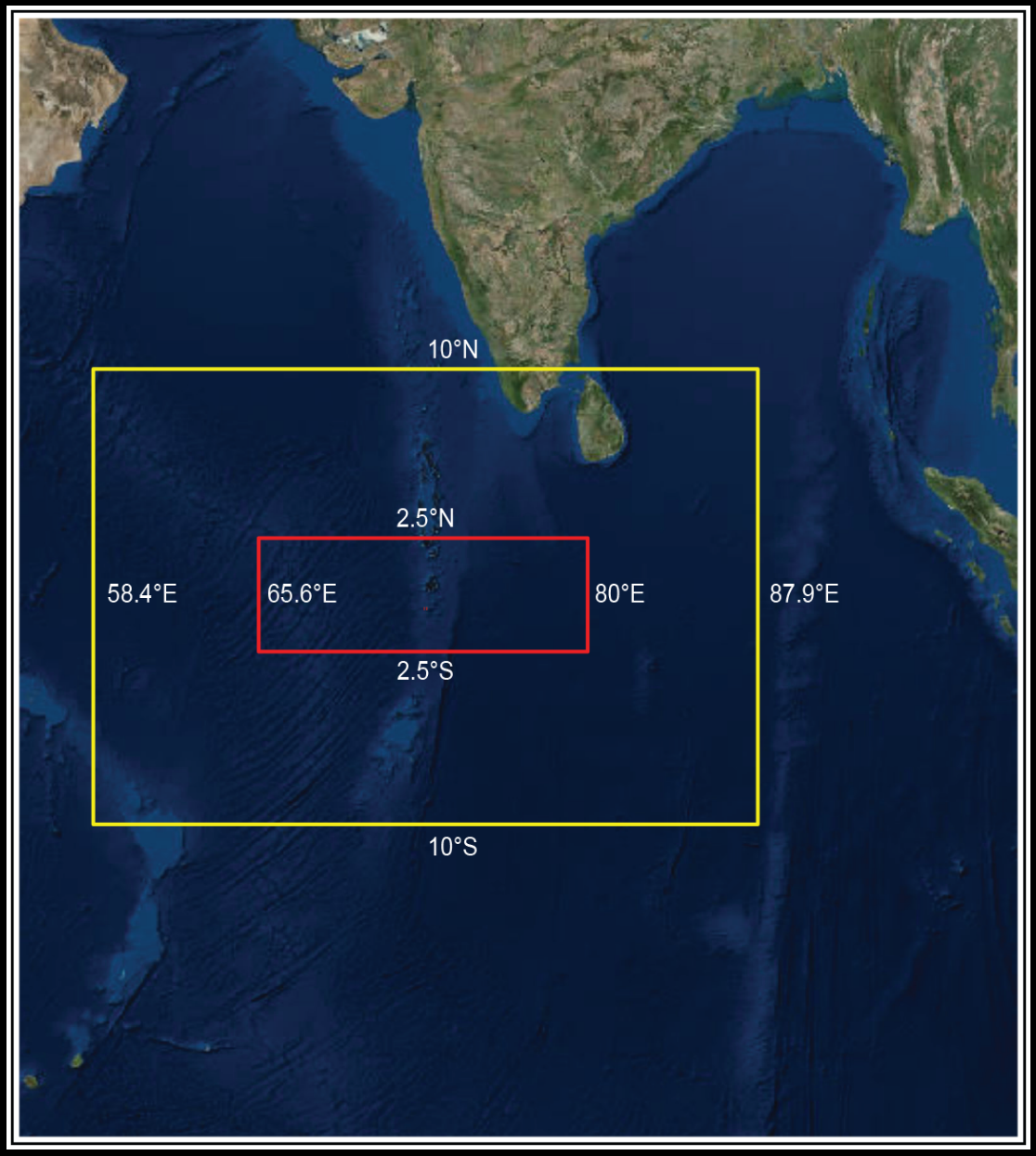

Pressure (hPa)
100
150
200
250
300
400
500
600
700
850
925
1000
Trans. Cg
−100
−50
0
50
100
150
200
Longitude relative to χ minimum
0.01
0.008
0.006
0.004
0.002
0
−0.002
−0.004
−0.006
−0.008
−0.01
ω anomaly (Pa s−1)


Pressure (hPa)
100
150
200
250
300
400
500
600
700
850
925
1000
-4
-3.5
-3
-2.5
-2
-1.5
-1
-0.5
0
0.5
Δω′ (Pa s-1)
x 10-3
-0.25
0.2
-.15
-0.1
-0.05
0
0.05
0.1
0.15
Δ Heating rate (K day-1)
Radiative heating
Adiabatic heating
Total heating

Updraft Buoyancy within Simulated Cumulonimbi

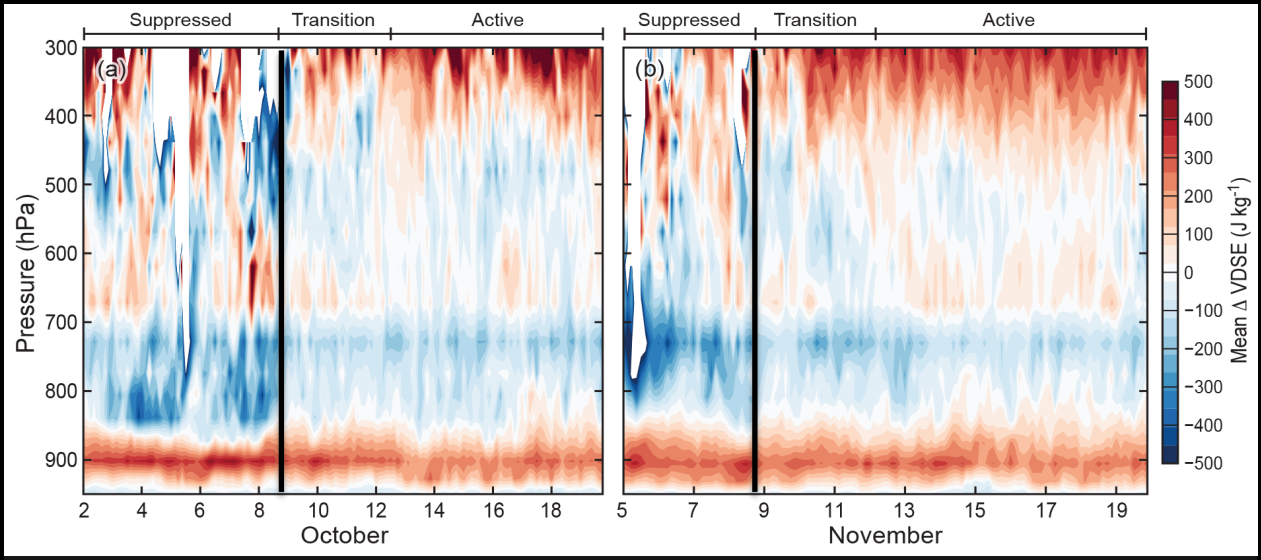
What causes sudden onset of transition periods?

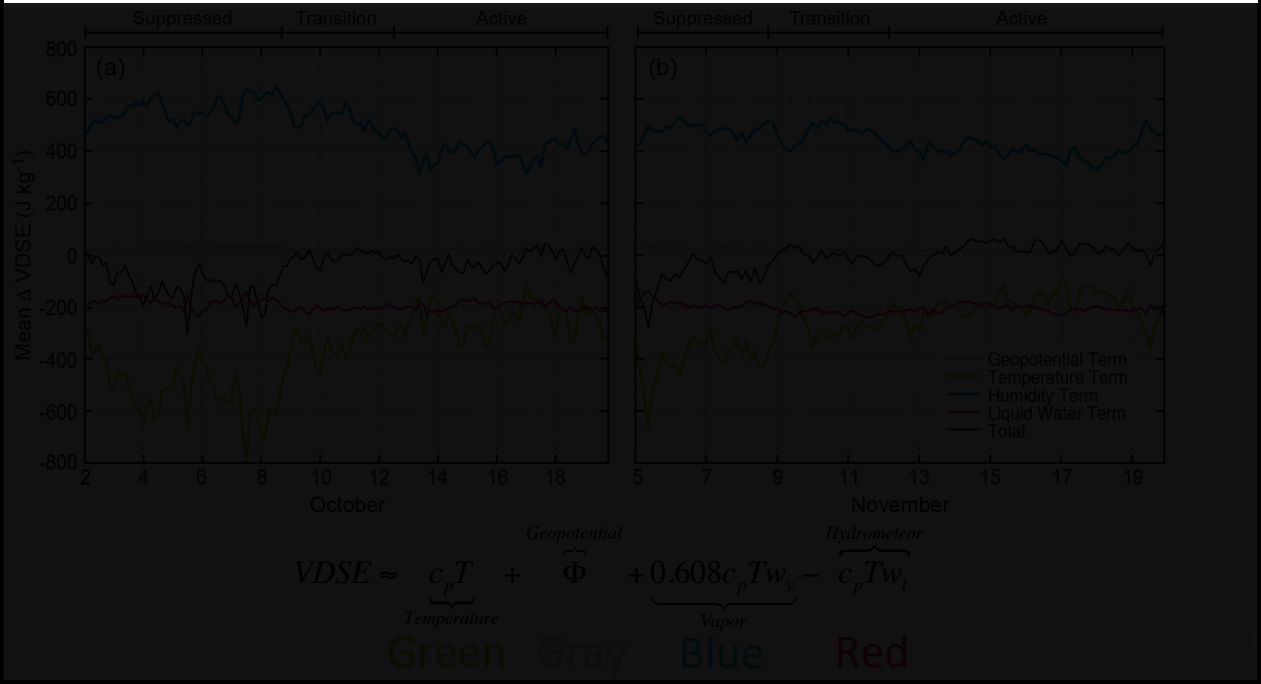
Powell, submitted to JAS


10°N
2.5°N
58.4°E
65.6°E
80°E
87.9°E
2.5°S
10°S

Virtual Dry Static Energy (VDSE): Updraft minus Environment

Blue = Cloud updraft, on average, is negatively buoyant in its environment





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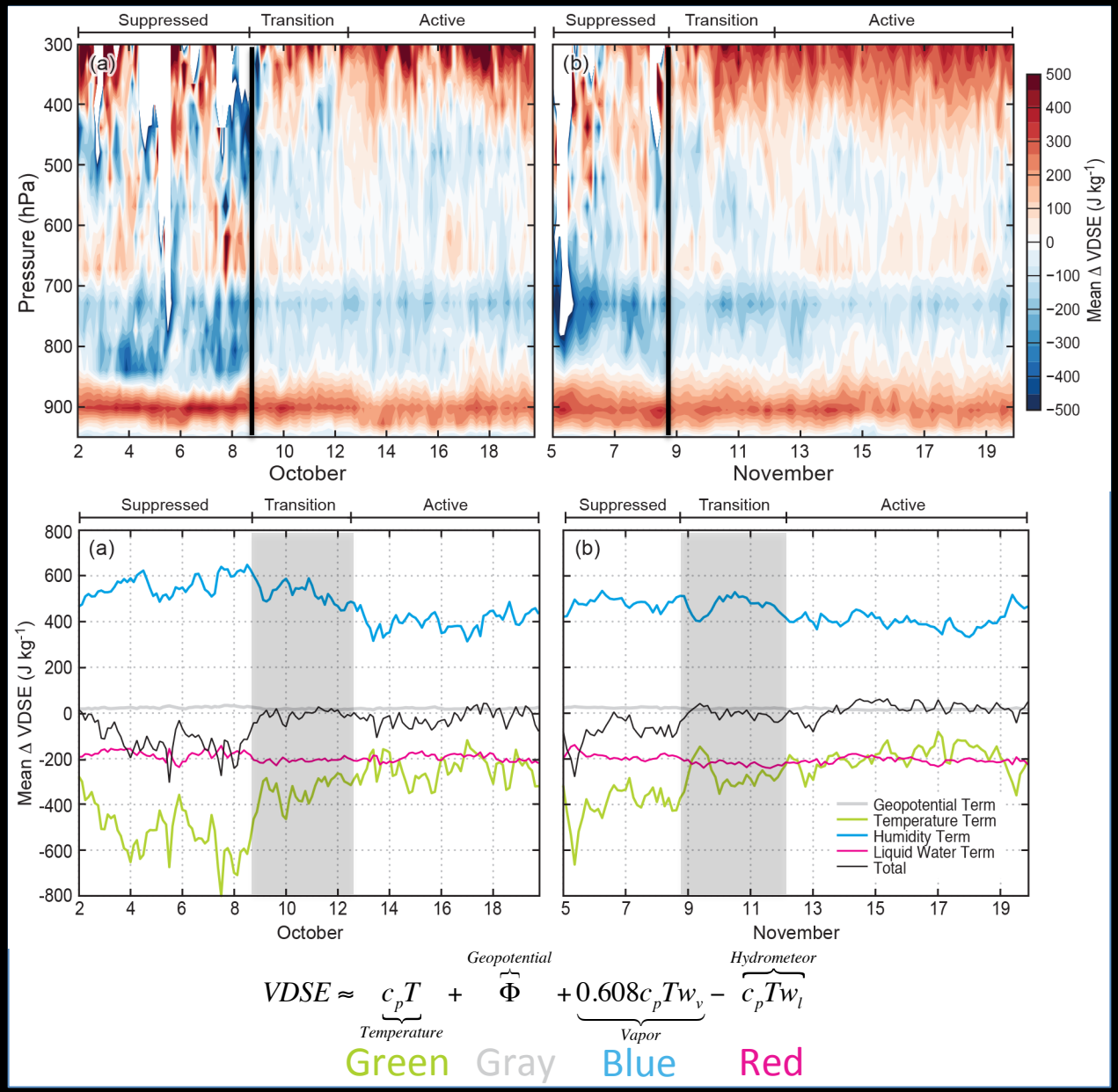
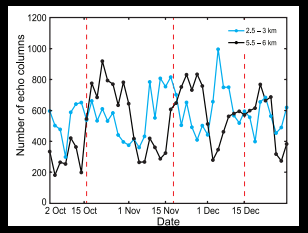
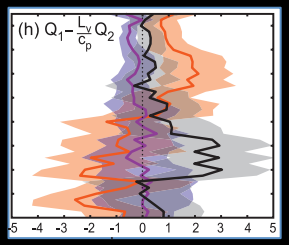


Conclusions

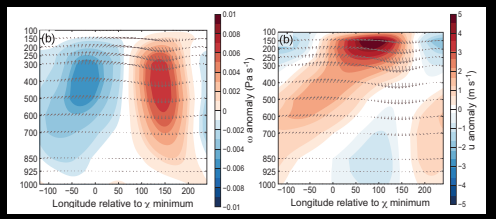
• 3–7 day build up in cloud population during transition periods prior to MJO convective onset.

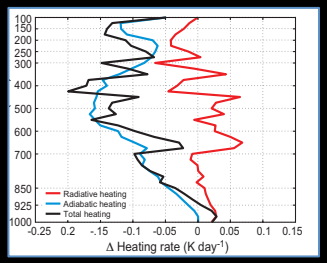




• During transition periods, moderately deep clouds make environment conducive to deep convection.

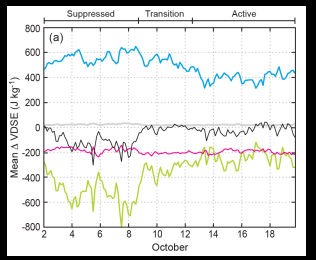
• Circumnavigating wave has impacts on low-wavenumber ω anomalies of O(0.01 Pa s^{-1}).





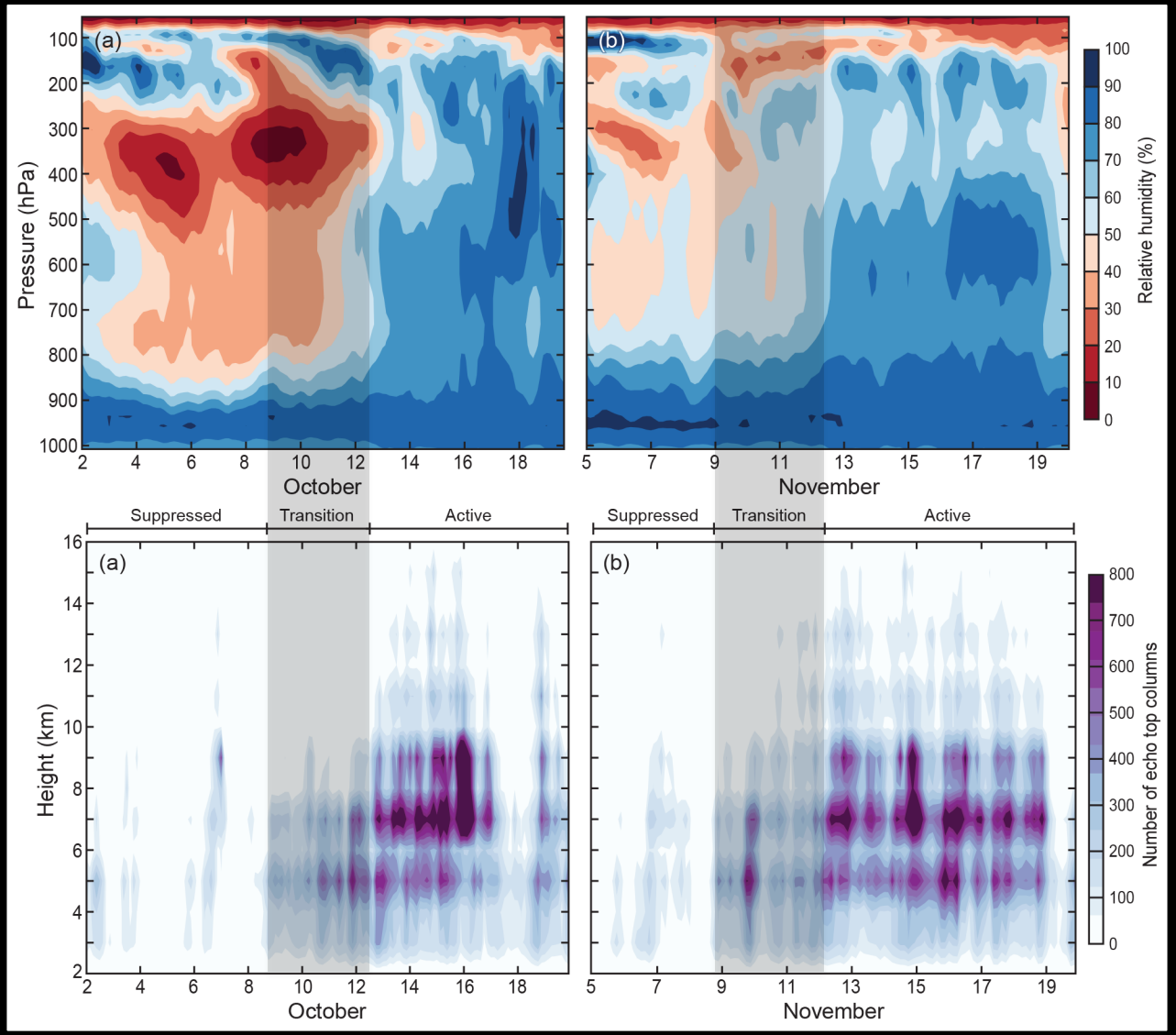
• Changes in vertical velocity cause small changes of O(0.1K) in tropospheric temperature below 500 hPa.

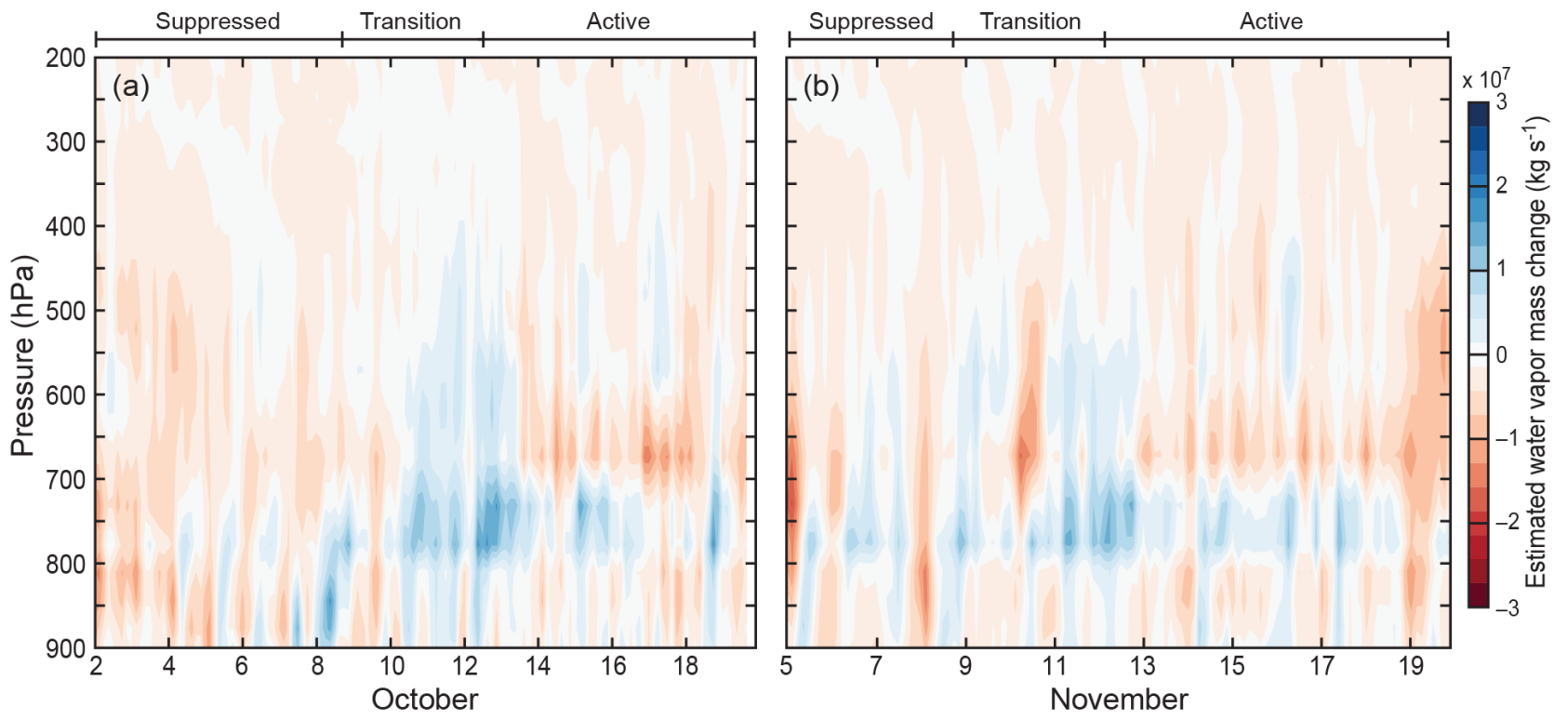
• Small changes in environmental temperature dramatically alter mean buoyancy of cloud updrafts in 700–850 hPa layer.



End

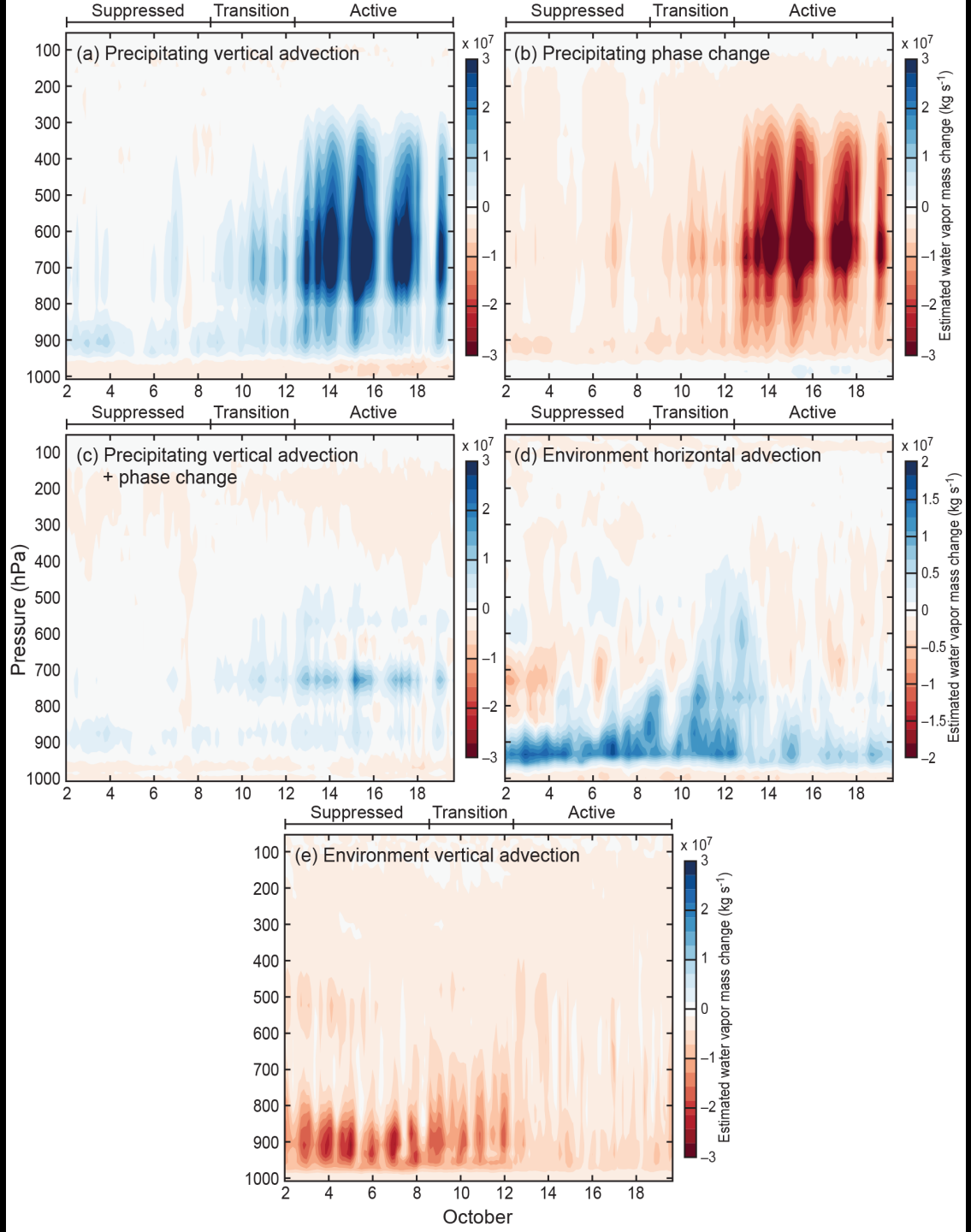
Extra Slides


(a)
(b)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
1000
2 4 6 8 10 12 14 16 18
October
5 7 9 11 13 15 17 19
November
Relative humidity (%)
100
90
80
70
60
50
40
30
20
10
0
Suppressed
Transition
Active
Height (km)
16
14
12
10
8
6
4
2
Number of echo top columns
800
700
600
500
400
300
200
100
0


Suppressed
Transition
Active
(a)
(b)
Pressure (hPa)
200
300
400
500
600
700
800
900
2
4
6
8
10
12
14
16
18
October
5
7
9
11
13
15
17
19
November
x 10^7
3
2
1
0
−1
−2
−3
Estimated water vapor mass change (kg s^-1)

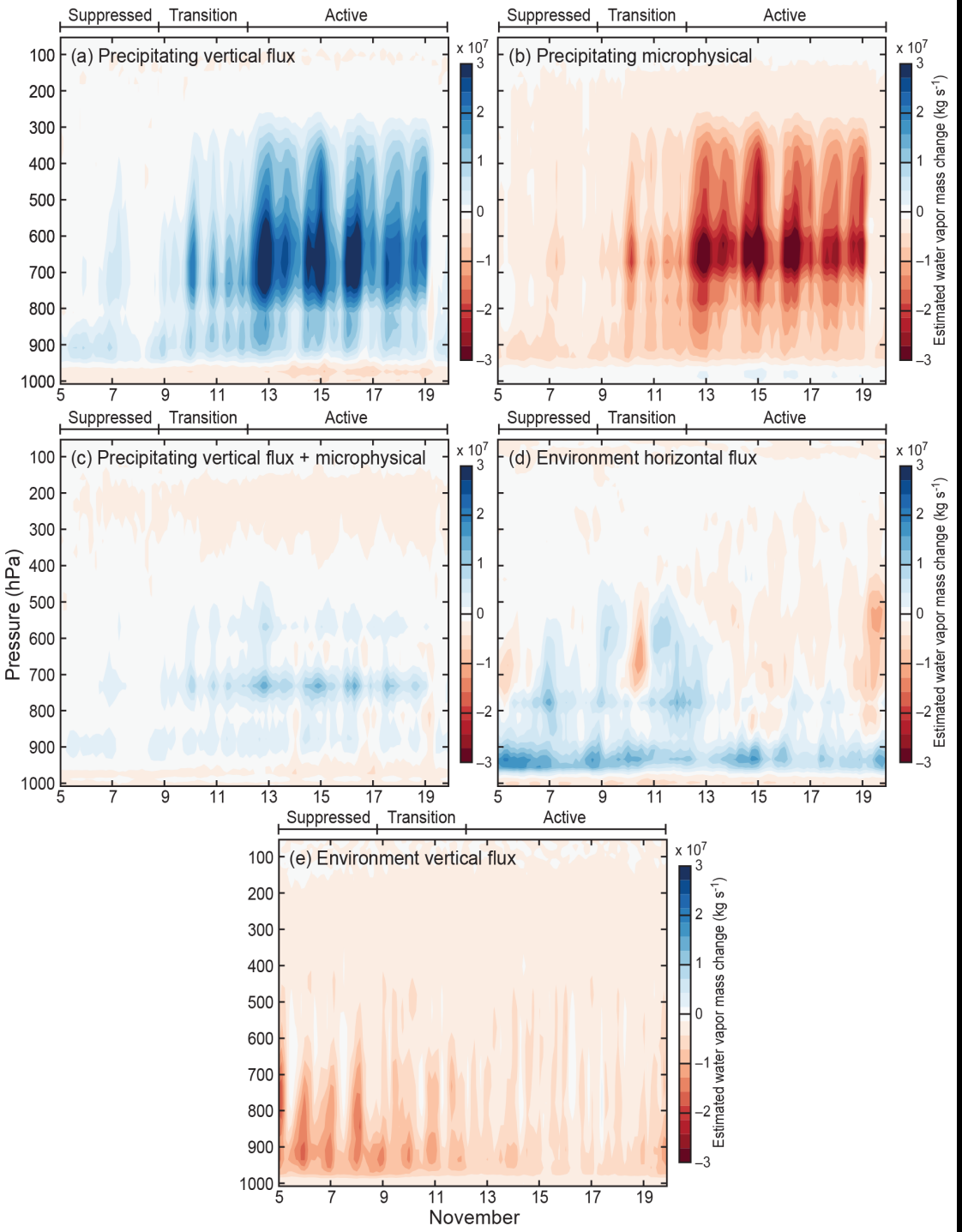
Model grid points separated into 4 categories:

- Precipitating
- Non-precipitating liquid
- Anvil
- Environment

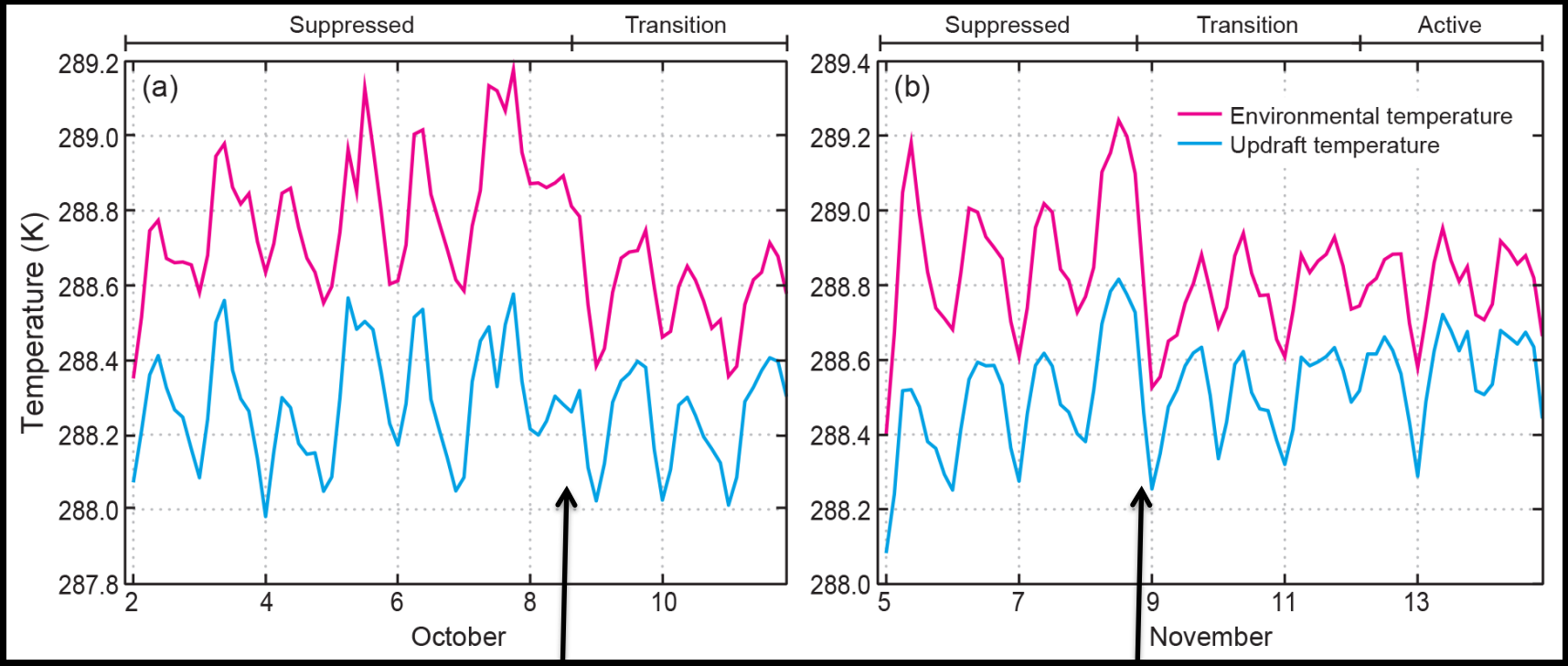


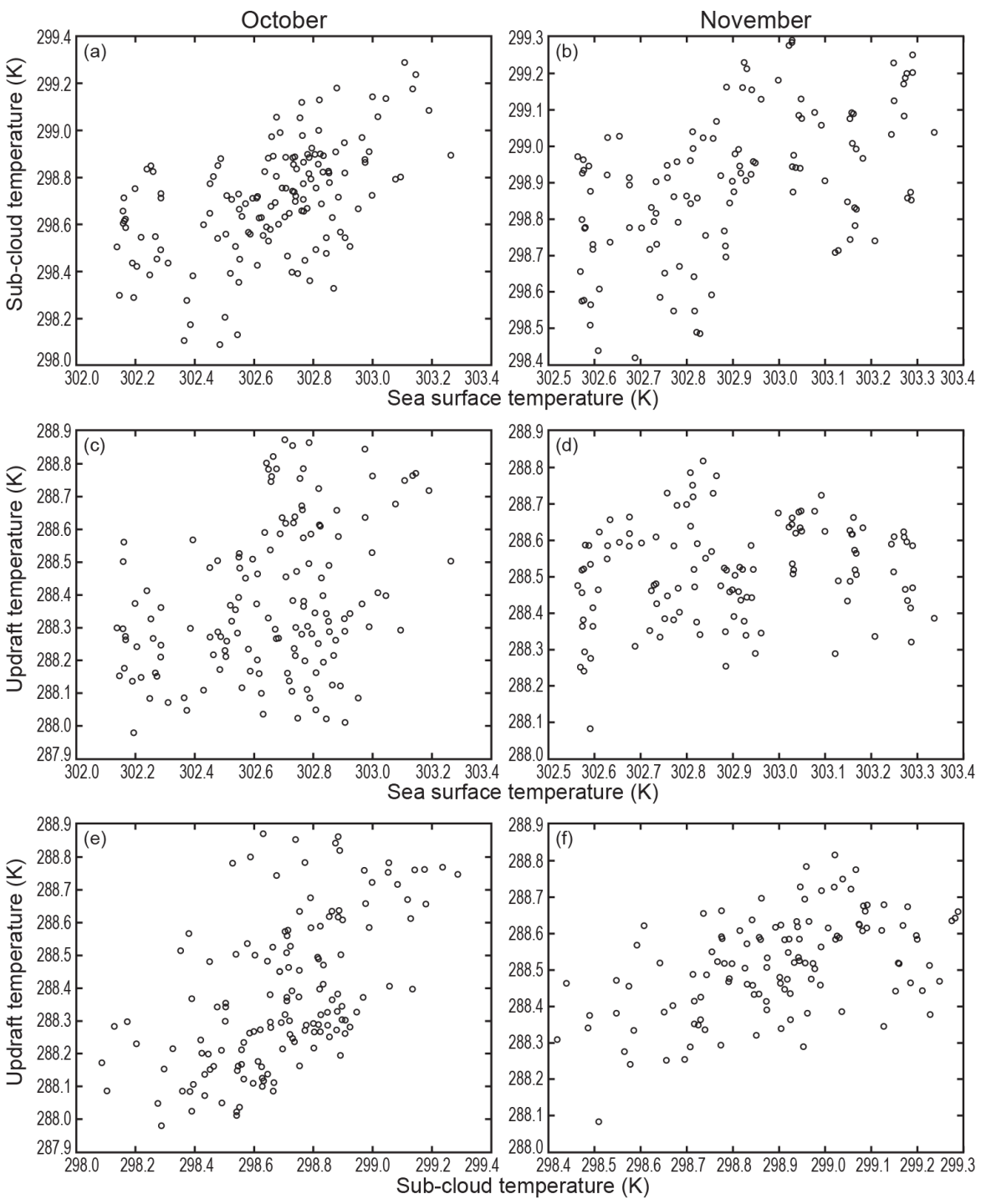
Model grid points separated into 4 categories:

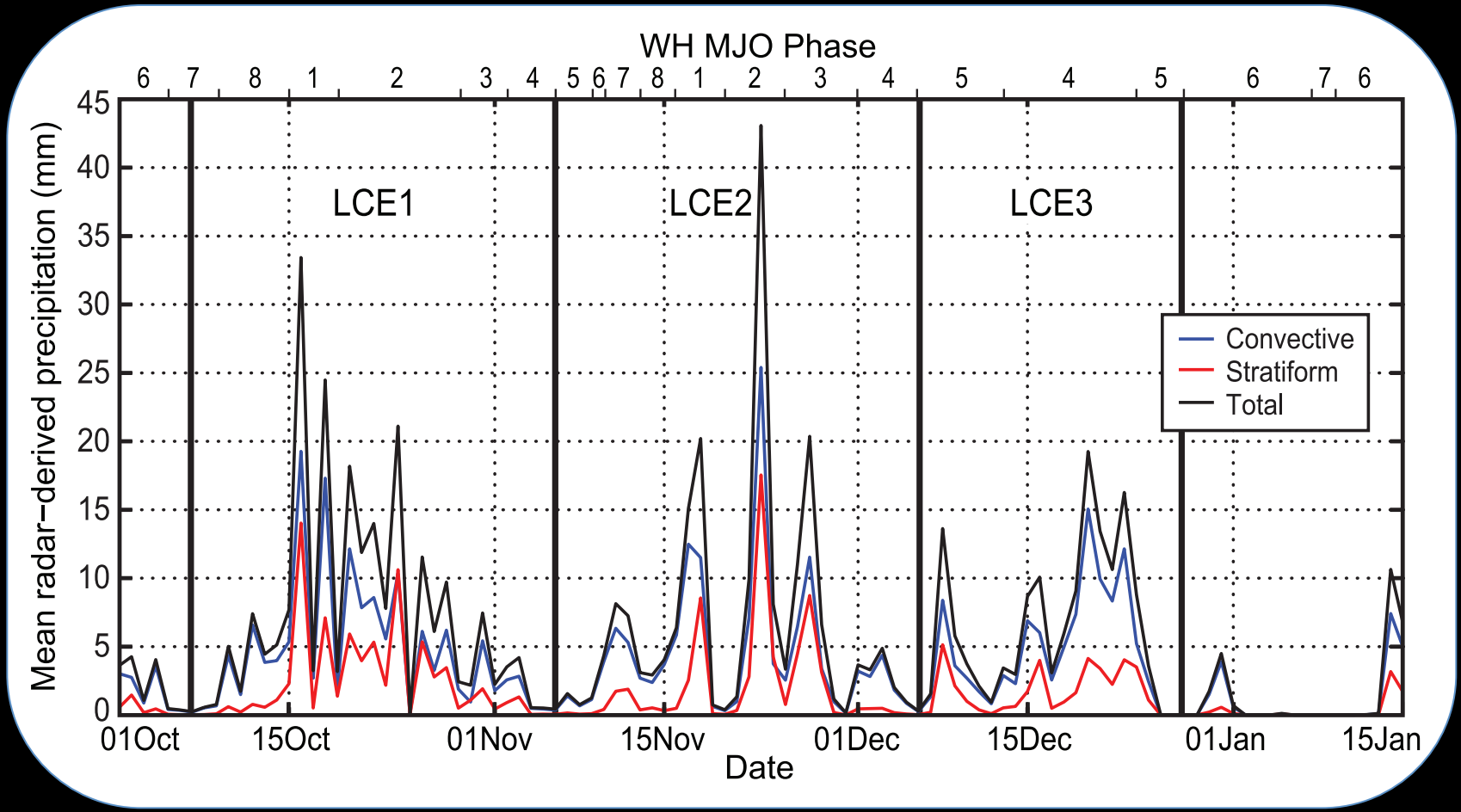
- Precipitating
- Non-precipitating liquid
- Anvil
- Environment



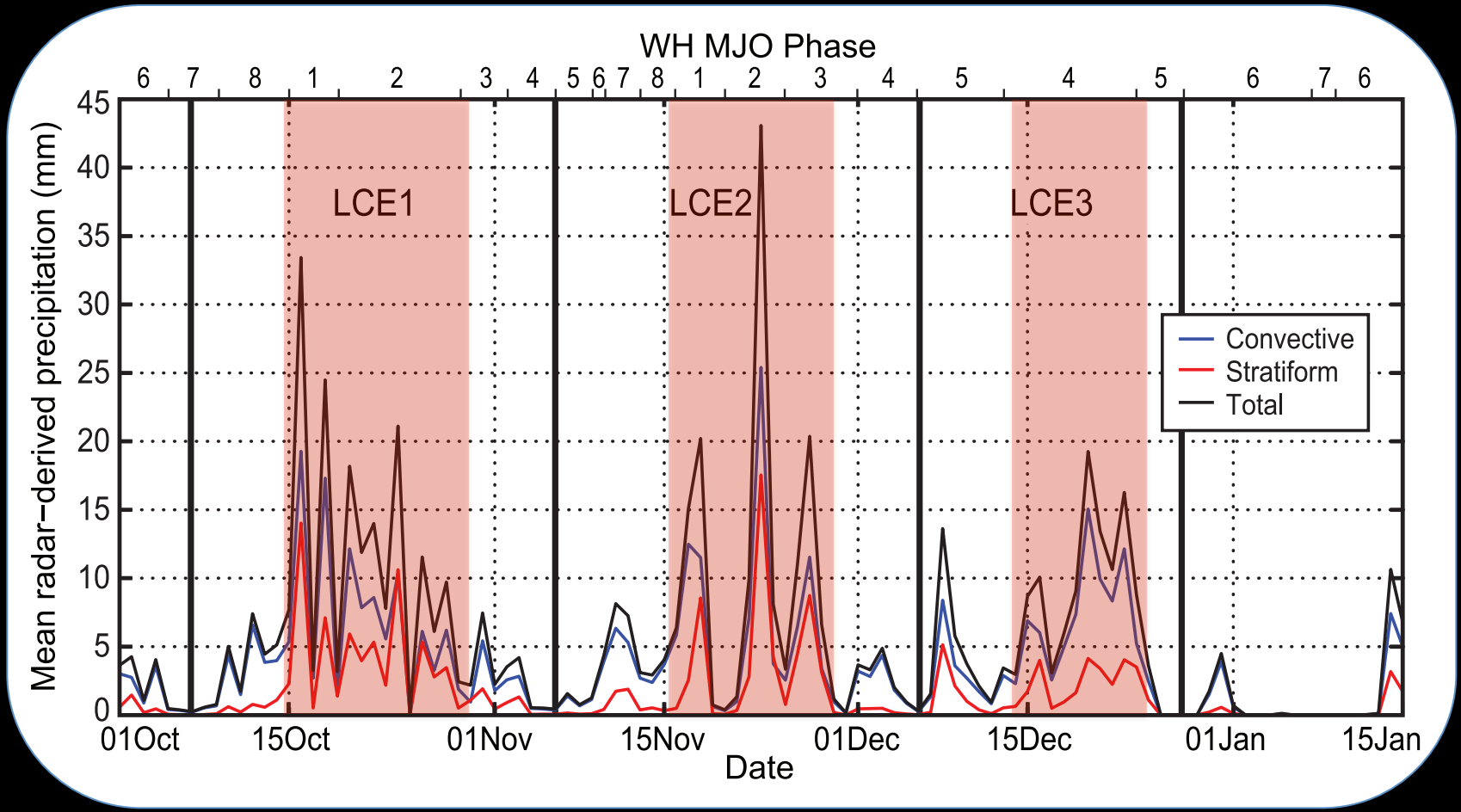
Composited between 700–850 mb.



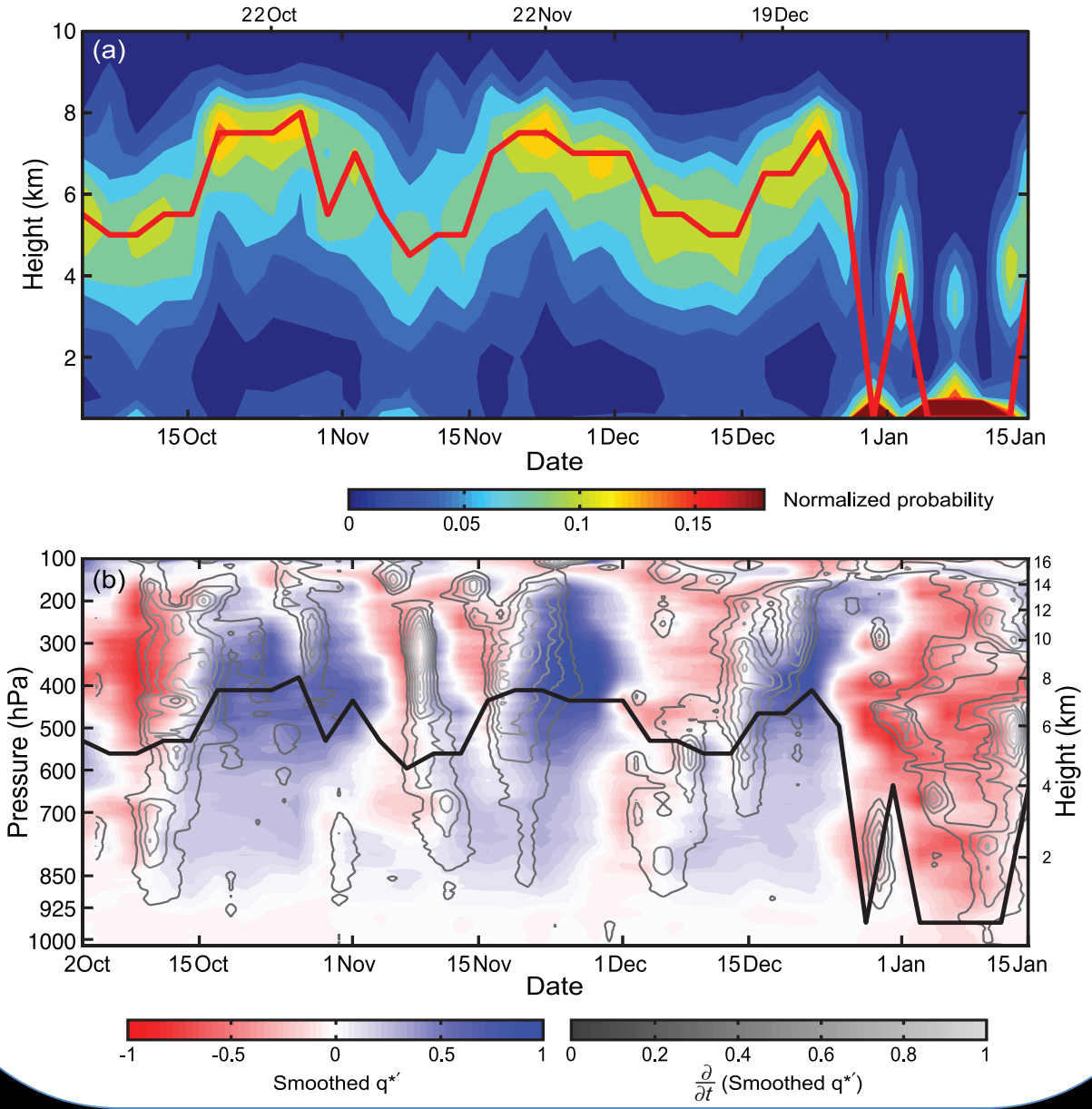

October
November
(a)
(b)
(c)
(d)
(e)
(f)
Sub-cloud temperature (K)
Updraft temperature (K)
Sea surface temperature (K)
Sea surface temperature (K)
Updraft temperature (K)
Sub-cloud temperature (K)

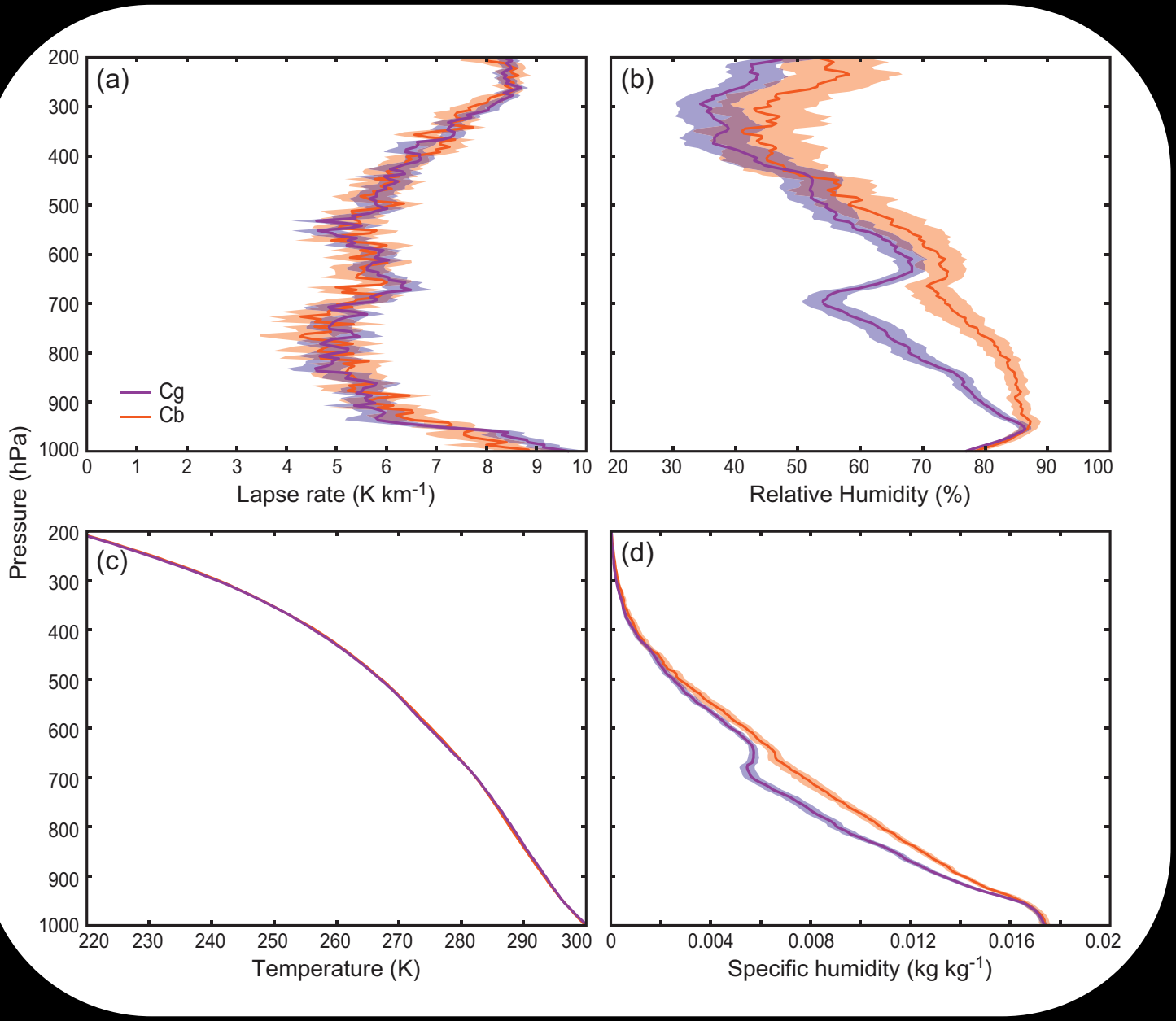


Powell and Houze (2013)

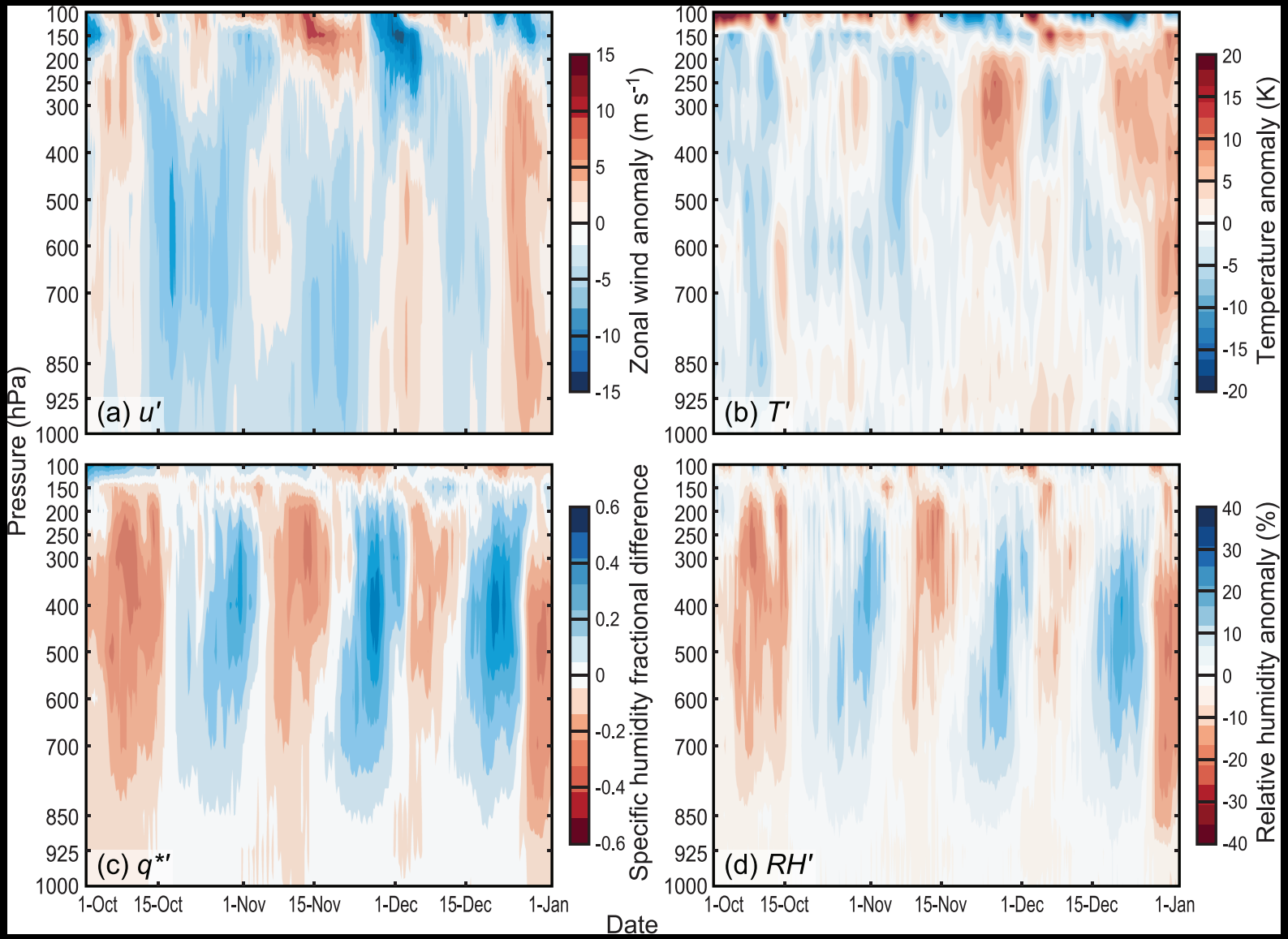


Powell and Houze (2013)

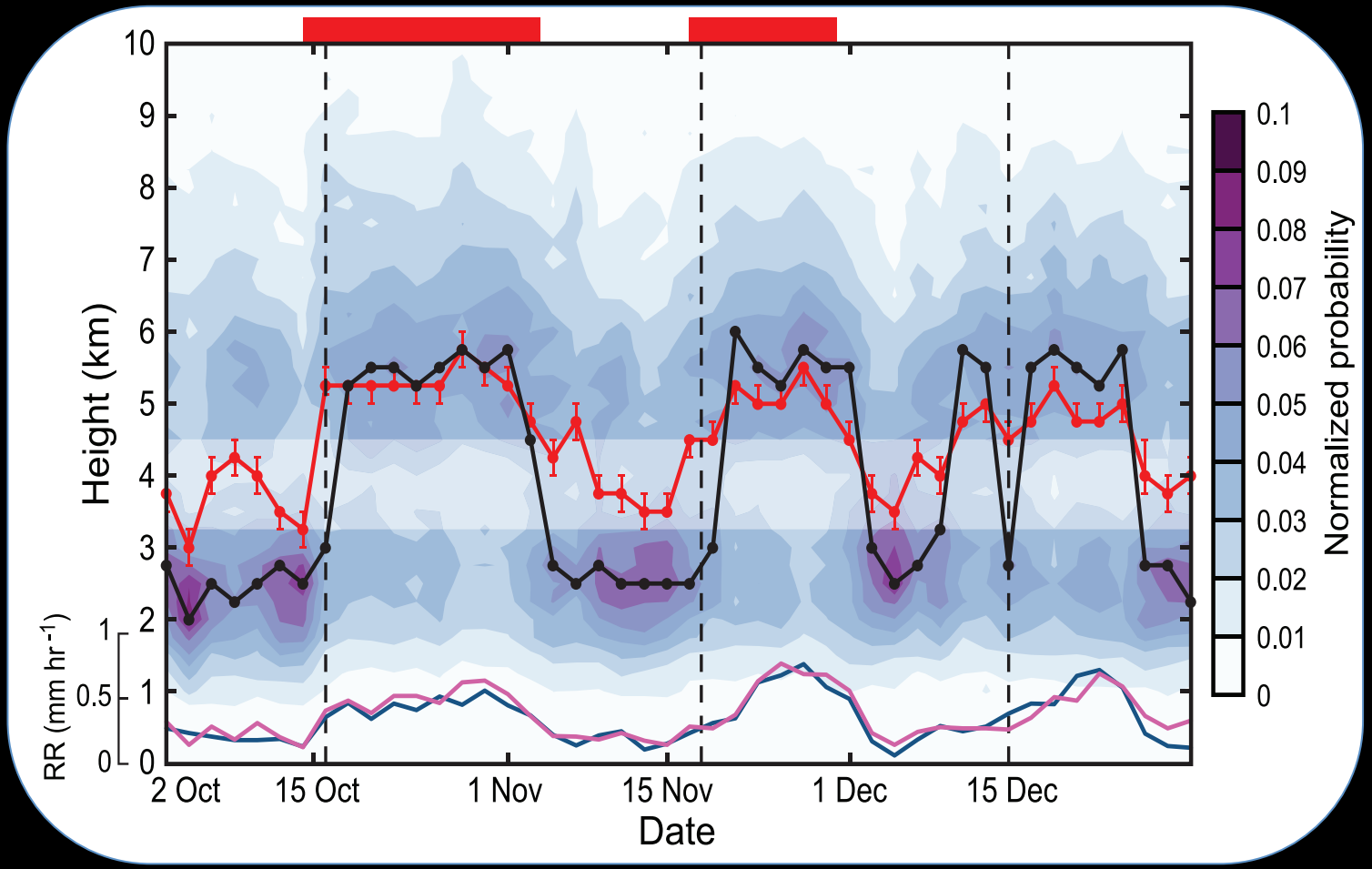

22 Oct
22 Nov
19 Dec
(a)
Height (km)
10
8
6
4
2
15 Oct
1 Nov
15 Nov
1 Dec
15 Dec
1 Jan
15 Jan
Date
Normalized probability
0
0.05
0.1
0.15
(b)
Pressure (hPa)
100
200
300
400
500
600
700
850
925
1000
Height (km)
16
14
12
10
8
6
4
2
2 Oct
15 Oct
1 Nov
15 Nov
1 Dec
15 Dec
1 Jan
15 Jan
Date
-1
-0.5
0
0.5
1
Smoothed q*′
0
0.2
0.4
0.6
0.8
1
∂/∂t (Smoothed q*′)


(a)
(b)
(c)
(d)
Cg
Cb
Pressure (hPa)
Lapse rate (K km^{-1})
Relative Humidity (%)
Temperature (K)
Specific humidity (kg kg^{-1})

ERA-Interim


Pressure (hPa)
100
150
200
250
300
400
500
600
700
850
925
1000
(a) u′
(b) T′
(c) q*′
(d) RH′
15
10
5
0
-5
-10
-15
Zonal wind anomaly (m s-1)
20
15
10
5
0
-5
-10
-15
-20
Temperature anomaly (K)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
Specific humidity fractional difference
40
30
20
10
0
-10
-20
-30
-40
Relative humidity anomaly (%)
1-Oct
15-Oct
1-Nov
15-Nov
1-Dec
15-Dec
1-Jan
Date

Powell and Houze (2015a)



WRF (V3.5.1) Specifications

- 1–20 October and 4–20 November
- ERA-I forcing with NOAA RTG High-Res SST
- 2km grid spacing, 38 vertical levels
- Microphysics: Thompson
- Radiation: RRTMG
- PBL: MYJ
- Monin-Obukhov surface layer physics
- Noah LSM