Circumnavigation and Convective Onset of Successive MJO Events

Scott Powell
Colorado State Univ., Ft. Collins
24 February 2017

Picture from Addu City, MV
11/11/11

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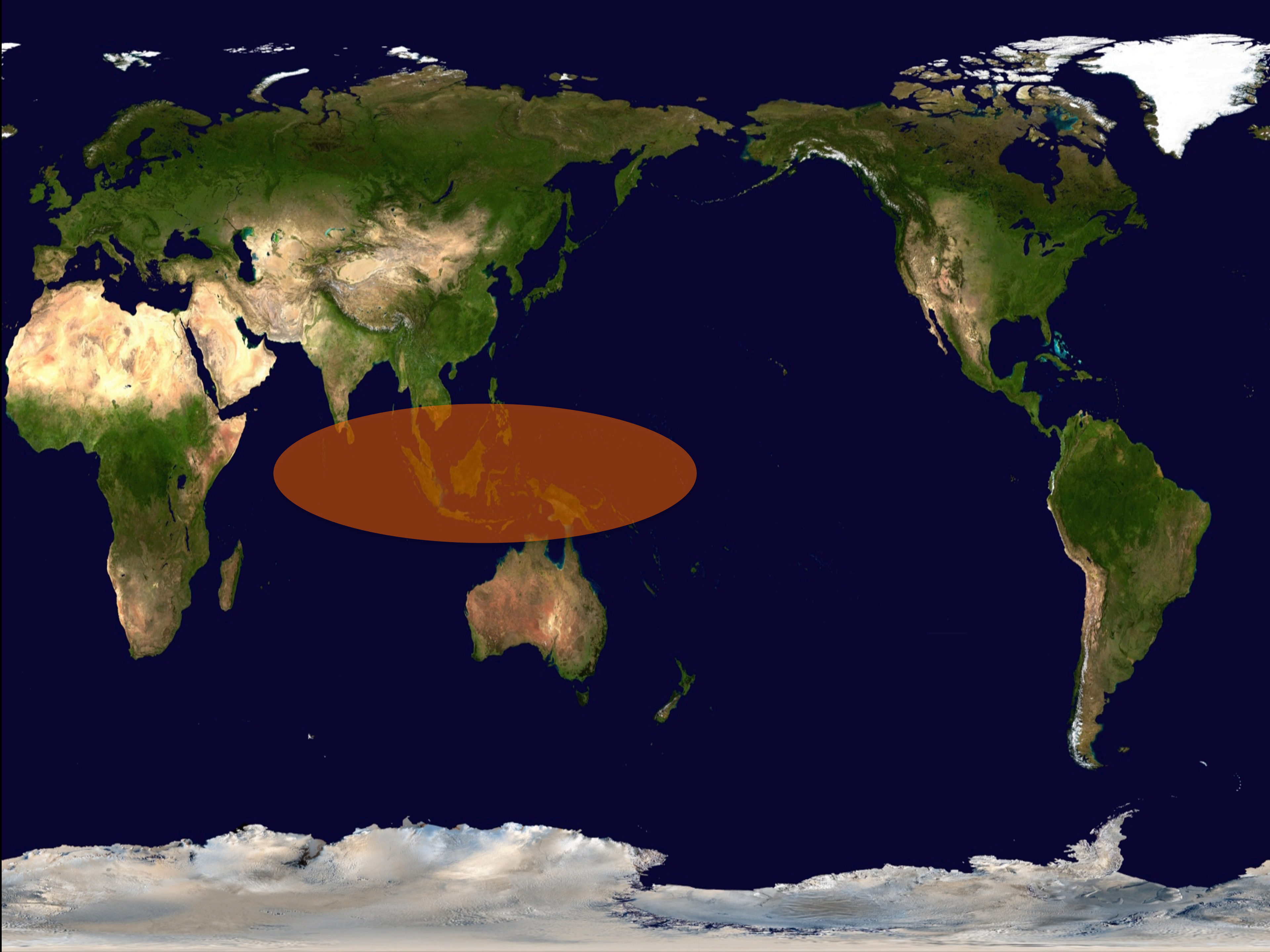
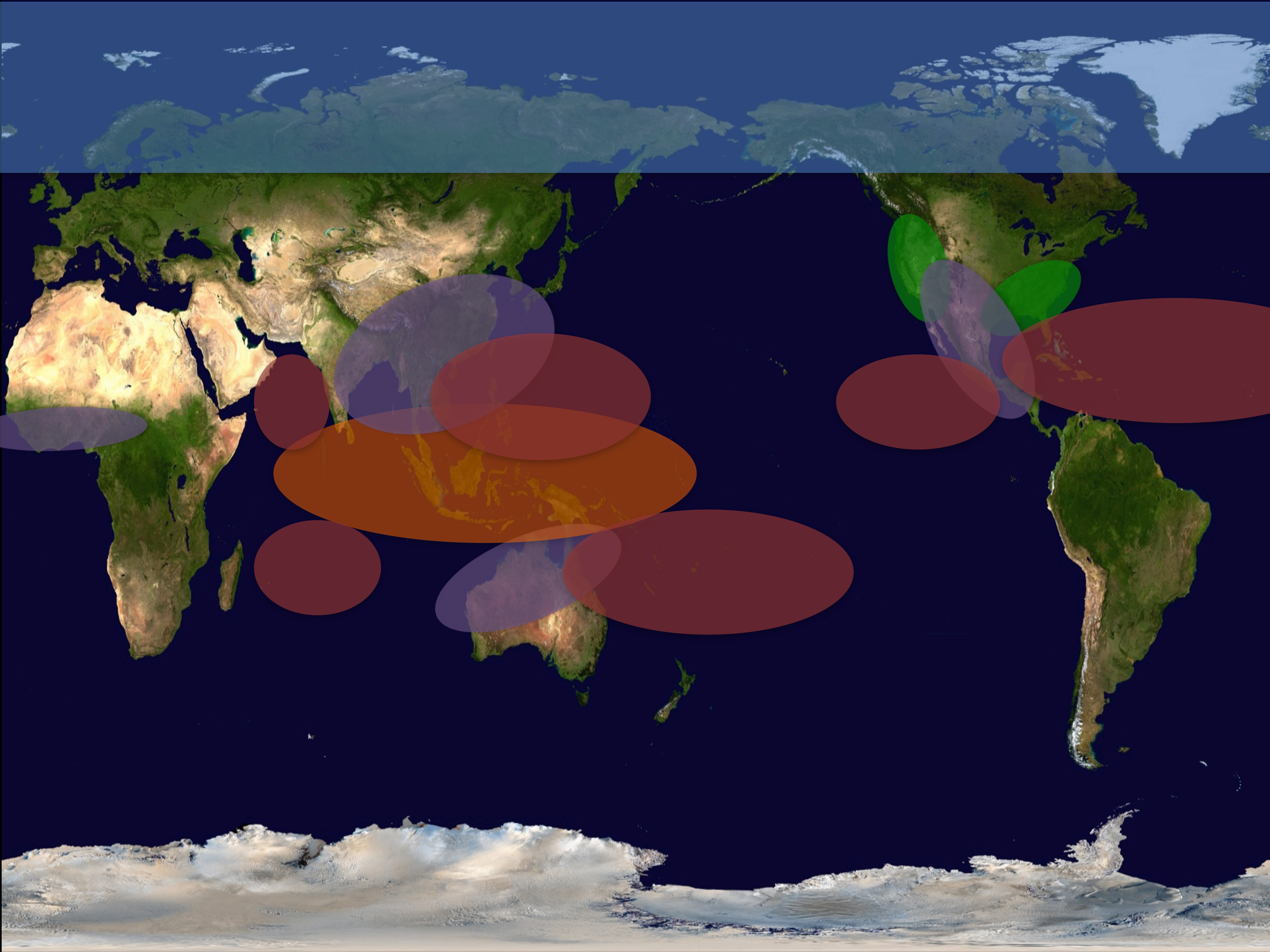
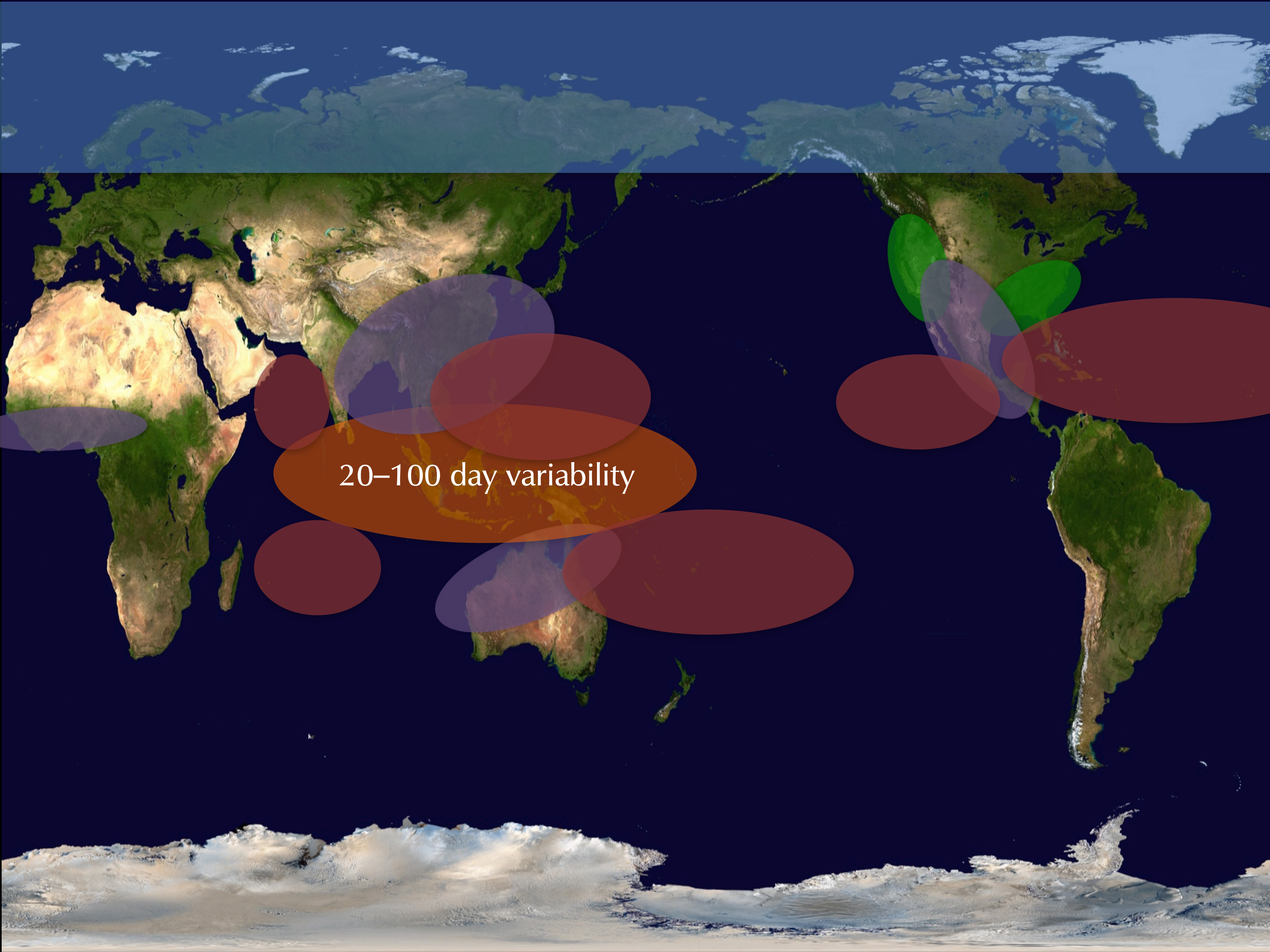
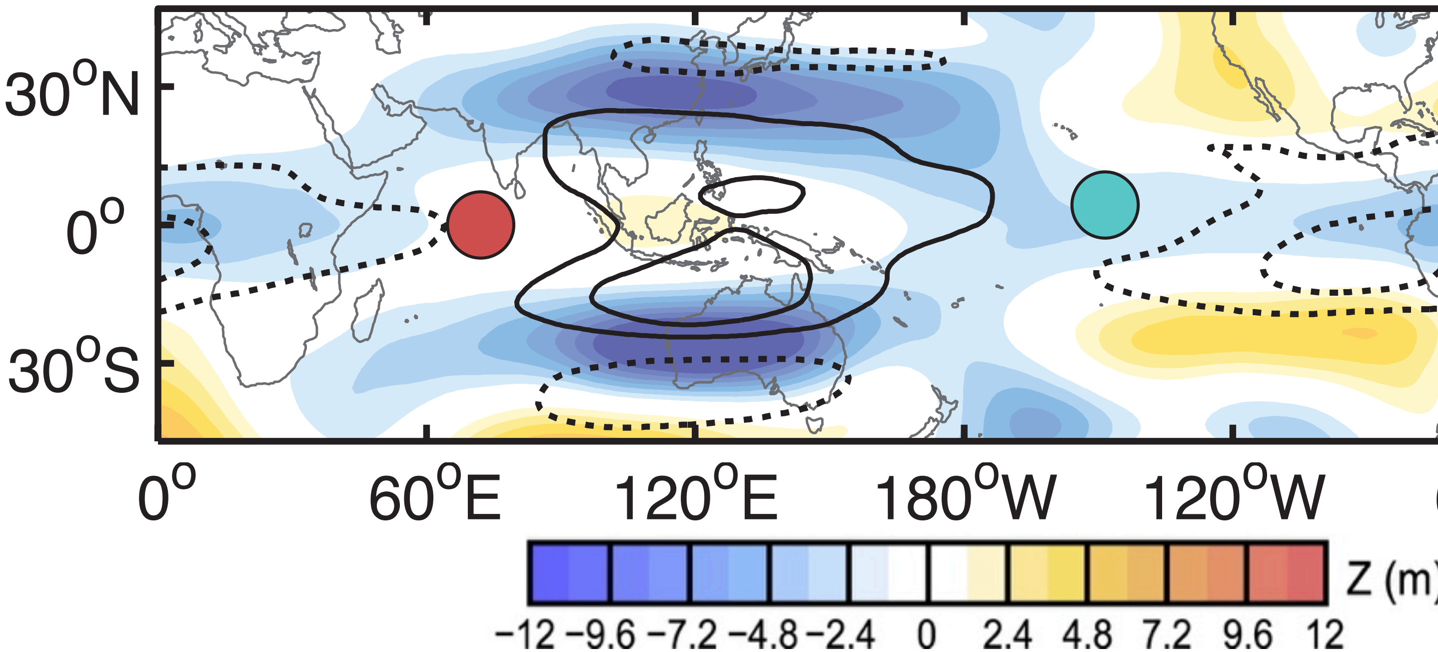
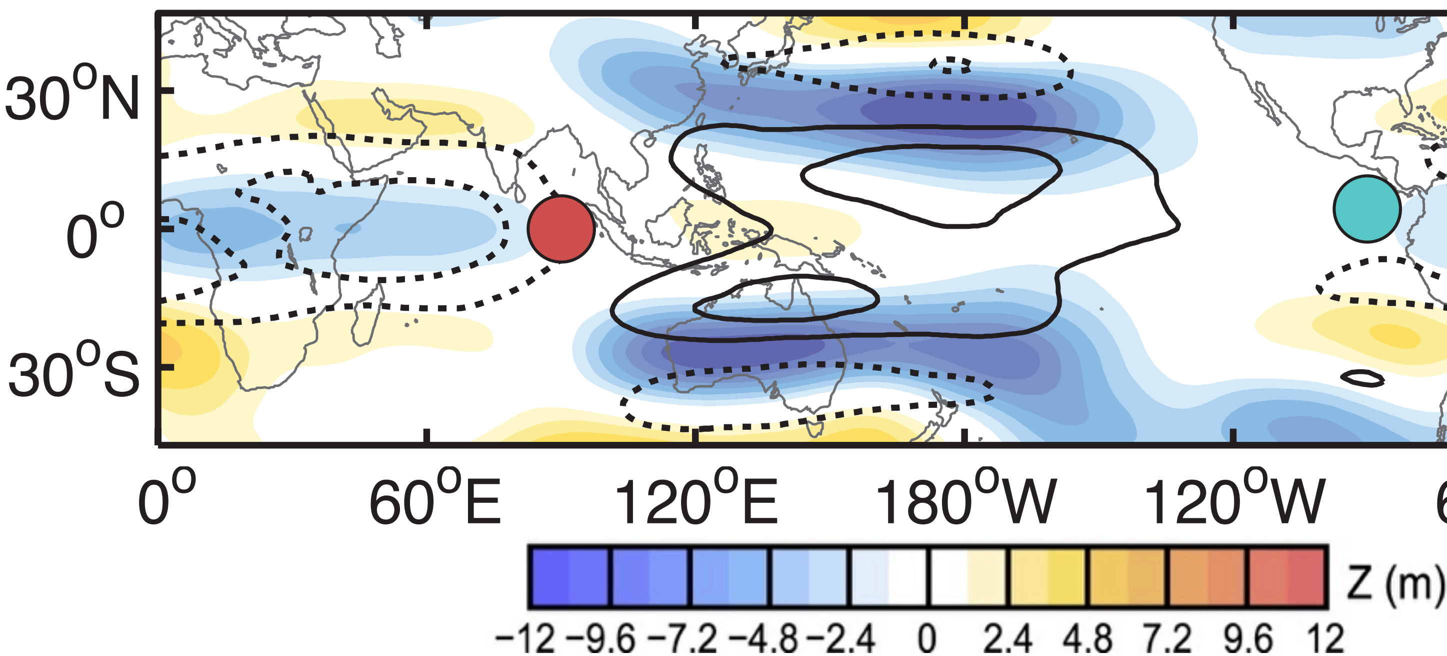




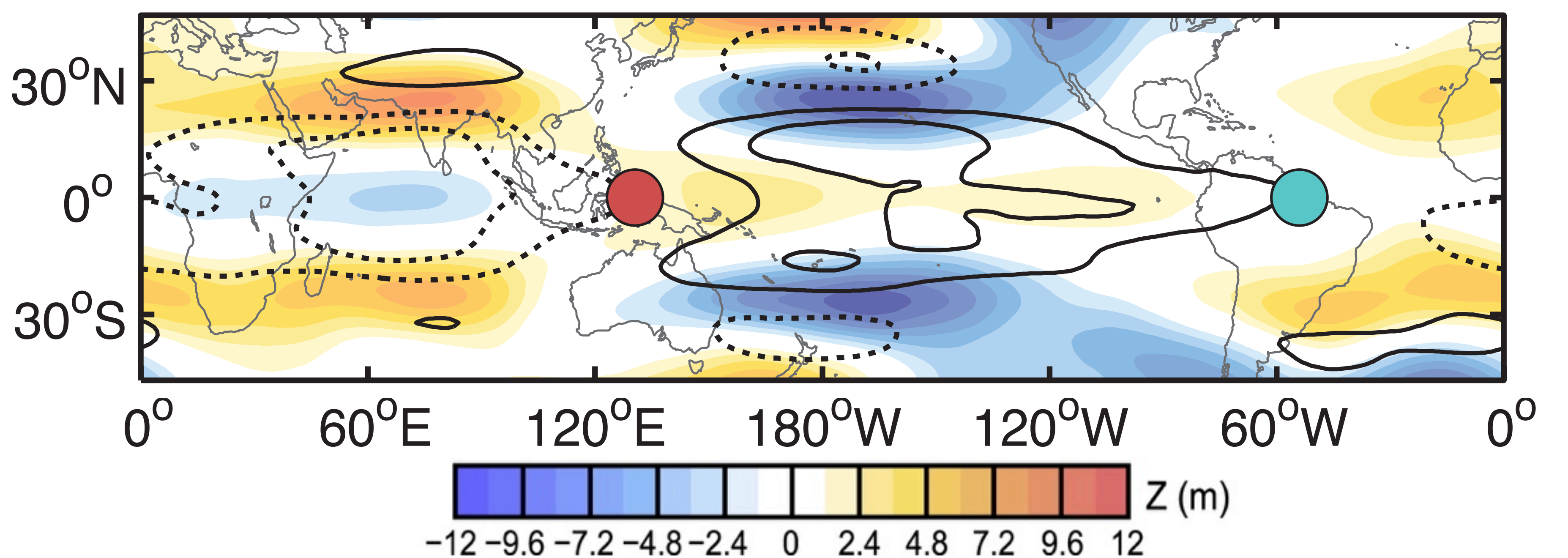

20–100 day variability


30°N
0°
30°S
0°
60°E
120°E
180°W
120°W
60°W
0°
Z (m)
−12 −9.6 −7.2 −4.8 −2.4 0 2.4 4.8 7.2 9.6 12

Adames and Wallace (2014)



Adames and Wallace (2014)



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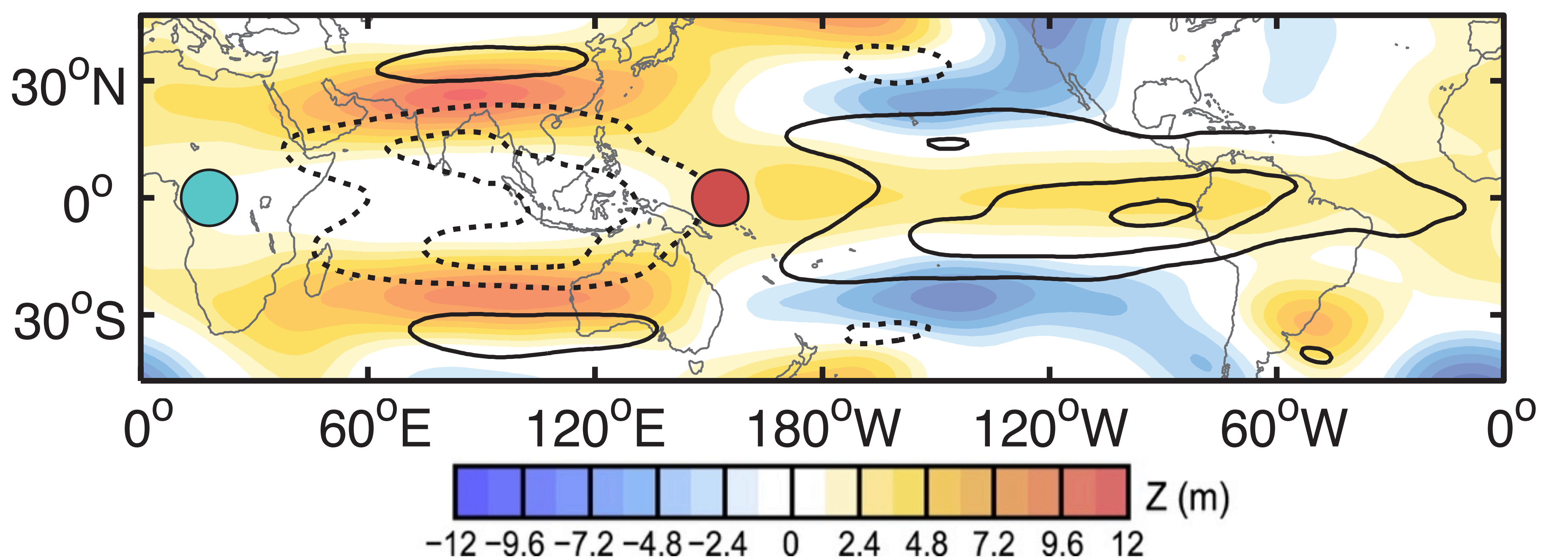

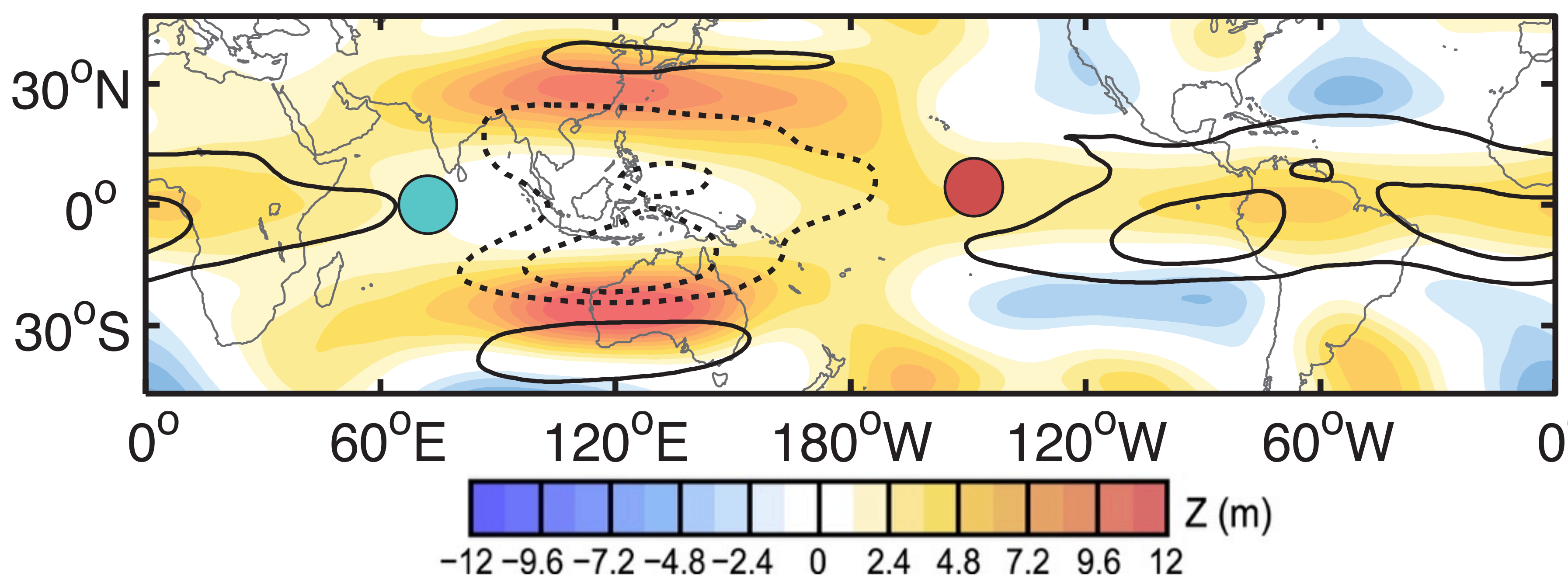

30°N
0°
30°S
0°
60°E
120°E
180°W
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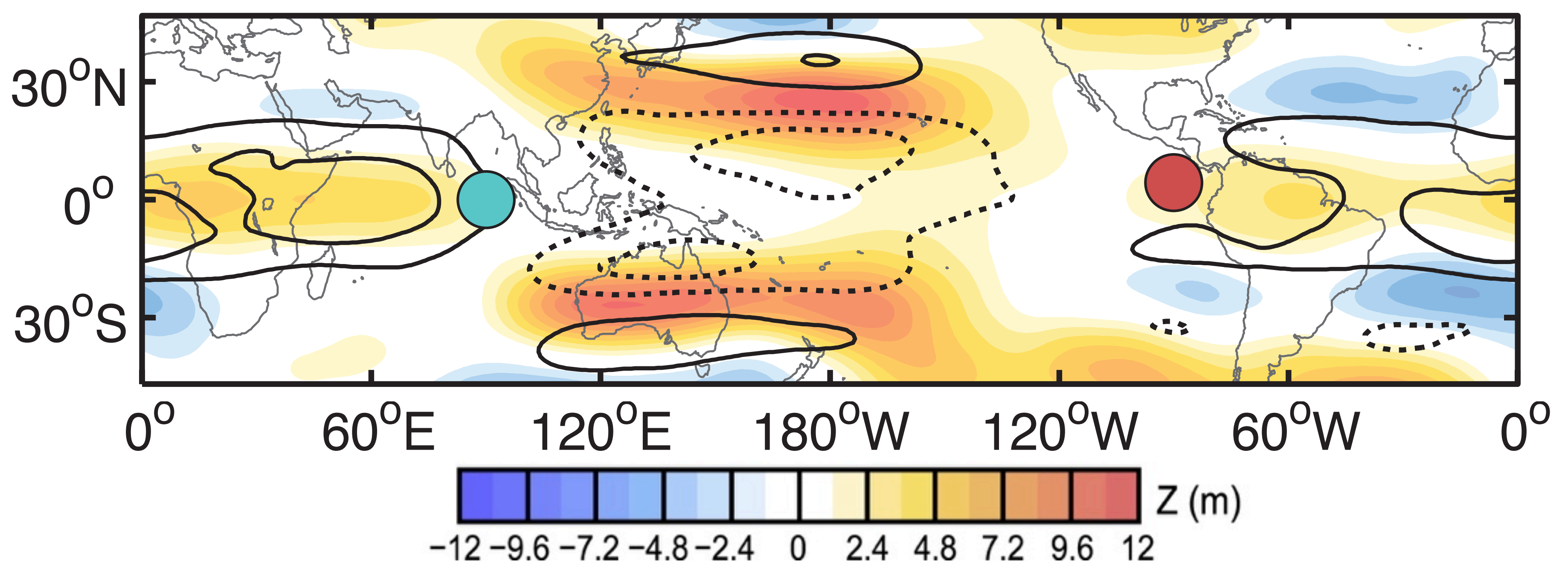
Z (m)
−12 −9.6 −7.2 −4.8 −2.4 0 2.4 4.8 7.2 9.6 12


30°N
0°
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60°E
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180°W
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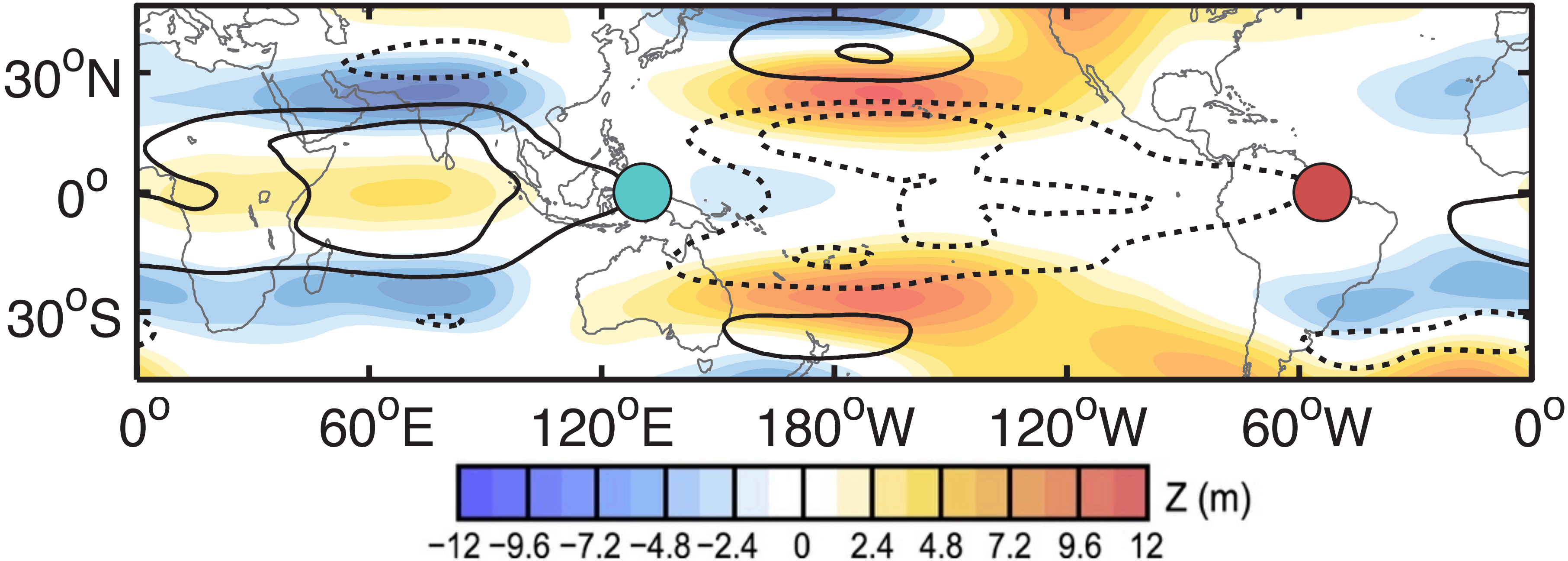
Z (m)
−12 −9.6 −7.2 −4.8 −2.4 0 2.4 4.8 7.2 9.6 12


30°N
0°
30°S
0°
60°E
120°E
180°W
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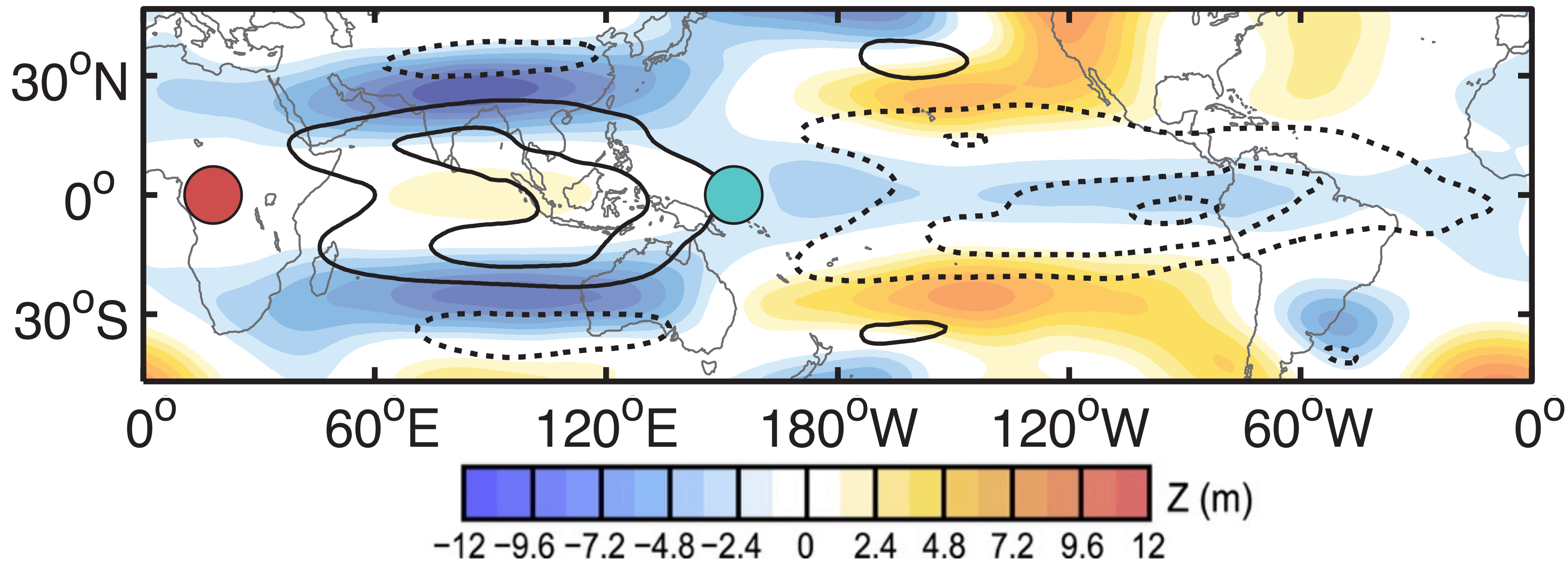
0°
Z (m)
−12 −9.6 −7.2 −4.8 −2.4 0 2.4 4.8 7.2 9.6 12


30°N
0°
30°S
0°
60°E
120°E
180°W
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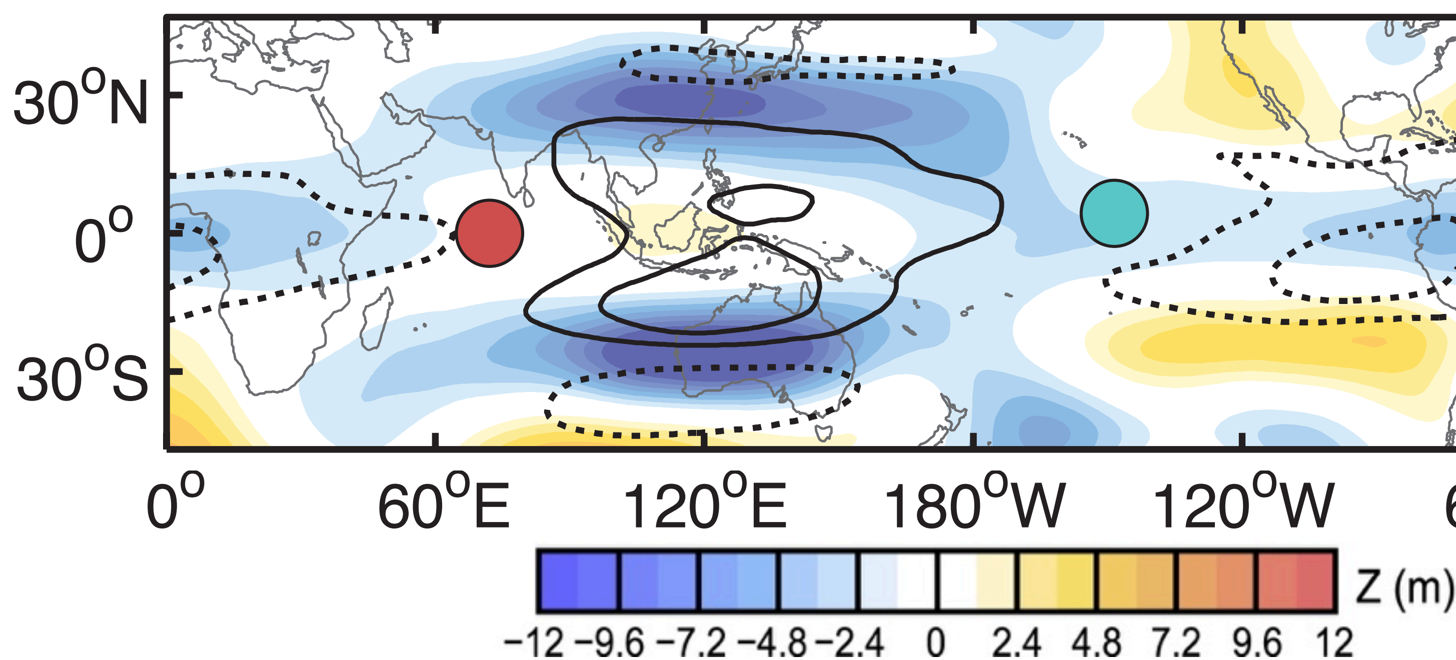
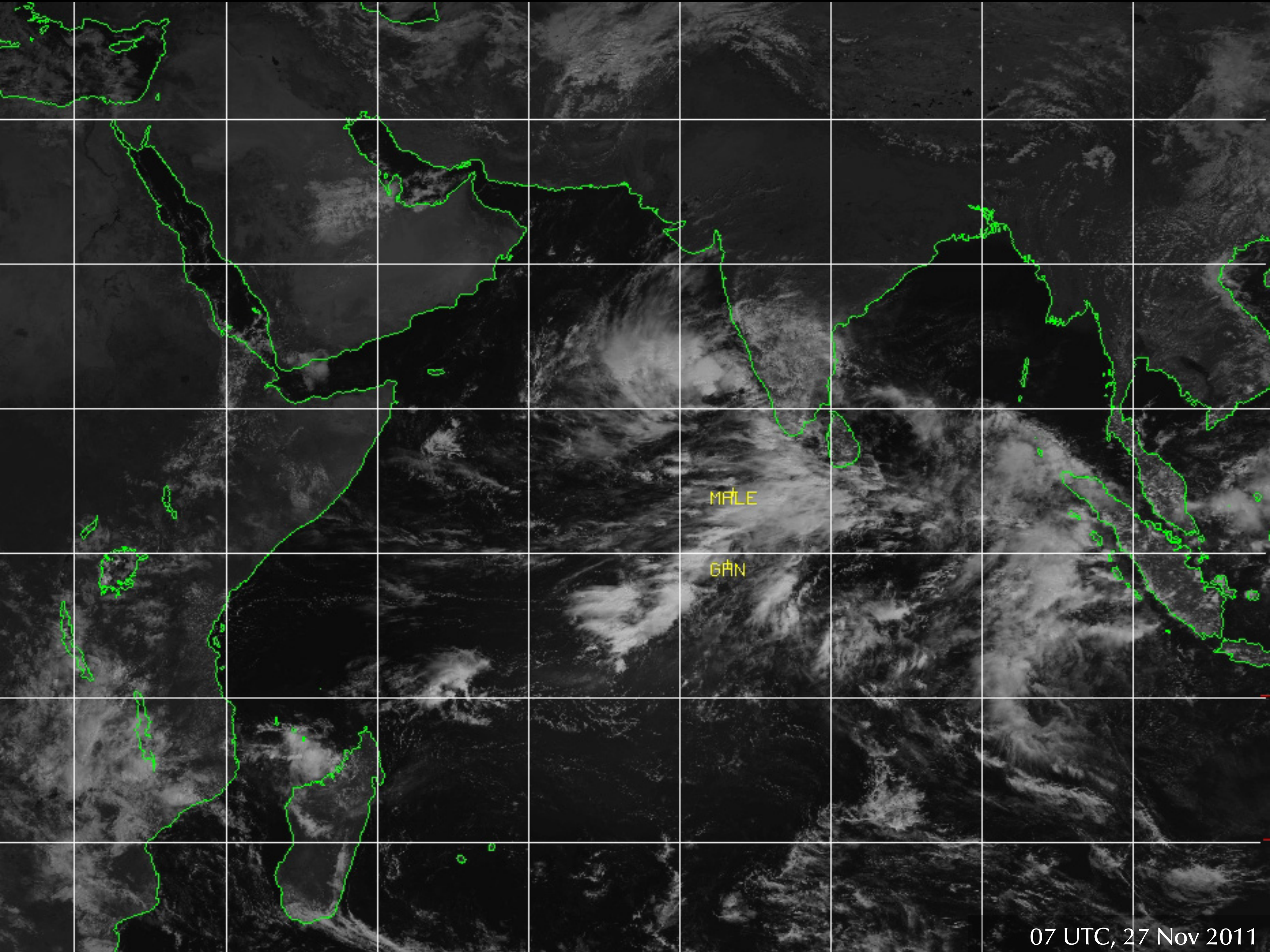
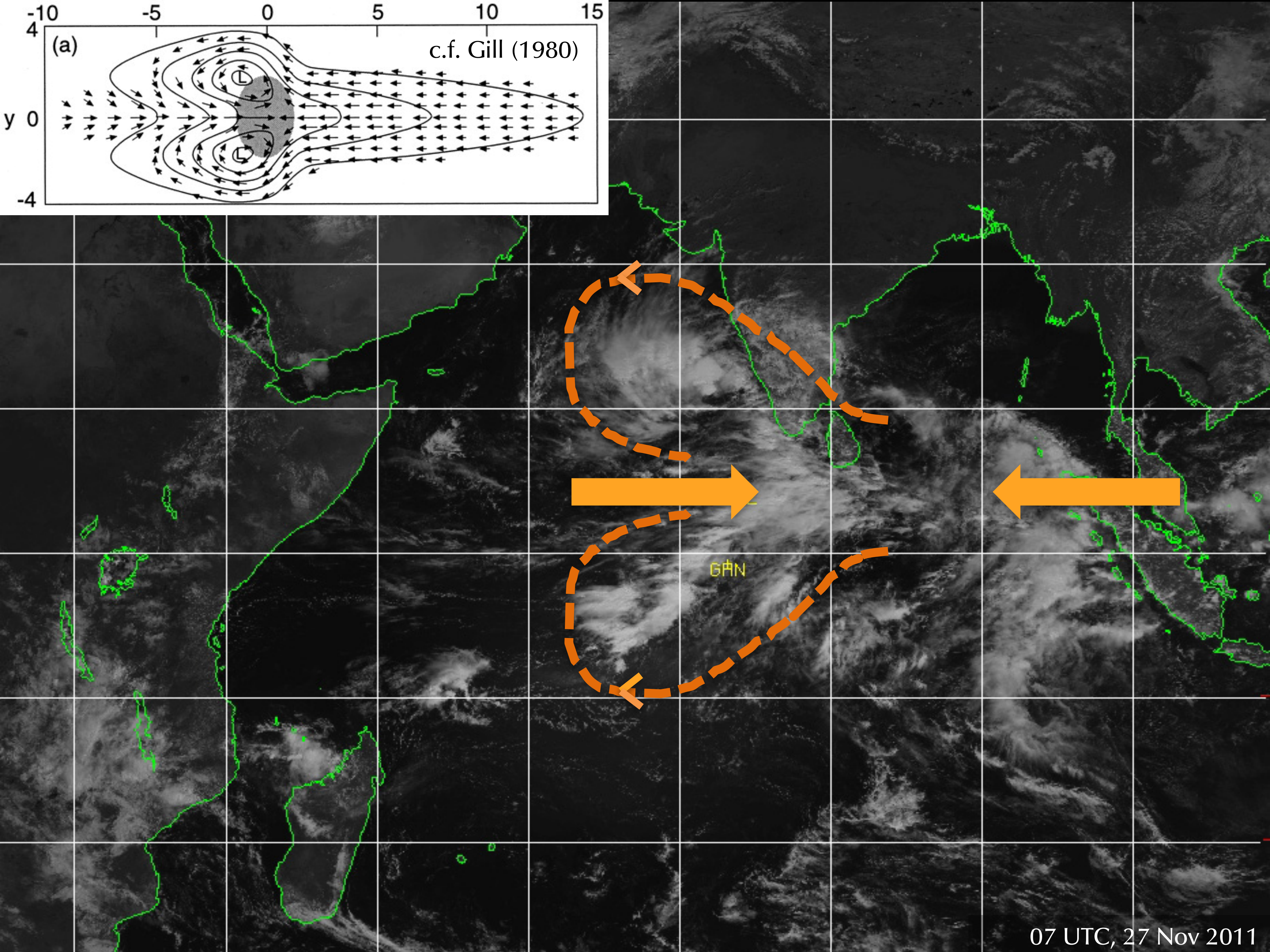
0°
Z (m)
−12 −9.6 −7.2 −4.8 −2.4 0 2.4 4.8 7.2 9.6 12

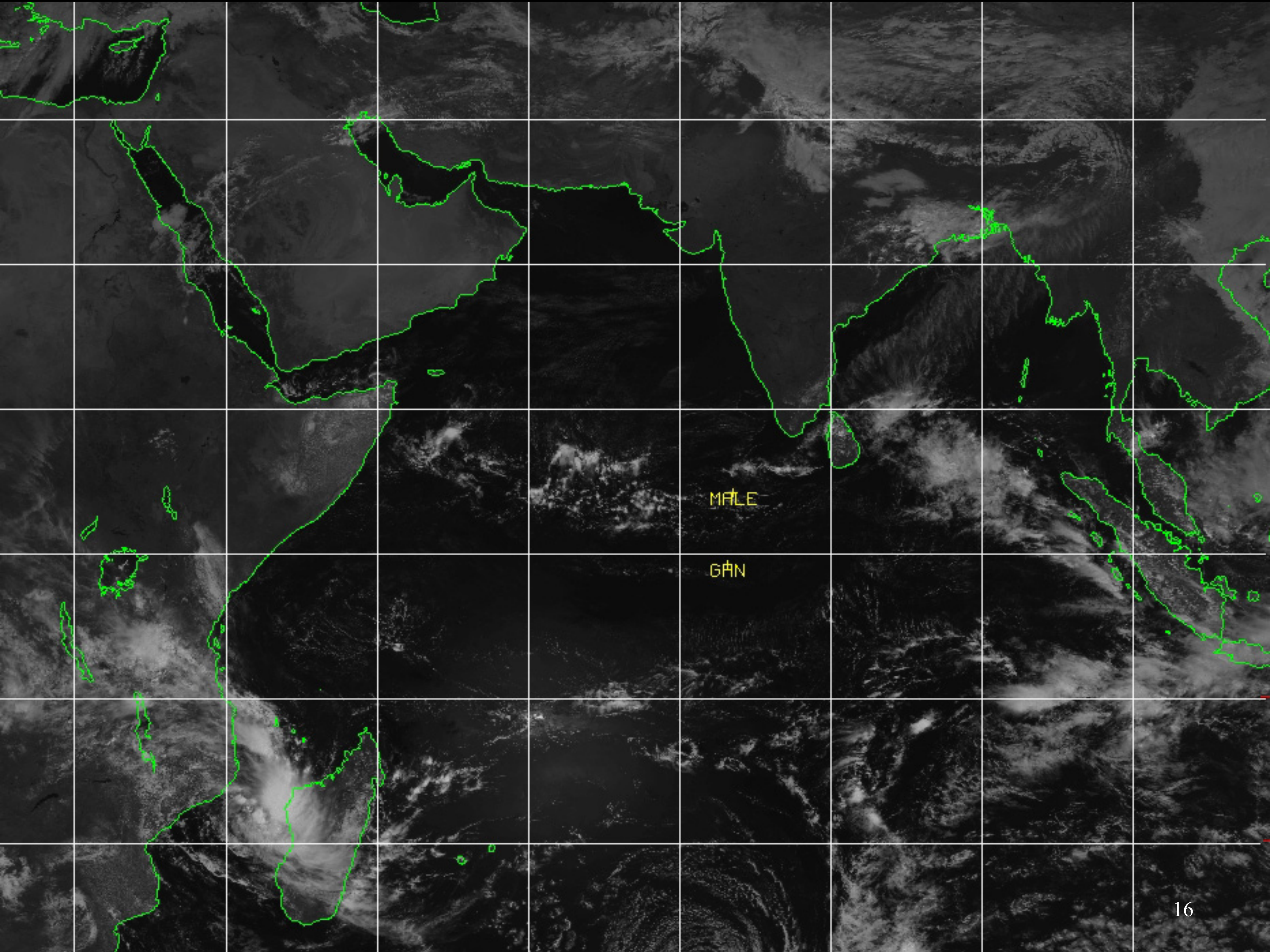

30°N
0°
30°S
0°
60°E
120°E
180°W
120°W
60°W
0°
Z (m)
−12 −9.6 −7.2 −4.8 −2.4 0 2.4 4.8 7.2 9.6 12

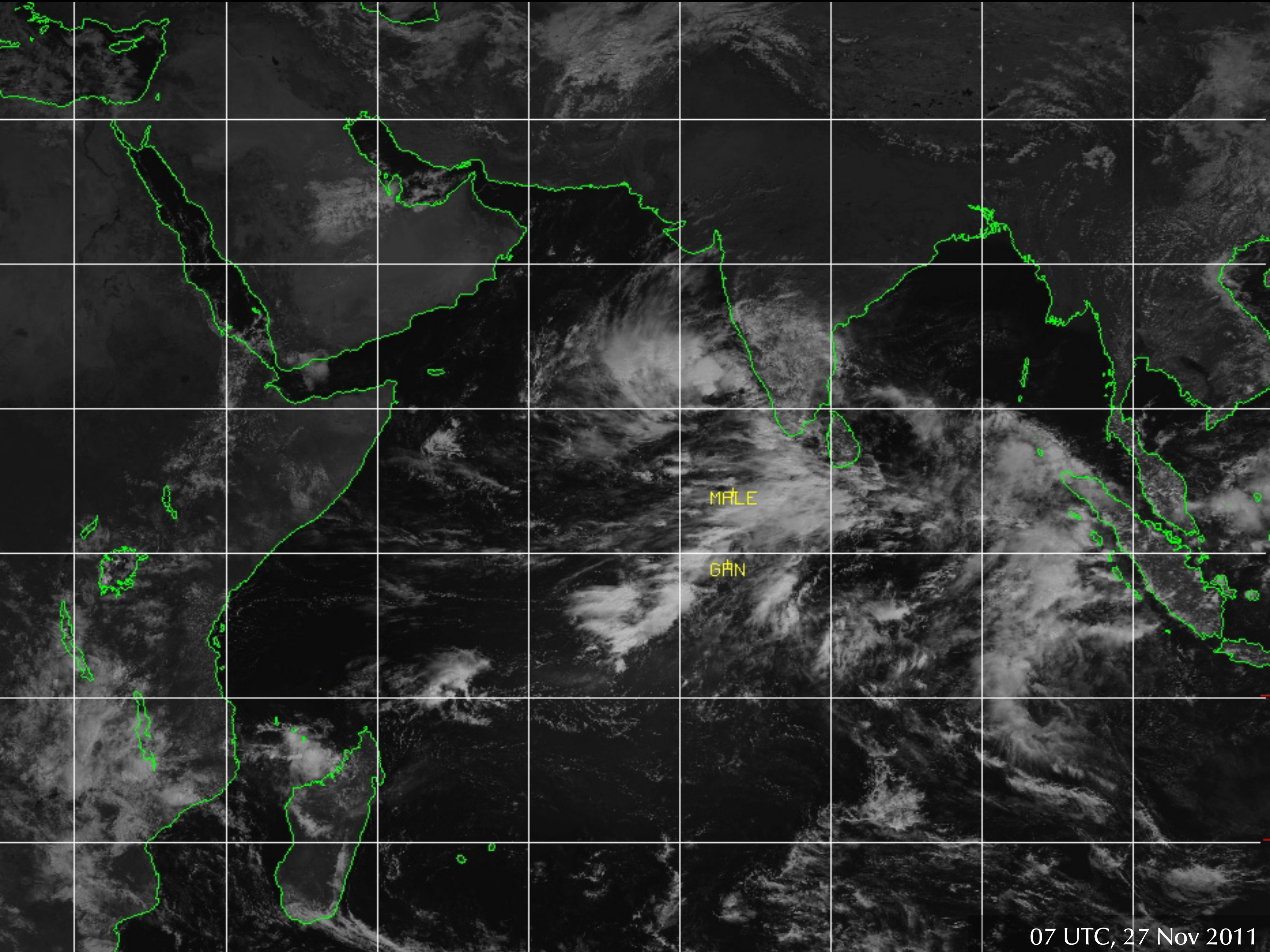


07 UTC, 27 Nov 2011

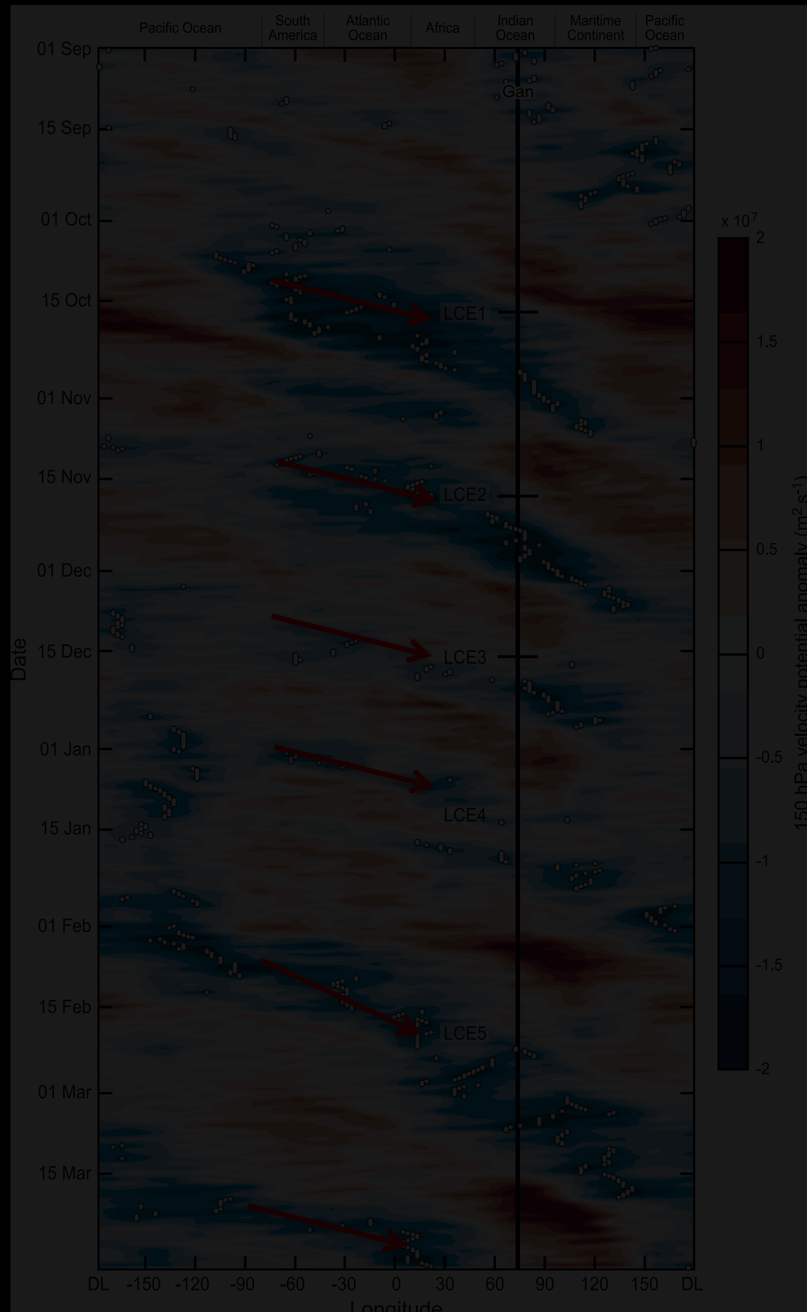


-10
-5
0
5
10
15
4
(a)
c.f. Gill (1980)
L
L
y 0
-4
GAN
07 UTC, 27 Nov 2011


MALE
GAN


MALE
GAN
07 UTC, 27 Nov 2011

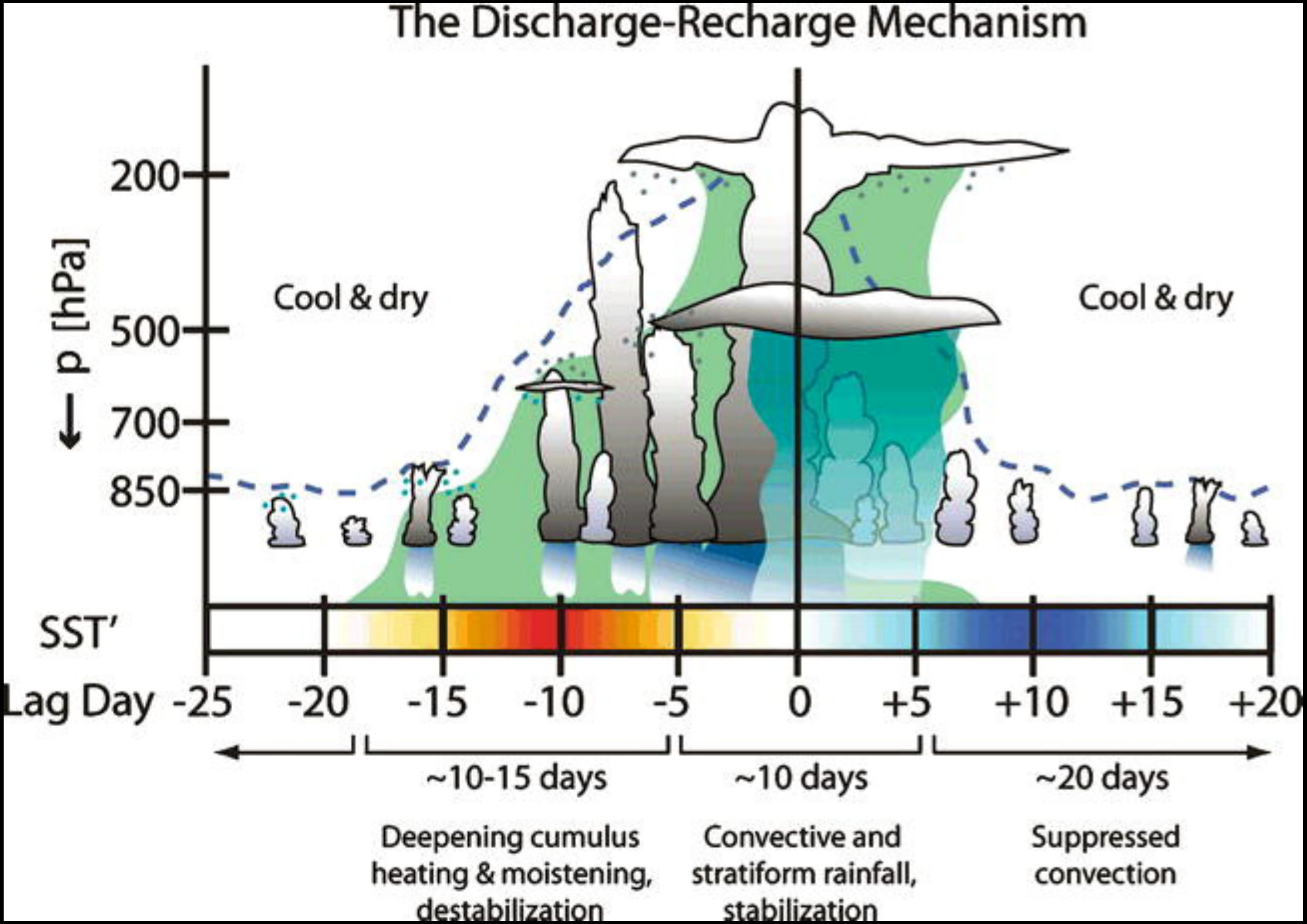
Hypothesis: Convection passively responds to changes in the large-scale environment.



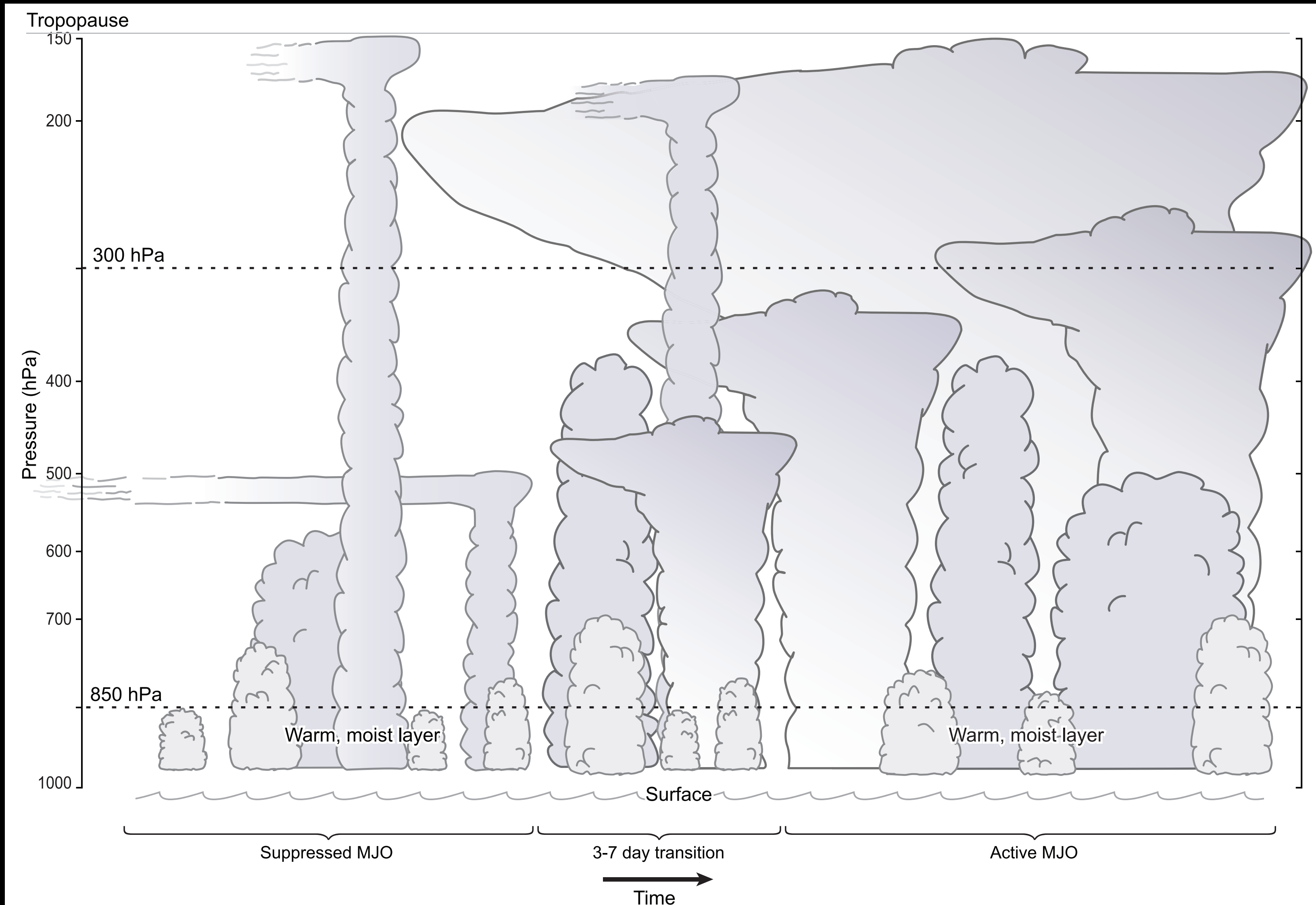
Originally: Knutson and Weickmann (1987)

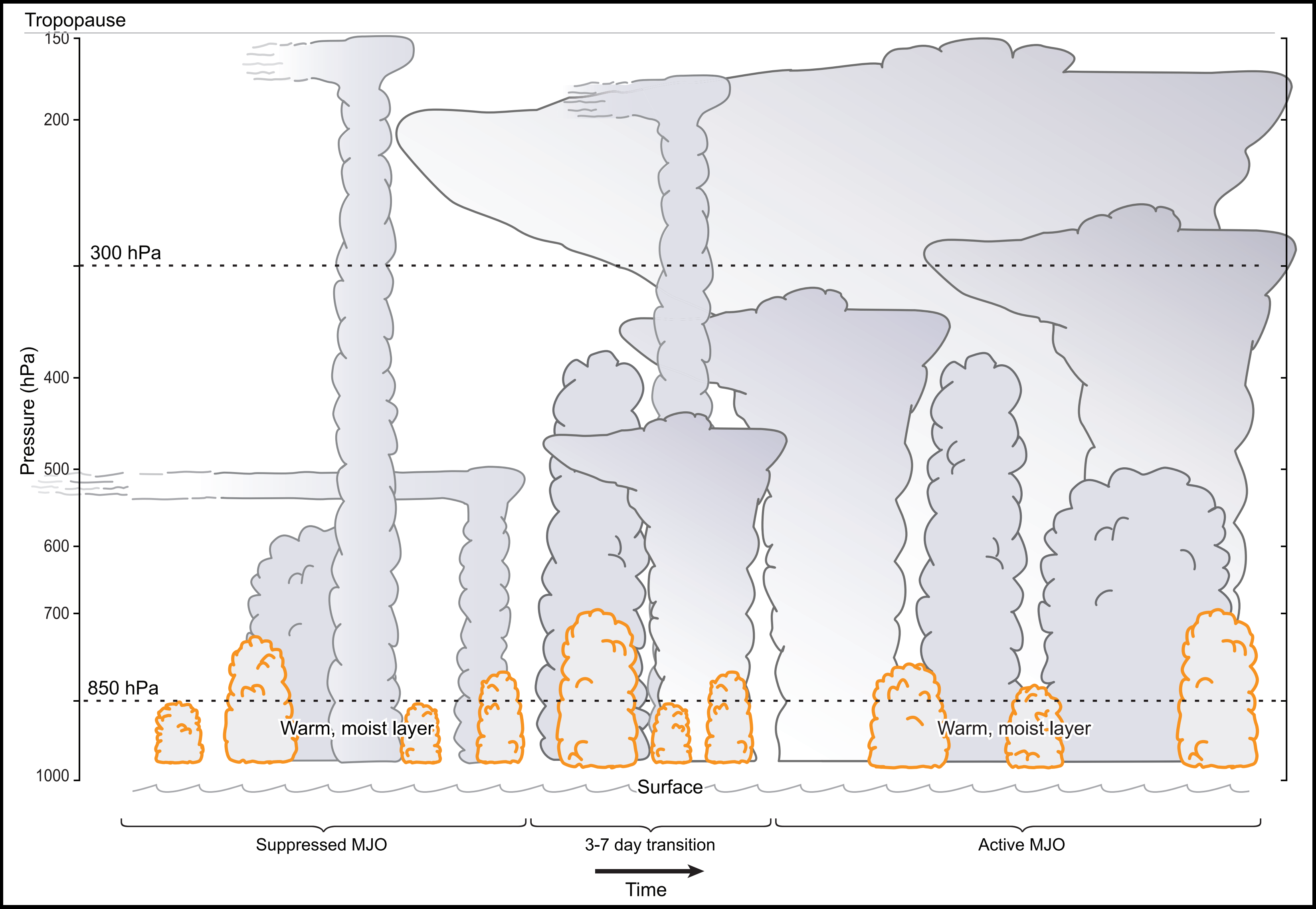
Figure: Powell and Houze (2015b)

Hypothesis: Clouds are actively involved in "preconditioning" environment for MJO.

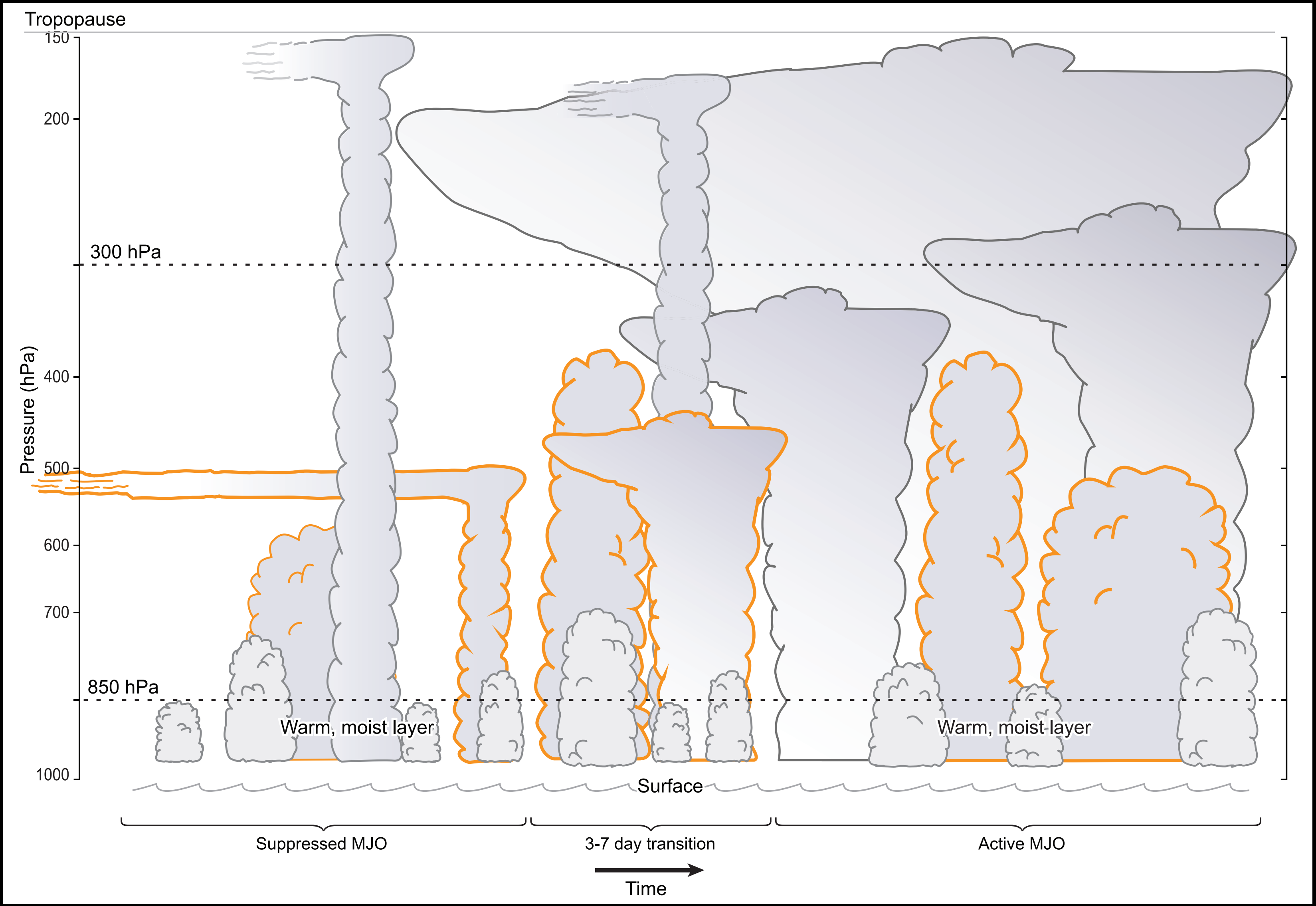


Benedict and Randall (2007), following Bladé and Hartmann (1993) and Kemball-Cook and Weare (2001)

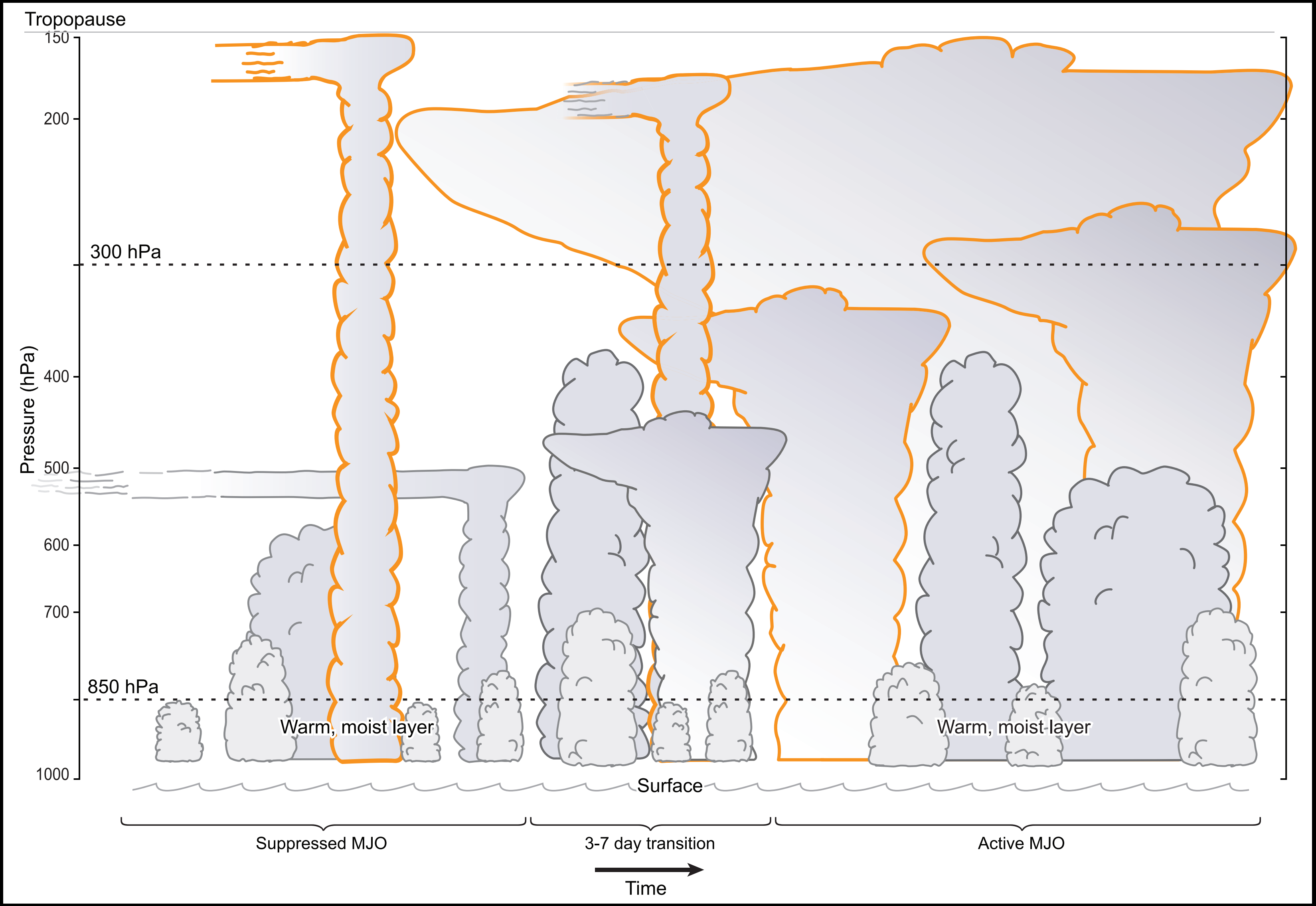

Tropopause
150
200
300 hPa
400
500
600
700
850 hPa
1000
Pressure (hPa)
Warm, moist layer
Warm, moist layer
Surface
Suppressed MJO
3-7 day transition
Active MJO
Time

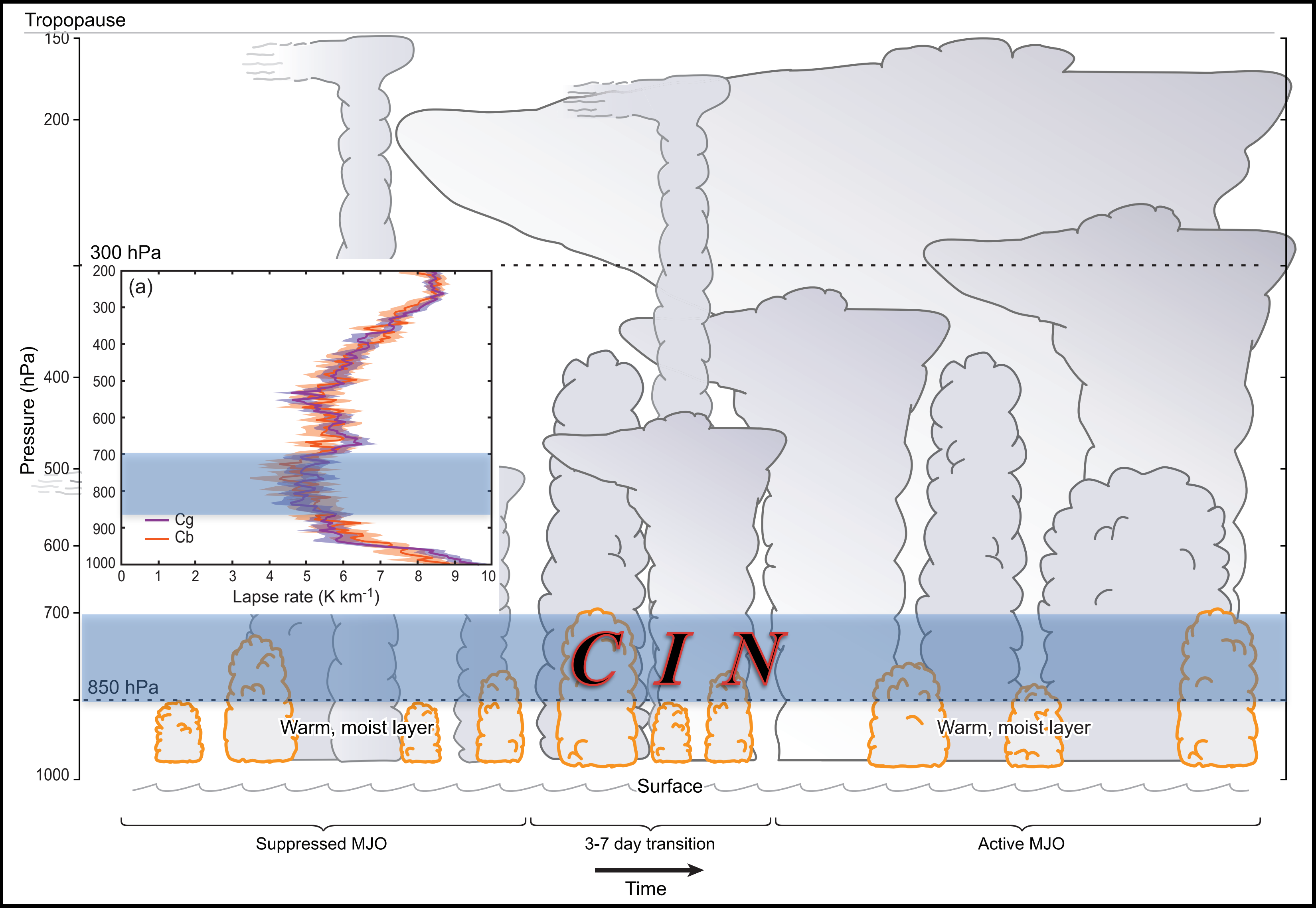

Tropopause
150
200
300 hPa
400
500
600
700
850 hPa
1000
Pressure (hPa)
Warm, moist layer
Warm, moist layer
Surface
Suppressed MJO
3-7 day transition
Active MJO
Time

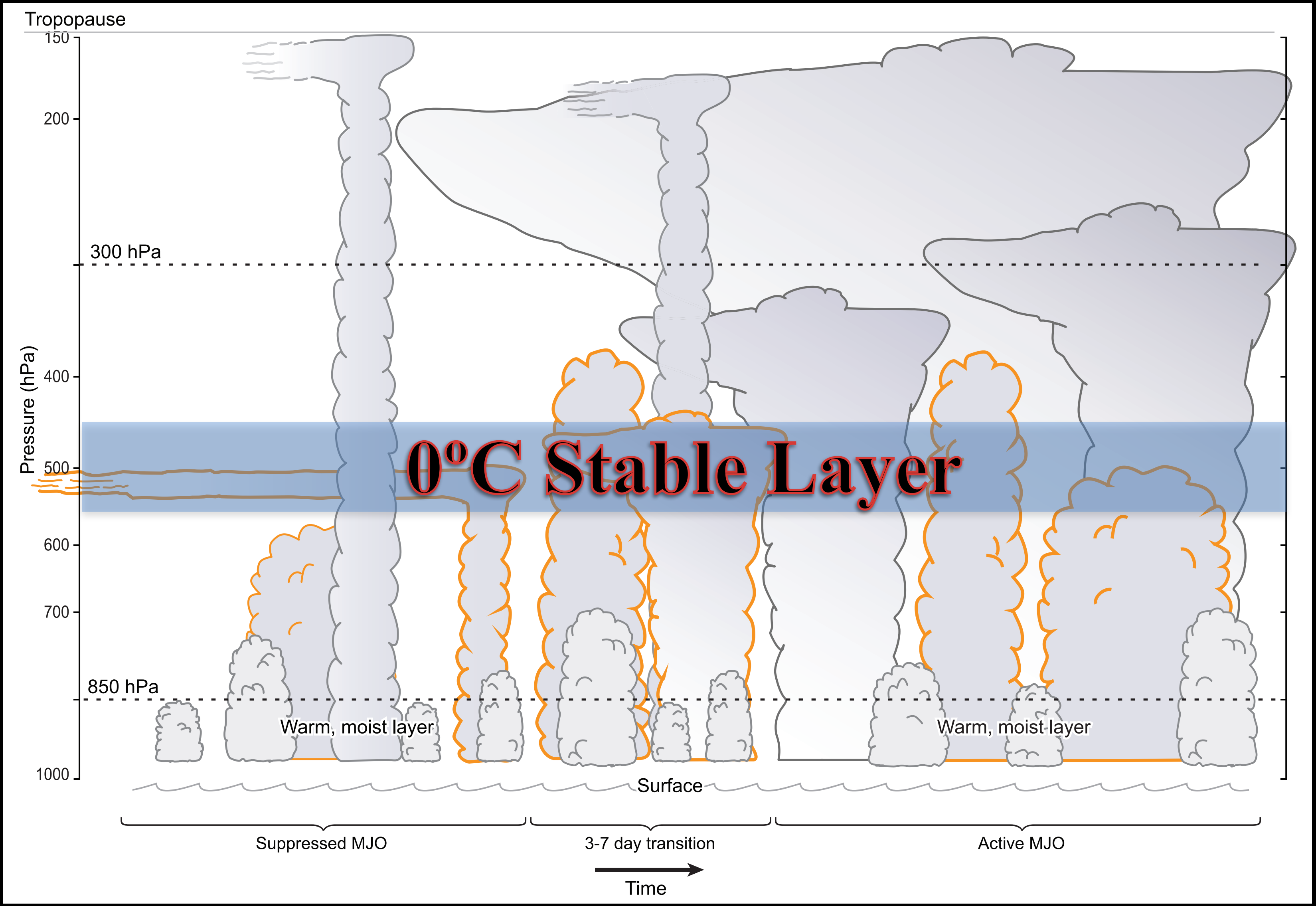
Powell and Houze (2015b)



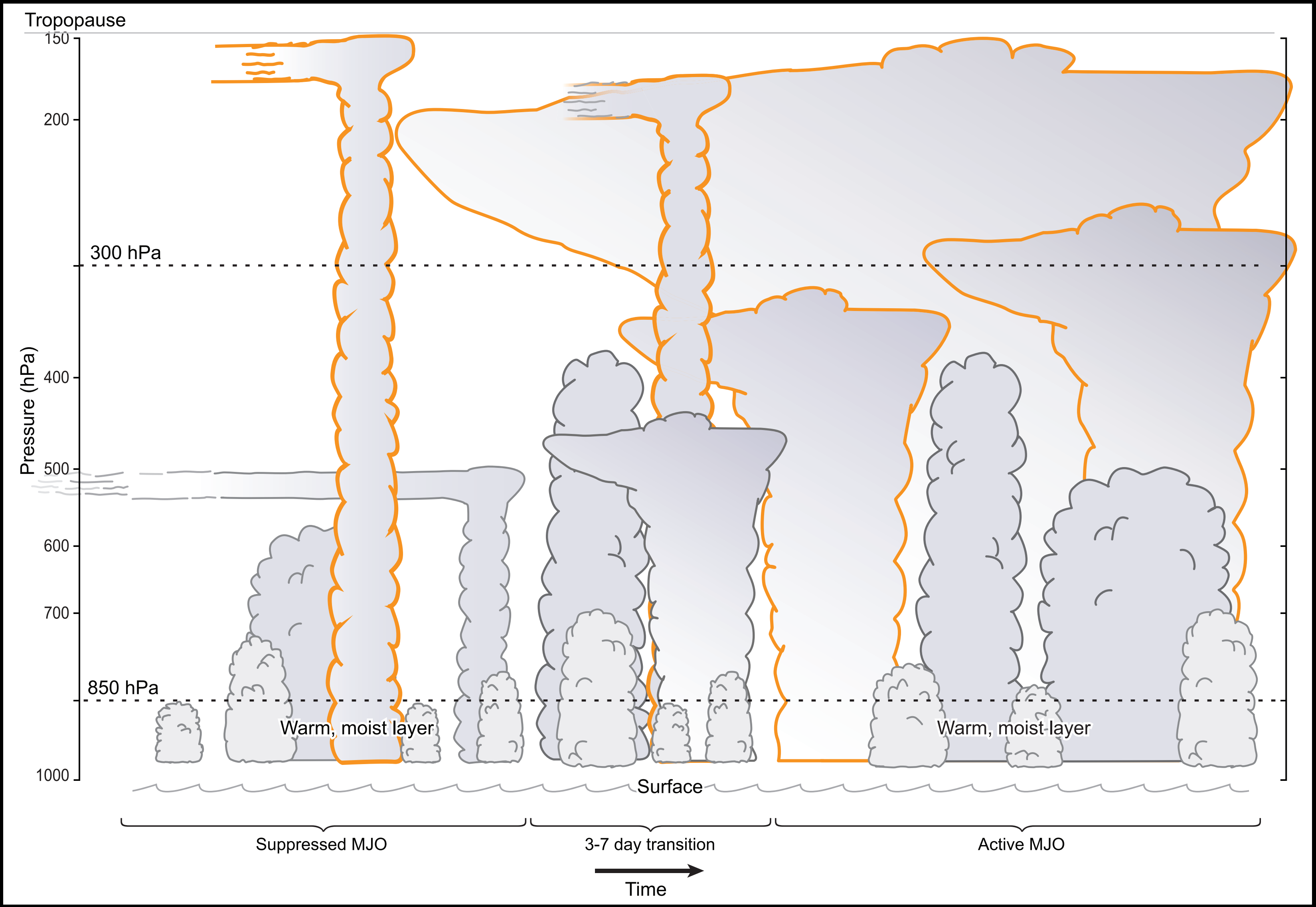
Powell and Houze (2015b)



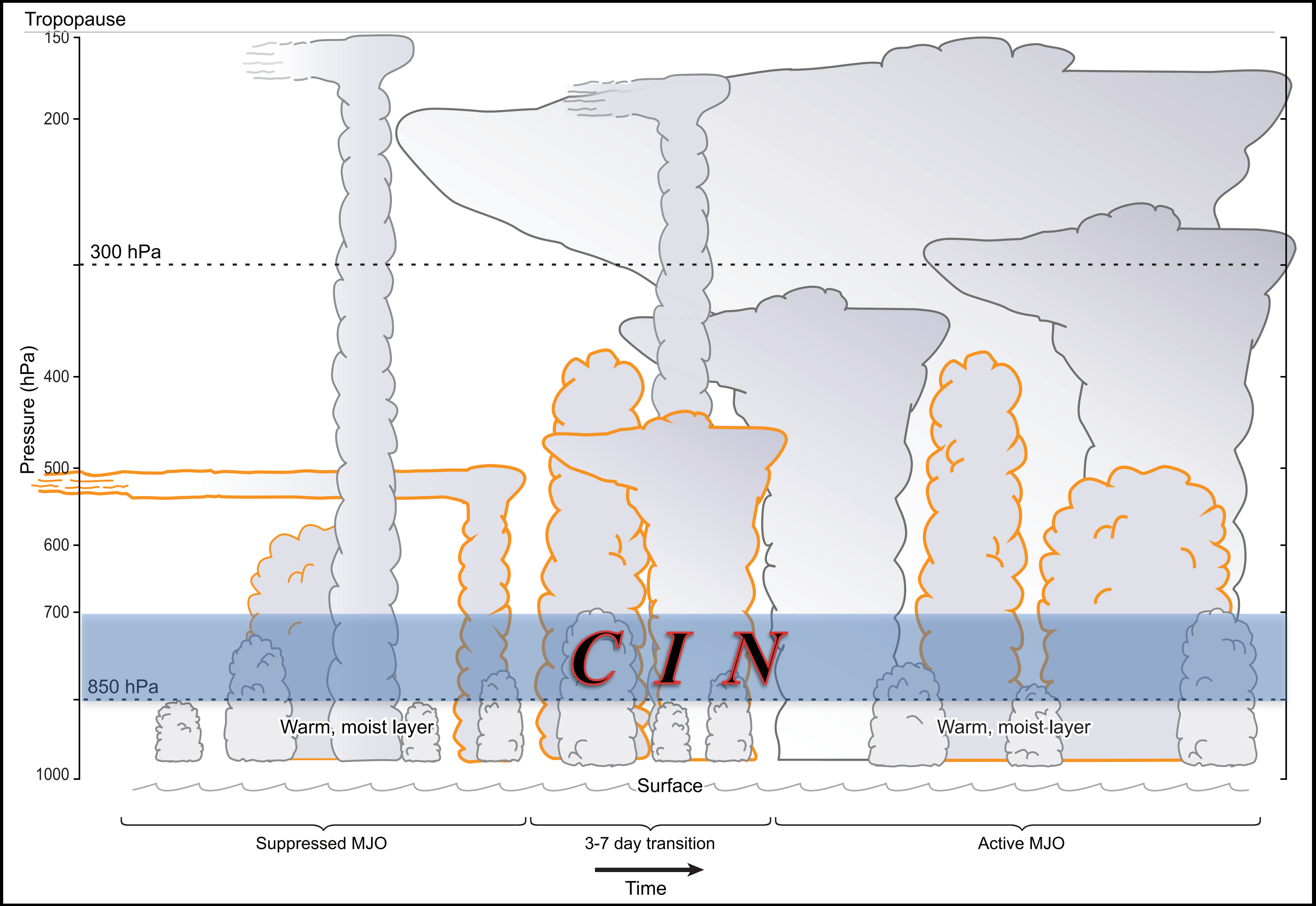

Tropopause
150
200
300 hPa
400
500
600
700
850 hPa
1000
Pressure (hPa)
(a)
200
300
400
500
600
700
800
900
1000
0 1 2 3 4 5 6 7 8 9 10
Lapse rate (K km-1)
Cg
Cb
CIN
Warm, moist layer
Warm, moist layer
Surface
Suppressed MJO
3-7 day transition
Active MJO
Time



Tropopause
150
200
300 hPa
400
500
600
700
850 hPa
1000
Pressure (hPa)
0°C Stable Layer
Warm, moist layer
Warm, moist layer
Surface
Suppressed MJO
3-7 day transition
Active MJO
Time



Tropopause
150
200
300 hPa
400
500
600
700
850 hPa
1000
Pressure (hPa)
Warm, moist layer
Warm, moist layer
Surface
Suppressed MJO
3-7 day transition
Active MJO
Time


Tropopause
150
200
300 hPa
400
500
600
700
850 hPa
1000
Pressure (hPa)
C I N
Warm, moist layer
Warm, moist layer
Surface
Suppressed MJO
3-7 day transition
Active MJO
Time

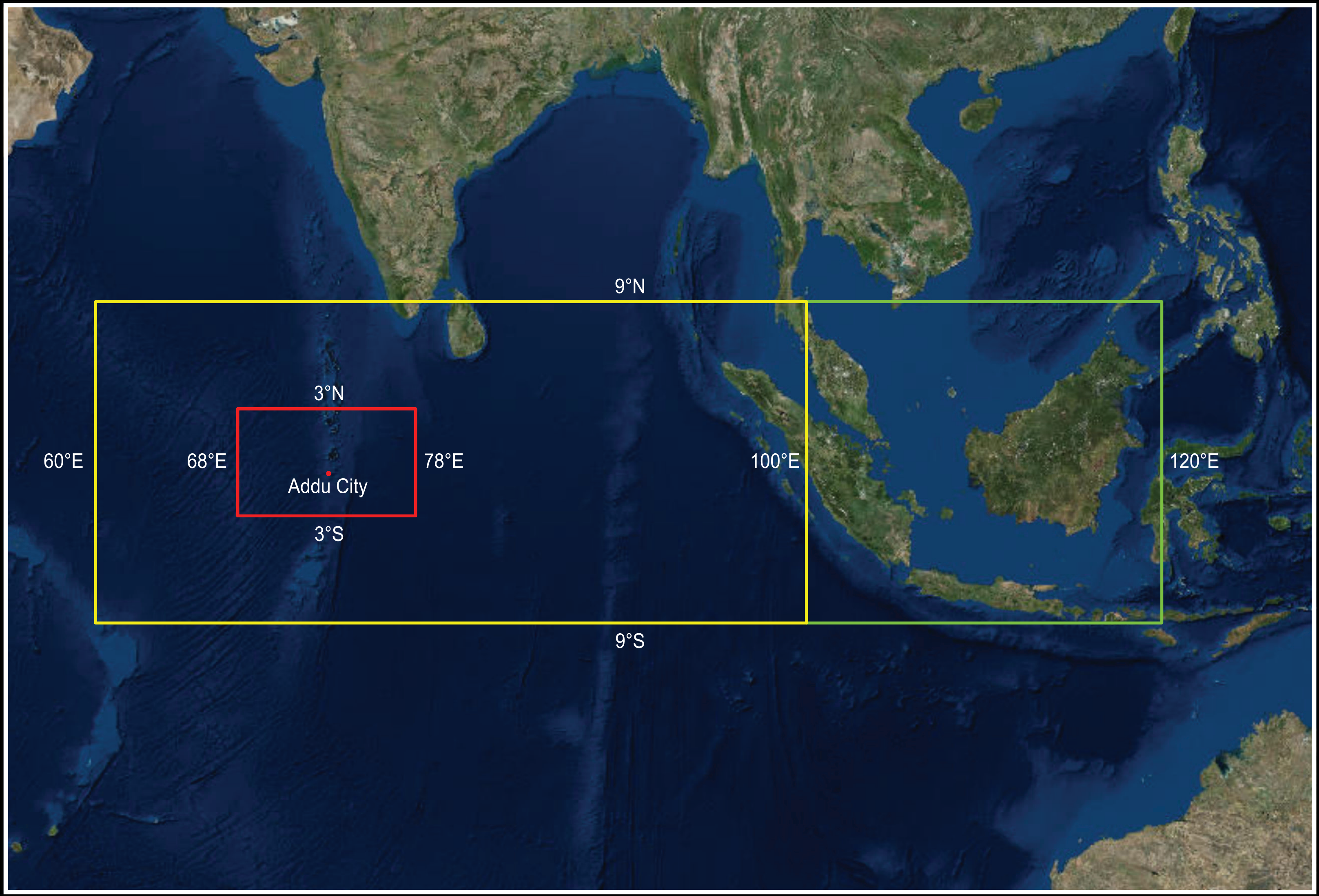
Objectives

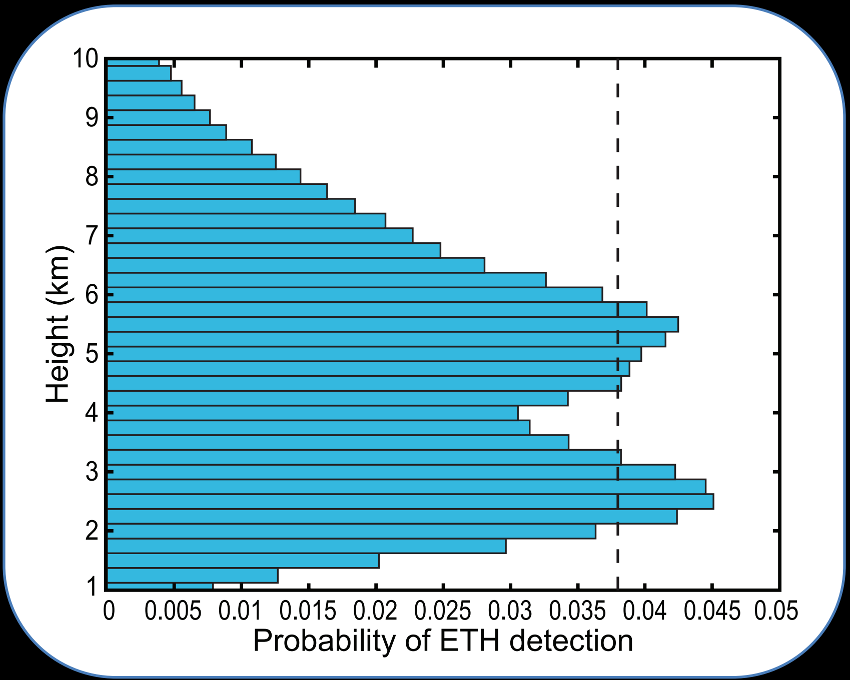
1. Do clouds moisten environment or does something else, allowing for cloud development?

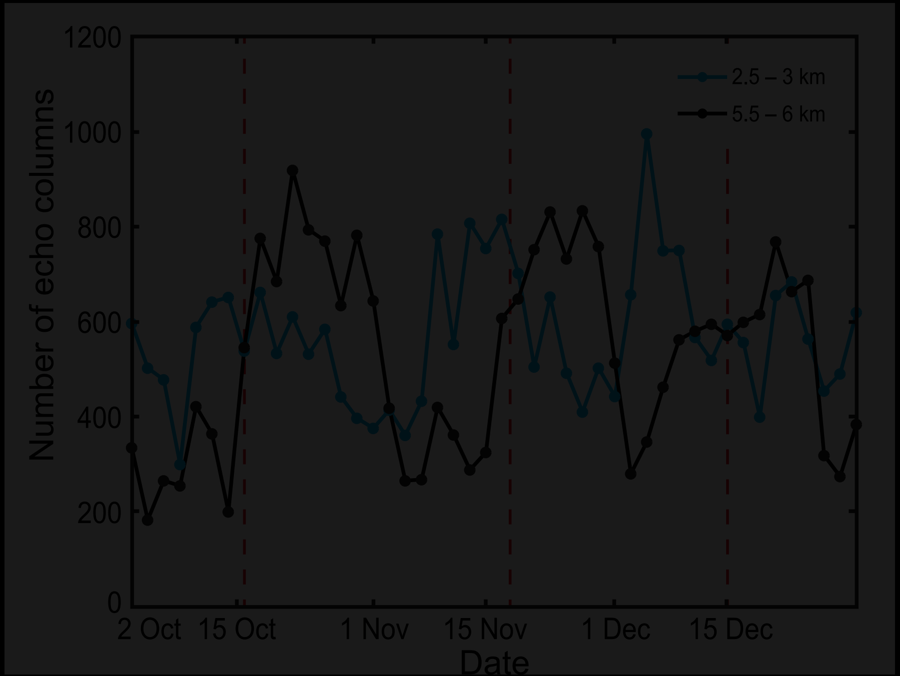
2. How do circumnavigating circulation anomalies promote cloud growth?

Moistening by Cumulonimbi

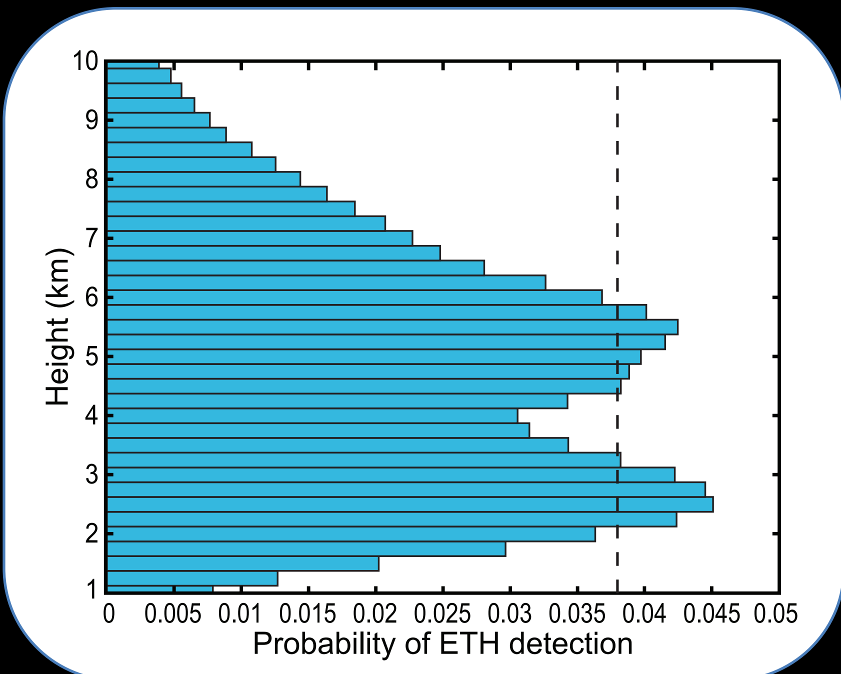
Do moderately deep clouds moisten the troposphere during transition periods, or does moistening permit observed cloud deepening?

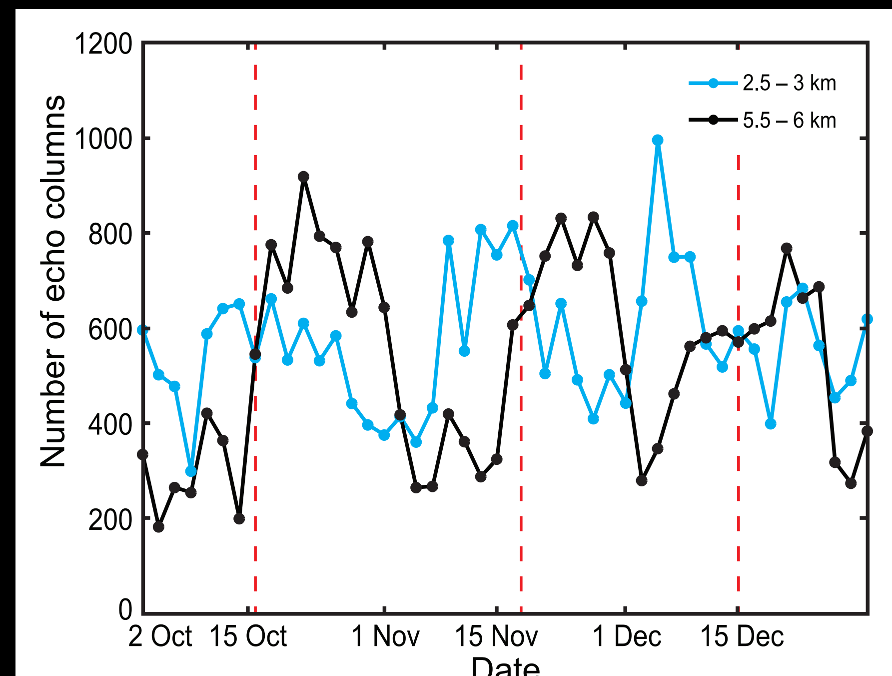

9°N
3°N
60°E
68°E
78°E
100°E
120°E
Addu City
3°S
9°S





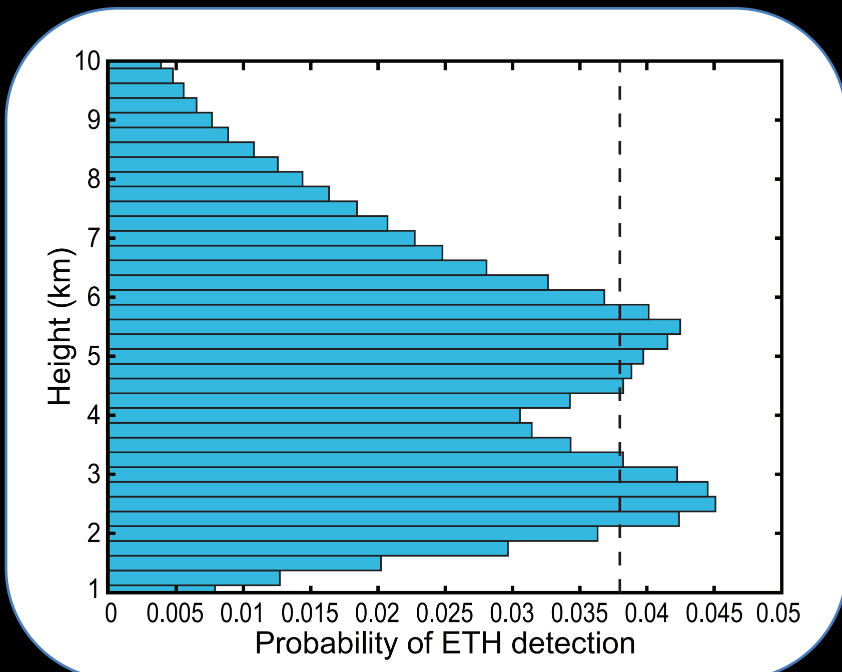
TRMM 20dBZ echo tops: 9N–9S; 60–100E

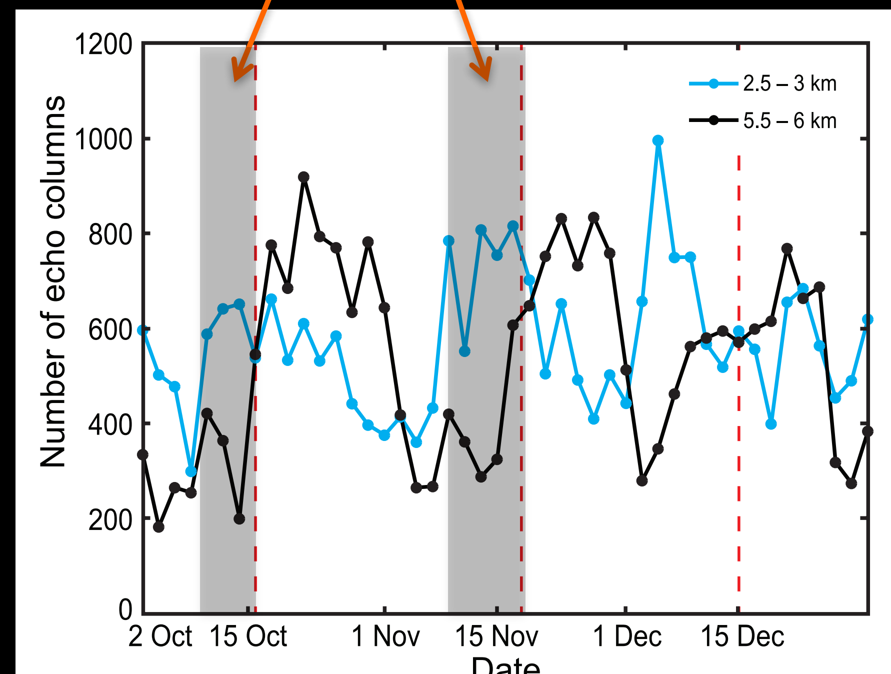




TRMM 20dBZ echo tops: 9N–9S; 60–100E

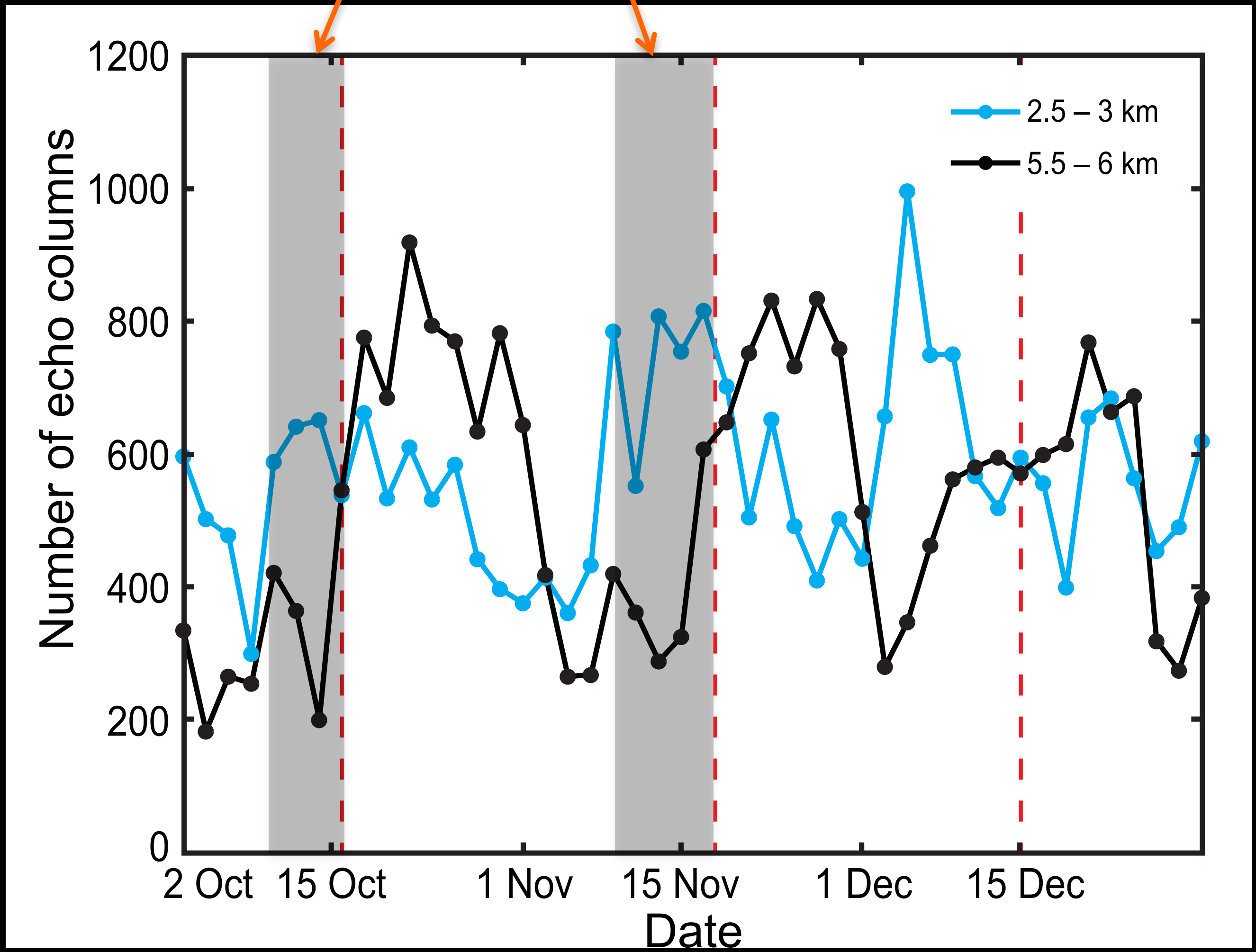
Transition periods



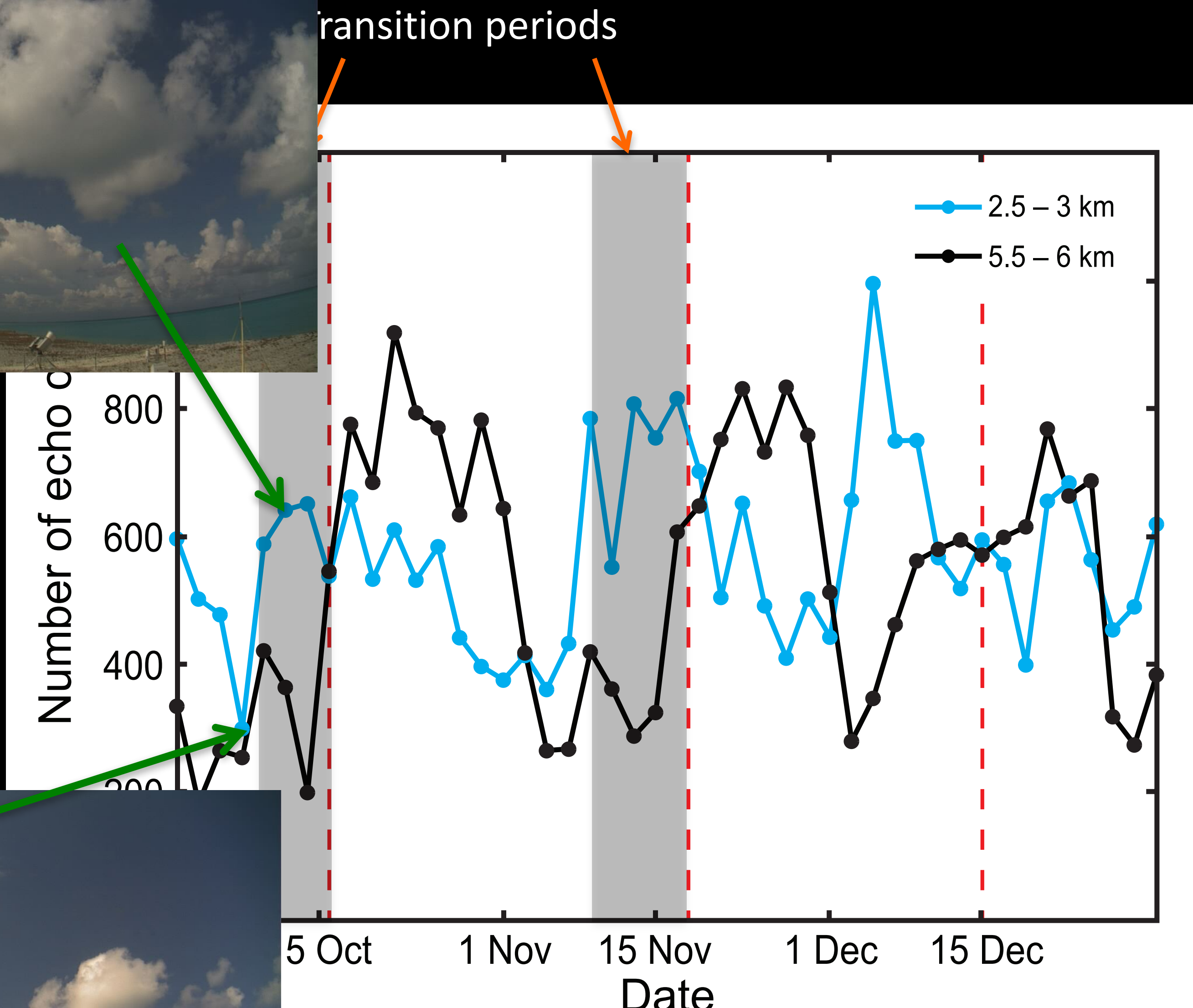


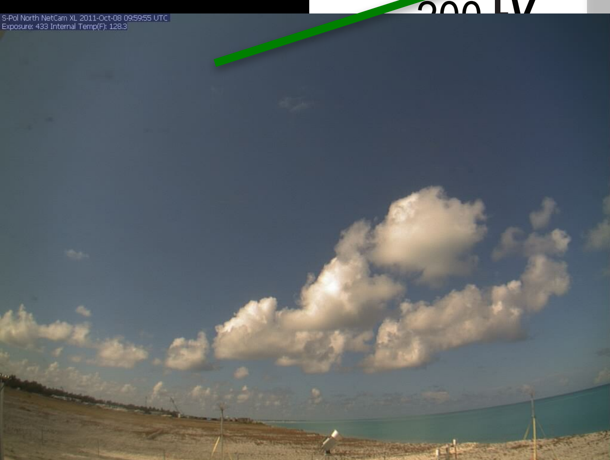
TRMM 20dBZ echo tops: 9N–9S; 60–100E

Transition periods



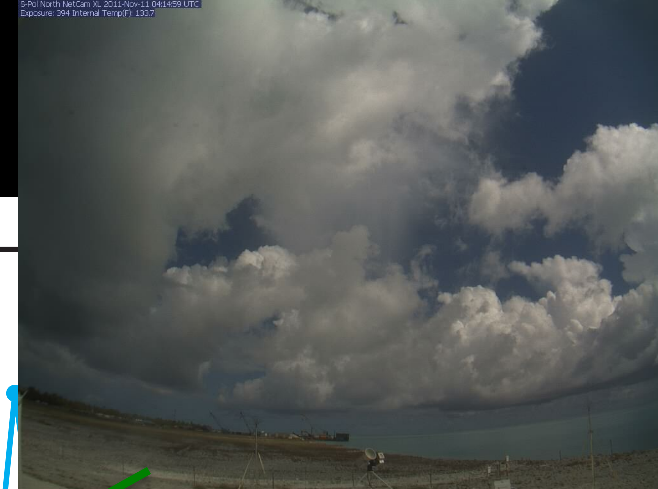
TRMM 20dBZ echo tops: 9N–9S; 60–100E

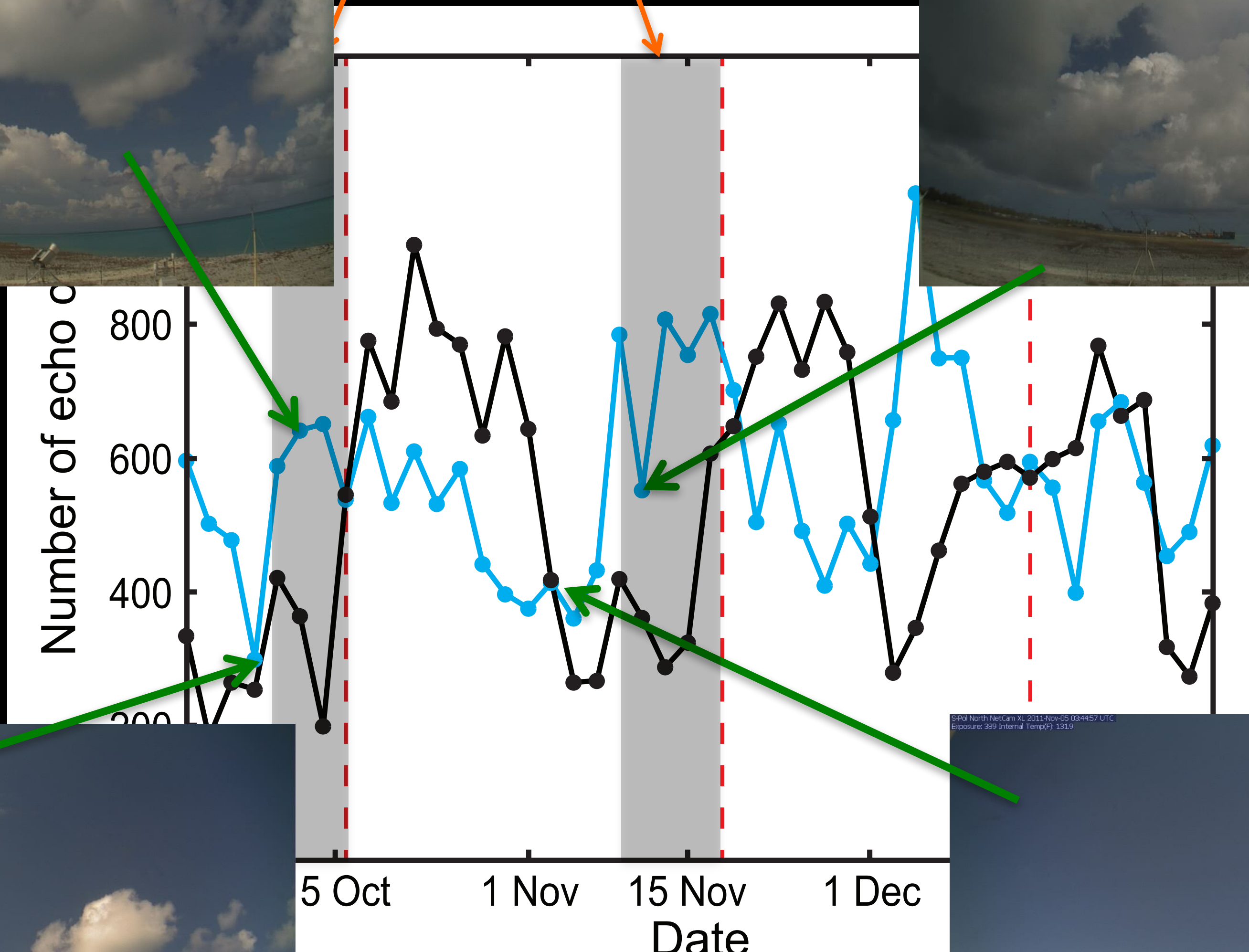


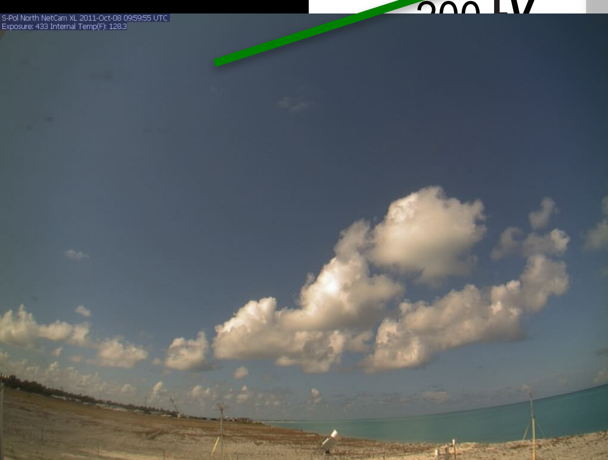


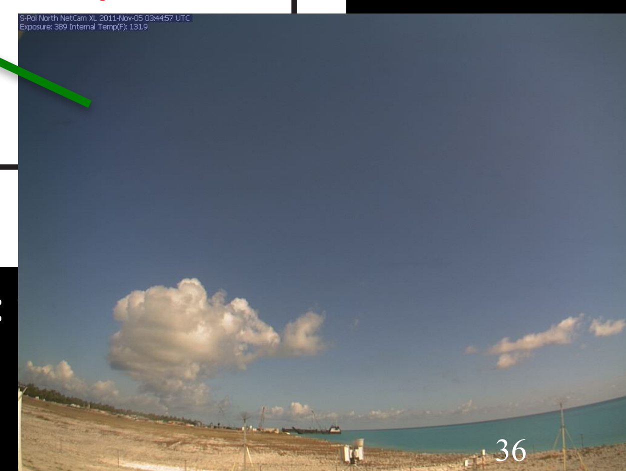
TRMM 20dBZ echo tops: 9N–9S; 60–100E

ransition periods

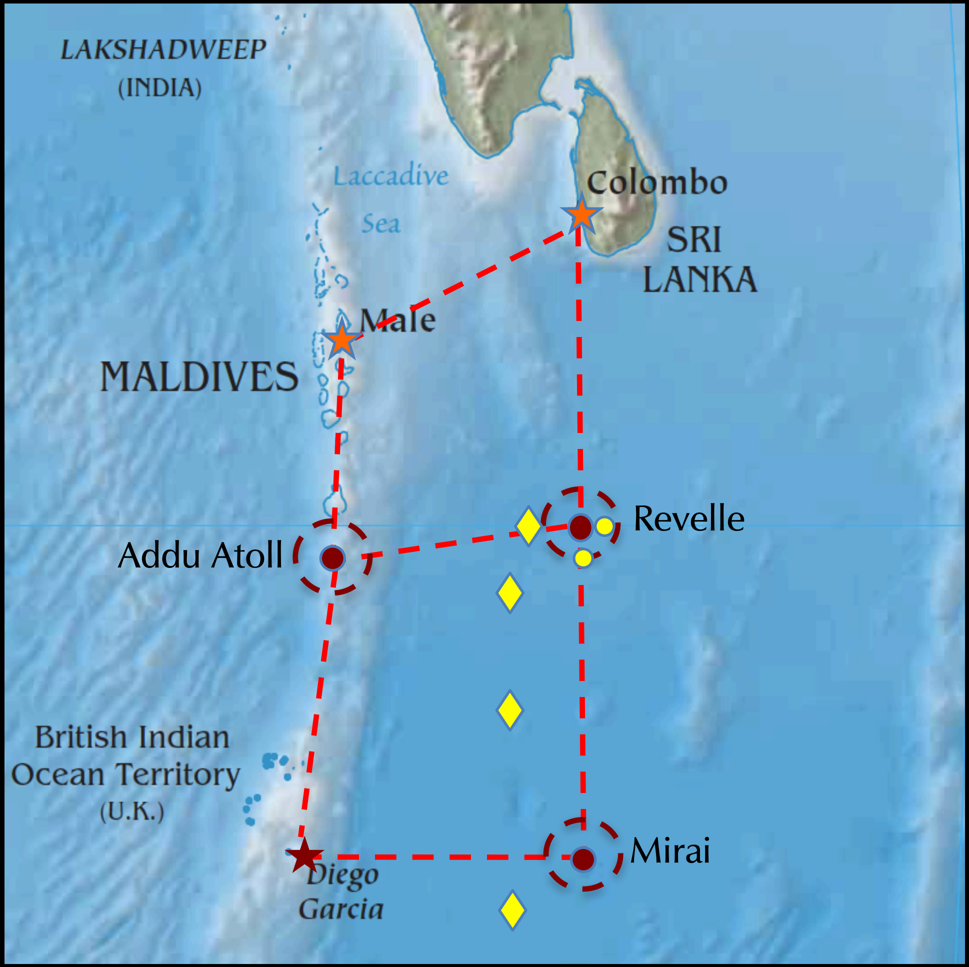


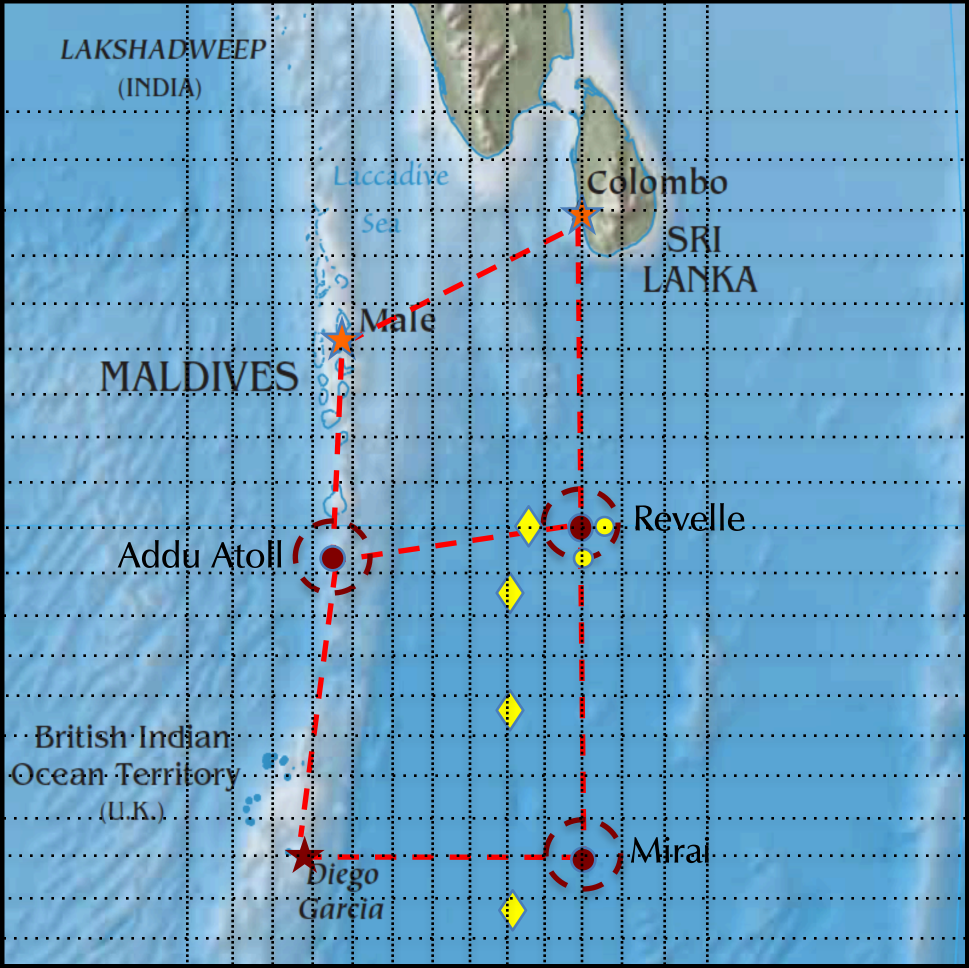






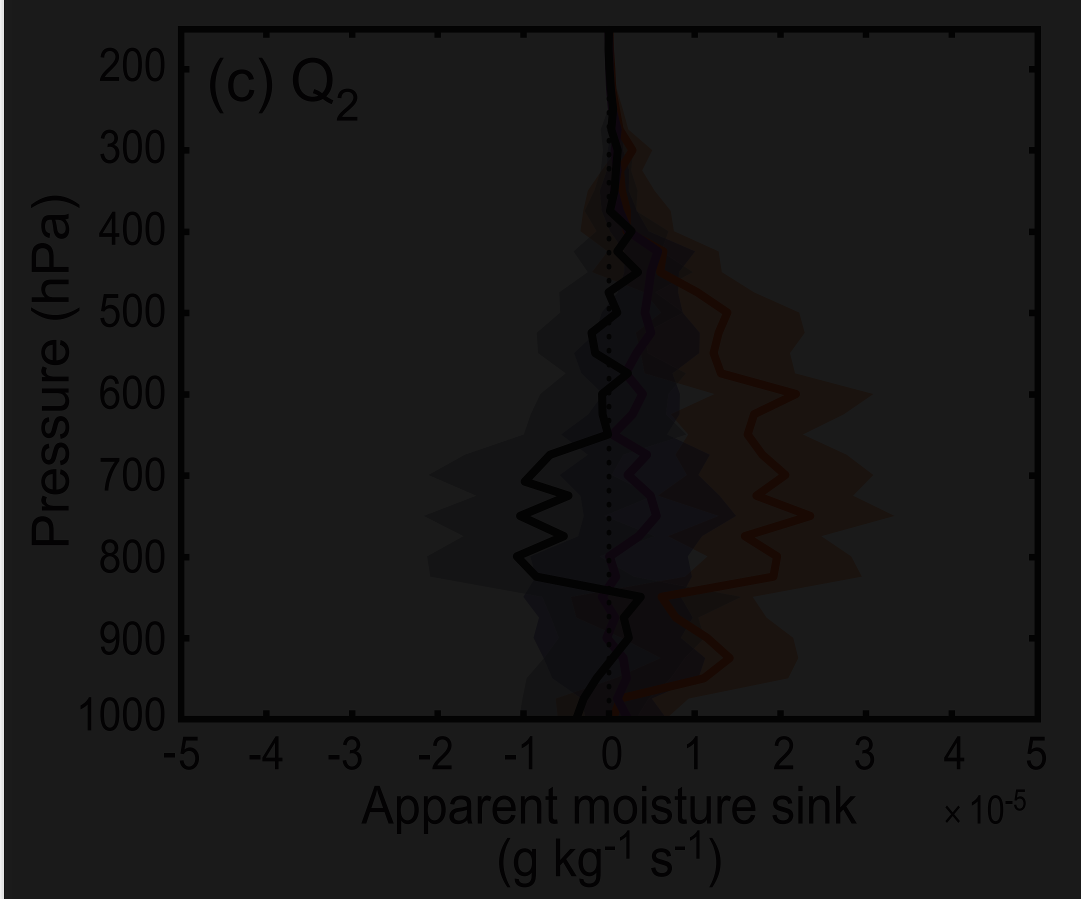
TRMM 20dBZ echo tops:


LAKSHADWEEP
(INDIA)
Laccadive
Sea
Colombo
SRI
LANKA
Male
MALDIVES
Revelle
Addu Atoll
British Indian
Ocean Territory
(U.K.)
Mirai
Diego
Garcia


LAKSHADWEEP
(INDIA)
Laccadive
Sea
Colombo
SRI
LANKA
Male
MALDIVES
Revelle
Addu Atoll
British Indian
Ocean Territory
(U.K.)
Mirai
Diego
Garcia

$$\frac{\partial q}{\partial t} = -\mathbf{v}_h \cdot \nabla q - \omega \frac{\partial q}{\partial p} - Q_2$$

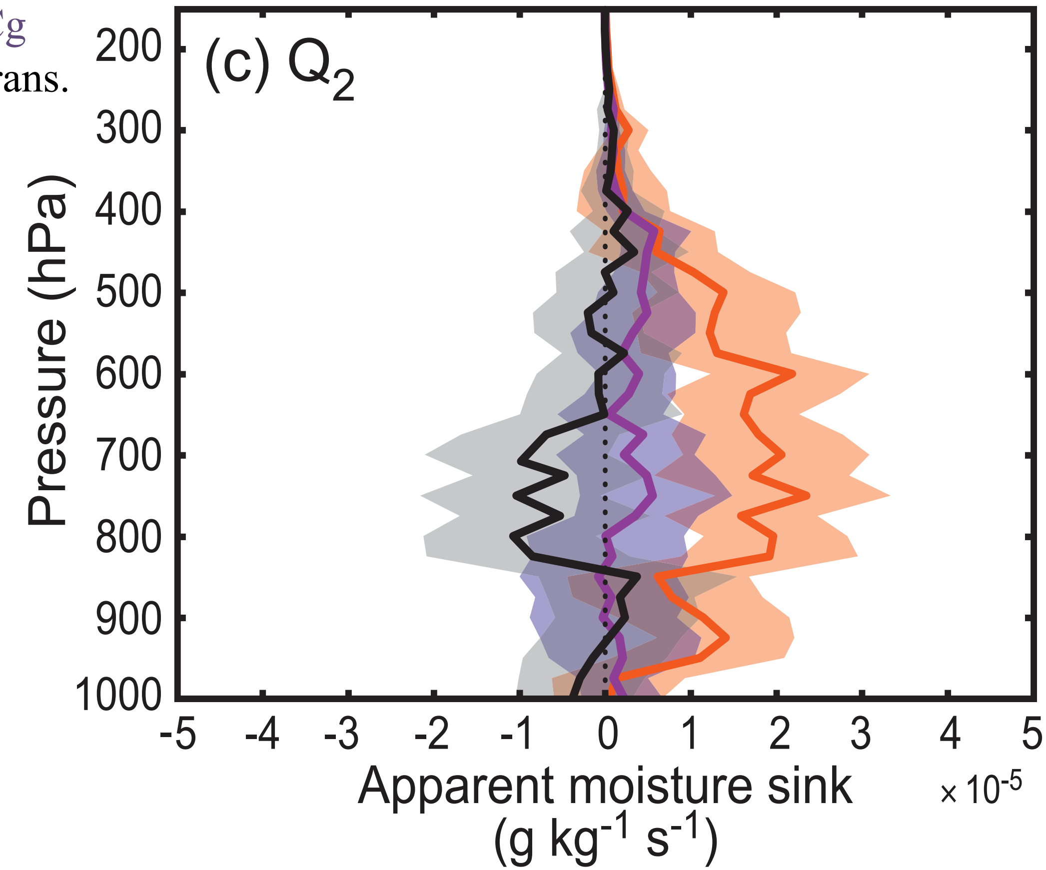
$$Q_2 = \left(\overline{c} - \overline{e}\right) + \frac{\partial}{\partial p}\left(\overline{\omega' q'}\right)$$



$$\frac{\partial q}{\partial t} = -\mathbf{v}_h \cdot \nabla q - \omega \frac{\partial q}{\partial p} - Q_2$$

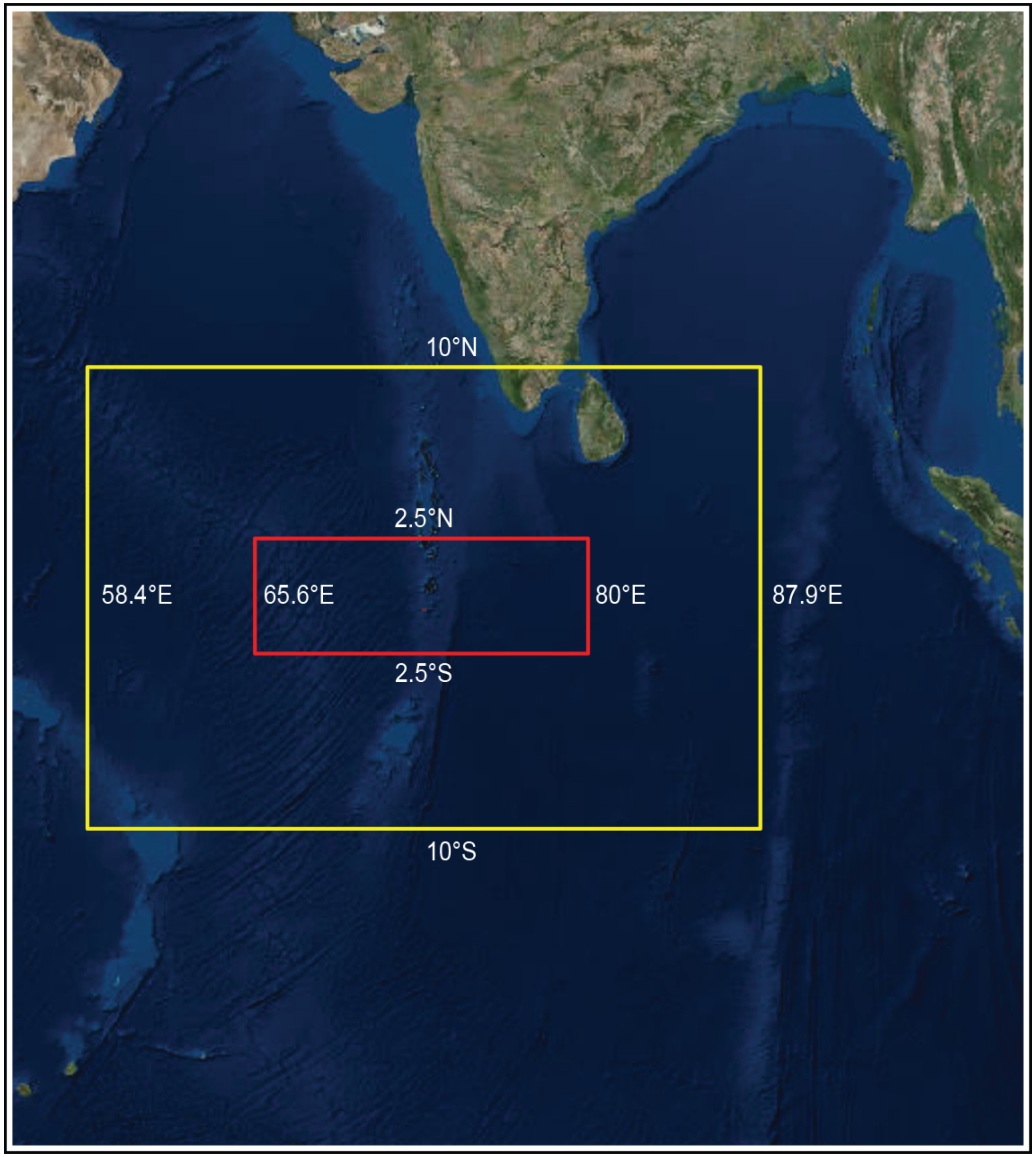
$$\boxed{Q_2 = \left(\overline{c} - \overline{e}\right) + \frac{\partial}{\partial p}\left(\overline{\omega' q'}\right)}$$

Purple = Cg
Black = Trans.
Red = Cb



WRF V3.5.1

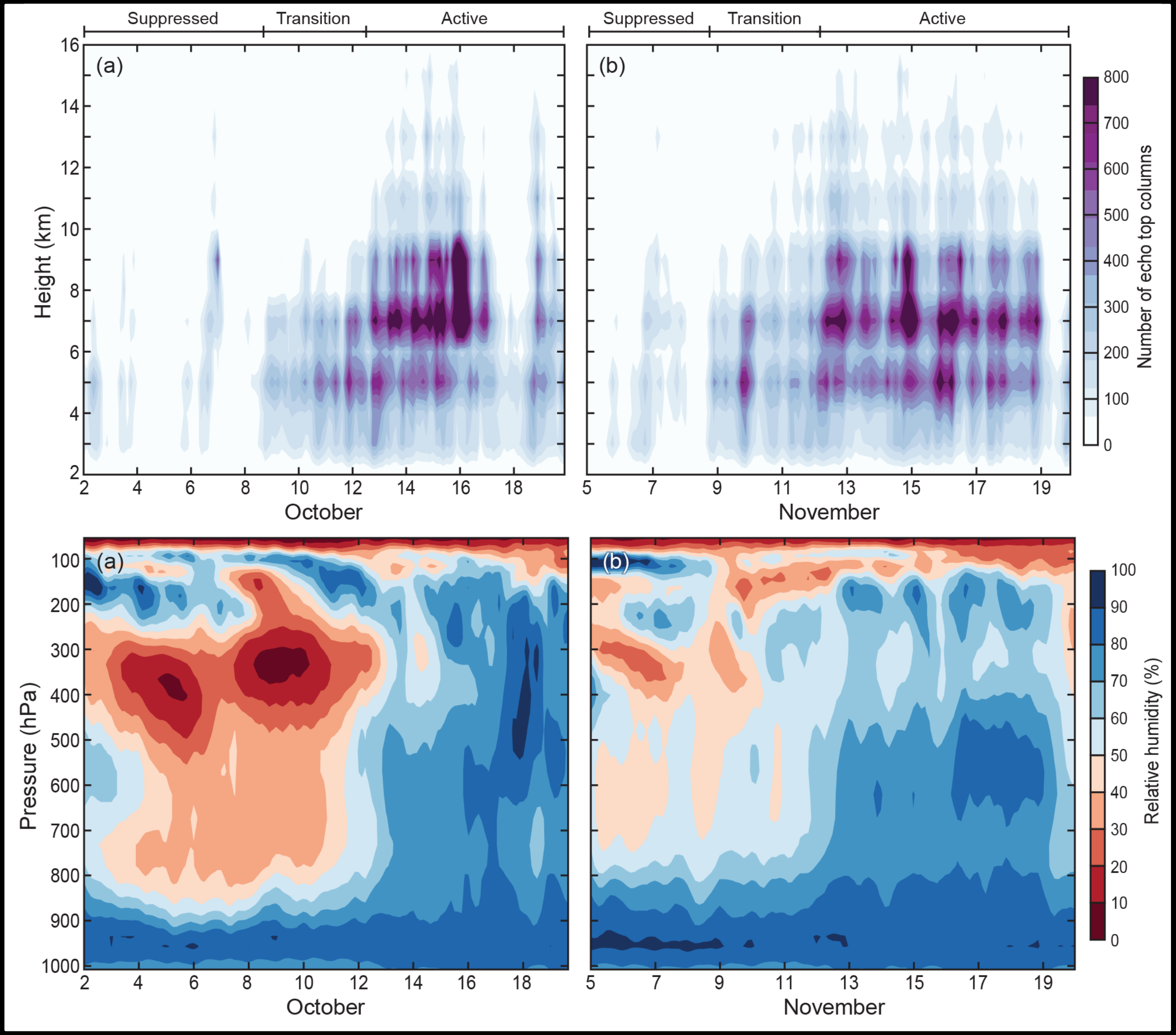
- 2 km grid spacing
- Thompson microphysics (following, e.g., Powell et al. 2012)
- MYJ PBL scheme
- Forced with ERA-I every 6 hours and NOAA RTG for sea surface temperature
- 1–20 October and 4–20 November 2011



Powell (2016)
Rain-type classification following
Powell et al. (2016)

20 dBZ echo top height frequency

Relative Humidity



Powell (2016)
Rain-type classification following
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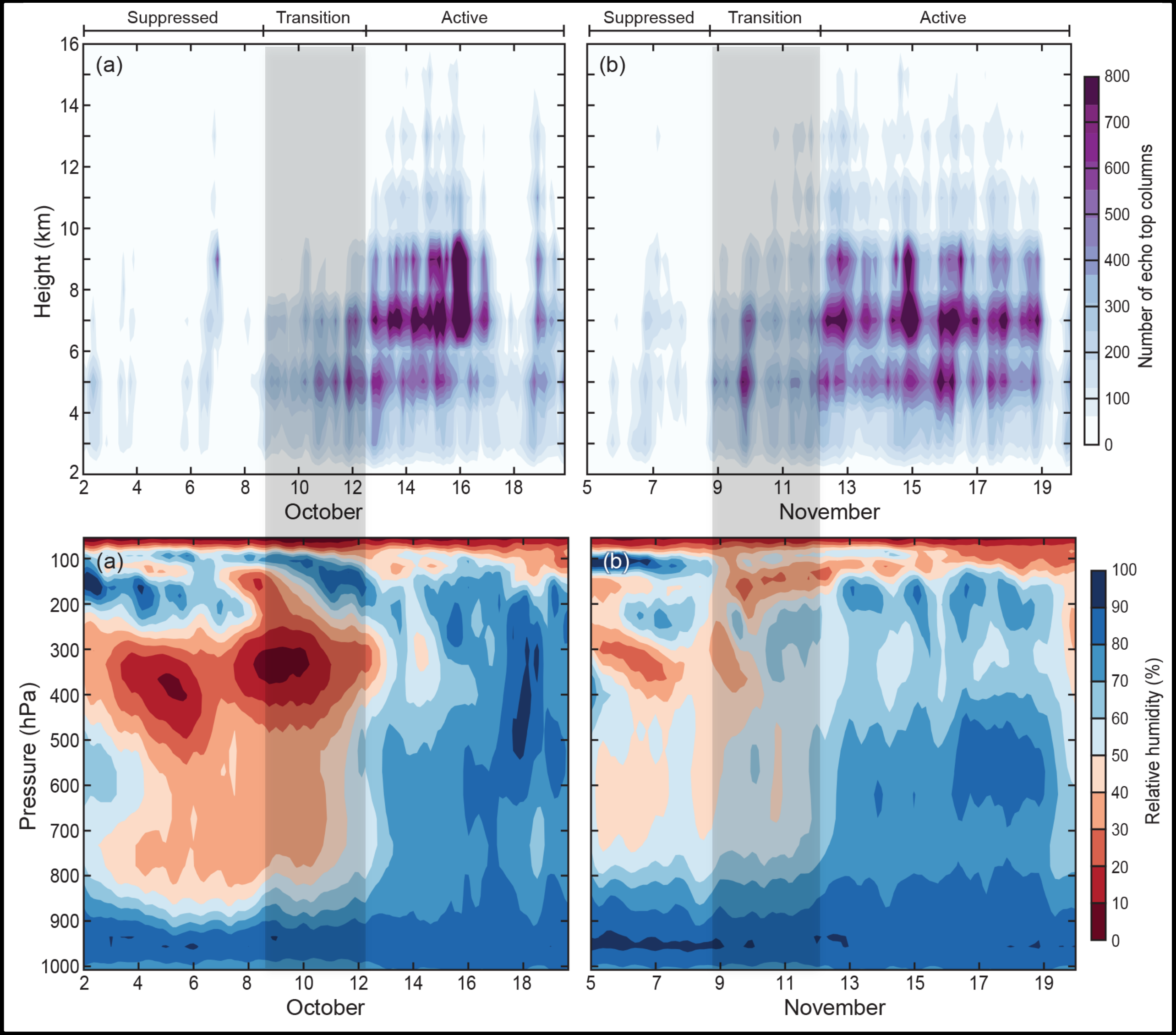
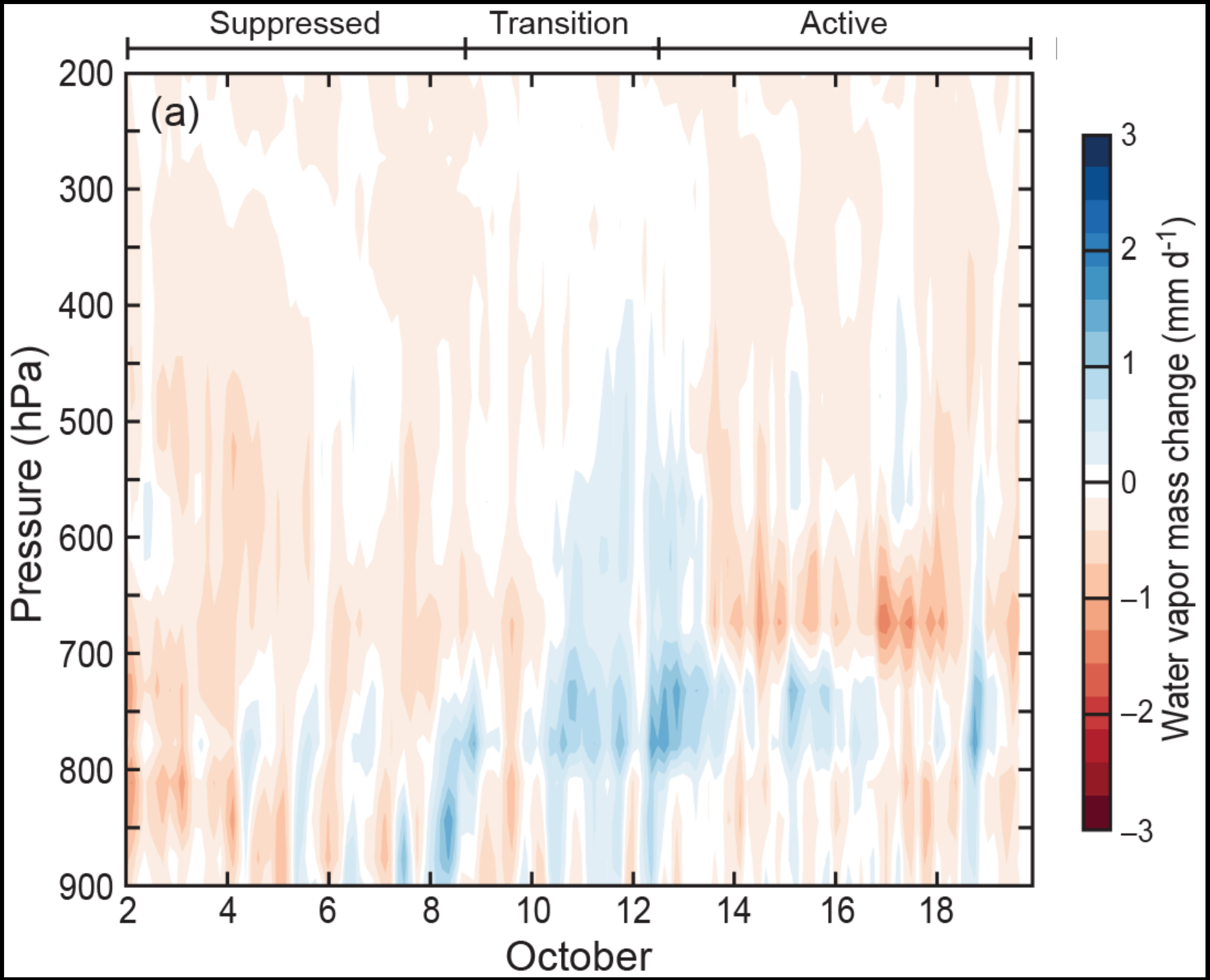
20 dBZ echo top height frequency

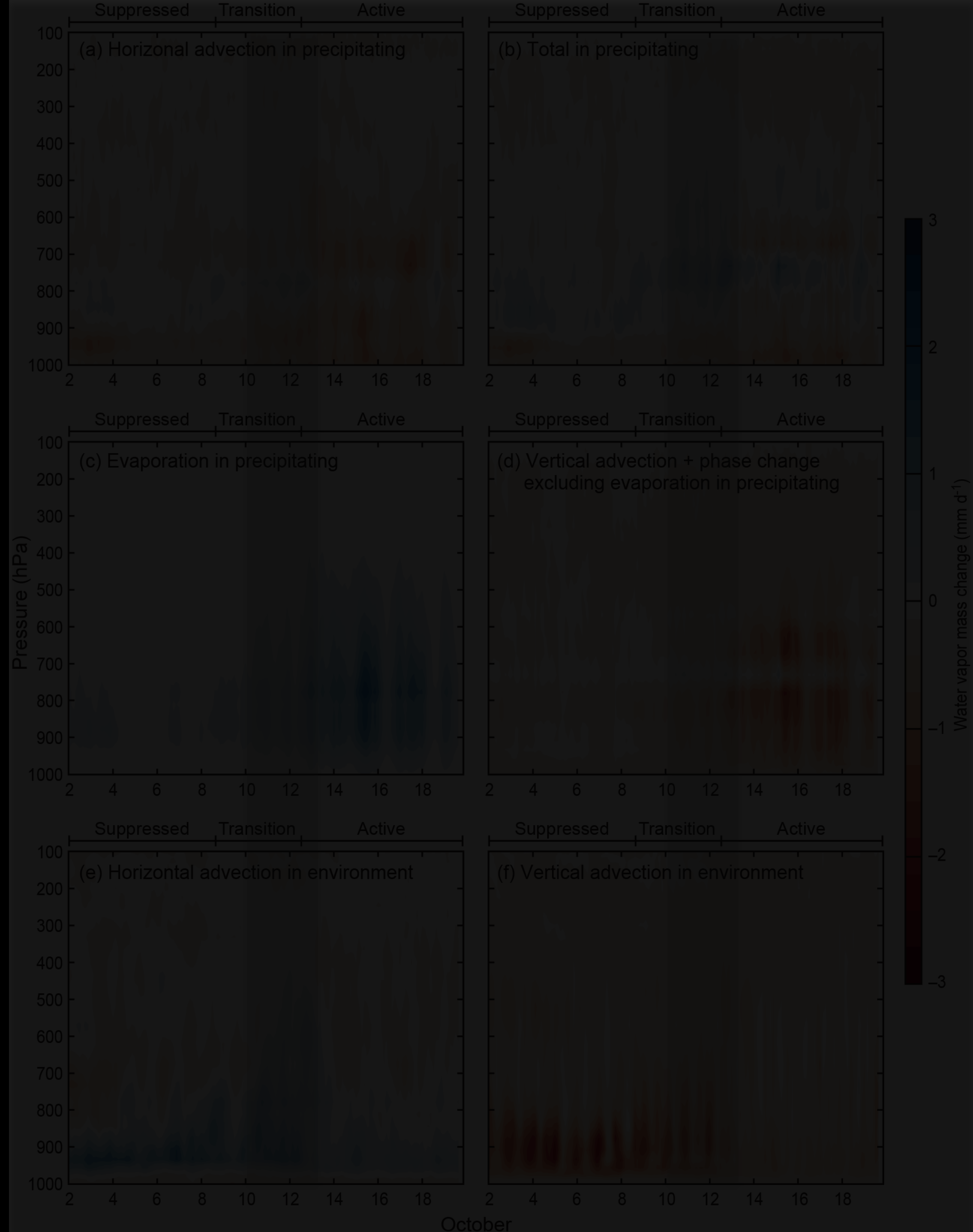
Relative Humidity




Suppressed
Transition
Active
(a)
Pressure (hPa)
200
300
400
500
600
700
800
900
2
4
6
8
10
12
14
16
18
October
Water vapor mass change (mm d^{-1})
3
2
1
0
−1
−2
−3

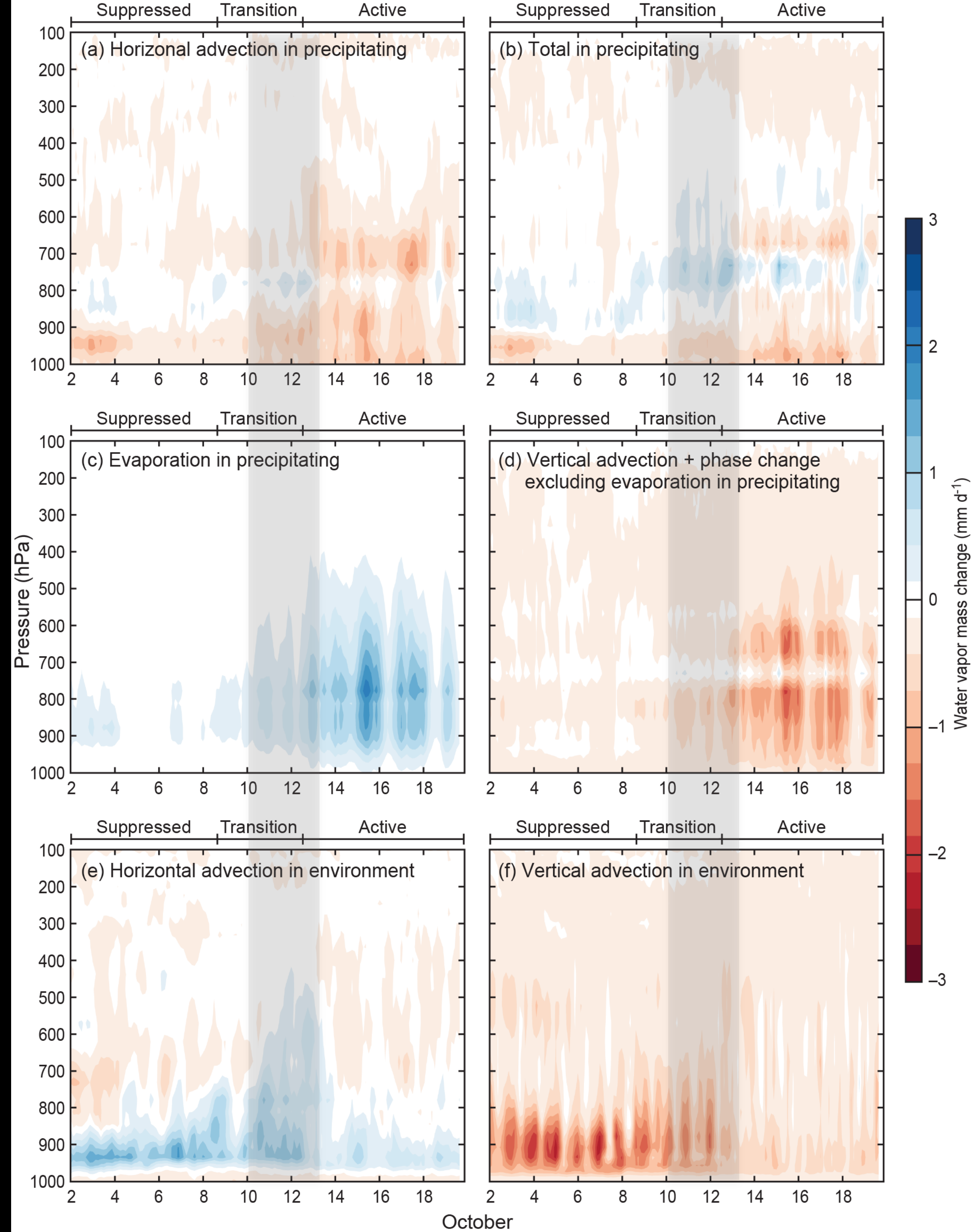
$$\frac{\partial m_{grid}}{\partial t} = -\frac{dP}{g} dx^2 (\mathbf{u} \cdot \nabla q) + M$$

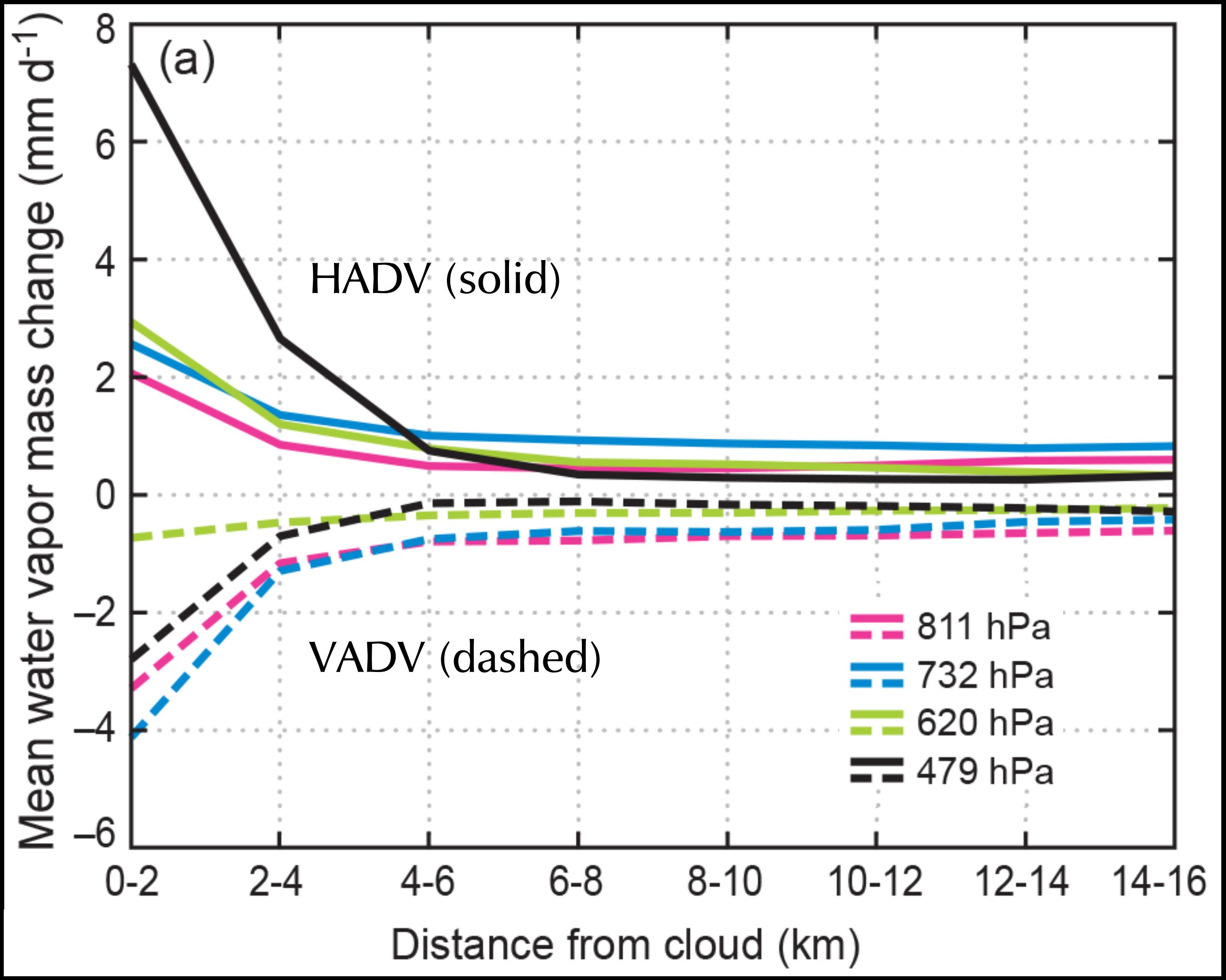
- HADV in precipitating clouds
- VADV in precipitating clouds
- Net phase change in precipitating clouds
- HADV in clear-air environment
- VADV in clear-air environment



$$\frac{\partial m_{grid}}{\partial t} = -\frac{dP}{g} dx^2 (\mathbf{u} \cdot \nabla q) + M$$

- HADV in precipitating clouds
- VADV in precipitating clouds
- Net phase change in precipitating clouds
- HADV in clear-air environment
- VADV in clear-air environment



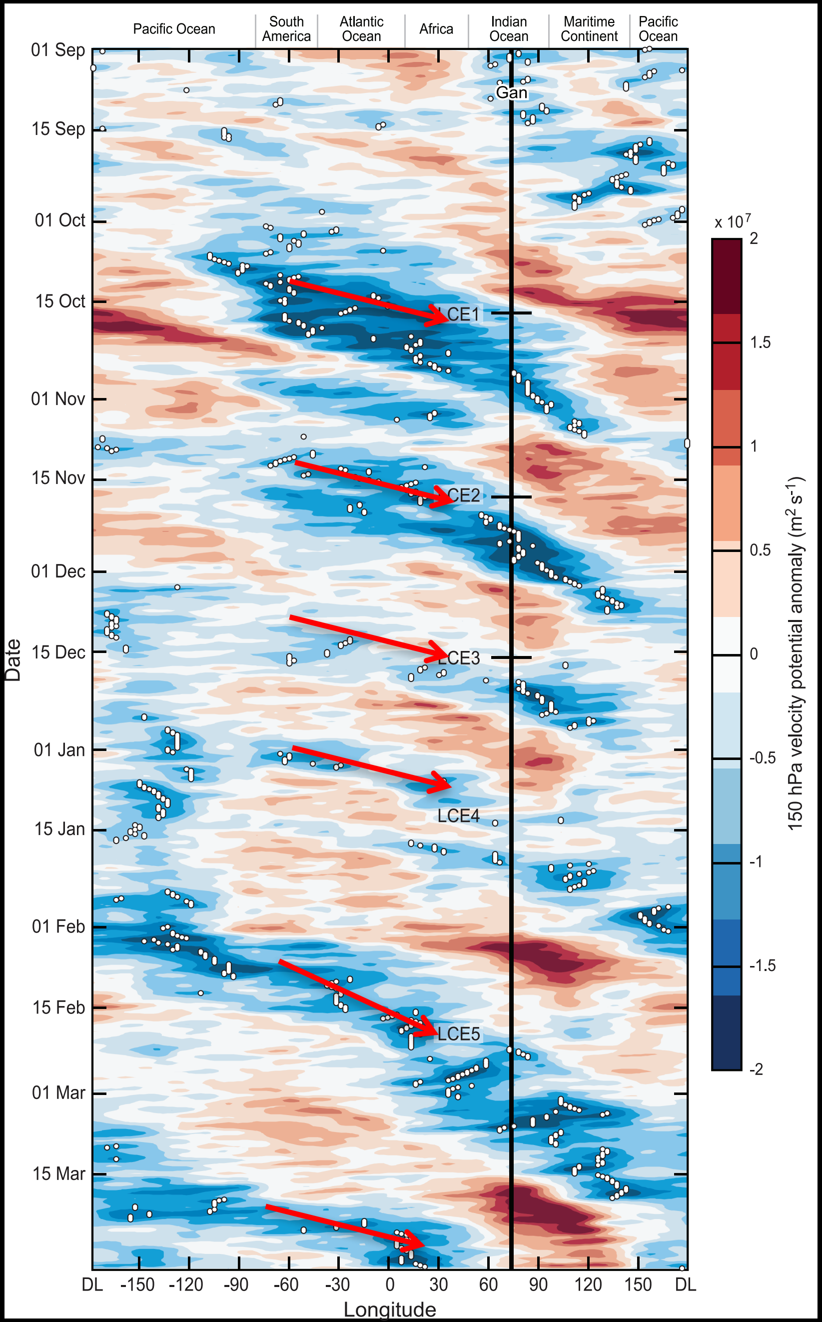


(a)
HADV (solid)
VADV (dashed)
Mean water vapor mass change (mm d^{-1})
8
6
4
2
0
−2
−4
−6
0-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
Distance from cloud (km)
811 hPa
732 hPa
620 hPa
479 hPa

The Circumnavigating Kelvin Wave

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

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



Originally: Knutson and Weickmann (1987)

Figure: Powell and Houze (2015b)

Large-scale vertical velocity anomalies are in phase with velocity potential anomalies.

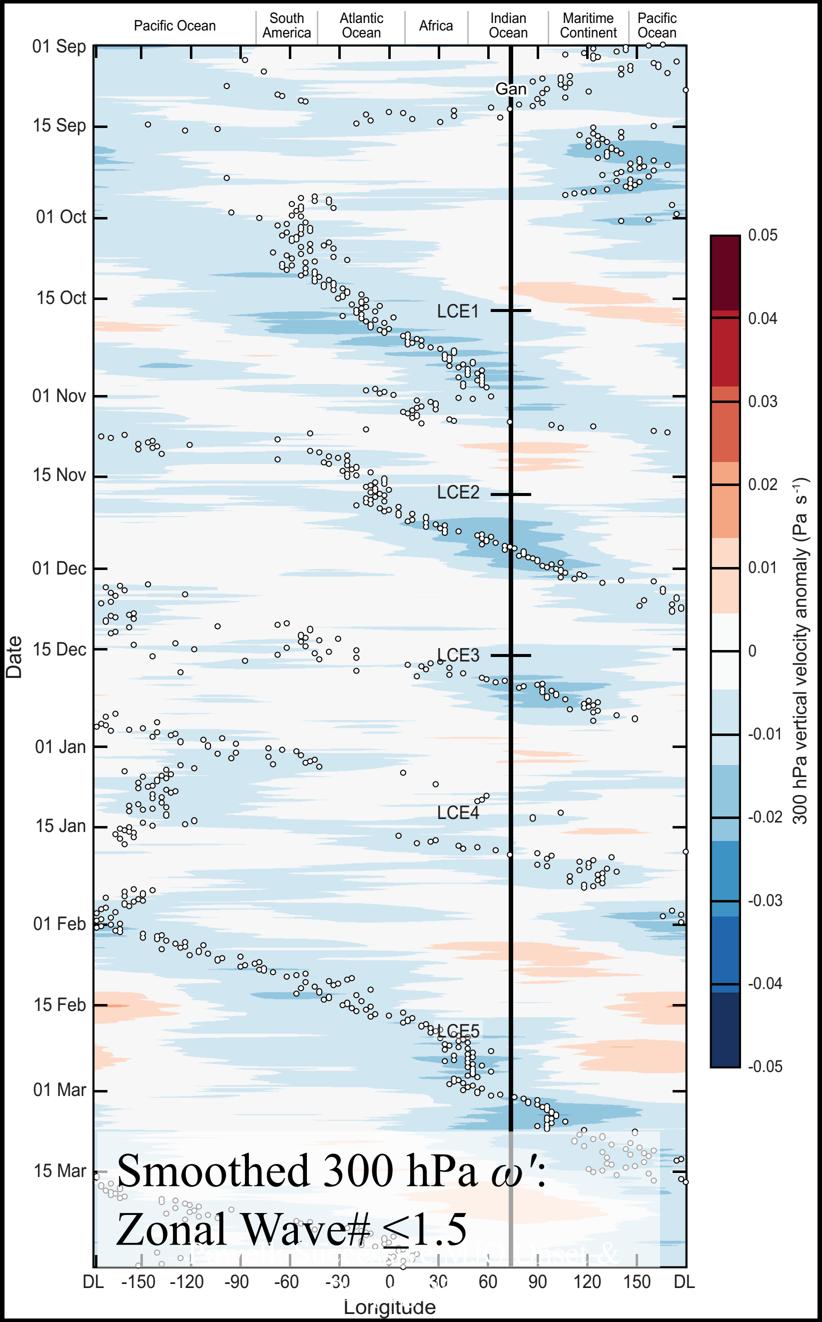
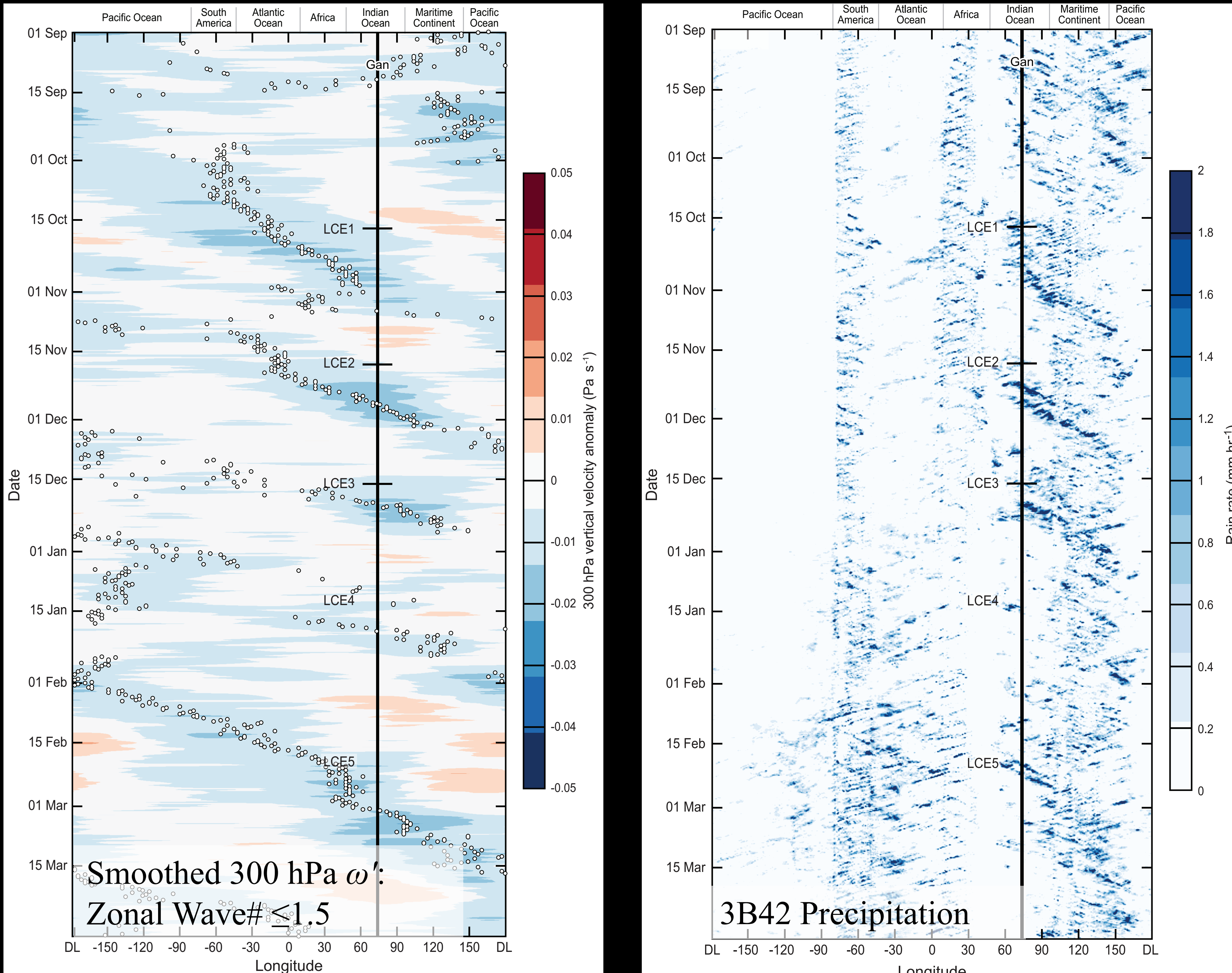
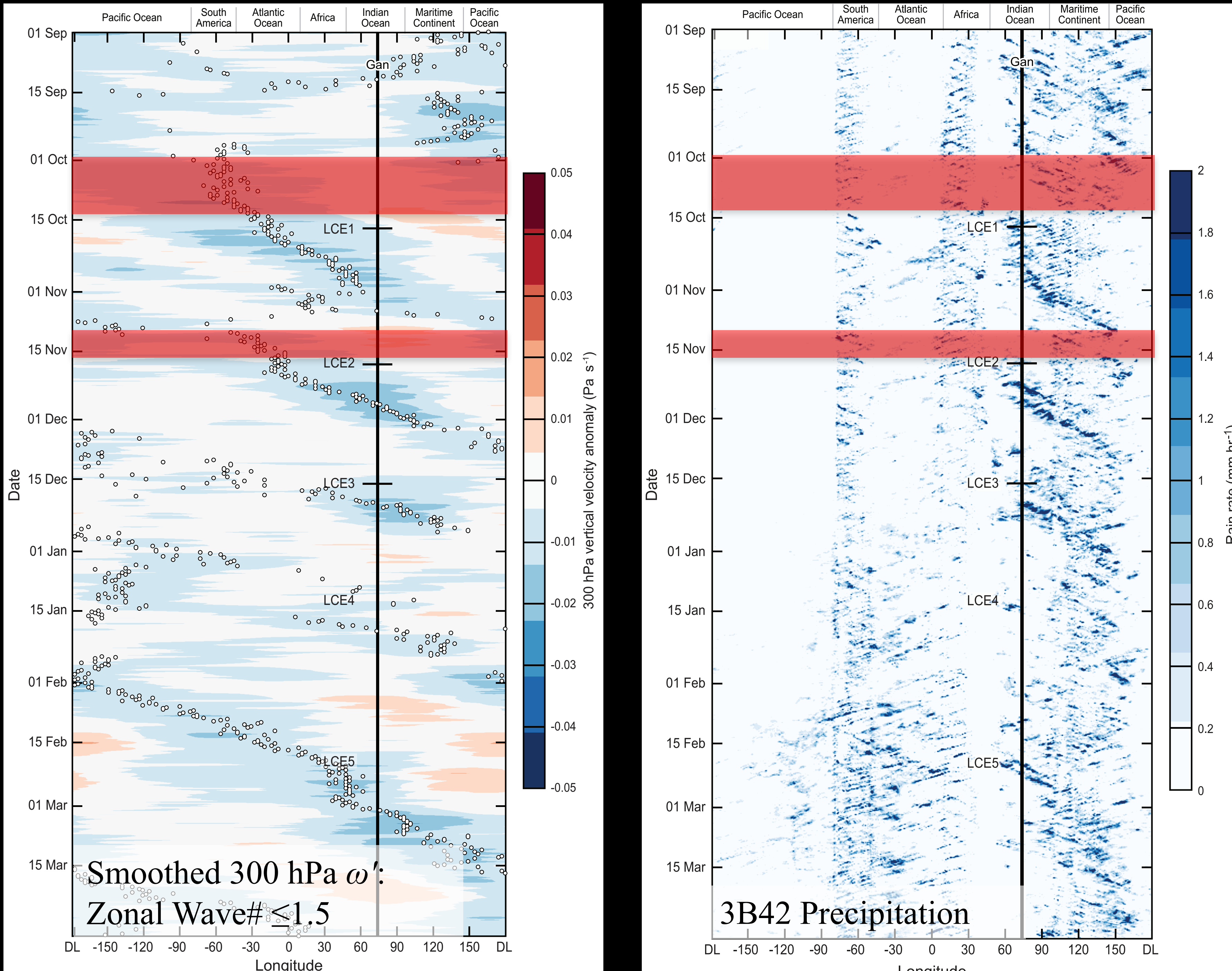


Figure: Powell and Houze (2015b)

27 February 2017



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
Smoothed 300 hPa ω′:
Zonal Wave# ≤1.5
DL -150 -120 -90 -60 -30 0 30 60 90 120 150 DL
Longitude
300 hPa vertical velocity anomaly (Pa s-1)
0.05 0.04 0.03 0.02 0.01 0 -0.01 -0.02 -0.03 -0.04 -0.05
3B42 Precipitation
Rain rate (mm hr-1)
2 1.8 1.6 1.4 1.2 1 0.8 0.6 0.4 0.2 0



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Rain rate (mm hr-1)
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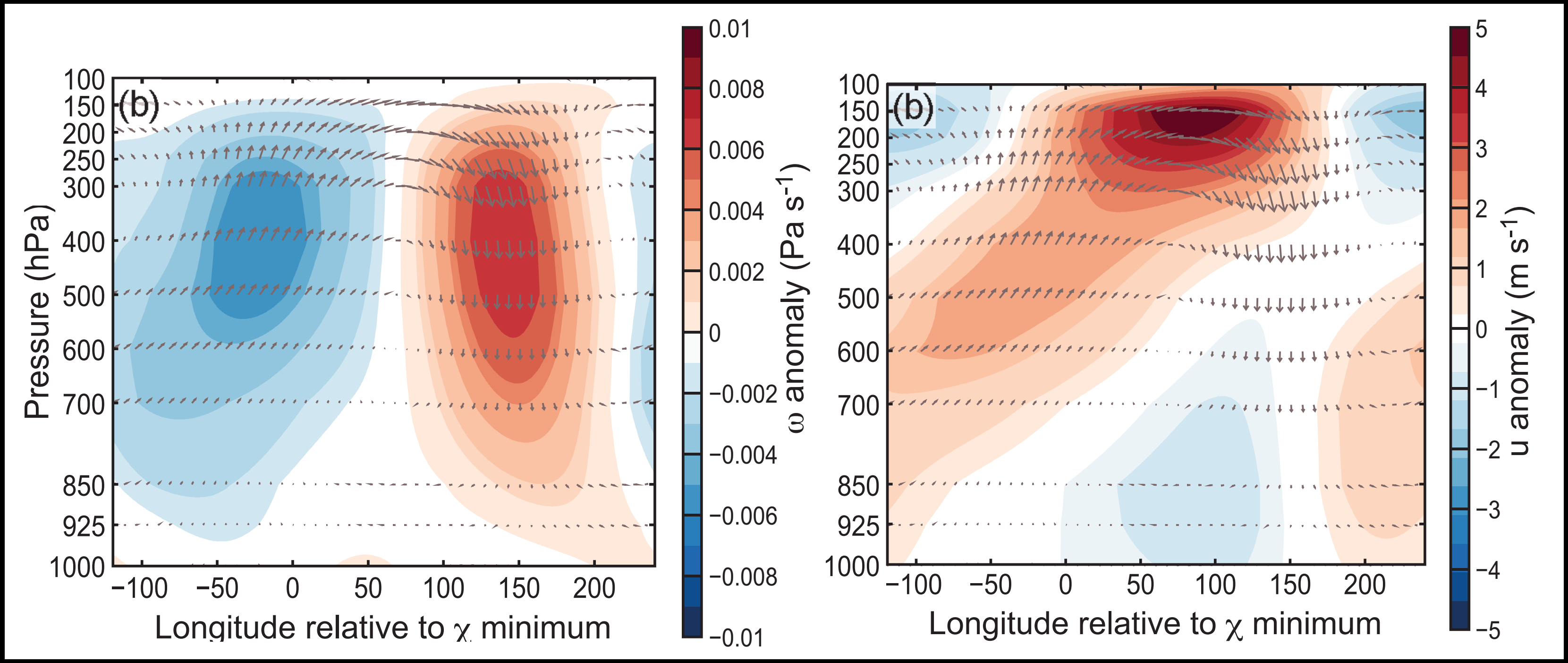
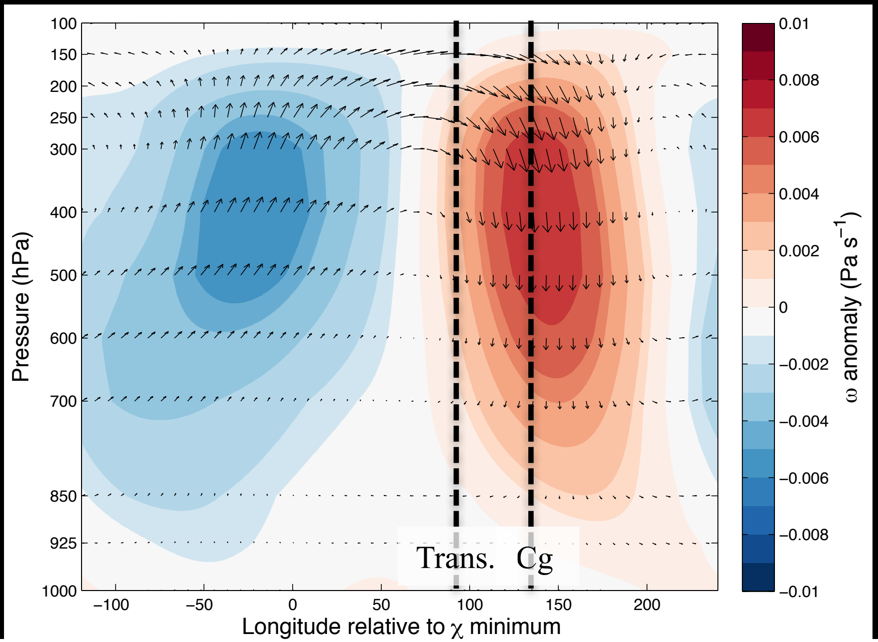
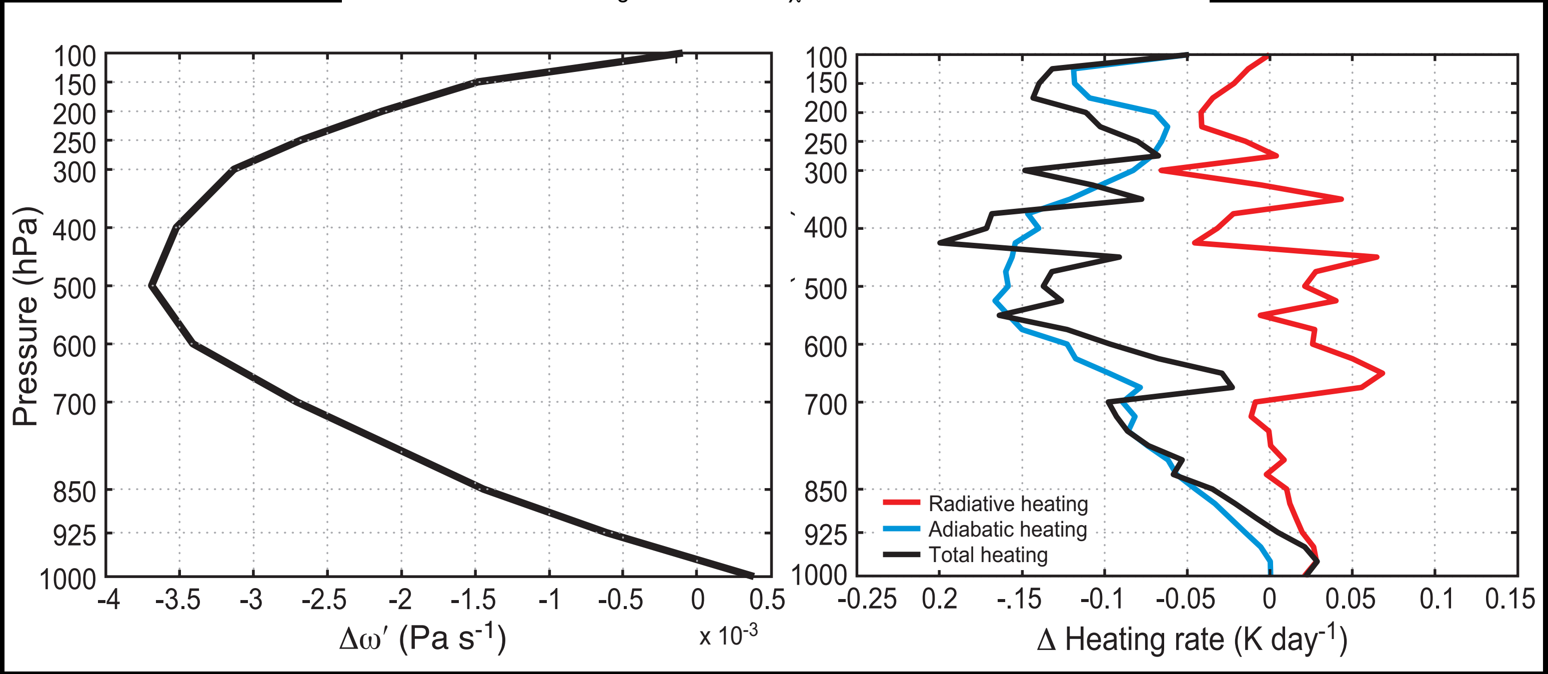
ω' u'



Wave # ≤ 1.5

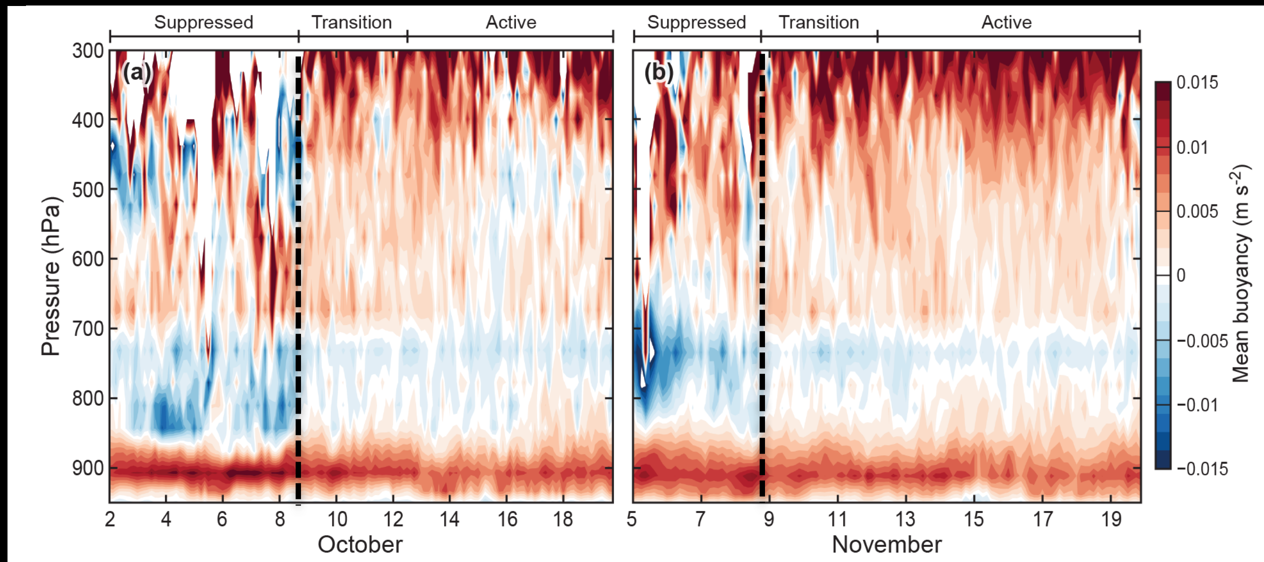


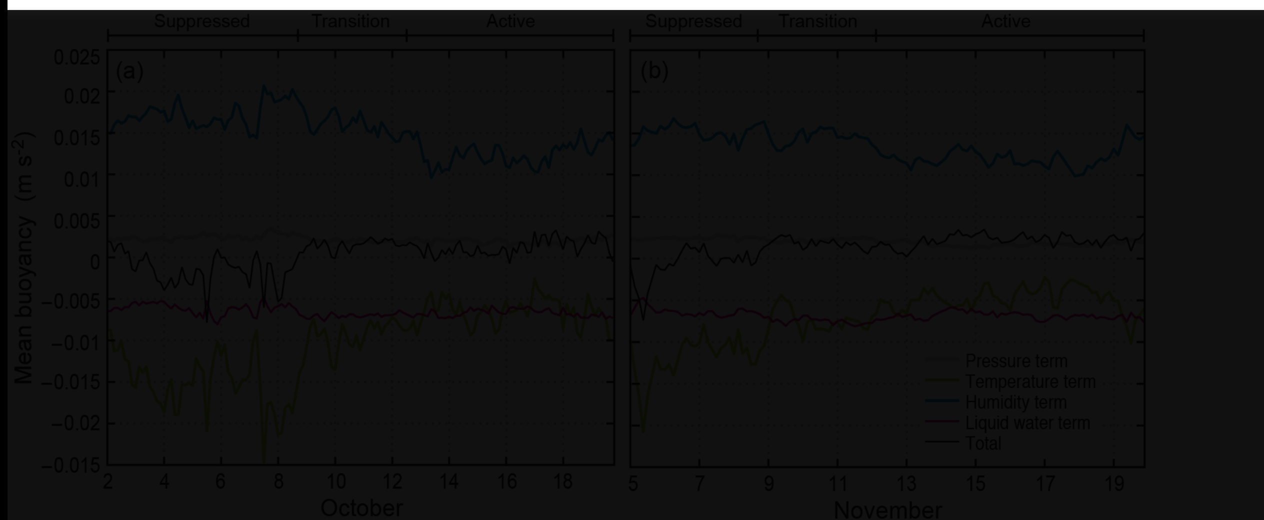
Pressure (hPa)
Longitude relative to χ minimum
Trans.
Cg
ω anomaly (Pa s^{-1})



Pressure (hPa)
Δω′ (Pa s^{-1})
x 10^{-3}
Radiative heating
Adiabatic heating
Total heating
Δ Heating rate (K day^{-1})

Updraft buoyancy for convective echoes with $w \geq 0.3$ m s^{-1}

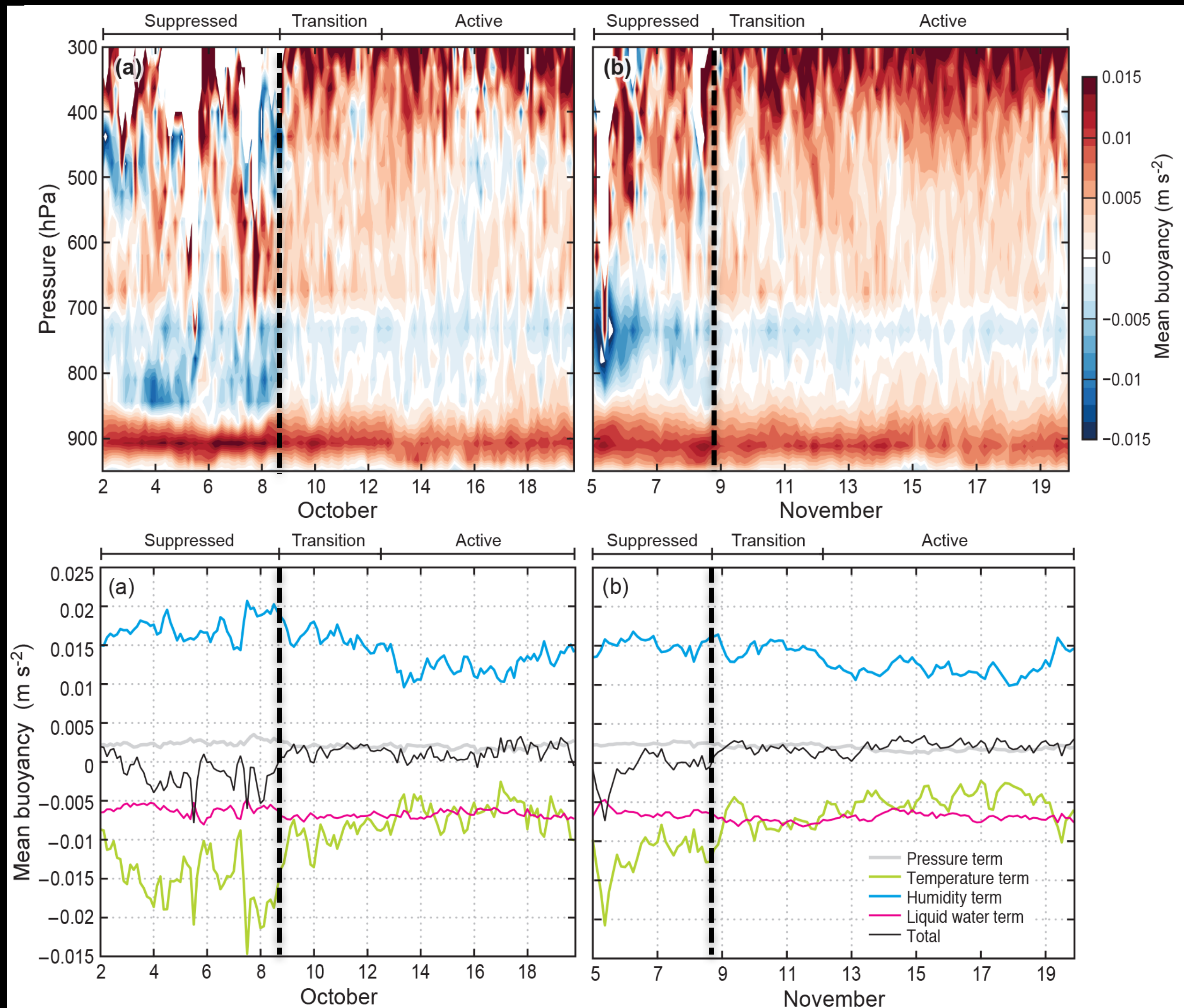




$$B \approx g\left(\underbrace{\frac{T^*}{T_e}}_{Temperature} - \overbrace{\frac{p^*}{p_e}}^{Pressure} + \underbrace{0.608\left(w^*\right)}_{Vapor} - \overbrace{w_H}^{Hydrometeor}\right)$$

Green Gray Blue Red

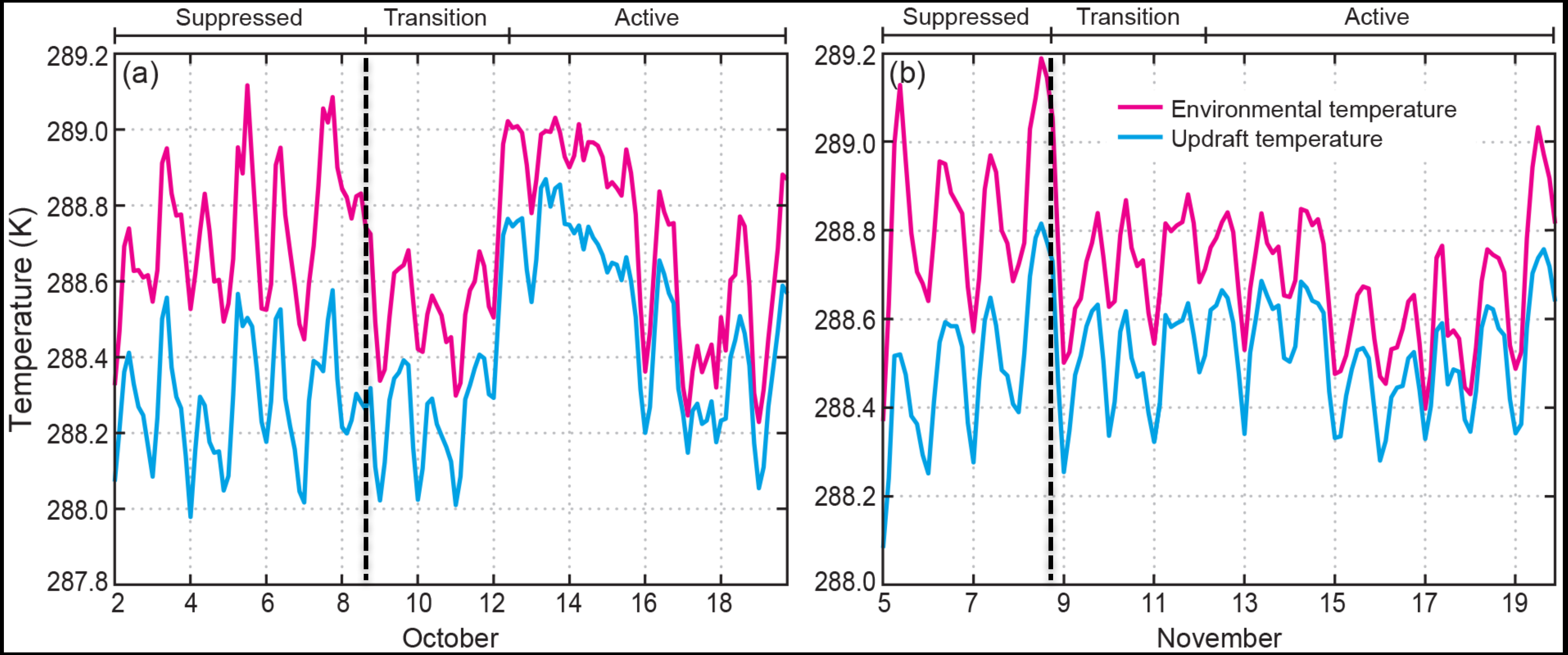
Individual terms in buoyancy equation: Mean in 700–850 mb layer



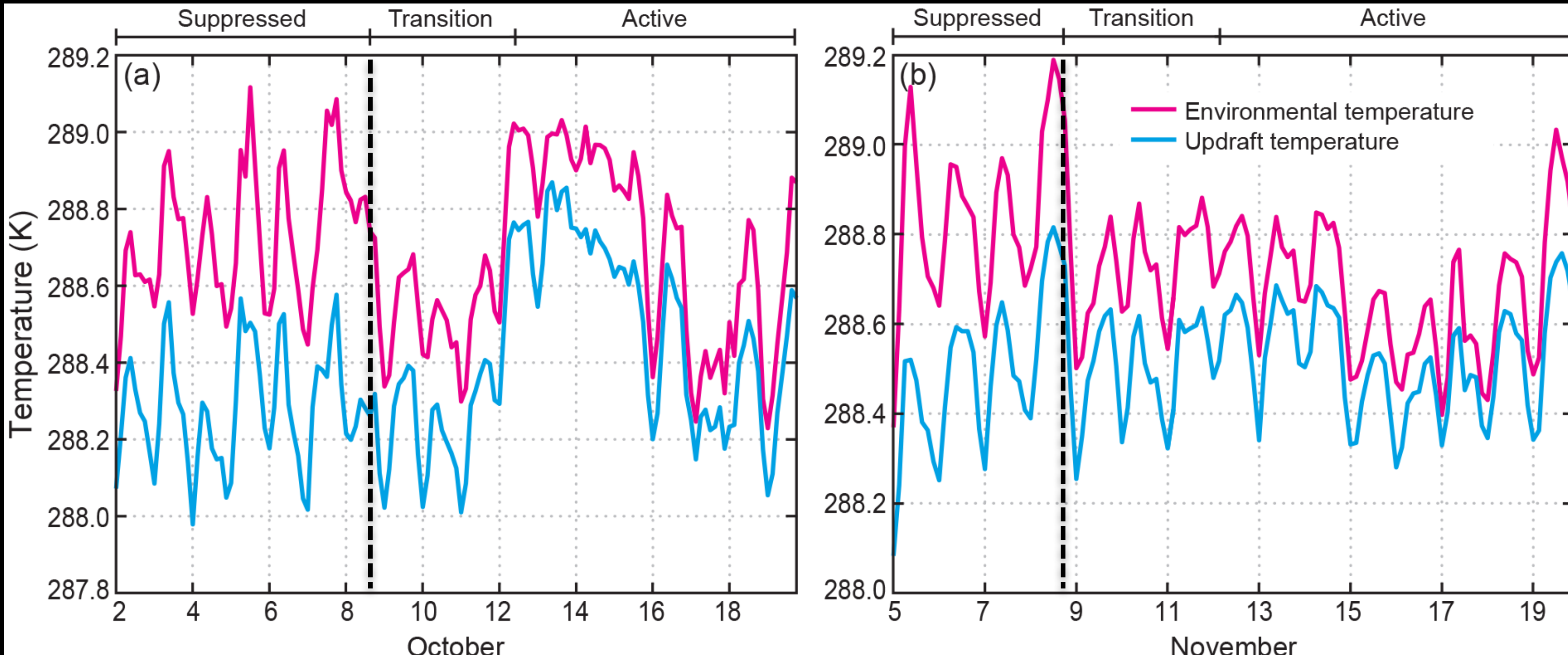
$$B \approx g\left(\underbrace{\frac{T^*}{T_e}}_{Temperature} - \overbrace{\frac{p^*}{p_e}}^{Pressure} + \underbrace{0.608\left(w^*\right)}_{Vapor} - \overbrace{w_H}^{Hydrometeor}\right)$$

Green Gray Blue Red

Mean 700–850 mb temperature

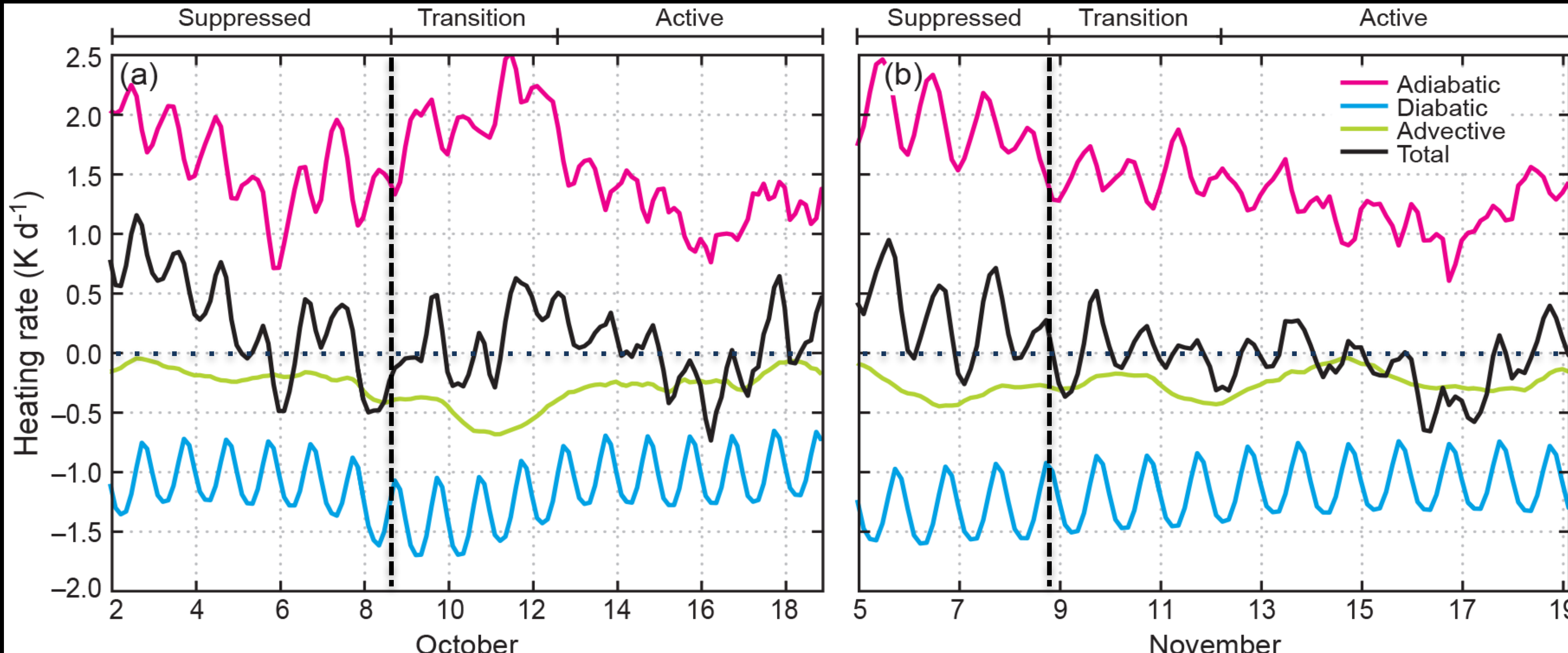


Mean 700–850 mb temperature



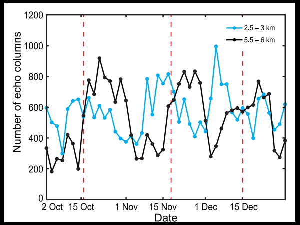
Changes in environmental temperature at start of transition periods are less than 1K!

Temperature tendency at 700–850 hPa in clear-air

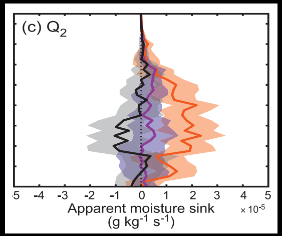


$$\frac{\partial T}{\partial t} = \underbrace{-\mathbf{u}_{\mathrm{h}} \cdot \nabla T}_{advective} \overbrace{- w\left(\frac{g}{c_p} + \Gamma\right)}^{adiabatic} + \underbrace{\frac{J}{c_p}}_{diabatic}$$

Conclusions

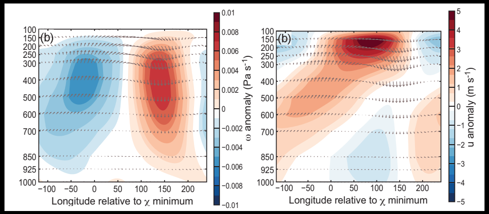


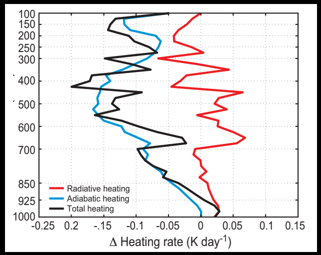
• 3–7 day build up in cloud population during transition periods prior to MJO convective onset.



• During transition periods, moderately deep clouds moisten environment via evaporation, making environment conducive to deeper convection.

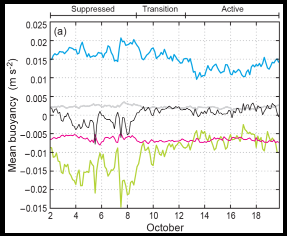
• Circumnavigating wave has impacts on low-wavenumber ω anomalies of O(0.01 Pa s^{-1}).





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

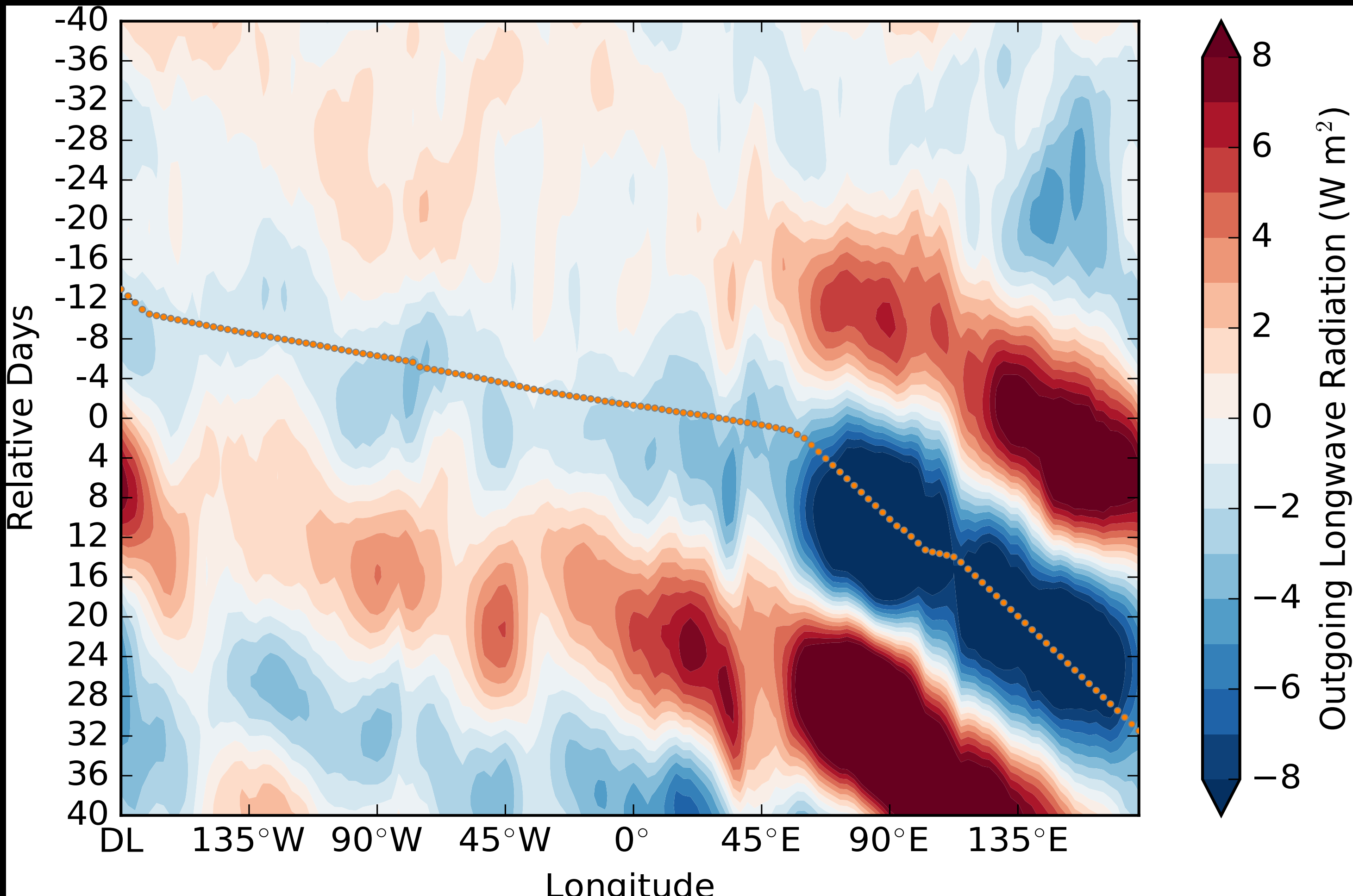
• Small changes in environmental temperature dramatically alter mean buoyancy of cloud updrafts in 700–850 hPa layer.




End

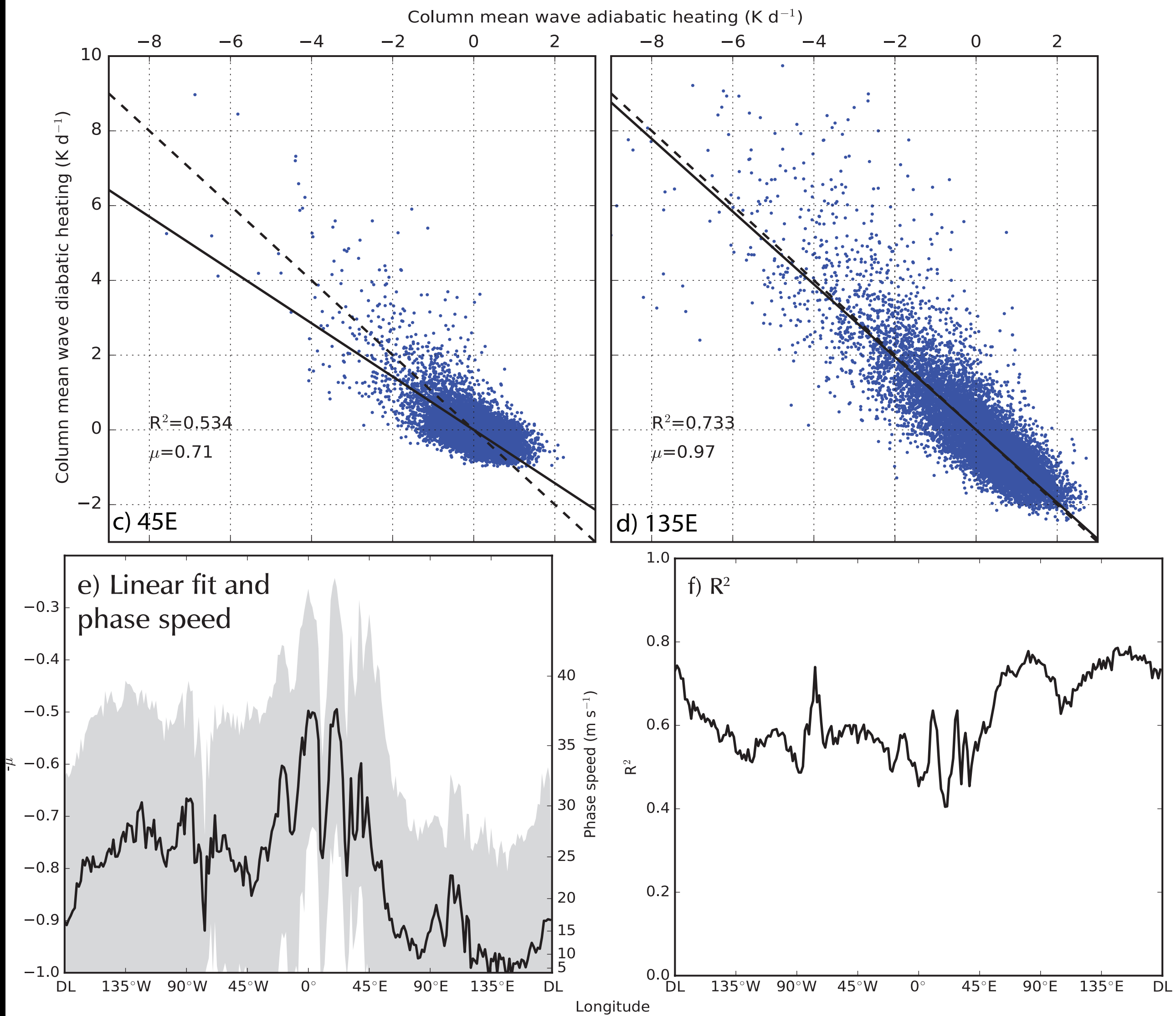
Extra Slides

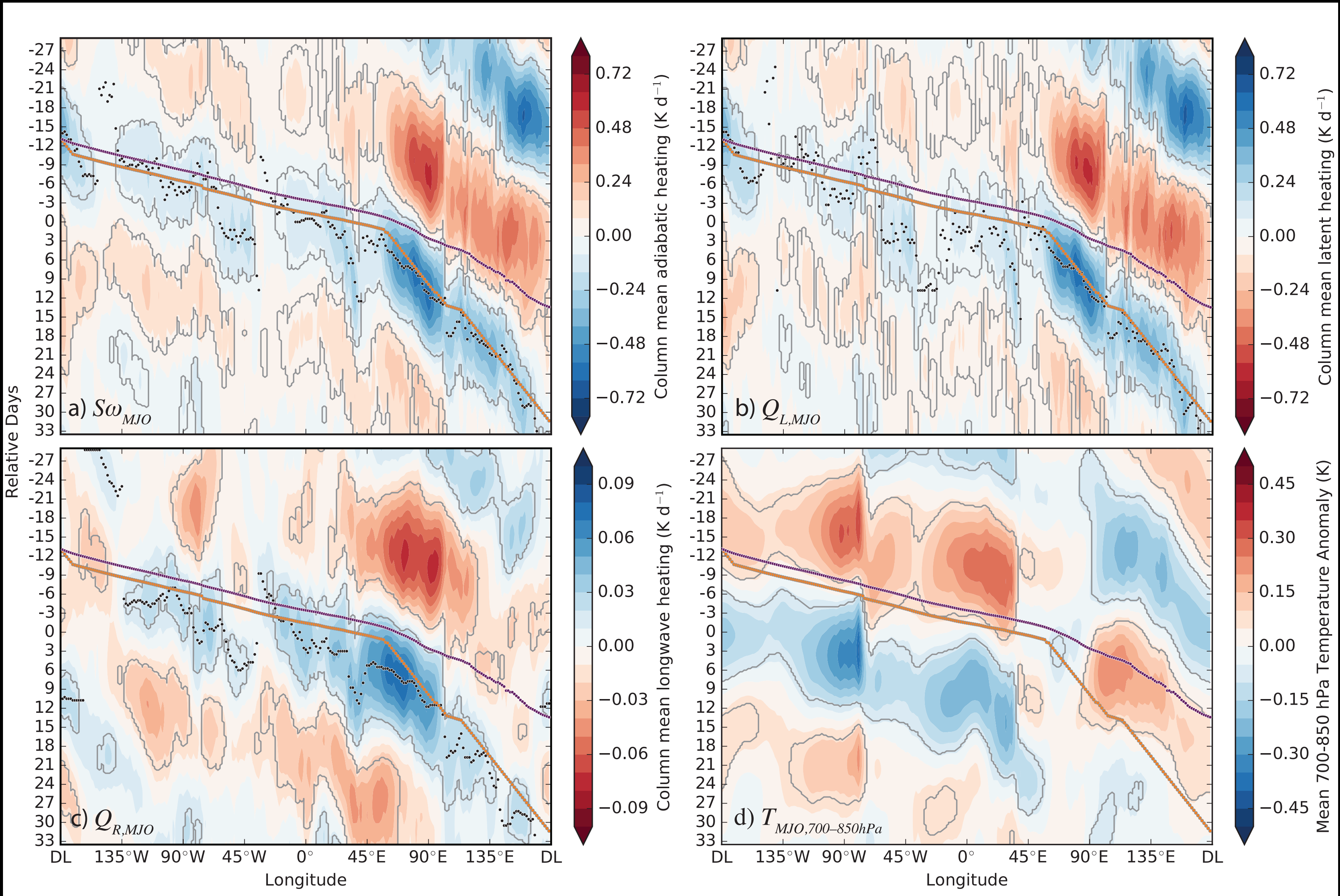
OLR anomalies during successive MJO events



Powell (2017)

$$\frac{\partial T}{\partial t} - S\omega = Q, Q \approx -\mu S\omega, c = \sqrt{(1-\mu)gh_e}$$





a) $S\omega_{MJO}$
b) $Q_{L,MJO}$
c) $Q_{R,MJO}$
d) $T_{MJO,700–850hPa}$
Relative Days
Longitude
DL 135°W 90°W 45°W 0° 45°E 90°E 135°E DL
Column mean adiabatic heating (K d^{-1})
Column mean latent heating (K d^{-1})
Column mean longwave heating (K d^{-1})
Mean 700-850 hPa Temperature Anomaly (K)