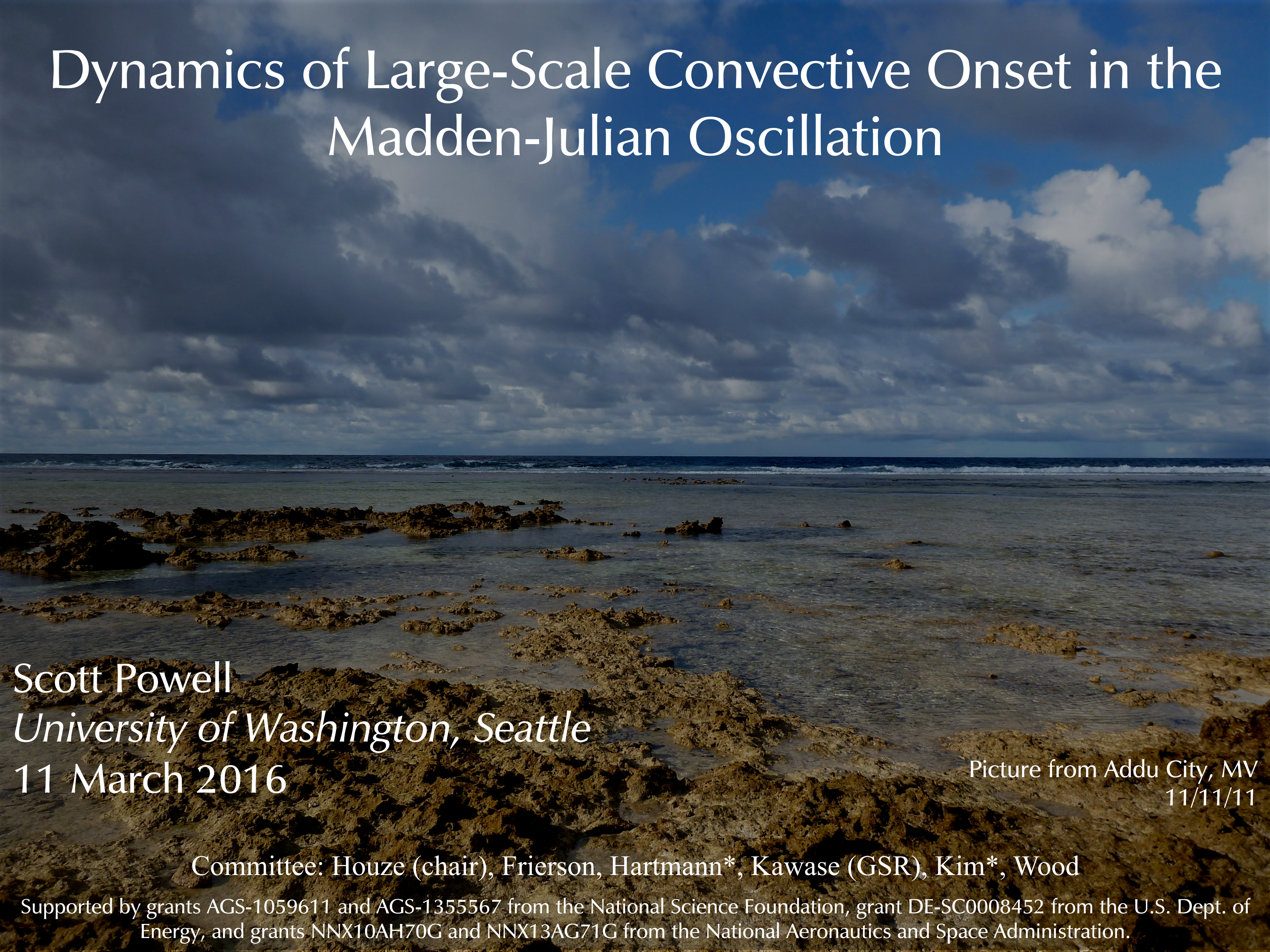
Dynamics of Large-Scale Convective Onset in the Madden-Julian Oscillation

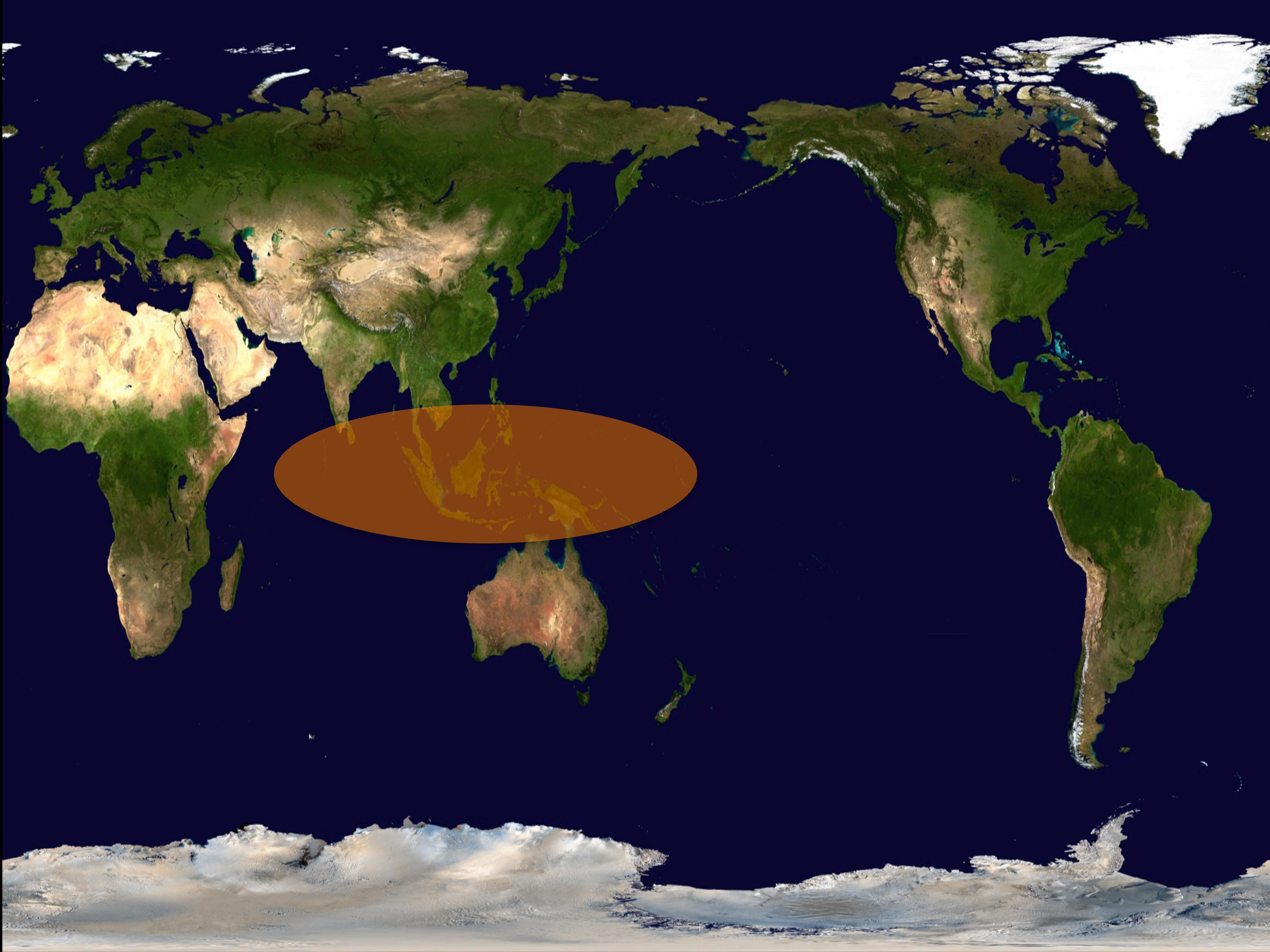


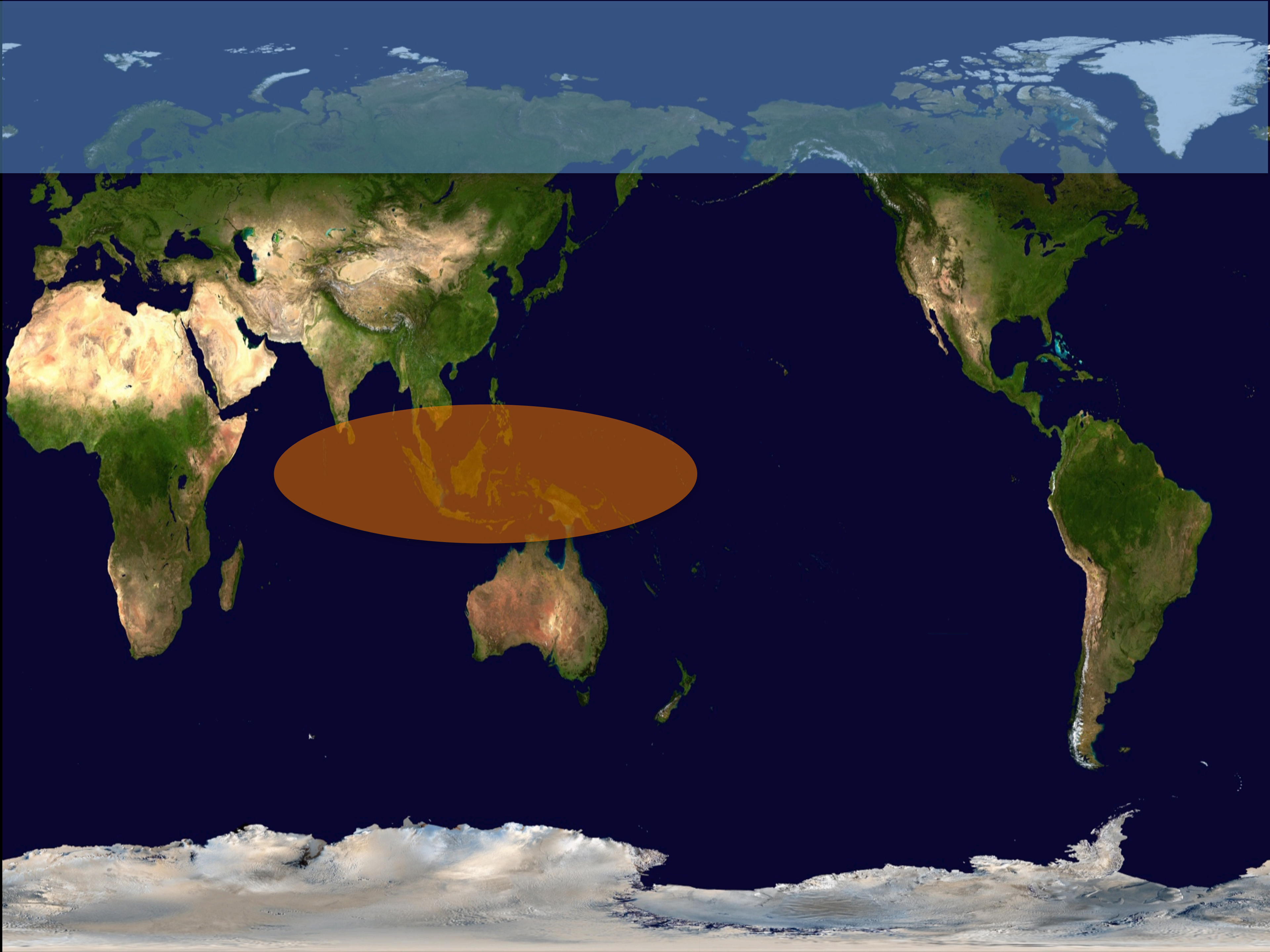
Scott Powell
University of Washington, Seattle
11 March 2016

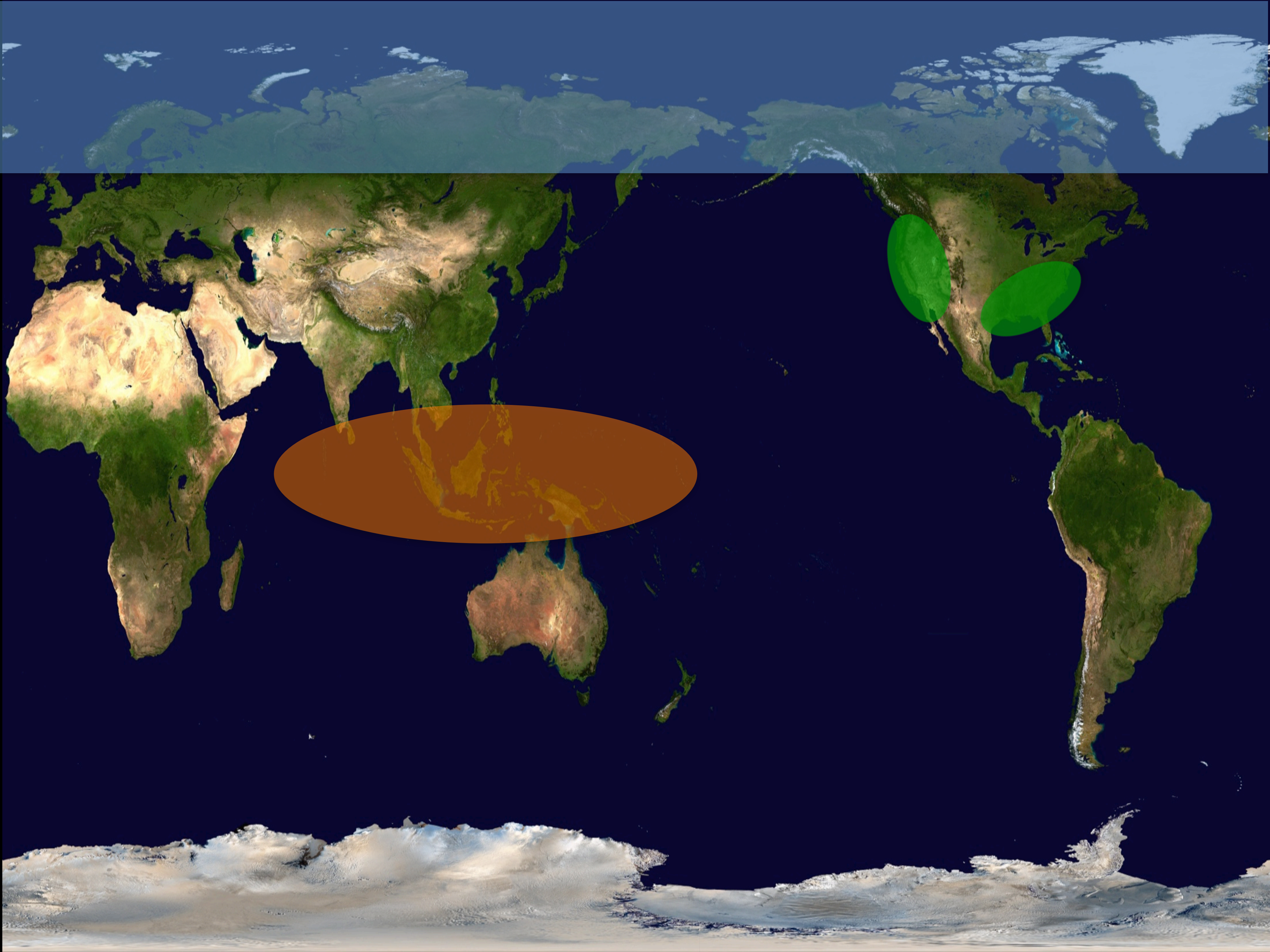
Picture from Addu City, MV
11/11/11

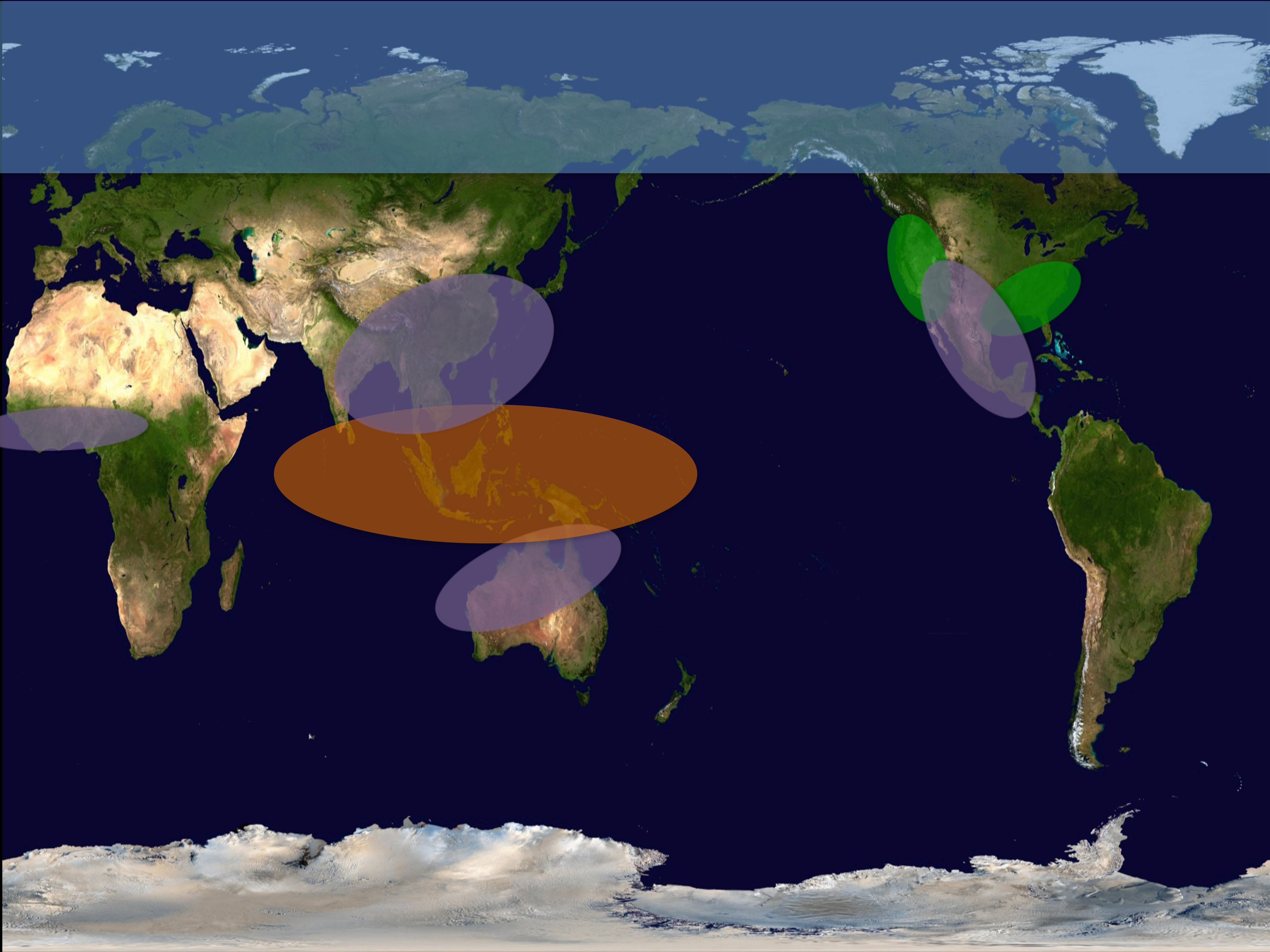
Committee: Houze (chair), Frierson, Hartmann*, Kawase (GSR), Kim*, Wood

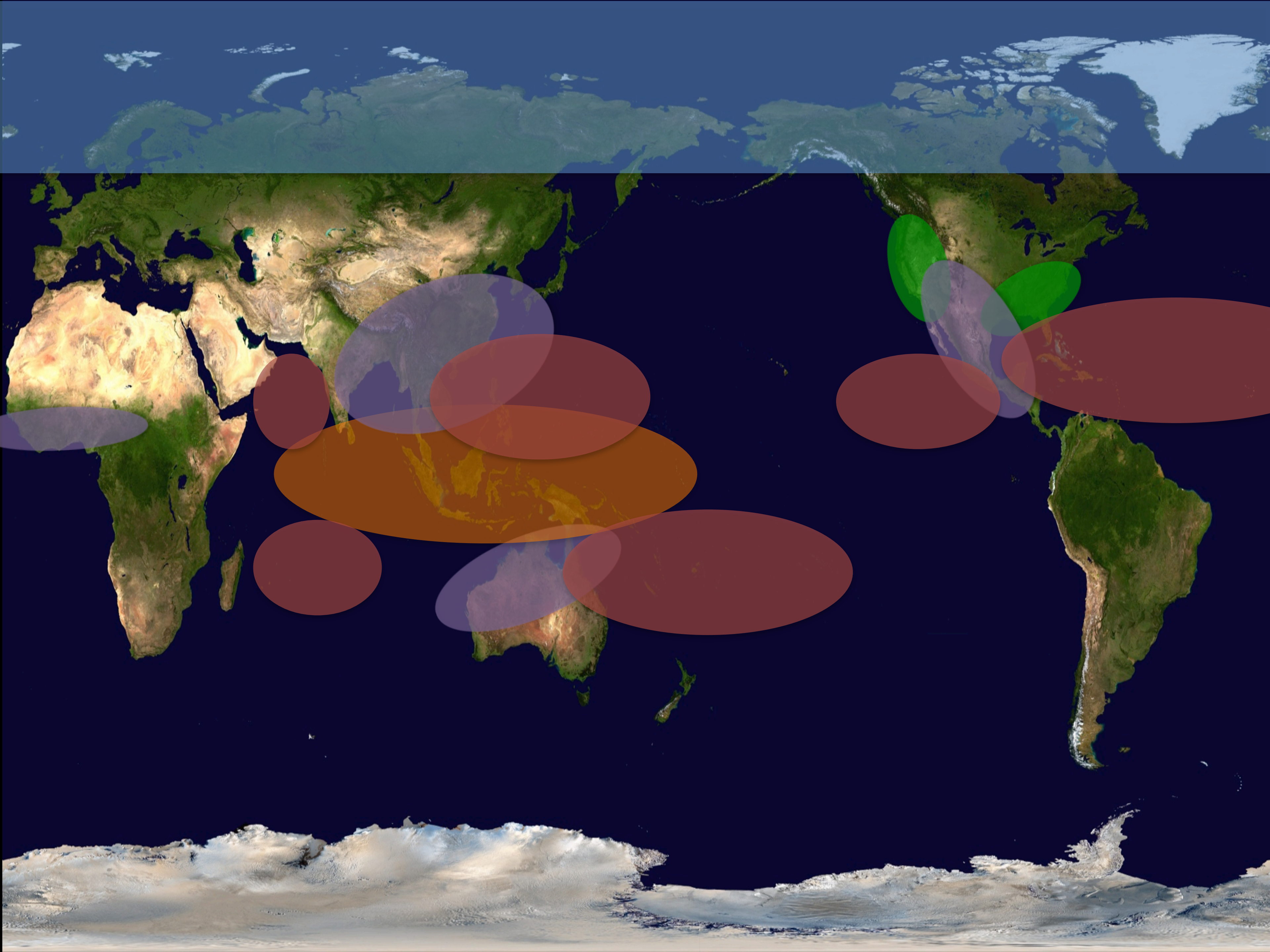
Supported by grants AGS-1059611 and AGS-1355567 from the National Science Foundation, grant DE-SC0008452 from the U.S. Dept. of Energy, and grants NNX10AH70G and NNX13AG71G from the National Aeronautics and Space Administration.

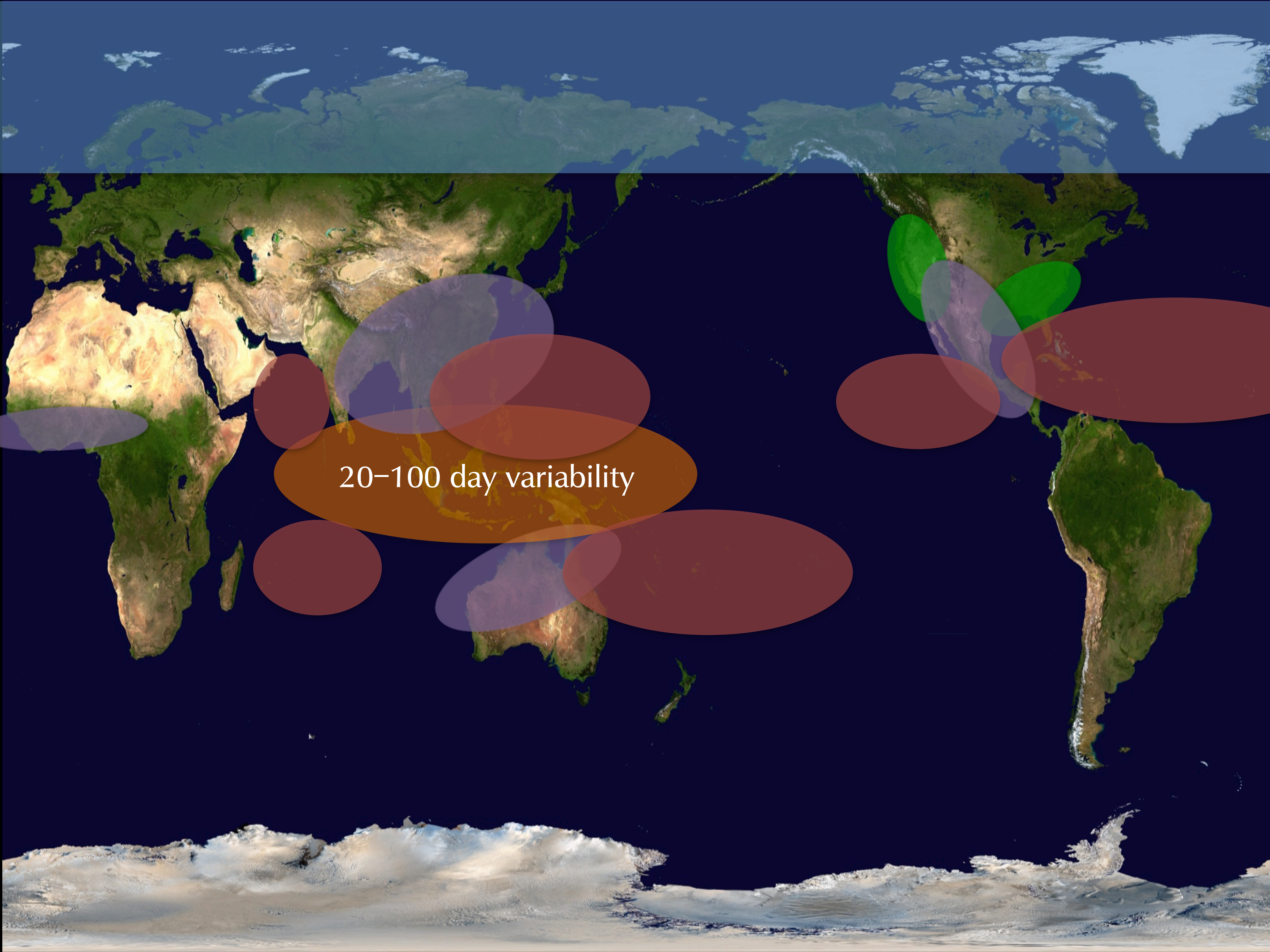




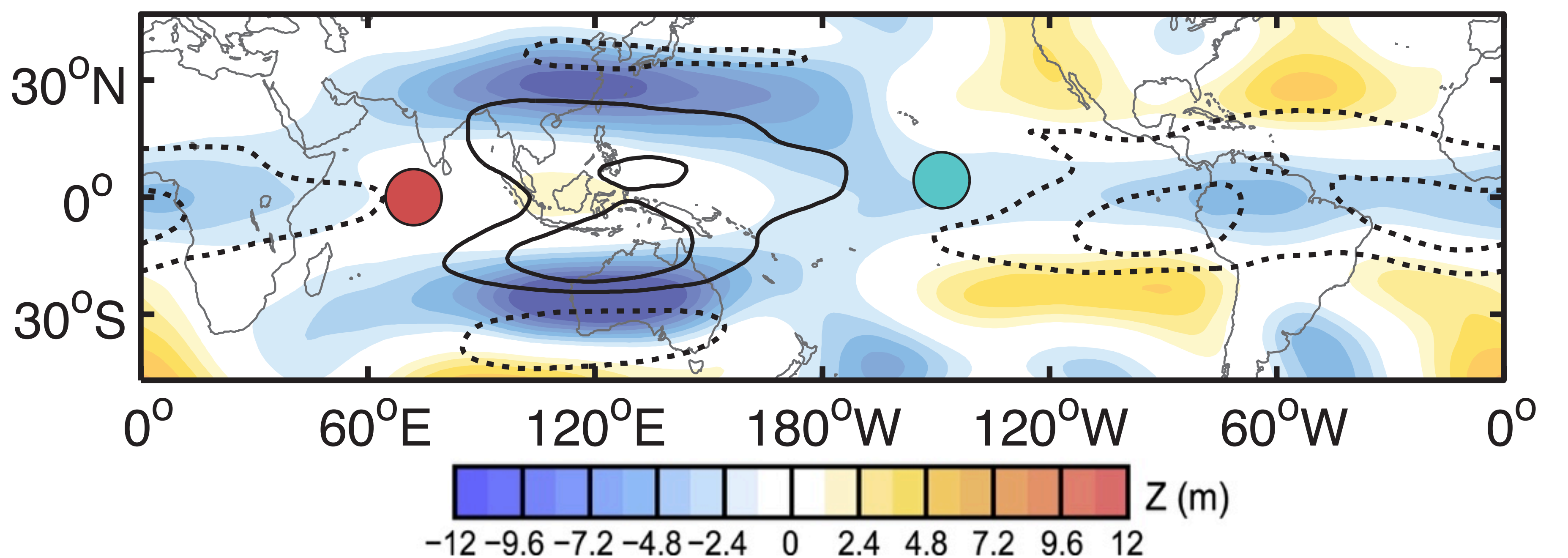


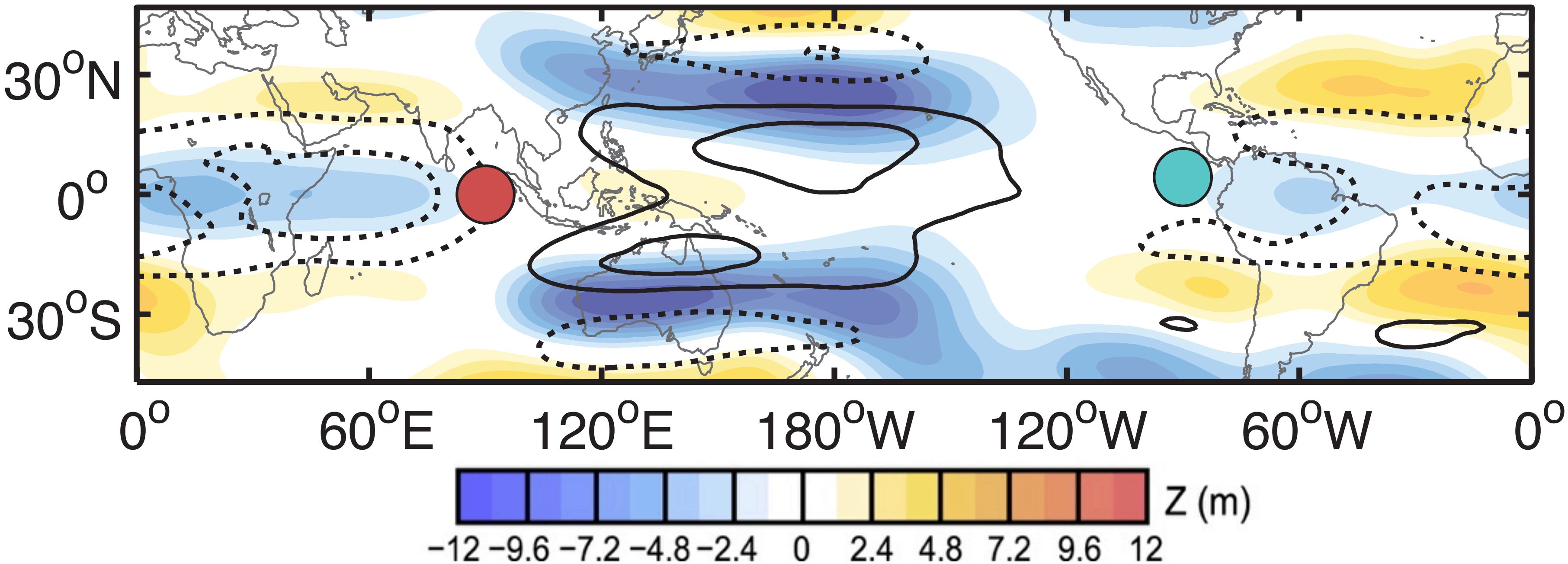


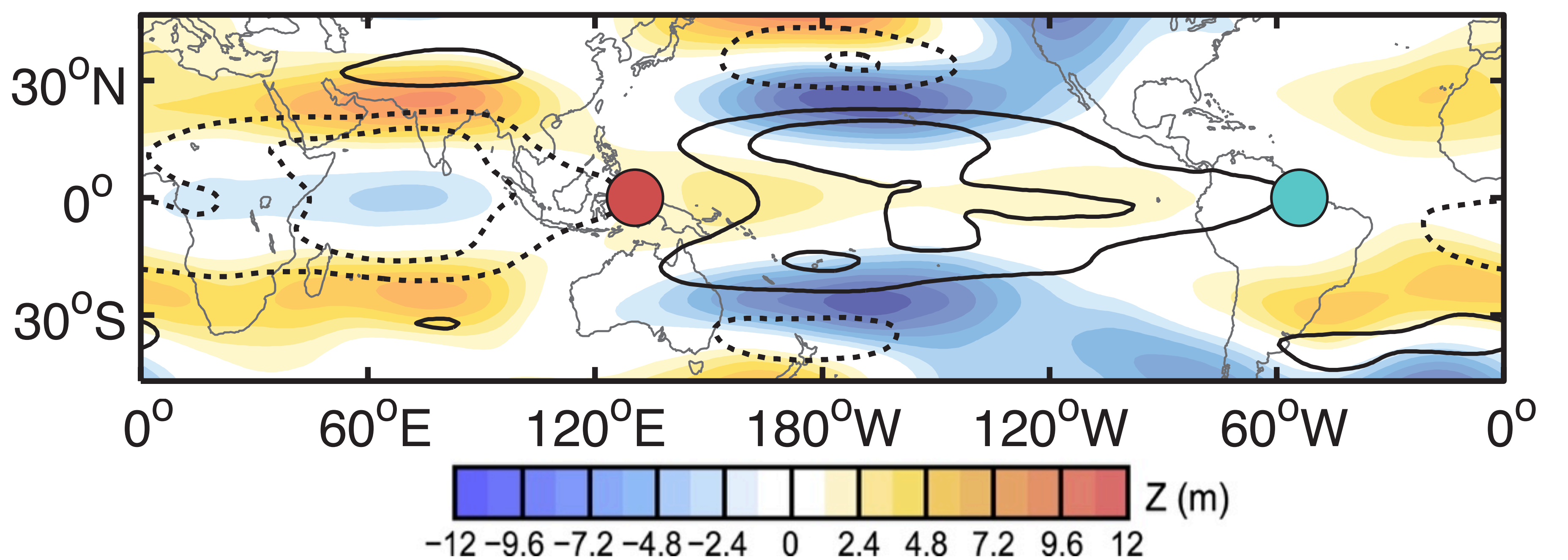


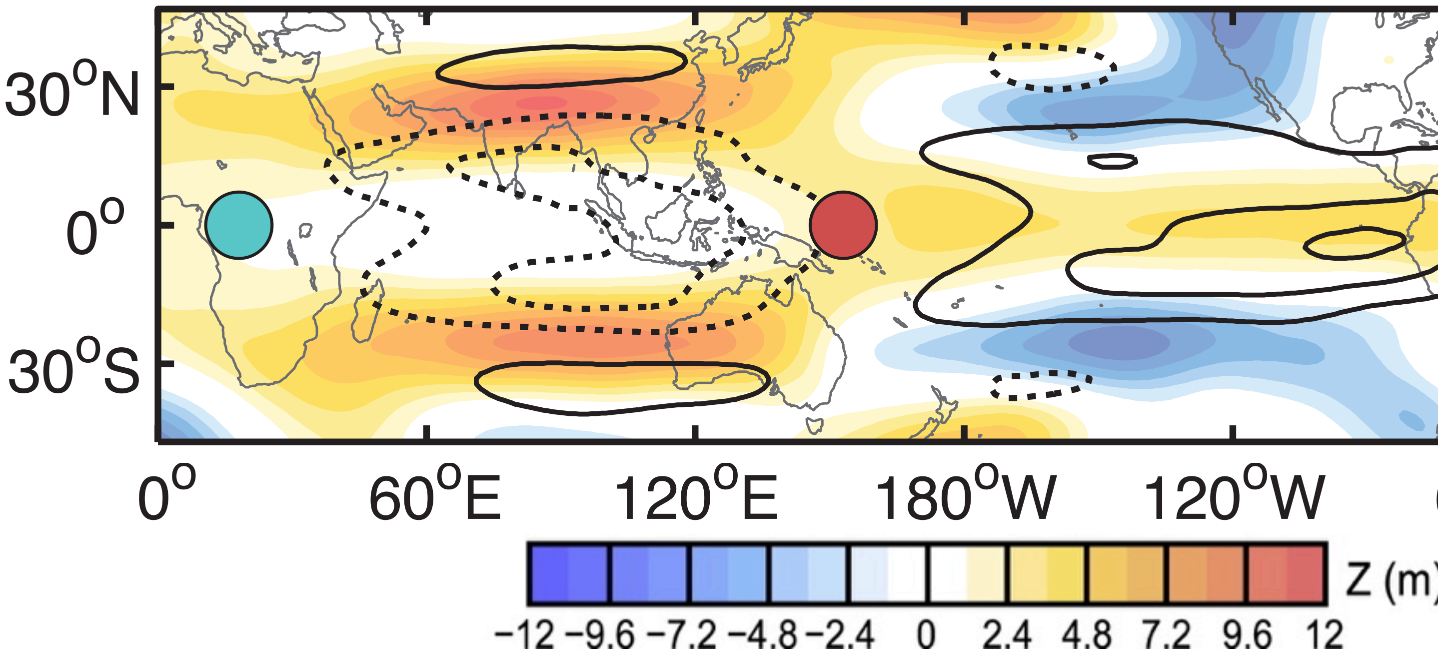

20–100 day variability

Adames and Wallace (2014)



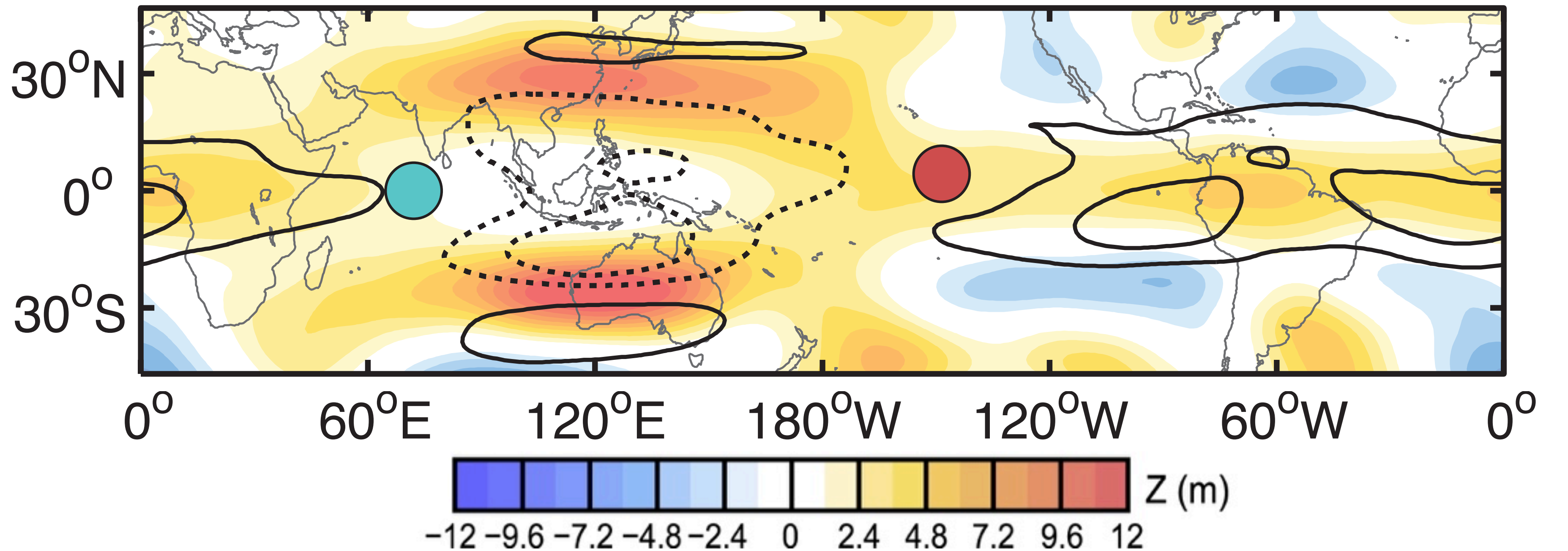

30°N
0°
30°S
0°
60°E
120°E
180°W
120°W
60°W
0°
Z (m)
−12 −9.6 −7.2 −4.8 −2.4 0 2.4 4.8 7.2 9.6 12


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

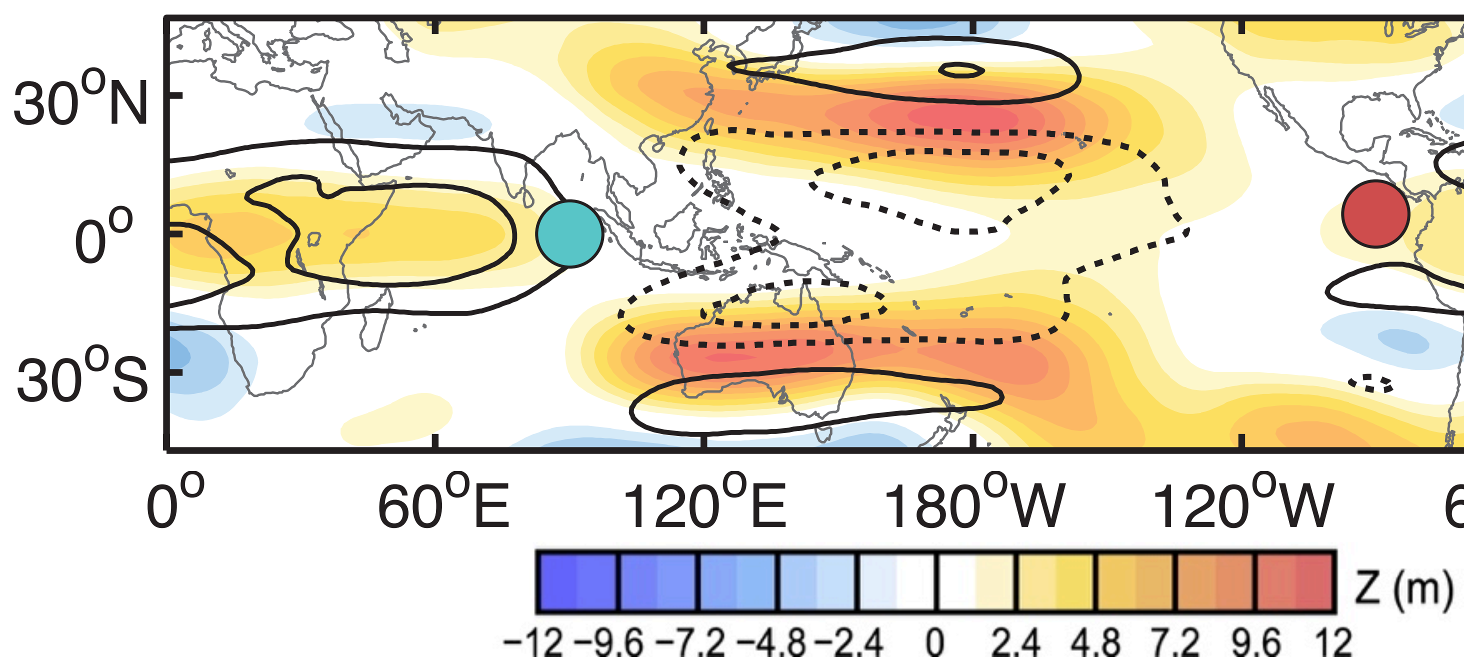


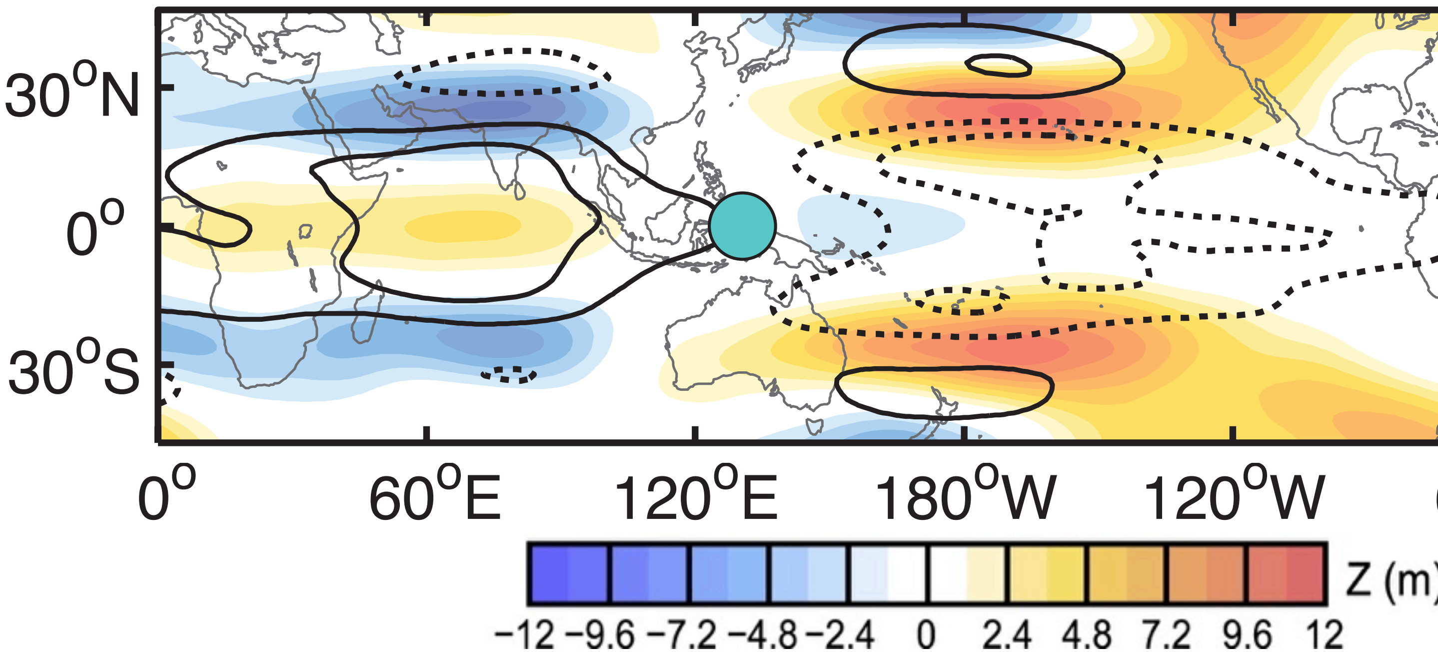
30^{o}N
0^o
30^{o}S
0^o
60^{o}E
120^{o}E
180^{o}W
120^{o}W
60^{o}W
0^o
Z (m)
−12 −9.6 −7.2 −4.8 −2.4 0 2.4 4.8 7.2 9.6 12

Adames and Wallace (2014)

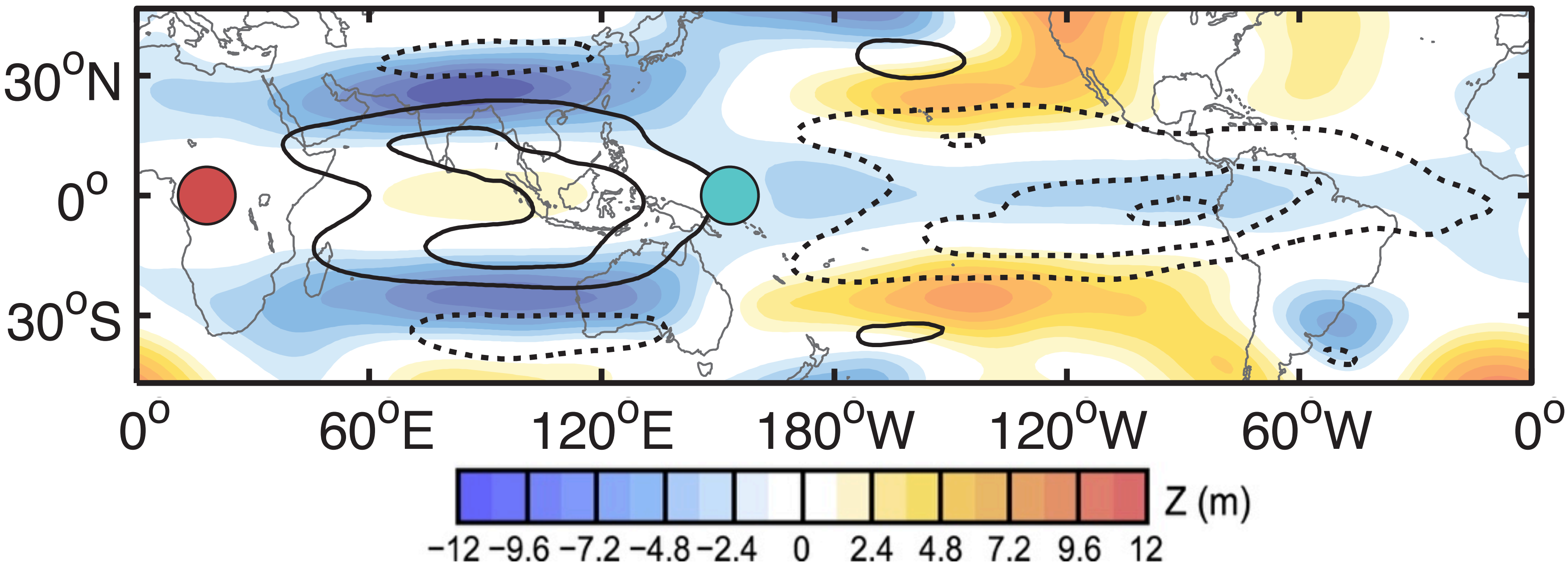


Adames and Wallace (2014)

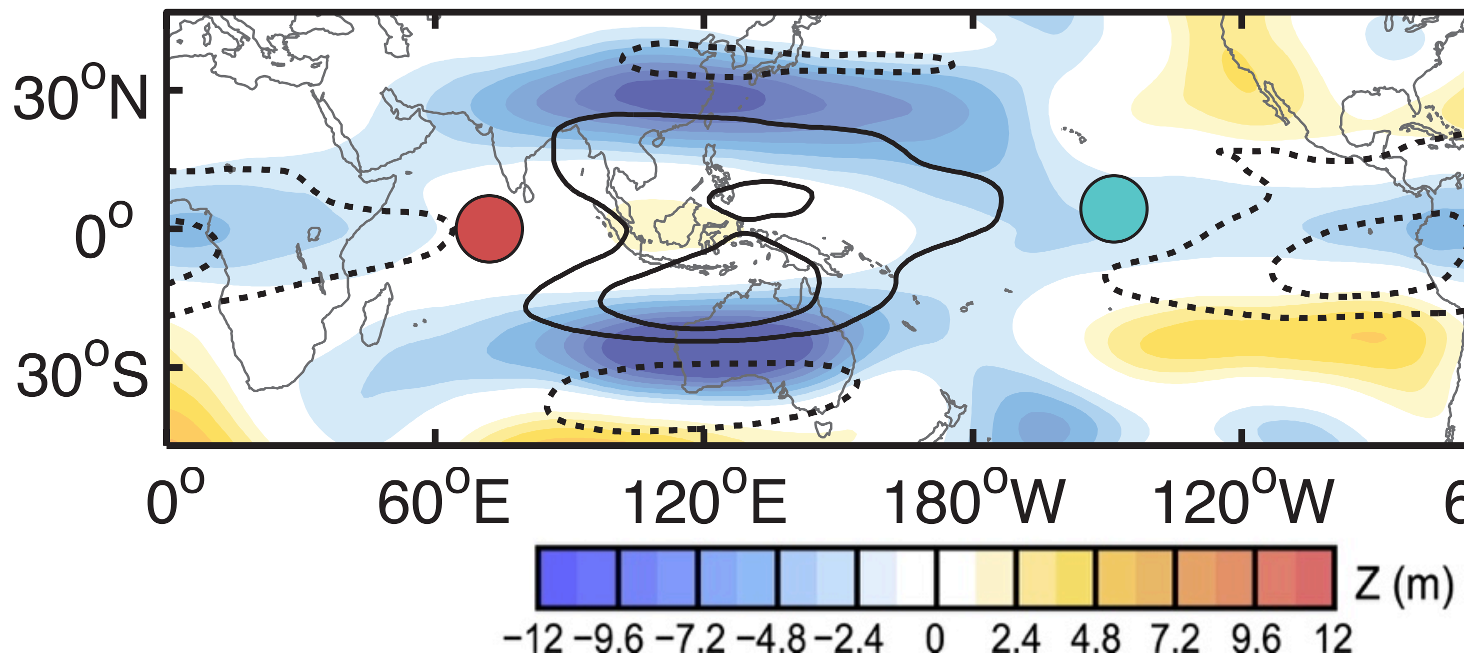


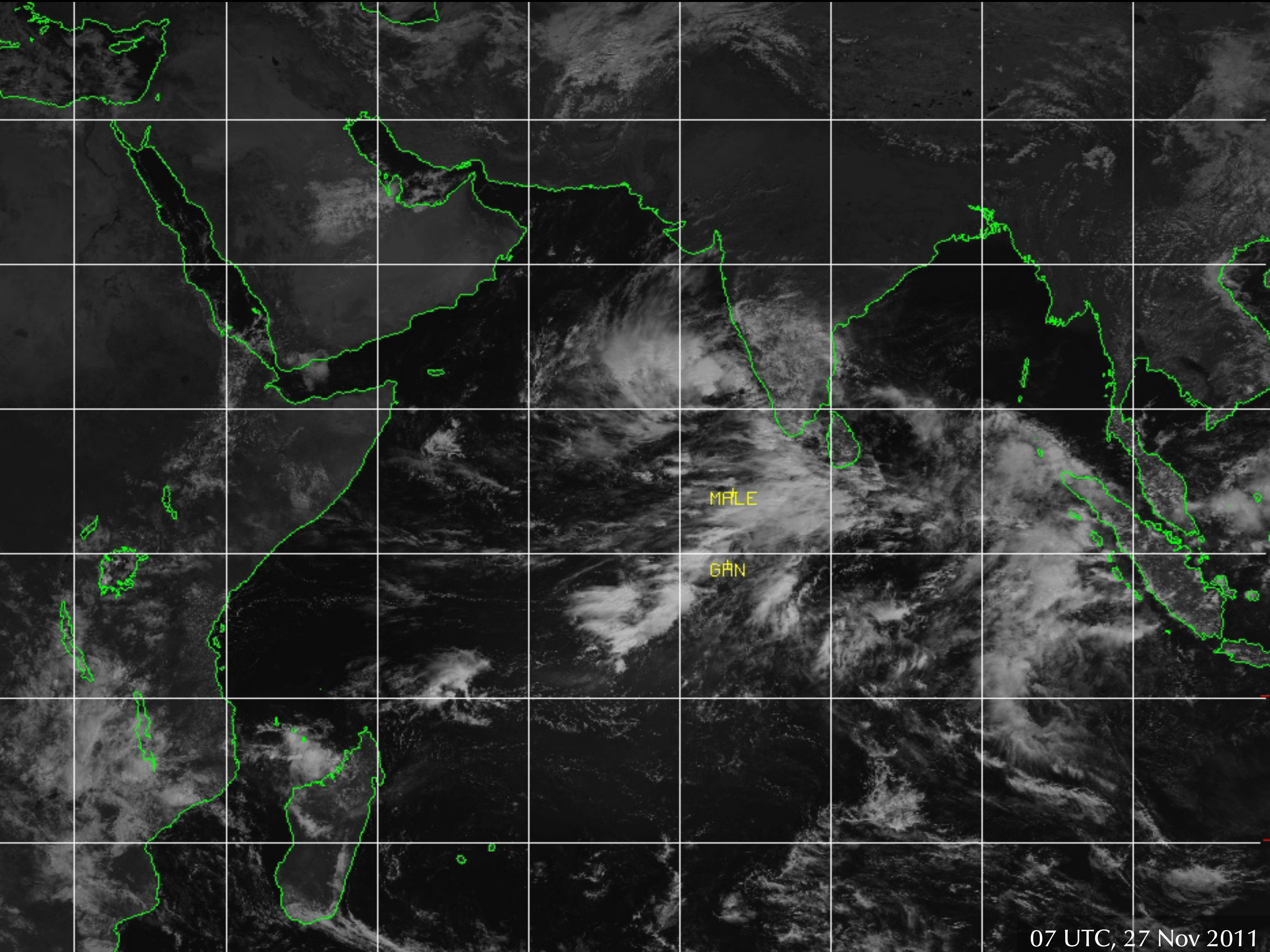

30°N
0°
30°S
0°
60°E
120°E
180°W
120°W
60°W
0°
Z (m)
−12 −9.6 −7.2 −4.8 −2.4 0 2.4 4.8 7.2 9.6 12

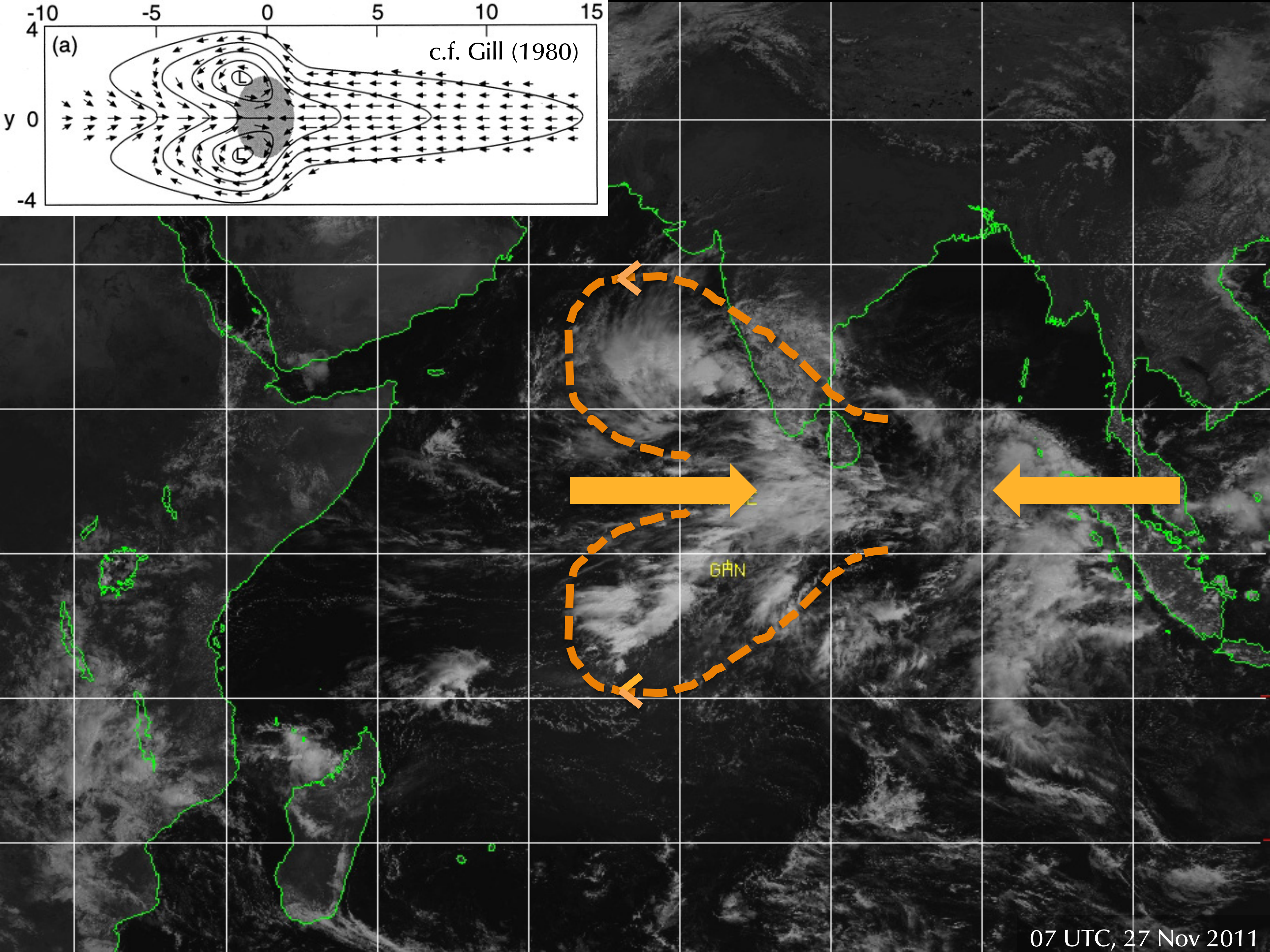
Adames and Wallace (2014)

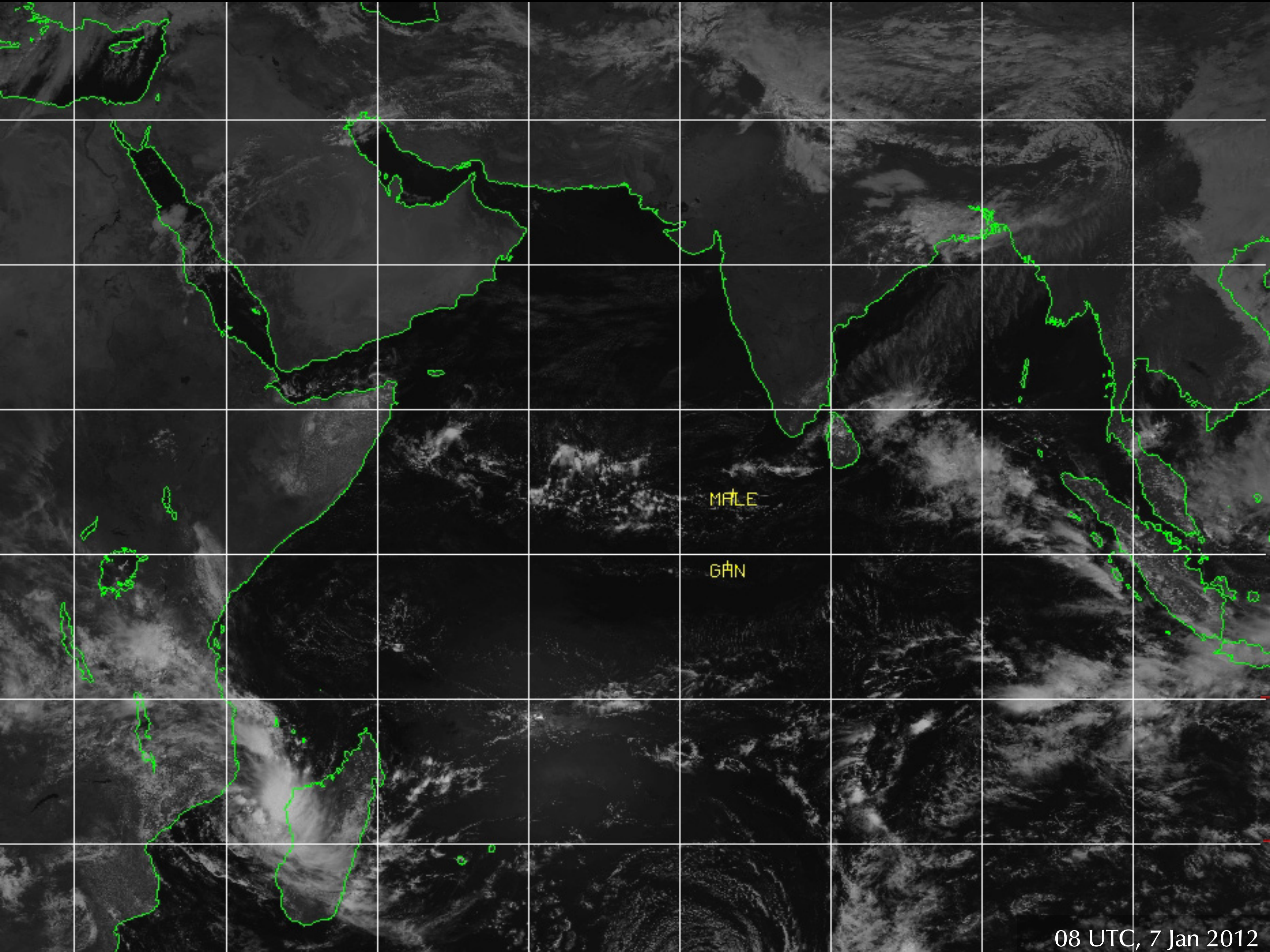


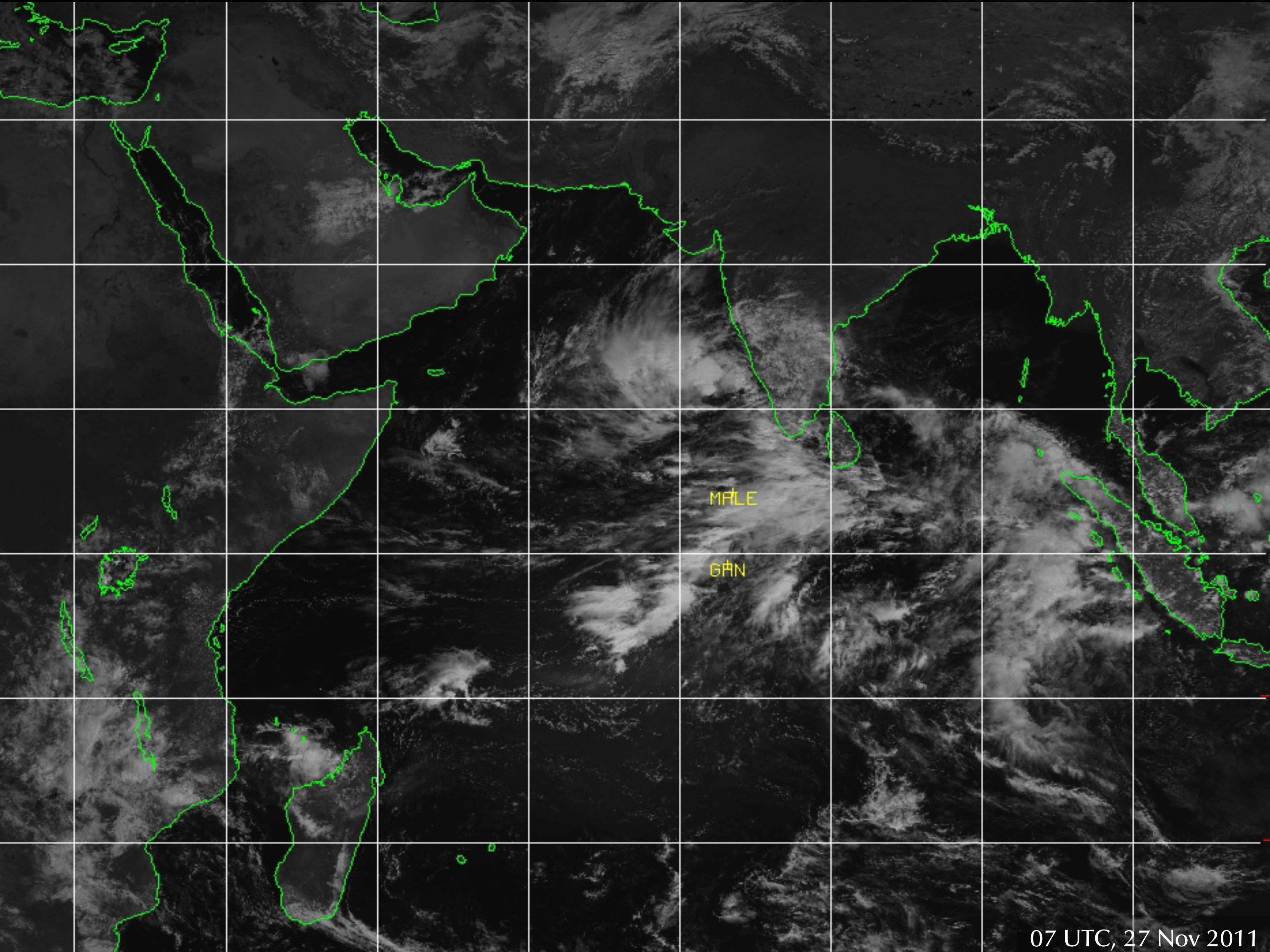
Adames and Wallace (2014)




MALE
GAN
07 UTC, 27 Nov 2011

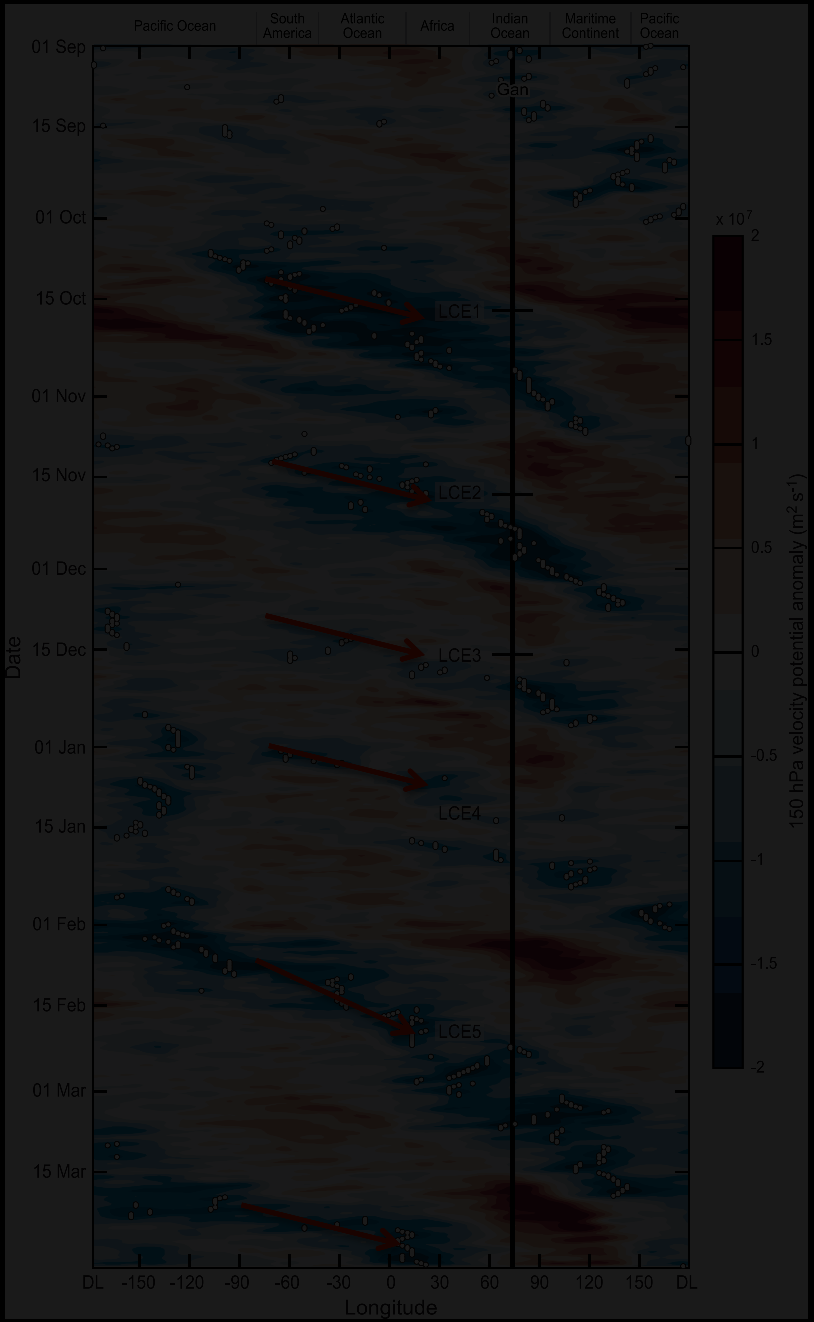

(a)
c.f. Gill (1980)
-10
-5
0
5
10
15
4
y 0
-4
L
L
GAN
07 UTC, 27 Nov 2011


MALE
GAN
08 UTC, 7 Jan 2012



07 UTC, 27 Nov 2011

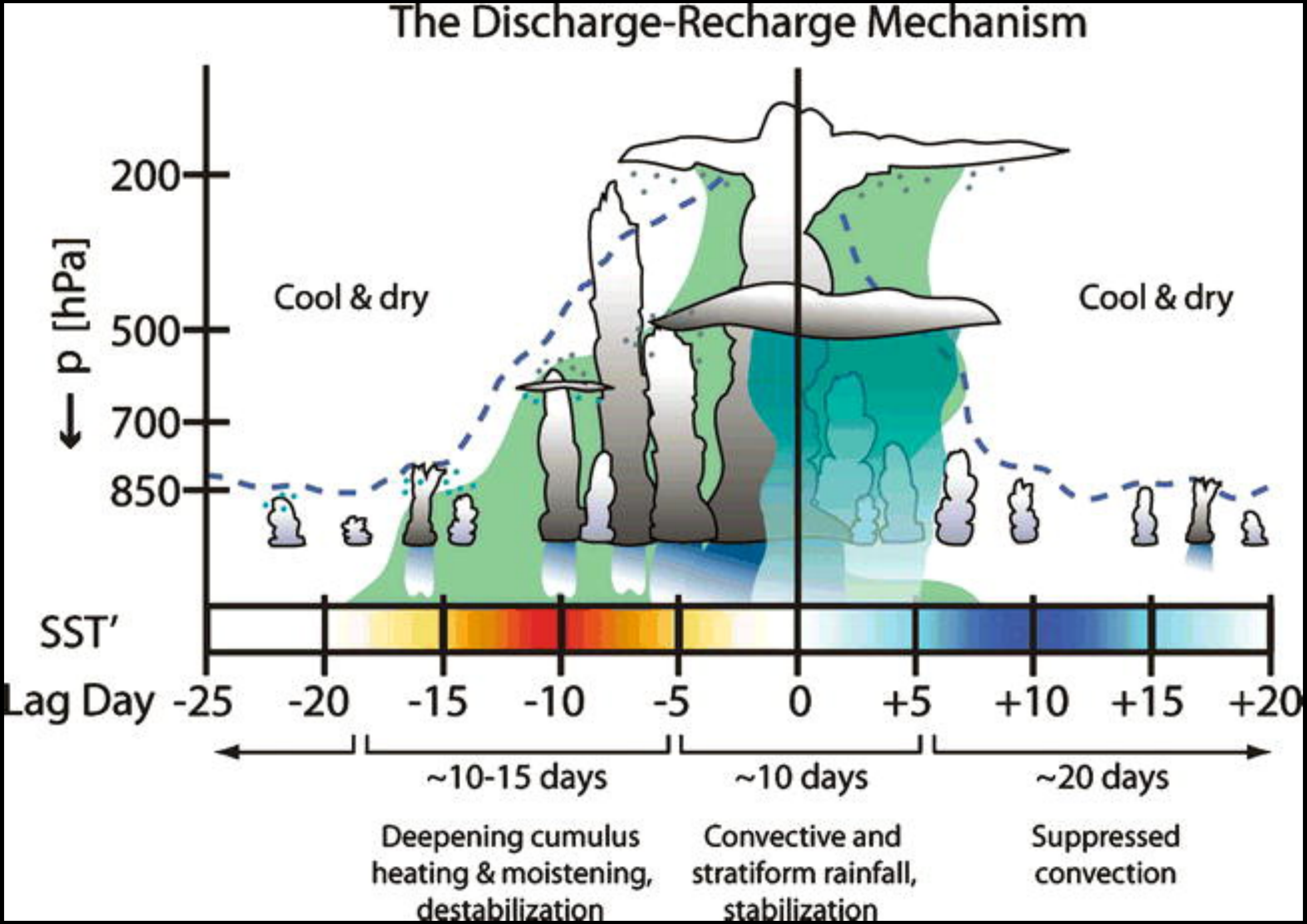
Hypothesis: Convection passively responds to changes in the large-scale environment.



Originally: Knutson and Weickmann (1987)

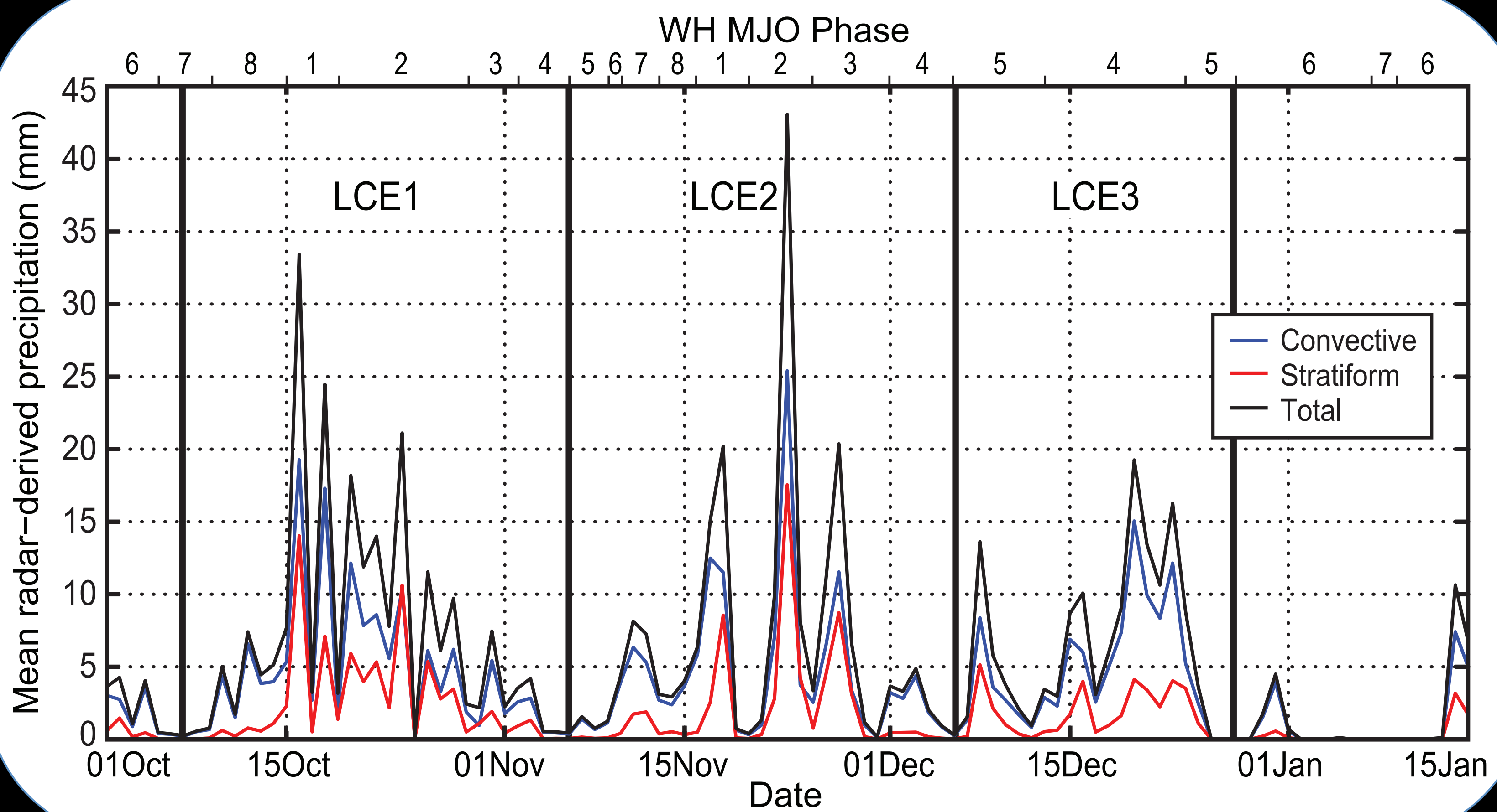
Figure: Powell and Houze (2015b)

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

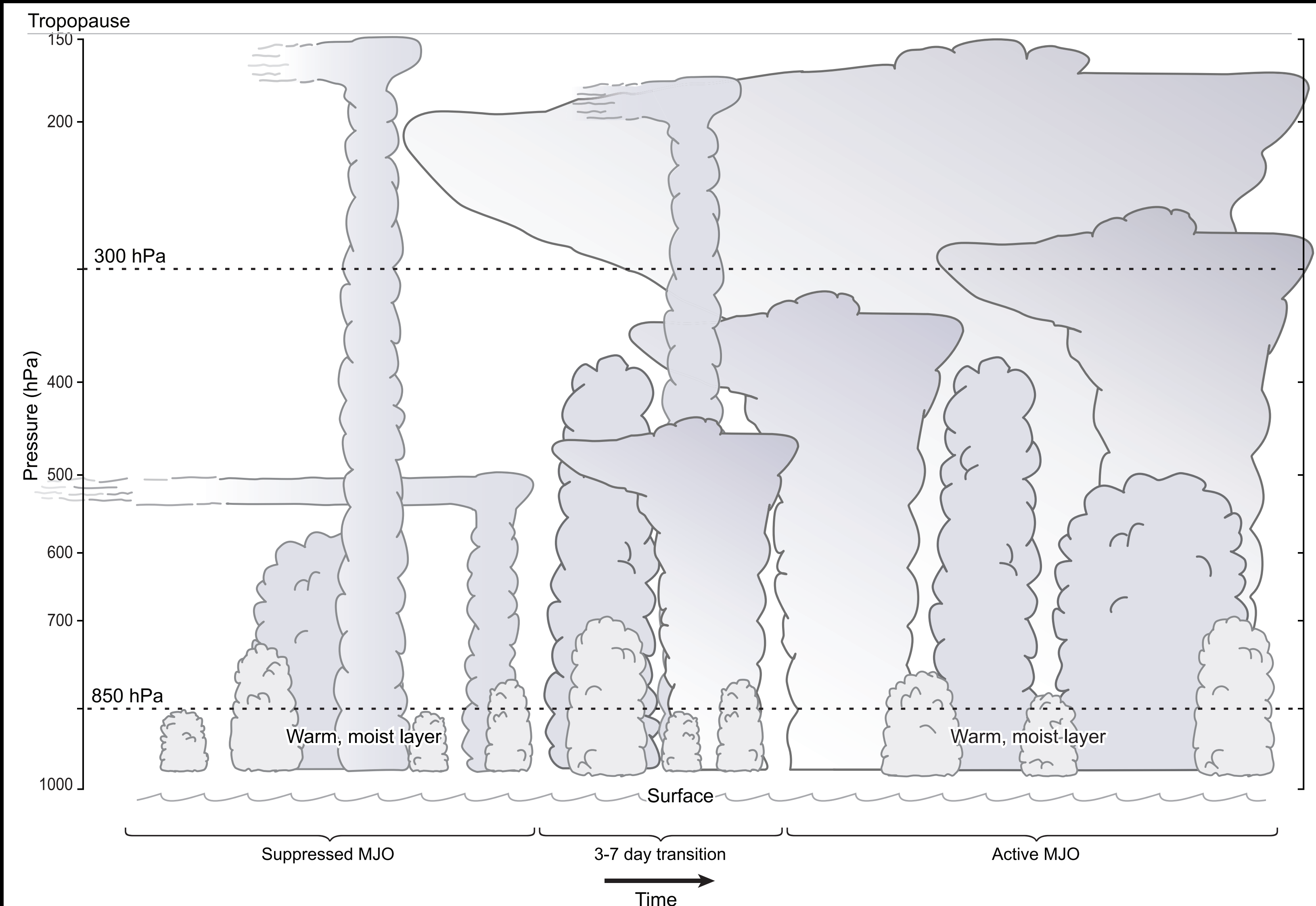


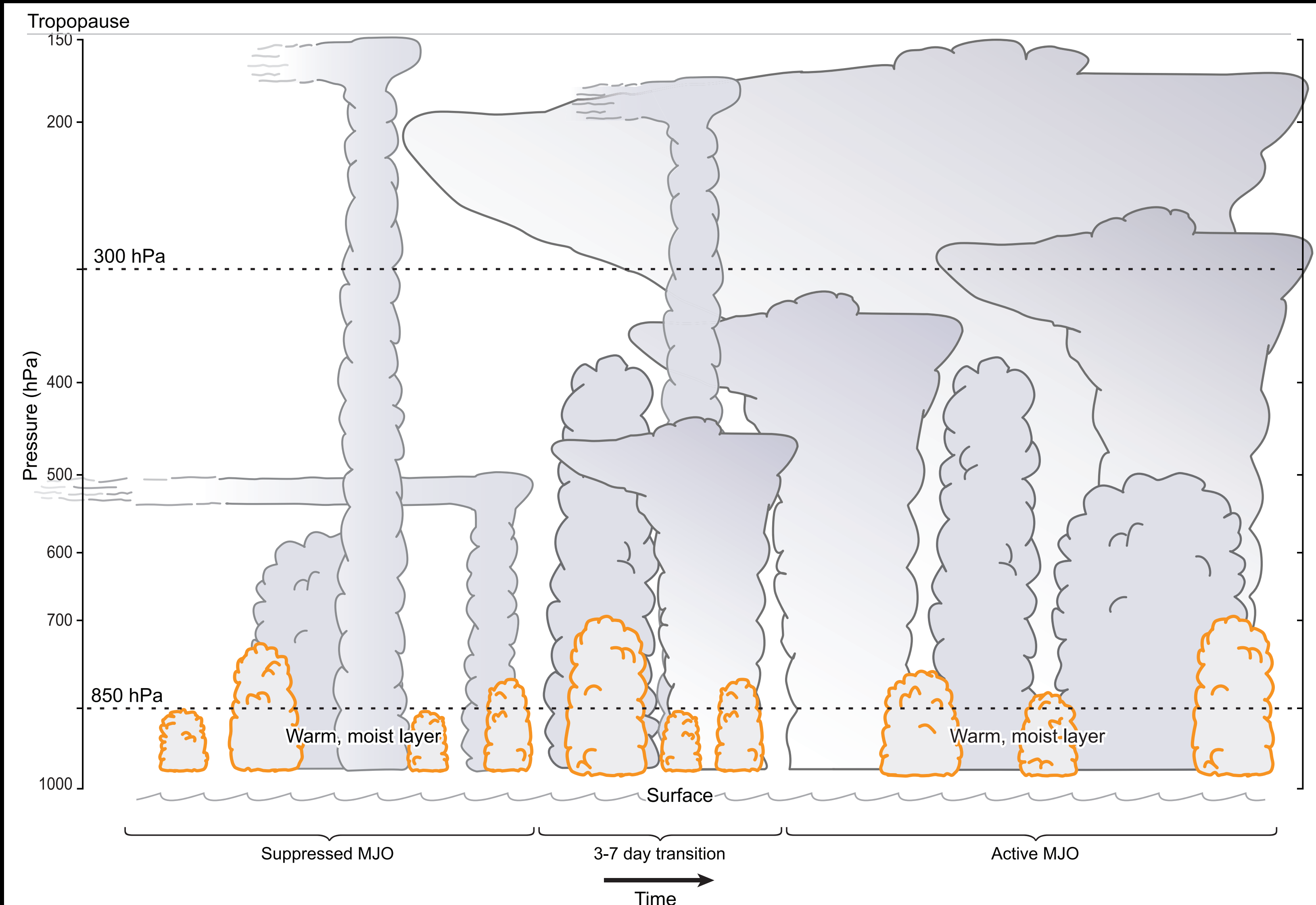
Benedict and Randall (2007), following Bladé and Hartmann (1993) and Kemball-Cook and Weare (2001)

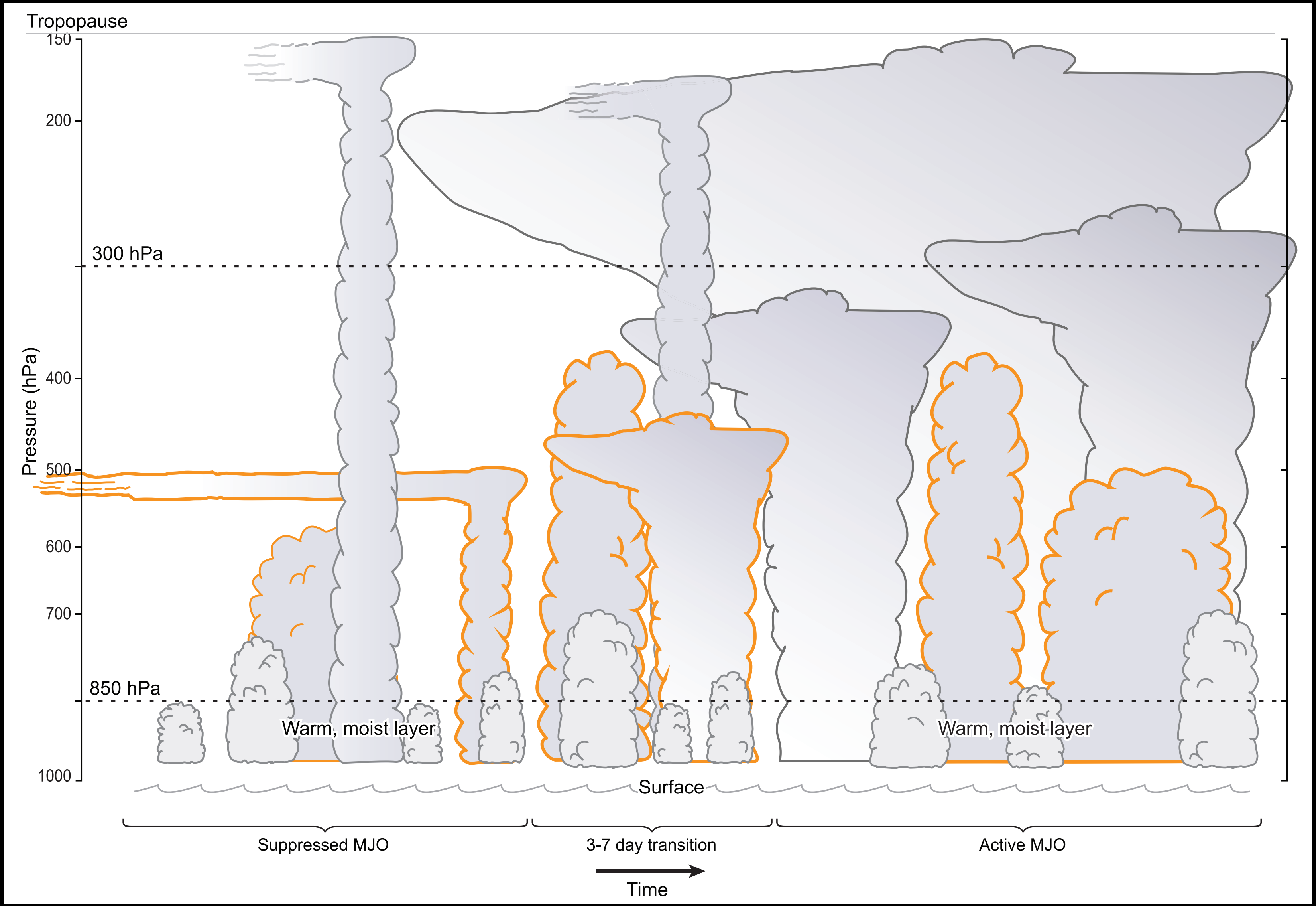

DYNAMO Field Experiment (October 2011 − March 2012)
Falcon
S-PolKa
SMART-R
AMF2
ISS
P-3
Sounding Network
BRAZIL
SOUTH ATLANTIC OCEAN
INDIAN OCEAN
AUSTRALIA
INDONESIA
LAKSHADWEEP (INDIA)
Laccadive Sea
Colombo
SRI LANKA
Male
MALDIVES
Addu Atoll
Revelle
British Indian Ocean Territory (U.K.)
250 km
Diego Garcia
Mirai
Slide from C. Zhang
R/V B. Jaya-III
R/V R. Revelle
R/V S. Kanya
R/V Mirai

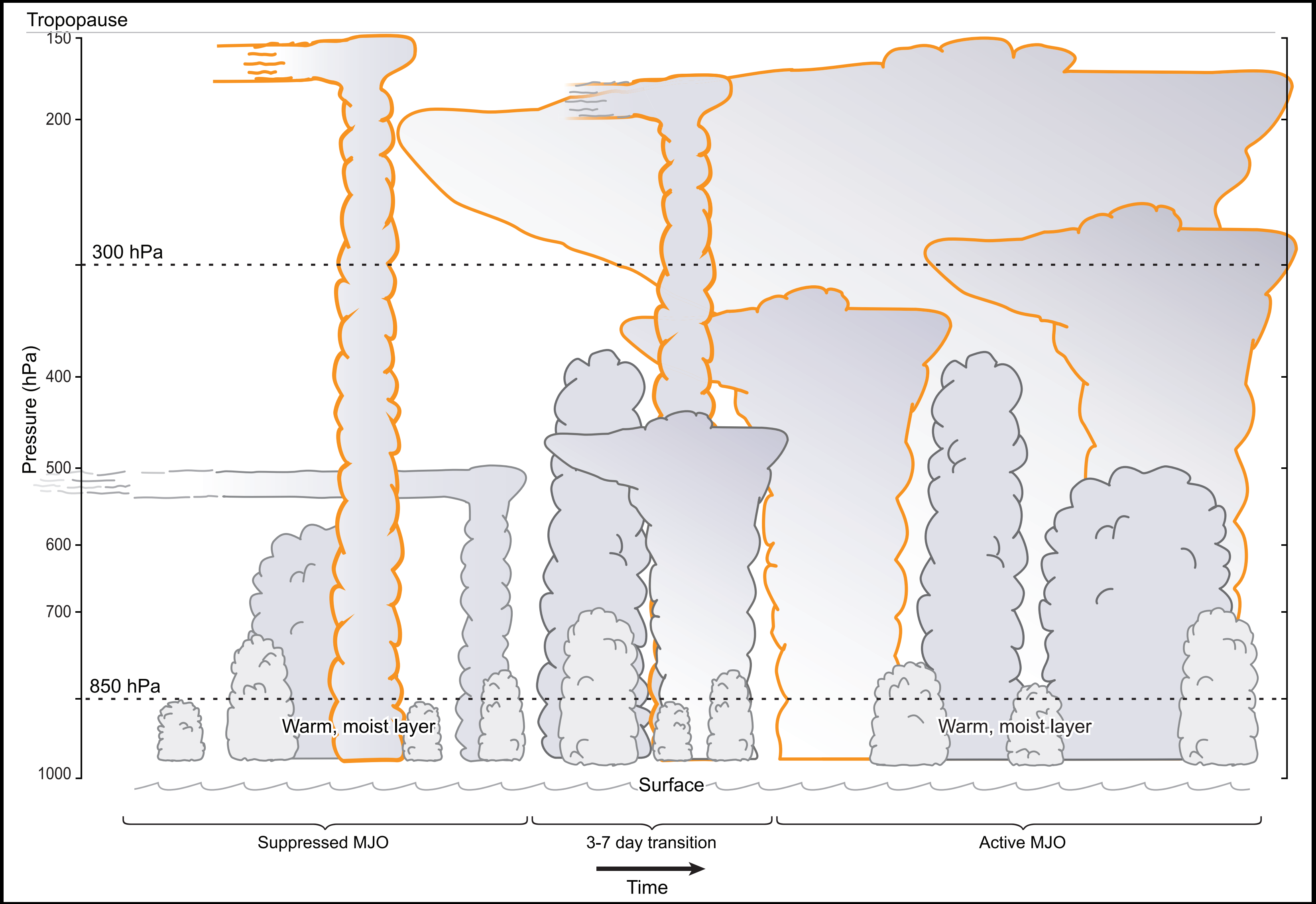

WH MJO Phase
6
7
8
1
2
3
4
5
6
7
8
1
2
3
4
5
4
5
6
7
6
LCE1
LCE2
LCE3
Mean radar−derived precipitation (mm)
45
40
35
30
25
20
15
10
5
0
Convective
Stratiform
Total
01Oct
15Oct
01Nov
15Nov
01Dec
15Dec
01Jan
15Jan
Date

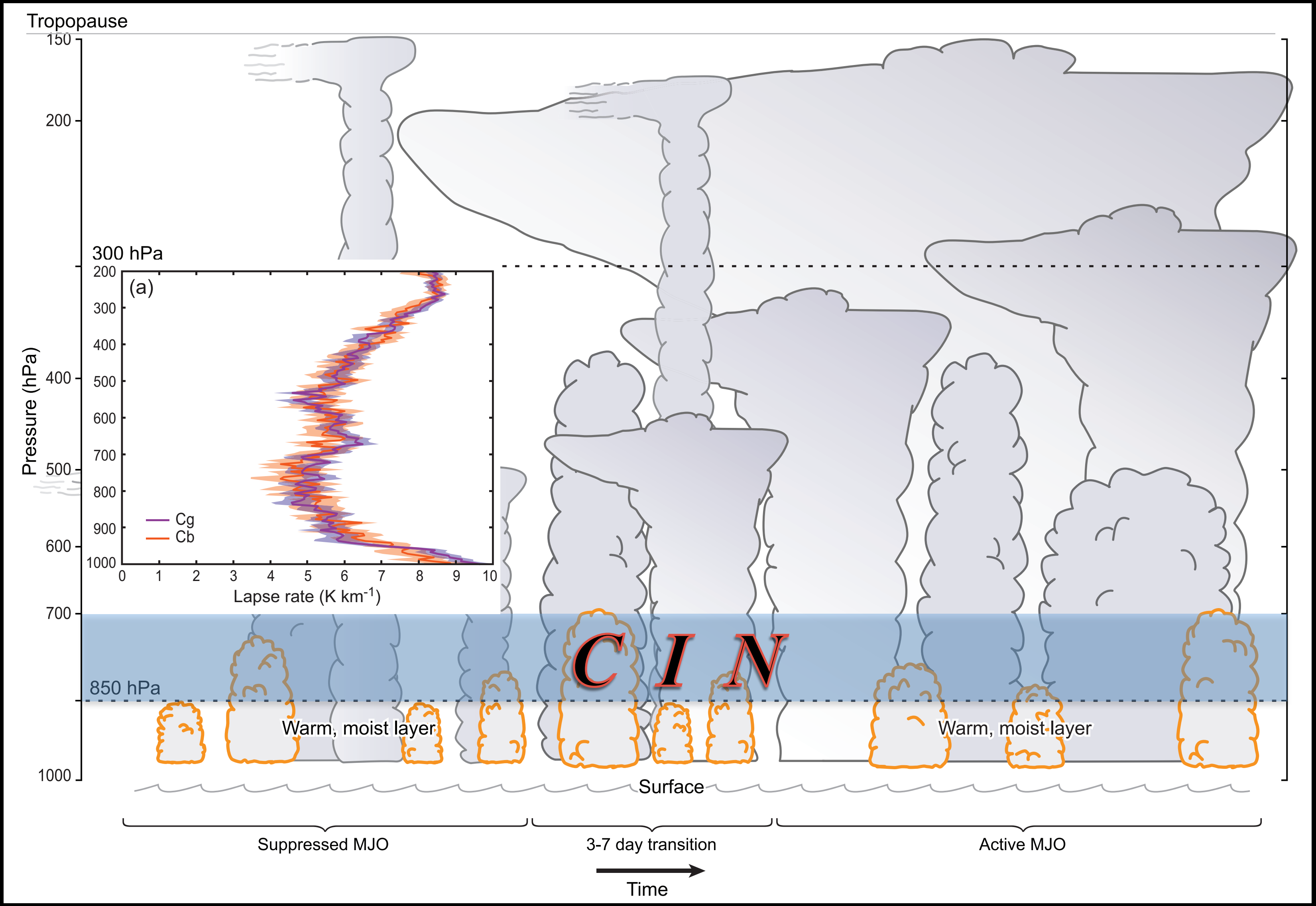
Powell and Houze (2015b)

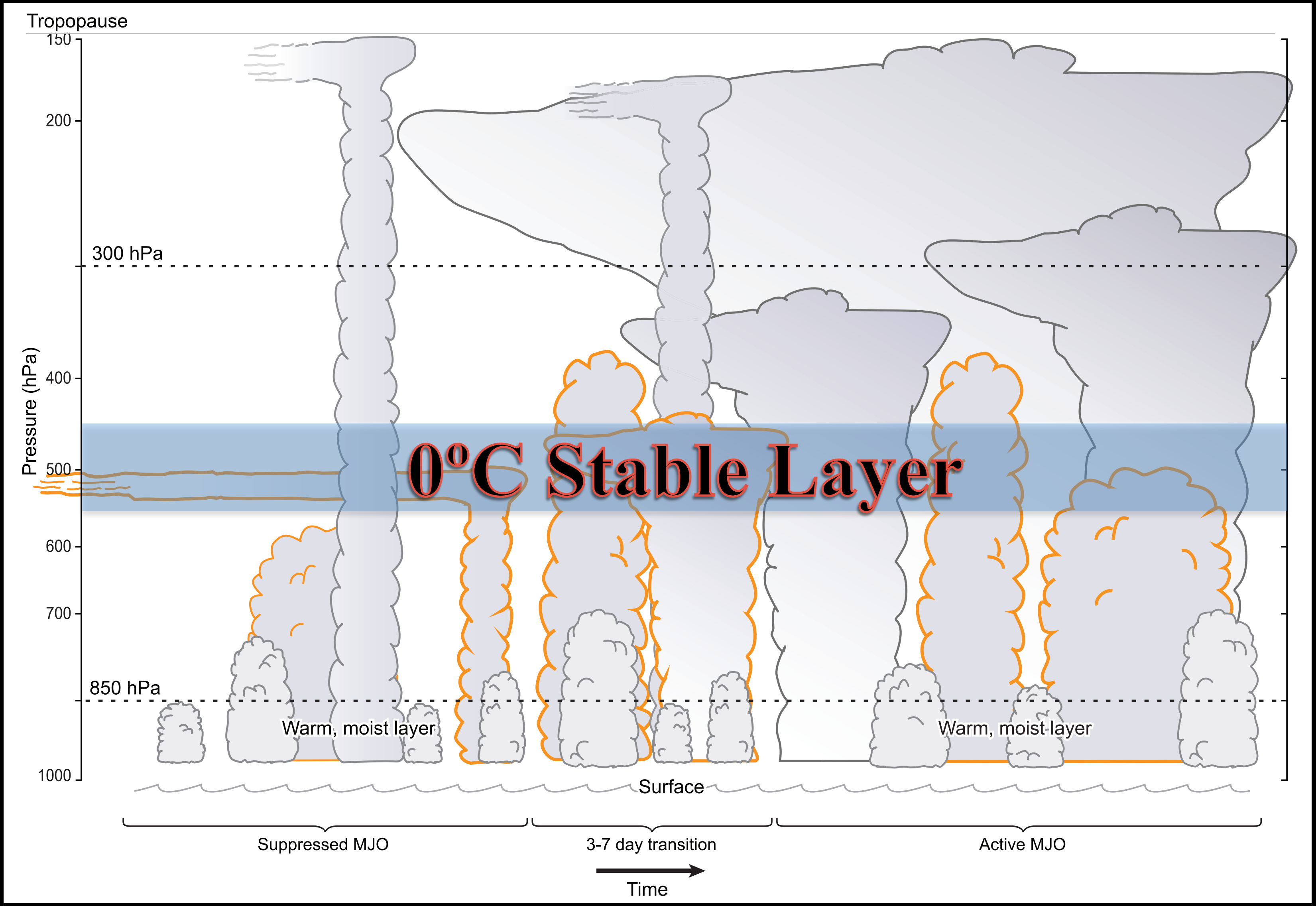


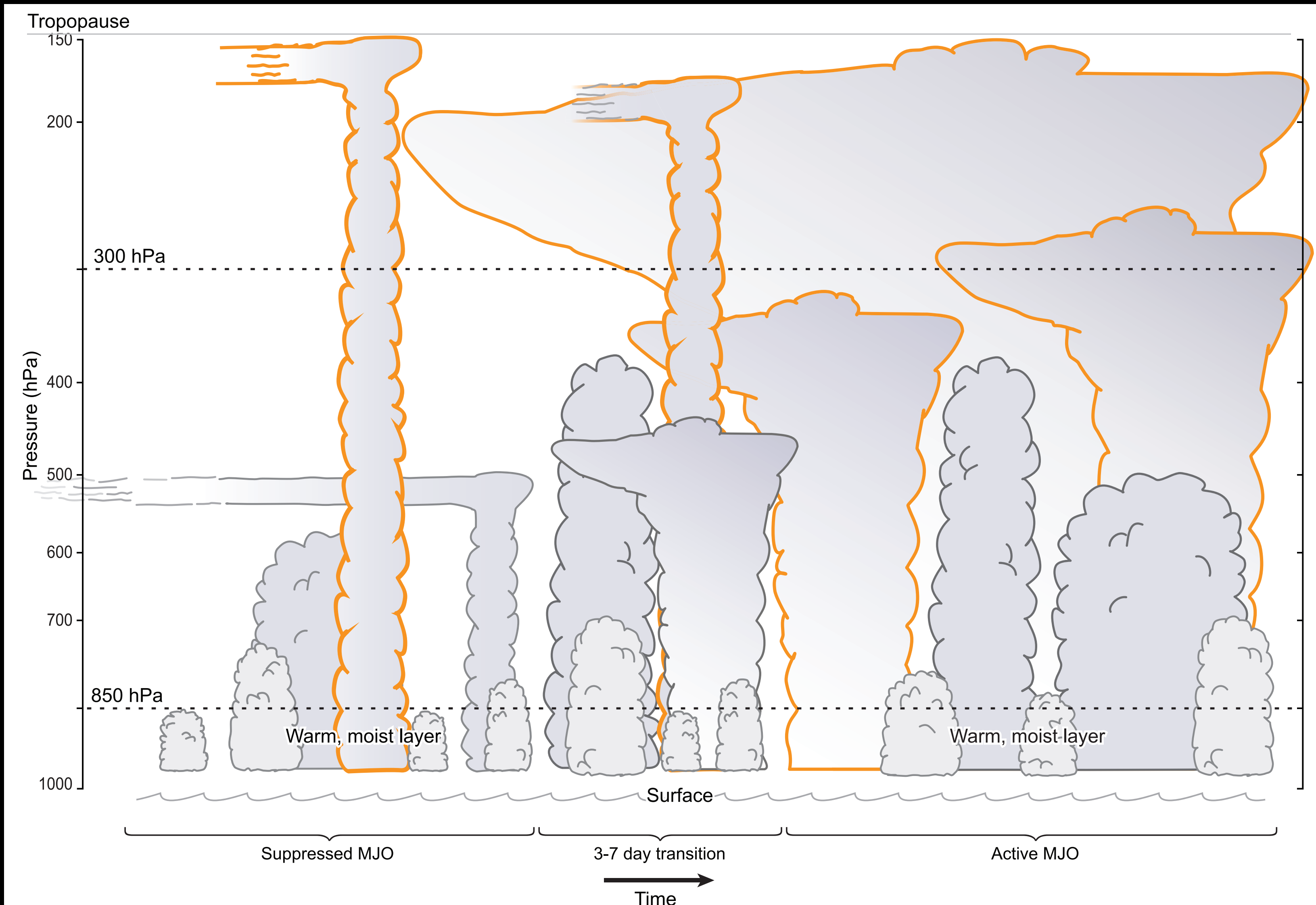

Tropopause
150
200
300 hPa
400
500
600
700
850 hPa
1000
Pressure (hPa)
Warm, moist layer
Warm, moist layer
Surface
Suppressed MJO
3-7 day transition
Active MJO
Time

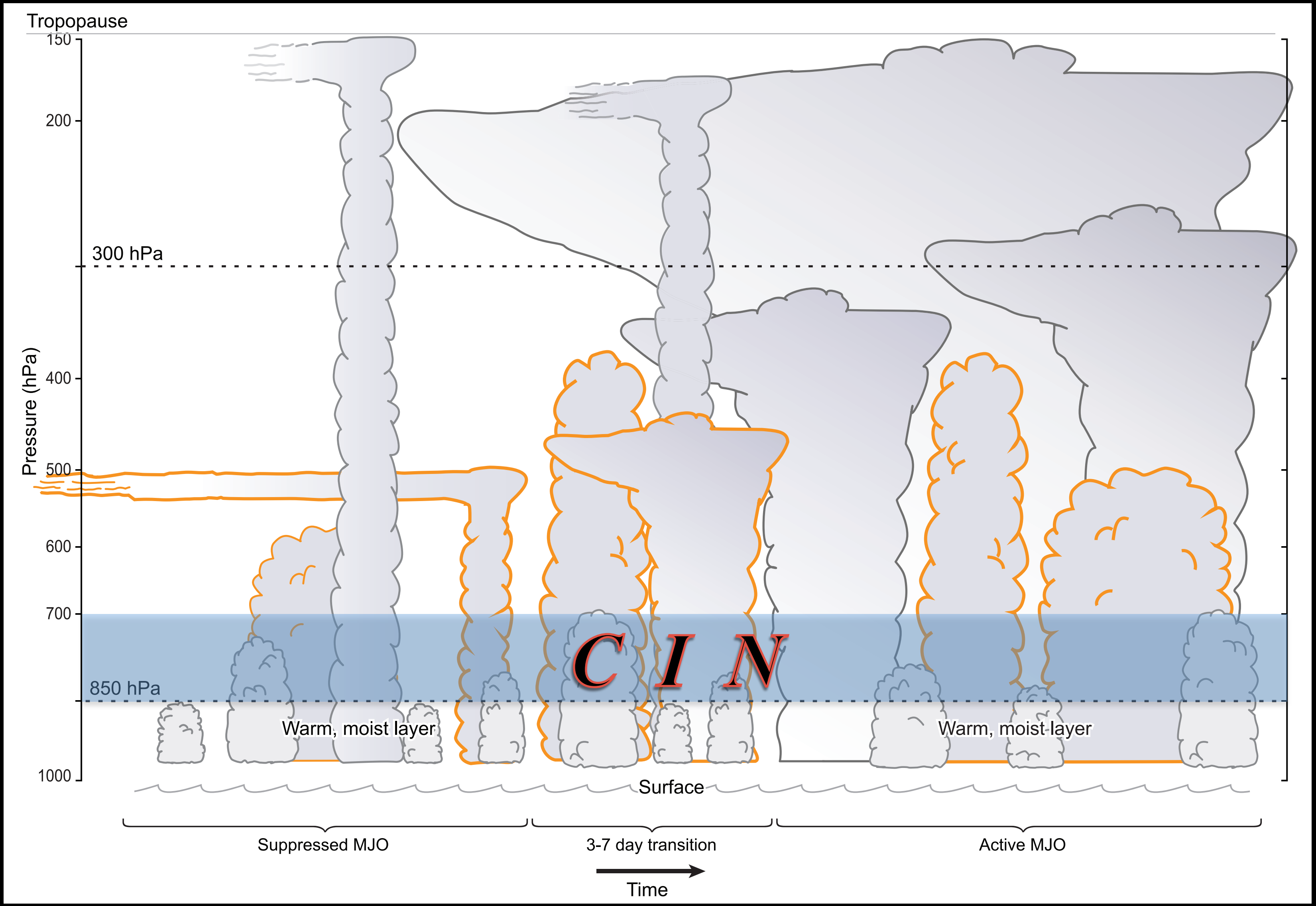

Tropopause
150
200
300 hPa
400
500
600
700
850 hPa
1000
Pressure (hPa)
Warm, moist layer
Warm, moist layer
Surface
Suppressed MJO
3-7 day transition
Active MJO
Time


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)
(a)
200
300
400
500
600
700
800
900
1000
Cg
Cb
0 1 2 3 4 5 6 7 8 9 10
Lapse rate (K km-1)
C I N
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

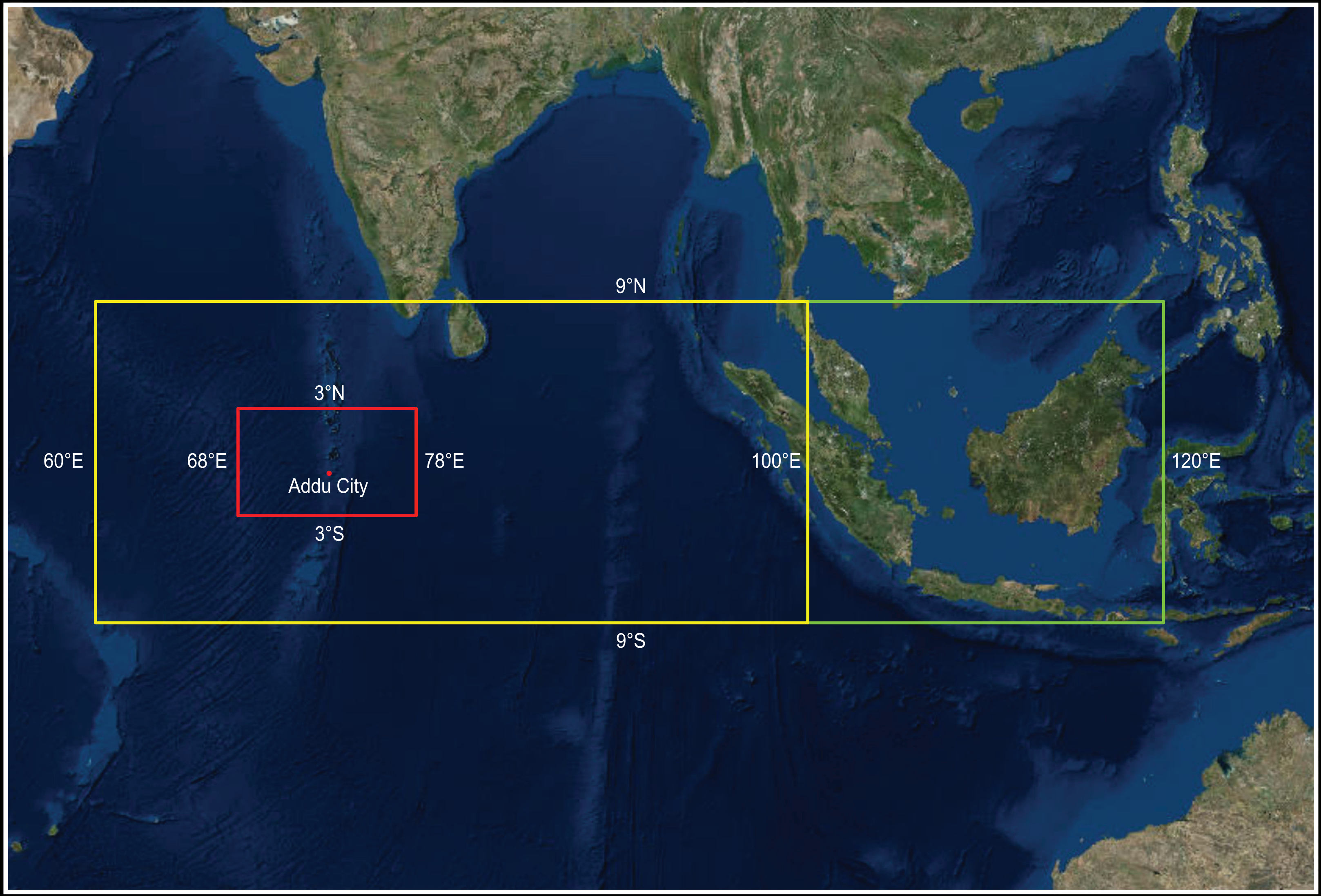
1. Timescale

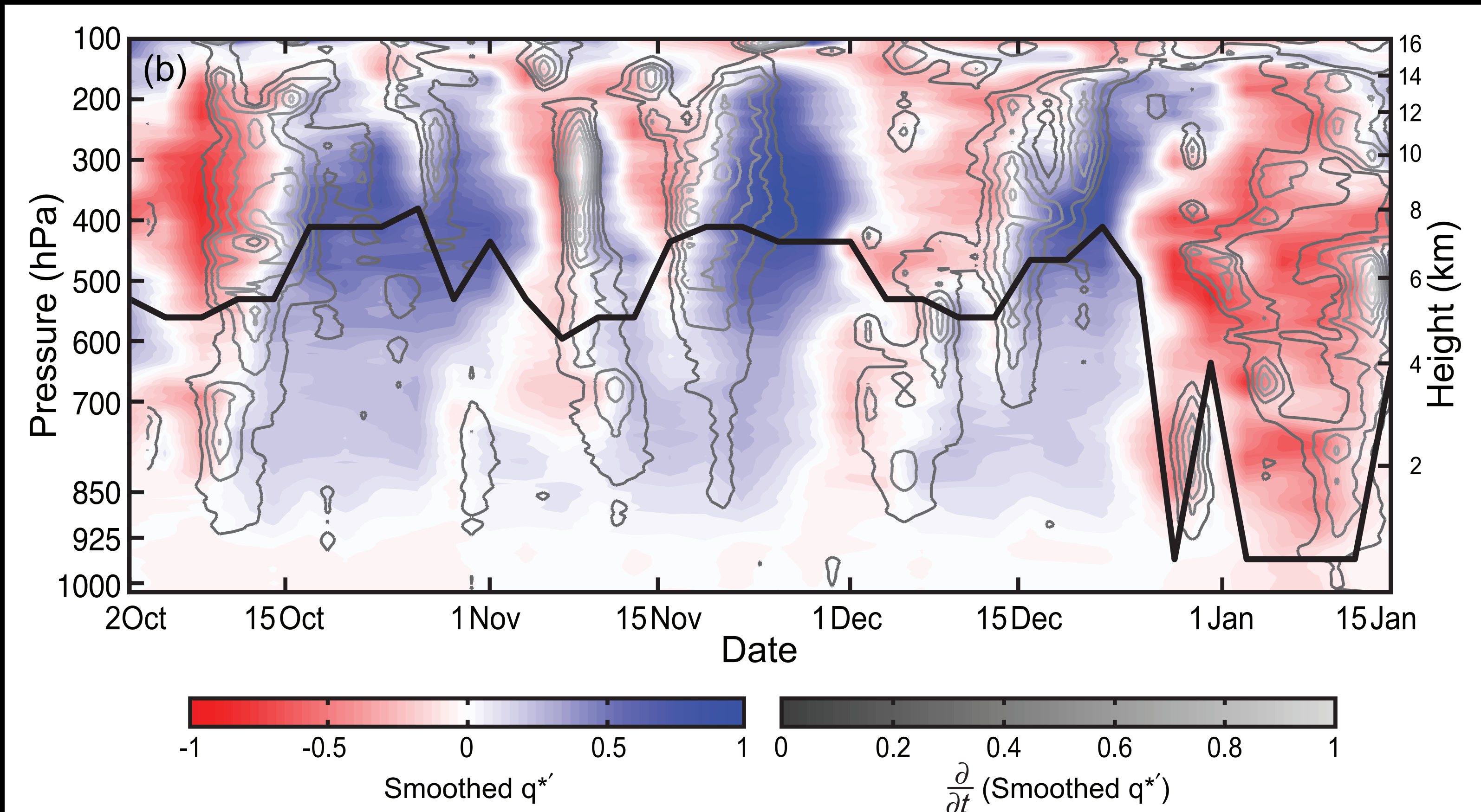
2. Do clouds moisten environment or does something else, allowing for cloud development?

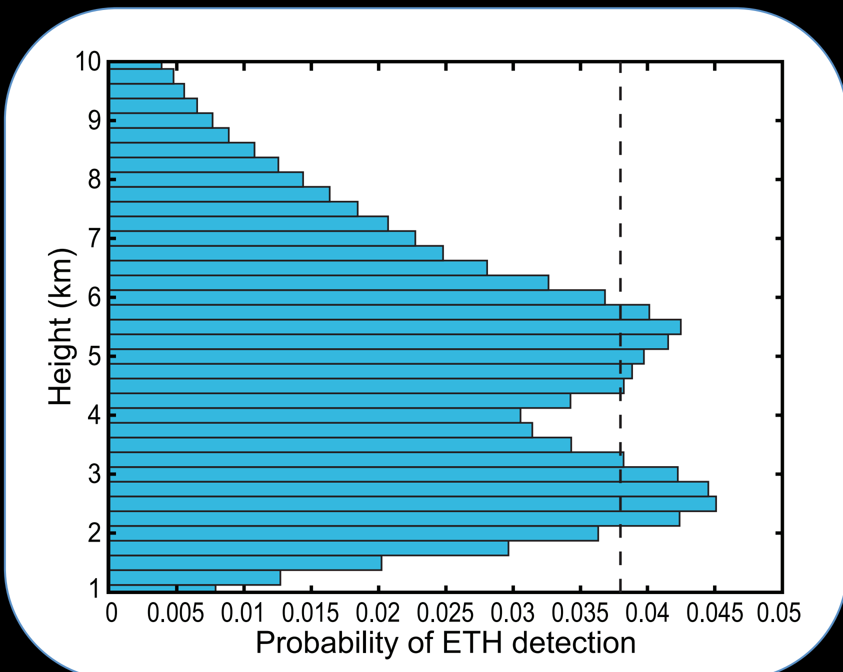
3. Role of global circulation anomalies in cloud growth

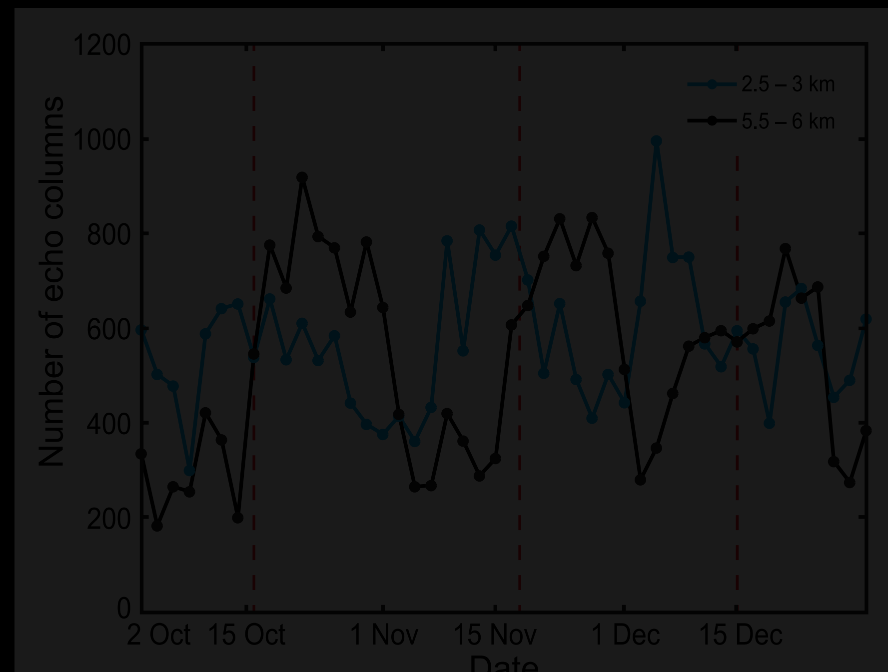
Timescale of MJO Convective Build-up

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

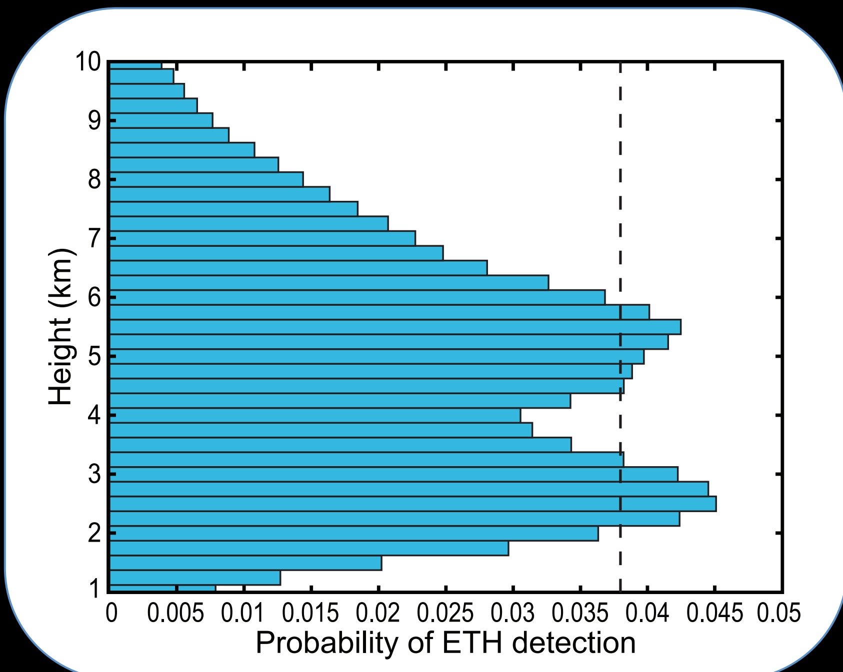

9°N
3°N
60°E
68°E
78°E
100°E
120°E
Addu City
3°S
9°S


(b)
100
200
300
400
500
600
700
850
925
1000
Pressure (hPa)
16
14
12
10
8
6
4
2
Height (km)
2Oct
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*′)

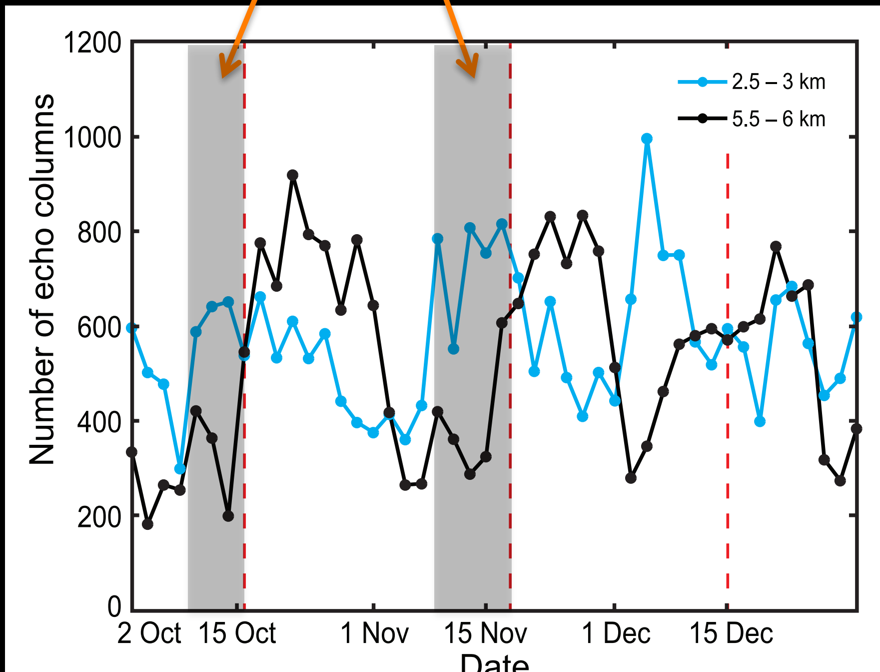




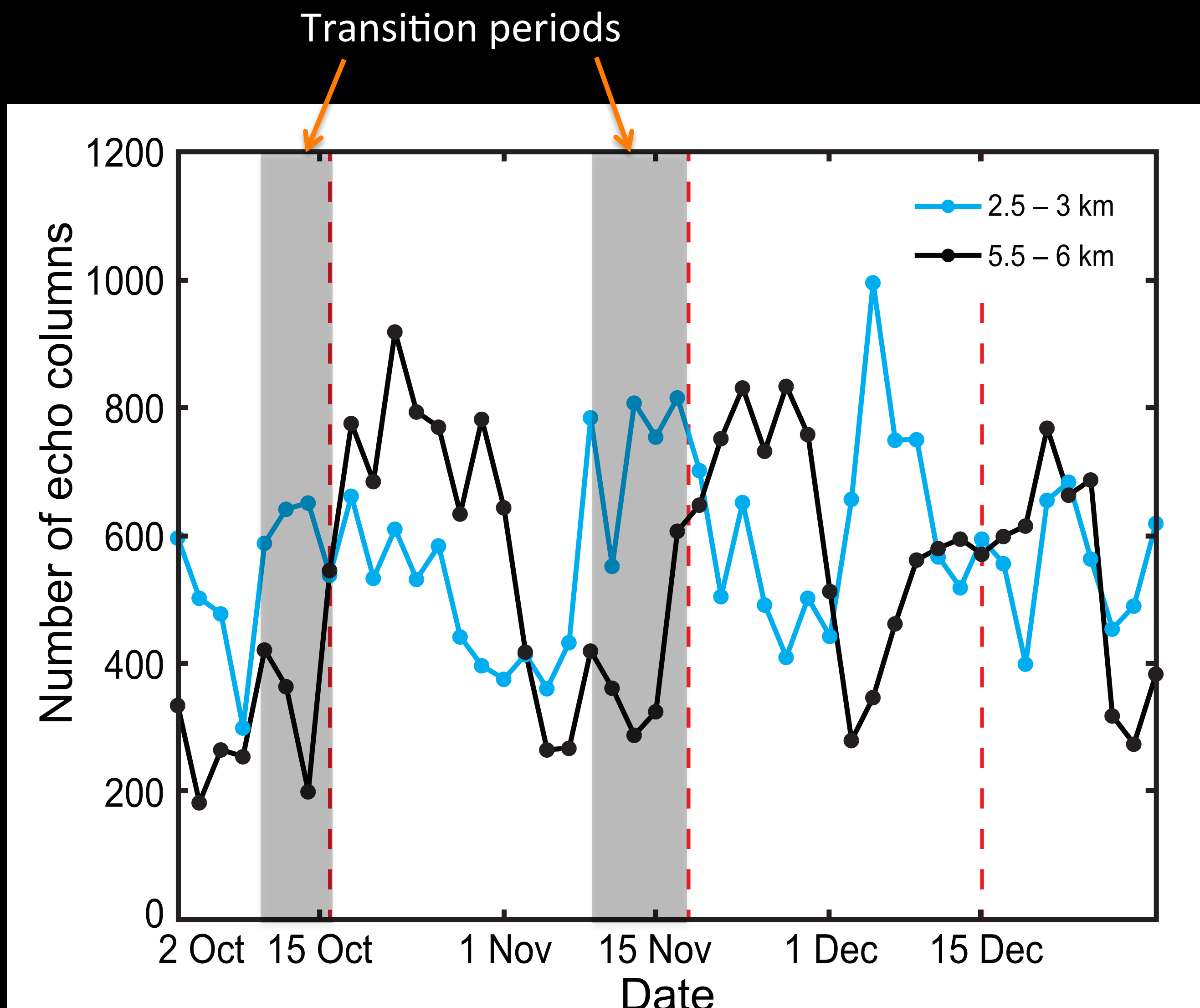
TRMM 20dBZ echo tops: 9N–9S; 60–100E



Transition periods

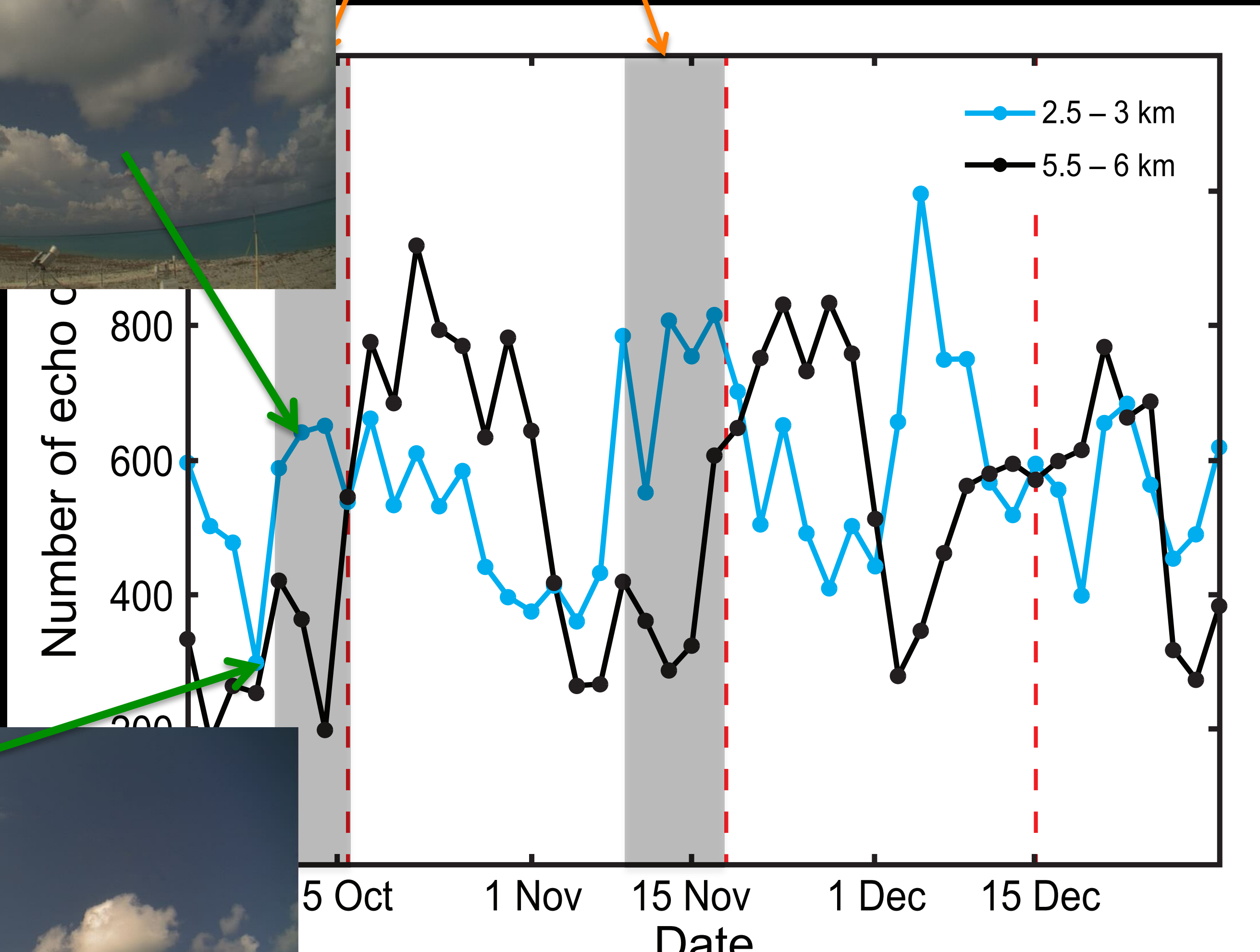


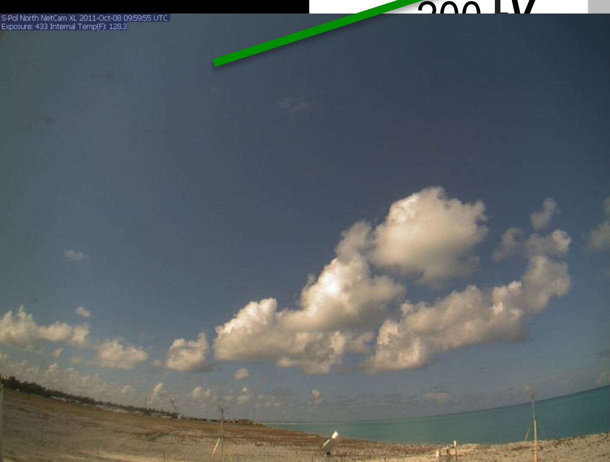
TRMM 20dBZ echo tops: 9N–9S; 60–100E



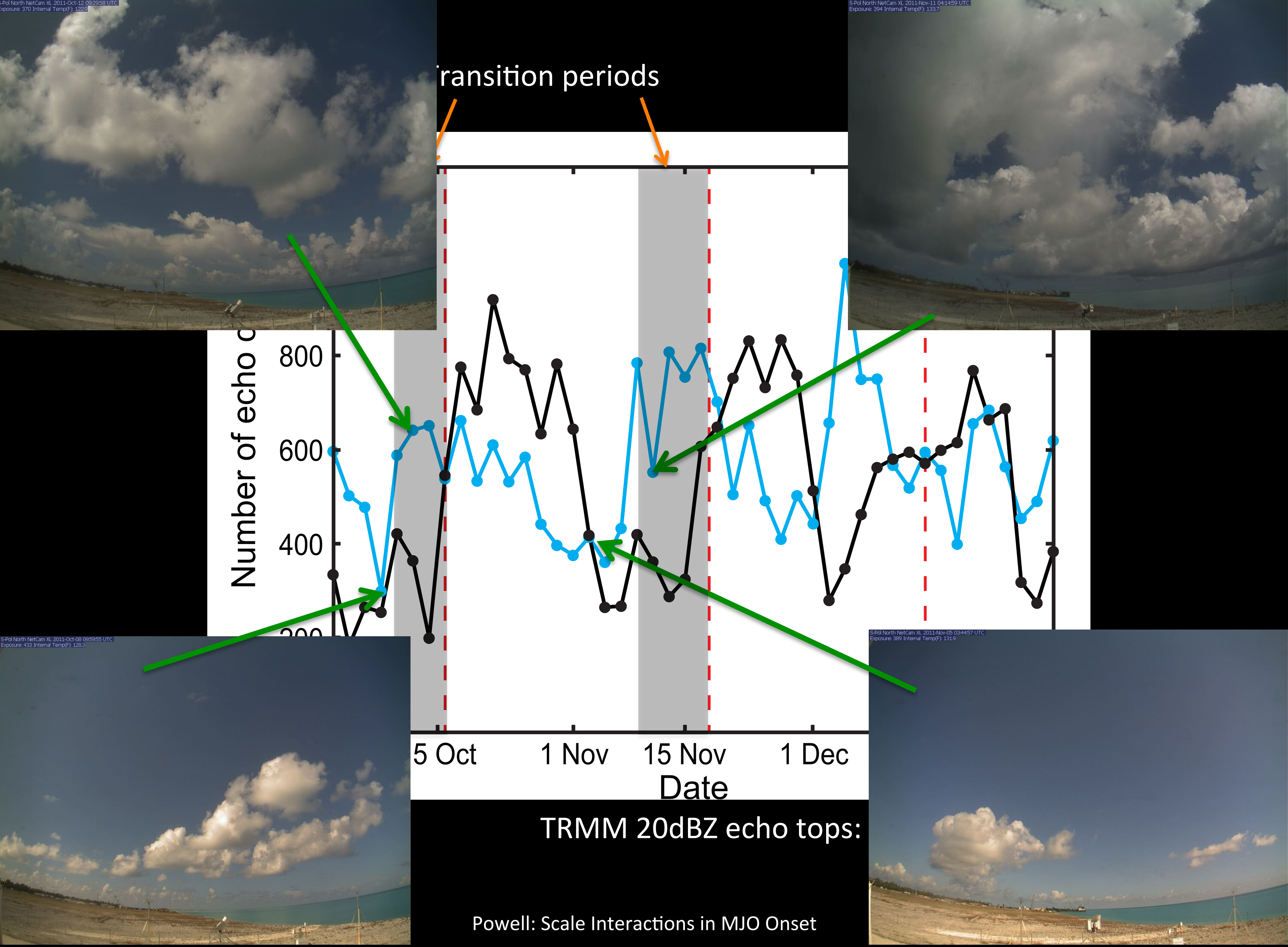
TRMM 20dBZ echo tops: 9N–9S; 60–100E

ransition periods



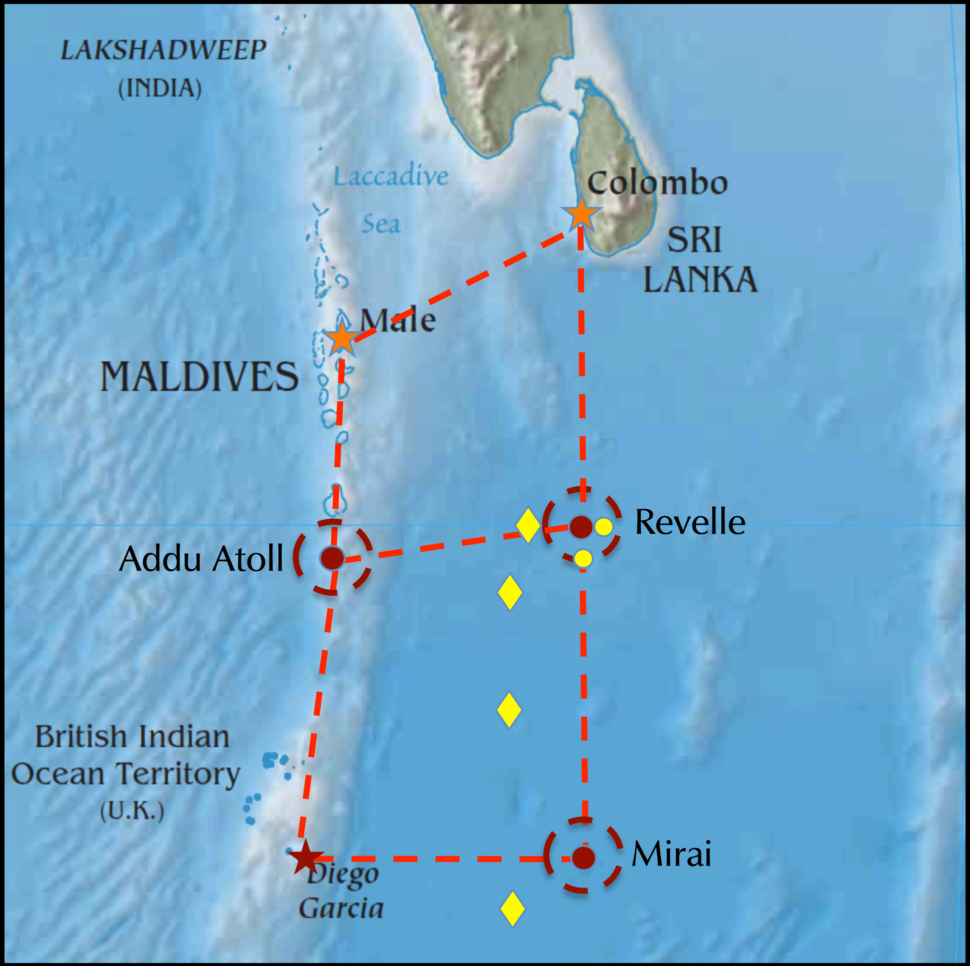


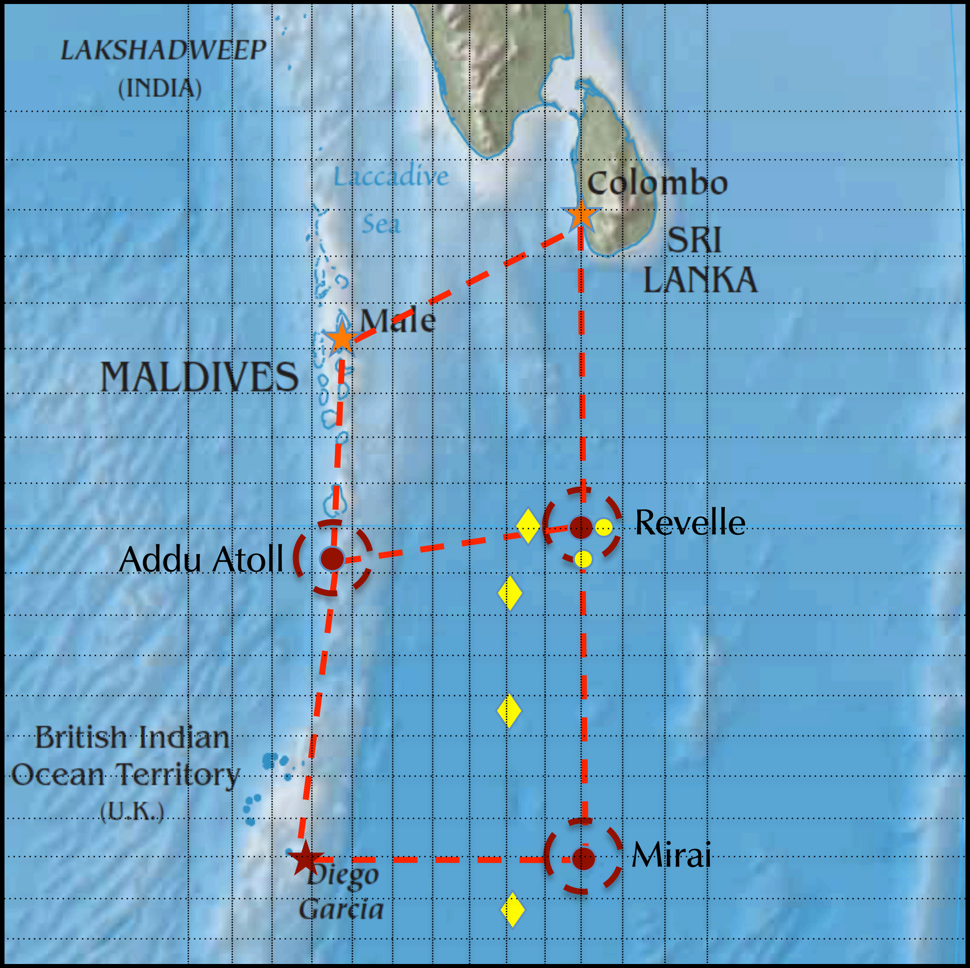
TRMM 20dBZ echo tops: 9N–9S; 60–100E


ransition periods
Number of echo c
800
600
400
5 Oct
1 Nov
15 Nov
1 Dec
Date
TRMM 20dBZ echo tops:

Moistening by Cumulonimbi

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

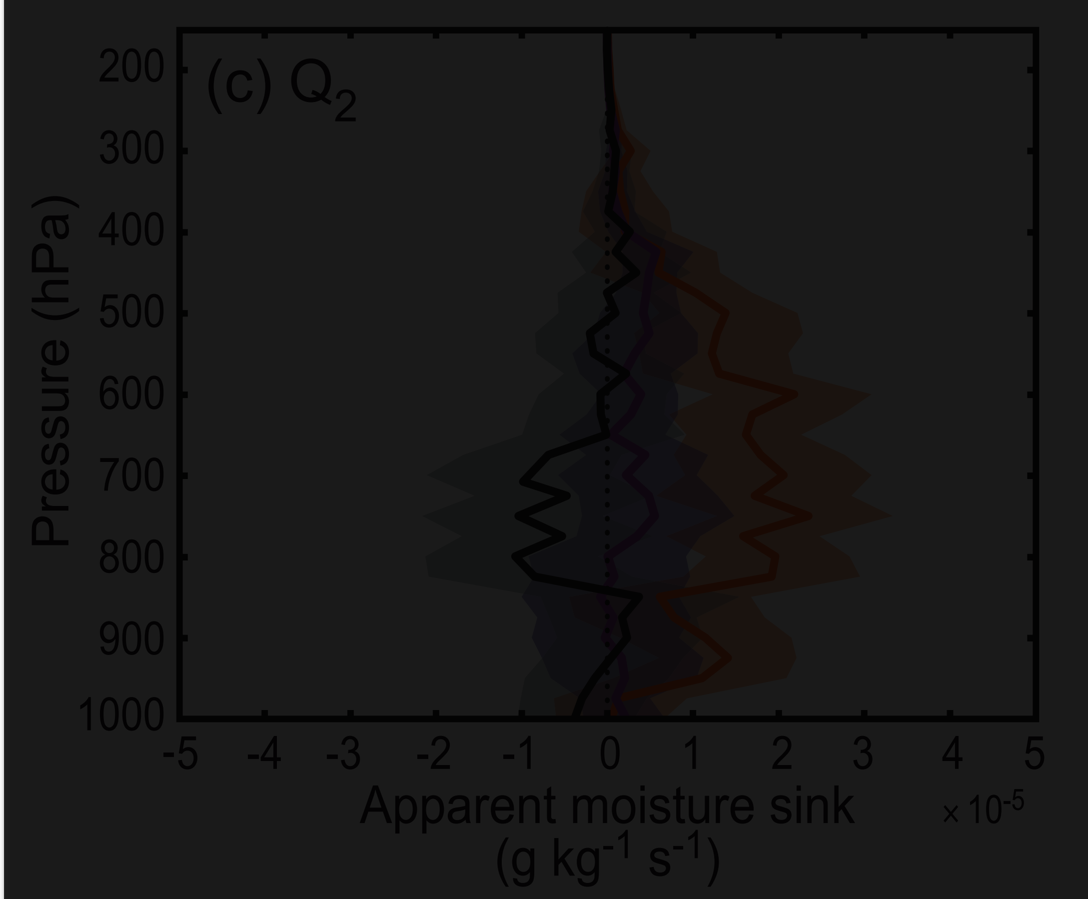

LAKSHADWEEP
(INDIA)
Laccadive
Sea
Colombo
SRI
LANKA
Male
MALDIVES
Revelle
Addu Atoll
British Indian
Ocean Territory
(U.K.)
Mirai
Diego
Garcia



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

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

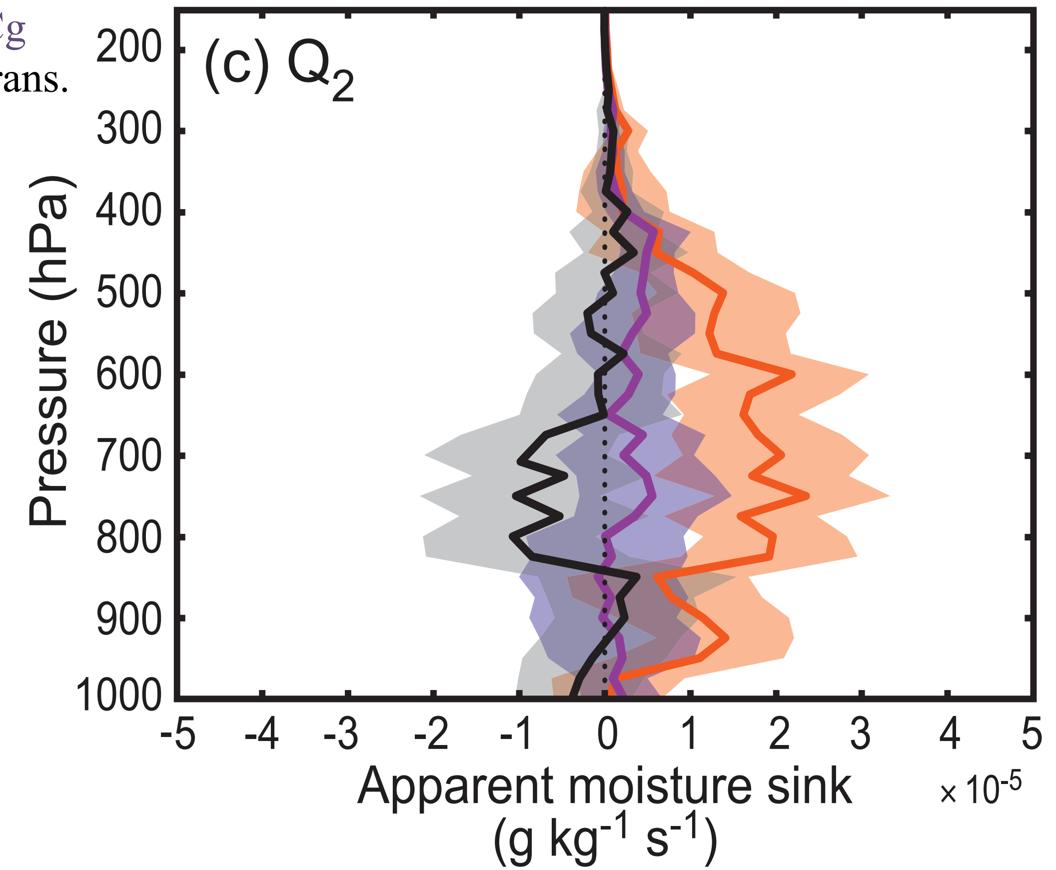
$$Q_2 = \left(\overline{c} - \overline{e}\right) + \frac{\partial}{\partial p}\left(\overline{\omega' q'}\right)$$



Purple = Cg
Black = Trans.
Red = Cb

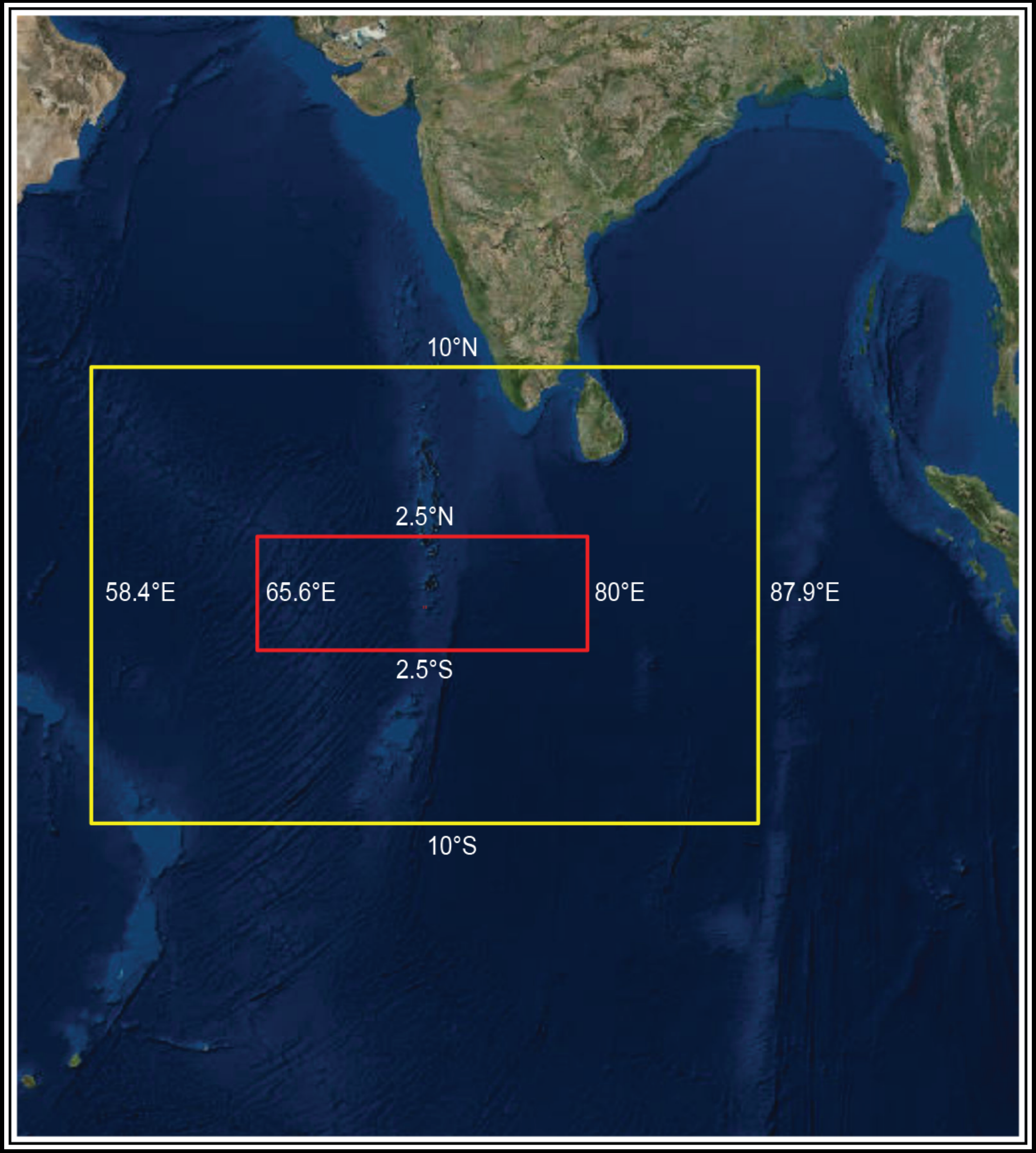
$$\frac{\partial q}{\partial t} = \mathbf{v}_h \cdot \nabla q + \omega \frac{\partial q}{\partial p} + Q_2$$

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



WRF V3.5.1

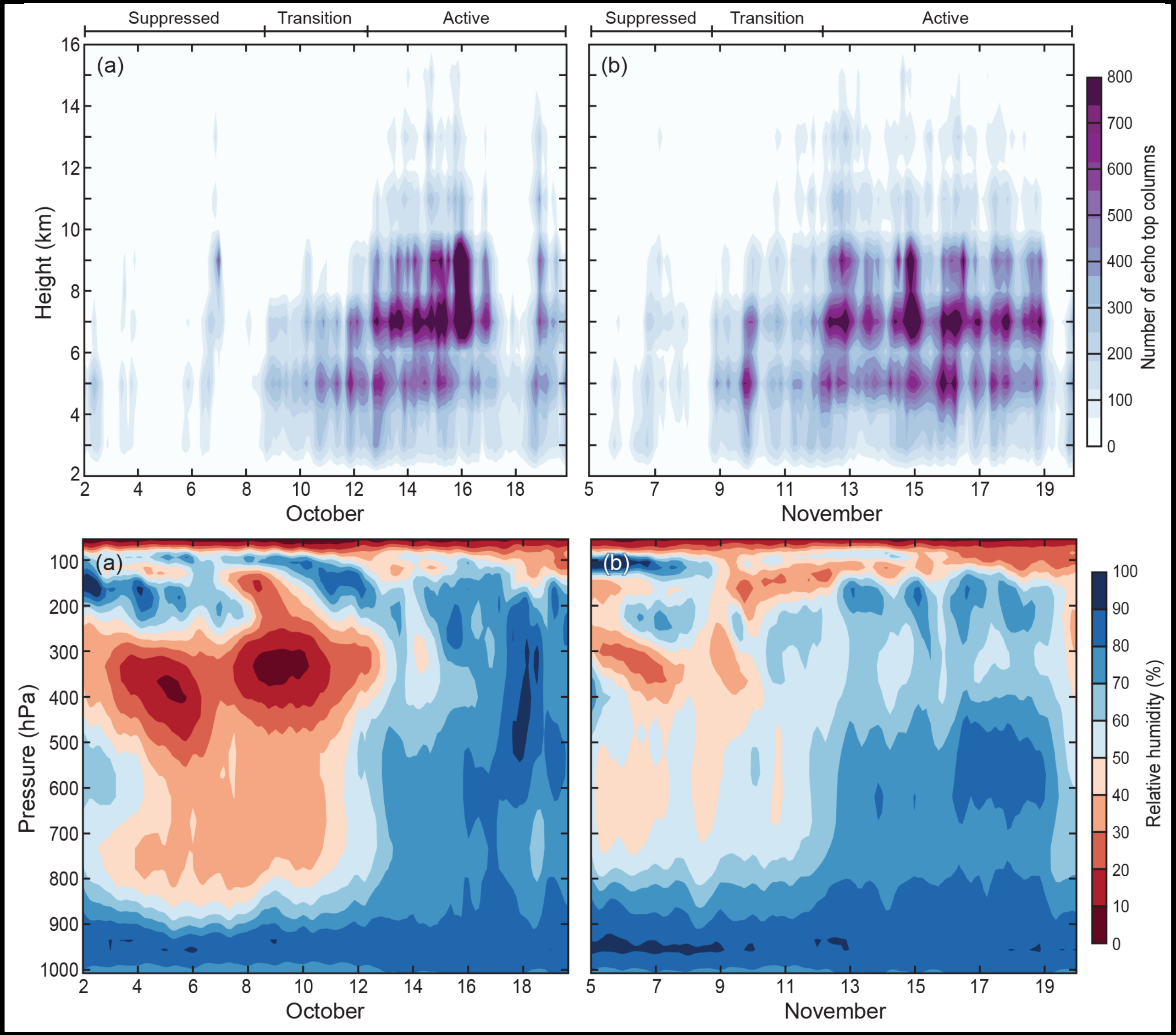
- 2 km grid spacing
- Thompson microphysics (following, e.g., Powell et al. 2012)
- MYJ PBL scheme
- Forced with ERA-I every 6 hours and NOAA RTG for sea surface temperature
- 1–20 October and 4–20 November 2011



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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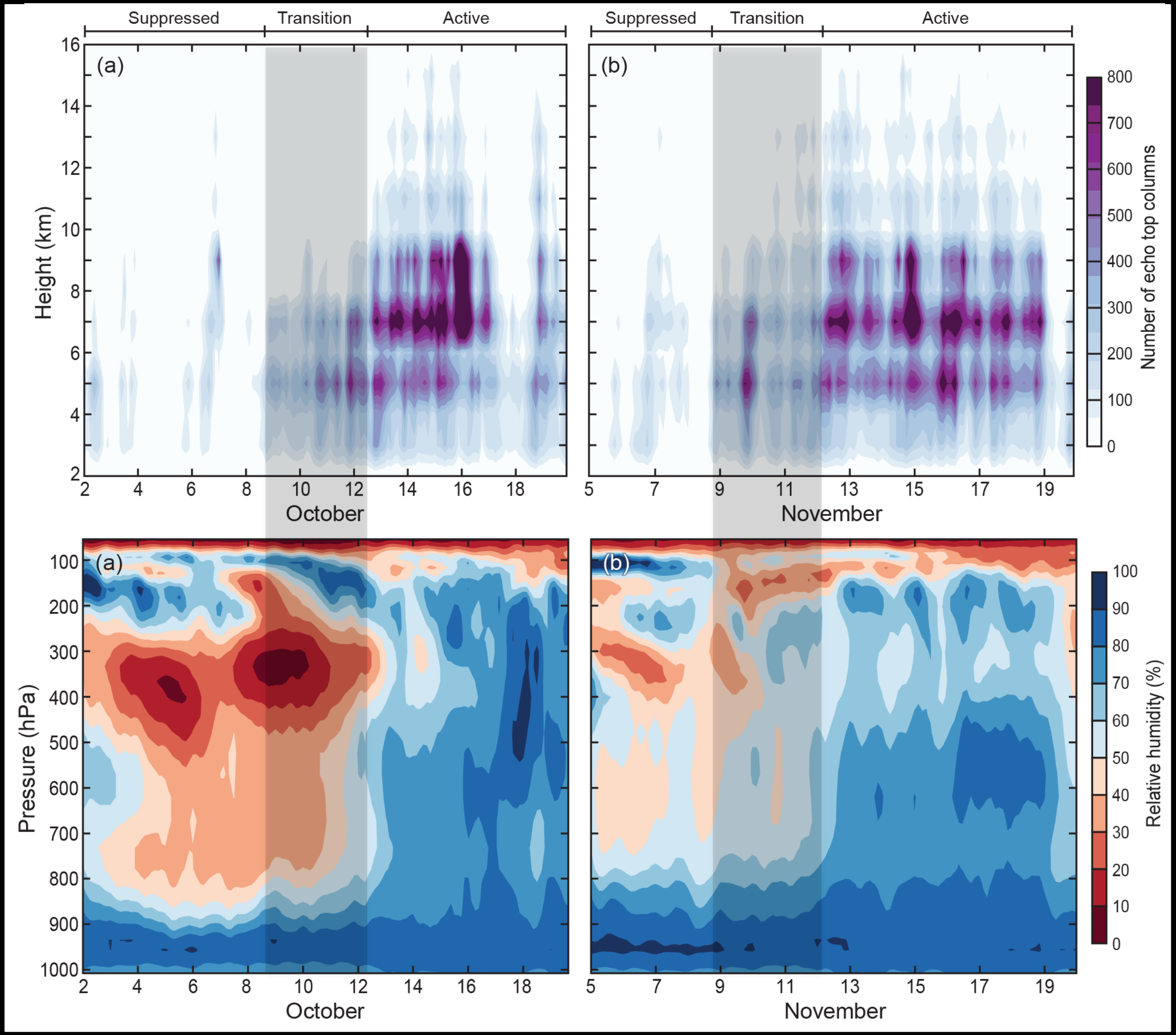
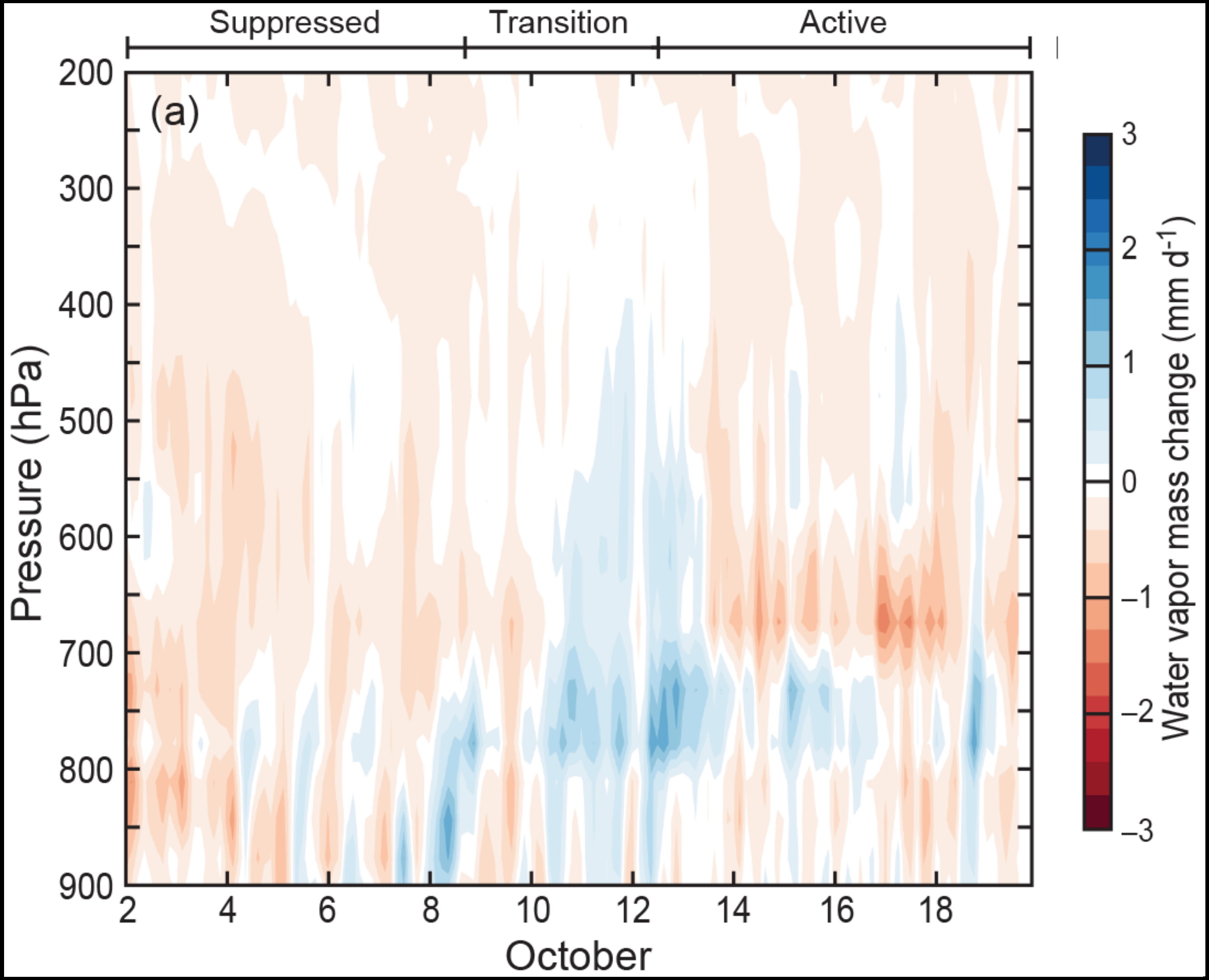
20 dBZ echo top height frequency

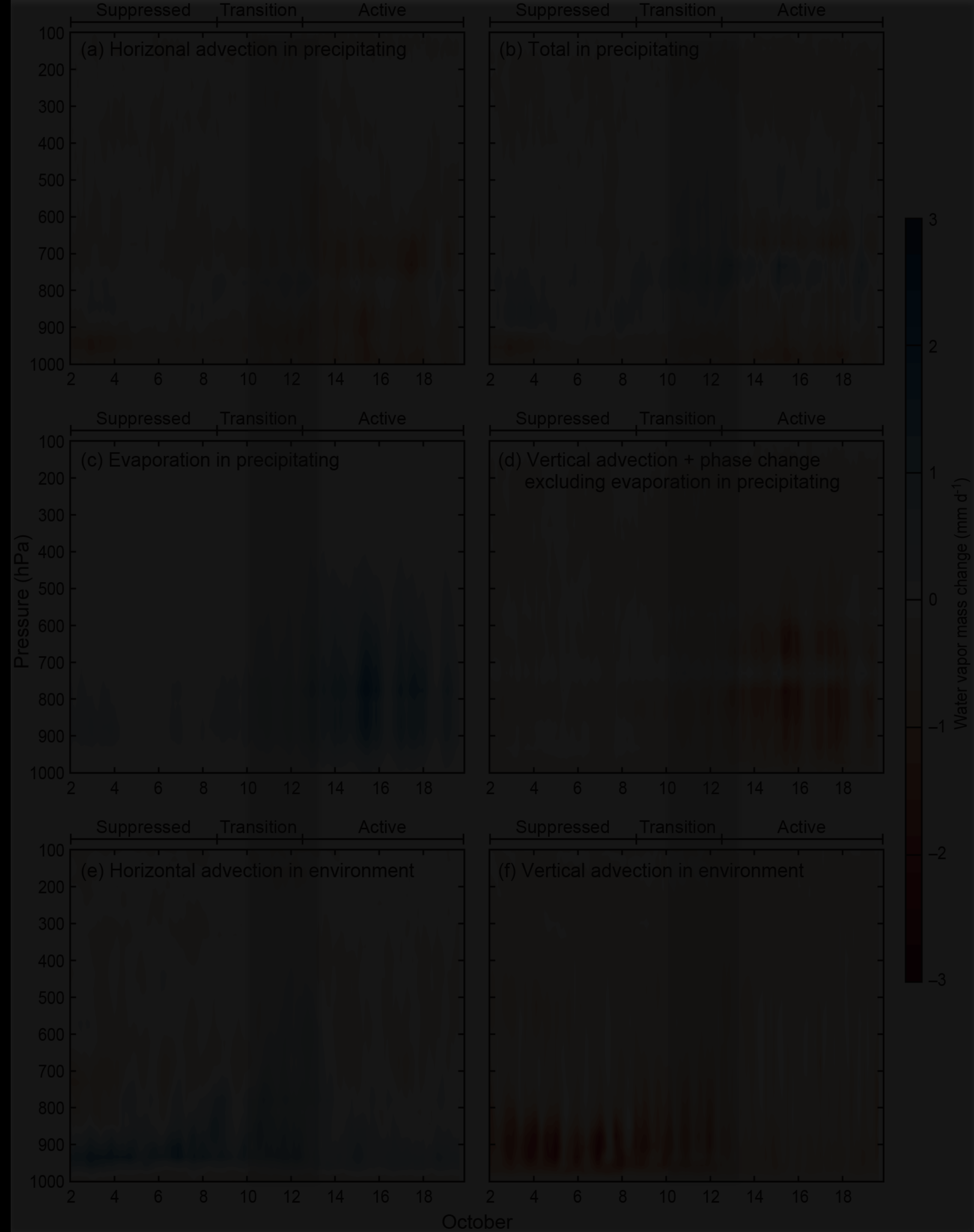
Relative Humidity




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

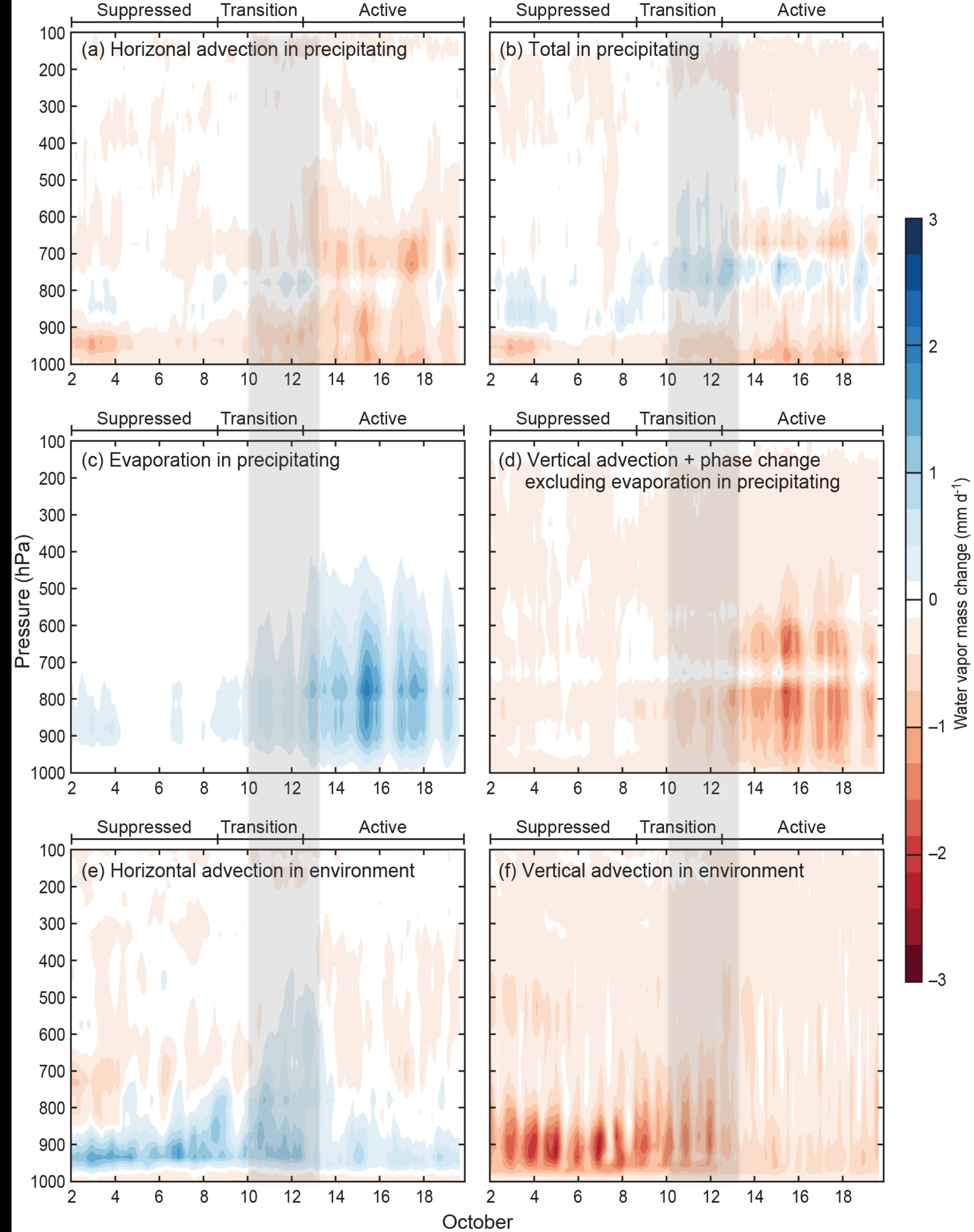
$$\frac{\partial m_{grid}}{\partial t} = -\frac{dP}{g} dx^2 (\mathbf{u} \cdot \nabla q) + M$$

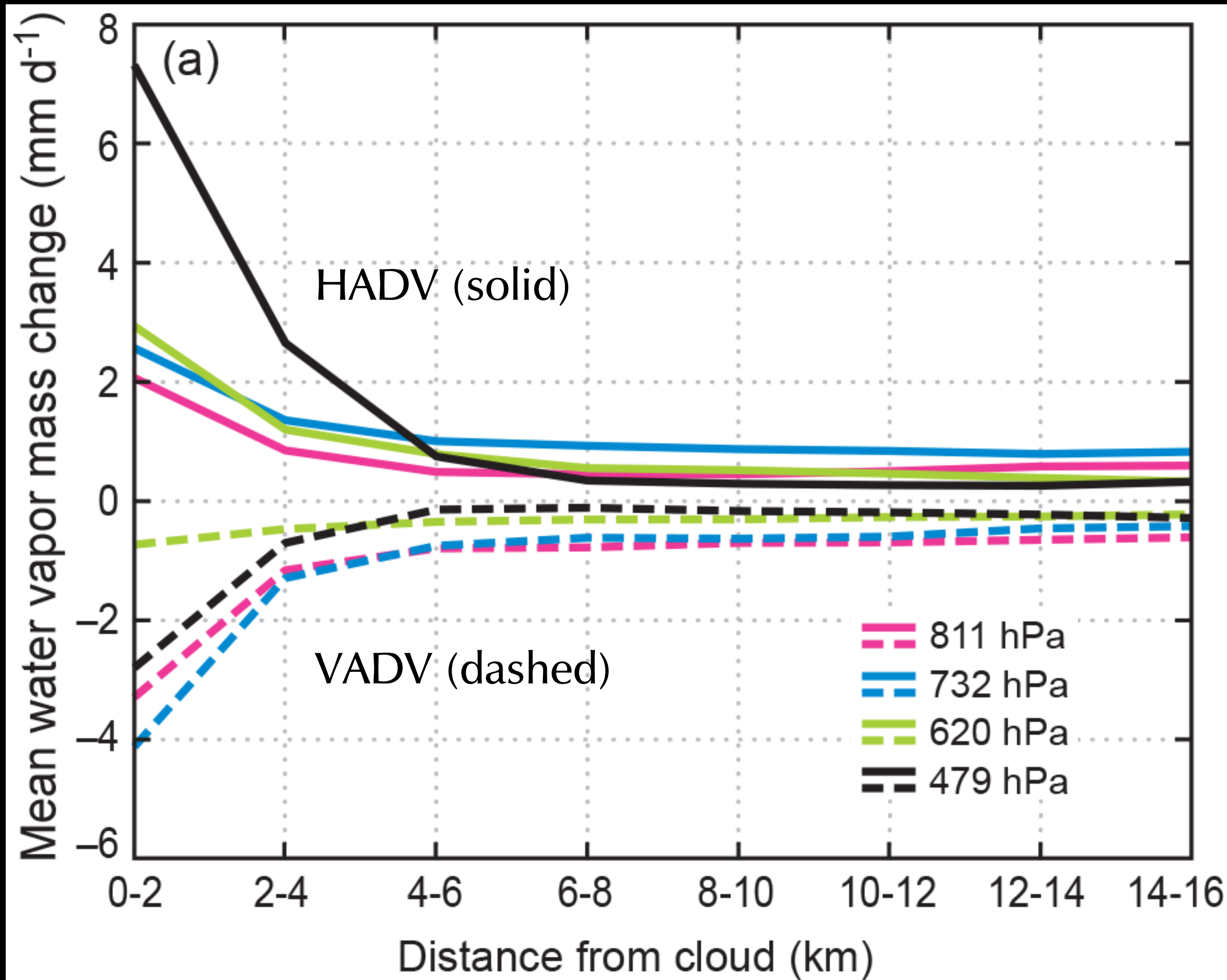
- HADV in precipitating clouds
- VADV in precipitating clouds
- Net phase change in precipitating clouds
- HADV in clear-air environment
- VADV in clear-air environment



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

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

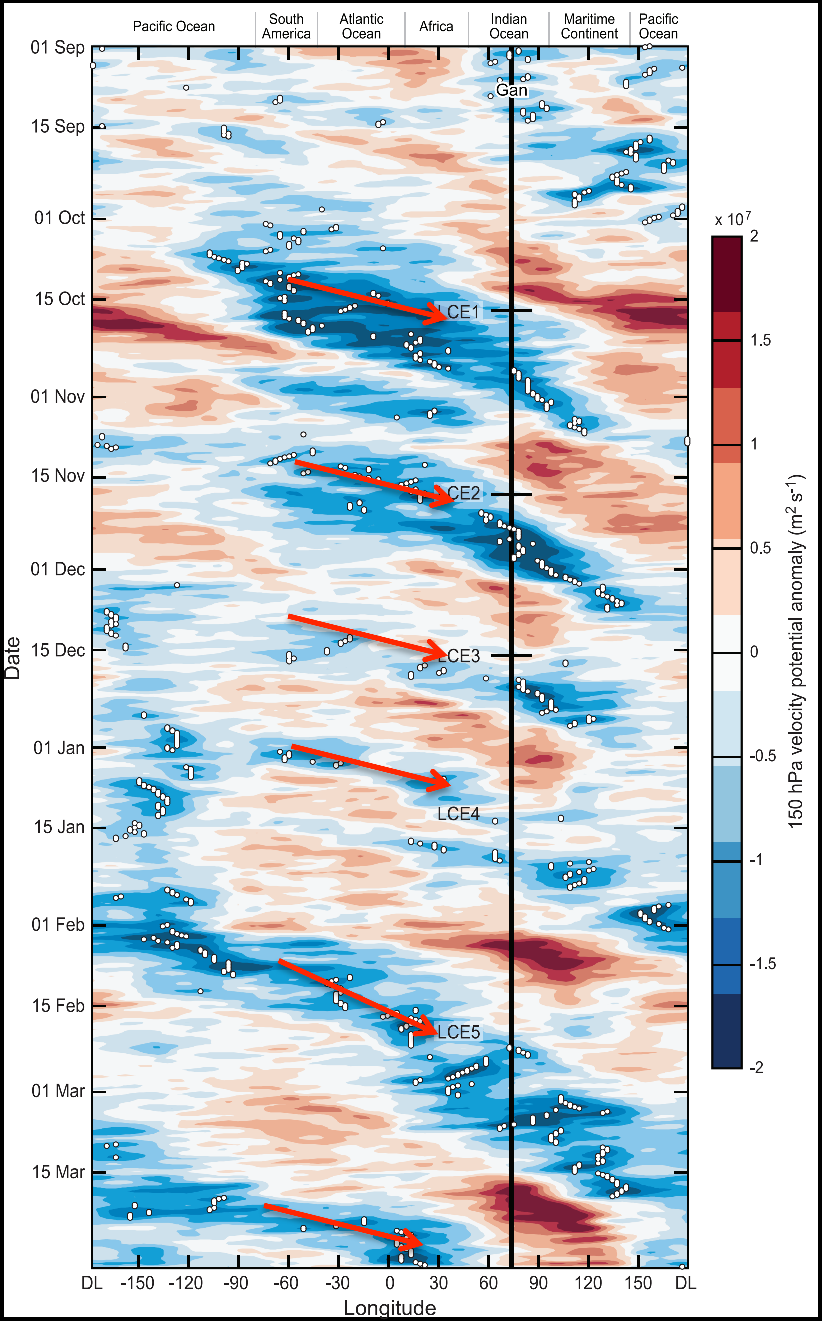



(a)
HADV (solid)
VADV (dashed)
811 hPa
732 hPa
620 hPa
479 hPa
Mean water vapor mass change (mm d-1)
8
6
4
2
0
−2
−4
−6
0-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
Distance from cloud (km)

The Circumnavigating MJO (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.

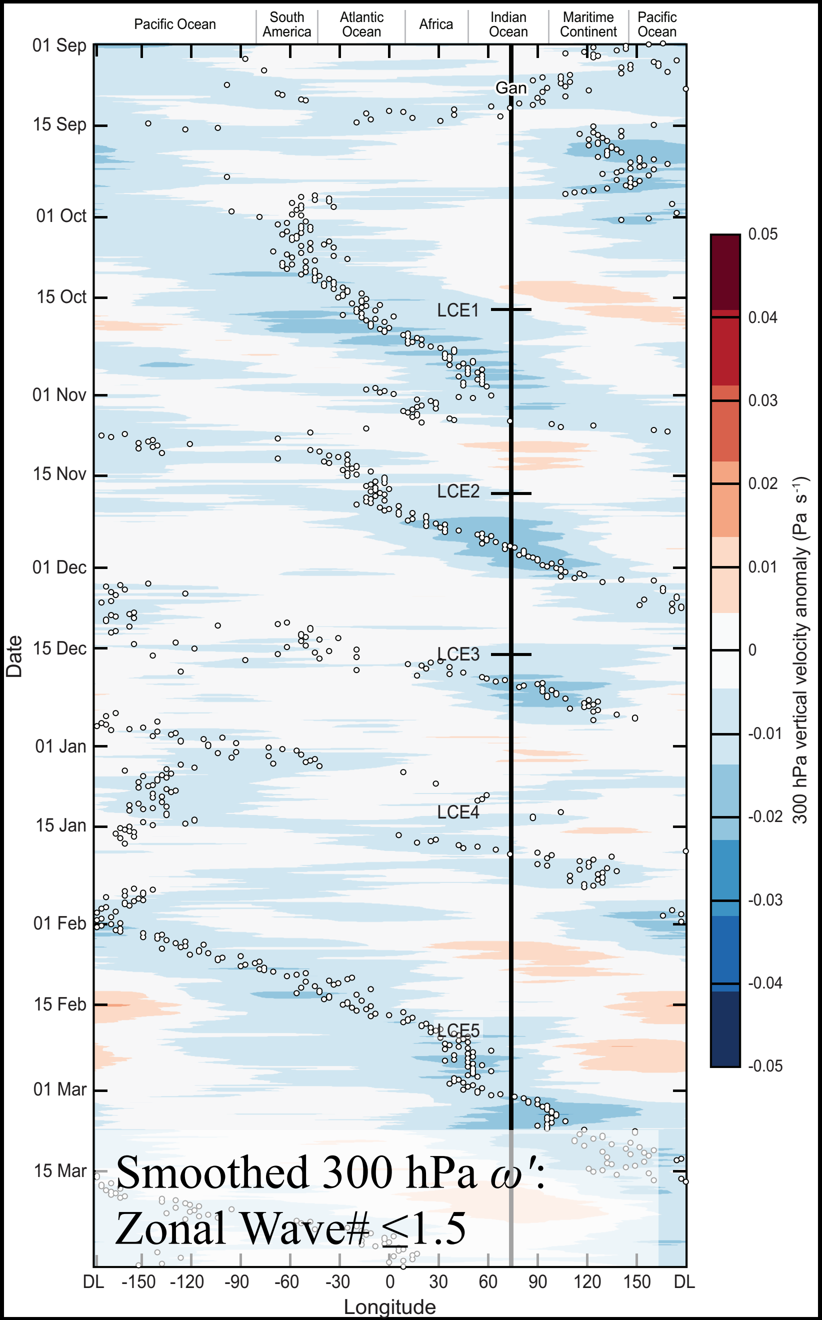
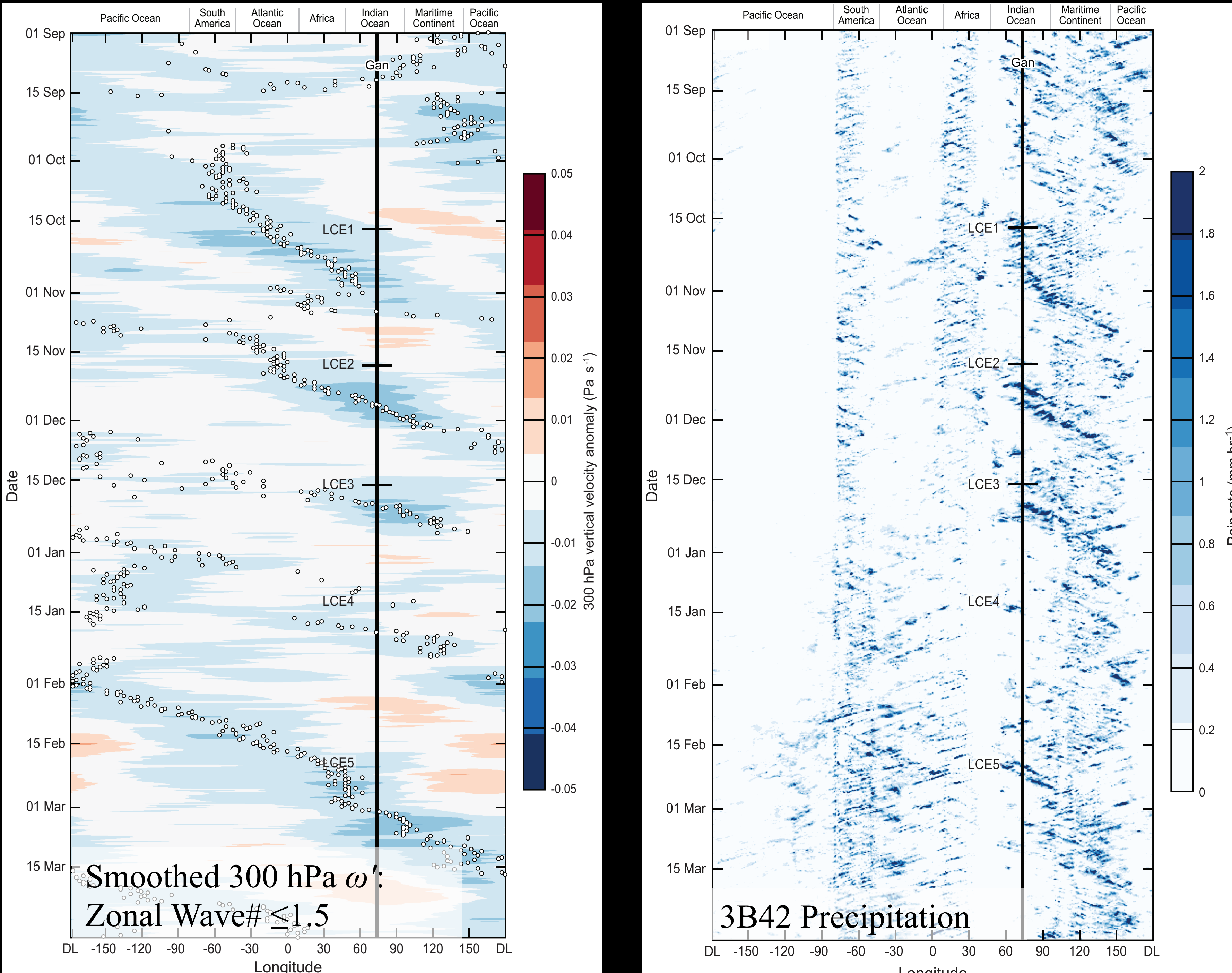
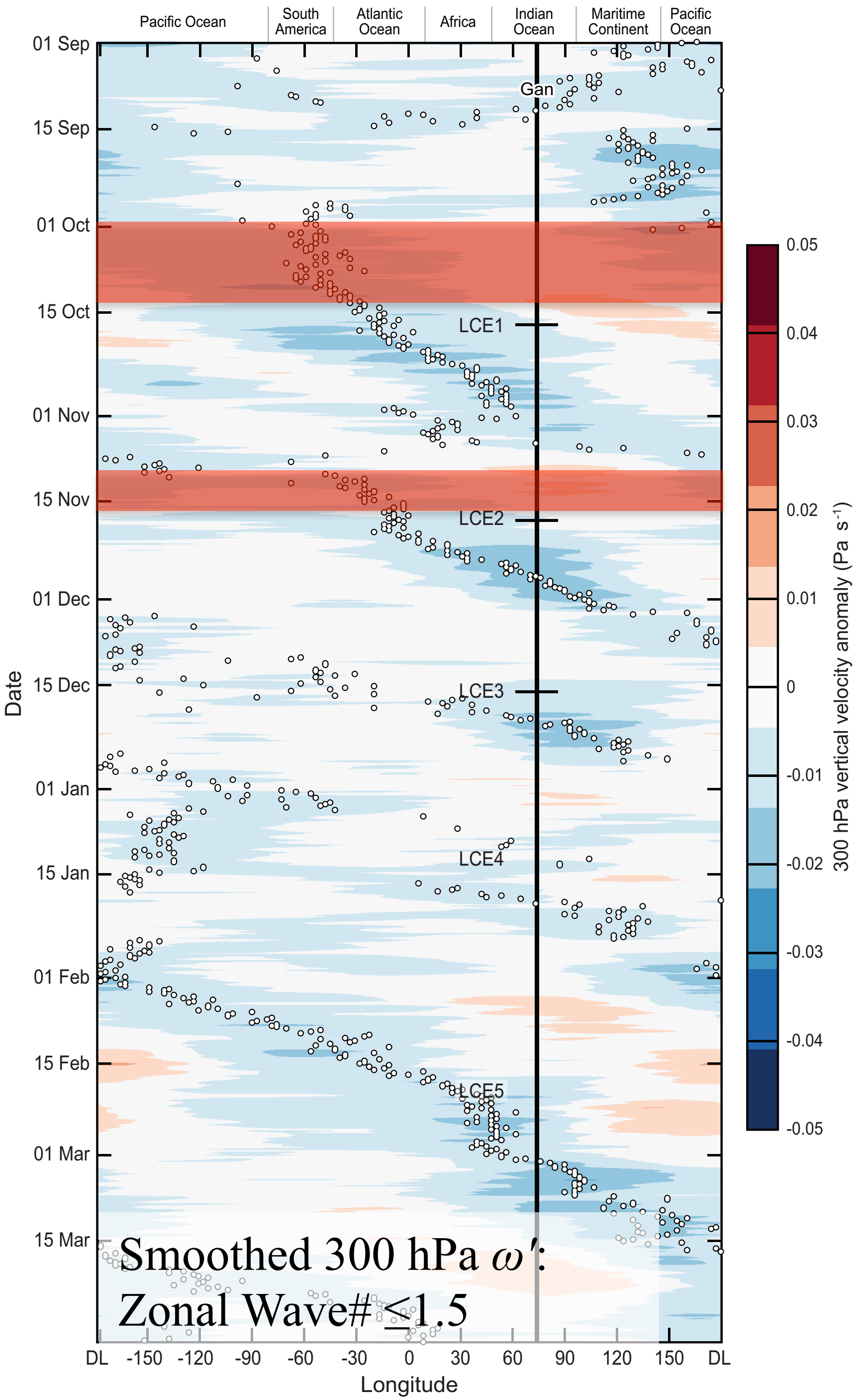


Figure: Powell and Houze (2015b)



Pacific Ocean
South America
Atlantic Ocean
Africa
Indian Ocean
Maritime Continent
Pacific Ocean
Gan
LCE1
LCE2
LCE3
LCE4
LCE5
Date
Longitude
300 hPa vertical velocity anomaly (Pa s-1)
Smoothed 300 hPa ω':
Zonal Wave# ≤1.5
Rain rate (mm hr-1)
3B42 Precipitation


Pacific Ocean
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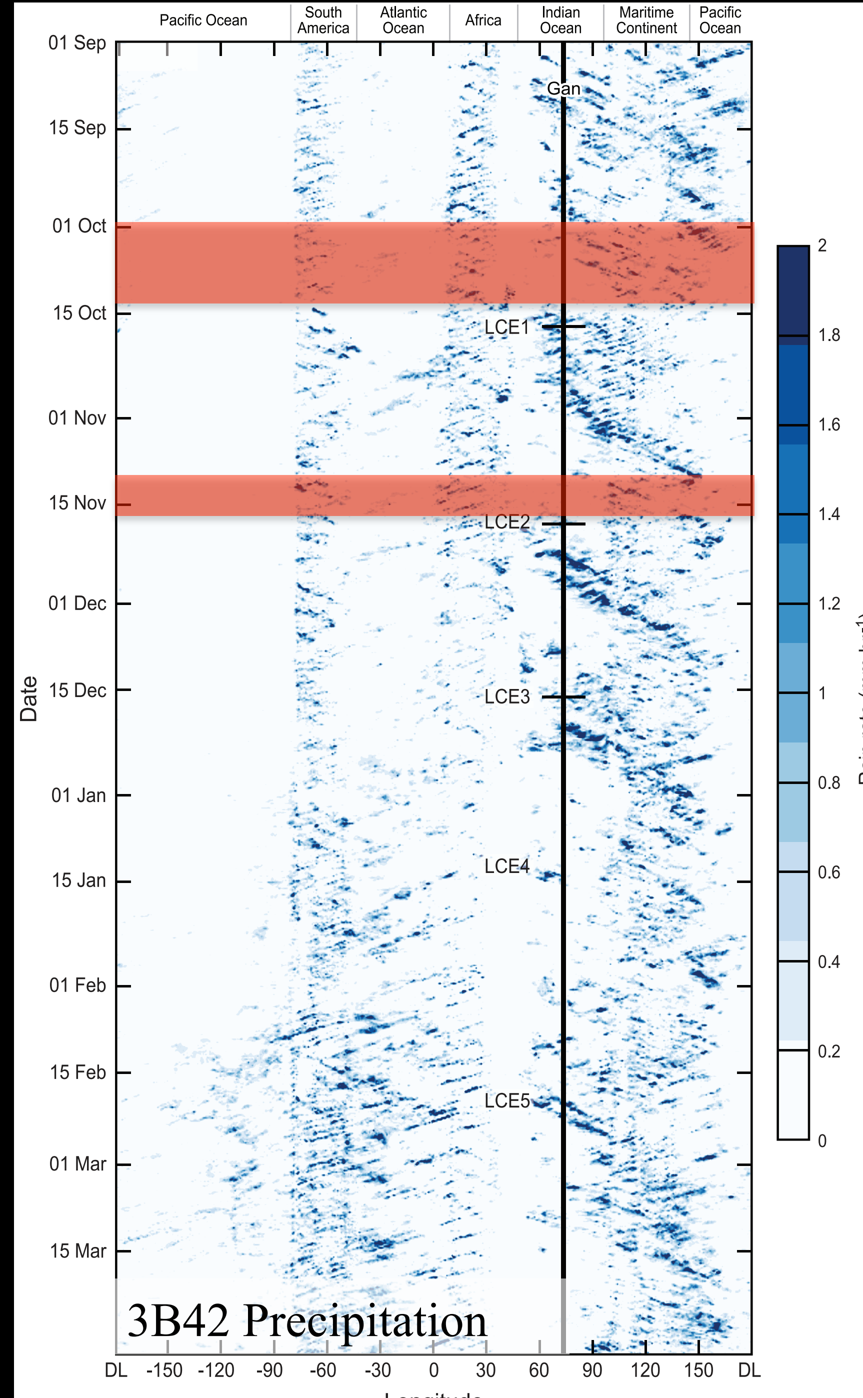
Pacific Ocean
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Pacific Ocean
Gan
LCE1
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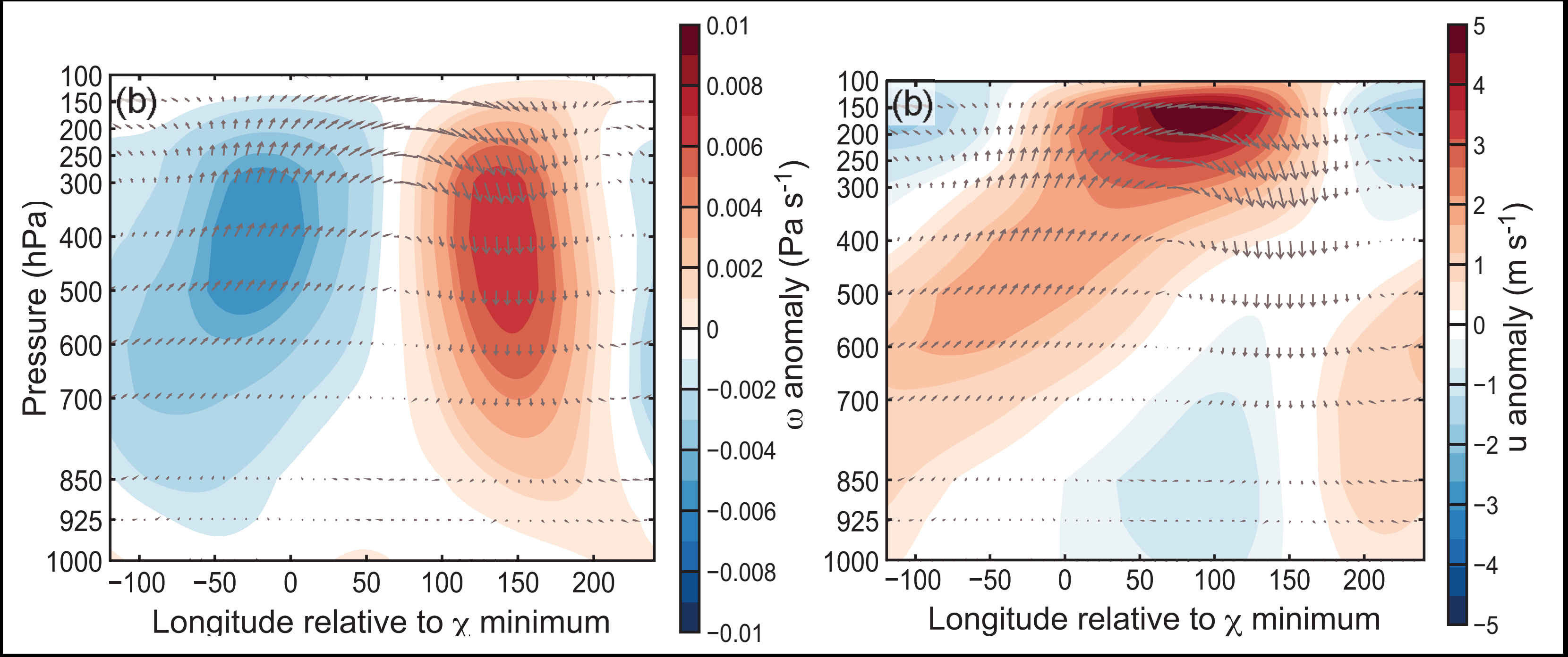
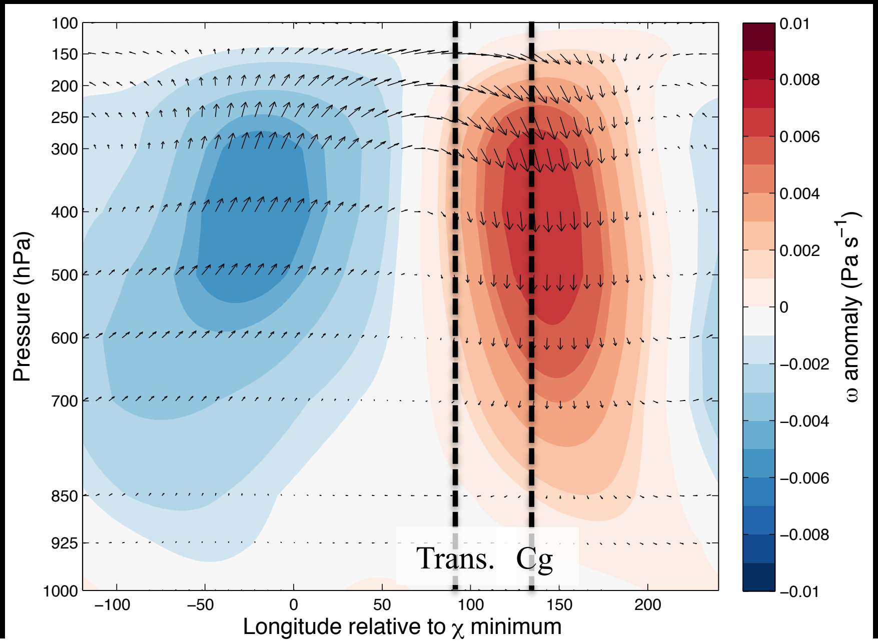
LCE3
LCE4
LCE5
Date
Longitude
Rain rate (mm hr-1)
3B42 Precipitation

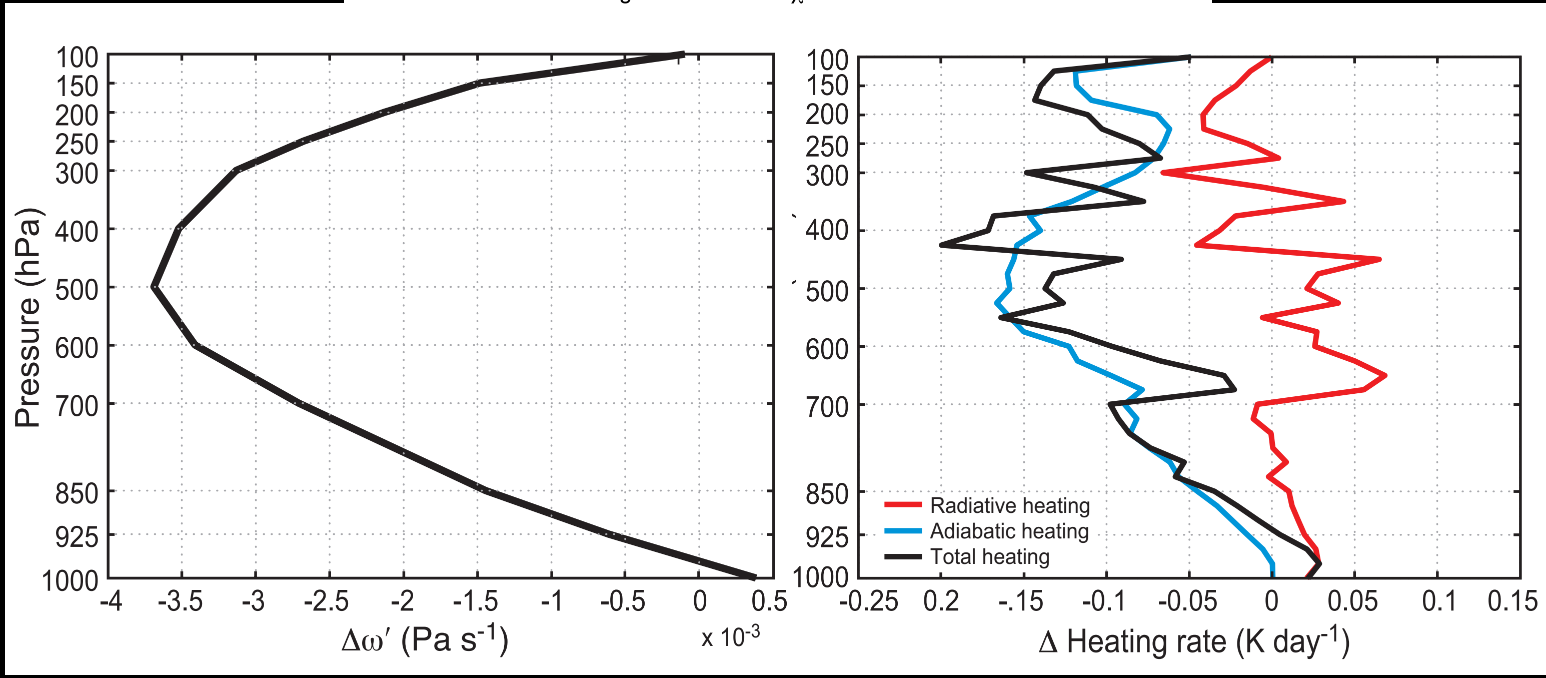
ω' u'

Wave # ≤ 1.5





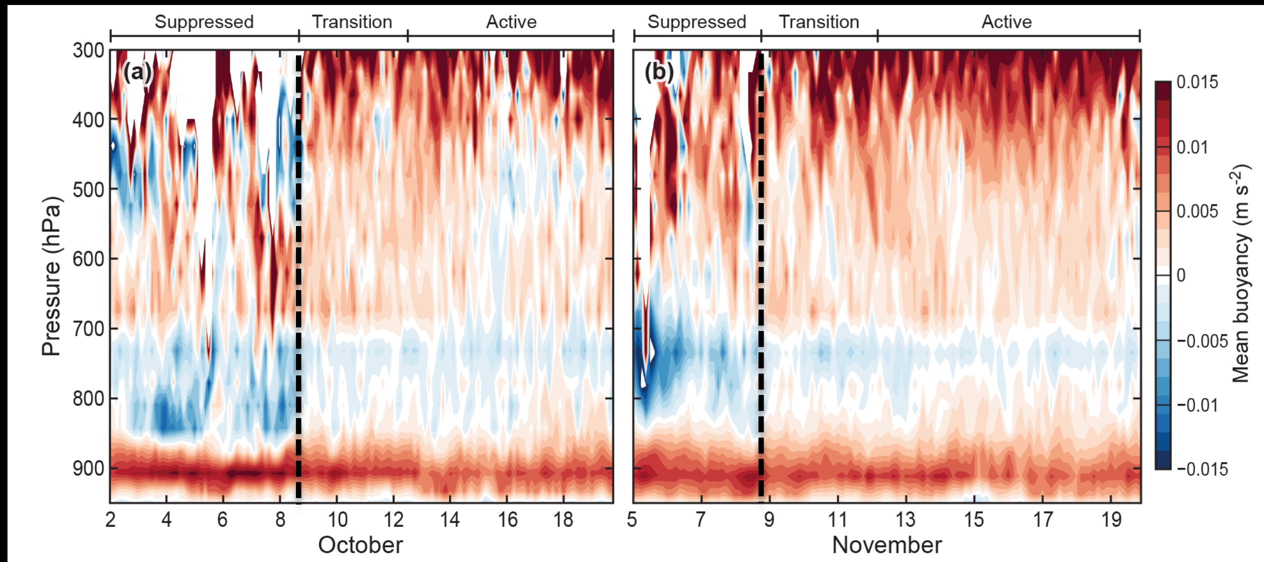
Pressure (hPa)
Longitude relative to χ minimum
ω anomaly (Pa s⁻¹)
Trans.
Cg

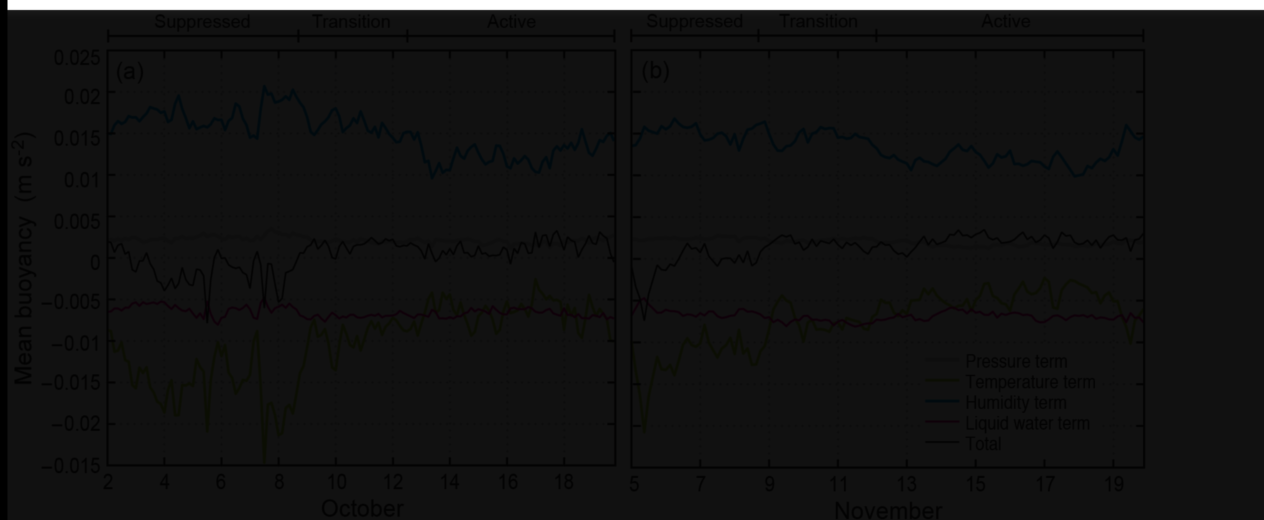


Pressure (hPa)
Δω′ (Pa s-1)
x 10-3
Radiative heating
Adiabatic heating
Total heating
Δ Heating rate (K day-1)

Powell (2016)

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

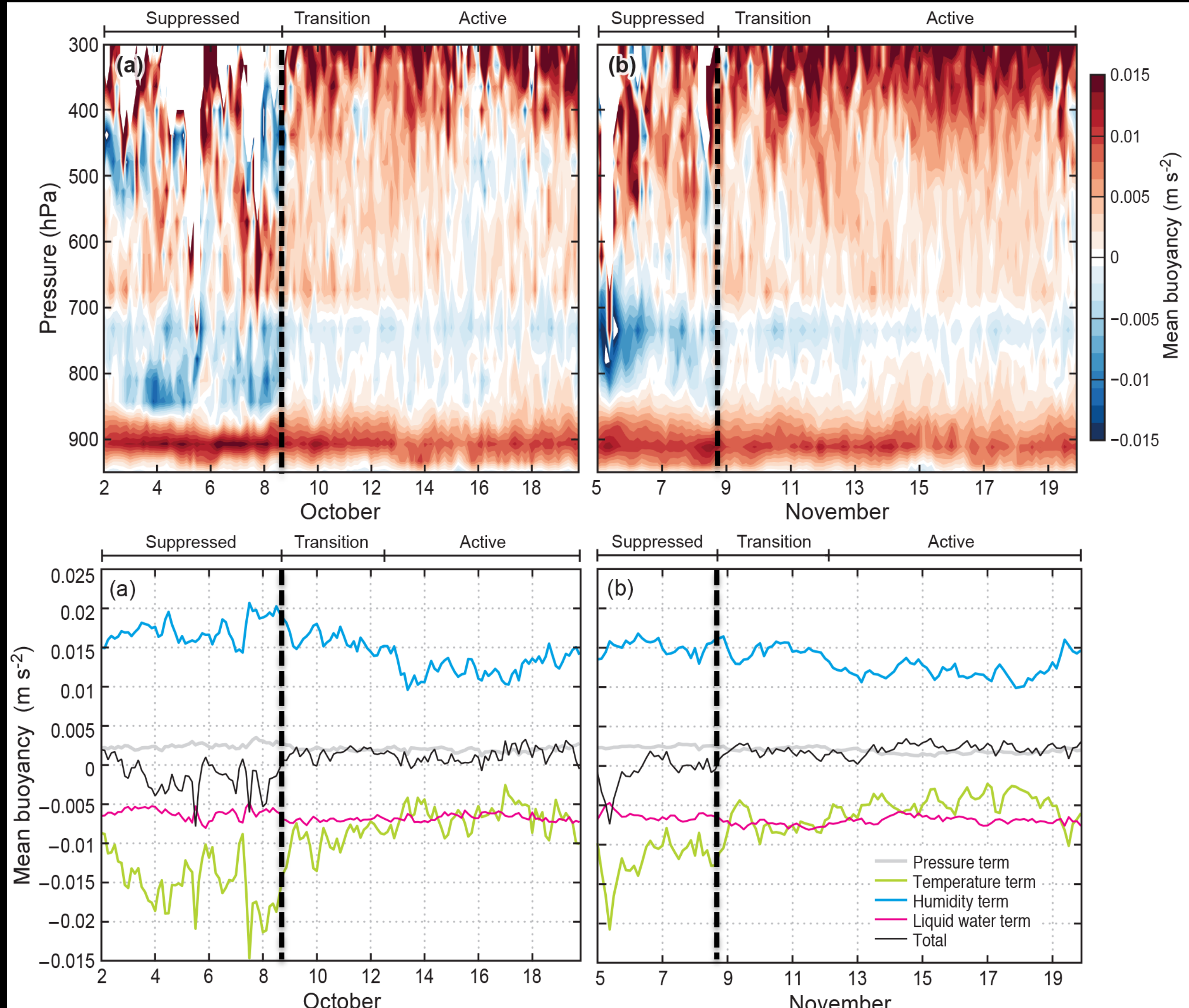




$$B \approx g\left(\underbrace{\frac{T^*}{T_e}}_{Temperature} - \overbrace{\frac{p^*}{p_e}}^{Pressure} + \underbrace{0.608\left(w^*\right)}_{Vapor} - \overbrace{w_H}^{Hydrometeor}\right)$$

Green Gray Blue Red

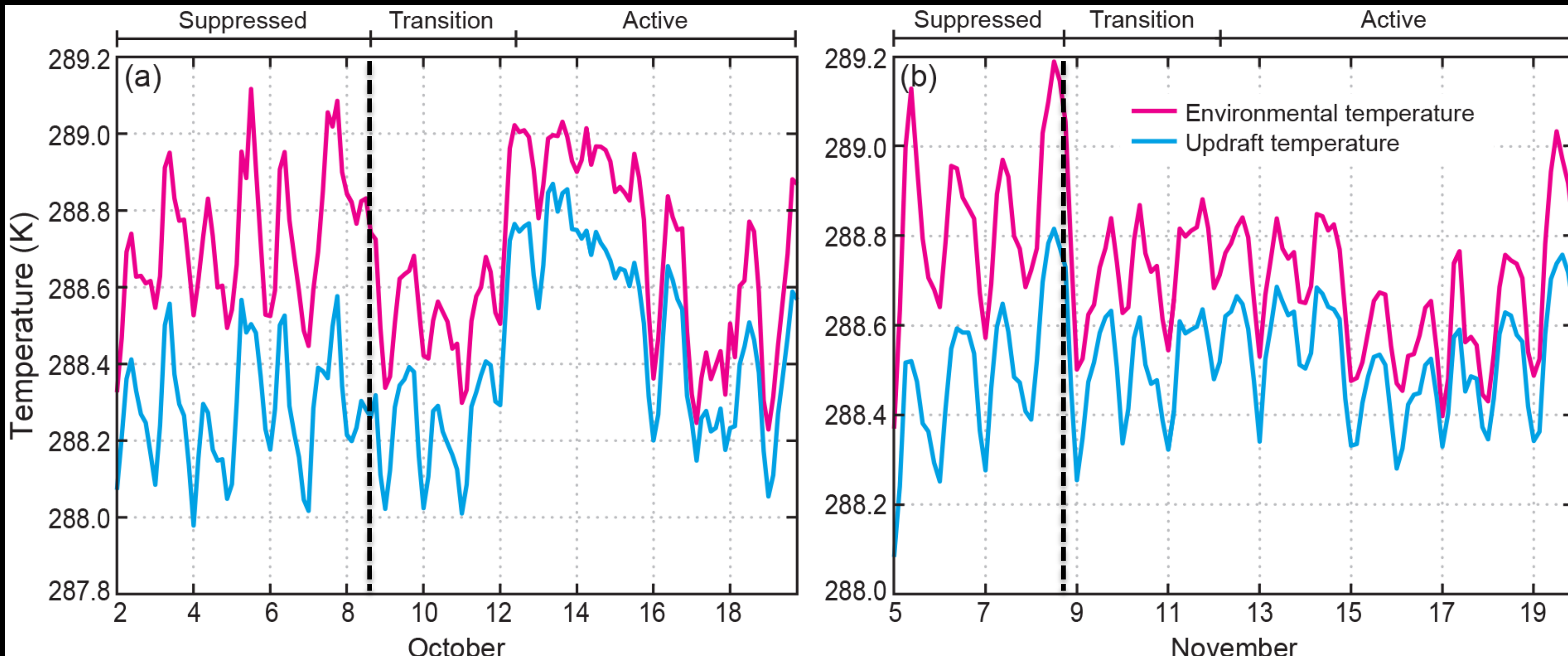
Individual terms in buoyancy equation: Mean in 700–850 mb layer



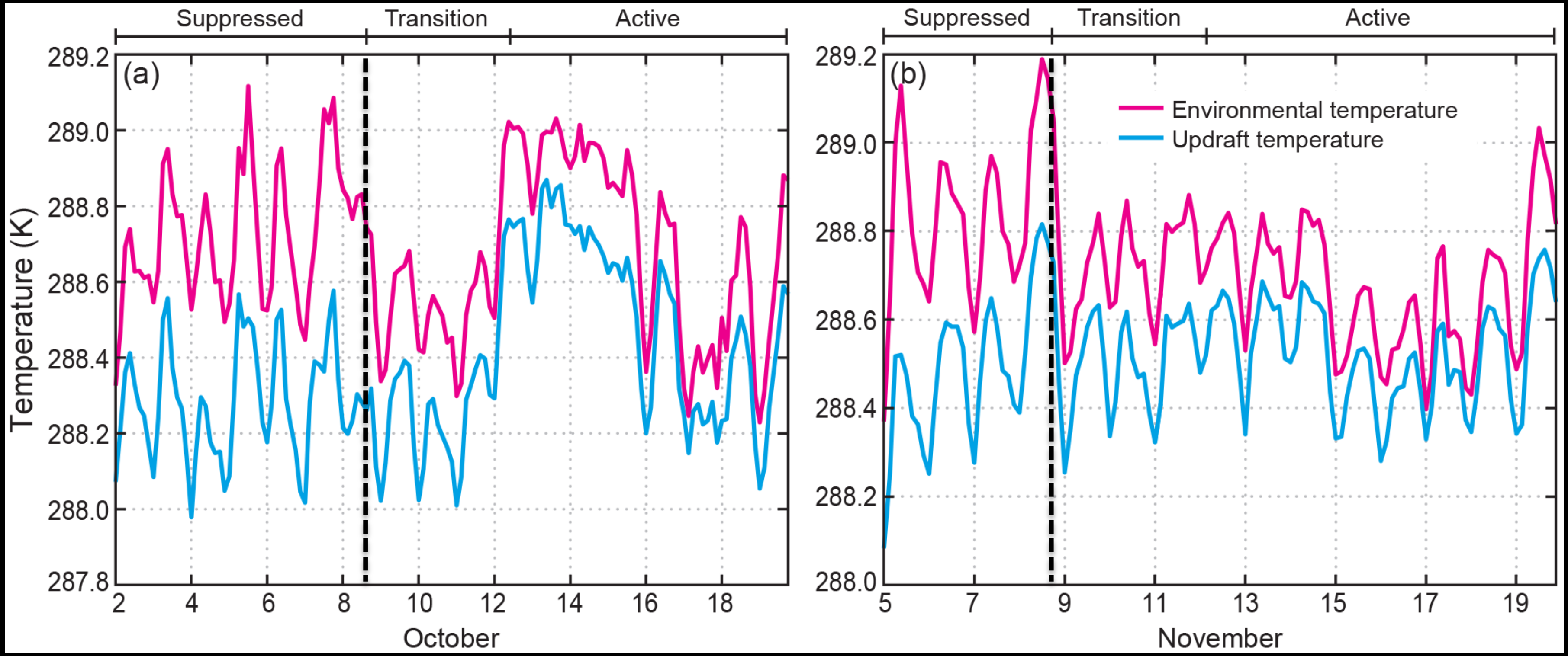
$$B \approx g\left(\underbrace{\frac{T^*}{T_e}}_{Temperature} - \overbrace{\frac{p^*}{p_e}}^{Pressure} + \underbrace{0.608\left(w^*\right)}_{Vapor} - \overbrace{w_H}^{Hydrometeor}\right)$$

Green Gray Blue Red

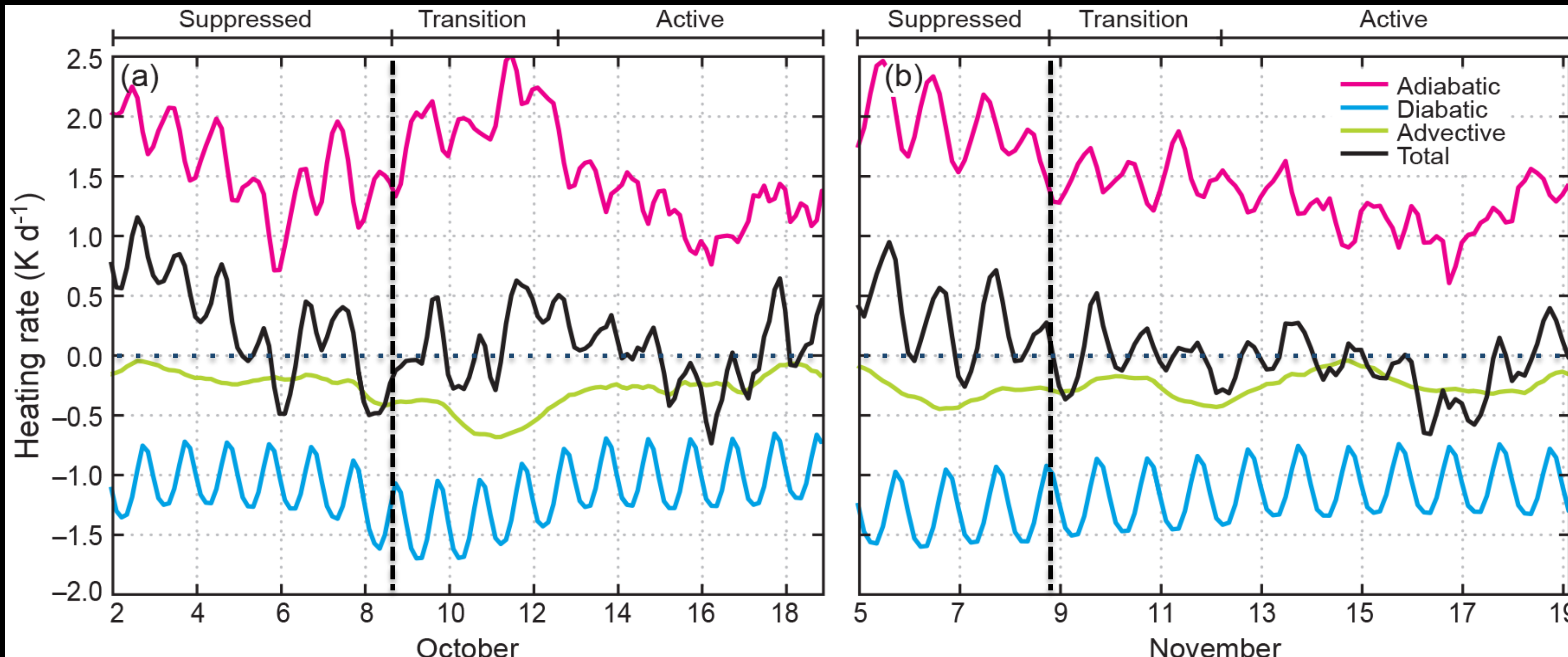
Mean 700–850 mb temperature



Mean 700–850 mb temperature

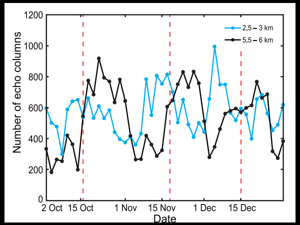


Changes in environmental temperature at start of transition periods are less than 1K!

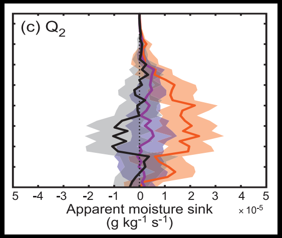


$$\frac{\partial T}{\partial t} = \underbrace{-\mathbf{u}_{\mathrm{h}} \cdot \nabla T}_{advective} \overbrace{-w\left(\frac{g}{c_p} + \Gamma\right)}^{adiabatic} + \underbrace{\frac{J}{c_p}}_{diabatic}$$

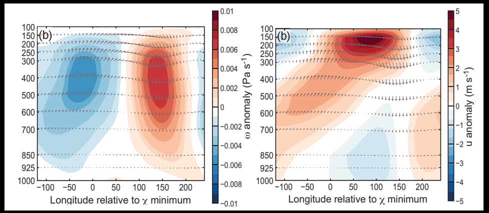
Conclusions



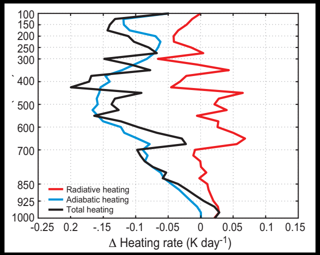
- 3–7 day build up in cloud population during transition periods prior to MJO convective onset.



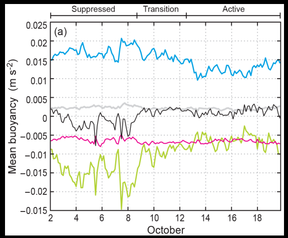
- During transition periods, moderately deep clouds moisten environment via evaporation, making environment conducive to deeper convection.



- 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