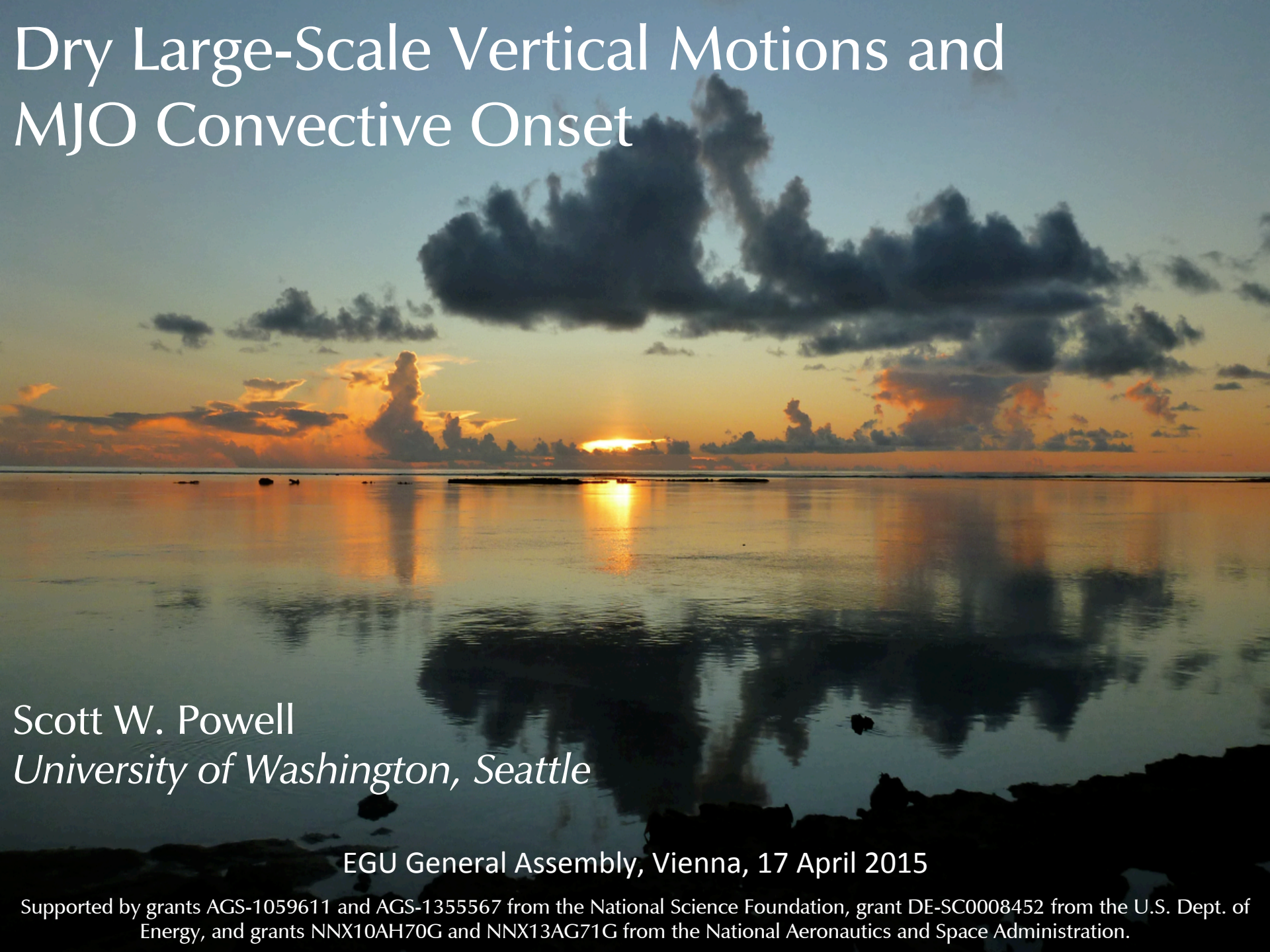
Dry Large-Scale Vertical Motions and MJO Convective Onset



Scott W. Powell
University of Washington, Seattle

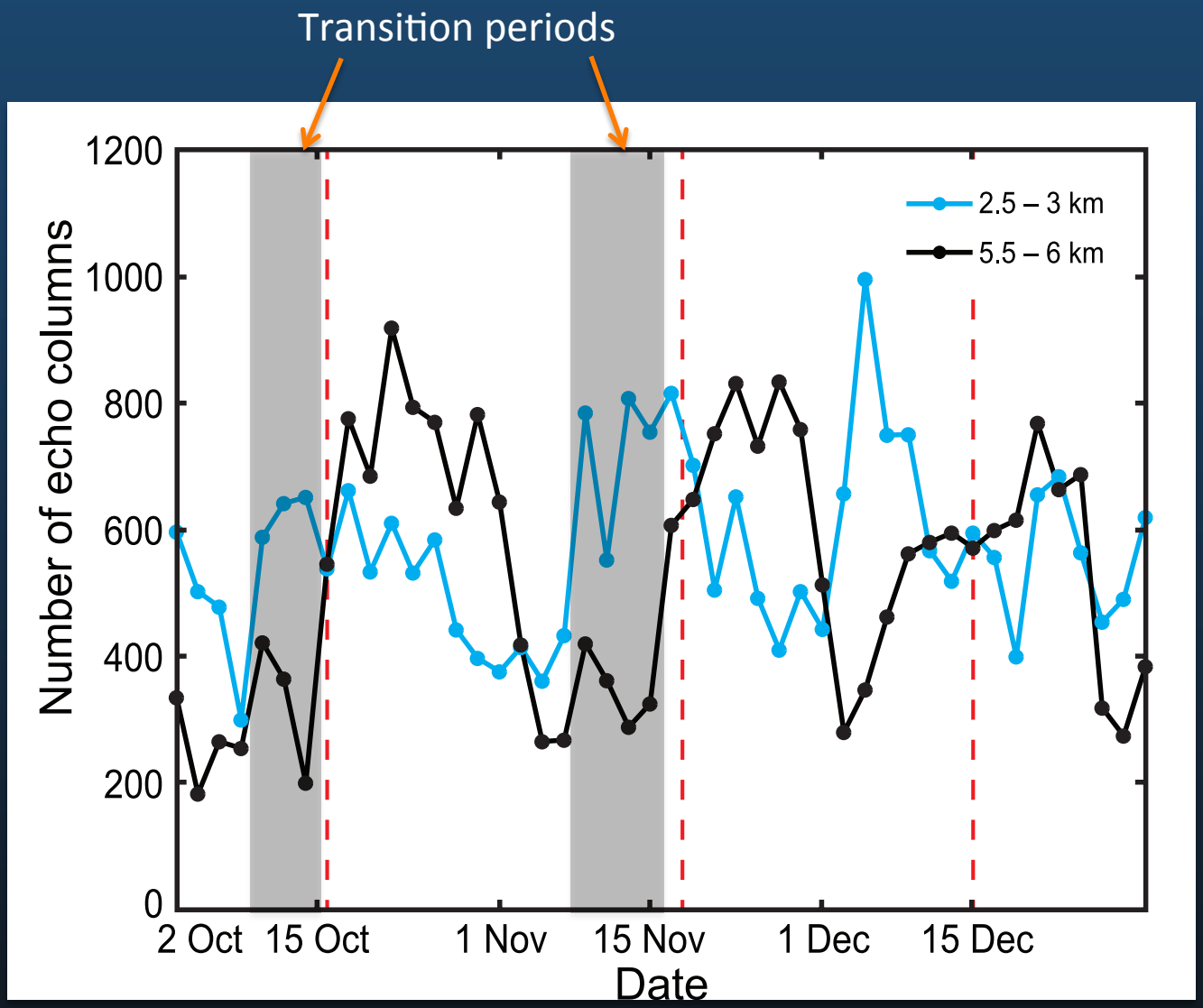
EGU General Assembly, Vienna, 17 April 2015

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.

Moistening by Cumulonimbi

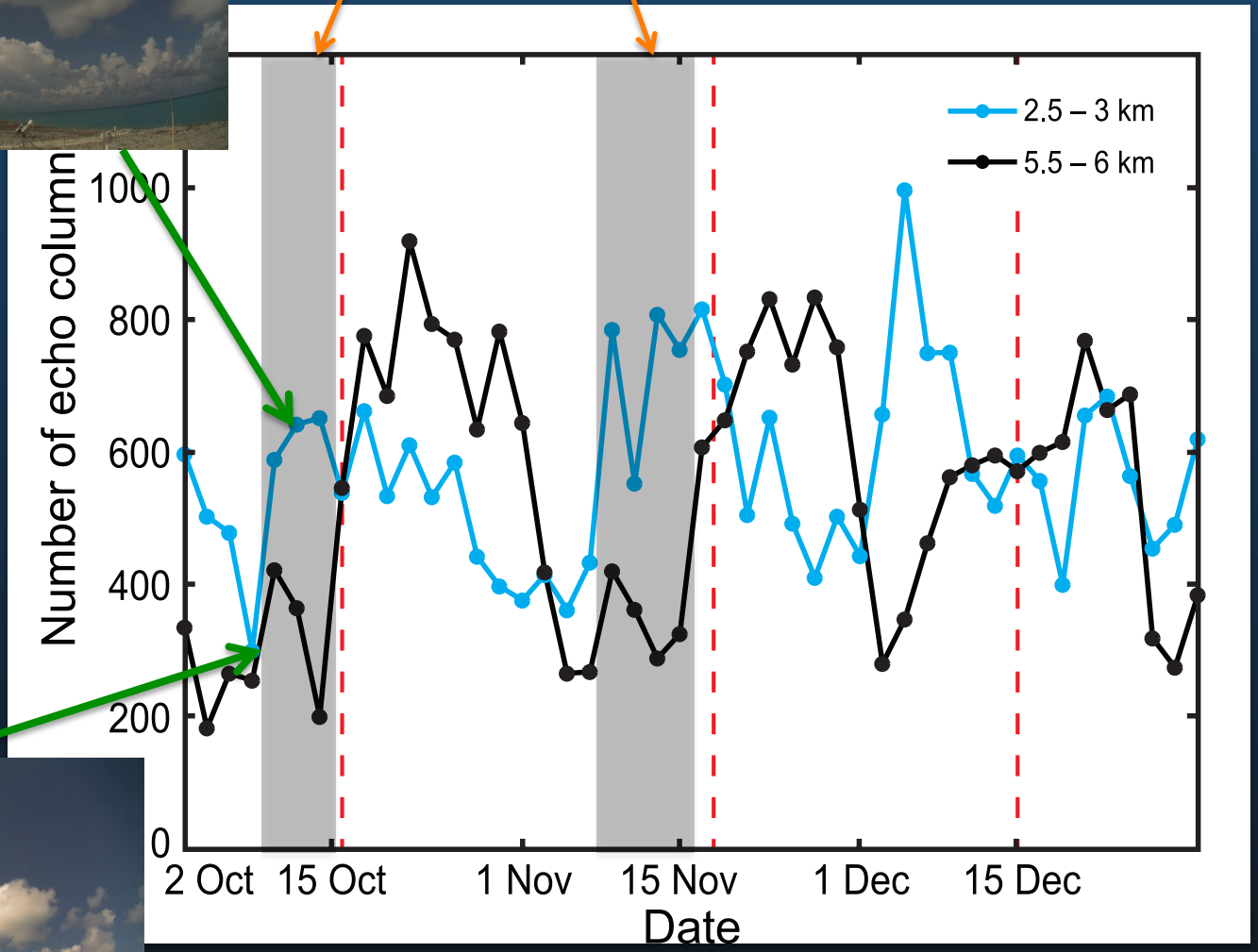

S-Pol North NetCam XL 2011-Oct-08 09:59:55 UTC
Exposure: 433 Internal Temp(F): 128.3

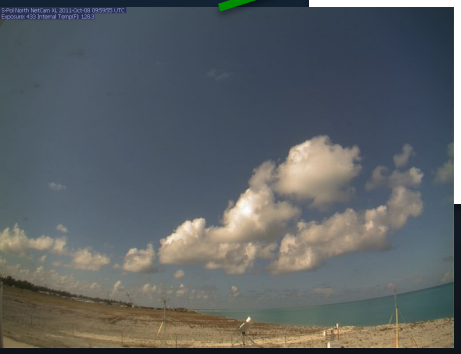

S-Pol North NetCam XL 2011-Oct-12 09:29:58 UTC
Exposure: 370 Internal Temp(F): 122.9



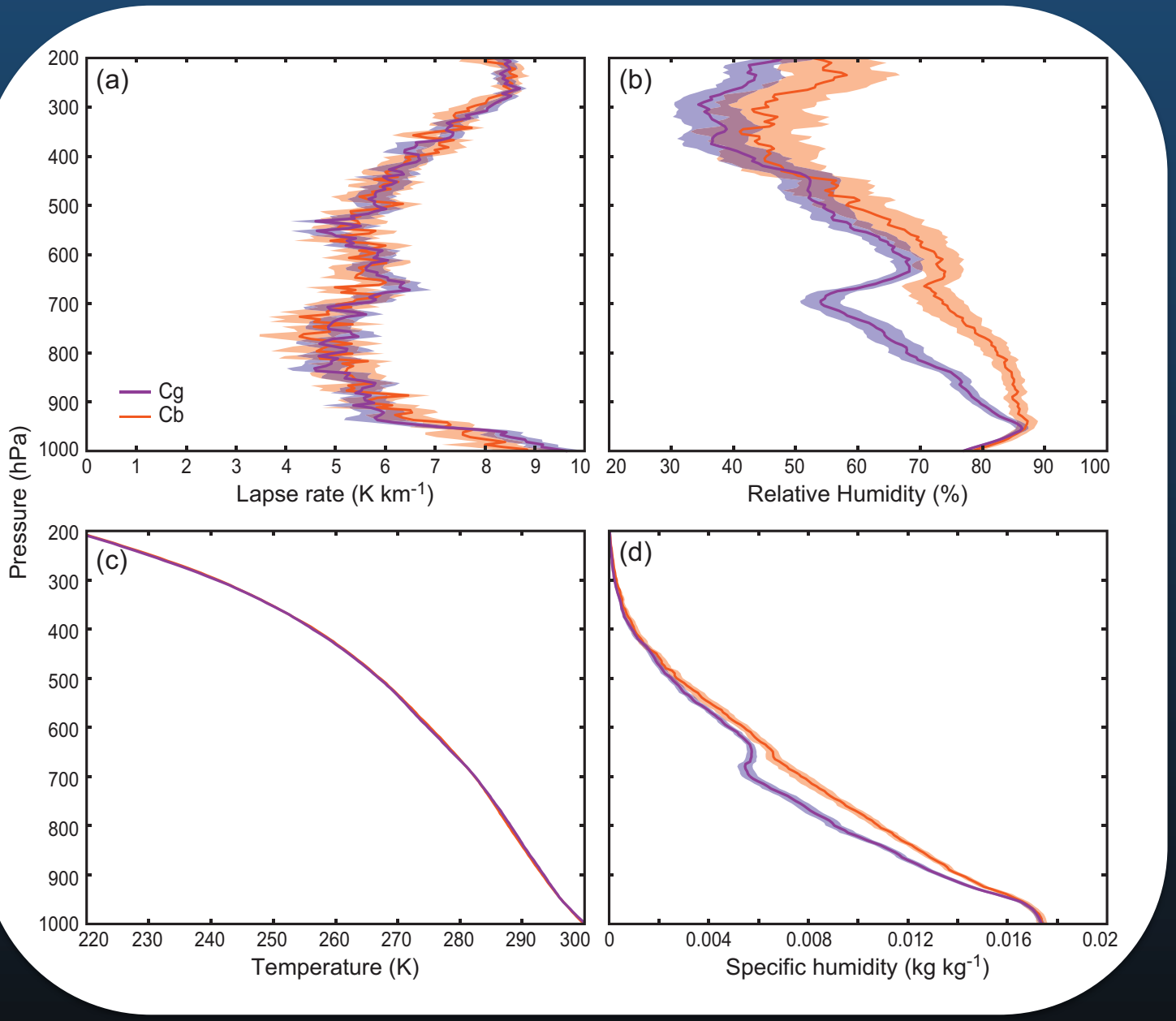
TRMM 20dBZ echo tops: 9N–9S; 60–100E

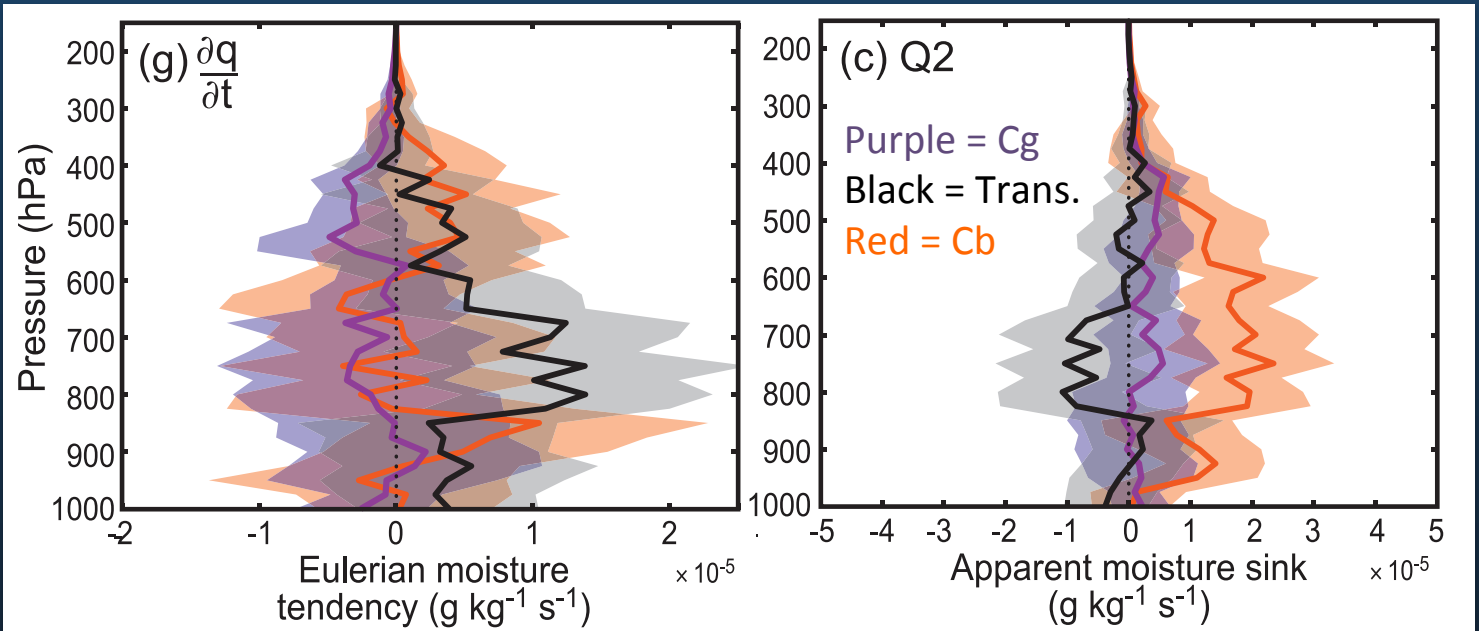
Transition periods





TRMM 20dBZ echo tops: 9N–9S; 60–100E

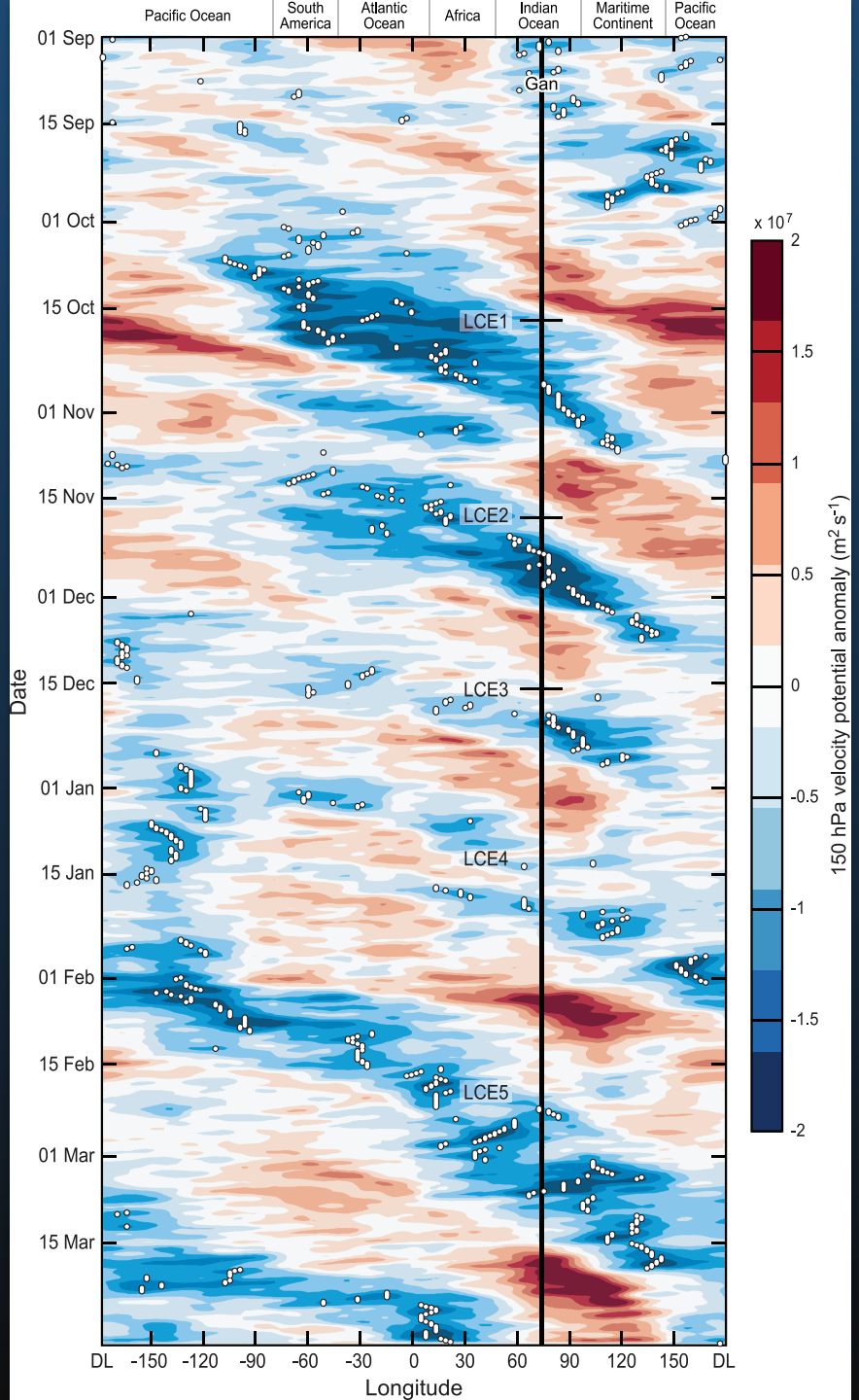

(a)
(b)
(c)
(d)
Cg
Cb
Pressure (hPa)
Lapse rate (K km^{-1})
Relative Humidity (%)
Temperature (K)
Specific humidity (kg kg^{-1})
200
300
400
500
600
700
800
900
1000
0
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
220
230
240
250
260
270
280
290
300
0
0.004
0.008
0.012
0.016
0.02



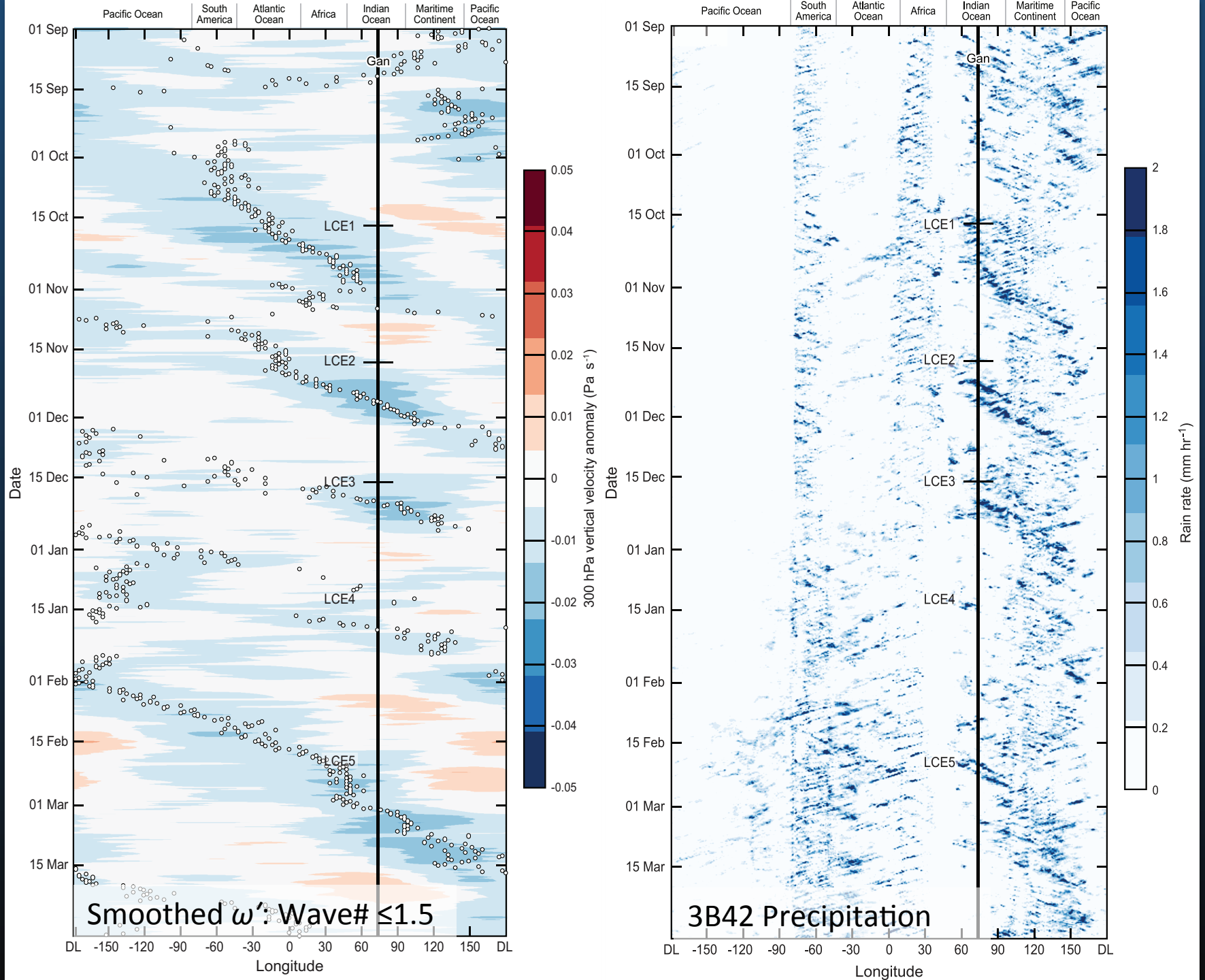
$$\frac{\partial q}{\partial t} = \mathbf{v}_h \cdot \nabla q + \omega \frac{\partial q}{\partial p} + Q_2$$

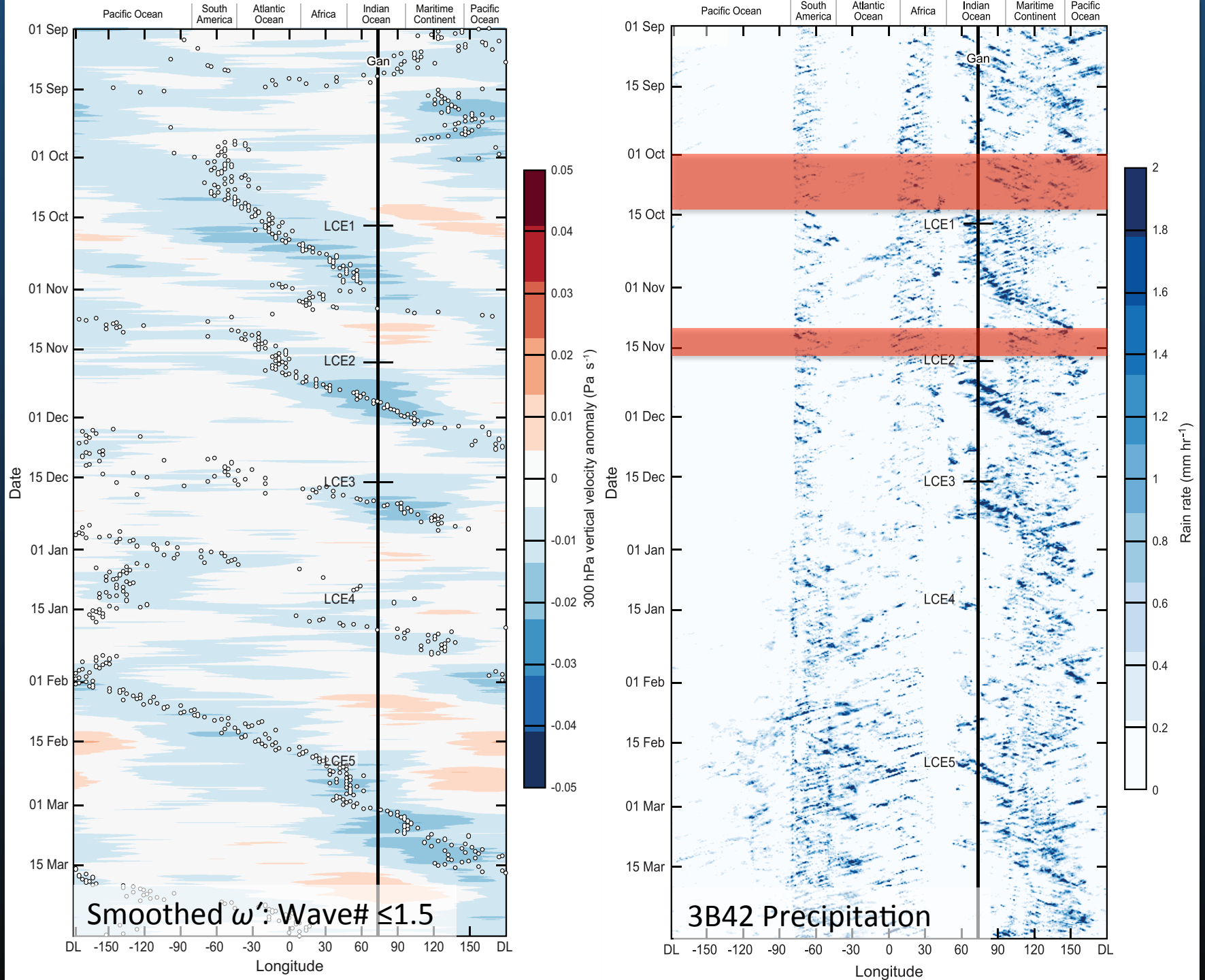
$$Q_2 = \left(\overline{c} - \overline{e}\right) + \frac{\partial}{\partial p}\left(\overline{\omega' q'}\right)$$

A Potential Mechanism for Driving Congestus Moistening


Pacific Ocean
South America
Atlantic Ocean
Africa
Indian Ocean
Maritime Continent
Pacific Ocean
Gan
LCE1
LCE2
LCE3
LCE4
LCE5
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
DL -150 -120 -90 -60 -30 0 30 60 90 120 150 DL
Longitude
x 10^7
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
150 hPa velocity potential anomaly (m^2 s^-1)

From ERA-I

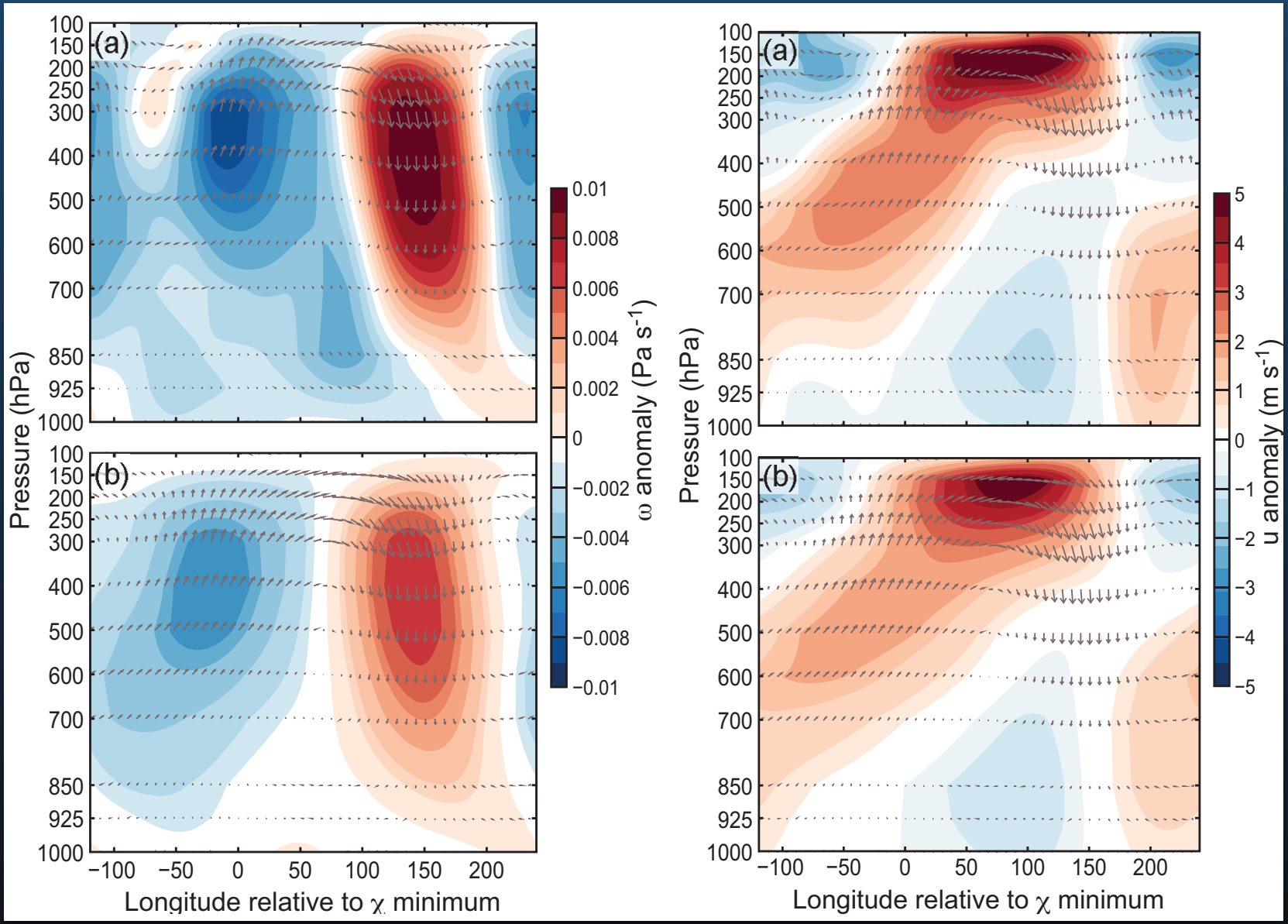

Pacific Ocean
South America
Atlantic Ocean
Africa
Indian Ocean
Maritime Continent
Pacific Ocean
01 Sep
15 Sep
01 Oct
15 Oct
01 Nov
15 Nov
01 Dec
15 Dec
01 Jan
15 Jan
01 Feb
15 Feb
01 Mar
15 Mar
Date
Gan
LCE1
LCE2
LCE3
LCE4
LCE5
DL -150 -120 -90 -60 -30 0 30 60 90 120 150 DL
Longitude
0.05
0.04
0.03
0.02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

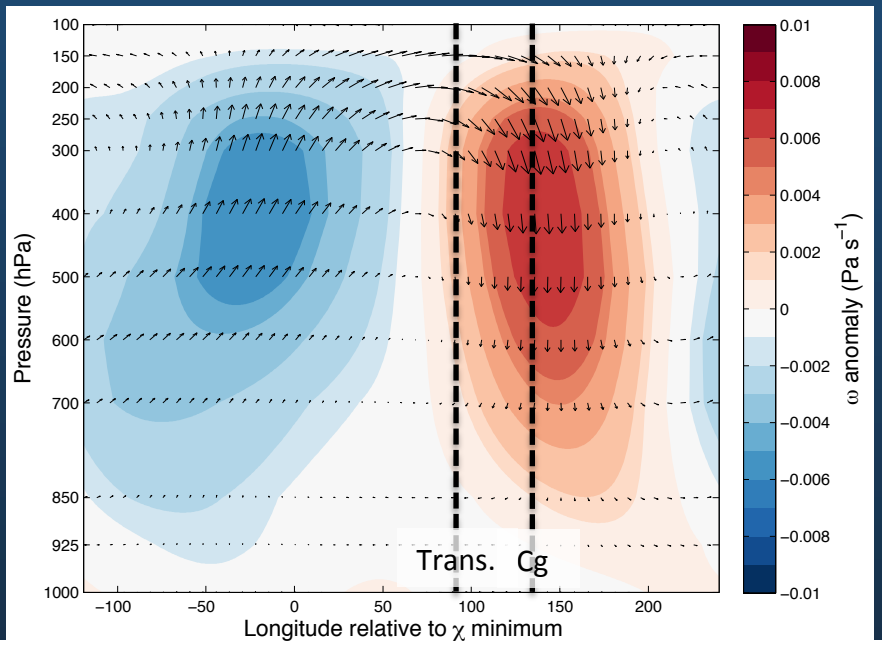

Pacific Ocean
South America
Atlantic Ocean
Africa
Indian Ocean
Maritime Continent
Pacific Ocean
01 Sep
15 Sep
01 Oct
15 Oct
01 Nov
15 Nov
01 Dec
15 Dec
01 Jan
15 Jan
01 Feb
15 Feb
01 Mar
15 Mar
Date
Gan
LCE1
LCE2
LCE3
LCE4
LCE5
DL -150 -120 -90 -60 -30 0 30 60 90 120 150 DL
Longitude
0.05
0.04
0.03
0.02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

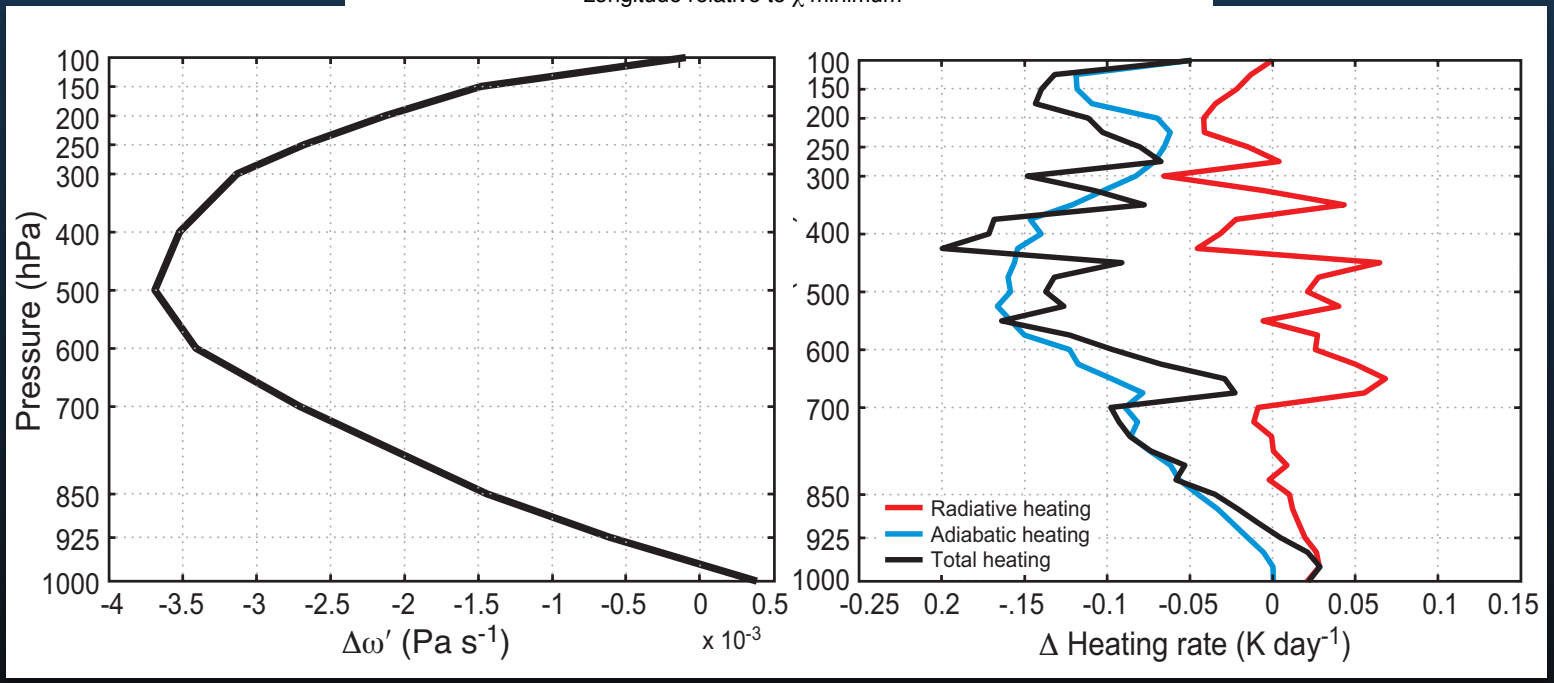
ω' u'

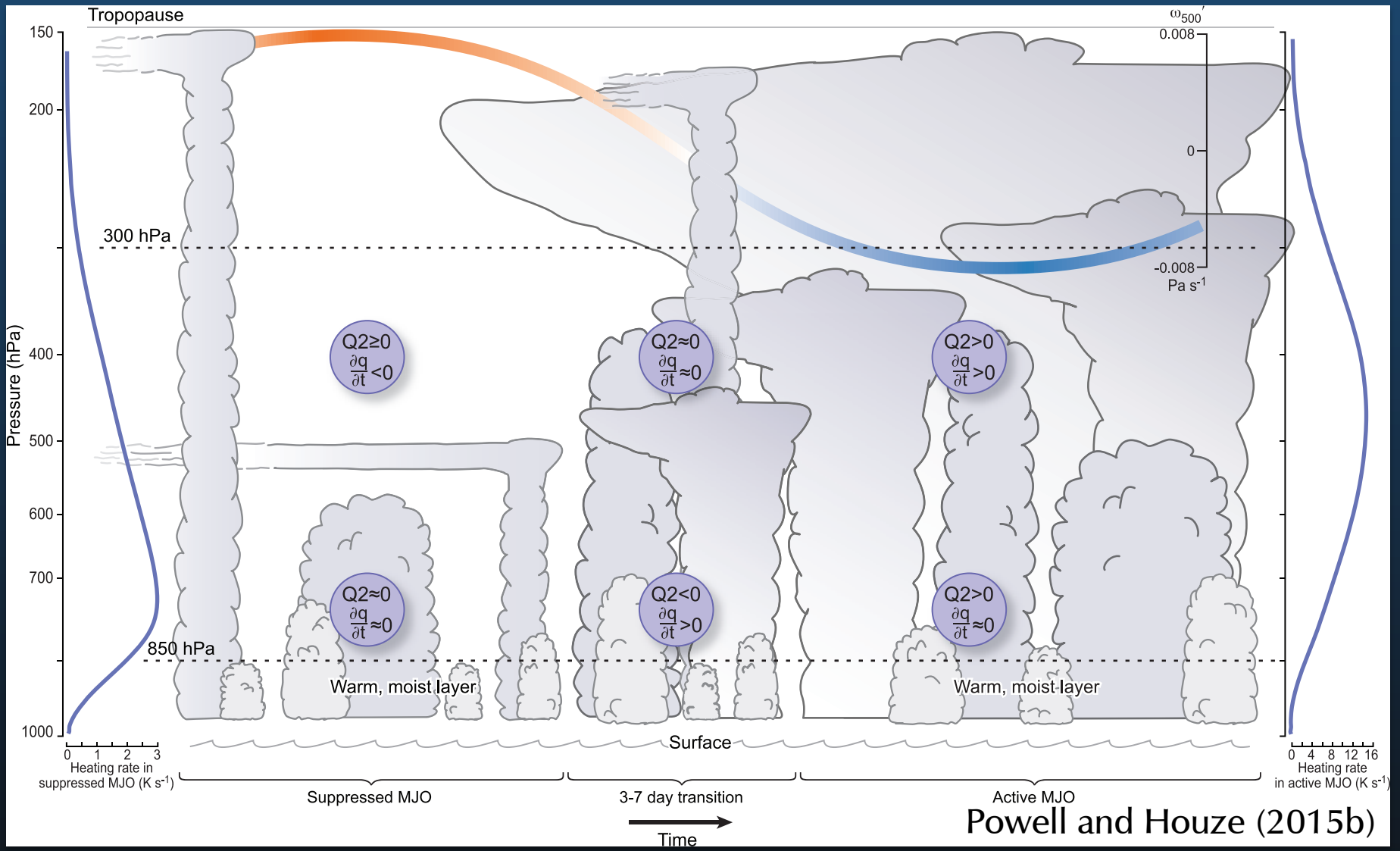
Wave # ≤ 3

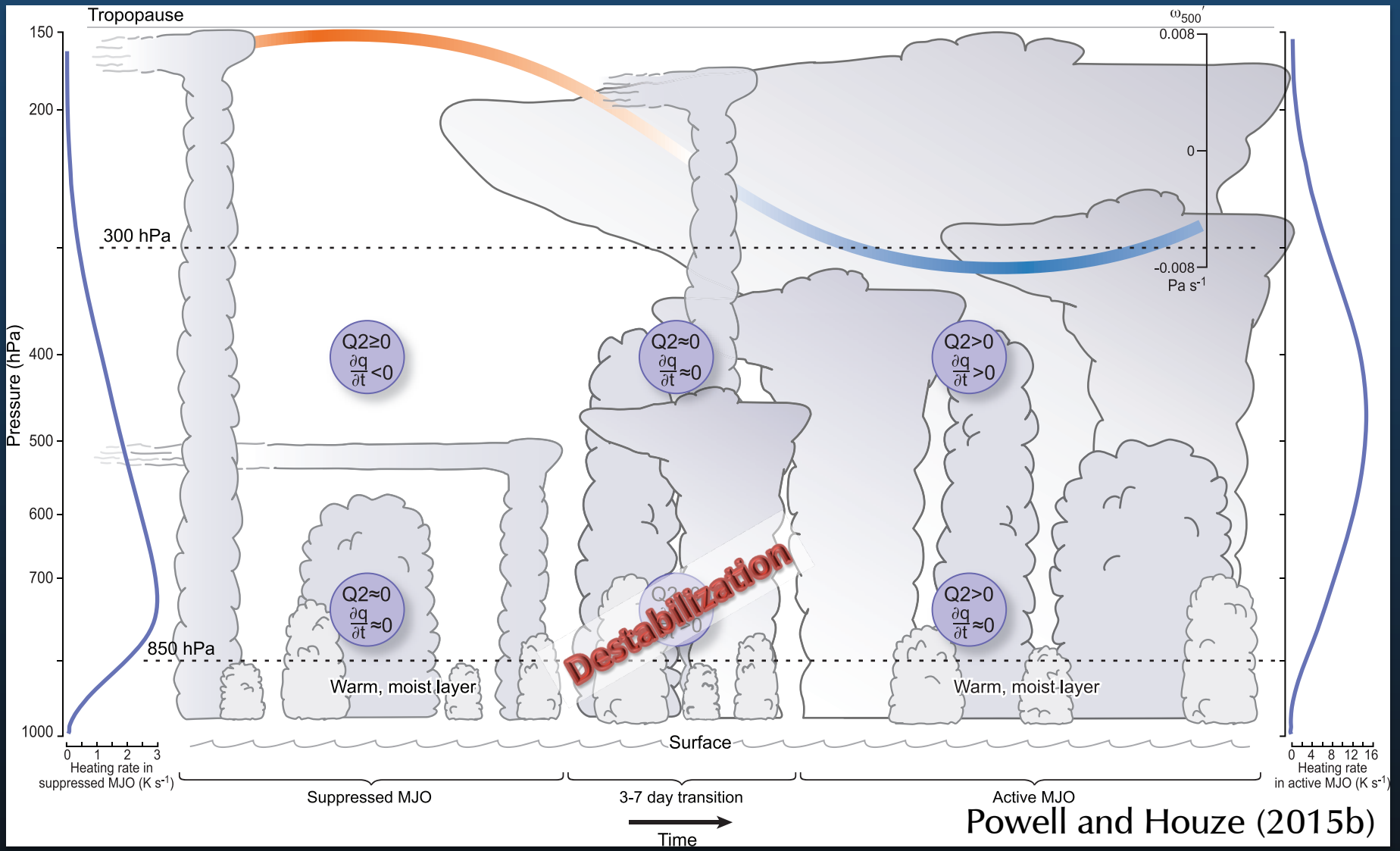
Wave # ≤ 1.5



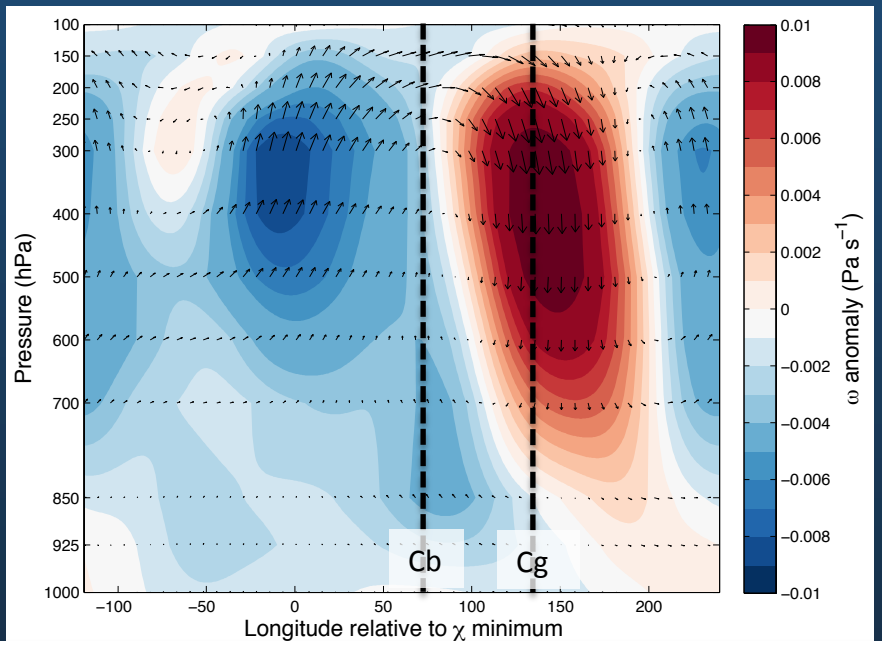

Pressure (hPa)
100
150
200
250
300
400
500
600
700
850
925
1000
−100
−50
0
50
100
150
200
Longitude relative to χ minimum
Trans. Cg
0.01
0.008
0.006
0.004
0.002
0
−0.002
−0.004
−0.006
−0.008
−0.01
ω anomaly (Pa s−1)

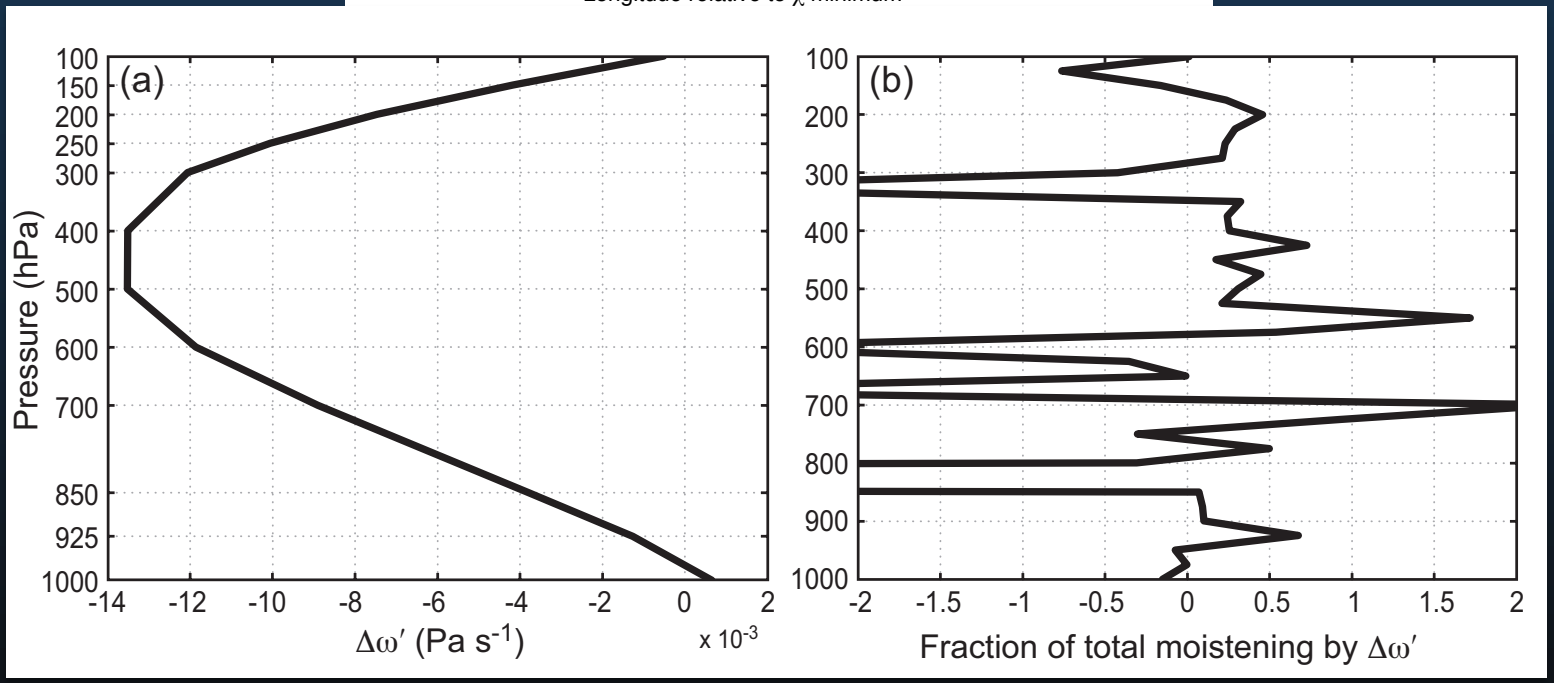

Pressure (hPa)
100
150
200
250
300
400
500
600
700
850
925
1000
-4
-3.5
-3
-2.5
-2
-1.5
-1
-0.5
0
0.5
Δω′ (Pa s-1)
x 10-3
-0.25
0.2
-.15
-0.1
-0.05
0
0.05
0.1
0.15
Δ Heating rate (K day-1)
Radiative heating
Adiabatic heating
Total heating

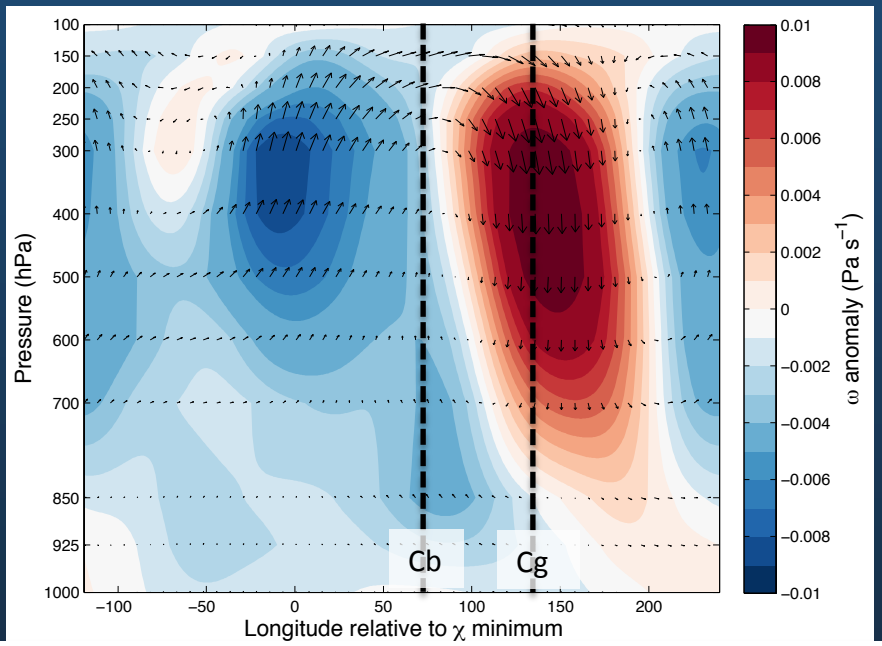

Tropopause
150
200
300 hPa
400
500
600
700
850 hPa
1000
Pressure (hPa)
ω_{500}
0.008
0
-0.008
Pa s^{-1}
Q2≥0 $\frac{\partial q}{\partial t}$<0
Q2≈0 $\frac{\partial q}{\partial t}$≈0
Q2>0 $\frac{\partial q}{\partial t}$>0
Q2≈0 $\frac{\partial q}{\partial t}$≈0
Q2<0 $\frac{\partial q}{\partial t}$>0
Q2>0 $\frac{\partial q}{\partial t}$≈0
Warm, moist layer
Warm, moist layer
Surface
0 1 2 3
Heating rate in suppressed MJO (K s^{-1})
0 4 8 12 16
Heating rate in active MJO (K s^{-1})
Suppressed MJO
3-7 day transition
Active MJO
Time
Powell and Houze (2015b)

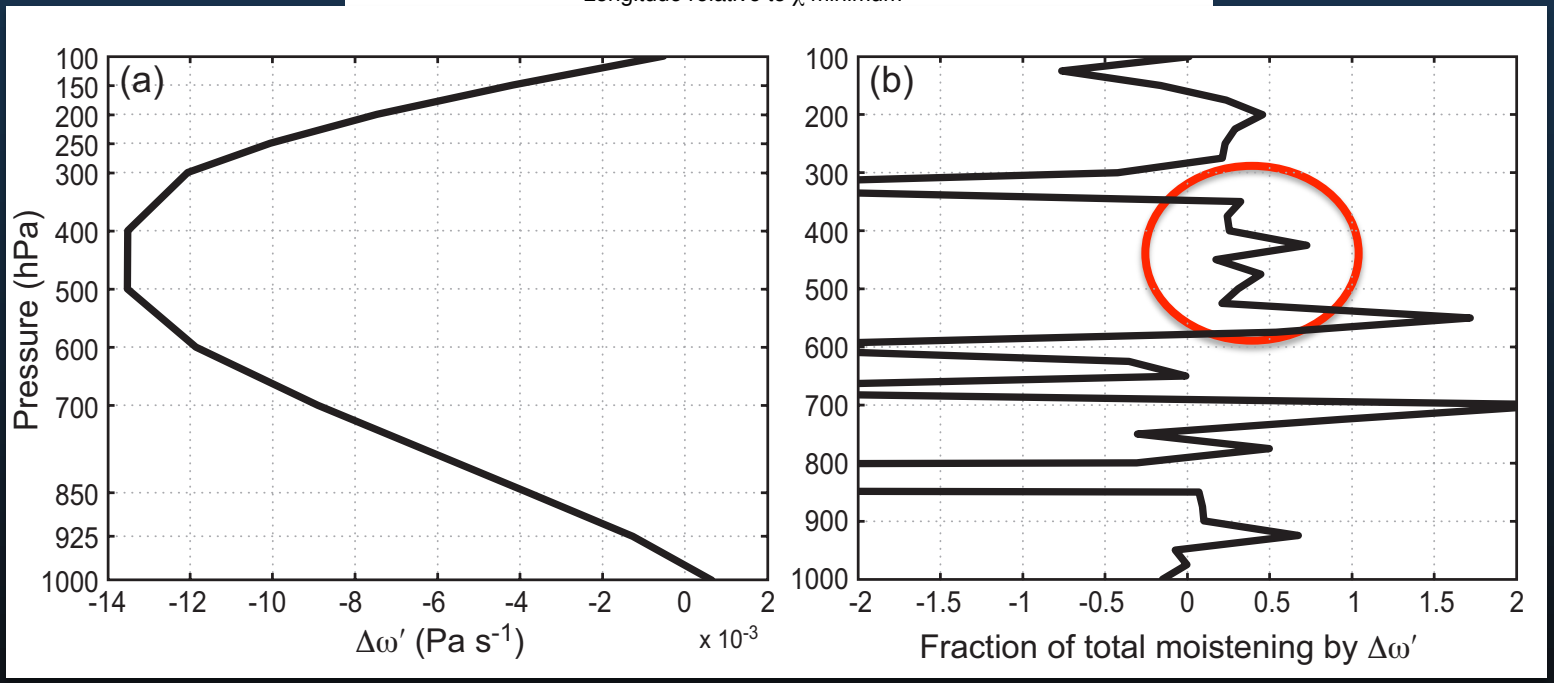

Tropopause
150
200
300 hPa
400
500
600
700
850 hPa
1000
Pressure (hPa)
ω_{500}
0.008
0
-0.008
Pa s^{-1}
Q2≥0 $\frac{\partial q}{\partial t}$<0
Q2≈0 $\frac{\partial q}{\partial t}$≈0
Q2>0 $\frac{\partial q}{\partial t}$>0
Q2≈0 $\frac{\partial q}{\partial t}$≈0
Q2>0 $\frac{\partial q}{\partial t}$≈0
Destabilization
Warm, moist layer
Warm, moist layer
Surface
0 1 2 3
Heating rate in suppressed MJO (K s^{-1})
0 4 8 12 16
Heating rate in active MJO (K s^{-1})
Suppressed MJO
3-7 day transition
Active MJO
Time
Powell and Houze (2015b)

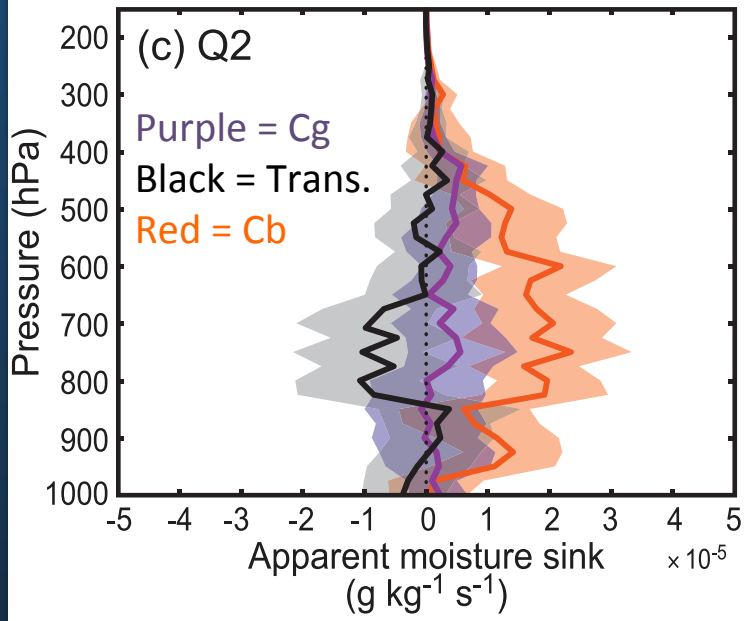
Extras


Pressure (hPa)
100
150
200
250
300
400
500
600
700
850
925
1000
Cb
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)


(a)
Pressure (hPa)
100
150
200
250
300
400
500
600
700
850
925
1000
-14
-12
-10
-8
-6
-4
-2
0
2
Δω′ (Pa s-1)
x 10-3
(b)
100
200
300
400
500
600
700
800
900
1000
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Fraction of total moistening by Δω′


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
Cb
Cg
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)


(a)
Pressure (hPa)
100
150
200
250
300
400
500
600
700
850
925
1000
-14
-12
-10
-8
-6
-4
-2
0
2
Δω′ (Pa s-1)
x 10-3
(b)
100
200
300
400
500
600
700
800
900
1000
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Fraction of total moistening by Δω′

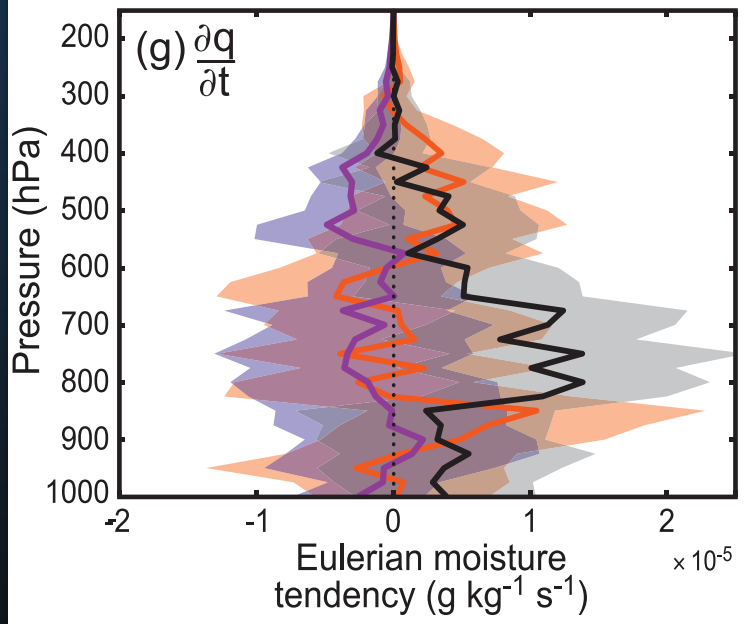


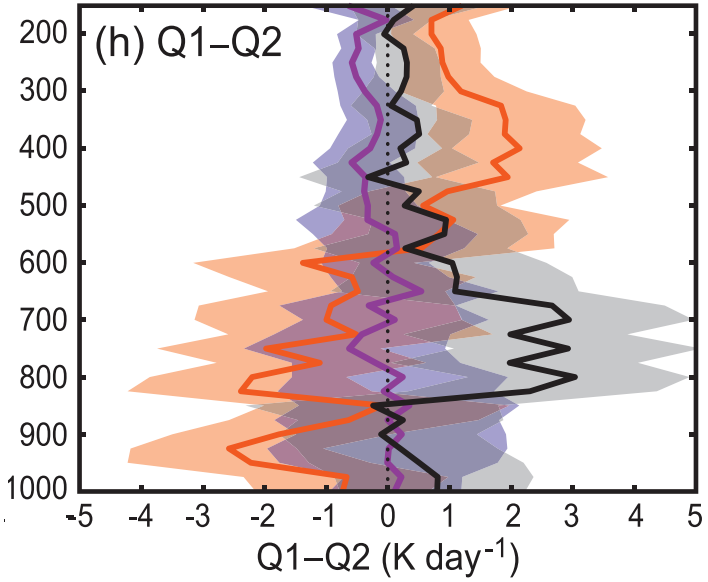
$$Q_2 = \left(\overline{c} - \overline{e}\right) + \frac{\partial}{\partial p}\left(\overline{\omega' q'}\right)$$

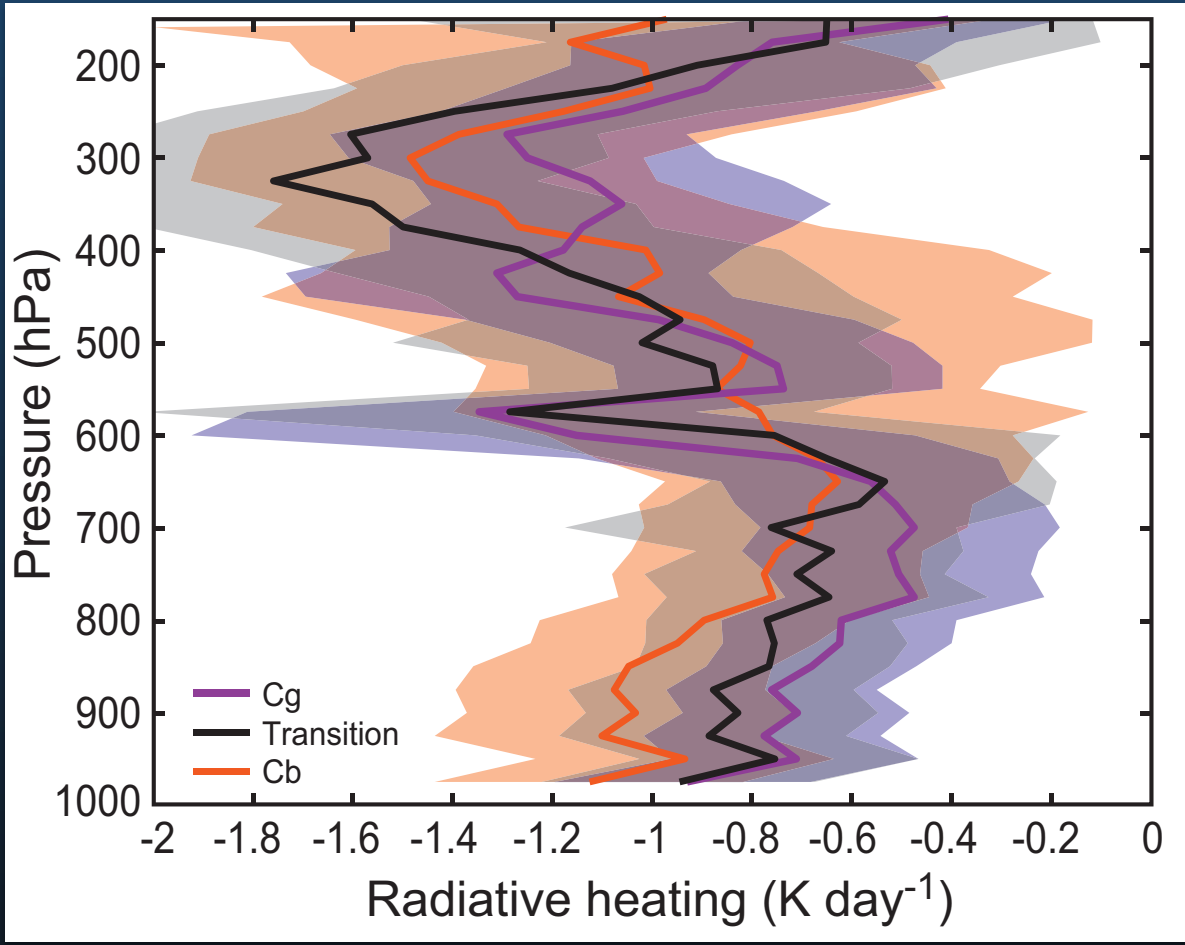
$$\frac{\partial q}{\partial t} = \mathbf{v}_h \cdot \nabla q + \omega \frac{\partial q}{\partial p} + Q_2$$

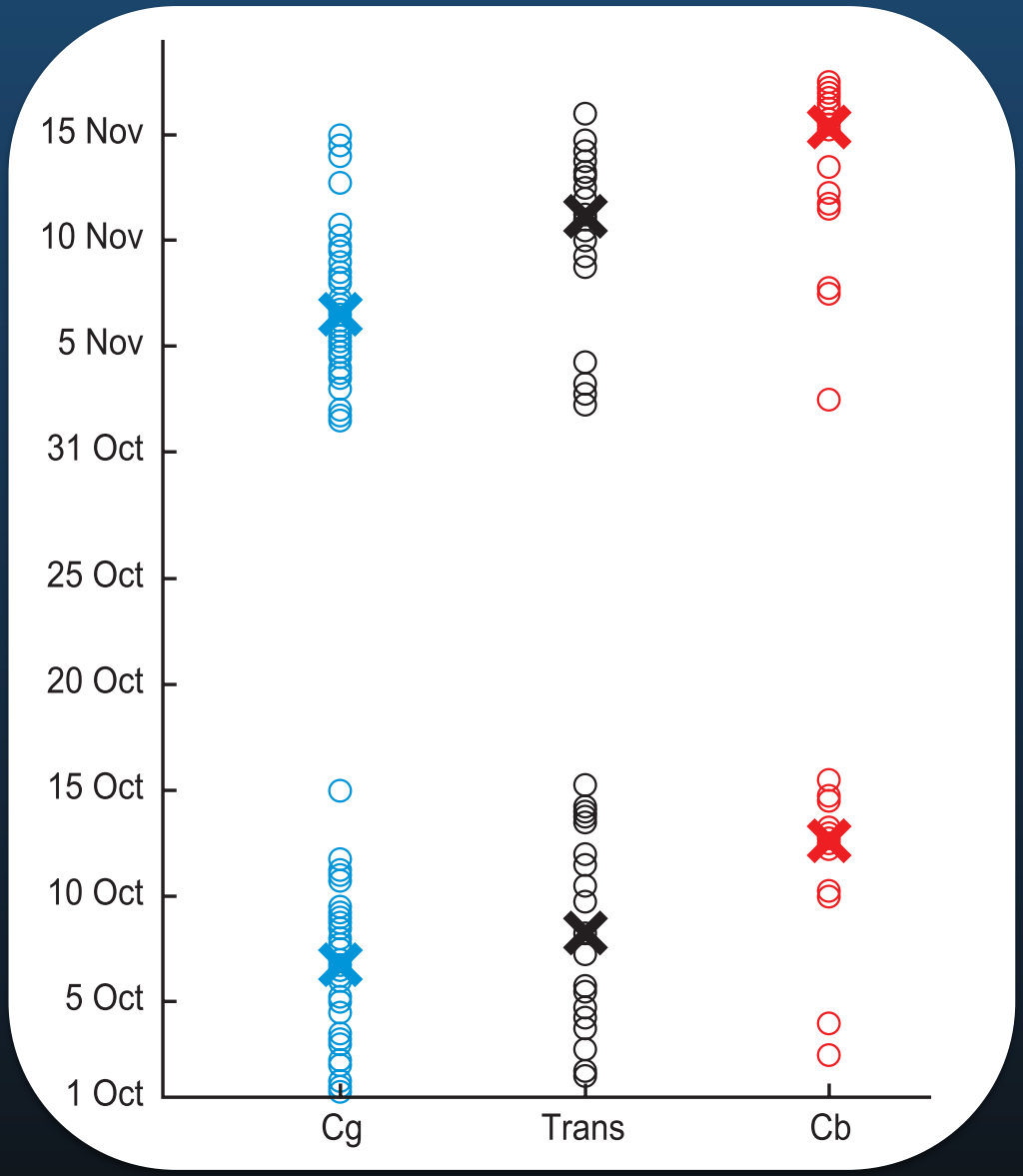
$$Q_1 = Q_R + \frac{1}{c_p}\left[L_v\left(\overline{c} - \overline{e}\right) + \frac{\partial}{\partial p}\left(\overline{\omega' s'}\right)\right]$$

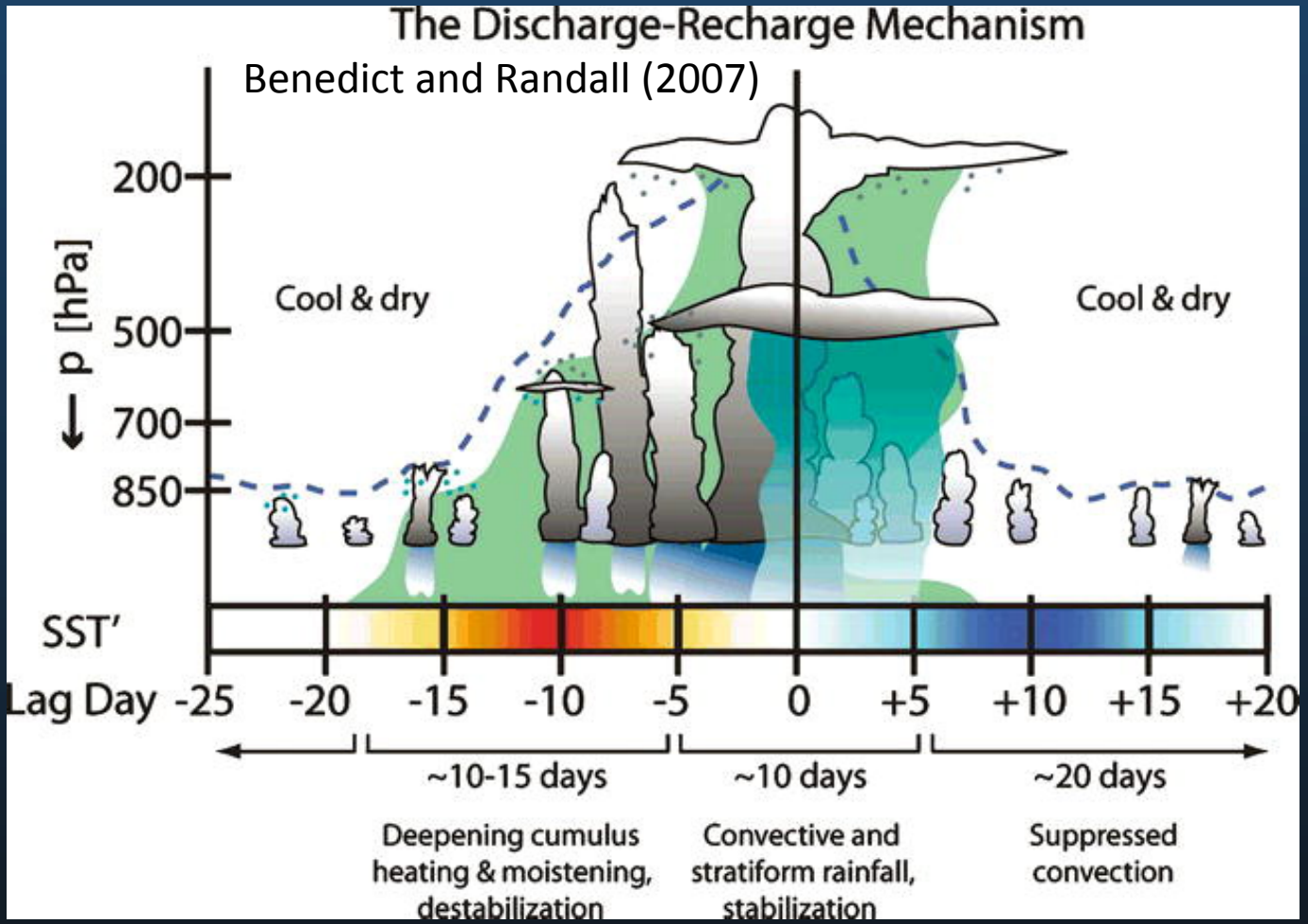
$$Q_1 - \frac{L_v}{c_p} Q_2 = Q_R - \frac{1}{c_p}\frac{\partial}{\partial p}\left(\overline{\omega' h'}\right)$$

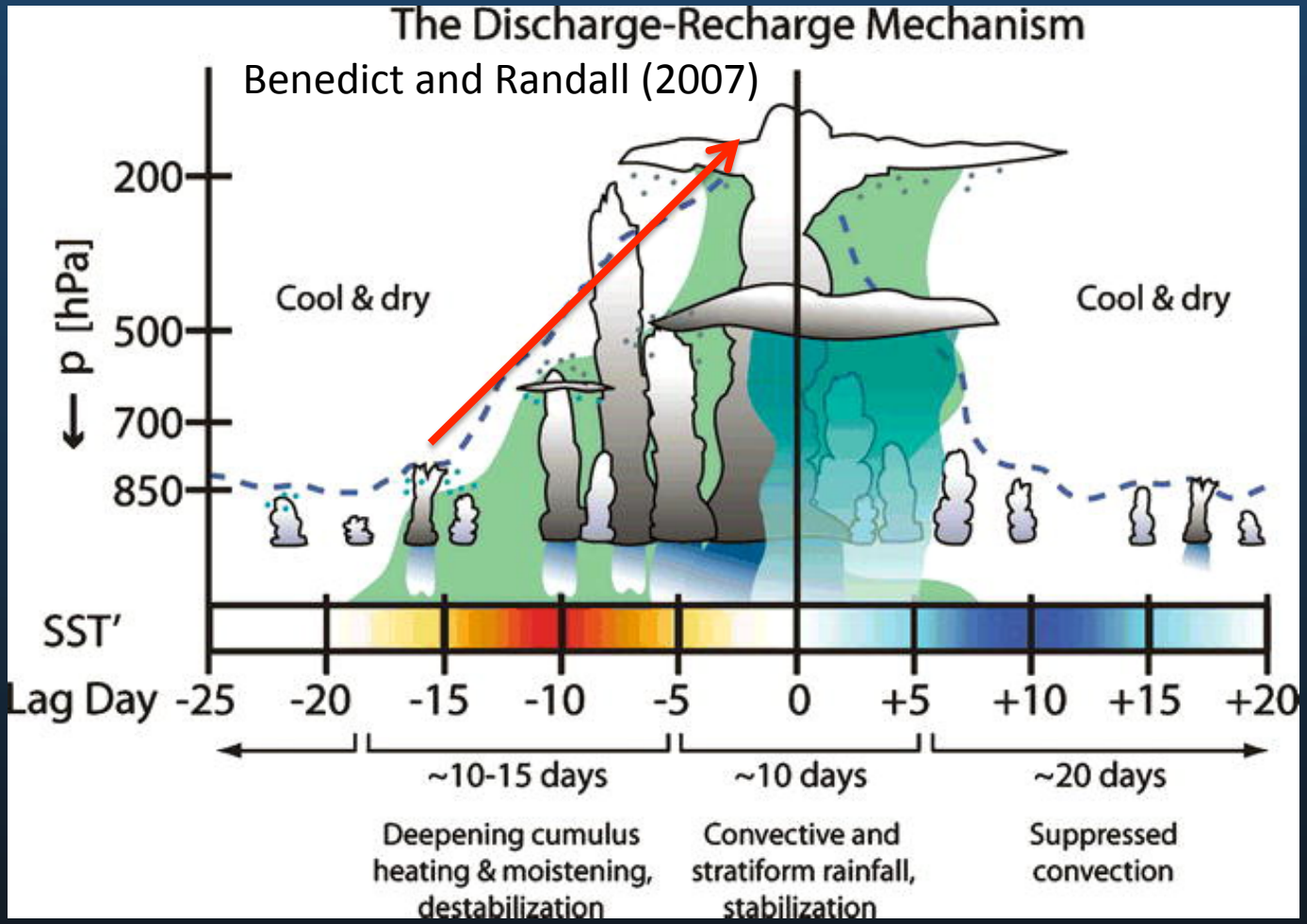


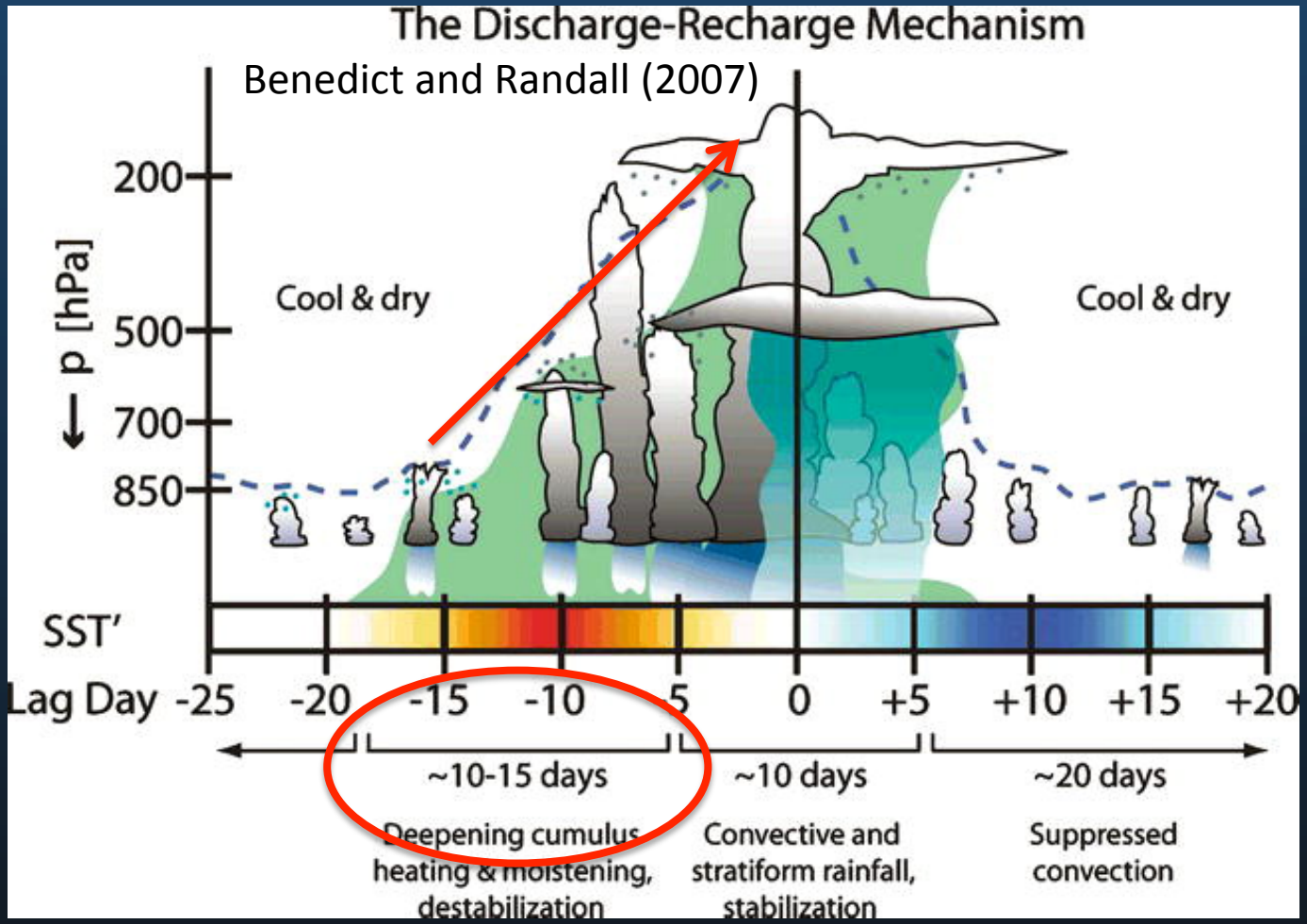



Pressure (hPa)
200
300
400
500
600
700
800
900
1000
-2
-1.8
-1.6
-1.4
-1.2
-1
-0.8
-0.6
-0.4
-0.2
0
Radiative heating (K day-1)
Cg
Transition
Cb

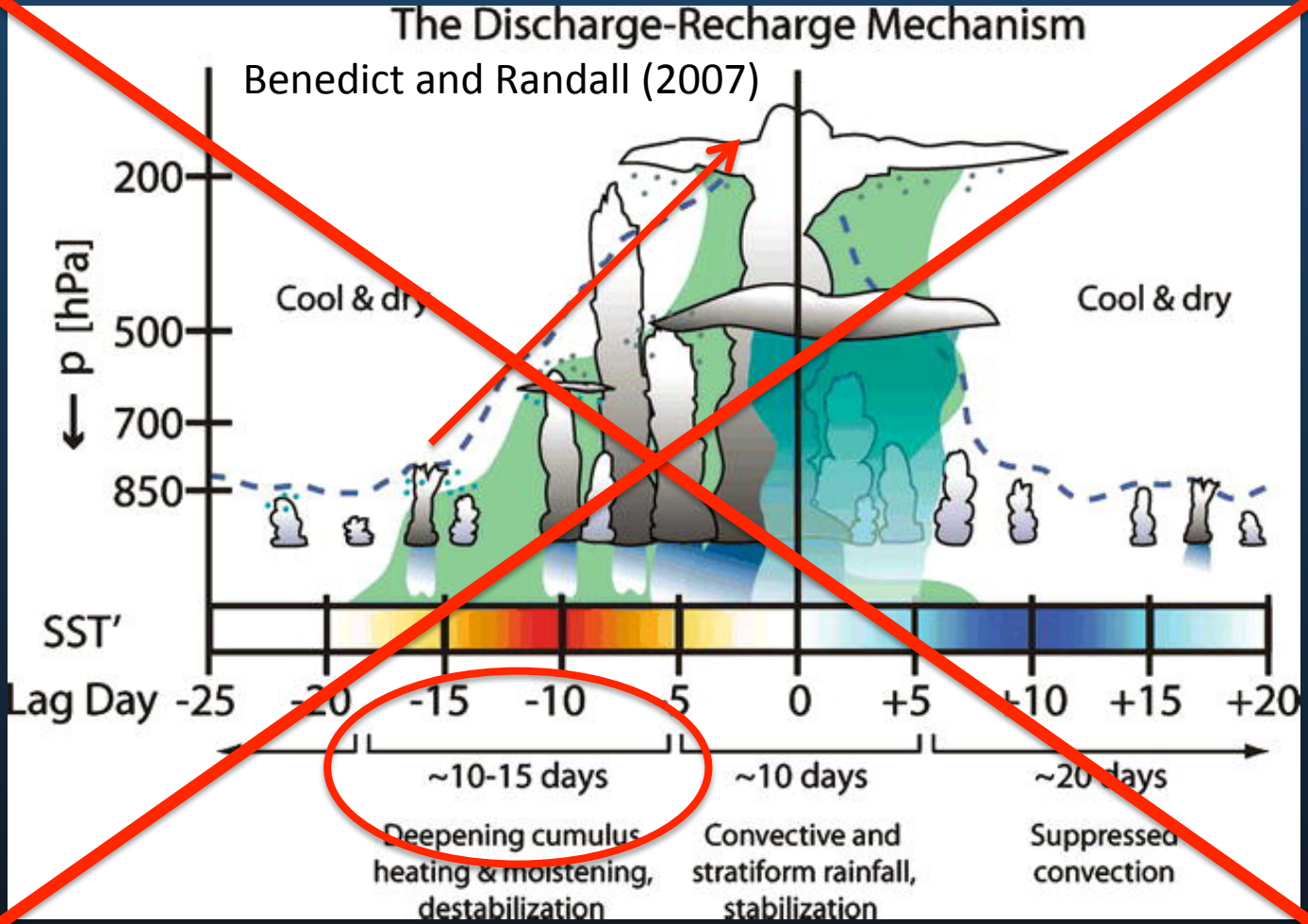

15 Nov
10 Nov
5 Nov
31 Oct
25 Oct
20 Oct
15 Oct
10 Oct
5 Oct
1 Oct
Cg
Trans
Cb

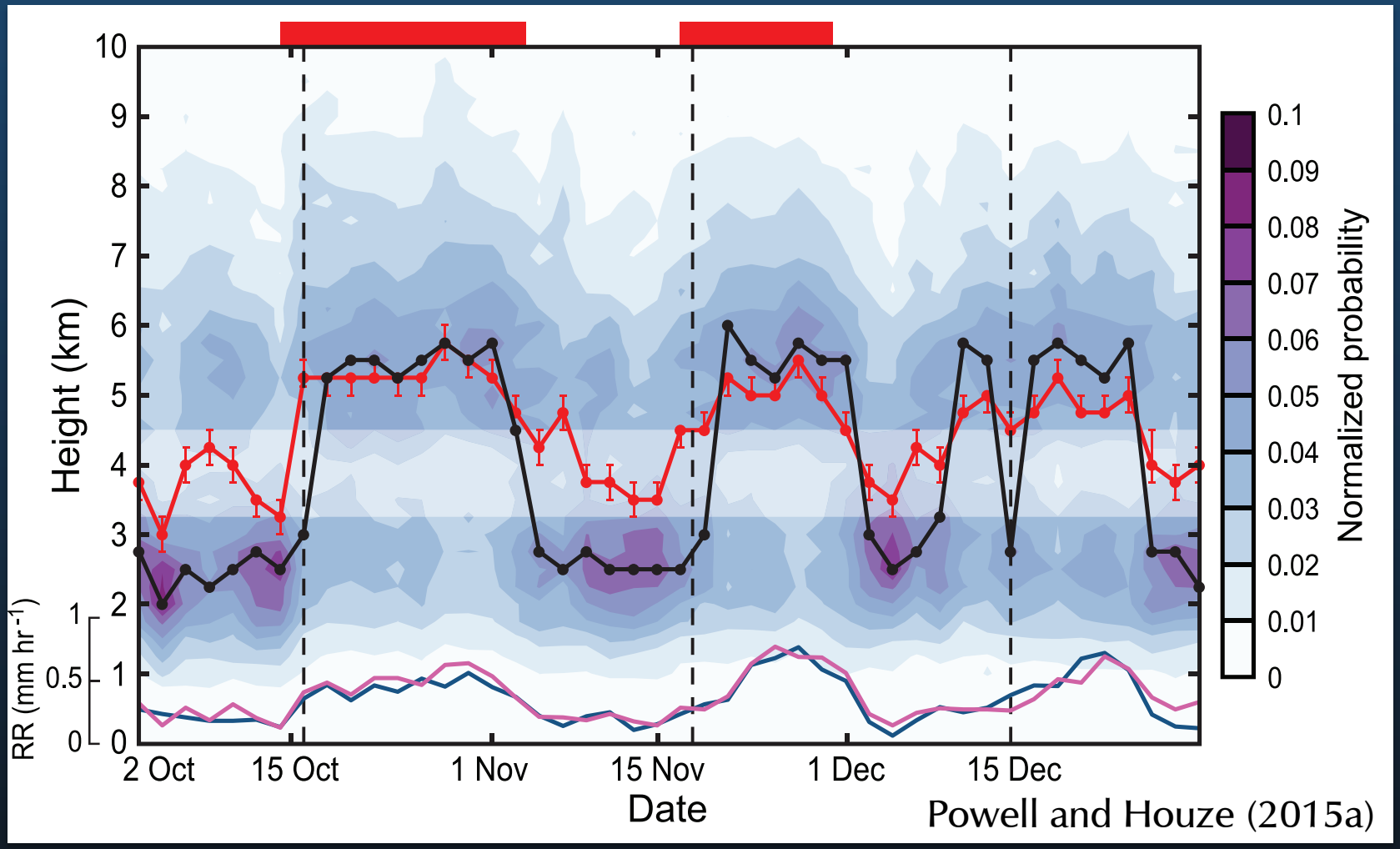

The Discharge-Recharge Mechanism
Benedict and Randall (2007)
200
500
700
850
p [hPa]
Cool & dry
Cool & dry
SST'
Lag Day -25 -20 -15 -10 -5 0 +5 +10 +15 +20
~10-15 days
~10 days
~20 days
Deepening cumulus heating & moistening, destabilization
Convective and stratiform rainfall, stabilization
Suppressed convection

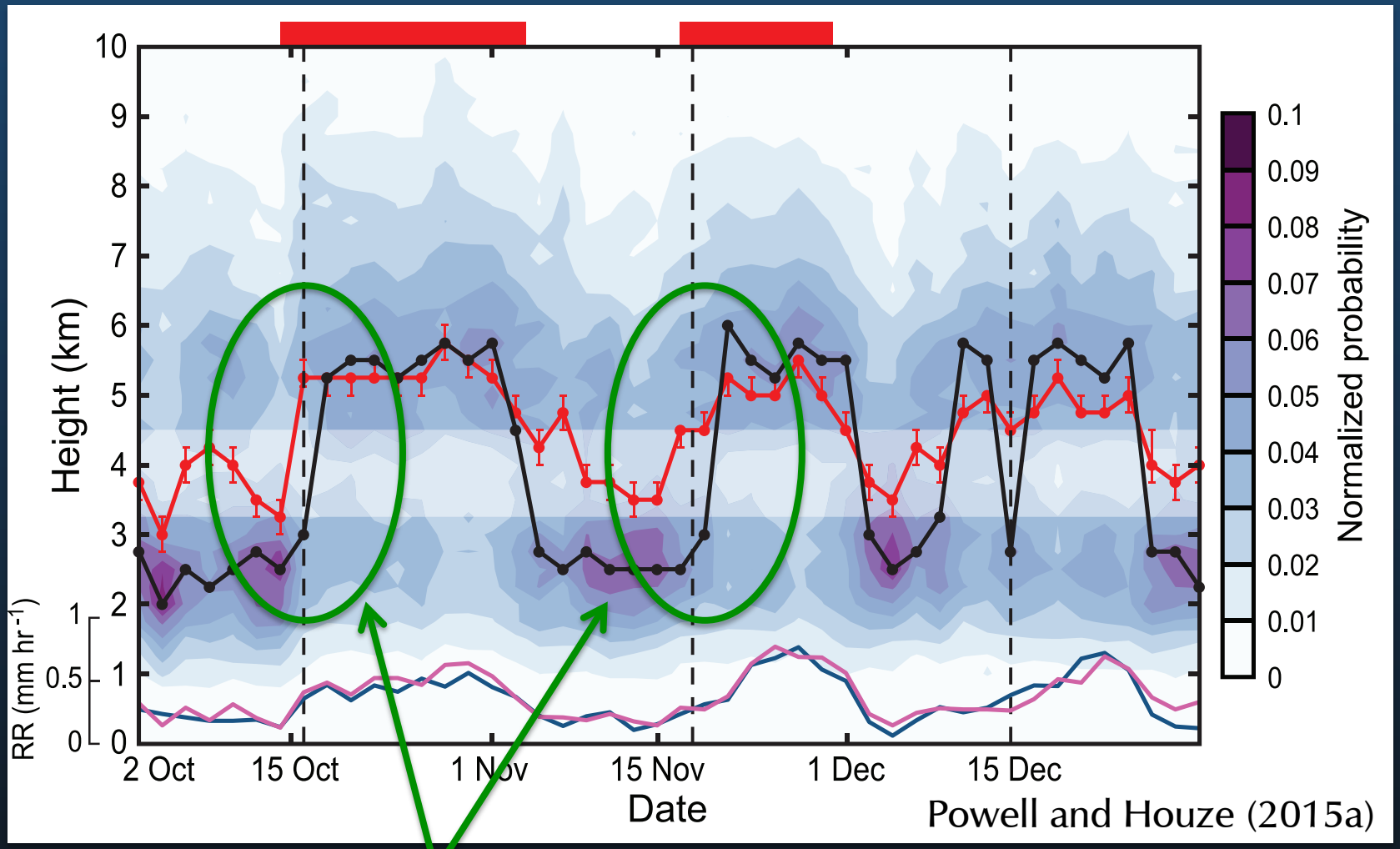

The Discharge-Recharge Mechanism
Benedict and Randall (2007)
200
500
700
850
p [hPa]
Cool & dry
Cool & dry
SST'
Lag Day -25 -20 -15 -10 -5 0 +5 +10 +15 +20
~10-15 days
~10 days
~20 days
Deepening cumulus heating & moistening, destabilization
Convective and stratiform rainfall, stabilization
Suppressed convection



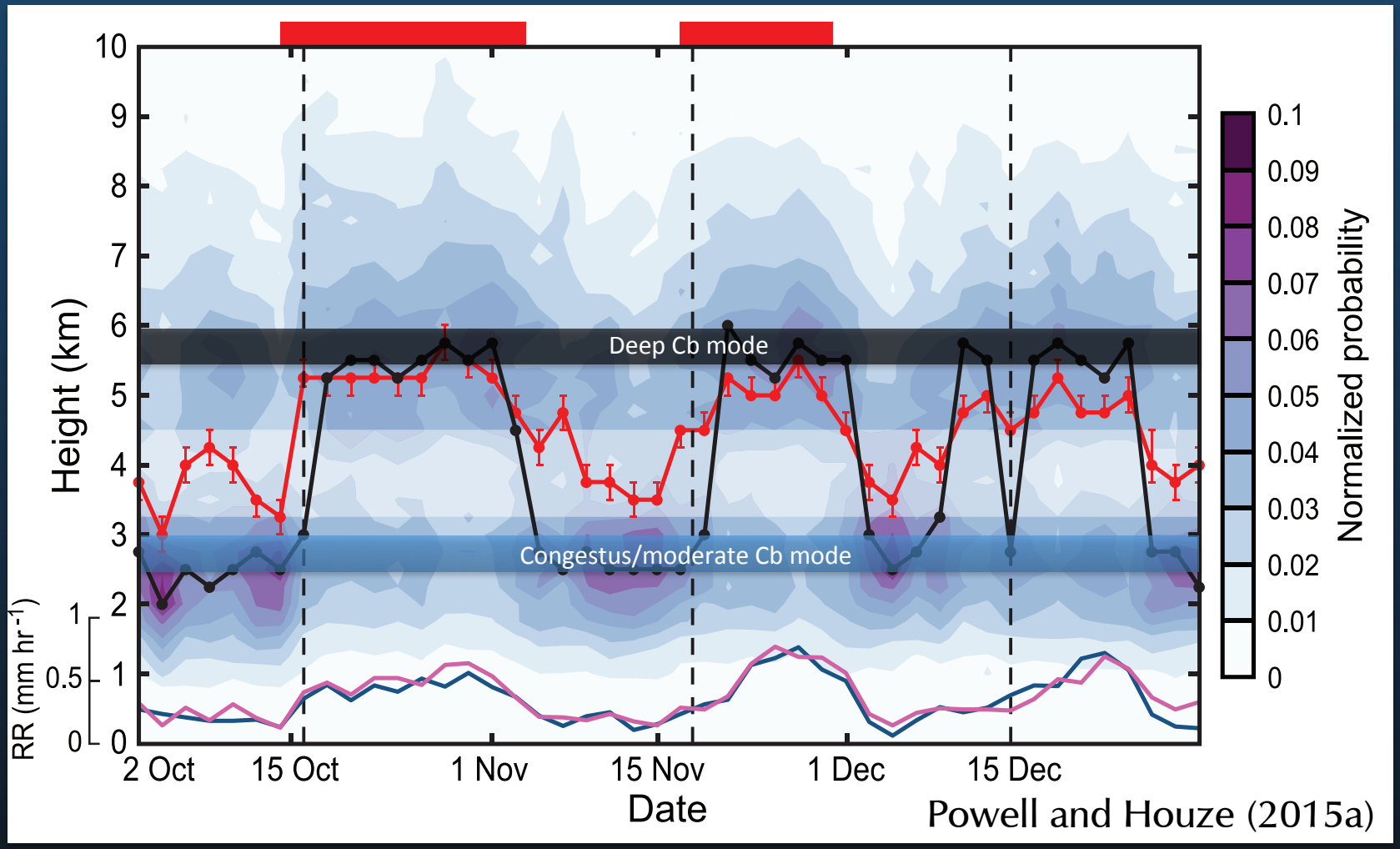
10–15 days or more!

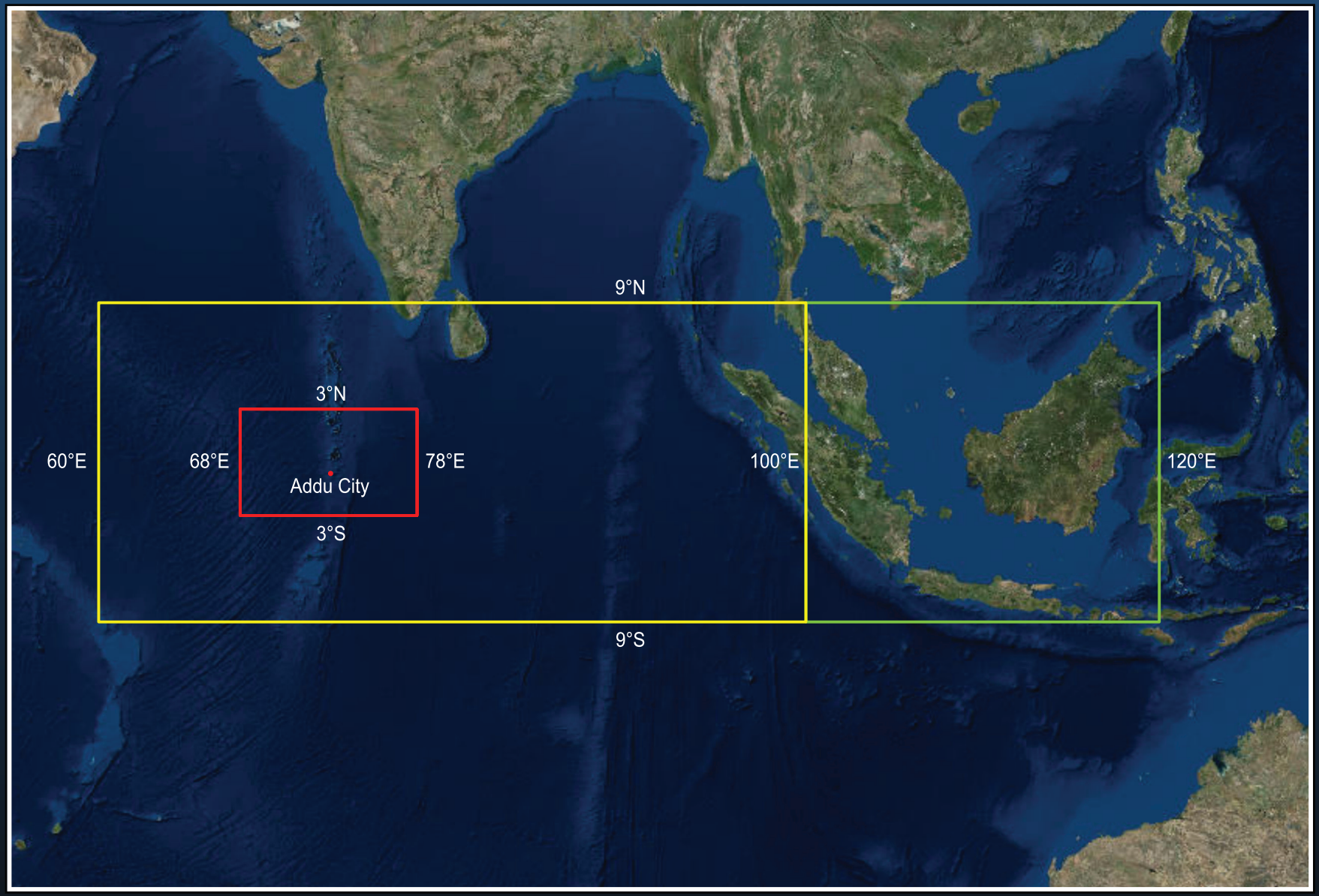

The Discharge-Recharge Mechanism
Benedict and Randall (2007)
200
500
700
850
p [hPa]
Cool & dry
Cool & dry
SST'
Lag Day -25
-15
-10
5
0
+5
+10
+15
+20
~10-15 days
~10 days
Deepening cumulus
heating & moistening,
destabilization
Convective and
stratiform rainfall,
stabilization
Suppressed
convection

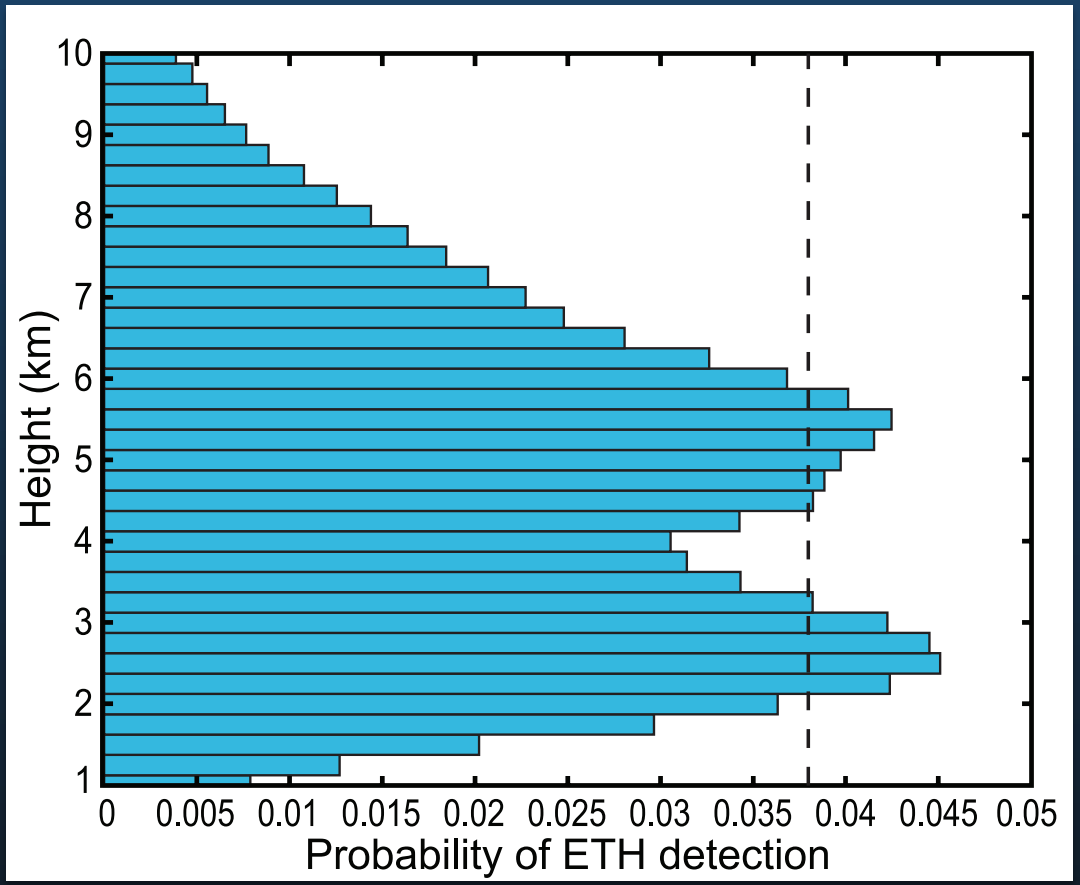

Height (km)
10
9
8
7
6
5
4
3
2
1
0
RR (mm hr-1)
1
0.5
0
2 Oct
15 Oct
1 Nov
15 Nov
1 Dec
15 Dec
Date
Normalized probability
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Powell and Houze (2015a)

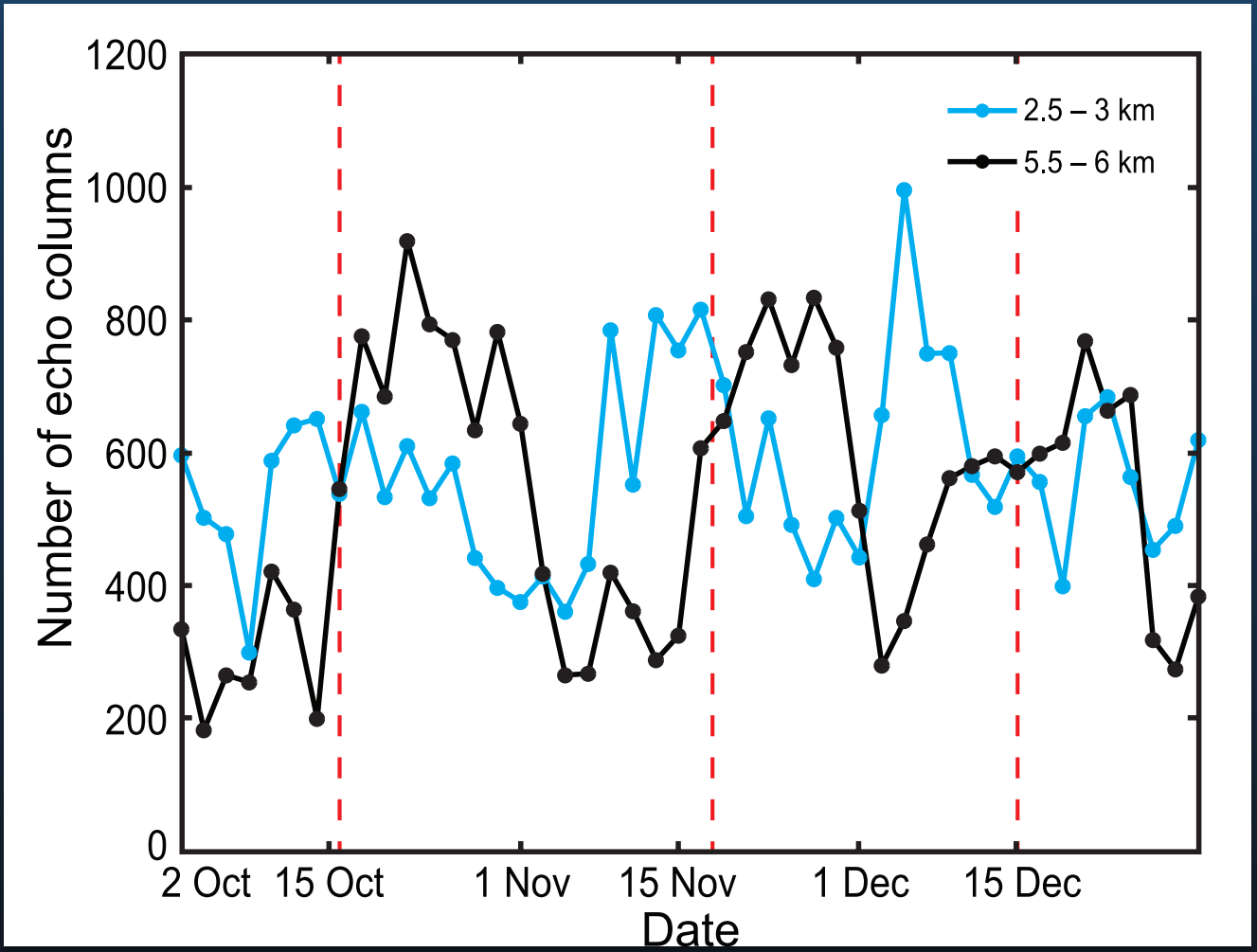


Actually 2–6 days


Height (km)
10
9
8
7
6
5
4
3
2
1
0
Deep Cb mode
Congestus/moderate Cb mode
RR (mm hr-1)
1
0.5
0
2 Oct
15 Oct
1 Nov
15 Nov
1 Dec
15 Dec
Date
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Normalized probability
Powell and Houze (2015a)


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


Height (km)
10
9
8
7
6
5
4
3
2
1
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05
Probability of ETH detection


1200
1000
800
600
400
200
0
Number of echo columns
2.5 – 3 km
5.5 – 6 km
2 Oct
15 Oct
1 Nov
15 Nov
1 Dec
15 Dec
Date