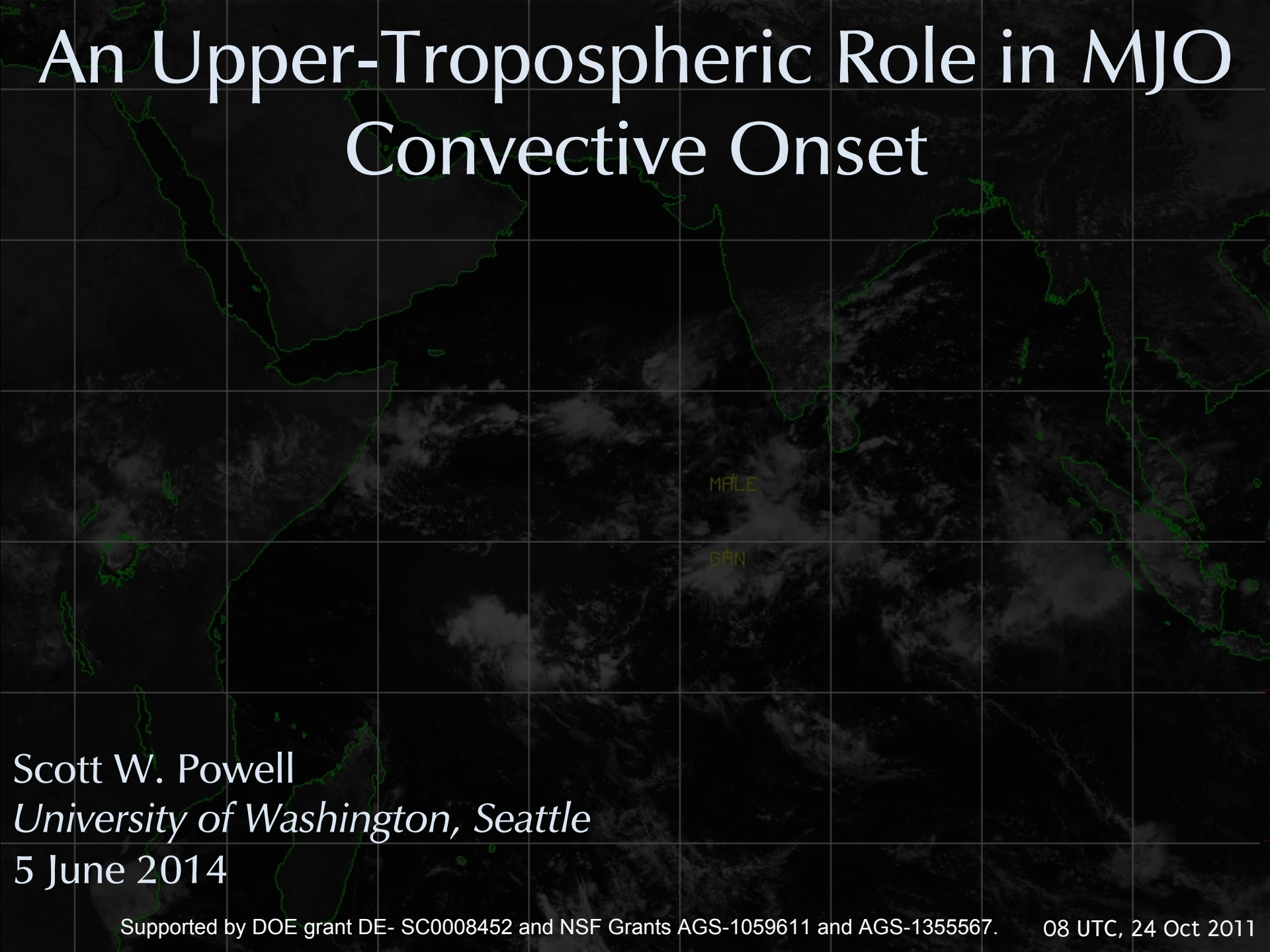
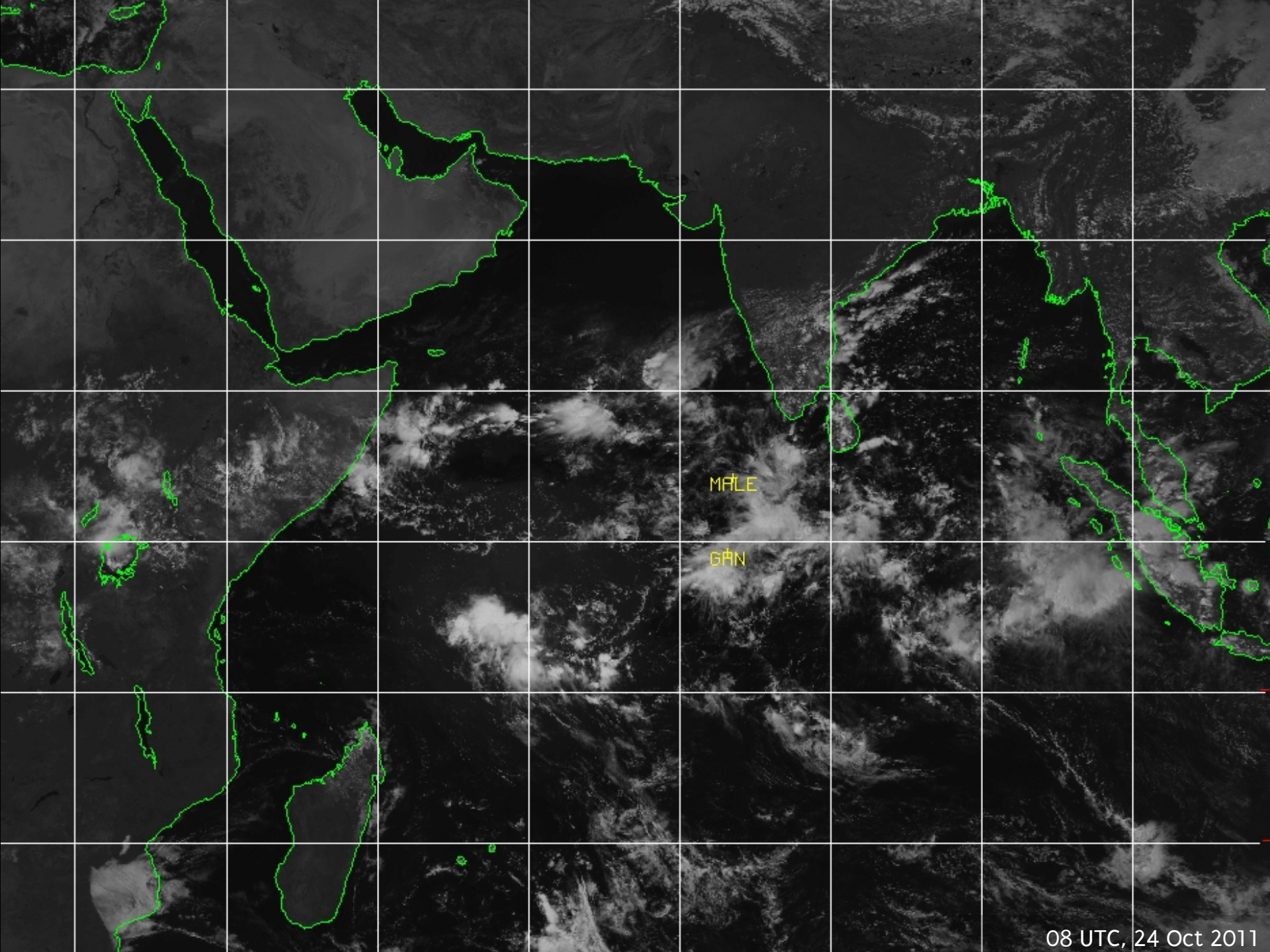
An Upper-Tropospheric Role in MJO Convective Onset

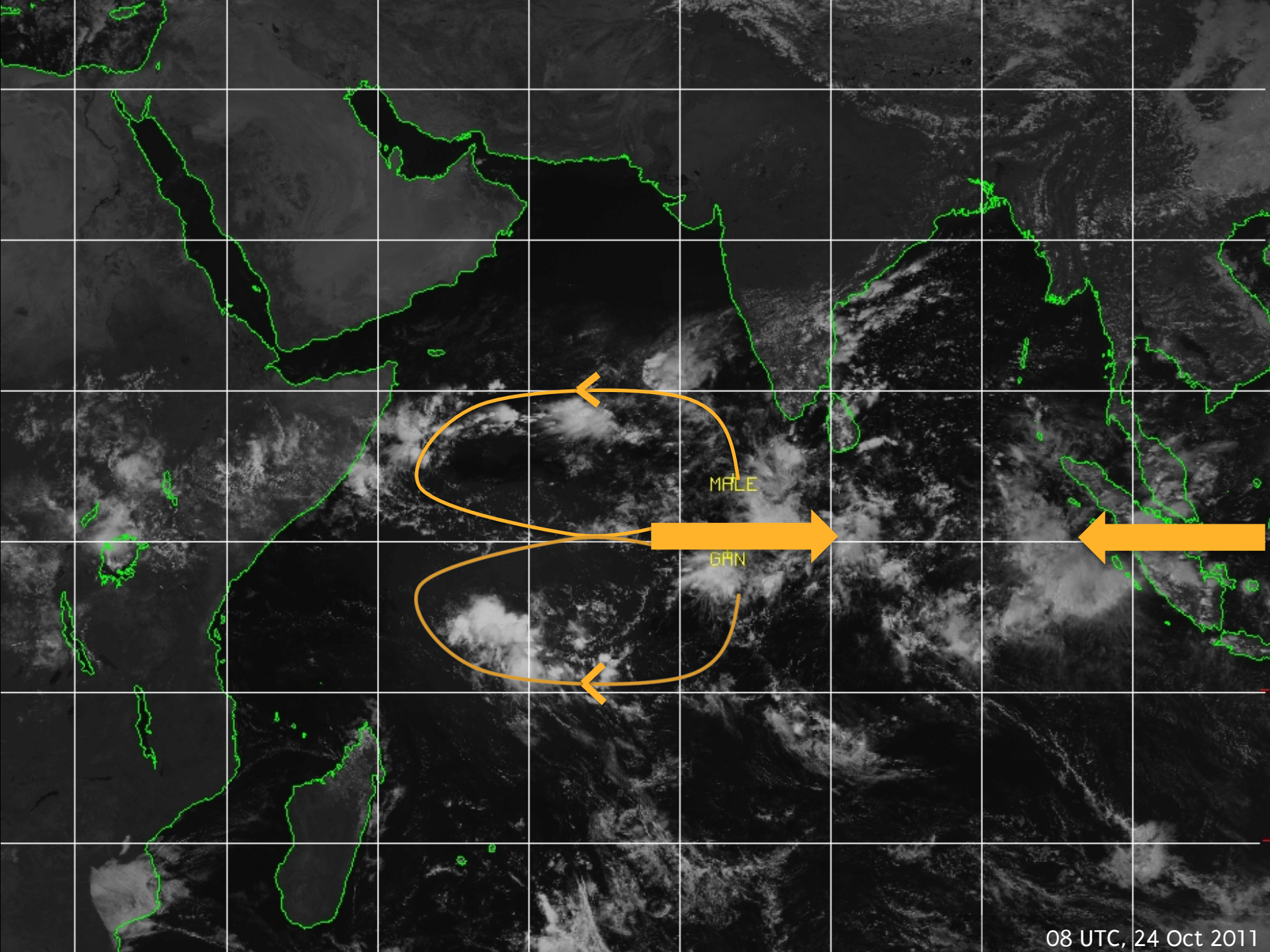


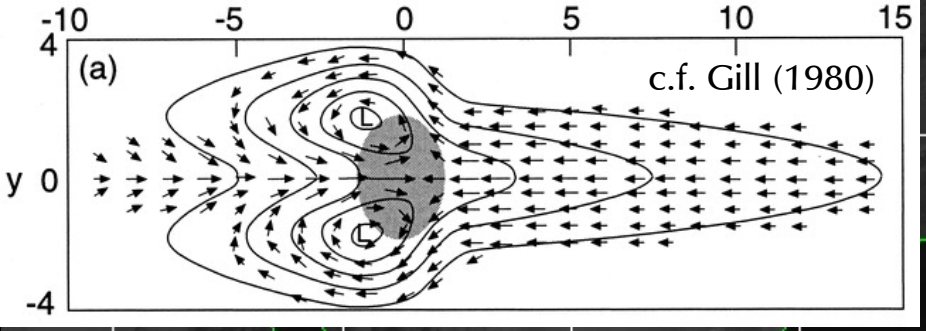
Scott W. Powell
University of Washington, Seattle
5 June 2014

Supported by DOE grant DE- SC0008452 and NSF Grants AGS-1059611 and AGS-1355567.

08 UTC, 24 Oct 2011


MALE
GAN
08 UTC, 24 Oct 2011

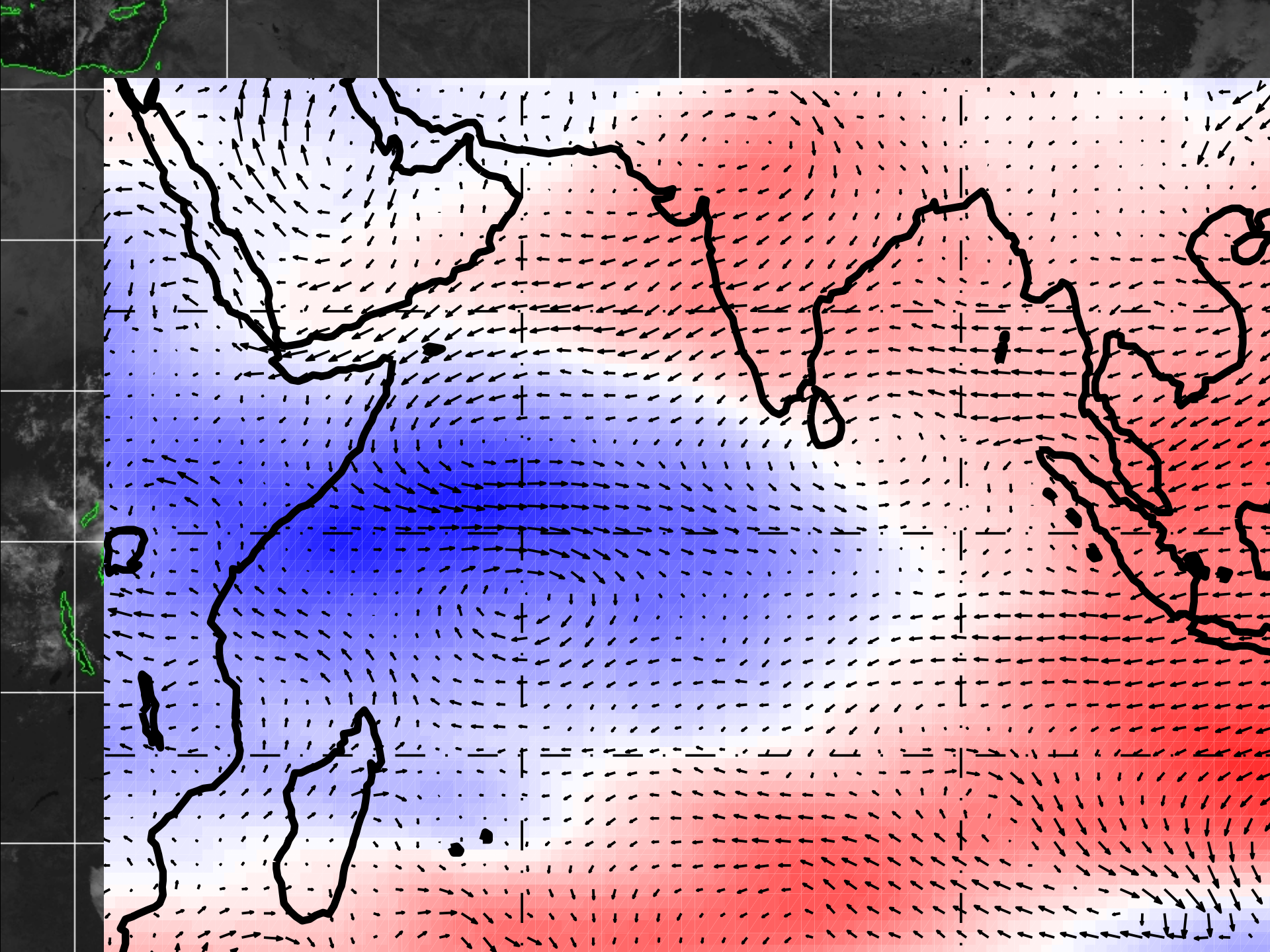

MALE
GAN
08 UTC, 24 Oct 2011

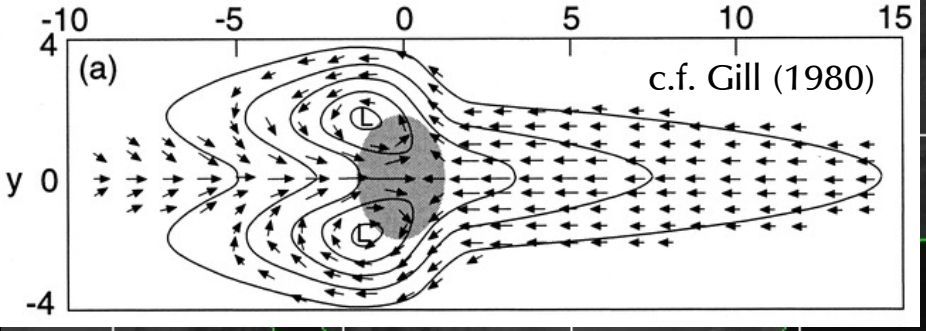


MALE

GAN

08 UTC, 24 Oct 2011

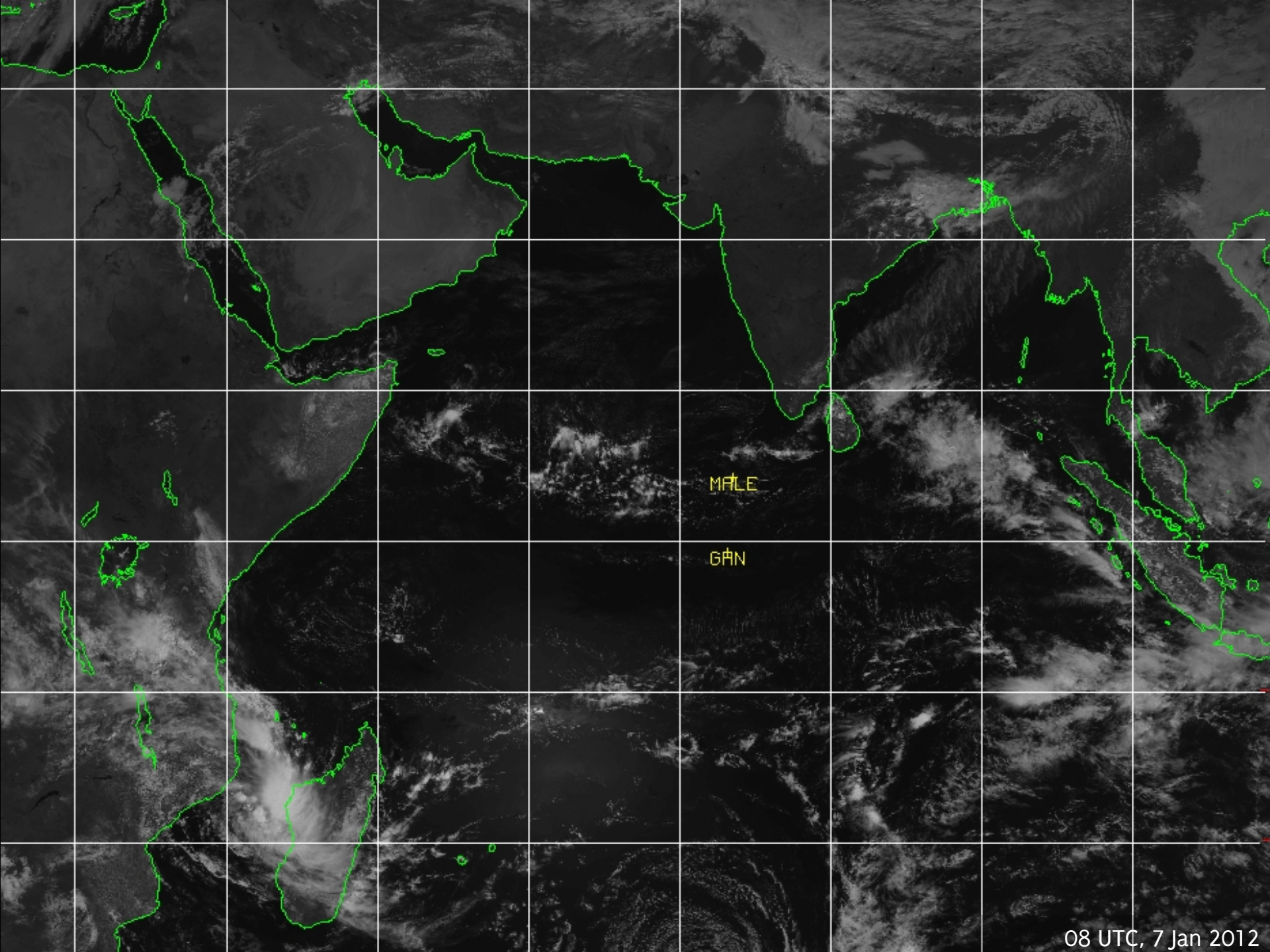




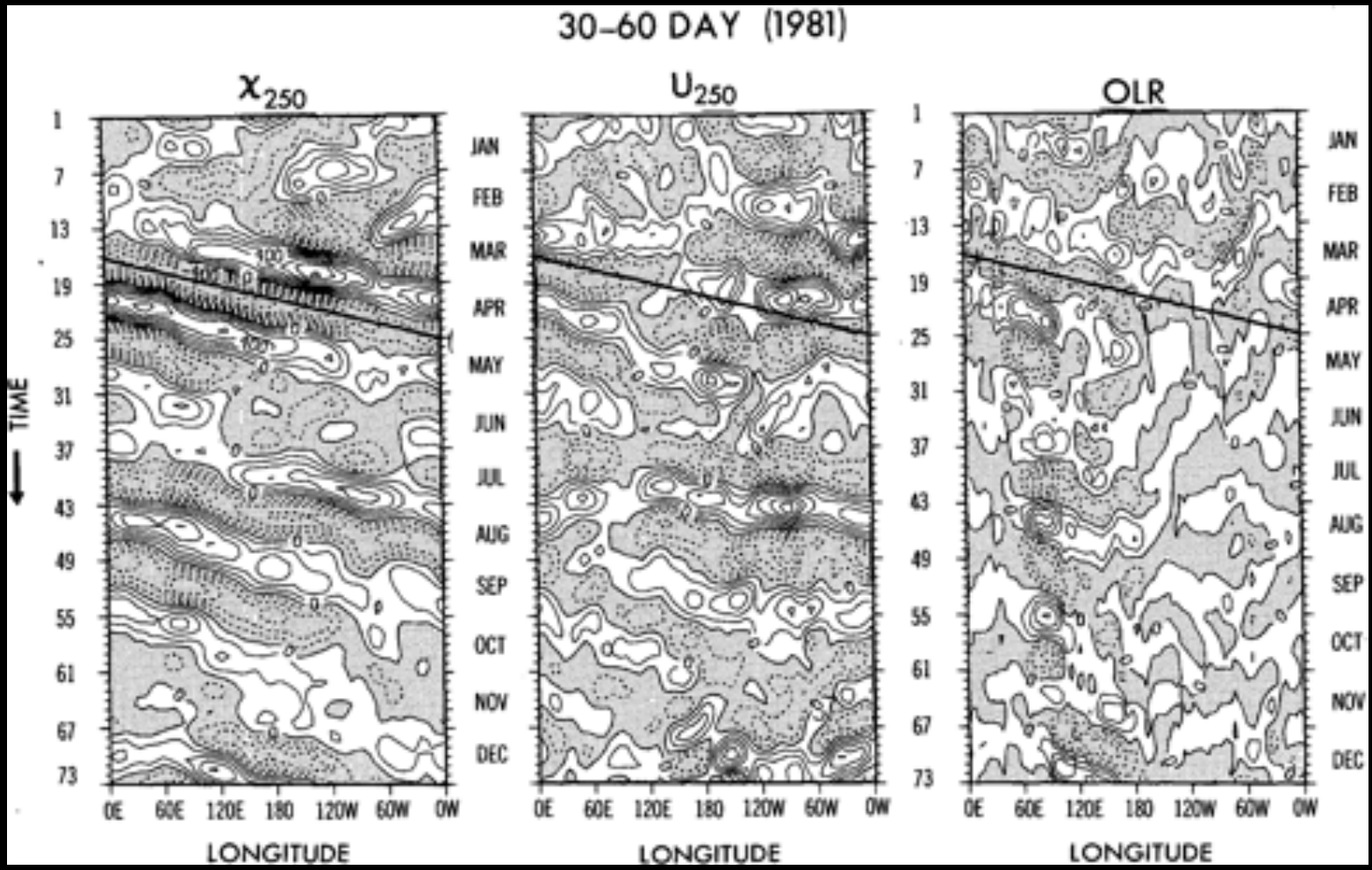
MALE

GAN

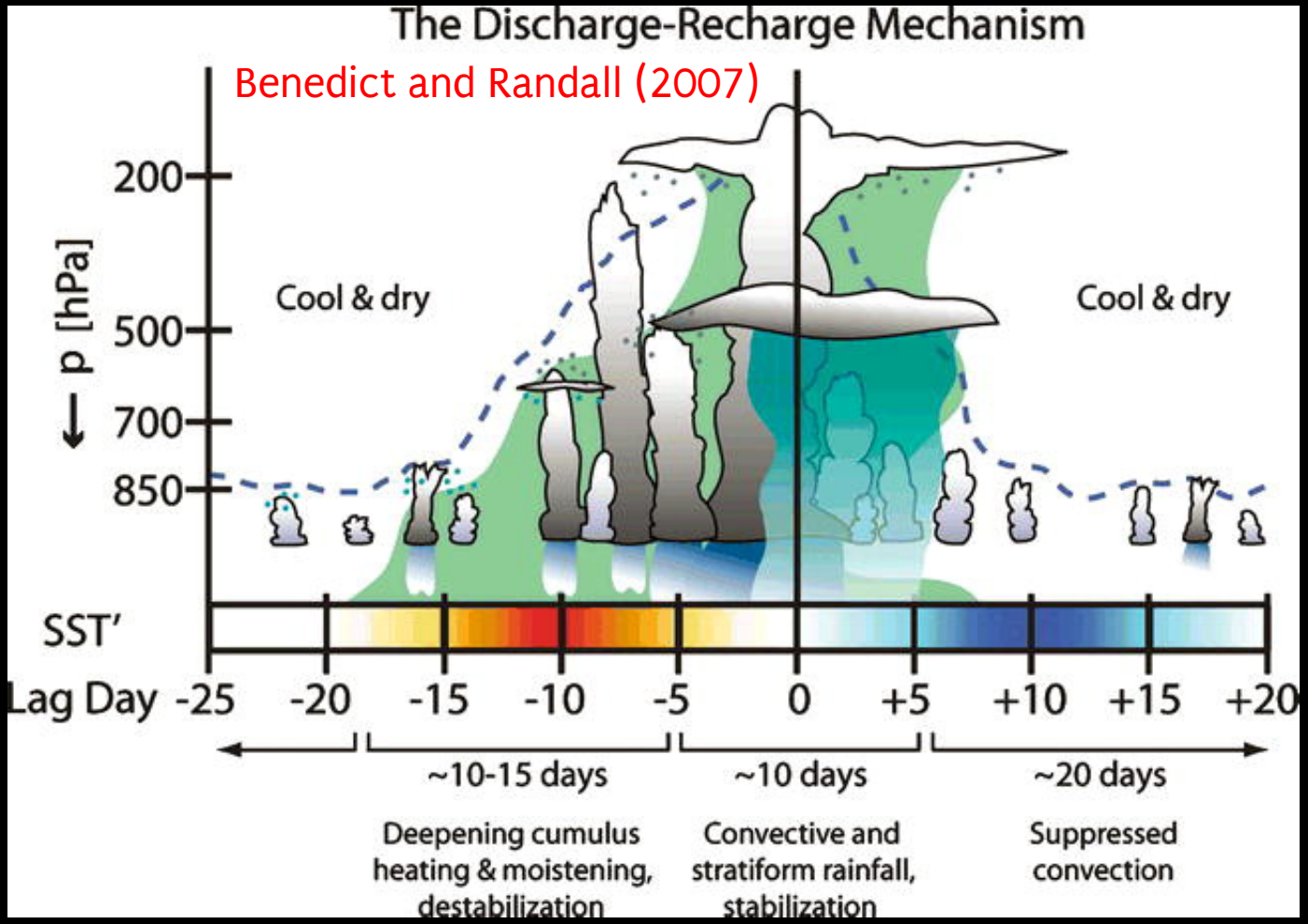
08 UTC, 24 Oct 2011


MALE
GAN
08 UTC, 7 Jan 2012

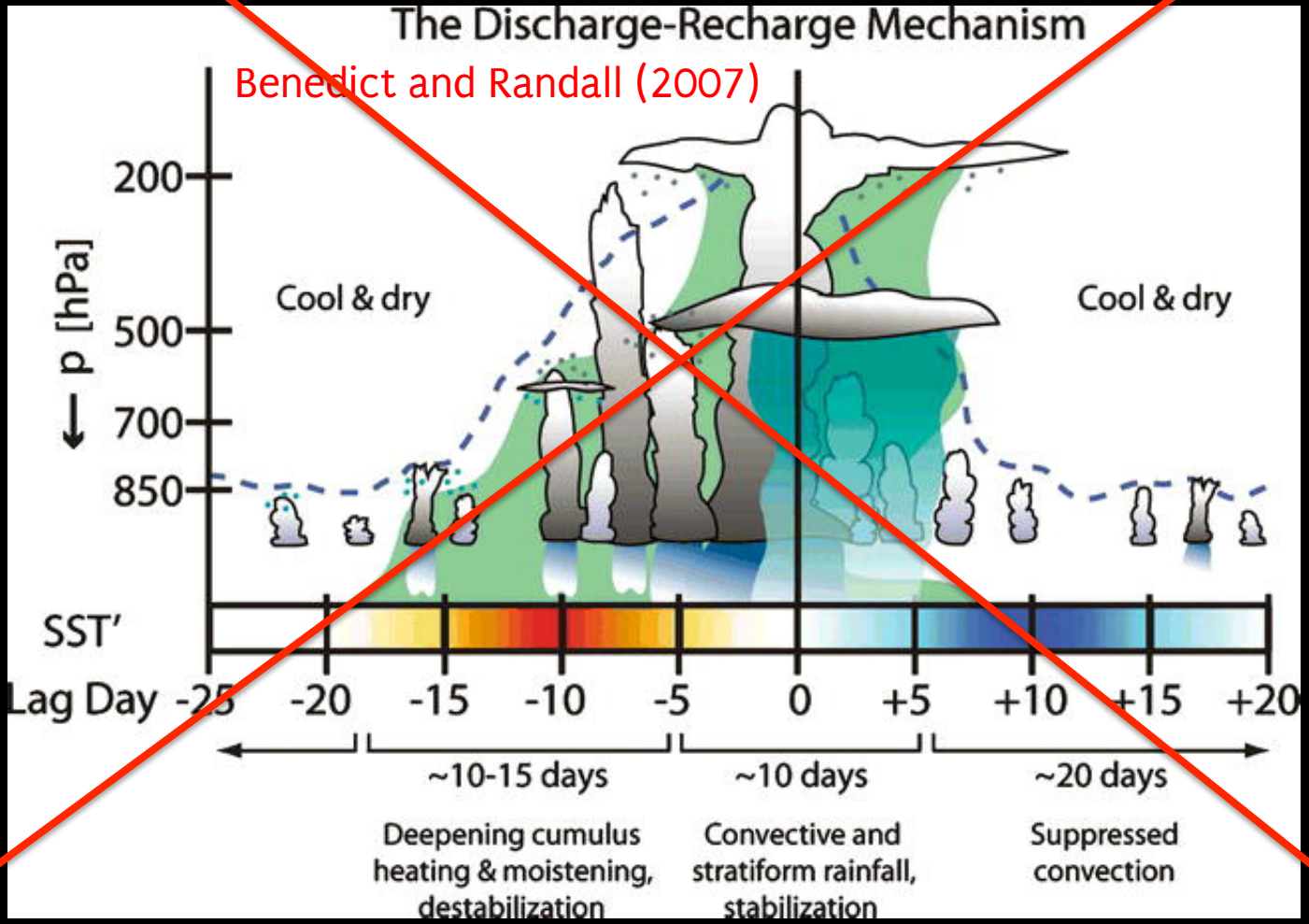
Knutson and Weickmann (1987)

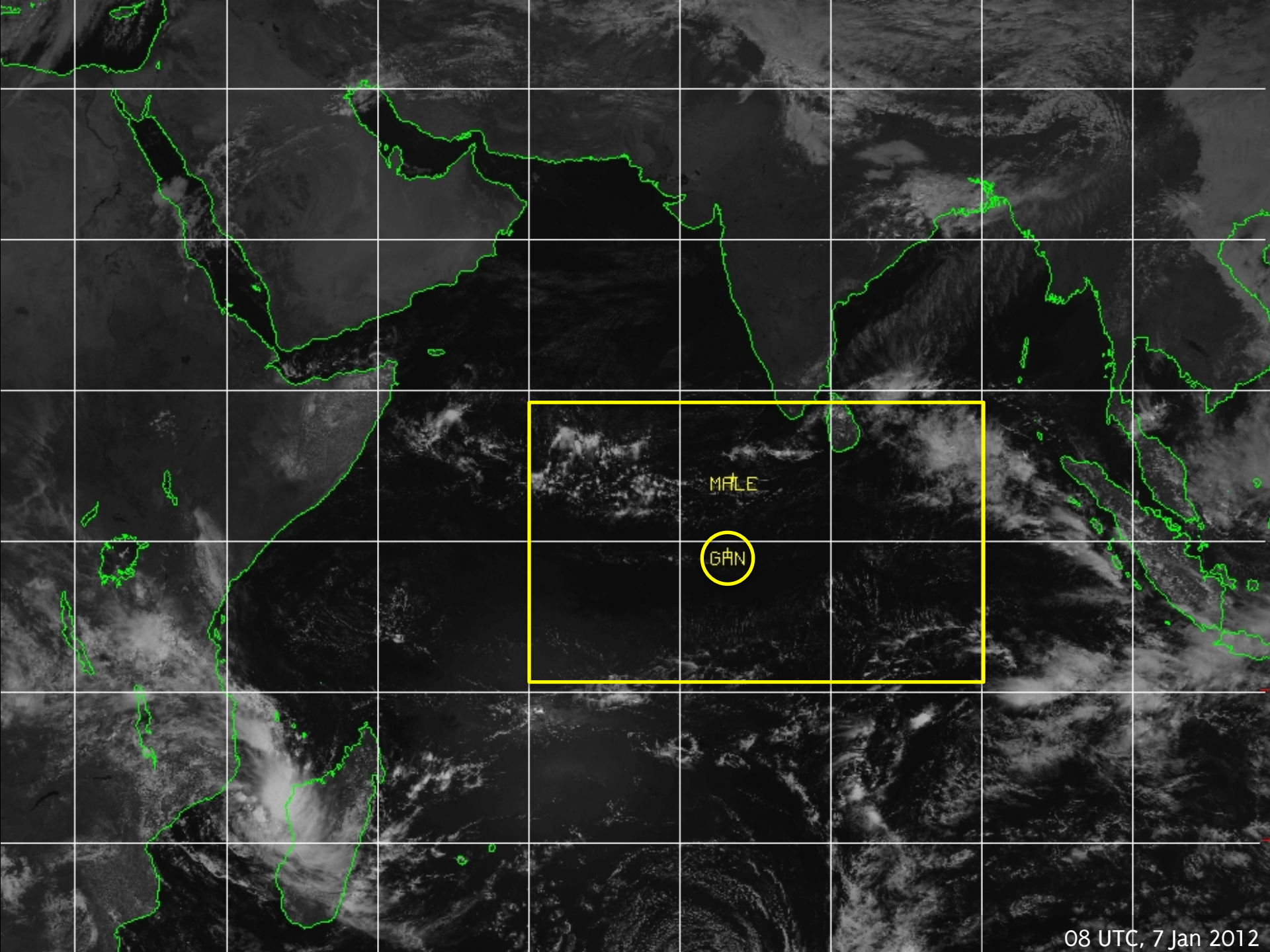


Hypothesis: Gradual moistening leads to systematic build-up of convection, ultimately resulting in MJO ("discharge-recharge"; Bladé and Hartmann (1993), Kemball-Cooke and Weare (2001), Benedict and Randall (2007), and others.)

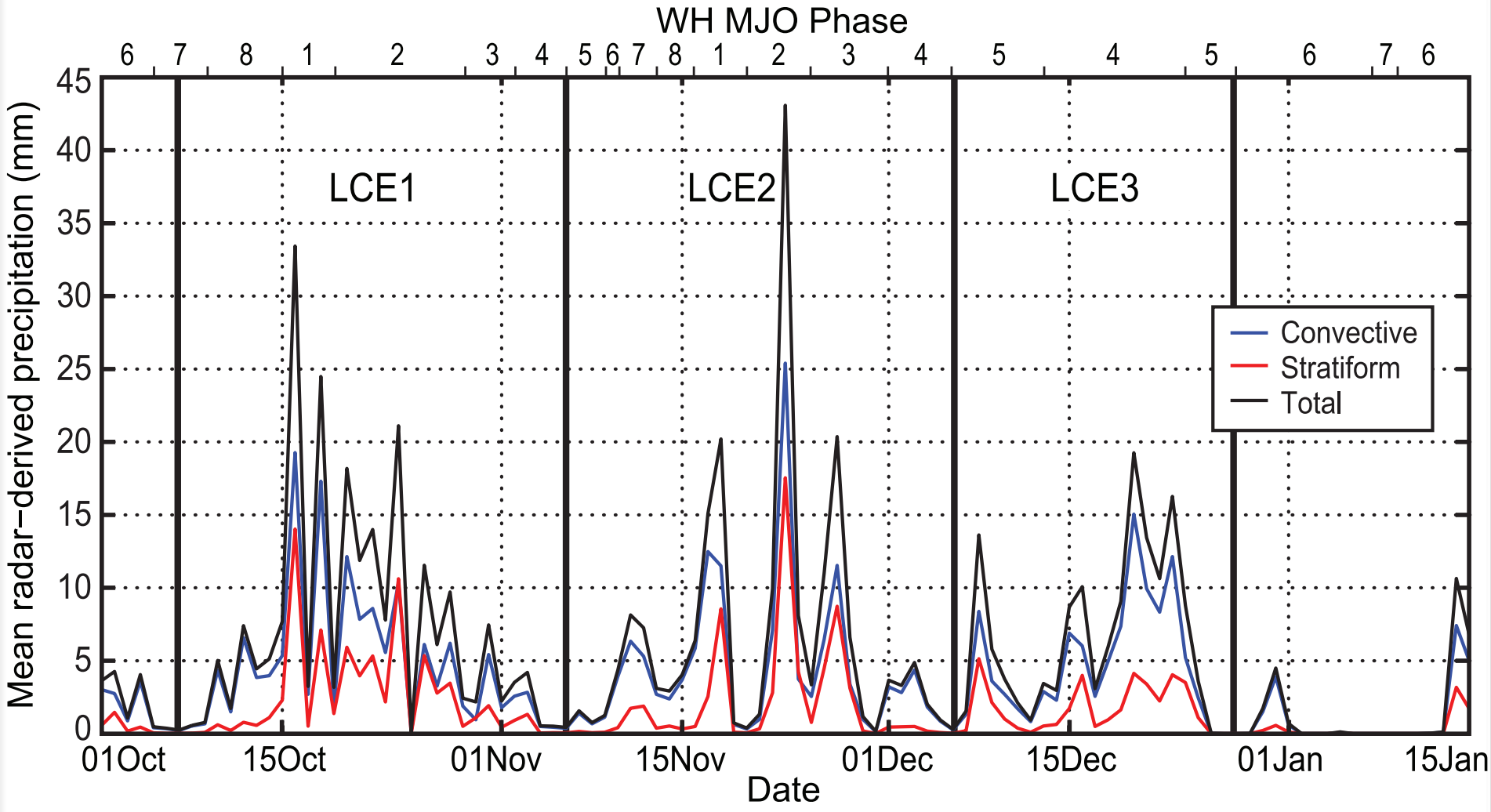


Hypothesis: Gradual moistening leads to systematic build-up of convection, ultimately resulting in MJO ("discharge-recharge"; Bladé and Hartmann (1993), Kemball-Cooke and Weare (2001), Benedict and Randall (2007), and others.)

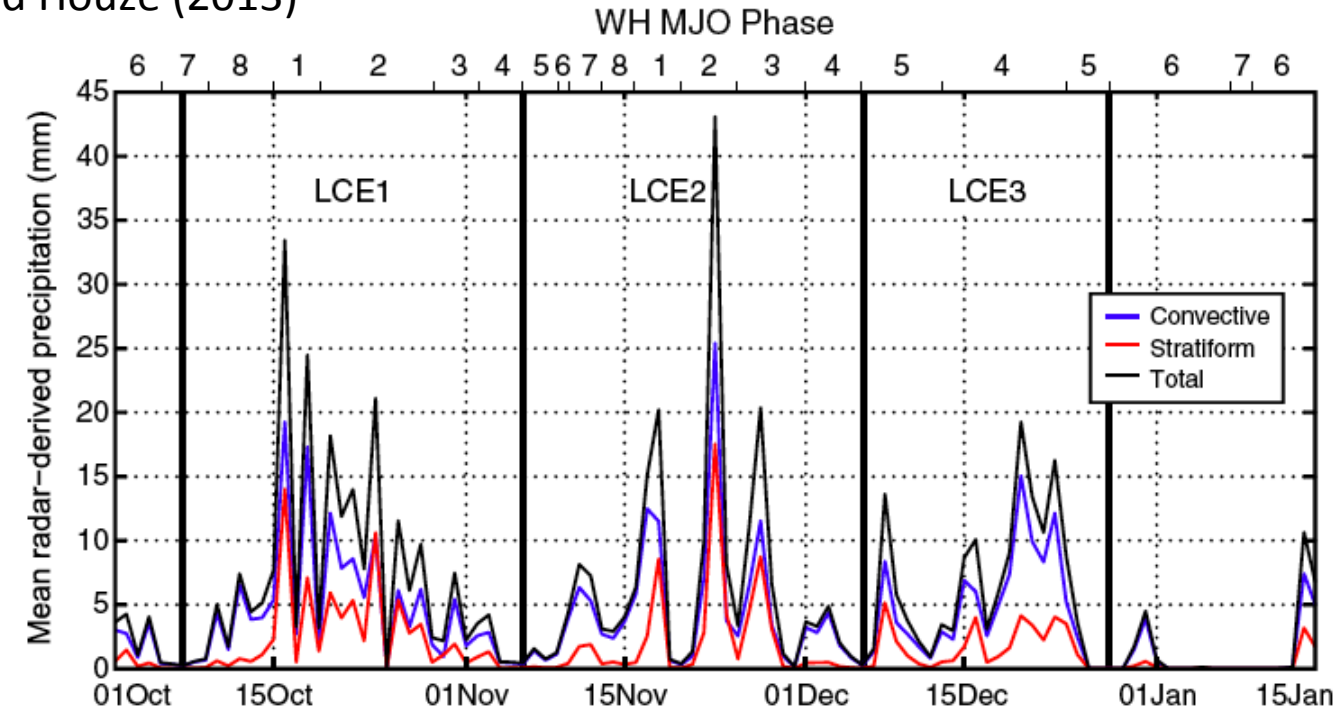


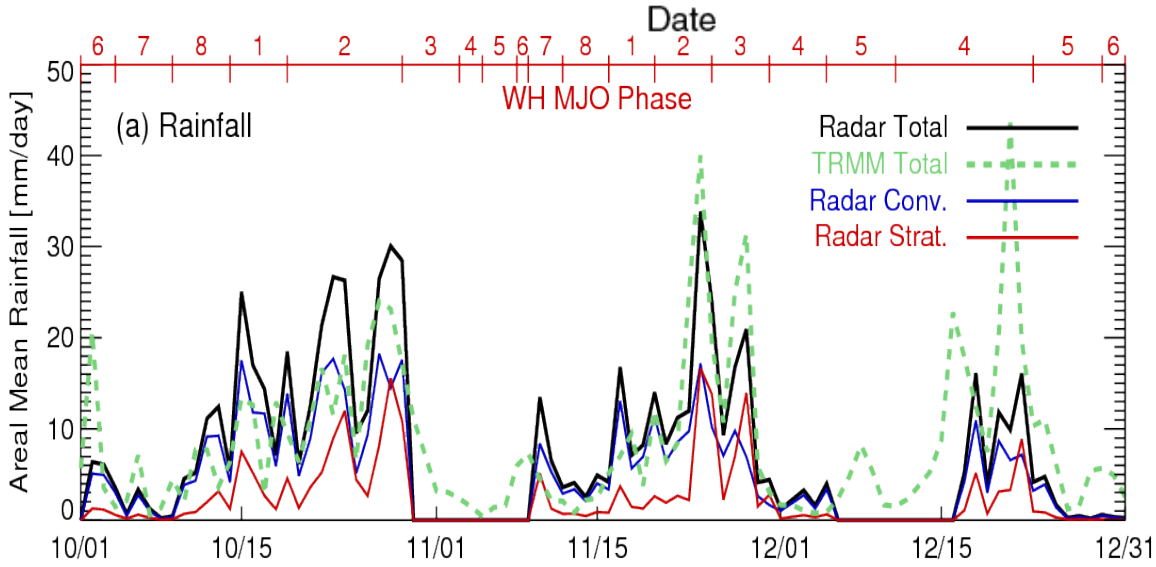

MALE
GAN
08 UTC, 7 Jan 2012

Evolution of Cloud Population, Precipitation, and Humidity Fields


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
Convective
Stratiform
Total
Mean radar−derived precipitation (mm)
0 5 10 15 20 25 30 35 40 45
01Oct 15Oct 01Nov 15Nov 01Dec 15Dec 01Jan 15Jan
Date

Powell and Houze (2013)

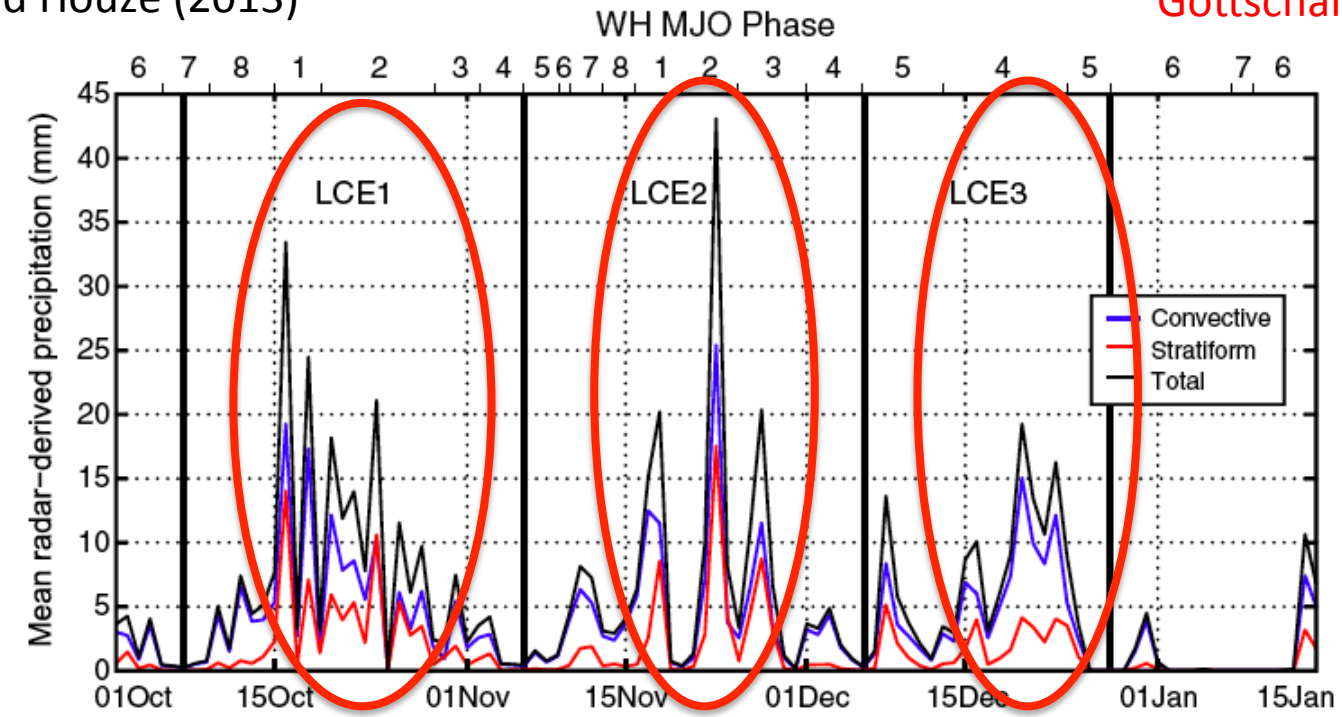


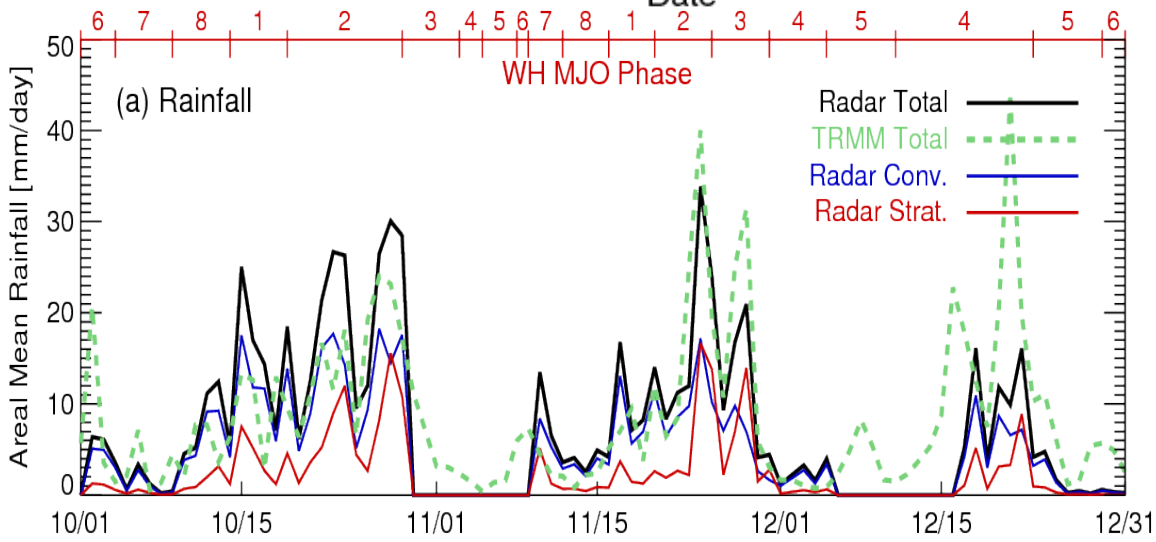


Xu and Rutledge (2014)

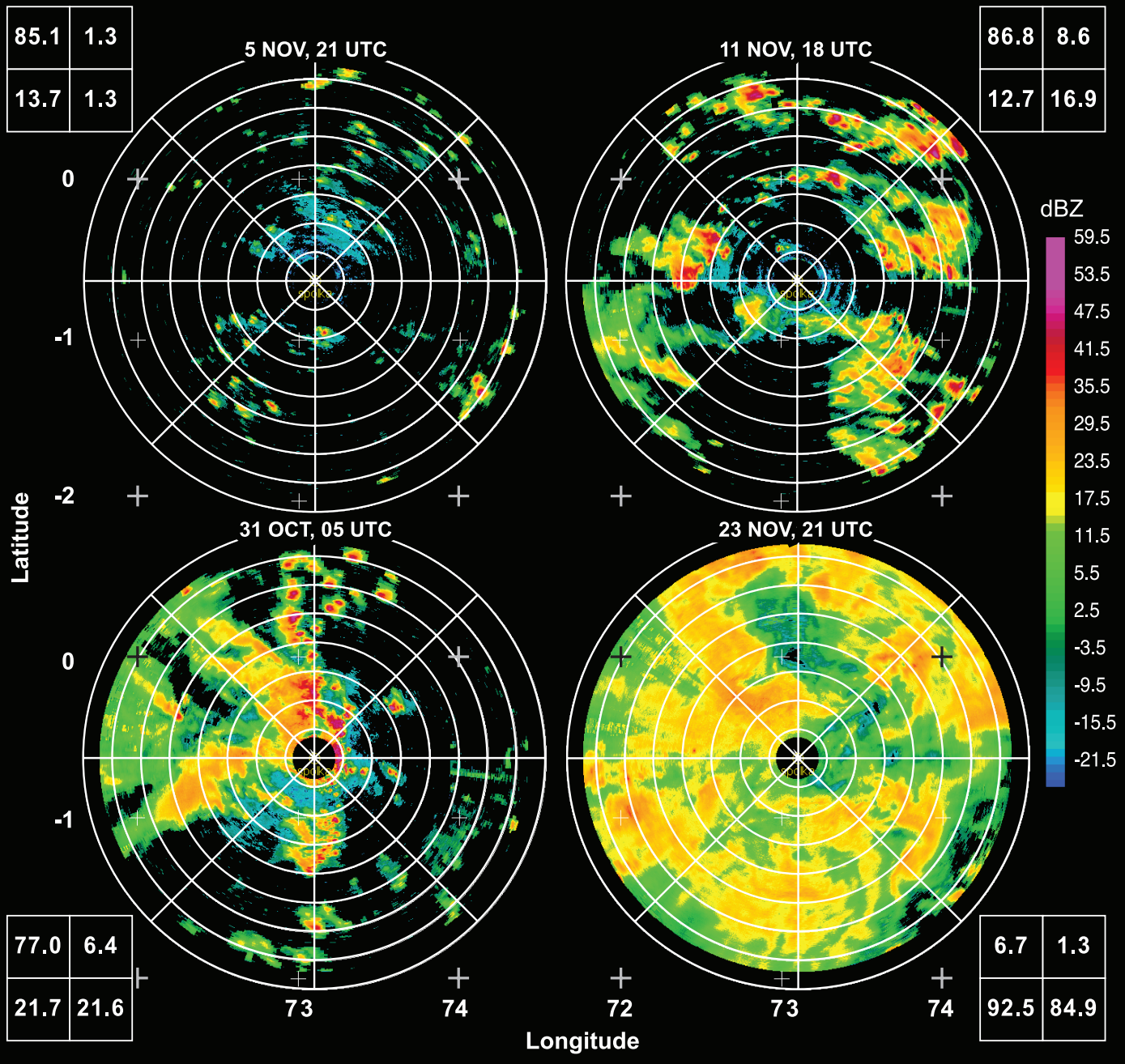
Powell and Houze (2013)

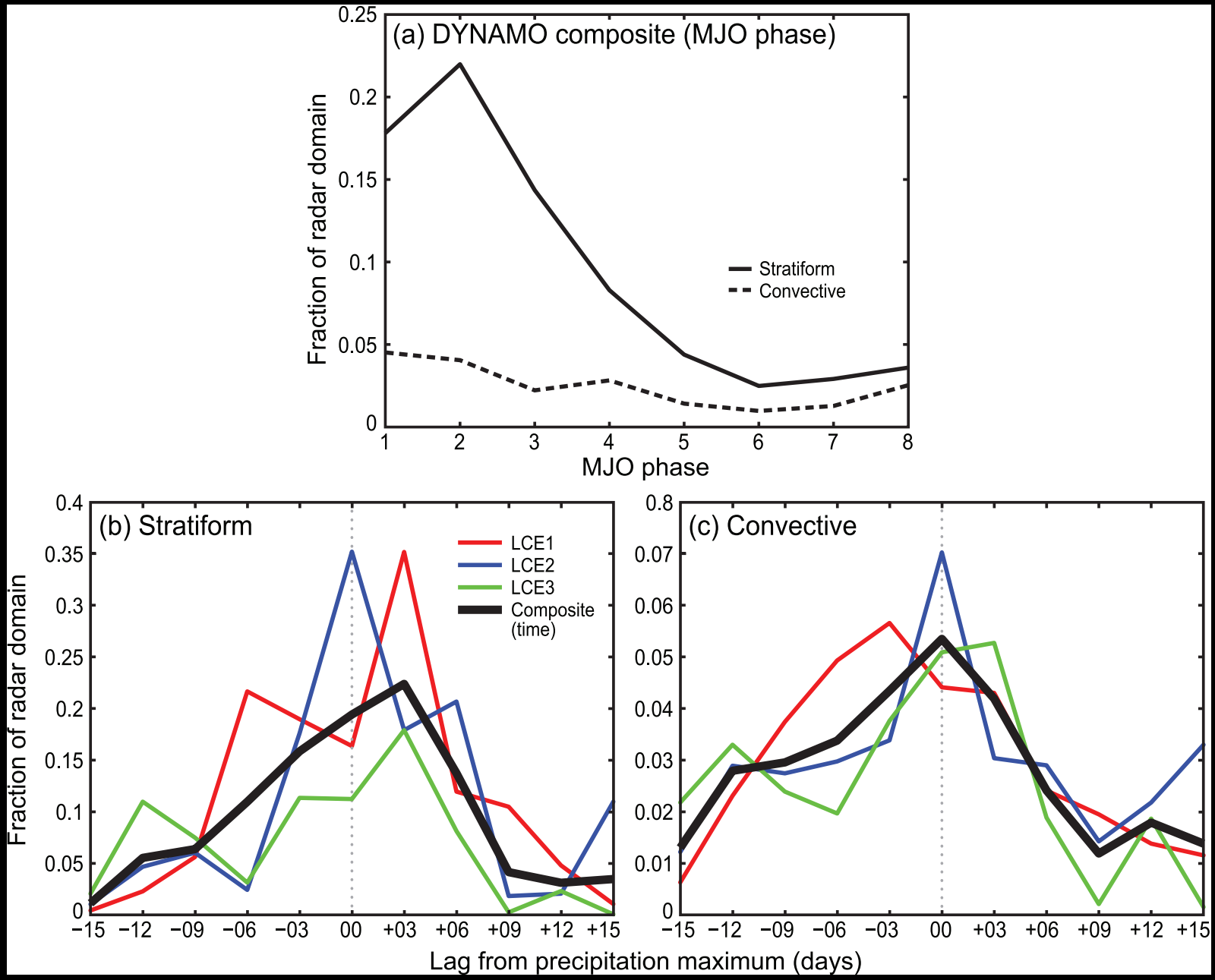
Gottschalck et al (2013)

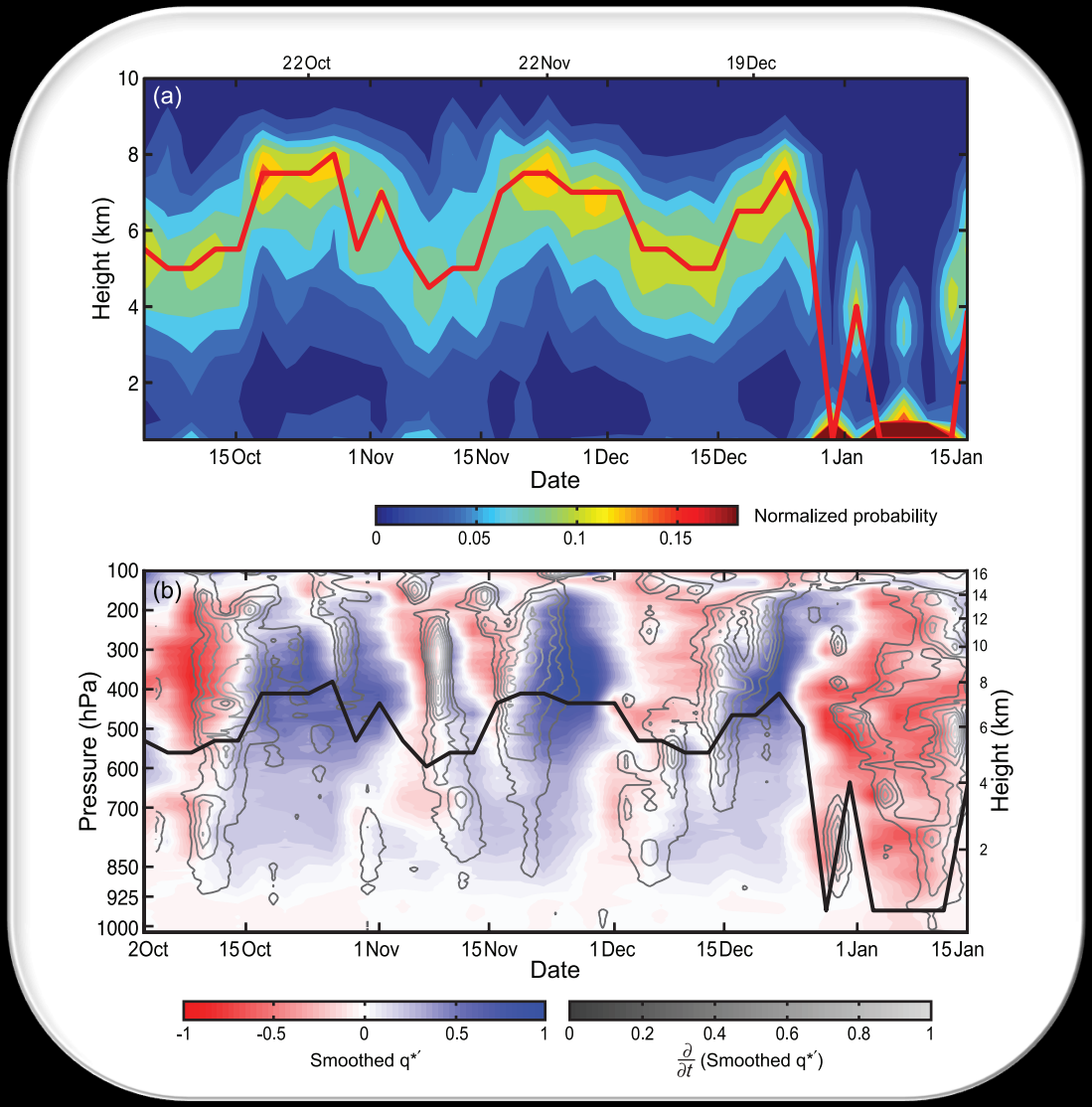


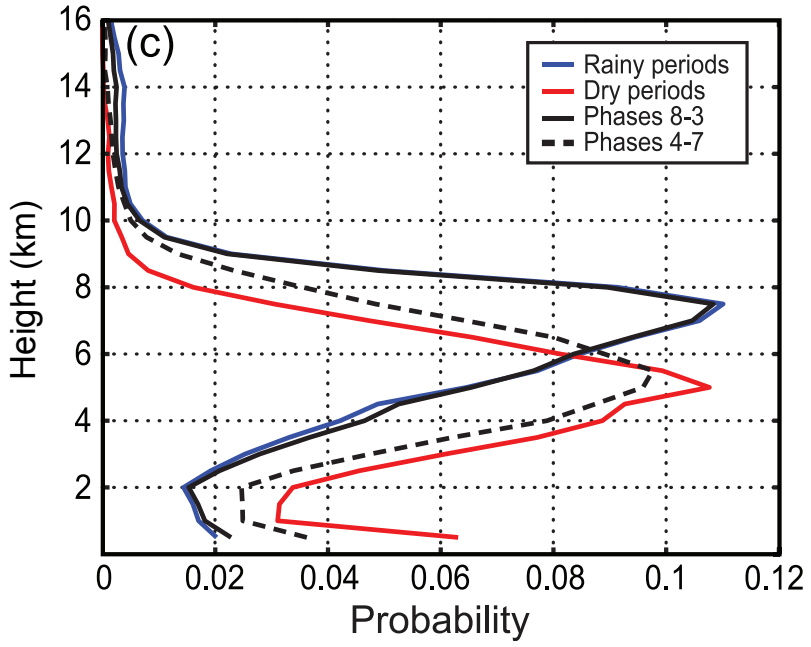


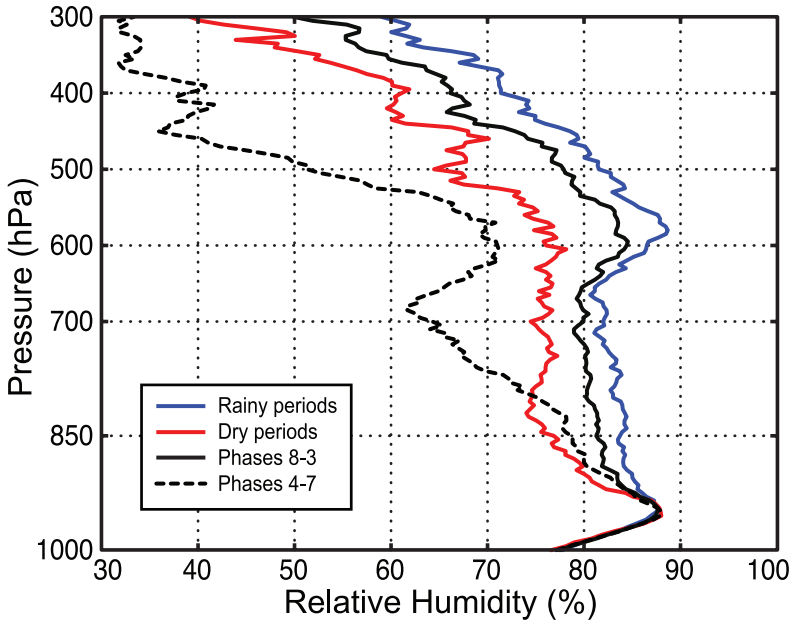
Xu and Rutledge (2014)

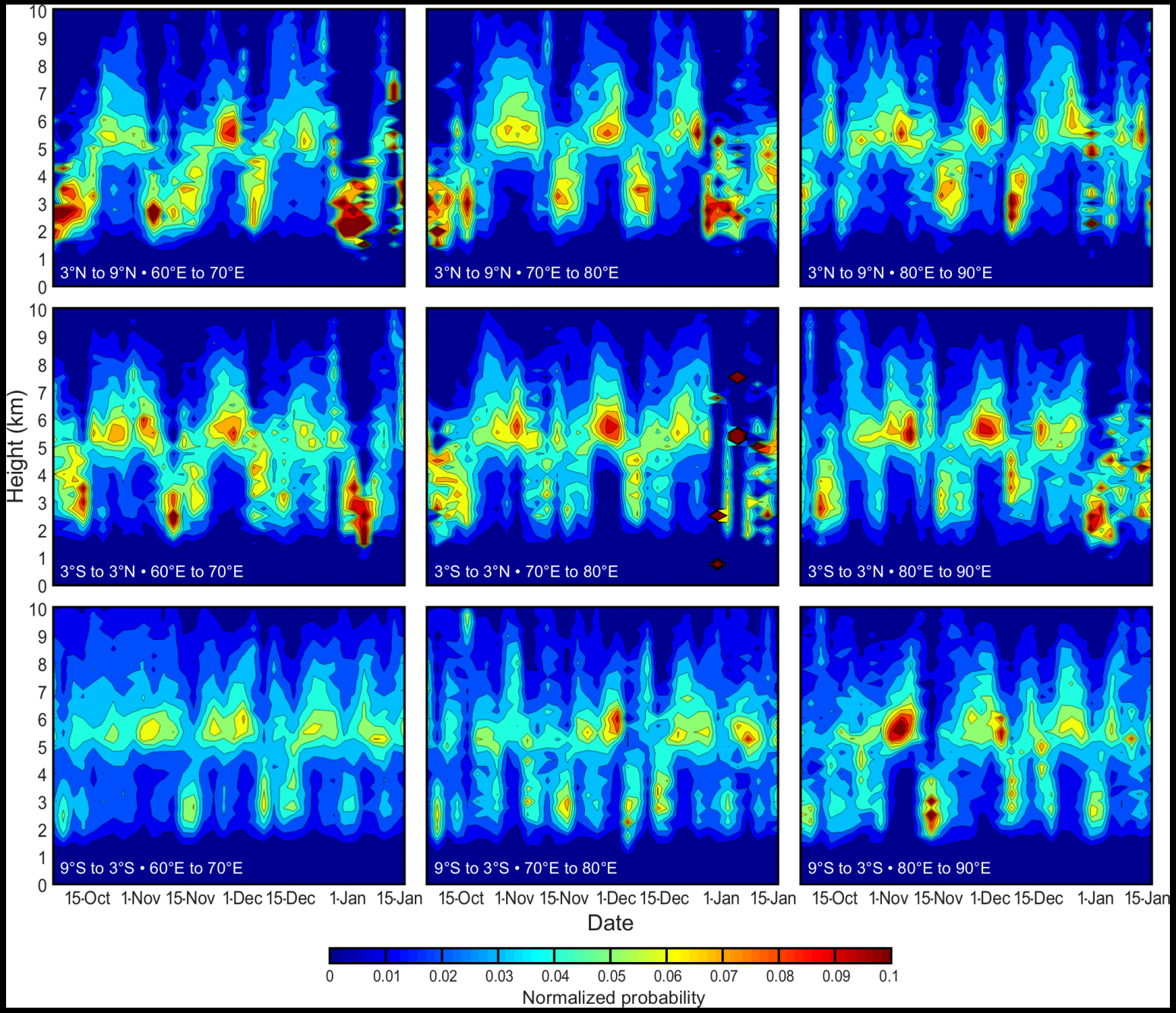

85.1
1.3
13.7
1.3
5 NOV, 21 UTC
86.8
8.6
12.7
16.9
11 NOV, 18 UTC
31 OCT, 05 UTC
23 NOV, 21 UTC
77.0
6.4
21.7
21.6
6.7
1.3
92.5
84.9
0
-1
-2
Latitude
73
74
72
73
74
Longitude
dBZ
59.5
53.5
47.5
41.5
35.5
29.5
23.5
17.5
11.5
5.5
2.5
-3.5
-9.5
-15.5
-21.5

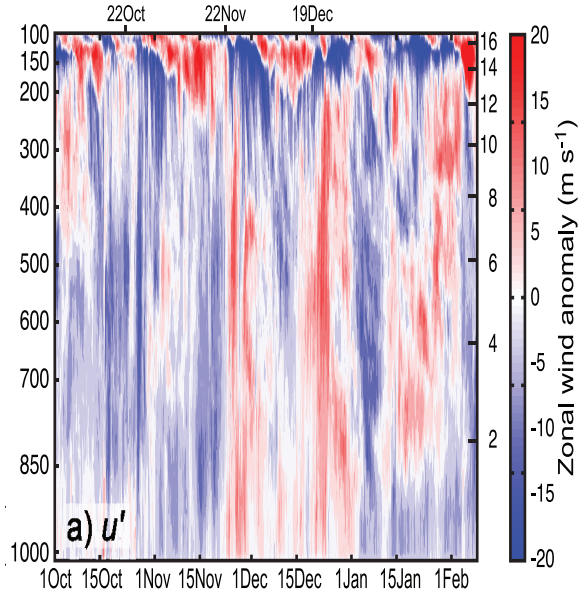

(a) DYNAMO composite (MJO phase)
Fraction of radar domain
0.25
0.2
0.15
0.1
0.05
0
1
2
3
4
5
6
7
8
MJO phase
Stratiform
Convective
(b) Stratiform
LCE1
LCE2
LCE3
Composite (time)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
−15
−12
−09
−06
−03
00
+03
+06
+09
+12
+15
(c) Convective
0.8
0.07
0.06
0.05
0.04
0.03
0.02
0.01
Lag from precipitation maximum (days)

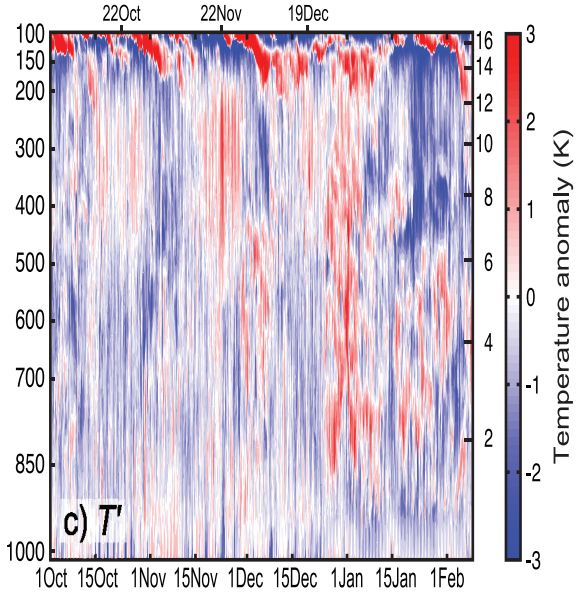

22 Oct
22 Nov
19 Dec
(a)
Height (km)
10
8
6
4
2
15 Oct
1 Nov
15 Nov
1 Dec
15 Dec
1 Jan
15 Jan
Date
Normalized probability
0
0.05
0.1
0.15
(b)
Pressure (hPa)
100
200
300
400
500
600
700
850
925
1000
Height (km)
16
14
12
10
8
6
4
2
2 Oct
15 Oct
1 Nov
15 Nov
1 Dec
15 Dec
1 Jan
15 Jan
Date
-1
-0.5
0
0.5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

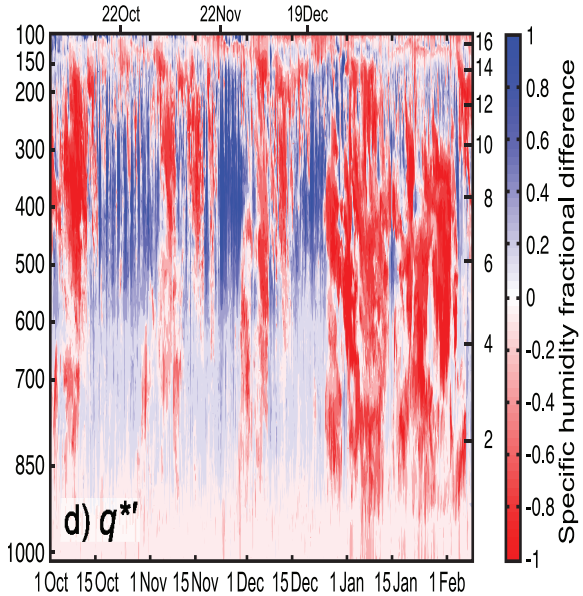

(c)
Rainy periods
Dry periods
Phases 8-3
Phases 4-7
Height (km)
16
14
12
10
8
6
4
2
0
0.02
0.04
0.06
0.08
0.1
0.12
Probability


Rainy periods
Dry periods
Phases 8-3
Phases 4-7
Pressure (hPa)
300
400
500
600
700
850
1000
30
40
50
60
70
80
90
100
Relative Humidity (%)


3°N to 9°N • 60°E to 70°E
3°N to 9°N • 70°E to 80°E
3°N to 9°N • 80°E to 90°E
3°S to 3°N • 60°E to 70°E
3°S to 3°N • 70°E to 80°E
3°S to 3°N • 80°E to 90°E
9°S to 3°S • 60°E to 70°E
9°S to 3°S • 70°E to 80°E
9°S to 3°S • 80°E to 90°E
Height (km)
0 1 2 3 4 5 6 7 8 9 10
15-Oct 1-Nov 15-Nov 1-Dec 15-Dec 1-Jan 15-Jan
Date
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1
Normalized probability

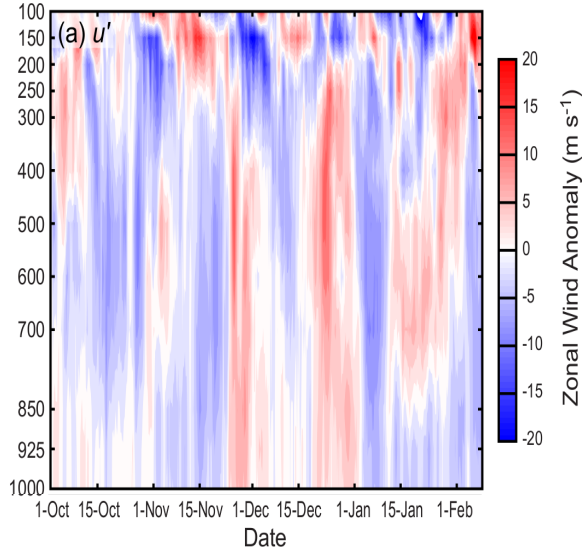


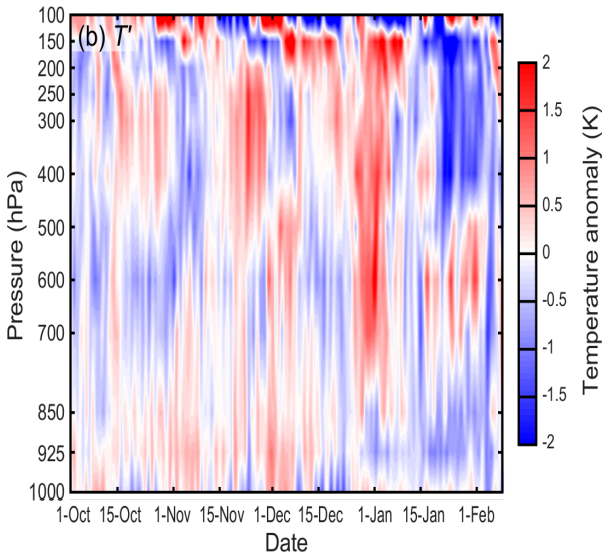


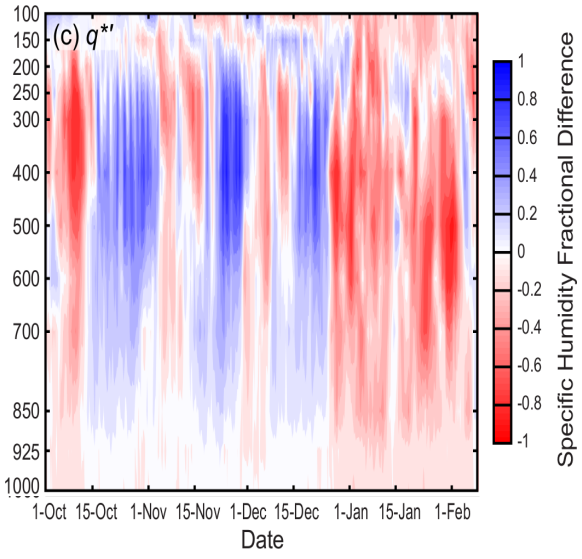


Top row: Gan rawinsonde data

Bottom row: ERA-Interim (3°N – 3°S, 68°E – 78°E)



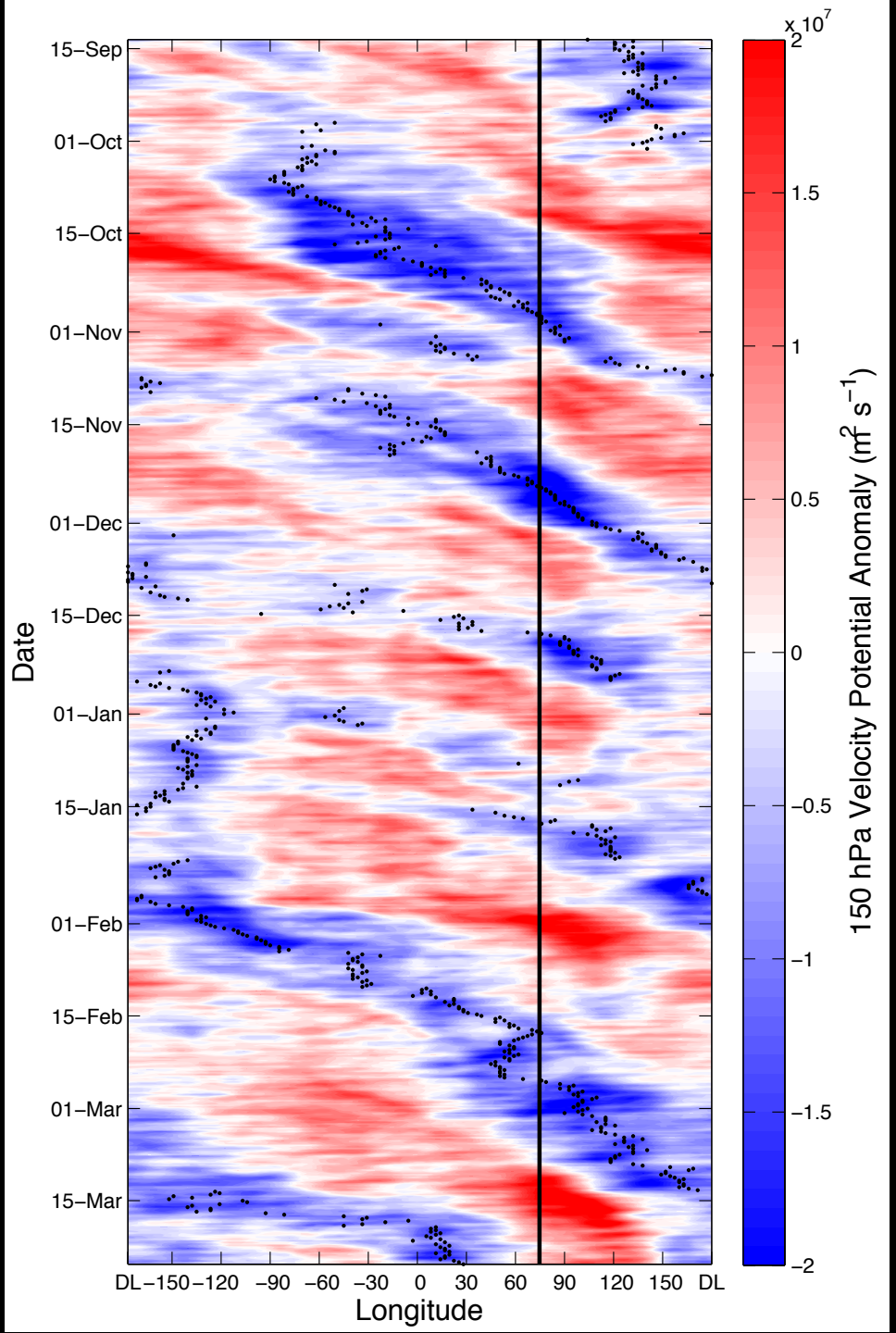




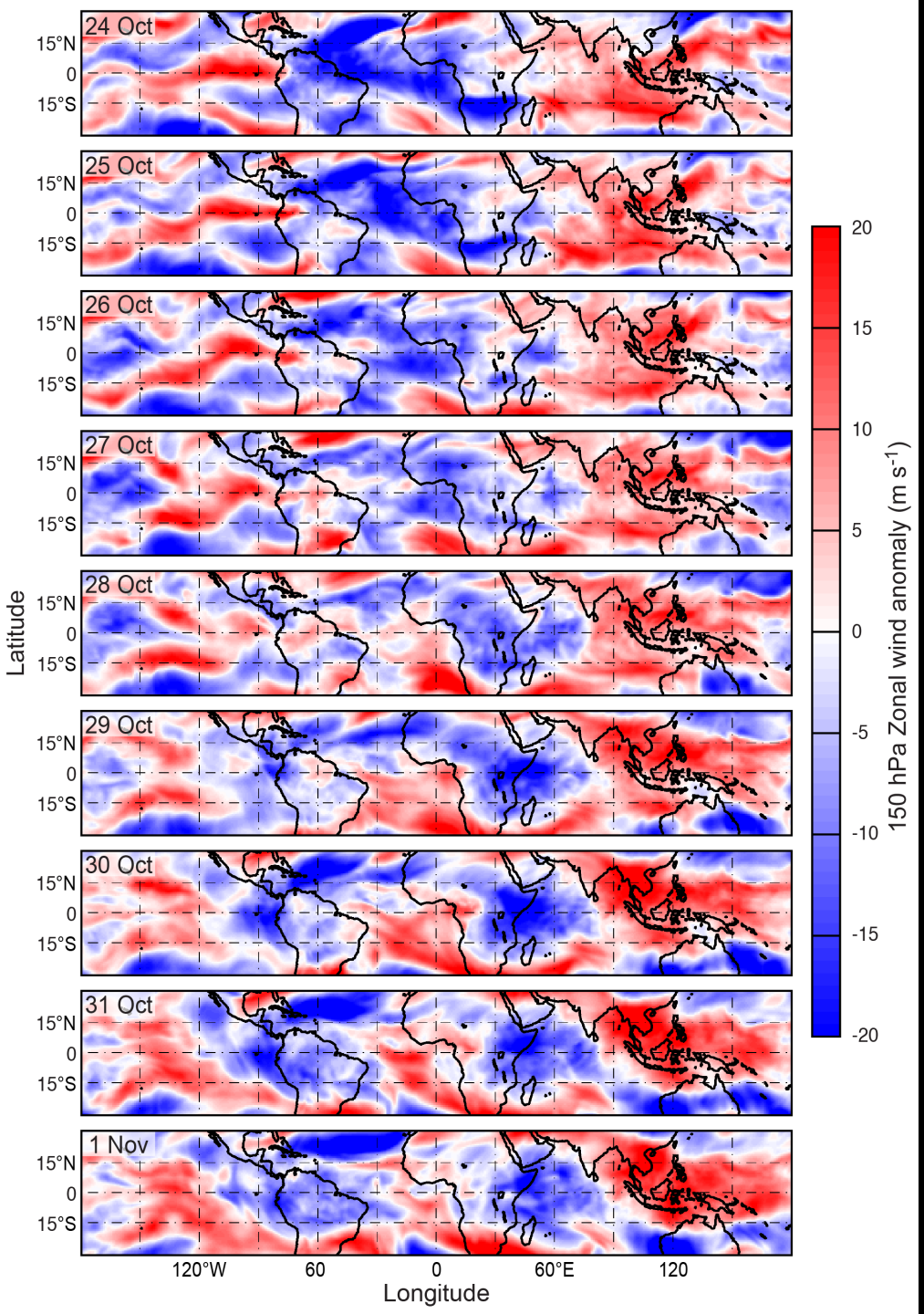
Upper-Tropospheric Dynamics

χ_{150}'

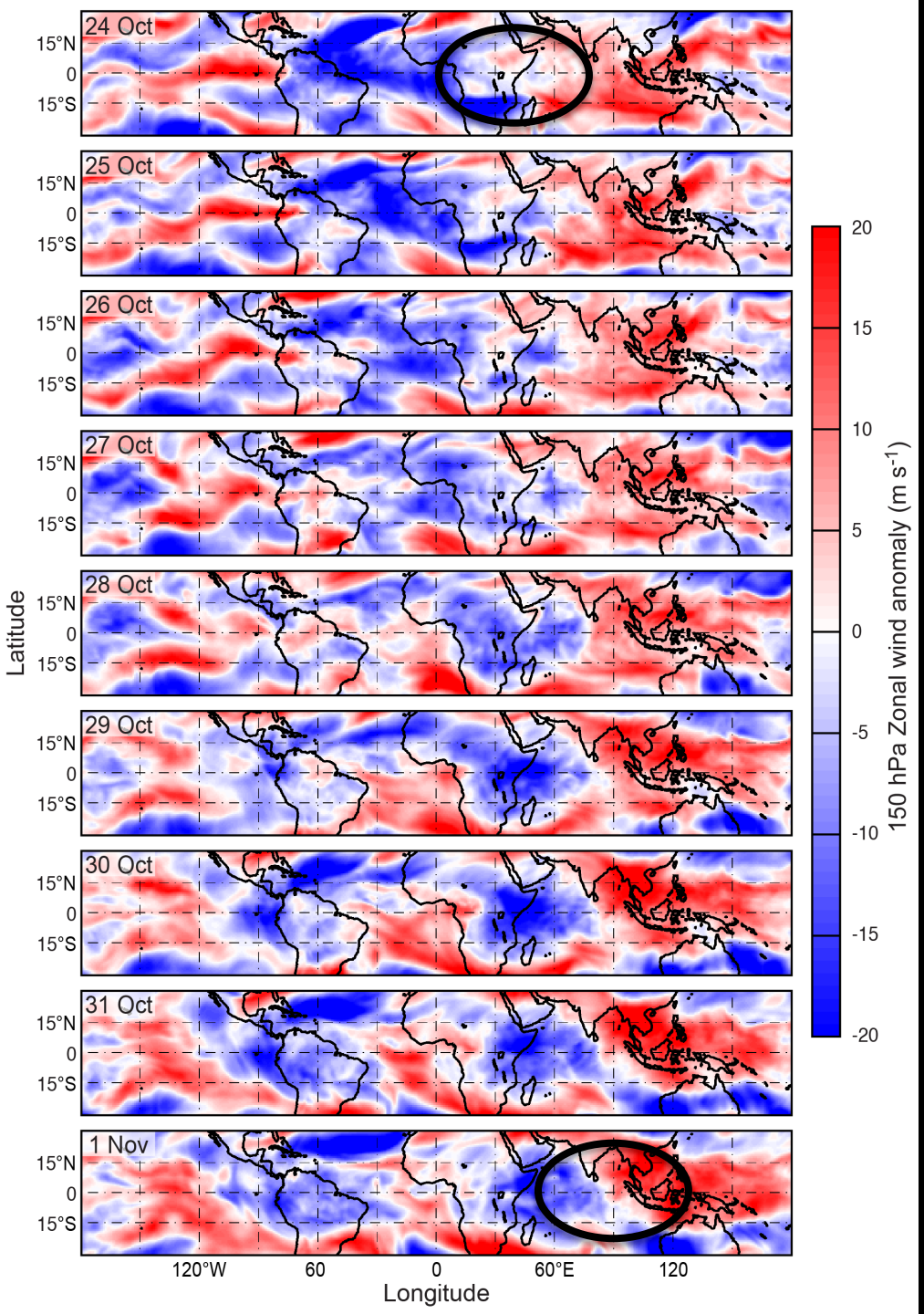
$$U = \nabla\chi$$



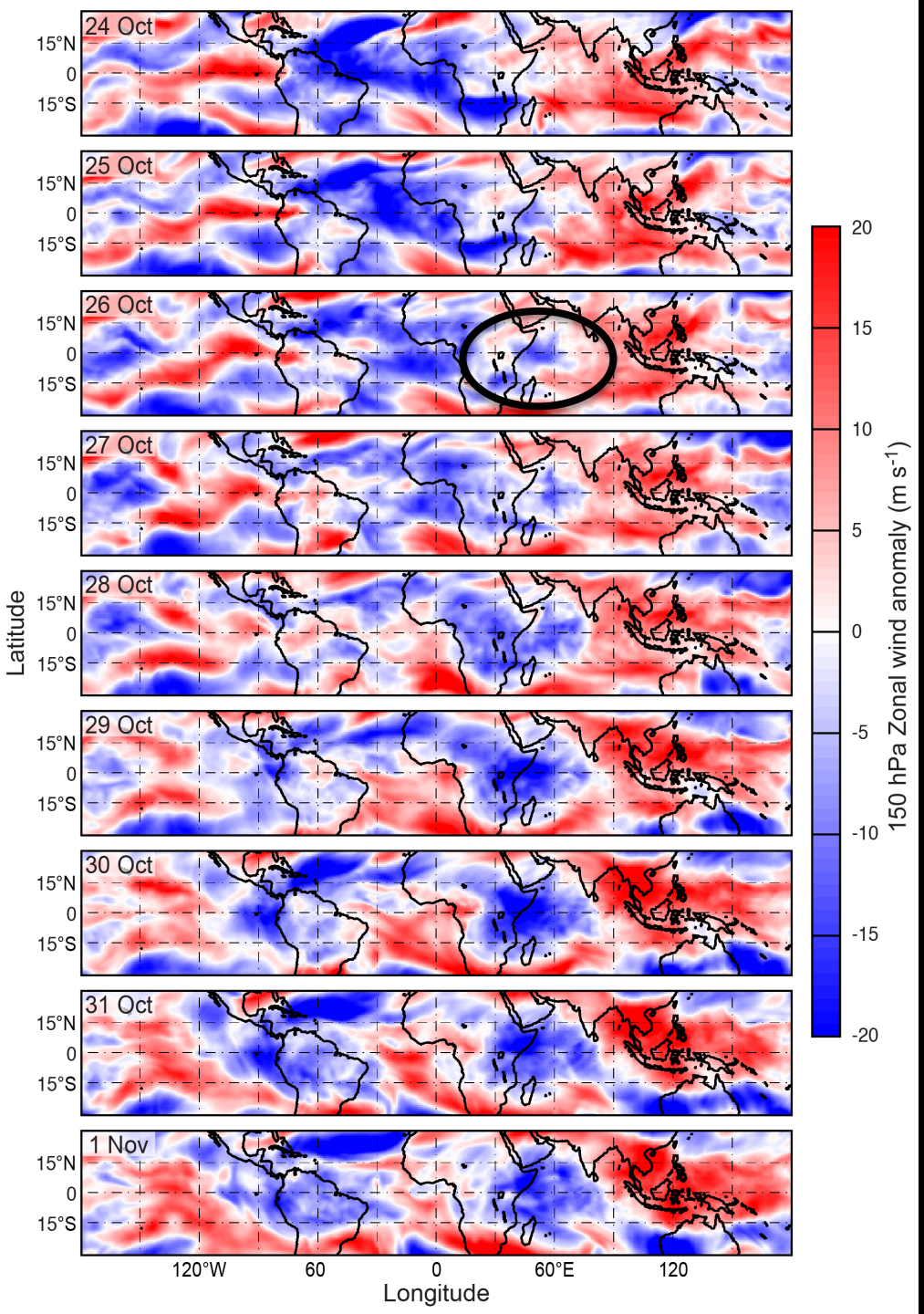
150 hPa *u'*
Blue: Easterly
Red: Westerly

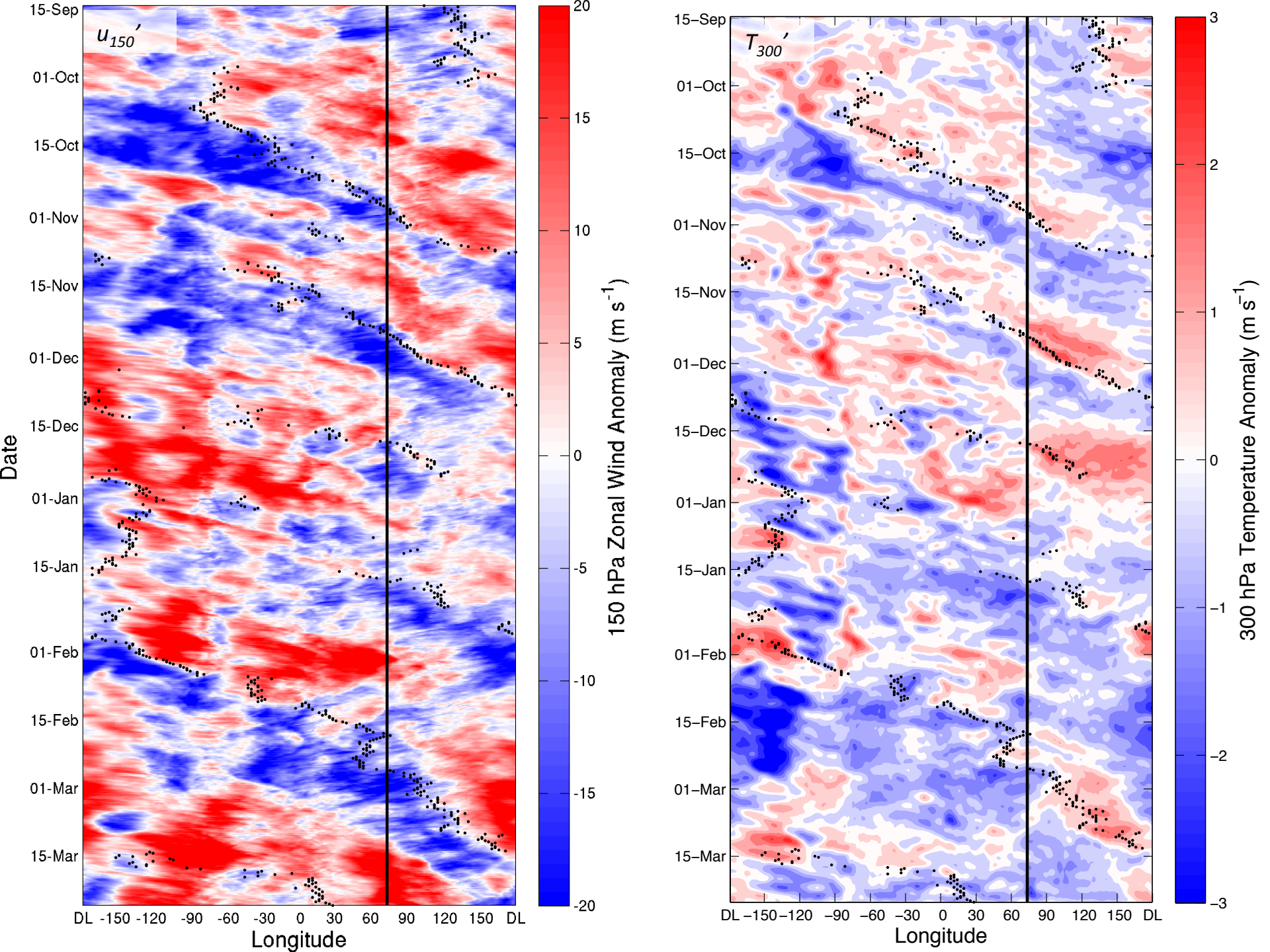


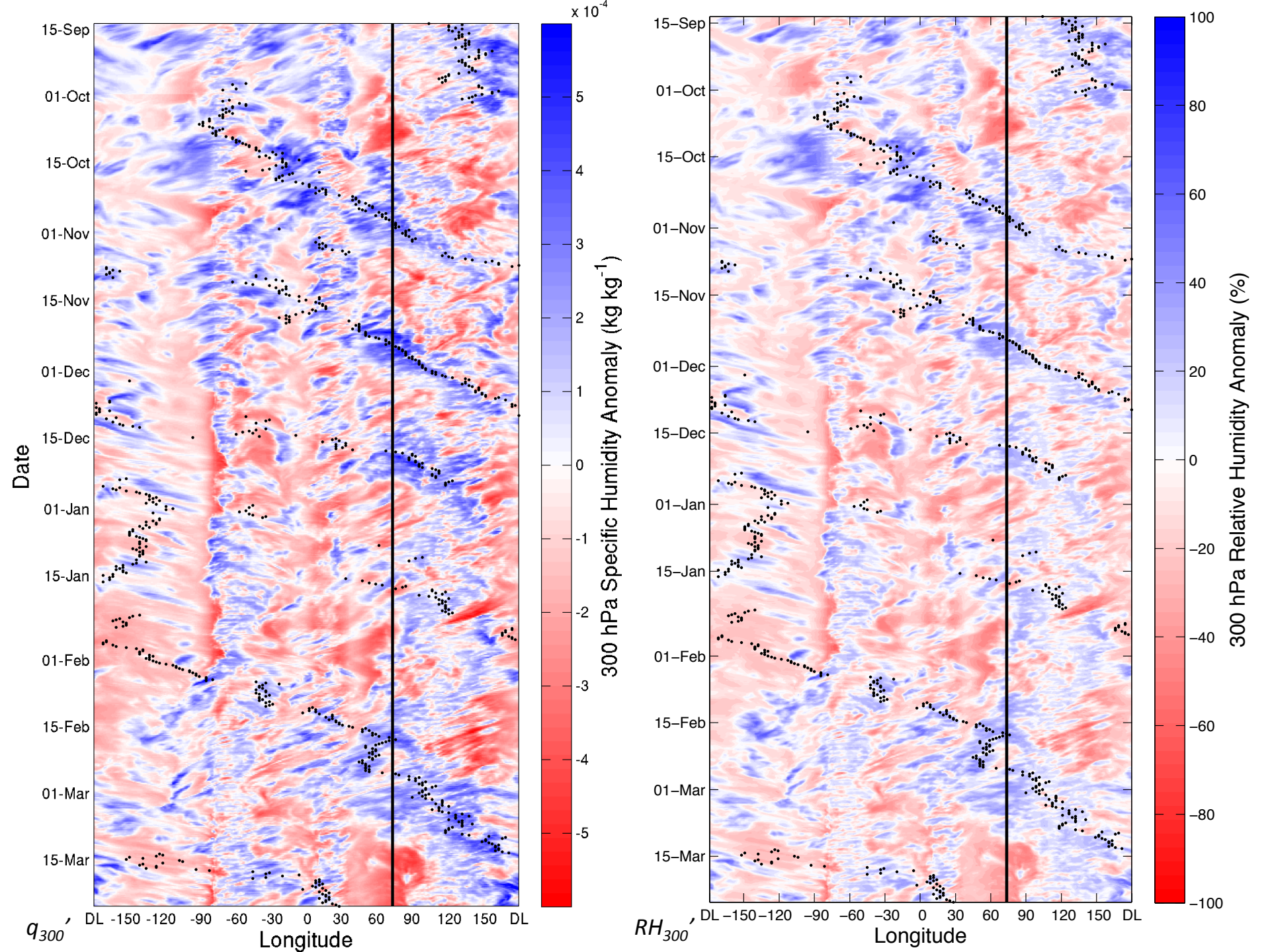
150 hPa *u'*
Blue: Easterly
Red: Westerly



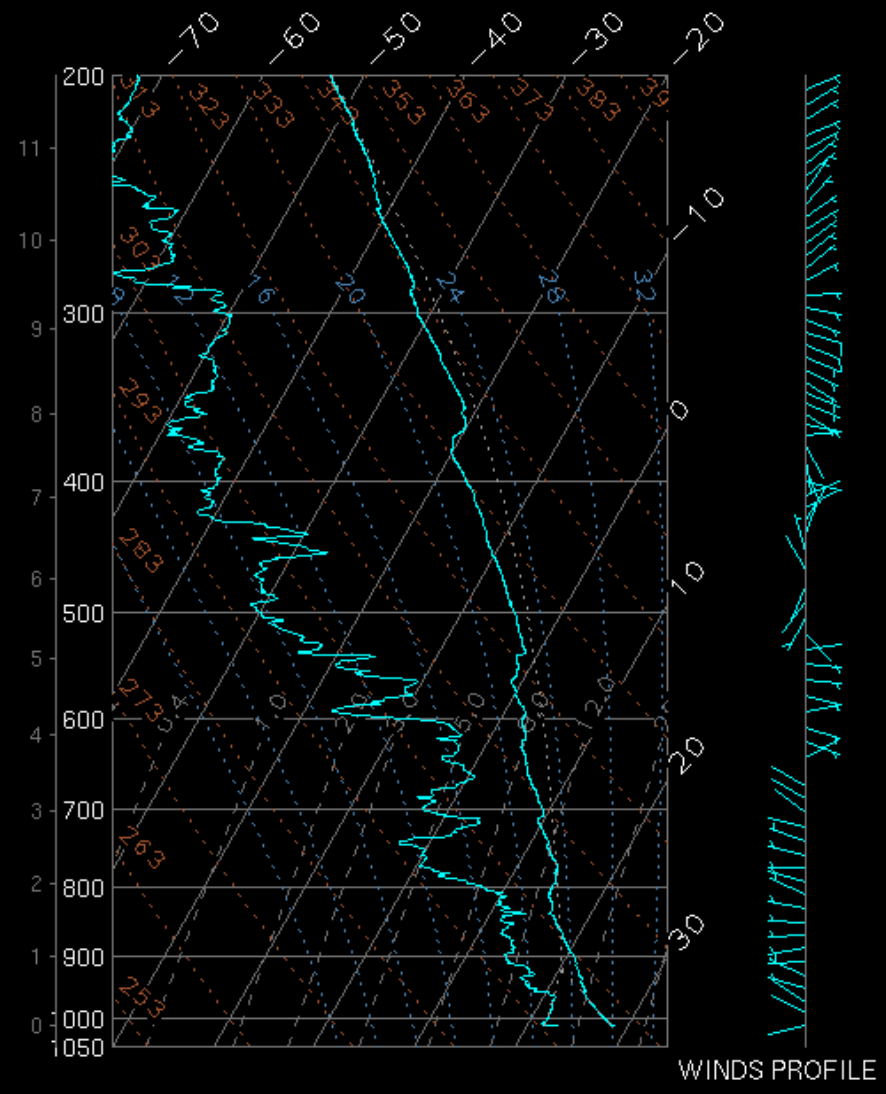
150 hPa *u'*
Blue: Easterly
Red: Westerly



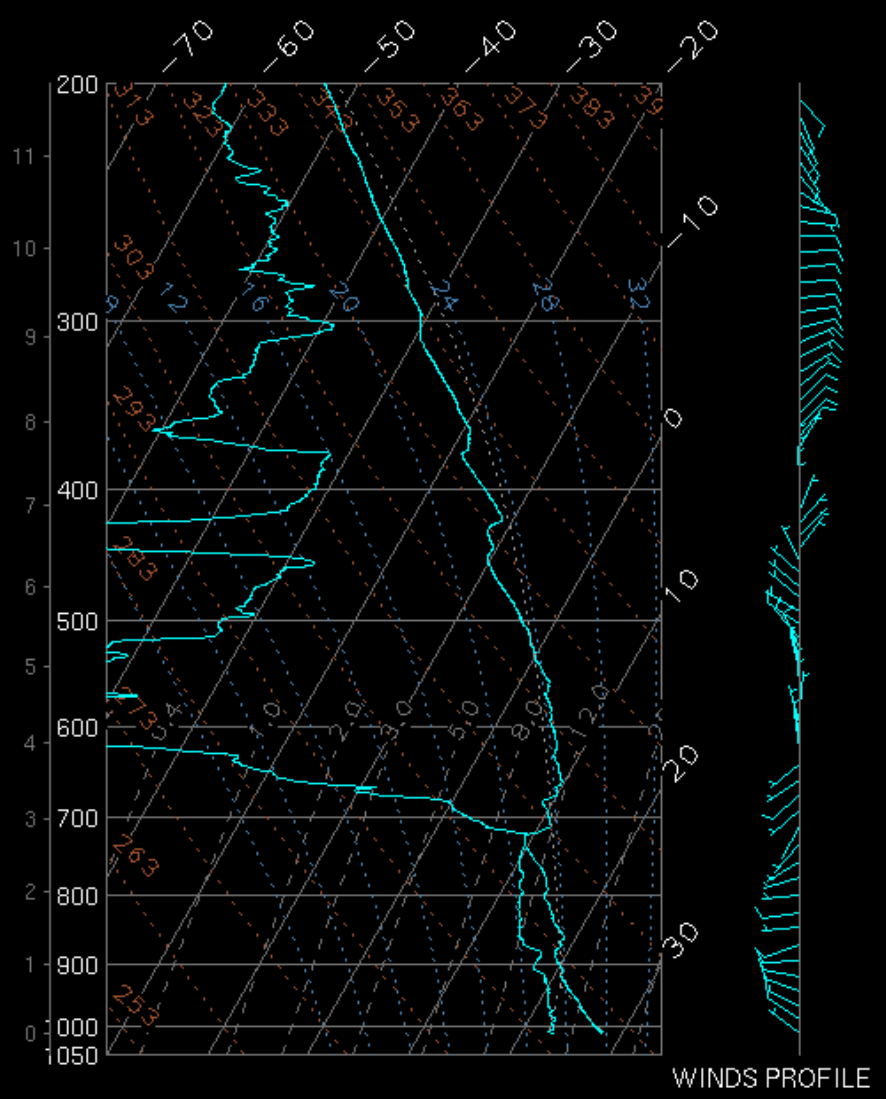

u_{150}'
15-Sep
01-Oct
15-Oct
01-Nov
15-Nov
01-Dec
15-Dec
01-Jan
15-Jan
01-Feb
15-Feb
01-Mar
15-Mar
Date
DL -150 -120 -90 -60 -30 0 30 60 90 120 150 DL
Longitude
20
15
10
5
0
-5
-10
-15
-20
150 hPa Zonal Wind Anomaly (m s^{-1})
T_{300}'
15–Sep
01–Oct
15–Oct
01–Nov
15–Nov
01–Dec
15–Dec
01–Jan
15–Jan
01–Feb
15–Feb
01–Mar
15–Mar
DL –150 –120 –90 –60 –30 0 30 60 90 120 150 DL
Longitude
3
2
1
0
–1
–2
–3
300 hPa Temperature Anomaly (m s^{-1})


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
q_{300}'
x 10^{-4}
5
4
3
2
1
0
-1
-2
-3
-4
-5
300 hPa Specific Humidity Anomaly (kg kg^{-1})
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
DL –150 –120 –90 –60 –30 0 30 60 90 120 150 DL
Longitude
RH_{300}'
100
80
60
40
20
0
–20
–40
–60
–80
–100
300 hPa Relative Humidity Anomaly (%)

0234 UTC, 9 October

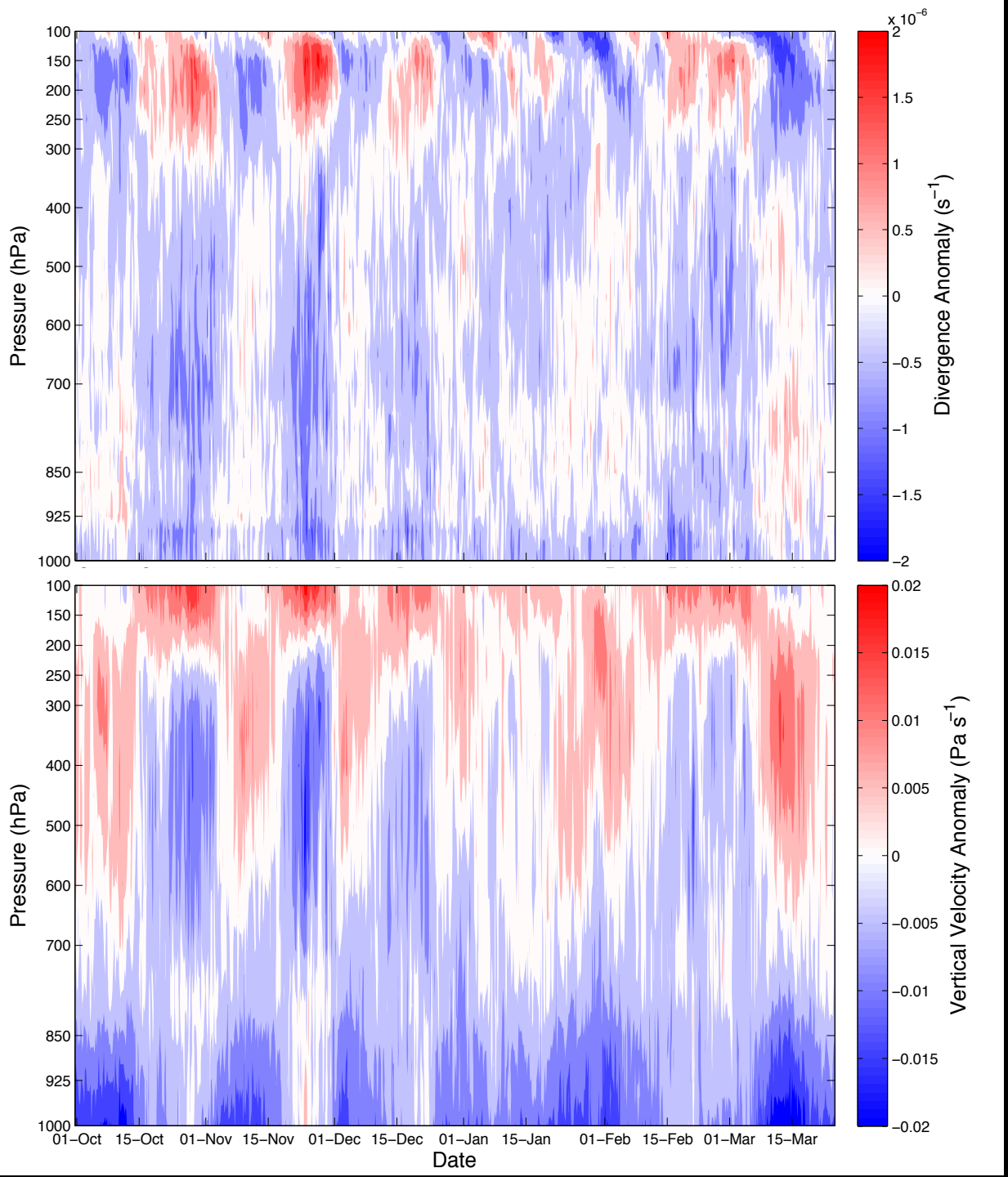


0236 UTC, 1 January



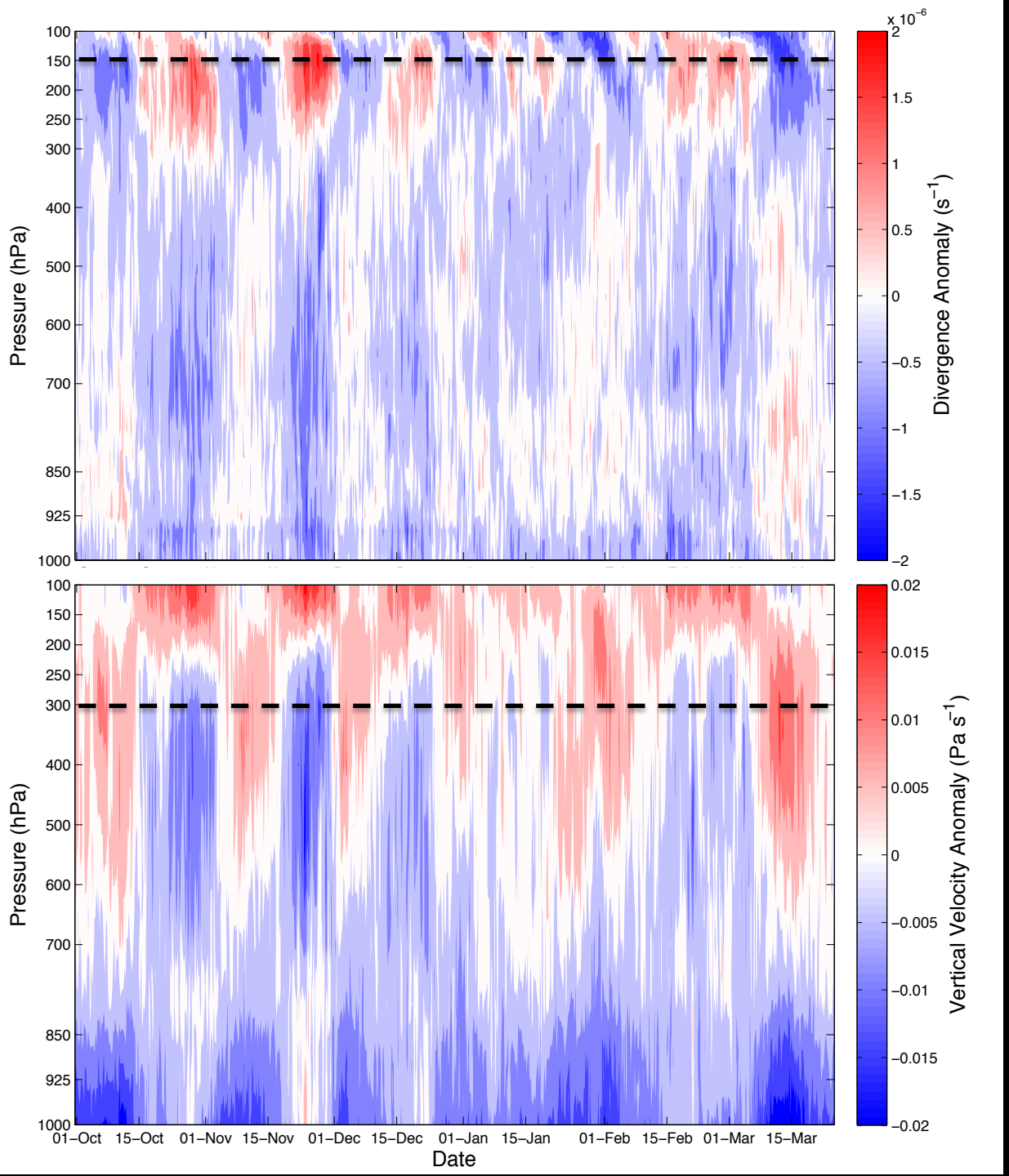
$\nabla \cdot U'$

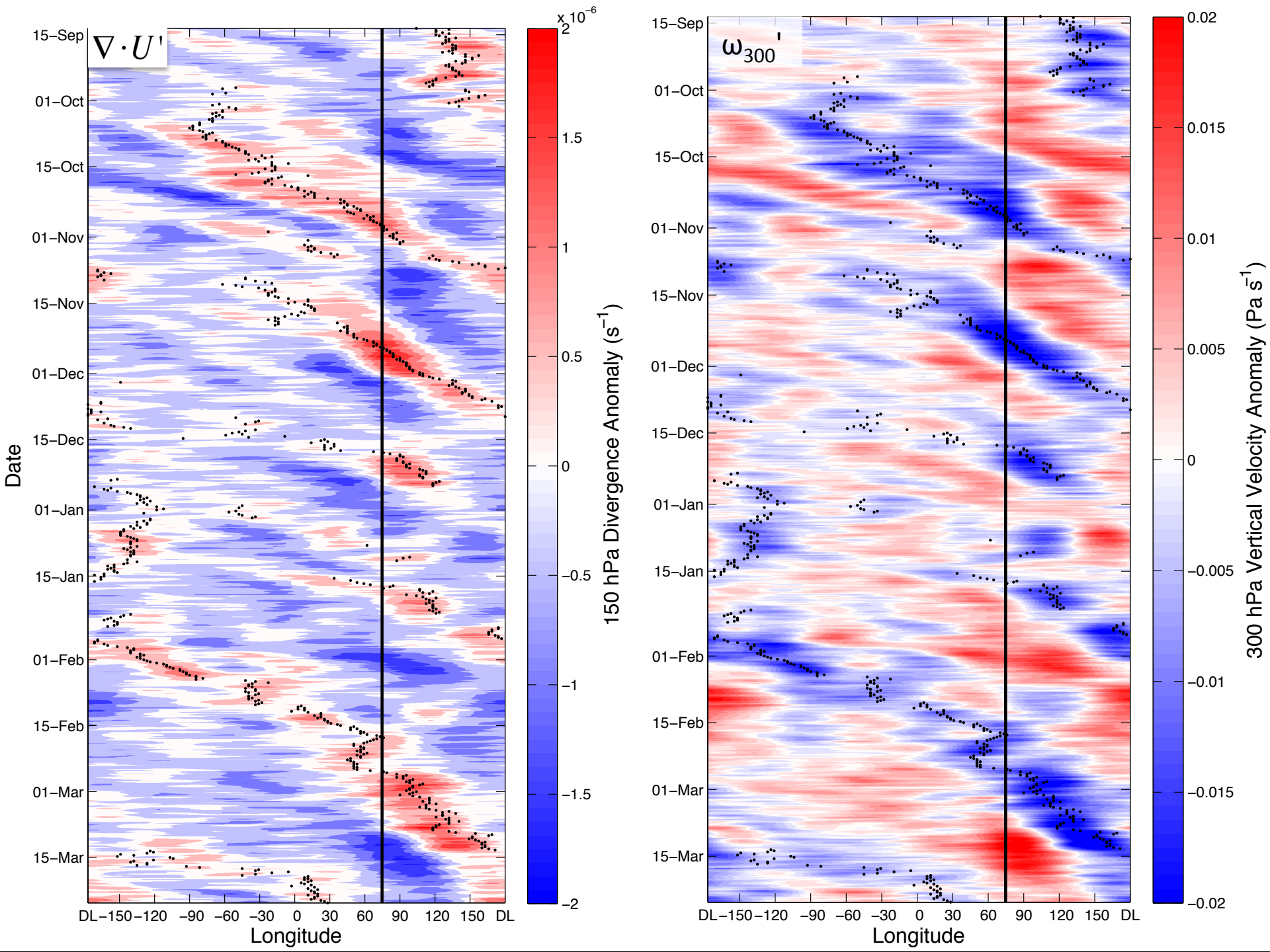
ω'

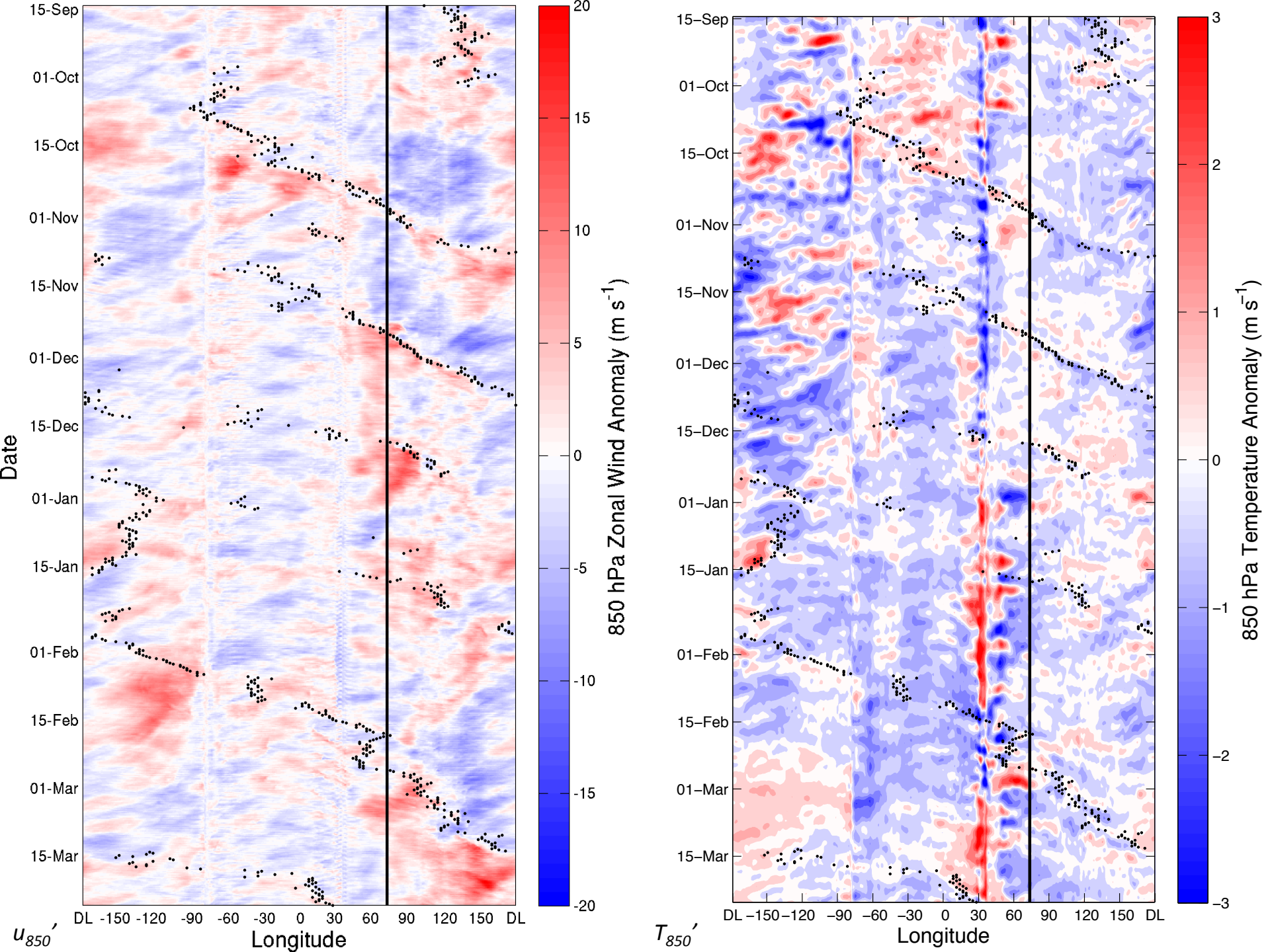


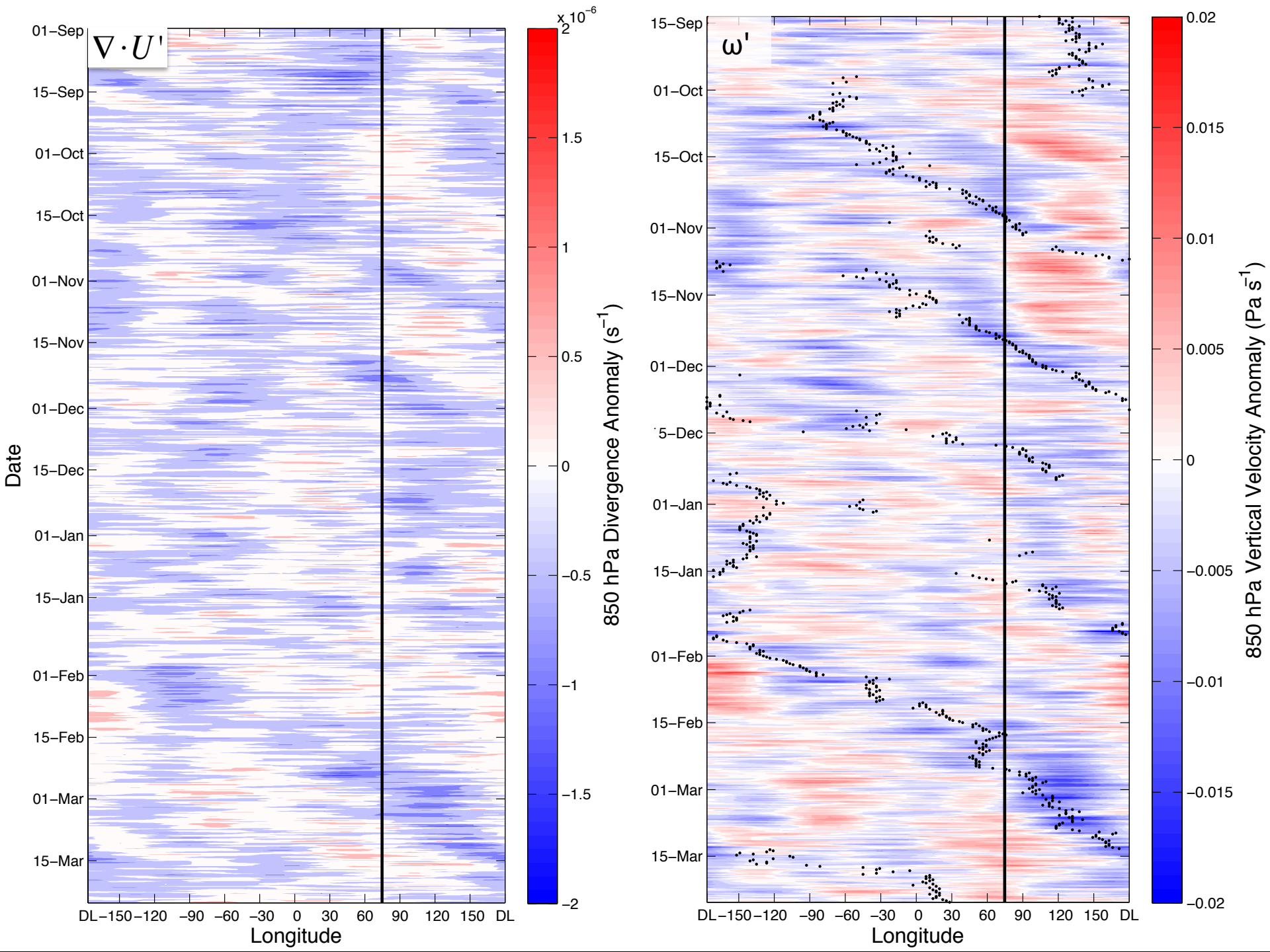
$\nabla \cdot U'$

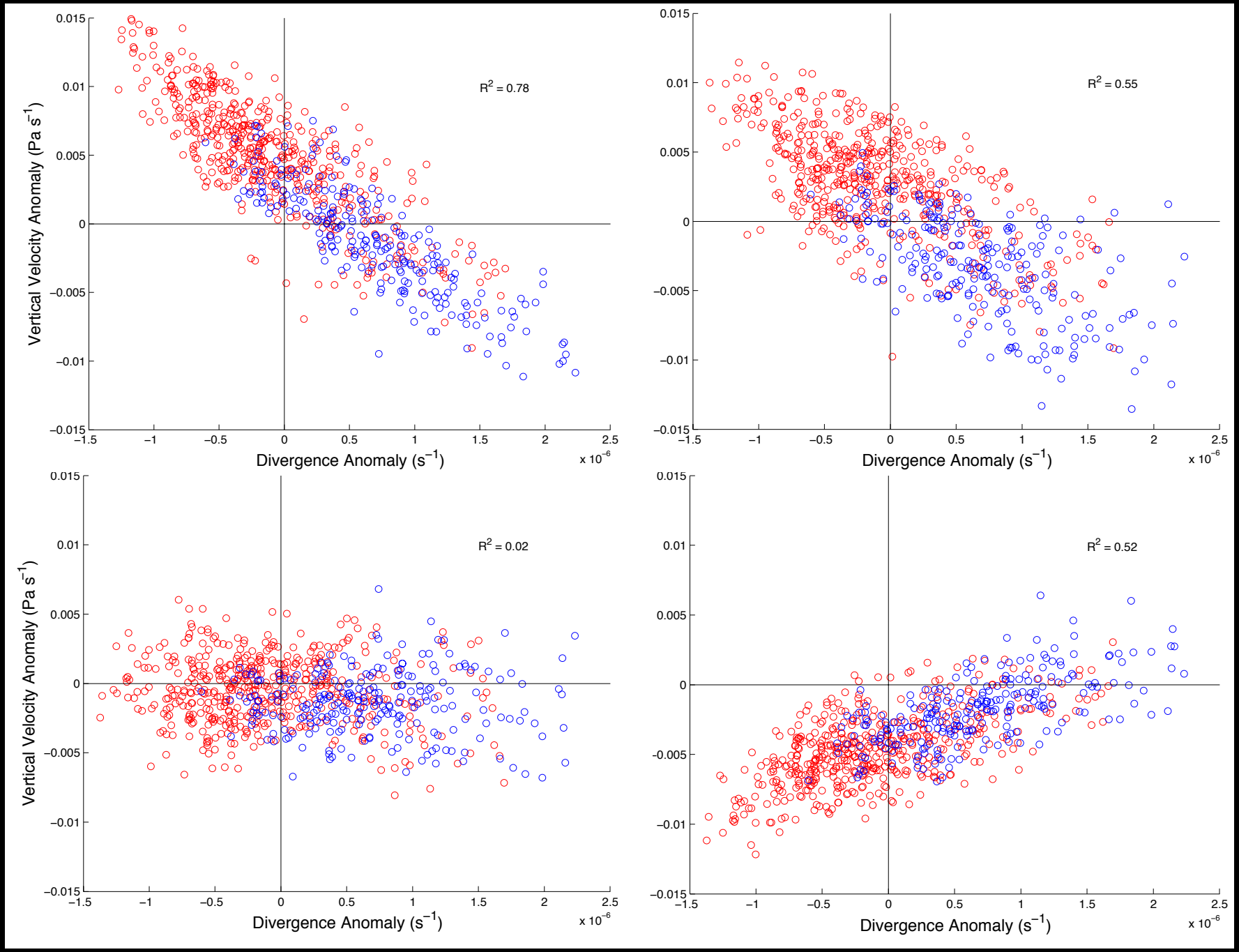
ω'




$\nabla \cdot U'$
$\omega_{300}{}'$
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^{-6}
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
150 hPa Divergence Anomaly (s^{-1})
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
300 hPa Vertical Velocity Anomaly (Pa s^{-1})

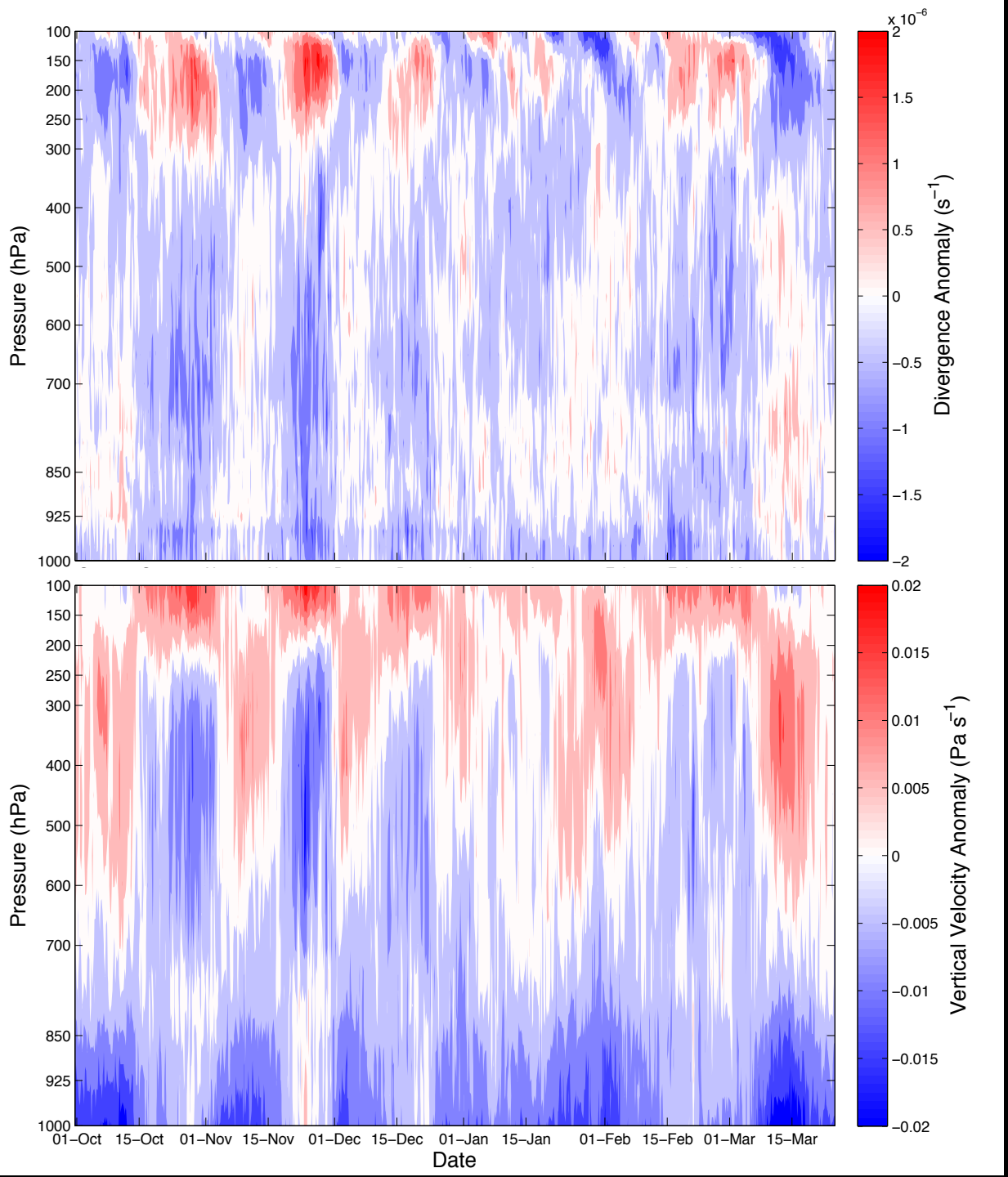

15-Sep
01-Oct
15-Oct
01-Nov
15-Nov
01-Dec
15-Dec
01-Jan
15-Jan
01-Feb
15-Feb
01-Mar
15-Mar
Date
DL -150 -120 -90 -60 -30 0 30 60 90 120 150 DL
Longitude
u_{850}'
20
15
10
5
0
-5
-10
-15
-20
850 hPa Zonal Wind Anomaly (m s^{-1})
15–Sep
01–Oct
15–Oct
01–Nov
15–Nov
01–Dec
15–Dec
01–Jan
15–Jan
01–Feb
15–Feb
01–Mar
15–Mar
DL –150 –120 –90 –60 –30 0 30 60 90 120 150 DL
Longitude
T_{850}'
3
2
1
0
–1
–2
–3
850 hPa Temperature Anomaly (m s^{-1})

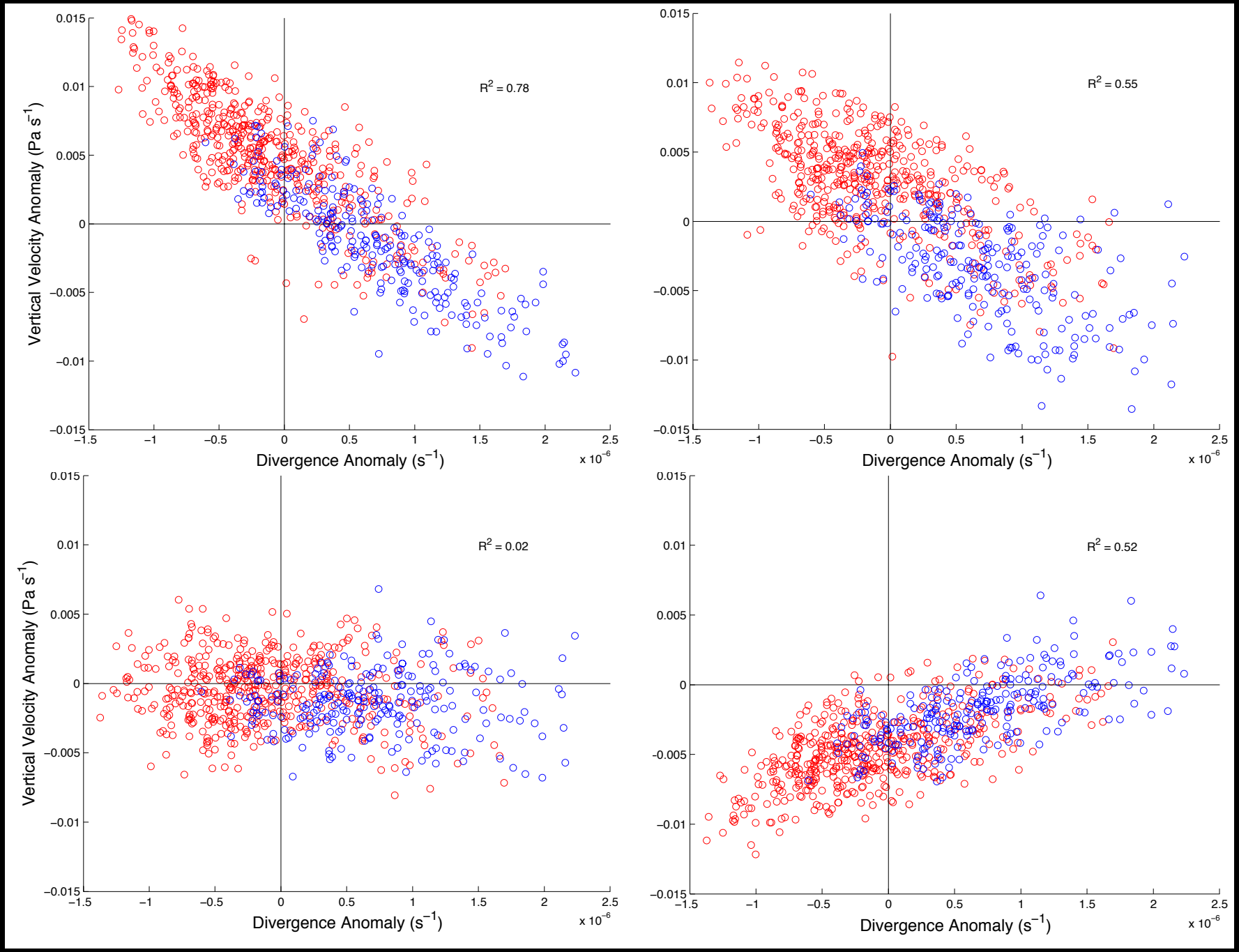

$\nabla \cdot U'$
Date
01–Sep
15–Sep
01–Oct
15–Oct
01–Nov
15–Nov
01–Dec
15–Dec
01–Jan
15–Jan
01–Feb
15–Feb
01–Mar
15–Mar
DL –150 –120 –90 –60 –30 0 30 60 90 120 150 DL
Longitude
x 10^{-6}
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
850 hPa Divergence Anomaly (s^{-1})
ω'
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
850 hPa Vertical Velocity Anomaly (Pa s^{-1})


R2 = 0.78
R2 = 0.55
R2 = 0.02
R2 = 0.52
Vertical Velocity Anomaly (Pa s−1)
Divergence Anomaly (s−1)
x 10−6
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−1.5
−1
−0.5
0
0.5
1
1.5
2
2.5

$\nabla \cdot U'$

ω'

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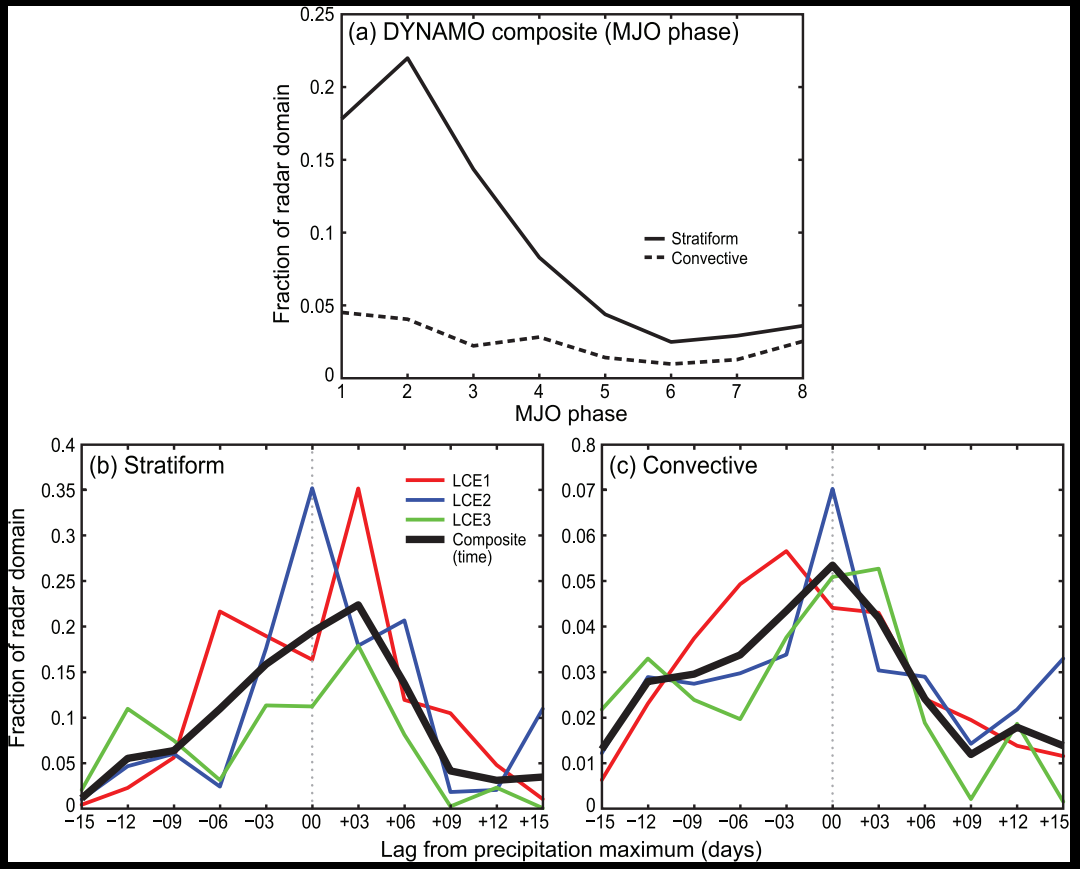
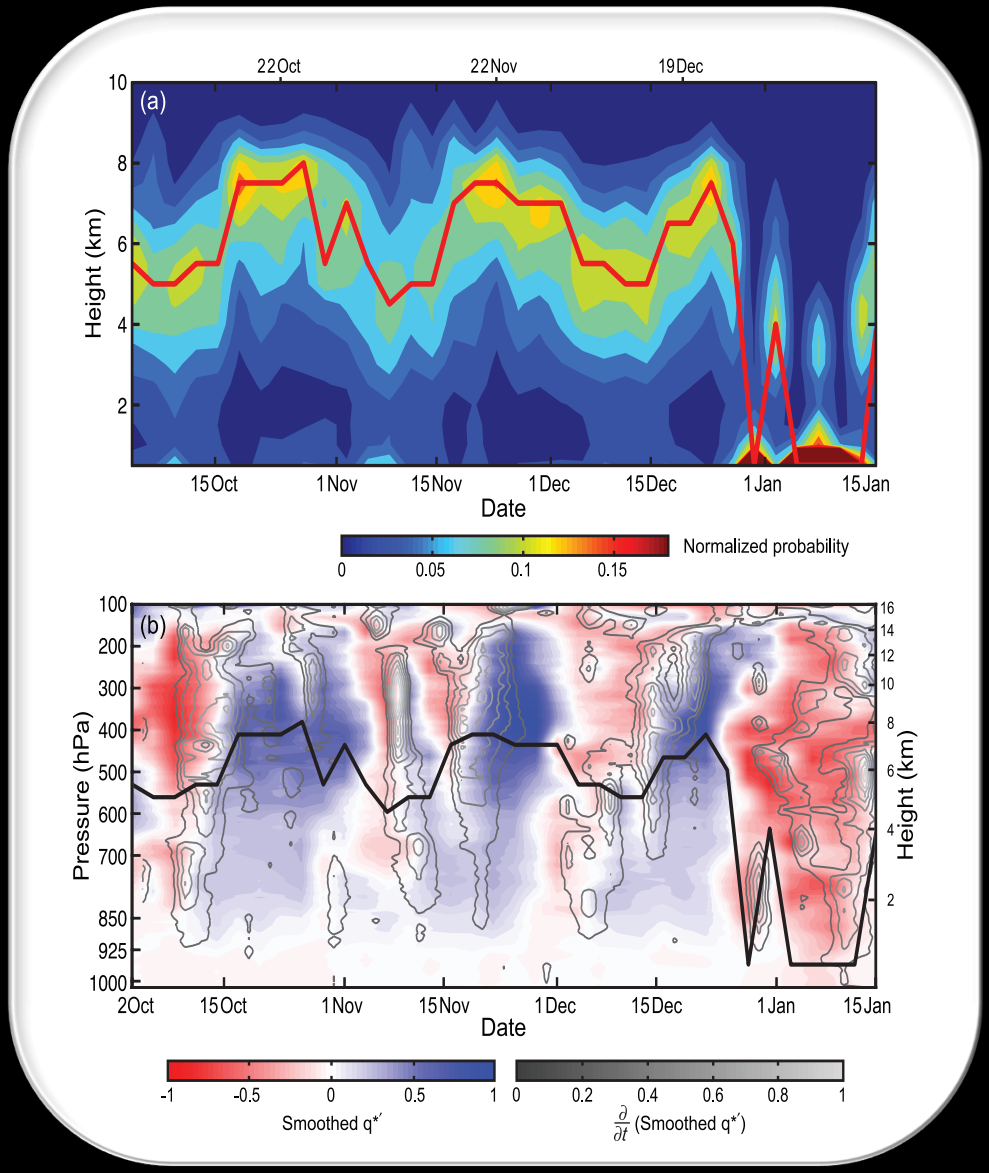
Vertical Velocity Anomaly (Pa s−1)
Divergence Anomaly (s−1)
x 10−6
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−1.5
−1
−0.5
0
0.5
1
1.5
2
2.5

Conclusions

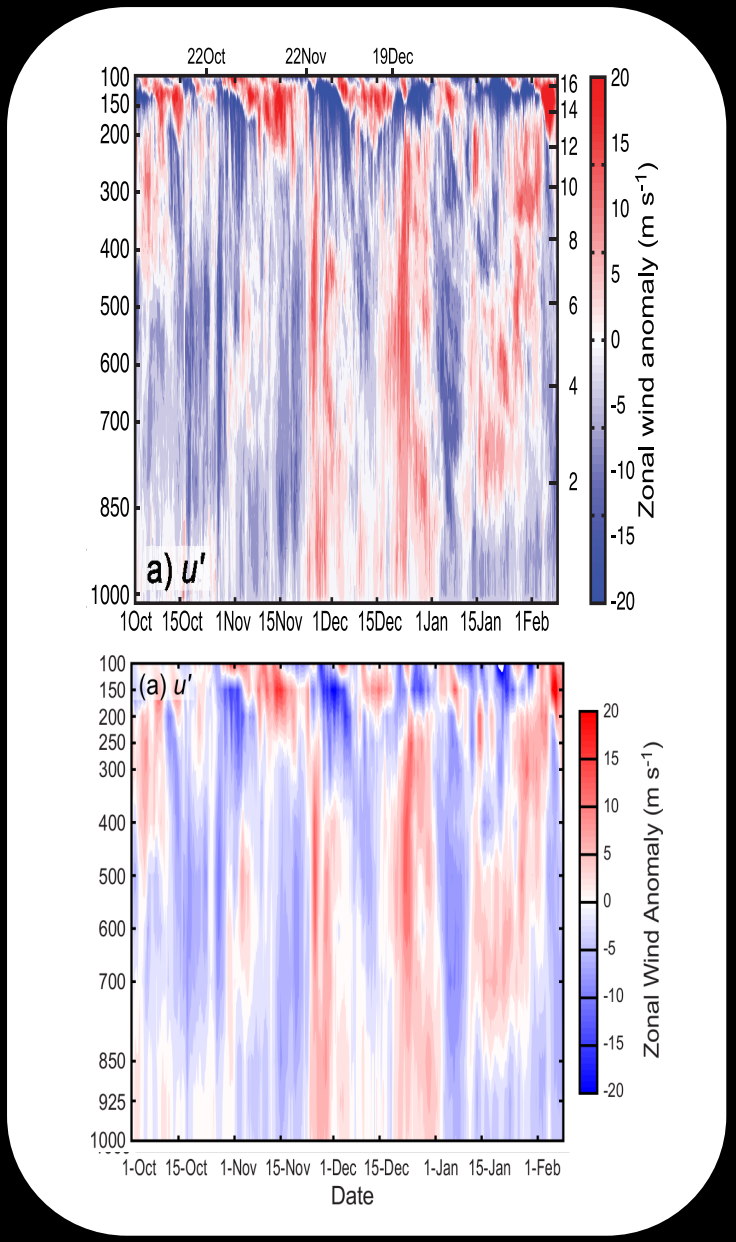
1. Variability in stratiform elements is a key part of the evolution of the cloud population during an MJO episode.

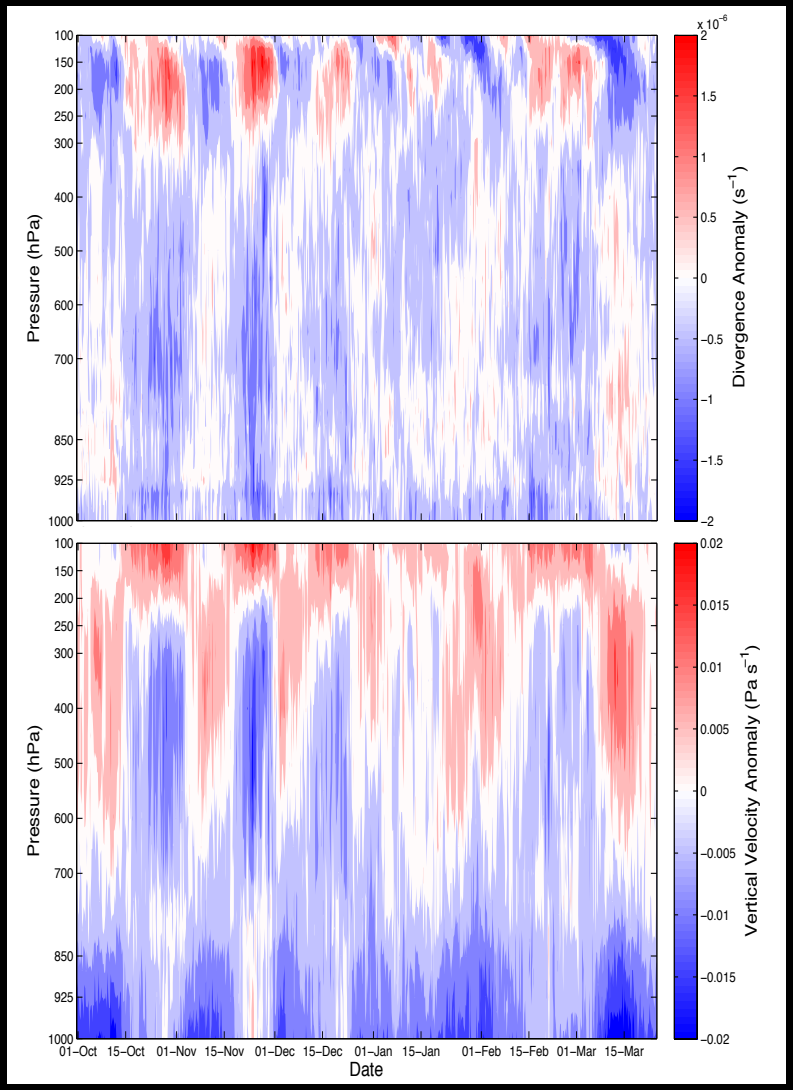




2. Humidity anomalies at various levels and depth of convection increase rapidly at MJO convective onset.

3. ~30 day variability in fields observed by radar and rawinsonde are consistent with that over larger domain in Indian Ocean where initial MJO convective onset occurs.

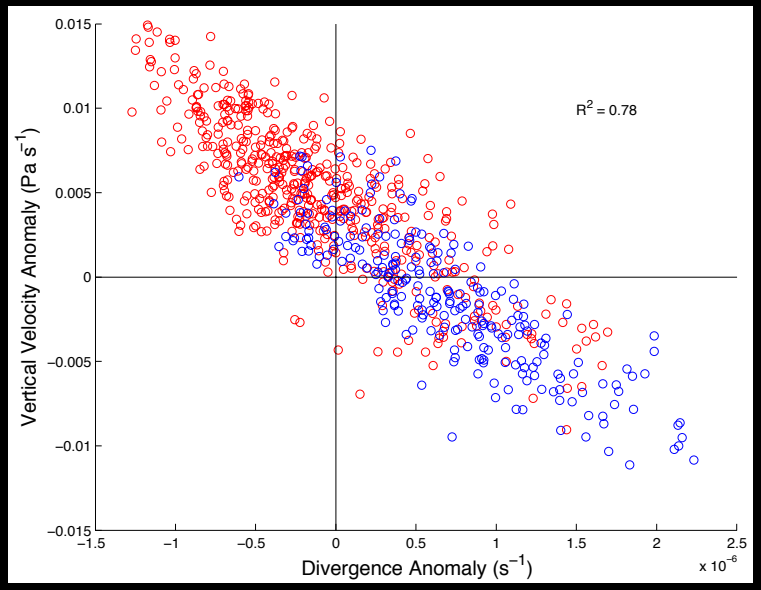


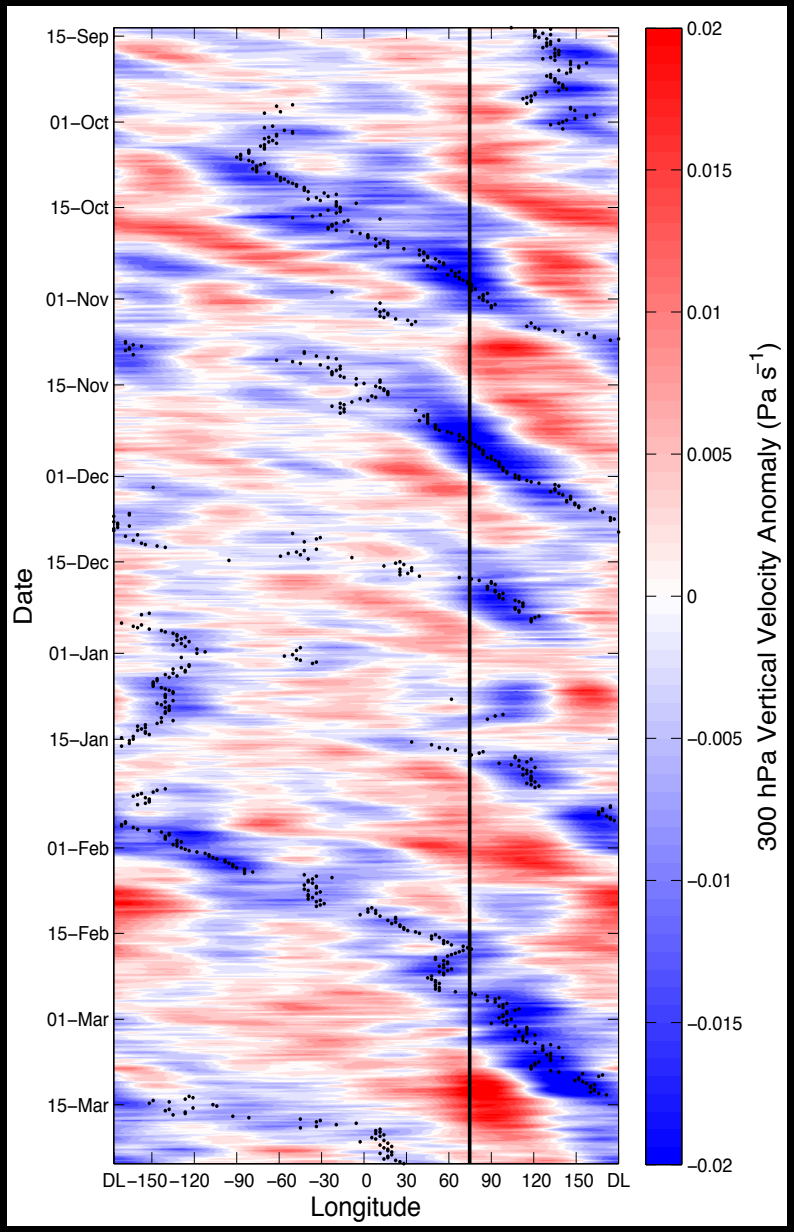


4. Periods of suppressed convection characterized by low-level upward motion. Enhanced convection occurs with upper-level upward motion.

5. Anomalies of vertical velocity are coupled with divergence and circumnavigate tropics.

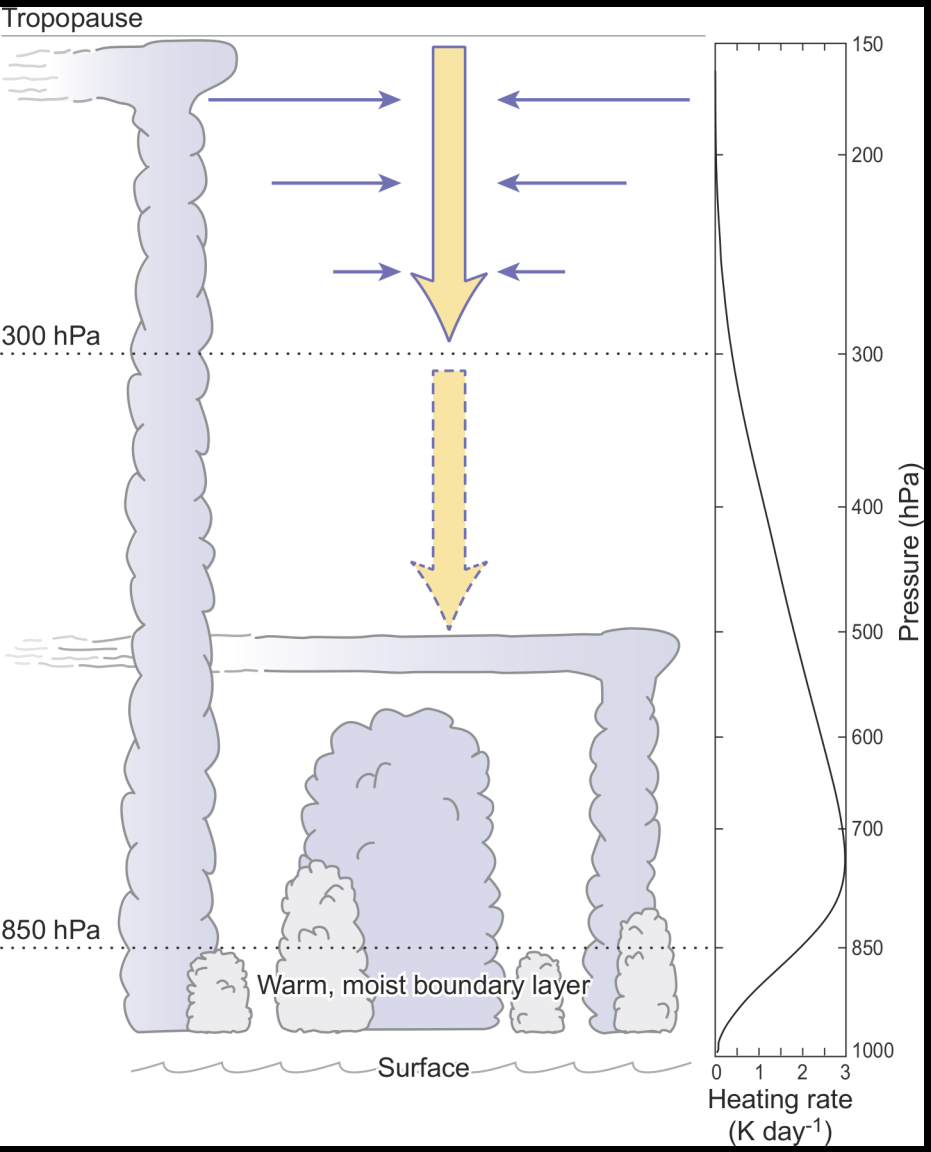
6. MJO convective onset occurs when UT upward motion anomaly reaches Indian Ocean.

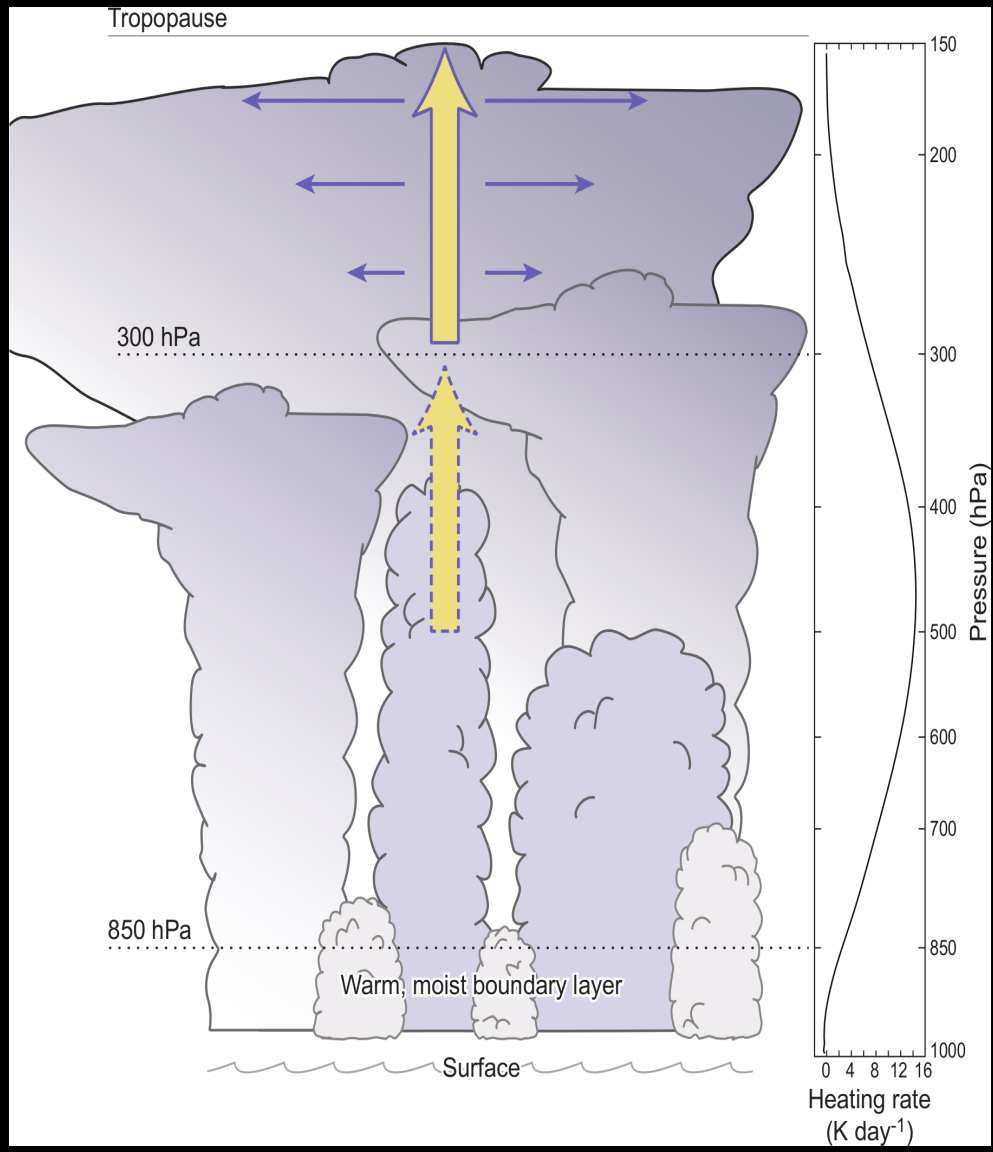




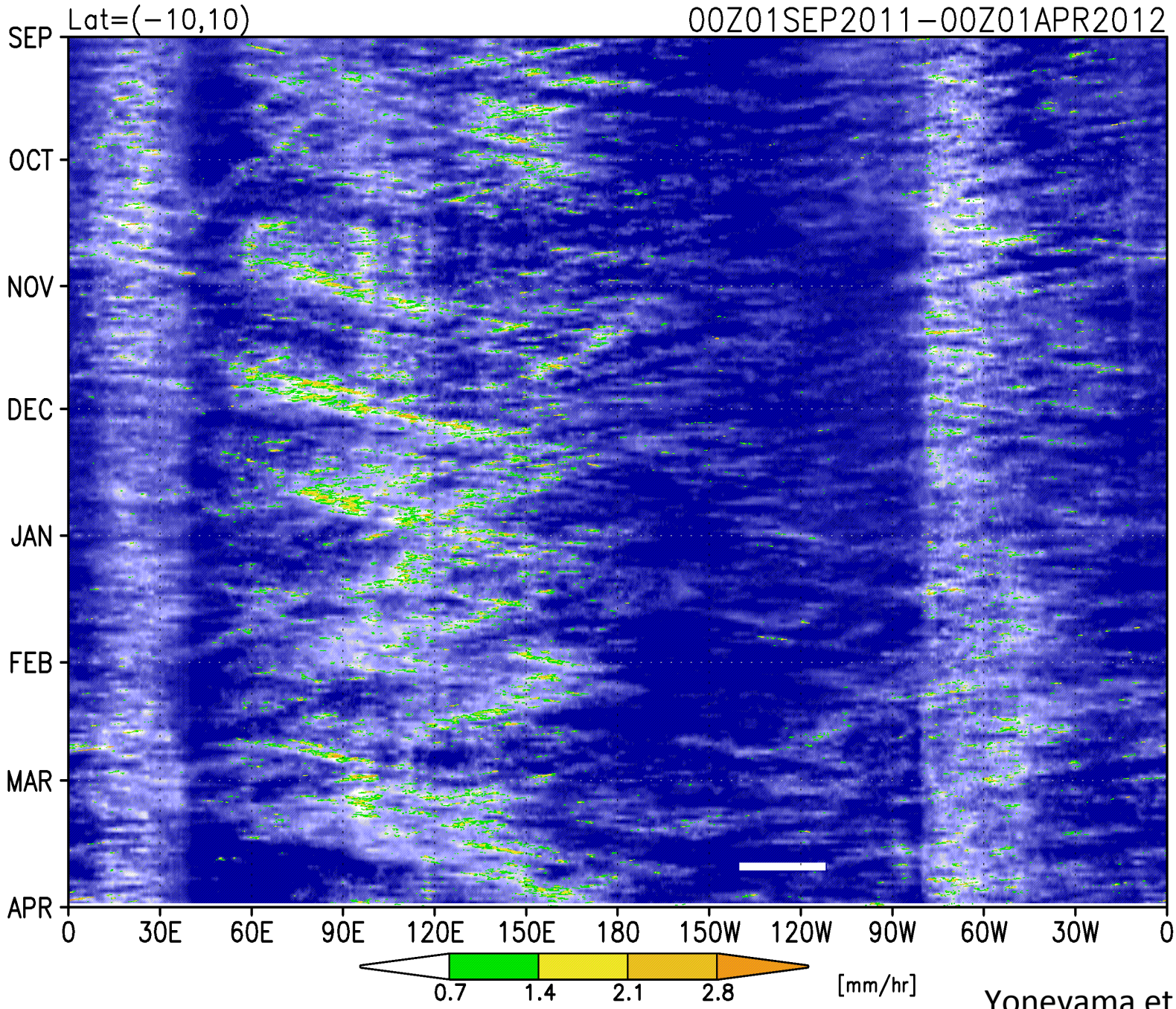
Suppressed Convection

Enhanced Convection



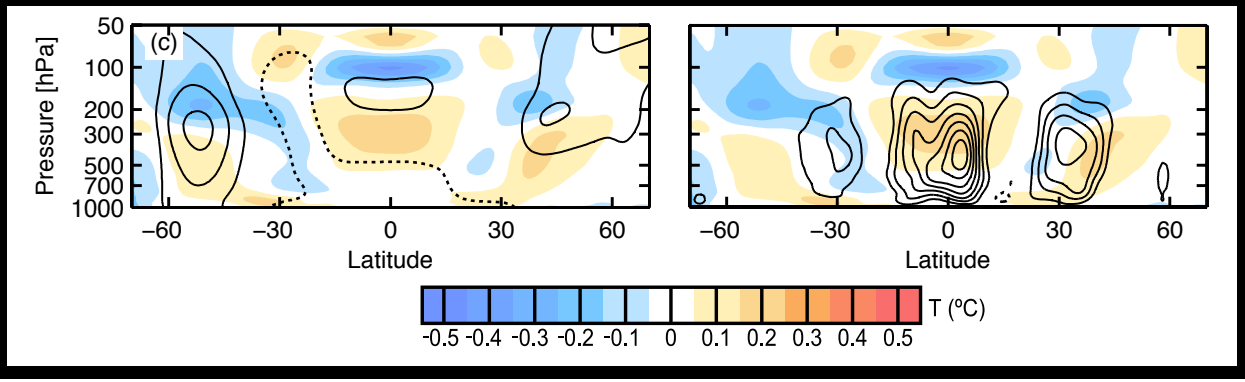


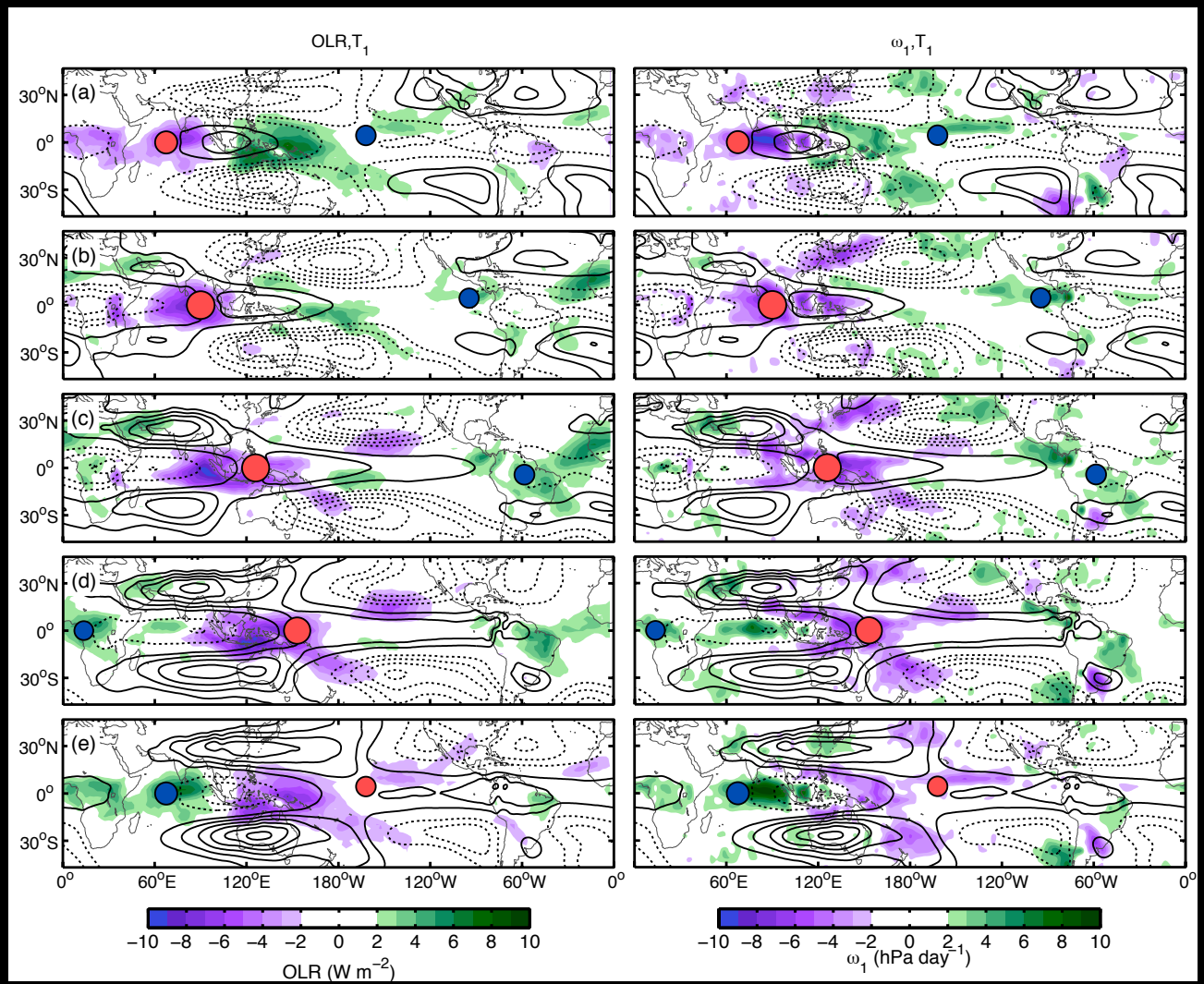
End

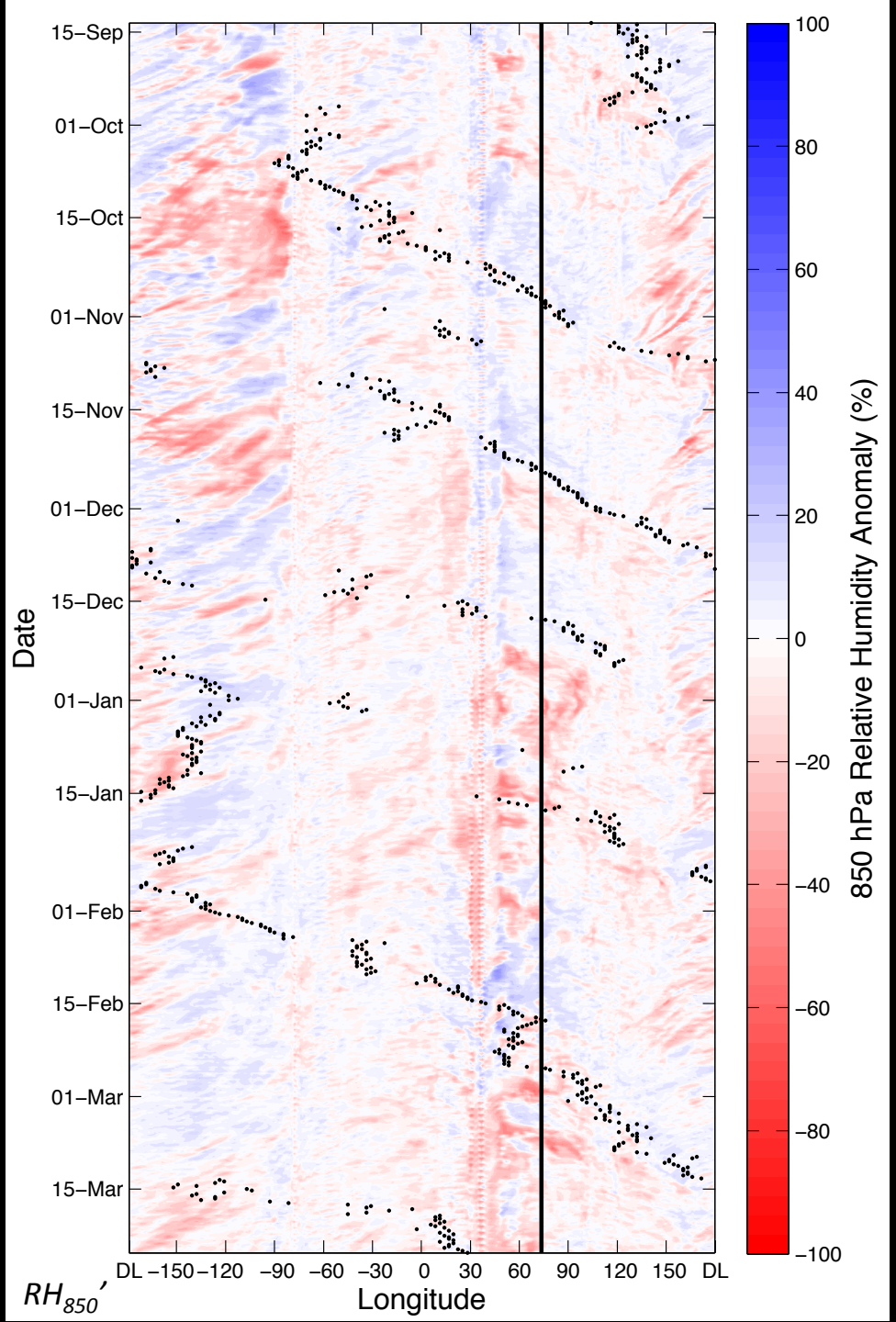


Yoneyama et al (2013)

Adames and Wallace (2014)






15–Sep
01–Oct
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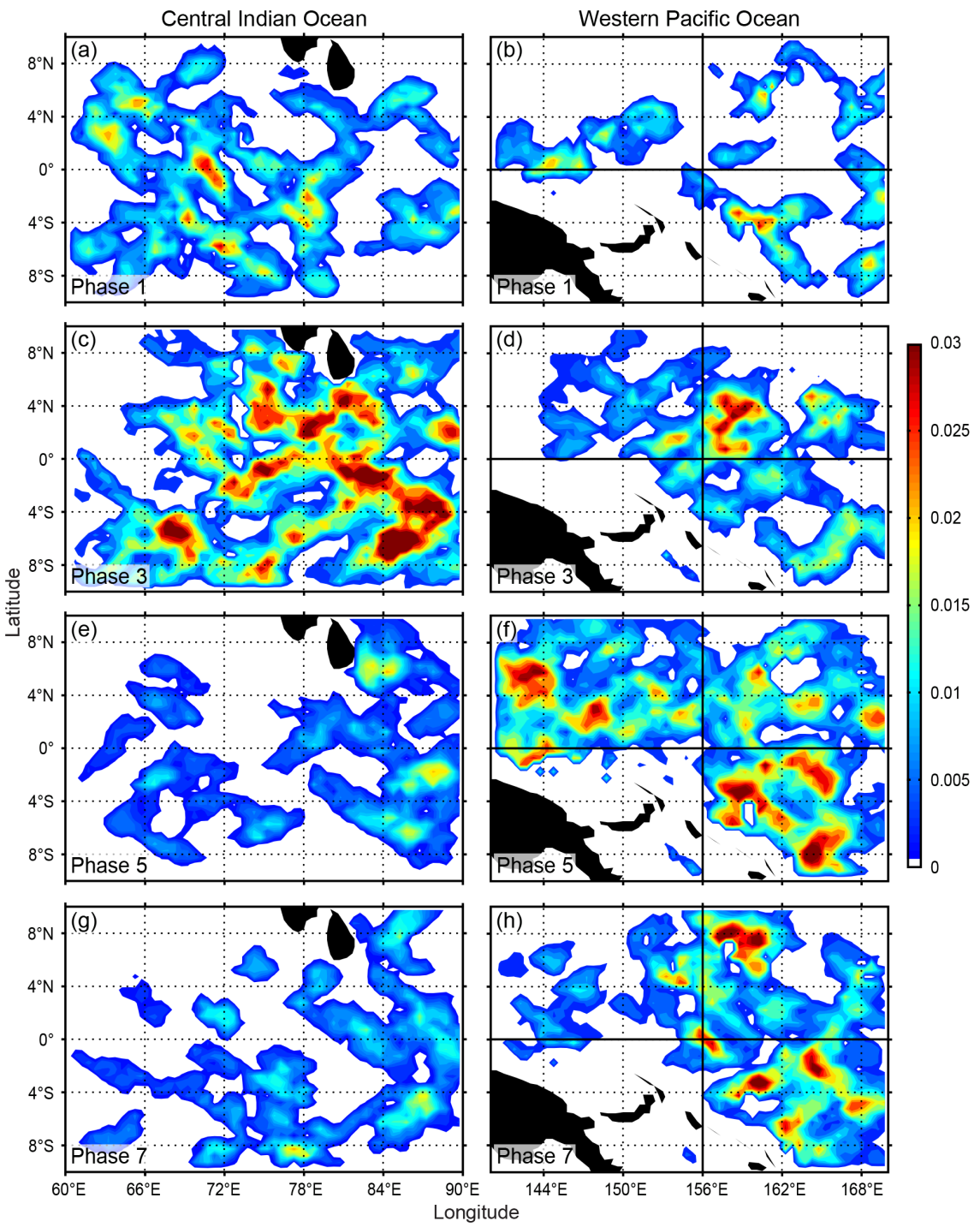
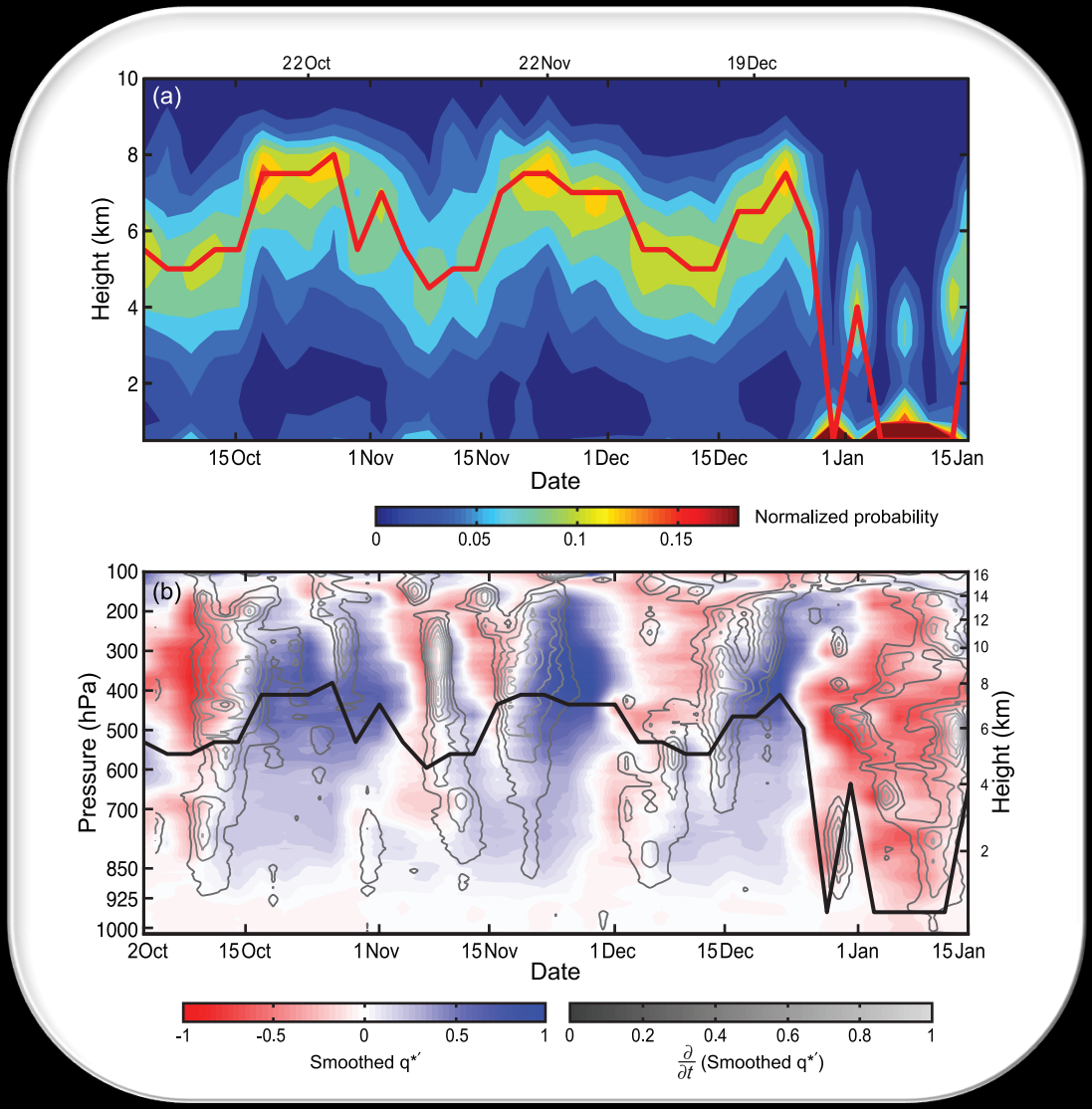
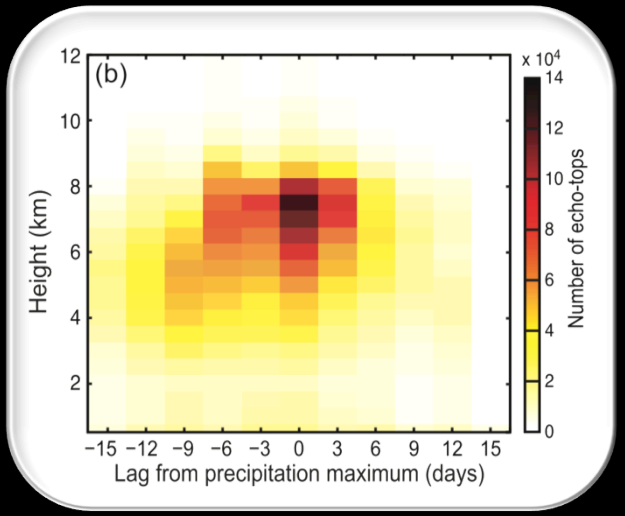
01–Dec
15–Dec
01–Jan
15–Jan
01–Feb
15–Feb
01–Mar
15–Mar
Date
DL –150 –120 –90 –60 –30 0 30 60 90 120 150 DL
Longitude
100
80
60
40
20
0
–20
–40
–60
–80
–100
850 hPa Relative Humidity Anomaly (%)
RH_{850}'

Barnes and Houze (2013)




22Oct
22Nov
19Dec
(a)
Height (km)
10
8
6
4
2
15Oct
1Nov
15Nov
1Dec
15Dec
1Jan
15Jan
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
2Oct
15Oct
1Nov
15Nov
1Dec
15Dec
1Jan
15Jan
Date
-1
-0.5
0
0.5
1
Smoothed q*′
0
0.2
0.4
0.6
0.8
1
∂/∂t (Smoothed q*′)


(b)
Height (km)
12
10
8
6
4
2
x 10^4
14
12
10
8
6
4
2
0
Number of echo-tops
−15 −12 −9 −6 −3 0 3 6 9 12 15
Lag from precipitation maximum (days)

Conclusions