The 2015-16 Winter: A story of mid-latitude atmospheric wave activity

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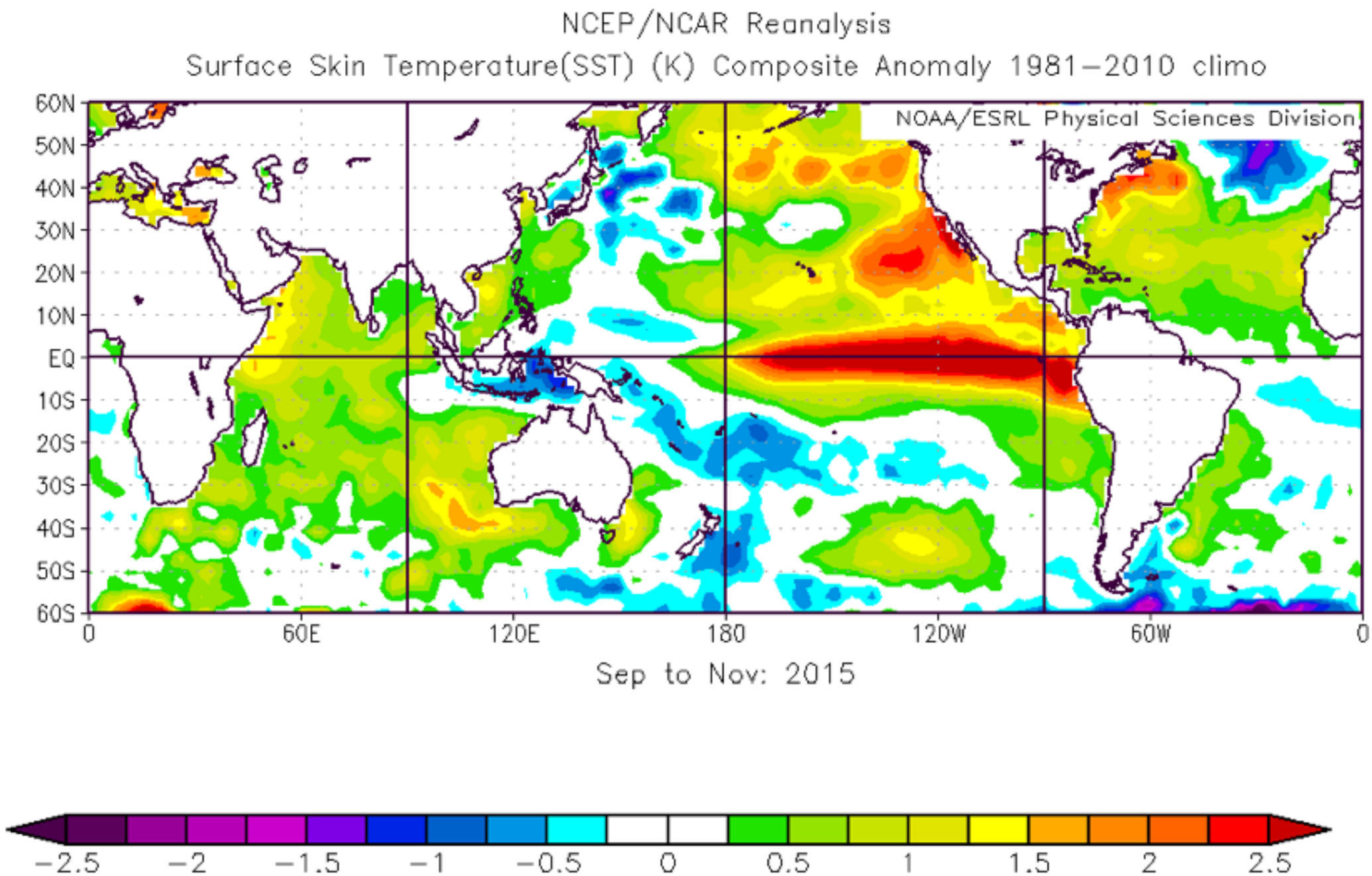
Setting the stage

- For the 2015-16 winter, seasonal predictions were based heavily on an already strong El Nino and westerly QBO.

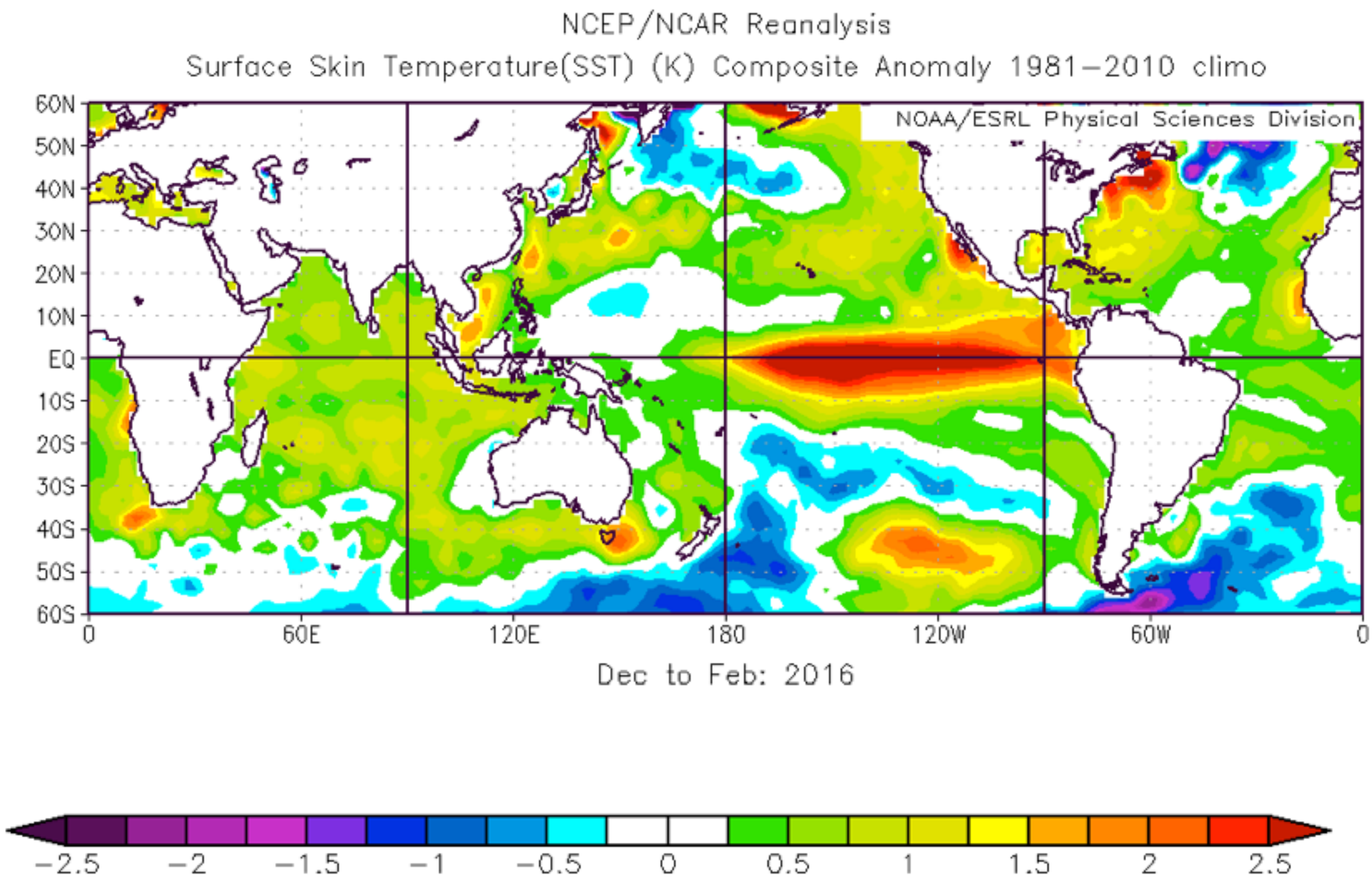
- Prominent events of the winter:

Christmas US East Coast heat wave
Kara Sea ridge
US Mid Atlantic blizzard
US Southeast tornado outbreak
Mexico trough

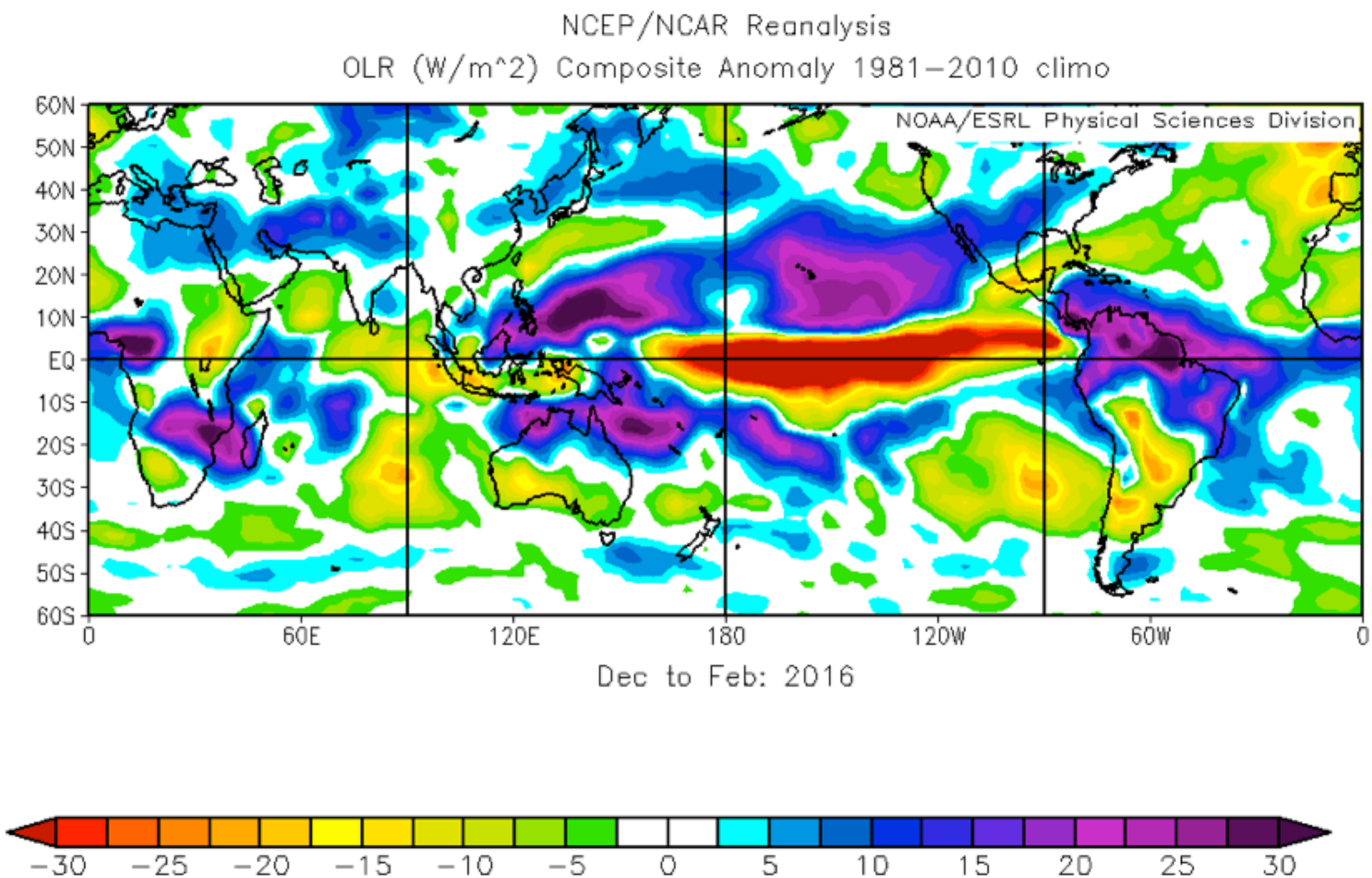
- Already strong El Nino in fall
- Very warm across entire North Pacific
  (warm “blob” noted in subtropical E Pacific)



- Strong El Nino, +PDO
- Warm across entire Indian Ocean



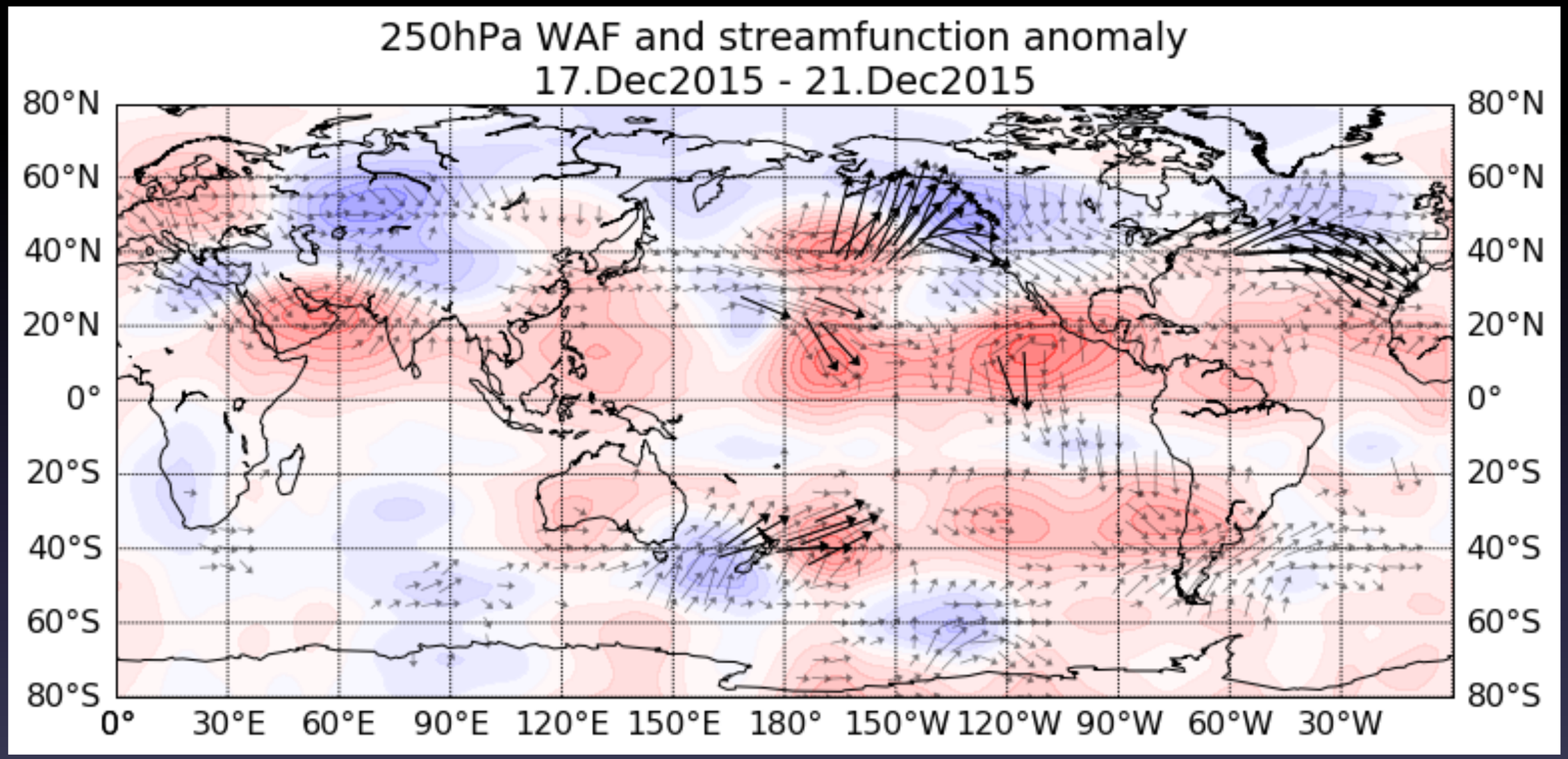
- Classic anomalous Pacific Hadley cell
- Enhanced convection in E Indian Ocean



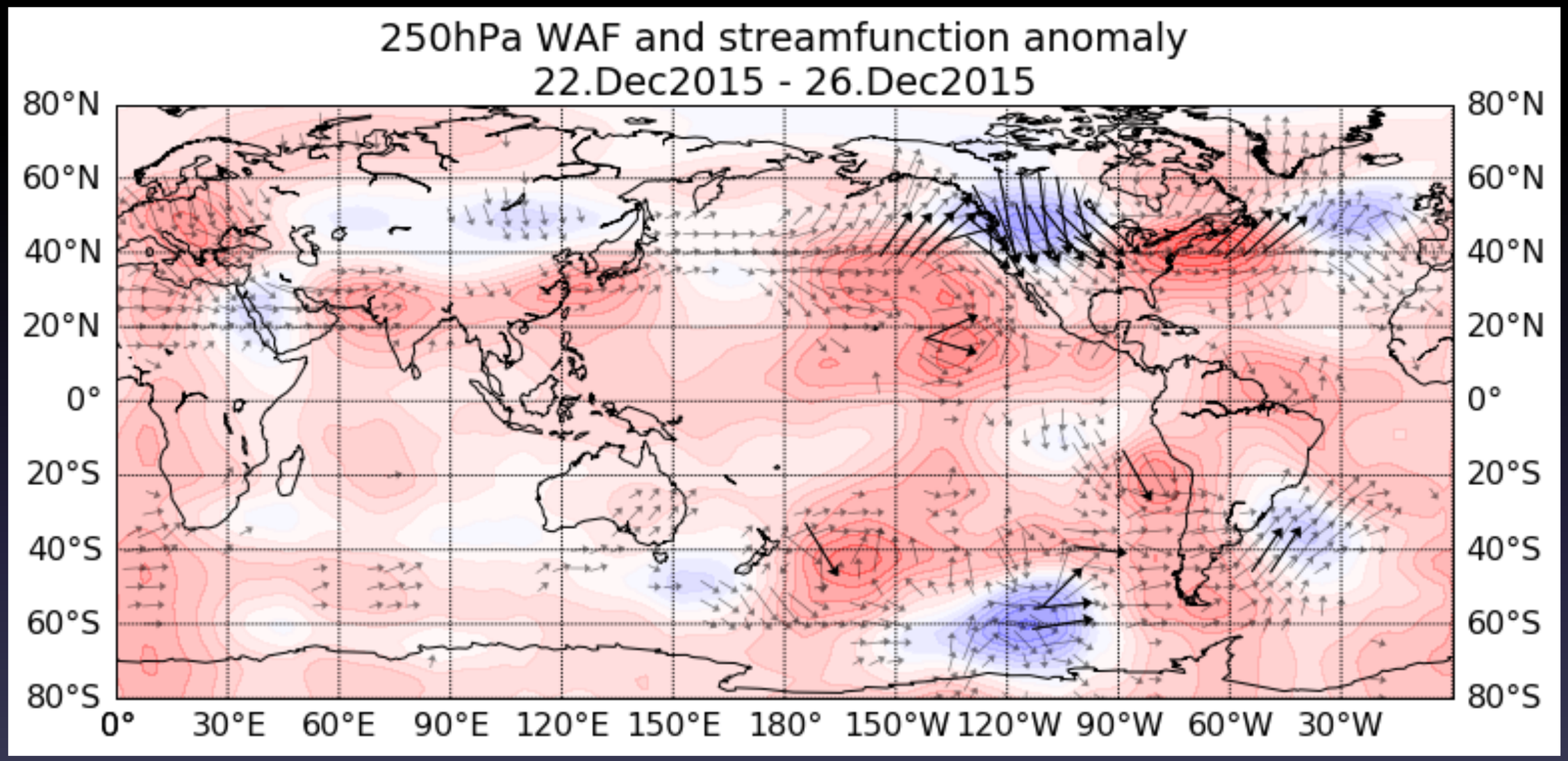
Wave Activity Flux

- Tropical convection known to set off Rossby wave trains, especially in interaction with the Tibetan Plateau. But the future of the wave activity is dependent on the background flow field.
- Following equations from Plumb (1985), and Takaya and Nakamura (2001), used 250hPa wave activity flux to inspect Rossby wave packets.
- Convenient diagnostic tool for providing a snapshot analysis of RWPs; where activity is being emitted, absorbed, and how waves within the packet are breaking.
- The following plots include the 250hPa streamfunction anomaly, and wave activity flux

Anticyclone over the Northeast Pacific breaks toward the Gulf of Alaska

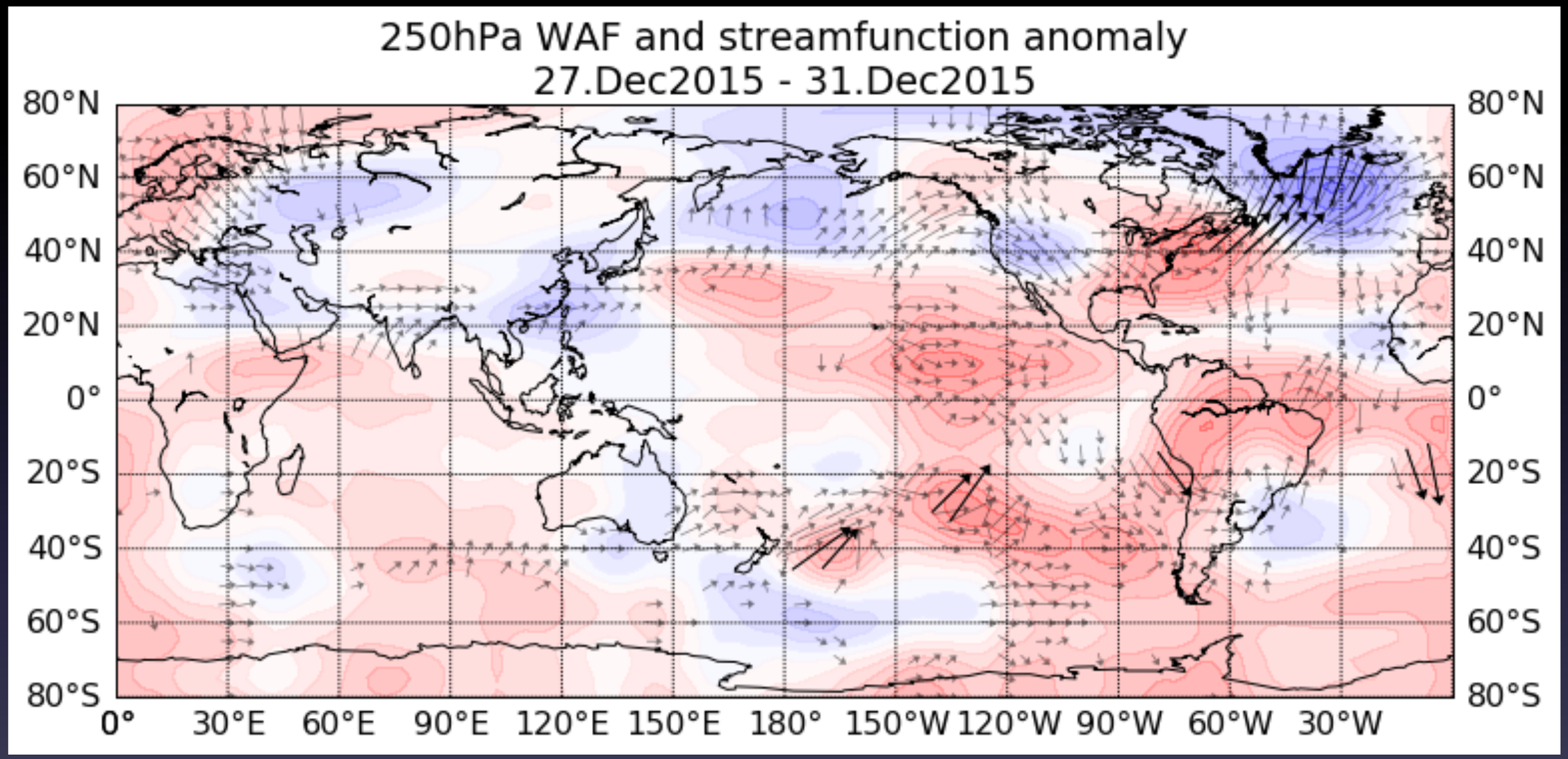


Downstream trough breaks equatorward, amplifying large ridge over the E US

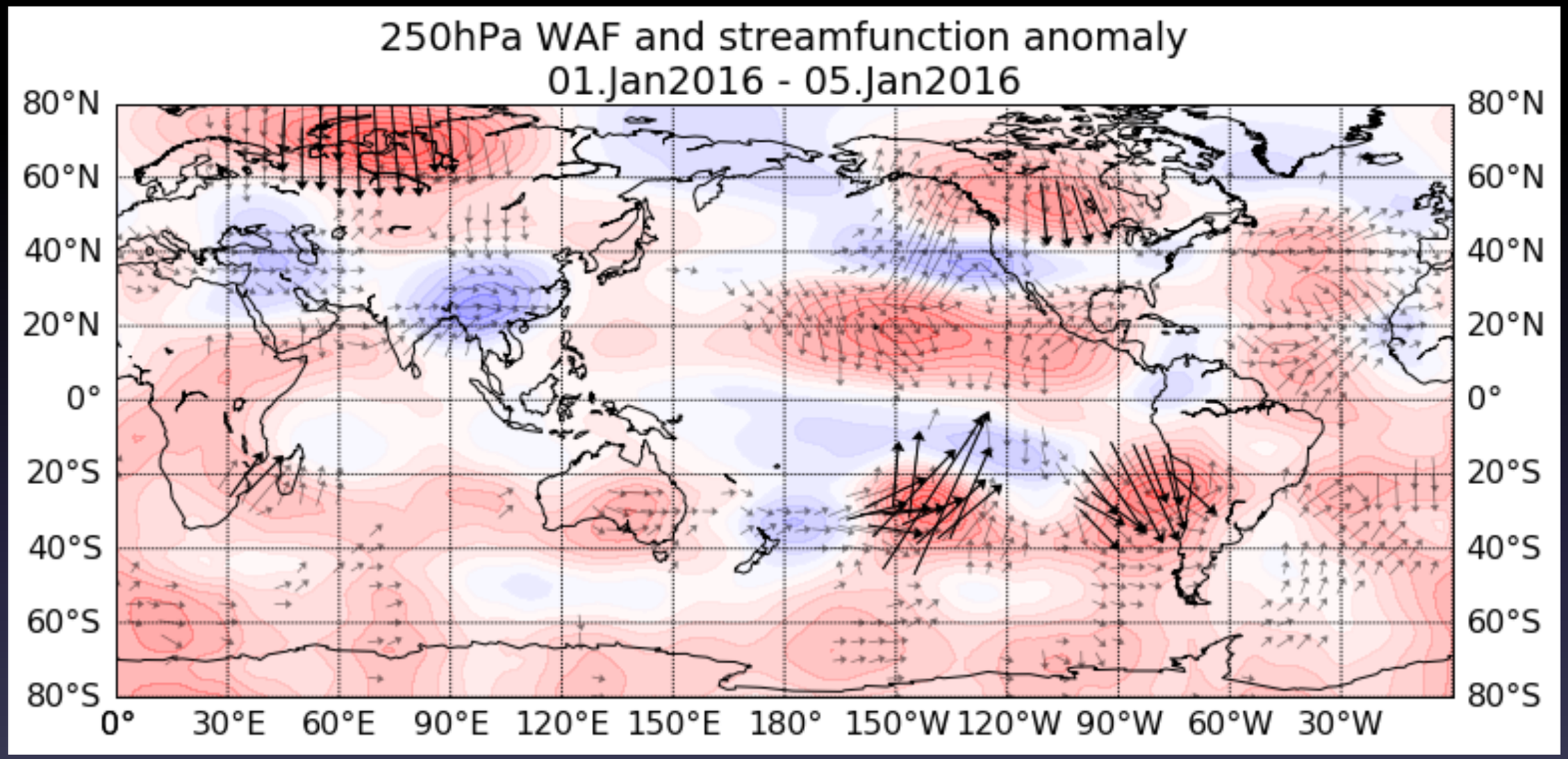


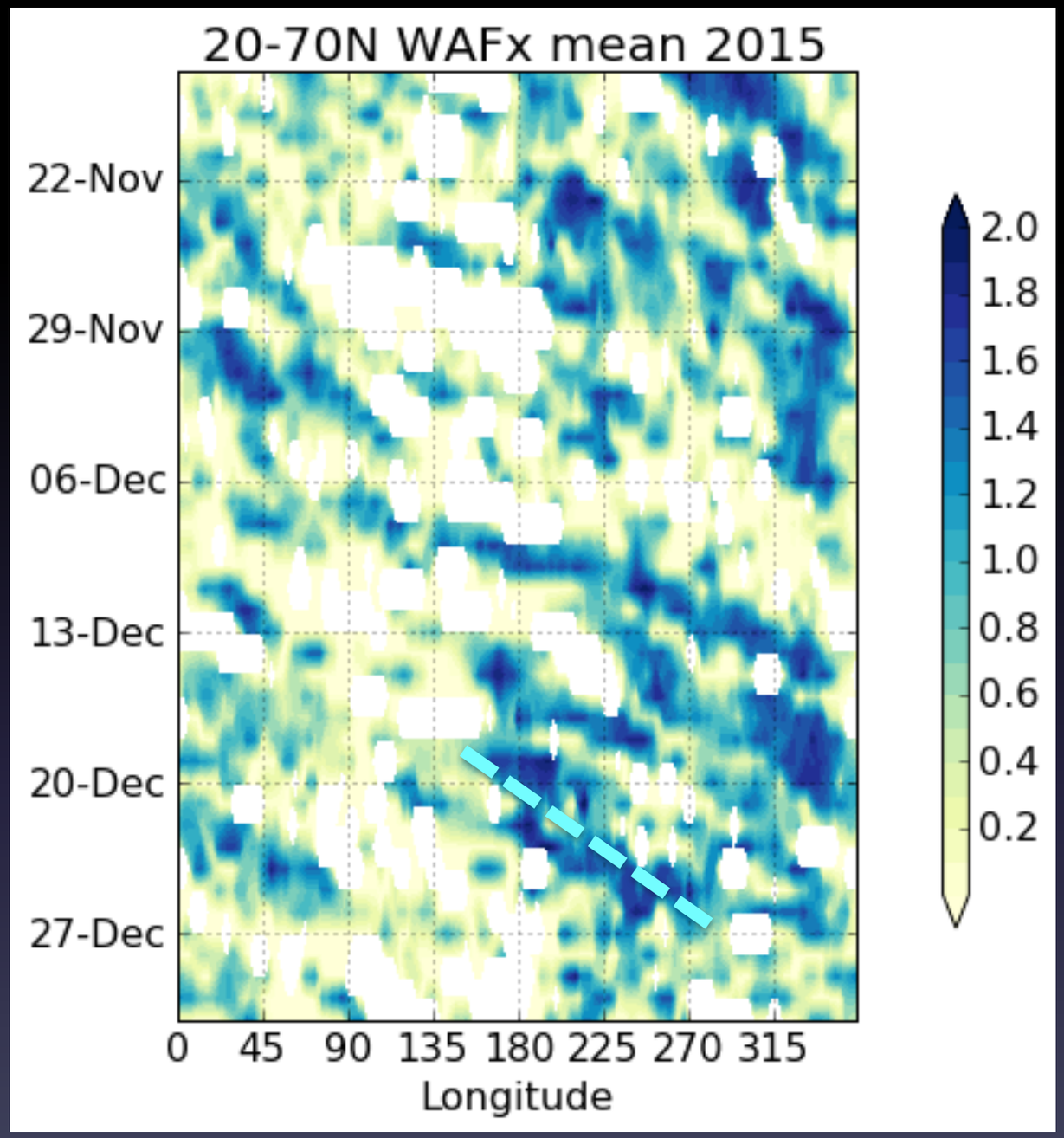
Record breaking warmth over Northeast US for Christmas

Trough deepens downstream over the N Atlantic



Finally, the N Atlantic trough breaks poleward, culminating in an anomalous anticyclone over the Kara Sea



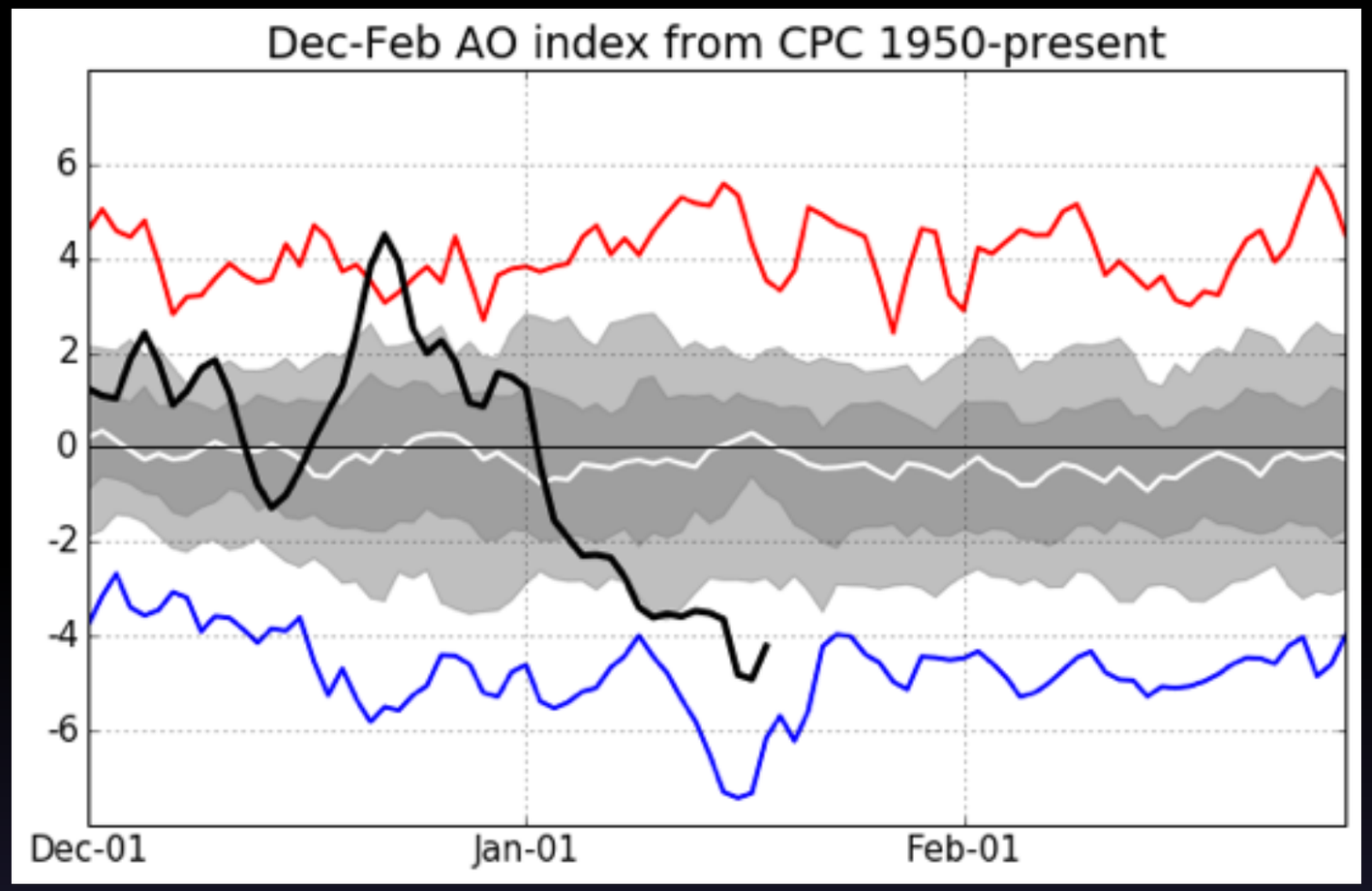


Hovmoller plot of the zonal component of WAF.

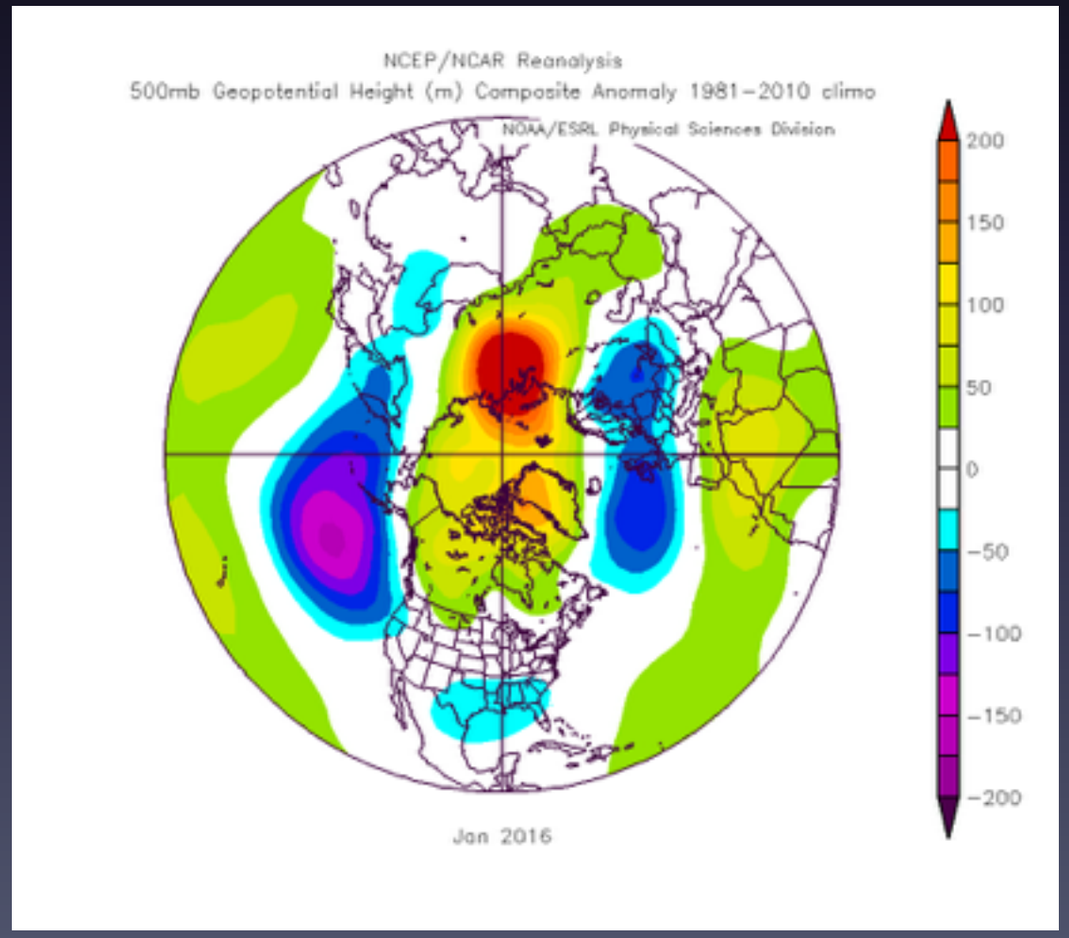
Here WAF has been scaled by 10^{-3} m^2/s^2

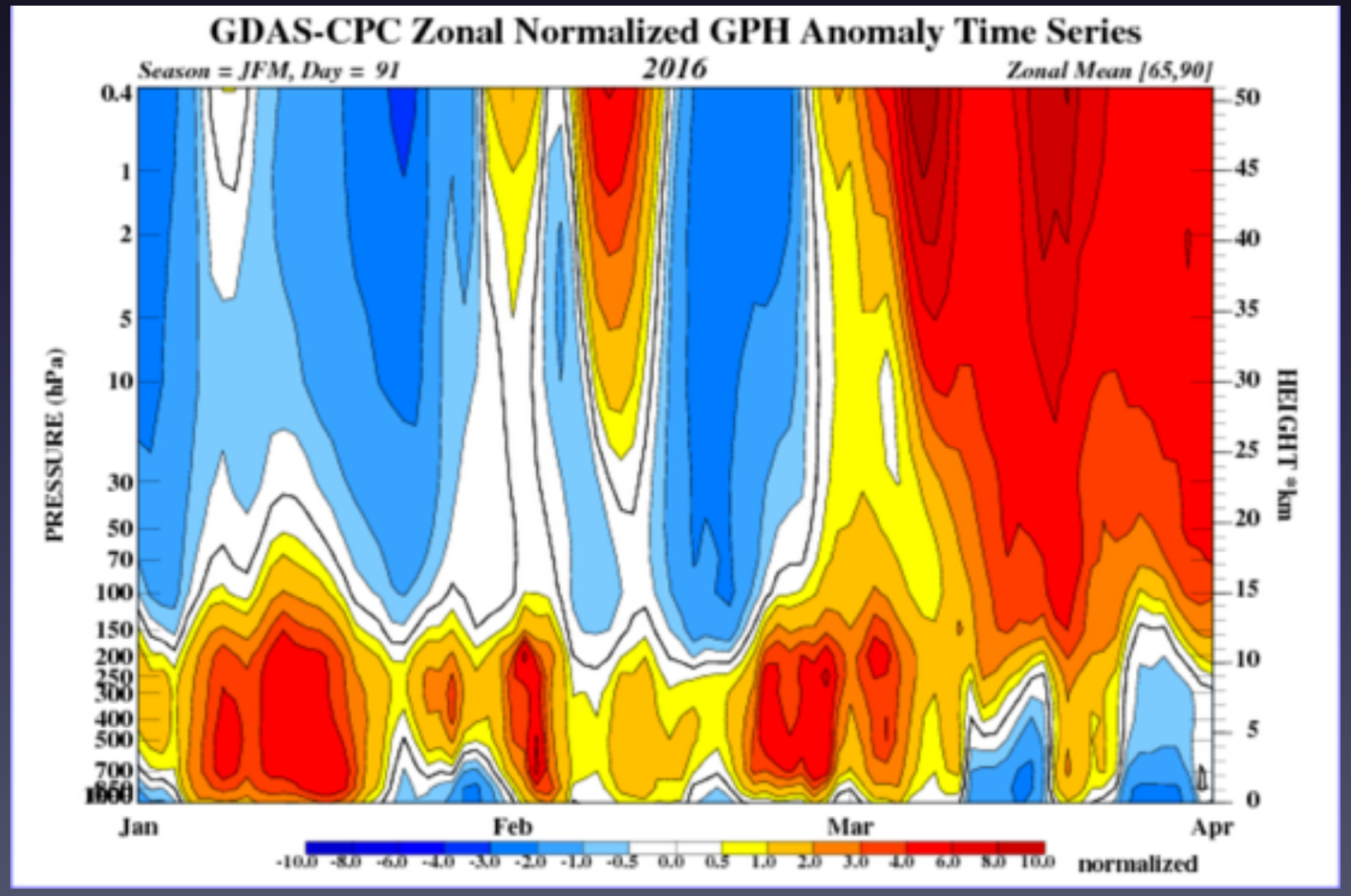
Then masking out values less than 0.5

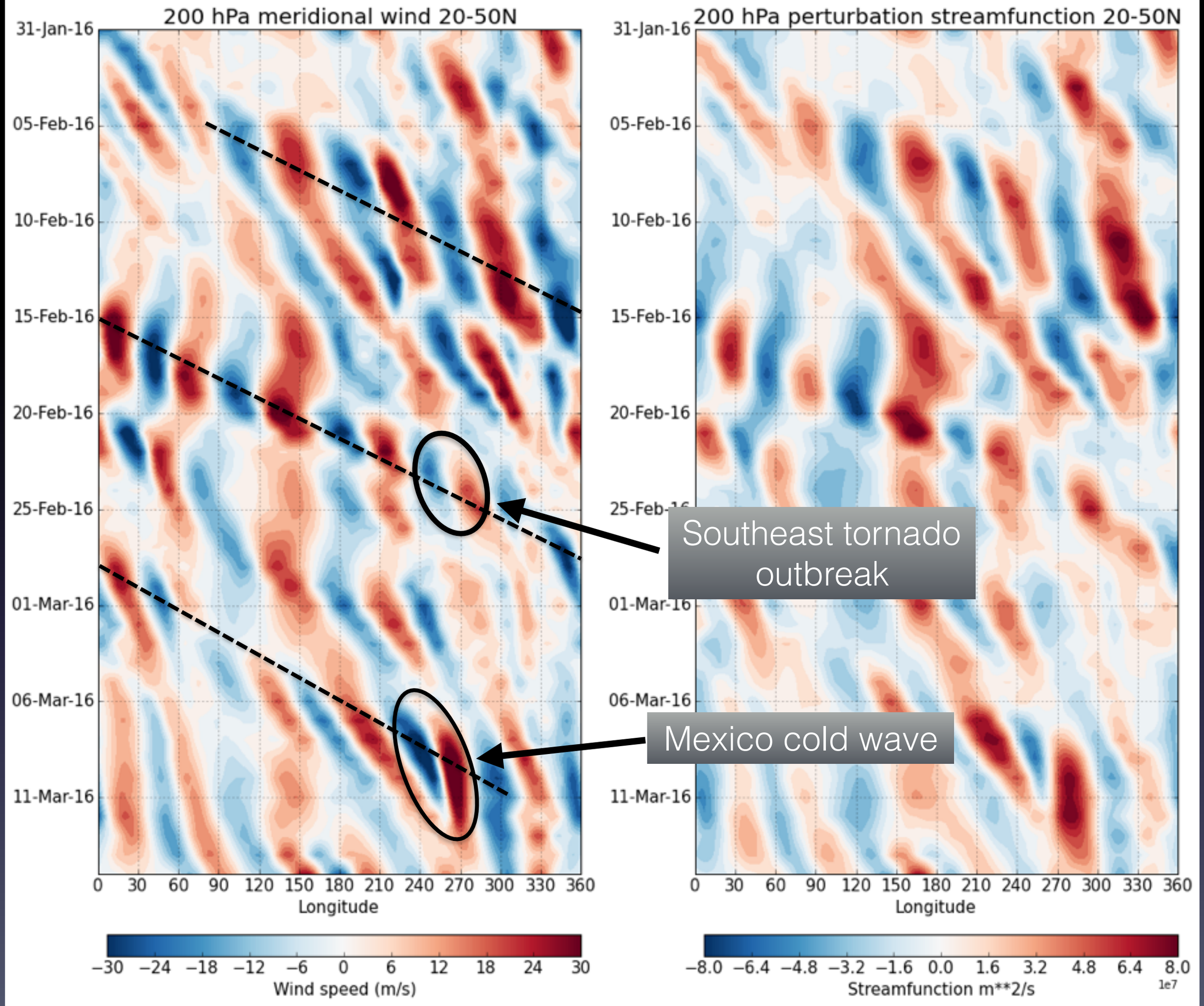
Focuses attention solely on existing RWPs within the 20-70N latitude band, without the impact of the null values in the averaging



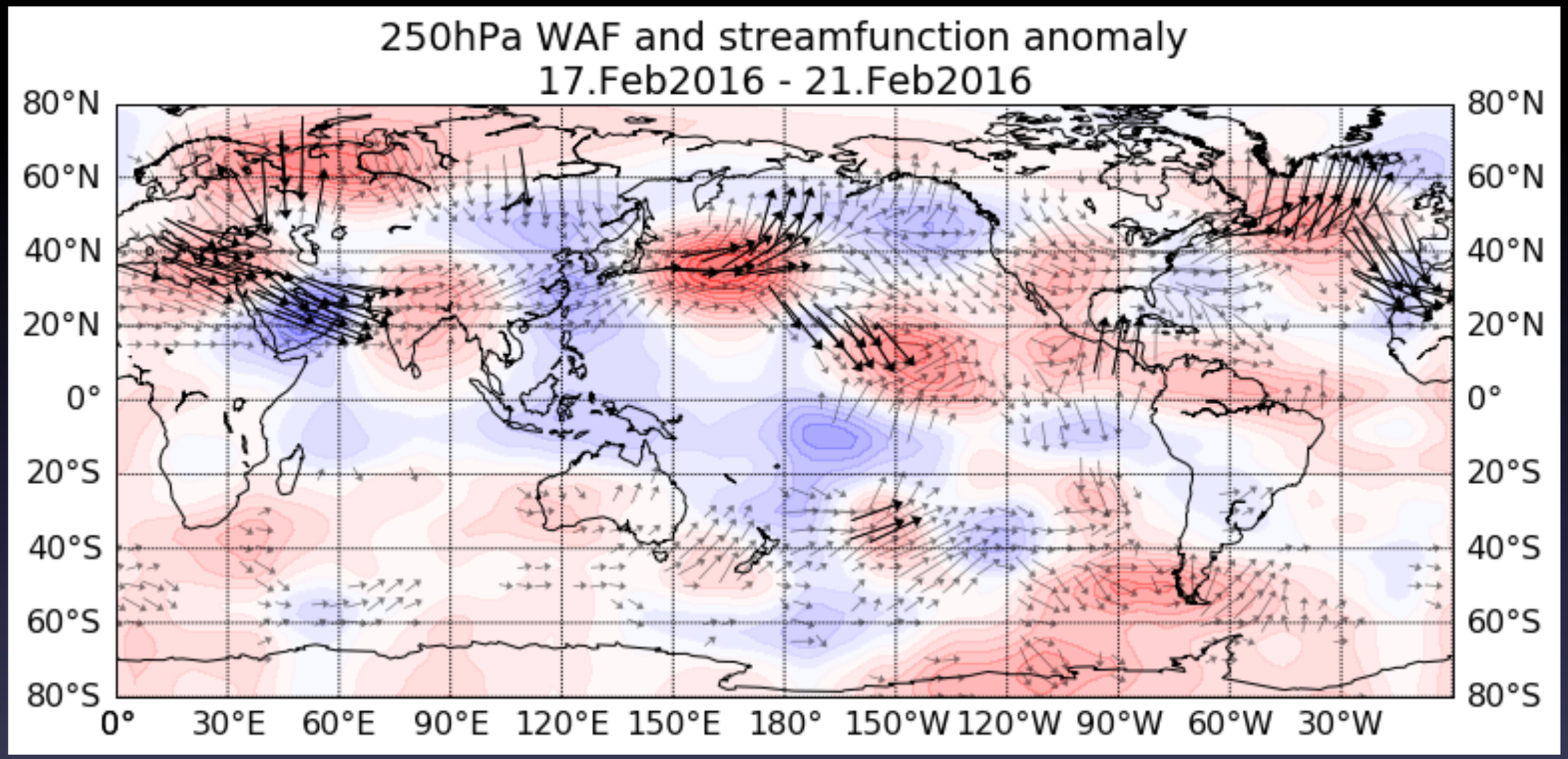
- Kara Sea ridge amplifies to strongest on record.
- Arctic Oscillation plummets from +4SD to -4SD in less than a month.
- Breakdown of polar vortex entirely tropospheric.
- Precedes Mid Atlantic blizzard

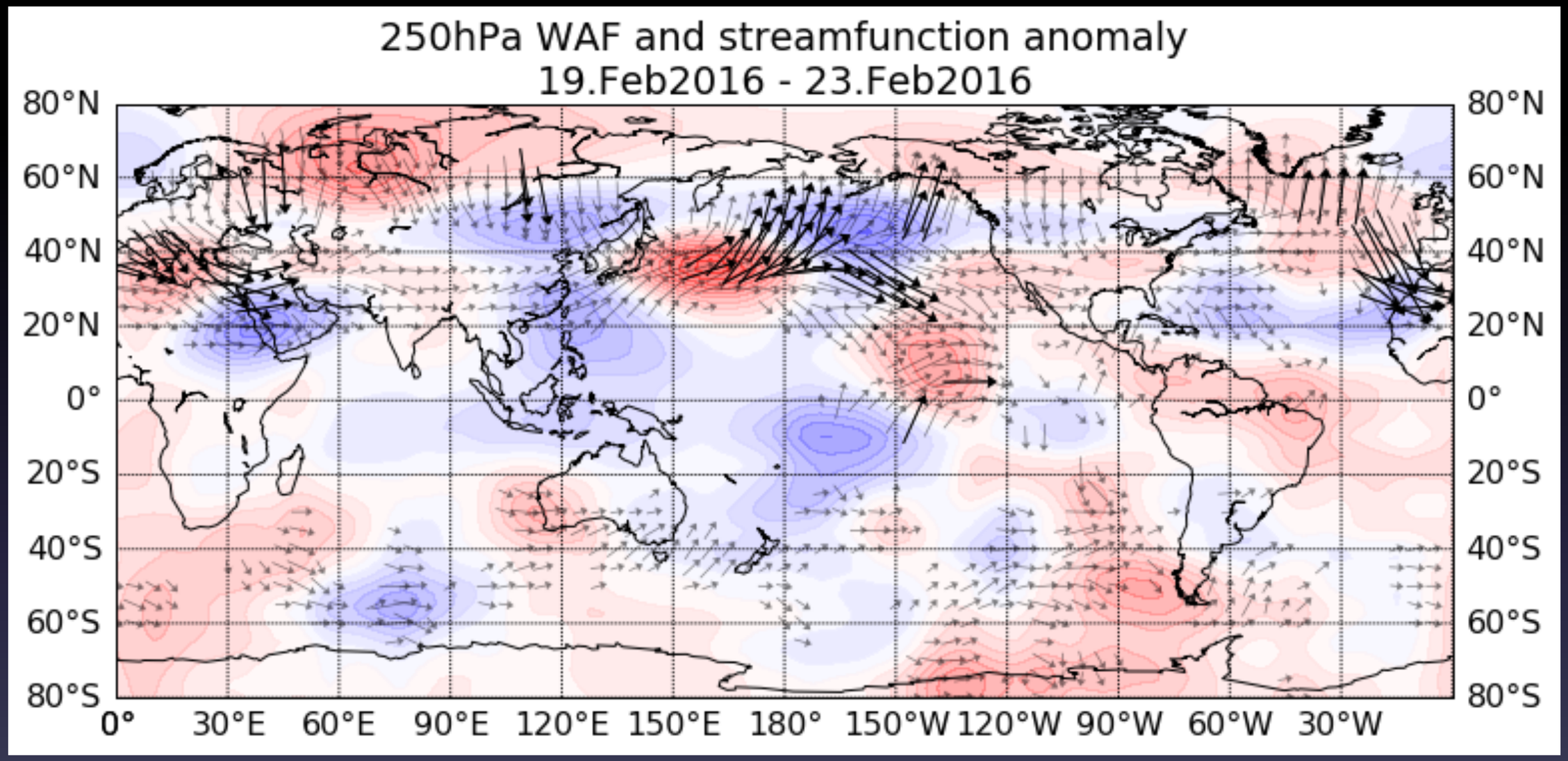




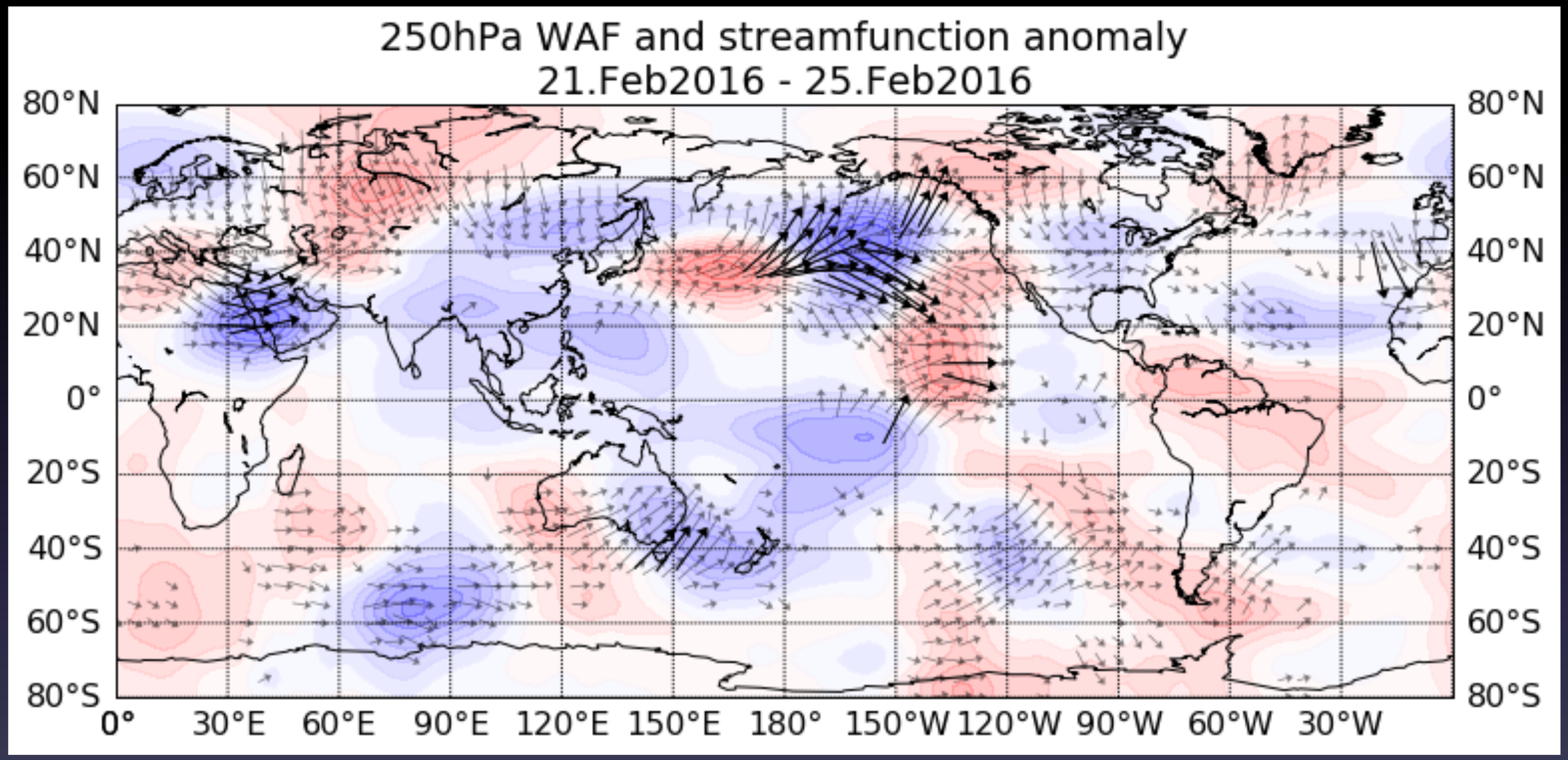

200 hPa meridional wind 20-50N
200 hPa perturbation streamfunction 20-50N
31-Jan-16
05-Feb-16
10-Feb-16
15-Feb-16
20-Feb-16
25-Feb-16
01-Mar-16
06-Mar-16
11-Mar-16
0 30 60 90 120 150 180 210 240 270 300 330 360
Longitude
Southeast tornado outbreak
Mexico cold wave
−30 −24 −18 −12 −6 0 6 12 18 24 30
Wind speed (m/s)
−8.0 −6.4 −4.8 −3.2 −1.6 0.0 1.6 3.2 4.8 6.4 8.0
1e7
Streamfunction m**2/s

Very well-defined wave train extending from N Africa, across India, and into the W Pacific



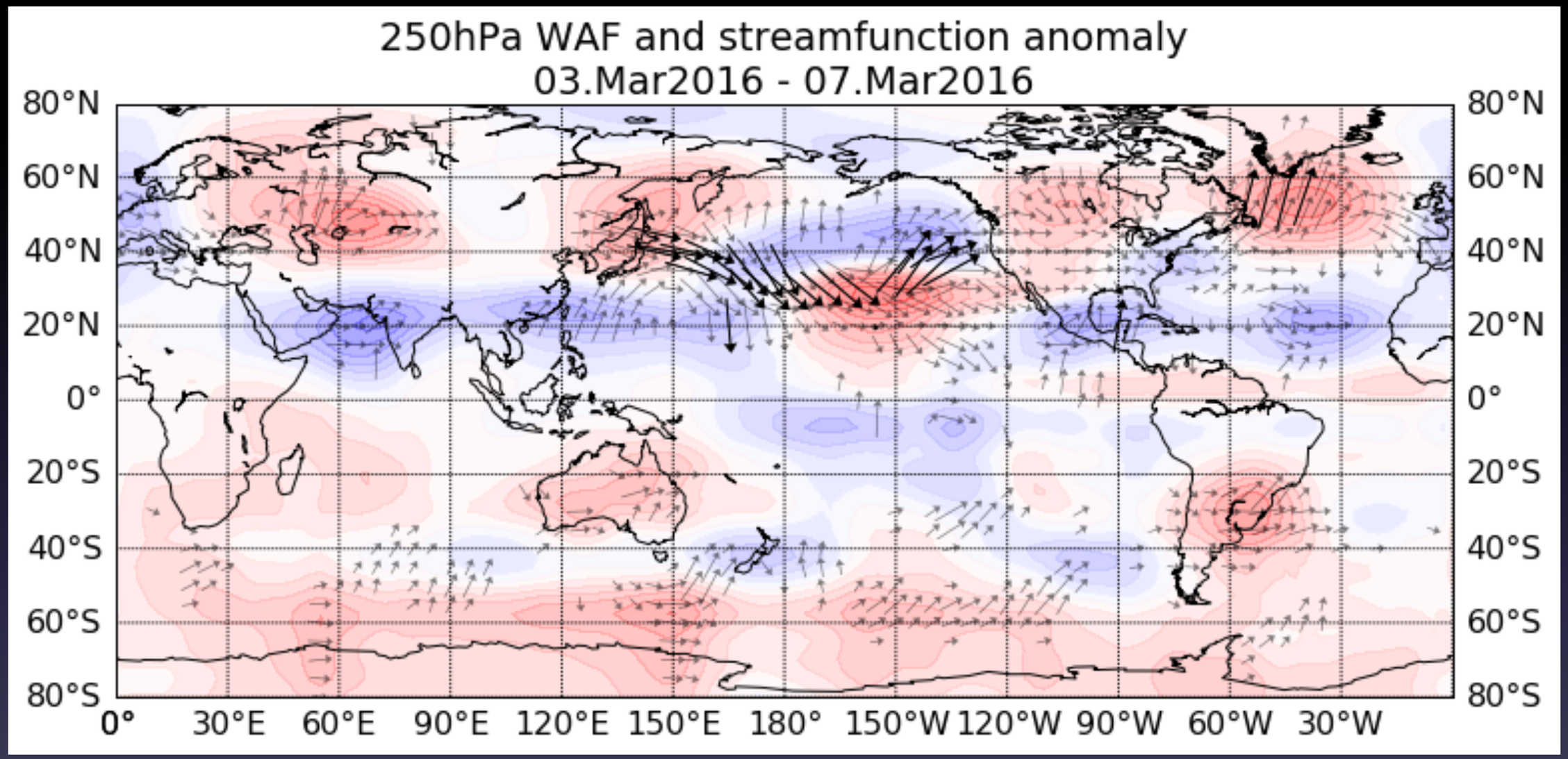

250hPa WAF and streamfunction anomaly
19.Feb2016 - 23.Feb2016
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
80°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W

Wave packet amplifies Northeast Pacific trough.
WAF leaking from mid-latitude wave guide
to subtropical wave guide in E Pacific

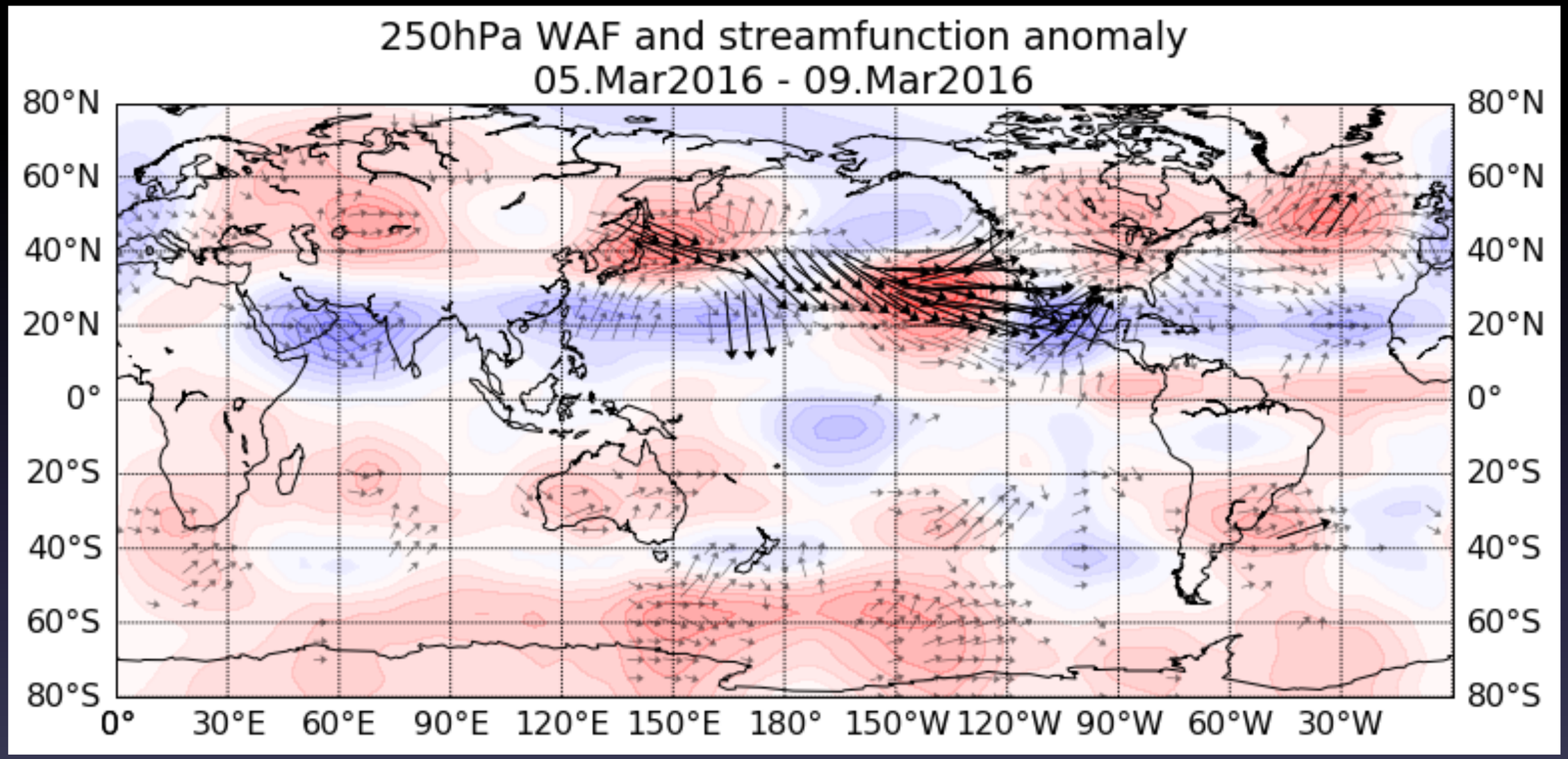


Leads to trough over central US
and tornado outbreak in the Southeast on 23-24 February

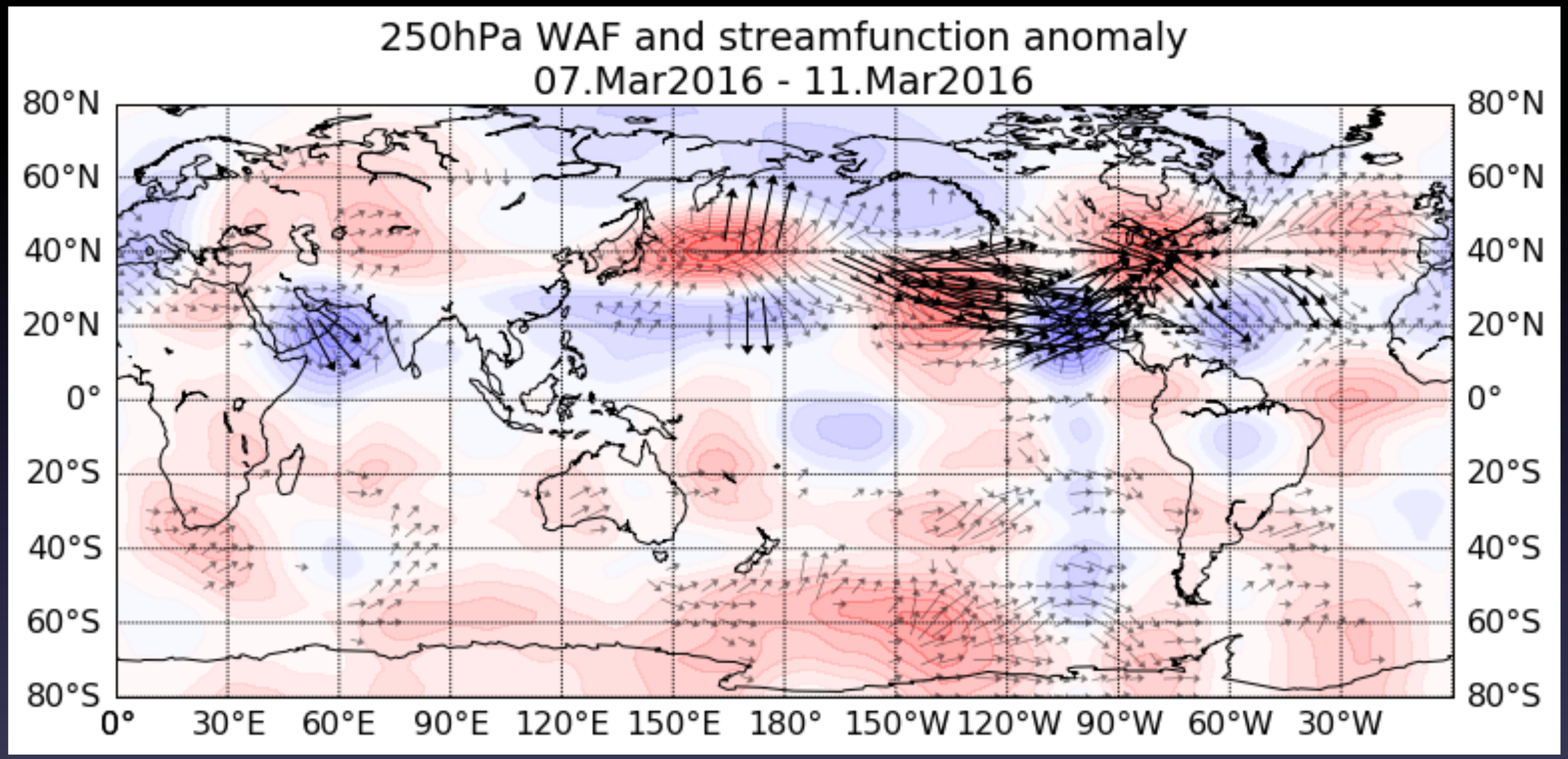
Wave train reinvigorated over North Pacific.
Amplifies subtropical anticyclone in E Pacific.

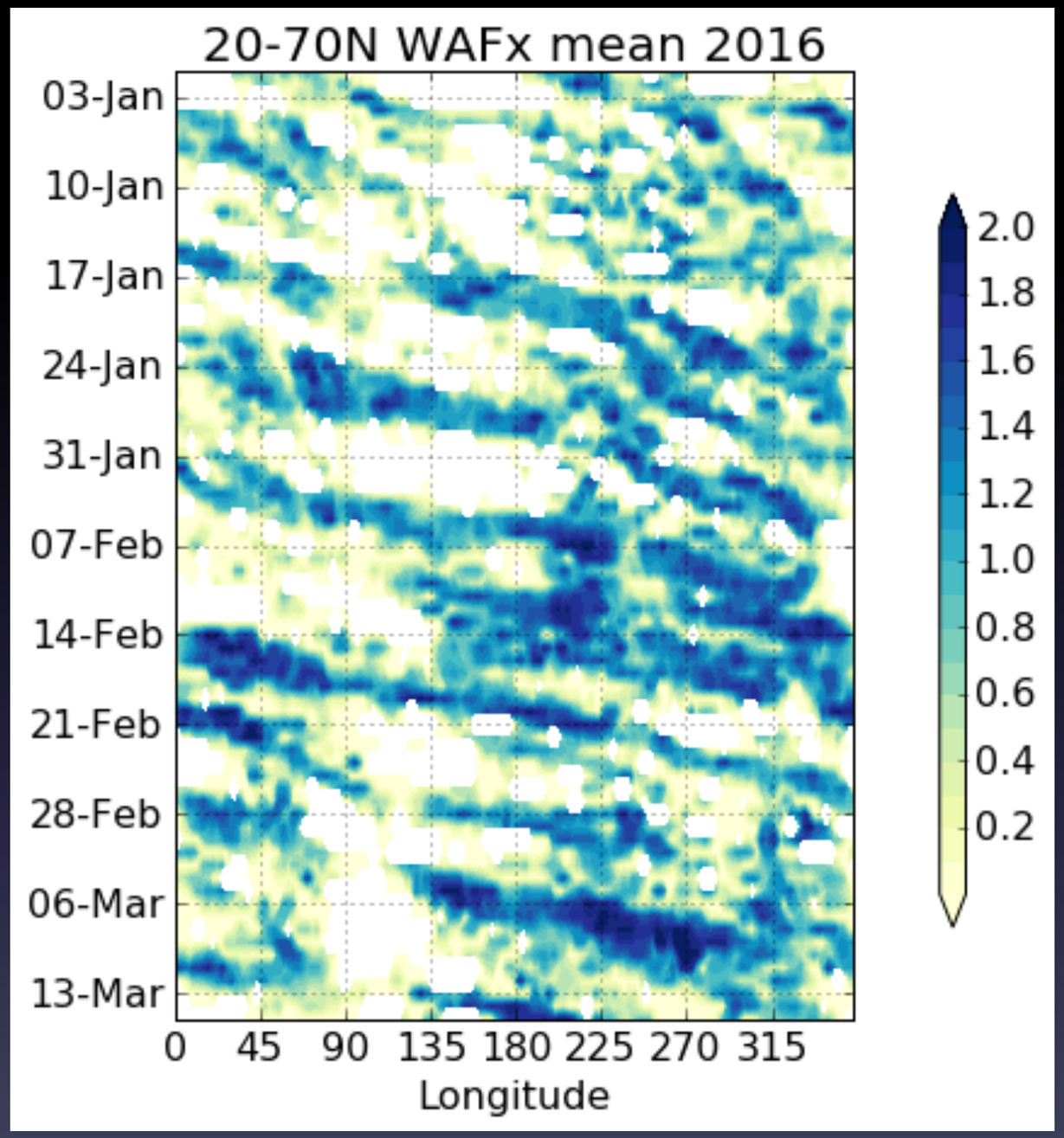


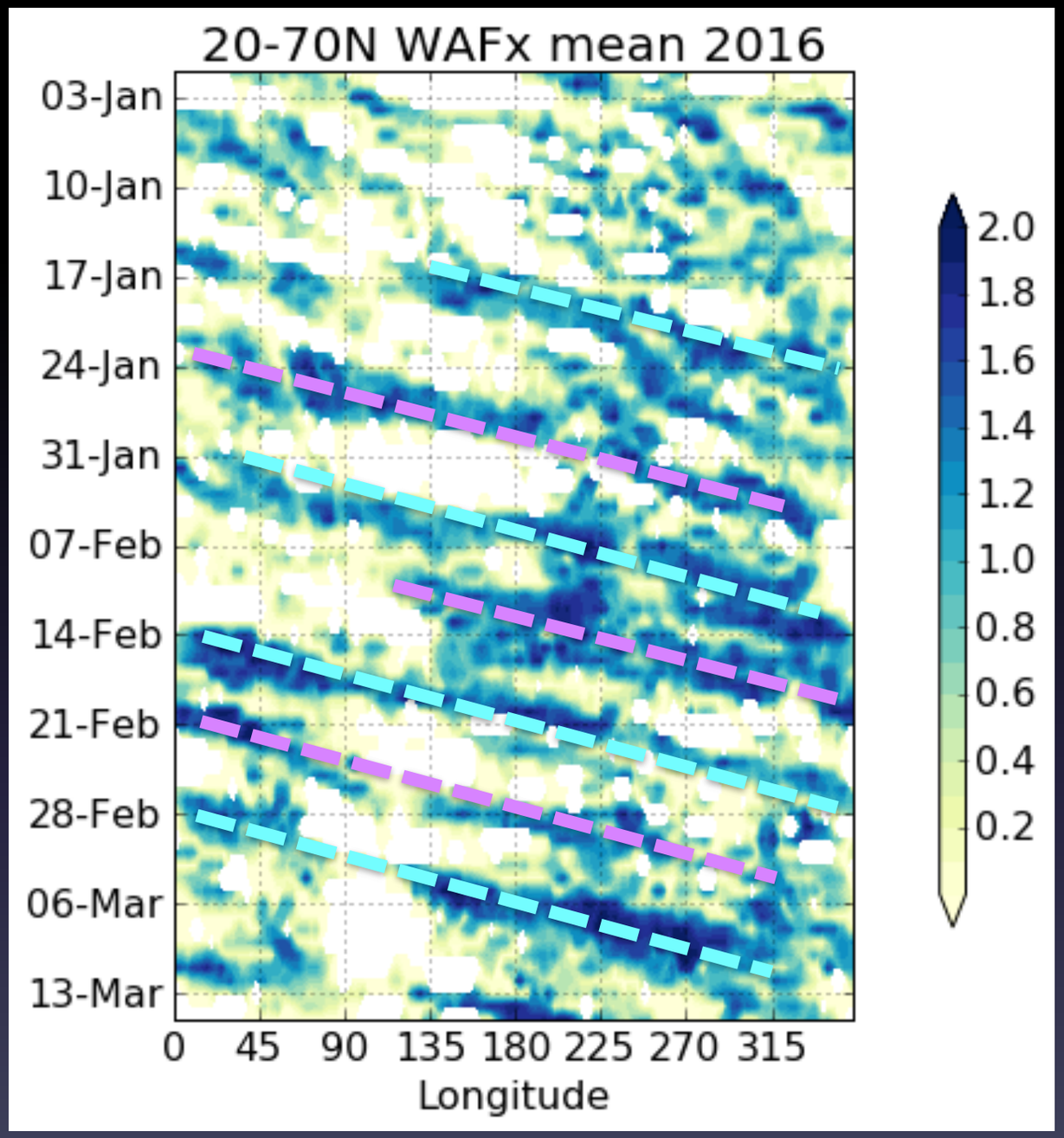
Strong anticyclonic wave breaking toward Mexico.
Begins deepening downstream trough.



Highly amplified trough-ridge wave from Mexico to E US




20-70N WAFx mean 2016
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan
07-Feb
14-Feb
21-Feb
28-Feb
06-Mar
13-Mar
0 45 90 135 180 225 270 315
Longitude
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2


20-70N WAFx mean 2016
03-Jan
10-Jan
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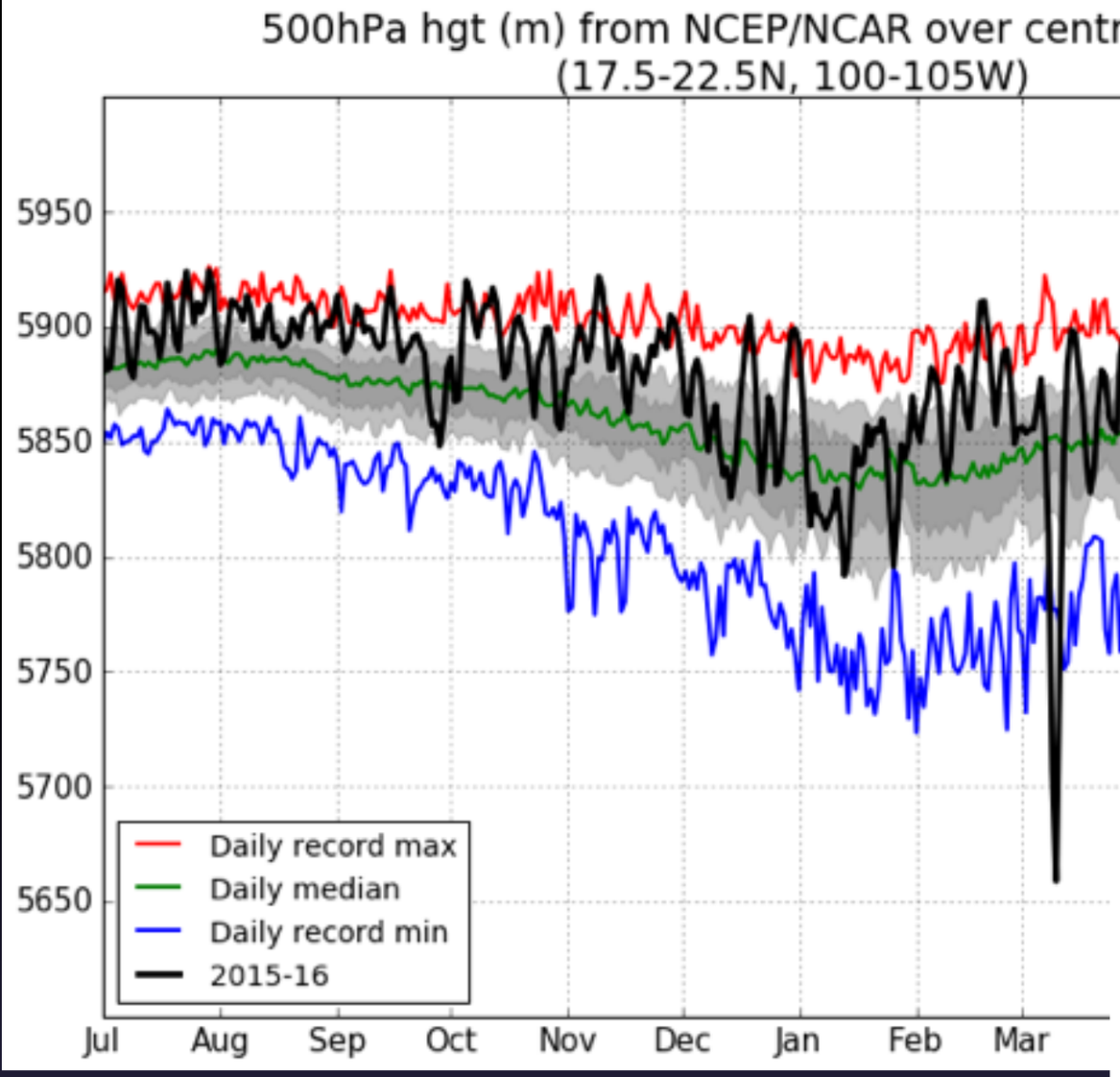
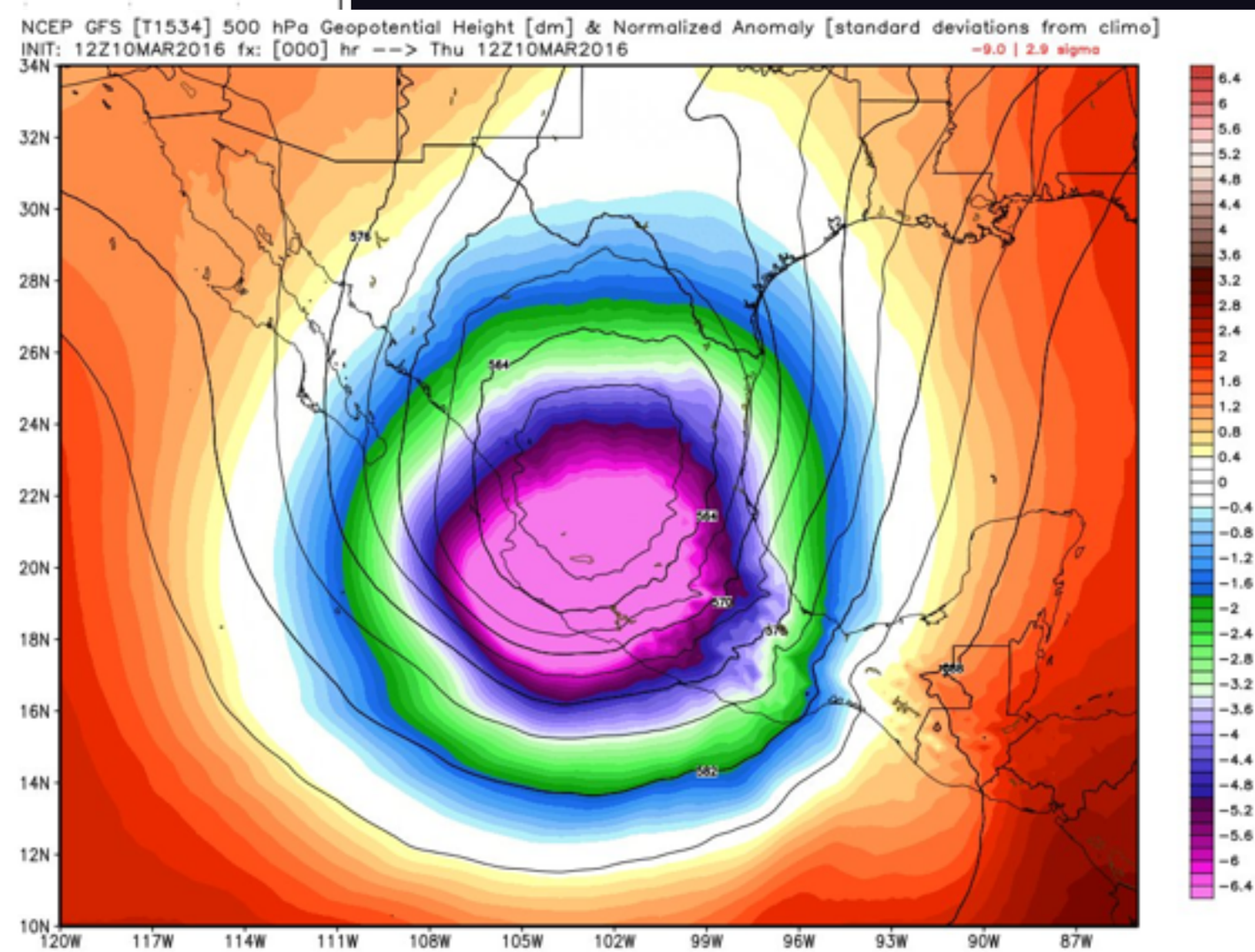
24-Jan
31-Jan
07-Feb
14-Feb
21-Feb
28-Feb
06-Mar
13-Mar
0 45 90 135 180 225 270 315
Longitude
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2



Historic trough over Mexico.

500hPa heights 8sd below normal!

Intense cold and snow as far south as Guadalajara.



Same trough responsible for flooding in Louisiana and Arkansas, with over a foot of rain, locally up to 20 inches.

Predictability and Wave Flux

- Increased medium range forecast skill can be associated with long-lasting RWPs (Grazzini and Vitart, 2015),
- e.g. across the Pacific.

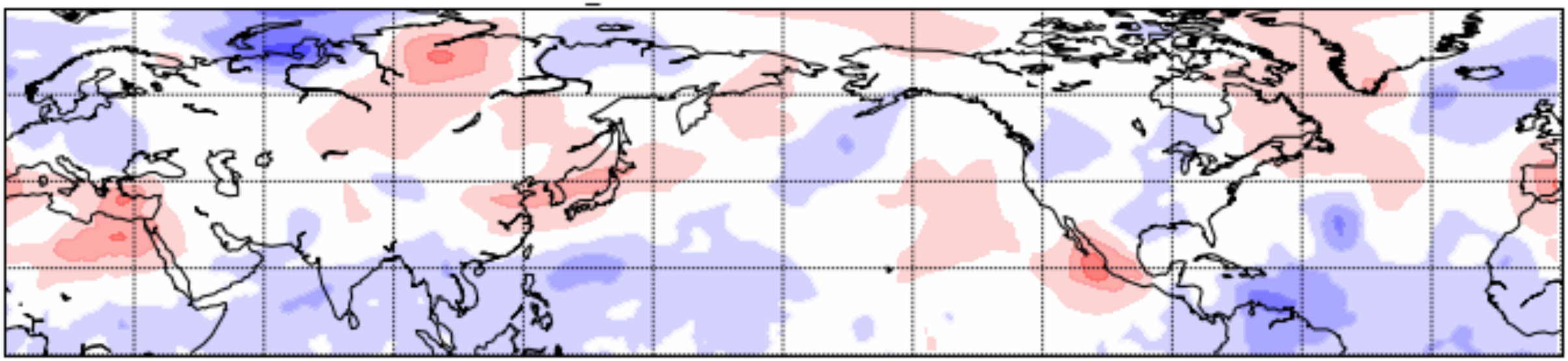
- In contrast, shorter RWPs originating over North America and tracking across the Atlantic are associated with lower skill.

- The caveat is the existence of the RWP in the initialization.

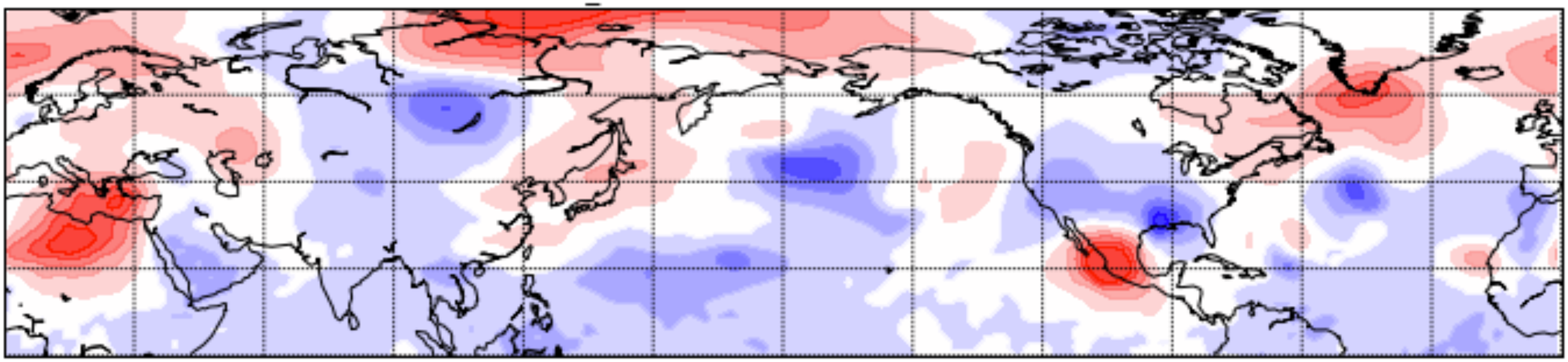
- RWPs triggered by convection can be associated with significant drops in forecast skill, when the model is mishandling the convection in the first place (Lillo and Parsons 2016).

- An accurate forecast requires correct recognition of RWPs (or in general, WAF), and correct recognition of wave guides in the background flow field.

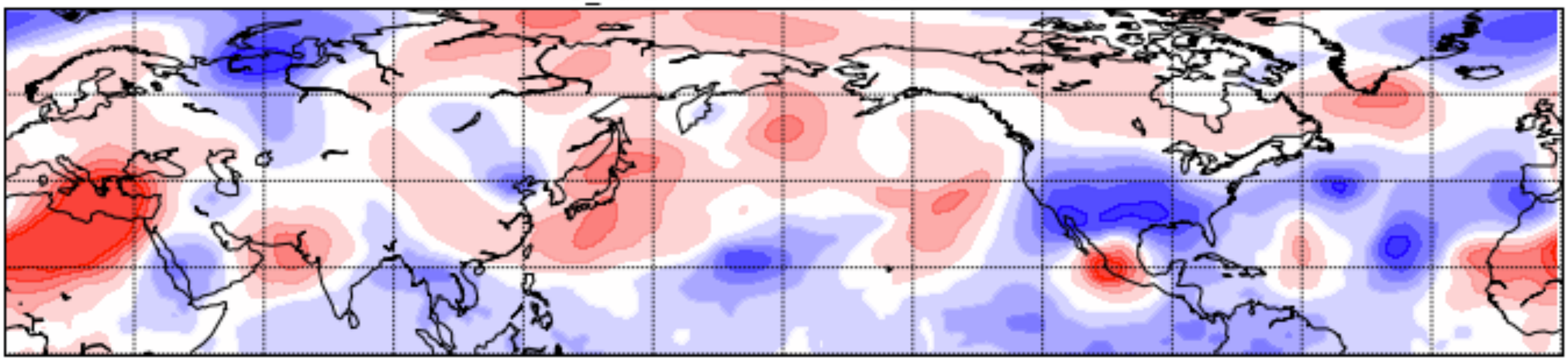
ECMWF H5_sd ERROR init 03Mar16 valid 10Mar16



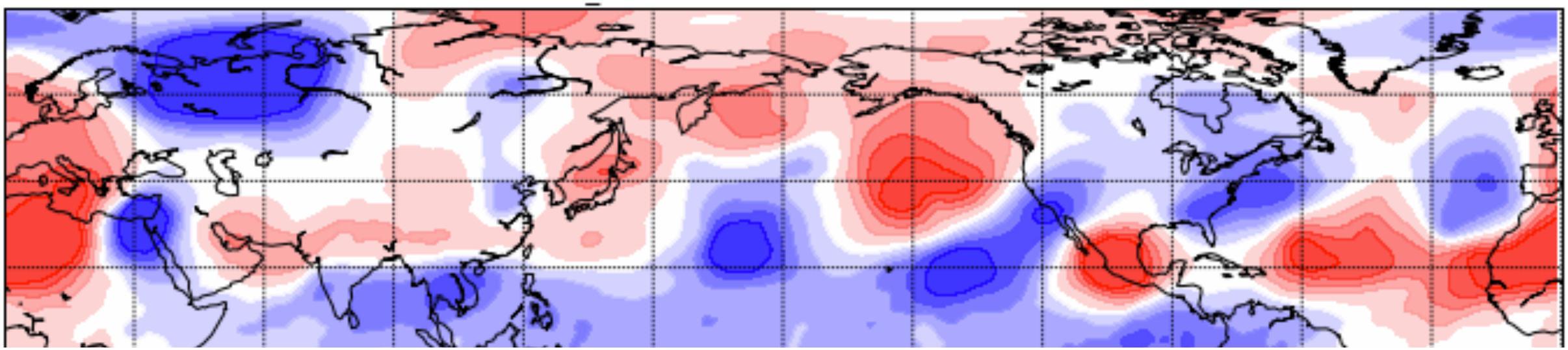
ECMWF H5_sd ERROR init 29Feb16 valid 10Mar16



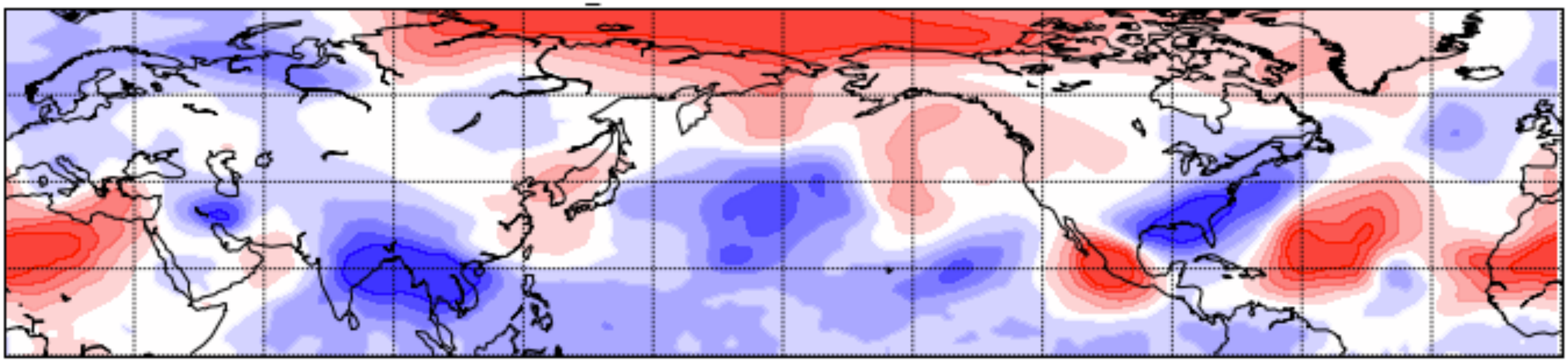
ECMWF H5_sd ERROR init 25Feb16 valid 10Mar16



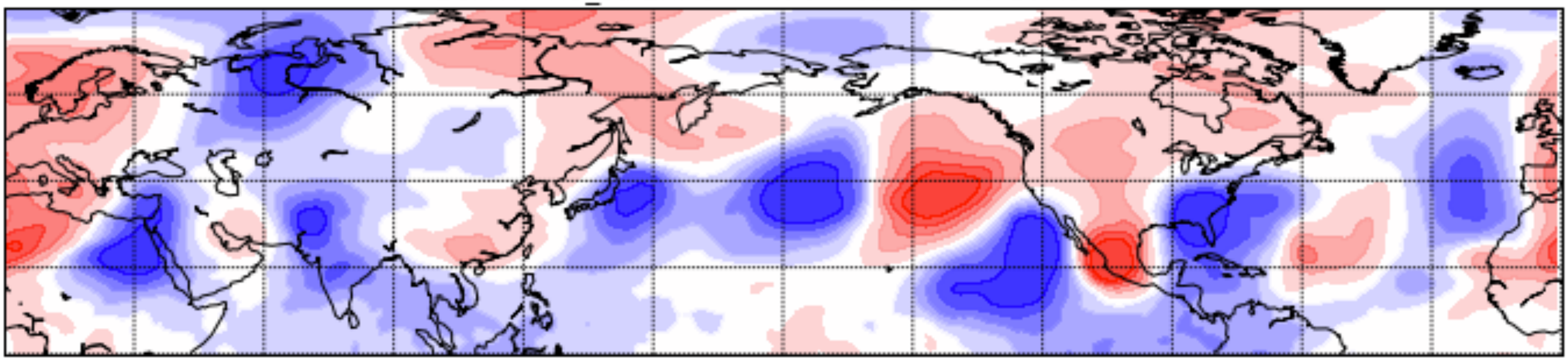
ECMWF H5_sd ERROR init 11Feb16 valid 10Mar16

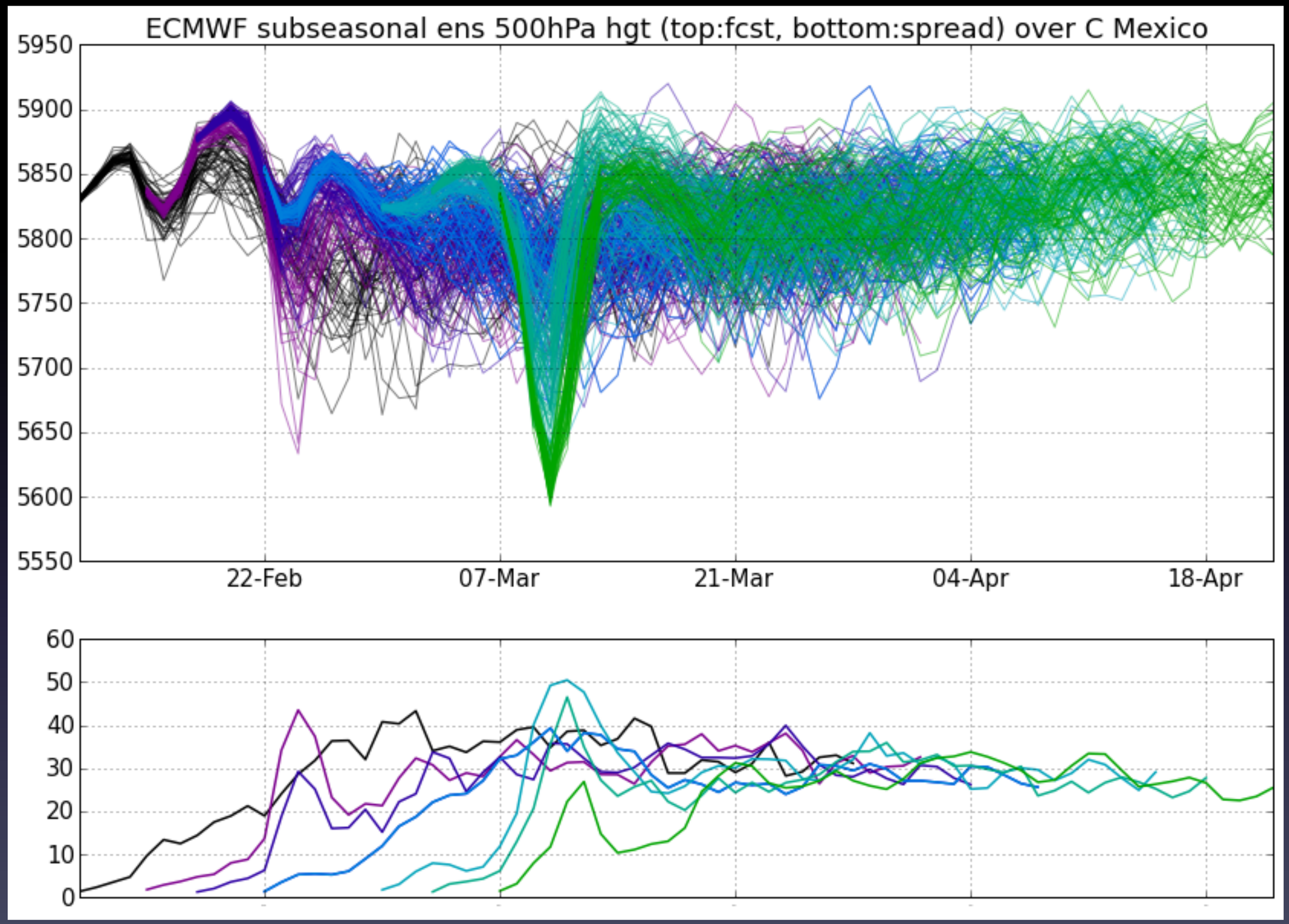


ECMWF H5_sd ERROR init 08Feb16 valid 10Mar16



ECMWF H5_sd ERROR init 04Feb16 valid 10Mar16




ECMWF subseasonal ens 500hPa hgt (top:fcst, bottom:spread) over C Mexico
5950
5900
5850
5800
5750
5700
5650
5600
5550
22-Feb
07-Mar
21-Mar
04-Apr
18-Apr
60
50
40
30
20
10
0

Compare to modern strong El Ninos

1982-83
1997-98
2009-10

Rossby wave refraction and wave guides

Hoskins and Karoly (1981) —

- Refraction of Rossby wave activity dependent on the meridional gradient of absolute vorticity in the background flow field.
- Reflection occurs at turning latitudes dictated by the background vorticity gradient, and varies by the zonal wavenumber of the Rossby waves.
- A waveguide can then be defined as a meridional maximum in the vorticity gradient. Or more specifically, parallel and opposite turning latitudes.

Figures from Hoskins and Ambrizzi (1993)

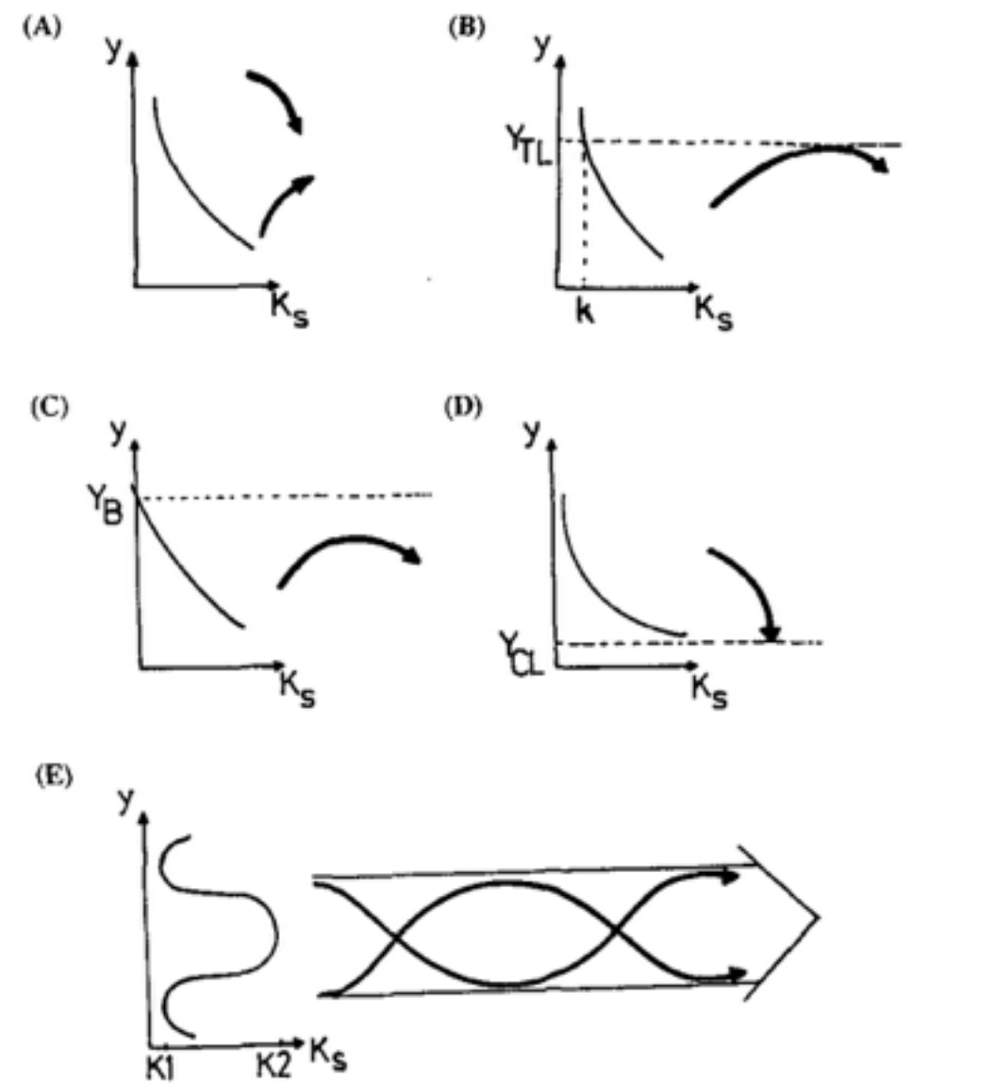
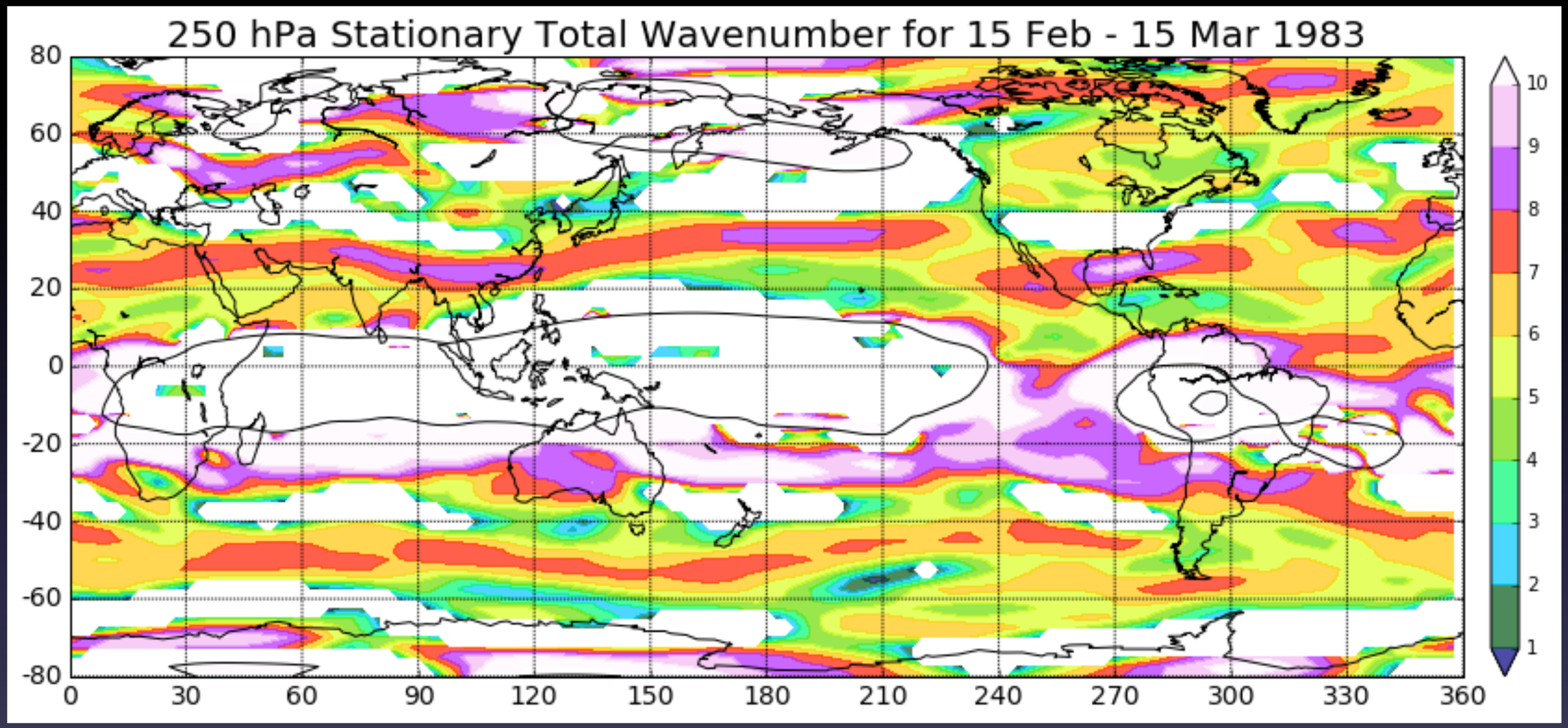
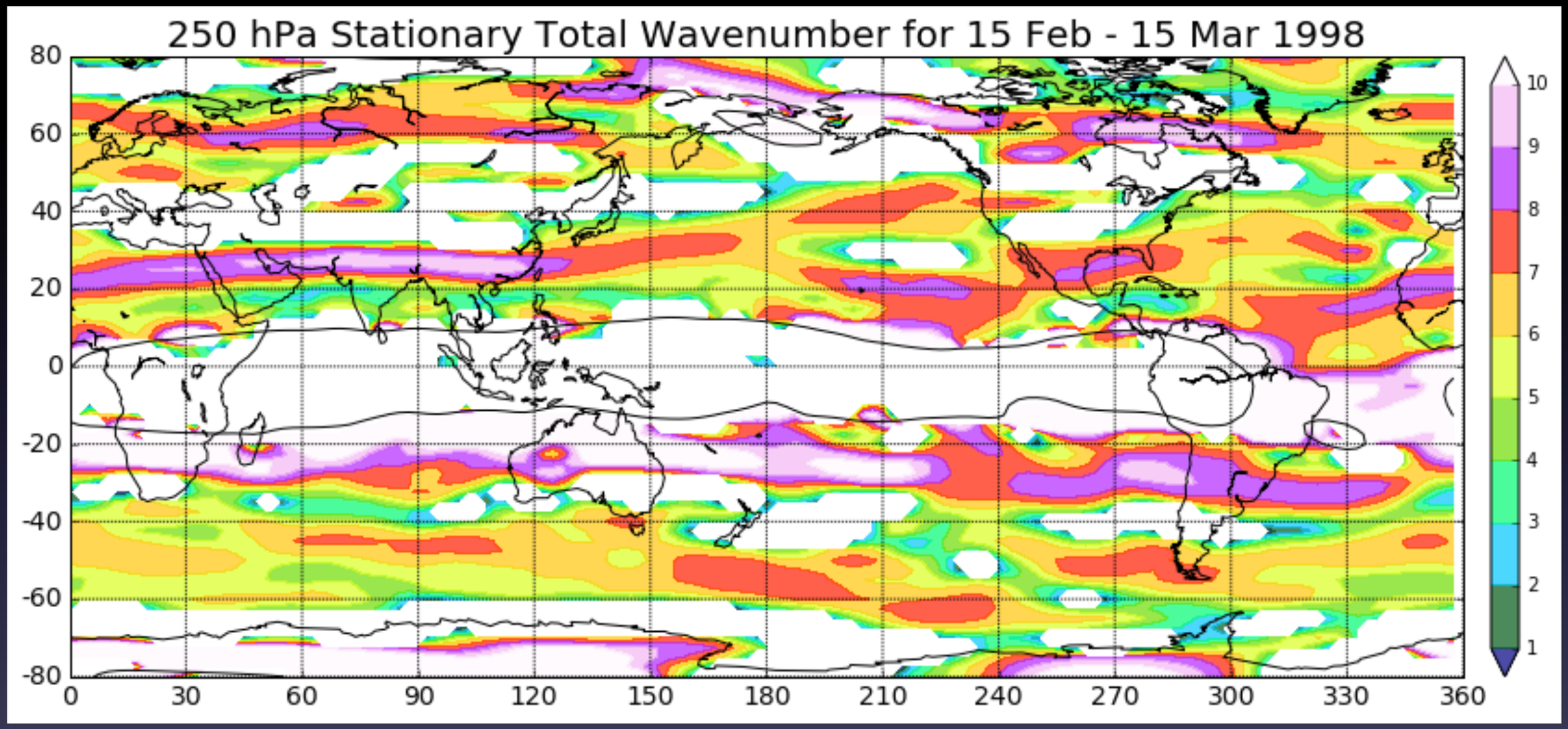
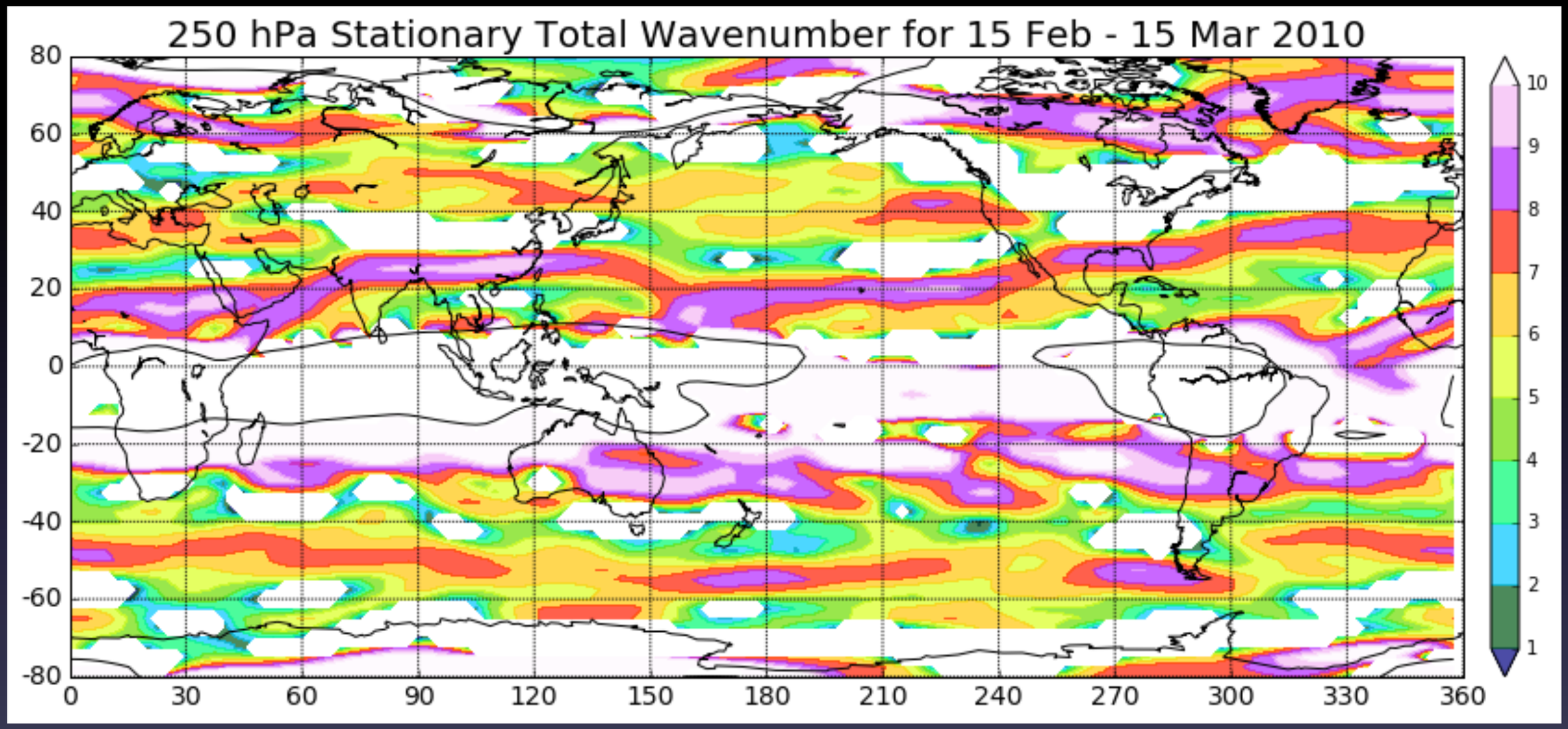
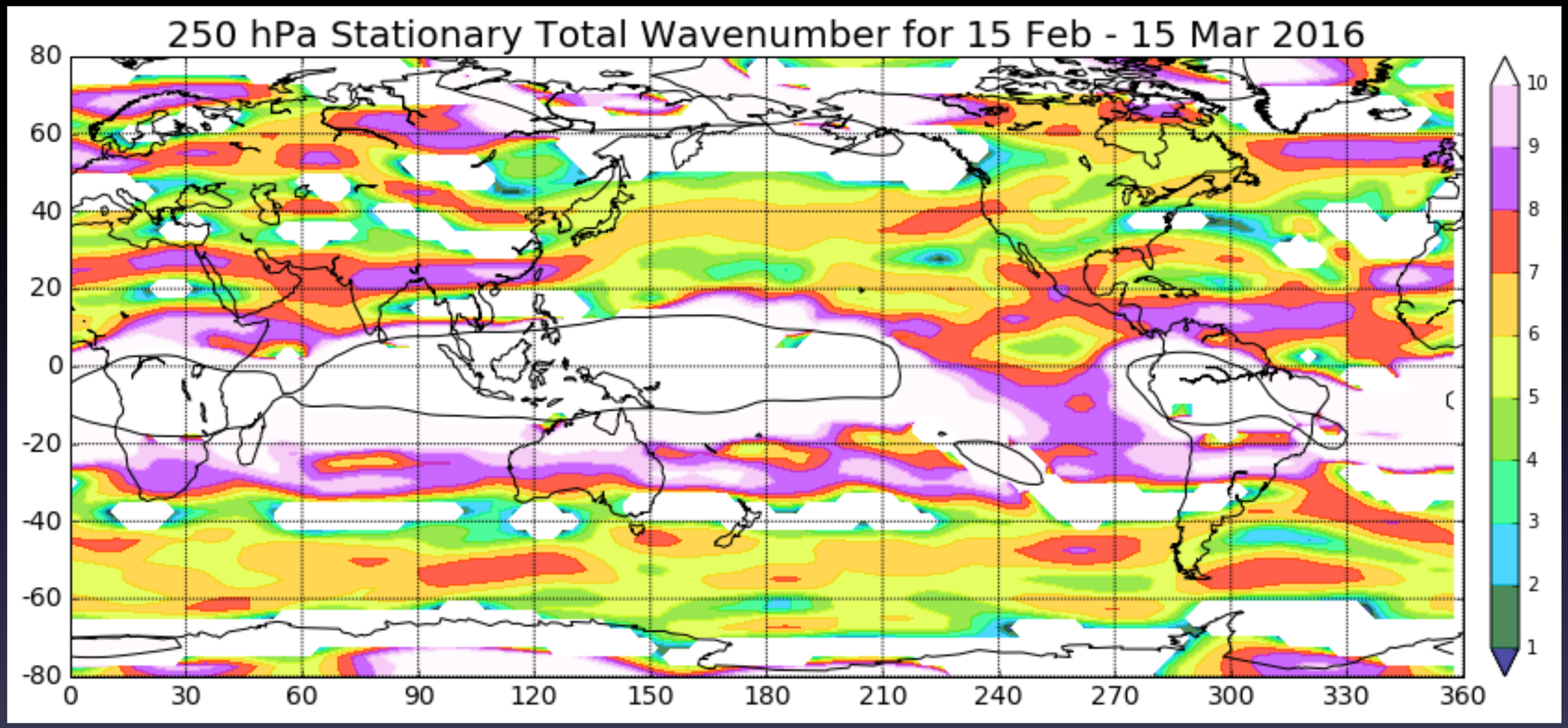


FIG. 2. Schematic stationary Rossby wavenumber (K_s) profiles and ray path refraction. In each panel, K_s is shown as a function of y and schematic ray paths are shown by heavy lines with arrowheads. (a) simple refraction; (b) reflection from a turning latitude Y_{TL} at which $K_s = k$; (c) reflection of all wavenumbers before a latitude Y_B at which $\beta_* = 0$; (d) refraction into a critical latitude Y_{CL} at which $\bar{U} = 0$; (e) waveguide effect of a K_s maximum. For more discussion see text.


250 hPa Stationary Total Wavenumber for 15 Feb - 15 Mar 1983
80
60
40
20
0
-20
-40
-60
-80
0
30
60
90
120
150
180
210
240
270
300
330
360
10
9
8
7
6
5
4
3
2
1


250 hPa Stationary Total Wavenumber for 15 Feb - 15 Mar 1998
80
60
40
20
0
-20
-40
-60
-80
0
30
60
90
120
150
180
210
240
270
300
330
360
10
9
8
7
6
5
4
3
2
1


250 hPa Stationary Total Wavenumber for 15 Feb - 15 Mar 2010
80
60
40
20
0
-20
-40
-60
-80
0
30
60
90
120
150
180
210
240
270
300
330
360
10
9
8
7
6
5
4
3
2
1


250 hPa Stationary Total Wavenumber for 15 Feb - 15 Mar 2016
80
60
40
20
0
-20
-40
-60
-80
0
30
60
90
120
150
180
210
240
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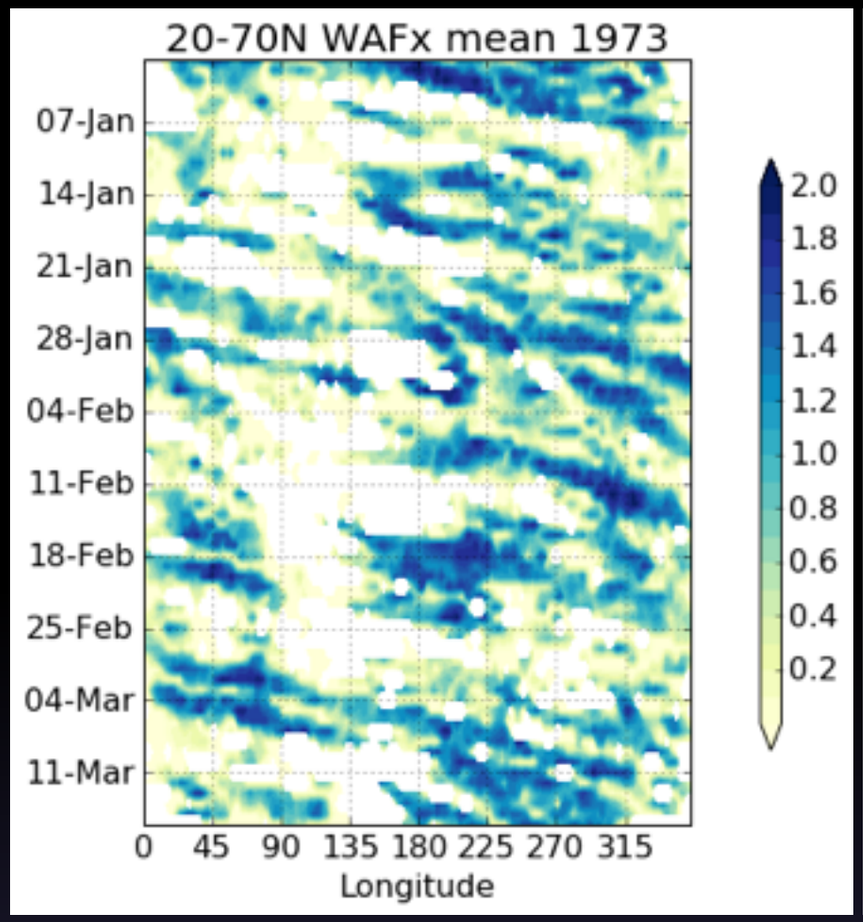
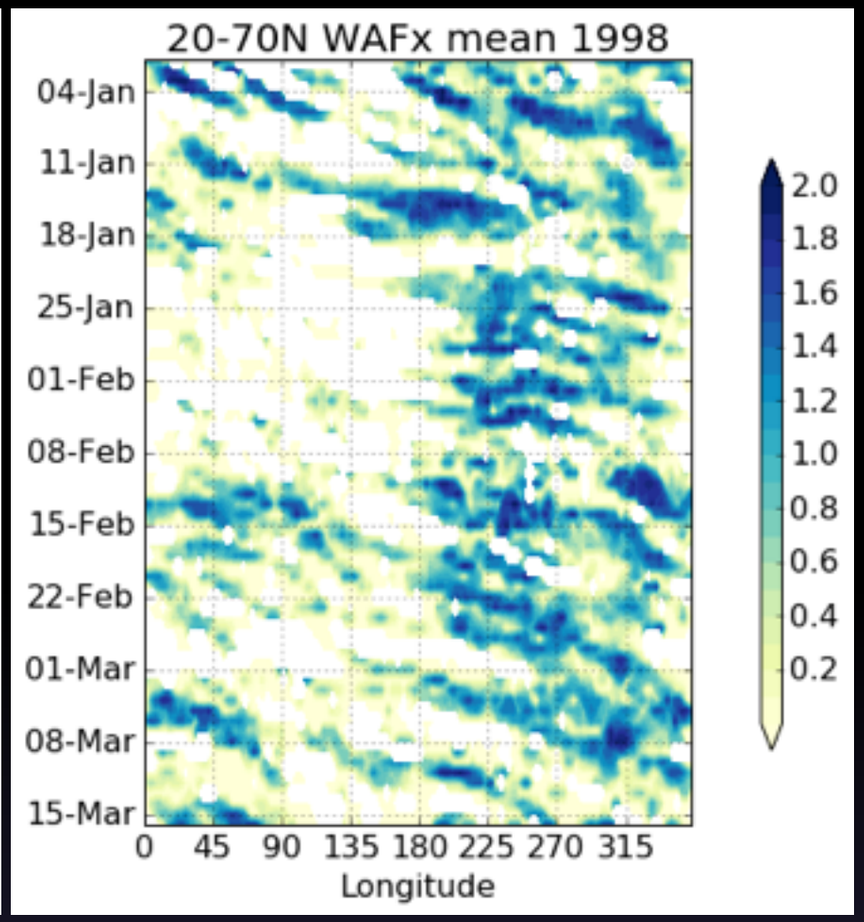
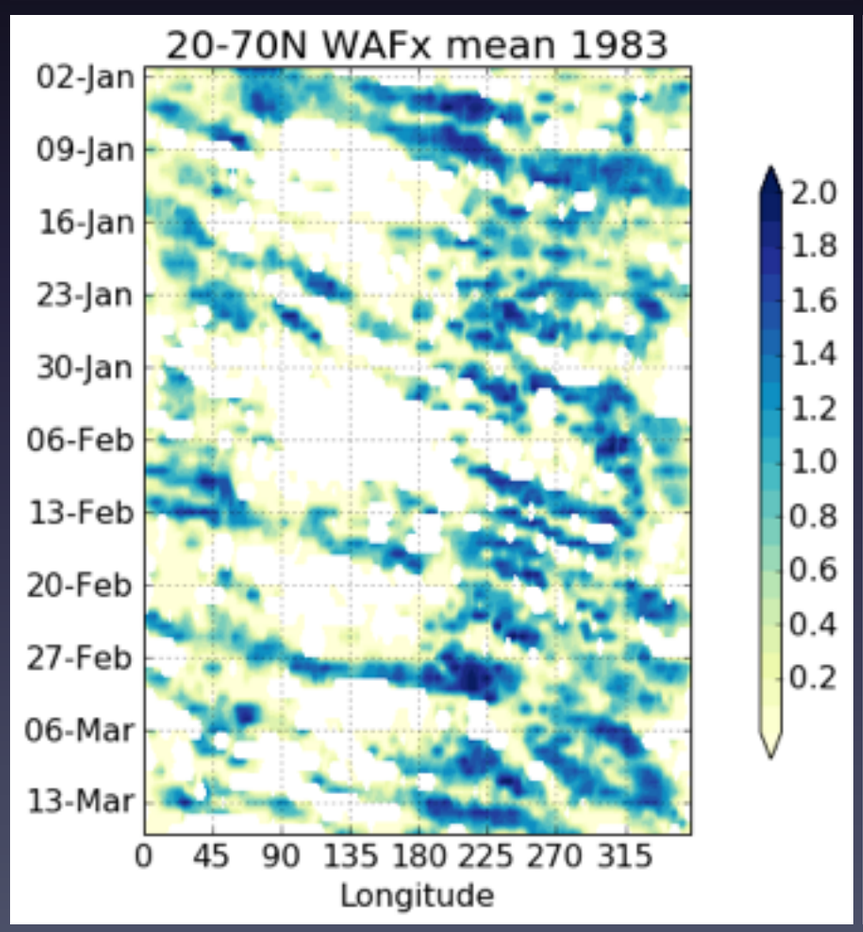
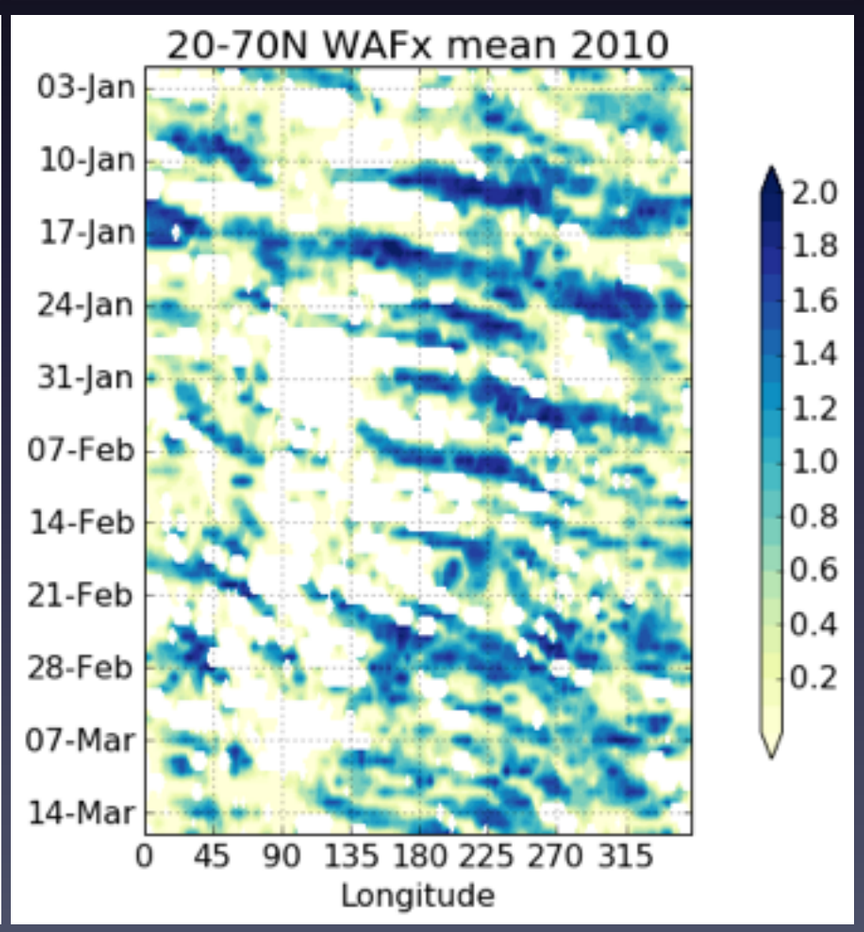
300
330
360
10
9
8
7
6
5
4
3
2
1

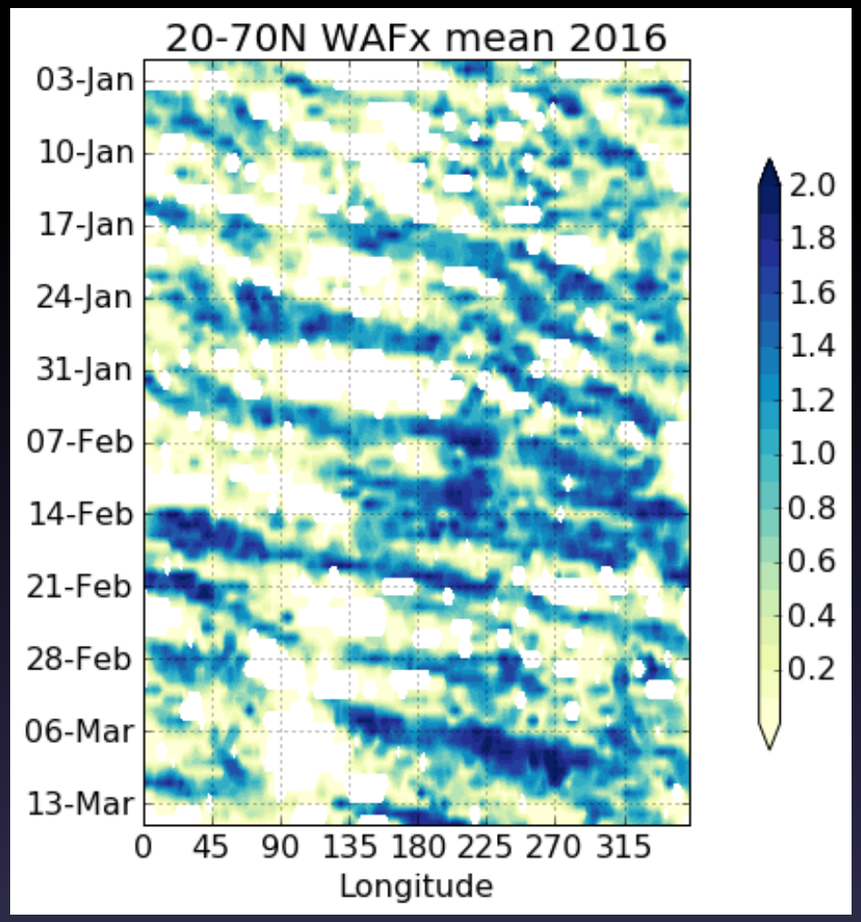




Note the dearth of wave activity crossing over E Asia

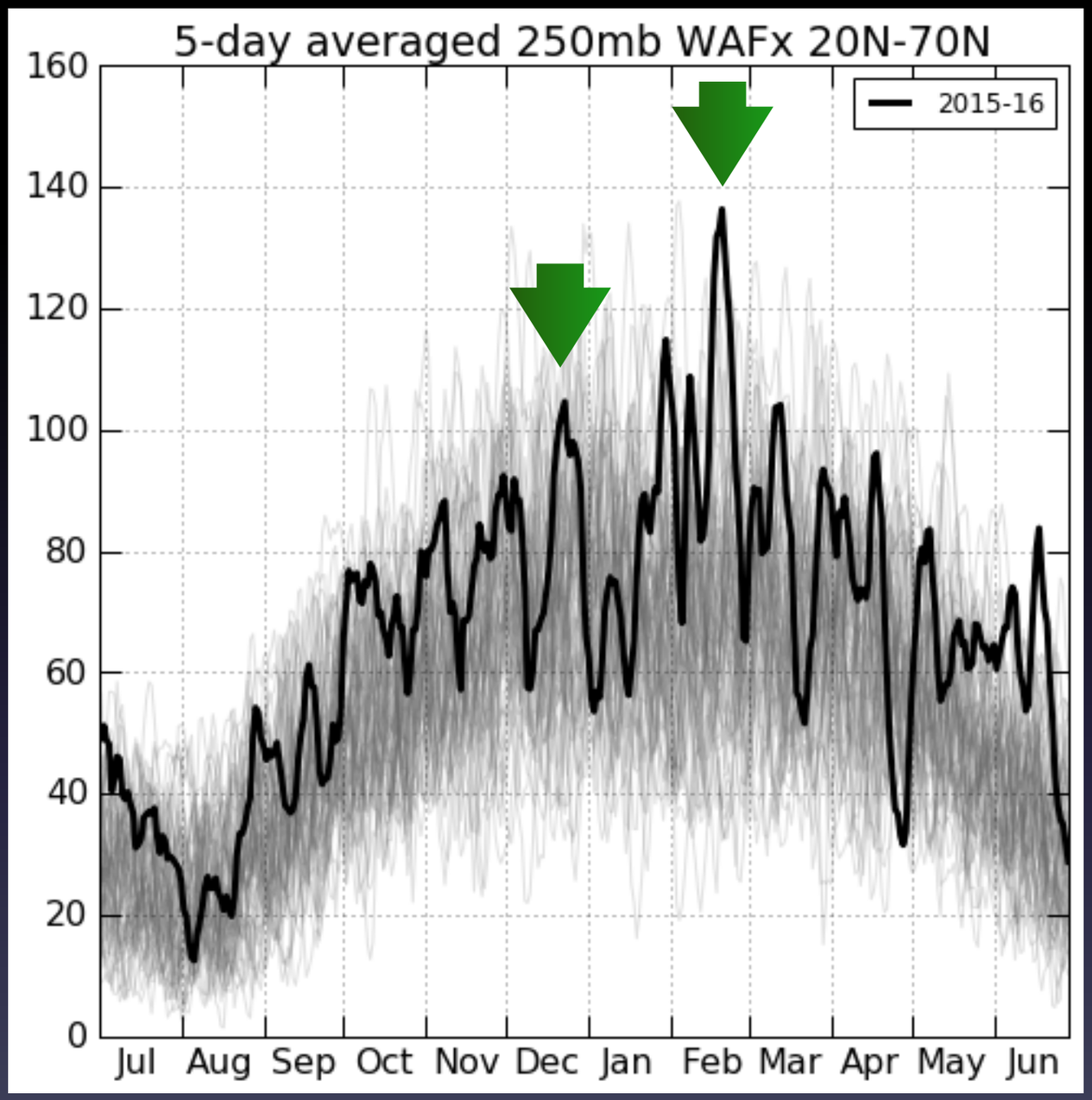


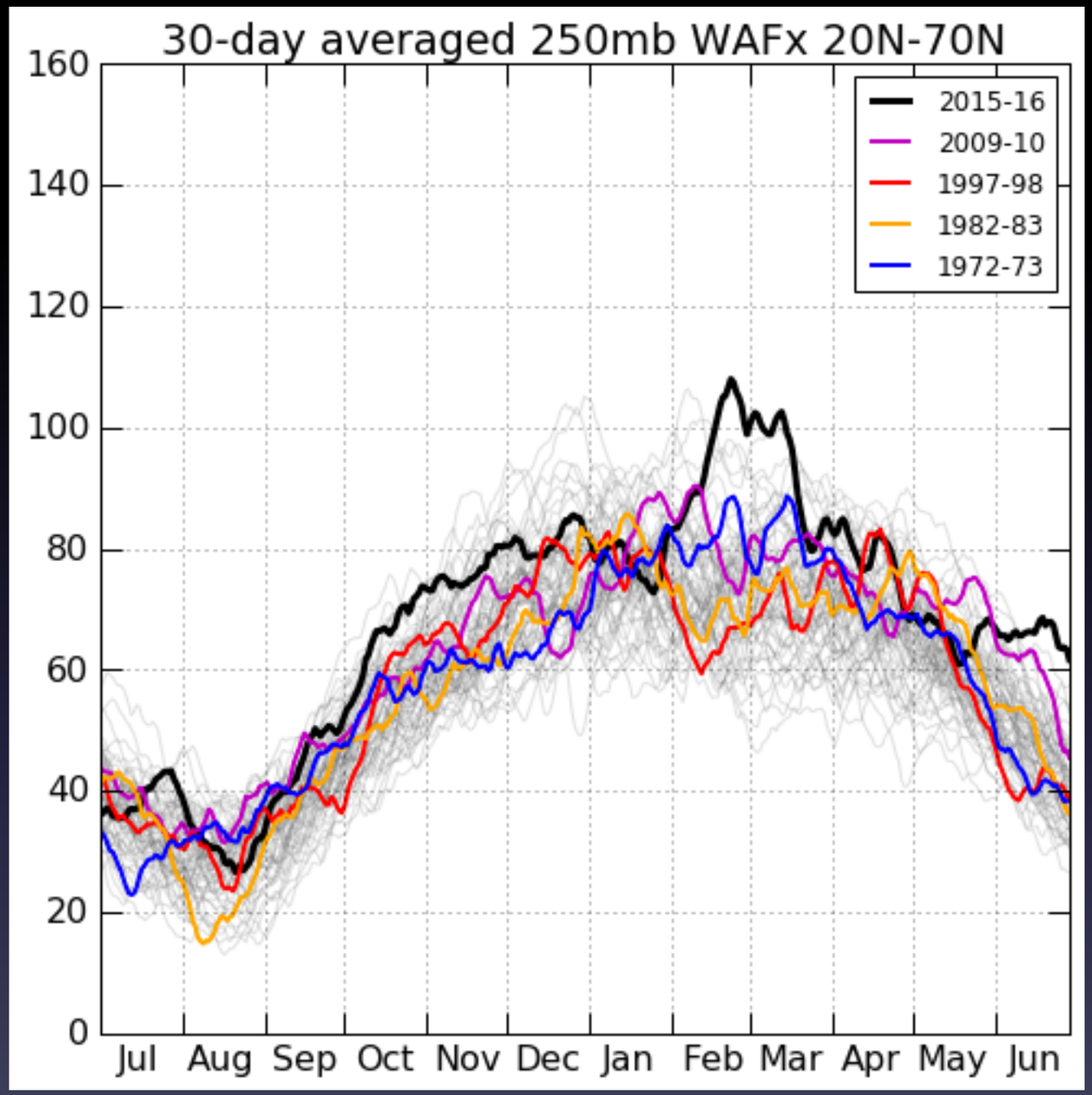




While 2016 featured multiple wave trains maintaining greater coherence and amplitude around the globe

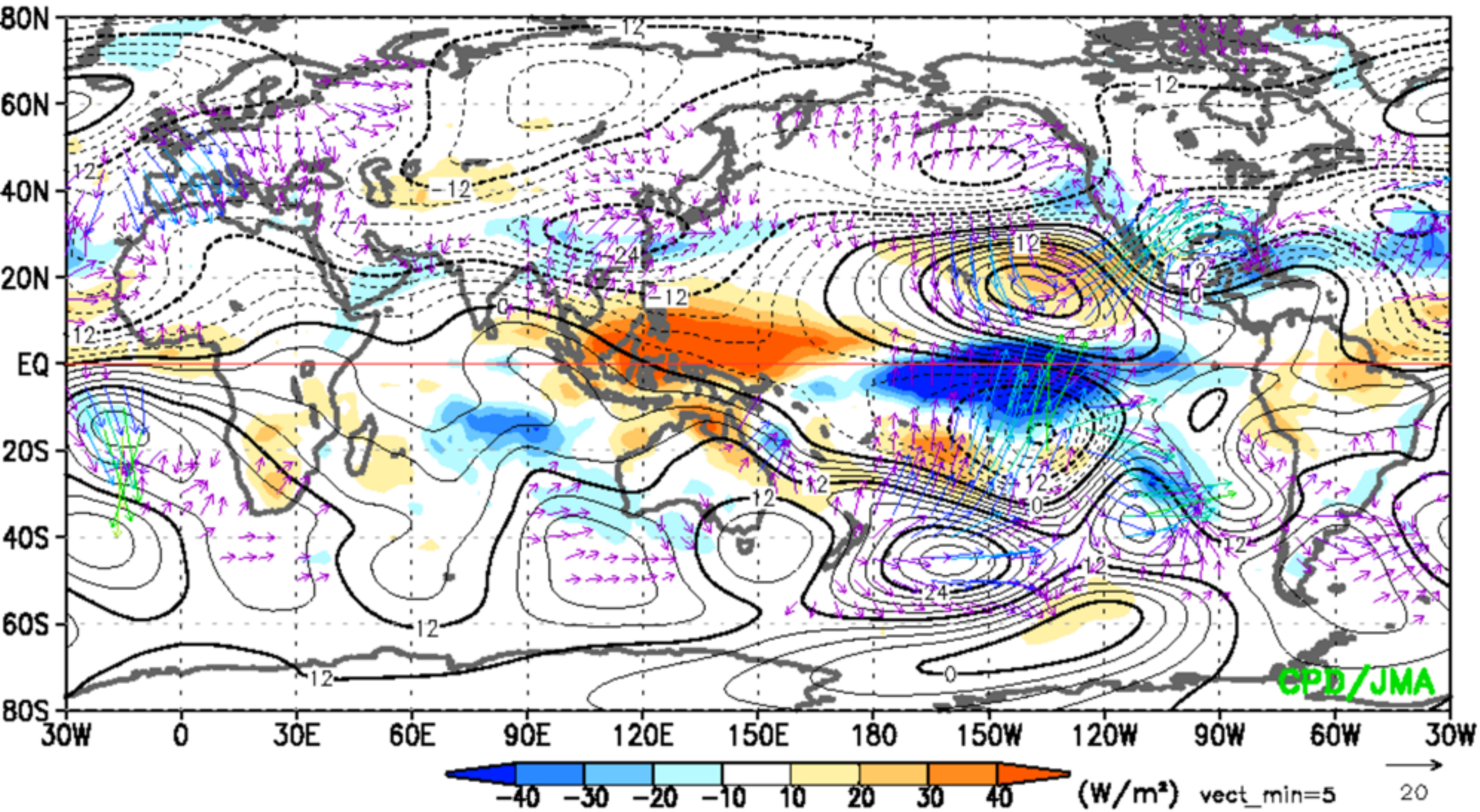
1) Preceded Kara Sea ridge
2) Wave train responsible for tor outbreak and Mexico trough



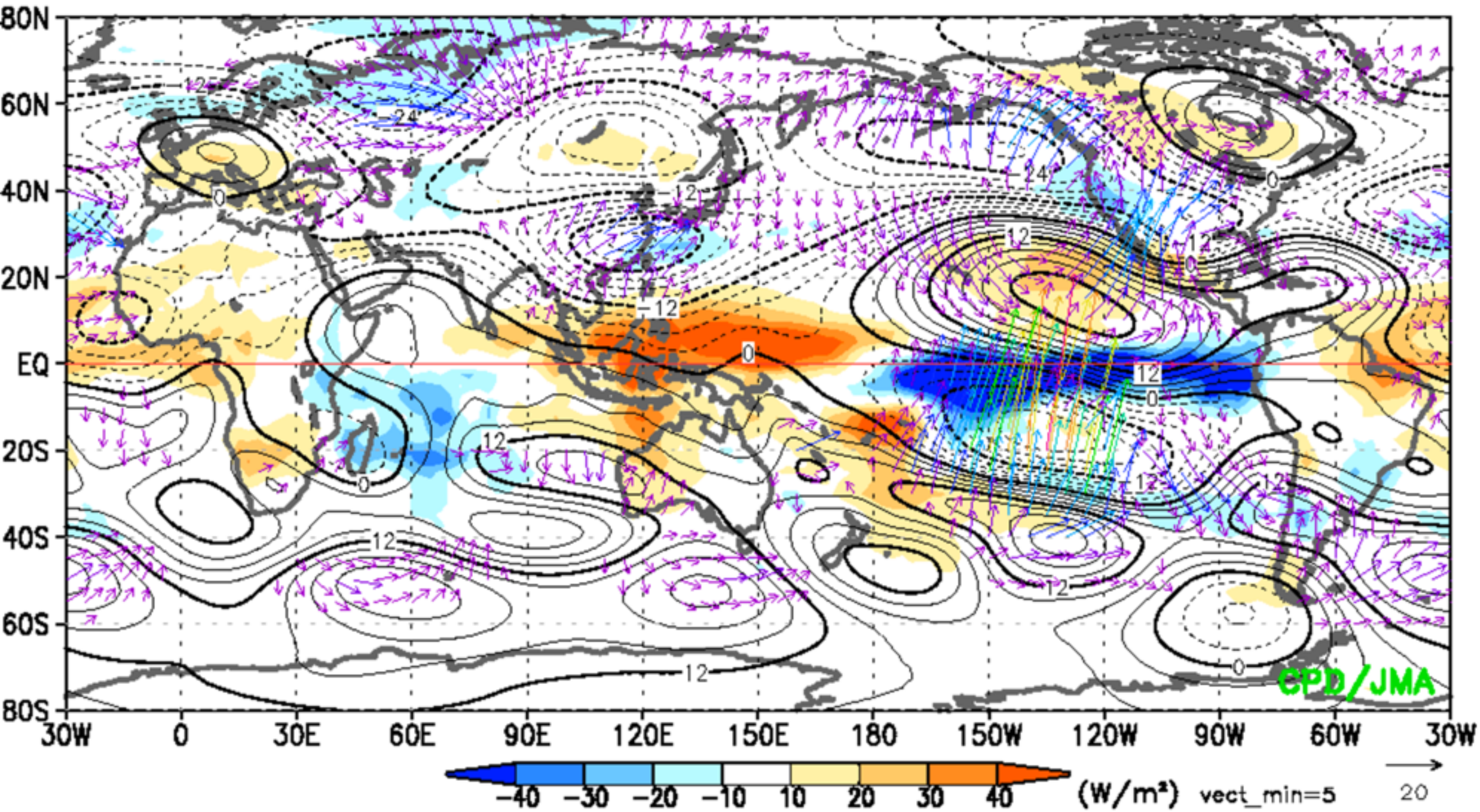


Record high wave activity with wave train
in late Feb - early March

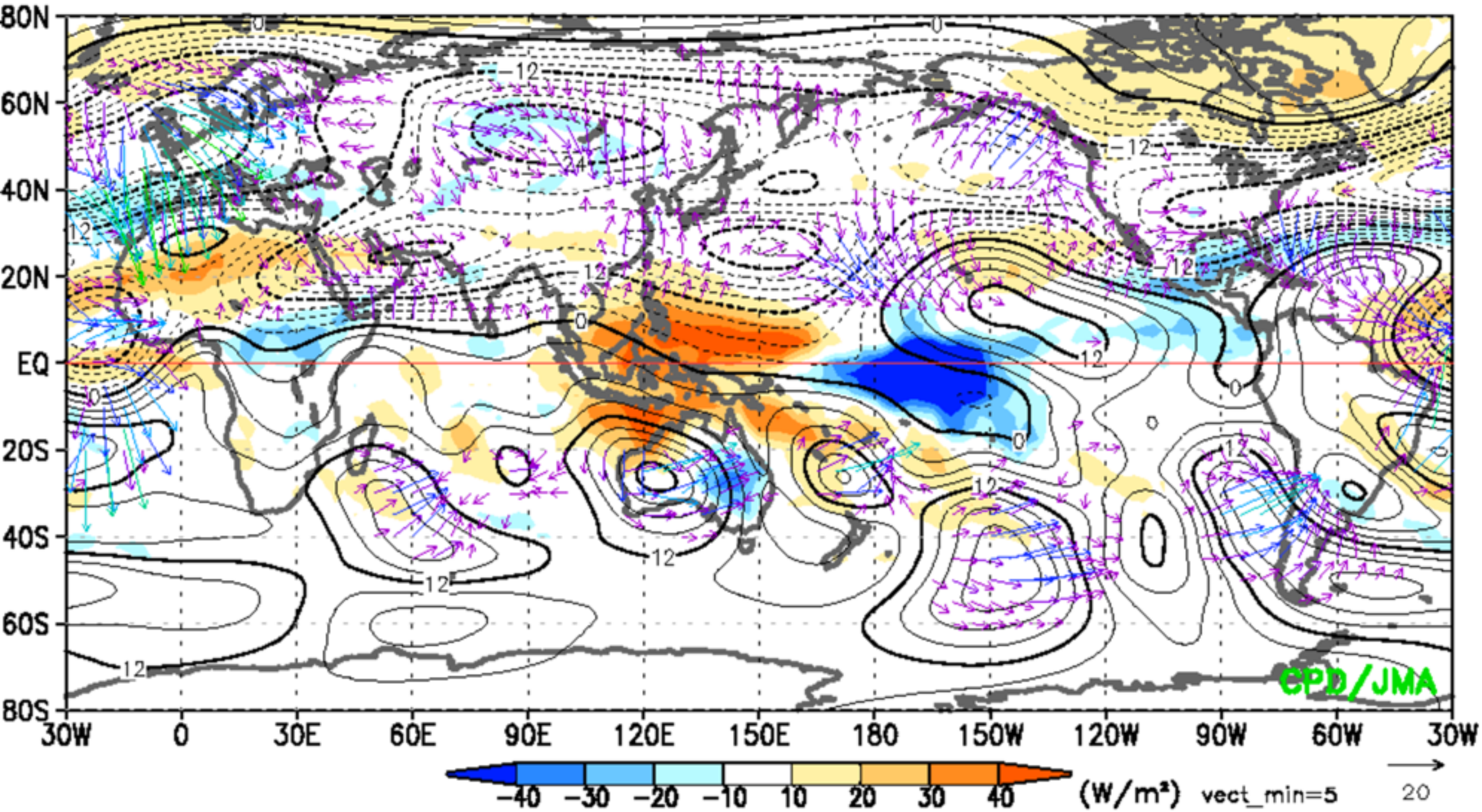
31Jan.1983 – 01Mar.1983



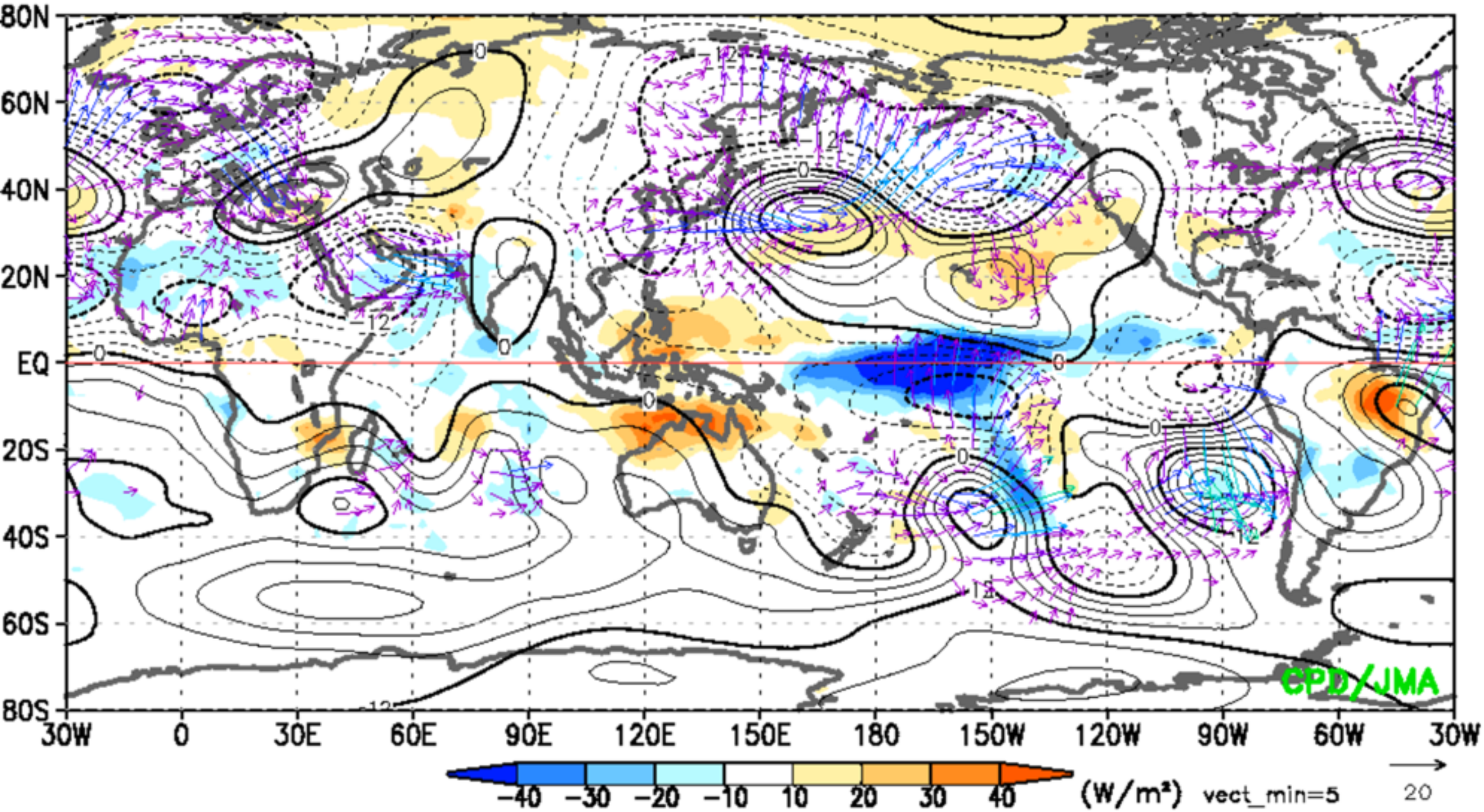
31Jan.1998 – 01Mar.1998



31Jan.2010 – 01Mar.2010



01Feb.2016 – 01Mar.2016



Summary

- Unusual level of mid-latitude wave activity observed during the 2015-16 strong El Nino event.
- Anomalous Indian Ocean convection may have helped to set off wave trains from Tibetan Plateau.
- Warm North Pacific diffused the normal Nino tropics-subtropics temp gradient, broadening the Hadley cell, weakening the subtropical jet wave guide.
- Allows higher wavenumber wave activity to leak into mid-latitude wave guide, and vice-versa.
- Active mid-latitude wave guide responsible for several high impact weather events.