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

Sam Lillo
David Parsons
School of Meteorology, University of Oklahoma
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
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.
Southeast tornado outbreak

Mexico cold wave
Very well-defined wave train extending from N Africa, across India, and into the W Pacific
250hPa WAF and streamfunction anomaly
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
Historic trough over Mexico.

500hPa heights 8σd 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.
Compare to modern strong El Ninos

1982-83
1997-98
2009-10
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 $\beta_s = 0$; (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
250 hPa Stationary Total Wavenumber for 15 Feb - 15 Mar 2010
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
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.