What Caused the Abnormal North America Climate in 2013/14 winter?

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Draught in California is the severest in record;

Cold in middle and east of US broke record of past 20 years
Monthly anomaly patterns are quite persistent
Z200 and SST anomalies associated with the climate anomalies
1. A ridge off the west coast and a trough over the inner part of the land; ENSO was neutral, but an east-to-west SST gradient was in equatorial Pacific.
3. Warm SST anomaly in NE Pacific is prominent (>2.5C). It was likely wind driven, but feedback is also possible.
1. Monthly Z200 patterns over NA region were quite persistent through the winter.

2. The warm SST pattern in NE Pacific was very persistent too, but the circulation over it changed a lot in the period, suggesting the SST feedback might not be strong.
The wave anomalies over NA region are basically originated from the jet exit region of North Pacific.

wave activity flux formulas are based on Takaya and Nakamura (2001)
Any tropical forcing responsible for the circulation anomaly?
1. A moderate diabatic heating (prate) dipole in Equatorial Pacific, but hard to see a Gill-type circulation near the equator.

2. A barotropical linear model response to tropical divergence forcing with the prate pattern.

3. Subtropical cyclonic circulation in OBS is not likely directly forced by tropical Heating on the seasonal time scale.
Only December circulation in tropics and subtropics is likely forced from tropics, thus the circulation anomalies in other months are possibly due to extra-tropical atmospheric dynamics and air-sea interactions.
Possible mechanism in OBS:

1. An equatorial heating dipole in Dec2013 initiated a wave train across the PNA region;

2. In the following months the circulation anomalies are maintained by mid-latitude atmospheric dynamics and air-sea interactions.
AGCM Simulations

• **GOGA**: GFS model forced with observed global SSTs from Jan1957-Mar2014. 18 members.

• **TOGA**: GFS forced with observed SSTs in tropics (30S-30N) but climatological SSTs elsewhere. 10 members for Jan2013 - Mar2014

• Analyses are based on ensemble averaged data. Anomalies are w.r.t. 1981-2010 climate of GOGA.
1. Both GOGA and TOGA have simulated major features observed in PNA region. Major differences from OBS are in tropics.
2. TOGA results suggest the tropical forcing is the primary driving in the model.
3. Does GOGA-TOGA difference implies the potential impact of SST feedback in NE Pacific?
GOGA vs. TOGA for DJFM Mean Prate and PSI200

1. Tropical heating dipole exists in both GOGA and TOGA. The heating-circulation patterns suggest the tropical circulation are directly forced by the heating dipole.

2. GOGA-TOGA map suggests a part of circulation differences are due to the differences in tropical heating, not only due to the differences in SSTs.
Similar to that in OBS, The wave anomalies over NA region also originated from the North Pacific.
Mechanisms in AGCM simulations

• Both GOGA and TOGA have successfully simulated major features of observed circulation anomalies in middle and higher latitudes;

• Tropical SST forcing is the primary driving of the circulation anomalies for the whole season (not just for December as in OBS)

• GOGA-TOGA differences in circulation may suggest a SST feedback in middle latitude, but a substantial part of the differences are due to the differences in tropical heating between the two simulations.

• Similar to that in OBS, The wave anomalies over NA region also propagated from the North Pacific.
Any footprint of decadal variability or long-term trend?

(Wang et al, 2014 in GRL)
Northeast Pacific and North America (NEP-NA) Area
Both OBS and GOGA show some contribution from the trend; less inter-annual variability in GOGA due to the ensemble mean of model data.
Z200 and SST Composites based on Pattern COR

Amplitude of the trend is small
Any such a long-lasting circulation anomalies over NEP-NA area happened before? Or, what is the chance for this it to happen?

- Persistency analysis for cold season monthly Z200 anomalies (Nov-Mar) with both OBS and AGCM data.
- Persistence is defined as the pattern correlation $> 0.5$ for a month to its successive months.
Persistency in GOGA are similar to that in OBS. 4-mon and 5-mon persistence happen in GOGA, though with minor probability.
Summary

1. The circulation anomalies over the NEP-NA region persisted for 4 months (DJFM). Such a long persistence happened only 3 times in past 65 winters. Two other cases are with ENSO (74/75 and 76/77).

2. The seasonal mean circulation anomalies over NA was a part of wave train propagated from North-East Pacific region.

3. The wave train was likely initiated by tropical heating in December and maintained by extra-tropical atmospheric dynamics (also possibly air-sea interactions) in the following months.

4. Both GOGA and TOGA experiments have successfully simulated major features of the observed seasonal circulation anomalies in middle and higher latitudes. It means the primary forcing in the model is the tropical SST for the whole season, and the role of middle latitude SST feedback is minor.

5. Circulation anomalies over NA in the season may contain some footprints of long-term trend.
Lagged pattern correlation for NEP-NA Z200

OBS

Histogram of OBS Z200 Pat Cor over NA for NDJFM

0-mon Lag, 260 CORs
Mean=0.23 STD=0.36

1-mon Lag, 195 CORs
Mean=0.07 STD=0.38

2-mon Lag, 130 CORs
Mean=0.04 STD=0.37

3-mon Lag, 65 CORs
Mean=0.06 STD=0.34

GOGA

Histogram of AMIP Z200 Pat Cor over NA for NDJFM

0-mon Lag, 4104 CORs
Mean=0.20 STD=0.36

1-mon Lag, 3078 CORs
Mean=0.08 STD=0.37

2-mon Lag, 2052 CORs
Mean=0.05 STD=0.36

3-mon Lag, 1926 CORs
Mean=0.03 STD=0.35
Linear model results confirm that GOGA-TOGA differences in tropical heating can explain some differences in global circulation.
Barotropical linear model response to tropical divergence anomalies of GOGA mimic the tropical circulation anomalies in GOGA for DJFM mean data. It is thus confirmed that tropical heating is the primary driving of the circulation anomalies in the model. This is different from OBS.