Toward the Seasonal Prediction of Atmospheric Rivers over the northeast Pacific Ocean and western North America

Hyemi Kim and Yang Zhou

School of Marine and Atmospheric Sciences, Stony Brook University, New York

* Kim and Zhou (submitted)
Atmospheric River (AR)

- Filamentary features (400-600 km wide, >2000 km long)
- Transports ~90% of the water vapor from the tropics into the extra-tropics.
- Induce heavy wintertime precipitation along the west coast states.
- Provide up to 50% of California’s water supply.

**Total precipitable water: Jan-27 to 29, 2016 (hourly)**

Image credit: CIMSS/University of Wisconsin, Madison
ENSO induced circulation change

Figure: http://www.weatherwise.org/
Research questions

• How does ENSO (EP vs. CP) impact on ARs and moisture transport?
• How well do the current models (NMME) predict the AR activity?

Approach

• AR activity (frequency, intensity, landfall location) in the three ENSO phases: EP, CP El Nino, and La Nina
• Causes of change in seasonal moisture transport related to ENSO
  - Low-frequency vs. synoptic variability
  - Dynamic vs. thermodynamic factors
  - Divergence vs. advection term (moisture budget)
• AR-ENSO prediction in NMME reforecasts
Three ENSO phases

- Boreal Winter (DJF), HadISST
- CP El Niño (4 years): 94/95, 2002/03, 04/05, 09/10
- La Niña (6 years): 84/85, 88/89, 98/99, 99/00, 07/08, 10/11

(Selection is based on Nino indices, Kim et al. 2009, 2012)
AR definition

AR detection

- ERA-Interim: 6hr data from 1979/80-2015/16, DJF
- Vertically-integrated moisture flux $\geq 250$ kg/m/s (Rutz et al. 2014)

Landfalling AR

(a) $Q$, Jan 28, 2016
(b) Averaged $Q$ along the coastal area

\[ Q = \frac{1}{g} \int_{PS}^{300} \vec{V} \cdot q \, dP \]

Landfalling AR $> 250$
Extreme landfalling AR $> 450$

Latitude: 46°N
Intensity: 538.8 kg m\(^{-1}\) s\(^{-1}\)
AR Frequency

Shading: Frequency (#/year)
Vector: Moisture flux

* The vectors shown exceed the 90% significant level.
Landfalling AR

- EPEN $\rightarrow$ More landfalling ARs in the northwest
- CPEN $\rightarrow$ More extreme ARs in the southwest due to the southward shift of the Low.
Moisture flux divergence

\[ \frac{\partial \langle q \rangle}{\partial t} + \nabla \cdot Q = E - P \]

Shading: Moisture flux divergence

Vector: Moisture flux

Convergence  Divergence  \((10^{-6} \text{ kg m}^{-2} \text{ s}^{-1})\)
Winter precipitation

Precipitation (CMAP) and 500GPH anomalies
Relative contribution of multi-factors on mean moisture flux

\[ \frac{\partial \langle q \rangle}{\partial t} + \nabla \cdot Q = E - P \]

1) Low-frequency vs. synoptic

\[ \bar{Q} = \bar{Q}^m + \bar{Q}^{LF} + \bar{Q}^s + \bar{Q}^R \]

LF: low-frequency (>10 days)
S: synoptic (<10 days)

2) Dynamic vs Thermodyn. factor

\[ \bar{Q}^{LF} \sim < \bar{q} V^{LF} + q^{LF} \bar{V} + q^{LF} V^{LF} > \]

3) Advection vs. divergence

\[ \nabla \cdot Q^{LF} \sim (q \nabla \cdot V)^{LF} + (V \cdot \nabla q)^{LF} \]
Moisture flux divergence

Anomalous Moisture Flux Divergence

Anomalies along the west coast

EPEN: 45-60N
CPEN: 30-45N

\[ \nabla \cdot Q \]
\[ \nabla \cdot Q^{LF} \]
\[ \nabla \cdot Q^S \]
\[ (\overline{q} \nabla \cdot V)^{LF} \]
\[ q^{LF} \nabla \cdot V \]
\[ (q \nabla \cdot V)^{LF} \]
\[ (V \cdot \nabla q)^{LF} \]
Last winter: 2015/2016 DJF

Moisture flux divergence & moisture flux

SST & 500GPH anomaly
NMME hindcasts

- **ENSO prediction**
- **Moisture flux prediction**

  - Daily data: \( u, v, T_s, q, \) \( ps \) (1000~300hPa)
  - DJF mean
  - CFSv2: 1982-2010 12 members (IC: 10/28~11/07)
  - CanCM3: 1981-2009 10 members (IC: Nov-01)
  - CanCM4: 1981-2009 10 members (IC: Nov-01)
  - CCSM4: 1982-2012 10 members (IC: Nov01)

\[
Q = \frac{1}{g} \int_{P_s}^{300} \mathbf{V} \cdot q \, dp
\]
ENSO prediction

OBS  CFSv2  CCSM4  CanCM3  CanCM4

(a) EPEN ERA–I  (a) EPEN CFSv2  (a) EPEN CCSM4  (a) EPEN CanCM3  (a) EPEN CanCM4

(b) CPEN ERA–I  (b) CPEN CFSv2  (b) CPEN CCSM4  (b) CPEN CanCM3  (b) CPEN CanCM4

(c) NINA ERA–I  (c) NINA CFSv2  (c) NINA CCSM4  (c) NINA CanCM3  (c) NINA CanCM4

* Contour interval: 20 m
* CanCM3 and CanCM4: Surface temperature
DJF Moisture Flux (IC: Nov)

ERAI  CFSv2  CCSM4  CanCM4

CLIM

EPEN

NINA
Prediction skill: DJF Moisture Flux

- CFSv2
- CCSM4
- CanCM4
- CanCM3
Summary

• The year-to-year changes in cool season atmospheric rivers (ARs) and moisture transport over the northeast Pacific and western North America are associated with ENSO variability.

• In CP El Nino winters, the Aleutian low shifts further southward relative to its position in EPEN, resulting an increase in the frequency and intensity of landfalling ARs over the southwestern US.

• Utilizing the moisture budget equation, the change in low-frequency mass convergence by circulation is the main reason for the anomalous moisture transport in different ENSO phases.

• While the prediction skill is still low over the Northeast Pacific, the NMME hindcasts simulate the ENSO-moisture flux relationship, thus have potential to predict the seasonal moisture flux and AR activity.

Thank you

Questions/comments: hyemi.kim@stonybrook.edu