The East Asian winter monsoon

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Outline

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1. Introduction
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2. Decadal timescale

- Weakening of EAWM in the late 1980s
- Although the global mean temperature keeps rising, frequent strong cold spells were observed in recent years, such as in:
  - 2004/05 (Lu & Chang 2009)
  - 2005/06 (Park et al. 2008)
  - 2007/08 (Zhou et al. 2009)
  - 2009/10 (Wang & Chen 2010)
  - 2011/12 (TCC 2012)
  - 2015/16 (Cheung et al. 2016, Song & Wu 2017)

Number of cold days over EA

![Graph showing number of cold days over East Asia](image)

Luo X & Wang B (2017)
2. Decadal timescale

- Weakening of EAWM in the late 1980s
- Although the global mean temperature keeps rising, more strong cold spells were observed in recent years, such as in
- EAWM re-amplified after early 2000s

Wang L & Chen W (2014b), Huang RH et al. (2014)
Ding YH et al. (2014, 2015), Xiao X et al. (2016)
Direct cause: changes of Ural blocking

- Formation of the AC due to changes of Ural blocking
  - Frequency increases significantly
  - Persistence increases due to weakened westerly winds
- Enhanced cold advection to the east of the AC leads to cooling

Likely driver: reduced Arctic sea ice (ASI)

- Response to ASI in AGCM resembles observed pattern
- Magnitude of response in AGCM is only 25% of observation, implying large uncertainty to attribute the observed decadal change of EAWM to ASI alone.

Mori M et al. (2014), Luo D et al. (2016)
2. Interannual timescale

- SST is an important driver for EAWM variability
- Besides ENSO, SST in other regions can influence EAWM

✓ Warm SST south of Gulf Stream $\rightarrow$ intensified $\partial$SST/$\partial$y
  $\rightarrow$ enhanced baroclinicity $\rightarrow$ enhanced TE $\rightarrow$ AC response
  $\rightarrow$ EU-like wave train $\rightarrow$ deep EA trough $\rightarrow$ cold advection $\rightarrow$ cold EA

Liu YY et al. (2014)
Cold Indian Ocean SST favors strong EAWM via two ways

- → more rain over MC → Rossby wave train along EA coast → deep EA trough → cold advection → cold EA

Cold Indian Ocean SST favors strong EAWM via two ways

- More rain over MC → Rossby wave train along EA coast → deep EA trough → cold advection → cold EA
- Less rain over IO → descending motion → upper level div. over Mediterranean → AC RWS → mid-latitude wave train → deep EA trough → cold advection → cold EA

\[ S = -\nabla \cdot \mathbf{v} - \nabla \cdot \mathbf{v}' + \nabla \cdot \nabla \mathbf{v} - \mathbf{v} \cdot \nabla \mathbf{v}' - \frac{1}{2} \nabla \cdot \nabla \mathbf{v} \]

Divergence → AC RWS

In addition to dynamical processes, the feedback btw. circulation and radiation are also important.

- Through the climate feedback-response analysis method (CFRAM, Lu & Cai 2009, Cai & Lu 2009), the changes of temperature can be separated into those resulting from individual feedback processes.

Li & Yang (2017)
In addition to dynamical processes, the feedback between circulation and radiation are also important.

Dynamical process
- Cold advection $\rightarrow$ cooling

Radiation-related feedback
- Dry air $\rightarrow$ small q $\rightarrow$ weak greenhouse effect $\rightarrow$ cold ground
- Dry air $\rightarrow$ less cloud $\rightarrow$ more outgoing long wave $\rightarrow$ cold ground
- Cold ground $\rightarrow$ sensible HF $\rightarrow$ cooling

Li & Yang (2017)
3. Intra-seasonal timescale

3.1 Subseasonal features of the temperature variation

Winter mean may obscure subseasonal features of the EAWM 2001/02: Cold in early winter, warm in late winter

Wei W et al. (2014)
3. Intra-seasonal timescale

3.1 Subseasonal features of the temperature variation

Winter mean may obscure subseasonal features of the EAWM 2015/16: Warm in Dec & Feb, cold in Jan

Cheung H et al. (2016), Song L & Wu R (2017)
Two types of temperature evolution in winter

**ND**

**SAT**

**JFM**

**SEOF1**: in-phase evolution from E to L winter

**SEOF2**: out-of-phase evolution from E to L winter

Wei W et al. (2014)
Evolution of AC/C anomaly over Ural region is the key

ND  500hPa Z  JFM

SEOF1: in-phase evolution from E to L winter

SEOF2: out-of-phase evolution from E to L winter

Wei W et al. (2014)
3.2 Intraseasonal variations of temperature
SAT anomalies show clear propagating & intensifying feature

EOF1 of SAT

EOF2 of SAT

Lag c.c. btw. PC1&2

Yang S & Li T (2016), Yao S et al. (2016)
SAT signal arises from a low-freq wave train originating from the Atlantic

- When the wave train reaches EA, it intensifies significantly and shows strong upward propagation
- Due to strong interaction btw. upper-level & surface

Vertical profile along wave train

Song L et al. (2016)
• Upper-level AC increases lower-level coldness by advecting cold air southward → amplify surface cold over E. Asia
• Lower-level cold anomaly acts as AC PV anomaly → advect low PV air into AC at upper level → intensifies upper-level AC.
• Interactions btw. upper-level RW and surface coldness tend to intensify each other, resulting in enhanced northward eddy heat flux (v’T’, i.e., upward propagating wave)
5. Summary

- Decadal timescale
  - EAWM becomes strong again after 2000s
  - Ural blocking & Arctic sea ice

- Interannual timescale
  - SST over Indian Ocean & Atlantic
  - Dynamical & radiation-related processes contribute

- Intra-seasonal timescale
  - SAT evolves with clear subseasonal difference
  - Propagation of SAT anom. due to upstream wave train

- Common: Ural blocking & upstream wave train
Open issues

• Understanding the EAWM variability from multi-timescale interaction
• How will the EAWM behave in the future & the possible influences of ASI and the mechanism
• Influences of EAWM on air quality and the possible circulation-radiation feedback
• ......