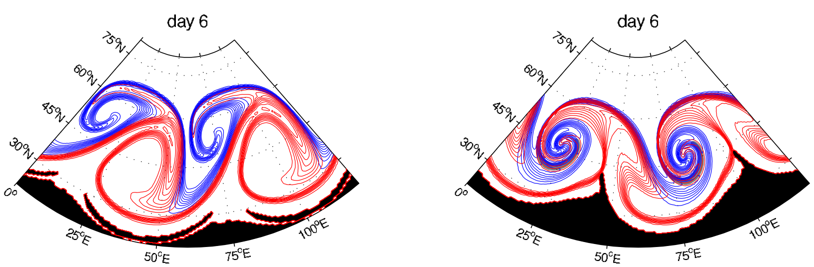
Rossby wave-breaking and moisture transport into the Arctic

Elizabeth A. Barnes & **Chengji Liu**
Colorado State University

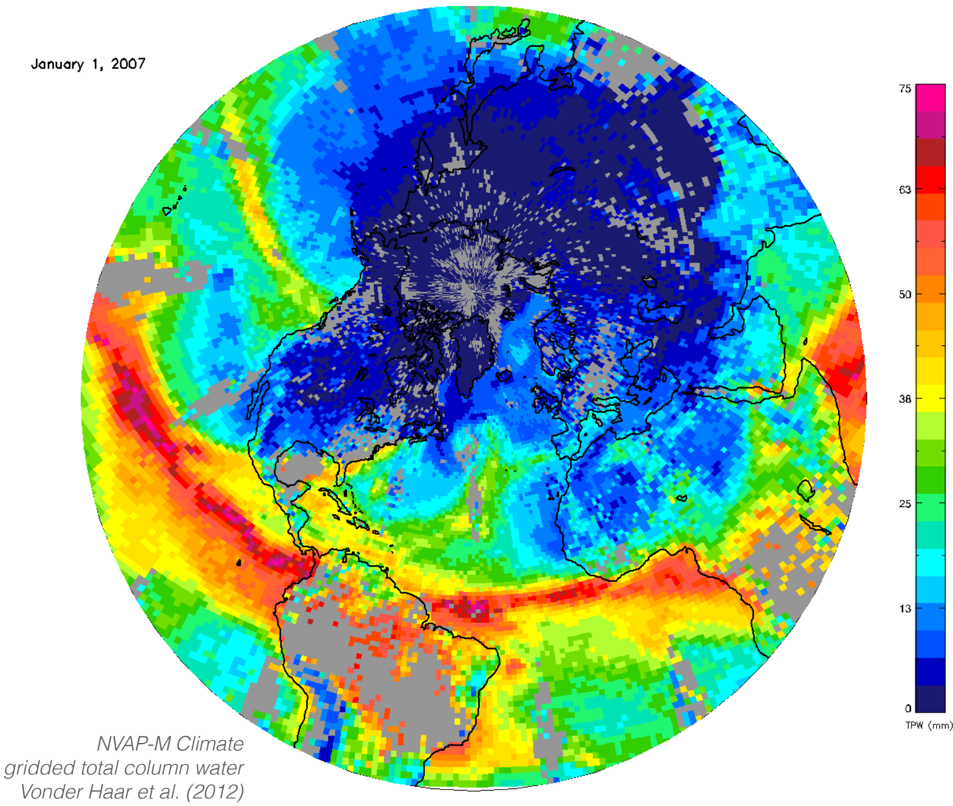


Anticyclonic
Rossby wave breaking

Cyclonic
Rossby wave breaking

boundary layer tracer
stratospheric tracer

Polvani & Esler (2007)



NVAP-M Climate
gridded total column water
Vonder Haar et al. (2012)

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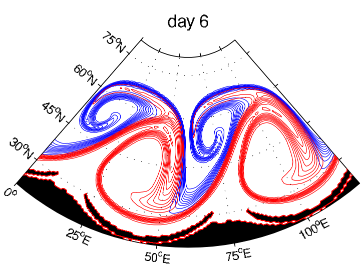

Anticyclonic
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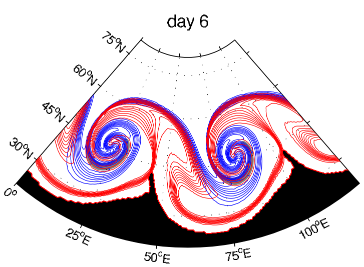

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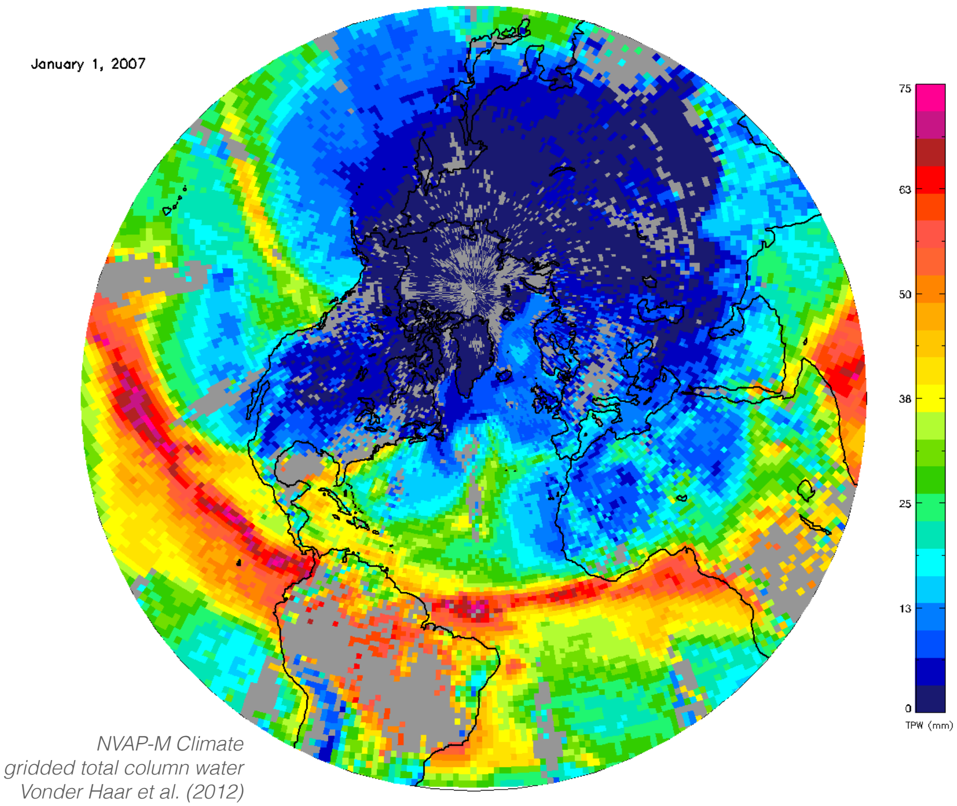

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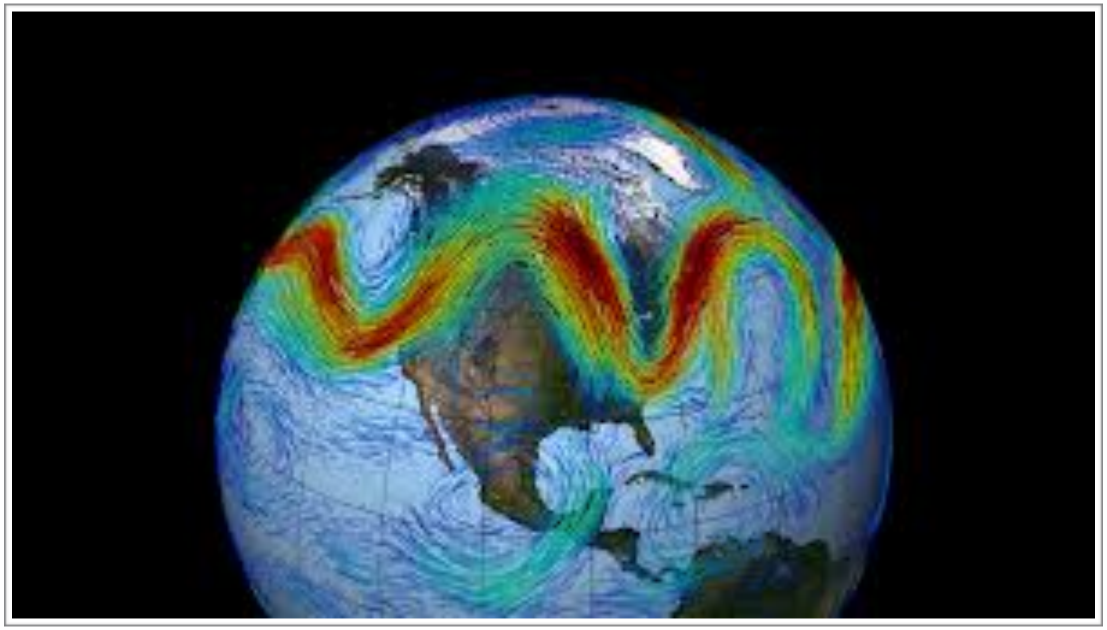
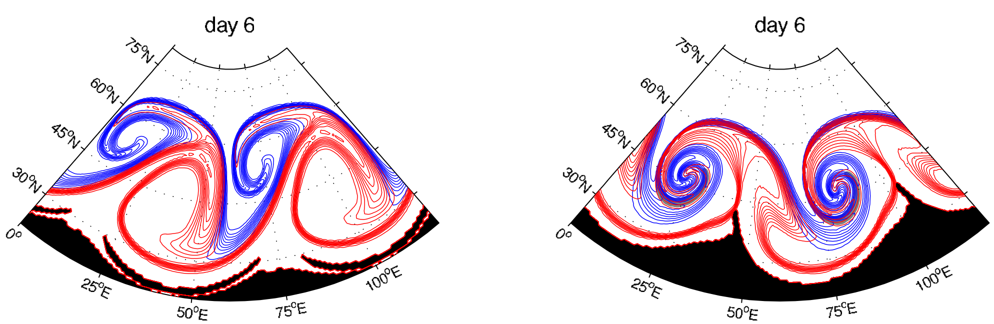
Rossby waves: undulations in the jet-streams



The Polar Jet Stream
NASA Scientific Visualization Studio



Anticyclonic
Rossby wave breaking

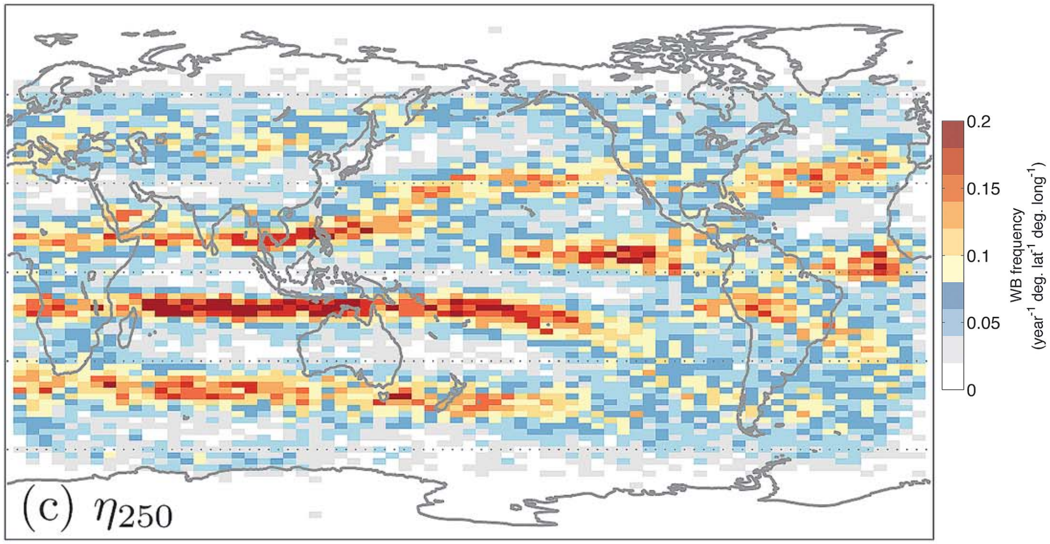
Cyclonic
Rossby wave breaking

boundary layer tracer
stratospheric tracer

Polvani & Esler (2007)

- midlatitude Rossby waves often propagate on the jet-streams
- they often overturn, or “break”
  - clockwise = anticyclonic wave breaking
  - counter-clockwise = cyclonic wave breaking
- wave breaking is important for momentum fluxes and maintaining the jet-stream
- it may also play a role in transport

RWB occurs on the flanks of the jets

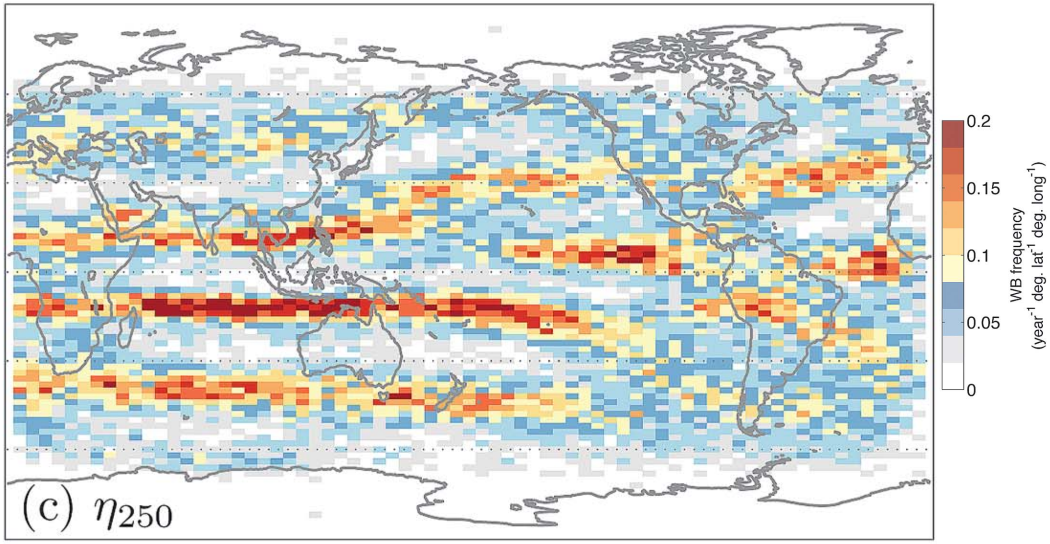


- the momentum fluxes due to RWB largely maintain the midlatitude jet stream
- the jet-stream also modifies the RWB frequencies through its vorticity gradient, speed and position

RWB and the jet-streams form a tightly coupled system

Barnes & Hartmann (2012)

RWB occurs on the flanks of the jets



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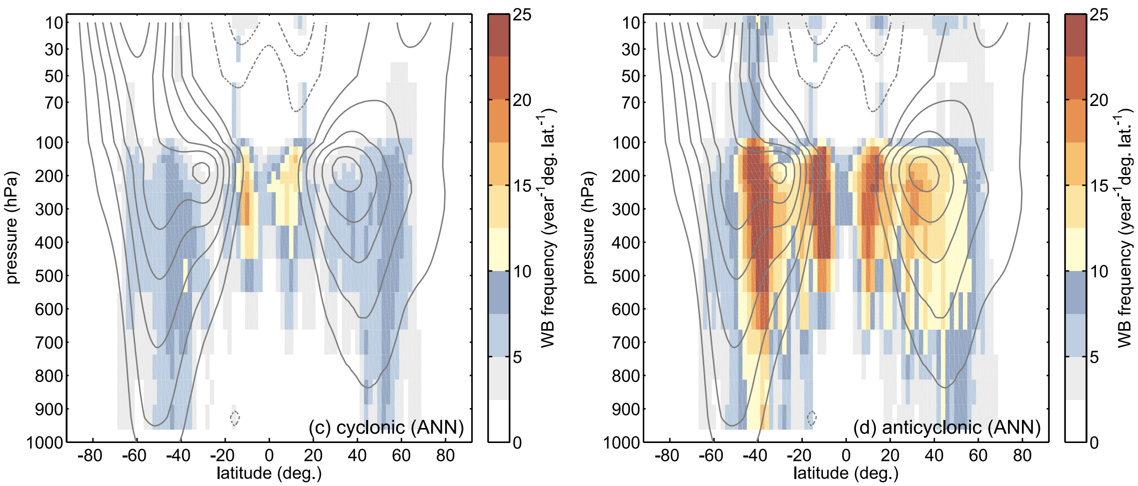
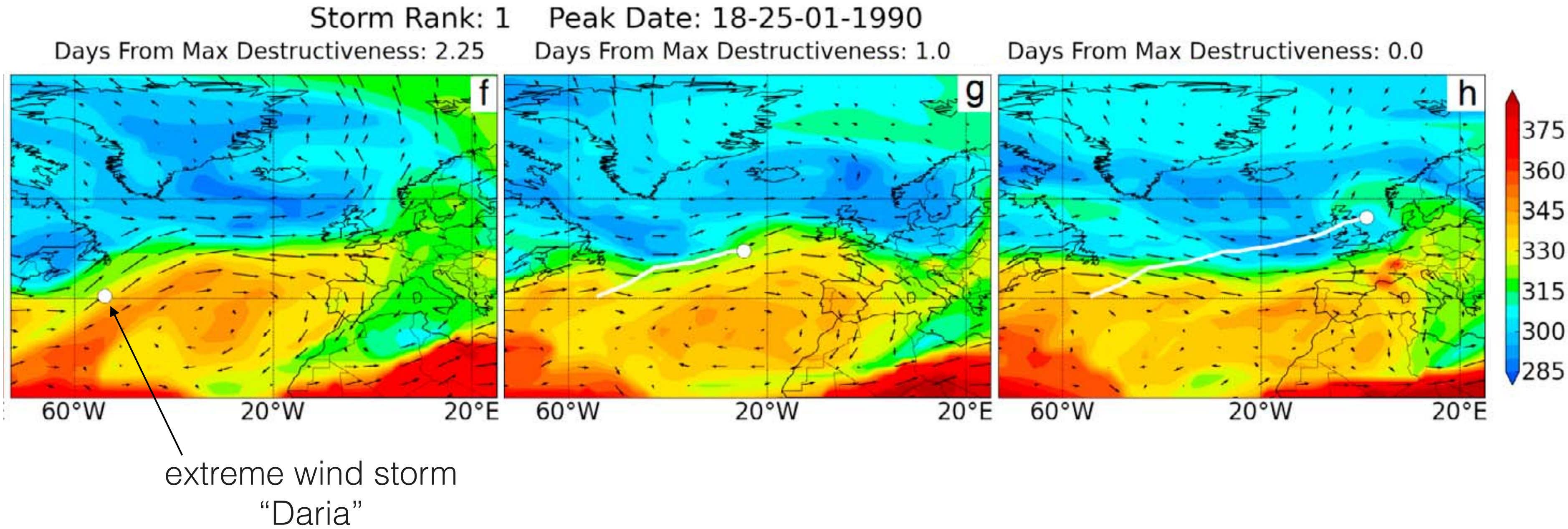


RWB and the jet-streams form a tightly coupled system

Barnes & Hartmann (2012)

RWB and actual weather: *wind storms*

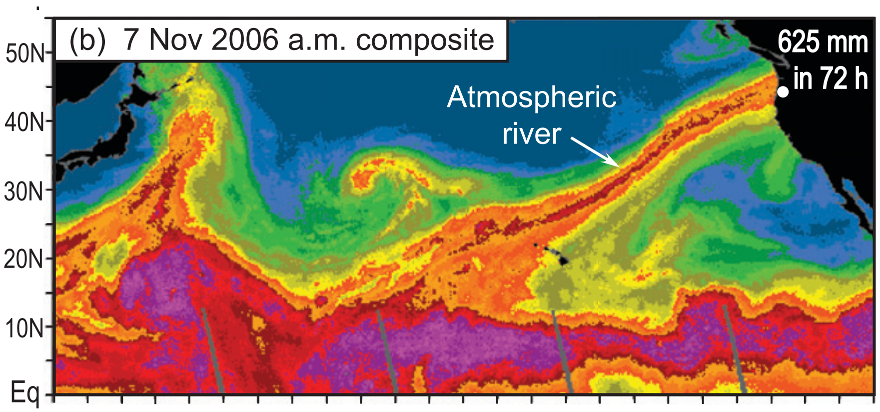


- evolution of extreme wind-storms over Europe linked to RWB that occur during +NAO events

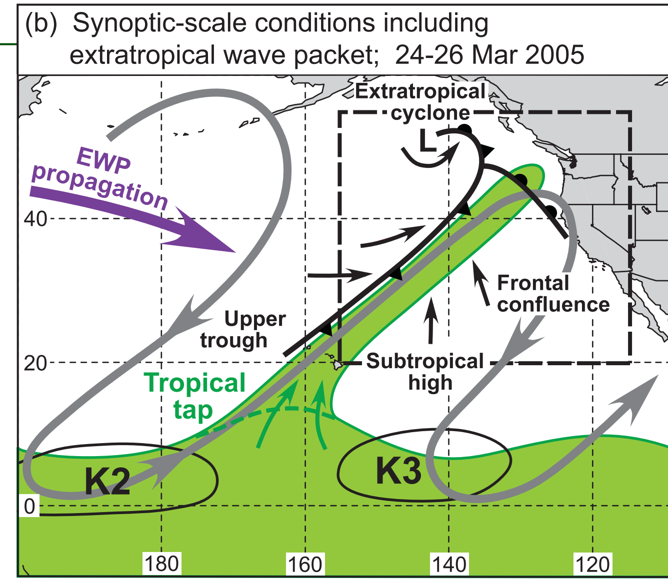
- the most intense storms are associated with the simultaneous occurrence of both cyclonic and anticyclonic flavors

Hanley & Cabellero (2012)

Atmospheric rivers and RWB



Ralph et al. (2011)

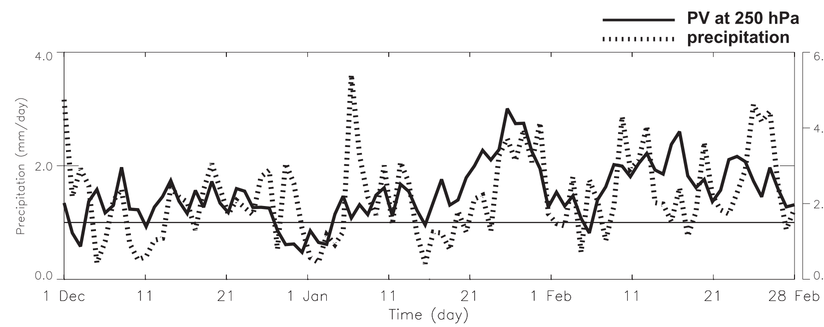


- Atmospheric rivers bring intense precipitation to the west coast of the U.S.

- Many previous studies have suggested a role for the large-scale circulation in this transport

Impact of Rossby Wave Breaking on U.S. West Coast Winter Precipitation during ENSO Events

Ju-Mee Ryoo,* Yohai Kaspi,+ Darryn W. Waugh,# George N. Kiladis,@ Duane E. Waliser,& Eric J. Fetzer,** and Jinwon Kim++

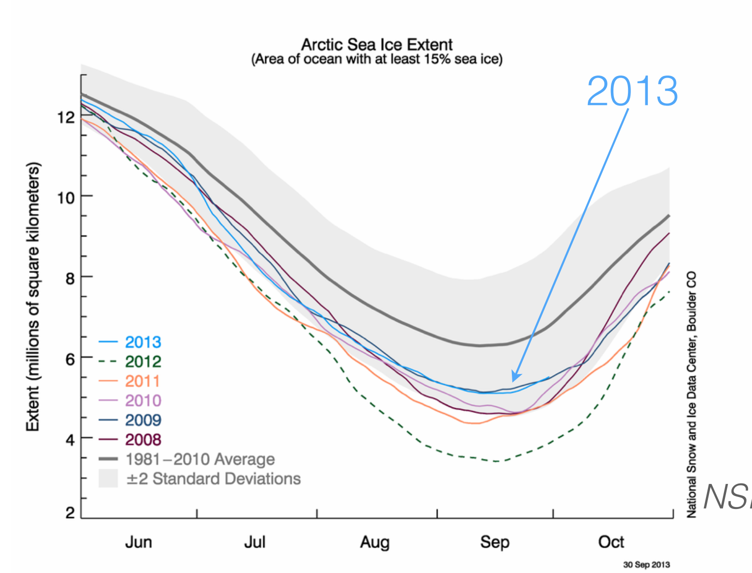


composite on 4 La Nina years
correlation = 0.7

Ryoo et al. (2013)

Why do we care about water vapor in the Arctic?

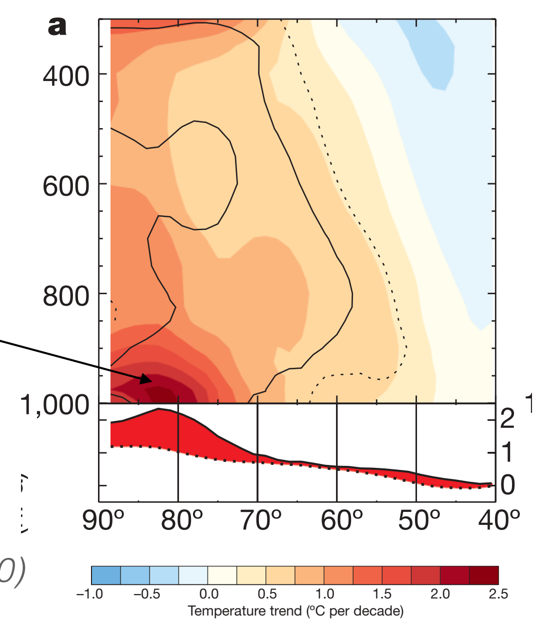
- Arctic is warming rapidly compared to the rest of the globe ("Arctic amplification")
- surface energy budget of the Arctic is key in determining its temperature
- water vapor plays a critical role in the surface energy balance



NSIDC

Temperature trends (1989-2008)

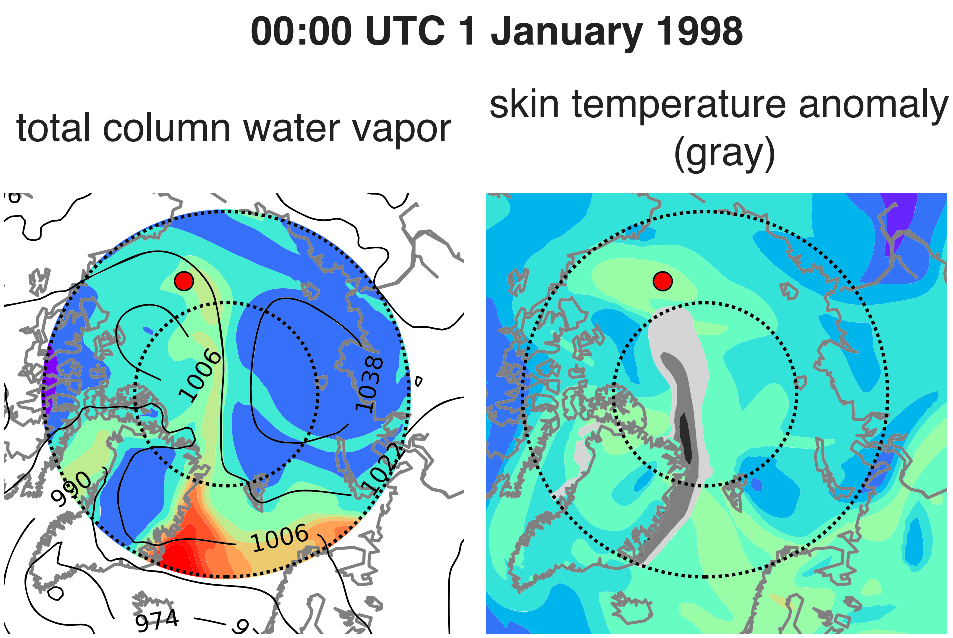
Arctic is warming faster



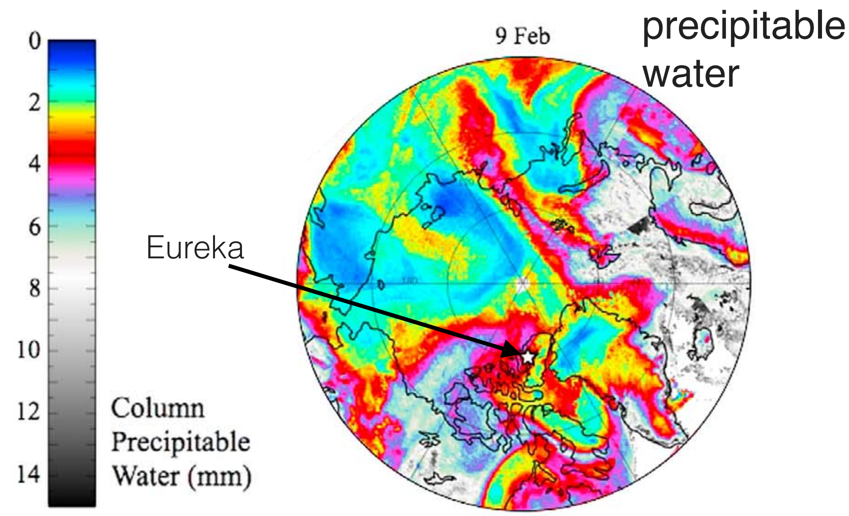
Screen & Simmonds (2010)

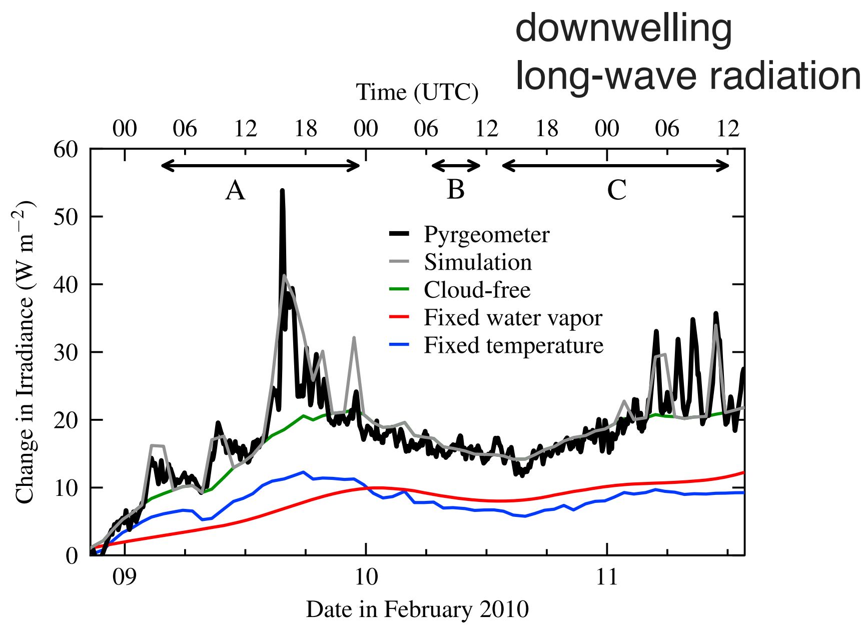
Intense moisture intrusions can change LW fluxes

- Intense, filamentary moisture intrusions into the Arctic can modulate the long-wave radiation reaching the surface



Woods et al. (2013) adapted from Figure 1





Doyle et al. (2011)

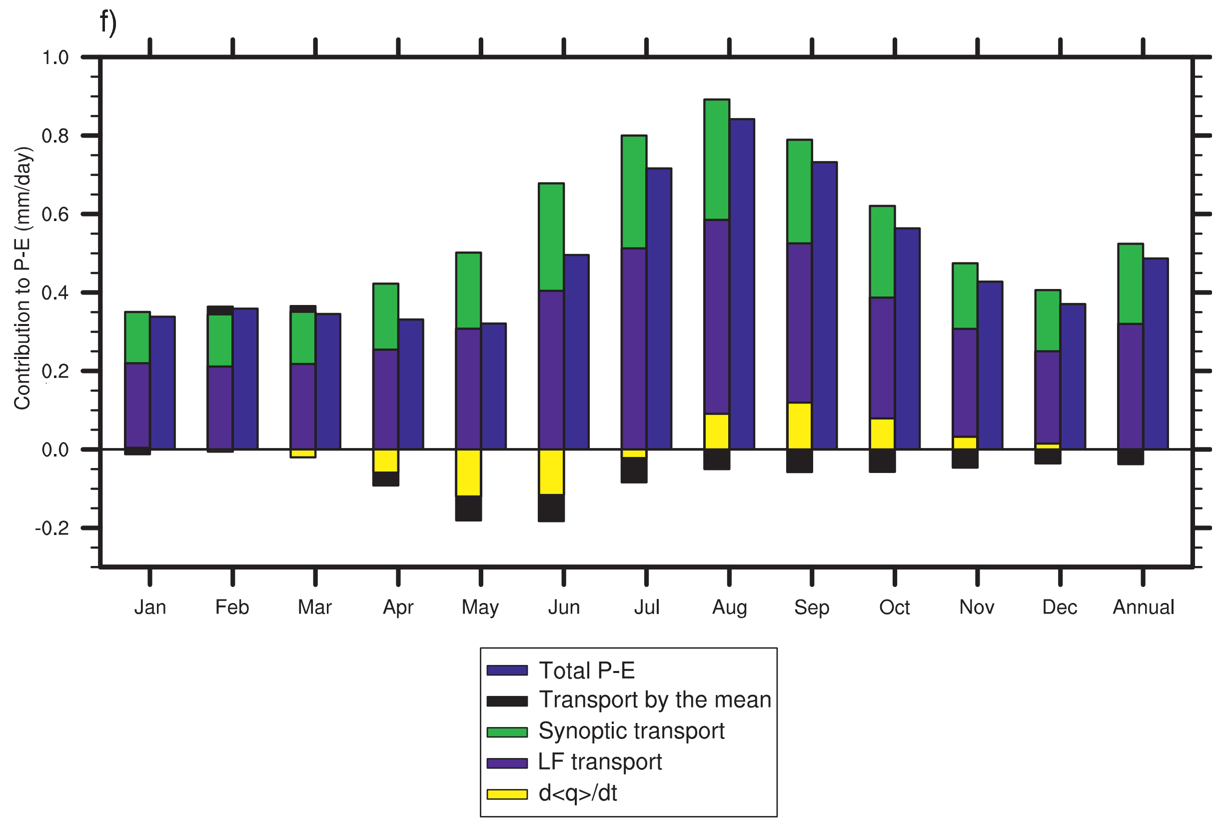
Moisture transport into the Arctic

- Total moisture transport into the Arctic:
  - largest in summer
  - smallest in winter

- Synoptic + Low-Frequency provides almost all of the transport (transients)

- Synoptic transport is an important component of the total transport into the Arctic

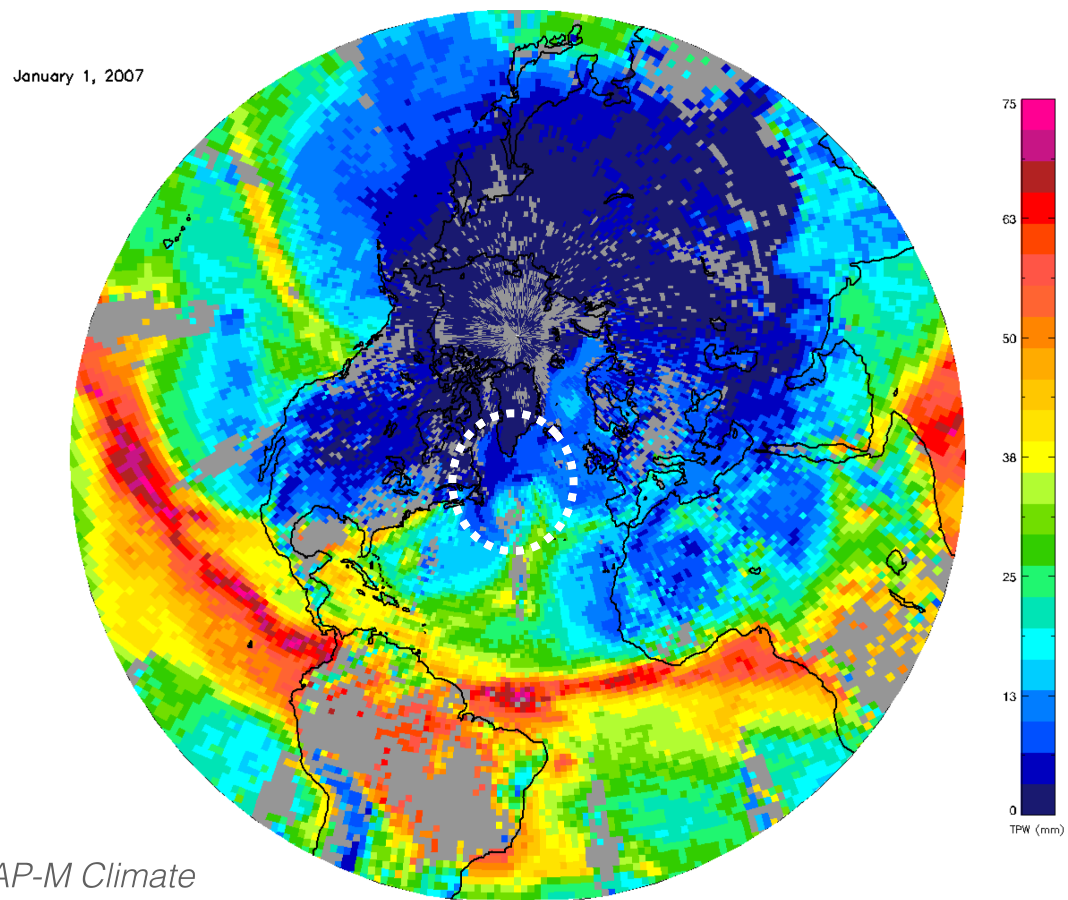
Moisture transport into Arctic (>70N)



Newman et al. (2012)

Moisture transport occurs in bursts

- high-latitude moisture transport often occurs as high-intensity plumes
- 6-hourly transport has a very large tail (skewed toward positive extremes)



NVAP-M Climate gridded total column water Vonder Haar et al. (2012)

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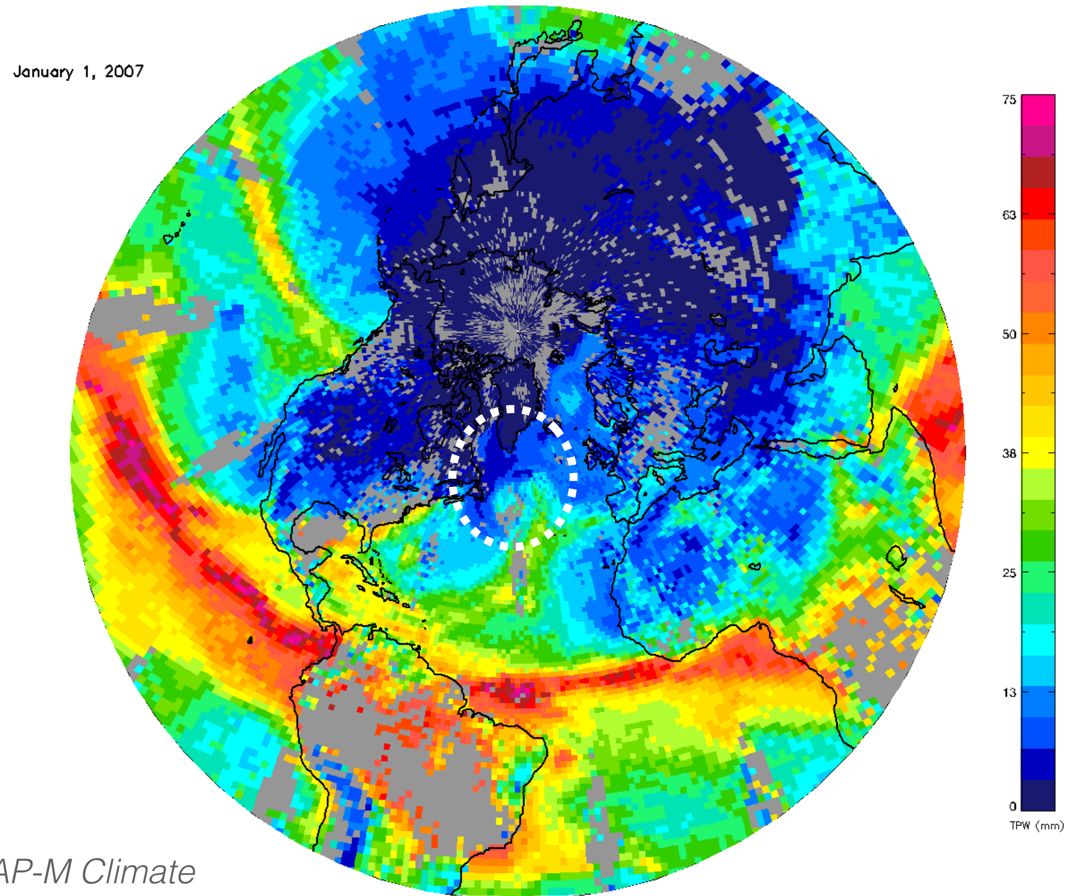

NVAP-M Climate
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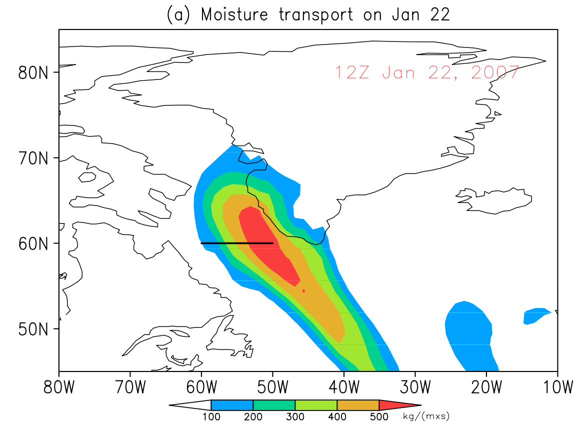
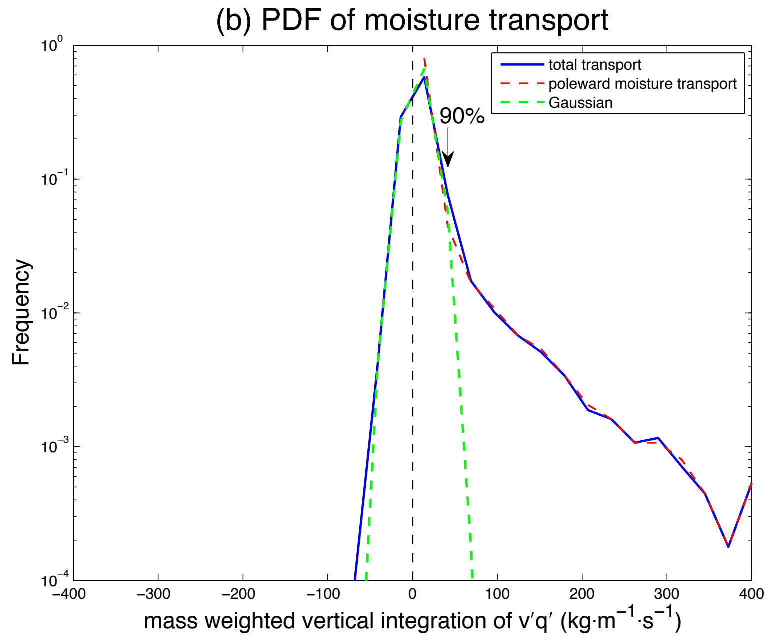
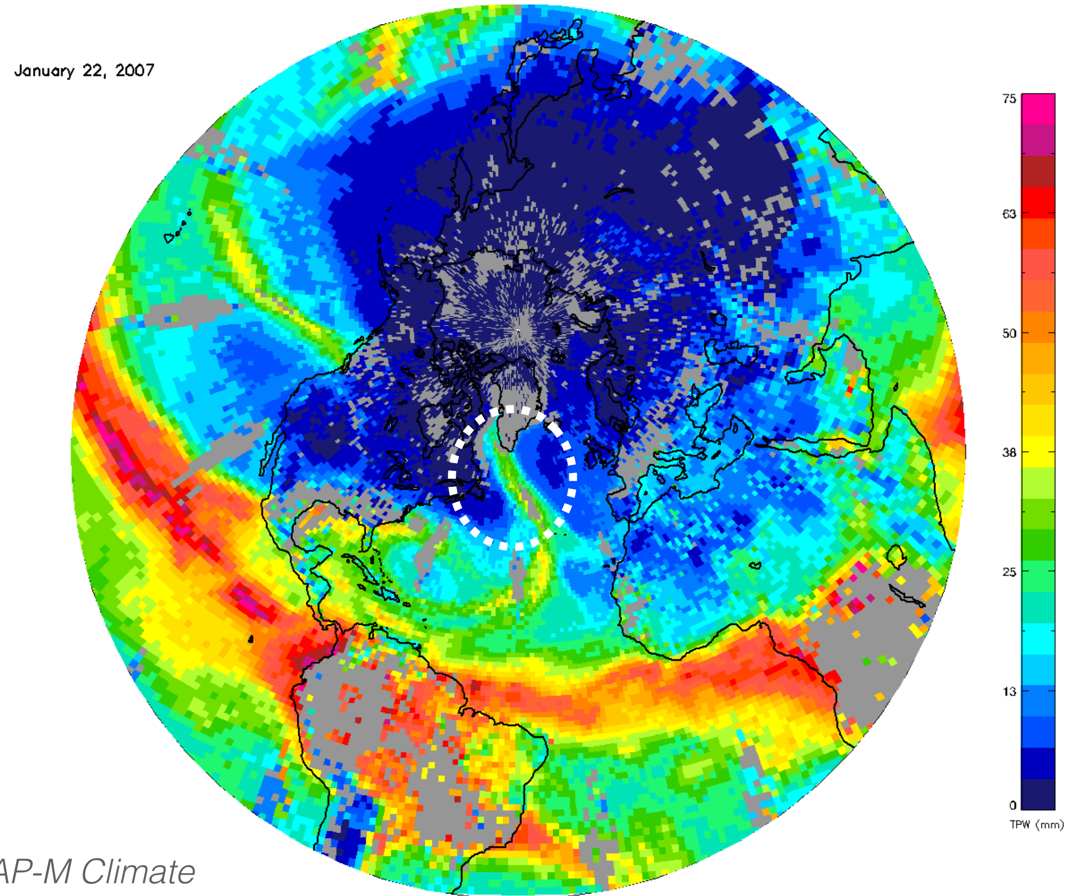
Liu & Barnes (in prep)







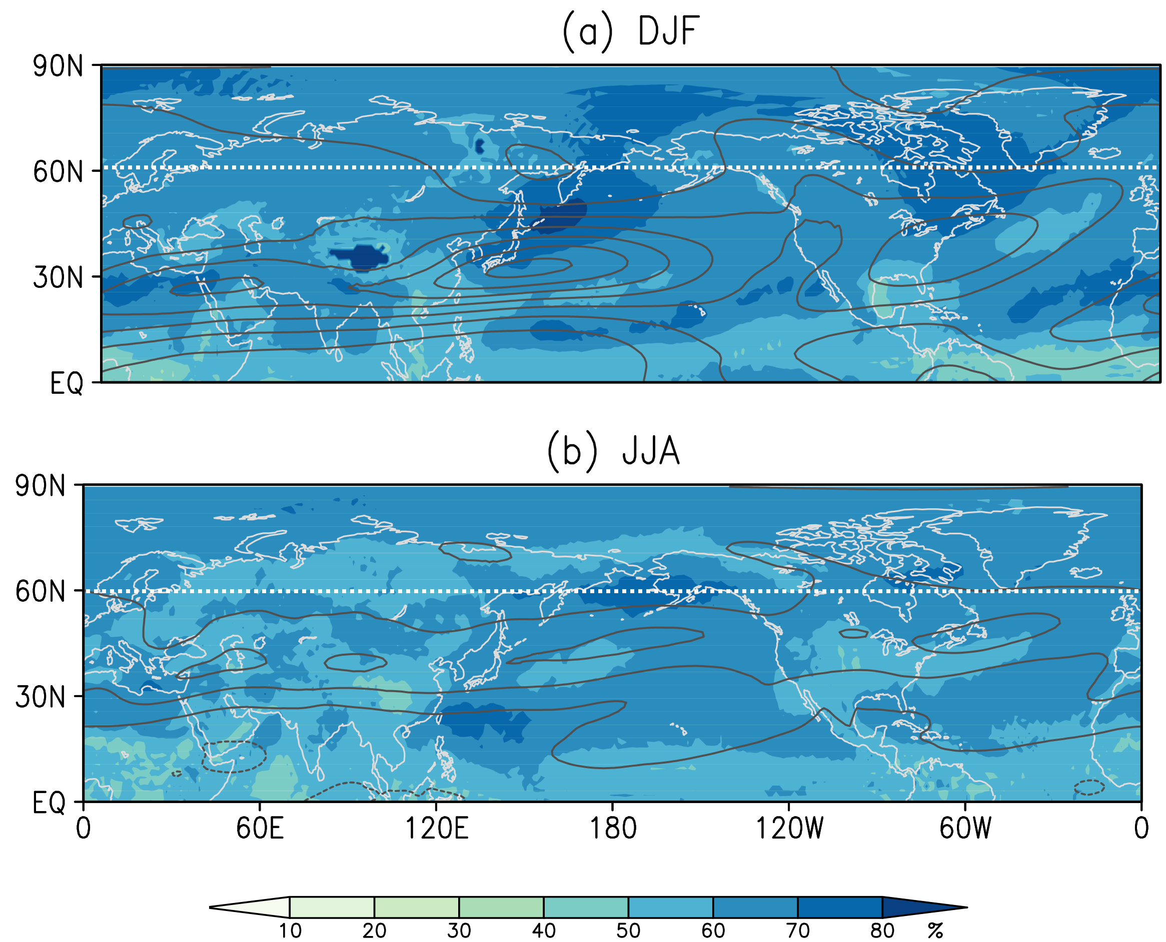
NVAP-M Climate gridded total column water Vonder Haar et al. (2012)

similar conclusions reached by others e.g. Woods & Caballero (2013), Doyle et al. (2011)

Extreme transport is important in total budget

- Extreme transport accounts for more than 60% of total transient poleward moisture transport (v'q')
- Across 60N, extremes account for…
  - 69% in winter
  - 66% in summer

Extreme moisture transport
(90th %tile of fluxes)



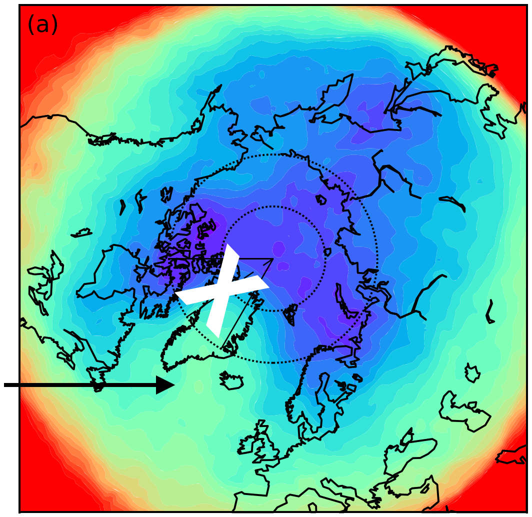
Liu & Barnes (in prep)

What does the circulation look like during these events?

Large-scale circulation associated with moisture intrusions into the Arctic during winter

Cian Woods,[1] Rodrigo Caballero,[1] and Gunilla Svensson[1]

Potential temperature on 2PVU



blocking structure

composite at time of maximum moisture fluxes through Labrador Sea

Woods et al. (2013)

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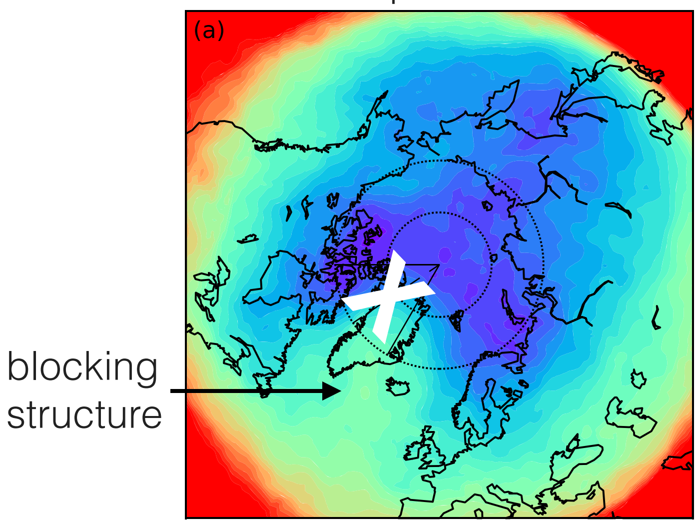
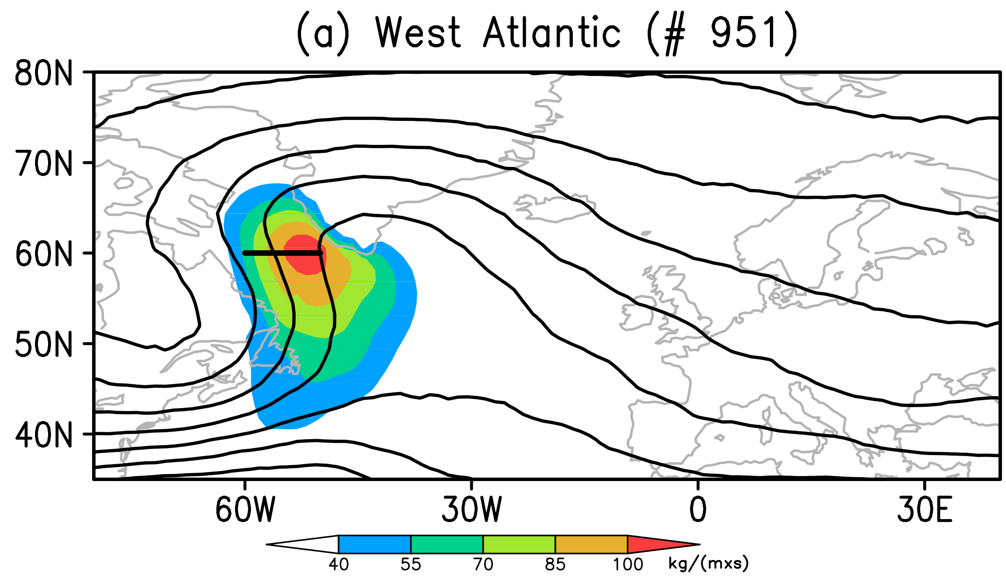


composite at time of maximum moisture fluxes through Labrador Sea

Moisture transport (Shading)
Potential Temperature (Contour)



composite on 90th %tile fluxes across the Labrador Sea

Cyclonic wave breaking!

Woods et al. (2013)

Liu & Barnes (in prep)

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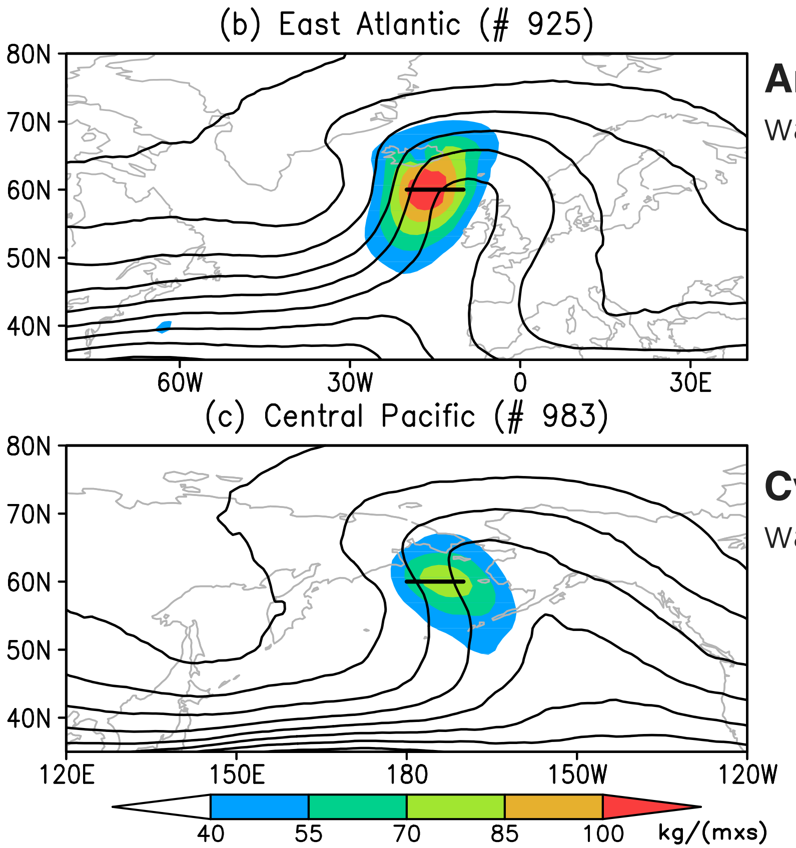
Composites of potential temperature on 2PVU
during extreme poleward moisture transport events



Anticyclonic
wave breaking

Cyclonic
wave breaking

Liu & Barnes (in prep)

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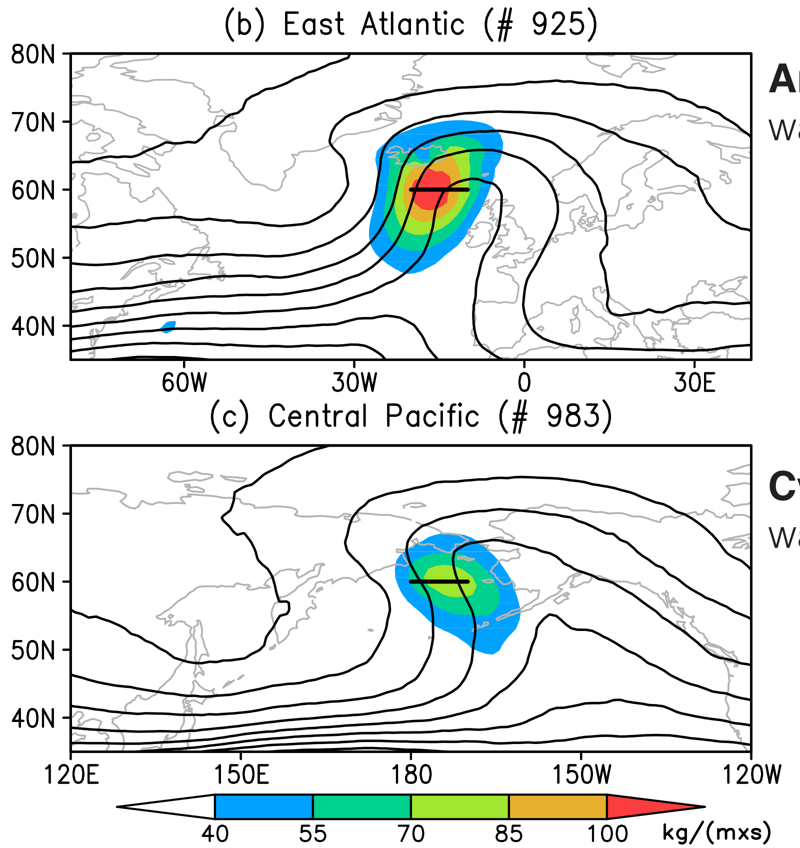


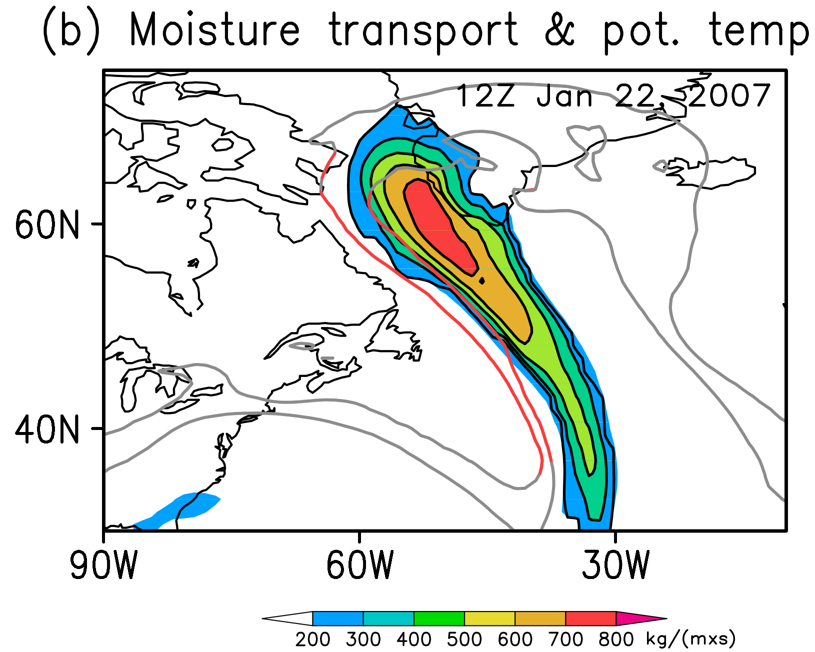
Anticyclonic wave breaking

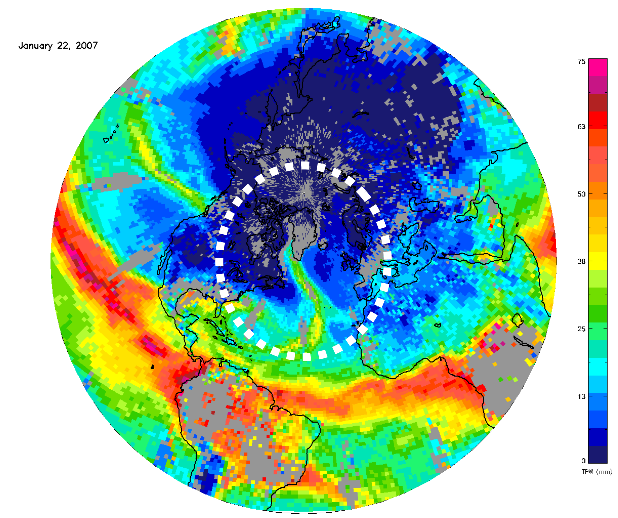
Cyclonic wave breaking

The goal of this work is to quantify the contribution of RWB to moisture transport into the polar cap.

Liu & Barnes (in prep)

Our approach





Liu & Barnes (in prep)

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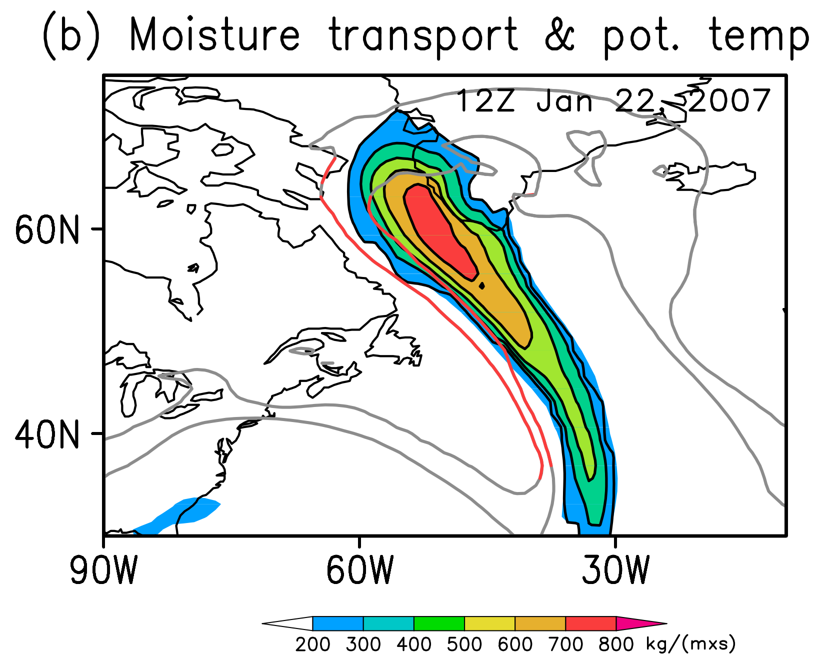
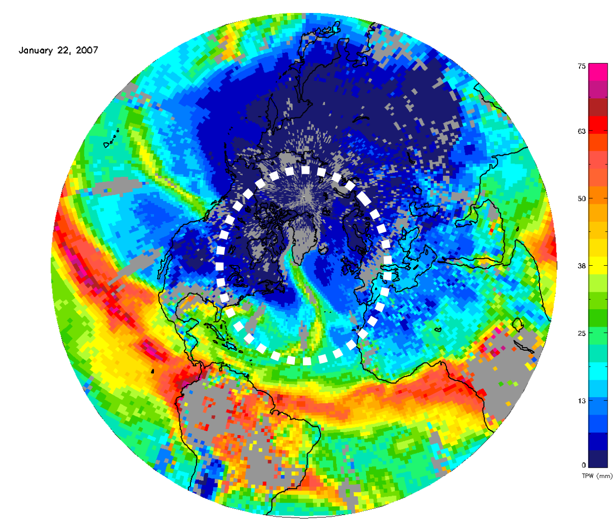
1. identify RWB by searching for overturning of potential temperature on the 2PVU surface Liu et al. (2014)





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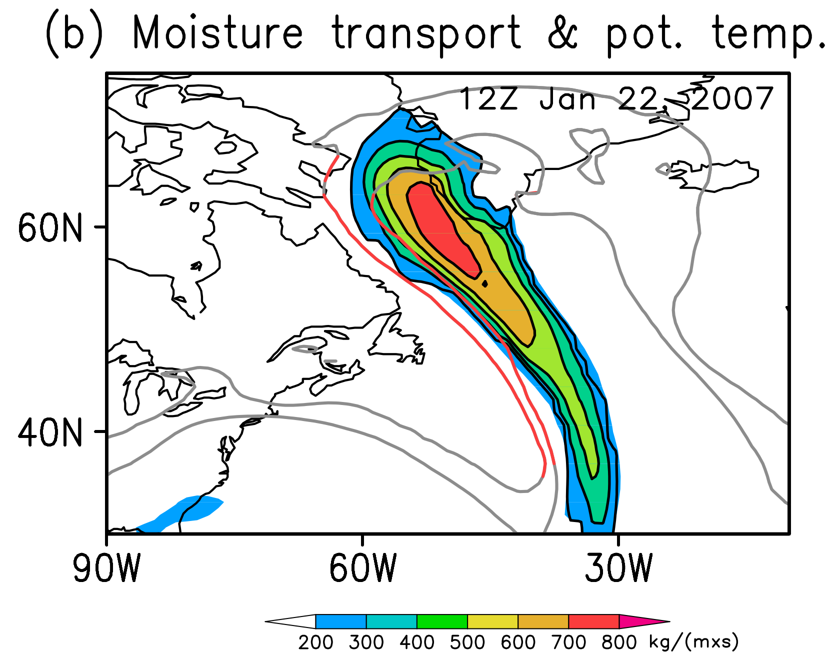

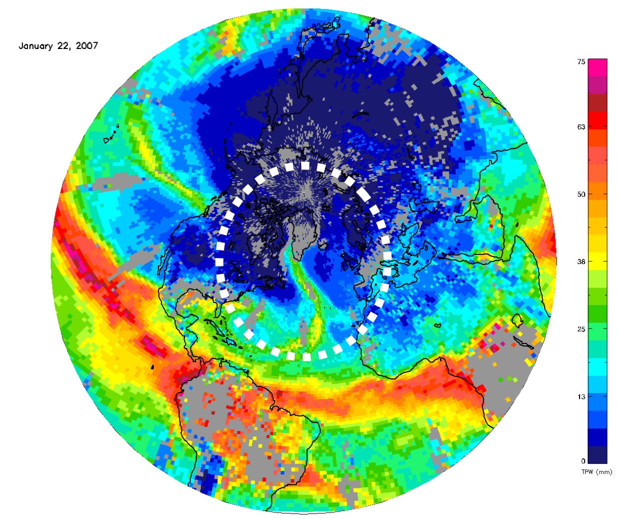

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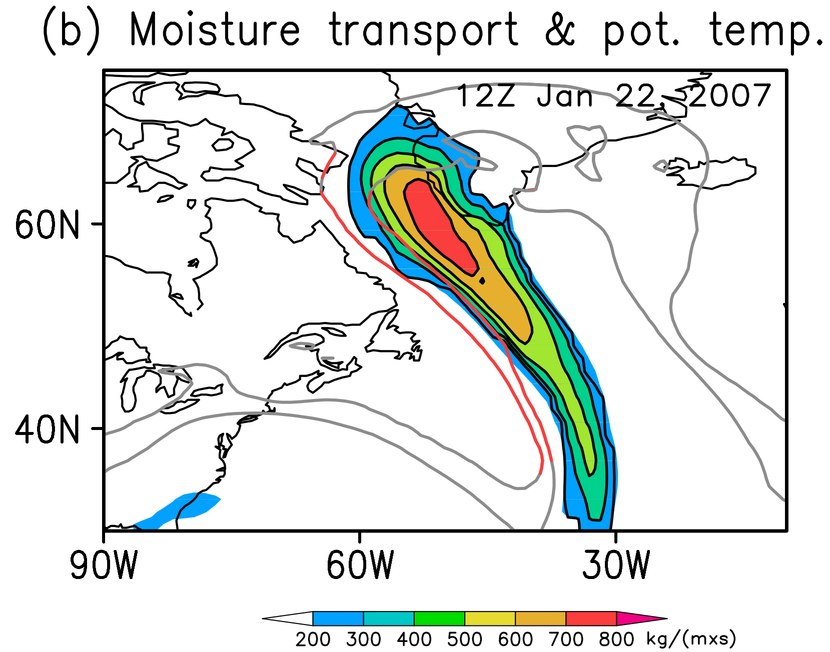

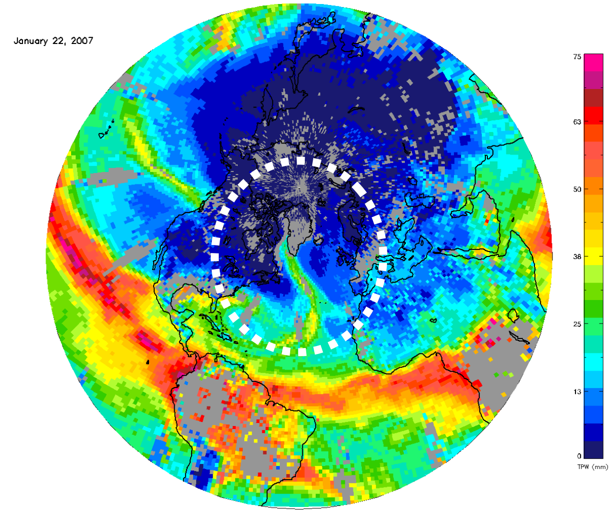

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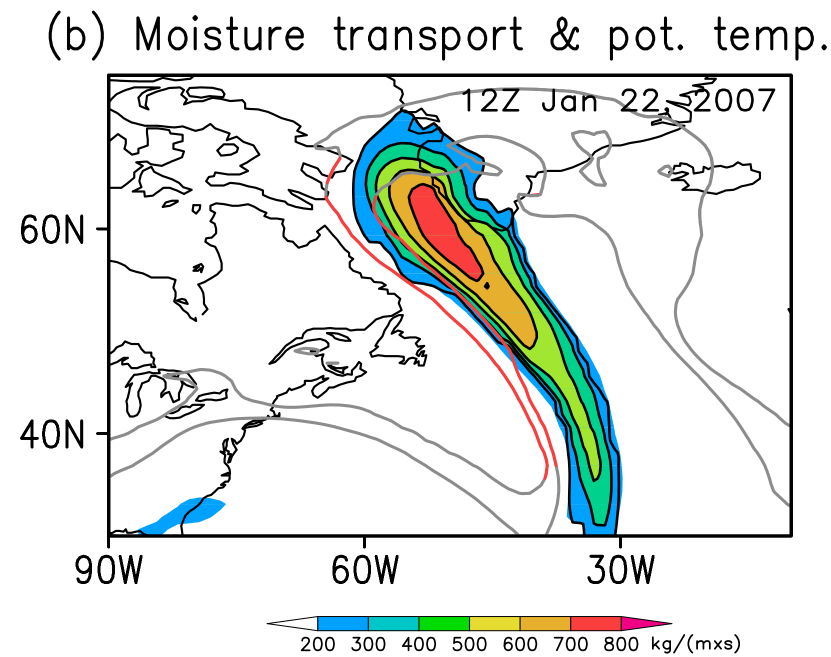

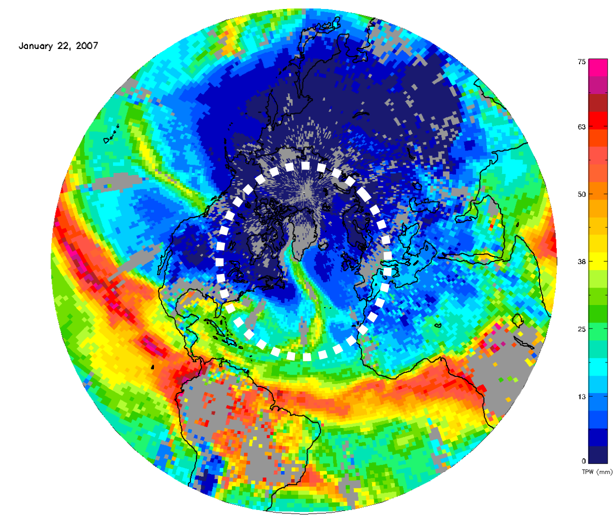

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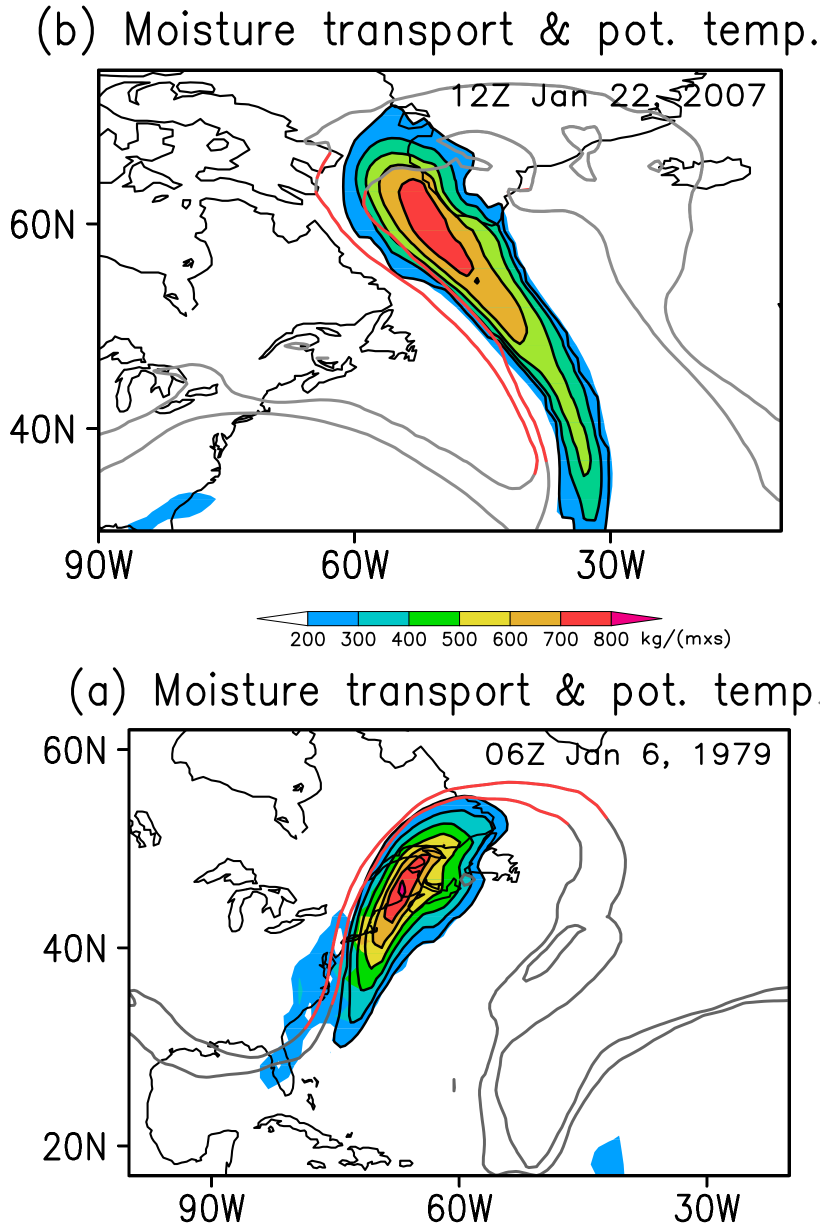
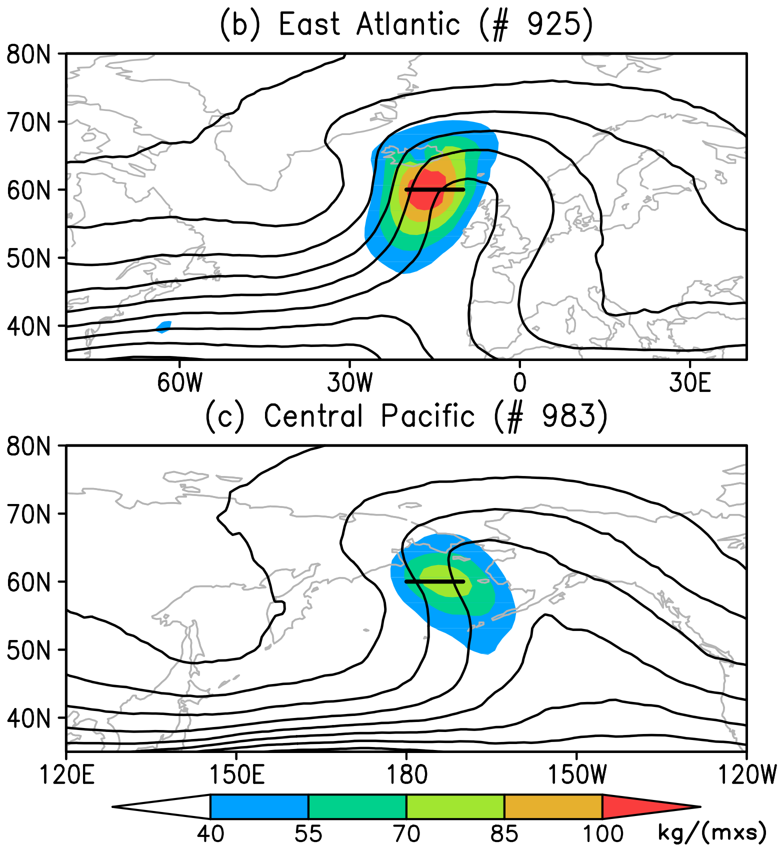


Liu & Barnes (in prep)

Sanity check

Composites of potential temperature on 2PVU
during poleward moisture transport events



Anticyclonic
wave breaking

Cyclonic
wave breaking

Liu & Barnes (in prep)

Sanity check

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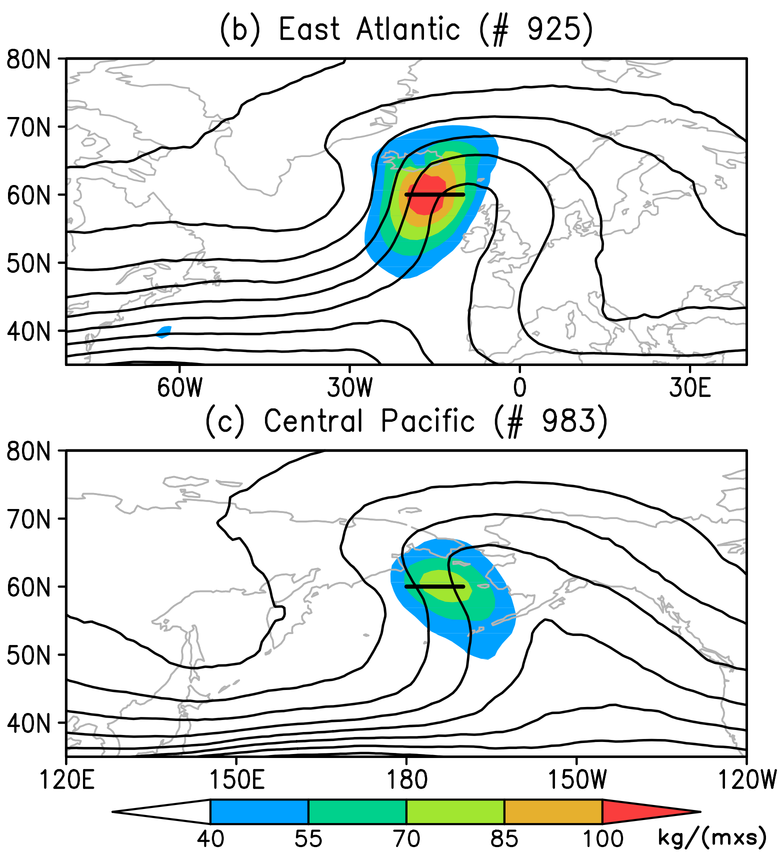
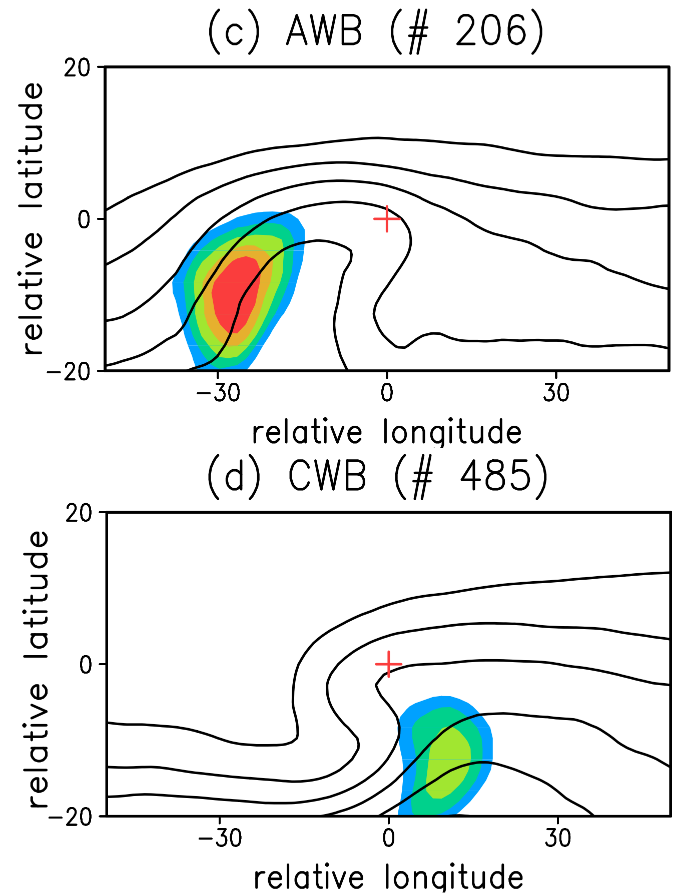


Anticyclonic wave breaking

Cyclonic wave breaking

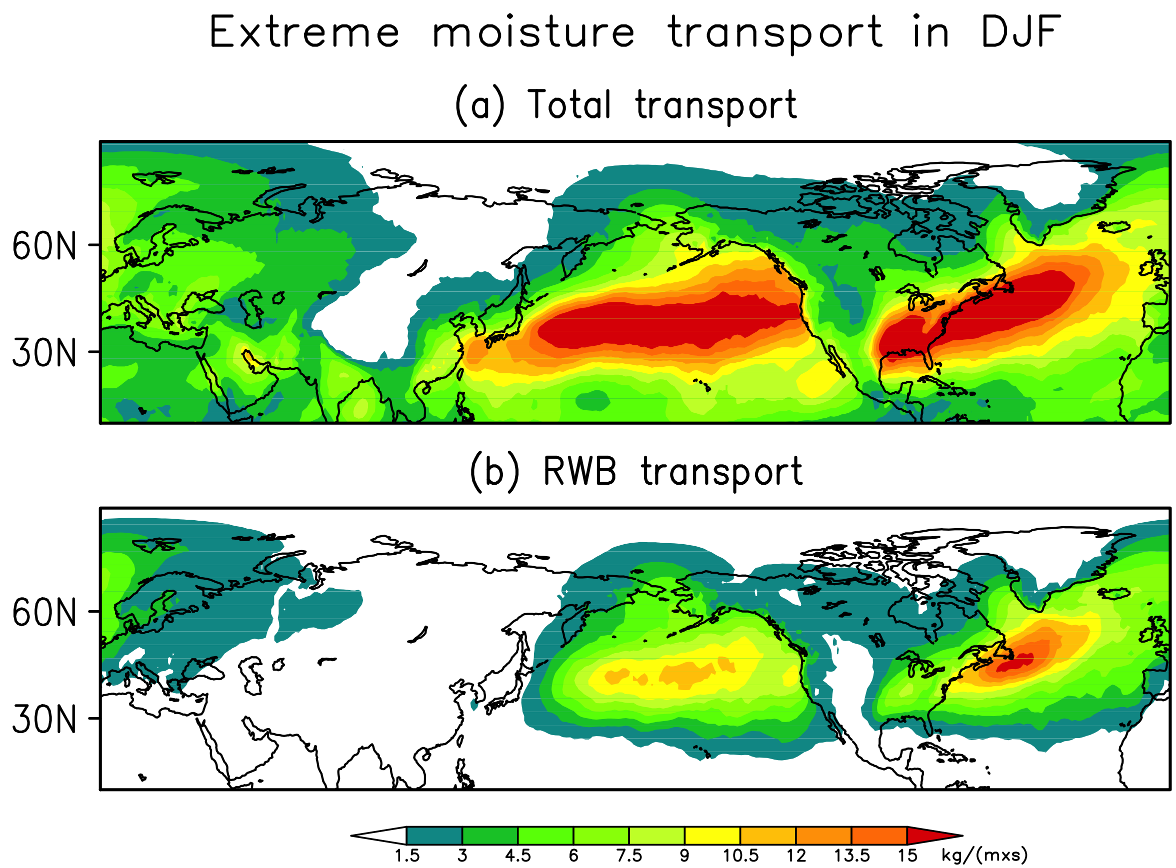
Composites of poleward moisture transport on wave breaking events



Liu & Barnes (in prep)

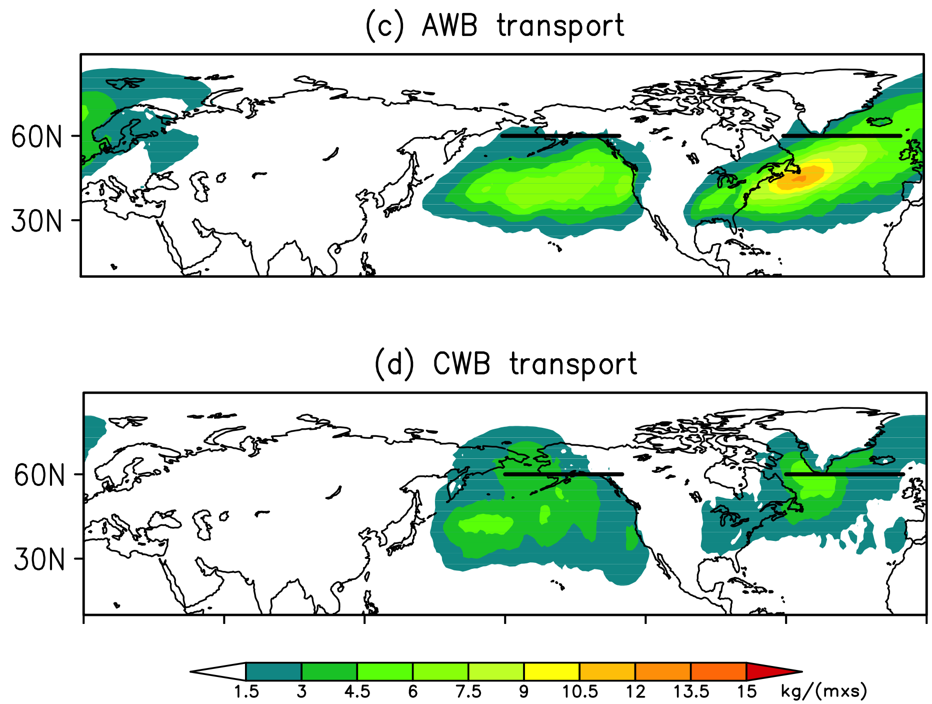
Contribution of RWB to transport

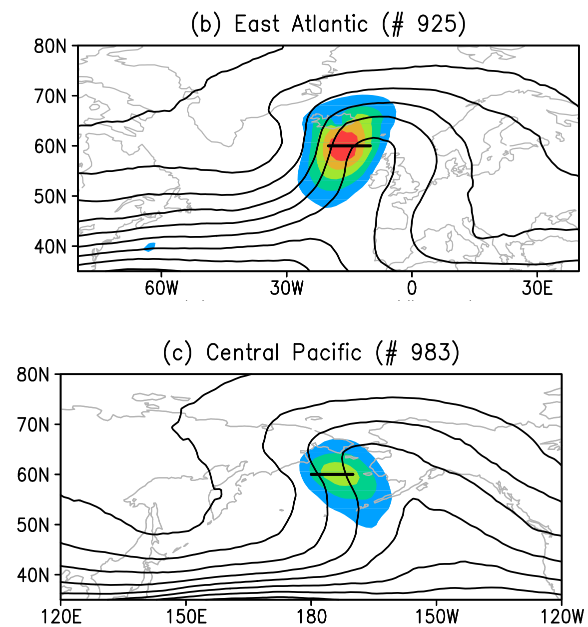
- RWB contribution occurs along the storm tracks
- RWB accounts for a large fraction of extreme transient poleward moisture transport across 60N
  - **68%** in winter
  - **56%** in summer
- Of the total transient transport across 60N, RWB accounts for more than
  - 47% in winter
  - 37% in summer



Liu & Barnes (in prep)

Cyclonic vs Anticyclonic





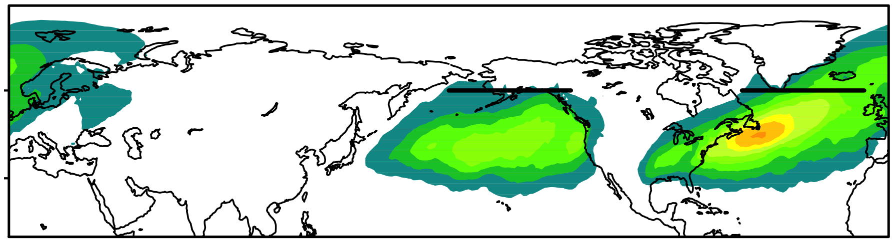
Anticyclonic

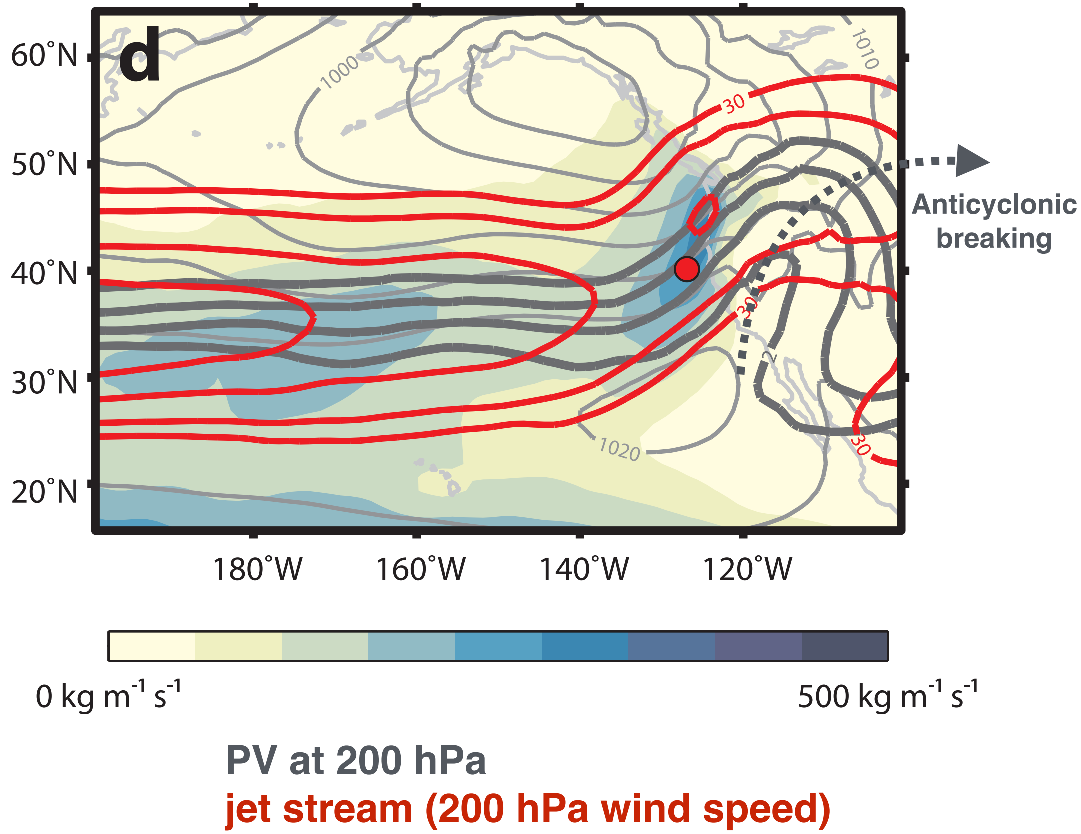
Cyclonic

- Cyclonic breaking has a larger contribution at higher latitudes (on the cyclonic flank of the jet)
- Anticyclonic breaking contributes more overall than cyclonic

Liu & Barnes (in prep)

Contribution of Anticyclonic RWB in midlatitudes

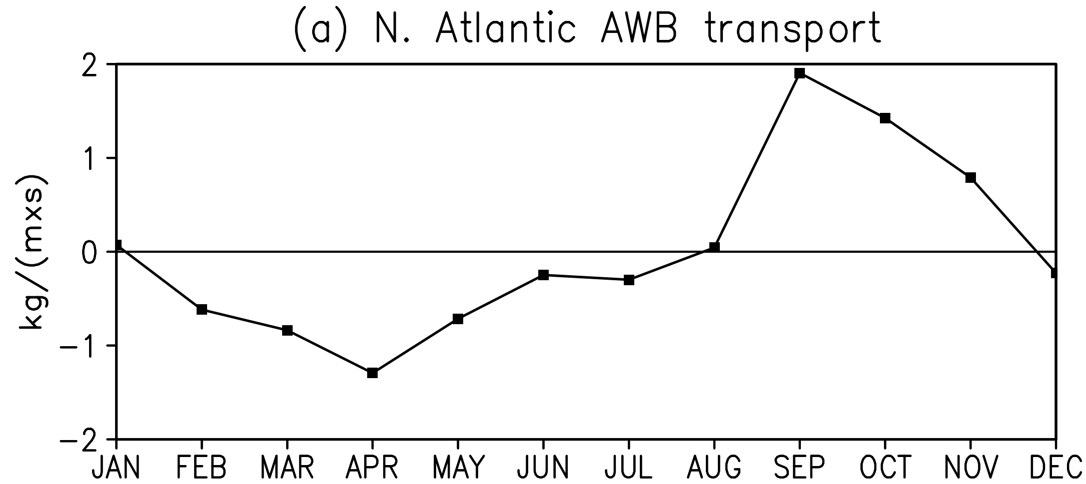




- Hot-off-the-press results by Payne & Magnusdottir:
    - role of anticyclonic wave breaking in extreme moisture transport to the western US

Payne & Magnusdottir (2014)

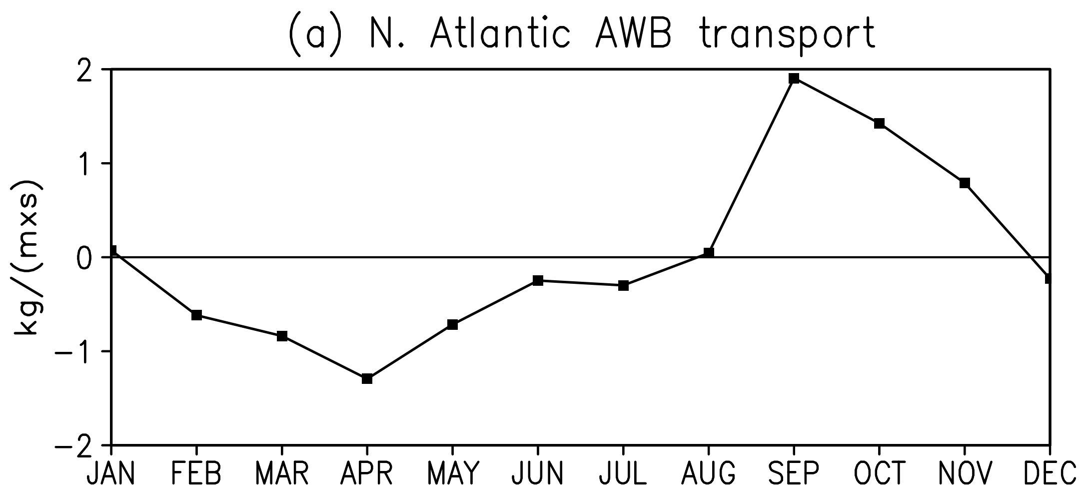
Seasonality of RWB-related transport



Liu & Barnes (in prep)

Seasonality of RWB-related transport

- What determines the seasonal cycle of RWB contribution?
    - **Magnitude:** are we getting more moisture flux per RWB?
    - **Frequency:** is RWB becoming more frequent?



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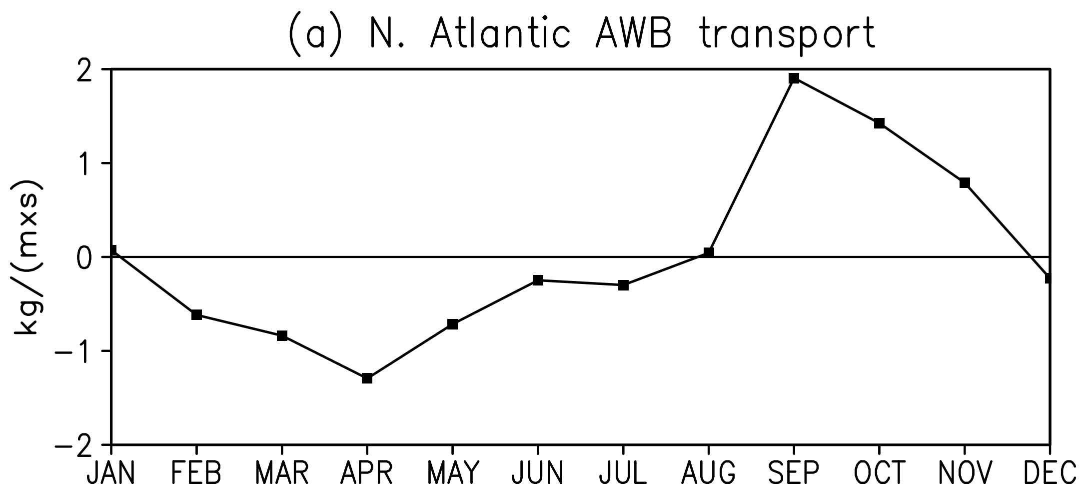


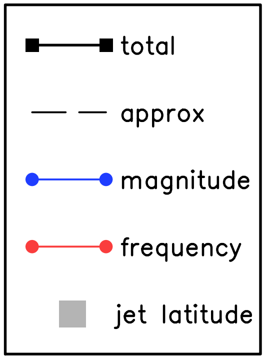
TOTAL moisture transport due to RWB
=
(M) Magnitude of moisture per event x **(F)** Frequency of RWB

$$(MF)' = M'\overline{F} + \overline{M}F' + \text{other terms}$$

these are small

Liu & Barnes (in prep)

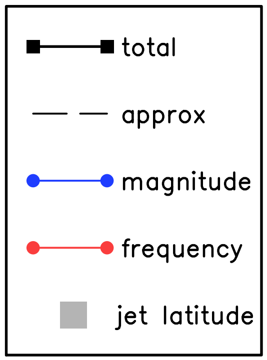
Seasonality of RWB-related transport

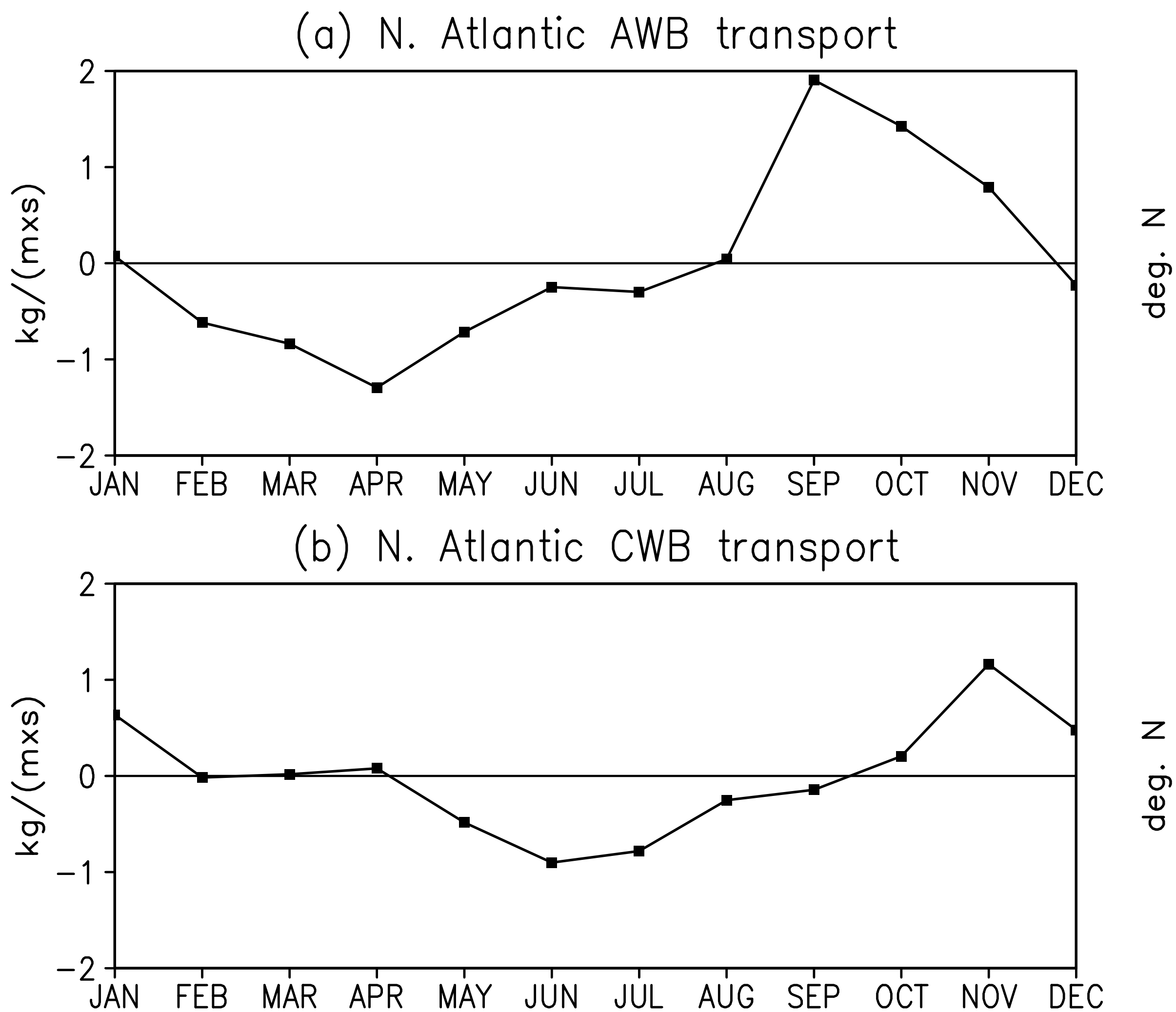


- seasonality of the RWB-related transient transport is due to
    - (a) amount of moisture flux
    - (b) frequency of RWB
- frequency of RWB is tightly coupled to the jet position

Liu & Barnes (in prep)

Seasonality of RWB-related transport





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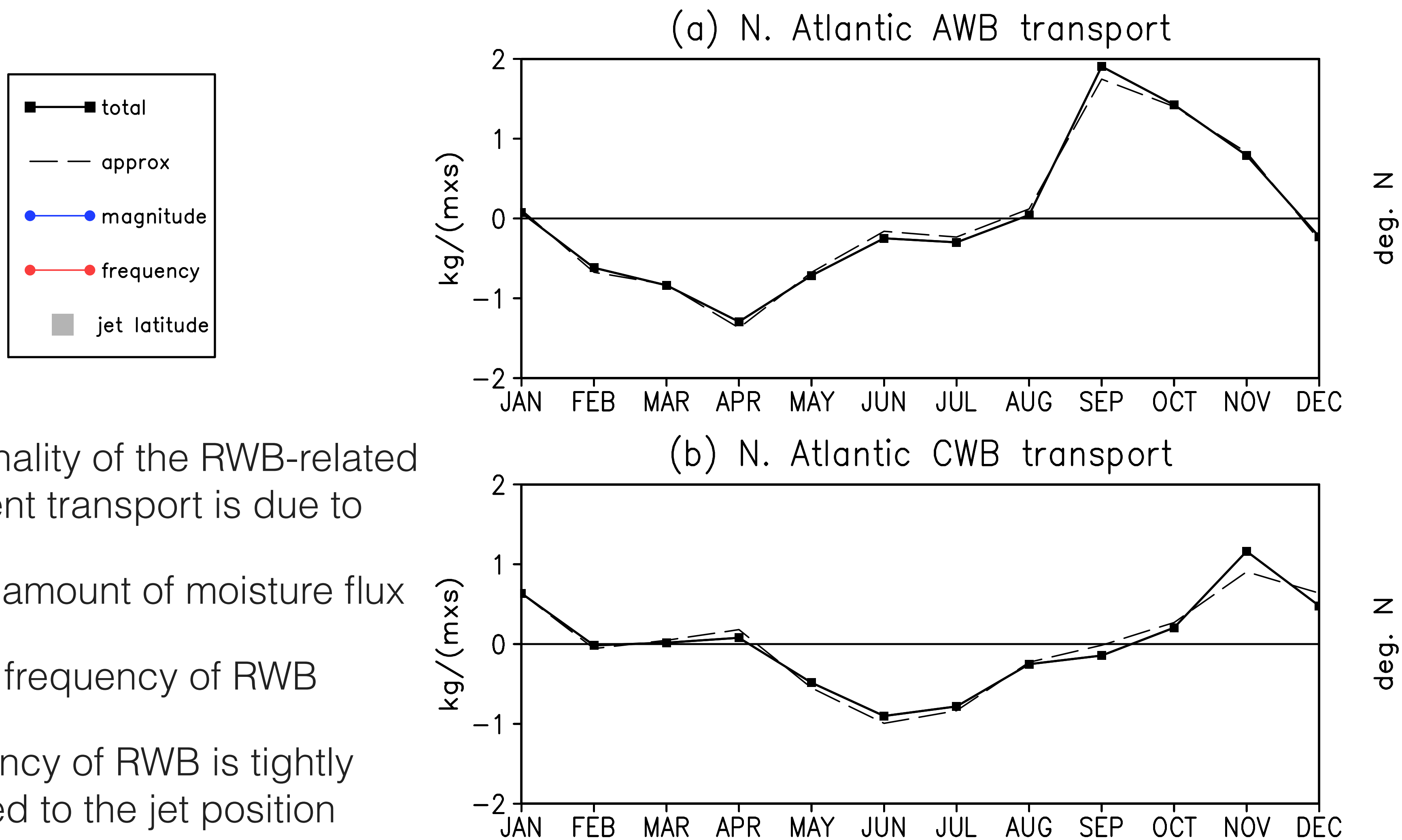

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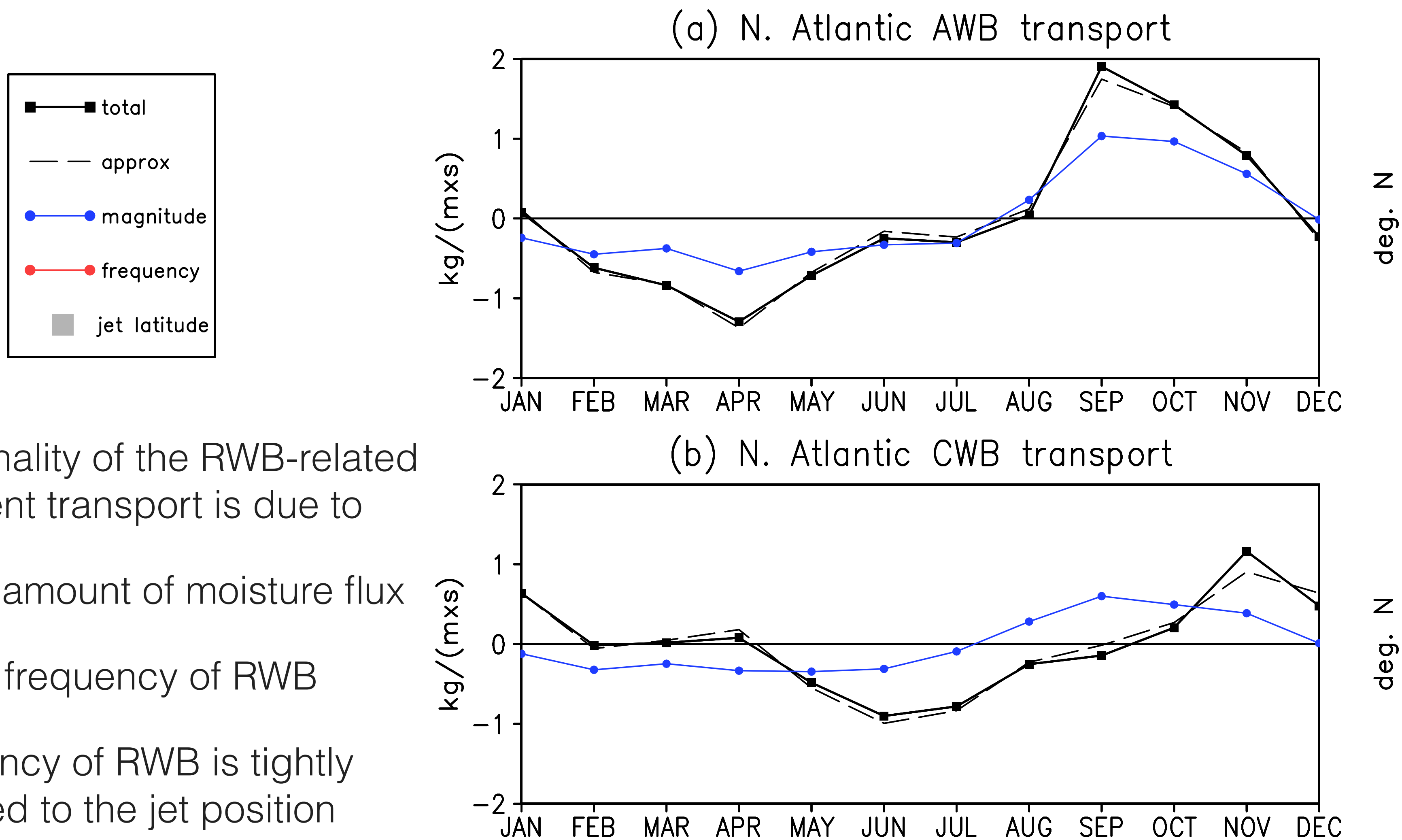

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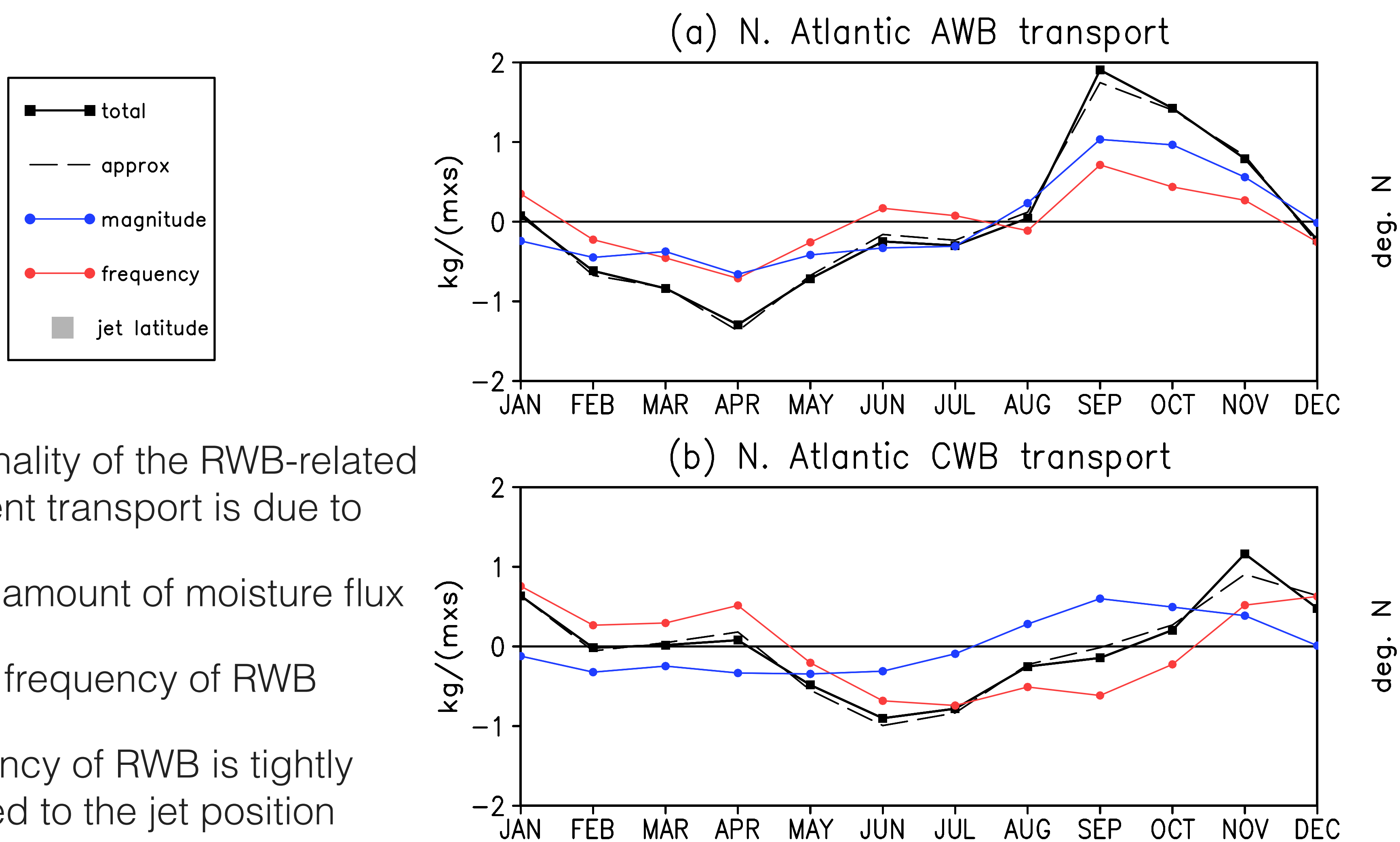

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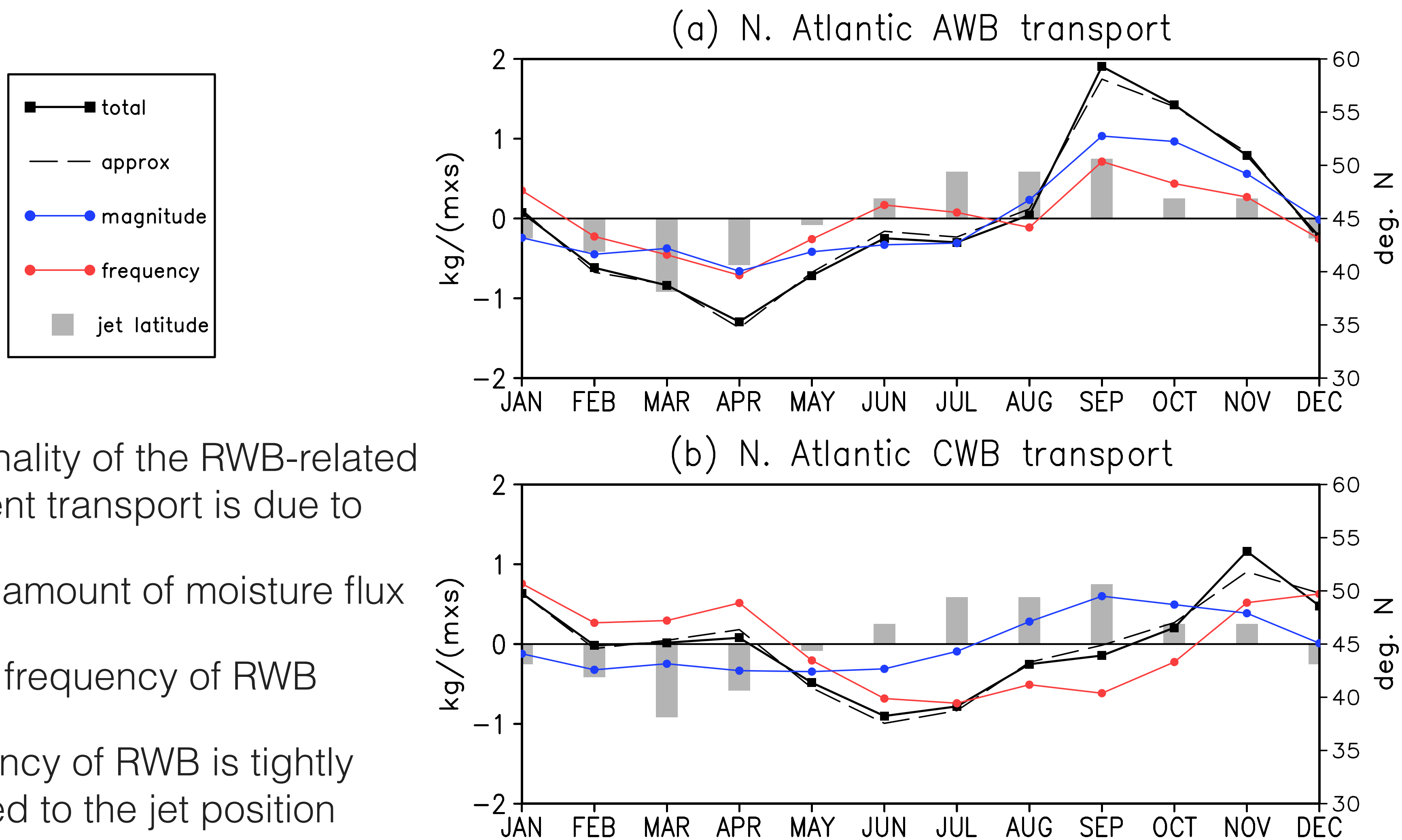

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Liu & Barnes (in prep)

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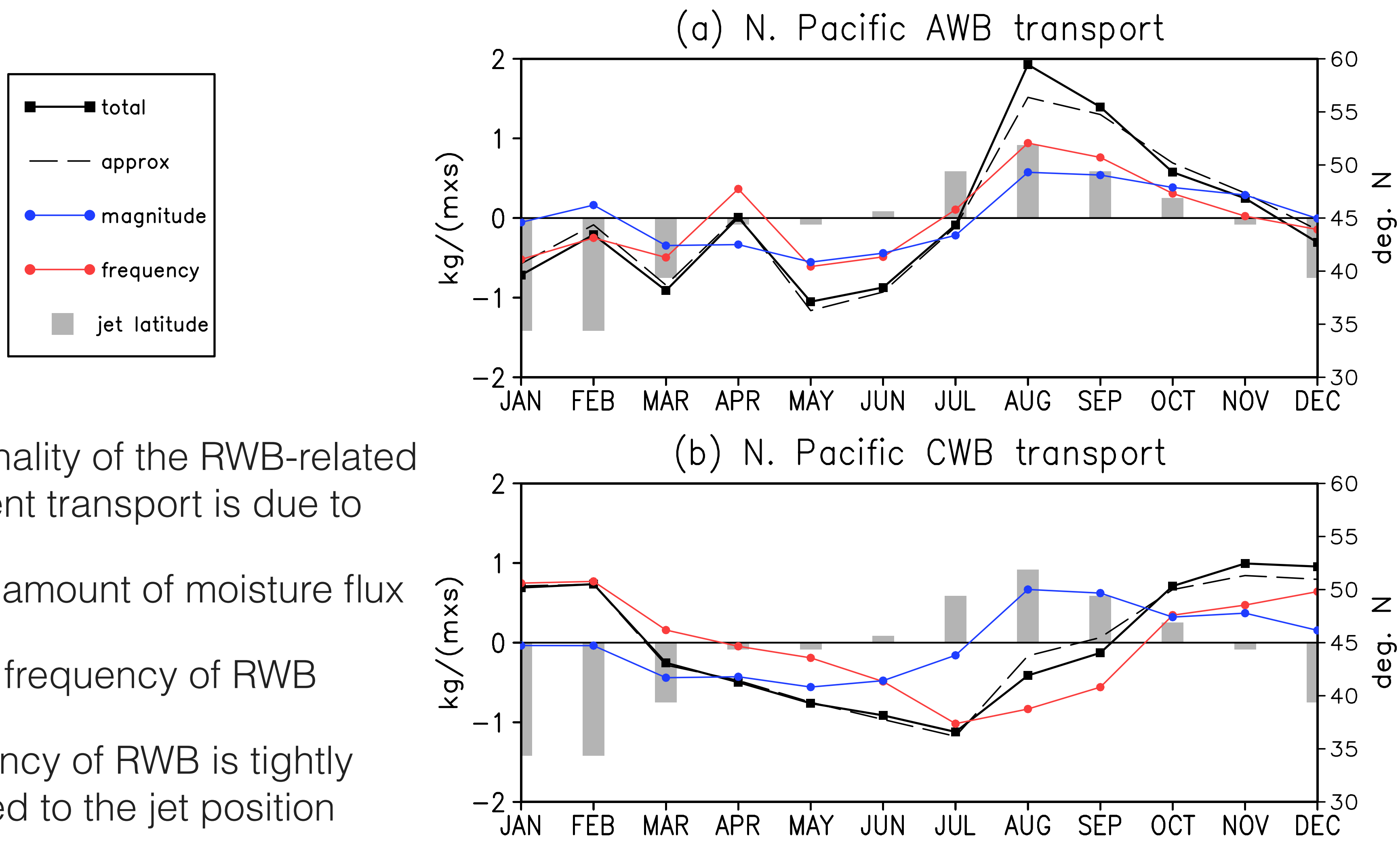

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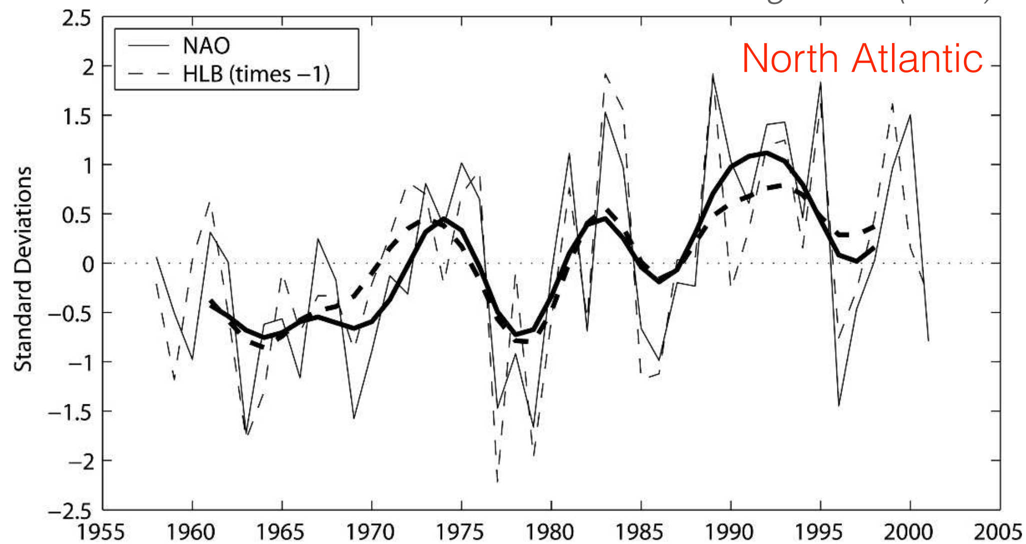
Liu & Barnes (in prep)

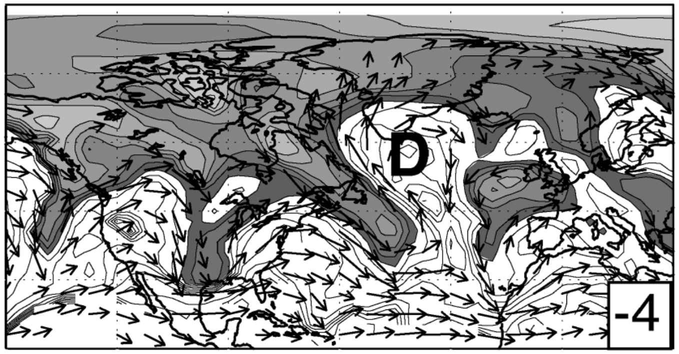
Year-to-year variability: NAO

- RWB is tightly-tied to the low-frequency variability of the jet-streams
- Some studies suggest that in fact they are one and the same!
- Also, the type of RWB and location can be important in driving jet-variability Benedict et al. (2004), Strong & Magnusdottir (2008)

Woollings et al. (2008)



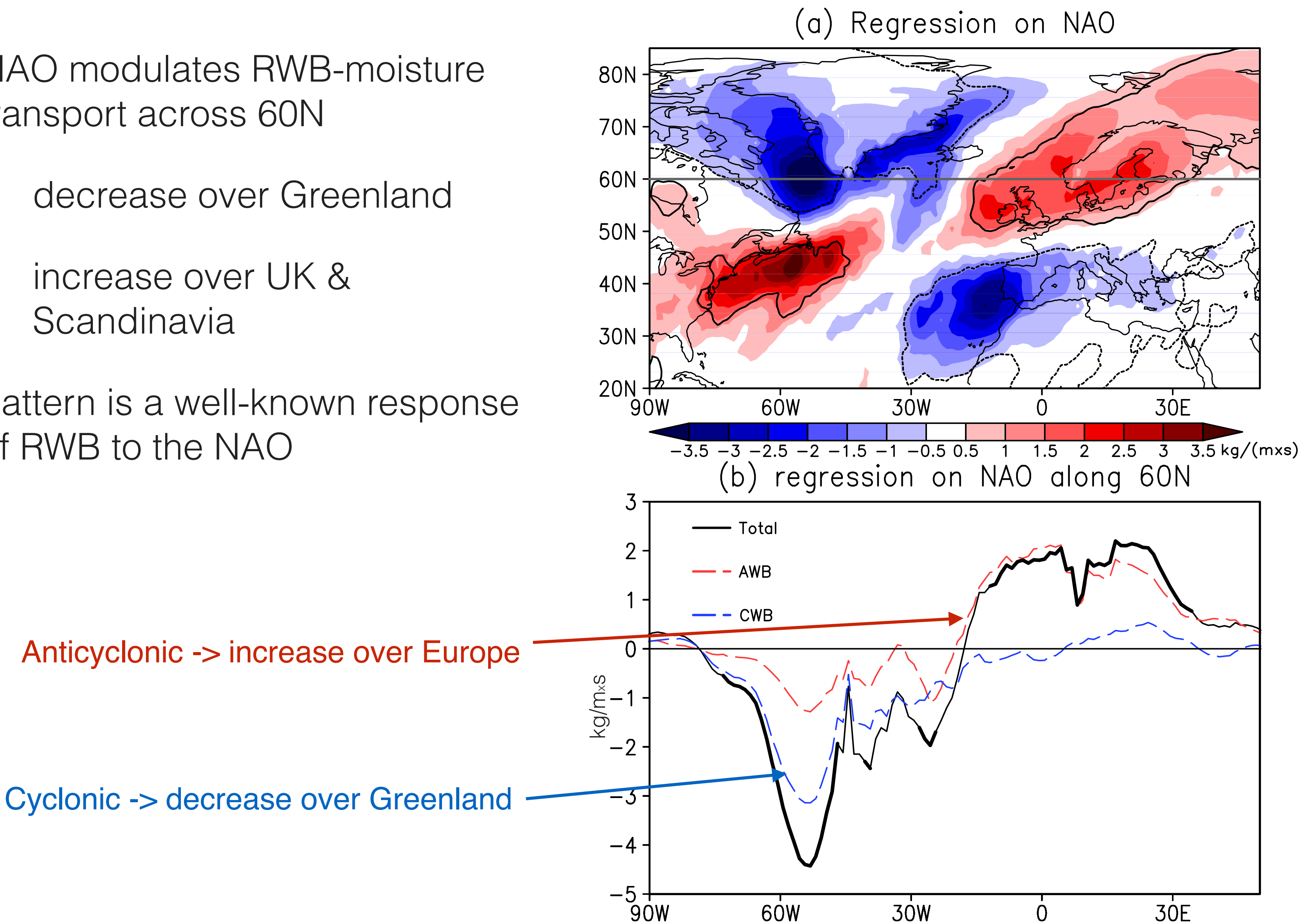
Cyclonic Greenland wave breaking correlated with the NAO



Benedict et al. (2004)

Year-to-year variability: NAO

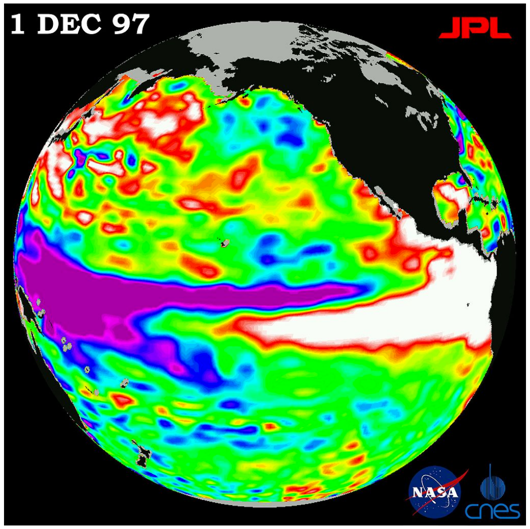
- NAO modulates RWB-moisture transport across 60N
    - decrease over Greenland
    - increase over UK & Scandinavia
- Pattern is a well-known response of RWB to the NAO

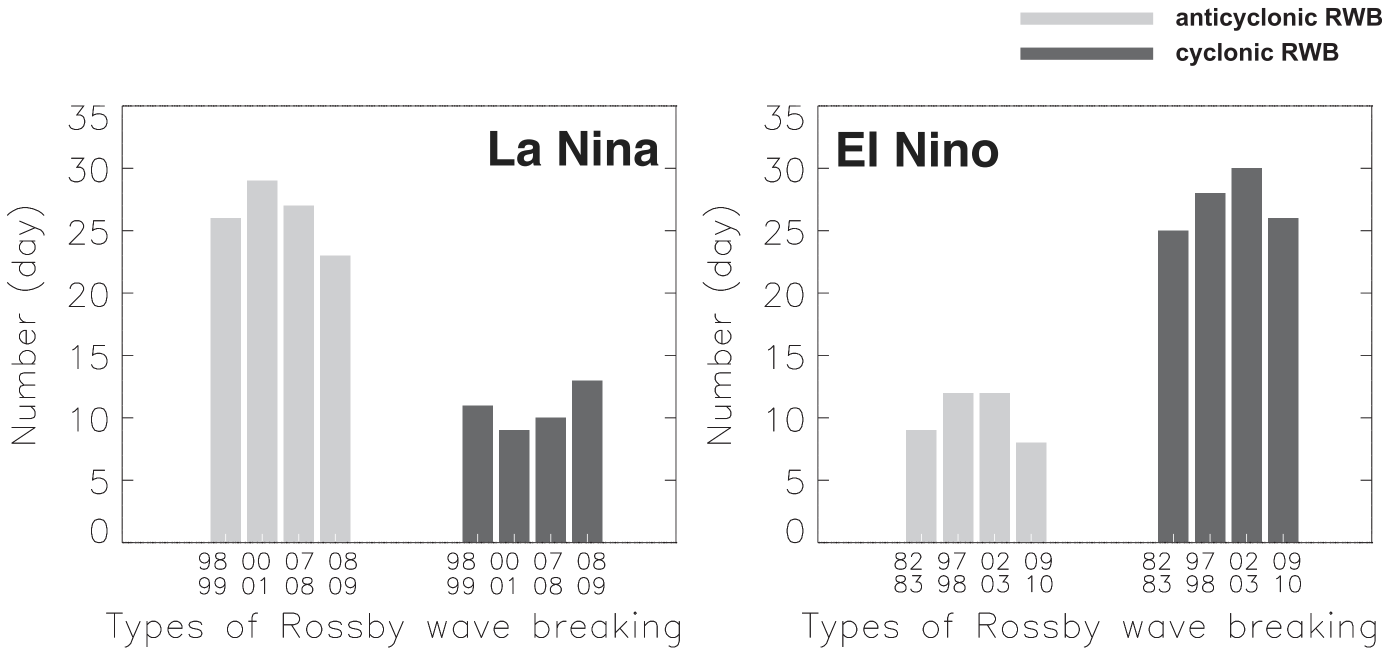


Liu & Barnes (in prep)

Year-to-year variability: ENSO

- During El Nino events, jet shifts equatorward
- More cyclonic RWB
- Less anticyclonic RWB



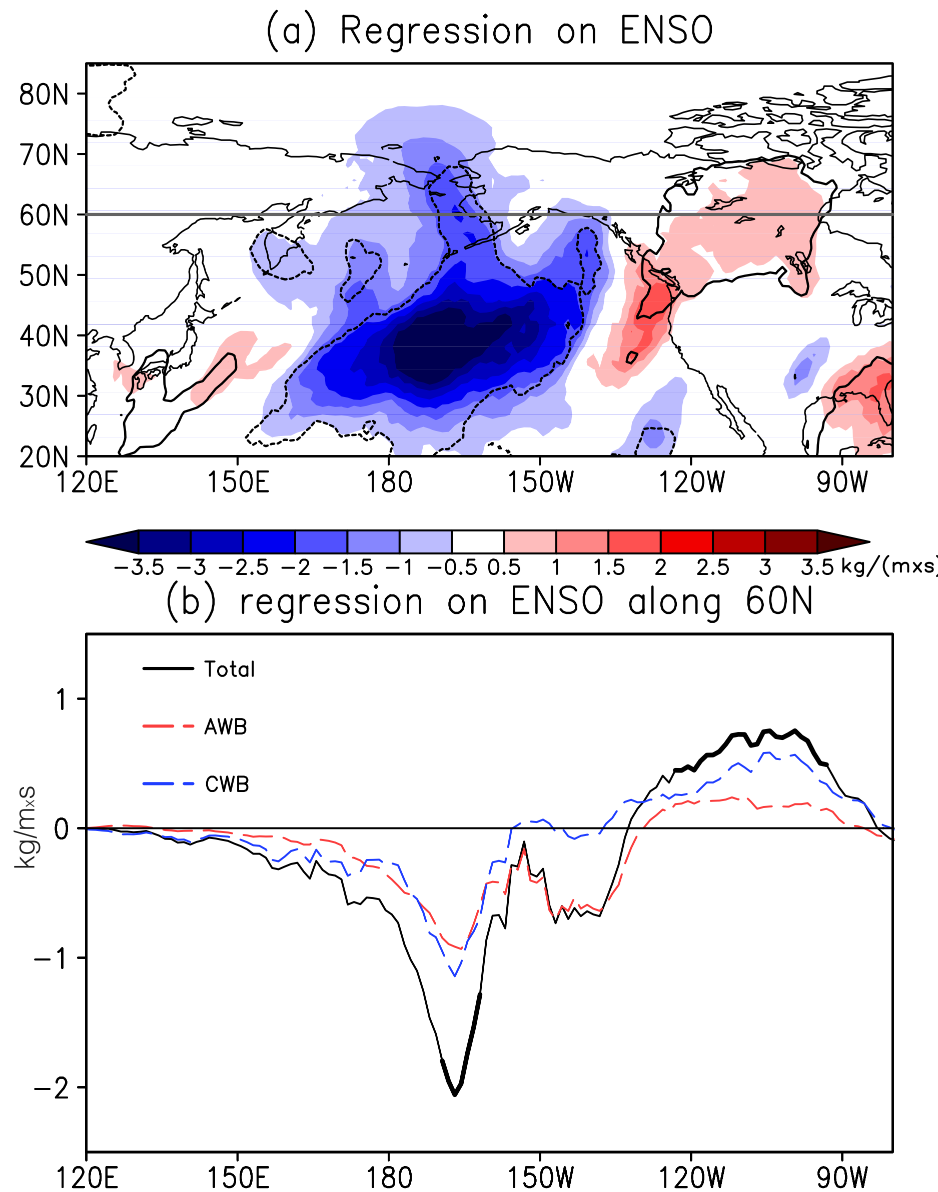


Ryoo et al. (2013)

Year-to-year variability: ENSO

- ENSO modulates RWB-moisture transport across 60N
  - decrease over North Pacific
  - increase over western Canada
  - overall decrease across 60N

- both flavors of RWB contribute to these changes



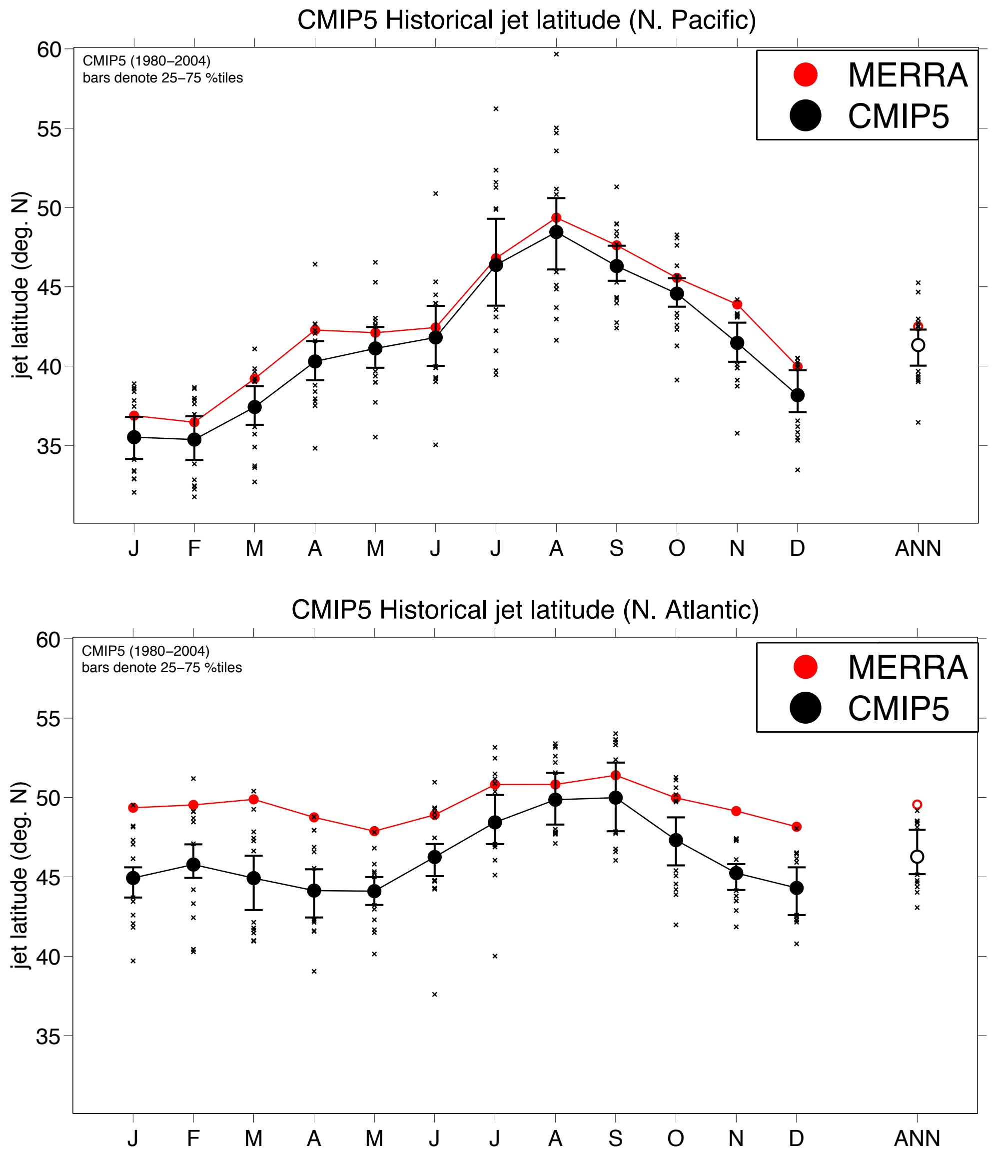
Liu & Barnes (in prep)

One more thing…models have difficulties with the jet

- models place the jet too far equatorward

- models tend to over-estimate the seasonal cycle of the jet

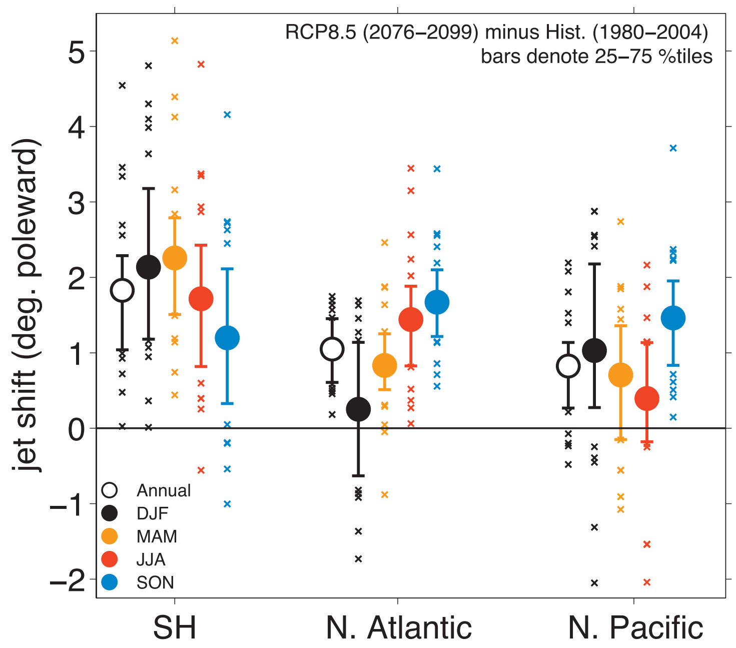
Jet biases may have implications for how models simulate moisture into the Arctic

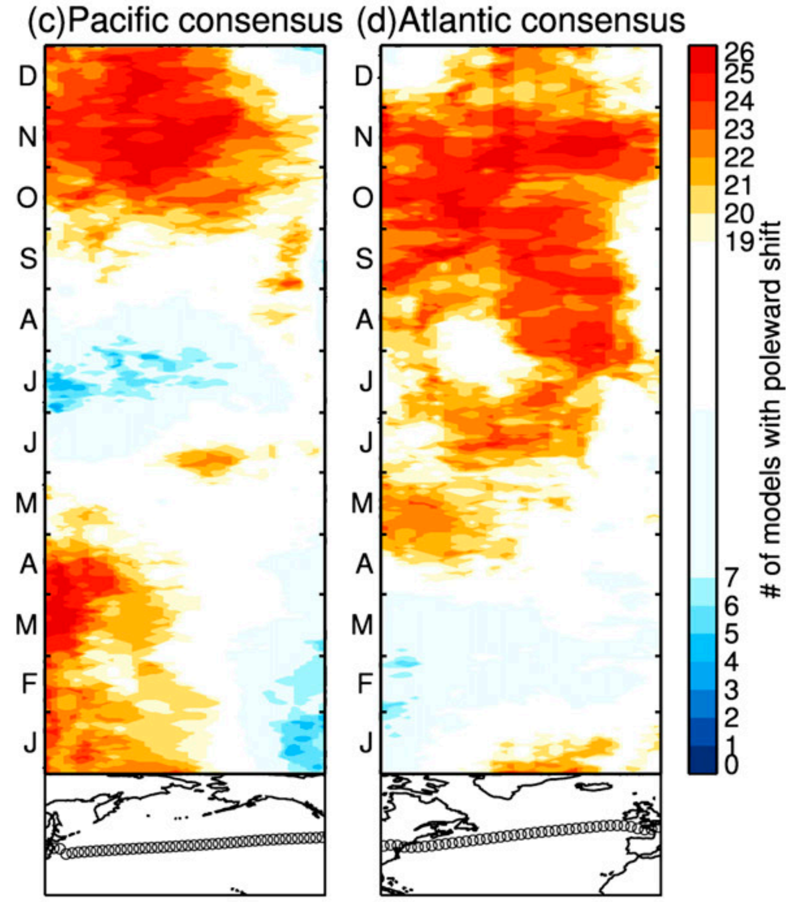


The Future: jet shifts

- CMIP5 models project poleward shifts of the jet-stream in most seasons

- zonal differences in the North Pacific jet response in winter





Barnes & Polvani (2013)

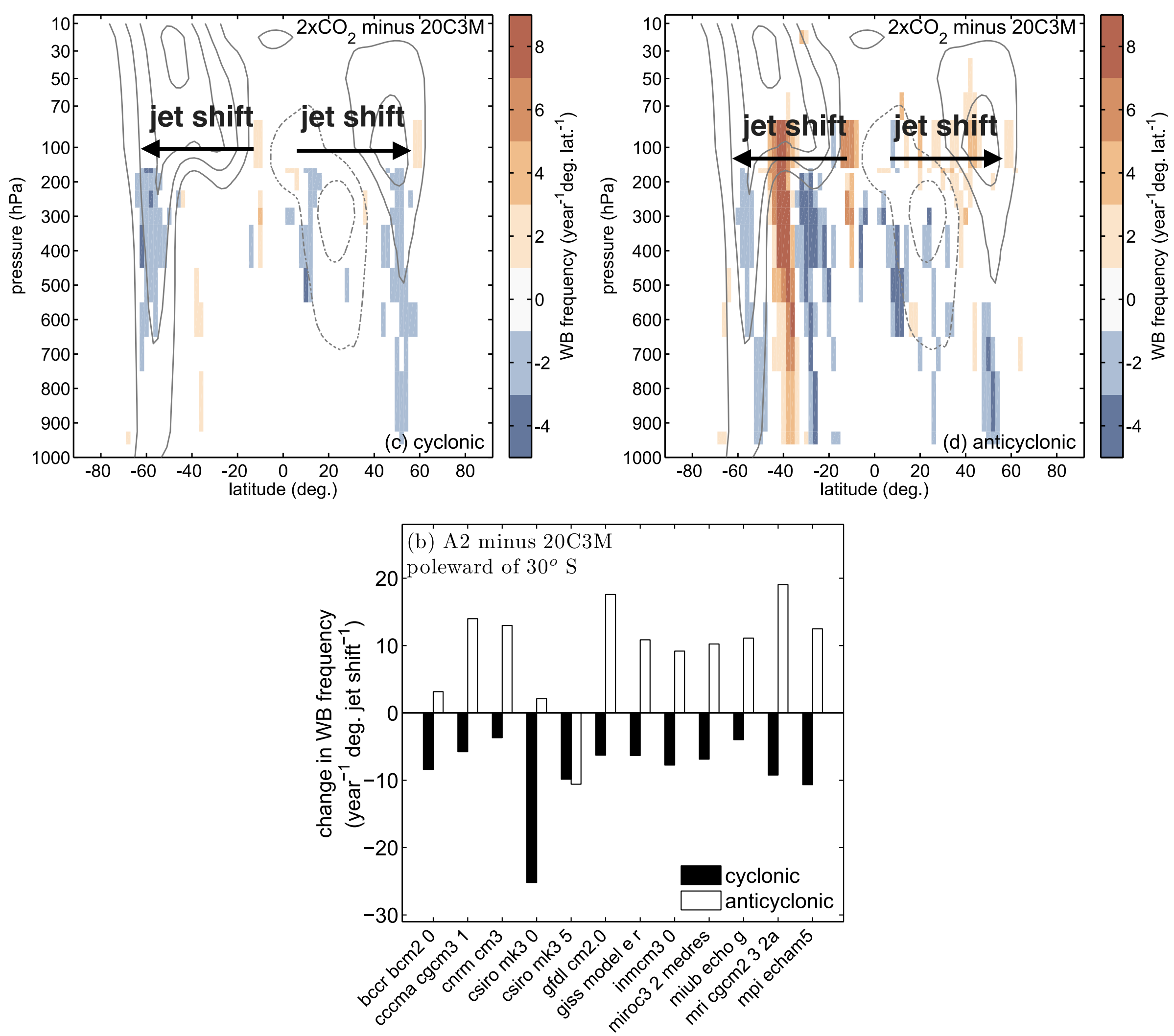
Simpson et al. (2014)

The Future: jet shifts & RWB

- future poleward jet shifts are tied to changes in the distribution of RWB

decrease in cyclonic

shift in anticyclonic



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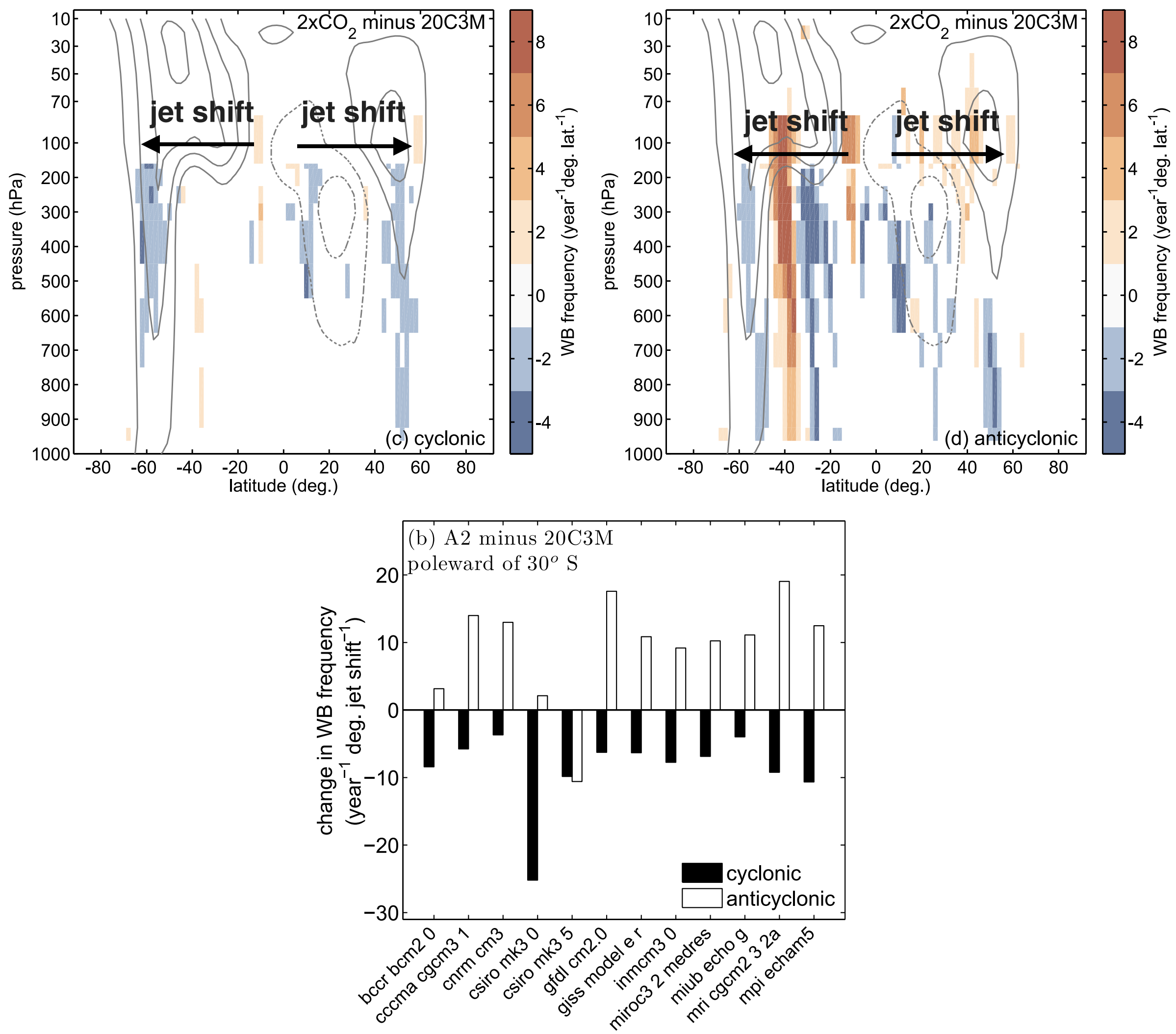
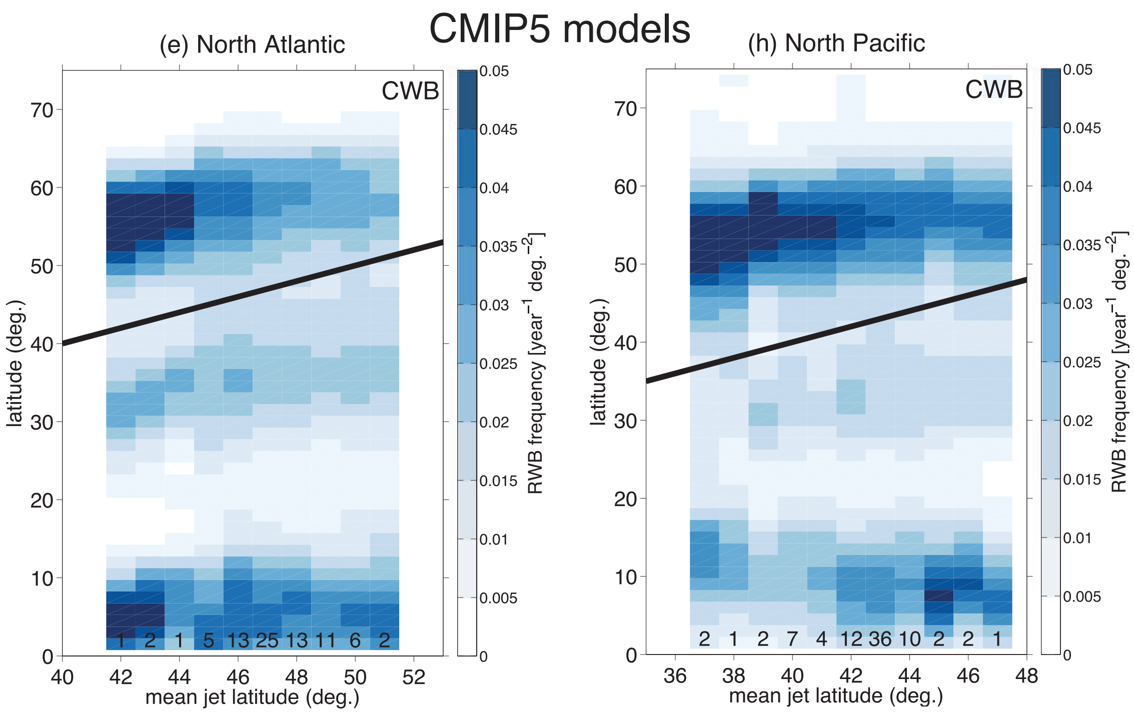


Barnes & Hartmann (2012)
results from CMIP3

The Future: decreases in cyclonic RWB

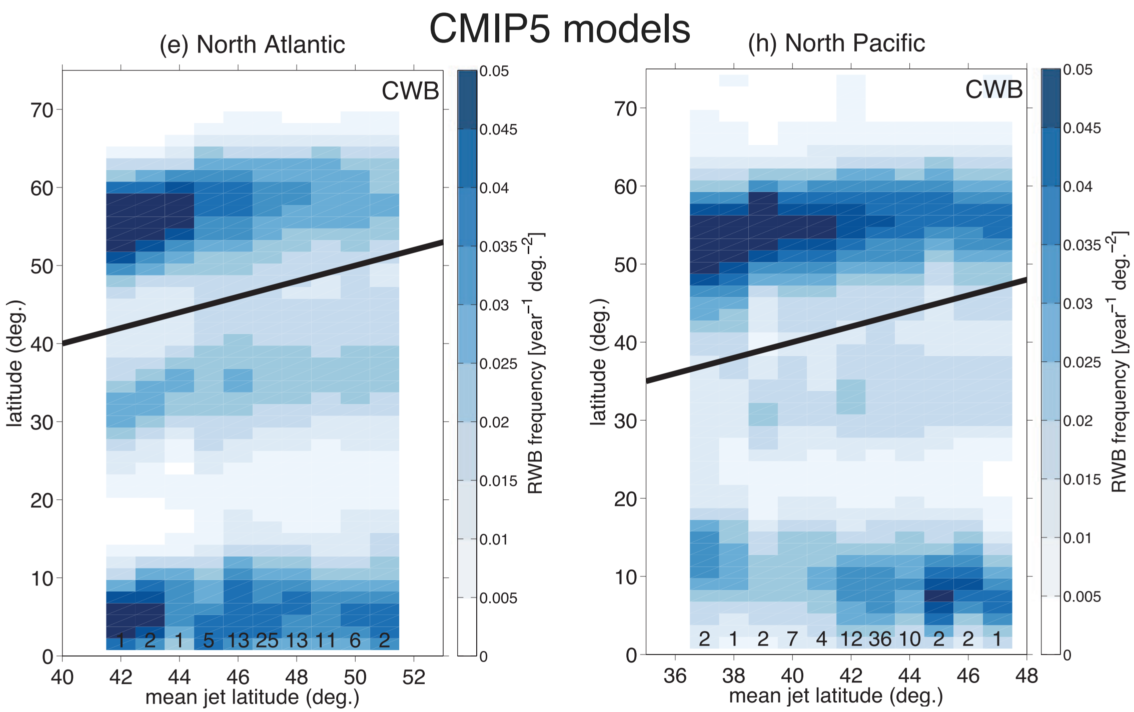


Barnes & Polvani (2013)

poleward jet-stream
=
fewer cyclonic RWB

- More poleward jets are linked to less cyclonic RWB

The Future: decreases in cyclonic RWB



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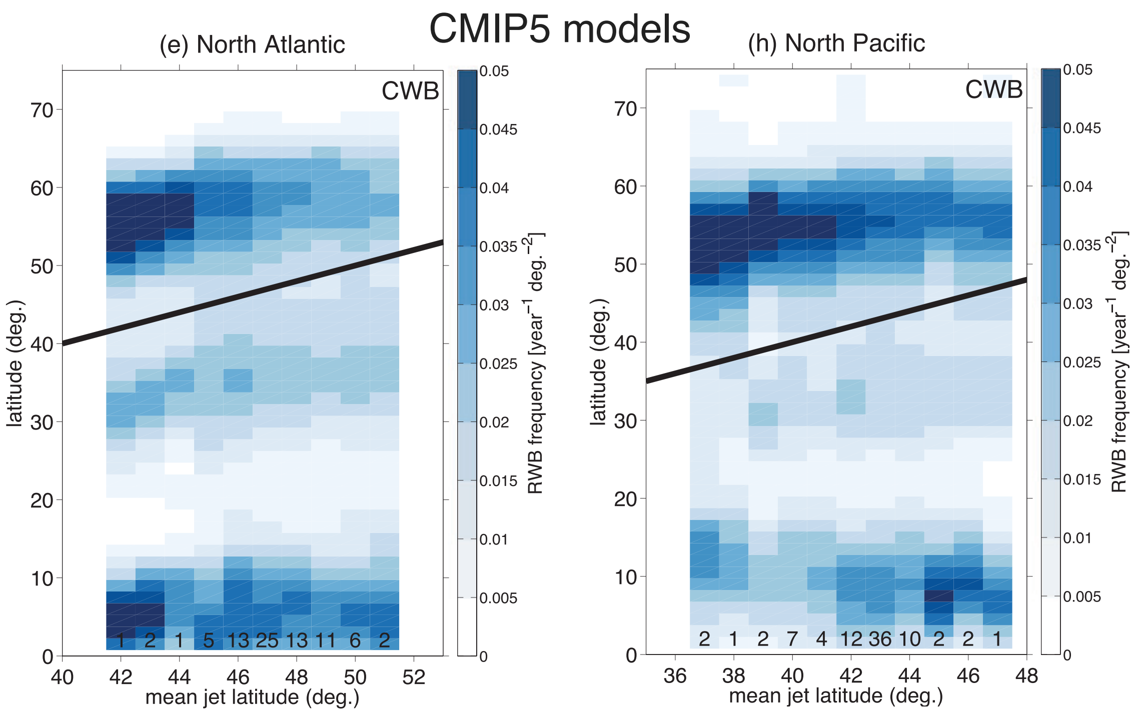

Barnes & Polvani (2013)

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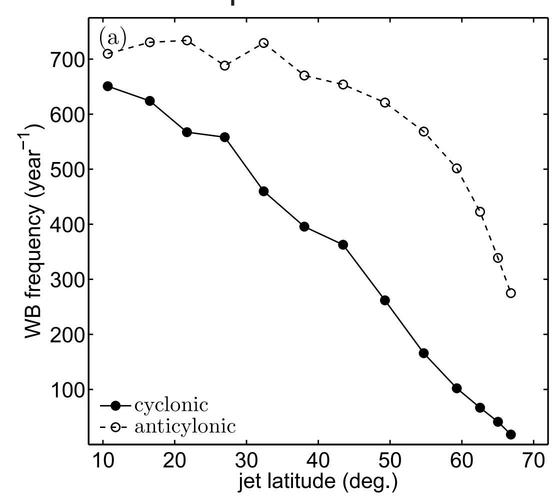
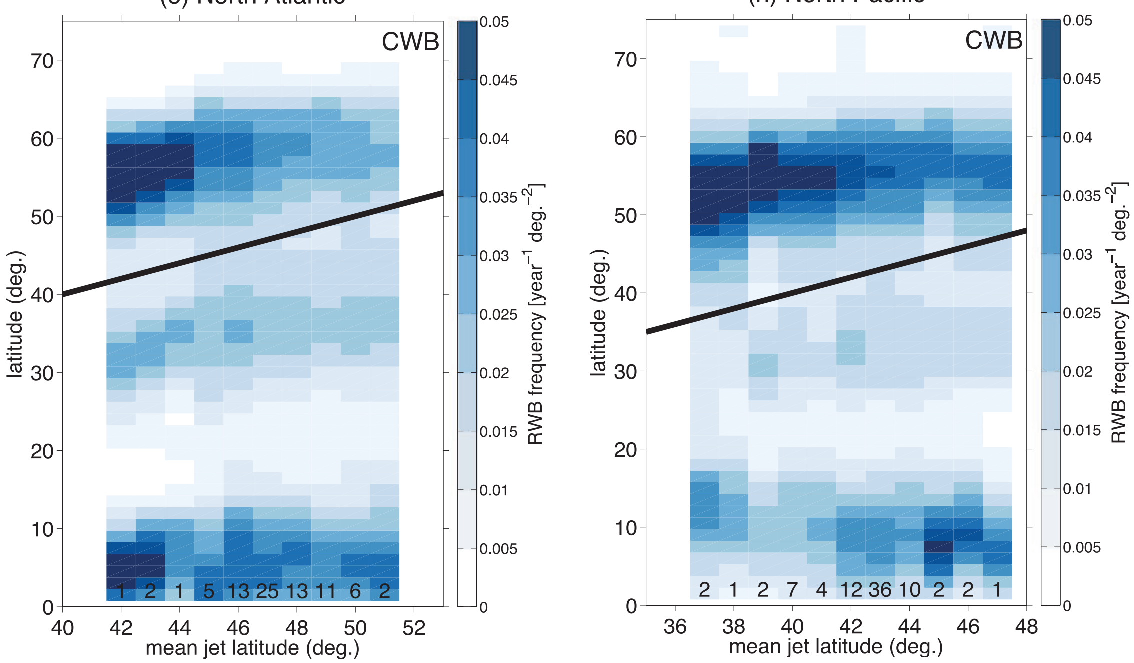
Simple 2-D model



Barnes & Polvani (2013)

The Future: decreases in cyclonic RWB

CMIP5 models



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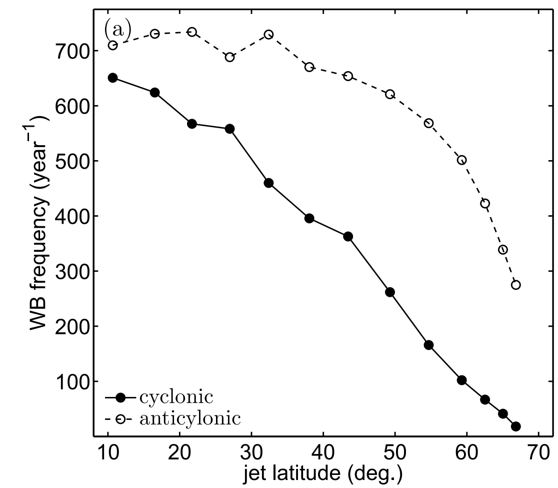
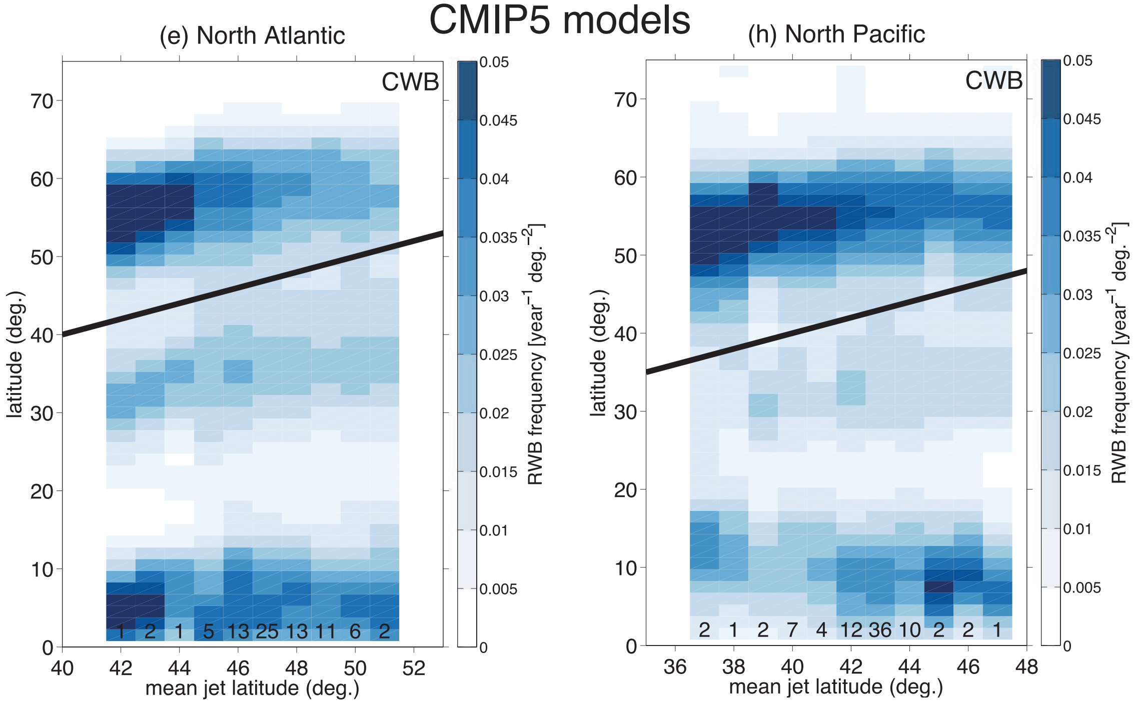


If the jet shifts poleward in the future, will we have less cyclonic RWB-induced moisture transport at 60N?

Barnes & Polvani (2013)

The Future: decreases in cyclonic RWB

CMIP5 models



Barnes & Polvani (2013)

- More poleward jets are linked to less cyclonic RWB

poleward jet-stream
=
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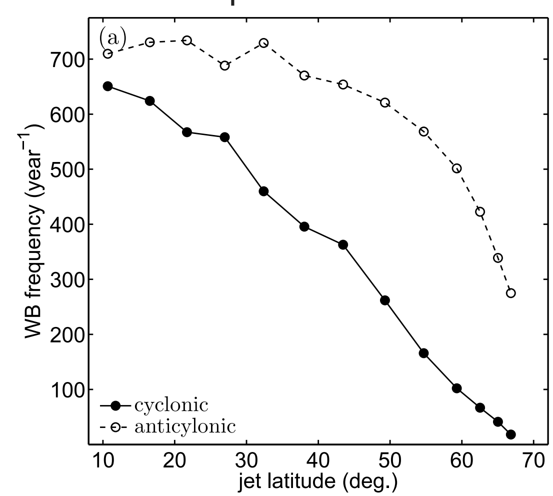
If the jet shifts poleward in the future, will we have less cyclonic RWB-induced moisture transport at 60N?

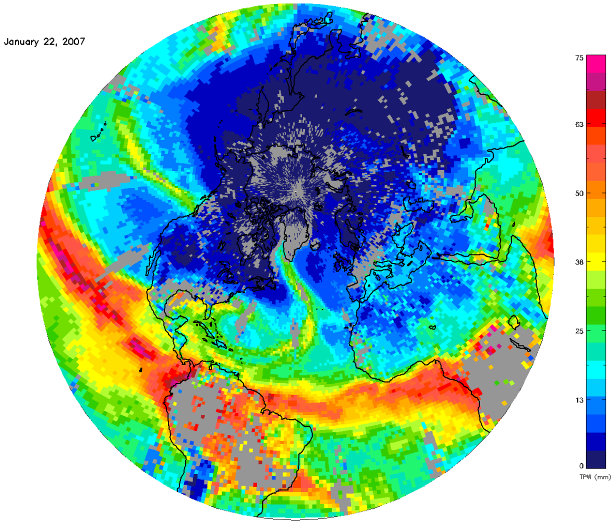
We don't know yet!
(but changes in the moisture capacity of the atmosphere will likely dominate)

Simple 2-D model



Barnes & Polvani (2013)

Conclusions



1. Extreme synoptic moisture transport events contribute a substantial amount to the total transient moisture transport across 60N

2. Synoptic Rossby waves are an important driver of these extreme intrusion events

3. Future changes in the jet-stream and Rossby wave breaking frequency have the potential to drive changes in the intensity and frequency of these intrusions