Relative Contributions of Synoptic and Low Frequency Eddies to Atmospheric Moisture Transport

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Motivation

What are the processes that drive moisture transport in the present climate?

How is the moisture transport partitioned between synoptic, intraseasonal and interannual time scales?

To what extent do "atmospheric rivers" contribute to the water cycle?

How will the water cycle change in future climate and how much of this can be related to circulation versus thermodynamic changes (e.g. "Clausius-Clapeyron scaling")?

Methodology

Estimate the time-varying moisture budget from various reanalysis products (here NCEP-NCAR reanalysis)

Total Moisture Budget

$$\frac{\partial \langle q \rangle}{\partial t} + \nabla \bullet \vec{Q} = E - P$$

q *Specific humidity*

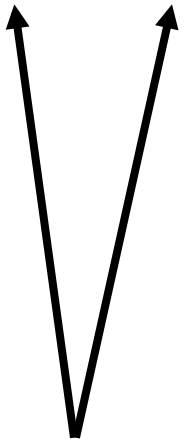
$\langle \ \rangle$ *Vertical integral (on sigma coordinates)*

$\langle q \rangle$ *Vertically integrated specific humidity (precipitable water)*

$\vec{Q}$ *Vertically integrated moisture flux*

$E - P =$ *Evaporation minus precipitation*

$$\frac{\partial \langle q \rangle}{\partial t} + \nabla \bullet \vec{Q} = E - P$$

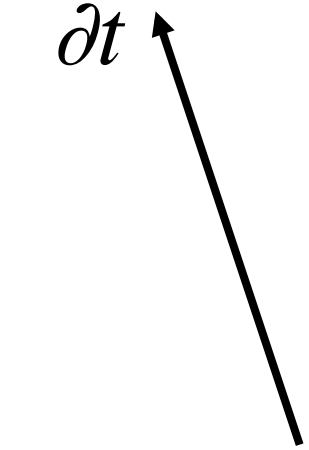


Problematic in reanalyses

$$\frac{\partial \langle q \rangle}{\partial t} + \nabla \bullet \vec{Q} = E - P$$

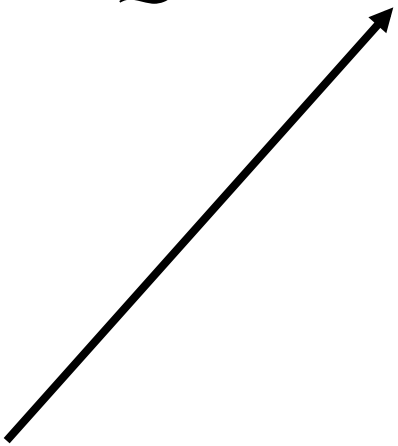
Straightforward to calculate and consistent among reanalyses

$$\frac{\partial \langle q \rangle}{\partial t} + \nabla \bullet \vec{Q} = E - P$$



Small for time mean (especially during the solstice seasons)

$$\frac{\partial \langle q \rangle}{\partial t} + \nabla \bullet \vec{Q} = E - P$$



Calculated as a residual

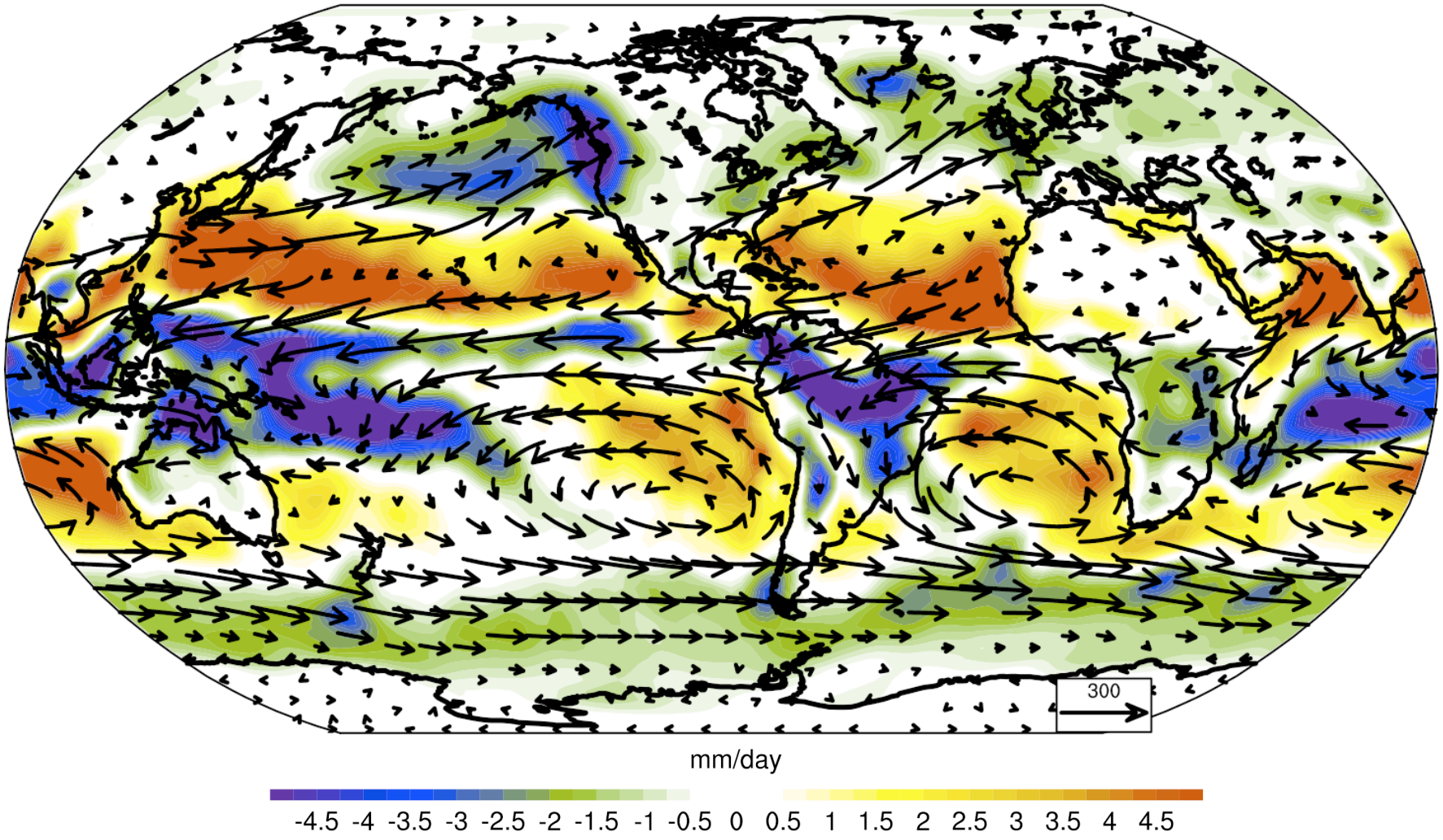
Time Mean Total Moisture Budget

$$\overline{\vec{Q}} = \overline{\langle q\vec{v}p_s \rangle}$$

Where the overbar is a time mean p_s *is the surface pressure and* $\vec{v}$ *is the total wind*

December-February 1968-2007

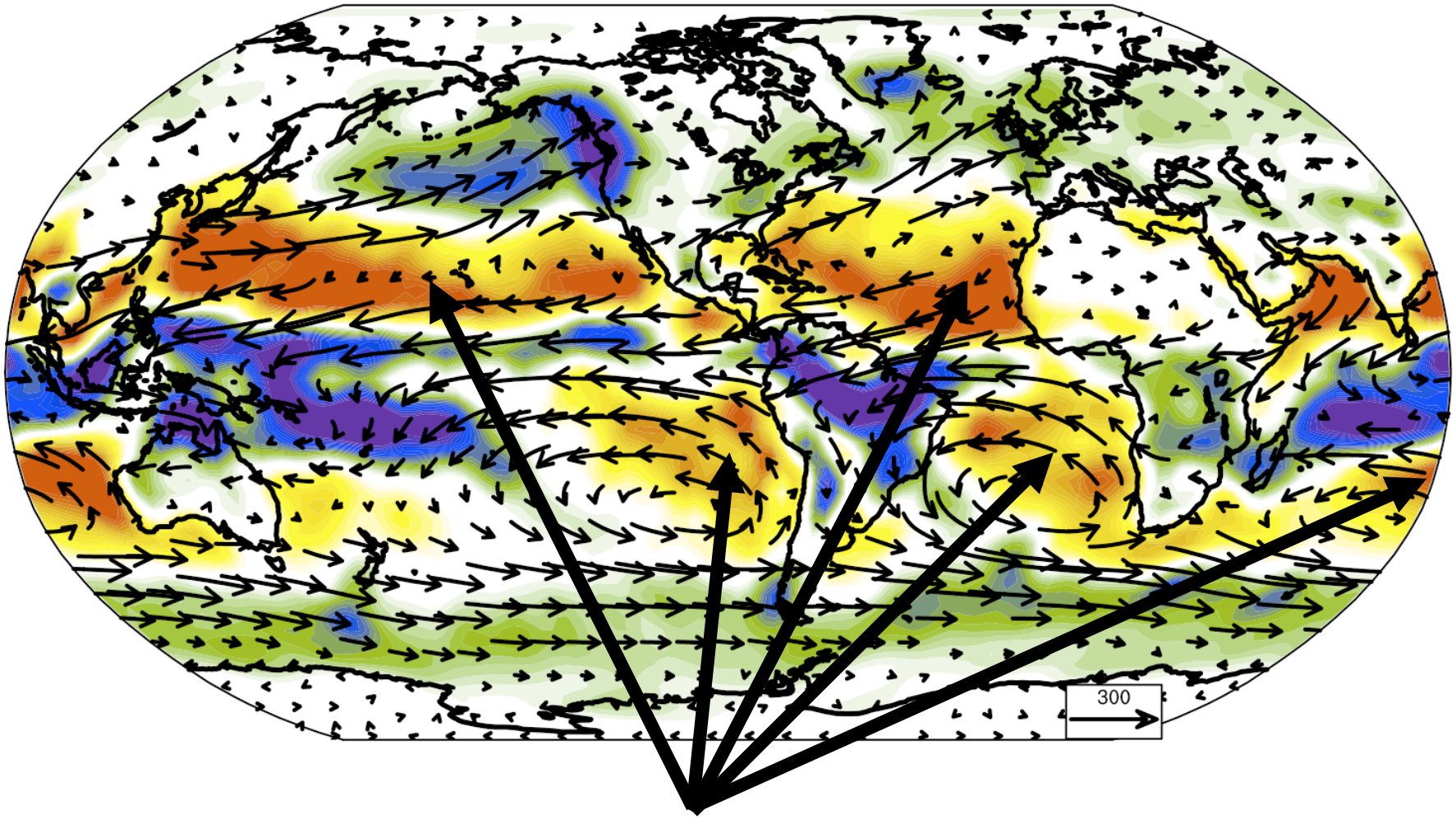
a) Total transport



Total Moisture Flux (vectors) and its flux divergence (shading)

December-February 1968-2007

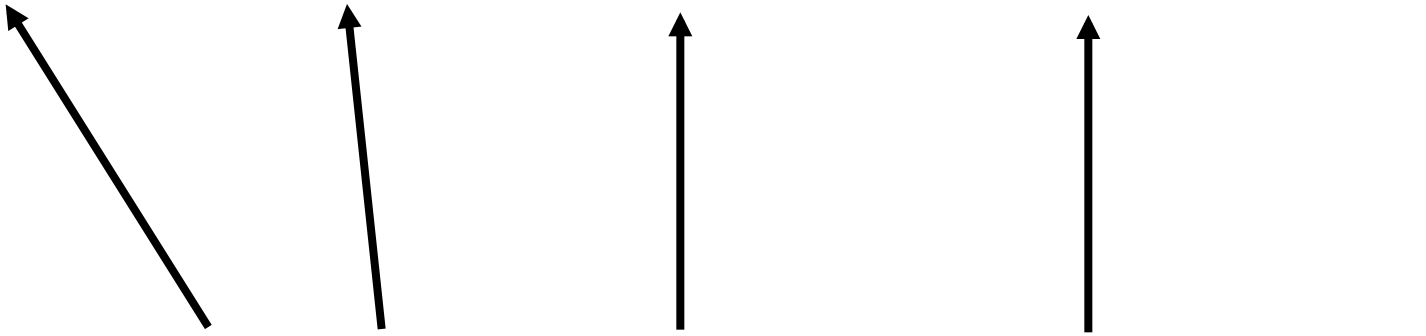
a) Total transport



Moisture Sources (E>P)

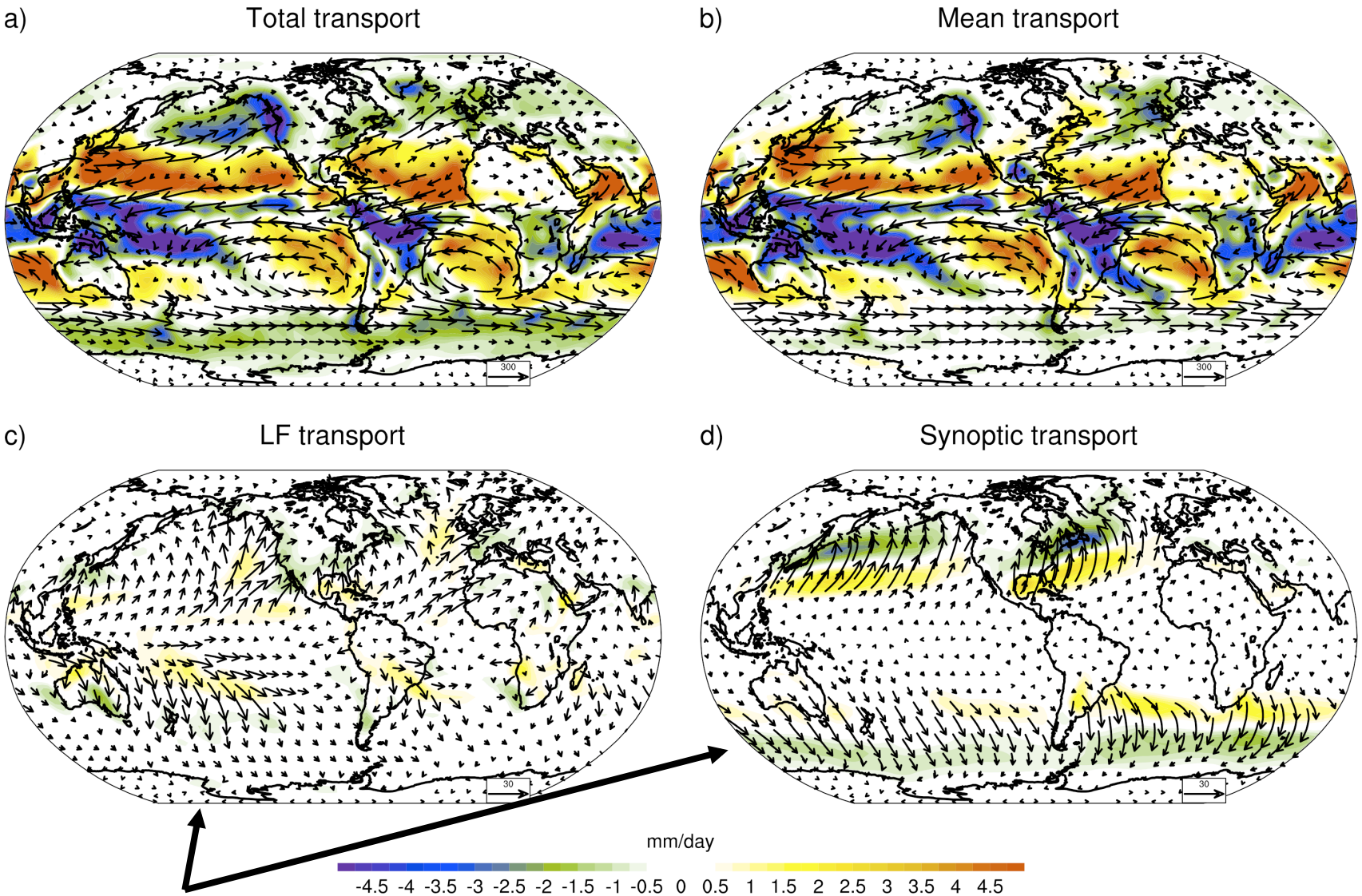
Contributions to the Time Mean Moisture Budget

$$\overline{\vec{Q}} = \overline{\langle q\vec{v}p_s \rangle} = \langle \bar{q}\bar{\vec{v}}\bar{p}_s \rangle + \overline{\langle p_s\vec{v}'q' \rangle} + \overline{\langle p_s\vec{v}''q'' \rangle}$$



e.g. by Synoptic we mean the contribution to the total transport by synoptic eddies

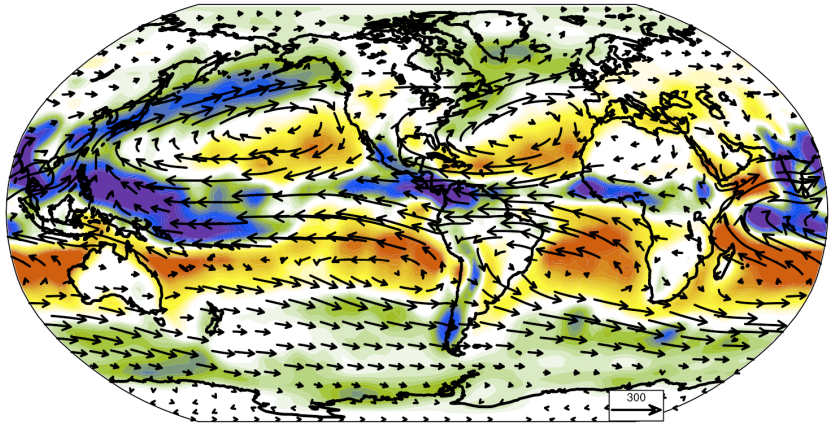
December-February Transport



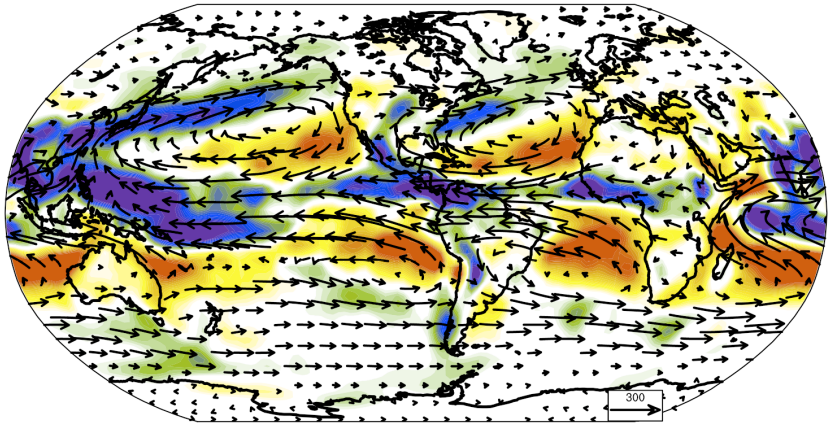
Flux scaled by 10

June-August Transport

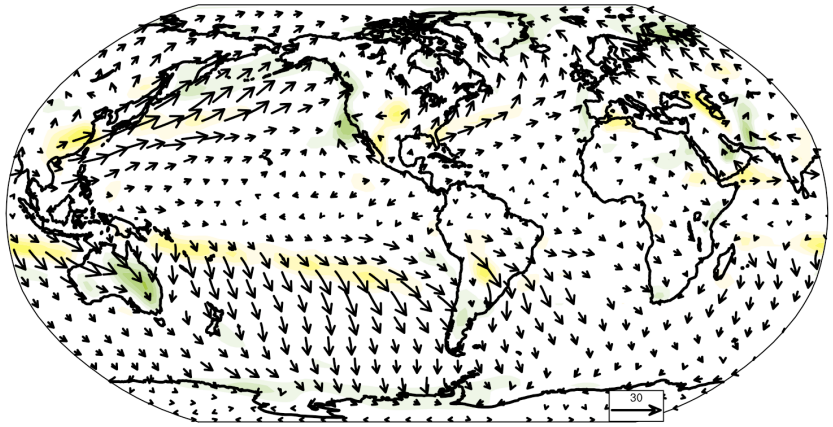
a) Total transport



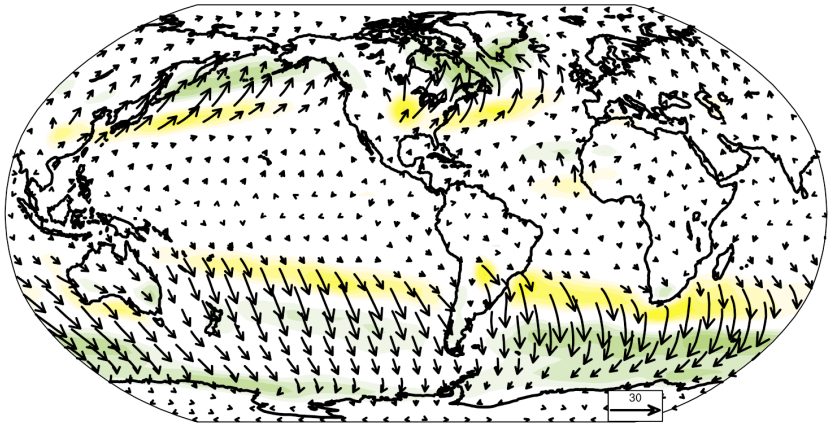
b) Mean transport



c) LF transport



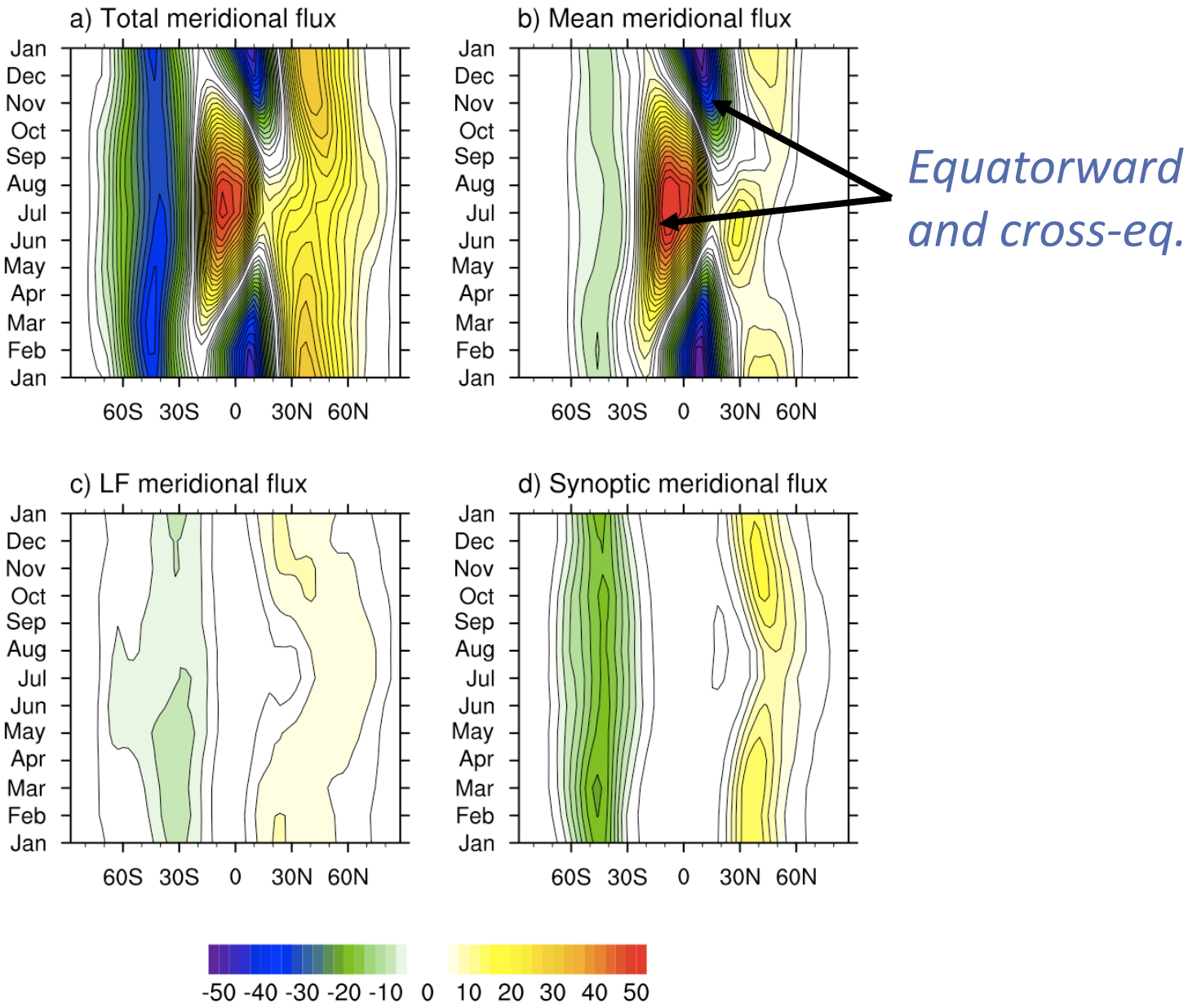
d) Synoptic transport



mm/day

-4.5 -4 -3.5 -3 -2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5

Zonal Mean Transport



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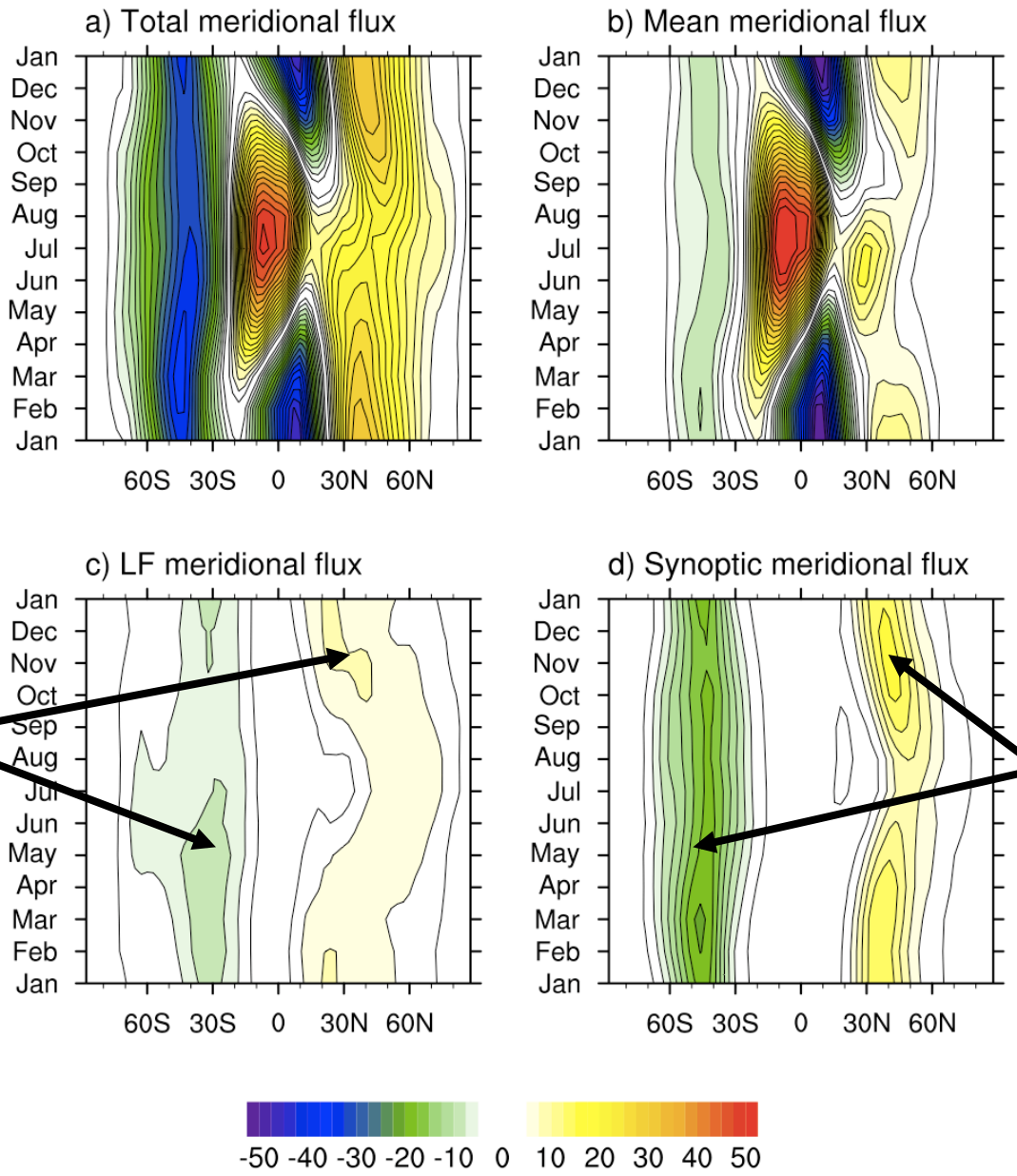


Broad, extending to low latitudes

Confined to storm tracks

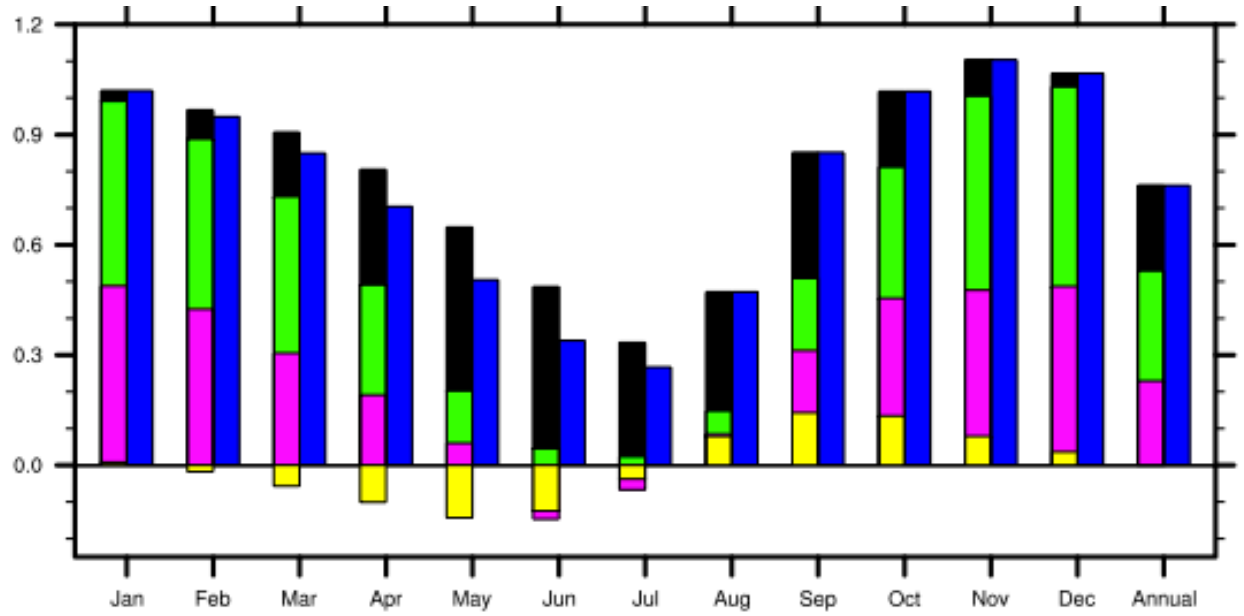
Key Points so far:

Total (and mean) moisture transport, especially over the oceans, is primarily zonal

There is meridional transport away from subtropical source regions at all time scales

Transport by the mean is dominant globally, however this is not the case for ocean to land transport

Moisture transport from ocean into North America



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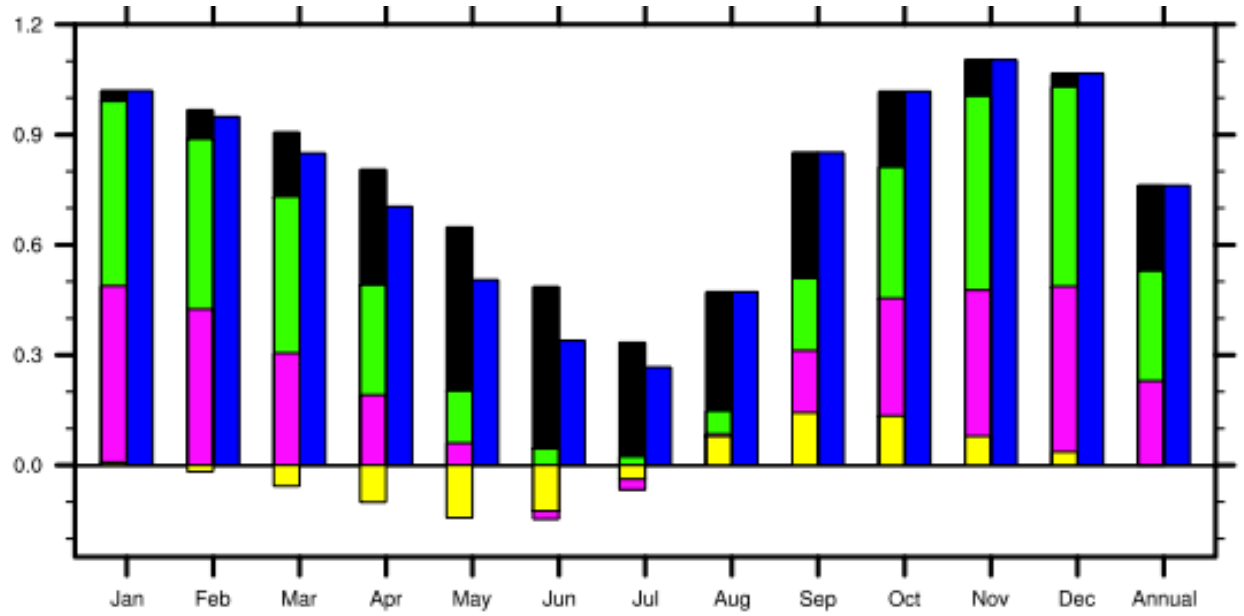
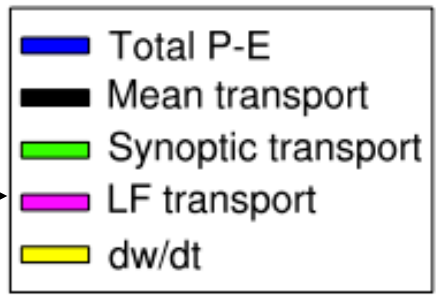


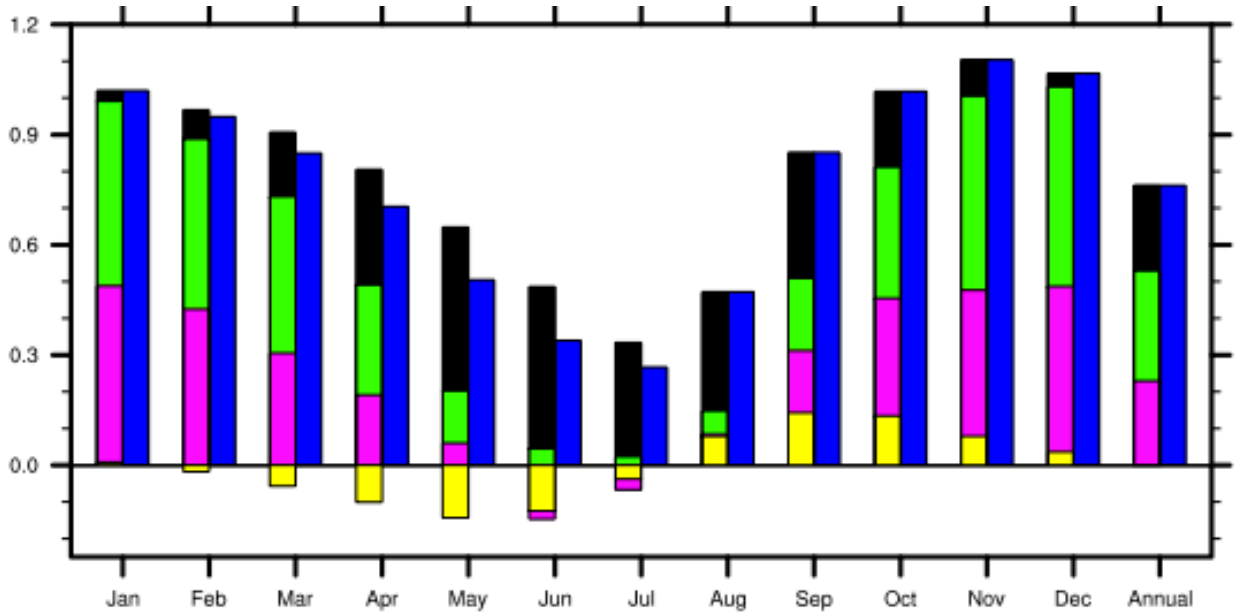
Months



Mostly Western North America

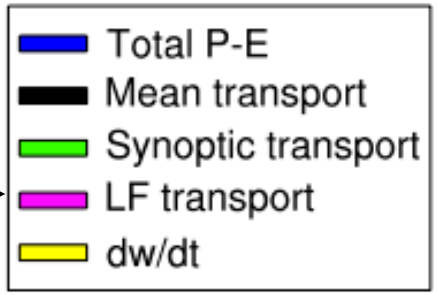
Mostly Eastern North America

Moisture transport from ocean into North America

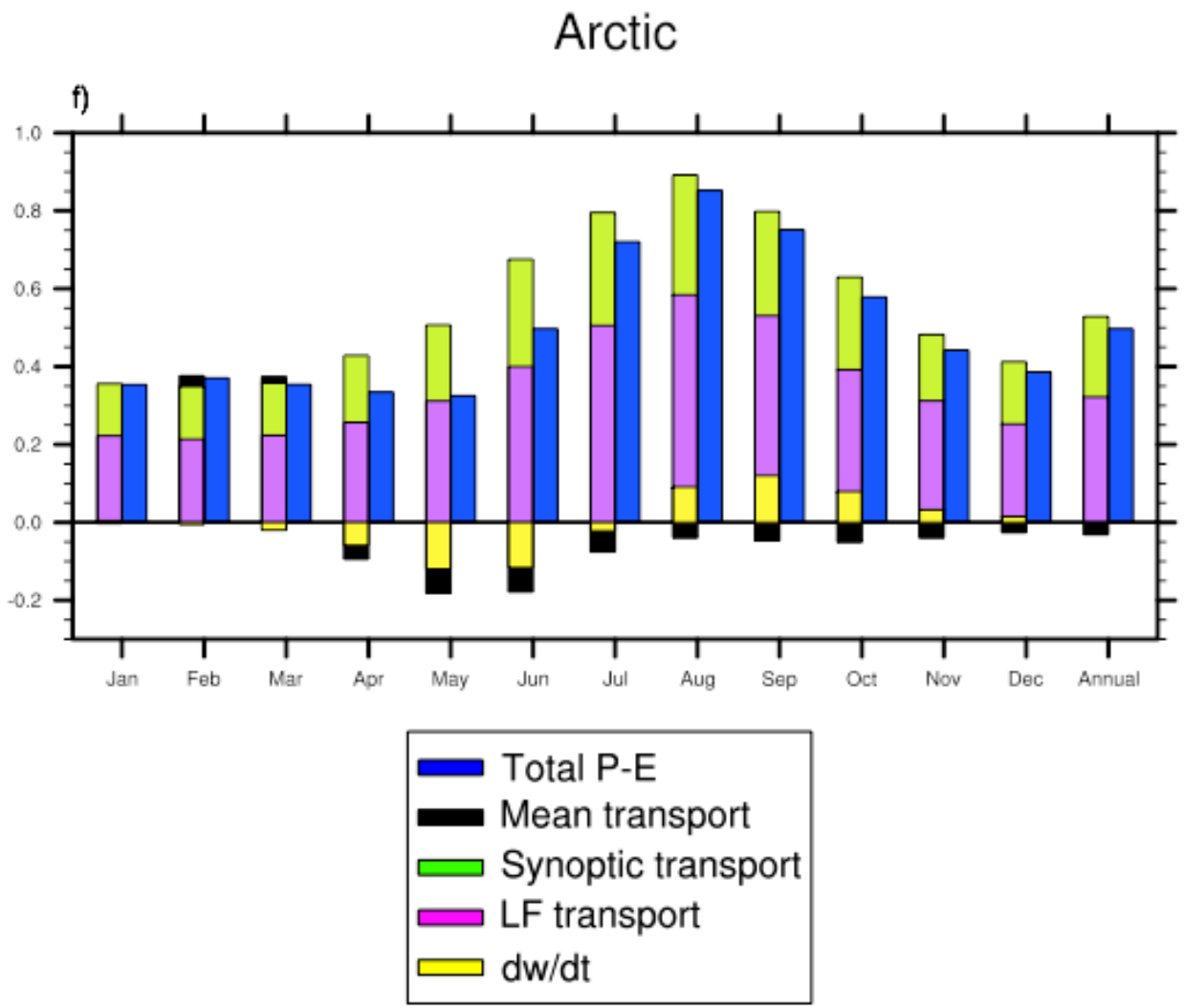


Months

Related to ENSO and Aleutian Low



Moisture transport into the Arctic (north of 70N)



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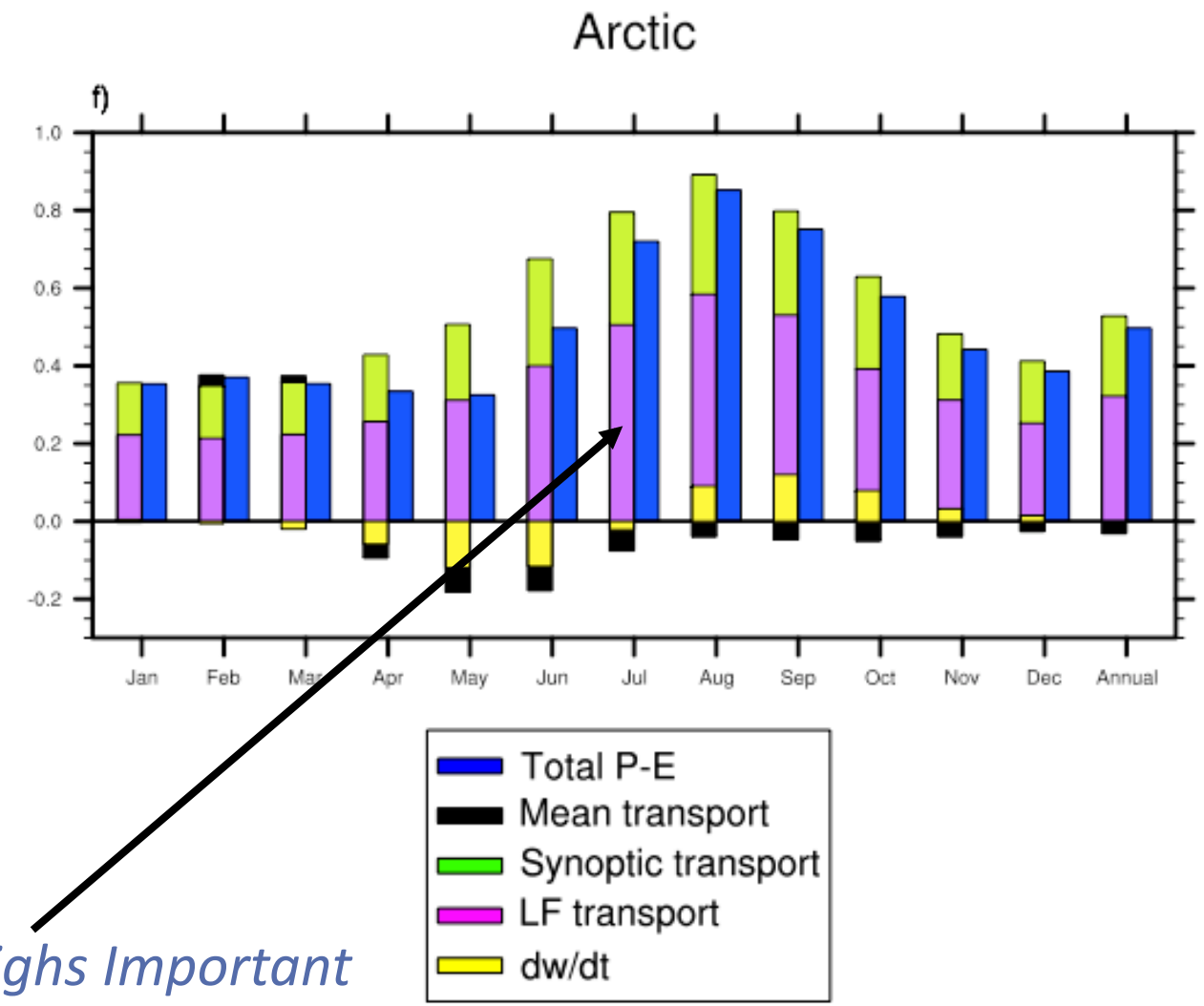
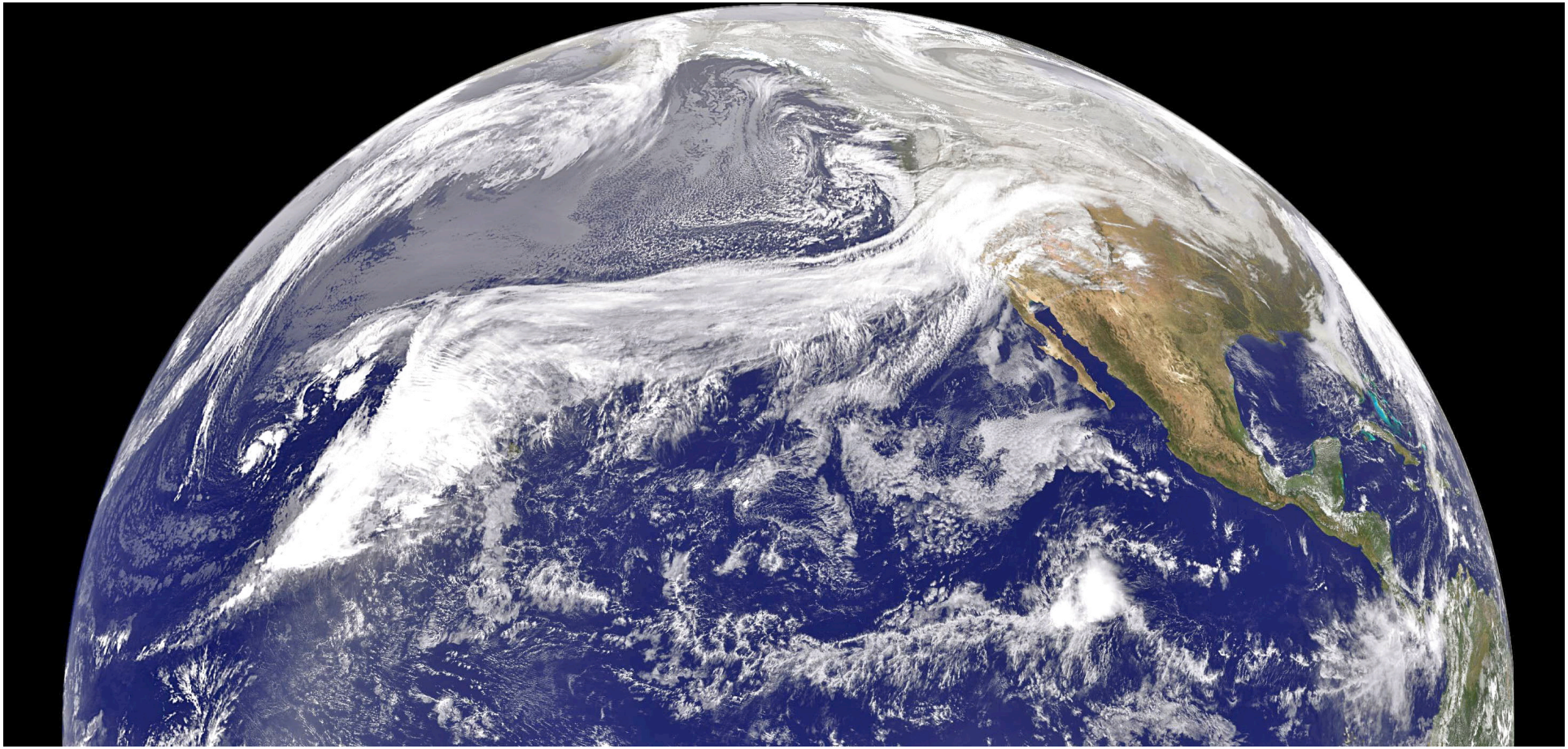


Blocking Highs Important

The Role of Atmospheric Rivers



Yong Zhu and Reginald E. Newell, 1998 Monthly Weather Review:

"…The results show that tropospheric rivers may carry essentially the total meridional transport observed in the extratropical atmosphere but may occupy only about 10% of the total longitudinal length at a given latitude…"

Zhu and Newell (1998) Atmospheric River Definition

An atmospheric river exists wherever and whenever:

$$\vec{Q}_r \geq Q_{mean} + 0.3(Q_{\max} - Q_{mean})$$

Where Q_{mean} *is the amplitude of the zonal mean flux*

and $Q_{\max}$ *is the longitudinal maximum of the flux amplitude*

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i.e. where the flux is > (70% of the zonal mean flux + 30% of the maximum flux)

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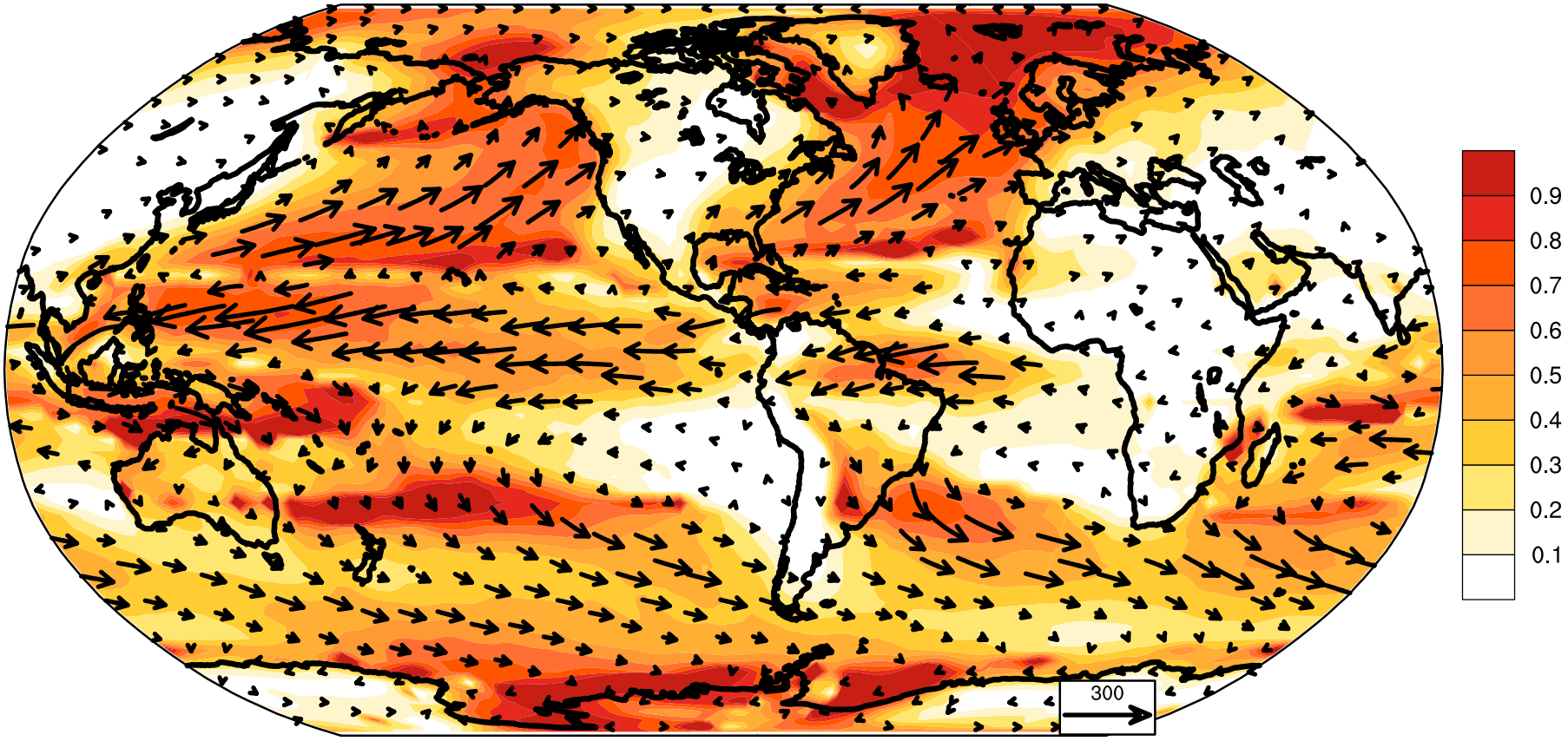
i.e. where the flux is > (70% of the zonal mean flux + 30% of the maximum flux)

Does not differentiate between transient and steady transport

Moisture Transport by Atmospheric Rivers

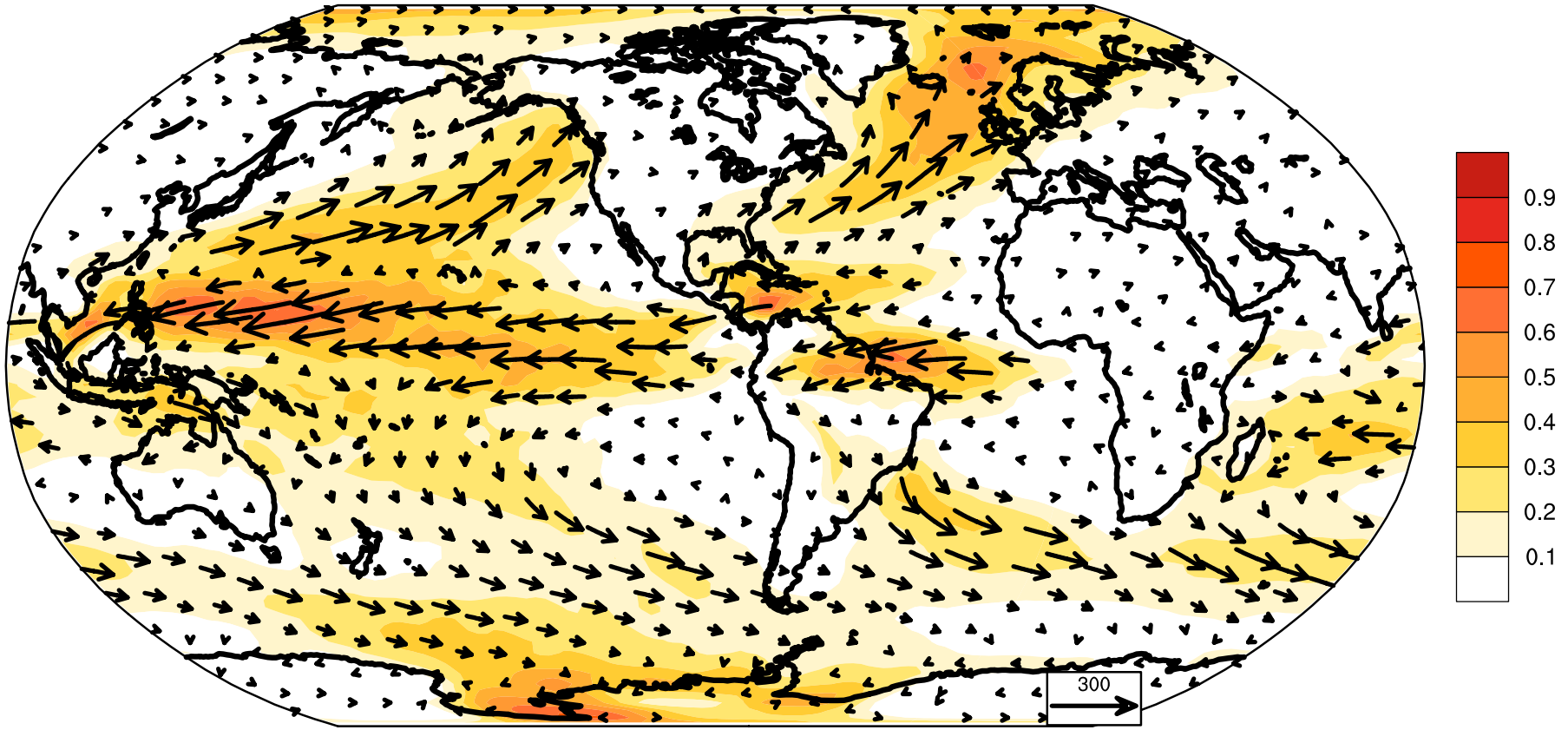
AR flux composite



Total Moisture Flux by Atmospheric Rivers (vectors) and its ratio to the total flux (shading) during December-February

Moisture Transport by Atmospheric Rivers

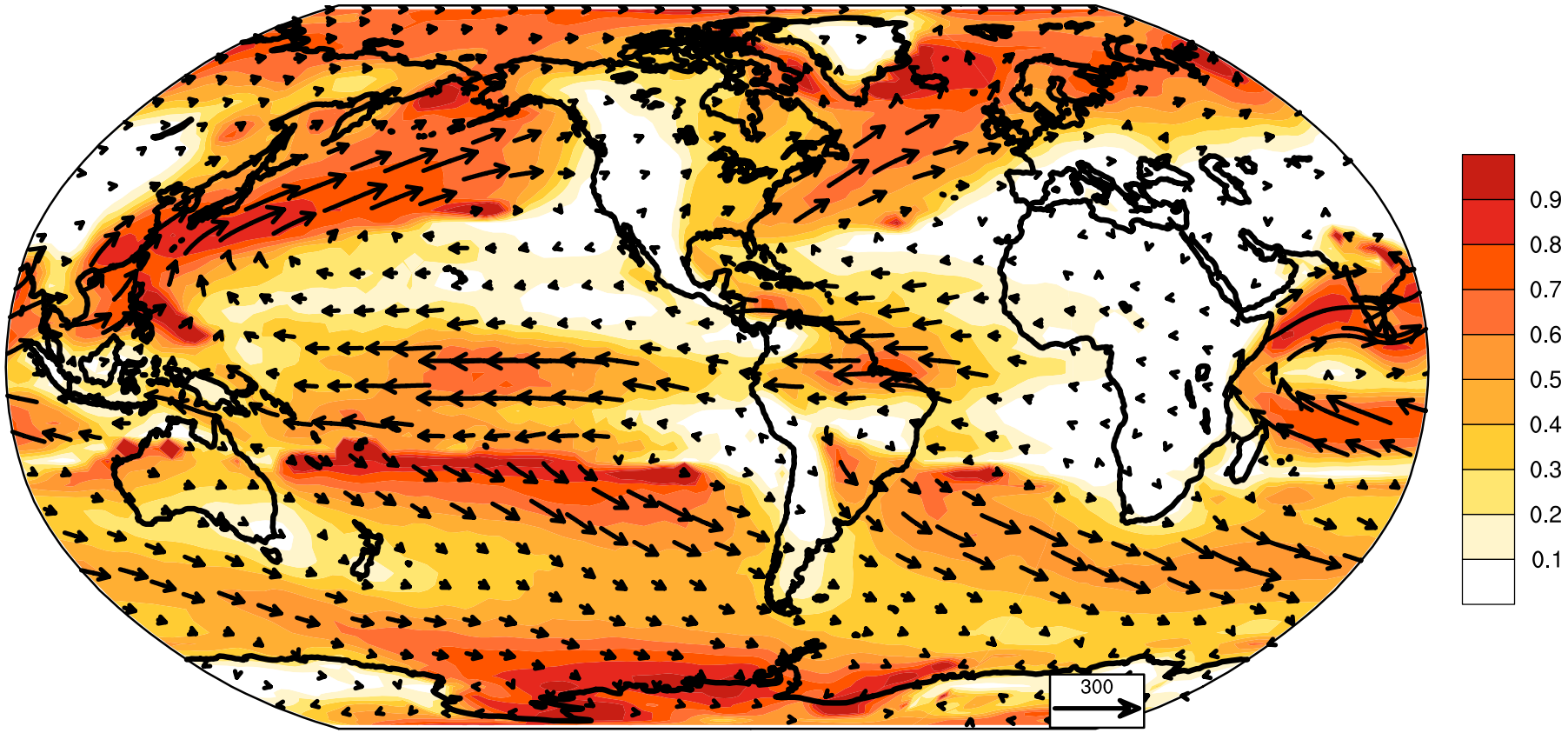
AR flux composite



Total Moisture Flux by Atmospheric Rivers (vectors) and its frequency (shading) during December-February

Moisture Transport by Atmospheric Rivers

AR flux composite



Total Moisture Flux by Atmospheric Rivers (vectors) and its ratio to the total flux (shading) during June-August

Conclusions

Time mean circulation transports moisture primarily zonally within ocean basins

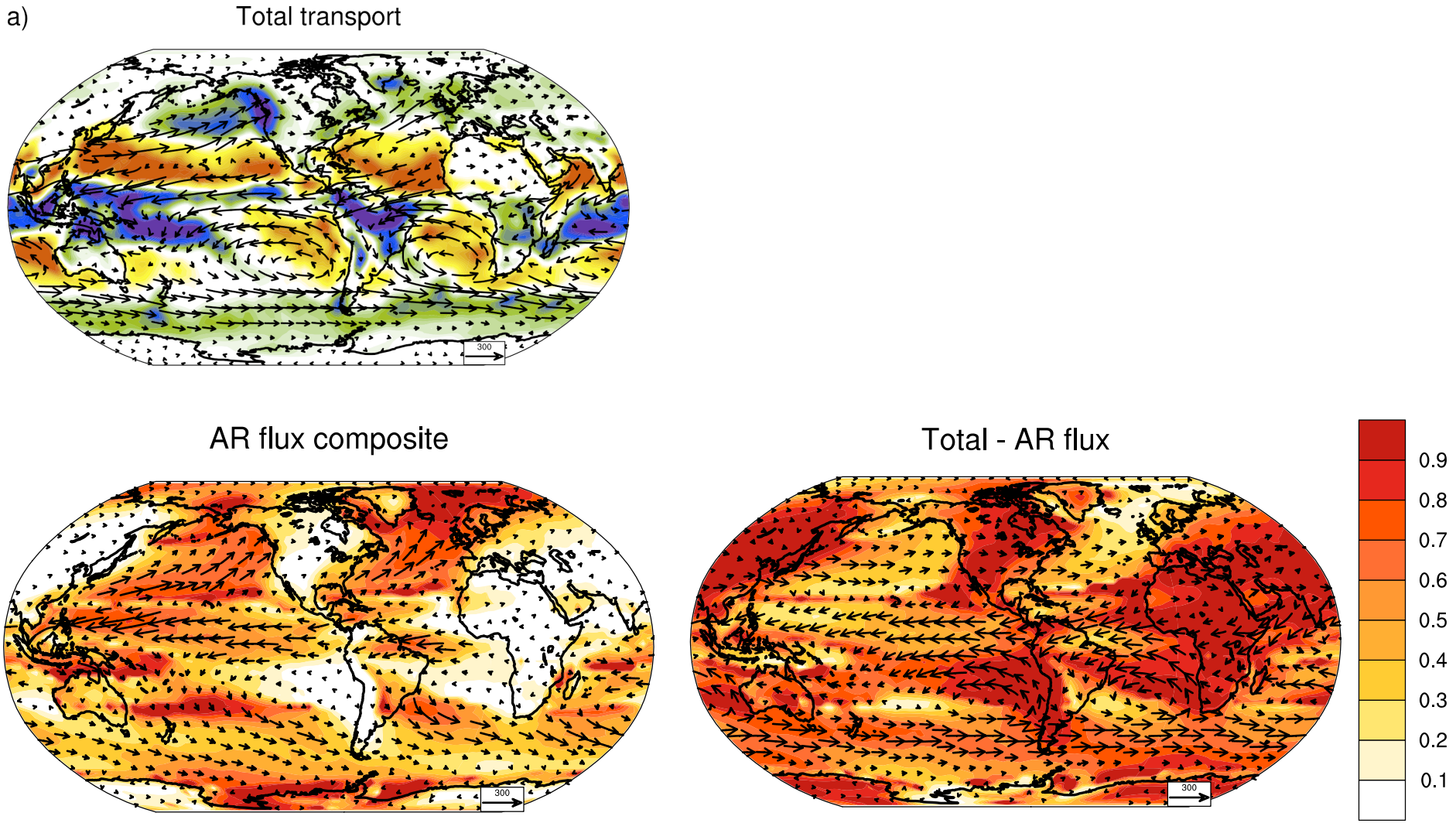
Extratropical synoptic and low frequency variations drive primarily meridional transports

Synoptic and low frequency variations are responsible for most of the transport from ocean to land (except during summer)

Moisture transport into the extratropical continents under climate change will likely depend not only on changes in moisture content (CC scaling) but on changes in LF circulation as well

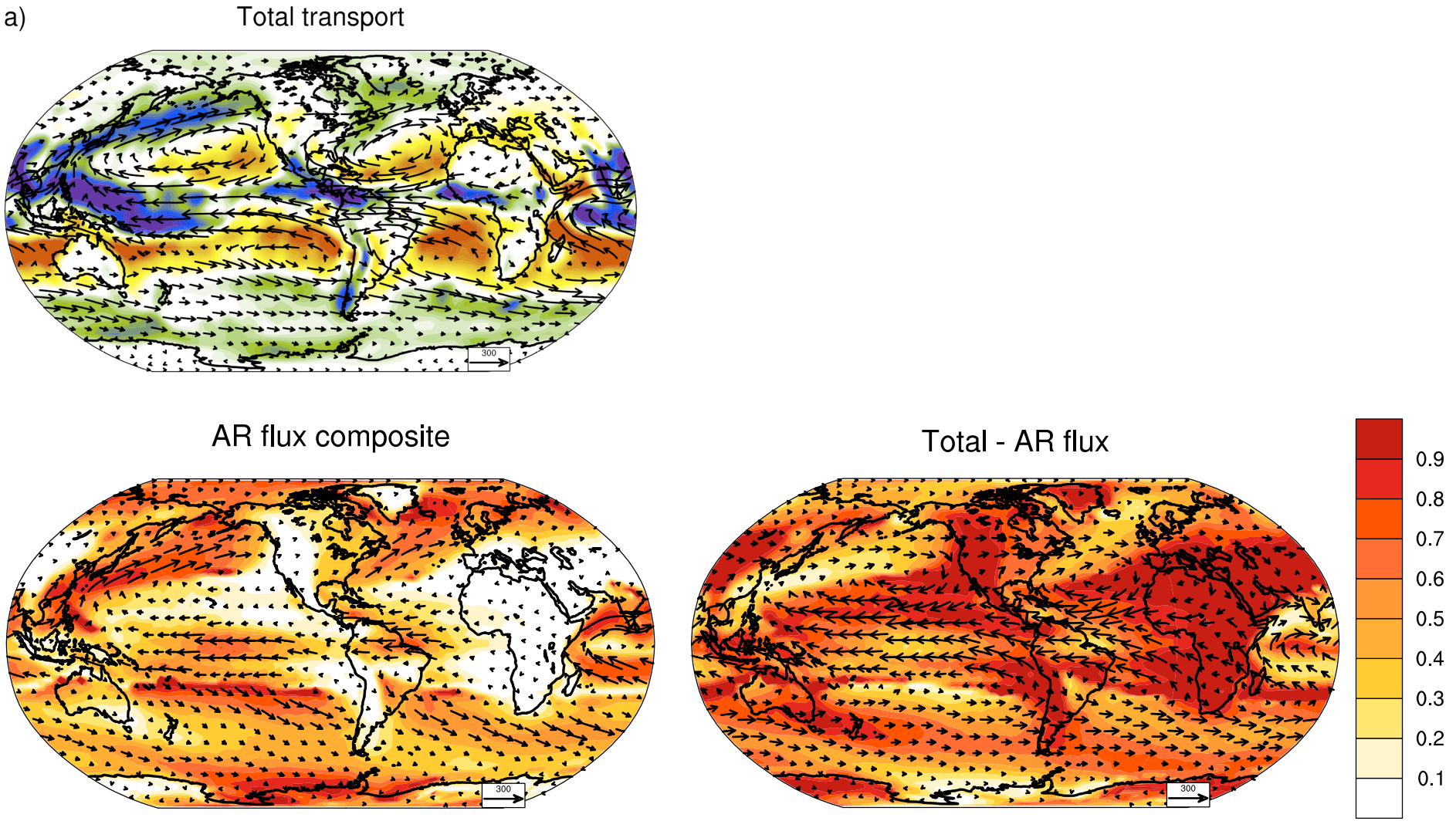
Much if not most of the transport indeed occurs within "Atmospheric Rivers" (but these are difficult to define objectively), and these signals project strongly on the mean and LF transport

Moisture Transport by Atmospheric Rivers

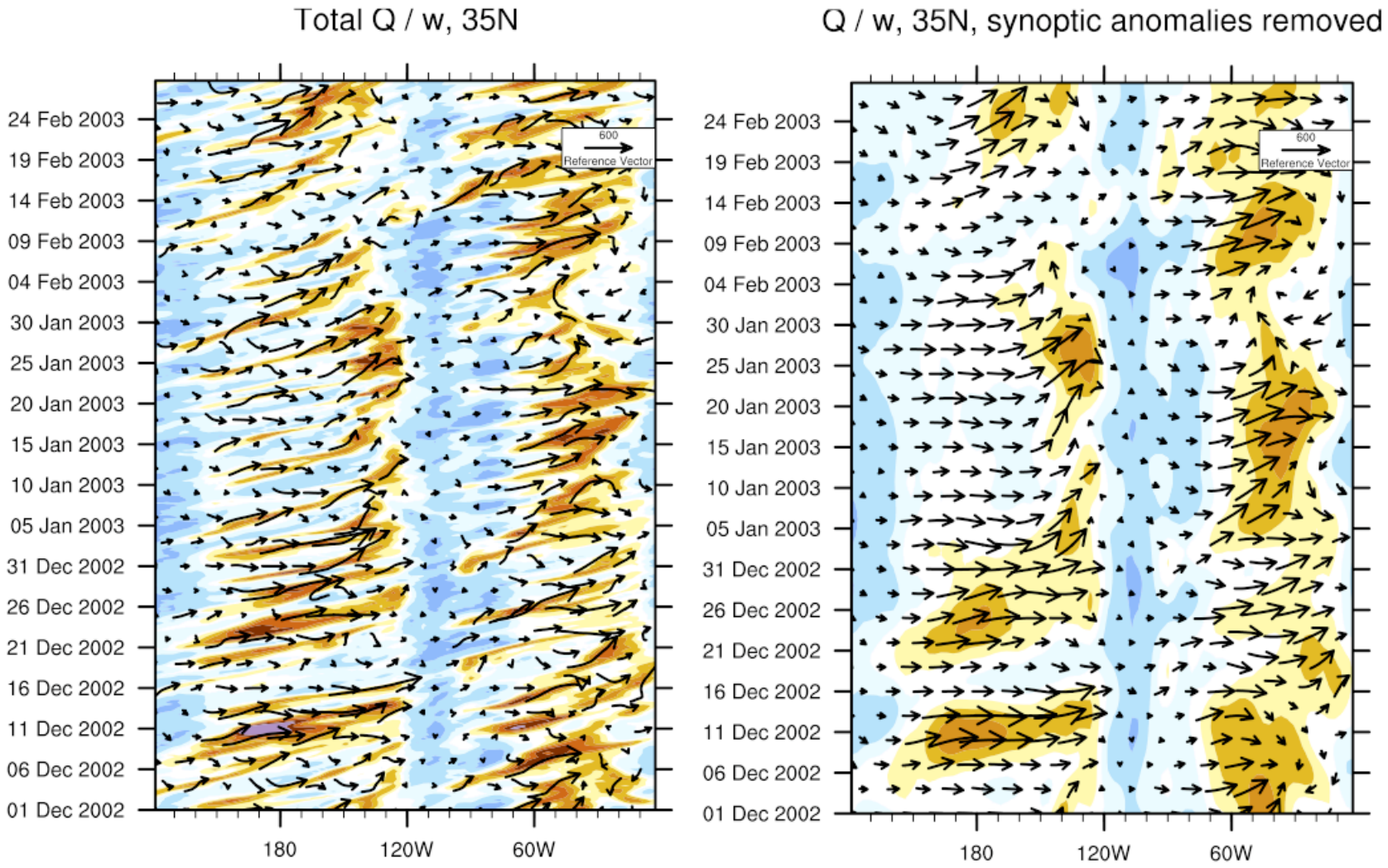


Total Moisture Flux by Atmospheric Rivers (vectors) and its ratio to the total flux (shading) during December-February

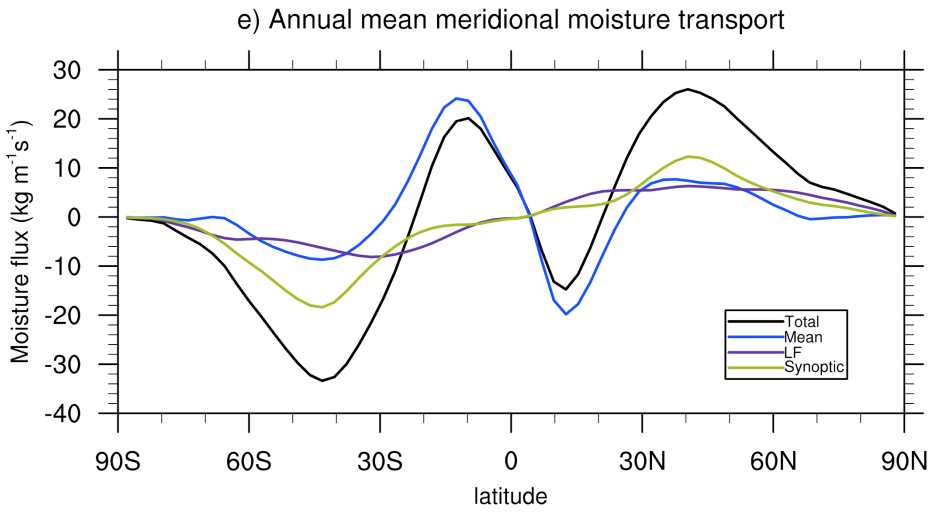
Moisture Transport by Atmospheric Rivers

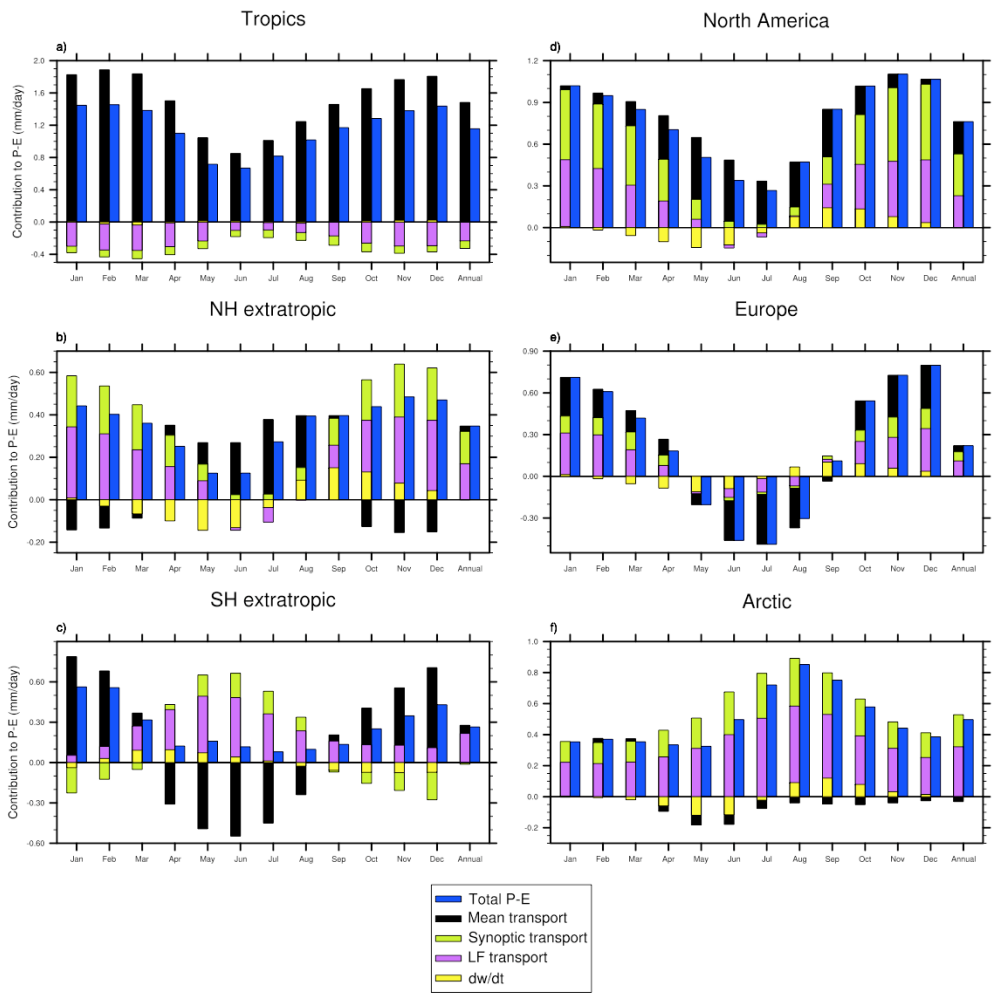


Total Moisture Flux by Atmospheric Rivers (vectors) and its ratio to the total flux (shading) during June-August

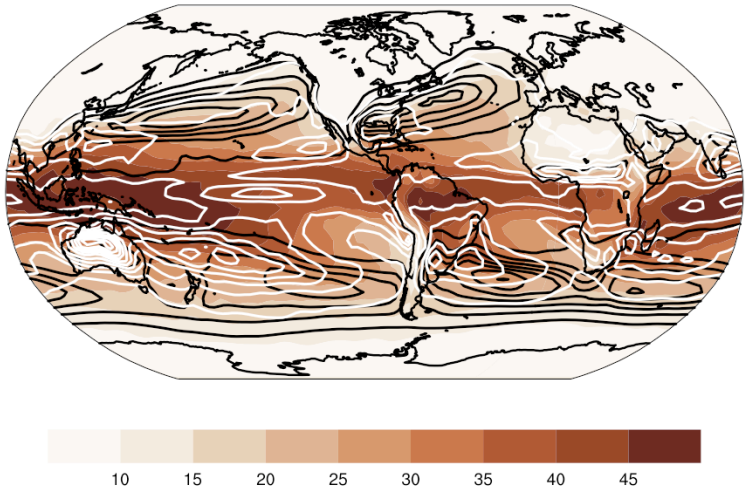


Total Moisture Flux (vectors) PW > 10 filtered Flux and PW

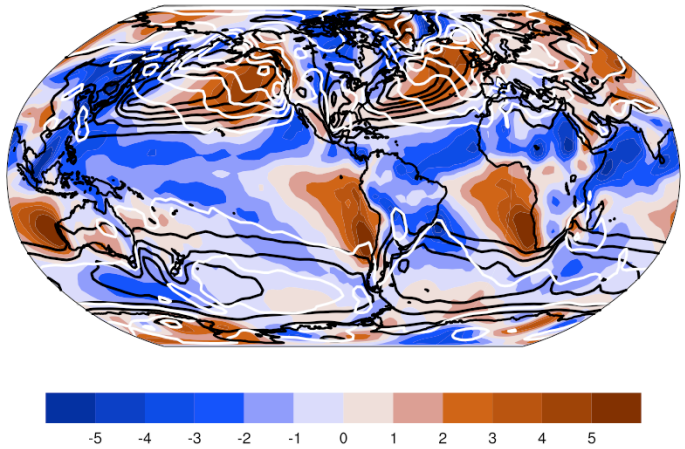

e) Annual mean meridional moisture transport
Moisture flux (kg m-1s-1)
30
20
10
0
-10
-20
-30
-40
90S
60S
30S
0
30N
60N
90N
latitude
Total
Mean
LF
Synoptic

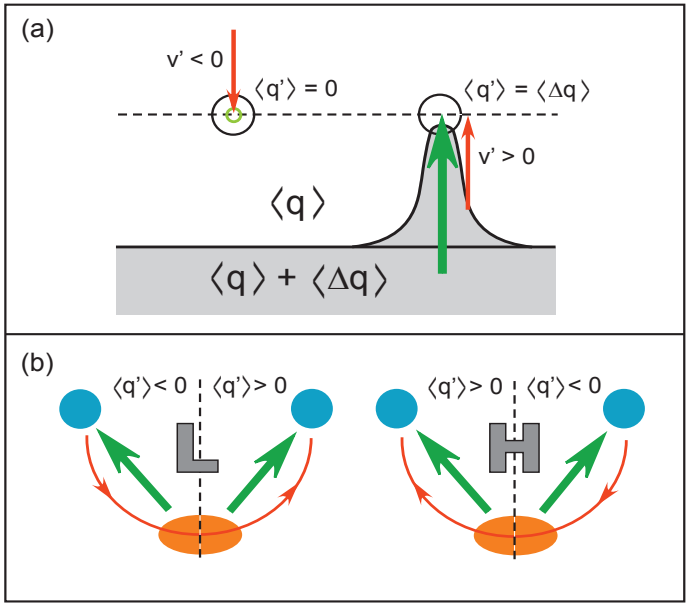

Moisture transport into selected regions
Tropics
North America
NH extratropic
Europe
SH extratropic
Arctic
a)
b)
c)
d)
e)
f)
Contribution to P-E (mm/day)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Annual
Total P-E
Mean transport
Synoptic transport
LF transport
dw/dt

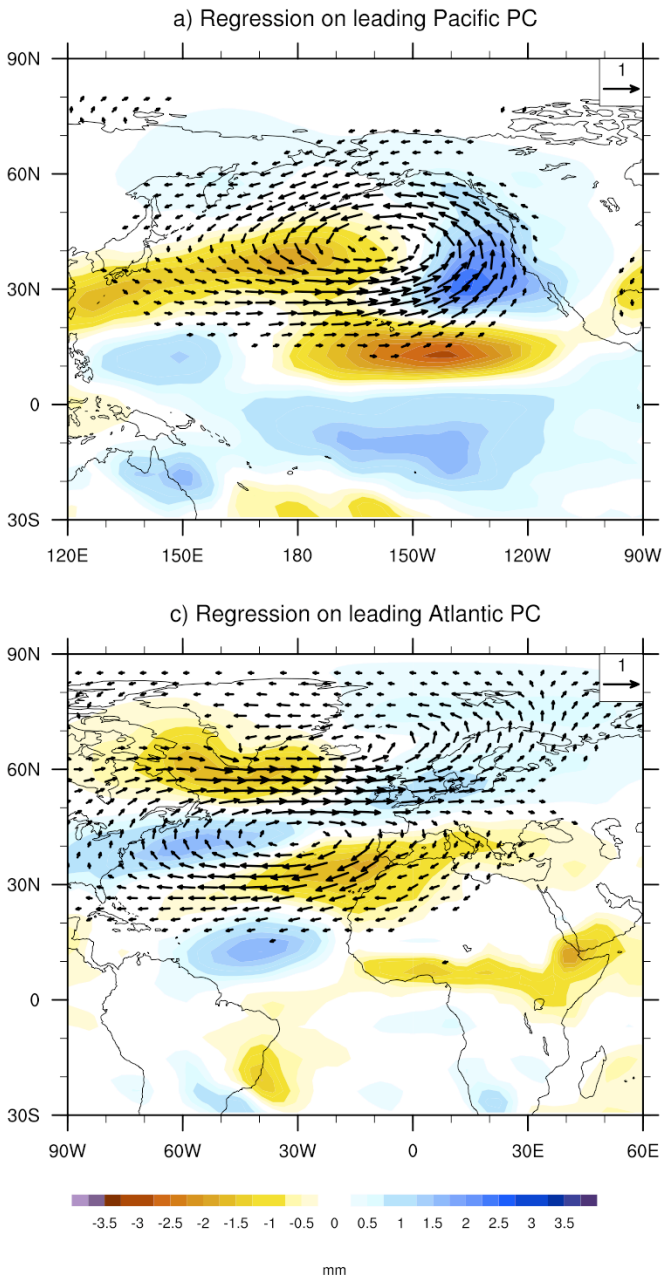
Precipitable water climatology/highpass variance/lowpass variance DJF 1968-2007

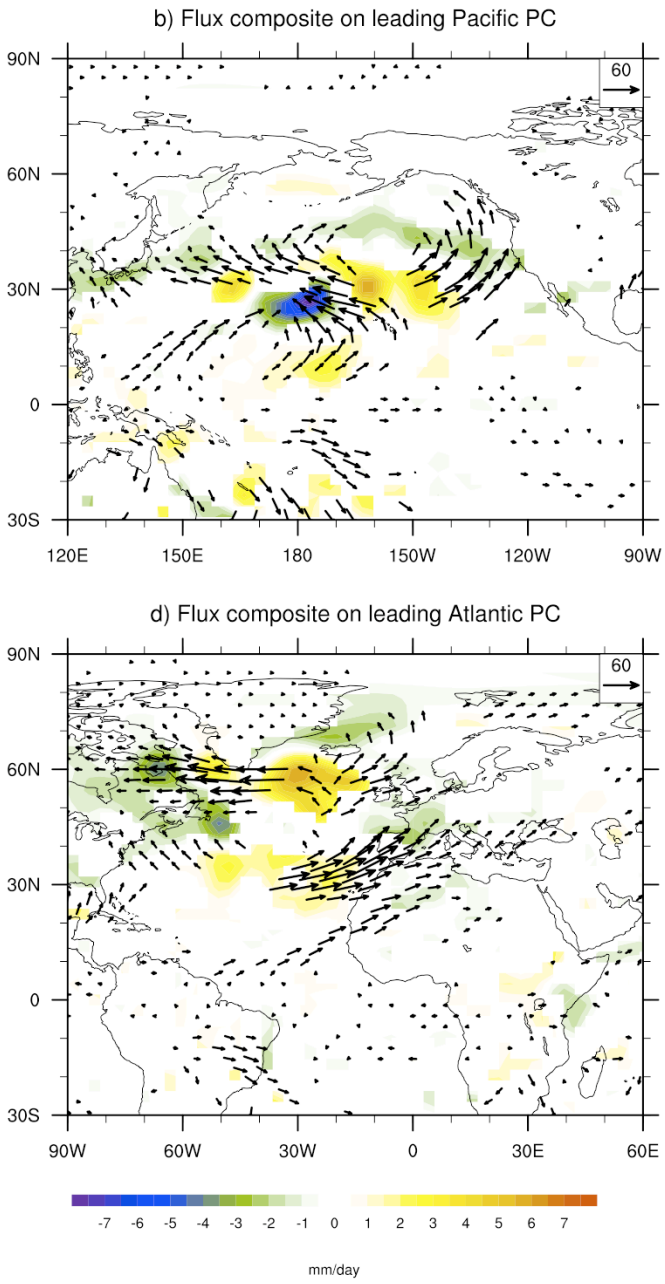


Low-level meridional wind climatology/highpass variance/lowpass variance DJF 1968-2007




(a)
v' < 0
⟨q'⟩ = 0
⟨q'⟩ = ⟨Δq⟩
v' > 0
⟨q⟩
⟨q⟩ + ⟨Δq⟩
(b)
⟨q'⟩< 0
⟨q'⟩> 0
L
⟨q'⟩> 0
⟨q'⟩< 0
H

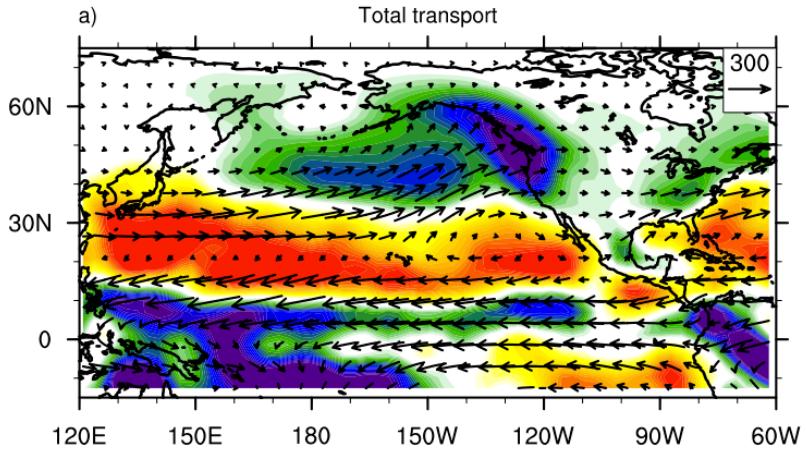

a) Regression on leading Pacific PC
90N
60N
30N
0
30S
120E
150E
180
150W
120W
90W
1
c) Regression on leading Atlantic PC
90N
60N
30N
0
30S
90W
60W
30W
0
30E
60E
1
-3.5 -3 -2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5 3 3.5
mm

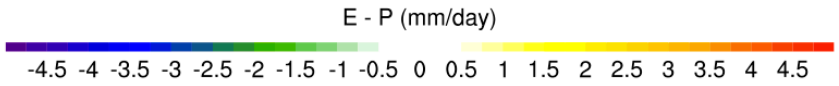

b) Flux composite on leading Pacific PC
90N
60N
30N
0
30S
120E
150E
180
150W
120W
90W
60
d) Flux composite on leading Atlantic PC
90N
60N
30N
0
30S
90W
60W
30W
0
30E
60E
60
-7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7
mm/day

Wintertime mean moisture transport (1968-2007)

Total transport = Transport by time-mean flow
+ Transport by synoptic eddies (>10 days)
+ Transport by "low-frequency" eddies (<10 days)

Flux vectors: kg/(ms)





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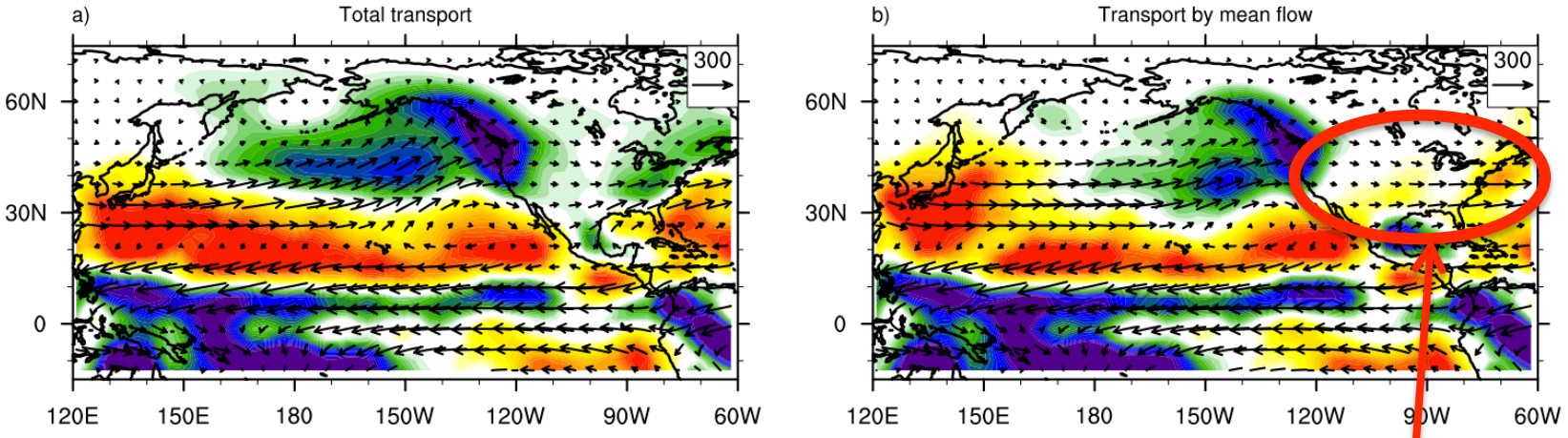
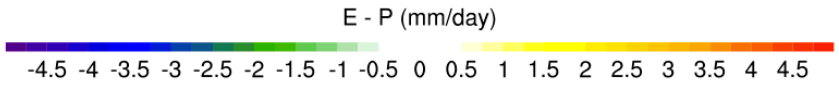


Mean flow acts to dry the land



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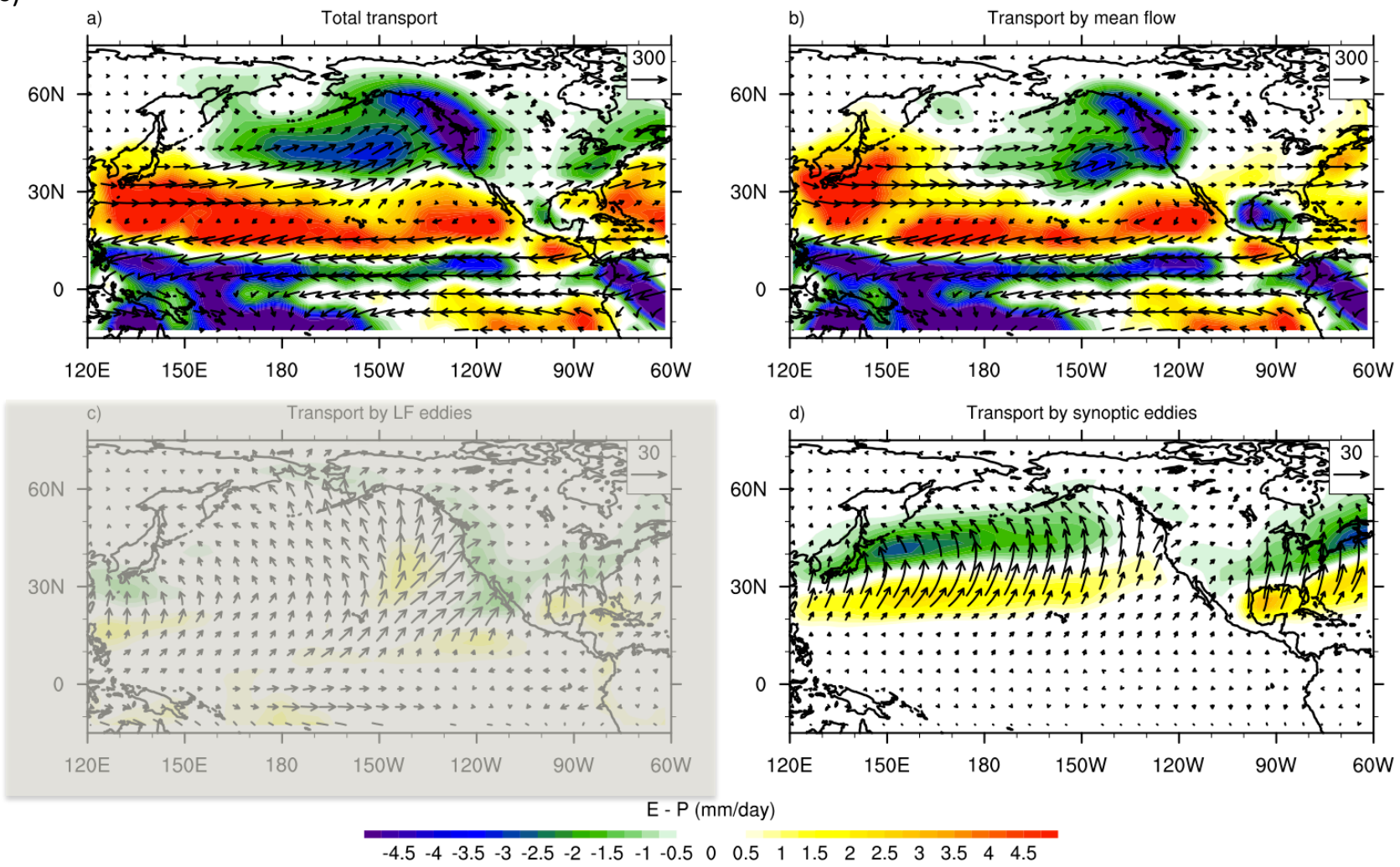

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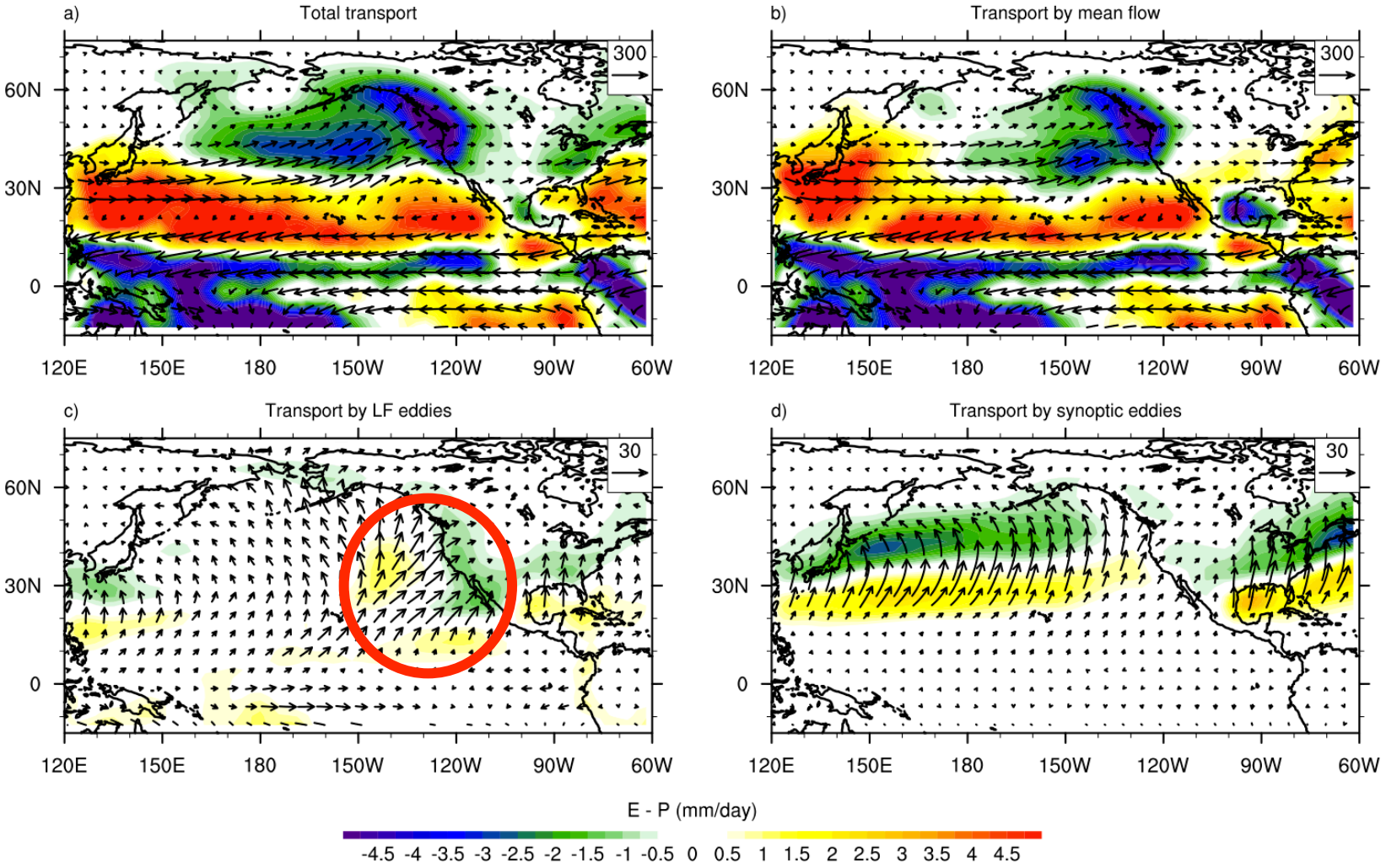
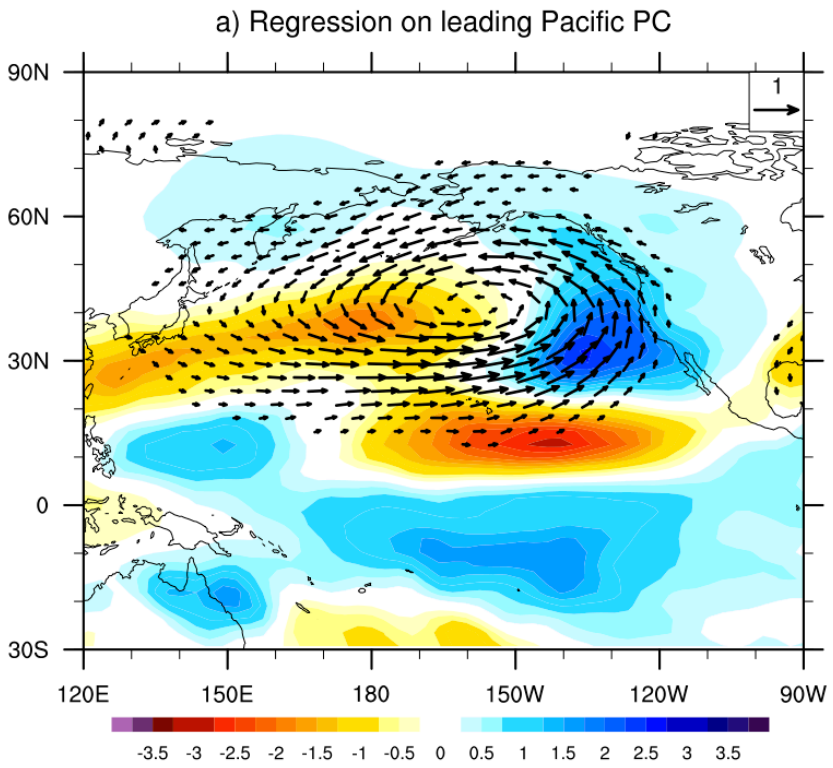
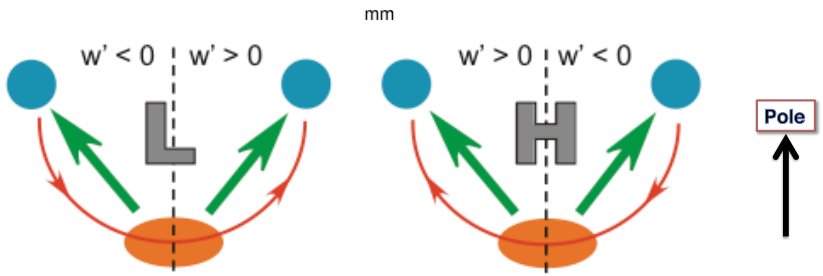
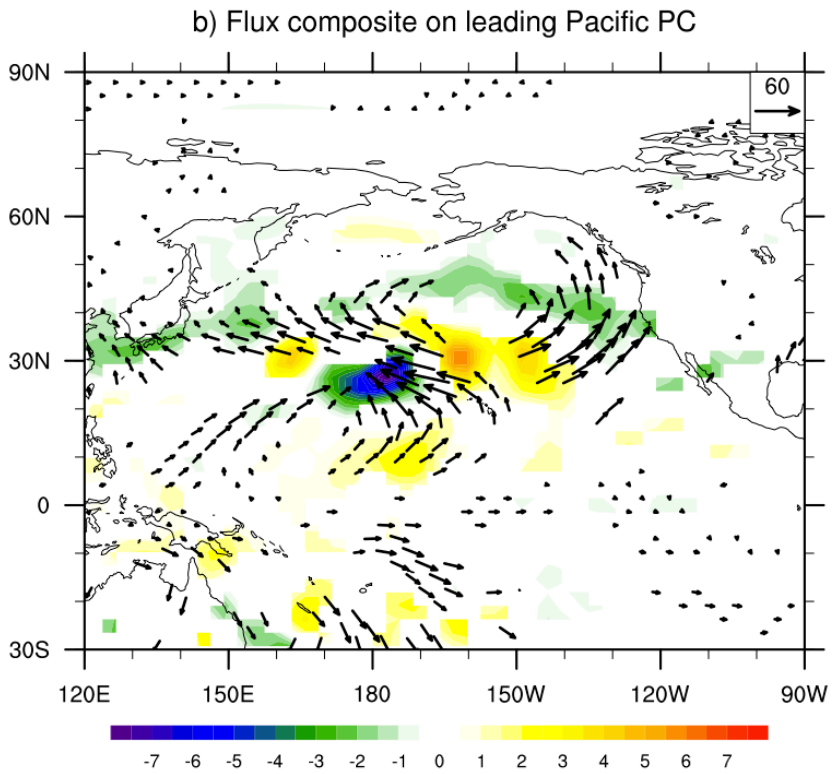
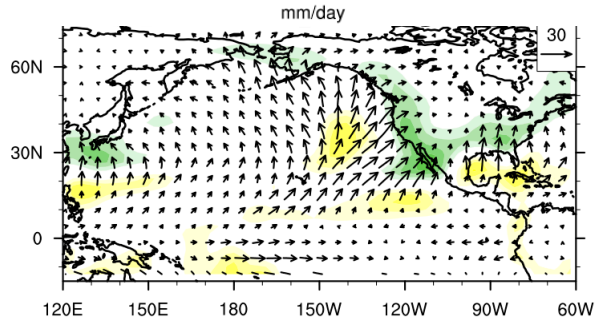


Low-frequency variability of the Aleutian Low drives moisture transport from NE Pacific to North America

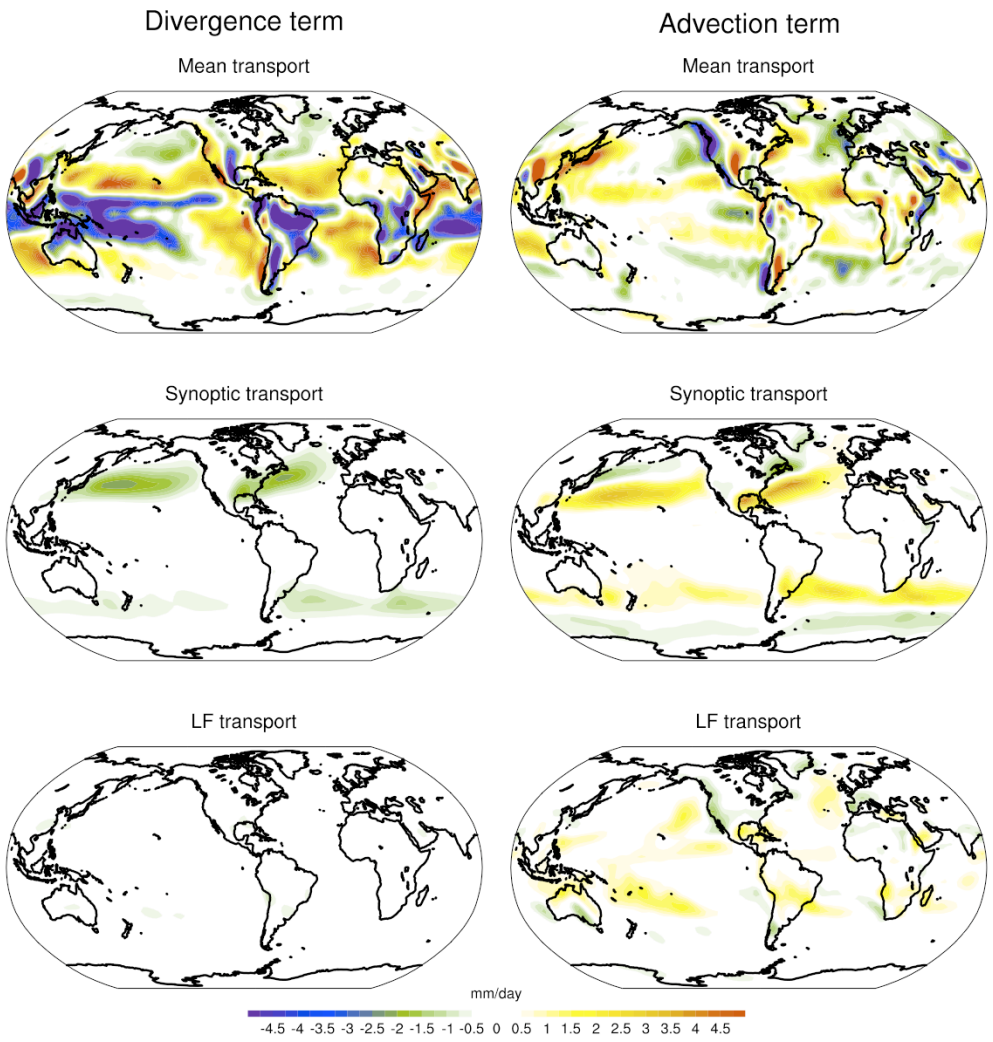




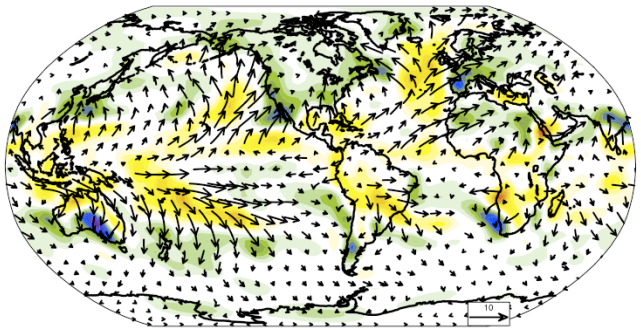




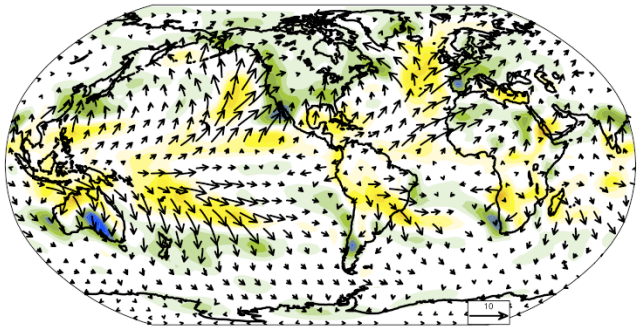
- If variability on “low-frequency” time scales (e.g., Aleutian Low) drives the climatological moisture flow into western North America…
- …then what is the predictable part of this variability, and how does this affect precipitation anomalies?


Divergence term
Advection term
Mean transport
Mean transport
Synoptic transport
Synoptic transport
LF transport
LF transport
mm/day
-4.5 -4 -3.5 -3 -2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5

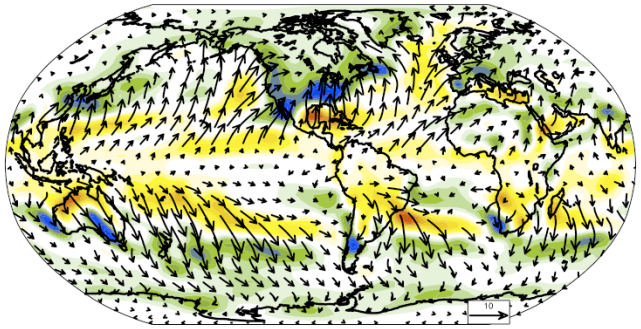
Transport by 90+ day anomalies



Transport by bandpass (30-90) anomalies

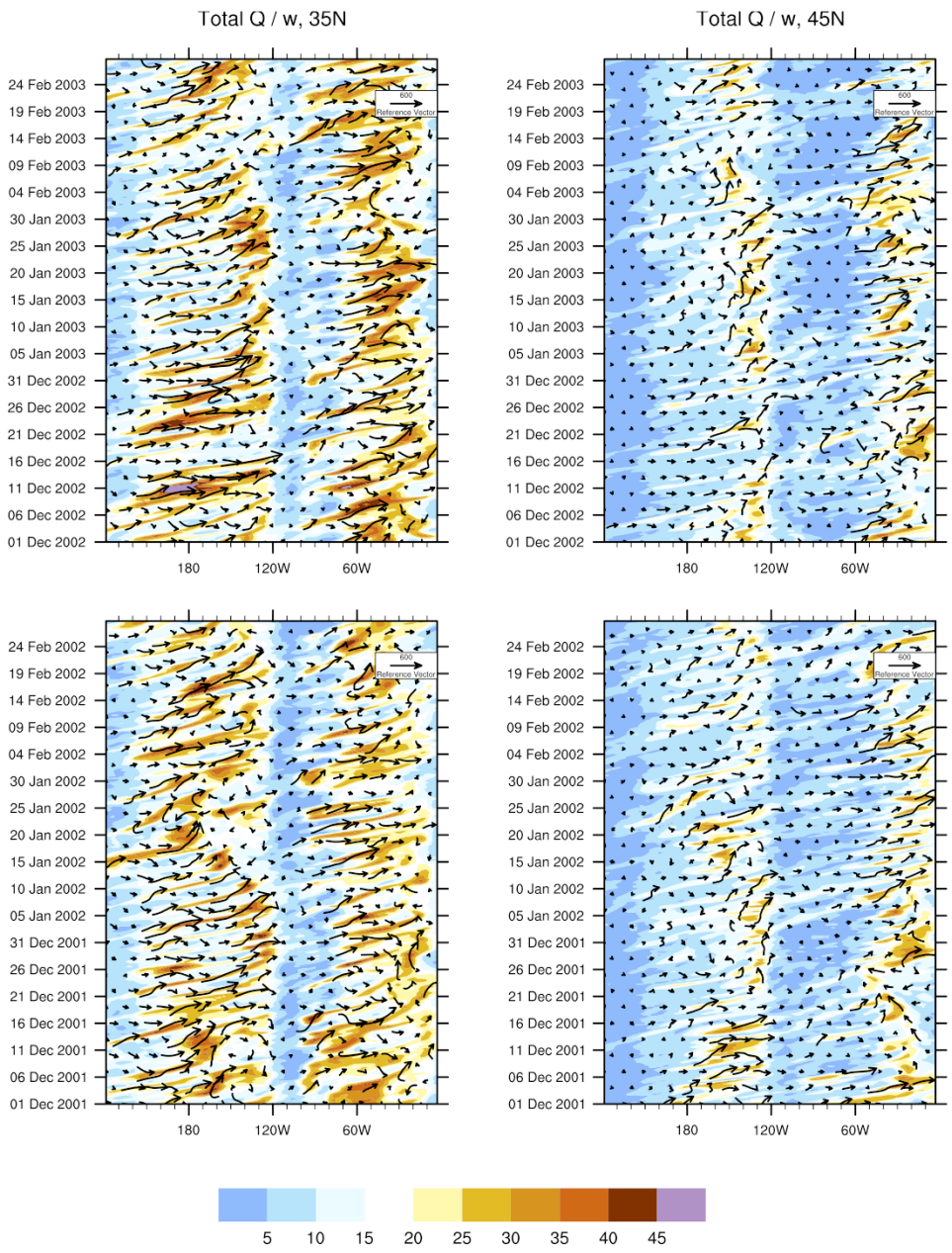


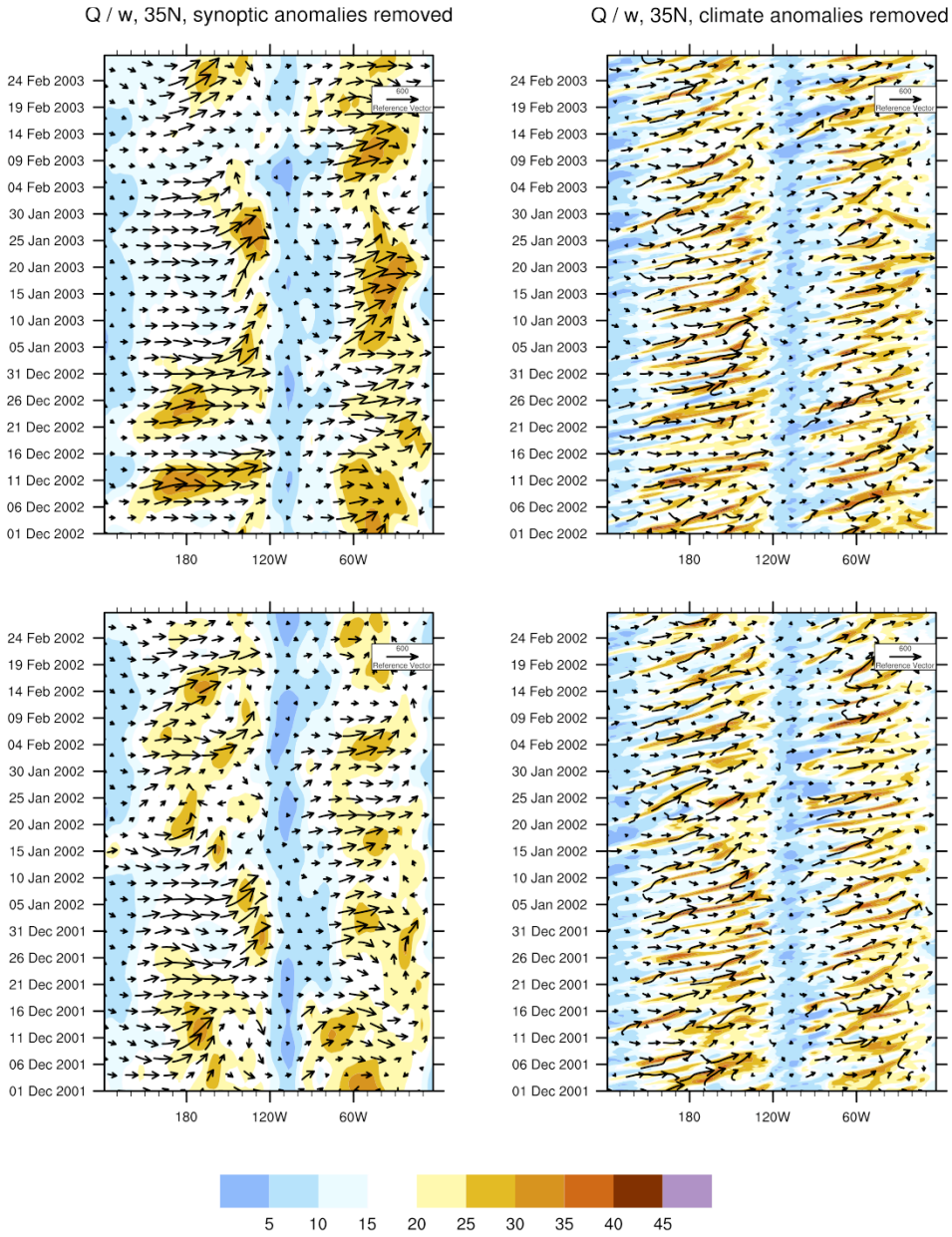
Transport by bandpass (10-30) anomalies



mm/day

-0.8 -0.64 -0.48 -0.32 -0.16 0 0.16 0.32 0.48 0.64 0.8


Total Q / w, 35N
Total Q / w, 45N
24 Feb 2003
19 Feb 2003
14 Feb 2003
09 Feb 2003
04 Feb 2003
30 Jan 2003
25 Jan 2003
20 Jan 2003
15 Jan 2003
10 Jan 2003
05 Jan 2003
31 Dec 2002
26 Dec 2002
21 Dec 2002
16 Dec 2002
11 Dec 2002
06 Dec 2002
01 Dec 2002
24 Feb 2002
19 Feb 2002
14 Feb 2002
09 Feb 2002
04 Feb 2002
30 Jan 2002
25 Jan 2002
20 Jan 2002
15 Jan 2002
10 Jan 2002
05 Jan 2002
31 Dec 2001
26 Dec 2001
21 Dec 2001
16 Dec 2001
11 Dec 2001
06 Dec 2001
01 Dec 2001
180
120W
60W
600
Reference Vector
5
10
15
20
25
30
35
40
45


Q / w, 35N, synoptic anomalies removed
Q / w, 35N, climate anomalies removed
600
Reference Vector
24 Feb 2003
19 Feb 2003
14 Feb 2003
09 Feb 2003
04 Feb 2003
30 Jan 2003
25 Jan 2003
20 Jan 2003
15 Jan 2003
10 Jan 2003
05 Jan 2003
31 Dec 2002
26 Dec 2002
21 Dec 2002
16 Dec 2002
11 Dec 2002
06 Dec 2002
01 Dec 2002
24 Feb 2002
19 Feb 2002
14 Feb 2002
09 Feb 2002
04 Feb 2002
30 Jan 2002
25 Jan 2002
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15 Jan 2002
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05 Jan 2002
31 Dec 2001
26 Dec 2001
21 Dec 2001
16 Dec 2001
11 Dec 2001
06 Dec 2001
01 Dec 2001
180
120W
60W
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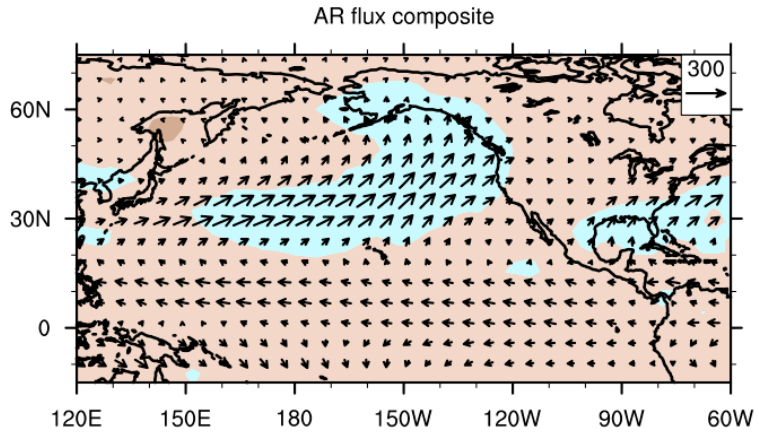
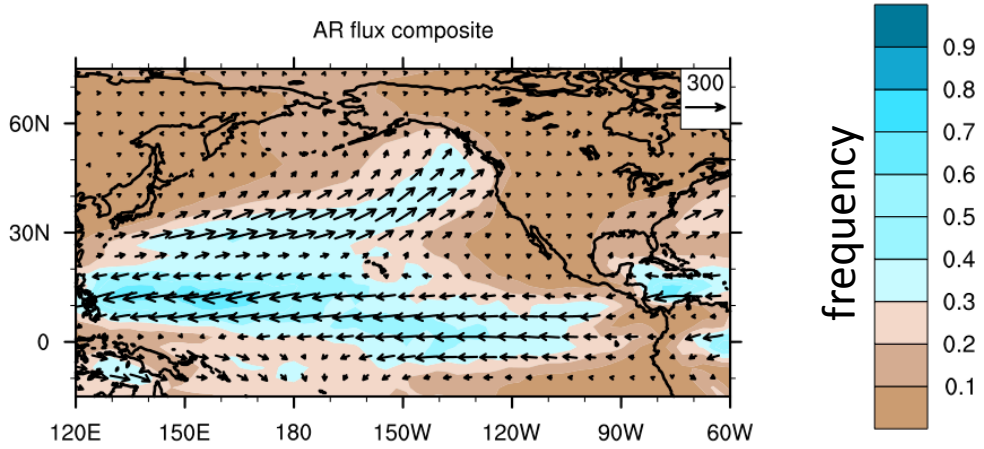
20
25
30
35
40
45

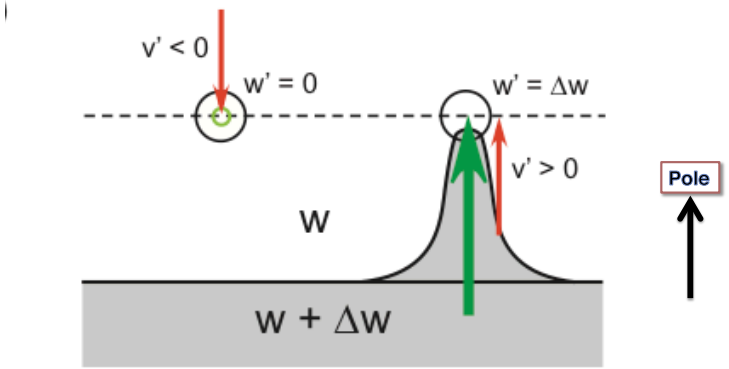
Moisture transport by atmospheric rivers (ARs)

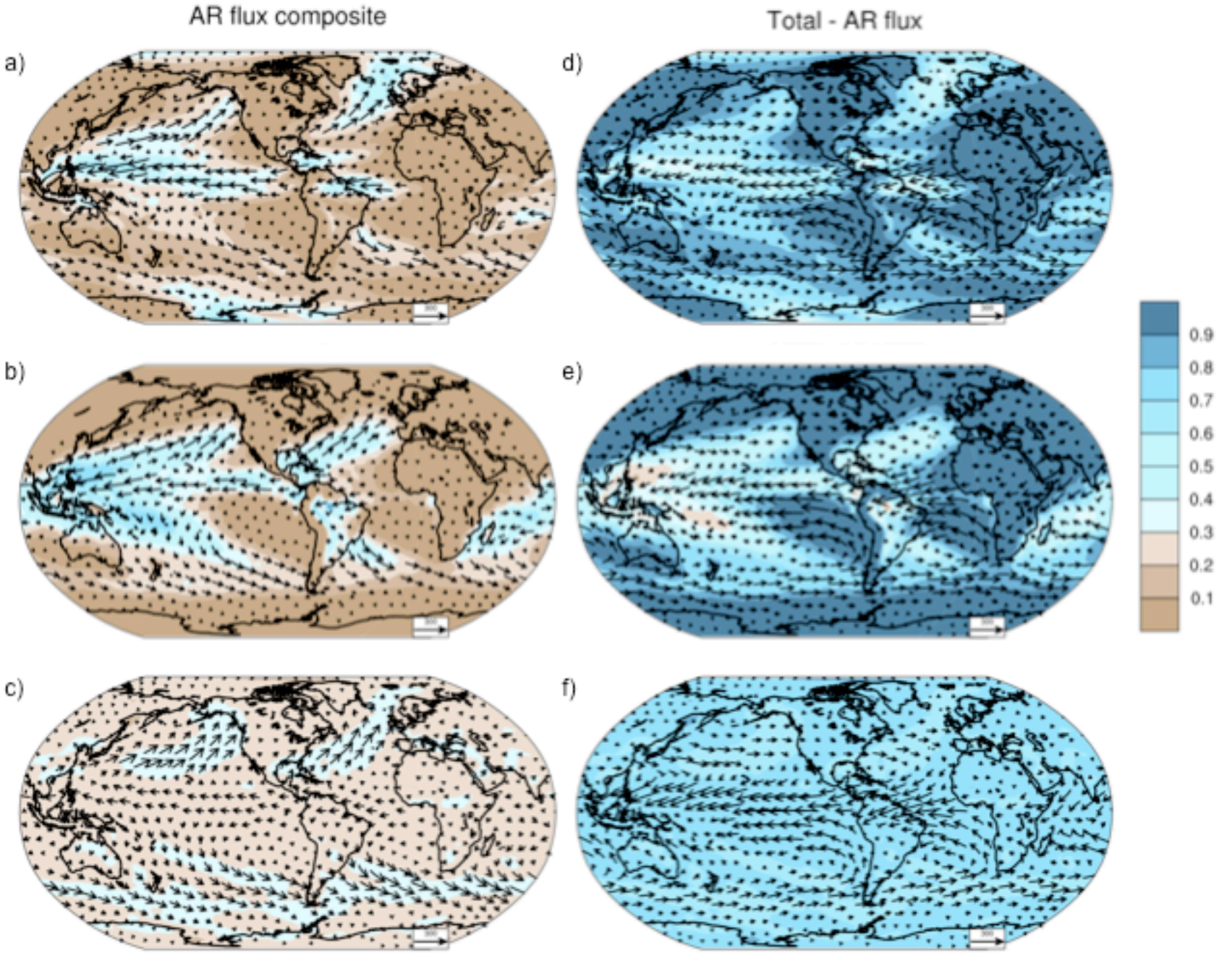


Composite: *both* poleward wind anomaly and positive column-integrated water anomaly



Composite: based on zonal narrowness of regions of intense moisture flux (Zhu and Newell 1998)




AR flux composite
Total - AR flux
a)
b)
c)
d)
e)
f)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

Conclusions

Moisture transport varies substantially on synoptic to low frequency timescales, especially for ocean to land transports

Most of the moisture transport variability is due to changes in circulation (rather than in moisture sources and sinks)

This means that climate change scenarios have to take into account not only mean atmospheric moisture content changes (due to Clausius-Claperon) but intraseasonal circulation changes as well

"Atmospheric Rivers" are relevant, and their signals project strongly on the mean transport

The role of Atmospheric Rivers in direct transport from tropical moisture sources has yet be assessed by detailed trajectory studies

Gross features of the moisture transport signals and their sources and sinks depend almost entirely on the wind field