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

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

\( q \) Specific humidity

\( \langle q \rangle \) Vertical integral (on sigma coordinates)

\( \langle \rangle \) Vertically integrated specific humidity (precipitable water)

\( \vec{Q} \) Vertically integrated moisture flux

\( E - P \) Evaporation minus precipitation
\[ \frac{\partial \langle q \rangle}{\partial t} + \nabla \cdot \mathbf{Q} = E - P \]

*Problematic in reanalyses*
Straightforward to calculate and consistent among reanalyses
\[
\frac{\partial \langle q \rangle}{\partial t} + \nabla \cdot \vec{Q} = E - P
\]

Small for time mean (especially during the solstice seasons)
\[ \frac{\partial \langle q \rangle}{\partial t} + \nabla \cdot \vec{Q} = E - P \]

Calculated as a residual
Time Mean Total Moisture Budget

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

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)*
Contributions to the Time Mean Moisture Budget

\[
\bar{Q} = \langle \bar{q} \bar{v} \bar{p}_s \rangle = \langle \bar{q} \bar{v} \bar{p}_s \rangle + \langle p_s \bar{v}'q' \rangle + \langle p_s \bar{v}''q'' \rangle
\]

- Total
- Mean
- > 10 days (LF)
- < 10 days (Synoptic)

*Example: by Synoptic we mean the contribution to the total transport by synoptic eddies*
December-February Transport

a) Total transport

b) Mean transport

c) LF transport

d) Synoptic transport

Flux scaled by 10
Zonal Mean Transport

a) Total meridional flux

b) Mean meridional flux

c) LF meridional flux

d) Synoptic meridional flux

Equatorward and cross-eq.
Zonal Mean Transport

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
Moisture transport from ocean into North America

Mostly Western North America

Mostly Eastern North America
Moisture transport from ocean into North America

Related to ENSO and Aleutian Low
Moisture transport into the Arctic (north of 70N)
Moisture transport into the Arctic (north of 70N)

Blocking Highs Important
The Role of Atmospheric Rivers
“...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:

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

Where $Q_{\text{mean}}$ is the amplitude of the zonal mean flux

and $Q_{\text{max}}$ is the longitudinal maximum of the flux amplitude
Zhu and Newell (1998) Atmospheric River Definition

An atmospheric river exists wherever and whenever:

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Where $Q_{\text{mean}}$ is the amplitude of the zonal mean flux

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

i.e. where the flux is $> (70\%$ of the zonal mean flux $+ 30\%$ of the maximum flux)
Zhu and Newell (1998) Atmospheric River Definition

An atmospheric river exists wherever and whenever:

\[ \tilde{Q}_r \geq Q_{\text{mean}} + 0.3(Q_{\text{max}} - Q_{\text{mean}}) \]

Where \( Q_{\text{mean}} \) is the amplitude of the zonal mean flux

and \( Q_{\text{max}} \) is the longitudinal maximum of the flux amplitude

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

**Total Moisture Flux by Atmospheric Rivers (vectors) and its frequency (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
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
Precipitable water climatology/highpass variance/lowpass variance DJF 1968-2007
Low-level meridional wind climatology/highpass variance/lowpass variance DJF 1968-2007
\[ q' = 0 \]
\[ q' > 0 \]
\[ v' < 0 \]
\[ v' > 0 \]

**Diagram (a):**
- \( \langle q' \rangle = 0 \)
- \( \langle q' \rangle = \langle \Delta q \rangle \)
- \( \langle q \rangle + \langle \Delta q \rangle \)

**Diagram (b):**
- \( \langle q' \rangle < 0 \) and \( \langle q' \rangle > 0 \)
- \( \langle q' \rangle > 0 \) and \( \langle q' \rangle < 0 \)
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)
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)

Mean flow acts to dry the land
Wintertime mean moisture transport (1968-2007)

\[
\text{Total transport} = \text{Transport by time-mean flow} + \text{Transport by synoptic eddies (>10 days)} + \text{Transport by “low-frequency” eddies (<10 days)}
\]
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)
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?
Transport by 90+ day anomalies

Transport by bandpass (30-90) anomalies

Transport by bandpass (10-30) anomalies
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)
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-Clapeyron) 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.