Sinuosity of mid-latitude atmospheric flow in a warming world

Julien Cattiaux[1], Yannick Peings[2], David Saint-Martin[1], Nadège Trou-Kechout[1], and Steve Vavrus[3].

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Jeudi du Climat
March 17, 2016

Mid-latitude dynamics and global warming

- The mid-latitude dynamics is driven by the equator-to-pole T gradient. . .

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- . . . which is modified by climate change, differently at surface and aloft.

Large-Scale Dynamics and Global Warming

Isaac M. Held
Geophysical Fluid Dynamics Laboratory/ NOAA, Princeton University, Princeton, New Jersey

Abstract

Predictions of future climate change raise a variety of issues in large-scale atmospheric and oceanic dynamics. Several of these are reviewed in this essay, including the sensitivity of the circulation of the Atlantic Ocean to increasing freshwater input at high latitudes; the possibility of greenhouse cooling in the southern oceans; the sensitivity of monsoonal circulations to differential warming of the two hemispheres; the response of midlatitude storms to changing temperature gradients and increasing water vapor in the atmosphere; and the possible importance of positive feedback between the mean winds and eddy-induced heating in the polar stratosphere.

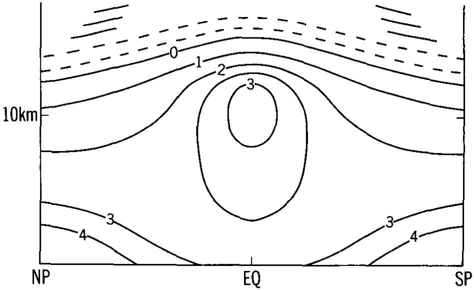

FIG. 6. A schematic of the equilibrium annual mean temperature response to a doubling of CO_2, as typically predicted by GCMs, emphasizing the maxima at upper-tropospheric levels in the tropics and at low levels in the polar regions. Polar amplification is present only in winter.

Held, 1993, *BAMS*.

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How does the mid-latitude dynamics respond?

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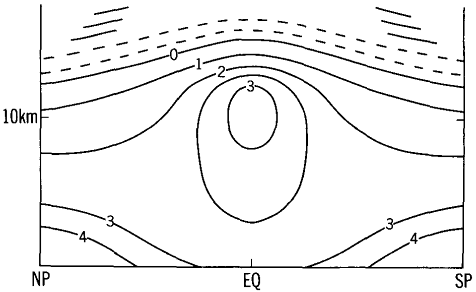

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The dominant wintertime baroclinic eddies are coherent through the depth of the troposphere in midlatitudes. As a result, it is unclear whether the eddies would respond primarily to the decrease in lower-tropospheric temperature gradient or the increase in the upper-tropospheric gradient. (In the

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The example of the NAO

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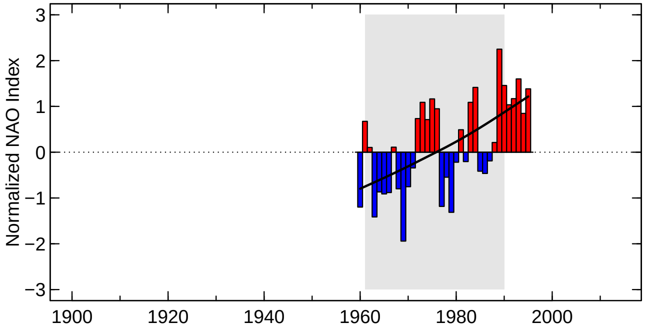

Data: Z500 NCEP 1960–1995.

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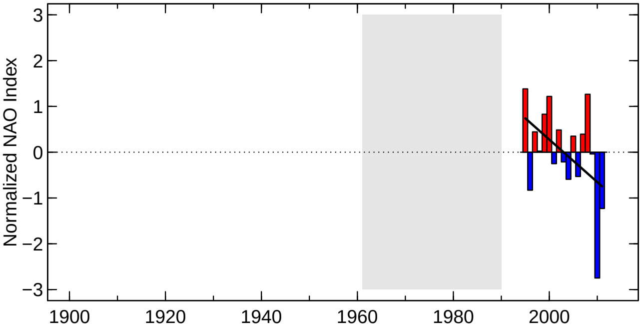

Data: Z500 NCEP 1995–2011.

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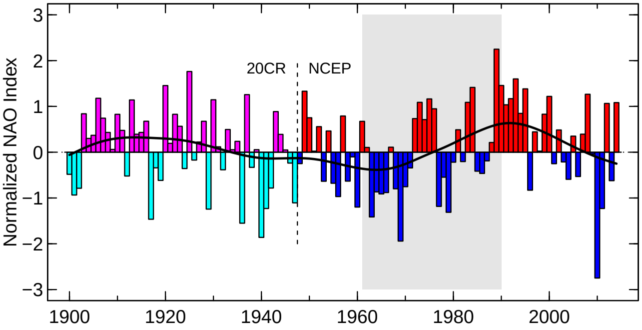
Compensating mechanisms or just decadal internal variability?



Data: Z500 NCEP + 20CR 1900–2014.

Beyond the NAO

Towards a wavier jet stream? More blocking episodes?

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Evidence linking Arctic amplification to extreme weather in mid-latitudes

Jennifer A. Francis[1] and Stephen J. Vavrus[2]

Received 17 January 2012; revised 20 February 2012; accepted 21 February 2012; published 17 March 2012.

[1] Arctic amplification (AA) – the observed enhanced warming in high northern latitudes relative to the northern hemisphere – is evident in lower-tropospheric temperatures and in 1000-to-500 hPa thicknesses. Daily fields of 500 hPa heights from the National Centers for Environmental Prediction Reanalysis are analyzed over N. America and the N. Atlantic to assess changes in north-south (Rossby) wave characteristics associated with AA and the relaxation of poleward thickness gradients. Two effects are identified that each contribute to a slower eastward progression of Rossby waves in the upper-level flow: 1) weakened zonal winds, and 2) increased wave amplitude. These effects are particularly evident in autumn and winter consistent with sea-ice

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Revisiting the evidence linking Arctic amplification to extreme weather in midlatitudes

Elizabeth A. Barnes[1]

Received 17 July 2013; revised 8 August 2013; accepted 14 August 2013; published 4 September 2013.

[1] Previous studies have suggested that Arctic amplification has caused planetary-scale waves to elongate meridionally and slow down, resulting in more frequent blocking patterns and extreme weather. Here trends in the meridional extent of atmospheric waves over North America and the North Atlantic are investigated in three reanalyses, and it is demonstrated that previously reported positive trends are likely an artifact of the methodology. No significant decrease in planetary-scale wave phase speeds are found except in October-November-December, but this trend is sensitive to the analysis parameters. Moreover, the frequency of blocking occurrence exhibits no significant

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LETTER

Evidence for a wavier jet stream in response to rapid Arctic warming

Jennifer A Francis[1] and Stephen J Vavrus[2]

[1] Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, New Jersey, USA

[2] Center for Climatic Research, University of Wisconsin-Madison, Madison, Wisconsin, USA

E-mail: francis@imcs.rutgers.edu

Keywords: jet stream, Arctic amplification, extreme weather

Abstract

New metrics and evidence are presented that support a linkage between rapid Arctic warming, relative to Northern hemisphere mid-latitudes, and more frequent high-amplitude (wavy) jet-stream configurations that favor persistent weather patterns. We find robust relationships among seasonal and regional patterns of weaker poleward thickness gradients, weaker zonal upper-level winds, and a more meridional flow direction. These results suggest that as the Arctic continues to warm faster than elsewhere in response to rising greenhouse-gas concentrations, the frequency of extreme weather events caused by persistent jet-stream patterns will increase.

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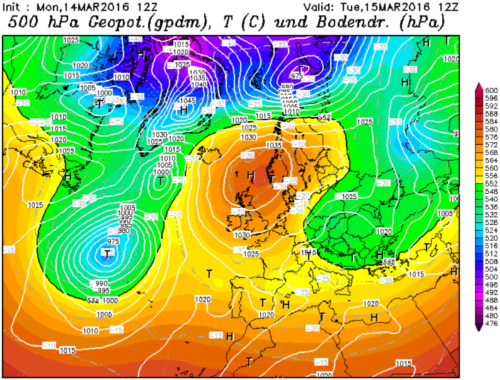
The use of isohypses

- Flow waviness assessed from latitudinal range of a given Z500 iso-contour.

Example of March 15, 2016
© Wetterzentrale.



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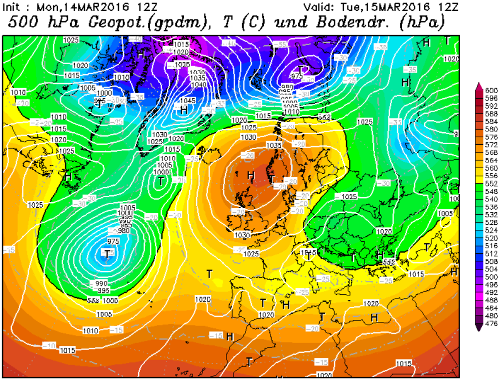


Limitations

1. Min. and max. latitudes poorly characterize the whole trajectory.
2. Isohypse position affected by both seasonal cycle and climate change.

The concept of *sinuosity* applied to mid-latitude flow

- Sinuosity: length of the trajectory divided by the length of the straight line.

Illustrations from Wikipedia

The concept of *sinuosity* applied to mid-latitude flow

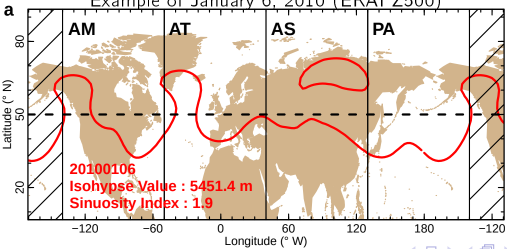
- Sinuosity: length of the trajectory divided by the length of the straight line.

Illustrations from Wikipedia



- Selected isohypse: for each day, the Z500 average over 30–70 °N.

Example of January 6, 2010 (ERAI Z500)

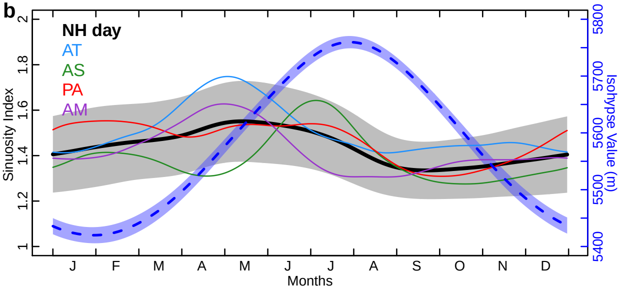


Annual cycle of sinuosity

Selected isohypse ∼5400 m in winter, and ∼5800 m in summer.

Greater sinuosity in spring.

ERAI 1979–2014



Annual cycle obtained by averaging over the 36 years for each day, and smoothing by splines. Shading indicates $\pm 1\sigma$.

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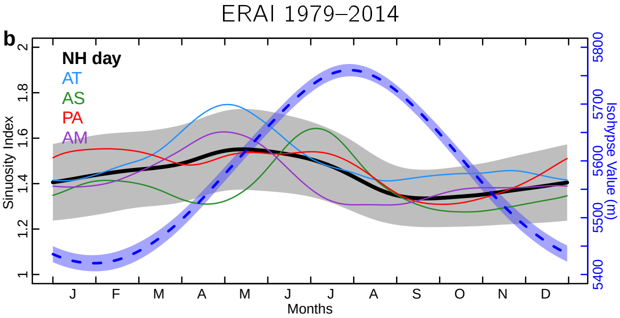
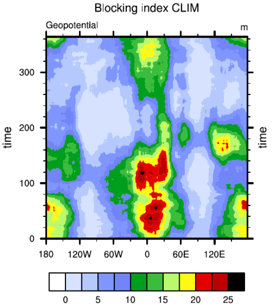
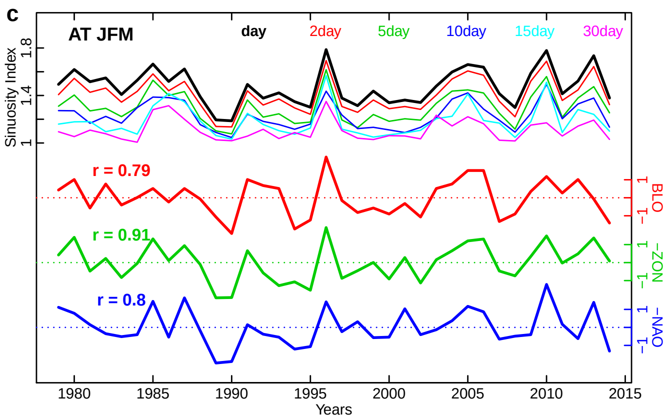




Annual cycle obtained by averaging over the 36 years for each day, and smoothing by splines.
Shading indicates $\pm 1\sigma$.

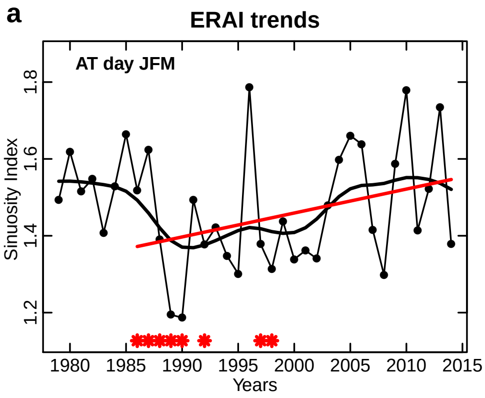
Link with more classical metrics

In the North-Atlantic, highly correlated with blocking[1], zonal[2] and NAO[3] indices.



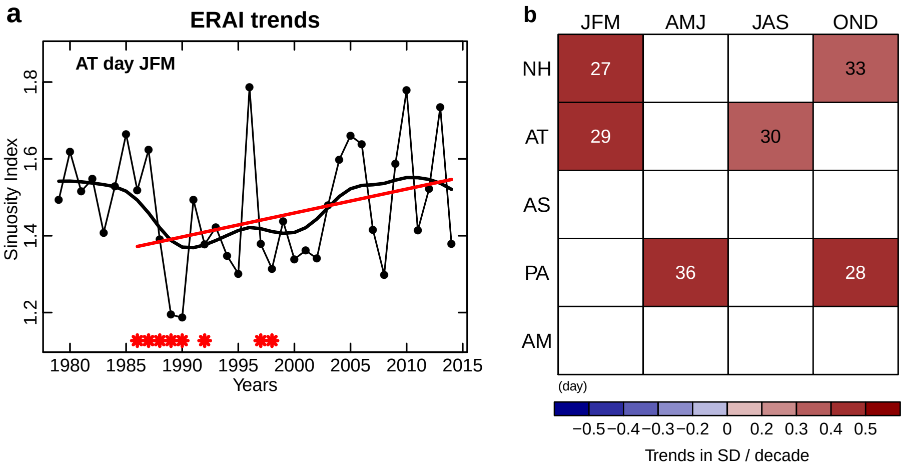
[1] Tibaldi and Molteni index computed on ERAI Z500 (link).
[2] ERAI Z500 difference between 20–50 °N and 60–90 °N (Woolings 2008).
[3] Station-based Hurrell index (link).

Recent trends



ERAI 1979–2014. Only trends >20yr & 90%-level significant.

Recent trends



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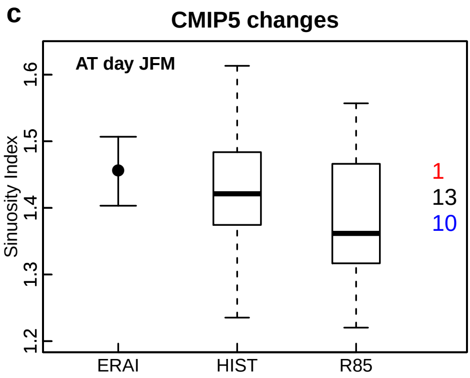
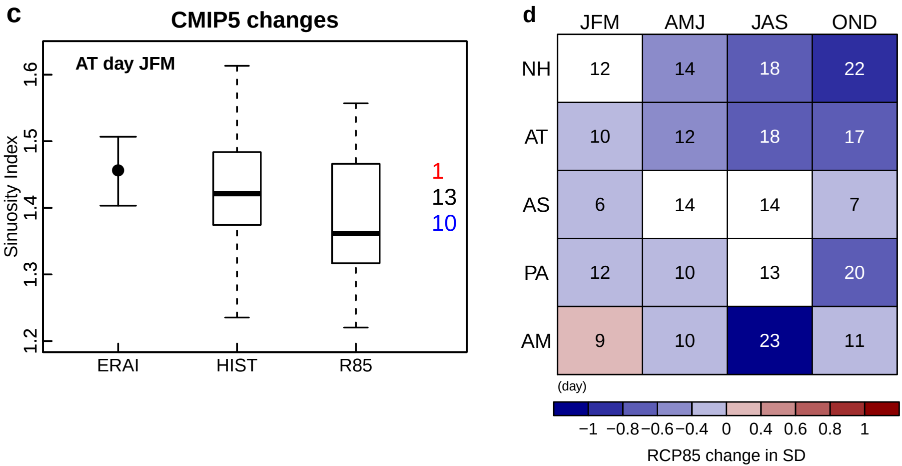
Projected changes



24 CMIP5 models. RCP85 2070–2099 vs HIST 1979–2008. Only changes 90%-level significant.

Projected changes



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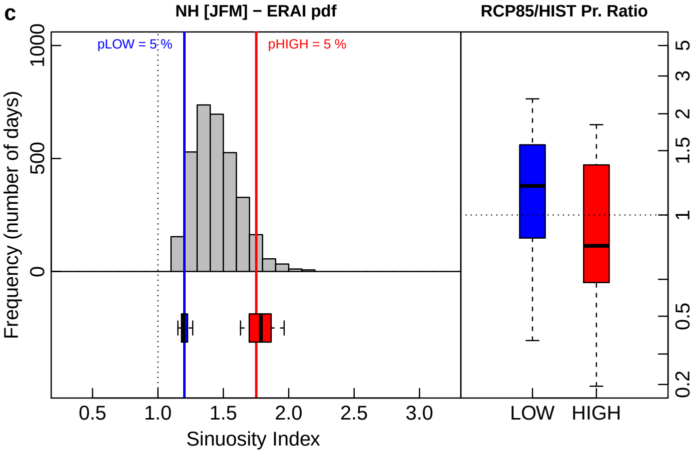
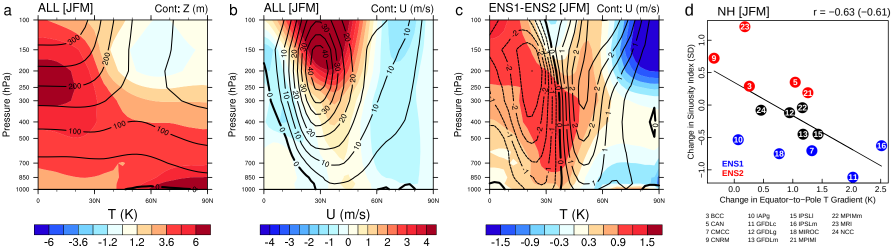
Projected changes Zoom on extremes



Pdfs estimated from 30×90 days (36×90 days for ERAI).

Link with temperature changes

High sinuosity decrease (ENS1) ⇔ strong high-tropospheric tropical warming, strong low-stratospheric polar cooling, weak Arctic Amplification.



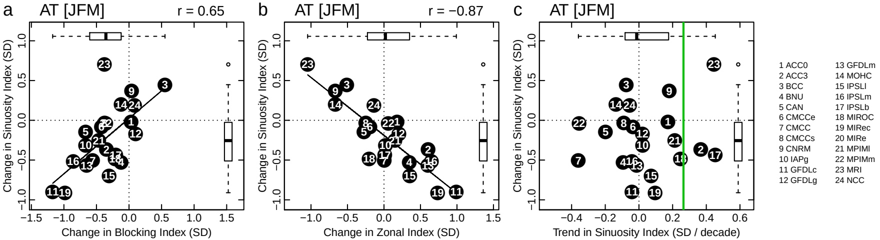
a. Ensemble mean of ΔT (colors) and ΔZ (contours).
b. Ensemble mean of ΔU (colors) and U (contours).
c. Difference ENS1−ENS2 of ΔT (colors) and ΔU (contours).
d. Scatter plot ΔSIN vs. $\Delta Grad(T)$.

Δ = RCP85 − HIST.
Grad(T) = T[0–55N] − T[55–90N] (vertically averaged).

Link with other circulation indices

Inter-annual relationships confirmed by inter-model dispersion.
[contradicts Hassanzadeh & Kuang (2015)?]

No link between recent trends and projected changes.



ΔSIN vs **a.** ΔBLO, **b.** ΔZON and **c.** SIN recent trend (obs in green).

Concluding remarks

So far:

- Sinuosity is an interesting metric.
- Recent trends support a wavier jet stream, but the projected response to climate change is opposite.
- The model dispersion is partially explained by the model-dependent response of the equator-to-pole T gradient.
- The model dispersion confirms the *slower gets wavier* paradigm.

Concluding remarks

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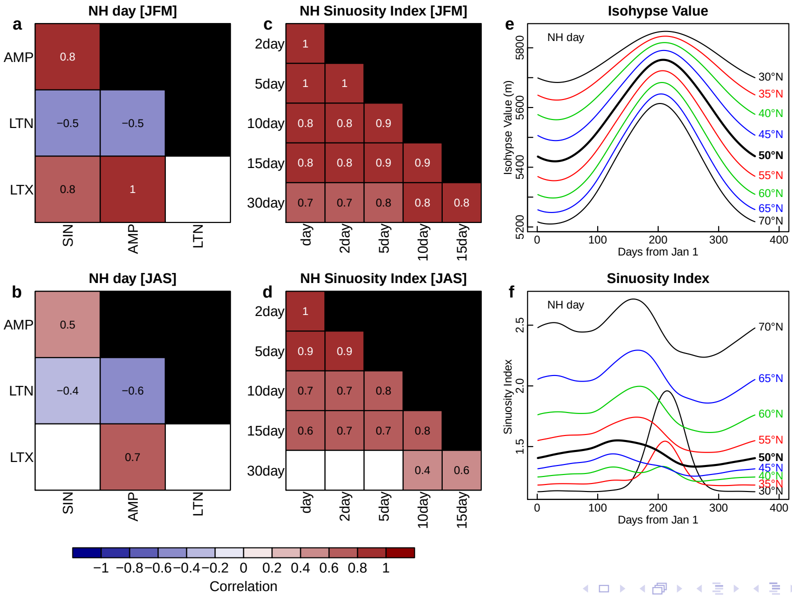
Next:

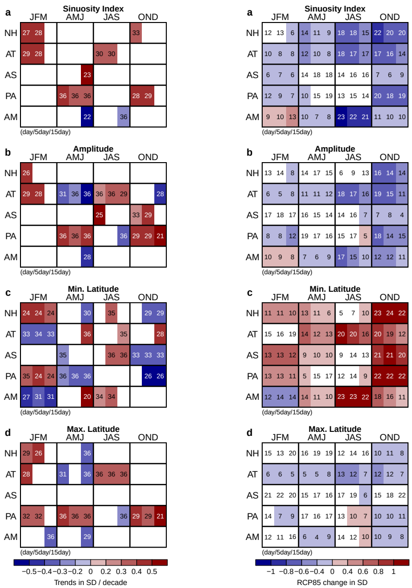
- Different time scales?
- Characterization of the persistence? (day-to-day distance between contours?)
- Link with surface weather extremes?
- Any idea welcome. . .

Fin.

Validation


NH day [JFM]
a
AMP
LTN
LTX
0.8
−0.5
−0.5
0.8
1
SIN
AMP
LTN
NH Sinuosity Index [JFM]
c
2day
5day
10day
15day
30day
1
1 1
0.8 0.8 0.9
0.8 0.8 0.9 0.9
0.7 0.7 0.8 0.8 0.8
day
2day
5day
10day
15day
Isohypse Value
e
NH day
Isohypse Value (m)
5800
5600
5400
5200
30°N
35°N
40°N
45°N
50°N
55°N
60°N
65°N
70°N
0
100
200
300
400
Days from Jan 1
NH day [JAS]
b
AMP
LTN
LTX
0.5
−0.4
−0.6
0.7
SIN
AMP
LTN
NH Sinuosity Index [JAS]
d
2day
5day
10day
15day
30day
1
0.9 0.9
0.7 0.7 0.8
0.6 0.7 0.7 0.8
0.4 0.6
day
2day
5day
10day
15day
Sinuosity Index
f
NH day
Sinuosity Index
2.5
2.0
1.5
70°N
65°N
60°N
55°N
50°N
45°N
40°N
35°N
30°N
0
100
200
300
400
Days from Jan 1
−1
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
0.8
1
Correlation

Trends and changes



Other time scales, other statistics. . .

Sensitivity to latitude