Detection and tracking of atmospheric blocks: a Lagrangian flow network approach

UNIT OF EXCELLENCE MARÍA DE MAEZTU

CAFE Climate Advanced Forecasting of sub-seasonal Extremes

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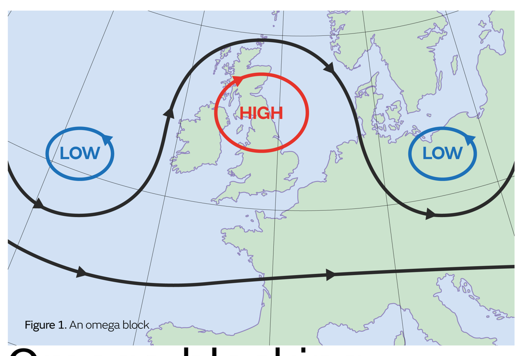
Atmospheric blocking events, which are large-scale nearly stationary atmospheric pressure patterns, are often associated with extreme weather in the mid-latitudes such as heat waves and cold spells. Despite numerous studies, motivated by the high impact of blocking, a comprehensive understanding of these events is still missing.
The aim of the current work is to ascertain the potential of Lagrangian flow networks for their detection and perhaps prediction. Indeed flow networks have recently been successfully employed to characterize transport and mixing dynamics in geophysical flows. In particular, Ser-Giacomi et al. [1] showed how Most Probable Paths obtained from such networks highlight distinctive circulation patterns associated with blocking. We further explore the behavior of flow network measures at the onset of, during and after blocking situations.

1. Blocking



Omega blocking
https://www.metoffice.gov.uk/

A nearly stationary high-pressure cell "blocks" westerly winds in the mid- and high-latitudes, causing the usual eastward progress of weather systems to stall.

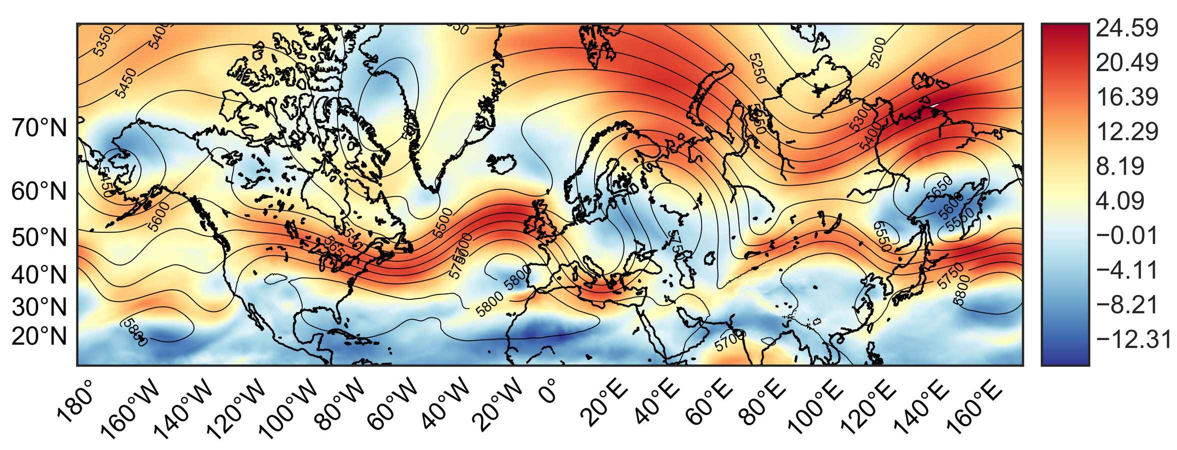
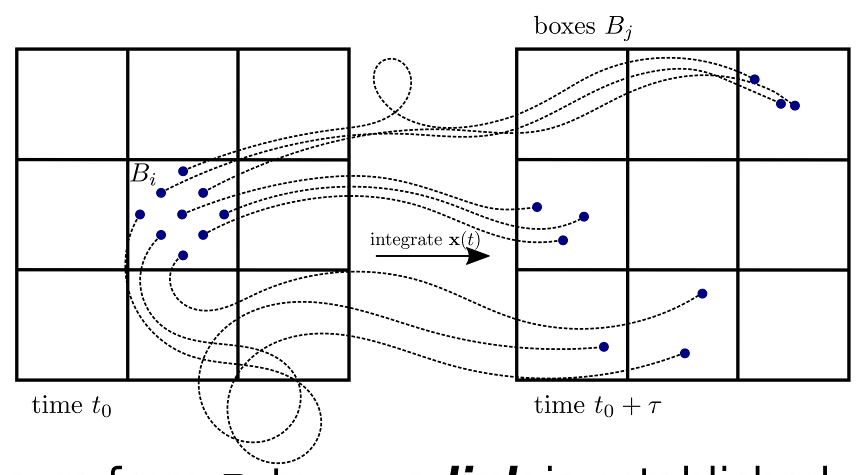


Figure 1 : 500-hPa geopotential height contours [m] and zonal wind speed [m/s] (colour) in the Northern Hemisphere extratropics averaged over 4 days from July 25 to July 29 2010, during a blocking event over Western Russia (ERA5 hourly data on pressure levels)

2. Flow network construction

- The fluid domain Ω is subdivided into N boxes $\{B_i\}_{i=1}^{N}$ defining the network ***nodes***.
- At time t_0, M particles are initialized in each box and advected for a fixed time τ within the 3D velocity (wind) field using Flexpart [2].



- If a transition occurs from B_i to B_j, a ***link*** is established, weighted by the transition probability

$$P_{ij} = \frac{\#\{\mathbf{x} : \mathbf{x}(t_0) \in B_i \ \wedge \ \mathbf{x}(t_0+\tau) \in B_j\}}{M}$$

$\mathbf{P}(t_0, \tau)$ defines the adjacency matrix of a **temporal, *weighted and directed*** network.

3. Results

Selected network measures before, during and after blocking situations

OUT-DEGREE K

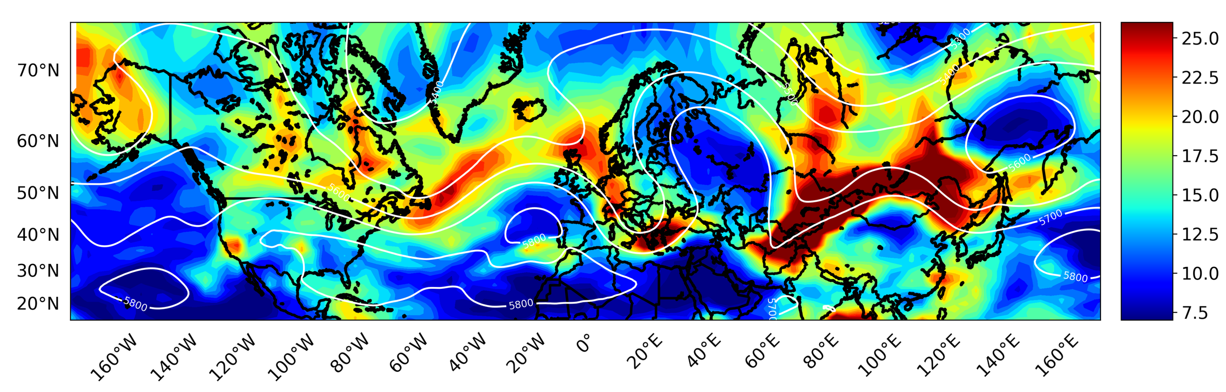


Figure 2: **Degree field (colour) at 300 hPa during a blocking event**. Geopotential height contours at 500 hPa are shown as reference. Both fields are averaged over 4 days from 25/07/2010, 12:00 to 29/07/2010, 12:00.

$$K_i(t_0, \tau) = \sum_{j=1}^{N} \Theta(P_{ij}(t_0, \tau))$$

Θ Heaviside function

$$H_i(t_0, \tau) = -\frac{1}{\tau} \sum_{j=1}^{N} P_{ij} \log(P_{ij})$$

$$C_i(t_0, \tau) = \left(\frac{1}{N-1}\right) \sum_{j \neq i} \frac{1}{d_{ij}}$$

with d_{ij} weighted distance from i to j, link distances set to $\frac{1}{P_{ij}} \ \forall \ P_{ij} \neq 0$

ENTROPY H

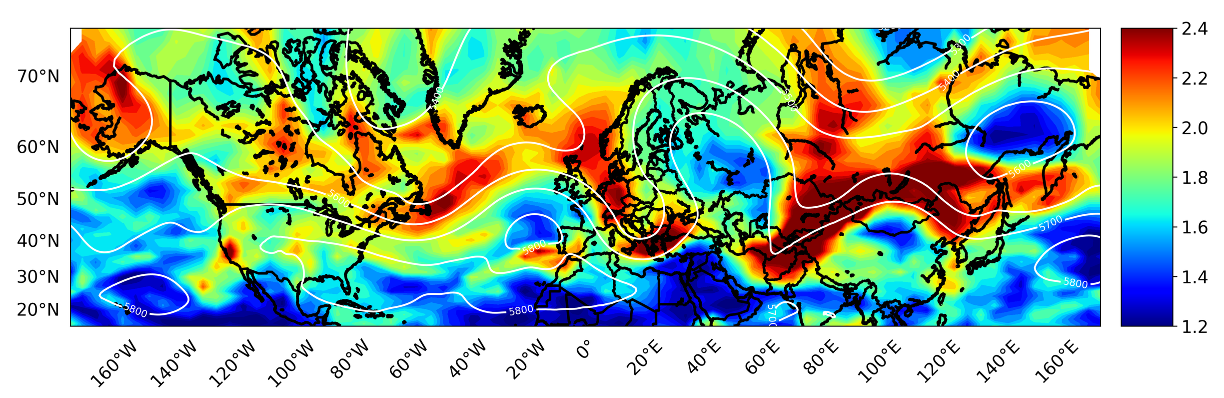


Figure 3: **Entropy field (colour) at 300 hPa during a blocking event**. Geopotential height contours at 500 hPa are shown as reference. Both fields are averaged over 4 days from 25/07/2010, 12:00 to 29/07/2010, 12:00.

HARMONIC CLOSENESS CENTRALITY C

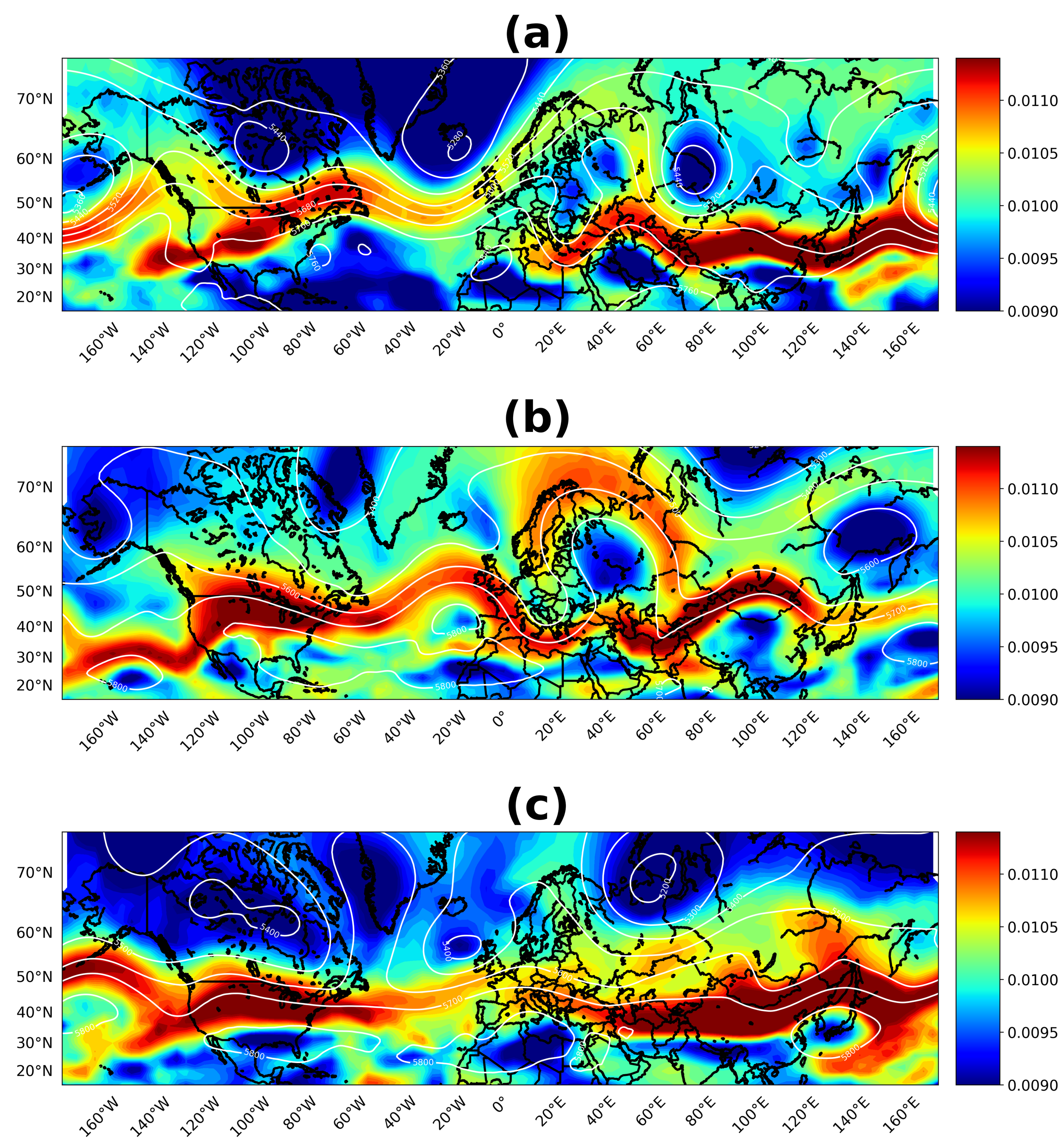


Figure 4: **Closeness field (colour) and geopotential height (contours) at 500 hPa before (a), during (b) and after (c) a blocking event**. The fields are averaged over 4-days periods : 07-11/07/2010, 25-29/07/2010 and 18-22/08/2010 respectively.

4. Conclusion and future work

Network measures such as degree, entropy and harmonic closeness centrality clearly trace the spatio-temporal characteristics of blocking situations. However their predictive power remains unclear. In future work, we will attempt to uncover specific flow configurations characteristic of the transition to a blocking regime.

[1] Ser-Giacomi, E., Vasile, R., Recuerda, I., Hernández-García, E., & López, C. (2015). Dominant transport pathways in an atmospheric blocking event. Chaos: An Interdisciplinary Journal of Nonlinear Science, 25(8), 87413. https://doi.org/10.1063/1.4928704
[2] Stohl et al. (2019). The Lagrangian particle dispersion model FLEXPART version 10.4. Geoscientific Model Development, 12(12), 4955–4997. https://doi.org/10.5194/gmd-12-4955-2019

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 813844.

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