Diagnostics for assessing changes in the mid-latitude atmospheric dynamics

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APPLICATE General Assembly, Reading, UK | January 2019

APPLICATE context

WP1: Weather and climate model evaluation.

> Task 1.2.3: Development of metrics that describe [Arctic / mid-latitudes] linkages in atmosphere and ocean and implementation in ESMValTool.

>> Deliverable 1.2: Provision of process-focused, user-relevant and Arctic linkages metrics through ESMValTool (M24).

Submitted in Nov 2018: https://www.overleaf.com/read/pghsnbhtdxkp

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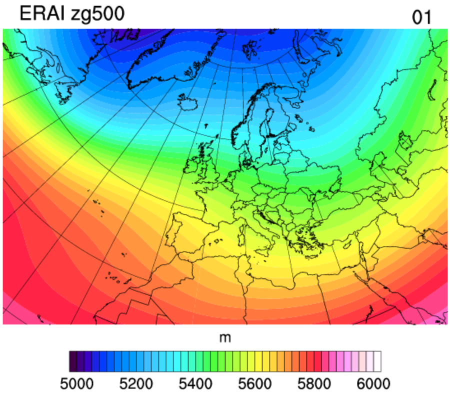
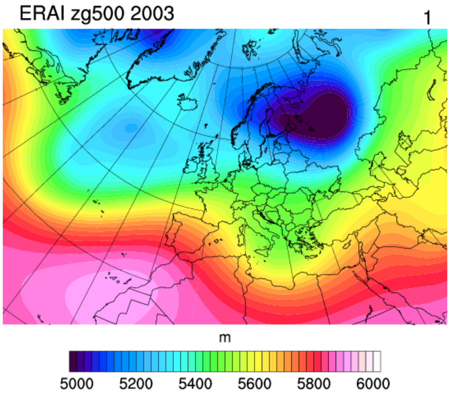
CNRM contribution: collect, develop and provide diagnostics/metrics for mid-latitude atmospheric dynamics and linkages with the Arctic, both for model evaluation and assessment of future changes.

Motivation

- The mid-latitude surface weather is primarily driven by the atm. dynamics.
- Mean state (jet stream, surface westerlies) + quasi-chaotic variability.

Example: Z500 January climatology + Z500 January 2003





Plotted from ERA-Interim data.

Need for diagnostics that synthesize the various features of the dynamics.

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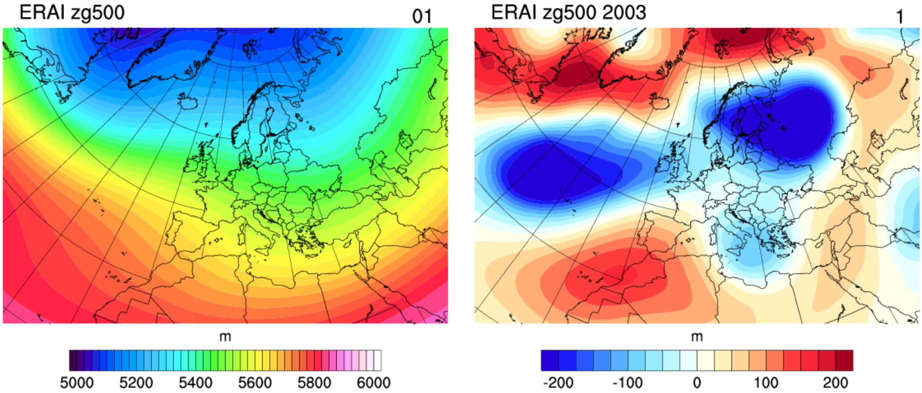
Example: Z500 January climatology + Z500 January 2003 (anomalies)



Plotted from ERA-Interim data.

Need for diagnostics that synthesize the various features of the dynamics.

Large-scale westerly flow

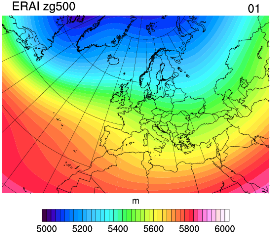
. Several simple indices have been proposed in the literature to quantify the strength of the large-scale westerly flow.

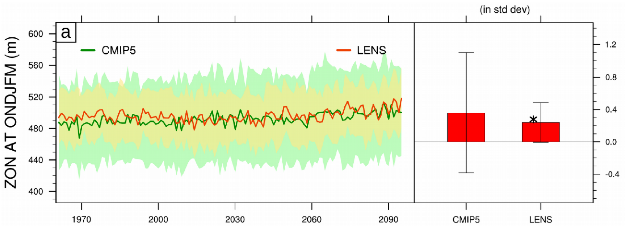
> Zonal wind index = average of zonal wind.
Francis and Vavrus (2012), Barnes and Polvani (2015), Zappa and Shepherd (2017).

> Zonal geopotential index = mid- vs high-latitude difference of geop. height.
Woollings (2008).

> Zonal SLP index = mid- vs high-latitude difference of SLP.
Li and Wang (2003).

Example: Changes in the North-Atlantic zonal Z500 index





Peings et al., 2018, *ERL*.

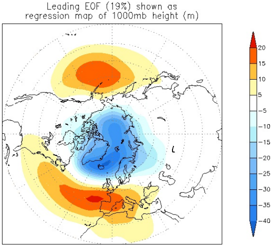
Inter-annual variability

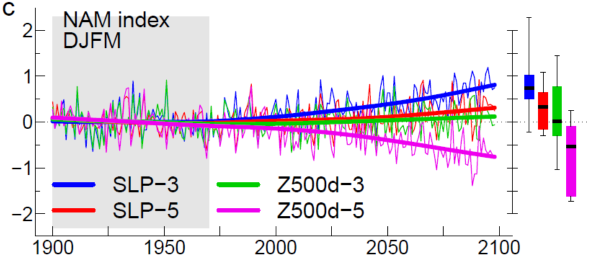
. The dominant mode of atm. variability (the NAM/NAO) explains ∼ 30 % of variance of wintertime European temperatures.

> Station-based index = difference of SLP between Lisbon and Reykjavik.
Hurrell (2003).

> PCA-based index = principal component analysis of SLP or Z500 anomalies.
Miller et al. (2006), Cattiaux and Cassou (2013).

Example: NAM/NAO pattern obtained by PCA (EOF1) + changes in the index (PC1)





NCEP website + Cattiaux & Cassou, 2013, *GRL*.

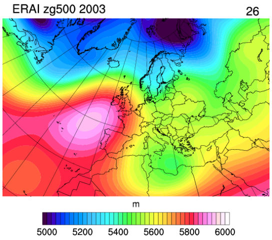
Jet stream / daily flow trajectory

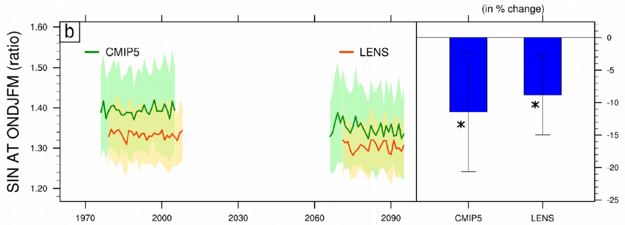
. At synoptic scale, the variability of the eddy-driven jet stream / waviness of the westerly flow drives the surface weather.

> Jet stream analysis = identification of the jet from low-tropospheric zonal wind; position/speed = latitude/value of the max wind – width = latitudes at half of the max wind.
Woollings et al. (2010), Barnes and Polvani (2013, 2015).

> Daily flow analysis = identification of the flow from an iso-contour of Z500; sinuosity index = length of the trajectory divided by length of the straight line, monthly amplitude = monthly range of latitudes encompassing daily trajectories.
Barnes (2013), Cattiaux et al. (2016), Vavrus et al. (2017), Peings et al. (2018).

Example: Changes in the North-Atlantic sinuosity index





Peings et al., 2018, *ERL*.

Specific patterns: blockings

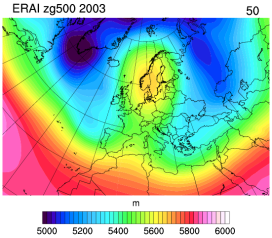
. Persistent high-pressure systems that temporarily block the westerly flow; in Europe, associated with cold spells in winter and heat waves in summer.

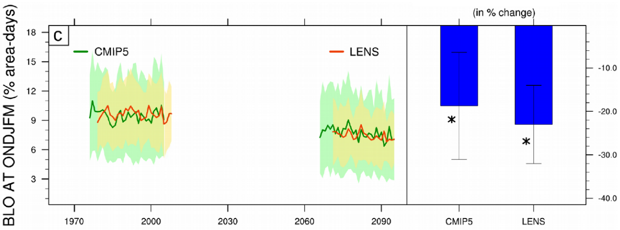
> 1D blocking index = identifies reversals in the daily Z500 meridional gradient.
Tibaldi and Molteni (1990).

> 2D blocking index = same as 1D but with latitudinal dependence.
Scherrer et al. (2006).

> Blocking tracking algorithm = tracks anomalies of high-tropo. potential vorticity.
Schwierz et al. (2004), Croci-Maspoli et al. (2007a, 2007b).

Example: Changes in the North-Atlantic 1D blocking index





Peings et al., 2018, *ERL*.

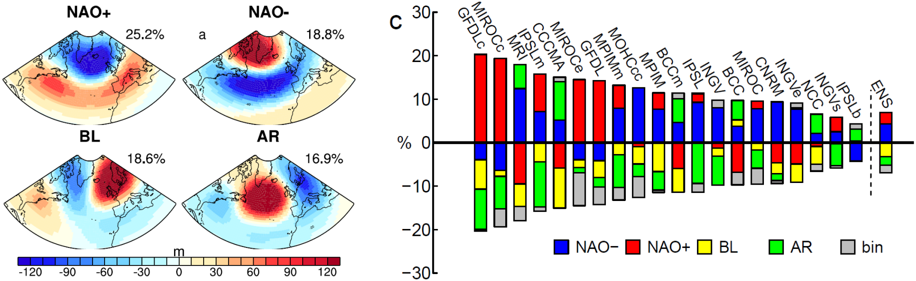
Specific patterns: weather regimes

- Preferred circulation patterns whose frequencies of occurrence explain up to ~ 60 % of variance of the wintertime European temperatures.

> North-Atlantic WRs = classification of daily SLP or Z500 anomalies into 4 regimes using the *k-means* clustering algorithm.

Vautard (1990), Cassou (2008), Cattiaux et al. (2013).

Example: WR patterns + CMIP5 changes in frequencies of occurrence



Cattiaux et al., 2013, *Clim. Dyn.*

Linkages – 1/2

. The mid-latitude dynamics is controlled by the equator-to-pole T gradient, which is modified by climate change, differently at surface and aloft.

> Tug-of war between upper-tropospheric tropical warming & polar amplification.

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.

Held, 1993, *BAMS*.

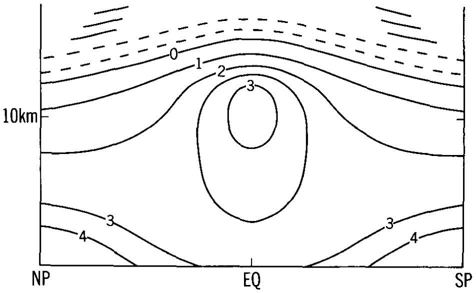


FIG. 6. A schematic of the equilibrium annual mean temperature response to a doubling of CO_2, as typically predicted by GCMs, emphasizing the maxima at upper-tropospheric levels in the tropics and at low levels in the polar regions. Polar amplification is present only in winter.

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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

Held, 1993, *BAMS*.

Linkages – 2/2

. Several diagnostics have been proposed to describe some of the potential drivers of changes in the Northern mid-latitude dynamics.

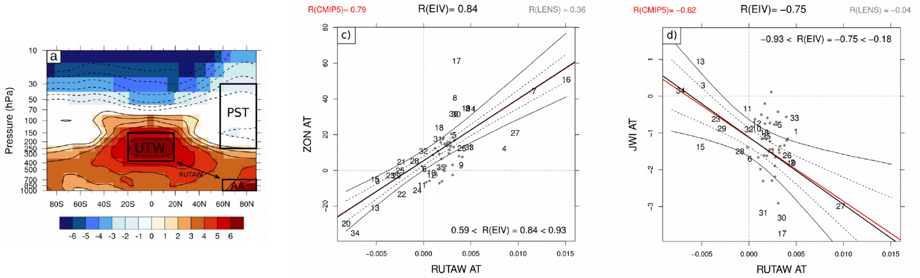
> In the tropics: upper-tropospheric warming (UTW), Hadley cells poleward expansion, changes in SST patterns.

> In the mid-latitudes: changes in SST meridional gradients.

> In the Arctic: Arctic Amplification (AA), decrease in Arctic sea ice extent/volume, changes in polar vortex strength.

Cohen et al. (2014), Manzini et al. (2014), Zappa and Shepherd (2017), Peings et al. (2018).

Example: changes in zonal index & flow amplitude correlated with the ratio UTW/AA



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Conclusions and outlook

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This collection of diagnostics (existing + a few novel) is non-exhaustive.
Wave-number analysis, storm tracks, seasonal linkages with Arctic sea-ice extent or Siberian snow cover, etc. (see D1.2 document).

These atmospheric *diagnostics* can be turned into *metrics* since reference products are generally available through reanalyses.
Used at CNRM for the evaluation of CNRM-CM6-1 (see Thomas Oudar's talk).

These diagnostics have been coded using common programming languages (CDO, NCO, R, NCL) and can easily be shared on demand.
Generic shell syntax: `./<diagnostic>.sh <ifile(s)> <ofile(s)>` .

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Next steps include:

> evaluate multi-model ensembles from the upcoming CMIP6 (Task 1.3) and PAMIP (WP3) experiments;

> investigate how these diagnostics/metrics can be used as emergent constraints to reduce future uncertainties in climate projections (Task 1.5);

> implement selected diagnostics into ESMValTool and/or think about alternative and possibly more efficient ways to share codes (to be discussed this week).

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