A tool for objective detection of abrupt transitions in CMIP6 models

Sharing is encouraged

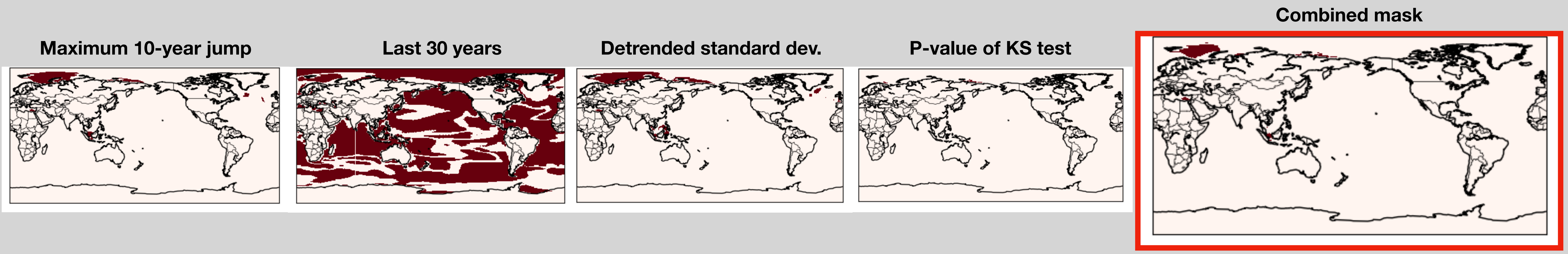
Valerio Lembo[1], Susanna Corti[1], Joran Angevaare[2], Sybren Drijfhout[2][3]

[1]National Research Council of Italy (CNR), Institute for Atmospheric Sciences and Climate (ISAC), Italy [2]Royal Netherlands Meteorological Institute (KNMI), Netherlands [3]University of Southampton, United Kingdom

Introduction

There is a growing concern that the unabated increase of anthropogenic emissions in the near future may push the climate system beyond some of the thresholds that may signal the occurrence of a **tipping point** (McKay et al. 2022). In this respect, it is crucial that state-of-the-art Earth System Models are coherently and reliably reproducing critical transitions in commonly identified tipping elements (cfr. Loriani et al. 2024). Models are in fact instrumental in addressing the boundaries of **safe operating spaces**, in which effective mitigation and adaptation policies are conceived and implemented. In a previous work (Drijfhout et al. 2014), tipping points were investigated in **CMIP5 model outputs**, benchmarking successive model inter comparisons and enabling the interpretation of processes lying behind the highlighted tipping points. Nowadays, the outputs of the CMIP6 exercise have been made publicly available for most of the anthropogenic climate change scenarios (namely, the “shared socio-economic pathways”, SSP) and, with the unfolding of the discussions on experimental protocols for the 7th phase of the CMIP exercise, the timing is appropriate to revisit the Drijfhout’s 2014 catalogue. We hereby present a publicly available software to **detect abrupt changes in CMIP6 model outputs**, including those classifiable as “tipping points”, and apply it to a set of oceanic (near-surface temperature and salinity, sea-ice concentration) and atmospheric variables (precipitation) to highlight some common features across the multi-model ensemble and hint at processes possibly responsible for such abrupt changes.

Combining masks

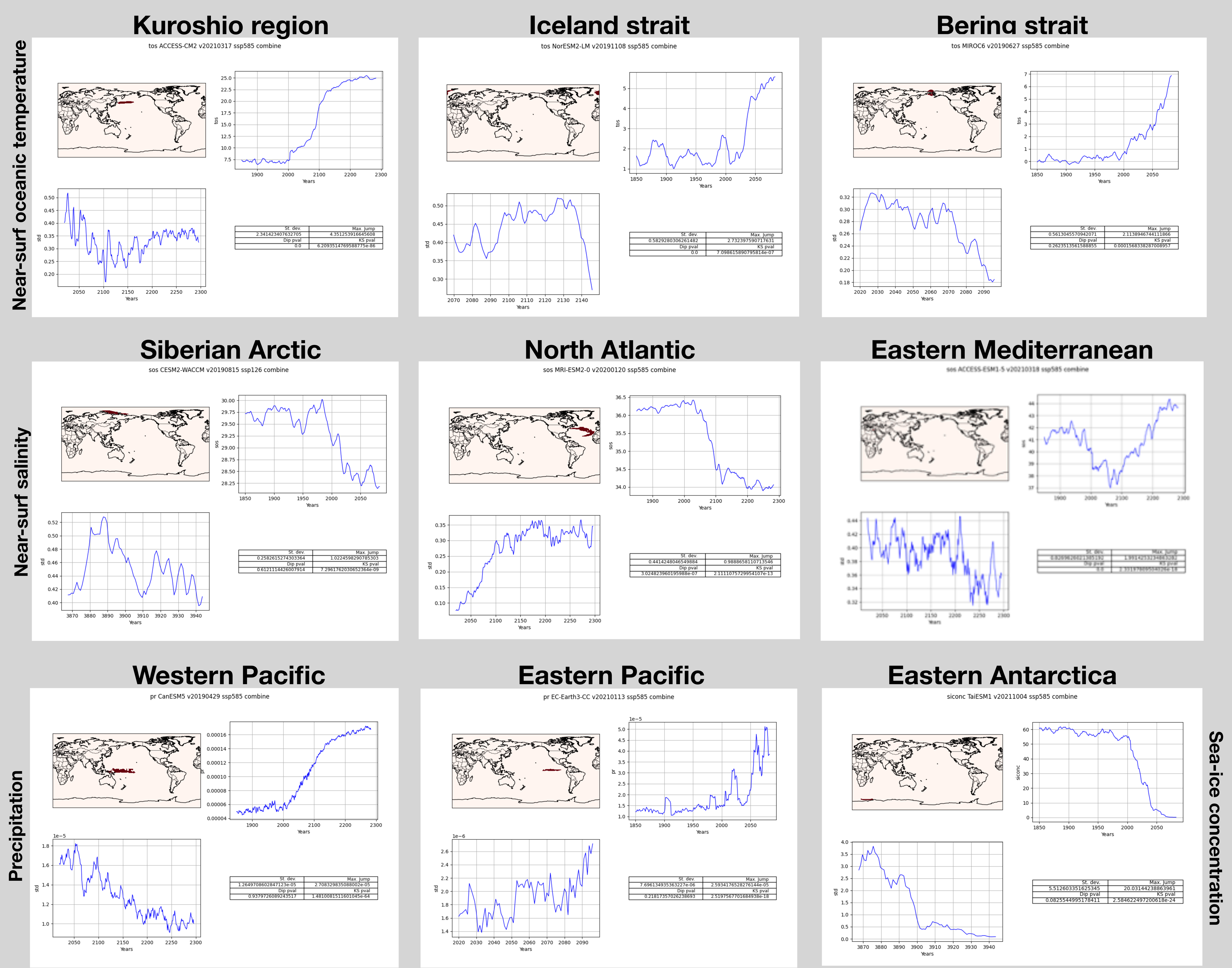


Methodology

The tool is a Python package downloadable from a Github repo.
The algorithm for abrupt changes selection is constituted by three macro-steps:

1. **Data crunching**
   (a) Once users provide their preference on the scenarios, list of models and variables to be analyzed, the program scan through an ESGF-like folder tree;
   (b) For each field, a single dataset is created throughout the whole integration period;
   (c) Fields are **remapped** over a common rectilinear (1x1) grid;
   (d) A 10-year running mean is computed;
2. **Gridpoint selection**
   A gridpoint is considered if:
   i) the **standard deviation** of the detrended time series exceeds the 99 percentile of the standard deviation for each grid point in the preindustrial run;
   ii) the **maximum 10-year jump** exceeds the 99 percentile of all 10-year jumps in the preindustrial run;
   iii) The p-value of the Kolmogorov-Smirnov **test for normality** is lower than 0.05;
   iv) Each year in the **last 30 years** of the forced run exceeds the 99 or 1 percentiles of the preindustrial time series;
3. **Clustering and statistics**
   (e) Only those grid points meeting at least **3 out of the 4** criteria above are selected;
   (f) Neighboring grid points are **clustered** according to a density-based algorithm (Ester et al. 1996) and a spatial smoothing is applied;
   (g) A **threshold** on the area can be applied (according to user’s preferences) to retain sufficiently large clusters;
   (h) Average anomalies and standard deviation are computed within the cluster and displayed in standard tables;

Some examples (scenario ssp585)



Take-home messages

- Locally, oceanic variables show signatures of non-linear interaction of feedbacks, especially at high latitudes;
- Features of the hydrological cycle seem to respond abruptly to GHG forcing, especially in **closed seas** and over the **equatorial Pacific**;
- Sea-ice melting is only in some cases considered to be an abrupt change;
- Results have to be assessed against several **intra-model ensemble members** before a process-based interpretation is carried out;

References

- Drijfhout, Sybren, et al. "Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models." Proceedings of the National Academy of Sciences 112. 43, E5777-E5786. 2015
- Ester, Martin, et al. "A density-based algorithm for discovering clusters in large spatial databases with noise." edd. Vol. 96. No. 34. 1996
- Loriani, Sina, et al. “Tipping points in ocean and atmosphere circulations”, EGUsphere, 2023
- McKay, David I. Armstrong et al., Exceeding 1.5°C global warming could trigger multiple climate tipping points. Science 377, eabn7950. 2022

Acknowledgments

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