Climate shift of the Atlantic Meridional Overturning Circulation (AMOC) in Reanalyses (ORAS5): possible causes, and sources of uncertainty

Vincenzo de Toma[1], Chunxue Yang[2], Vincenzo Artale[3]

[1] University of Rome Tor Vergata, Department of Physics, Viale Della Ricerca Scientifica1, 00133 Rome, Italy
[2] CNR Artov-Ismar, Via Fosso del Cavaliere 100, 00133 Rome, Italy
[3] ENEA Research Center of Frascati, Via Enrico Fermi 45, 00044 Frascati, Italy

Keywords: Atlantic Meridional Overturning Circulation, Reanalyses, Regime Stability Transition, Tipping Points, Labrador Sea, Kinetic Energy Extreme Events Redistribution

Introduction & Motivation

The ECMWF Reanalysis ORAS5 (Zuo et al. 2018) has been used to study the long term variability of the AMOC: a comparison has been carried out both with the in-situ data of the RAPID program, which monitor the Volume Transport at 26.5^{o}N from 2004, and the members of CMEMS_GLO_RAN project, which gather other reanalyses from 1993 onward. We observed a declining signal of the AMOC strength signal in the mid-1990s, of about $5Sv$, which we tried to characterize from a dynamical point of view. The AMOC strength is defined for each latitude y, depth z and time t as:

$$\psi(y, x, t) = \max_z \int_\eta^z dz' \int_{x_w}^{x_e} dx\ v(x, y, z', t). \quad (1)$$

where η is the free surface of the ocean, v is the meridional velocity and x_w, x_e the Atlantic Boundaries for each latitude.

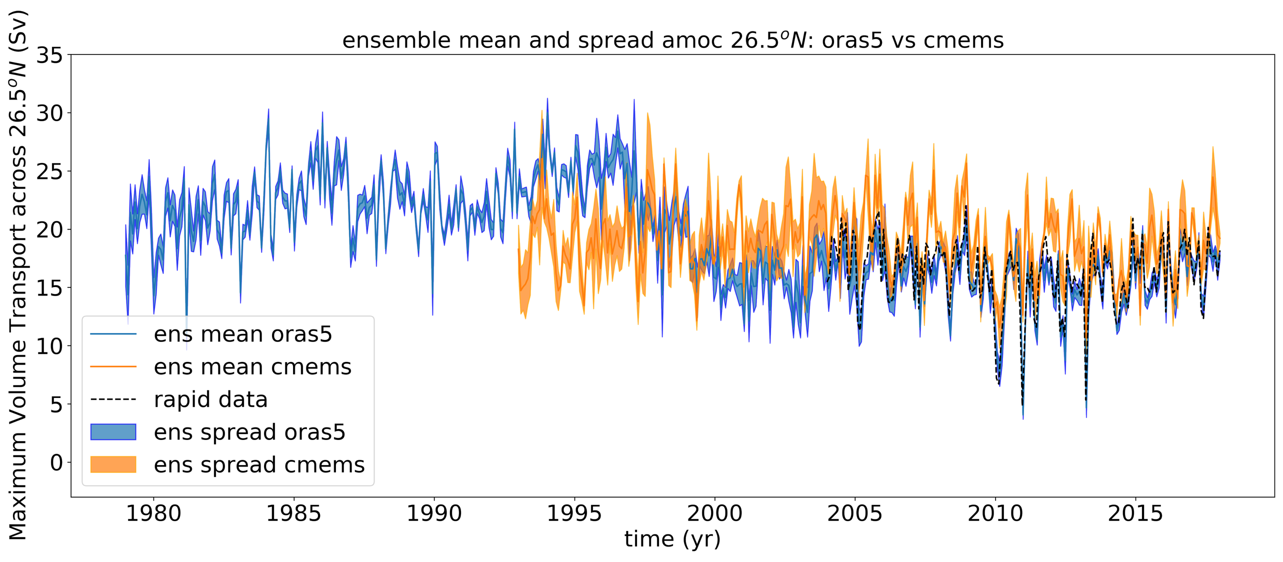

Fig. 1: The shift at the RAPID latitude: Comparison with CMEMS and in-situ data.

All the data show a good agreement on the common period. We show also that the shift is present at other latitudes, in particular involving depths between $1000m$ and $3000m$, and latitudes between 25^oN and 45^oN. Searching for reasons of the shift in the Labrador Sea, we found a transition pattern in the same years, regarding temperature, salinity, potential density and also heat fluxes. The use of a dynamical metric (Liu et al. 2017) helped us to understand that this declining signal can be thought as a stability regime transition of the AMOC.

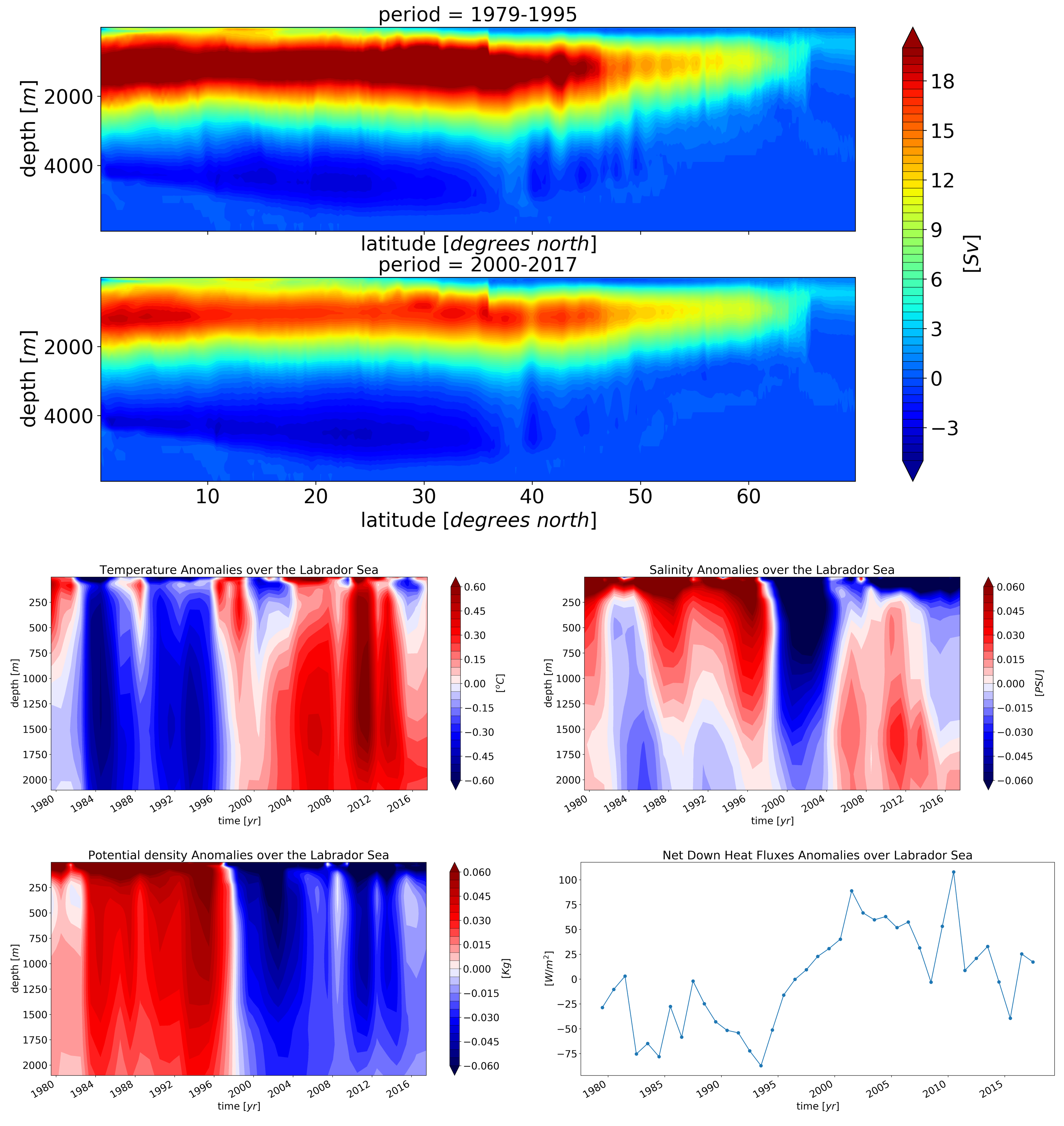

Fig. 2: The shift in the entire Stream Function, and variablity in the Labrador Sea

Analysis & Conclusions

The dynamical metrics Σ characterizing the AMOC-induced Freshwater transport follows Liu et al. 2017 definition:

$$\Sigma = M_{ov,S} - M_{ov,N} \quad \text{where} \quad M_{ov}(\phi) = -\frac{1}{S_0}\int_{-D}^{0} \bar{v}^*(\phi, z)\langle S(\phi, z)\rangle dz. \quad (2)$$

We found that passing the transition there's an activation of the Eastern Atlantic expressed in a redistribution of surface Kinetic Energy Extreme Events, which we have defined as

$$\mathcal{N} = \sum_{n=1}^{T} \Theta\left(|\mathcal{K}_n| - 3\sigma_{\mathcal{K}}\right) \text{ where } \Theta(x) = \begin{cases} 1 \text{ if } x > 0 \\ 0 \text{ if } x < 0 \end{cases} \quad (3)$$

this redistribution can be interpreted as a balance mechanism for the loss of Gravitational Potential Energy suffered by the AMOC (Kuhlbrodt et al. 2007).

Conclusion: We have shown that this transition is coherent with physical processes descending from a decreased mass transport. Through dynamical metrics we found a different connectivity ($\Sigma > 0 \Rightarrow \Sigma < 0$) among the North and South Atlantic domain, linked to the West-East redistribution of activity in the two periods ($\mathcal{N}$). Mechanisms at the origins of this link need further investigations.

Results

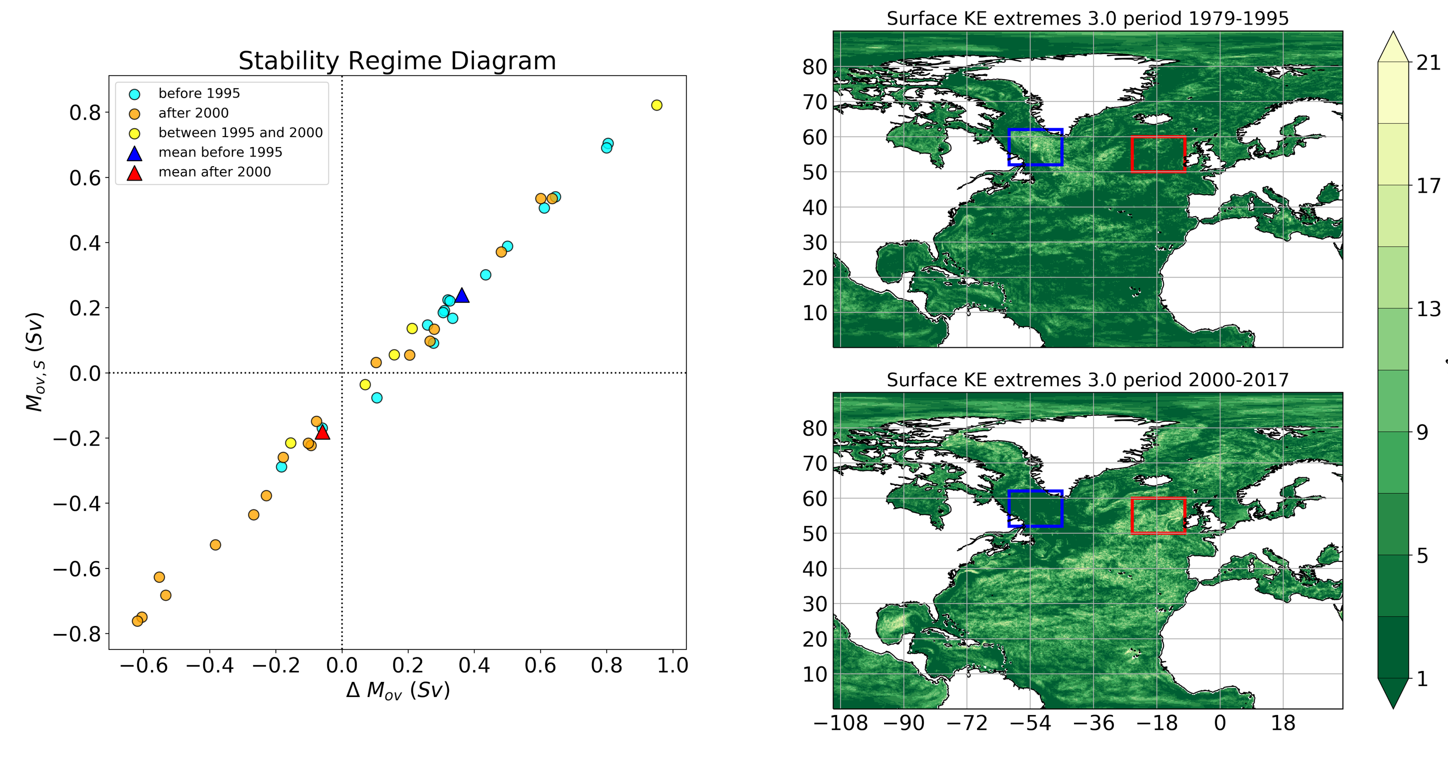

Fig. 3: Regime Stability Diagram and Kinetic Energy Extreme Events redistribution

Short List of References:

Liu, W., Xie, S. P., Liu, Z., & Zhu, J. (2017). Overlooked possibility of a collapsed Atlantic Meridional Overturning Circulation in warming climate. Science Advances, 3(1), e1601666.

Kuhlbrodt, T., Griesel, A., Montoya, M., Levermann, A., Hofmann, M., & Rahmstorf, S. (2007). On the driving processes of the Atlantic meridional overturning circulation. Rev. of Geophysics, 45(2).

Zuo, H., Balmaseda, M. A., Mogensen, K., & Tietsche, S. (2018). OCEAN5: the ECMWF Ocean Reanalysis System and its Real-Time analysis component (p. 44). ECMWF.