# Relation of ocean heat content to surface climate and the impact of resolution: open questions and methodological challenges

Eleftheria Exarchou[1], Sybren Drijfhout[2,3], Virginie Guemas[1,4]

1. Barcelona Supercomputing Center (BSC) 2. Royal Netherlands Meteorological Institute (KNMI) 3. National Oceanography Centre, Southampton (NOCS) 4. Centre National de Recherches Météorologiques (CNRM)

## Motivation and goal of study

In a forced climate (due to anthropogenic forcing etc) it has been shown that there is a linear relationship between radiative forcing F and global mean surface temperature change T, **F = ρT** (Gregory and Forster, 2008). The net top-of-the-atmosphere radiation N, which is equal to the difference between F and the radiative feedback λT, can thus be written as

$$\mathbf{N = F - \lambda T = (\rho - \lambda)\, T = \kappa T = dH/Dt} \qquad \textbf{(Eq 1)}$$

where H is the ocean heat content.

During hiatus periods (dT/dt=0), Eq 1 implies dN/dt=dF/dt, i.e. there is an accelerated ocean heat uptake. However, this is not supported by observations for the recent hiatus period (Xie et al., 2015). Addressing this discrepancy, Xie et al proposed an alternative energy budget to Eq 1, where the climate feedback is decomposed into a forced and a natural variability component

$$\mathbf{N = F - \lambda_F T_F - \lambda_N e^{-i\varphi} T_N}, \qquad \textbf{(Eq 2)},$$

which is more consistent with observations.

Here, we analyse two 100-years long present day (2000 DA forcing) simulations performed with HadGEM3-GC2.0, where a high resolution ocean (ORCA025) is coupled to a low (N96, "Atm-LR") and a high resolution (N512, "Atm-HR") atmosphere, **with the goal to investigate the energy balance occurring from natural variability and the impact of increased atmospheric resolution.**

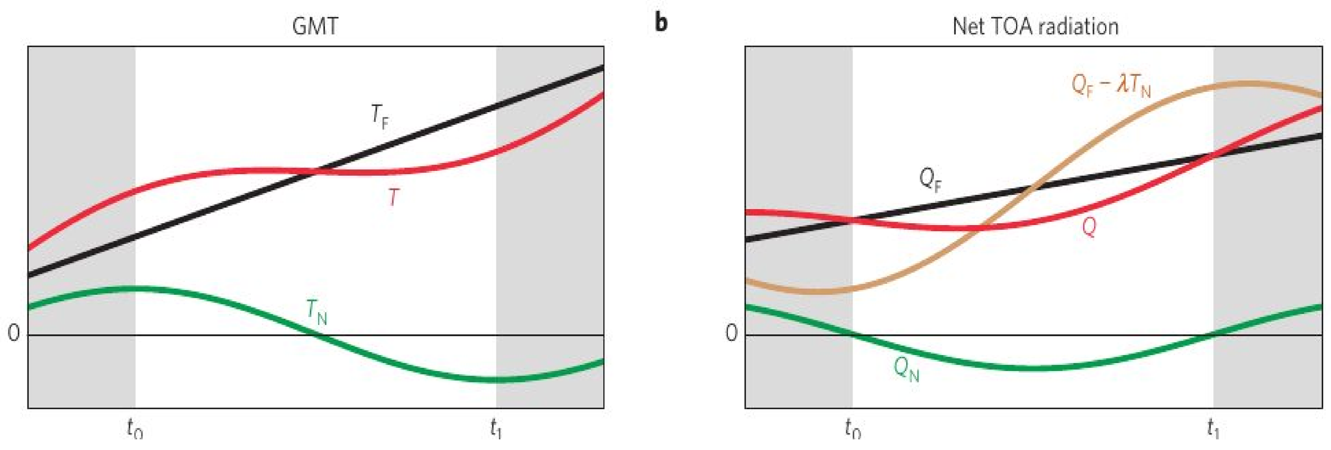


Fig 1: Schematic of T, $T_N$ and $T_F$ (left), Q, $Q_N$ and $Q_F$ (right) for a hiatus period occurring between $t_0<t<t_1$ under Eq 2 (Xie et al.).

## Methods

The simulations have strong drifts. We throw away the first 25 years and then detrend by subtracting a 4th order polynomial. In the remaining 75 years we use 36 months running means and subtract any remaining mean and linear trend. **Given the shortness of the simulations, is there a better way to detrend?**

## First results

We found that the relation between N and T is low at lag=0 (Fig 2), consistent with previous estimates (Xie et al). **N is not strongly related to T in decadal timescales under natural variability.** The top-of-the-atmosphere shortwave and longwave radiation correlate strongly with T but cancel each other out (Fig 2).

The autocorrelation of T is different between the Atm-HR and Atm-LR, suggesting different persistence (Fig 2). **Does this imply different spatial patterns too?**

Strong correlations in Atm-HR, but low in Atm-LR between T and OHC (Fig 2). Positive correlations between deeper (300-800 or 800-6000) and T with lag about 8 years. **Why N96 does not show strong correlations**?

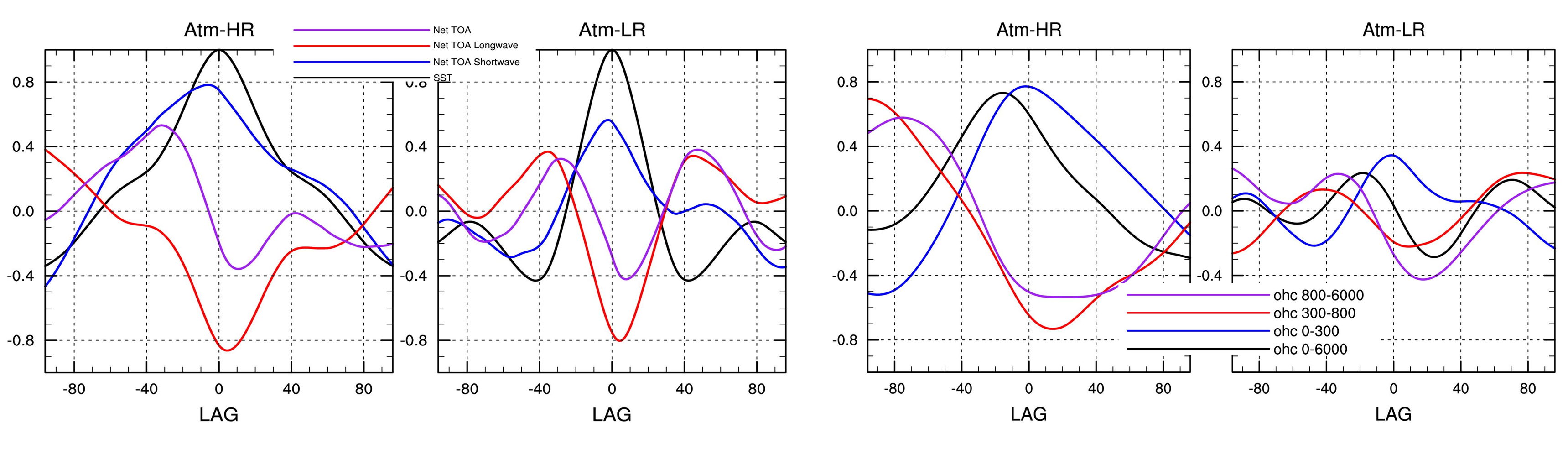


Fig 2: Lagged correlations (in months) between T and (left, center left) N, and top-of-the-atmosphere radiation components, and (center right, right) ocean heat content at different depths. In positive lags T is leading.

## First Results

ENSO-like pattern of SST (Fig 3). Differences between Atm-LR and Atm-HR are pronounced in North Pacific and the atlantic subpolar gyre. **Is this related to differences in in the phase of the PDO, AMOC and/or subpolar gyre circulation?**

Labrador Sea: warming at surface but net 0-bottom heat loss (Fig 4, Atm-HR): **does this imply stronger convection/stronger AMOC when +ve T anomalies**? Atm-LR is different.

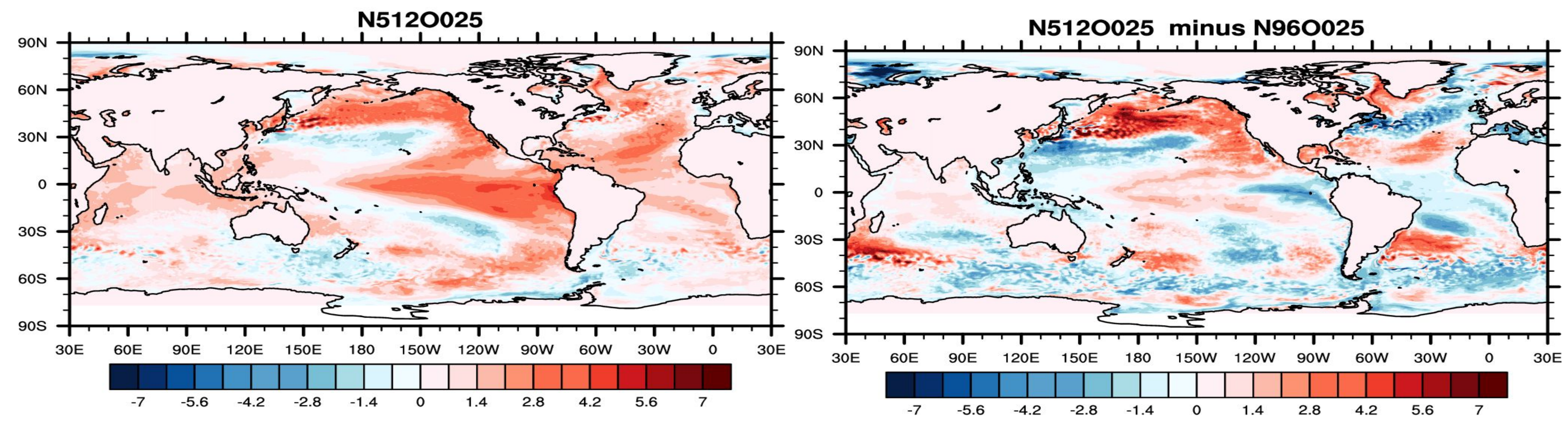


Fig 3: Regression of SST on global mean T.

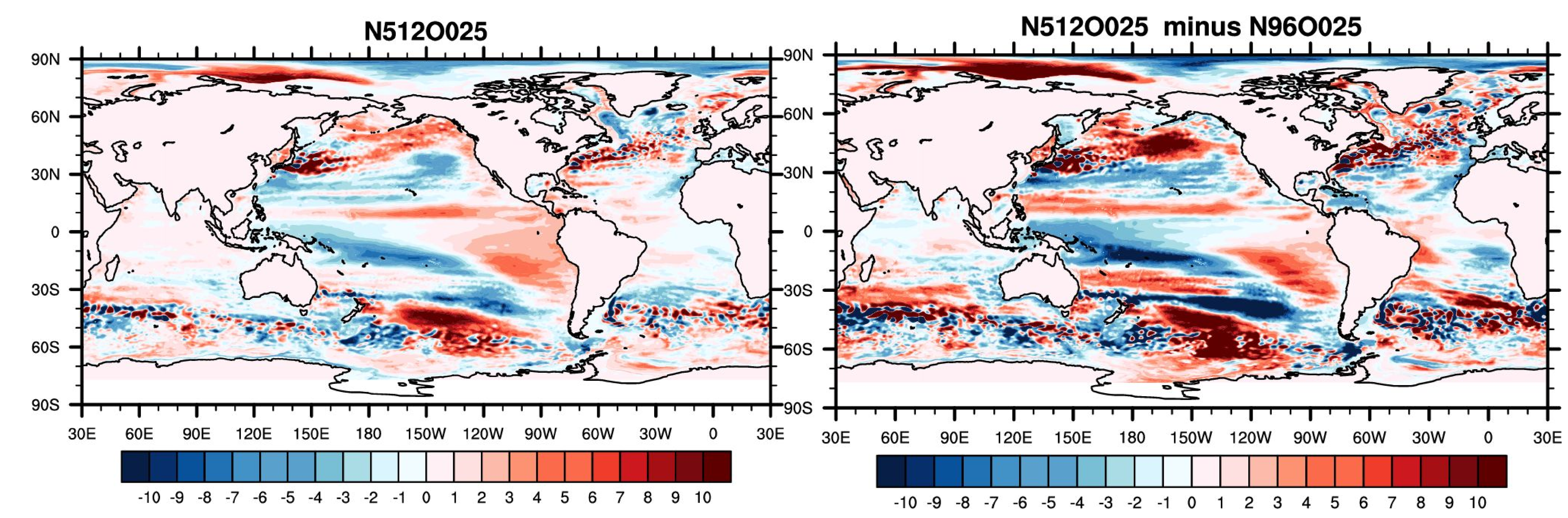


Fig 4: Regression of OHC 0-bottom on global mean T.

## Summary

Pre-stream1 analysis using HadGEM3-GC2 present-day simulations

Net top-of-the atmosphere (TOA) is poor constraint on global mean T change, in contrast to the classical view of the energy budget under forced response.

A revised energy budget contains a natural variability component with a sinusoidal form in the energy budget.

This natural variability component seems to be sensitive to atmospheric resolution.

**Caveats and difficulties:**

**Large oceanic drift is an important problem** when calculating ocean heat content, choice of detrending might impact results.

**Size of data** makes analysis strenuous: need to load into memory large arrays (timeseries of 2D high resolution ORCA025 data) and book lot of RAM. Requires considerable amount of time.

**Can the different results in Atm-HR and Atm-LR simply be due to different sampling of climate variability modes (e.g. PDO-like signal in Atm-HR)?**

## Outlook

Continue analysis, look into AMOC changes and their relation to T, N and OHC.

Will repeat the analysis in stream1 historical simulations (drift is removed using control experiments) and focus on key regions (such as North Atlantic), and compare with control simulations. Effect of natural variability sampling on the T-N relationships can be assessed in long low-resolution control simulations.

**References**

Gregory, J. M., and P. M. Forster. "Transient climate response estimated from radiative forcing and observed temperature change." Journal of Geophysical Research: Atmospheres 113.D23 (2008).

Xie, Shang-Ping, Yu Kosaka, and Yuko M. Okumura. "Distinct energy budgets for anthropogenic and natural changes during global warming hiatus." Nature Geoscience 9.1 (2016): 29-33.

PRIMAVERA
www.primavera-h2020.eu

PRIMAVERA is a collaboration between 19 leading European research and technology organisations with complementary expertise in climate science, climate change modelling, and high-performance computing. The project is led by the Met Office and the University of Reading.

Discover more about PRIMAVERA

PRIMAVERA has received funding from the European Union's Horizon 2020 Research & Innovation Programme under grant agreement no. 641727.