Energy budgets to evaluate seasonal forecasts

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Introduction

Diagnosis of the coupled energy budget is an essential tool for climate monitoring but also to evaluate models. This contribution presents various examples from different areas where diagnosis of quantities related to the energy budget prove useful in understanding seasonal forecasts and associated errors of ECMWF's operational seasonal forecasting system SEAS5.

- Example 1 relates SEAS5's predictions of the 2014-16 ENSO evolution to the anomalous ocean heat budget of that period
- Example 2 investigates the cause of the non-stationary SST bias of SEAS5 in the North-west North Atlantic
- Example 3 evaluates SEAS5 predictions of Earth's Energy Imbalance (EEI)

Example 1: Predicting the 2015/16 El Niño event

Background

The tropical Pacific sub-surface (30N-30S) did not cool during the strong 2015/16 El Niño event. Reanalysis data shows that during 2014-16 the Indonesian Throughflow (ITF) was extremely weak, which acted to retain warm waters in the Pacific. The reduction in ocean heat export balanced the surface heat loss and helped to keep OHC at high levels (Fig 1.1). Mayer et al. (2018) hypothesized that the reduction of the ITF was due to the anomalously warm Indian Ocean and associated weak inter-basin sea level gradient.

Idea

Run two-year-long forecasts started in Feb 2014 where Indian Ocean conditions are replaced with those in 1997 and evaluate the impact on ENSO forecasts and Pacific heat budget:

- REF_14: initialized with unchanged ICs in 2014/02 (same setup as SEAS5)
- IndO_97: as REF_14, but swapped Indian Ocean ICs with conditions in 1997/02

Results (Fig. 1.2)

REF_14 predicts ENSO probabilities consistent with observations in Dec 2014 and 2015. REF_14 also correctly predicts weak ITF and anomalous ocean heat convergence that kept the Pacific warm

IndO_97 shows enhanced probability of a strong El Niño in year 1 and enhanced probability of La Niña in year 2 (compared to REF_14). IndO_97 predicts much stronger OHC decrease as result of surface heat loss and neutral ocean heat convergence (=neutral ITF)

Conclusions 1

Forecast experiments confirm hypothesis that warm Indian Ocean in 2014 was responsible for i) weak ITF volume flux and heat transport, ii) absence of tropical Pacific OHC discharge, and iii) absence of La Niña conditions in 2015 and 2016. Also, having at hand a two-year forecast in 2014 (like REF_14) may have moderated wrong expectations for a strong El Niño in 2014/15. SEAS6 will issue two-year-long forecasts.

References

Mayer, M., Balmaseda, M.A. Indian Ocean impact on ENSO evolution 2014–2016 in a set of seasonal forecasting experiments. Clim Dyn 56, 2631–2649 (2021)

Mayer, M., Alonso Balmaseda, M., & Haimberger, L. (2018). Unprecedented 2015/2016 Indo-Pacific Heat Transfer Speeds Up Tropical Pacific Heat Recharge. Geophysical Research Letters, 45(7), 3274-3284.

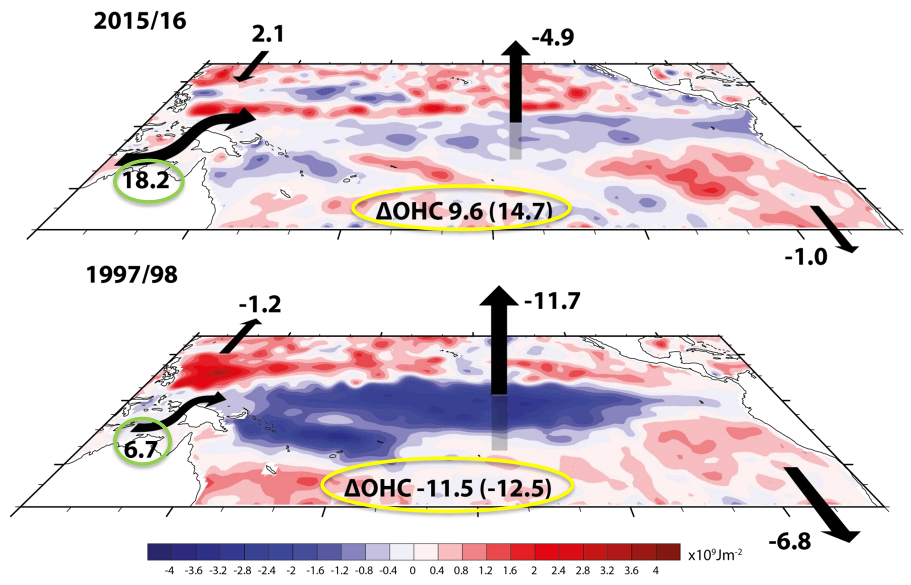


Fig. 1.1. Two-yearly changes in OHC (maps) and accumulations of anomalous energy fluxes across tropical Pacific boundaries [ZJ]: Pacific warmed during 2015/15 (top), while it cooled strongly during previous strong El Niño 1997/98 (bottom). Difference in ITF strength explains most of the OHC difference

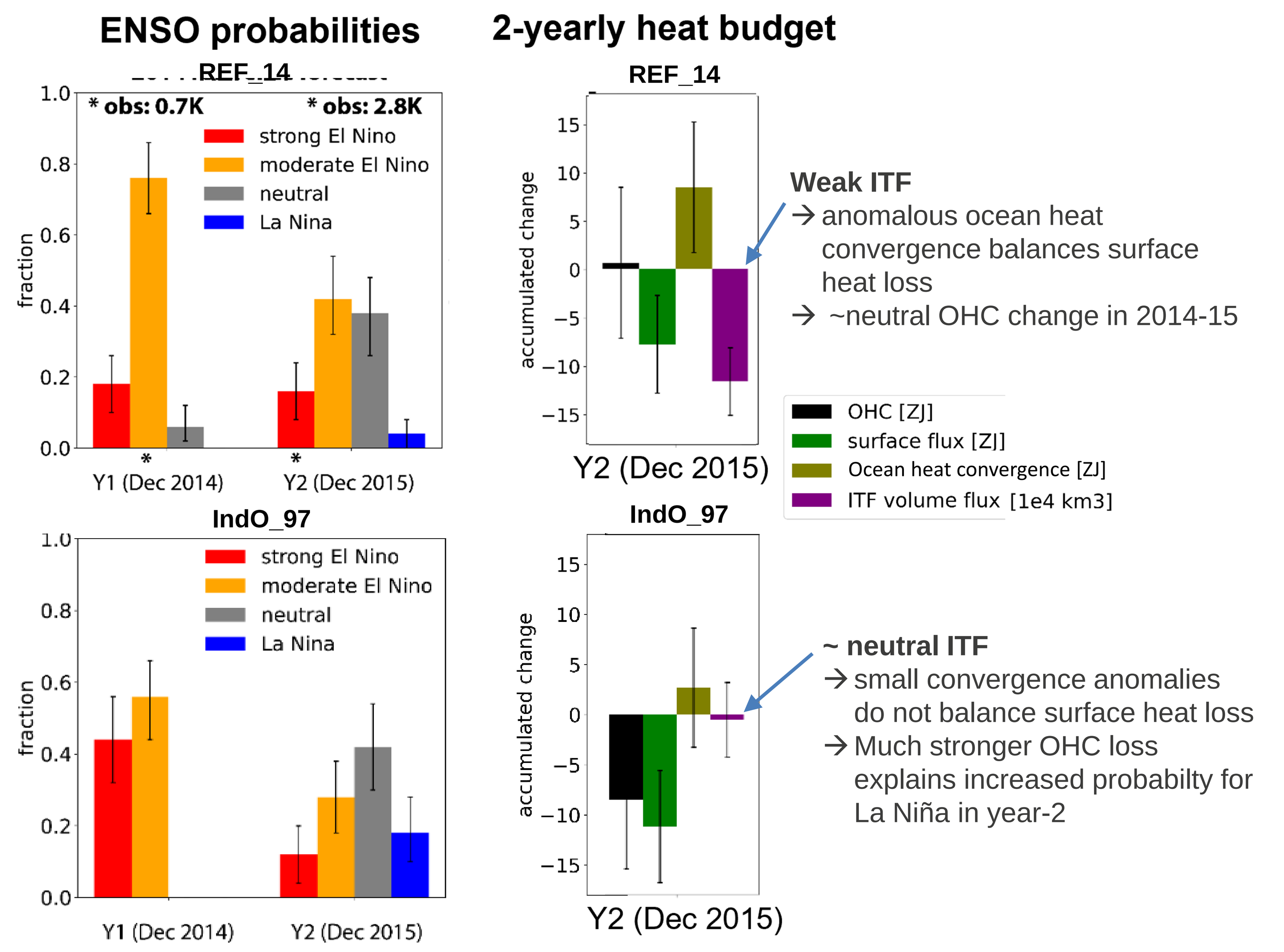


Fig. 1.2. Predicted ENSO states (left) and ocean heat budget evolution in (right) REF_14 and IndO_97

Example 2: Non-stationary bias in the North Atlantic

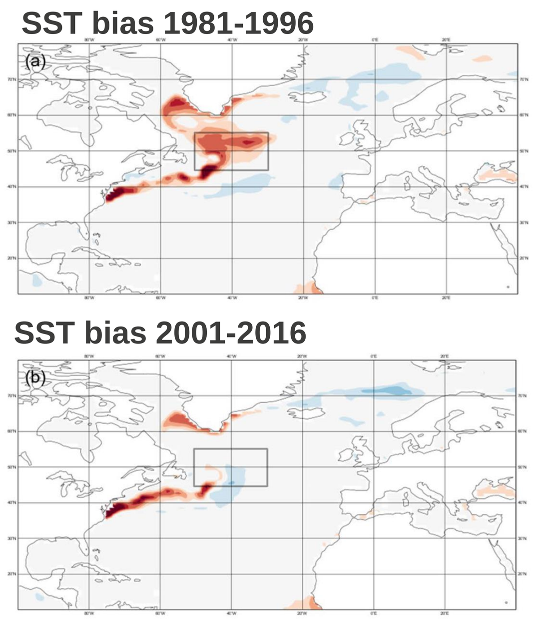


Fig. 2.1. SEAS5 DJF SST bias in early and late period

In the western part of the North Atlantic Subpolar Gyre, the SEAS5 seasonal winter forecasts suffer from a warm SST bias during the pre-Argo period 1981-1996 (Fig 2.1). This has been traced back to unbalanced initial conditions that come from the ORAS5 ocean reanalysis. In ORAS5, excessive heat transport into the region by the North Atlantic ocean circulation (Figs 2.2 and 2.3) is balanced by additional surface cooling from relaxing towards observed SST (Fig 2.4), which in turn reinforces the excessive ocean heat transport. The fit to SST observations in the reanalysis is acceptable, but the unrealistic balance between ocean heat transport and surface heat flux in the region leads to the rapid appearance of the strong SST biases shown in Fig 2.1, which negatively impact seasonal forecast skill and hamper forecast calibration.

Conclusions 2

Physically balanced (i.e., in terms of energy transports and fluxes) and temporally homogeneous ocean reanalyses are key for avoidance of excessive and non-stationary biases in seasonal hindcasts

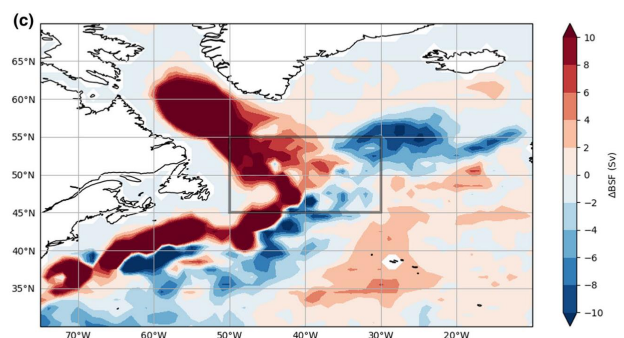


Fig 2.2: Difference in ORAS5 barotropic stream function DJF 2001-2016 vs. 1981 - 1996

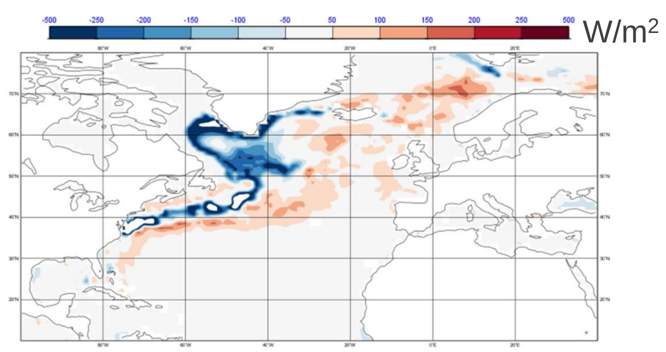


Fig 2.4: DJF SST restoring heat flux bias in ORAS5 1981 - 1996

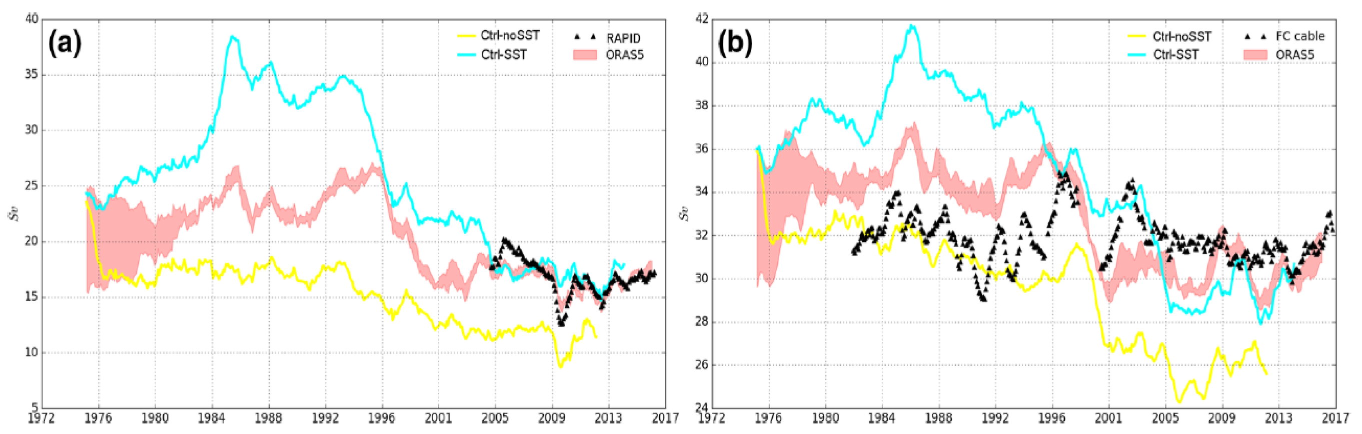


Fig 2.3: Time series of a) AMOC strength at 26.7N and b) Florida Strait transport in ORAS5, reanalysis experiments, and observations

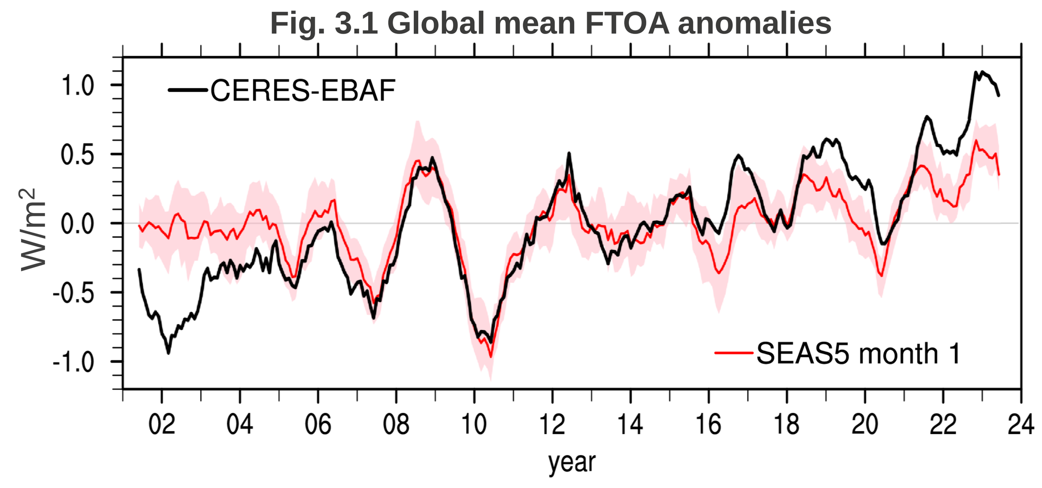
Reference

Tietsche, S., Balmaseda, M., Zuo, H., Roberts, C., Mayer, M., Ferranti, L. (2020): The importance of North Atlantic Ocean transports for seasonal forecasts. Clim Dyn 55, 1995–2011

Example 3: predicting Earth's Energy Imbalance (EEI)

- Each ensemble member of SEAS5 lead month-1 forecasts represents a plausible realization of EEI since the ocean state is still close to observations. Does SEAS5 capture observed EEI variability and trends?
- Month-1 predictions of global mean net TOA imbalance anomalies (FTOA) from SEAS5 exhibit good correlation with satellite observations, but the observed positive EEI trend is outside the ensemble range (Fig. 3.1).
- Trend maps indicate underestimation of increasing heat uptake particularly in mid-latitudes and Western tropical Pacific (Fig. 3.2)
- Need to investigate further potential role of ocean initial conditions and tropospheric aerosols

Fig. 3.1 Global mean FTOA anomalies



Conclusions 3

Lead month-1 SEAS5 forecasts do not reproduce observed EEI trend, i.e. cannot be used as observational surrogate of EEI. However, due to the constrained ocean state (thanks to frequent initialization) EEI trend errors in SEAS5 may be easier to understand in terms of processes compared to free-running climate models

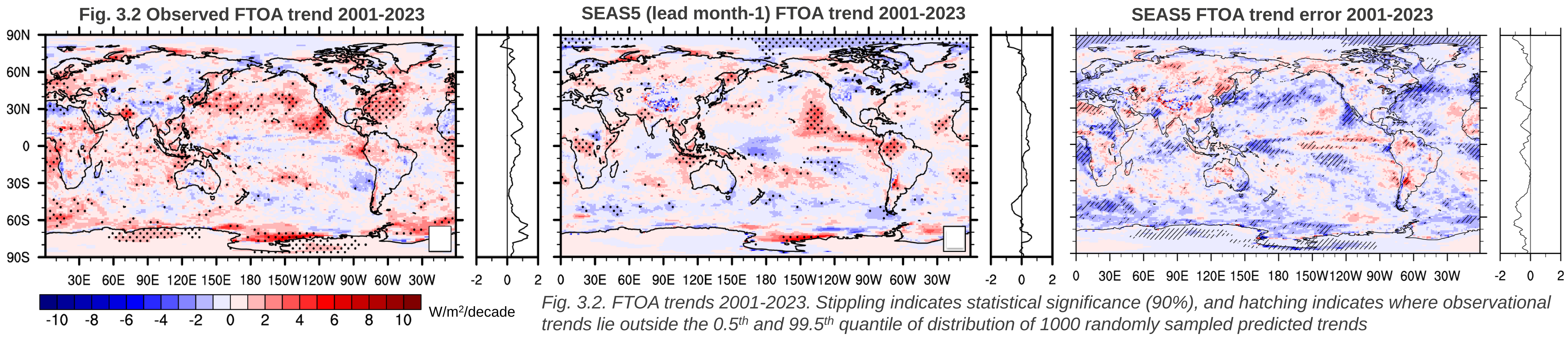


Fig. 3.2. FTOA trends 2001-2023. Stippling indicates statistical significance (90%), and hatching indicates where observational trends lie outside the 0.5th and 99.5th quantile of distribution of 1000 randomly sampled predicted trends