DETECTION OF HUMAN INFLUENCE IN RECENT UPPER OCEAN TEMPERATURE AND SALINITY CHANGES

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Introduction: Evidence is building that increasing anthropogenic greenhouse gases atmospheric concentrations leads to upper ocean warming with consequences on the marine hydrological cycle. In order to confirm the human influence on tropical and subtropical oceanic climate trends for the past decades, we examine recent changes in two variables with high signal-to noise ratio. The mean temperature above 14°C isotherm is taken as a tracer of the upper ocean warming signature while sea surface salinity is used as a tracer of the marine hydrological cycle modifications. The three following questions are invastigated:

1) What are the recent observed trends in these two variables? **2) Are they emerging from the internal variability?** **3) Can a human influence be detected in the recent observed changes?**

Subsurface temperature

- **Variable:** the mean temperature above 14°C isotherm (Tiso14) → no sensitive to XBTs biais and isolating radiative warming.
- **Data:** 6 objective analyses: WOA09 (*Levitus et al. 2009*), IK09 (*Ishii and Kimoto 2009*) EN3_OA_corr / EN3_OA (*S. Good, MetOffice*) with/without XBTs correction of *Wijffels et al. (2008)* CH11_corr / CH11 (*M. Hamon, Ifremer*) with/without XBTs correction of *Hamon et al. (2011)*

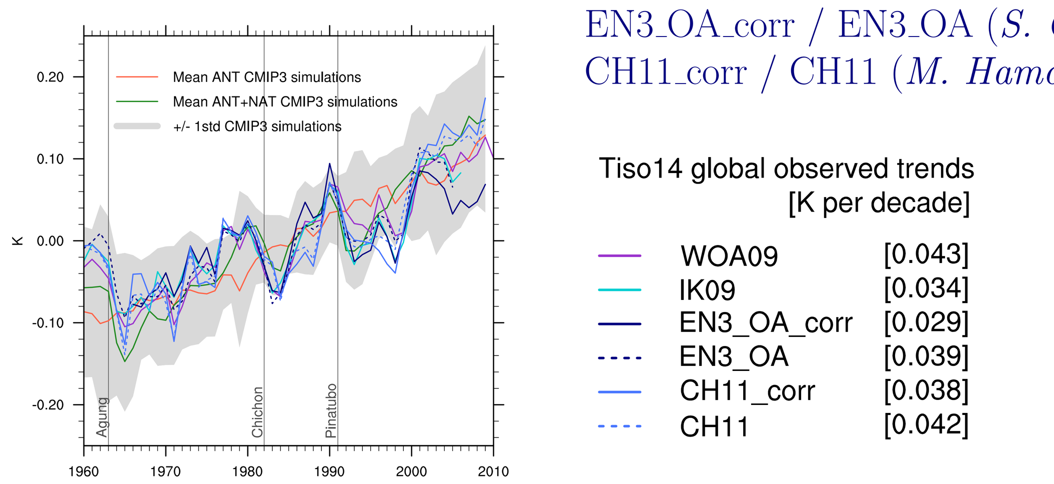

FIG. 1: Tiso14 global yearly anomalies

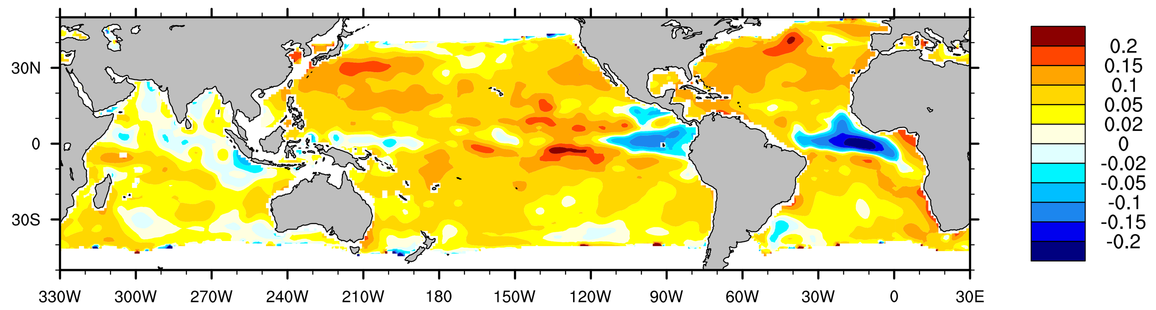

FIG. 2: 1965–2010 trend (in K per decade) of Tiso14 from WOA09.

- **Recent evolution: mean warming superimposed with decadal variations (short term coolings after volcanic eruptions).**
- **Global observed trend very consistent with the CMIP3 ensemble mean trend (for both ANT and ANT+NAT ensembles).**
- **Spatially : warming quite uniform (except limited cooling areas at the equator).**

Surface salinity

- **Variable:** the ocean surface salinity (SSS) in the Tropical Atlantic and Pacific Oceans.
- **Data:** a compilation of 2 surface (0-10m) salinity objective analyses: – from 1955 to 2008 in the Pacific (*Cravatte et al. 2009*) – from 1970 to 2002 in the Atlantic (*Reverdin et al. 2007*)

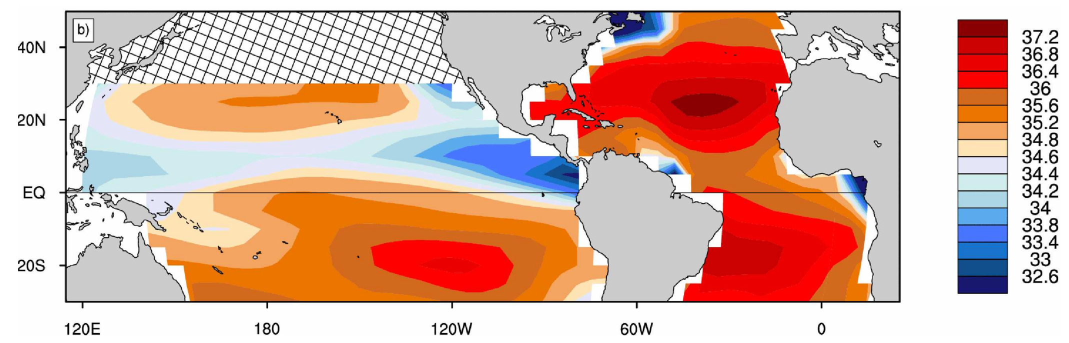

FIG. 3: SSS observed climatology (in psu) over the 1970–2002 period.

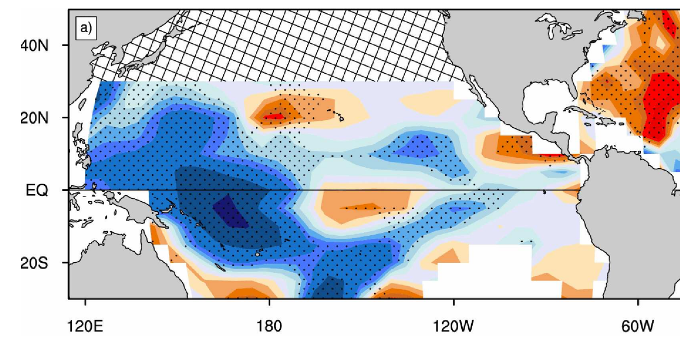

FIG. 4: SSS observed 1970–2002 trend (in psu per century)

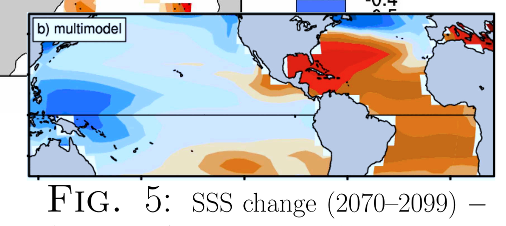

FIG. 5: SSS change (2070–2099) – (1970–1999) from CMIP3 A1B scenario.

- **Recent evolution: increasing spatial regional contrasts : fresher regions becoming fresher, and vice versa. Enhanced inter-basin salinity contrast with a tropical Pacific freshening and Atlantic saltening.**
- **Same main spatial characteristics as SSS change projected by 2100.**

The Temporal Optimal Detection (TOD) method

- **Hypothesis 1:**

The scalability assumption : the spatial structure of the transient forced response is quasi-invariant with time given a homothetic transformation.

- **Statistical model:** $\psi(s,t) = g(s) \cdot \mu(t) + \epsilon(s,t)$,

s and t : the spatial and temporal indices
ϵ : a centered noise term representing internal variability
g and μ : the response spatial and temporal patterns to anthropogenic forcing

- **Hypothesis 2:**

The internal variability is an autoregressive process of order 1 in time, with some unspecified covariance structure in space : $\epsilon(s,t) = \alpha \cdot \epsilon(s,t\text{-}1) + \theta(s,t)$, with $\theta(s,t)$ independent identically distributed random variables. The choice of α is addressed by using the CMIP3-CTRL simulations.

- **Statistical test** (two-step process):

1) evaluate μ from model simulations
2) estimate g from the observations via generalised regression and test the null hypothesis H_0:"$g = 0$" versus H_1:"$g \neq 0$".

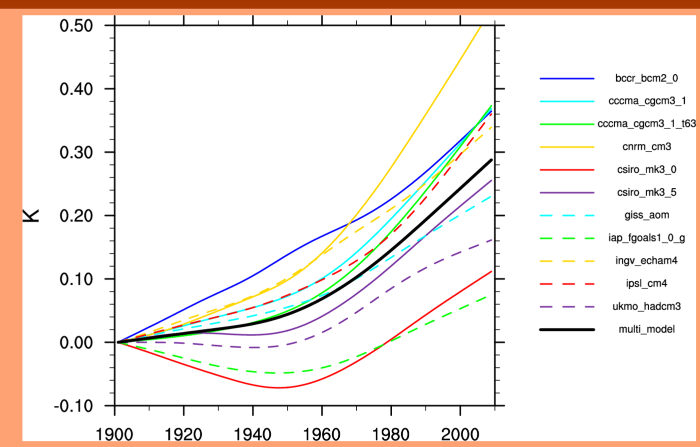

FIG. 6: Estimates of the temporal patterns μ (in °C) derived from annual mean Tiso14 from individual CMIP3 models, with 1901 as a time reference for all curves. A smoothing spline with 4 equivalent degrees of freedom is applied to each serie between 1901 and 2009 (historical simulations and A1B scenarii).

Observed and internal variability temperature trends

Temporal detection results

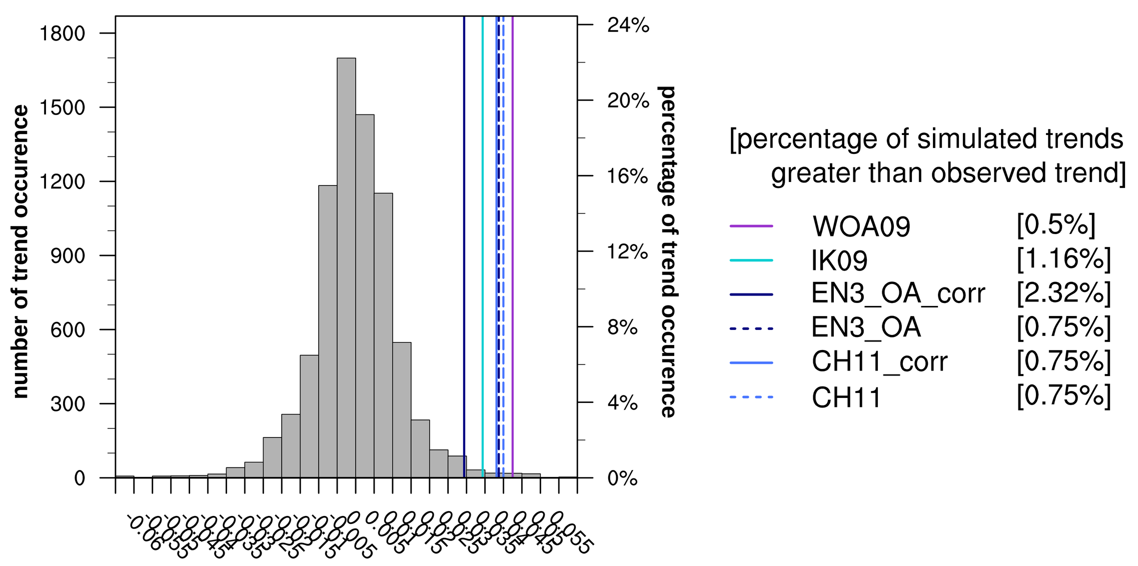

FIG. 7: Tiso14 global trends (K per decade): observed versus unforced trends from CMIP3 control simulations. Vertical color lines: 1966-2005 trends derived from each of the 6 observed datasets.

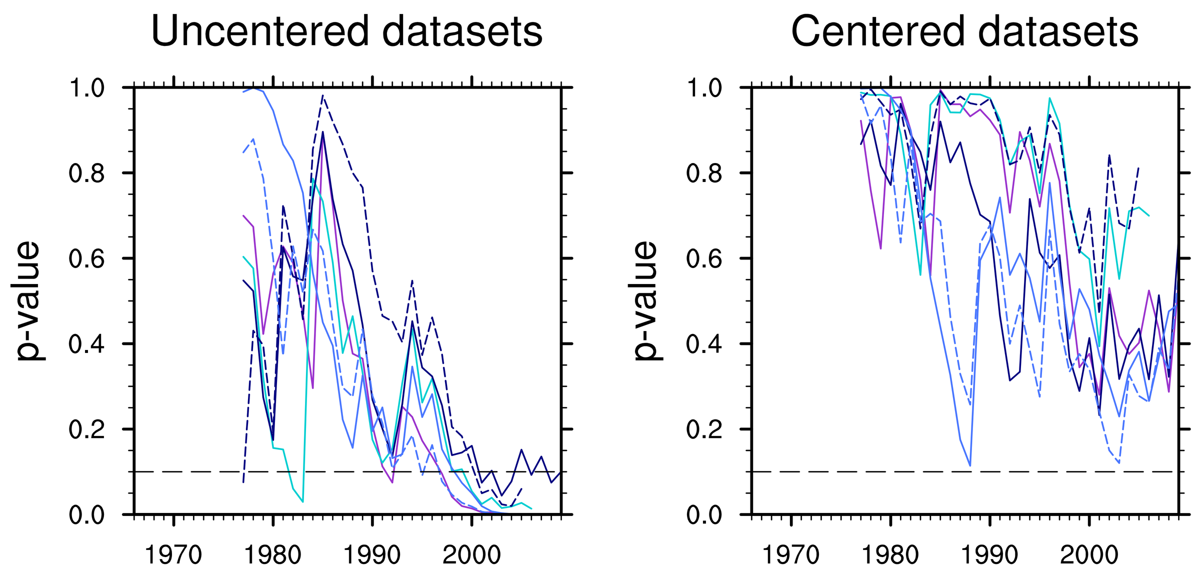

FIG. 8: P-value for the multi-model μ pattern (α = .75), for each observed dataset. Black dashed line: the 90% confidence threshold. Rejection of H_0 is achieved when the curve is under this line.

Tiso14 detection results

- **The global Tiso14 observed trend is significantly different from what is expected from internal variability alone.**
- **Anthropogenic forcing contributed significantly to the observed Tiso14 trend.**
- **For the centered datasets, there is no rejection of the H_0 hypothesis, thus no evidence of a non-uniform change.**

Observed and internal variability salinity trends

Temporal detection results

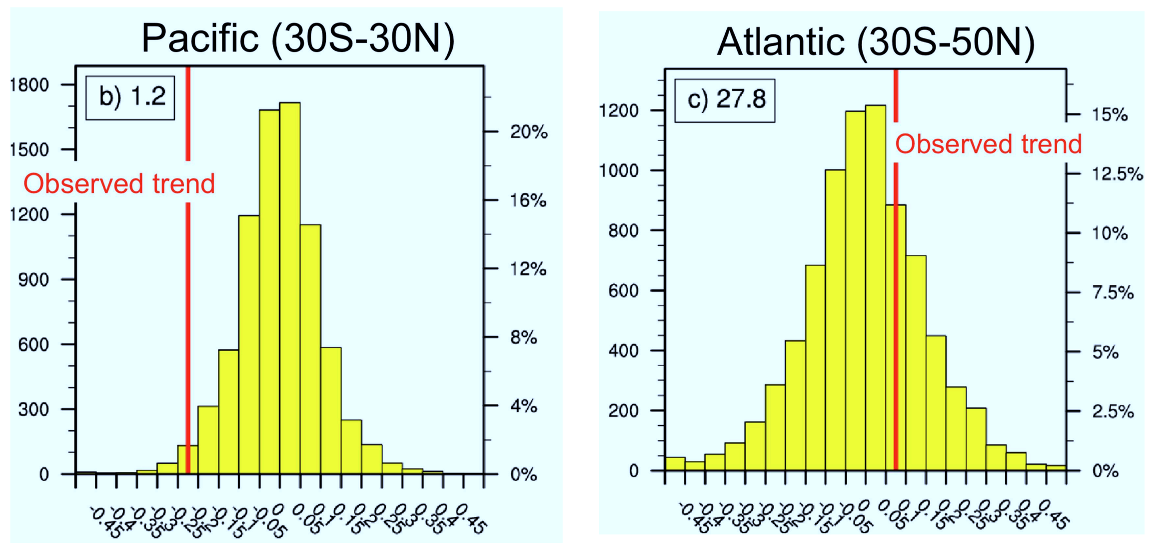

FIG. 9: Observed versus simulated unforced SSS trends (psu per century). Number in left box: percentage of simulated trends smaller (Pacific) or greater (Atlantic) than the observed value.

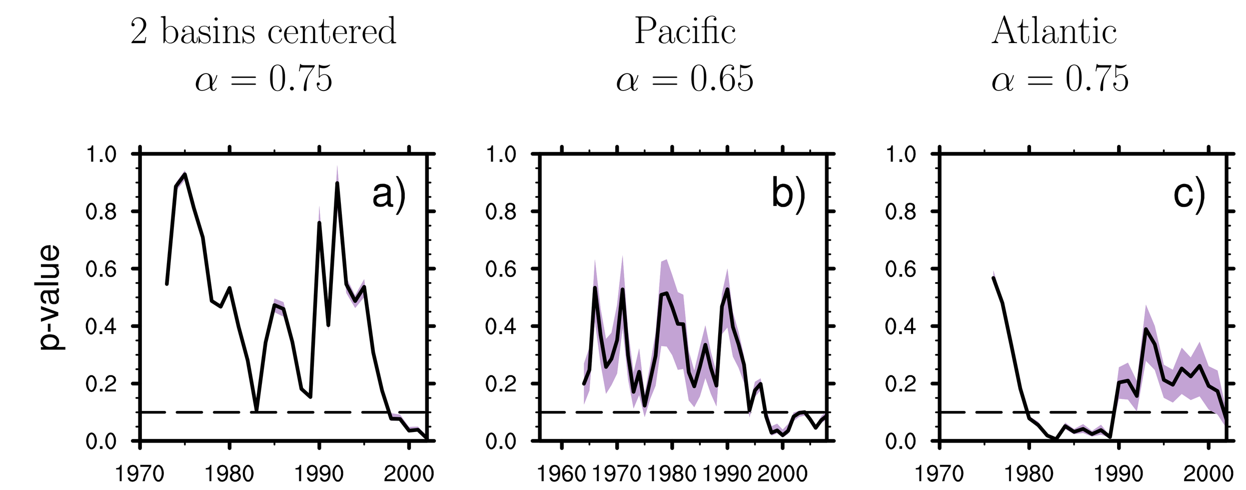

FIG. 10: P-value for (black line) the multi-model μ pattern and (shading) the minimum and maximum of the p-value range for all μ patterns derived from individual models.

SSS detection results

- **The mean-basin SSS observed trends are significantly different from what is expected from internal variability alone for the Pacific and inter-basin contrast, but not for the Atlantic.**
- **Anthropogenic forcing contributed significantly to the observed tropical Pacific freshening and to enhanced inter-basin contrast.**

References: Corre L., L. Terray, M. Balmaseda, A. Ribes, and A. Weaver, 2010: Can oceanic reanalyses be used to assess recent anthropogenic changes and low-frequency internal variability of upper ocean temperature? *Climate Dyn.*, **1**, 289; Terray L., L. Corre, S. Cravatte, T. Delcroix, G. Reverdin, and A. Ribes, 2011: Near-surface salinity as nature's rain gaue to detect human influence on the tropical water cycle. *J. Climate*, **in press**, doi:10.1175/JCLI-D-10-05025.1; Ribes, A., J. Azais, and S. Planton, 2010: A method for regional climate change detection using smooth temporal patterns. *Climate Dyn.*, **35(2)**, 391–406.