Salinity and Water Cycle - Sea Surface Salinity Changes: Constant or Changing Trend or Mean Regime Shift

A. L. Aretxabaleta[1], R. W. Schmitt[2], J. Ballabrera-Poy[1], K. W. Smith[2], J. Gourrion[1], J. Schanze[2], J. Font[1]

[1] Institut de Ciències del Mar – CSIC, SMOS Barcelona Expert Centre, Barcelona, Spain alfredo@icm.csic.es

[2] Woods Hole Oceanographic Institution, Woods Hole, MA, USA

Abstract

Several recent studies have shown significant global surface salinity (SSS) changes at scales ranging from regional to global (Antonov et al., 2002; Boyer et al., 2005). Durack & Wijffels (2010) found that SSS increases in regions dominated by evaporation while freshening occurs in precipitation-dominated areas. They suggested the change was a consequence of an intensification of the global hydrological cycle.

The question is whether these SSS changes are due to: 1) a regime shift in which the SSS has moved from one equilibrium state to another (maybe even several regime shifts); 2) a constant SSS trend (no new equilibrium has been achieved); 3) a varying SSS trend (not only is SSS changing, but the rate of change varies); or 4) a combination of the above.

In this study, we separate the different components of the global SSS (1950-2011) using Expectation-Maximization to distinguish, not only the means (regimes), but also the trends. The procedure uses a non-subjective method (BIC) to extract the optimal number of means and trends. Data comes from the UK Met. Office Hadley Centre, with SMOS satellite data used as a reference. A future goal is to use satellite data from SMOS and Aquarius to determine if the estimated means and trends are realistic.

Method

A Gaussian Mixture Model (GMM) is a model of random processes whose PDF is a sum of Gaussians. Expectation Maximization (EM) produces a maximum likelihood estimate of the parameters of a GMM (ζ^k, probability of regime k; μ^k and Σ^k, mean and covariance of the k^{th} component). The method has an expectation step in which the likelihoods, $\omega^k(t_m)$, are computed:

$$\left[\omega^k(t_m)\right] = \frac{e^{-\frac{1}{2}\left(\psi(t_m)-\mu^k\right)^T\left[\Sigma^k\right]^{-1}\left(\psi(t_m)-\mu^k\right)}}{\sqrt{(2\pi)^{n_d}\left|\Sigma^k\right|}}$$

The maximization step produces optimal weights. Frequencies are computed and normalized:

$$n^k = \sum_{m=1}^{n_t} \omega^k(t_m)$$

and the mean, trend, and covariance of the k^{th} component are computed:

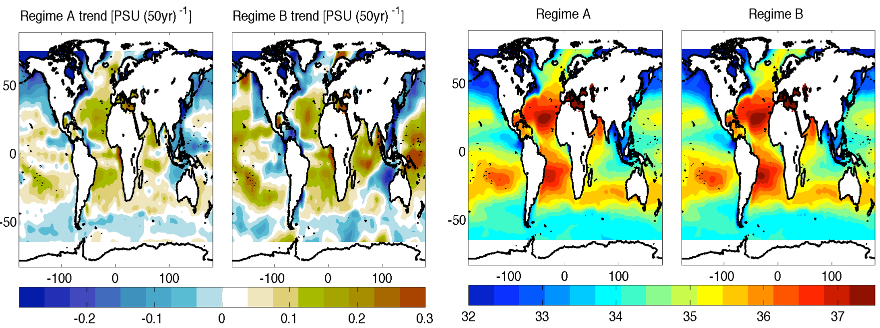
$$\mu^k = \sum_{m=1}^{n_t} \omega^k(t_m)\,\psi(t_m)/n^k$$

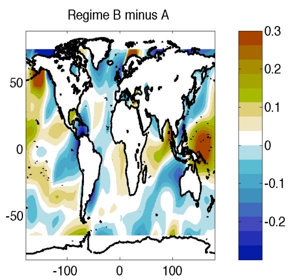
EOF modes can easily be extracted:

$$\psi(t_m) = \sum_{l=1}^{n_d} \alpha(t_m)\,\phi_l$$

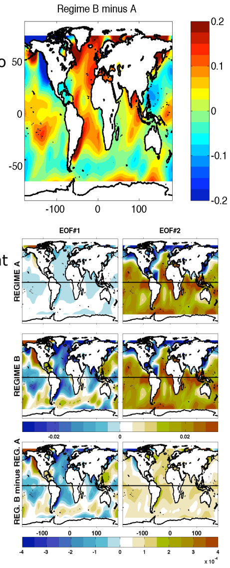
Smith & Aretxabaleta (2007)
Aretxabaleta & Smith (2011)

Results: two means + two trends

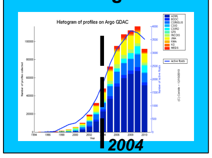


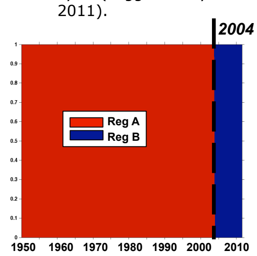


When the global SSS monthly data from UK Met. Office Hadley Centre (Ingleby and Huddleston, 2007) is analyzed, the EM method distinguishes two separate regimes. These regimes are characterized by different means but also different trends. The separation between the two regimes occurs in 2004. Regime A (1950-2004) is consistent with the results obtained by Durack & Wijffels (2010) and the references therein. Regime B (2004-2011) exhibits saltier mean values in low- and, especially, mid-latitudes. The trend associated with Regime B exhibits increased magnitudes (positive trends being more positive and negative areas being more negative). In both regimes the trends are consistent with an intensification of the global hydrological cycle (suggested by Schanze et al., 2010; Yu, 2011).



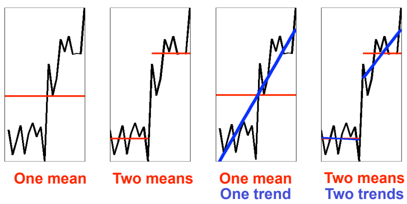
Real regime change or real observational change?





The method also allows for the separation of the modes of variability. The 1st EOF of Regime A is spatially consistent with Regime B, but its magnitude is much smaller. The 2nd EOF for both regimes is quite similar.

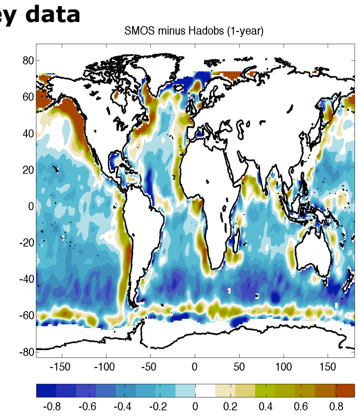
Means vs. Means + Trends



The EM method allows for the separation of regimes based on their averages and trends assuming the spatial time series is a combination of Gaussians. The method uses Bayesian Information Criterion (BIC) to choose the appropriate number of means/trends by penalizing excessive overfitting. The resulting fit represents the Maximum Likelihood Estimate (MLE) chosen using a non-arbitrary separation.

SMOS vs. Hadley data

The SMOS satellite data exhibits significant issues especially near coastal areas and in high latitudes. The comparison with the last year of available data from the Hadley Center demonstrates these deficiencies. In the center of the basins (where SMOS errors are smallest), the satellite SSS is fresher than the interpolated data. The inclusion of the recent SMOS data in the analysis in substitution of the Hadley data for 2010-2011 completely alters the EM separation results (not shown). This suggests that careful validation of any new data is fundamental for the success of the EM method.



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Acknowledgements

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