OBSERVATIONS OF ATMOSPHERE-OCEAN FRESHWATER INPUT WITH *IN SITU* AND SATELLITE MEASUREMENTS OF SURFACE SALINITY AND RAIN

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1. ABSTRACT

We report on studies of sea surface salinity (SSS) in the Atlantic in preparation for the calibration and validation of the European Space Agency Soil Moisture and Ocean Salinity (SMOS) satellite due for launch in November 2009. First order validation of SMOS SSS will check if the satellite can detect features such as the meridional gradient of SSS, the maximum SSS in the Atlantic subtropical gyres or freshwater plumes from large rivers (e.g. Amazon). Finer validation against *in situ* data will require considerable effort to build multi-pass products and careful handling of errors and biases in both in situ and satellite data. Early comparisons of in situ SSS from ARGO and PIRATA show good consistency between different data sources. The important relation between SSS, precipitation and evaporation is tentatively explored but made difficult by the dearth of SSS data close to the surface. Plans to deploy a new conductivity-temperature micro-sensor to sample the top few meters are discussed.

2. INTRODUCTION

The ESA Soil Moisture and Ocean Salinity (SMOS) satellite is due for launch in November 2009, followed in Autumn 2010 by the launch of the US/Argentine Aquarius mission. Both instruments aim to provide synoptic data on sea surface salinity (SSS) and will provide the first global quasi-synoptic view of the variability over oceanic basins and seasonal to inter-annual scales of this hitherto poorly known field.

SSS and sea surface temperature (SST) are important for ocean circulation, air-sea interactions and climate. In the North Atlantic, sinking of dense waters associated with the Meridional Overturning Circulation leads to the heat transport, which gives Northern Europe its relatively mild climate compared to other regions at the same latitude. Operational models assimilate some *in situ* data from Argo, PIRATA, XBTs, as well as satellite SST data, but insufficient salinity data means that most models relax surface salinity to climatologies. New observations of SSS from satellites could therefore significantly help improve the performance of ocean circulation and climate models.

3. SCIENTIFIC ISSUES IN VALIDATING SATELLITE SSS

The measurement of SSS from space relies on passive microwave brightness temperature observations at L-band (1.4 GHz, ~20 cm wavelength). SMOS is the first-ever L-band interferometric radiometer to be flown in space. Given the technical and scientific innovation, there are many challenging aspects to the validation of SMOS SSS. For example, while L-band is the frequency with highest sensitivity to salinity, that sensitivity remains weak and is dominated instead by surface roughness effects. These effects are poorly understood, so much so that, for each measurement, SMOS will provide three estimates of SSS from three different brightness temperature inversion models.

The spatial resolution in single-pass SMOS products varies between 35 and 50 km across a ~700 km swath. The accuracy of SSS in these products should be around 1 psu. Therefore, in the first instance, the satellite SSS will be verified, for example, against the meridional gradient in SSS in the low latitude Atlantic (see Fig. 1). These "Level 2" (L2) products will be characterised by relatively poor accuracy but high spatio-temporal resolution and will form the basis of the SMOS mission initial validation.

The accuracy of satellite SSS can be significantly improved with spatio-temporal averaging over multiple overpasses. Composite salinity maps averaged over 10-30 days and 1-2 degree grids should come close to providing the 0.1 psu SSS accuracy requirement set by GODAE (Global Ocean Data Assimilation Experiment). These "Level 3" (L3) must be constructed with great care though, to account for the complex error characteristics of SMOS, particularly due to image reconstruction biases. The L3 averaged products will feature relatively coarse spatio-temporal resolution but much higher accuracy in SSS. Comparing L3 data against accurate but sparse in time and space *in situ* observations of near-surface salinity will call for new methodologies to combine related information from different sources, each with different error and sampling characteristics.

Finally, most *in situ* near-surface salinity measurements relate to depths of 5 meters or deeper. In contrast, the L-band microwave emission measured by the satellite originates from an ocean surface layer typically only a few cm deep [1]. For SST, the thermal skin effect is well studied [2] and the possibility of a similar salinity skin effect, particularly in tropical regions, has been suggested [3]. In preparation for SMOS cal/val, Boutin and Martin [4] tried to quantify vertical differences in salinity in the top 10 meters with 1 year of global Argo float data. Profiles with measurements in the ranges 0-5 m and 5-10 m depth were selected and binned in 2 by 2 degree cells. Salinity differences between these two depth bins showed that vertical differences in salinity were generally small (<0.005), except for systematic regional biases reaching 0.05 psu on yearly average in tropical regions. These results were thought likely to underestimate the variability between 1 cm and 5 m.

4. SOURCES OF *IN SITU* SSS DATA

Initial preparations have focussed on identifying sources of *in situ* SSS observations, building consolidated products and assessing the horizontal and vertical variability of SSS in the Atlantic. The main data considered to date are: 1) Argo: a global network of drifting floats providing temperature and salinity profiles up to a minimum depth of a few metres. Here, we used data in the Atlantic between 60°N and 60°S, obtained through the Coriolis data centre (www.coriolis.eu.org/); 2) PIRATA (Prediction and Research Moored Array in the Atlantic): an array of fixed stations in the Tropical and Equatorial Atlantic providing measurements of salinity and temperature at various fixed depths, up to a minimum depth of 1 m. The data were accessed through the Tropical Atmosphere Ocean Data Display and Delivery service of the NOAA Pacific Marine Environmental Laboratory (www.pmel.noaa.gov/tao/disdel/disdel.html).

Both datasets are freely available for download through ftp/internet browsers and provide invaluable access to critical *in situ* data. Online data resources like these are particularly useful as they provide access to data within short time-scales, bordering on real time. Other freely available SSS data exist, including some from research cruises and vessels of opportunity (VOS), but have not been considered so far.

5. MONTHLY GRIDDED *IN SITU* SSS DATASETS

5.1. ARGO

For each month between January 2006 and July 2009, Argo profiles for the Atlantic Ocean were downloaded from the Coriolis Global Data Assembly Centre (www.coriolis.eu.org/cdc). All profiles with at least one measurement at a depth less than 10 m are included. For each profile, we take the average of all salinities shallower than this critical depth. Work is ongoing to establish whether this is the most appropriate methodology, or whether it is preferable to use the shallowest value, or to weight different salinity values according to depth.

The average SSS from each profile are then binned over a 1° by 1° grid. Again, studies are ongoing to investigate alternative spatial averaging procedures, e.g. by weighting profiles by the number of shallow measurements. The choice of grid size will readily allow comparisons of these Argo SSS fields with monthly climatologies from the World Ocean Atlas 2005 [5].

5.2. PIRATA

For the same time period (January 2006 to July 2009), PIRATA monthly averaged surface salinity data were downloaded for a depth of 1 m. For comparison, the shallowest of any Argo profile measurements of salinity for July 2009 was 2 m. The PIRATA data are provided as averages over all data collected during each month, with a minimum of 15 daily values in each month.

6. IN SITU SSS CONSISTENCY AND VARIABILITY

Fig.1 shows the Argo and PIRATA surface salinity in the Tropical and Equatorial Atlantic for July 2009 to assess the consistency between SSS measurements from different in situ data sources. The monthly Argo SSS averaged over 1° by 1° boxes are shown as filled squares, the PIRATA salinity data as filled circles. Despite local variability, the meridional gradient of SSS is clearly visible in both datasets. On casual inspection, there is reasonable point-to-point agreement between the two data sources. Further analysis will be needed for a quantitative estimate of the agreement.

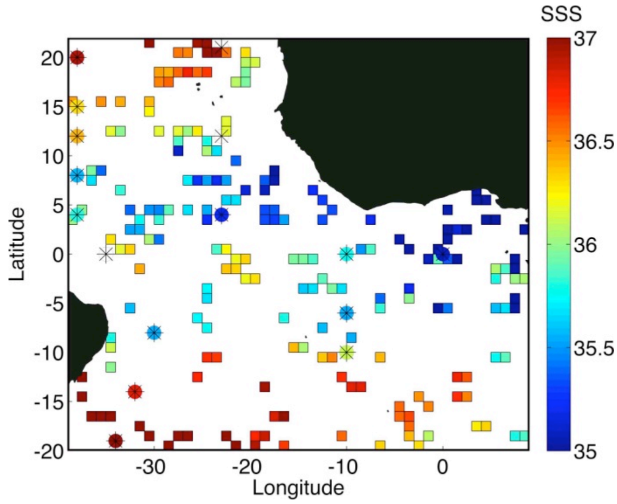

Figure 1. Monthly averaged surface salinity for July 2009 for PIRATA (fixed station, 1 meter depth, shown as filled circles) and Argo (1° by 1° averages, all measurements shallower than 10 meters, shown as filled squares). Asterisks show the locations of all PIRATA fixed moorings.

7. SSS, PRECIPITATION and E-P

As far back as 1936, Wüst [6] suggested that there is a positive, linear relationship between E-P and SSS. We tentatively examine this hypothesis using observations currently at hand. Rainfall data, also available from the PIRATA database, were downloaded for comparison with SSS. An example is shown in Fig. 2. At this station, the data show a high level of anti-correlation between rainfall rate and SSS on monthly averaged values. However, missing data at other sites means we cannot conclude if this case is perhaps atypical.

It is well known that precipitation can have a signature in SSS, particularly in regions characterised by heavy downpours and low wind conditions. In regions of high precipitation, differences between *in situ* “surface” salinity (measured at a few meters depth) and satellite salinity at the interface (measured at a few cm depth) may result in important insight into the level of atmospheric freshwater input and the degree of near-surface ocean mixing.

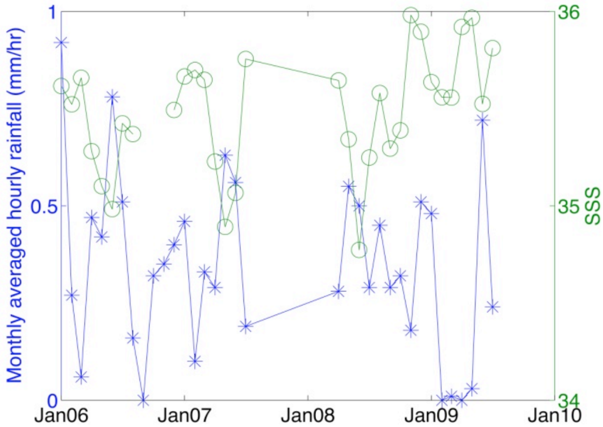

Figure 2. Monthly averaged rainfall rate (mm/hr) and sea surface salinity at 1 m (psu) between January 2006 and July 2009 for PIRATA mooring at 38°W, 4°N.

8. NEW SSS AND SST SENSOR DEVELOPMENT

The scientific questions we face call for observations of SSS in the top few cm of the ocean and thus for the development of specialised sensors capable of measuring accurately close to the air-sea interface. Similar work is already under-way for SST, for which special SST sensors have started to feature on some Argo floats. In this study, we hope to benefit from recent development of "lab-on-a-chip" technology and deploy a chain of near-surface, conductivity-temperature micro-sensors during research cruises in the forthcoming year. These would coincide with ship-based deployments of full water column CTD in a series of locations in the Atlantic, including during the 6-months commissioning phase of the SMOS satellite in 2010. This should provide data on the short-term (time and space) variability of near-surface salinity as well as vertical gradients in the top 10 meters of the water column.

9. CONCLUSIONS AND FUTURE WORK

Monthly gridded climatologies of SSS based on Argo and PIRATA data for a period covering over three years have been developed and qualitatively show good agreement between these two types of *in situ* observations. A thorough quantification of possible differences between different sources of *in situ* data, their sampling and error characteristics and their relationship to the oceanic variability in SSS on various spatial and time scales is required before comparisons can be made with satellite measurements. New methodologies are required to assess the level of agreement between different datasets. Such work will provide a baseline against which SMOS data, when available, can be compared.

In the longer term, the value of SMOS data for assimilation into models will need to be assessed. Currently, most ocean models produce spurious drifts in SSS, primarily because of uncertainties in the forcing fields (e.g. E-P, river run-off). These salinity drifts are transferred to deeper layers and result in the formation of unrealistic water masses and hence changes in circulation. The availability of new SSS climatological products from *in situ* and satellite should shed new light on ocean-atmosphere exchanges of freshwater and help validate and improve the forecasting ability of ocean and climate models.

10. ACKNOWLEDGEMENTS

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11. REFERENCES

1.Srokosz, M. A. (1995), Ocean surface salinity - the why, what and whether, in Proc. Consultative meeting on Soil Moisture and Ocean Salinity measurement requirements and radiometer techniques (SMOS), 20-21 April 1995, edited, pp. 49-56 ESA WPP-87, Noordwijk.

2. Stuart-Menteth, AC *et al.* (2003), A global study of diurnal

warming using satellite-derived sea surface temperature, Journal of Geophysical Research-Oceans, 108(C5), 3155.

3. Saunders, P. M. (1967), The temperature at the ocean-air interface, J. Atmos. Sci., 24, 269-273.

4. Boutin, J., and N. Martin (2006), ARGO upper salinity measurements: Perspectives for L-band radiometers calibration and retrieved sea surface salinity validation, IEEE Geoscience and Remote Sensing Letters, 3(2), 202-206.

5. Antonov, J. I., *et al.* (2006), Volume 2: Salinity, 182 pp, NOAA, U.S. Department of Commerce, Silver Spring, Maryland, USA.

6. Wüst, G. (1936), Oberflächensalzgehalt, Verdunstung und Niederschlag auf dem Weltmeere, 347-359 cited in The Oceans, Their Physics, Chemistry and General Biology. New York: Prentice-Hall, 1942. (http://ark.cdlib.org/ark:/13030/kt167nb66r/).