

# Combining Argo and remote-sensing data in the North Atlantic

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Despite the impressive increase of the number of temperature and salinity profiles from the Argo array, in-situ data still undersample the temporal and spatial variability of the ocean thermohaline structure. In contrast, remote-sensing measurements provide synoptic observations of sea level and sea surface temperature (SST) over the world ocean, but with no direct estimation of the ocean's vertical structure. In order to reconstruct instantaneous temperature (T) fields at high temporal and spatial resolution, a merging method is developed to combine the accurate but sparse in-situ T profiles with the high-resolution but less accurate (as synthetic T profiles) altimeter and SST measurements.

Three sources of data from the year 2002 are used. In-situ T profiles are from the Coriolis center<sup>1</sup> and correspond to real-time data including Argo profiling floats and also XBT and CTD measurements. Altimeter sea level anomalies are from the SSALTO/DUACS center<sup>2</sup> and are weekly combined maps of Jason-1 (Topex/POSEIDON), ERS-2 and GFO with a 1/3° Mercator horizontal resolution. SST data are from the NAVOCEANO center<sup>3</sup> and correspond to maps of weekly means of MCSST AVHRR with an 18-km horizontal resolution.

The first step of the method consists in deriving synthetic T profiles from the surface down to 700-meter depth from altimeter and SST data through a multiple linear regression method. Pre-processing of altimeter SLAs includes the extraction of the steric part of the SLA using regression coefficients deduced from an altimeter/in-situ comparison study (Guinehut et al., 2002). Validation of the vertical projection of SLA and SST is performed on a subset of 3,500 T profiles from the year 2002. Results indicate that extracting the steric part of the SLA greatly reduces the differences between the in-situ reference profiles and the reconstructed synthetic profiles (Figure 1). The impact of SST is also clearly visible from the surface down to 300-meter depth where SST compensates the weak correlations between SLA and temperature, which means that SST is highly

complementary to SLA when deriving T profiles from remote-sensing measurements.

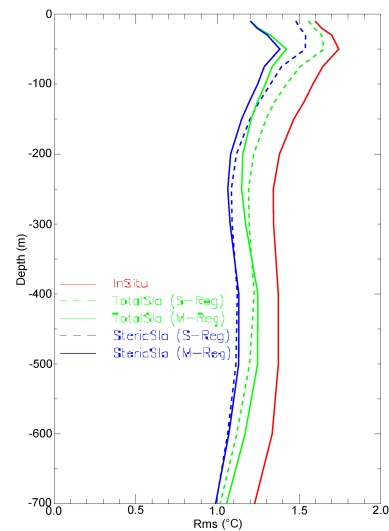


Figure 1: Rms of in-situ T anomalies (red) – anomalies calculated from the Levitus monthly mean climatology, rms of the differences between in-situ T fields and the synthetic profiles deduced from total SLA (green) and steric SLA (blue), and from a simple (SLA - dotted line) or a multiple (SLA+SST – unbroken line) regression method (in °C).

The second step of the method consists in combining the synthetic profiles with in-situ T profiles using an optimal interpolation method (Bretherton et al., 1976). Analyses are performed at a weekly period on a 1/4° horizontal grid on each Levitus vertical level from the surface down to 700-meter depth. To gain maximum benefit from the qualities of both data sets, namely the accurate information given by in-situ T profiles and the mesoscale variability given by the T synthetic profiles, a precise statistical description of the errors of these observations must be introduced in the optimal interpolation method. For the in-situ profiles, since these observations are considered almost perfect, a very low white noise is applied. For the synthetic profiles, simulating remote-sensing (altimeter and SST) observations, since these observations are not direct measurements but are derived from the regression method, correlated errors have to be applied to correct long-wavelength errors or biases present in the synthetic fields and introduced by the regression method.

<sup>1</sup> <http://www.coriolis.eu.org/coriolis>

<sup>2</sup> <http://www.aviso.oceanobs.com/duacs>

<sup>3</sup> [http://podaac.jpl.nasa.gov/navocean0\\_mcsst](http://podaac.jpl.nasa.gov/navocean0_mcsst)

The merging method performances are analyzed by comparing merged fields with in-situ and synthetic profiles used to construct the merged fields. An example is shown in Figure 2 for an instantaneous T field at 200 meters. The merged field shows warmer T in the Azores area than those derived from remote-sensing measurements, and colder T in the Northern part of the domain, which demonstrates the ability of the merging method to take into account the information contained in the sparse in-situ measurements to correct the synthetic fields.

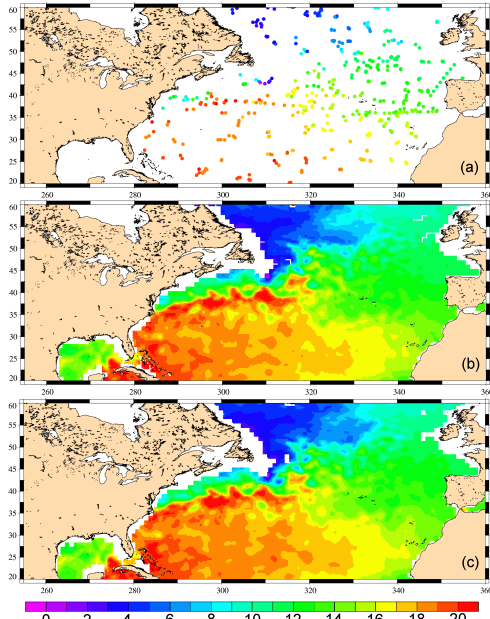


Figure 2: Instantaneous T field at 200 m (02/10/02) from (a) in-situ data selected within a temporal window of  $-15/+15$  days, (b) synthetic T and (c) merged synthetic and in-situ T (in  $^{\circ}\text{C}$ ).

The merging method is now validated using an independent data set. The in-situ T data set of the year 2002 is divided into two sets; set 1 to be combined with synthetic profiles, and set 2 to be used to validate the merged fields. Statistics over the year 2002 (Figure 3) indicate that the rms of mapping error is greatly reduced for all depths when combining synthetic and in-situ profiles, compared to the results obtained using only in-situ T(z) or remote-sensing (SLA+SST) data. For example, at 200-meter depth, mapping error decreases from  $1.15^{\circ}\text{C}$  when using only in-situ data to  $1^{\circ}\text{C}$  for the synthetic profiles and to  $0.9^{\circ}\text{C}$  for the combination. Moreover, results obtained using only remote-sensing profiles are better than those obtained using only in-situ profiles. This is because it is impossible to obtain fields at high temporal and spatial resolution by any means using in-situ profiles alone, due to aliasing of mesoscale variability.

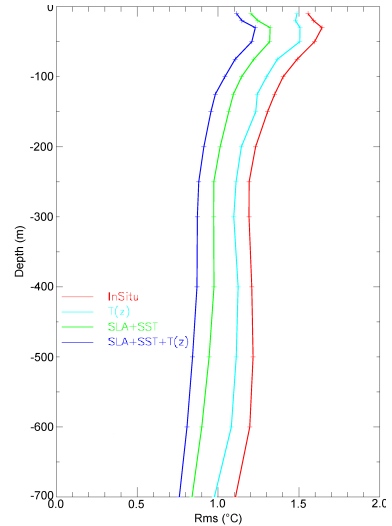


Figure 3: Rms of instantaneous T anomalies from set 2 (red) and rms error in predicting subsurface T anomalies using only in-situ profiles from set 1 (turquoise), using only synthetic profiles (green) and using in-situ combined with synthetic profiles (blue). Statistics are calculated over the whole studied domain (in  $^{\circ}\text{C}$ ).

The method is now illustrated along a cross-Atlantic section between Gibraltar and Florida (Figure 4).

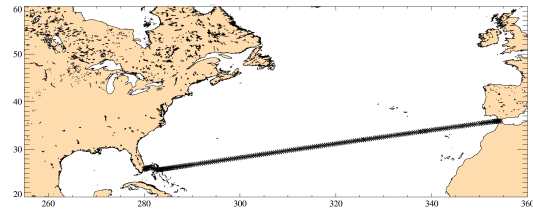


Figure 4: Hydrographic section between Gibraltar and Florida (28/02/02-09/03/02).

Temperature sections from the in-situ measurements, the Levitus monthly mean climatology, the vertical projection of satellite SLA and SST, and from the combination (SLA, SST, in-situ profiles, except those from the Gibraltar/Florida section) are compared on Figure 5. The large-scale structure of T is relatively well represented by Levitus monthly mean climatology. Temperatures are nevertheless too cold in the surface layers for all longitudes. In addition to the large-scale structure, the vertical projection of SLA and SST restores the mesoscale variability present along the section as well as T much closer to the in-situ data. Further constraints added by a few near in-situ profiles correct the synthetic field appreciably to produce a combined field closer to the in-situ reference field. Statistics calculated over the 180 profiles of the section indicate that the combination induces an rms error of  $0.5^{\circ}\text{C}$ . This is half the rms difference between the section and the monthly Levitus climatology. Additionally, even if the merging method is performed individually on each

vertical level, the combined field shows very good vertical coherence.

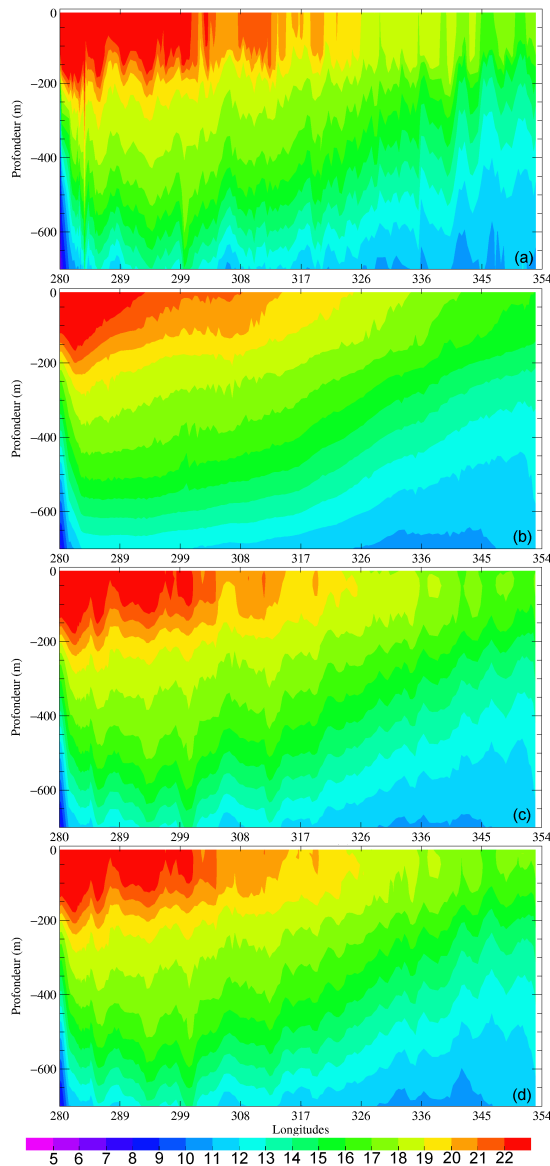


Figure 5: *T* field from (a) the Gibraltar/Florida section, (b) Levitus monthly mean climatology, (c) the vertical projection of SLA and SST, and (d) the combination of synthetic and in-situ profiles (in °C).

This study confirms that it is possible to combine accurate but sparse in-situ data with high-resolution satellite altimeter and SST measurements. The merging method developed makes it possible to estimate the North Atlantic *T* field with a mean precision of 1°C over the first 700 meters. Considering the precision of such analyses, the combined *T* fields can be used to study the ocean heat content variability (heat transport, variability along specific hydrographic sections, etc.). Furthermore, more than 50% of the in-situ data come from profiling floats in our studied area where Argo is already close to its nominal resolution (particularly thanks to the

European Gyroscope project, which deployed more than 80 instruments during the last three years). This underlines the major role of the Argo data set in studying the variability of the vertical structure of the ocean at high temporal and spatial resolution.

### References

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