The integration of ARGO floats data in numerical weather prediction (NWP)

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Context

An important and discipline activity, in the framework of the Greek Euro-ARGO project, is the exploitation of ARGO measurements in the numerical weather prediction (NWP). Along this direction, the Hellenic Center for Marine Research (HCMR) established a network of relevant Greek scientific groups, which constitute the Greek ARGO Users group/network. These different groups are already using or will be using ARGO data in ocean/atmospheric forecasting, climate studies and for educational purposes.

In the framework of the scientific use of ARGO measurements, Harokopio University of Athens (HUA) integrated the data of the ARGO floats in numerical weather prediction (NWP). This is accomplished through the following steps:

- Statistical evaluation of the gridded SST data having as reference ARGO profiling floats measurements over the Mediterranean Sea.
- Sensitivity assessment of the NWP on the sea surface temperature.

Statistical evaluation of the RTG_SST_HR data

The daily, high-resolution, real-time, global, sea surface temperature (RTG_SST_HR) dataset analysis has been developed at the National Centers for Environmental Prediction/Marine Modeling and Analysis Branch (NCEP/ MMAB). The analysis was implemented in the NCEP parallel production suite 16 August 2005. The daily sea surface temperature product is produced on a twelfth-degree (latitude, longitude) grid, with a two-dimensional variational interpolation analysis of the most recent 24-hours buoy and ship data, satellite-retrieved SST data, and SST's derived from satellite-observed sea-ice coverage (Gemmill et al., 2007).

The native horizontal resolution of the RTG data is 1/12°x1/12° and it has been statistically evaluated against ARGO floats measurements for a six month period, from December 2013 to May 2014. The evaluation methodology is based on the point-to-point hourly comparison between RTG and the ARGO measurements (Papadopoulos and Katsafados, 2009).

The RTG SST appears a maximum underestimation on December 2013 which turns to overestimation on May 2014 (Fig. 1). The minimum bias scores are in the period February to April and they have a strong dependence on the pressure heights. The RMS errors follow the general trend of bias and appear total and secondary minimums on April and March respectively. The seasonal distribution of bias and RMS errors confirms a systematic underestimation on winter which turns to slight overestimation during spring (Tables 1, 2). However, the comparison with ARGO floats data in the range of 0-6mb provides consistent scores and larger sample of records. In general, RTG show a cold bias for the entire period of evaluation and an average RMS error of 0.50°C (Table 3).

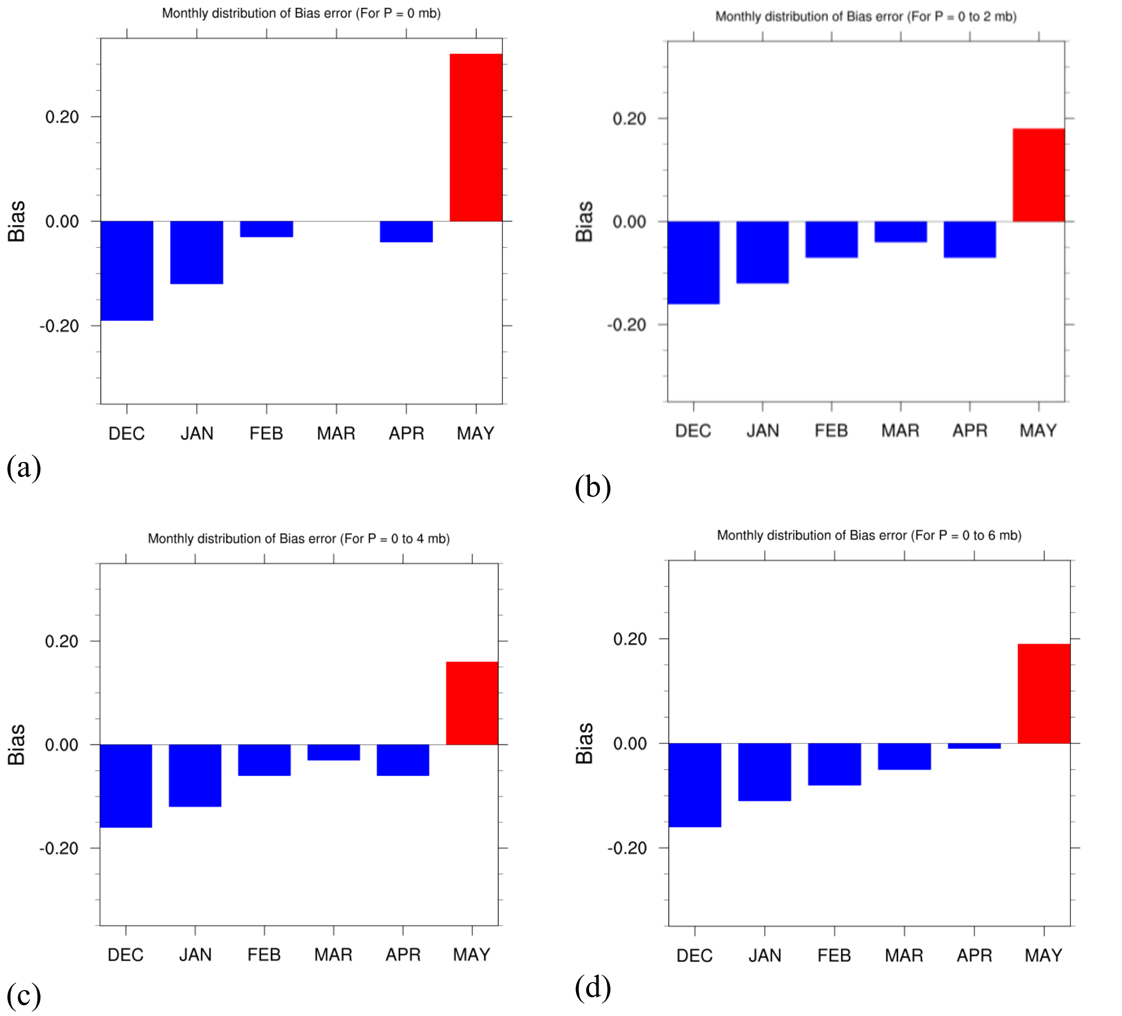

Figure 1: Monthly distribution of the bias error for the period December 2013-May 2014. The sea pressure levels that were considered for ARGO measurements are (a) P = 0 mb (b) P = 0-2 mb (c) P = 0-4 mb and (d) P = 0-6 mb.

Table 1: Total bias and RMS error for the period December 2013-February 2014. The sea pressure levels that were considered for ARGO measurements are the following (a) P = 0 mb (b) P = 0-2 mb (c) P = 0-4 mb and (d) P = 0-6 mb.

WINTER	P = 0 mb	P = 0-2 mb	P = 0-4 mb	P = 0-6 mb
Bias error	**-0.11**	**-0.12**	**-0.11**	**-0.12**
RMS error	**0.51**	**0.55**	**0.54**	**0.54**
Records	**149**	**402**	**430**	**667**

Table 2: Total bias and RMS error for the period March-May 2014. The sea pressure levels that were considered for ARGO measurements are the following (a) P = 0 mb (b) P = 0-2 mb (c) P = 0-4 mb and (d) P = 0-6 mb.

SPRING	P = 0 mb	P = 0-2 mb	P = 0-4 mb	P = 0-6 mb
Bias error	**0.08**	**0.00**	**0.01**	**0.03**
RMS error	**0.47**	**0.47**	**0.46**	**0.45**
Records	**159**	**378**	**404**	**618**

Table 3: Total bias and RMS error for the period December 2013-May 2014. The sea pressure levels that were considered for ARGO measurements are (a) P = 0 mb (b) P = 0-2 mb (c) P = 0-4 mb and (d) P = 0-6 mb.

TOTAL	P = 0 mb	P = 0-2 mb	P = 0-4 mb	P = 0-6 mb
Bias error	**-0.01**	**-0.06**	**-0.05**	**-0.05**
RMS error	**0.49**	**0.51**	**0.50**	**0.50**
Records	**308**	**780**	**834**	**1285**

As a conclusion, ARGO floats proved to be particular useful for the investigation of the sources of errors reproduced in the RTG gridded data. The ARGO measurements in the range of 0-6 mb pressure depths are finally preferred because they offer sufficient sample of data and they provide consistent results. The systematic error of RTG sea surface temperature for the 6 months evaluation period is -0.05°C and the overall RMS error is 0.5°C. These scores are also in agreement with relevant recent studies (eg. Kara et al. 2007).

Sensitivity test in a case study of a high impact weather event

A high impact weather event, from 29 January to 3 February, has been simulated by a non-hydrostatic atmospheric model in order to investigate the impact of the ARGO temperature assimilation on the atmospheric conditions. That incident was chosen due to the severity of the prevailed atmospheric conditions characterized by continuous barometric systems over eastern Mediterranean Sea.

The sensitivity tests for the ARGO temperature assimilation and its impact on the development of the barometric systems were carried out by the Weather Research and Forecasting (WRF) This numerical experiment performed on a 516×294 horizontal grid which covered the Mediterranean Sea, a widespread part of Europe and the north part of Africa, with horizontal resolution 10km×10km, time step of 60 s and 38 vertical levels stretching from surface to 50 mb. The initial and boundary conditions are based on the Global Forecasting System (GFS) operational analyses in horizontal resolution 0.5°×0.5° and in 25 pressure levels. The initial sea surface temperature (SST) field is based on daily RTG_SST_HR analyses in horizontal resolution 1/12°×1/12°. Also, in order to include better information about the SST pattern, the model adjusted to run in SST update mode. During the simulation, the SST was being updated every 6 simulation hours by the time weighted linear interpolated daily RTG_SST_HR analyses. Also, for a more accurate description of the initial development and the upper-air interactions of the barometric systems, the simulation period was from 29 January at 00 UTC to 3 February at 00 UTC (120 simulation hours). The impact of the ARGO temperature assimilation on the atmospheric conditions has been investigated in two sensitivity simulations. The first is a numerical simulation using update RTG SST without ARGO assimilation (CTRL hereafter) and the second is the simulation with updating RTG SST including ARGO temperature assimilation (ARGO hereafter).

ARGO measurements assimilation methodology

The methodology applied for the ARGO temperature measurements assimilation in the RTG gridded SST is based on spatial and temporal interpolation schemes. Firstly, ARGO measurements were distributed per 6 hours from 29 January at 00 UTC to 3 February at 00 UTC. For example, for the total amount of ARGO measurements which corresponded to 29 January at 00 UTC a 6-hourly time window was used.

Measurements from 28 January at 21 UTC (-3 hours) to 29 January at 03 UTC (+3 hours) were chosen. The same methodology was used for the total 120 simulation hours. Thus, an ARGO temperature distribution with 21 6-hourly aggregations was formatted. Measurements which characterized by low quality flags were excluded from the distribution. Also, the sea pressure level that was considered for ARGO temperature measurements was P = 0-6 mb.

Analysis of the CTRL and ARGO simulations

In general, CTRL and ARGO simulations produced almost similar results because of the limited number of the assimilated ARGO temperature measurements in the ARGO simulation. Wind speed, temperature and MSL pressure were negligibly impacted by ARGO temperature assimilation. Nevertheless, some local changes on the SST pattern due to the ARGO temperature assimilation moved eastward from the western and central Mediterranean Sea, following the main atmospheric circulation. In general, the sea surface affects the development and the intensification of the extratropical cyclones through the air-sea exchange of momentum and heat fluxes. Thus, the spatial and temporal distributions of the surface heat flux and the precipitation have been mostly responded to the ARGO temperature assimilation.

Figure 2a depicts the severe rainfall during the period 29 January to 3 February 2015 due to the passage of a deep cyclonic system over Greece. The maximum rainfall exceeded the 200 mm in 5 days which is close to the mean monthly accumulated precipitation for this period.

The 120-hour accumulated precipitation patterns of ARGO and CTRL simulations are depicted in Figure 2b. The maximum differences are mainly located around the areas of the precipitation peaks forming positive and negative bands of rain. Such response is an indication of the SST disturbances propagation which affected the phase speed and the intensity of the cyclonic system. In more details, the simulation which is based on the ARGO temperatures assimilation produced a faster propagation of the system due to the changes in the spatial distribution of the latent heat flux, especially during the first 48 hours of the simulation. In the next hours the precipitation differences have been amplified and located mainly over NW Greece and the Ionian Sea.

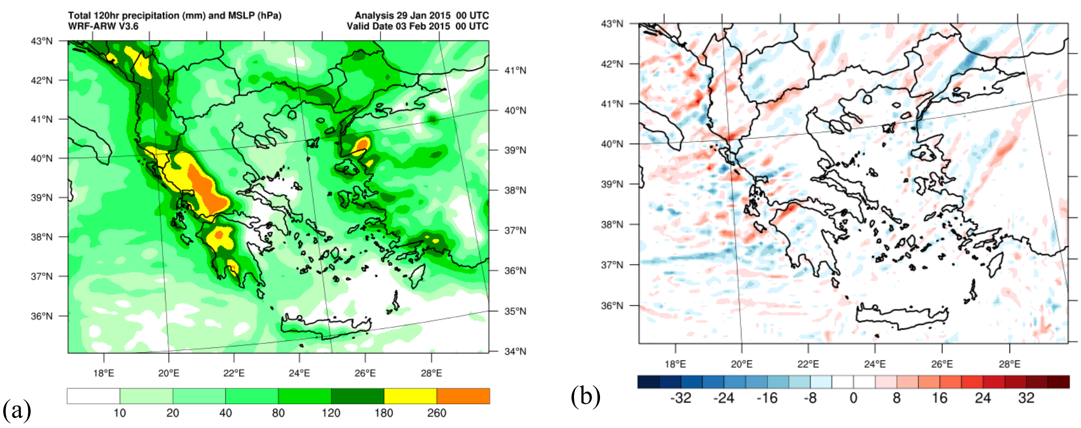

Figure 2: Spatial distribution of the a) total 120-hourly accumulated precipitation b) total 120-hourly accumulated precipitation differences between ARGO and CTRL simulations from 29 January at 00 UTC to 3 February at 00 UTC, 2015.

Statistical evaluation of the results against land surface observations

Both simulations have been evaluated over land in order to assess the impact of the SST changes and the dynamic air-sea interaction to the atmospheric conditions over

land. The systems results are compared against Greek land surface stations records from the GTS network. The meteorological variables considered in the evaluation are: the near surface wind speed, the near surface temperature, the mean sea level pressure (MSLP) and the accumulated precipitation (Wilks, 1995).
The basic scores of the continuous variables are almost identical indicating a slight impact of the ARGO temperature assimilation on the atmospheric conditions over land (Table 4). The near surface temperature and the MSLP are underestimated with a negligible improvement of Bias for the ARGO run while the near surface wind speed is overestimated by both simulations.

Table 4: Overall bias and RMSE scores at the positions of the surface meteorological stations for the near surface wind speed (ms^{-1}), the near surface temperature (°C) and the MSL pressure (hPa).

	Wind speed		**Air temperature**		**MSLP**	
	Bias	**RMSE**	**Bias**	**RMSE**	**Bias**	**RMSE**
CTRL	0.59	1.83	-1.11	1.96	-0.52	1.39
ARGO	0.60	1.83	-1.10	1.95	-0.51	1.39

The evaluation of the discrete variable (precipitation) has been performed for 6 predefined rainfall thresholds (0.1, 0.5, 1, 2, 4, and 8 mm). In general, the impact of local SST changes on the precipitation is not significant, as it is shown in Fig. 5 and 6. However, both simulations overestimate the precipitation more prominent for the medium and higher thresholds with better BS scores for the run with the assimilated ARGO measurements (Fig. 3a). Also, ETS shows a slight improvement for the ARGO run (Fig. 3b). Overall, the ARGO temperatures assimilation offers an up to 5% improvement in the precipitation scores for the entire rainfall thresholds.

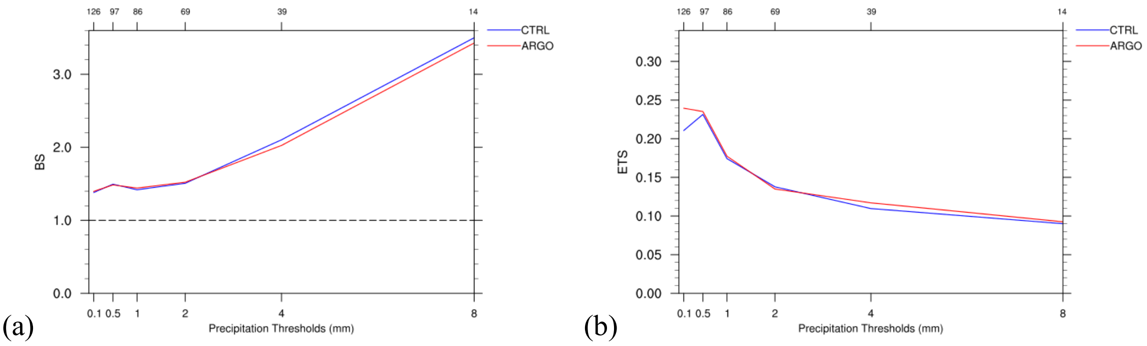

Figure 3: (a) Bias scores for the CTRL (blue line) and the ARGO (red line) simulations for specific precipitation thresholds. (b) As in (a) for the equitable threat score (ETS). The numbers above tick marks denote the sample for each corresponding threshold value.

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