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QUALITY INFORMATION DOCUMENT

Black Sea Production Centre
BLKSEA_ANALYSIS_FORECAST_PHYS_007_001

Issue: 2.1

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CHANGE RECORD

When the quality of the products changes, the QuID is updated and a row is added to this table. The third column specifies which sections or sub-sections have been updated. The fourth column should mention the version of the product to which the change applies.

Issue	Date	§	Description of Change	Author	Validated By
2.0	31 January 2017	All	Creation of the document for V3	S. Ciliberti	
	1 February 2017	all	Revision	E. Peneva, A. Storto	
2.1	24 February 2019	all	General revision of the text. Updated BS-PHY NRT system and product quality	S. Cilberti	Mercator Ocean
2.2	08 September 2019		Including quality control after BS-PHY processing system upgrade. First draft highlighted in yellow in Section VI.2	S. Ciliberti, E. Jansen, L. Stefanizzi	Mercator Ocean

APPLICABLE DOCUMENTS

	Ref	Title	Date / Version
DA 1	CMEMS-BS-ScQR	CMEMS Black Sea Scientific Qualification Report	Jan 2017
DA 2	CMEMS-BS ScVP	CMEMS Black Sea Scientific Validation Plan	Jan 2017
DA 3	CMEMS-BS-QUID_007_001	Black Sea QUID for BLKSEA_ANALYSIS_FORECAST_PHYS_007_001 for V2.2	Sep 2016

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

BS	Black Sea
CF	Climate Forecast (convention for NetCDF)
CLS	Collecte Localisation Satellites
CMAP	CPC Merged Analysis of *Precipitation*
CMCC	Centro Euro-Mediterraneo sui Cambiamenti Climatici
CMEMS	Copernicus Marine Environment Monitoring Service
CTD	Conductivity Temperature Depth
DAC	Dynamic Atmospheric Correction
ECMWF	European Centre for Medium-Range Weather Forecasts
EOF	Empirical Orthogonal Function
FAQ	Frequently Asked Question
FTP	File Transfer Protocol
MDT	Mean Dynamic Topography
Meridional Velocity	West to East component of the horizontal velocity vector
MFC	Monitoring and Forecasting Centre
NEMO	Nucleous for European Modelling of the Ocean
NetCDF	Network Common Data Form
NOAA	*National Oceanic and Atmospheric Administration*
OA	Objective Analyses
OCEANVAR	Oceanographic variational data assimilation scheme developed at CMCC
OGCM	Ocean General Circulation Model
OpenDAP	Open-Source Project for a Network Data Access Protocol. Protocol to download subset of data from a n-dimensional gridded dataset (ie: 4 dimensions: lon,lat,depth,time)

OSI	Ocean and Sea Ice
PU	Production Unit
SL	Sea Level
SLA	Sea Level Anomaly
SSH	Sea Surface Height
SST	Sea Surface Temperature
Subsetter	CMEMS service tool to download a NetCDF file of a selected geographical box using values of longitude and latitude, and time range
TAC	Thematic Assembly Centre
XBT	eXpandable BathyThermograph
Zonal Velocity	South to North component of the horizontal velocity vector
3DVAR	Three-Dimensional Variational

TABLE OF CONTENTS

I EXECUTIVE SUMMARY

I.1 Products covered by this document

This document describes the quality of the analysis and forecast nominal product of the physical component of the Black Sea at CMEMS Apr 2018 (BS-PHY EAS3.0, herein V3):

BLKSEA_ANALYSIS_FORECAST_PHY_007_001.

The product includes:

- 3D daily mean and hourly mean fields of: Potential Temperature, Salinity, Zonal and Meridional Velocity
- 2D daily mean and hourly mean fields of: Sea Surface Height, Mixed Layer Depth, Bottom Temperature.

Output data are produced at 1/36°x1/27° horizontal resolution, 31 vertical levels as daily/hourly means delivered at daily temporal frequency.

I.2 Summary of the results

The quality of the V3 BS-Currents for operations is assessed over 2 years period, from 01/01/2014 to 31/12/2015, by comparison with insitu and satellite observations and with respect of the previous V2.2 BS-Currents, operational from October 2016 to Apr 2017.

BS-Currents model horizontal grid resolution is 1/36° in zonal direction, 1/27° in meridional direction (ca. 3 km) and has 31 unevenly spaced vertical levels.

The main results of the BLKSEA_ANALYSIS_FORECAST_PHY_007_001 quality product assessment are summarized below:

Sea Surface Height: the V3 system presents a satisfactory accuracy in terms of sea surface height as well as the V2.2 one. The model skill enhancement is evident when considering the RMS of misfits between model and satellite observations achieving an error around 3.5 cm.

Temperature: the temperature is accurate with a RMS error of about 1^{o}C. Higher errors in the first 100-200 m, which characterized the previous system V2.2, are slightly improved due to the model configuration, as described in the next section, decreasing in the deepest layers.

Salinity: the salinity is accurate with RMSE EAN values equal or lower than 1.0 PSU in the upper layer, that could be due to constraint at the Bosporus Strait, actually modeled as a surface boundary condition as in V2.2 BS-Currents, which is essential to the water balance.

I.3 Estimated Accuracy Numbers

Estimated Accuracy Numbers (EANs), that are the mean and the RMS of the difference between the model and in-situ or satellite reference observations, are provided in the Table I-1 to I-4.

EAN are computed for:

- Temperature; layers 2-5, 5-10, 10-20, 20-30, 30-50, 50-75, 75-100, 100-200, 200-500 and 500-1000 m
- Salinity; layers 2-5, 5-10, 10-20, 20-30, 30-50, 50-75, 75-100, 100-200, 200-500 and 500-1000 m
- Sea Surface Temperature (SST).
- Sea Level Anomaly (SLA)

The observations used are:

- vertical profiles of temperature and salinity from CMEMS INS-TAC:INSITU_BS_NRT_OBSERVATIONS_013_034

SST satellite data from CMEMS SST-TAC:

- SST_BS_SST_L4_NRT_OBSERVATIONS_010_006

Satellite Sea Level along track data from CMEMS SL-TAC:SEALEVEL_EUR_PHY_L3_NRT_OBSERVATIONS_008_059 The EANs are evaluated for the V3 system over 2-years period from January 2014 to December 2015 with respect to the ones computed considering V2.2 system and are computed over 10 vertical layers (for temperature and salinity) and for the whole Black Sea region (Figure I.1).

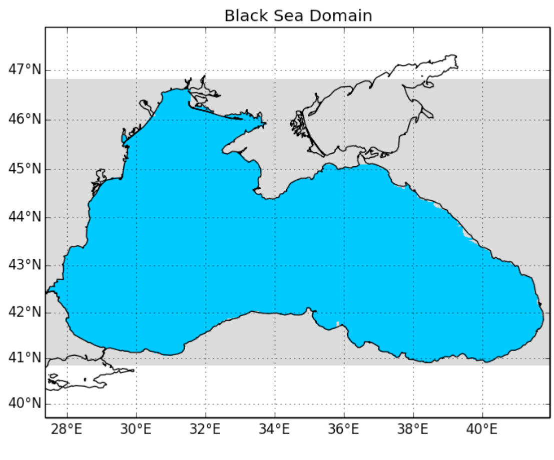

Figure I.1. The Black Sea spatial domain for validation metrics.

Table I-1. EANs of temperature at different vertical layers evaluated for the V3 system for the period 2014-2015 and previously compared with the corresponding statistics computed for V2.2 system: T-CLASS4-EAN-MEAN_LAYER and T-CLASS4-EAN-RMS_LAYER in [DA1].

T prod - T ref [°C]	V2.2 system		V3 system	
Layer (m)	Mean T-CLASS4-EAN-MEAN_LAYER	RMS T-CLASS4-EAN-RMS_LAYER	Mean T-CLASS4-EAN-MEAN_LAYER	RMS T-CLASS4-EAN-RMS_LAYER
2-5	0.05	0.55	0.05	0.54
5-10	0.34	0.95	0.26	0.90
10-20	0.21	1.26	0.20	0.95
20-30	-0.18	1.18	0.10	1.12
30-50	-0.22	0.90	-0.17	0.90
50-75	-0.14	0.57	-0.13	0.56
75-100	-0.09	0.30	-0.07	0.28
100-200	-0.06	0.14	-0.06	0.14
200-500	-0.02	0.05	-0.02	0.045
500-1000	-0.07	0.08	-0.07	0.08

Table I-2. EANs of sea surface temperature evaluated for the V3 system for the period 2014-2014 and compared with the corresponding statistics previously computed for V2.2 system: SST-CLASS4-EAN-RMS_BASIN and SST-CLASS4-EAN-MEAN_BASIN in DA 3.

SST prod – SST ref [°C]	V2.2 system		V3 system	
REGION	Mean SST-CLASS4-EAN-MEAN_BASIN	RMS SST-CLASS4-EAN-RMS_BASIN	Mean SST-CLASS4-EAN-MEAN_BASIN	RMS SST-CLASS4-EAN-RMS_BASIN
BS SEA	-0.01	0.28	-0.01	0.27

Table I-3. EANs of salinity at different vertical layers evaluated for the V3 system for the period 2014-2015 and previously compared with the corresponding statistics computed for V2.2 system: T-CLASS4-EAN-MEAN_LAYER and T-CLASS4-EAN-RMS_LAYER in [DA1].

S prod - S ref [PSU]	V2.2 system		V3 system	
Layer (m)	Mean T-CLASS4-EAN-MEAN_LAYER	RMS T-CLASS4-EAN-RMS_LAYER	Mean T-CLASS4-EAN-MEAN_LAYER	RMS T-CLASS4-EAN-RMS_LAYER
2-5	0.05	0.54	0.05	0.54
5-10	0.31	0.91	0.30	0.89
10-20	0.19	1.20	0.19	1.18
20-30	-0.16	1.12	-0.15	1.12
30-50	-0.20	0.86	-0.20	0.85
50-75	-0.13	0.57	-0.13	0.56
75-100	-0.08	0.32	-0.08	0.32
100-200	-0.05	0.16	-0.04	0.16
200-500	-0.02	0.06	-0.02	0.05
500-1000	-0.06	0.07	-0.06	0.07

Table I-4. EANs of sea level evaluated for evaluated for the V3 system for the period 2014-2014 and compared with the corresponding statistics previously computed for V2.2 system: SL-CLASS4-EAN-RMS_BASIN in [DA1]

SLA prod – SLA ref [cm]	V2.2 system	V3 system
REGION	RMS SL-CLASS4-EAN-RMS_BASIN	RMS SL-CLASS4-EAN-RMS_BASIN
BS SEA	3.60	3.45

The metrics of Table I-1 and

Table I-2 give indications about the accuracy of BLKSEA_ANALYSIS_FORECAST_PHYS_007_001 temperature variable along the water column and at the surface for the Black Sea considering the new system V3 with respect to V2.2 system. The values for all the levels are computed using ARGO profiles and satellite product. The RMS and mean of both systems are higher in the upper layer (5-50m), decreasing significantly in the middle layer, with slightly improvements in the V3 system due to the effect of the implementation of a different vertical mixing scheme.

The statistics listed in Table I-3 give indications about the accuracy of BLKSEA_ANALYSIS_FORECAST_PHYS_007_001 salinity product. The values for all the levels are computed using ARGO profiles. Also in this case, the upper layer (5-50m) is characterized by higher RMS than in the middle layer: this problem will be overcome with the next evolution of the system which will acts specifically on the vertical spatial accuracy and the open boundary at the Bosporus Strait.

The metrics shown in Table I-4 define the accuracy of BLKSEA_ANALYSIS_FORECAST_PHYS_007_001 sea level anomaly. The statics are computed along the satellite track. Statistics show a satisfactory attitude of the V3 system to reproduce the sea surface height as for the V2.2 one.

II PRODUCTION SYSTEM DESCRIPTION

II.1 Production centre details

In the following, a list of synthetic information related to Physics Production Unit:

- Production Center Name: CMCC
- Production Subsystem Name: Analysis and Forecasts Black Sea EAS3 system
- Production Unit: BS-PHY

and

- External products: Temperature (3D), Salinity (3D), Bottom Temperature (new since V3, 2D), Mixed Layer Depth (2D), Sea Surface Height (2D), Currents (U and V in T-grid, 3D).
- Frequency of model output: daily means (24-hours average) and hourly means (1-hour average).
- Geographical coverage: 27.73°E → 41.96°E ; 40.86°N → 46.80°N (the Azov Sea is excluded).
- Spatial resolution: 1/36°x1/27° in the horizontal, 31 levels with partial steps in vertical, reaching the maximum depth of 2140 m.
- Forecast release: 10-days for the daily means, 5-days for the hourly means in length, released at daily frequency.
- Hindcast release: 1-day for daily and hourly means in length, released at daily frequency.
- Analysis release: 3-days for daily and hourly means every day excepted on Tuesday, when the temporal window for analysis is 14-days.

BS-Currents analysis and forecast products are produced with two different cycles. One cycle is daily, in which the system produces 3-day analysis, 1-day hindcast and 10-days forecast every day. The second cycle is weekly, in which on Tuesday the system produces 14-day analysis, 1-day hindcast and 10-days of forecast in order to incorporate a large number of in-situ and satellite observations into the data assimilation. Irrespective of the cycle the starting fields for the initialization of each forecast are taken as the instantaneous field at 12:00:00 UTC of day J resulting from the chain of daily analyses done for the previous 3 (or 14) days and 1-day hindcast (Figure II.1).

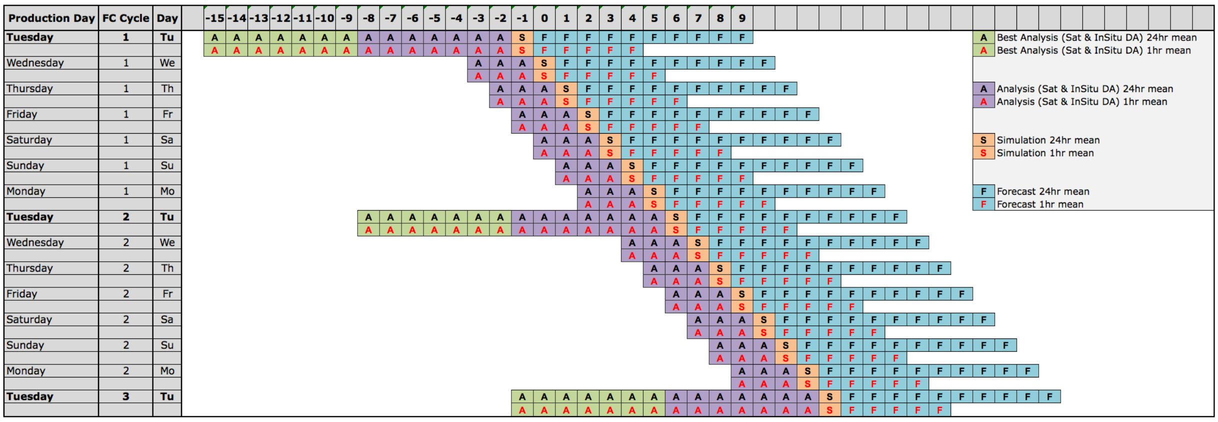

Figure II.1. Scheme of the BS-Currents operational system organization.

The BS-Currents system processing chain is composed by a number of numerical procedures:

1. Upstream Data Acquisition, Pre-Processing and Control of: ECMWF atmospheric forcing, Satellite (SLA and SST) and in-situ (T and S) data.
2. Forecast/Hindcast: NEMO state-of-the-art since V3 to produce one day of hindcast and 10-day forecast.
3. Analysis (every day): NEMO code is combined with OceanVar in order to produce the best estimation of the sea (i.e. analysis). Every day, except on Tuesday, NEMO-OceanVar system is run for 3-days into the past in order to provide a good quality initial condition for the 10-days forecast. Once a week, on Tuesday, the NEMO-OceanVar system is run for 14-days into the past in order to use the best available along track SLA, SST and the major number of in-situ products collected in the reference time window. The latest days of the 14-days of analysis and 1-day hindcast produce the initial condition for the 10-days forecast.
4. Post processing: the model output is processed in order to obtain products according to CMEMS catalogue to be delivered. The model output are also operationally visualized on a dedicated webpage, http://oceanlab.cmcc.it/blacksea/, maintained by CMCC (Figure II.2).
5. Output Delivery: the PU-PHY is connected to DU. Every day, at the end of the processing chain, the PU-PHY upload products by BS-Currents on service platform.

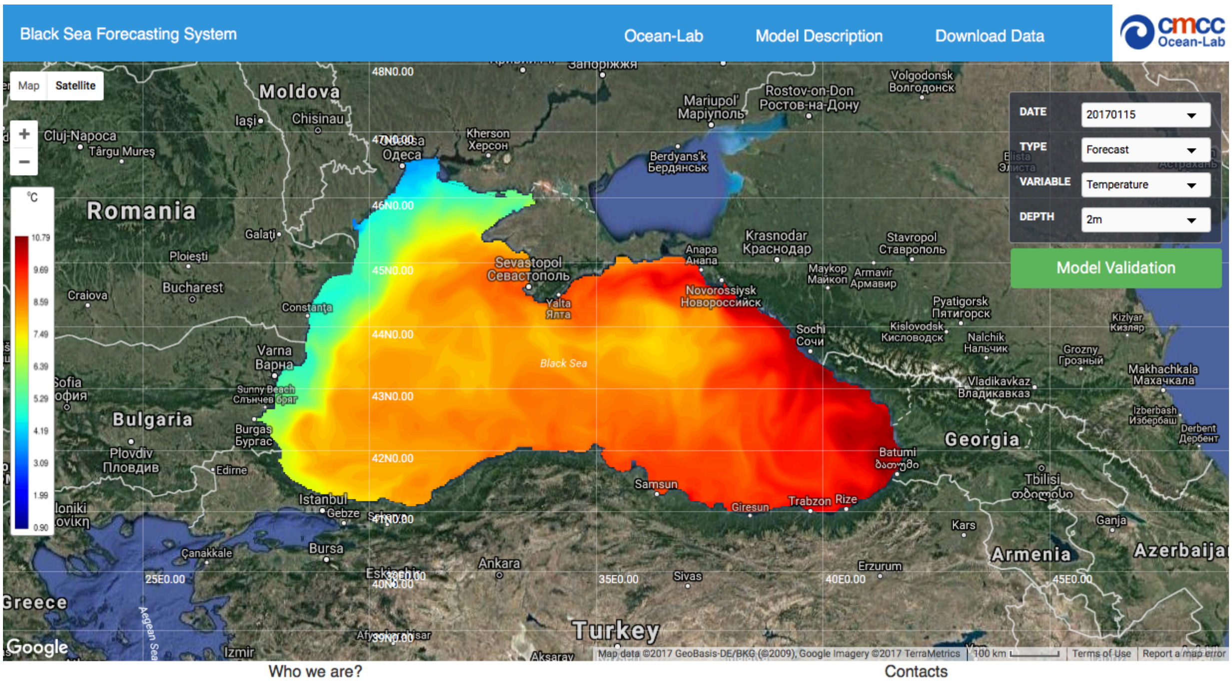

Figure II.2. Dedicated web portal for the visualization of BS-Currents products as delivered by CMEMS BS-MFC

II.2 Description of the model system

The Black Sea Forecasting System, BSFS, (Ciliberti et al., 2016) is the physical component of the BS-Currents and is providing since October 2016 analysis and forecast for the Black Sea within CMEMS. The model horizontal grid resolution is 1/36° in zonal resolution, 1/27° in meridional resolution (ca. 3 km) and has 31 unevenly spaced vertical levels.

The hydrodynamic state is supplied by the Nucleus for European Modeling of the Ocean (NEMO, v3.4, Madec et al., 2012). The model solution is corrected by the variational assimilation (based on a 3DVAR scheme), originally developed for the Mediterranean Sea and later extended to the global ocean. The observations assimilated in the BS-Currents include in-situ temperature and salinity profiles from ARGO, along-track sea level anomalies (SLA) and gridded sea surface temperature (SST) from satellite observations provided by Copernicus TACs.

II.2.1 Circulation model component

BS-Currents model configuration is based on NEMO v3.4. The code is developed and maintained by the NEMO-consortium and members of the BS-MFC Consortium participates in the System Team for the ordinary maintenance of the code and improvements.

The primitive equations are discretized on a horizontal grid with 1/27° resolution in zonal direction and 1/36° resolution in meridional direction and a vertical grid of 31 levels with partial-steps, integrated in time using a linear free-surface formulation (Ciliberti et al, 2016). The horizontal spatial resolution is chosen in order to have the same Cartesian resolution in latitude and longitude, approximately 3 km at the model domain latitudes, which is conforming to the mesoscale eddy-resolving scale (Rossby radius of deformation in the Black Sea ~20 km). Bathymetry is based on GEBCO dataset (www.gebco.net).

The BS-Currents model for analysis and forecast uses ECMWF 1/8° spatial resolution: for forecast, 3 h time resolution fields are used for the first three days while 6 h time resolution fields are used for the remaining 7 days. In particular, the atmospheric fields used are: zonal and meridional components of 10 m wind (ms^{-1}), total cloud cover (%), 2 m air temperature (K), 2 m dew point temperature (K) and mean sea level pressure (Pa). Precipitation fields over the basin are from GPCP rainfall monthly data (Adler et al., 2003; Huffman et al., 2009). The atmospheric fields are used for computing the momentum, heat and water fluxes at the air-sea interface based on the Black Sea bulk formulae (Grayek et al., 2010). Concerning the land forcing, in particular the river runoff contribution, an estimate of the inflow using monthly mean inflow provided by SESAME project (Ludwig et al., 2009) is used. The impact of the Bosporus Strait on the Black Sea dynamics is accounted for in terms of a surface boundary condition, taking into account the barotropic transport, which has been computed to balance the freshwater fluxes on monthly basis (Stanev and Beckers, 1999, Peneva et al., 2001). The Azov Sea is represented actually as surface boundary condition (river-runoff input as climatology, computed from previous studies, see Peneva et al., 2001) and its representation will be part of the improvements of the Phase II to accounting properly its hydrodynamical contribution in the Black Sea.

II.2.2 Description of the data assimilation scheme

The data assimilation system is the OCEANVAR scheme developed by Dobricic and Pinardi (2008). The background error correlation matrix, B, is estimated from 12 years time series of Sea Level Anomaly, Temperature and Salinity from MyOcean Reanalysis datasets. Tri-variate Background Error Correlation matrices are defined monthly and for each grid point deeper than 75m in the Mediterranean Sea. Observation Error Correlation Matrix, R, has a monthly and z-dependent variability evaluated from Desrozier's relationship (Desrozier et al. 2005).

The data assimilation system of BS-Currents is based on a three-dimensional variational (3DVAR) assimilation scheme, originally developed for the Mediterranean Sea (Dobricic and Pinardi, 2008) and later extended for the global ocean (Storto et al., 2011; Storto et al., 2015). The system is called OceanVar. The variational cost function is solved with the incremental formulation (Courtier et al. 1994). The pre-conditioning of the cost function minimization is achieved through a change-of-variable transformation. In the BS-Currents implementation of the OceanVar, the control vector in physical space is formed by the three-dimensional fields of temperature and salinity. The assimilation frequency is daily, with a 1-day assimilation time-window. Background-error covariances are decomposed in vertical covariances and horizontal correlations. The former are modelled through 15-mode multi-variate Empirical Orthogonal Functions (EOFs). EOFs were calculated from a dataset of anomalies with respect to the long-term mean of a model simulation without data assimilation, using the full model resolution. Horizontal correlations are modelled through a third-order recursive filter (Farina et al., 2015), with spatially inhomogeneous correlation length-scales (Storto et al., 2014) specified as a function of the distance from coast, ranging approximately from 9 to 27 km. The assimilation of sea level anomaly (SLA) is performed by imposing local hydrostatic adjustments as multi-variate balance between the sea level innovation and vertical profiles of temperature and salinity (Storto et al. , 2011).

II.2.3 Upstream data and boundary conditions

The BS-Currents system uses the following upstream data:

- Atmospheric forcing (except precipitation): NWP 6-h (3-h for the first 3 days of forecast), 0.125° horizontal-resolution operational analysis and forecast fields from the European Centre for Medium-Range Weather Forecasts (ECMWF) distributed by the Italian National Meteo Service (USAM/CNMA) through INGV. Precipitation field is from GPCP rainfall monthly data.
- Runoff: Climatological monthly mean runoff contribution by SESAME Project (Ludwig et al., 2009). Numerical treatment of the Bosporus Strait contribution as explained in Section II.2.1.
- Data assimilation:
  - Temperature and Salinity vertical profiles from CMEMS INS-TAC:
    - INSITU_BS_NRT_OBSERVATIONS_013_034
  - Satellite along track Sea Level Anomaly from CMEMS SL-TAC:
  - SEALEVEL_EUR_PHY_L3_NRT_OBSERVATIONS_008_059Satellite SST from CMEMS SST-TAC:
    - SST_BS_SST_L4_NRT_OBSERVATIONS_010_006
- Initial conditions: restart file provided by the multi-annual run 2000-2014 at 1st December 2013 (DA 2) and described in the next section.
- Physical parameterization:
  - Air-Sea interaction: Reed formula (1975, 1977) for Solar Radiation, Berliand & Berliand (1952) for Net Long Wave Radiation, Kondo (1975) parameterization for Latent and Sensible Heat Fluxes, Hellerman and Rosenstein (1983) for Drag Coefficient, 2-bands light penetration scheme. References are available in Madec et al., 2008.
  - Bottom Boundary Conditions: non-linear boundary friction and diffusive boundary layer.
  - Tracers & Physical Parameters: TVD advection scheme for tracers, bilaplacian horizontal diffusion for tracers and bilaplacian horizontal diffusion for momentum, momentum advection in vector form, filtered free surface for surface pressure gradient
  - Vertical Mixing: Turbulent Kinetic Energy scheme (TKE), which represents a new feature in V3.

III VALIDATION FRAMEWORK

The BS-Currents V3 system performance and the associated product quality are provided according to the recommendations provided in [DA2]. In the following, a list of metrics that are used and constantly improved for BS-Currents NRT products is reported from [DA2].

Table III.1: List of metrics that are used for validation (continues overleaf).

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of BS-Currents forecasts and analyses using semi-independent data – weekly updated				
T-CLASS4-RMS_ LAYER_BASINS	Temperature vertical profiles comparison with Copernicus INSITU TAC data at 11 layers for the Balck Sea basin.	Temperature	Argo floats from the Copernicus INSITU TAC products: INSITU_BS_NRT_OBSERVATIONS_013_ 034	Time series of temperature daily RMSs of the difference between model and insitu observations evaluated over 2-weeks period. This quantity is evaluated on the model analysis. The statistics are defined for the whole Black Sea and are evaluated for 6 different layers (8, 15, 30, 150, 300, 600 m). The time series starts from Jan 2016. This quantity is updated every week and is available at http://oceanlab.cmcc.it/bsfs-evaluation/
T-CLASS4-BIAS_ LAYER_BASINS	Temperature vertical profiles comparison with Copernicus INSITU TAC data at 11 layers for the Black Sea basin.	Temperature	Argo floats from the Copernicus INSITU TAC products: INSITU_BS_NRT_OBSERVATIONS_013_ 034	Time series of daily bias (difference between model and insitu observations) computed for temperature evaluated over 2-weeks period. This quantity is evaluated on the model analysis The statistics are defined for the whole Black Sea and are evaluated for for 10 different layers (8, 15, 30, 150, 300, 600 m). The time series starts from Jan 2016. This quantity is updated every week and is available at oceanlab.cmcc.it/blacksea/#validation.

Table III.1: (continued) List of metrics that are used for validation (continues overleaf).

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of BS-Currents forecasts and analyses using semi-independent data – weekly updated				
S-CLASS4-RMS_LAYER_BASINS	Salinity vertical profiles comparison with Copernicus INSITU TAC data at 10 layers for the Black Sea basin.	Salinity	Argo floats from the Copernicus INSITU TAC products: INSITU_BS_NRT_OBSERVATIONS_013_034	Time series of salinity daily RMSs of the difference between model and insitu observations evaluated over 2-weeks period. This quantity is evaluated on the model analysis The statistics are defined for the whole Black Sea and are evaluated for for 10 different layers (8, 15, 30, 150, 300, 600 m). The time series starts from Jan 2016. This quantity is evaluated on the model analysis and updated every week and is available at http://oceanlab.cmcc.it/bsfs-evaluation/
S-CLASS4-BIAS_LAYER_BASINS	Salinity vertical profiles comparison with Copernicus INSITU TAC data at 10 layers for the Black Sea basin.	Salinity	Argo floats from the Copernicus INSITU TAC products: INSITU_BS_NRT_OBSERVATIONS_013_034	Time series of daily bias (difference between model and insitu observations) computed for salinity evaluated over 2-weeks period. This quantity is evaluated on the model analysis The statistics are defined for the whole Black Sea and are evaluated for 10 different layers (8, 15, 30, 150, 300, 600 m). The time series starts from Jan 2016. This quantity is evaluated on the model analysis and updated every week and is available at http://oceanlab.cmcc.it/bsfs-evaluation/

SL-CLASS4-RMS_BASIN	Sea level anomaly comparison with Copernicus Sea Level TAC (satellite along track) data for the whole Black Sea basin.	Sea Level Anomaly	Satellite Sea Level along track data from Copernicus Sea Level TAC product: SEALEVEL_BS_SLA_L3_NRT_OBSERVATIONS_008_039	Time series of sea level anomaly daily RMSs of the difference between model and satellite observations evaluated over 2-weeks period. This quantity is evaluated on the model analysis. The statistics are defined for the whole Black Sea. The time series starts from Jan 2016. This quantity is evaluated on the model analysis and updated every week and is available at http://oceanlab.cmcc.it/bsfs-evaluation/

Table III.1: (continued) List of metrics that are used for validation (continues overleaf).

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of BS-Currents forecasts and analyses using semi-independent data – weekly updated				
SL-CLASS4-BIAS_BASIN	Sea level anomaly comparison with Copernicus Sea Level TAC (satellite along track) data for the Black Sea basin.	Sea Level Anomaly	Satellite Sea Level along track data from Copernicus Sea Level TAC product: SEALEVEL_BS_SLA_L3_NRT_OBSERVATIONS_008_039	Time series of daily bias (difference between model and insitu observations) computed for sea level anomaly. The time series starts from Jan 2016. This quantity is evaluated on the model analysis.. The statistics are defined for the whole Black Sea. This quantity is evaluated on the model analysis and updated every week and is available at http://oceanlab.cmcc.it/bsfs-evaluation/

SST-CLASS4-RMS_BASIN	Sea Surface Temperature comparison with SST Copernicus OSI TAC L3 (satellite) data for the Black Sea basin.	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L3 product: SST_BS_SST_L3S_NRT_OBSERVATIONS_010_013	Time series of sea surface temperature daily RMSs of the difference between model and satellite observations evaluated since Jan 2018. This quantity is evaluated on the model analysis The statistics are defined for the whole Black Sea. This quantity is evaluated on the model analysis and updated every week and is available at: http://oceanlab.cmcc.it/blacksea/#validation
SST-CLASS4-BIAS_BASIN	Sea Surface Temperature comparison with SST Copernicus OSI TAC L3 (satellite) data for the Black Sea basin.	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L3 product: SST_BS_SST_L3S_NRT_OBSERVATIONS_010_013	Time series of daily bias (difference between model and insitu observations) computed for sea surface temperature evaluated since Jan 2018 This quantity is evaluated on the model analysis The statistics are defined for the whole Black Sea. This quantity is evaluated on the model analysis and updated every week and is available at:oceanlab.cmcc.it/blacksea/#validation

The PU-PHY team is working, in collaboration with the Product Quality Responsible, to complete the evaluation of the system performances with respect to mixed layer depth, bottom temperature and currents as reported in [DA2]. In particular, for the newly introduced in V3 product Bottom Temperature, validation will be done against ARGO measurements and climate estimates for the deep part. Discussion on the possibility to use the geostrophic current anomaly from altimeter data for validation of the model surface currents will be initiated within the BS PQWG. This will be part of the updated version of the present QUID, since the numerical procedures for the BS-Currents are under development according to the evolution of the system.

IV VALIDATION RESULTS

In order to evaluate and assure the quality of the BLKSEA_ANALYSIS_FORECAST_PHYS_007_001 product for V3, a numerical experiment has been performed using the pre-operational model setup that represents the core model of V3 BS-Currents.

This product is a long term model run overlapping two periods of different spatial resolution of the atmospheric forcing: from January 2000 until September 2008, ECMWF at 50 km resolution has been used, while from September 2008 until December 2014, ECMWF at 25 km resolution has been used for performing the model run.

The scientific question incoming within the BS-Currents system evolution and part of the V3 model improvements is: how to keep correctly the termohaline stratification in the Black Sea? In particular, how to keep the Cold Intermediate Layer existence, formation and evolution along time?

To answer the question, starting from the BS-Currents V2.2 system, the PU-PHY Team proposed to embed the Turbulent Kinetic Energy vertical mixing scheme instead of the General Length Scale one with no diffusive terms.

A 15-years run has been performed for V2.2 (whose model setup, details and quality is described in [DA3]) and newly V3 models setup in hindcast mode without assimilation to assess the V3 configuration.

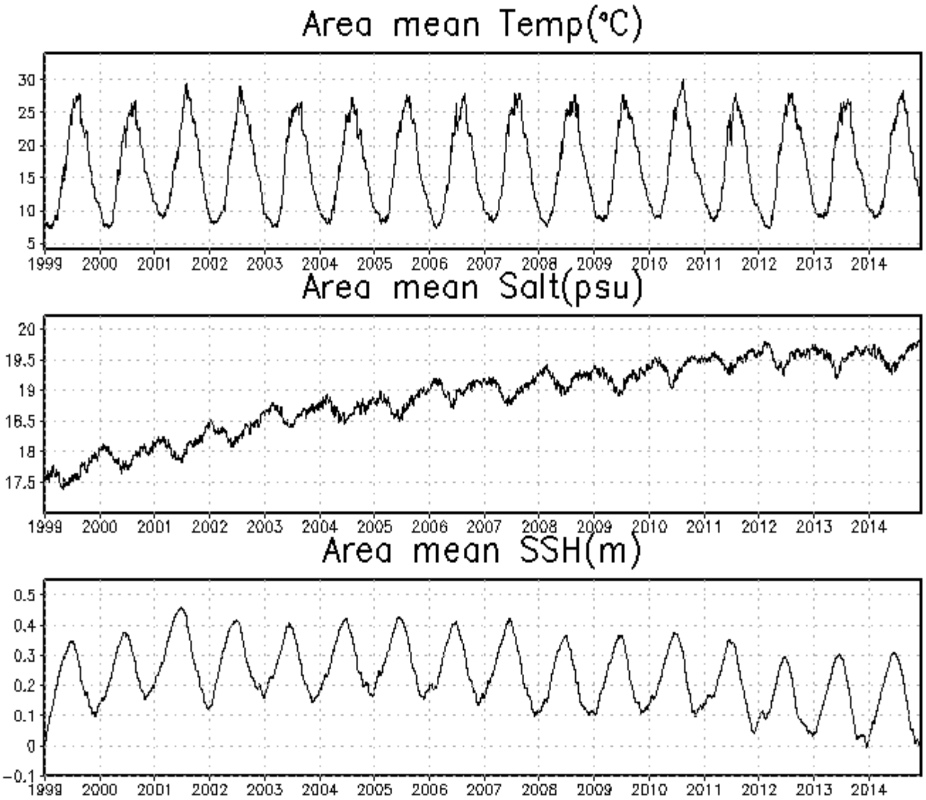

Figure IV.1. Basin averaged temperature (top), salinity (middle) and sea surface height (bottom) for the V2.2 BS-Currents system.

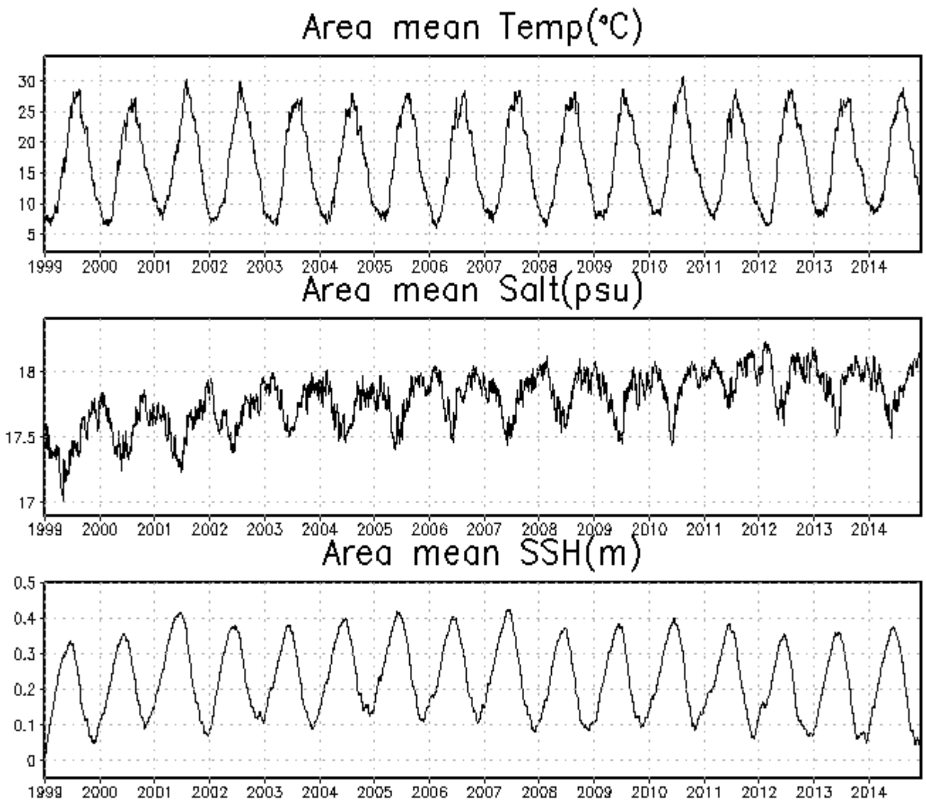

Figure IV.2. Basin averaged temperature (top), salinity (middle) and sea surface height (bottom) for the new V3 BS-Currents system.

Basin averaged quantities for temperature, salinity and sea surface height are here discussed: in particular, Figure IV.1 shows surface means for the V2.2 BS-Currents while Figure IV.2 shows the corresponding quantities for the new V3 BS-Currents. Both systems goodly represent the seasonal temperature cycle over the period; V3 improves in particular SSS and SSH trends, showing for SSS a smaller trend with respect to V2.2 BS-Currents and better controlled SSH trend.

To evaluate the quality of vertical mean characteristics, Figure IV.3 and Figure IV.4 shows the performances of V2.2 and V3 BS-Currents, respectively. V3 BS-Currents, based on TKE scheme, shows a better representation of the haline stratification and persistency in CIL with respect to V2.2 BS-Currents, based on GLS scheme for vertical mixing. This attitude is emphasized also in the vertical Hovmuller diagram at 30°E,43°N and reported in Figure IV.5 and Figure IV.6.

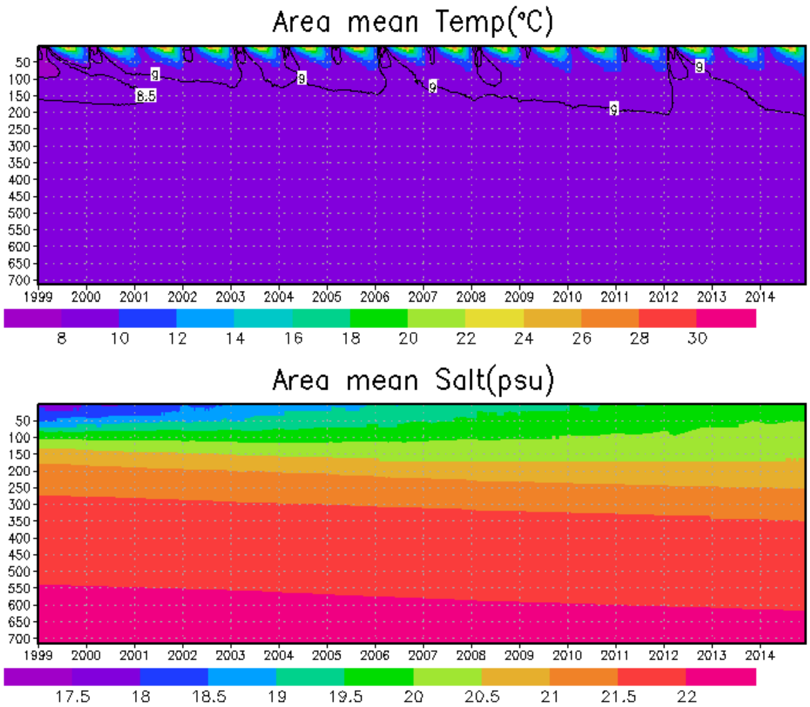

Figure IV.3. Vertical mean temperature (top) and salinity (bottom) computed using V2.2 BS-Currents based on GLS.

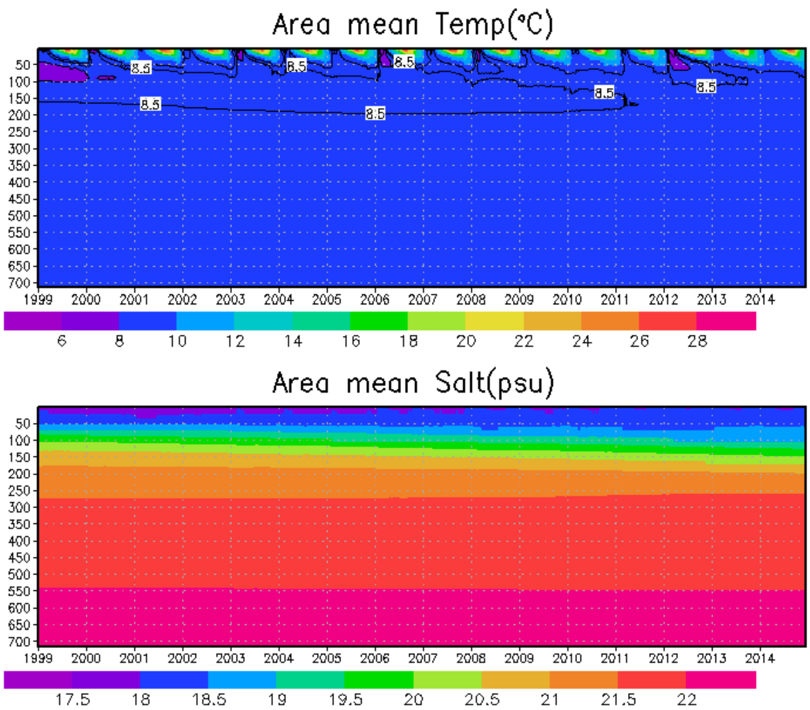

Figure IV.4. Vertical mean temperature (top) and salinity (bottom) computed using V3 BS-Currents based on TKE.

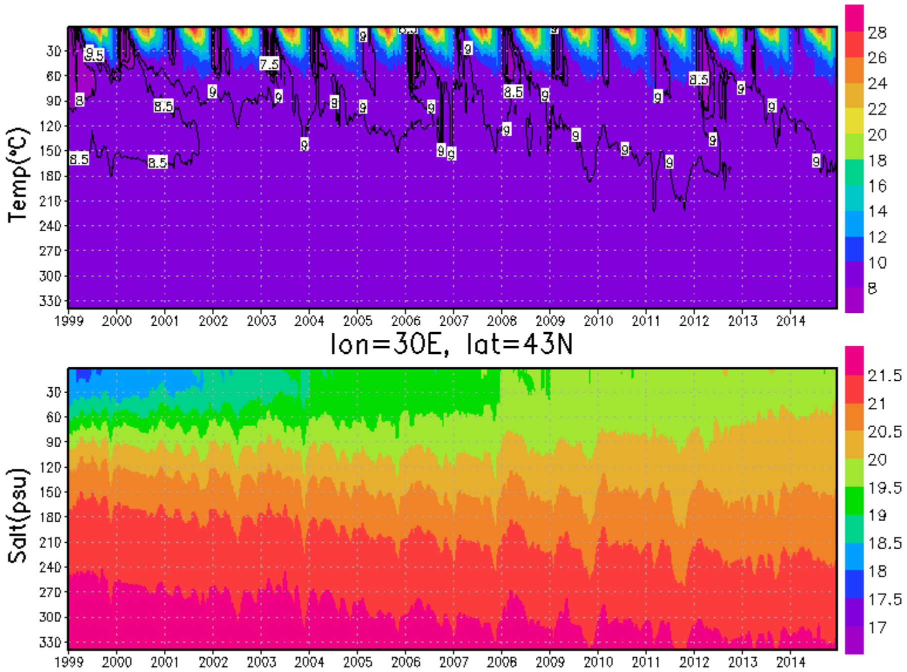

Figure IV.5. Vertical Hovmoller diagram for temperature (top) and salinity (bottom) computed using V2.2 BS-Currents based on GLS at 30°E,43°N point

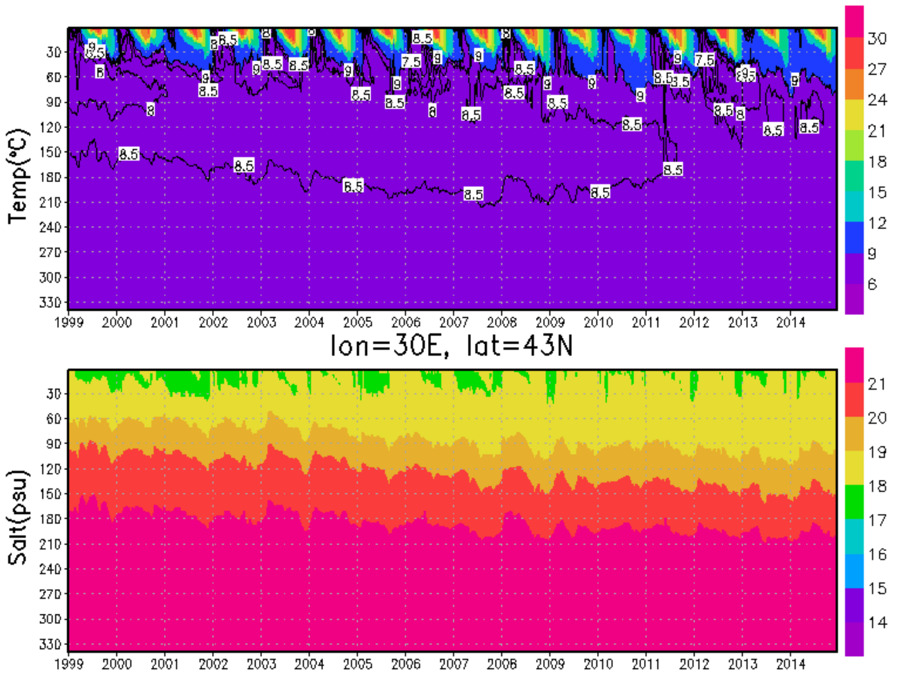

Figure IV.6. Vertical Hovmoller diagram for temperature (top) and salinity (bottom) computed using V3 BS-Currents based on TKE at 30°E,43°N point

Finally, Table IV-1 shows, in particular, the statistics over the whole basin for the periods 2001-2008 and 2009-2014 considering SST seasonal signal. These two periods were separated because ECMWF forcing was different: in 2009 the horizontal resolution of the meteorological analysis of ECMWF was enhanced double (from ~25 to ~12.5 km). Thus the influence of the resolution of the forcing atmospheric data is revealed – the better resolution has decreased the error with 20%, slightly improved with the V3 BS-Currents system.

Table IV-1. BIAS and RMSE form SST misfits over the whole basin for the period 2001-2008 and 2009-2014 computed considering the V2.2 BS-Currents setup and the V3 BS-Currents setup, respectively.

Variable	System	BIAS 2001-2008	RMSE 2001-2008	BIAS 2009-2014	RMSE 2009-2014
SST (ºC)	V2.2 BS-Currents	-1	1.3	-0.8	1
	V3 BS-Currents	-0.9	1.1	-0.8	0.9

An online validation of the V3 BS-Currents performance will be provided on the dedicated website (http://bsfs.cmcc.it/). Within the BS PQWG has started also a discussion for homogenizing the publication of statistics, improving the sections dedicated to results visualization and integration of new statistics.

V SYSTEM'S NOTICEABLE EVENTS, OUTAGES OR CHANGES

As described in the previous section an important change for the performance of the hindcast experiment for the period 2000-2014 is the enhanced spatial resolution of the atmosphere forcing data of ECMWF in 2008. Thus the influence of the resolution of the forcing atmospheric data is revealed – the better resolution has decreased the error with ~20%.

Date	Change/Event description	System version	other
2018	Change in the horizontal resolution of the atmospheric forcing data: ECMWF analysis and forecast product resolution was enhanced double (from ~25 to ~12.5 km)	V3	
Apr 2019	Revision of BS-PHY NRT data assimilation component and physical core	V3	
Sep 2019	Updated processing system to have products centered at 12:00 UTC	V3	

VI QUALITY CHANGES SINCE PREVIOUS VERSION

The evolution from BS-Currents V2.2 to V3 has seeing some improvements in the modelling configuration, related in particular on the model core version (NEMO v3.4 to v3.6) and vertical mixing scheme (GLS to TKE).

The model setup in V3 is demonstrating to represent better the thermohaline stratification – the CIL is much more persistent in time also with respect to the previous V2.2.

The EANs computed for V3 shows some improvements with respect to V2.2 BS-Currents especially in the intermediate layer. A more detailed view of the general assessment of the NRT BS-Currents will be provided once completed also the metrics for 2016.

VI.1 Revision of BS-PHY NRT data assimilation component and physical core

In the period Sep 2018-Feb 2019, the BS-PHY team completed a revision of the operational system with some upgrades able to improve the quality of the NRT system. Upgrades include:

- Revision of the 3DVAR version scheme for the assimilation of all available satellite platforms (Altika, Cryosat, Jason2/3, Sentinel3A), including bug fixing in interpolating vertical profiles and operational script
- Revision of the physical parameterization to improve the numerical stability (in particular, revision of the vertical eddy viscosity and diffusivity values (1.2e-5 m2/s and 1.2e-6 m2/s, respectively)
- Assessment of the upgraded version of the NRT operational scripts, implementation of online BS-PHY NRT system evaluation (pre-operational version of the website is available at the following link: http://oceanlab.cmcc.it/bsfs-evaluation/)

The following figure shows the time series of weekly RMSs of temperature, salinity and sea level misfits (observation minus model value transformed at the observation location and time before being assimilated)

- at 6 reference depths only for temperature and salinity (8, 15, 30, 150, 300, 600 m), T<S>-<X-Y>m-W-CLASS4–PROF-RMSD-BS-Jan2016-Mar2019,
- at surface for sea level, SL-CLASS4-RMS_BS-Jan2016-Mar2019

for the CMEMS BS-PHY EAS3 system operational since Apr 2018 (green line, label “BSFS v3.0”) and the EAS3 system with aforementioned improvements (purple line, label “BSFS v3.1”); the values of the mean RMS difference are reported in the legend of the figures; the number of observed profiles are represented in dashed coloured lines.

Figure VI.1 shows the plot of RMS of sea level misfits computed using all available satellite platforms operational since 2016: statistics show an improvement in BSFS v3.1 with increased number of assimilated observations from Q1/2017. Figure VI.2 to Figure VI.4 demonstrate the current problem in BSFS v3.0 that we solved with BSFS v3.1: the operational CMEMS satellite observations have been not consistently assimilated in time. Additionally, BSFS v3.0 is currently not assimilating Sentinel3A data. Thanks to revision in data assimilation scheme and operational script, the BSFS v3.1 is now consistently assimilating all CMEMS SL data, guaranteeing an average error of about 2.4 cm.

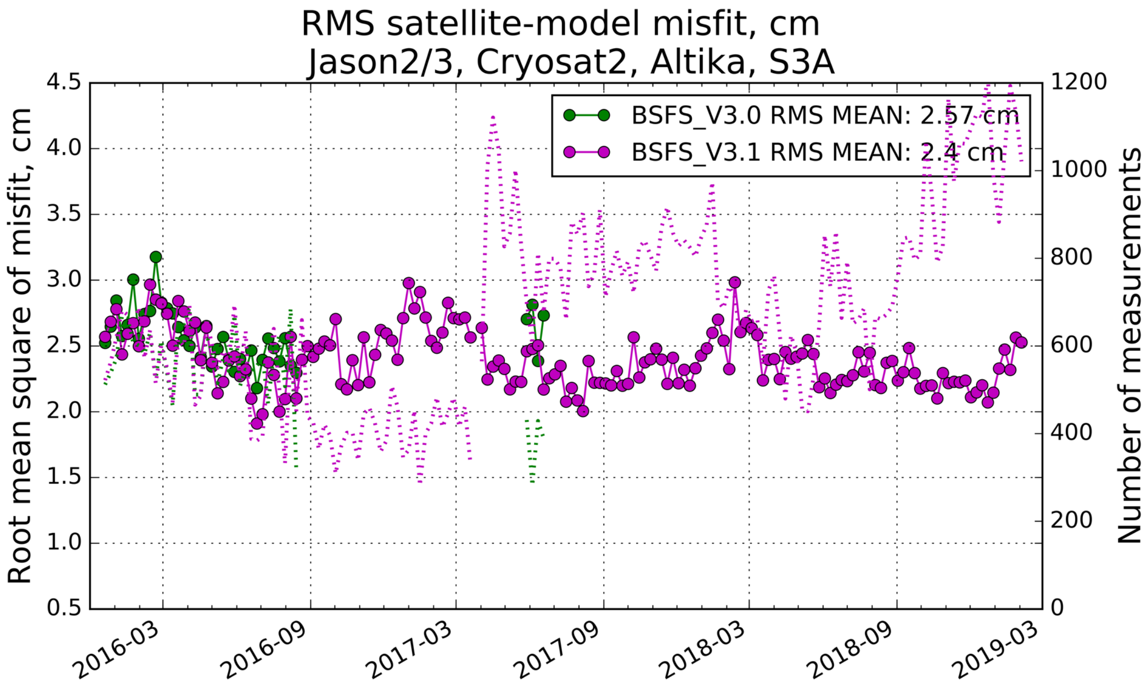

Figure VI.1.: RMS misfits (in cm) considering all available CMEMS SL satellite data: BSFS v3.0 in red, new upgraded BSFS v3.1 in purple

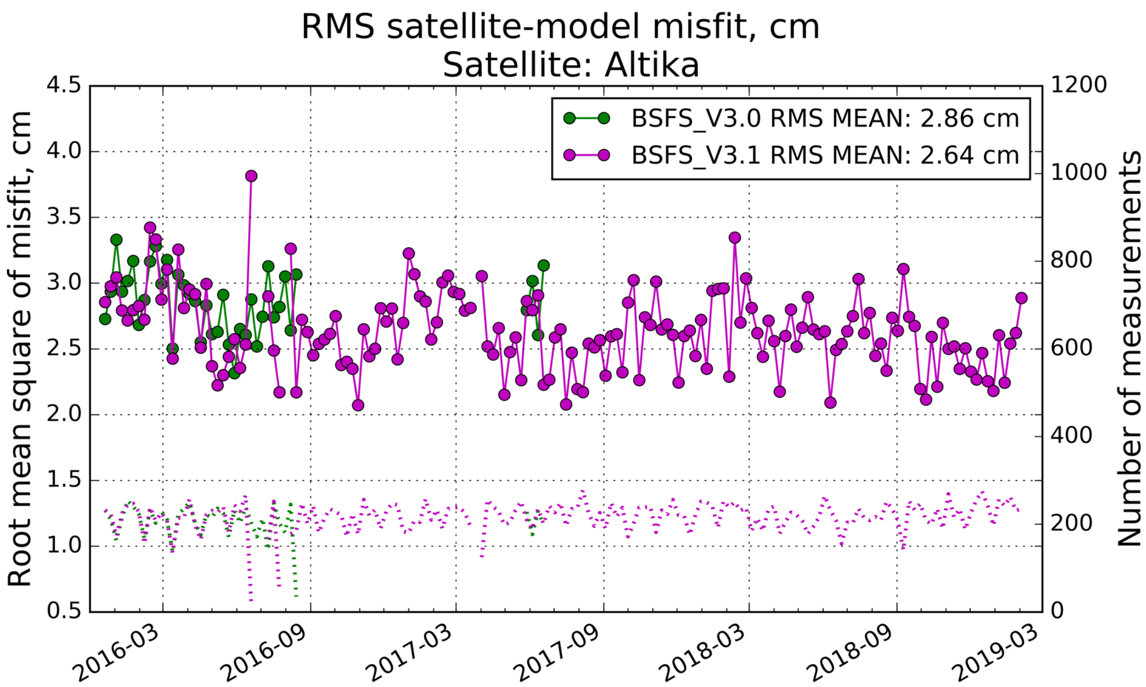

Figure VI.2.: RMS misfits (in cm) considering Altika SL satellite data: BSFS v3.0 in red, new upgraded BSFS v3.1 in purple

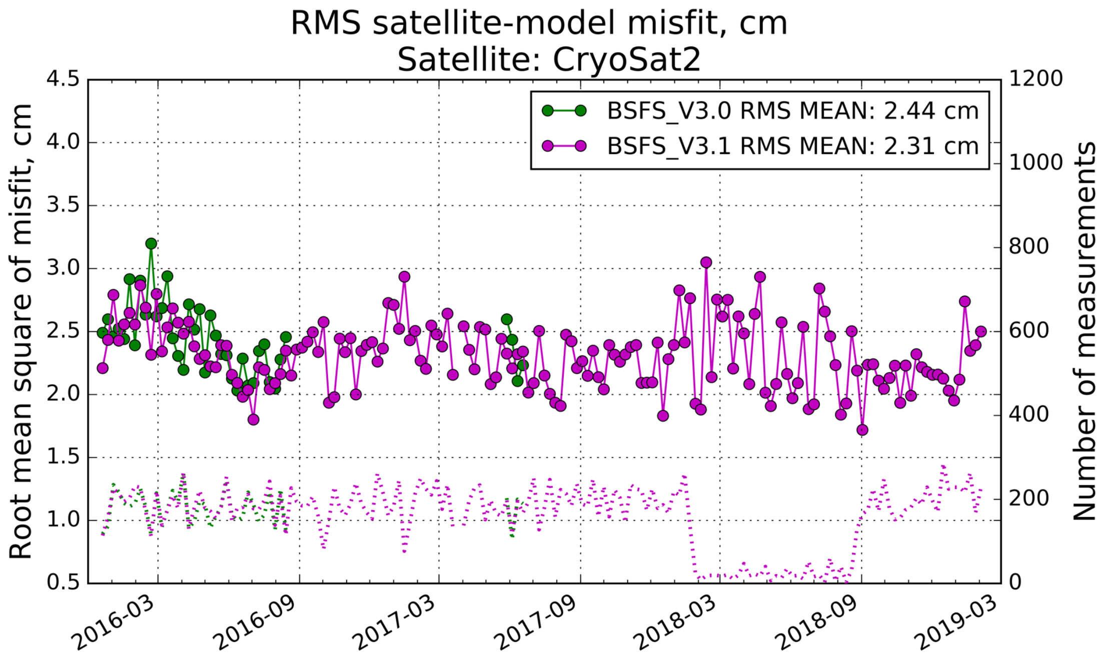

Figure VI.3: RMS misfits (in cm) considering CryoSat SL satellite data: BSFS v3.0 in red, new upgraded BSFS v3.1 in purple

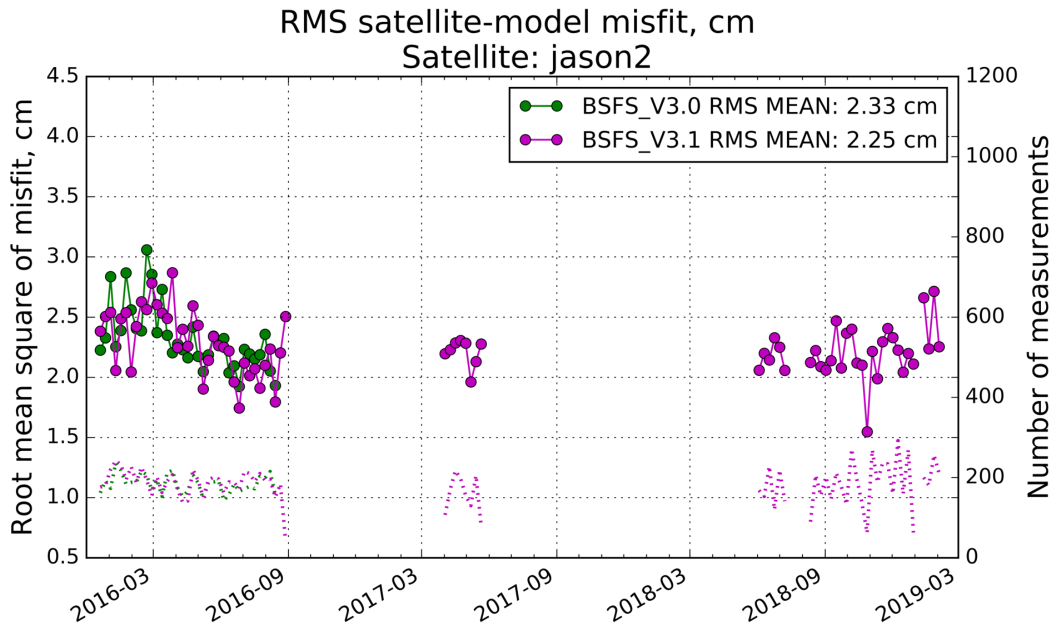

Figure VI.4.: RMS misfits (in cm) considering Jason2 SL satellite data: BSFS v3.0 in red, new upgraded BSFS v3.1 in purple

Figure VI.5 to Figure VI.10 show the RMS of temperature misfits: in general, BSFS v3.1 is quite improved with respect to BSFS v3.0. During the period Q3/2016-Q3/2017, BSFS v3.0 did not assimilated any profile due to a bug in the operational script, now fixed in BSFS v3.1. At surface layers, the average error computed for BSFS v3.1 is less than 1ºC (Figure VI.5): highest errors are concentrated during summer time (about 2ºC at maximum). The thermocline is still critical in the BSFS configuration, even if the revision of physical parameterization and data assimilation scheme has helped to decrease the error in BSFS v3.1 with respect to BSFS v3.0 (Figure VI.6 to Figure VI.8). No significative differences of performances between the 2 systems in the deepest layers.

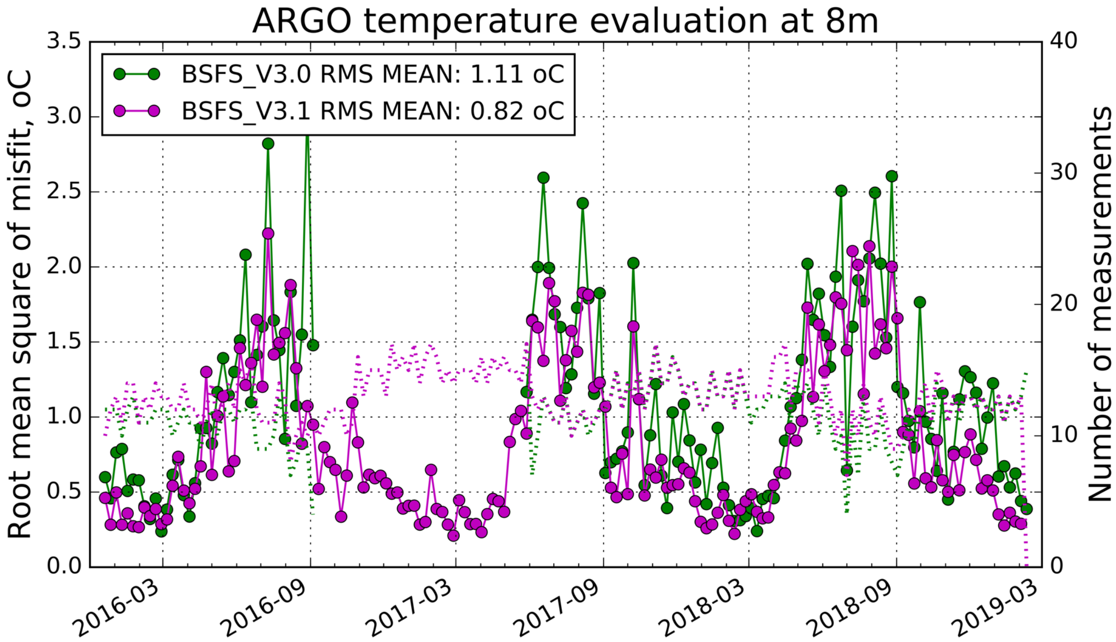

Figure VI.5. : Temperature RMS misfits (in ºC) at 8m reference depth: BSFS v3.0 in red, new upgraded BSFS v3.1 in purple

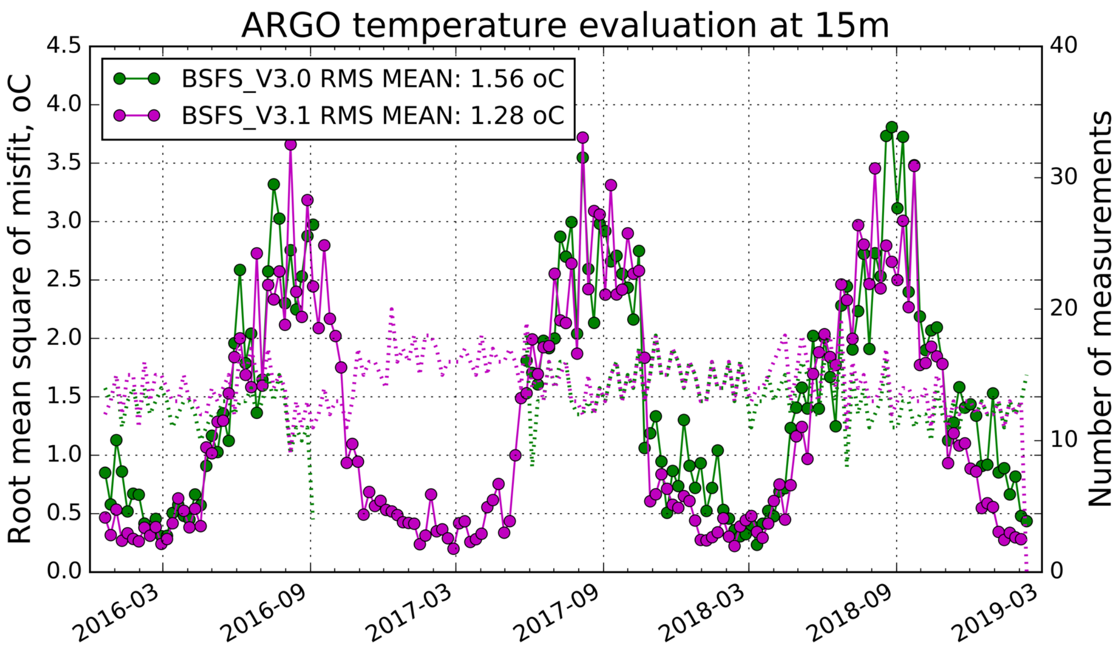

Figure VI.6.: Temperature RMS misfits (in ºC) at 15m reference depth: BSFS v3.0 in red, new upgraded BSFS v3.1 in purple

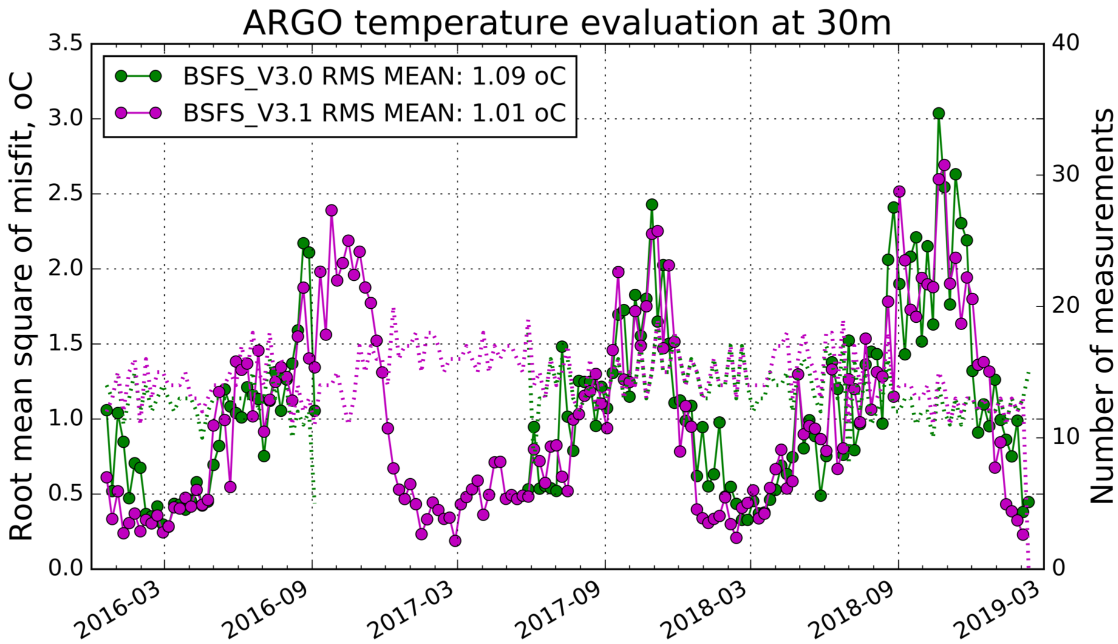

Figure VI.7.: Temperature RMS misfits (in ºC) at 30m reference depth: BSFS v3.0 in red, new upgraded BSFS v3.1 in purple

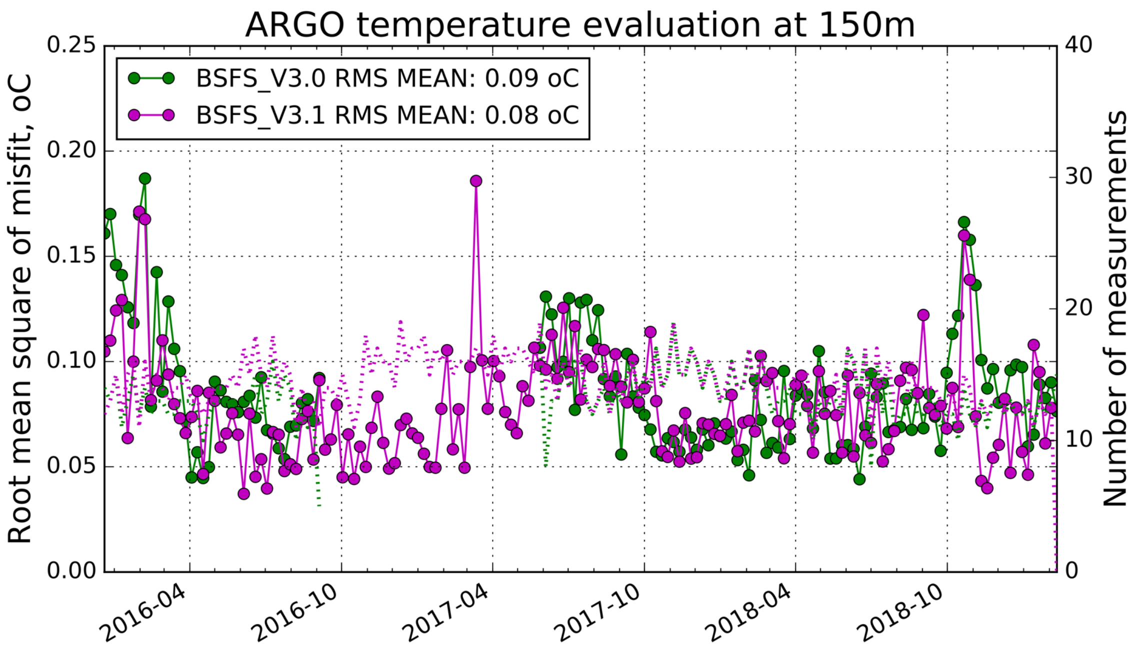

Figure VI.8.: Temperature RMS misfits (in ºC) at 150m reference depth: BSFS v3.0 in red, new upgraded BSFS v3.1 in purple

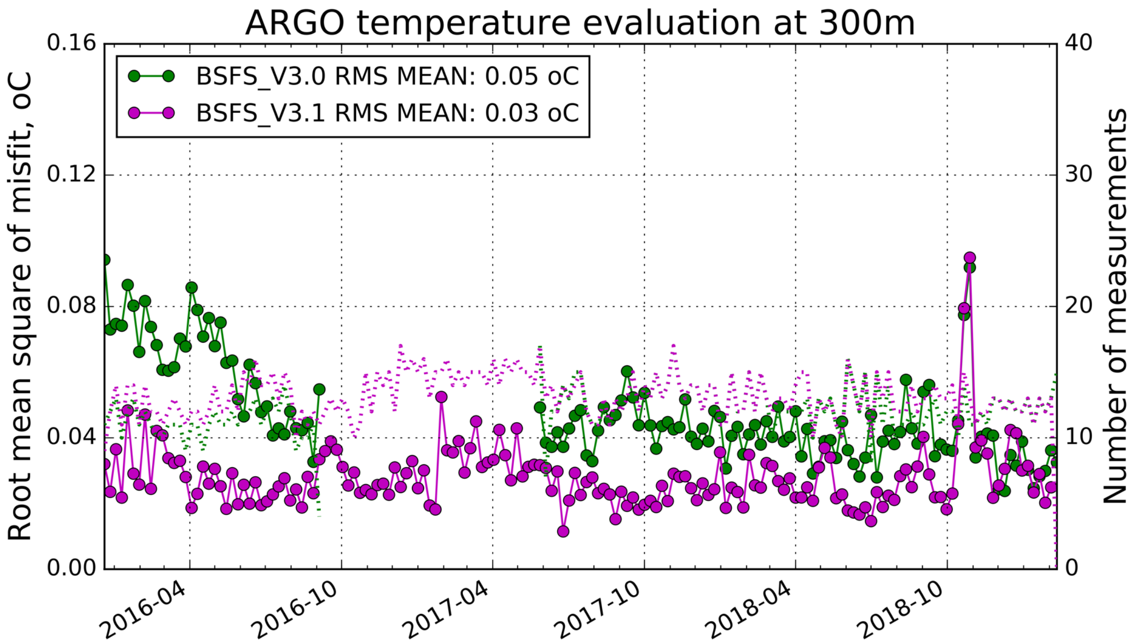

Figure VI.9.: Temperature RMS misfits (in ºC) at 300m reference depth: BSFS v3.0 in red, new upgraded BSFS v3.1 in purple

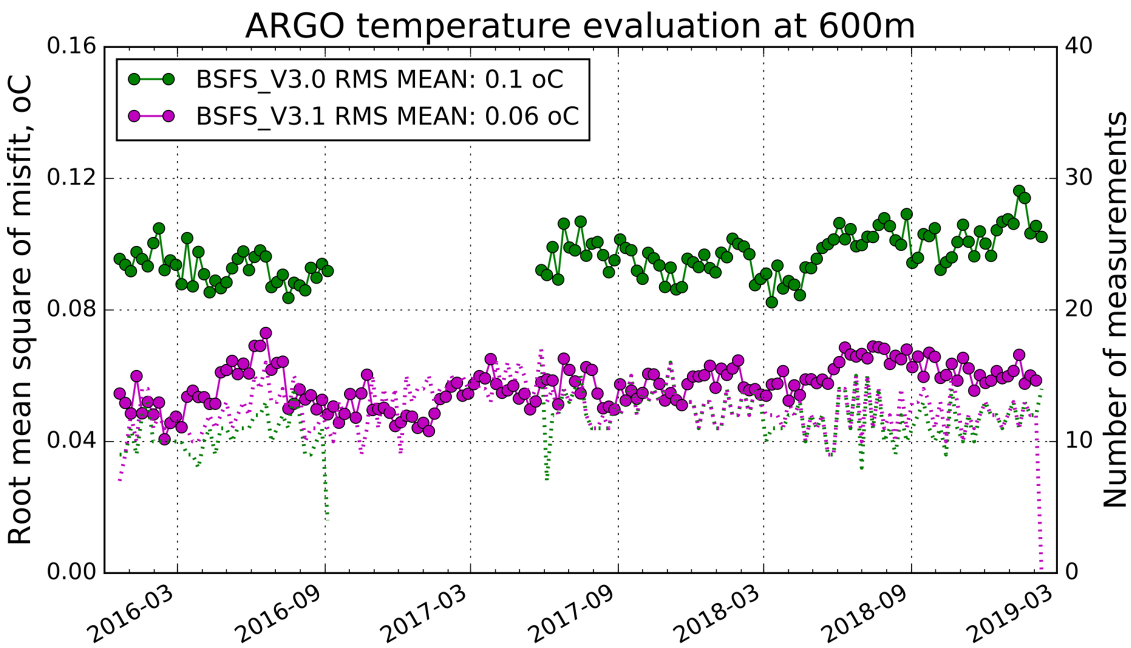

Figure VI.10.: Temperature RMS misfits (in ºC) at 600m reference depth: BSFS v3.0 in red, new upgraded BSFS v3.1 in purple

Figure VI.11 to Figure VI.16 show the RMS of salinity misfits: we do not have significative improvements in BSFS v3.1 due to the model constraint at the Bosporus Strait, which is treated as surface boundary condition.

Next version release, based on open boundary condition at the Bosporus Strait, increased number of vertical levels and increased EOFs accuracy, will improve the numerical performances for temperature and salinity products.

The BS-PHY team has also developed, as prototype, a pre-operational tool for checking and controlling NRT product quality, including information on rejected data, freely available at http://oceanlab.cmcc.it/bsfs-evaluation/

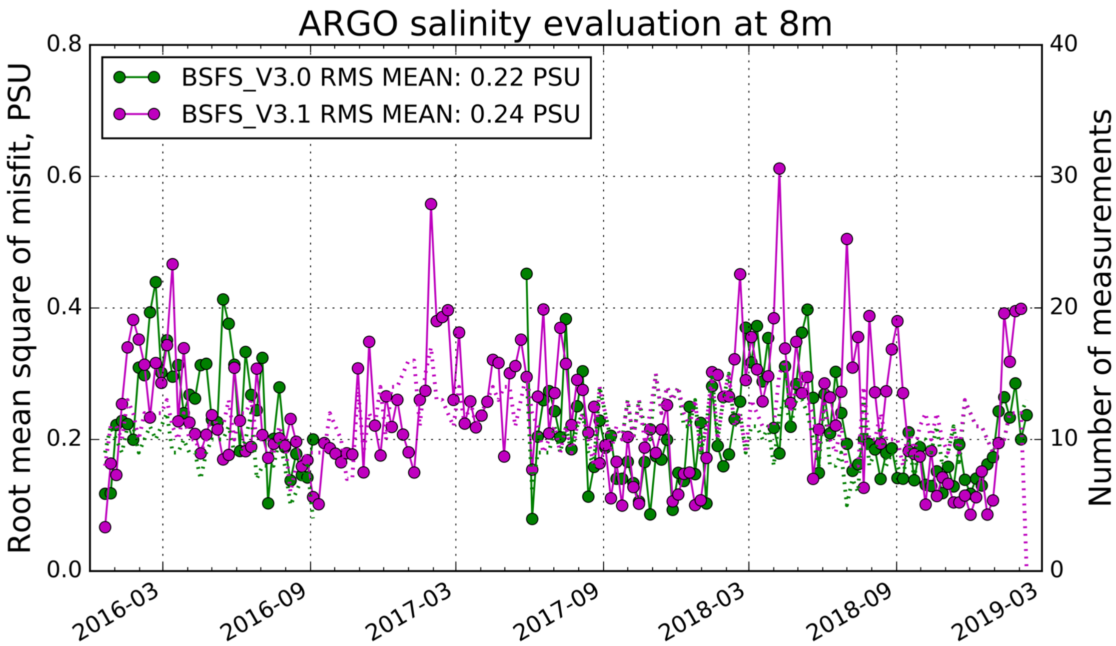

Figure VI.11.: Salinity RMS misfits (in PSU) at 8m reference depth: BSFS v3.0 in red, new upgraded BSFS v3.1 in purple

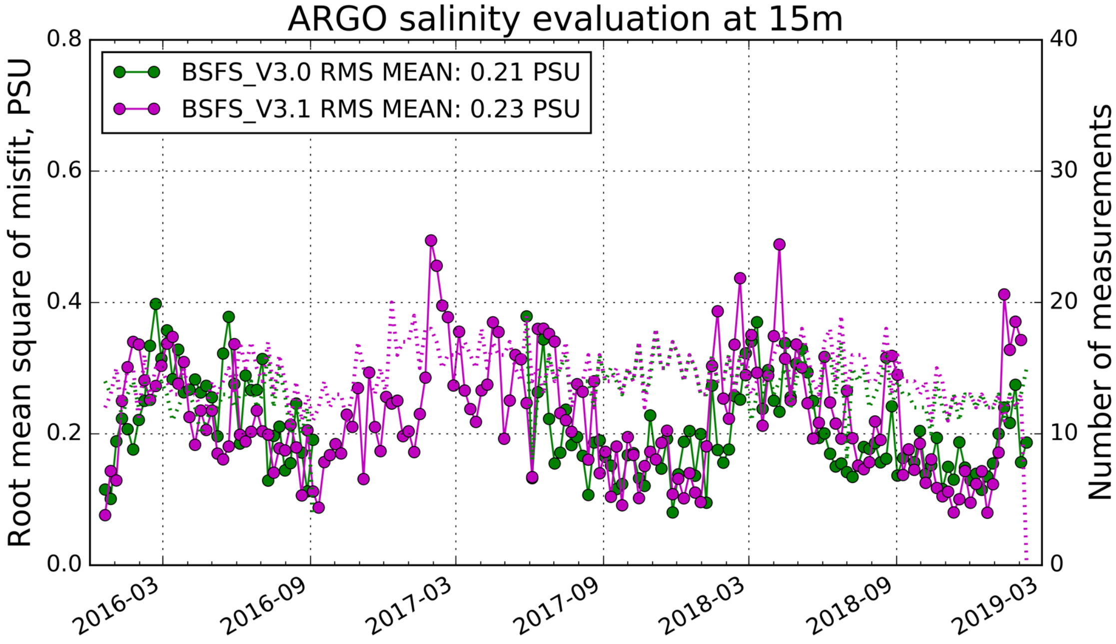

Figure VI.12.: Salinity RMS misfits (in PSU) at 15m reference depth: BSFS v3.0 in red, new upgraded BSFS v3.1 in purple

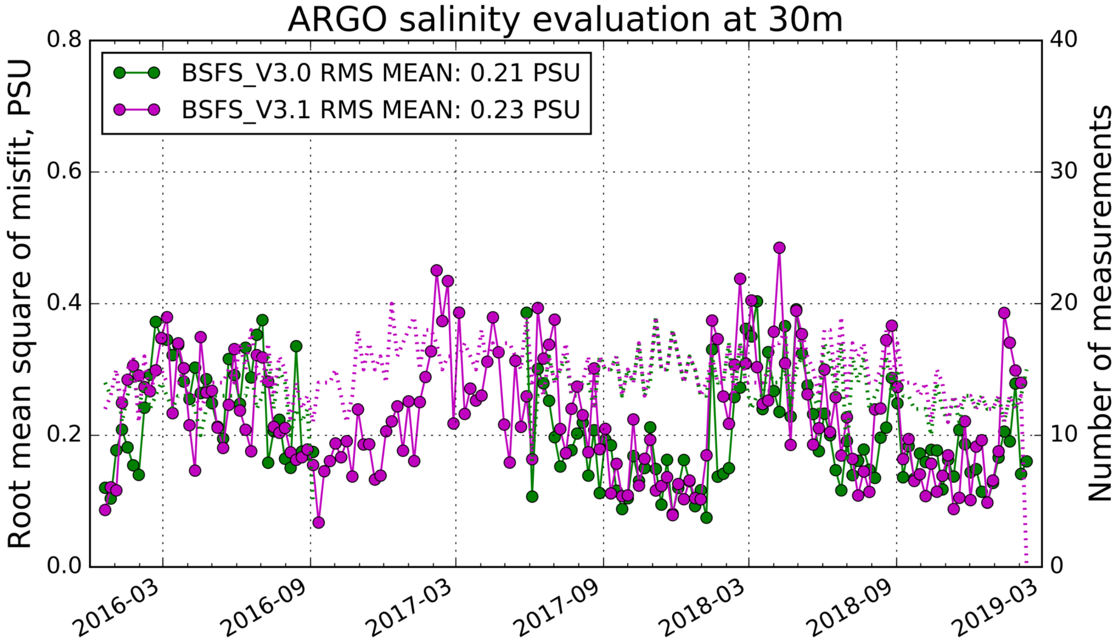

Figure VI.13.: Salinity RMS misfits (in PSU) at 30m reference depth: BSFS v3.0 in red, new upgraded BSFS v3.1 in purple

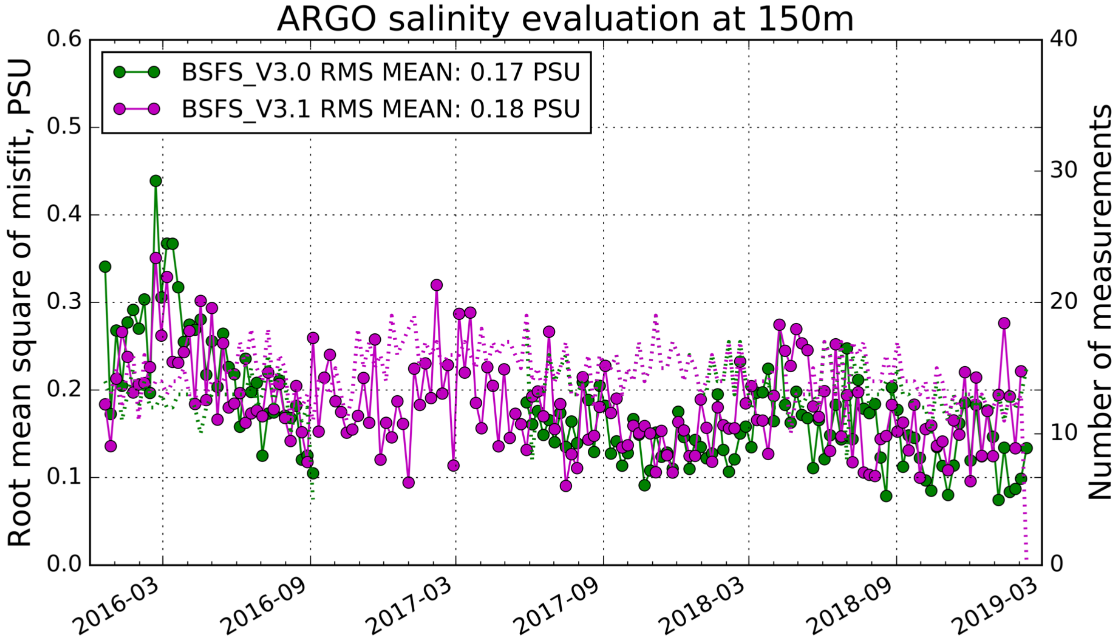

Figure VI.14.: Salinity RMS misfits (in PSU) at 150m reference depth: BSFS v3.0 in red, new upgraded BSFS v3.1 in purple

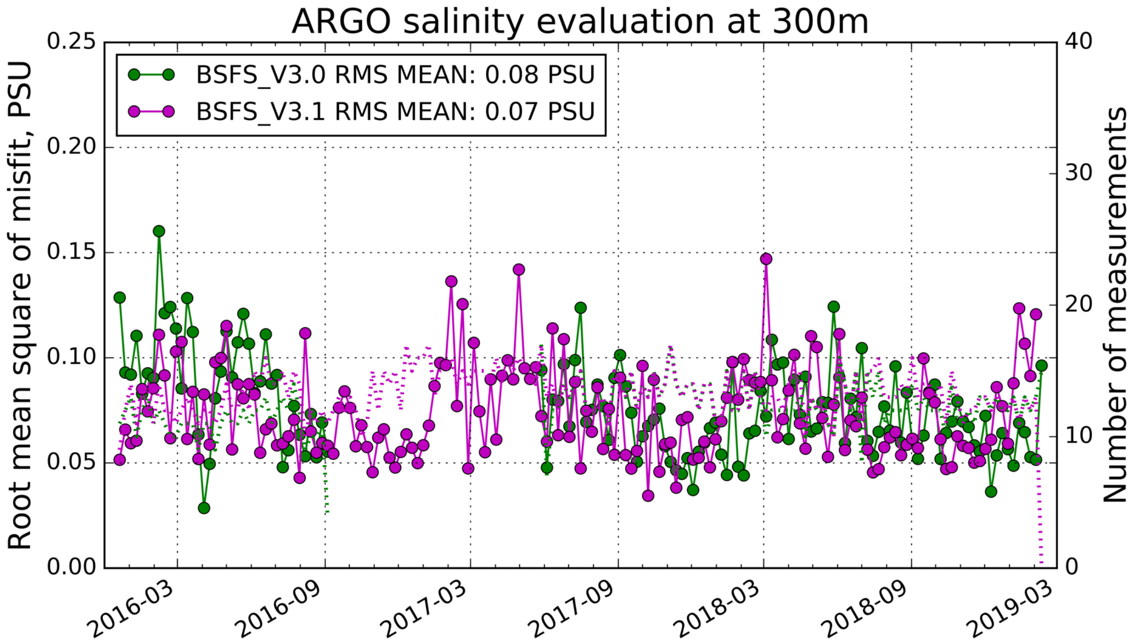

Figure VI.15.: Salinity RMS misfits (in PSU) at 300m reference depth: BSFS v3.0 in red, new upgraded BSFS v3.1 in purple

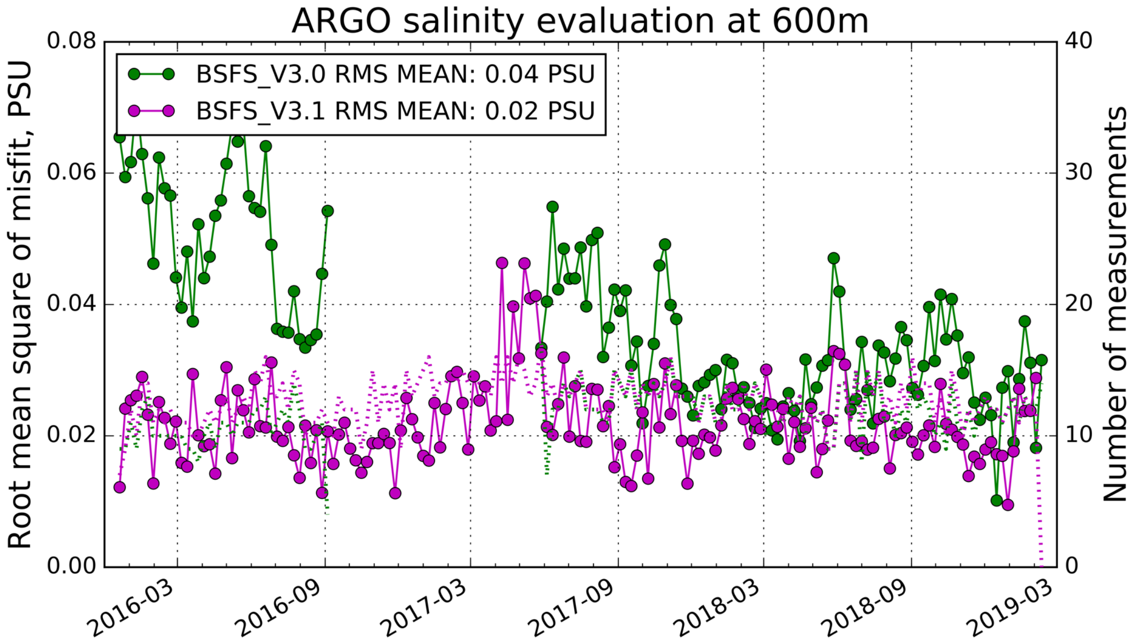

Figure VI.16. : Salinity RMS misfits (in PSU) at 600m reference depth: BSFS v3.0 in red, new upgraded BSFS v3.1 in purple

VI.2 Updated processing system to have products centered at 12:00 UTC: quality check

In the period Aug 2019-Sep 2019, the BS-PHY team completed a revision of the operational system with some upgrades on the processing chain and keeping the revised core model as described in Section VI.1. Upgrades include:

- Revision of DA module to account the production of Black Sea ocean fields centered to 12:00 UTC (so nominal start at 00:00 UTC at a given day)
- Revision of the BS-PHY processing chain, including ECMWF pre-processing and output post-processing

The evaluation period is 2016/01/01 – 2018/12/31. We compared the ongoing operational BSFS_v3.1 and the upgraded proposed one BSFS_v3.2 (*herein temporary indicated as "restart_midnight"*).

Results here proposed are only for 2016/01/01 – 2016/06/01: the updated time series for operations is under developing. We compared, for demonstrating purposes. Preliminary results show no significant changes in quality.

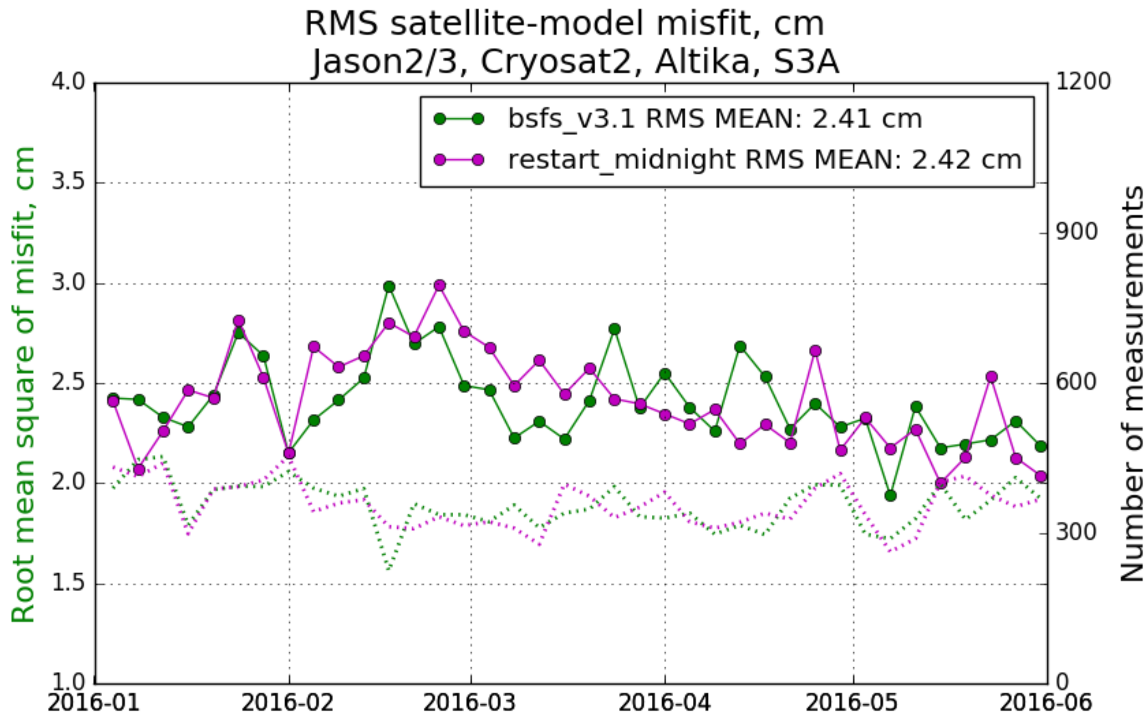

Figure VI.17: SLA RMS misfit for all available SL platforms: current operational system BSFS_v3.1 (green), upgraded version (purple)

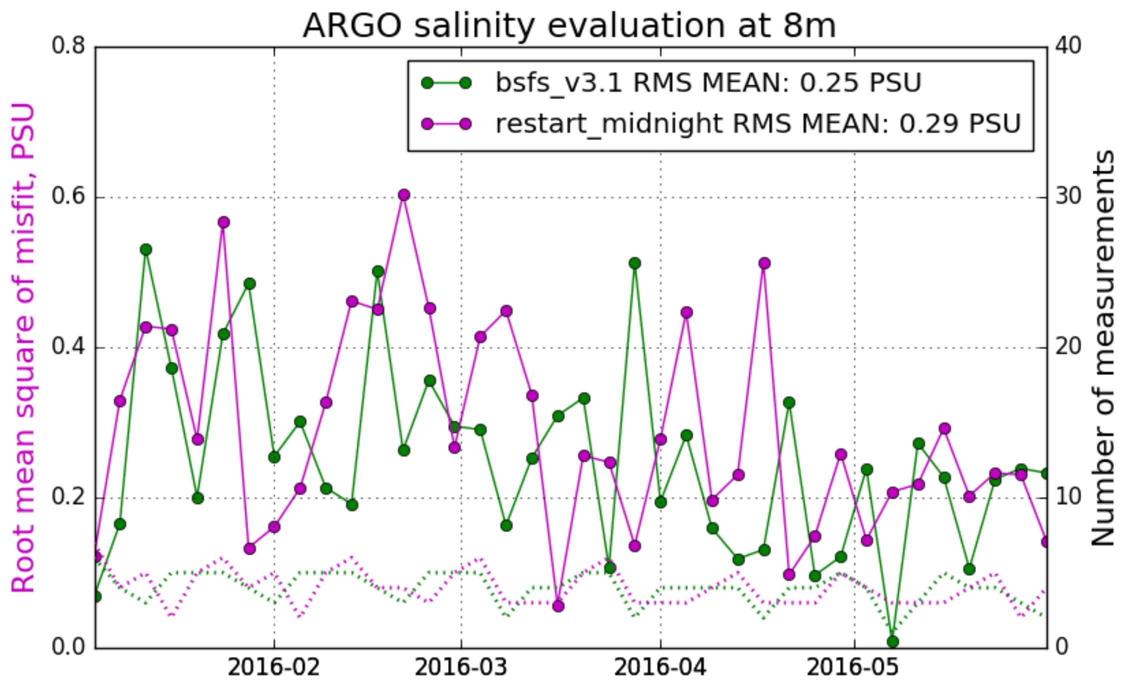

Figure VI.18: Salinity RMS misfit at 8 m: current operational system BSFS_v3.1 (green), upgraded version (purple)

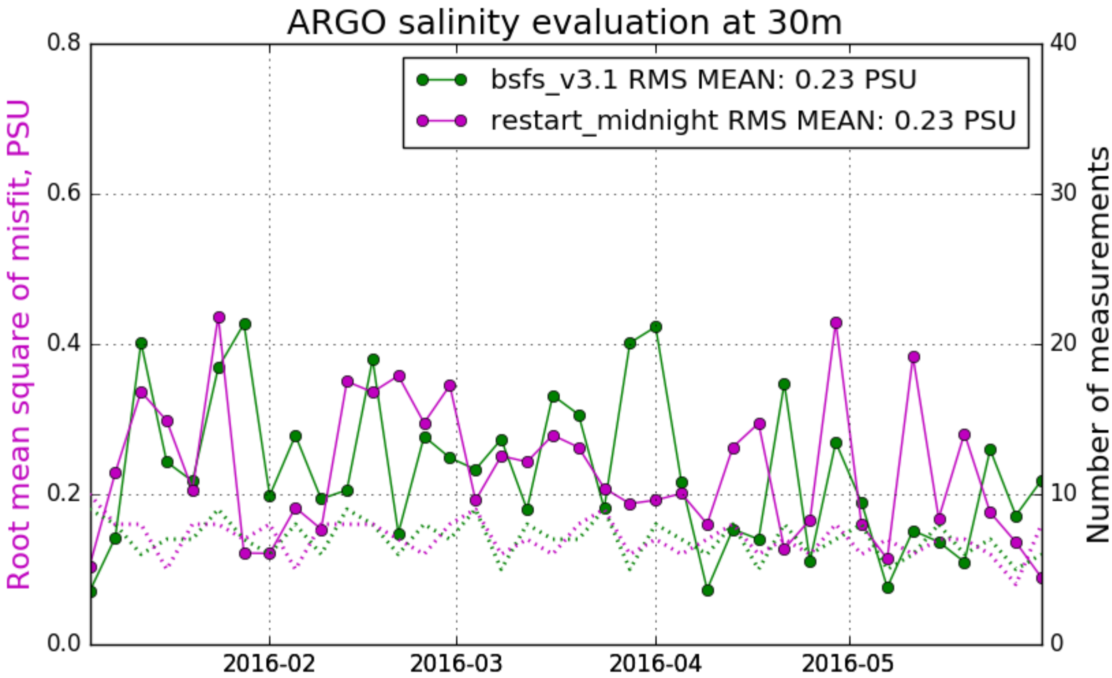

Figure VI.19: Salinity RMS misfit at 30 m: current operational system BSFS_v3.1 (green), upgraded version (purple)

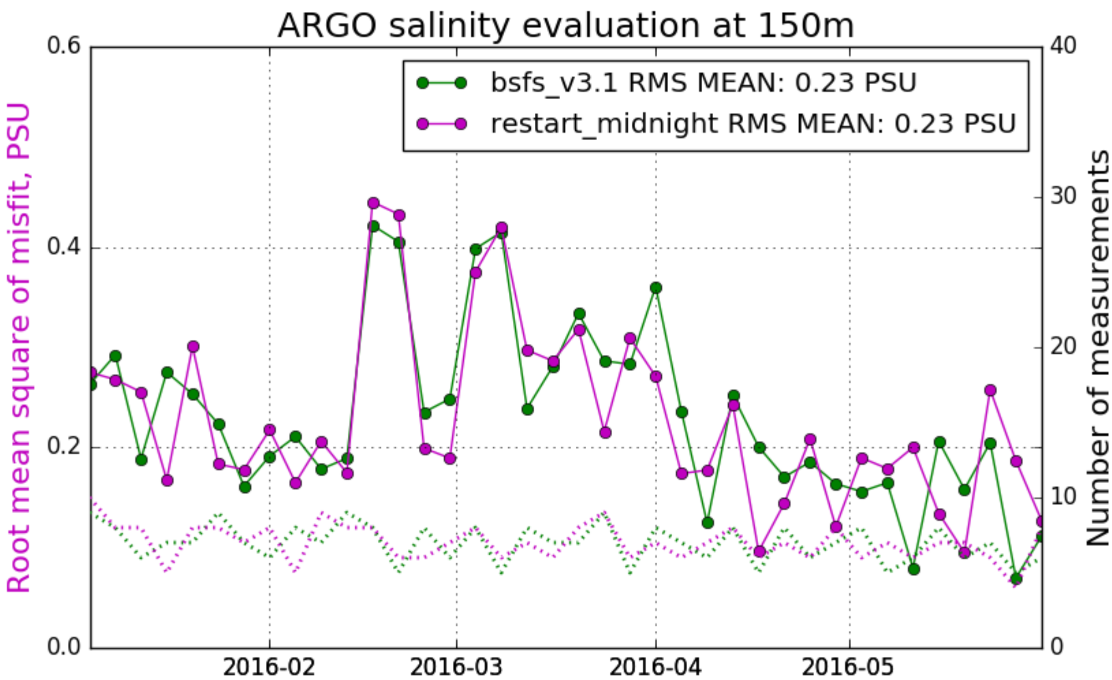

Figure VI.20Salinity RMS misfit at 150 m: current operational system BSFS_v3.1 (green), upgraded version (purple)

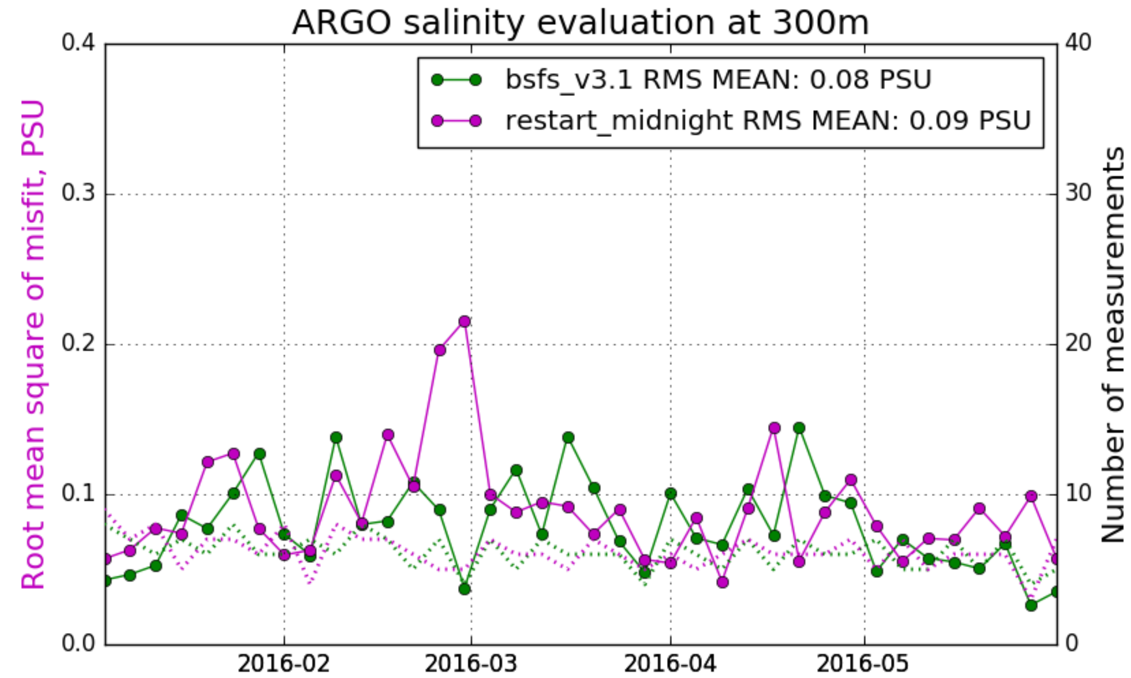

Figure VI.21: Salinity RMS misfit at 300 m: current operational system BSFS_v3.1 (green), upgraded version (purple)

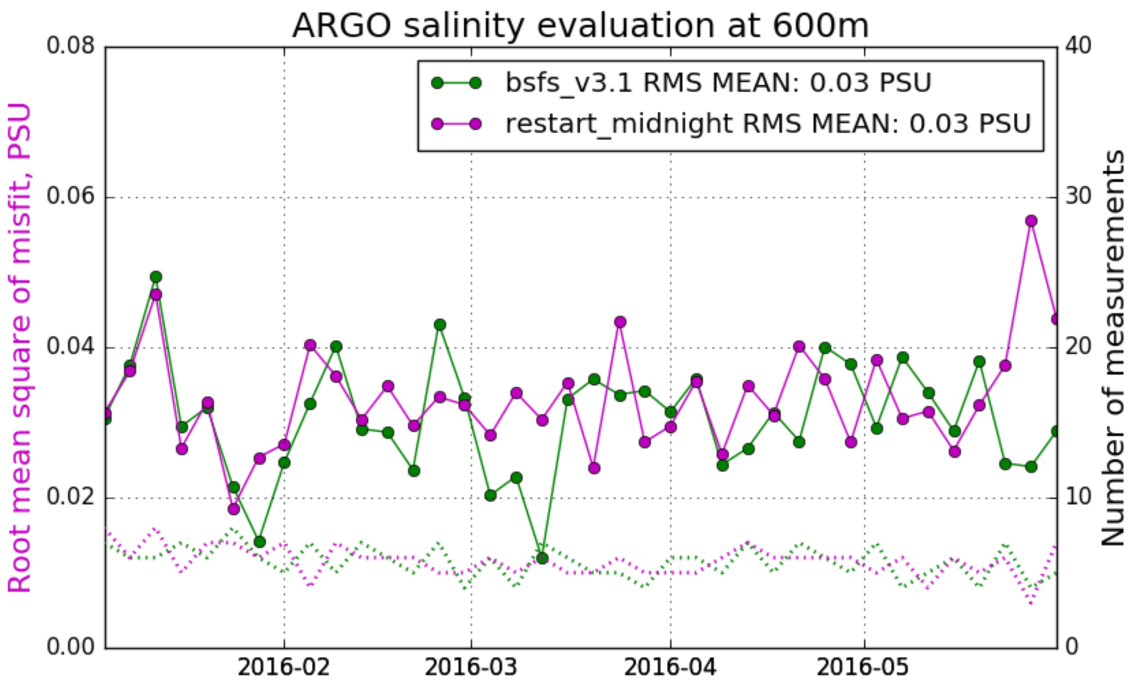

Figure VI.22Salinity RMS misfit at 600 m: current operational system BSFS_v3.1 (green), upgraded version (purple)

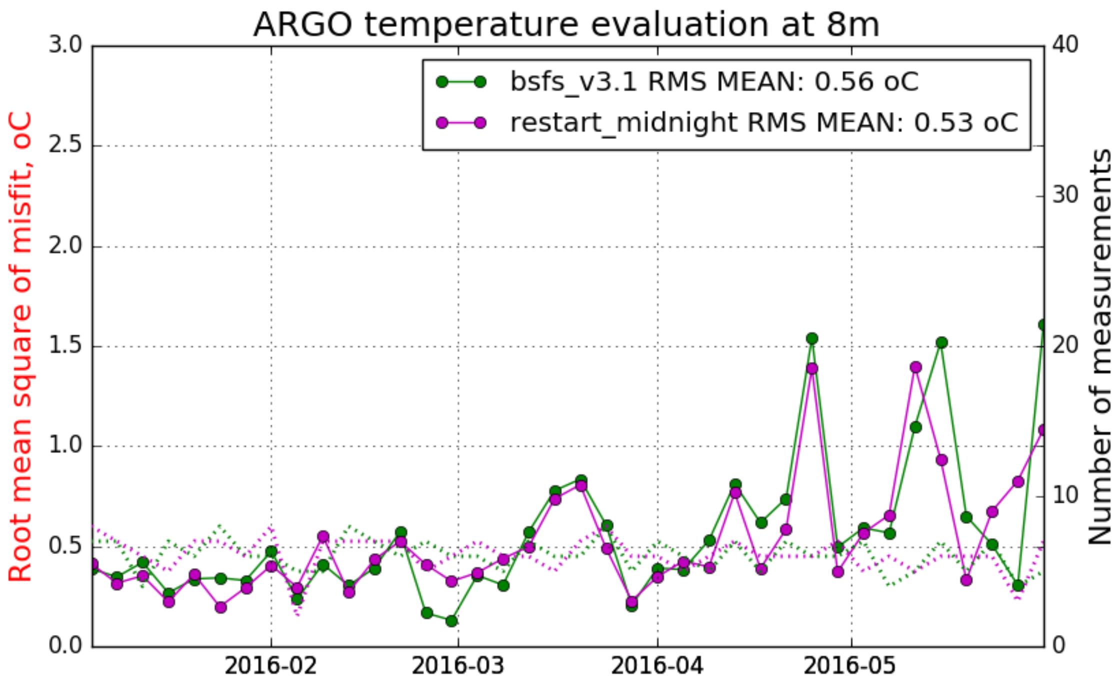

Figure VI.23: Temperature RMS misfit at 8 m: current operational system BSFS_v3.1 (green), upgraded version (purple)

Figure VI.24Temperature RMS misfit at 30 m: current operational system BSFS_v3.1 (green), upgraded version (purple)

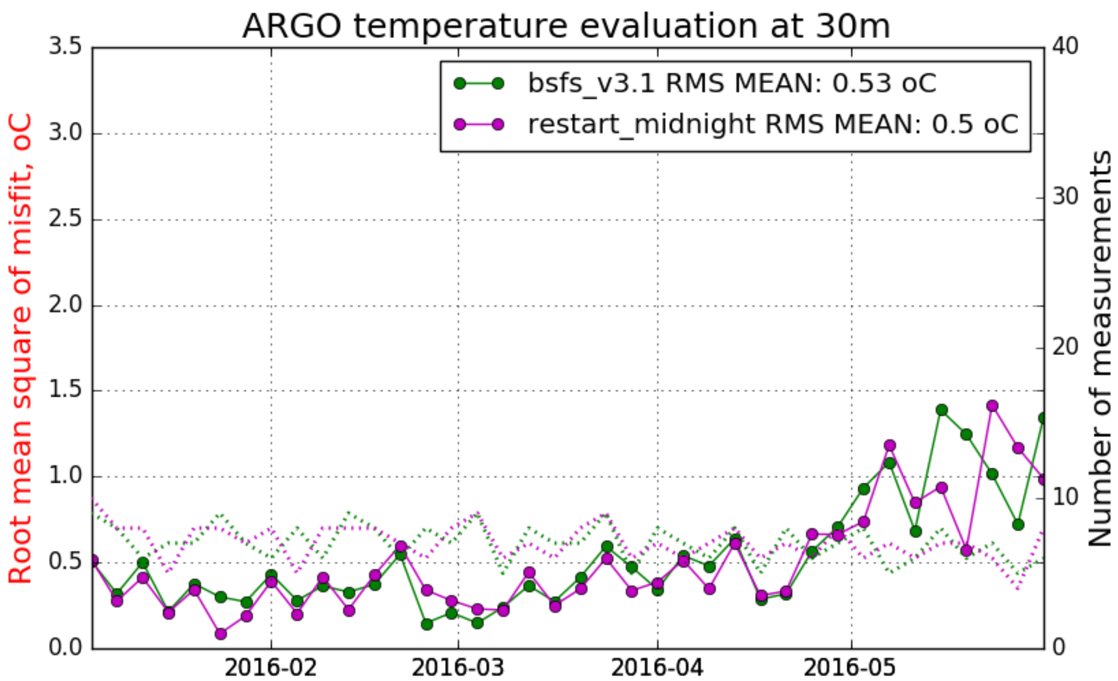

Figure VI.25Temperature RMS misfit at 30 m: current operational system BSFS_v3.1 (green), upgraded version (purple)

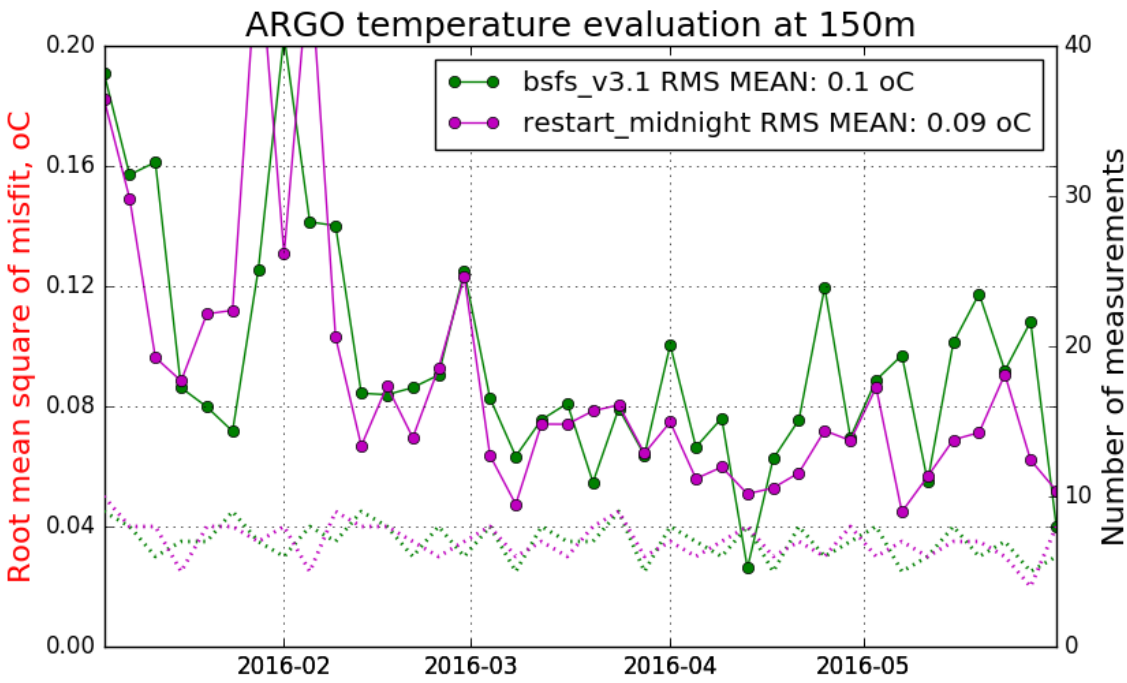

Figure VI.26Temperature RMS misfit at 150 m: current operational system BSFS_v3.1 (green), upgraded version (purple)

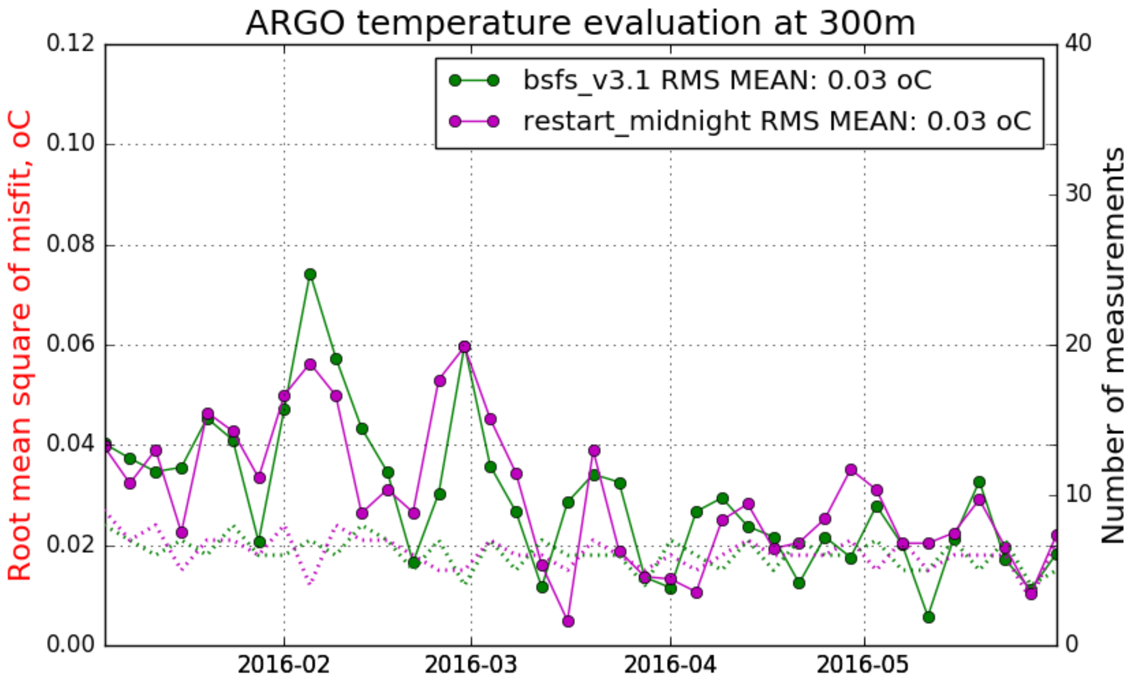

Figure VI.27Temperature RMS misfit at 300 m: current operational system BSFS_v3.1 (green), upgraded version (purple)

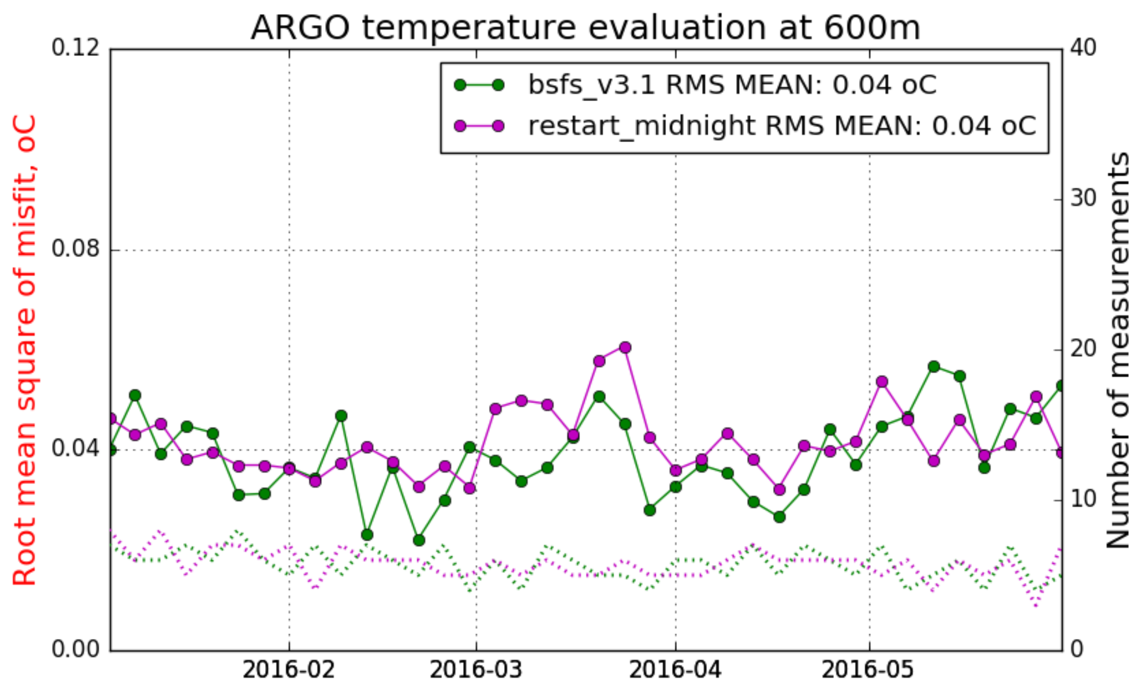

Figure VI.28Temperature RMS misfit at 600 m: current operational system BSFS_v3.1 (green), upgraded version (purple)

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