SST FROM POLAR ORBITER SATELLITES (METOP, NOAA AND NPP); NEW OSI-SAF PRODUCTS AND DEVELOPMENTS

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Abstract

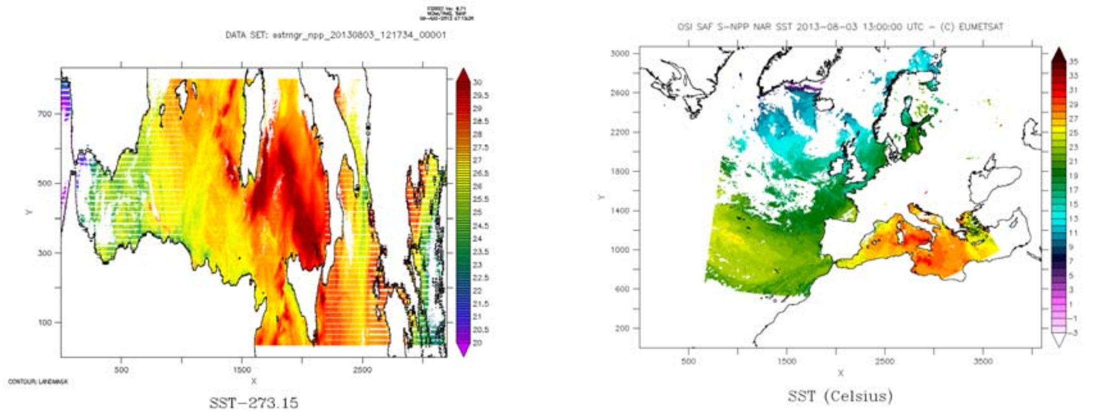
New instruments and new methods are being used by the EUMETSAT/Ocean and Sea Ice Satellite Application Facility (OSI-SAF) at Météo-France/Centre de Météorologie Spatiale (CMS) to produce Sea Surface Temperature (SST) products. Data of the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard Suomi National Polar-orbiting Partnership (NPP) have been acquired at CMS in Lannion (Brittany) in direct readout mode since April 2012. OSI-SAF has developed a new operational chain to process these radiometer data. On the other hand, the classical multispectral SST algorithms which have been used so far to process polar orbiter data show regional/seasonal biases, due to their inability to cope with the whole range of oceanic atmospheres. In consequence, OSI-SAF have developed a bias correction method based on using Numerical Weather Prediction (NWP) model profile derived brightness temperature simulations to better account for the actual state of the local atmosphere. This method, already operationally used for processing geostationary satellite data, has been tested on a METOP-A prototype for more than one year and will be adopted for the processing of METOP-B Advanced Very High Resolution (AVHRR) data.

INTRODUCTION

The Ocean and Sea Ice Satellite Application Facility (OSI-SAF) has produced global Sea Surface Temperature (SST) data derived from the METOP-A Advanced Very High Resolution Radiometer (AVHRR) since July 2007. These data have shown satisfactory validation results over these years (Marsouin et al, 2013) with a ± 0.1 K bias and error standard deviations lower than 0.6 K by day and 0.5 K by night when compared to buoy measurements. Two significant changes are impacting the OSI-SAF polar orbiter SST production chains. One is the use of new instruments: the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard Suomi National Polar-orbiting Partnership (NPP) is now operational and VIIRS data have been processed at Météo-France/ Centre de Météorologie Spatiale (CMS) since October 2012 to retrieve SST over the European Seas. The second change results from the adaptation to polar orbiter data of a bias correction method already used operationally at CMS to produce geostationary data derived SST. This text is organized as follows: the next section describes the VIIRS SST processing chain that have been developed at CMS and the validation results obtained after about 8 months of preoperational running. A third section presents the new METOP SST prototype and results of one year of processing. Concluding remarks are given in the last section.

OSI-SAF VIIRS SST PROCESSING CHAIN AND RESULTS

An operational processing chain to derive SST products from NPP/VIIRS data has been developed by EUMETSAT/OSI-SAF. These data have been acquired at CMS in Lannion (Brittany) in direct readout mode since April 2012. As far as NPP data processing is concerned, OSI-SAF is committed to produce the 2km polar stereographic North Atlantic Regional product (NAR, cf Figure 1), as a continuity to the present NOAA/AVHRR derived OSI-SAF NAR products.



(a) (b)

Figure 1. **Example of a VIIRS granule (a) and North Atlantic Regional (NAR) product coverage by NPP/VIIRS SST data (b)**

The CMS VIIRS processing chain is based on the experience gained over several years in processing METOP/AVHRR and geostationary data at CMS. It includes the following main steps:

- preprocessing: ingestion of the VIIRS L1C (L1B + cloud mask) data
- cloud mask control and quality level value determination
- SST calculations

***Preprocessing*:** This step delivers granules corresponding to a fixed time period of 86 seconds (figure 1a). Radiometric data are acquired at CMS in direct readout which induces a coverage limited to European seas (Figure 1b). The outputs of the acquisition station are converted into Raw Data Record (RDR) using the NASA Real-time Software Processing System (RT-STPS).The Community Satellite Processing Package (CSPP) is then used for data calibration and geo-location.
A cloud mask (MAIA) is derived from the radiometric data. MAIA is a threshold based cloud mask originally developed for the AVHRR and upgraded and adapted to VIIRS processing (Lavanant, 2012). Figures 1a and 2a illustrate the difficulties generated by the VIIRS specific scanning mode (Schueller, 2003): at swath edges, RDR data show missing data (white lines) and quasi-duplicated data. The capacities of the Common Adjacency Software have been extended to define pixel adjacency over several scan lines in order to produce images of adjacent pixels (figure 2b), which are essential, when calculating a gradient or defining a box for smoothing or validation.

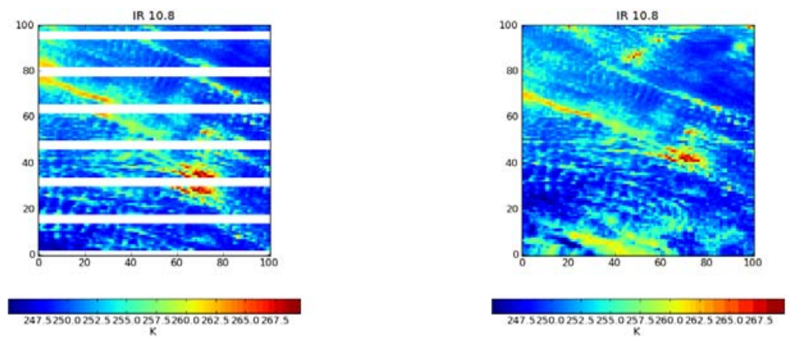


Figure 2: **Raw 11micron brightness temperature image (left); after adjacency algorithm is applied (right)**

A workfile including the radiometric data and creating all the further requested variables is built for this granule.

Cloud mask control*:* Similarly to what is done in the CMS AVHRR SST chain, a series of tests has been defined that consider various quantities such as the local values of gradient, temperature, probability of ice, Saharan dust. For each test, a test indicator has been defined by comparison of the tested quantity with a limit value and a critical value (see EUMETSAT, 2013). In this new chain, cloud mask control does not alter the original MAIA mask, whereas in the AVHRR chain, dubious pixels are masked during the cloud mask control step. This is conform to GHRSST recommendations and the same principle has been adopted in the CMS geostationary SST chain. As in the AVHRR chain, the synthesis of all the test indicators is used to reflect the quality of the mask. This synthetic mask indicator is used together with the satellite zenith angle in the definition of the quality levels. The quality of the retrieved SST increases as quality level increases on a scale from 2 to 5. **It is recommended not to use quality 2 level data for quantitative use.**

SST calculations: Based on Francois et al, 2002 and experiences gained with METOP/AVHRR or SEVIRI, the "NLC" algorithm (equation 1) and the "T37_1" algorithms (equation 2) have been selected for use by day and night, respectively.

NLC : $SST = (a + b\, S_\theta)\, T_{11} + (c + d\, S_\theta + e\, T_{CLI})\, (T_{11} - T_{12}) + f + g\, S_\theta$ (1)

T37_1 : $SST = (a + b\, S_\theta)\, T_{37} + (c + d\, S_\theta)\, (T_{11} - T_{12}) + e + f\, S_\theta$ (2)

$S_\theta = \sec(\theta) - 1$, θ is the satellite zenith angle and T_{CLI} is the mean climatologic SST.
a, b, ..., f are the algorithm coefficients determined by multilinear regression on the simulated brightness temperature databases, following Francois et al, 2002.
The coefficients of the noise resistant version of the algorithms are given in table 1.

	a	b	c	d	e	f	g
NLC	1.00055	0.00852	1.29073	0.77930	0.04010	1.05141	0.81520
T37_1	1.01612	0.01709	0.85154	0.36969	1.13960	0.82285	-

Table 1: **Coefficients of the non linear split window (NLC) and triple window (T37_1) algorithms for NPP/VIIRS, with all temperatures expressed in Celsius.**

NLC is applied for sun zenith angles below 90° and T37_1 for sun zenith angles above 110°. In twilight conditions, SST is calculated through a weighted mean of daytime and nighttime algorithms. A Saharan Dust Indicator (SDI, Merchant et al, 2006) derived correction term is calculated as a quadratic function of the SDI values. The same algorithms are applied to retrieve surface temperature over sea and lakes

Validation results: The operational validation of the OSI-SAF SST is based on the Matchup Data Base (MDB). This MDB is built with a 5 day delay to insure a good collection of the in situ data through the GTS. The reference VIIRS SST validation statistics are based on the exploitation of the MDB, as follows:

- Drifters only are considered
- Nighttime and daytime algorithms are considered separately

A blacklist of dubious buoys is used to eliminate erroneous measurements. In addition, cases where the absolute value of the difference between the insitu measurement and the climatology exceeds 5 K are eliminated
The statistics are calculated from the differences between the central pixel of the validation box (when clear) and the buoy measurement.
The validation results from 15 October 2012 till 31st of July (when the routine production of the SST products was in preoperational mode) are given in tables 2 and 3.

QL: 3-4-5		NPP	NOAA-19
Nighttime	nbc	**4584**	**3377**
	bias	**-0.04**	**-0.02**
	stdev	**0.39**	**0.43**
Daytime	nbc	**6806**	**7150**
	bias	**-0.14**	**-0.01**
	stdev	**0.48**	**0.53**

Table 2. OSI-SAF NPP and NOAA-19 SST validation statistics from 15 Oct. 2012 till 31st July 2013 by night and by day and for quality levels 3 to 5 (nbc is the number of cases)

QL		2	3	4	5
Nighttime	nbc	2213	1282	1193	**2109**
	bias	-1.07	-0.18	-0.02	**0.04**
	stdev	1.12	0.49	0.36	**0.28**
Daytime	nbc	2229	2527	1913	**2366**
	bias	-0.96	-0.22	-0.08	**-0.10**
	stdev	1.08	0.57	0.42	**0.37**

Table 3. **OSI-SAF VIIRS SST validation statistics from 15 Oct. 2012 till 31st July 2013 by night and by day for each quality level**

Table 2 gives the overall validation statistics for the period for NPP/VIIRS compared to NOAA-19/AVHRR. NPP results are better than that obtained with NOAA-19 over the same period. The NPP SST standard deviations by night and by day are below 0.4K and 0.5 K respectively. There is a slight daytime NPP negative bias (-0.14 K). The number of nighttime NPP cases is larger than that of NOAA-19, due to a more efficient nighttime cloud mask. By day, the coverage is slightly better for NOAA-19.

Results by quality levels are given in table 3: for quality 5 data, the standard deviation is lower than 0.3 K and 0. 4 K by night and day, respectively.

As soon as the chain is operational, routine validation statistics will be available through http://www.osi-saf.org. As shown in a detailed validation report (LeBorgne et al, 2013) the validation results are quite stable in time and space.

A METOP/AVHRR SST BIAS CORRECTION PROTOTYPE

OSI-SAF has been producing full resolution METOP-A /Advanced Very High Resolution Radiometer (AVHRR) derived Sea Surface Temperature (SST) data at a global scale since July 2007. SST fields have been produced in real time and validated routinely against drifter measurements. Two algorithms, one for nighttime and one for daytime conditions have been used with constant coefficients since 2007. Yearly global statistics obtained by comparison with drifter measurements are satisfying, with an absolute bias against drifters within 0.1 K and standard deviations better than 0.6 K by day and 0.5 K by night (Marsouin et al., 2013). Nevertheless, like any other multispectral algorithm derived SST, METOP/AVHRR SST data show regional biases (Merchant et al, 2009). The practical solutions adopted at present to correct for regional biases rely on using real time simulated Brightness Temperatures (BTs), either in Optimal Estimation (OE) methods or Bias Correction methods (Le Borgne et al., 2011; Petrenko et al., 2011). BTs are simulated in the adequate Infrared window channels by applying a Radiative Transfer Model (RTM) to Numerical Weather Prediction (NWP) atmospheric profiles, using a guess SST field (guessSST) as surface temperature. These simulations will be referred to as $simBT_i$ and the corresponding BTs, measured by the radiometer onboard the satellite as $obsBT_i$. Bias Correction or OE methods result in expressing the final SST as:

$$SST = guessSST + \sum a_i (obsBT_i - simBT_i) \qquad (1)$$

In the case of bias correction methods envisaged here, a correction to a classical multispectral algorithm is determined by applying the coefficients of this algorithm to simulations to produce a simulation derived SST. This “simulated” SST is compared to the “true” guess SST and the difference is used as a correction term to the operational SST derived with this algorithm. After addition of this correction term and reorganisation of the formulation, the final SST can be expressed in the form of equation (1), where a_i are the coefficients of the operational algorithm.

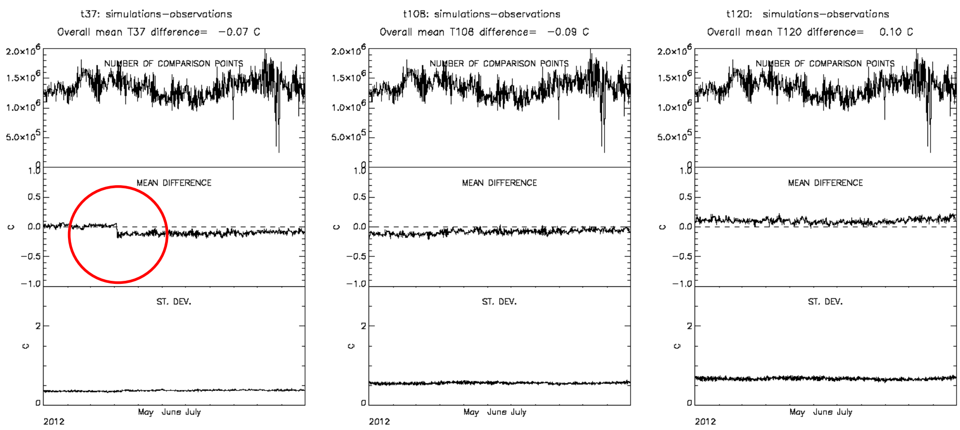
In the OSI-SAF chain, full resolution granules are delivered as operational products; they are also aggregated twice daily from 18:00 to 06:00 UTC (centered on 00:00 UTC) and from 06:00 to 18:00 UTC (centered on 12:00 UTC) and delivered on a global grid at 0.05° resolution (EUMETSAT, 2013). In this processing, METOP/AVHRR SSTs full resolution pixels allocated to a grid point are spatially averaged providing they have the same quality level. These gridded products are stored internally at CMS as “workfiles” with observed BTs and ECMWF outputs such as wind field and total water vapor content.

CMS has been running a prototype chain since November 2011 for testing the bias correction method applied operationally to SEVIRI data (Le Borgne et al., 2011) on METOP/AVHRR data. The prototype processing is based on using the workfiles described above. It is done in near-real time, to be as close as possible to operational conditions. This choice has several consequences:

— The prototype processing chain uses 3-hourly short lead-time atmospheric forecasts (6, 9, 12 and 15 hour forecasts) from ECMWF, initialized from the analyses at 0000 h and 1200 h UTC every day.
— ECWMF fields are gridded to L3C grid (0.05 deg)
— At each point of the 0.05° grid where a METOP SST value is present, the simulation is performed using the corresponding METOP/AVHRR satellite zenith angle and the closest in time ECMWF forecast, interpolated at grid point location.
— The Met Office operational analysis (OSTIA, Donlon et al, 2012) has been used as surface temperature field. To mimic operational conditions the OSTIA field used in the prototype is the one dated two days earlier than the METOP data being processed.
— The radiative transfer computations, based on RTTOV version 10.1, use a limited number of vertical levels from the model (15 levels at 1000, 950, 925, 900, 850, 800, 700, 600, 500, 400, 300, 250, 200, 150 and 100 hPa), due to limitations of the operational near-real time dissemination of ECMWF products to Météo-France.

Differences between simulated and observed BTs are routinely monitored at CMS. These differences are small on the average, and stable with time: Figure 3 shows the daily global comparison results for METOP/AVHRR over one year (the test year: December 2011 to November 2012). The step observed for METOP/AVHRR 3.7 μm simulations on the 2nd of April 2012 (red circle in Fig. 3) is due to a RTTOV version change (from 10.1 to 10.2). Simulation minus observation differences are not stable in space as shown by Figure 4a. Differences between observations and simulations are due to:

– Guess SST distinct from reality
– NWP profiles distinct from reality
– Cloud contaminated observations
– Inaccurate filter functions
– RTM errors
– Profile level sampling



(a) (b) (c)

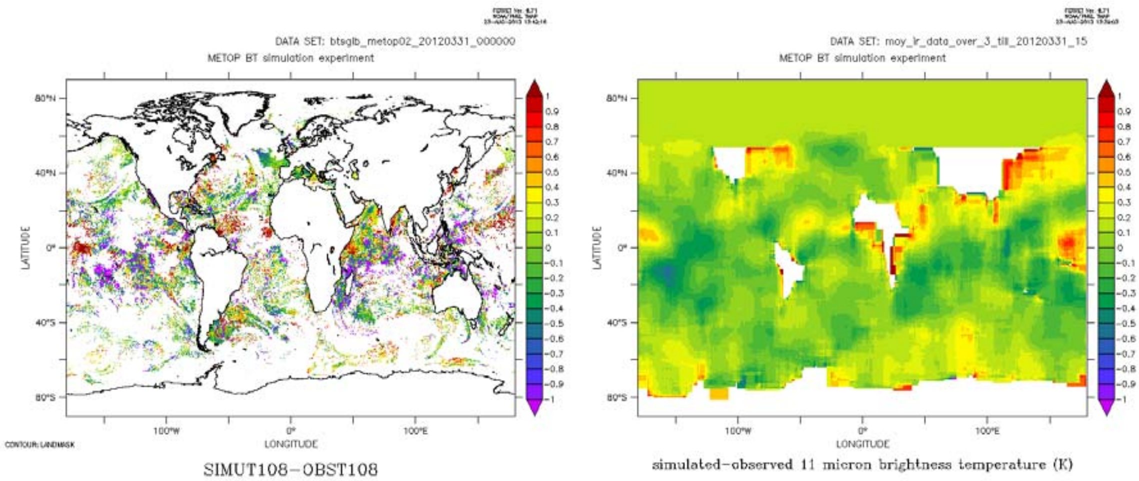
Figure 3: **Mean daily differences and standard deviation between simulated and observed METOP/AVHRR brightness temperatures, from December 1st 2011 till December 1st 2012, a) 3.7; b) 10.8 and c) 12.0 μm.**

Brightness temperature simulation adjustment: To be used in this bias correction scheme, simulated BTs must be free of errors : they should produce BTs equal to those that would be observed by the radiometer, given a surface temperature and an atmospheric profile. A simulation adjustment must be performed, based on comparing simulations and observations, providing:

1) there is not bias on the average between the Guess (OSTIA) and the true SST

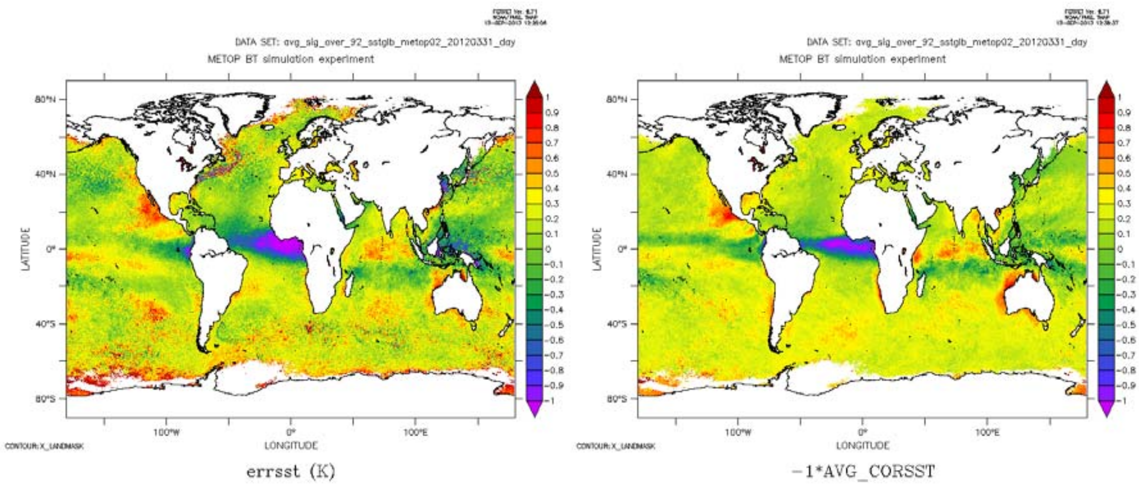
2) observations are cloudfree,
3) NWP profiles are not systematically biased.

As in the geostationary data processing case, adjustment values are derived from the geographical distribution of the errors averaged over space and time. The optimal temporal and spatial scales of this averaging (how many days, how many pixels) have been analyzed in Tomazic et al. 2013 and for the METOP/AVHRR prototype chain we adopted a time averaging of 3 days and a space averaging of 15 degrees. To build up BT adjustment fields, simulation - observation differences are filtered to fulfill the assumptions listed above. In the case of AVHRR, simulations are close to observations (Fig.3). Absolute simulation – observation differences larger than 1.5 K are filtered out and this threshold is reinforced to 0.5 K in high latitudes conditions, where cloud/ice contamination is frequent. To avoid diurnal warming, nighttime, or daytime data with wind speeds above 4 ms^{-1} are used. In permanent daylight conditions (such as summer Arctic), wind speed limit is reinforced to $10ms^{-1}$. In the Arctic, these drastic filtering conditions lead to very few data available and one unique adjustment value is used at latitudes above 60N (Fig. 4b).



(a) (b)

Figure 4: **a) Difference between simulated and observed METOP/AVHRR brightness temperatures at 10.8 μm on the 31st of March 2012; b) The corresponding 10.8 μm BT mean difference smoothed over the3 preceding days.**



(a) (b)

Figure 5: **a) Mean difference in the first quarter (Jan.-March) of 2012 between operational METOP-A daytime SST and OSTIA; b) The corresponding mean simulated multispectral algorithm error.**

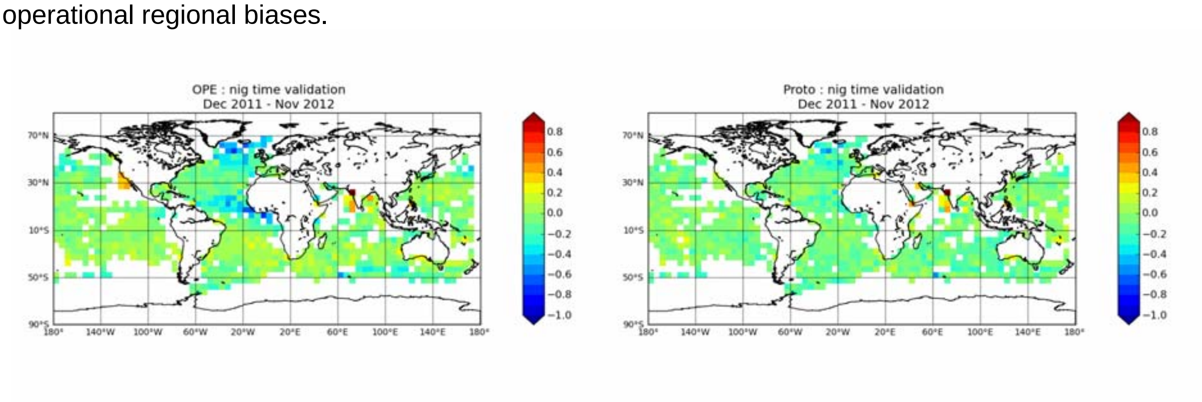
Bias correction: After adjustment of simulations, the multispectral equations are applied to the adjusted simulations to produce simulated SSTs, according to the (day or night) conditions. The difference between simulated SST and the guess SST used as surface temperature in the simulations represents the algorithm error, resulting from the local atmospheric conditions. This error is used as a correction term. Fig. 5 shows the mean difference between the operational METOP-A SST and OSTIA (Fig. 5a) and the mean simulated errors (Fig. 5b), which have been used in the prototype as correction terms. Errors are in general well predicted and the January to March observed daytime bias distribution is well reproduced by simulations.

Validation results: Table 4 shows the results obtained against drifting buoys from December 2011 till November 2012. The standard deviation of errors is significantly reduced and at night, global standard deviations have reached the 0.3 K level for quality 5 data.

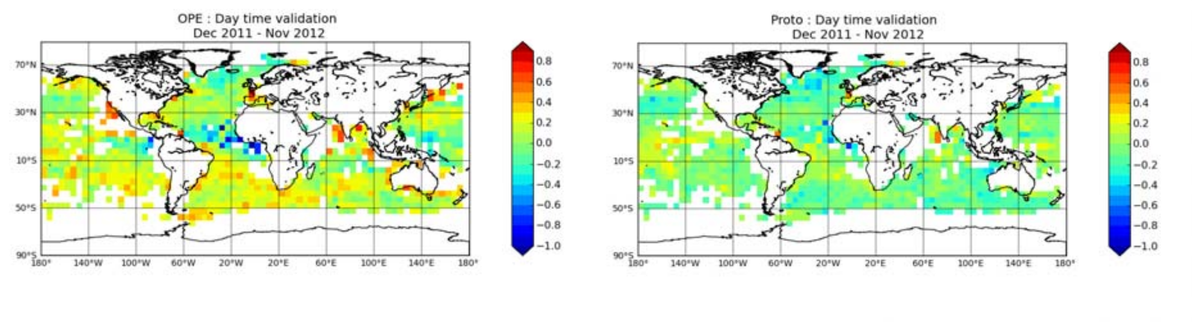
		Ope qual 3-5	Proto+cor qual 3-5	Ope qual 5	Proto +cor qual 5
DAY	n	123579	123579	55386	55386
	δ	0.11	-0.05	0.11	-0.06
	σ	0.51	0.46	0.45	0.42
NIGHT	n	94618	94618	42078	42078
	δ	-0.05	-0.07	-0.07	-0.08
	σ	0.34	0.33	0.31	0.30

Table 4: **Operational and bias corrected global validation statistics from December 2011 till November 2012**

As shown in Figure 6, the bias correction method has suppressed, or significantly reduced the operational regional biases.



(a) (b)



(c) (d)

Figure 6: **Mean Bias distribution in 5° boxes for the test year; left panel: operational bias map; right panel: bias after correction. Top panel, nighttime, bottom panel: daytime.**

CONCLUSIONS

VIIRS derived SST are now operationally produced over the European Seas by the OSI-SAF, and validation results (standard deviations below 0.5K by day and below 0.4K by night) are better than those obtained with NOAA-19 in the same conditions. Bias correction methods based on using NWP profiles have been adapted to METOP global processing. A METOP-A prototype has been run for one year and most regional biases are corrected by the new method. Validation statistics are improved. The nighttime global results obtained after bias correction for quality 5 data are now at the 0.3K standard deviation level, which corresponds to the most demanding users' requirements. This method will be applied in a new SST processing chain which will be developed for METOP-B data and which is due to start in 2014.

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