OPERATIONAL SST RETRIEVAL FROM METOP/AVHRR

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Abstract

The new EUMETSAT Polar Orbiter, METOP, carries an Advanced Very High Resolution Radiometer (AVHRR) that enables the retrieval of Sea Surface Temperature (SST) over the world ocean. The Ocean and Sea Ice Satellite Application Facility (OSI SAF) of EUMETSAT has developed an operational processing chain aiming to produce METOP derived SST fields globally in near real time (within a few hours after data acquisition onboard the satellite). The retrieval algorithms, based on multispectral methods, have been defined by using simulated brightness temperatures calculated by applying a Radiative Transfer Model (RTM) on an oceanic atmospheric profile database. These algorithms are applied on clear sky pixels as defined by the MAIA cloud mask. Complementary tests are made to check the quality of the masking procedure. The operational chain produces a series of indicators synthesized into a confidence level which is delivered with each SST value. SST data are delivered in satellite projection at full resolution, and as 12 hourly synthetic fields remapped onto a regular world grid at 0.05 degree resolution. The format of the delivered product will be fully compliant with the international standard recommended by the GODAE High Resolution Sea Surface Temperature (GHRSST) pilot project.
METOP derived SST are validated by comparison with other satellite derived SSTs and by comparison with in situ buoy measurements.

1. INTRODUCTION

The Centre de Météorologie Spatiale (CMS) of Météo-France has developed an operational processing chain to derive SST fields from the METOP Advanced Very High Resolution Radiometer (AVHRR) data. This work has been done in the frame of the Ocean and Sea Ice Satellite Application Facility (OSI SAF) of EUMETSAT. The OSI SAF is committed to produce:

- full resolution SST in satellite projection, corresponding to each granule of AVHRR data disseminated through EUMETCAST
- 12 hourly synthesis on a 0.05° global grid
- the 2km stereopolar NAR product, as a continuity to the present NOAA/AVHRR derived OSI SAF products.

These products will be referred to as MGR, GLB and NAR in this text, respectively.
It is the first time that SST is retrieved at the full AVHRR resolution over the globe. It is also the first time that the OSI SAF produces a global SST product. This required the development of a new processing chain in conditions of high data volume handling, processing and dissemination. This new chain also includes the use of fine scale global temperature and front climatologies. An attempt has been made to account for and, when possible, correct for dust aerosols.
This paper describes the processing chain that has been developed at CMS. It then shows a few examples of the products. It finally presents and comments the preliminary validation results.

2. PROCESSING CHAIN

Overview

The CMS processing chain includes the following main steps (see figure 1):

- preprocessing: ingestion of the AVHRR L1C (L1B + cloud mask) data
- cloud mask control
- SST calculations
- proximity confidence value determination,

that will be detailed in the next section.

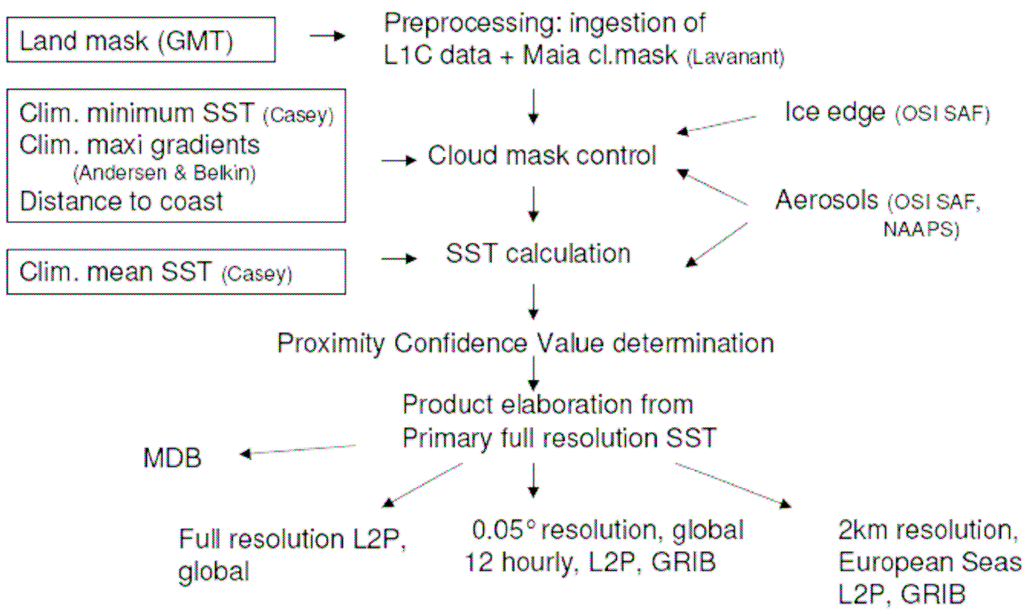

Figure 1: **Schematic diagram of the operational METOP SST chain**

This chain uses a set of static data which are briefly reviewed here below:

Land masks: Three landmasks are needed, corresponding to the resolutions used in the processing: 0.01° (MGR), 0.02° (NAR) and 0.05° (GLB). They have been derived from the Generic Mapping Tools (GMT) full dataset with a restriction of the original GMT codes to "ocean", "lake" and "land". Lakes covering less than 10000 km^2 have been filtered out (coded as land) except over an European area defined by 30N-80N, 20W-50E where the minimum value is reduced to 500 km^2. It is envisaged to homogenize the lake definition over the Globe.

SST climatology: Mean and minimum climatological SST values are used in the SST calculations and the cloud mask control. We have used the mean and minimum 5 day SST climatologies, at about 0.04° resolution, derived by Ken Casey from the "pathfinder" SST archive following the method developed by Casey and Cornillon, 1999.

Front climatology: A climatology of fronts has been derived from the University of Rhodes Island (URI) data base by Andersen and Belkin, 2006. For internal use at CMS, the monthly maximum front intensities have been converted in K/5km units (currently used at CMS), at the original pathfinder resolution (0.04°).

Main processing steps

<u>Preprocessing</u>: This task delivers a "metagranule" that corresponds to a fixed time period (3 minutes). The SST processing chain ingests the original granules in AVH1C format which corresponds to the usual AVH1B to which the MAIA cloud mask has been added. MAIA is a threshold based cloud mask described in Lavanant, 2007 and includes a clear/cloudy flag and quality information at the pixel level. A workfile including the AVHL1C data and creating all the further requested variables is built for this metagranule.

<u>*Cloud mask control*</u>*:* A series of tests has been defined that consider various quantities such as the local values of gradient, temperature, probability of ice, etc.. For each test, a test indicator has been defined by comparison of the tested quantity (test_value) with a limit value (limit_value) and a critical value (critical_value). Outside this range of values either there is no problem, or the risk of errors is too high. The test indicator is defined as:

test_indicator= 100 x (test_value-limit_value)/ (critical_value – limit_value) (1) indicator values below 0, or above 100 are assigned to 0 and 100, respectively. This approach enables the homogenisation of the test results on a unique scale: 0: no problem;]0-100[: potential problem; 100: critical problem.

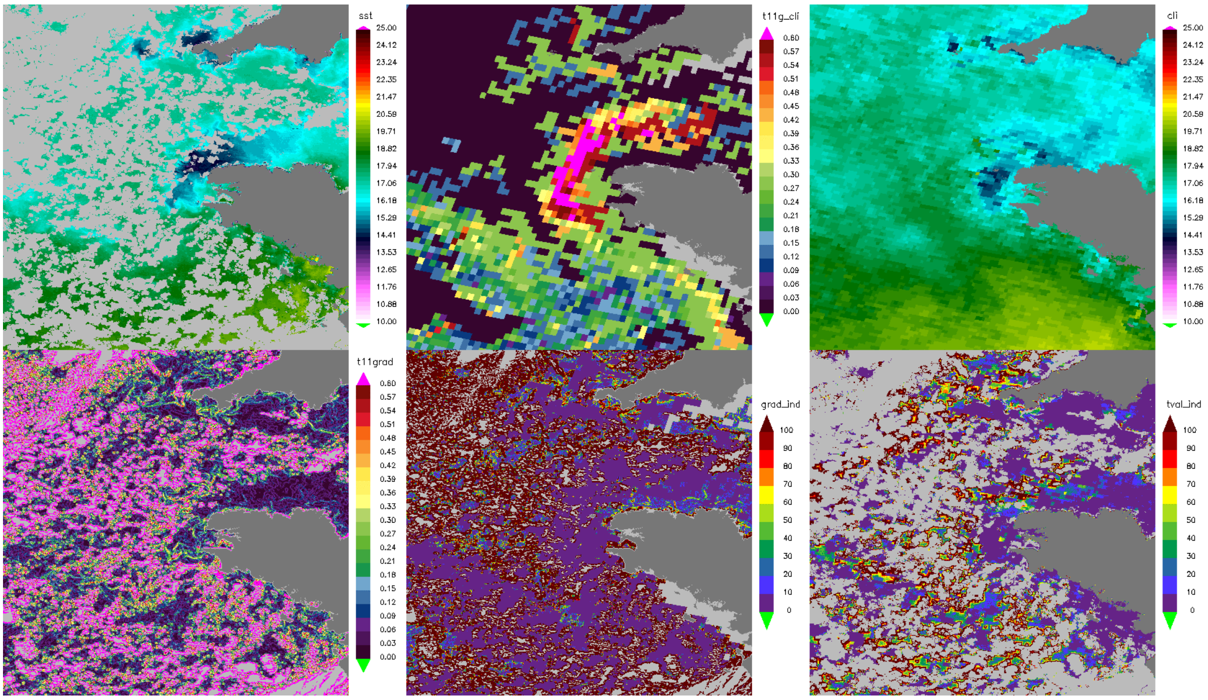

***Figure 2*: Subset of a metagranule over Brittany on the 5 August 2007 at 2116UTC:**
Top: SST, T11 gradient climatology, temperature climatology
Bottom: T11 gradient, gradient indicator, temperature value indicator

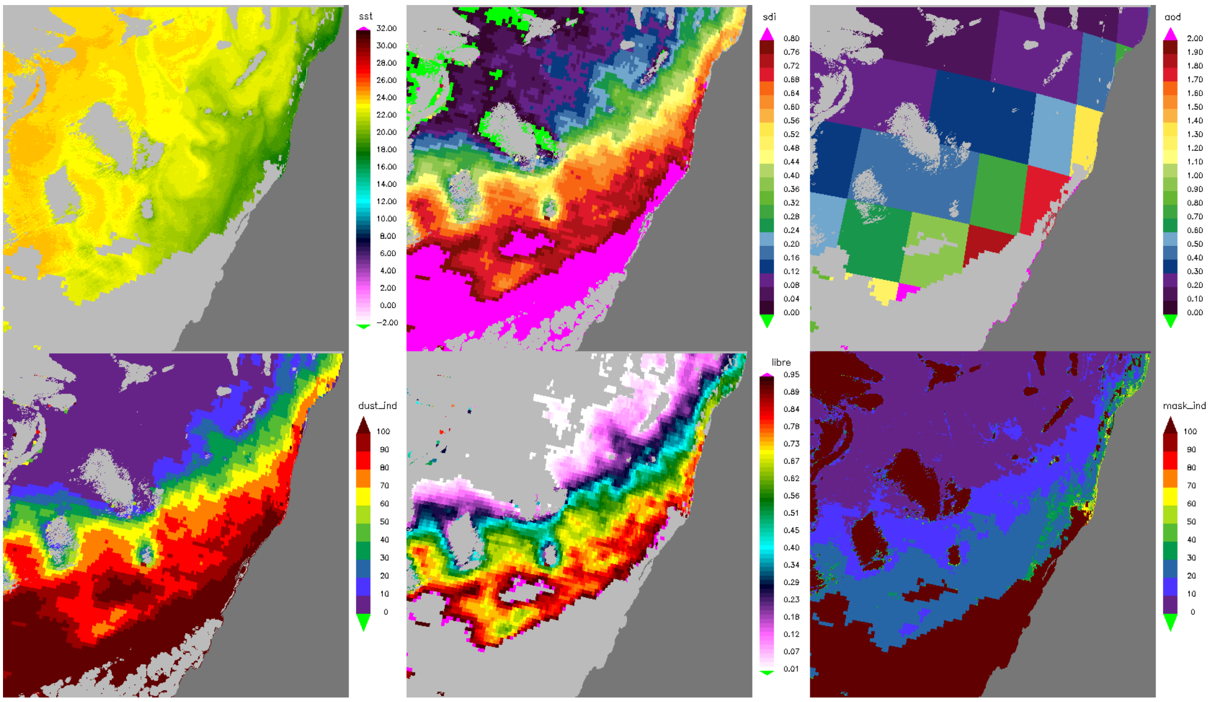

***Figure 3*: Subset of a metagranule off Mauritania on the 6 August 2007 at 2249UTC:**
Top: SST, SEVIRI Saharan Dust Index, NAAPS Aerosol Optical Depth
Bottom: Dust indicator, SDI correction, mask indicator

The mask_indicator is initialized (0 = clear, 100 = cloudy) from the MAIA flag values. After initialisation, the value of mask_indicator is monitored for each clear water pixel (sea or lake). If a test results in a critical problem identification (test_indicator =100), the mask_indicator takes also the critical value, the SST will take the missing value and the pixel will not be further considered. Hence the order of the tests matters. They are presented here below with the adopted hierarchy.

- Primary cloud mask indicator: derived from the MAIA quality information available.
- Gradient indicator: derived from the difference between the local 11 micron brightness temperatures gradients and the corresponding maximum climatological values calculated from the world Atlas of thermal fronts (see figure 2). The limit value of this quantity corresponds to the T11 noise equivalent gradient value. The critical value is a plausible margin which is reduced in the vicinity of cloud, so that for a pixel close to a cloud the critical value is more easily reached than far from clouds. The gradient indicator is calculated from the limit and critical values according to equation (1). In the present version, the gradient indicator is calculated by night only, because the use of visible channel allows in principle an efficient masking of the cloud edges and because diurnal warming may introduce local fronts that are not recorded in the climatology.
- Stratospheric aerosol indicator: in case of need, this indicator will record the intensity of Pinatubo like stratospheric aerosol phenomena. It will be calculated according to (1), where the test value is the aerosol optical depth.
- Saharan dust indicator: it is based on the use of the SEVIRI derived Saharan Dust Index (SDI, see Merchant *et al.,* 2006) or the NAAPS Aerosols Optical Depth (AOD, see US NAVY, 2003) where the SEVIRI information is not available. Both information are in general consistent (figure 3).
- Local temperature value indicator: the calculated SST is compared to limit and critical values of the temperature deduced from the Casey world SST climatology (see above), by adding margins to the local value of the minimum SST climatology. These margins are function of the interannual standard deviation of the temperatures, of the distance to cloudiness and of the distance to coast (see figure 2).
- Ice indicator: derived from the probability of ice calculated by applying the met.no (Eastwood and Andersen, 2006) ice probability method, based on the use of the local value of the IR and visible AVHRR channels north (resp. south) of 50°N (resp. 50°S) .

A synthesis of all the test indicators is made as the mean of all the meaningful test indicators. If an indicator is missing it is given a value =100 in the synthesis calculation. This synthesis is used, ultimately, to reflect the quality of the mask (see PCV determination below).

SST calculation

Two SST calculations are made: one in the context of cloud mask control, using the pixel values, and the final calculation using a smoothed atmospheric correction term over reliable data.
There are many formalisms usable to derive SST from the AVHRR IR brightness temperatures. Based on previous experiences with GOES-East (Brisson *et al.,* 2002) and SEVIRI (Le Borgne *et al.,* 2006), the following algorithms have been selected:

NL : $SST = a\,T_{11} + (b\,T_{CLI} + c\,S_\theta)\,(T_{11} - T_{12}) + d\,S_\theta + e$, for daytime, and
T37_1 : $SST = (a + b\,S_\theta)\,T_{37} + (c + d\,S_\theta)\,(T_{11} - T_{12}) + e\,S_\theta + f$, for nightime application
$S_\theta = \sec(\theta) - 1$, θ is the satellite zenith angle and T_{CLI} is the mean climatological value.

In twilight conditions, SST is calculated through a weighted mean of daytime and nightime algorithms.
The coefficients of the algorithms have been derived on a simulated brightness temperatures data base (see Francois *et al.,* 2002). The initial version of the coefficients are given in table 1. A SDI correction term is calculated as a quadratic function of the SDI values (Merchant *et al.,* 2006), for $0.1<SDI<0.8$ (see figure3). This correction depends on the algorithm used. No corrections are made when there is no SEVIRI observations. In these conditions there is a residual aerosol error that will be corrected, or flagged, in the future, using the NAAPS AOD (see also comments on the validation results).
At present the same algorithms are applied to retrieve surface temperature over sea and lakes.

	a	b	c	d	e	f
NL	0.99052	0.06641	1.16321	0.16400	1.49512	-
T37_1	1.01867	0.02109	0.68858	0.33056	1.27303	1.15351

Table 1: **Coefficients of the non linear split window (NL) and triple window (T37_1) algorithms for METOP-A, with all temperatures expressed in Celsius.**

Proximity confidence value (PCV) determination

PCV are dedicated on one hand to give the user a simple mean of filtering the data and on the other hand to partition the MDB in view of deriving the sensor specific error statistics (SSES) which are delivered for every SST calculation in the L2P/L3P format. It is essential here to adopt a method similar to or compatible with those of our partners in the GHRSST-PP project. For IR derived products, the normalised PCV scale shows 6 values : 0 : unprocessed, 1 : cloudy , 2: bad, 3: suspect, 4: acceptable, 5 : excellent.
To calculate the PCVs, a representation of the risk factors on two axis has been adopted, one representing the cloud mask problem, the other the algorithm known risk of errors, on a scale from 0 (no risk) to 100 (critical risk), see figure 4.

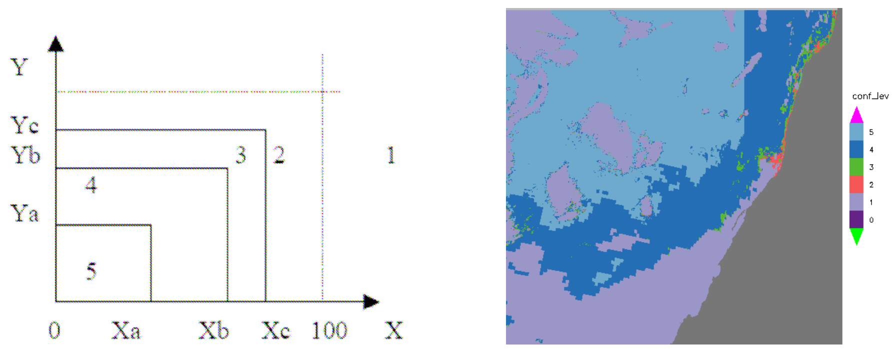

Figure 4. **Left: Schematic representation of the PCV attribution as a function of risks represented on a 2 axis system; right: example of PCV distribution corresponding to the case of figure 3.**

In practice the first axis (X) is the mask_indicator and the second (Y) is derived from the satellite zenith angle. The initial values (that will likely evolve) are the following: Xa= 20, Xb=35 and Xc=50; Ya, Yb, Yc correspond to satellite zenith angle values of 50, 60 and 70 degrees. Yc is off the limit of the AVHRR so practically no "bad" label is derived from the satellite zenith angle value.

3. PRODUCT DESCRIPTION

At the end of the processing a workfile in netcdf is filled up for each metagranule and contains:

- location and illumination conditions
- reflectances and brightness temperatures
- MAIA original information
- static data (landmask, climatology values,..)
- dynamic data (SEVIRI SDI, NAAPS AOD,..)
- intermediate calculation values (gradients, indicators..)
- final results (SST, missing reasons, PCV,..)

These workfiles are produced and archived at CMS for validation, control and further use. All the final products are derived from these workfiles.

The SST metagranules are sent to IFREMER in L2P format for further usages. Note that the processing time from the ingestion to the delivery in L2P format is about 1 minute for a 3 minute granule.

The global 0.05° resolution products (figure 5) are 12 hourly synthesis centred at 0000 and 1200 UTC. They are built progressively (when a new metagranule is ready to contribute) as follows:

- the metagranule pixel variables corresponding to one global grid point are averaged after selection of the best PCV
- the resulting values are candidate for the global file, but may compete with values already in place (originating from a previous metagranule). In such a case the selection is made according to the following criteria (with this priority order):
    - best PCV
    - nighttime cases have priority
    - lowest satellite zenith angle.

The NAR 2 km resolution products (figure 6) are made twice a day over the European waters. The same rules as those adopted for the global product are applied in this case. Prior to entering the contribution scheme, the metagranules are filtered according to their time: they must be dated to within ΔT from the NAR nominal times (e.g. 1000 UTC and 2000 UTC). At present ΔT=4.5h.

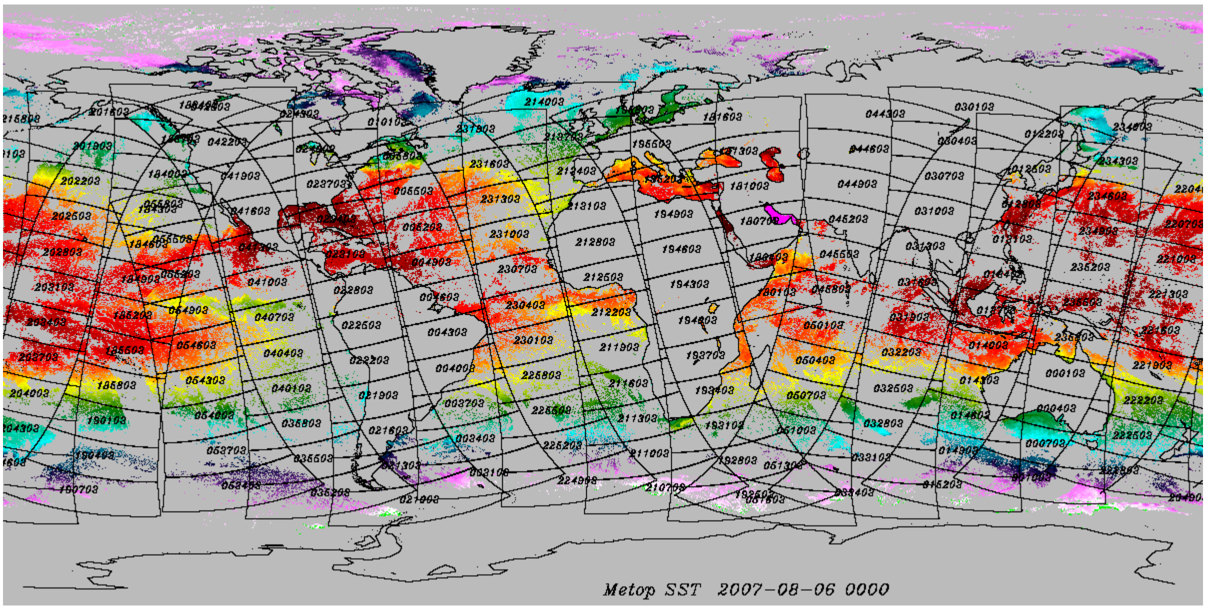

Figure 5**: 0.05° resolution global product on the 6th of August, showing the contributing metagranules superimposed**

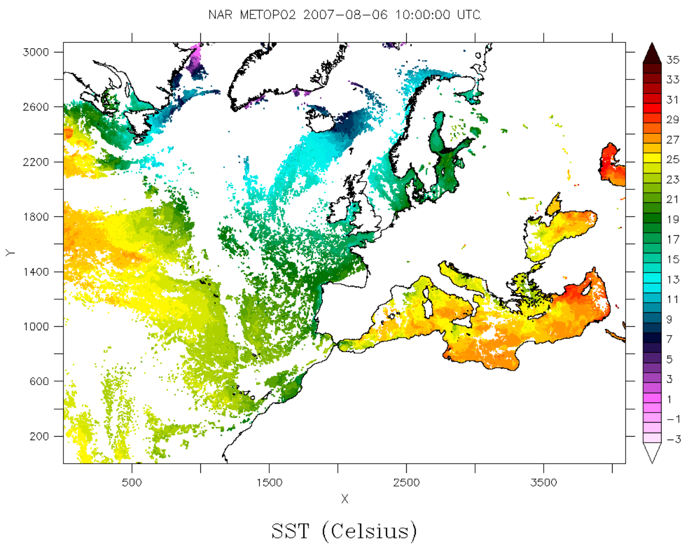

Figure 6**: 2 km resolution NAR product**

The NAR and GBL products will be available in L3P netcdf format through IFREMER and GRIB ed.2 disseminated through EUMETCAST (accounted for in the table 2 timeliness definition). L2P or L3P are the netcdf format recommended by the GODAE High Resolution Sea Surface Temperature Pilot Project (GHRSST-PP), see Donlon, 2005. L2P and L3P are identical, “2” refer to products in satellite projection and “3” to gridded products. Timeliness in table 2 is defined as the delay between acquisition on the platform and the final availability to all users.
To fulfil the timeliness requirements, data are provided first in a “core” version (limited content) then in the full version of the L2P/L3P format.

Name	Coverage	Resolution	Time characteristics	Format	Timeliness	Volume per unit : L2(3)P core
MGR	Global	Full res. (1 km)	Every granule	L2P	4h	38 MB
NAR	European Seas	2 km	Twice a day	L3P, GRIB2	4h	217 MB
GLB	Global	0.05°	12 hourly	L3P, GRIB2	6h	248 MB

Table 2: **Characteristics of the OSI SAF METOP derived SST products**

4. VALIDATION

The validation of the METOP SST is done i) by using the operational Matchup Data Base (MDB), ii) by intercomparison with other sensors
The MDB collects in situ SST measurements from ship, moored or drifting buoys, available through the Global Telecommunication System (GTS) and the coincident full resolution satellite information, within 3 hours from the in situ measurement. The satellite information is extracted in a 21x21 pixel box centred on the measurement location providing the coverage of the box by clear pixels is larger than 10%. The MDB includes the in situ measurements (platform ID +SST + auxiliary measures) and all the variables of the workfile.
The MDB is built with a 4 day delay to insure a good collection of the in situ data through the GTS.

The reference validation statistics are based on the exploitation of the MDB, as follows:
- Drifters only are considered
- Nighttime and daytime algorithms are considered separately
- To eliminate erroneous measurements, 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 presented in this paragraph correspond the two first months of routine delivery of the SST products in test mode, which started on the 11th of July 2007.

Operational statistics display a map of the observed errors (figure 7), as well as the distribution of errors as a function of the main parameters conditioning the SST calculations (figure 8). Those parameters are (from left to right and from top to bottom on figure 8): In situ SST, secant of the satellite zenith angle, latitude and longitude, PCV (confidence level), coverage of the validation box by clear pixels, mask indicator and time.
For nighttime cases, figure 8 (left) shows limited variations of the bias with either the temperature, the satellite zenith angle, the latitude or the longitude. The results are also stable in time. As expected, there is a clear dependency of the error characteristics with the mask indicator and consequently with the PCV. The clearer the validation box, the better the results, which illustrates the influence of the vicinity of clouds.
For daytime cases, the most striking features in figure 8 (right) is the negative bias for temperature above 30 Celsius or latitudes between 10 and 20 N. Detailed investigations (figure 7) allowed to identify the Northern Indian Ocean as the problematic area and showed a clear dependency of the errors as a function of the Aerosol Optical Depth (AOD) for temperature over 30℃. This is due to the fact that no correction for dust effect is attempted out of the SEVIRI disk. Using the AOD to filter out the contaminated data is a possible solution to this problem.

		All cases	2 (“bad”)	3 (“suspect”)	4 (“acceptable”)	5 (“excellent”)
Nighttime	n	33045	436	6464	12991	13154
	δ	-0.03	-0.68	-0.15	-0.05	0.07
	σ	0.48	0.88	0.62	0.48	0.33
Daytime	n	53971	472	7395	13683	32421
	δ	0.05	-0.65	-0.02	-0.02	0.10
	σ	0.61	1.24	0.74	0.68	0.51

***Table 3*: Validation results (number of cases, mean and standard deviation of the satellite estimate minus buoy measurement in K) as a function of the confidence levels for the period: 11 July to 31 August 2007**

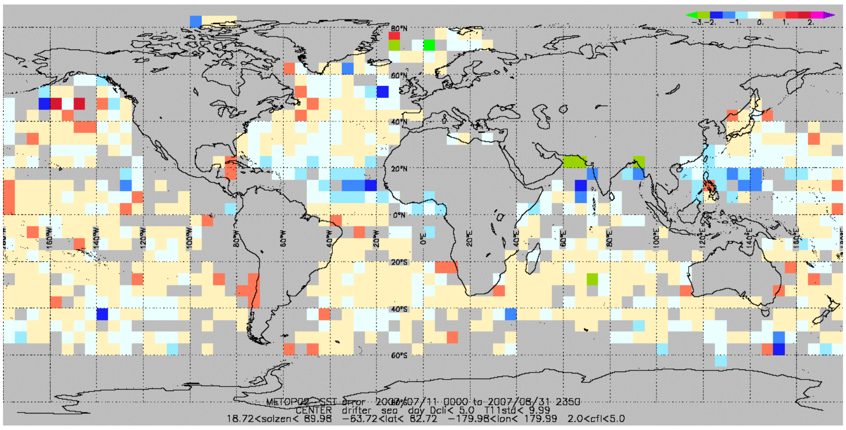

***Figure 7*: Map of errors (satellite estimates – in situ measurements), in 5° cells, of the daytime algorithm during the period: 11 July to 31 August 2007.**

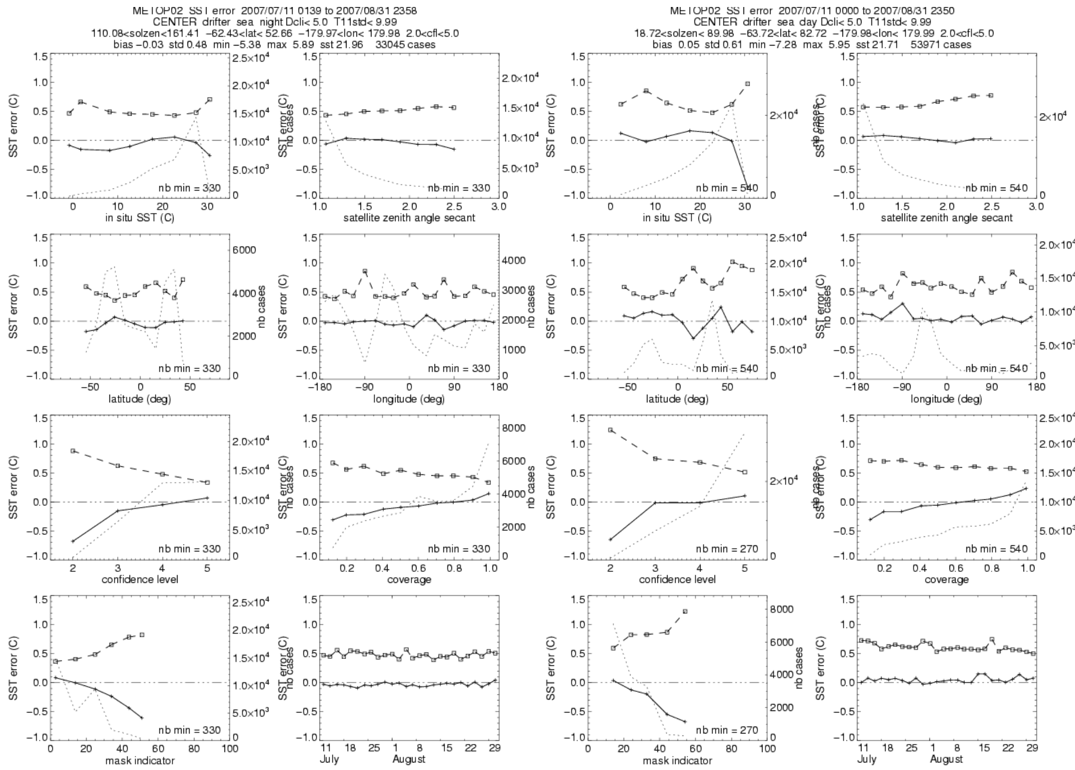

***Figure 8:* Distribution of nighttime error (left) and daytime error (right) with the main parameters conditioning the SST calculations for the period: 11 July to 31 August 2007.**

The METOP GBL SST is compared to a daily synthesis of (mostly) nighttime SST data from various sources (AATSR, SEVIRI, NOAA/AVHRR,..) over the Atlantic (figure 9 left). Statistics are then produced for each sensor used in the intercomparison. The results obtained against the AATSR, which is considered as the reference SST sensor, are particularly informative: figure 9 right shows the daily results of the nighttime METOP data, compared to the nighttime AATSR data.

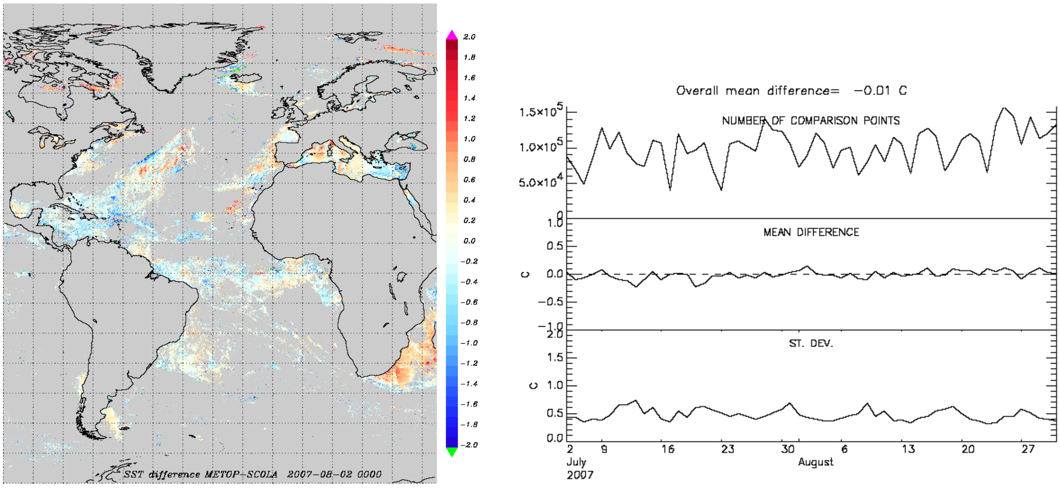

***Figure 9*: left: difference between the 0000 UTC METOP GBL field on 2 August 2007 and the nighttime synthesis of all SST sources over the Atlantic. Right: daily statistics of the differences between nighttime METOP and AATSR derived SST.**

In the frame of the test period (summer 2007), the Met Office has started to ingest the METOP granules in their OSTIA fine scale SST analysis, at the validation level (without inclusion into the analysis). Figure 10 illustrates the first results of the daily comparison of nighttime METOP SST with the fine scale analysis. They show a non significant bias on the global scale and rather limited regional biases.
See more details on: http://ghrsst-pp.metoffice.com/pages/latest_analysis/sst_monitor/monitor_op/index.html

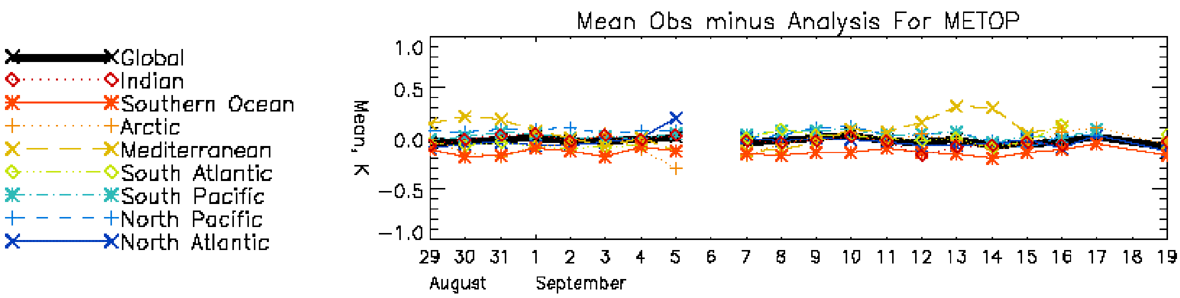

***Figure 10*: First validation results of METOP SST against the Met Office OSTIA fine scale analysis**

The validation results lead to the following remarks:

- They have been collected during the primary test phase of the METOP SST routine production. These phase is in particular dedicated to check and adapt the thresholds of the cloud mask control and the rule in this case is to start with relaxed thresholds to be able to observe the error behaviour. This indulgent cloud control may impact negatively on the validation statistics
- Nighttime results are quite satisfying with a standard deviation for all cases below 0.5K (table 3). They are confirmed by the routine comparison with AATSR data.
- Daytime results show regional biases, mainly for temperatures over 30 °C in the Northern Indian Ocean (residual aerosols and/or very high water vapour content). Biases apparent in the artic region are unstable and too rare to be commented. These biases may be partly induced by residual clouds or aerosols, and partly inherent to the split window technique limitations. Both problems are under investigation (see Merchant *et al.*, 2007).
- The mask indicator or the confidence values are good predictors of the errors, as expected; it is recommended not to use the confidence level 2 data for quantitative use.

5. CONCLUSION

The OSI SAF METOP SST chain is now implemented and L2P/L3P core products are routinely delivered to IFREMER in a test mode. The preoperational mode should start before the end of 2007. The preliminary validation results show the expected performances: the standard deviation of the errors for the first test months are 0.48 K for the nighttime algorithm and 0.61 K for the daytime

algorithm when all cases are considered, and respectively 0.33 K and 0.51 K for the "excellent " cases.
Concerning the processing techniques, the next development efforts will bear on tightening up the cloud mask control, for instance with an adapted use of the NAAPS AOD and improve the algorithm performances, in particular in daytime conditions. A first study has been launched to test the use of Numerical Weather Prediction (NWP) models outputs in view of optimizing the use of the AVHRR channels and gives encouraging results (Merchant *et al.*, 2007).
The comparison of the METOP SST with the SST of various origins will be extended over the world ocean.
This chain will soon replace the NOAA/ AVHRR SST chains at CMS, and will be used as a reference to upgrade the OSI SAF geostationary SST chains, in particular for what concerns the cloud mask control and the algorithm definition.

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