VALIDATION OF THE OSI SAF RADIATIVE FLUXES

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Abstract

The Ocean and Sea Ice Satellite Application Facility (OSI SAF) has been producing operationally the surface radiative fluxes, Surface Solar Irradiance (SSI) and Downward Longwave Irradiance (DLI), since July 2004. The validation results over a 28 month period (against in situ measurements, through GOES/MSG and NOAA/MSG comparisons) are presented and analyzed. The SSI and DLI r.m.s. errors differ significantly at hourly resolution, about 70 Wm^{-2} and 20 Wm^{-2} respectively, and are nearly the same, 15 Wm^{-2} at daily resolution. The PIRATA buoy pyranometer data appear questionable compared to those of the other stations. The GOES and MSG results are fully consistent, while the NOAA and MSG results show high values of the r.m.s. difference.

1. INTRODUCTION

The EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF) has been producing the surface radiative fluxes, Surface Solar Irradiance (SSI) and Downward Longwave Irradiance (DLI), through the combined use of GOES-12, MSG-1 (METEOSAT-8) and NOAA-17 satellites. The products cover the area 100W – 45E – 90N – 60S, on a regular grid at 0.1-degree resolution in latitude and longitude. The Centre de Météorologie Spatiale (CMS) process hourly GOES and MSG data from 60S to 60N to produce 3-hourly and daily fields, the daily field being merged with the daily field derived from NOAA data by the Norwegian Meteorological Institute (Met.no). More information can be found on http://www.osi-saf.org .

The OSI SAF operational scheme includes a validation against in situ measurements within a one month delay and inter-satellite comparisons, GOES/MSG and NOAA/MSG, in overlapping areas. This paper summarizes briefly the algorithms and describes the validation results from January 2004 to April 2006.

2. METHOD

The SSI and DLI are the irradiances reaching the Earth surface in the 0.3-4 µm and 4-100 µm bands, respectively, the irradiance being the radiant flux received per unit area. They are instantaneous values, which are derived from near instantaneous satellite images.

The SSI algorithm has been presented in Brisson et al., 1999 and is fully described in the SSI Product Manual, available on the OSI SAF web server. It can be summarized as follows:

- calibration of the satellite visible count into a bi-directional reflectance,
- conversion from the narrow band of the radiometer spectral filter to the broadband of the solar spectrum,
- anisotropy correction, i.e. conversion from the broadband bi-directional reflectance to the top of atmoshere (TOA) albedo, independent of the satellite viewing angles,

- physical parameterization of the SSI as function of the TOA albedo, the atmospheric transmittance (out of cloud) and the surface albedo. The atmospheric transmittance is obtained by analytical formulas depending on the viewing angles and on several climatologic or predicted atmospheric parameters. The surface albedo is calculated theoretically over sea and derived from an atlas, over land. Finally, the SSI is derived from the TOA albedo.

The calibration and narrow to broadband correction have been carefully revisited in 2005 and the algorithm coefficients have been updated on 8 March 2005. MSG-1 is calibrated according to the EUMETSAT operational coefficients and its narrow to broadband correction is based on the well-calibrated broadband radiometer CERES (Clouds and Earth's Radiant Energy System). GOES-12 is inter-calibrated against MSG-1 at 37.5W, following the method described in Le Borgne et al. 2004

The DLI algorithm is a bulk parameterization, fully described in the DLI Product Manual, available on the OSI SAF web server. The DLI is calculated as the sum of a clear sky and cloud sky contributions by the following equations:

$$L = (\varepsilon_0 + (1 - \varepsilon_0)\, C)\, \sigma\, T_a^4 \qquad (1)$$

$$C = 1 - E / E_{clear} \quad \text{for daytime cases} \qquad (2)$$

$$C = \Sigma(n_i\, C_i) \quad \text{for nighttime cases} \qquad (3)$$

with
L : downward longwave irradiance at the Earth's surface (W m^{-2})
T_a : near surface air temperature (K)
σ = 5.6696 10^{-8} W m^{-2} K^{-4}
ε_0 : clear sky emissivity
C : infrared cloud amount
E : effective SSI (W m^{-2})
E_{clear} : clear sky SSI (W m^{-2})
n_i : fractional sky cover of cloud type i
C_i : contribution coefficient of cloud type i

The clear sky emissivity ε_0 is derived, according to the formulation proposed by Prata, 1996, from the near surface air temperature and water vapor pressure, predicted by the NWP model ARPEGE. The infrared cloud amount, C, which gives the cloudy sky contribution, is directly deduced (2) from the actual to clear sky SSI ratio, by day (Crawford and Duchon, 1999) and is a weighted average (3) of the contributions of the cloud types covering the pixel, by night, where the C_i are empirical coefficients. The cloud types are simplified types, merging several types of the NWC SAF detailed cloud classification, presented in Derrien and Le Gléau, 2005.

3. VALIDATION AGAINST IN SITU DATA

3.1 Principles

The OSI SAF processing scheme includes Match-up Data Bases (MDB) gathering coincident GOES or MSG data and in situ measurements, from pyranometer or pyrgeometer (see figure 1) There are actually three types of MDB (hourly, 3-hourly and daily), updated in near real time for satellite data and monthly for in situ measurements, which may be ingested within a 1 to 24 month delay.

For all MDBs, the measured flux is a value centered on the time of the satellite data, obtained from the original in situ data by integration or interpolation. The calculated flux and its quality index are stored on a 0.3-degree square box centered on the measurement station and the averaged flux over this 9-pixel box is compared to the flux measured at the station.

Statistics of the SSI or DLI error, i.e. calculated value minus measured value, are calculated globally (all stations over the whole period), per month, per station or per month and station for the three temporal resolutions, hourly, 3-hourly and daily, on a routine basis. The operational validation uses a one year period but this paper presents the results over a longer period, starting in January 2004, when MSG-1 became operational, and ending in April 2006, the last month with enough in situ data at the time of this paper.

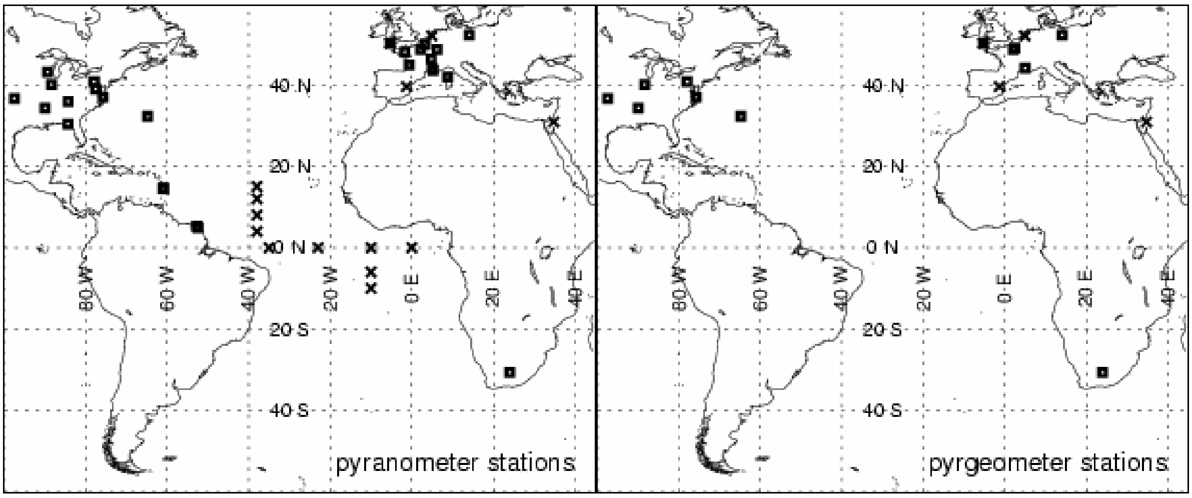

Figure 1 : map of the pyranometer stations (left) and pyrgeometer stations (right) used in the OSI SAF validation. The squares show the stations used by the operational validation and the crosses those that are candidates (their data are not yet available or are problematic).

3.2 Error statistics

The global statistics for the three temporal resolutions are given in table 1 and a summary of the results is presented in figure 2. The SSI and DLI show a negligible bias. The bias being low, the root mean square error (RMSE) is rather close to the error standard deviation. In terms of RMSE, the hourly SSI value is more than three times higher than the hourly DLI value, 68.4 Wm^{-2} against 20.8 Wm^{-2}, but the daily values are the same, 14.9 Wm^{-2}. When the temporal resolution increases, the SSI accuracy is significantly improved, both in Wm^{-2} and %, while the DLI accuracy does not vary much, the hourly and 3-hourly results being nearly identical. These statistics are fully consistent with those obtained previously by Brisson et al., 2001 and Le Borgne et al., 2005 on smaller data sets.

3.3 Geographical variation

Several problems complicate the analyze of the validation results. The stations are poorly distributed in the processed area, with most of them in mid-latitudes (only one, De Aar, being in the southern hemisphere) and a few stations in low latitudes, but having only pyranometers. Some stations, for instance De Aar (figure 4 and 5), provide the data after a one-year delay, at the best. Adding stations into the OSI SAF scheme may alter the temporal consistency; for instance, the 2004 DLI results in MSG area, with only Carpentras station, are hardly comparable to the 2005 results, with 6 stations. Erroneous data are not detected by the automatic operational scheme but are noticed later on. Due to all this, only a crude temporal or geographical analyze is possible.

The SSI performances can be assessed separately in mid-latitudes and low latitudes. Scatter plots of daily values (figure 3) and error statistics of hourly values (table 2) have been produced on four subsets of stations: mid-latitude stations in GOES area, mid-latitude stations in MSG area, stations in Antilles and Guyana and PIRATA buoys in equatorial Atlantic (this last subset is not used in the routine validation).The GOES and MSG mid-latitude performances are similar, with a low bias and error standard deviations of 64.0 Wm^{-2} and 58.9 Wm^{-2}, respectively. The Antilles-Guyana error standard deviation is significantly higher, 95.4 Wm^{-2}. The PIRATA buoys have an error standard deviation slightly better than the Antilles-Guyana stations, but they show an important positive bias, 41.4 Wm^{-2} (7.9% of the mean measure).

	SSI						DLI					
	mean Wm^{-2}	bias Wm^{-2}	stdev Wm^{-2}	RMSE Wm^{-2}	RMSE %	nbp	mean Wm^{-2}	bias Wm^{-2}	stdev Wm^{-2}	RMSE Wm^{-2}	RMSE %	nbp
hourly	403.4	1.9	68.4	68.4	17.0	165181	325.3	-1.6	20.7	20.8	6.4	149608
3-hrly	349.4	-2.2	49.5	49.6	14.2	62221	325.4	-1.6	19.0	19.1	5.9	50661
daily	170.5	0.7	14.9	14.9	8.7	16362	325.1	-1.5	14.8	14.9	4.6	6427
G/M	194.8	1.8	15.1	15.2	7.8	813	377.4	0.9	6.9	7.0	1.8	831
H/M	89.5	-3.9	26.7	27.0	30.2	552	309.6	-8.2	23.7	25.0	8.1	544

Table 1: Statistics of the radiative flux errors from January 2004 to April 2006. The statistics are given for the hourly, 3-hourly and daily flux validation against in situ data and, also, for the GOES/MSG and NOAA/MSG daily flux comparisons, “G/M“ and “H/M“.The H/M comparison starts on 23 August 2004 for the SSI and from 1 October 2004 for the DLI “mean” is the mean measure for the validations and the mean of the mono-satellite mean values for the comparisons. “bias” and “stdev” are the error mean and standard deviation, “RMSE” is the root mean square error, expressed in Wm^{-2} and in percentage of “mean” and nbp is the number of points (or daily fields, for G/M and H/M comparisons).

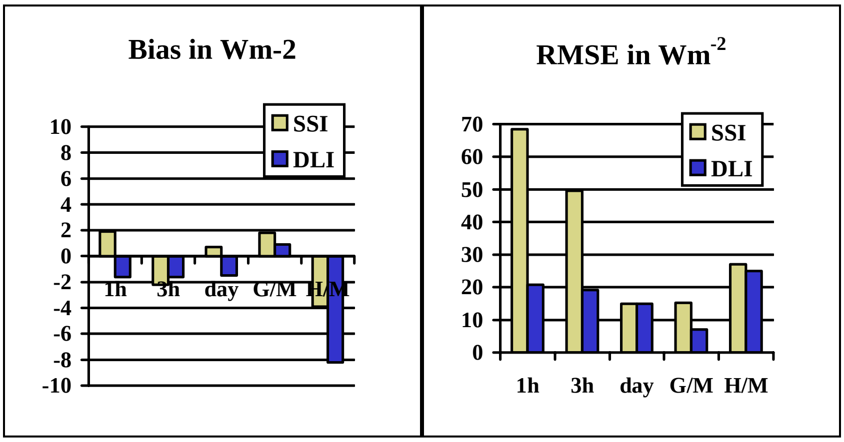

Figure 2: Bias (left) and RMSE (right) of the OSI SAF radiative fluxes, same data as in table 1

	mean Wm^{-2}	bias Wm^{-2}	stdev Wm^{-2}	RMSE Wm^{-2}	RMSE %	nbp
GOES mid-latitude	400.8	4.8	64.0	64.2	16.0	67226
MSG mid-latitude	371.1	-1.8	58.9	58.9	15.9	70375
Antilles-Guyana	492.2	4.3	95.5	95.6	19.4	27580
PIRATA	522.4	41.4	84.9	94.5	18.1	39393

Table 2: Statistics of the hourly SSI error from January 2004 to December 2005 on four subsets of stations. Same notations as in table 1.

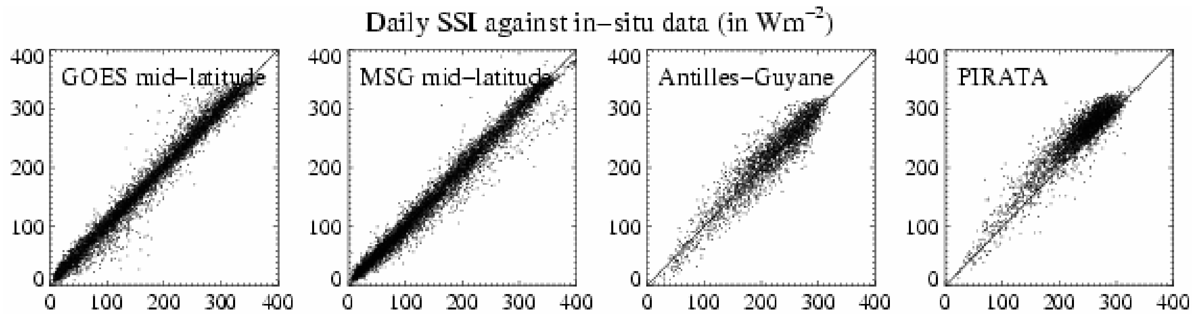

Figure 3: SAF OSI daily SSI against in-situ data on four subsets of stations.

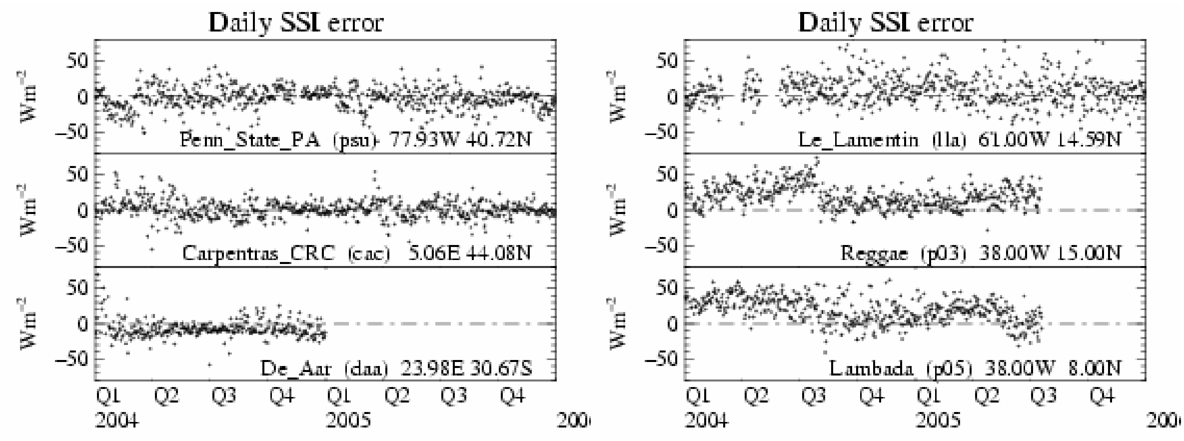

Figure 4: Daily SSI errors as a function of time for several stations.

The SSI error temporal variation differs on the four subsets of stations (figure 4). The mid-latitude stations (Penn State University, Carpentras, De Aar) show higher error values in summer than in winter (the SSI itself is higher). Le Lamentin in Antilles has higher error values than the mid-latitudes stations all year round. The PIRATA buoys, Reggae and Lambada, also have high error values, but the temporal variation of their error shows a buoy specific pattern. For instance, Reggae shows two periods with a trend, separated by a discontinuity on 2 August 2004, when the buoy was re-deployed. So, the quality of the buoy measurements seems questionable and we do not think that the positive bias of PIRATA buoys represents an actual SSI overestimation. Further studies should be made during the AMMA campaign, when pyranometer measurements will be made on a ship close to the buoys.

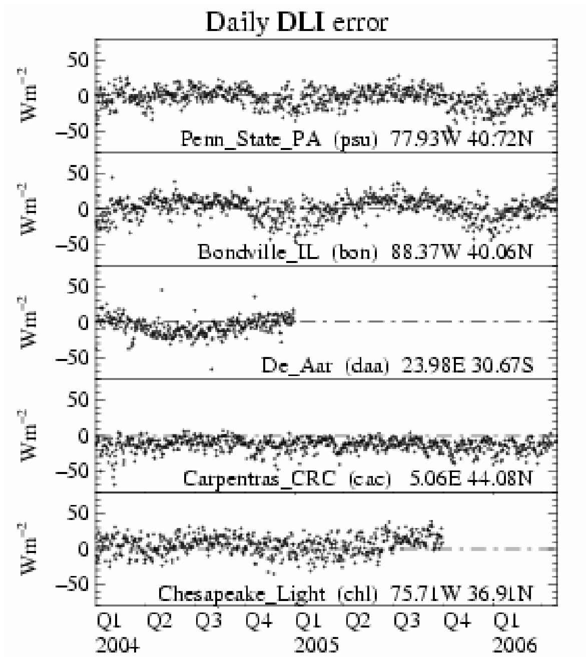

Figure 5: Daily DLI errors as a function of time for several stations.

Concerning the DLI, the MSG data are still less numerous than the GOES data in 2005, but the MSG results do not differ significantly from the GOES results. Figure 5 shows some typical DLI results. Higher errors are observed in winter (Bondville, Penn State University), which corresponds to known defaults of the algorithm: snow/cloud confusion and poor accuracy of the clear sky formula in case of inversion of the atmospheric profile (Brisson et al., 2000). Some stations, Chesapeake Lighthouse (maritime) and Carpentras (mild climate) do not have higher winter errors, however these stations show poor performances, due to inaccurate prediction of air temperature at these locations (Brisson et al., 2001 and Le Borgne et al., 2005). The limited results of the southern hemisphere station, De Aar, are rather similar to those of the northern hemisphere stations, which is also true for the SSI.

4. GOES/MSG AND NOAA/MSG comparisons

In order to check the consistency of the GOES, MSG and NOAA derived fluxes, statistical comparisons are routinely performed in the GOES/MSG (figure 5) and NOAA/MSG overlapping areas. The mean and standard deviation of the difference (GOES flux - MSG flux) are calculated over all points of the daily fields having the best confidence level for both satellites. These values are presented as a function of time in figure 6 and the overall statistics have been presented already in table 1 and figure 2. Due to the north-south symmetry of the GOES/MSG overlapping area, the radiative fluxes are rather constant all year round (figure 6 bottom), which makes the comparison easier (the additional seasonal cycle in SSI corresponds to the days when GOES data are available on a northern sector only).

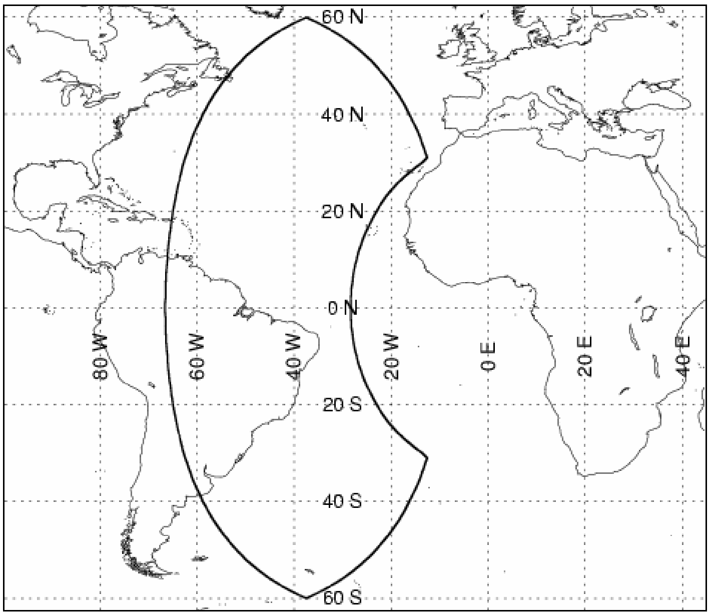

Figure 5: GOES/MSG overlapping area

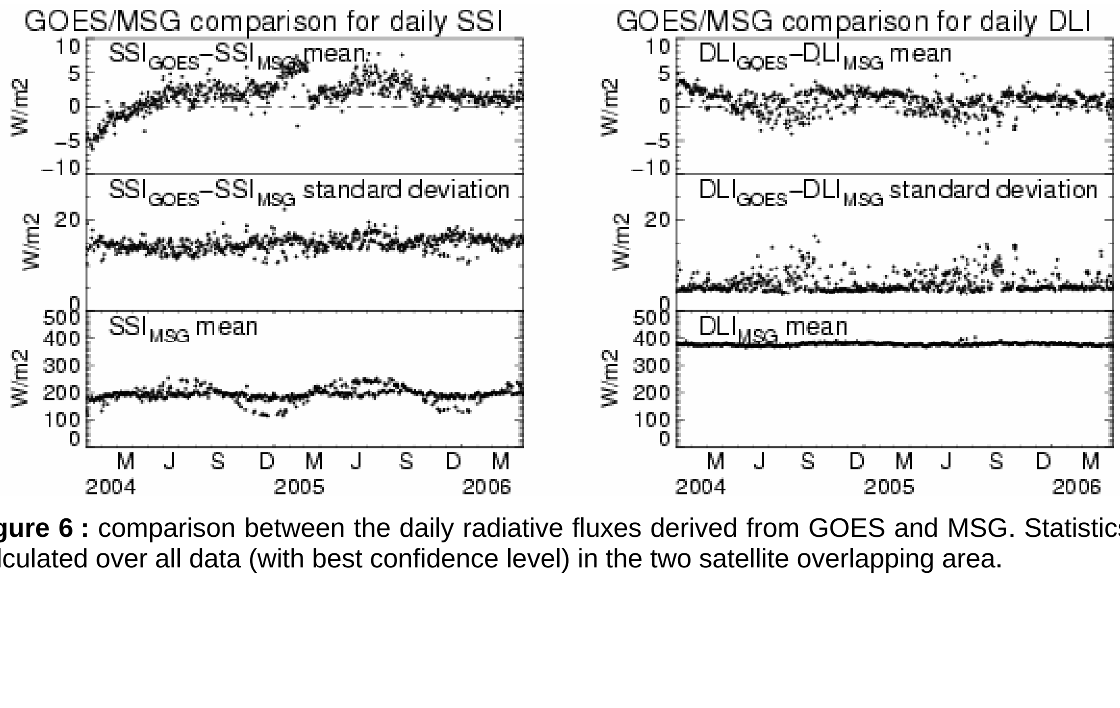

Figure 6 : comparison between the daily radiative fluxes derived from GOES and MSG. Statistics are calculated over all data (with best confidence level) in the two satellite overlapping area.

The mean SSI difference (figure 6 left) shows a discontinuity on 8 March 2005, when the SSI algorithm coefficients have been updated (see section 2). Before this date, the GOES radiometer sensitivity drift was not yet assessed and considered as zero, inducing the observed trend of the SSI difference. After this date, the difference is significantly reduced. The mean DLI difference (figure 6 right) is low, about 1 Wm^{-2} on the whole period, and shows acceptable temporal variations. The standard deviation values, about 15 Wm^{-2} in SSI and 7 Wm^{-2} in DLI, are similar or better than those of the validation against in situ data (it is the same for the RMSE values in figure 2).

A similar comparison is performed in the NOAA/MSG overlapping area, between 50N and 60N, on a restricted period to avoid some changes in the NOAA processing scheme during the first months. The results (figure 7) are obviously noisier than those of the GOES/MSG comparison, which can be explained by several reasons: the NOAA coverage and thus the overlapping area are not constant, the input satellite data significantly differ with a better temporal resolution of MSG and a better spatial resolution of NOAA and the SSI is very low in wintertime. The difference standard deviations are higher, 27 Wm^{-2} in SSI and 24 Wm^{-2} in DLI, than those of the GOES/MSG comparison or validation against in situ data. The NOAA derived DLI is lower than MSG derived SSI by about 8 Wm^{-2}, which was unexplained so far. However a bug has been corrected in met.no processing scheme on 22 May 2006 and, after this correction, the NOAA derived DLI is higher than the MSG derived DLI by about 4 Wm^{-2} (figure 8). This lower difference (in absolute value) remains to be confirmed on a longer period.

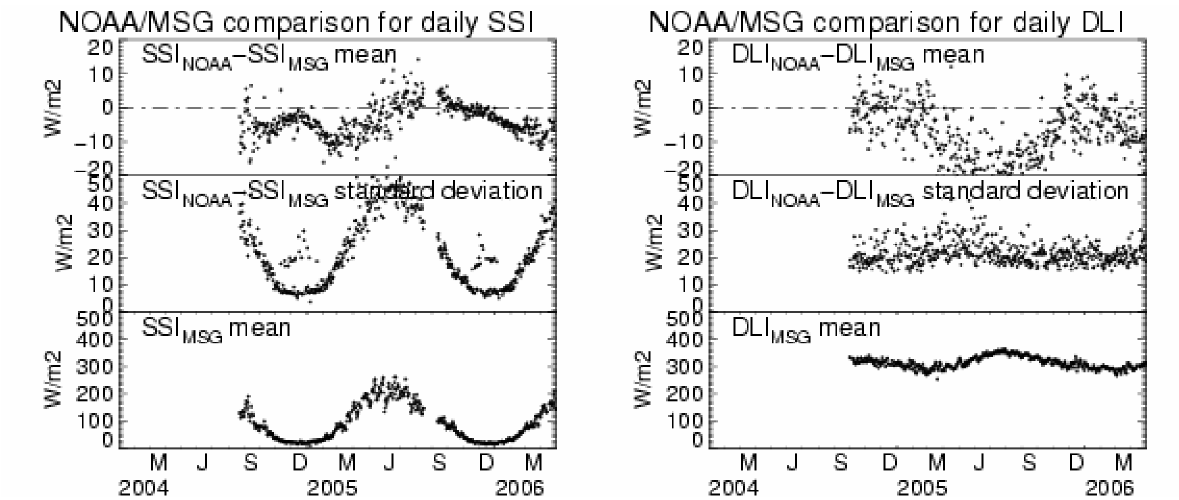

Figure 7 : comparison between the daily radiative fluxes derived from NOAA and MSG. Statistics are calculated over all data (with best confidence level) in the two satellite overlapping area.

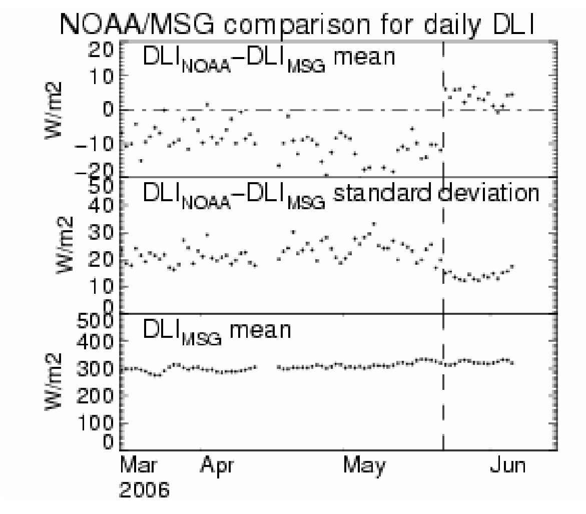

Figure 8 : NOAA/MSG comparison before and after a correction in met.no DLI scheme.

5. CONCLUSION

The OSI SAF radiative fluxes are routinely validated at CMS by comparing the GOES and MSG products against in situ measurements and by a cross-comparison of the mono-satellite products GOES, MSG and NOAA in the overlapping areas. Over a 28 month period, January 2004 to April 2006, the solar and longwave flux r.m.s. errors significantly differ at hourly resolution, about 70 Wm^{-2} and 20 Wm^{-2} respectively, and are nearly the same, 15 Wm^{-2} at daily resolution. Bad results have been obtained on the PIRATA buoys in Equatorial Atlantic, with a SSI bias of 40 Wm^{-2}, and the quality of the buoys measurements appears doubtful. The GOES and MSG products are fully consistent, both together and against in situ data. The NOAA and MSG products show higher values of the r.m.s. difference, partly explained by the different temporal and spatial resolution of the data, and further comparisons are needed for a better interpretation.

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