Preliminary study of the FCI instrument capability to detect dust aerosols

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Abstract

The Flexible Combined Imager (FCI) is an instrument on the future geostationary meteorological satellite Meteosat Third Generation (MTG). This communication presents preliminary results on its capability in measuring and characterizing the optical properties of the aerosols, their load, and nature. A numerical simulator has been built that includes top-of-atmosphere scene simulation obtained by a radiative transfer model in the clear atmosphere, and the transfer function of the FCI (spectral response, SNR…) to provide simulated outputs of the instrument. Changes of inputs depicting the atmosphere and the ground yield a series of FCI outputs that are analyzed by means of global sensitivity analysis to assess the sensitivity of FCI to changing aerosol properties.

1. Introduction : Dust and aerosols

In the climate changing context and increasing health awareness of public, the question of air pollution by transport mean of domestic heat is at the center of the attention. Reducing the pollution by increasing use of renewable energy is one strategy as much as the reduction of emission and more efficient technology. For solar energy the forecasting and estimation of the usable resource appear to be a critical point in order to settle solar power plant on the right spot. To estimate these resources for solar energy ones need a better knowledge of the atmospheric composition, their trend and behavior.

Concentrated solar technologies (CST) need an accurate estimation of available resources and a precise knowledge of the atmospheric aerosols behavior. CST use mirrors or lenses to focus direct solar irradiation in highly concentrated high quality solar cell or thermal exchanger. Hence they are only using the direct part of the solar radiation which is very sensitive to scattering properties of aerosols.

CST solar power plants are expensive and need large area to be settled in order to reduce the operational cost. It is then a better strategy to settle this power plant in deserts such as Saharan or Arabic desert in order to benefit of both extended place available and solar resource. For example the Ivanpah power plant in the Mojave Desert is settled to produce about 377 MW in a surface of 14 km² and with 173 500 mirrors. However these deserts are prone to large concentration of dust aerosol that will prevent the CST from producing electricity. Dust concentration is highly variable in space and time. Site selection for CST plants and efficiency in operating them would be greatly enhanced if an accurate monitoring of dust were available.

A high temporal resolution is needed for the monitoring of dust storm event because of the timespan of dust storm that can be very short. Figure 1 exhibits AERONET measurements at El Farafra in Egypt on 7 February 2014. Dust storm starts around 9:00 am in less than half an hour, lasts for 5 to 6 h and stops abruptly.

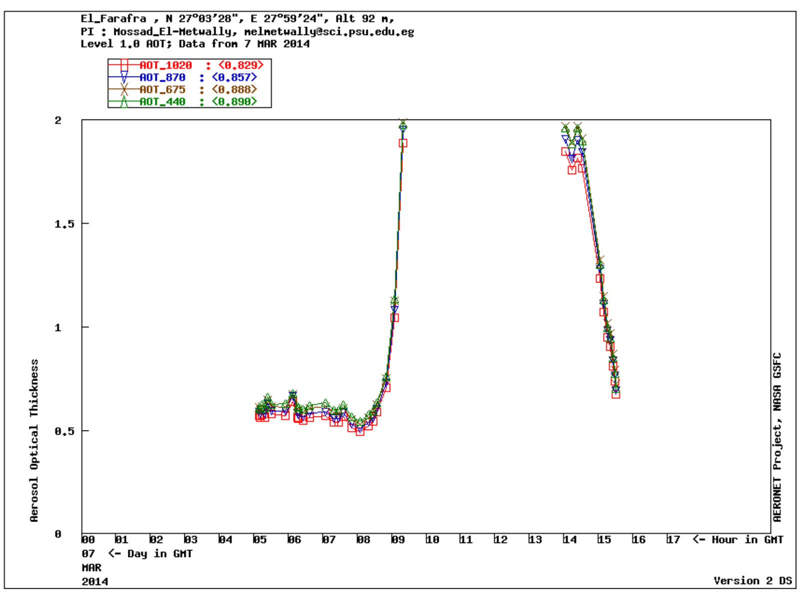

Figure 1 : Sandstorm observed by El Farafra AERONET site on 7 February 2014 (P.I.: Mossad El-Metwally)

The spatial resolution is a less important issue because dust storm often covers several km². Geostationary satellites such as Meteosat may offer such temporal and spatial capabilities.

The Flexible Combined Imager (FCI) is an instrument on the future geostationary meteorological satellite Meteosat Third Generation (MTG). It offers 16 channels from visible to infrared that may be used for a better knowledge of atmospheric properties. MINES ParisTech and Thales Alenia Space have undertaken a joint study on the capacity to assess properties of aerosols such as their concentrations and their types. This communication presents preliminary results on the capability of the FCI in measuring and characterizing the optical properties of the aerosols, their load, and nature in particular for solar energy conversion, namely for the concentrated solar technologies.

2. The Meteosat program

Meteosat program started in the early 70’s in order to help the forecast of dramatic weather event such as flooding, typhoon or thunder storm. In 1977 the first Meteosat was successfully launched and began the era of European meteorological observation. At this time it was and it still is a spinning imager.

A new European entity, EUMETSAT, was created in late 80’s to manage and operate Meteosat satellites. The Meteosat Second Generation (MSG) series of satellites began operations in 2004. Based on the same principle of spinning imager, this is the version actually in use. The first and second generation satellites scan the 1/3 of Earth surface by rotating on itself and recording a line by line image. The first generation of Meteosat satellites needed 25 min to get an entire image plus 5 min of processing and sending, leading to an image every 30 min of the observable Earth disc on 3 different channels. MSG characteristics are far better. Twelve imaging channels -instead of 3- are now available every 15 min.

Meteosat Third Generation (MTG) will be comprised of two different missions. The Imager MTG-I mission, encompassing two instruments, FCI and a Lighting Imager, has strong heritage of the current MSG satellites and will provide complete scan every 10 min with a nadir spatial resolution of 1 km and 500 m for visible channels and 1 km and 2 km for thermal channels. The Sounder MTG-S mission, with IRS and interferometer and UVN a UV spectrometer, will give more information on the 3D profile atmospheric layers. MTG as its predecessor will orbit at an altitude of about 36000 km over the gulf of Guinea at the 0° latitude and will be 3-axis stabilized. Its imager, the Flexible Combined Imager (FCI) will include 16 spectral channels (Figure 2).

Channel	Central Wavelength, λ_0	Bandwidth, $\Delta\lambda_0$	Spatial Resolution
VIS 0.4	**0.444 µm**	**0.060 µm**	**1.0 km**
VIS 0.5	**0.510 µm**	**0.040 µm**	**1.0 km**
VIS 0.6	0.640 µm	0.050 µm	1.0 km; 0.5 km
VIS 0.8	0.865 µm	0.040 µm	1.0 km
VIS 0.9	**0.914 µm**	**0.020 µm**	**1.0 km**
NIR 1.3	**1.380 µm**	**0.030 µm**	**1.0 km**
NIR 1.6	1.610 µm	0.050 µm	1.0 km
NIR 2.2	**2.250 µm**	**0.050 µm**	**1.0 km; 0.5 km**
IR 3.8 (TIR)	3.800 µm	0.400 µm	2.0 km; 1.0 km
WV 6.3	6.300 µm	1.000 µm	2.0 km
WV 7.3	7.350 µm	0.500 µm	2.0 km
IR 8.7 (TIR)	8.700 µm	0.400 µm	2.0 km
IR 9.7 (O_3)	9.660 µm	0.300 µm	2.0 km
IR 10.5 (TIR)	10.500 µm	0.700 µm	2.0 km; 1.0 km
IR 12.3 (TIR)	12.300 µm	0.500 µm	2.0 km
IR 13.3 (CO_2)	13.300 µm	0.600 µm	2.0 km

Figure 2 : channel on board of the Flexible Combined Imager, in bold the new channels compare to SEVIRI (EUMETSAT, 2013)

According to studies on their optical properties(McConnell, Formenti, Highwood, & Harrison, 2010; Lafon, Sokolik, Rajot, Caquineau, & Gaudichet, 2006; Sokolik, Andronova, & Johnson, 1993), dust aerosols seem to absorb and scatter more the blue than other parts of the visible spectrum. For example, the Deep Blue algorithm used on MODIS data to retrieve aerosol over bright target such as desert exploits the blue and near UV channel (450 nm and less) to discriminate aerosol from ground and the other visible channels to retrieve their specific properties. The FCI includes such a blue channel.

3. Simulator definition

The methodology adopted in the study is to simulate the outputs of the FCI under various cloud-free atmospheric conditions, ground albedo and aerosols and to study the sensitivity of these outputs to changes in aerosols. A numerical simulator has been built that includes top-of-atmosphere scene simulation obtained by a radiative transfer model in the clear atmosphere, and the transfer function of the FCI to provide simulated outputs of the instrument.

The LibRadtran code and the DISORT-2 solver were selected to model the radiative transfer in the atmosphere. The specifications used to model the instrument transfer function were deduced from the System Requirement Document (SRD) of MTG (EUMETSAT, 2013).

Outputs of the radiative transfer code are radiances averaged over the spectral band under concern following the spectral response. These radiances are converted into digital counts output by the FCI using calibration factors provided by the SRD.

4. Result of Global Sensitivity Analysis

A series of cloud-free atmospheric conditions and aerosol properties is randomly created by Monte-Carlo techniques for a given ground albedo. This series is input to the radiative transfer codes, yielding a series of FCI digital counts. Both series are inputs a global sensitivity analysis (GSA). The GSA is a statistical tool that determines the importance of the variability of each input on the variability of the FCI digital count (Saltelli, 2005; Sobol', Tarantola, Gatelli, Kucherenko, & Mauntz, 2007).

Fig. 5 exhibits the first results obtained by the GSA for the VIS 0.4 channel. Unsurprisingly, it shows that the solar zenithal angle and the ground albedo are very important inputs to the simulator

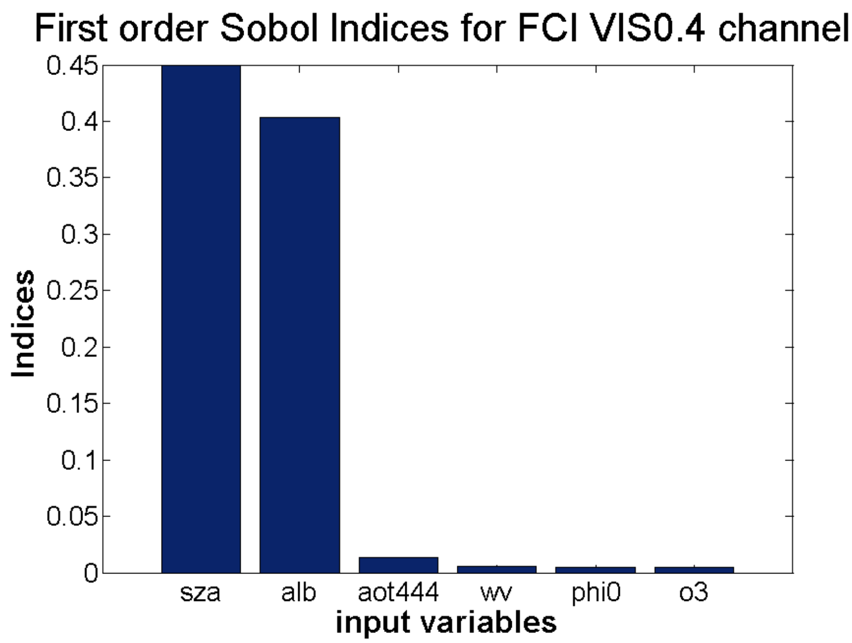

Figure 3 : Various impact of simulator input variables, sza =solar zenithal angle, alb = Ground albedo, aot444 = aerosols optical thickness at 444 nm, wv = total column of water vapor, phi0 = solar azimuthal angle (irrelevant here because of the undefined observer azimuthal angle) and o3 = total column of ozone.

6. Conclusion and perspectives

A simulator of the ensemble ground-atmosphere-FCI has been built and is working. It is intended to use it to feed a GSA for assessing the sensitivity of the FCI to changes in aerosol properties. The whole methodology has been tested on the case of the blue channel of FCI.

The next steps are to use extensively the simulator to provide inputs to the GSA for all wavelengths. Given the large importance of the solar zenithal angle and the ground albedo, and taking into account that these variables may be known with very high precision for the solar zenithal angle and with a relative uncertainty of 5-10% for the ground albedo, one may think of setting them to a constant value in order to enhance the smaller contributions of the other variables, especially aerosols properties. This has several disadvantages because it means that the same analysis must be done for several angles and albedos to hypothesize the influence of these two variables on the conclusions of the GSA. The GSA may provide second-order indices indicating the influence of joint variables on the outputs. The analysis of both first- and second-order indices yields in a single run, deep insights of the influence of the inputs.

By this way, the sensitivity of each FCI channel to changes in aerosol properties in a changing atmosphere will be established. Next, will come the analysis of the SNR, calibration factors and spectral response on this sensitivity.

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