Analysis of solar activity impact on thermospheric density during ESA GOCE mission



Francesco Berrilli, Mija Lovric, Carlo Cauli, Alberto Bigazzi, Marco Colace

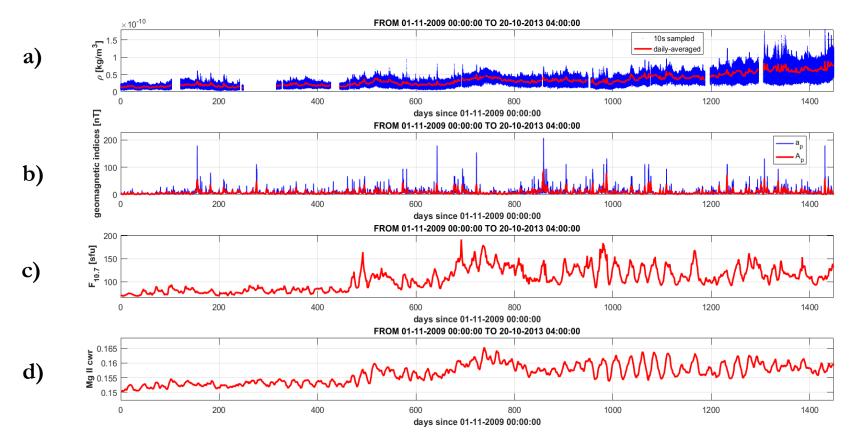
Department of Physics, University of Rome Tor Vergata, ITALY (https://www.fisica.uniroma2.it/~solare/en/)

Abstract

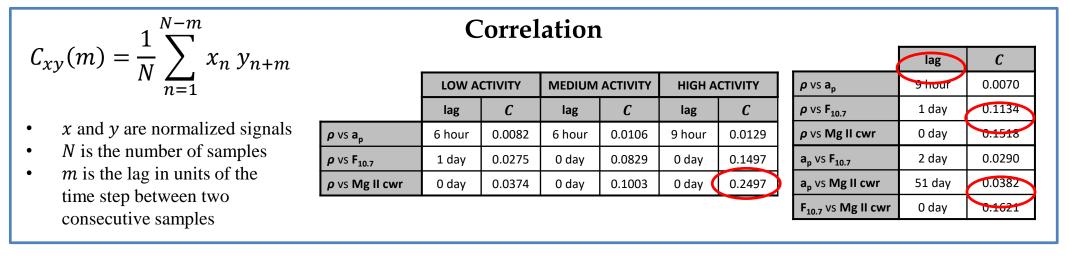
The impact of solar activity on thermospheric density during ESA's gravity mission GOCE (17 March, 2009 - 11 November, 2013, rising phase of solar cycle 24) has been investigated using different solar indices. Thermospheric densities at a mean altitude of 254 km, derived from the high-precision accelerometers on board the GOCE satellite, represent a unique low-altitude dataset. Solar activity indices such as the F10.7 flux, the Mg II core-to-wing ratio and the Ap geomagnetic index in the period of GOCE mission have been firstly examined in time and their correlations with GOCE thermospheric density have been studied. Then, solar indices have been analysed through the Empirical Mode Decomposition (EMD), a technique best suited in analysing non-stationary and non-periodic time signals. After extracting the individual components (IMFs) from the solar indices, thermospheric density have been reconstructed and compared with the GOCE dataset. The preliminary results presented in this work suggest how significant advantages may be gained using the Mg II index and EMD method in describing the solar-thermospheric connection.

GOCE (Gravity field & steady-state Ocean Circulation Explorer)

- Drag-Free Attitude and Orbit Control System to maintain altitude constant
- on-board ultra-sensitive accelerometers used to create dataset of **10s** sampled thermospheric density at 260 km altitude (*Eelco Doornbos et al.* of TU Delft [1]) available at ESA GOCE Archive (**01/11/2009 -20/10/2013**)
- the satellite was operated until few hours before destruction into the atmosphere.
- very high uncertainty (half an orbit) in the location of re-entry up to few hours before due to the highly variable level of solar and geomagnetic activity



- a) Atmospheric density vs time (both 10 s sampled and daily averaged) during GOCE mission; b) Geomagnetic index a_p and daily-averaged geomagnetic index A_p vs time during GOCE mission; c) and d) F10.7 and Mg II cwr vs time during GOCE mission (signal spikes are removed by interpolation)
- 1. Thermospheric density is badly-correlated with geomagnetic index and well-correlated with solar flux indices (especially with Mg II cwr)
- 2. The thermospheric response to a_p impulsive changes is within 6 to 9 hours
- 3. Impulsive variations of a_p , as well as long-term evolution of F10.7 and Mg II cwr are well reflected in the thermospheric density



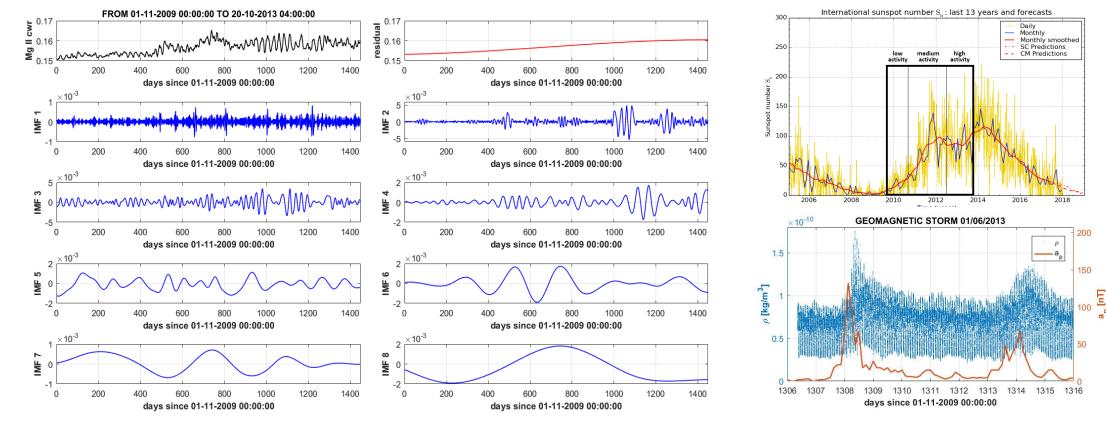
index/proxy	symbol	description	unit	sampling	source
geomagnetic index	a_p	proxy for the global level of geomagnetic activity	nT	3 hr	NASA Goddard Space Flight Center OMNIWeb
solar radio flux at 10.7 cm	F _{10.7}	good proxy for daily average level of overall solar radiation	sfu	1 day	NASA Goddard Space Flight Center OMNIWeb
Mg II core to wing ratio	Mg II cwr	excellent proxy for the solar MUV chromospheric line emission near 280 nm	-	1 day	UVSAT of Bremen University Institut für Umweltphysik

EMD (Empirical Mode Decomposition)

EMD is a purely empirical technique to break down a signal X(t) in a number of oscillation modes in the time domain, referred as the *Intrinsic Mode Functions* (IMFs) $c_i(t)$ and the residual trend $r_n(t)$

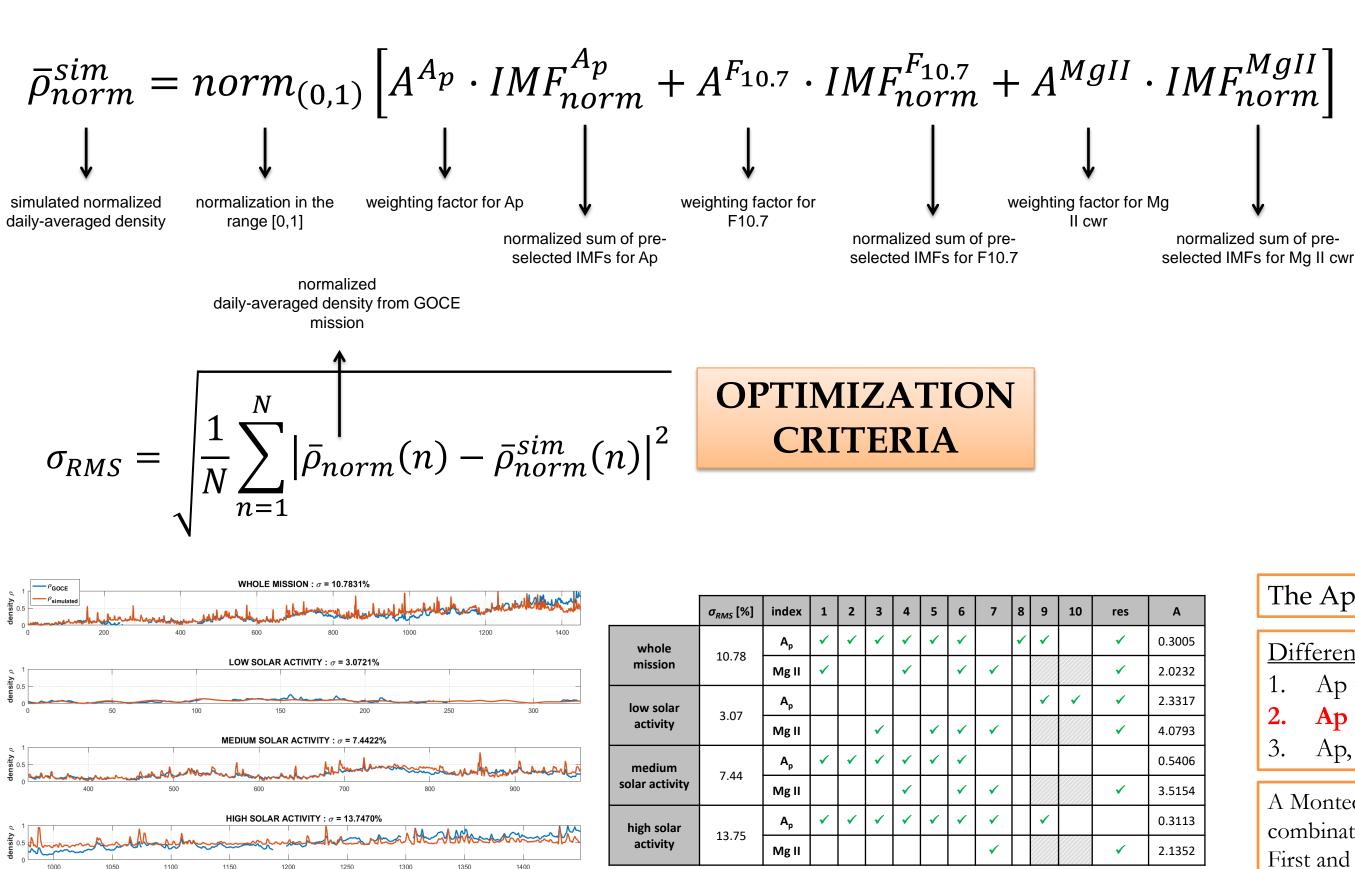
$$X(t) = r_n(t) + \sum_{i=1}^{n} c_i(t)$$

Each IMF has a time-variable frequency and amplitude, useful to analyze non-linear non-stationary signals. The algorithm is based on the recursive application of a *sifting* process, that consists in removing the mean envelope obtained from a cubic spline interpolation of local minima and maxima. As stopping criterion is used to arrest the sifting process



Left: Mg II EMD decomposition, **Right Up:** Sunspot number, GOCE mission period is highlighted in the black box with periods of different solar activity, **Right Down:** Effect of a solar storm on atmospheric density (the response time to a_p variations is in the order of hours).

Recreate thermospheric density time profile from Intrinsic Mode Functions and the residual trends of solar indices EMD



 $IMF_{norm}^{A} = norm_{(0,1)} \left[\sum_{i}^{10} I_{i}^{A_{p}} \cdot IMF_{i}^{A_{p}} + I_{res}^{A_{p}} \cdot res_{p}^{A_{p}} \right]$

$$IMF_{norm}^{F_{007}} = norm_{(0,1)} \left[\sum_{i}^{8} I_{i}^{F_{107}} \cdot IMF_{i}^{F_{107}} + I_{res}^{F_{107}} \cdot res^{F_{107}} \right]$$

$$IMF_{norm}^{MgII} = norm_{(0,1)} \left[\sum_{i}^{9} I_{i}^{MgII} \cdot IMF_{i}^{MgII} + I_{res}^{MgII} \cdot res^{MgII} \right]$$

 $IMF_i = i$ -th IMF res = residual trend $I_i = logical of the select the$

 I_i = logical operator to select the i-th IMF

ASSUMPTIONS

The Ap index is preliminary shifted by 9 h before the application of the EMD

Different cases of solar indices are analyzed:

. Ap and F10.7

2. Ap and Mg II

3. Ap, F10.7 and Mg II

4 cases are investigated whole mission, low solar activity (SA), medium SA, high SA

A Montecarlo-like approach (random extraction) is used to select for each solar index the combination of IMFs and the weighting factors to be included in the density simulation. First and last five points of IMFs are cut to avoid boundary effects (wing removal process)

Conclusions

Whole mission: good representation of long-term evolution (except for medium to high solar activity period) over-estimation of peaks; Low solar activity: very good representation both for long-term evolutions and peaks; Medium solar activity: good representation of long-term evolution of peaks; High solar activity: no satisfactory representation of long-term evolution (over-estimation and under-estimation) good representation of peaks (except for initial over-estimation).