The possible impact of cosmic rays to the total ozone column in Athens – Greece

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Abstract
During the last decade a number of studies have indicated connection between cosmic rays / solar activity and climatic parameters. The present study investigates the possible variation of cosmic rays / solar activity signal in a total ozone column above mid latitude Mediterranean city of Athens – Greece. The daily data used, covered 1978 – 2012 time interval while they included daily: multi sensor reanalysis data sets for ozone column, sunspot number from omniweb datasets and cosmic rays data from Moscow Neutron Monitor datasets. The results indicated a clear signal of solar activity variation (positive / negative and vice versa) in the total ozone column.

Keywords: Galactic Cosmic Rays, Total Ozone Column

1 Introduction
Galactic cosmic rays (GCR), consisting principally of energetic protons and particles emitted from the Sun and stars within our galaxy, are a primary source of the atmospheric ionization which affects cloud formation. The number of GCRs that reach a certain point on the surface of the Earth is influenced by solar activity, latitude, altitude, the diurnal cycle of the Sun and the weather (Svensmark & Friis-Christensen, 1997; Svensmark 1998; Todd & Kniveton, 2001). The primary cosmic rays interact in the atmosphere at around 30 km altitude, producing showers of secondary particles, which penetrate the troposphere below 7 km. The charged cosmic rays lose energy by ionization and, away from continental sources of radon, are responsible for essentially all of the fair-weather ionization in the troposphere. The solar wind, the geomagnetic field strength and the galactic environment of our solar system modulate the GCR flux, typically by a few tens of per cent, depending on latitude and altitude (Raspopov et al, 1998; Gehrels et al, 2003; Jackman & McPeters, 2004; Lastovicka & Krizan, 2005 & 2009; Gray et al, 2010). Also there are papers that refers to how upper stratospheric ozone changes may amplify observed, 11-year solar cycle irradiance changes to affect climate and it implies that these oscillations are likely driven, by solar variability (for example Penner & Chang, 1978; Blackshear & Tolson, 1978; Shintell et al., 1999). Lee & Smith 2003, discus the combined effects of solar cycle, quasi-biennial oscillation, and volcanic forcing on stratospheric ozone changes.
Emissions of matter and electromagnetic fields from the Sun, namely solar wind, increase during high solar activity, making it harder for GCRs to penetrate the inner solar system and reach the Earth. Nummik 1999 & 2007, has shown that, to within statistical deviations, the total number of SEP events observed during any given time interval is proportional to the sum of sunspot numbers (SSN). Thus, the GCR intensity is modulated by solar activity, expressed by (SSN). The phenomenon presents an approximately 11–year periodicity following the variation of SSN. Irregular decreases of GCR intensity on short time scales are of particular interest. These anomalies are known as Forbush decreases (FDs), and are associated with magneto-hydrodynamic disturbances following solar coronal mass ejections (Ney, 1959; Mannuel et al, 2002; Palle Bago et al, 2004). Also, Gehrels et al. 2003, discuss possible ozone depletion from nearby supernovae.

A strong correlation has also been observed between paleoclimate and GCRs, suggesting that the effects of SSN – GCR variation levels are more evident at larger rather than smaller time scales (LaViolette, 1987 & 2005; Kirkby, 2008).

Regarding energetic solar particles, the main effects reported in the literature could be summarized as follows: (i) an ozone response to solar proton events is generally observed at high latitudes where the shielding action of the geomagnetic field is reduced, (ii) solar particle with energies greater than 10 MeV affect the stratospheric chemistry, (iii) ozone depletion starts within few hours of the arrival of charged particles, (iv) the solar particle-induced effects in the atmosphere could last days or weeks, but no relevant long-lived effects were claimed (Lu and Sanche, 2001; Gehrels, et al., 2003; Kislyakov et al., 2004; Jackman and McPeters, 2004; Lu, 2009; Muller and Grooß, 2009; Tritakis et al., 2009). Krivolutsky (1999; 2003) and Krivolutsky et al. (2002) report a clearly distinguishable negative response of the total ozone to the strong solar proton events, a periodical ozone response to GCRs (with opposite phase to the decadal cycle of SSN), which has a negative trend, and a tendency of positive total ozone response to solar energetic particles, at lower latitudes.

Also Kellet, (2001), has revised Nye's "diagrammatic scenario" (Ney, 1959) showing a series of possible links between solar activity and atmospheric processes. Furthermore he has presented evidence that the various nitrogen components and nitrate ion data seem to have an almost ~5.3 years delay with respect to sunspot series. Lu and Sanche (2001) and Lu (2009) suggested a natural mechanism in order to explain their observations, mainly referring to the relation between cosmic rays – electron production and the stratospheric ozone. Lu (2009), used satellite data covering two full 11-year solar cycles (1980-2007), to demonstrate a strong correlation between cosmic rays intensity and ozone depletion. Thus, the cosmic ray flux could be one of the potential sources for the variability in total ozone content at high latitudes and to some extent in mid-latitudes as well. Yet, the uncertainties involved regarding the controlling mechanism and the associated physical explanation, as well as the time scales of the phenomenon are still considerable. Further, since meteorological parameters can also be affected (Tsiropoula 2003; Mavrakis & Lykoudis, 2006), could the variation in GCR/SSN levels influence or, from an observational point of view, relate to changes in air pollution levels at a local scale?

The aim of this study is to investigate, from an observational perspective, and on a local spatial scale, the possible relationship between the average, annual, monthly and daily levels of total ozone column (TOC), as recorded above the mid latitude Mediterranean city of Athens – Attica region, Greece and the fluctuation of GCR and solar activity (SSN).

2 Data and Methodology

The daily data used, covered 1978 – 2012 time interval while they included 4 values per day multi sensor reanalysis data sets for ozone column (van der A et al, 2010), sunspot number from omniweb datasets and cosmic rays data from Moscow Neutron Monitor datasets. In order to compare datasets, we calculate normalized values of GCR, SSN and Ozone Column data, removing seasonal variation for ozone data, in three time scales (daily, monthly and annually), correlated each other and graphs were made.

3 Results

Data for Total Ozone Column (TOC) adopting from Multi Sensor Reanalysis (MSR) datasets (Figure 1a, with blue line) and from Ozone Monitoring Instrument (OMI) datasets (Figure 1a, with pink line) for Athens, we show a slight decline of Total Ozone during the last few years. The normalized values are shown in Figures 1b (daily), 1c (monthly) and 1d (yearly). It is clear that the time interval play a key role to understand the effect / contribution of GCR / SSN to modulation of ozone column. When we proceed from daily scale to annually scale, the effect on ozone column is clear. Solar activity (SSN) is widely known as one of the most important factors influencing the levels of cosmic radiation reaching the surface of the Earth (Nummik 1999 & 2007). Thus, increased solar activity causes low GCR levels and vice versa. The correlation coefficients between them vary between -0,710, -0,792 and -0,814 for daily, monthly and annually data respectively.

Correlation coefficients for the effect / contribution of GCR / SSN to ozone column are: -0,035 / 0,069, -0,074 / 0,151 and -0,198 / 0,260 daily, monthly and annually data respectively in agreement with findings of LaViolette, 1987; Raspopov et al, 1998; Gehrels et al, 2003; Jackman & McPeters, 2004; Kirkby, 2008. The results are typically by a few tens of per cent, depending on time scales. It seems that the effects are more evident at larger rather than smaller time scales (a phase delay) and indicates how fast physical and chemical processes of the ozone column response to the external triggering of GCR / SSN variation

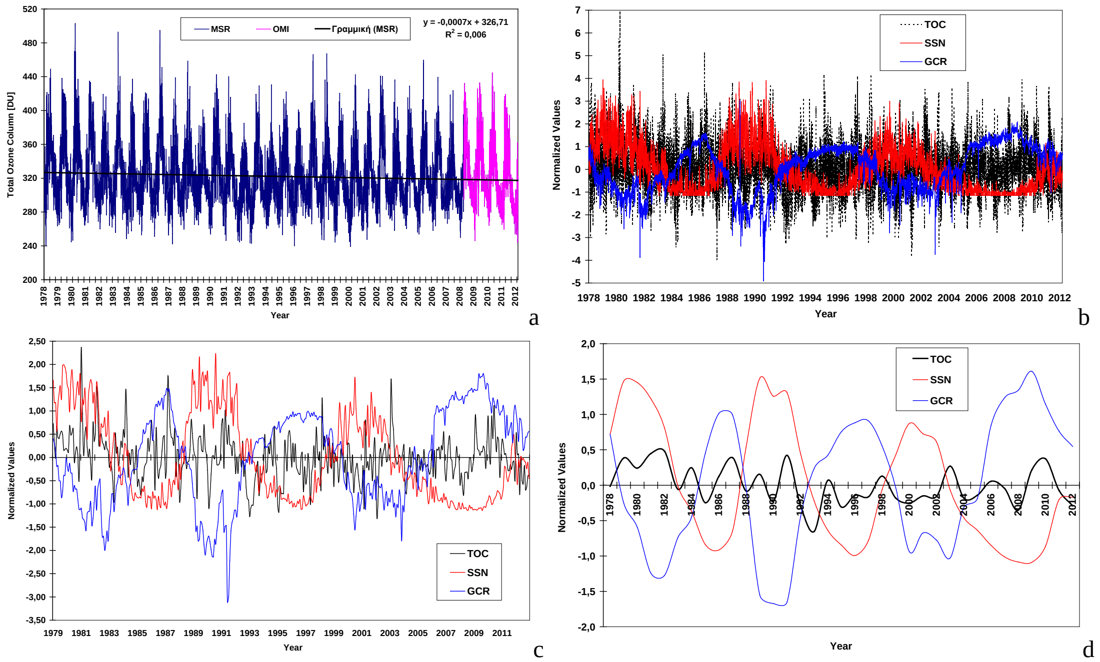

Fig. 1. a) Daily Ozone Column data from MSR & OMI for Athens (1978–2012). Normalized values for Total Ozone Column (TOC), Sun Spot Number (SSN) and Galactic Cosmic Rays (GCR): b) Daily, c) Monthly and d) Annually. Data cover three solar cycles

Table 1. Correlation coefficients for three time scales

		TOC	GCR	SSN
	TOC	1	-0,035	0,069
Daily	GCR		1	-0,710
	SSN			1
	TOC	1	-0,074	0,151
Monthly	GCR		1	-0,792
	SSN			1
	TOC	1	-0,198	0,260
Annually	GCR		1	-0,814
	SSN			1

Correlation is significant: ** at the 0.01 level (2-tailed).

4 Conclusions

In the present paper we attempted to investigate the relation among Total Ozone Column (TOC), Galactic Cosmic Rays (GCR) and SunSpot Number (SSN) from an observational perspective, on a limited spatial scale, in three time scales. The conclusions drawn can be summarized as follows:

- The results depict a positive correlation of TOC with sun spot number (SSN) and a negative correlation with galactic cosmic rays (GCRs) levels, as measured at the Earth's surface, in agreement with previous studies.
- Effects are more evident at larger rather than smaller time scales (a phase delay) indicates how fast is the response of the examined parameter to the external triggering, in this case GCR / SSN variation.

Besides the obvious interest on how, abrupt and intense variations of SSN or GCR, could potentially affect air quality, the relationship between SSN / GCR with TOC can contribute to the formation and investigation of scenarios regarding their behavior and their possible influence on atmospheric procedures.

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