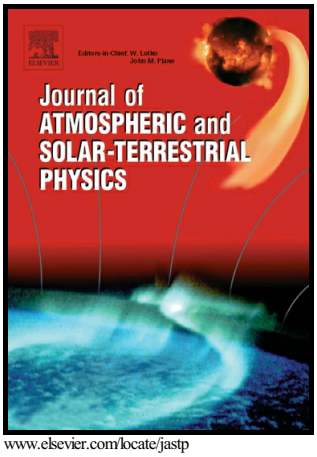
# A review of recent progress in trends in the upper atmosphere

Jan Laštovička

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# A review of recent progress in trends in the upper atmosphere

Jan Laštovička
Institute of Atmospheric Physics, Czech Academy of Sciences, Bocni II, 14131 Prague, Czech Republic; jla@ufa.cas.cz

**Abstract**.

The anthropogenic emissions of greenhouse gases affect not only the weather and climate in the troposphere; they affect also long-term trends in the mesosphere-thermosphere-ionosphere system, where the amplitudes of anthropogenic changes are substantially larger than in the troposphere. The last four years have seen significant progress in investigating these trends but also some new puzzles have been created. Observations of the $CO_2$ trend in the lower thermosphere appeared but their interpretation is a matter of debate. The role of ozone in mesospheric temperatures and E-region ionosphere has been confirmed and quantified. Agreement between observational and simulated trends in the thermospheric density, supported by satellite observations of radiative cooling was reached but the most recent result re-opened the problem. Much new partial information about trends in the ionospheric F region was reported. Also new information on other experimental trends helped to improve our understanding of long-term trends in the upper atmosphere. Significant progress has been reached in modelling the long-term trends; in a few parameters the agreement with observed trends is now not only quantitative but also qualitative. Several attempts to explain ionospheric trends without $CO_2$ appeared but they are shown not to be correct; $CO_2$ remains to be the primary (although not the only) trend driver. On the other hand, many open questions or puzzles, listed in Concluding remarks, remain to be investigated.

*Key words*: long-term trends; carbon dioxide; ionosphere; thermosphere and mesosphere

## 1. Introduction

The anthropogenic emissions of greenhouse gases affect the weather and climate in the troposphere. They appear to be the primary driver of a significant increase of surface