Trend analysis of climate change markers through ECMWF CERA-20C secular time series

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In this study, we analyse behaviour and trend of several climate change markers through the ECMWF (European Centre for Medium range Weather Forecasts) time series. Specifically, the CERA-20C dataset was used. CERA-20C is a 10-member ensemble of coupled climate reanalyses of the 20th century (1901-2010) and reconstructs the past climate of the Earth system including atmosphere, ocean, land, waves and sea ice. It is based on the CERA assimilation system, which assimilates surface pressure and marine wind observations as well as ocean temperature and salinity profiles. CERA-20C is available on 37 vertical pressure levels and the model spatial resolution is equal to 1.125° (~125 km).

In the present work, we used monthly averaged data from the secular reanalysis to represent the global trend of 109 years of climate observations. In particular, observables sensitive to ongoing climate change, highlighted by the international scientific community, were analysed: Skin Temperature, Sea Surface Temperature, Sea Ice Fraction, Cloud Coverage and Ozone. Furthermore, time series of CO_2 gas concentration (from 1979 to 2018) and CH_4 gas concentration (by CAMS system from 2003 to 2019) were analysed. Finally, monthly maps were also generated for each variable, showing the percentage variation between the last and the first year of the series. This is to highlight particular behaviours of the observables at a spatial level.

Description of ECMWF time series

Regarding the CERA-20C datasets, the resolution of the atmospheric model is of 1.125° horizontal grid (~125 km) with 91 vertical levels going up to 0.1 hPa (IFS version 41r2). The CERA-20 provides several parameters such as Skin Temperature, Sea Surface Temperature, Sea Ice Fraction, Cloud Coverage and Ozone.

The CH_4 concentration parameter is from CAMS reanalysis of reactive gases and aerosols. The CAMS reanalysis is the latest global reanalysis data set of atmospheric composition (AC) produced by the Copernicus Atmosphere Monitoring Service, consisting of 3-dimensional time-consistent AC fields, including aerosols, chemical species and greenhouse gases. TheCAMS reanalysis data have a resolution of approximately 80 km with a sub-daily and monthly frequency.

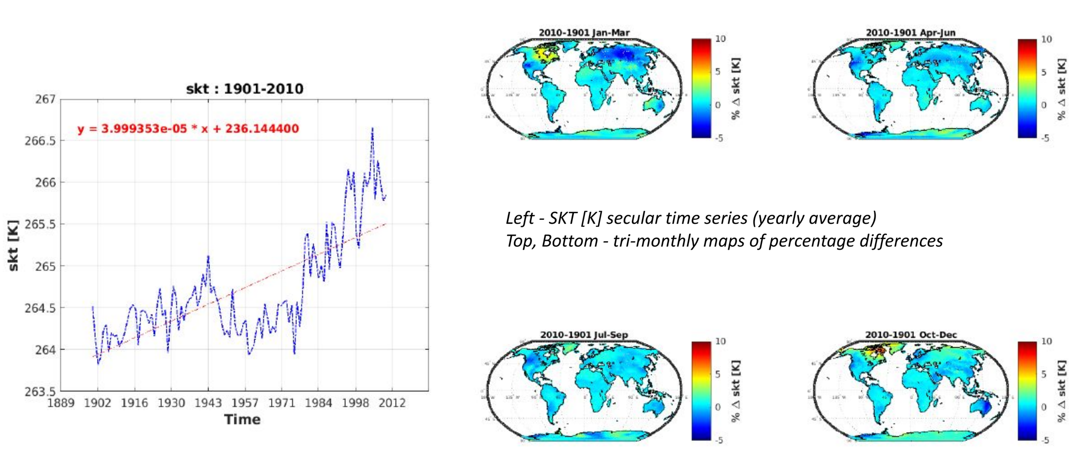
The OCO-2 instrument measures high-resolution spectra of the sun radiance reflected at the Earth's surface or scattered in the atmosphere. These spectra are used to estimate the column integrated CO_2 dry air mole fraction (XCO_2). Concentrations are estimated on a 3.75° × 2.5° (longitude-latitude) grid throughout the 40 years.

Methodology

The time series processing algorithm is based on two steps: firstly, the monthly data maps are spatially averaged; secondly, the algorithm removes the long-term trend on the entire data set month by month. This procedure is mainly used to remove a possible "global warming" effect, avoiding classifying a more recent year as anomalous precisely because of global warming. To remove this trend, each time series corresponding to the same month over all the years is analyzed separately, performing a linear fit of the studied CERA-20C variable for the single month of the year along the whole period (for example the temperature on January 1901, January 1902, January 1903,…, January 2010). The fit slope q (m) (i.e. the variation of temperature for the same month m, **Δ**T, per year) is then used to remove the long-term variation of the variable analyzed. A linear fit is a good trend considering the short period analyzed of 109 years in comparison to climate change. Furthermore, monthly maps were also generated for each variable, which express the percentage variation between the last year of the series and the first. This is to highlight particular behaviors of the observable at a spatial level in the entire time period.

Land Surface Temperature

The LST time series is depicted on yearly basis. The time series shows a general increment in the entire time period (109 year) estimated in about 2 K. Specifically, it results a moderate increasing in a first period (1901-1943) of about 1 K. A strong decrease occurs from 1943 to 1957 with a plateau up to 1978. A significative increasing results from 1978 up to 2010 with 1.5 K more. The spatial maps result from percentage difference (on tri-monthly basis) between 2010 and 1901.

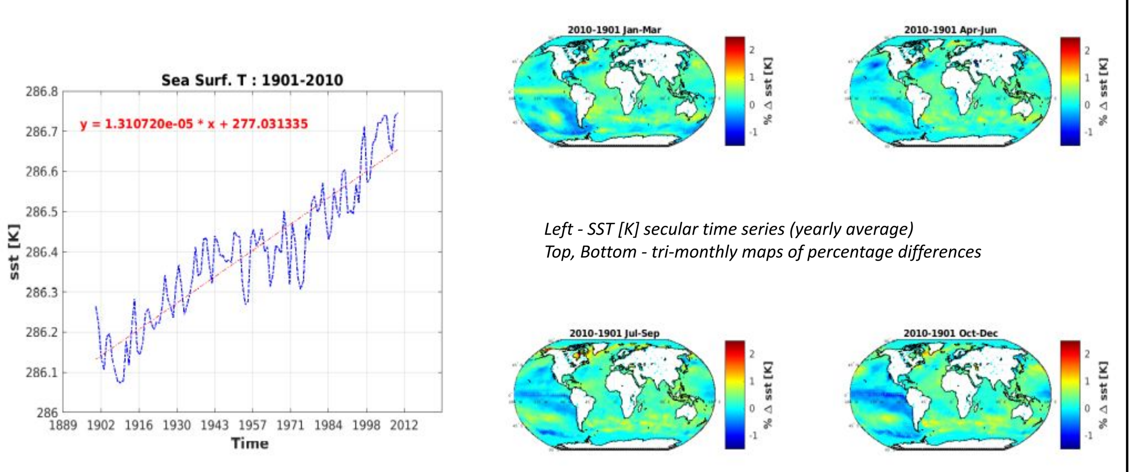


Left - SKT [K] secular time series (yearly average)
Top, Bottom - tri-monthly maps of percentage differences

Sea Surface Temperature

The SST time series is depicted on yearly basis. The time series shows a constant increment in the entire time period (109 year) estimated in about 0.5 K.

The spatial maps result from percentage difference (on tri-monthly basis) between 2010 and 1901. The maps show a colder temperature in the equatorial Pacific belts in the Antarctic area, for all months. Higher temperatures are found in the Atlantic area in the months Jan-Mar and Jul-Sep.

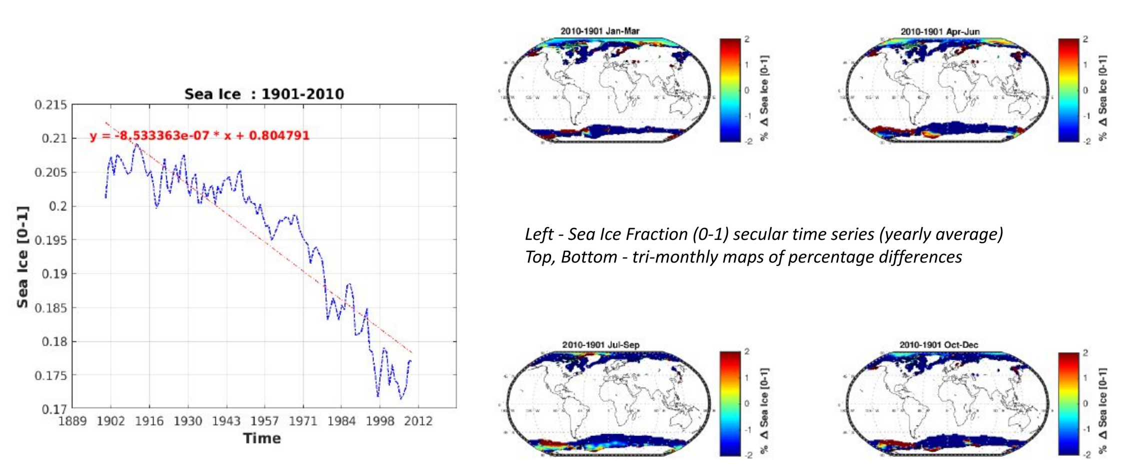


Left - SST [K] secular time series (yearly average)
Top, Bottom - tri-monthly maps of percentage differences

Sea Ice Fraction

The Sea Ice fraction yearly time series shows an almost linear decrease in the entire time period (109 year) estimated in about 0.038.

From the maps, we can see that the fraction of ice seems decreased in the Arctic and Antarctic areas and increased in the west part of Antartic continent.

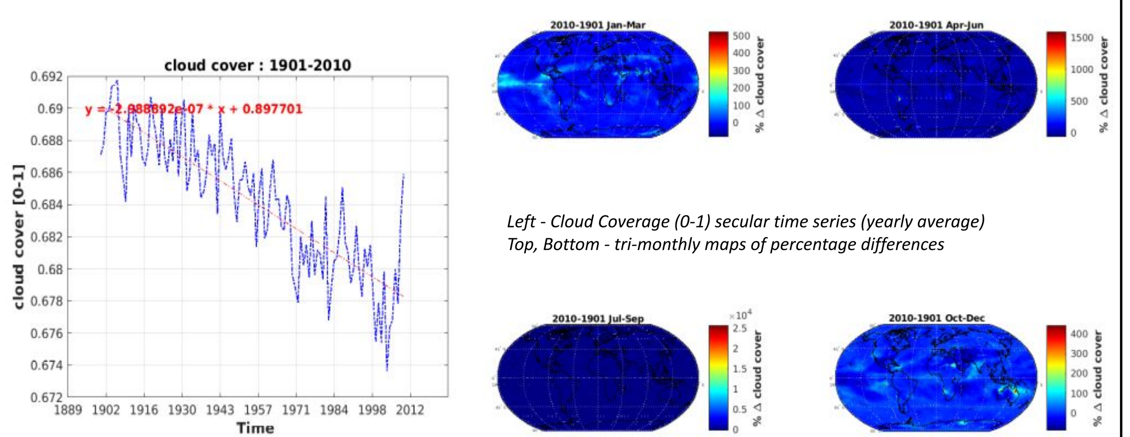


Left - Sea Ice Fraction (0-1) secular time series (yearly average)
Top, Bottom - tri-monthly maps of percentage differences

Cloud Coverage

The Cloud Cover yearly trend shows a constant decrease of 0.012 until 2008 when there was an increase up to 0.68.

The quarterly maps of percentage differences reveal a significant increase in the equatorial Pacific belt in the Jan-Mar period and in Australia for the Oct-Dec period.



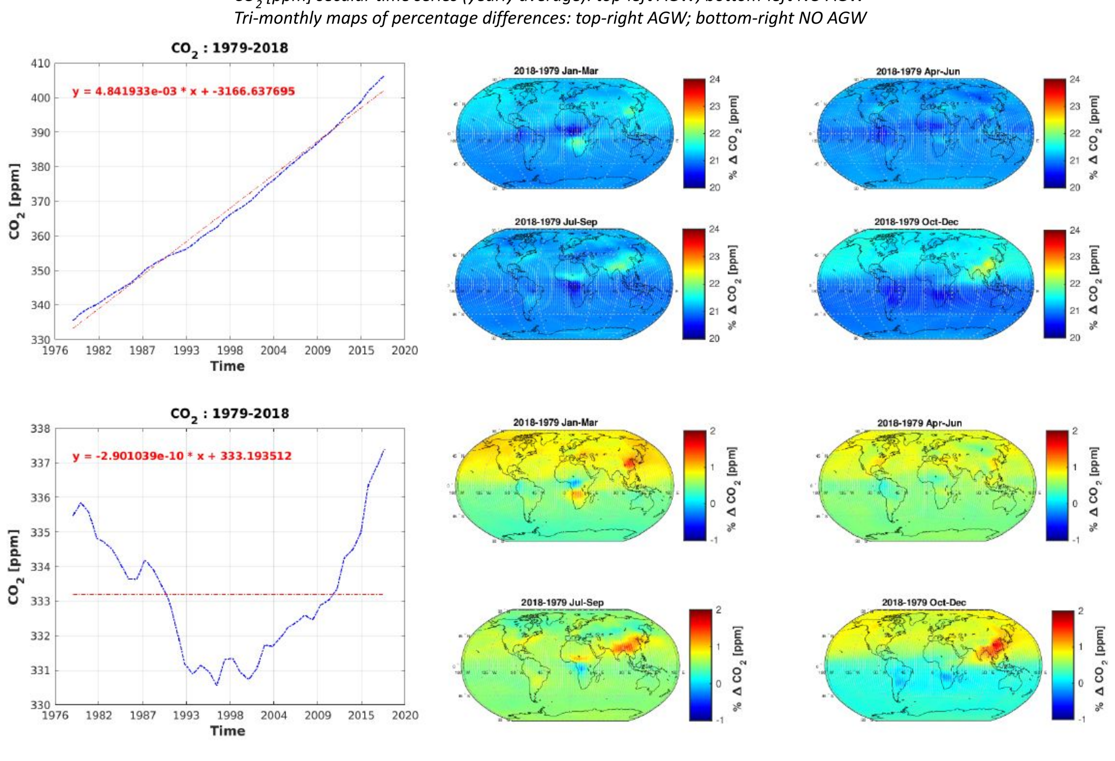
Left - Cloud Coverage (0-1) secular time series (yearly average)
Top, Bottom - tri-monthly maps of percentage differences

CO2

CO_2 yearly time series (1979-2018) show a constant increment of 70 ppm since 1979, with a rate of 1.8 ppm per year. If we consider the trend after eliminating the trend due to AGW, we note a decrease until 1998 and then a linear increase from here until 2018.

The tri-monthly maps of percentage differences highlight an increase in CO_2 concentration in the Northern Hemisphere, with a rather significant increase in Eastern Asia and Central South Africa, in particular in the periods Jan Mar, Jul-Sep and Oct-Dec.

CO_2 [ppm] secular time series (yearly average): top-left AGW; bottom-left NO AGW
Tri-monthly maps of percentage differences: top-right AGW; bottom-right NO AGW

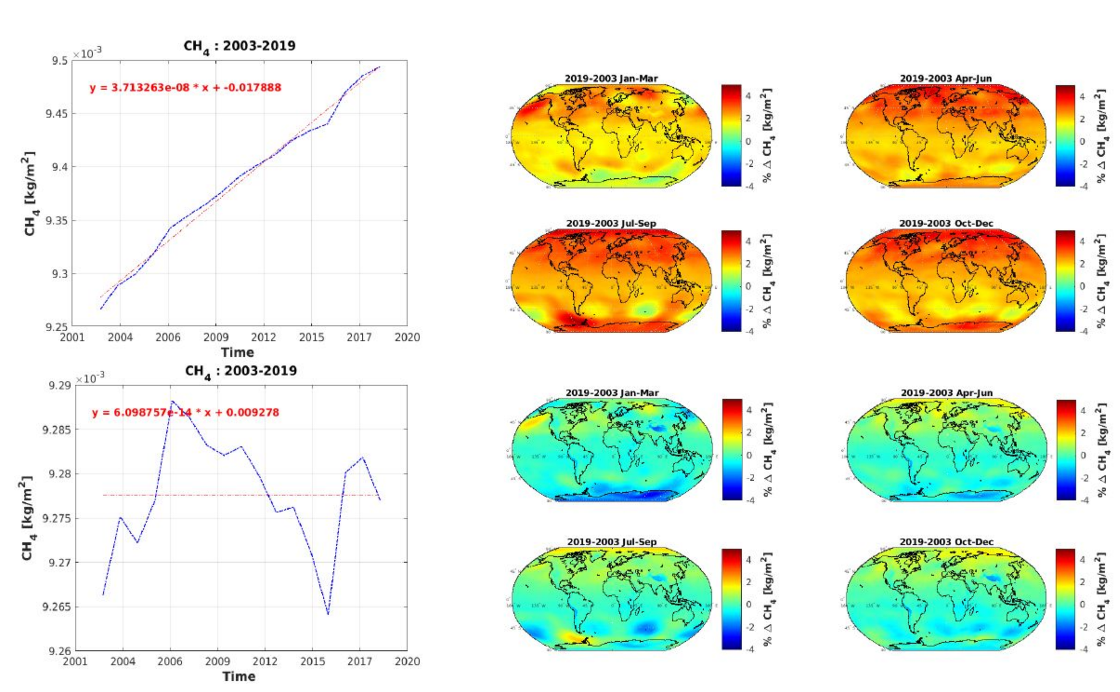


CH4

The yearly time series of CH_4 show, in the period 2003-2019, a linear increase from 9.25 to 9.50 Kg/m^2 with a rate of 0.016 Kg/m^2 per year. The behavior considering the exclusion of AGW reveals an oscillating trend from $9.265x10^{-3}$ up to $9.290x10^{-3}$ Kg/m^2.

The maps reveal a general percentage increase over the entire Earth surface, mainly in the Boreal and Antarctic belt. The maps without AGW show a decrease in the current concentration compared to 2003, of approximately 4%, in the Antarctic region in the Jan-Mar and Apr-Jun periods.

CH_4 [kg/m2] secular time series (yearly average): top-left AGW; bottom-left NO AGW
Tri-monthly maps of percentage differences: top-right AGW; bottom-right NO AGW

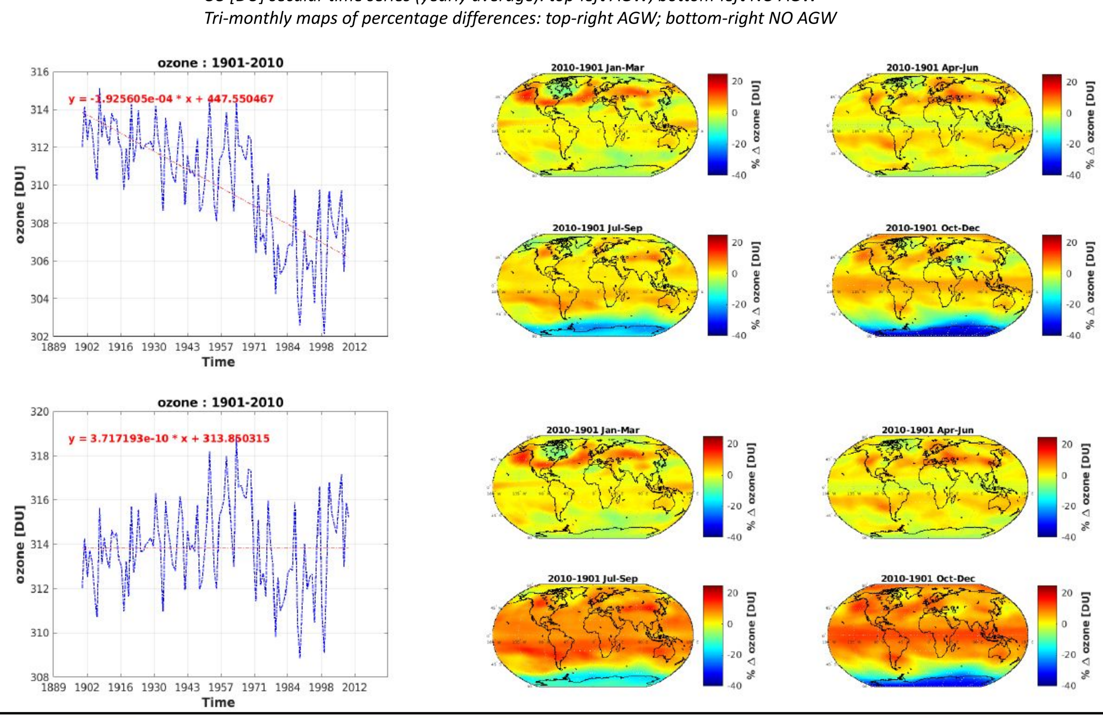


O3

O_3 yearly time series (1901-2010) show a decrease of 8 DU since 1901. If we consider the trend without AGW, we note a clearly increase from 70's years.

The tri-monthly maps of percentage differences highlight a strong decrease in Antarctic regions in the period Jul-Set and Oct-Dec.

O3 [DU] secular time series (yearly average): top-left AGW; bottom-left NO AGW
Tri-monthly maps of percentage differences: top-right AGW; bottom-right NO AGW



Conclusions

The trend analysis over all years (on monthly basis) of considered variables confirms the global warming thesis. First of all, the performed analysis puts into evidence the increase of approximately 1.5 °C in the global average Surface Temperature, compared to pre-industrial levels (from 1901 to 1940), as confirmed by the IPCC (Intergovernmental Panel on Climate Change). These growing trends are attributed to human intervention, the so-called AGW (Anthropogenic Global Warming). Moreover, an AGW removal technique applied to all years of the series allowed to analyse the variations of parameters due to natural cycles and local or temporally limited anthropic activities.

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