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Synchronous shifts in outgoing longwave radiation and their interpretation

Saltykov M.[1,*], Belolipetsky P.[1,2], Hari R. E.[3], Reid P. C.[4,5,6], And Bartsev S.[1]

[1]Institute of Biophysics, SB RAS, Akademgorodok 50/50, Krasnoyarsk, 660036, Russia

[2]Institute of Computational Modelling, SB RAS, Akademgorodok 50/44, Krasnoyarsk, 660036, Russia

[3]Emeriti of Eawag, Swiss Federal Institute of Aquatic Science and Technology, CH-8600 Duebendorf, Switzerland

[4]Sir Alister Hardy Foundation for Ocean Science, The Laboratory, Citadel Hill, Plymouth PL1 2PB, UK

[5]Marine Institute, Plymouth University, Drake Circus, Plymouth PL4 8AA, UK

[6]Marine Biological Association of the UK, The Laboratory, Citadel Hill, Plymouth PL1 2PB, UK

*corresponding author:

e-mail: saltykoff.mixail@yandex.ru

Abstract

Outgoing long-wave radiation (OLR) has increased substantially over the period 1979 to 2016. In time series averaged for northern and southern mid-latitudes two abrupt, synchronous and statistically significant step-like shifts (1988 and 1997/8) are shown to have occurred with only one shift in the tropics (1997). The timing of these events coincides with similar shifts recently described in a wide range of climate, Earth system and ecological time series. Surface temperature shows a very similar pattern of change to OLR in the northern mid-latitudes, but differs considerably in the southern mid-latitude belt. We demonstrate that low clouds are positively correlated with OLR and the reverse with medium and high clouds confirming that the growth in OLR can be explained via a reduction in cloud cover and atmospheric albedo.

Keywords: climate shifts, outgoing longwave radiation, troposphere, temperature, satellite measurements, clouds, albedo

1. Introduction

Outgoing long-wave radiation measured by satellites at the top of the atmosphere (TOA) is a fundamental parameter of the Earth's energy balance as the Earth only emits energy to space as OLR. OLR datasets are used in climatology (Knapp *et al.*, 2011; Davis & Rosenloff, 2013) and to test climate modelling (Turner & Tett 2014). In an updated energy budget (Wild *et al.*, 2015), of the 239 W/m^2 OLR only ~24% comes directly from the Earth's surface with most derived from the atmosphere. Natural (water vapour, clouds) and anthropogenic greenhouse gases (GHG) (CO_2, CH_4, N_2O) absorb longwave radiation reflected from the surface and re-radiate a proportion back to space as OLR. In a number of papers it has been shown that global climate change is at times monotonic, but has often a staircase-like pattern (Yasunaka and Hanawa, 2002; Chavez *et al.*, 2003; Lo and Hsu, 2010; Reid and Beaugrand, 2012; Jones, 2012; Belolipetsky *et al.*, 2015; Bartsev *et al.*, 2016; Reid *et al.*, 2016; Bartsev *et al.*, 2017; Jones and Ricketts, 2017). Belolipetsky *et al.* showed that this pattern was evident in global surface temperature anomalies for the period 1950-2014 with step shifts in 1987 and 1997 after adjustment for ENSO variability (Belolipetsky *et al.*, 2015). Reid *et al.* (2016) detected an analogous pattern in a range of climate and ecological parameters. Recently Jones and Ricketts (2017), in a comprehensive analysis of observations and models, discussed corresponding general physical conceptions.

Here we highlight connections between OLR, surface and tropospheric temperatures and clouds. We demonstrate that OLR averaged for mid-latitudes has the same staircase signal as previously observed for surface temperature and a range of other ecological parameters. Correlations between OLR and cloud cover allow us to propose that OLR growth can be explained via a reduction in total cloud cover and atmospheric albedo. Our discoveries will contribute to a better understanding of a rapidly changing climate.

2. Materials and methods

A number of different OLR datasets exist that are used in climate research. These include global data from the Nimbus Earth Radiation Budget (ERB), the Earth Radiation Budget Experiment (ERBE), the National Oceanic and Atmospheric Administration (NOAA) operational product, and the Clouds and the Earth's Radiant Energy System mission (CERES) (Lucas *et al.*, 2001). Each of these varying products has its own strengths and weaknesses with regard to accuracy, spatiotemporal sampling, and associated objectives. In this study the following datasets were used: OLR from the University of Maryland (UMD) (Lee *et al.*, 2007); cloud cover from the International Satellite Cloud Climatology Project (ISCCP) (Rossow and Schiffer 1991); HadCRUT4.5 surface temperature from the Hadley Centre of the UK Met Office and the Climatic Research Unit, University of East Anglia (Morice *et al.*, 2012); troposphere temperature anomalies from UAH MSU v6.0 (Spencer *et al.*, 2015). The OLR dataset is based on measurements taken by High Resolution Infrared Sounders and an advanced version carried by NOAA and Eumetsat satellites. All datasets were averaged to a grid of 2.5° x 2.5°, except HadCRUT4 at 5° x 5°. The ISCCP cloud dataset was divided into three categories in accordance with cloud top pressure: low clouds LC (1000-680 mb), medium clouds MC (680-440 mb) and high clouds HC (440-50 mb). Cloud cover was measured as percentage occurrence, thus total clouds TC is the percentage occurrence of all types of cloud (LC, MC and HC). Spatial correlations between each cloud type and OLR were assessed in order to analyze relationships between them. In order to detect regime shifts Hari's 'multiple sequential t-test' method (Reid *et al.*, 2016), improved but essentially the same, was used. First a running procedure tests each year of the whole time series (except some start and end years) as a possible shift year, by sequences of n years before a possible shift, and 1, 2 n years after a possible shift. Second, n varies from 6 years until as long as possible, with a maximum of half the length of the time series. Only if 50% of all n are significant is the year recognized as a shift year.

3. Results

Long-term changes in OLR averaged for three latitudinal belts: Northern Hemisphere mid-latitudes (30°N–70°N), tropics (30°S–30°N) and Southern Hemisphere mid-latitudes (70°S–30°S) are shown in Figure 1. The latitudinal belts were selected on the basis of atmospheric circulation with Hadley cells located in the tropics and Ferrel cells in the southern and northern mid-latitudes. In both mid-latitude belts the OLR time series exhibit two step-like shifts: 1988 and 1997/1998 (Figure 1a,c). The timing of these shifts is in good agreement with the global shifts described by Belolipetsky *et al*. (2015). Because of the smooth slightly exponential increase of atmospheric CO_2 during the examined time period no abrupt changes in OLR would be expected. In contrast, there was a substantial increase of about 4 W/m^2 in both mid-latitude belts. A similar disagreement between OLR observations and the HadAM3 climate model was noted by Allan and Slingo (2002). The most likely cause of the increase in ORL is a simultaneous change in cloud cover, as also suggested by Wild (2016) for decadal changes in incident solar radiation). A pointwise correlation between UMD OLR and ISCCP clouds in each cloud category and total cloud confirms their close relationship (Figure 2). As can be seen from Figure 2a, c, d, there is a highly negative correlation between OLR and TC, MC and HC over large areas of the globe. This means that OLR increases when MC and HC cover and the net effect as TC reduces (Figure 1) and can be explained by the influence these clouds have on the Earth's albedo. In contrast to LC, MC and HC consist of ice particles that have a minimal GHG effect, but block incoming shortwave solar radiation (Ramanathan and Collins 1991). In consequence surface temperature and OLR increase when MC and HC cover decreases and vice versa. A positive correlation between OLR and LC means that if low cloud cover increases OLR increases as well. That can be explained by two considerations: 1) that warmer air in the lower troposphere can hold more water vapour than colder air higher in the atmosphere and 2) that water vapour is the most potent GHG. What is rarely pointed out is that radiation is emitted in all directions from LC and also towards the TOA. Clouds reflect incoming solar shortwave radiation by 50 W/m^{-2} or 47.5 W/m^{-2}, but reduce the OLR by 20 or 26.4 W/m^{-2} with a net shading effect of about 20 W/m^{-2} (Kiehl & Trenberth, 1997, Stephens *et al.*, 2012). It is noteworthy that the northern and southern OLR time series are highly correlated (r 0.97) with a slightly greater amplitude in the north (Figure 3a). In contrast, the growth of surface temperature (and troposphere temperature, not shown) is markedly larger in northern compared to southern mid-latitudes, most likely reflects the greater area of land in the north (r 0.41, Figure 3c). Moreover OLR and surface temperature show a similar pattern of change in the north (r 0.93, Figure 3b), but are very different in the south (r 0.55, Figure 3d). Southern ORL correlates better with northern surface temperature (r 0.87) than with its own surface temperature (r 0.55). Synchrony of OLR shifts (Figure 1a,c) between greatly separated areas (north and south latitudinal belts) with very different ocean to land ratios suggests that at a global scale atmospheric processes associated with cloud cover are the main drivers.

4. Conclusions

We demonstrate that the long-term pattern of change in OLR over the period 1979 to 2016 for both north and south middle latitude belts is synchronous. In this period two abrupt shifts (1988 and 1997/1998) occurred in both mid-latitude belts, synchronous with previously detected shifts in surface temperature (Belolipetsky *et al*. 2015) and various other climate and ecological parameters (Reid *et al*. 2016). The existence of synchronous shifts in 1988 and 1997 in both temperature anomalies and OLR gives further proof of their reality and importance. We have also shown in a pointwise correlation on a global scale that OLR has a negative correlation with medium and high clouds over much of the world and is positively correlated with low cloud. These relationships allow us to propose that OLR growth can be explained via a reduction in total cloud cover and atmospheric albedo. The net effect of changes in cloud cover and both surface and troposphere temperatures has been a substantial increase in the OLR of mid-latitudes over the last few decades. This increase in OLR does not contradict the relationship between global warming and the growth in concentrations of GHG in the atmosphere. As well as GHG concentrations (including water vapour) OLR is dependent on several other factors that include temperature and, last but not least, cloud cover. More investigations are needed to produce a quantitative description of OLR behavior and its relationship to forcing factors. An explanation is also needed for the similarity of OLR behavior in both mid-latitude belts versus the contrasting behavior of temperature.

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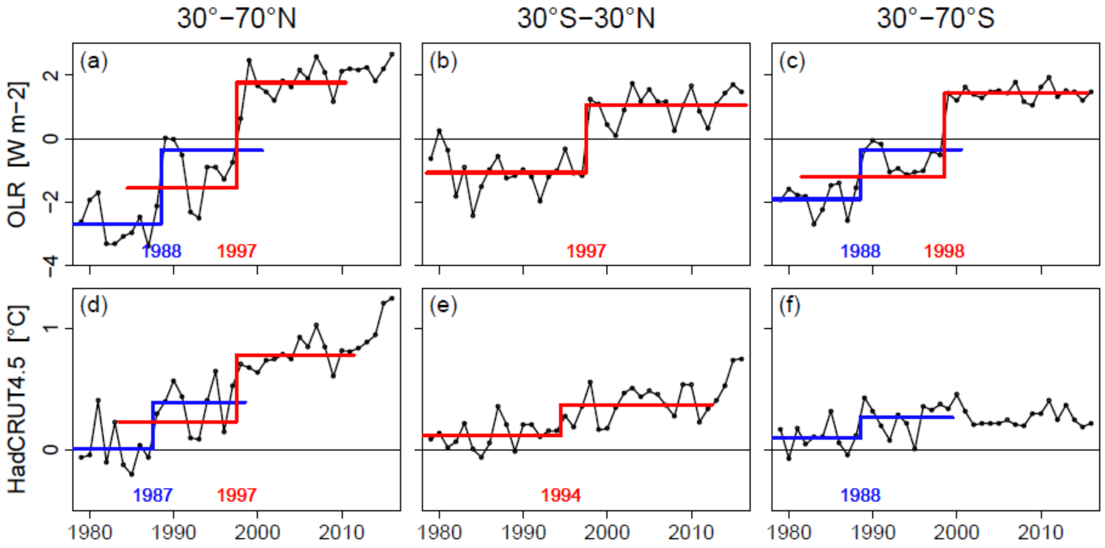

Figure 1. Shifts in OLR and HadCRUT4.5 combined land and sea surface temperature anomalies (respectively relative to 1979-2016 and 1961-1990). (a-c) OLR, (d-f) surface temperature. (a,d) northern mid-latitudes 30°-70°N, (b,e) tropics 30°S-30°N, (c,f) southern mid-latitudes 30°-70°S. Horizontal coloured lines mark the longest mean values of 'before-' and 'after-subsamples' used in the multiple t test, vertical coloured lines denote regime shift years (≥ 50% of possible tests were significant with $p \leq 0.05$). Black lines are annual values for the time period 1979 to 2016.

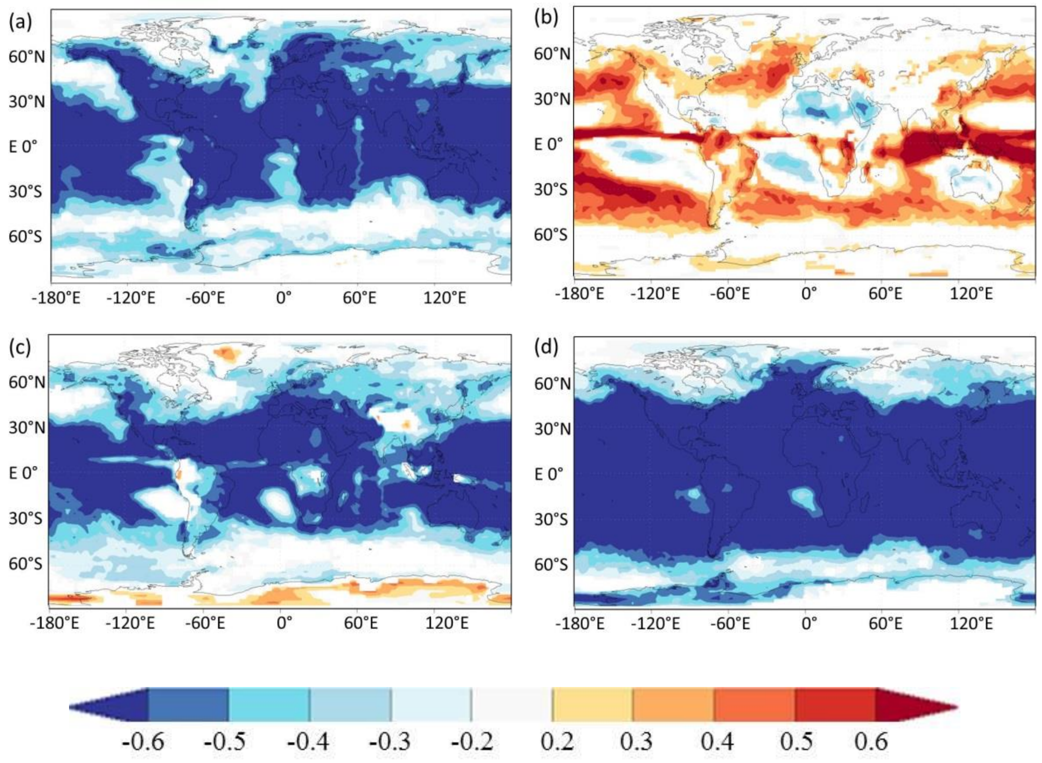

Figure 2. Pointwise correlation of OLR with: (a) all clouds, (b), low clouds, (c) medium clouds and (d) high clouds.

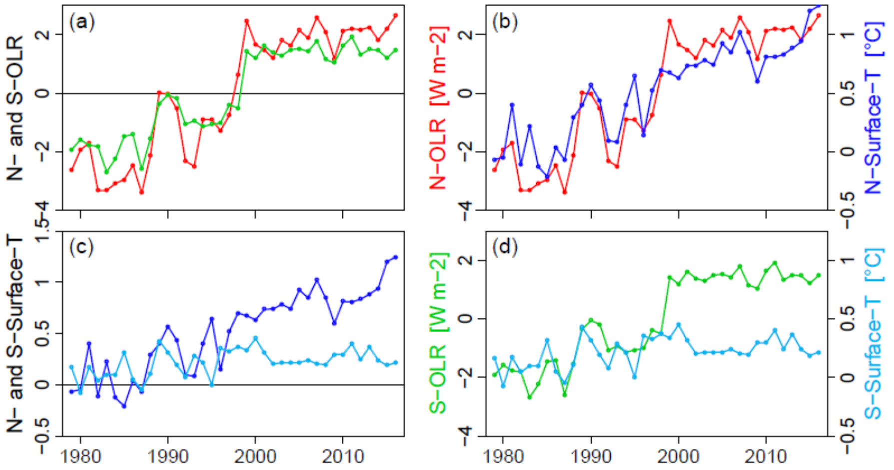

Figure 3. Comparison of OLR anomalies and HadCRUT4 surface temperature anomalies (relative to 1979-2016 and 1961-1990) at northern (30°-70°N) and southern (30°-70°S) mid-latitudes. (a) OLR for both mid-latitudes: northern (red) and southern (green). (b) Northern mid-latitude OLR (red) and surface temperature (blue). (c) Surface temperature for both mid-latitudes: northern (blue) and southern (pale blue). (d) Southern mid-latitude OLR (green) and surface temperature (pale blue).

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