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Short Communication

Comment on "Soon, W., and Legates, D.R., Solar irradiance modulation of Equator-to-Pole (Arctic) temperature gradients: Empirical evidence for climate variation on multi-decadal timescales" [J. Atmos. Sol.-Terr. Phys. 93 (2013) 45–56]

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ABSTRACT

The conclusion by Soon and Legates (2013) that "increase in solar radiation has caused an increase in both oceanic and atmospheric heat transport to the Arctic in the warm period since the 1970s, resulting in a reduced temperature gradient between the Equator and the Arctic", is discussed, and a different explanation of the results is proposed here.

Based on thermometer temperature records, Soon and Legates (2013) presented an empirical relationship between total solar irradiance (*TSI*) and the Equator-to-Pole (Arctic) surface temperature gradient (*EPTG*). They concluded that "any net increase in solar radiation has caused an increase in both oceanic and atmospheric heat transport to the Arctic in the warm period since the 1970s, resulting in a reduced temperature gradient between the Equator and the Arctic."

Their conclusion is based on the premise that "a *TSI* increase leads to an increase in the poleward atmospheric and/or oceanic heat transport which decreases the surface temperature gradients between the Equator and the Arctic (i.e. towards more positive values of the *EPTG* index shown in Fig. 1 of Soon and Legates (2013))."

The results shown on their Fig. 1 are interesting, however the interpretation given by Soon and Legates is questionable and, herein, we shall present another interpretation for those results.

The first question concerns Soon and Legates premise that a *TSI* increase should lead to an increase in the poleward heat transport and would decrease the surface temperature gradient between the Equator and the Arctic.

In fact, this premise is in contradiction with the common know how as reported by IPCC (2013) AR5 report which tells us that "under solar minimum conditions, there is less heating than average in the tropical upper stratosphere which weakens the Equator-to-Pole temperature gradient." Therefore, according to IPCC, a *TSI* increase should increase the Equator-to-Pole temperature gradient.

This IPCC statement is in full agreement with the interpretation we shall present later on.

The second question raised by Soon and Legates conclusions concerns the driving force for the poleward heat transport. When they claim that a poleward heat transport increase should decrease the Equator-to-Pole temperature gradient, what is the driving force for the poleward heat transport? We disagree with respect to that conclusion since, on the contrary, we claim that the main driving force for the poleward heat transport is the Equator-to-Pole temperature gradient and, consequently a smaller Equator-to-Pole temperature gradient means a weakened poleward heat transport.

In fact, the increased poleward heat transport requires a combination of increased *EPTG* with enhanced heat conductivity along the meridian. That is also the conclusion of Kukla and Gavin (2005) who stated: "…during the first millennia, the early glacial ice build-up was most likely accompanied by global warming. It was

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the associated increase of meridional insolation and temperature gradients, which were instrumental in the transition to a glacial."

To re-analyse interesting Soon and Legates results, let us first present our analysis of the relation between the Equator-to-Pole temperature gradient and the atmospheric properties, including solar radiation. That work is based on a simple thermodynamic model accounting for convection and radiation, thermal inertia and changes in solar radiation (through albedo ρ) and greenhouse factor γ (Clausse et al., 2012). The poleward heat current is driven by the buoyancy effect in the layer of fluid that covers the Earth's surface. It depends on the Equator-to-Pole pressure difference driven by the Equator-to-Pole temperature gradient. The heat balance performed on an infinitesimal latitudinal ring yields the excess heat current q in the ring which is convected towards the poles (the cold sinks) by the Earth's global circulation. The optimisation of the heat current is given by the constructal law (Bejan and Reis, 2005) which requires maximum heat flow at all latitudes. The latitudinal temperature T versus albedo (ρ) variations modulated by the Earth's greenhouse factor (γ) is given by (see Clausse et al. (2012))

$$\delta T = [\bar{T}/(1-\gamma)]\left[-(f\cos\theta/4\pi)(T_s/T)^4\delta\rho + (1/4)\delta\gamma\right] \tag{1}$$

where $\bar{T}$ is average surface temperature, T_s is the temperature of the Sun as a black body (~5762 K), f is the Earth–Sun view factor ($\sim 2.16\times10^{-5}$), θ represents latitude, ρ and γ stand for albedo and the greenhouse factor respectively.

The Equator-to-Pole Temperature Gradient (°C/degree latitude) is given by$EPTG = (T_P - T_E)/90$, where the subscripts P and E refer to Pole and Equator, respectively. By using Eq. (1) we are able to calculate the variation $\delta(EPTG) = (\delta T_P - \delta T_E)/90$ that respond to changes in the albedo, which reads

$$\delta(EPTG) = (1/90)[\bar{T}/(1-\gamma)]\left[TSI/(4\pi\sigma T^4)\right]\delta\rho \tag{2}$$

where $TSI = f\sigma T_s^4$. Note that $\delta(EPTG)$ while responding to changes in the albedo is modulated by the Earth's greenhouse factor γ, and TSI, which measures the amount of radiative solar energy incident on the whole Earth's upper atmosphere.

Eq. (2) shows that increase in the albedo provides a positive contribution to the $EPTG$, therefore contributing to the reduction of the absolute value of $EPTG$ (note that according to the definition above, $EPTG = (T_P - T_E)/90 < 0$, therefore the positive contribution from the increase in the albedo lowers the absolute value of the $EPTG$).

The global Earth's albedo is not easy to estimate, and only recently by using both satellite and earthshine data was possible to get reliable estimates (Pallé et al., 2009). As noted by Pallé et al. (2009) "…earthshine and flux data (FD) analyses show contemporaneous and climatologically significant increases in the Earth's reflectance from the outset of our earthshine measurements beginning in late 1998 roughly until mid-2000" and "…the trend toward an increasing terrestrial albedo seen in the earthshine is due to evolving cloud properties…". Moreover they showed that this trend likely occurred in the period (1998–2007) (see Fig. 2 in Pallé et al. (2009)).

In this way, and according to Eq. (2) a reduction in the $EPTG$ must have occurred in the period 1998–2007, and therefore might explain the results by Soon and Legates (2013) for that period. We do not analyse other periods represented in Fig. 1 of Soon and Legates (2013), due to uncertainties that affect albedo estimates prior to 1998. However we stress that our interpretation conciliates the results by Soon and Legates (2013), with those presented by IPCC and Kukla and Gavin (2005).

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