Ionospheric potential as a proxy index for global temperature

Ralph Markson a,*, Colin Price b

a Airborne Research Associates, 46 Kendal Common Road, Weston, MA 02493, USA
b Tel Aviv University, Ramat Aviv 69978, Israel

Received 15 December 1997; received in revised form 3 August 1998; accepted 15 November 1998

Abstract

Since the global circuit is maintained by currents from thunderstorms and electrified clouds, which are controlled by temperature, we are investigating the use of ionospheric potential \( V_1 \) as a measure of the variation of global temperature. We report positive correlation between \( V_1 \) and global temperature obtained from three different data sets. \( V_1 \) is also positively correlated with an inferred global lightning/deep cloud index which is positively correlated with global temperature. Thus, there is a consistent picture of warmer temperatures leading to more deep convection and higher \( V_1 \). Since a series of single \( V_1 \) soundings at any appropriate location may provide a globally representative measure of temperature variation in real time, it is suggested that routine monitoring of this parameter could provide considerable cost and operational advantages compared to current methodology involving observations at thousands of ground stations and satellite radiation measurements. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Ionospheric potential; Satellite; Surface temperature

1. Introduction

This is an interim report of an ongoing program to study the possibility of utilizing relatively simple and inexpensive measurements of the global circuit to monitor changes in global temperature. The ionospheric potential \( V_1 \), a measure of the totality of currents from all atmospheric electrical generators, is a simple scaler quantity which can
be determined from aircraft (Clark, 1958; Markson, 1976) or balloon (Mühleisen, 1971) electric field soundings. Because of convective activity leading to thunderstorms and electrified shower clouds, the generators maintaining $V_I$, are controlled by temperature, particularly in the equatorial zone, tropics and mid-latitudes. We have been investigating the possibility of using $V_I$ measurements to monitor global temperature variation.

The fact that $V_I$ is maintained by a natural phenomenon—deep convection and probably currents from less electrified shower clouds that cover a much larger fraction of the Earth’s surface than thunderclouds—is particularly appealing for observing atmospheric variability. One can consider $V_I$ data as in effect a remote thermometer in space continually taking the integrated average temperature of the Earth. (While most deep convection is at lower latitudes, Angell (1992) finds high correlation between radiosonde temperatures in the tropics and extratropical latitudes leading to the conclusion that tropical temperature variation is globally representative.) Satellite observations are subject to errors due to clouds, water vapor and other meteorological factors. Also, their instruments cannot measure surface temperatures in regions with clouds, the areas of most interest. The temperature records show significant short-term variations which may be affected by data collecting procedures. Monitoring $V_I$ variation may provide an independent parameter for comparison with temperature measurements both on the short-term as well as trends over decades. To obtain one globally representative $V_I$ measurement requires only a single sounding which can be obtained by two people in an hour. The measurement is available in close to real time.

The initial study of satellite cloud imagery compared to $V_I$ variation, (Markson, 1986) concluded that “$V_I$ time-series at just one location may provide a high-resolution measure of intense tropical convection”. Subsequent studies support this concept.

Williams (1992) reported an extremely nonlinear increase in tropical lightning rate when temperature rose above a critical threshold. This indicates a similar nonlinear sensitivity of thunderstorm activity to temperature. He also reported high correlation between monthly mean tropical surface air temperature and Schumann resonance measurements of global lightning activity. Williams (1994) continued analysis of global circuit response to global temperature variation and found both annual and semi-annual variations. He reports a 1°C (1/3%) increase in temperature results in a 10% increase in global lightning frequency.

Due to the lack of global lightning observations, Price and Rind (1992) developed an inferred index of global lightning activity using readily available satellite cloud data from the International Satellite Cloud Climatology Project (ISCCP). Price (1993) showed that global lightning frequency increased with satellite-derived global temperature. He suggested that a 1% increase in global surface temperature could result in a 20% increase in $V_I$.

The initial report of an ongoing program to investigate the relationship of $V_I$ to global temperature was by Markson and Lane-Smith (1994). Using radiosonde balloons, 31 electric field soundings of $V_I$ were obtained in August and September 1992. It was found that global temperature data from low altitudes correlated well with the $V_I$ measurements. The relationship was particularly pronounced with temperature data from the Americas continental region. This was probably because most of the soundings were obtained during the afternoon when temperature-forced convection maximized over the
Americas. In this period, thunderstorms from the Americas were the major contributor to the global generator. Lag analysis shows the correlation coefficient maximized for the temperature 2 h before the soundings. This is probably due to the time delay between maximum heating and maximum thunderstorm activity. An important factor in the time delay between heating and convective cloud development is that the outflows from the first storms trigger subsequent storms over a wider area.

2. Measurements and data analysis

Three global temperature data sets were utilized in the study reported here. The ISCCP data uses infrared (IR) measurements from several satellites. Surface temperatures from noncloudy pixels are used. Another data set is from the TIROS Operational Vertical Sounder (TOVS) using polar orbiting satellites employing a combination of IR sensing and microwave sounding systems. As with ISCCP data, surface temperatures are derived from blackbody radiances in clear areas. Only one global temperature is provided for each day. The National Meteorological Center (NMC) data set consists of in situ thermometer readings at ground stations. These data are biased toward mid-latitudes in the Northern Hemisphere where most of the stations are located.

The Inferred Global Lightning Index was derived by Price and Rind (1992) from ISCCP data by quantifying the clouds with optical depth greater than 23 above 440 mb. It assumes that lightning frequency over the ocean is proportional to the 1.7 power of cloud height (derived from cloud top temperature) and over land, the frequency is proportional to the 4.9 power. Thus, this index is basically a measure of the variation of deep continental convection. The index has a time resolution of 3 h, the resolution of the ISCCP data.

The \( V_1 \) data have been obtained by Markson during a dozen field programs starting in 1971 which have been continued at irregular intervals until the present (Markson, 1976; Markson, 1985; Markson and Lane-Smith, 1994; Markson et al., 1996). The measurements analyzed here were for the period when the earliest ISCCP temperature data became available in July 1983 extending through 1990. They include 69 measurements on 29 different days. The first 56 soundings were made with aircraft, the last 13 were made with balloons.

3. Results and discussion

3.1. Ionospheric potential–inferred global lightning / deep cloud relationship

Fig. 1 illustrates the relationship between the global lightning/deep cloud index and \( V_1 \) data on 29 days between July 1983 and September 1990. The Global Lightning Index data used are only for 1500 LST at all global locations since this is the time of maximum convection. The correlation coefficient is 0.59 \( (p < 0.001) \). This is to be expected since high clouds are associated with the global electrical generator.
3.2. Ionospheric potential–global temperature relationship

In order to insure data independence, only measurements that were separated from each other by at least 5 days were utilized. This reduced the available number of $V_I$ observations; however, as shown in Fig. 2a–c, significant positive correlations exist. These figures resulted from analysis of the three different data sets described earlier. Fig. 2a utilizes the ISCCP data, Fig. 2b is for the TOVS data, and Fig. 2c is for the NMC surface data. In each case, $V_I$ shows a similar sensitivity to temperature with each independent data set. A one degree warming corresponds to about a 13 kV increase in

![Graph](image)

Fig. 1. The relationship between ionospheric potential measured at a single location and a globally integrated lightning index derived from deep, mostly continental clouds. When more than one ionospheric potential measurement was made on a given day, these data were averaged.

Fig. 2. The relationship between ionospheric potential and global surface temperatures derived from (a) ISCCP satellite data, (b) TOVS satellite data, and (c) NMC ground-based temperature data.
V_i. Put differently, the sensitivity is such that a 1% increase in temperature (3°C) corresponds to about a 15% (33 kV) increase in V_i.

This result can be compared with the estimate of Price (1993) that a 1% change in global temperature would cause a 20% change in V_i. At this time, we are uncertain regarding the precision of V_i measurements and airplane measurements appear to be more reliable than those made from balloons (see companion paper in this volume). It is estimated that aircraft data have a precision of better than +/− 5% (Markson, 1985) and balloon data should be about +/− 5% under favorable meteorological conditions. Assuming +/− 5% precision, this would translate to 1/3% uncertainty (1°C) in global temperature. This precision can be applied to short-term temperature variations. The literature on global warming has focused on long-term variations so the various sources of fluctuations are filtered out. It is unclear what sort of resolution is possible from the existing satellite and surface data collection methods for short-term monitoring of global temperature, but it seems possible that the real time high precision of V_i-inferred observations may be useful for forecasting and weather research. For example, a large volcano could have a rapid effect on global temperature which could be observed with V_i measurements. The volcanic aerosol would affect satellite-derived surface temperature data and its possible affect on the global circuit would also have to be considered. This could be measured.

There are several advantages in being able to monitor global temperature variation indirectly through changes in the global circuit. The literature contains numerous discussions on the limitations and sources of error in surface measurements. The tropics, the region of particular interest for global change studies, is undersampled compared to mid-latitudes. The number of stations reporting surface temperatures on a given day vary from 1000 to 6000. These data must be obtained and transmitted to central repositories for analysis and subsequent dissemination. Satellites may provide a better way of observing global temperature variation than surface thermometer measurements because they sample the Earth more uniformly, but they have their own sources of error.

Acknowledgements

This work was supported in part by the National Science Foundation under Grant No. DMI-9304487, ‘New Technology for Monitoring Global Change’.

References

Angell, J., 1992. Personal communication. NOAA/Climatic and Global Change Program. Silver Spring, MD.