Anomalous Global Redistribution of the Earth Radiation Budget Components

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Abstract – Time-series of global outgoing radiation fields have been reconstructed for the last 20 years using satellite observations from various space systems including some Russian systems. It was detected that during the past two decades global outgoing longwave radiation (OLR) increased (considerably energy, emitted from the tropics and certain region of the northern hemisphere). The reflected solar radiation decreased by a smaller amount. Time domain (1985-1986) for beginning of cardinal redistribution of global characteristics for outgoing longwave and shortwave radiation has been established. Based on time-series satellite observations of global OLR fields, statistical models have been elaborated for spatial and temporal variability of the main ERB component. Typical spatial & temporal structures of the OLR anomalies describing dynamics of specific processes in the radiation field of the Earth have been identified while utilizing techniques of MSSA and POP analysis. An opportunity has been used of medium range prediction for spatial distribution of OLR in different latitudinal zones while taking these structures into account.

Keywords: Earth Radiation Budget, Outgoing Longwave Radiation, Albedo Change, Geostatistical Data-Analysis, Mathematical Modeling.

1. INTRODUCTION

The Earth radiation budget (ERB) at the top of the atmosphere (TOA) is a key parameter that measures the energy exchange between the Earth climate system and space. The long time-series of highly accurate radiation data provides a basis for scientific understanding of the mechanisms and factors that determine long-term climate variations and trends.

1.1 The ScaRaB mission

The Scanner for Radiation Budget (ScaRaB) is a cooperative project of Russia, France and Germany. The two flight models of ScaRaB instruments were integrated on the Russian satellites Meteor-3/7 and Resurs-01/4 (Kandel et al., 1998; Duvel et al., 2001; Golovko et al., 2003b). ScaRaB partly filled a gap in polar narrow-field-of-view coverage that otherwise would extend nearly 10 yr in the 1990s. The objective of this program was to make space measurements of the ERB in complement to those provided by the Earth Radiation Budget Experiment (ERBE) and the Clouds and Earth Radiant Energy System (CERES) missions.

Broadband radiance measurements made by the ScaRaB/Resurs instrument exhibit strong consistency with earlier ERB measurements, while at the same time revealing significant regional and zonal anomalies specific to the 1998/99 El Niño–La Niña transition. There is excellent agreement with the CERES/TRMM instrument, as demonstrated by direct comparison of simultaneous collocated codirectional broadband radiance measurements (Duvel et al., 2001). The highly accurate ScaRaB/Resurs broadband radiances are therefore valuable for case studies of the natural hazards related to 1998 El Niño events or in complement to field experiments such as the Indian Ocean Experiment (INDOEXP) in a period with no other ERB scanner in operation. This dataset makes it possible to quantify the regional radiative anomalies in the winter of 1999, particularly in regard to the La Niña phase of the Southern Oscillation.

1.2 Earth radiation budget observations for climate research

Outgoing radiation (OR) is one of major climatological factors, which determines in a great degree dynamics of natural phenomena in the underlying surface-atmosphere system of the Earth (Golovko et al., 2000a,b). Space monitoring of OR characteristics is considered as an important element of global observations for the practical purpose of outlining of current conditions of the climatic system and serves as a main information product for diagnostics and predictability of climate change. Any detection of climatic signals regarding energetic processes and the relevant identification of their relationships with anomalous natural phenomena is based on temporal data sets of space observations of the Earth Radiation Budget (ERB) components.

Time-series of global OR fields have been reconstructed for the last 20 years using satellite observations from various space systems including some Russian systems. Based on these data, statistical models have been elaborated of spatial and temporal variability of the ERB components; the obtained results could reflect many characteristic features of the anomalous natural phenomena in the dynamically unstable climatic system (Golovko et al., 2003a-e). Typical temporal & spatial structures of the OR anomalies describing dynamics of specific processes in the radiation field of the Earth have been identified while utilizing techniques of Multichannel Singular Spectrum Analysis (MSSA) and Principal Oscillation Pattern (POP) analysis.

As a research result of the ScaRaB project, several mathematical models have been elaborated for spatial & temporal variability of the Earth outgoing radiation (Golovko et al., 2003a,e). These models describing dynamics of specific processes in the radiation field of the Earth could diagnose the basic characteristics of radiation change and realize the medium range prediction of outgoing radiation (up to six months). Observed data indicate that the energy components of ERB were varied substantially in the past two decades. The current investigations are critical for improving our scientific understanding whether these changes represent a long-term trend or are part of a natural fluctuation that will reverse itself.

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2. ANOMALOUS CLIMATIC CHANCE OF THE ERB COMPONENTS

2.1 Trends

It was detected (Duvel et al., 2001) that during the past two decades global outgoing longwave radiation increased (considerably energy, emitted from the tropics (Chen, 2002; Wielicki, 2002) and certain region of the northern hemisphere). As we see in Fig. 1, global LW flux trend was about 4.4 Wm^{-2} pea decades (Golovko, 2003).

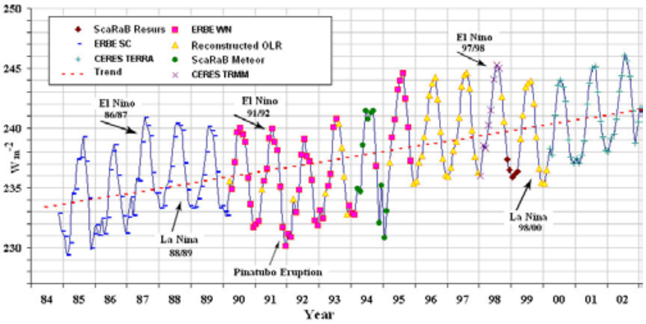

Figure 1. Reconstructed monthly mean global values for the outgoing LW radiation for the past two decades and main natural phenomena for this period.

Regional (2,5º × 2,5º) OLR trends are shown in Fig. 2. Absolute maximum and minimum (most positive and negative regional trends) were located in Tropics. So maximum of positive trend (11.8 Wm^{-2}/decade) was observed over East Indonesia (1.25º S, 161.25º E) and maximum of negative trend (– 2.5 Wm^{-2}/decade) – over North-West Indonesia (11.25º N, 96.25º E). Also shown in Fig.2 are several extensive regions with large positive trends near the Middle East, China, Mongolia, the USA and Brazil. For example, positive trend over southeast Iran (11.2 Wm^{-2}/decade) only is slightly less than absolute maximum. Significance of the detected trends has been proved based on statistical tests.

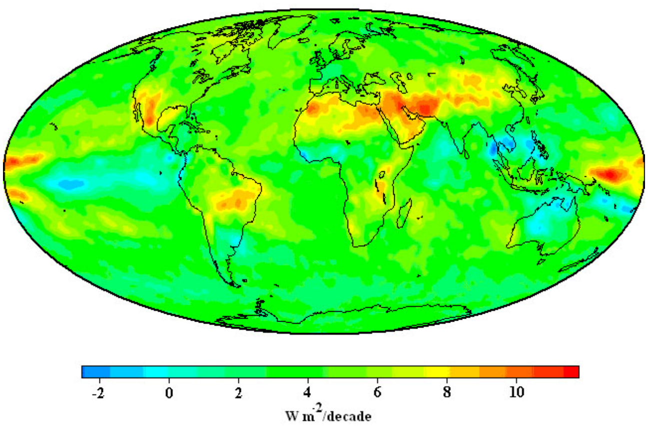

Figure 2. Regional trends of the outgoing LW radiation for the past two decades.

The reflected solar radiation during the last two decades was decreased by a smaller amount. Mutual evolution of the outgoing longwave and shortwave radiation anomalies for this period is shown in Fig. 3. More details may be found in the paper (Golovko, 2003).

2.2 Evolution of the outgoing LW and SW radiation

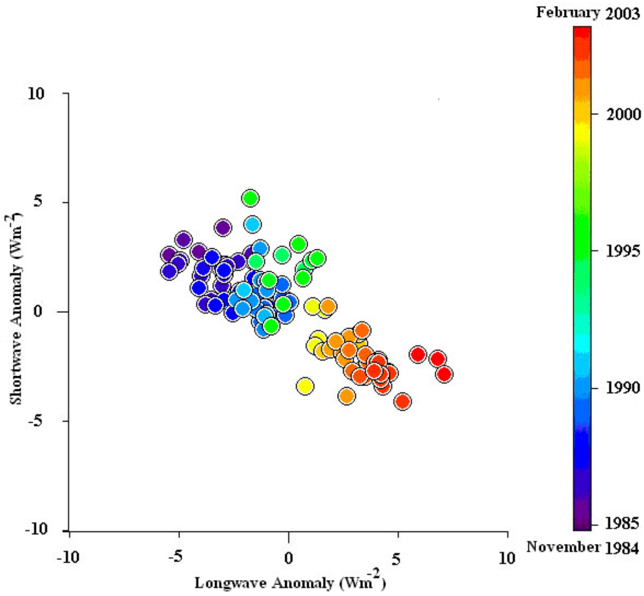

Figure 3. Mutual evolution of the outgoing LW and SW radiation anomalies for the last two decades.

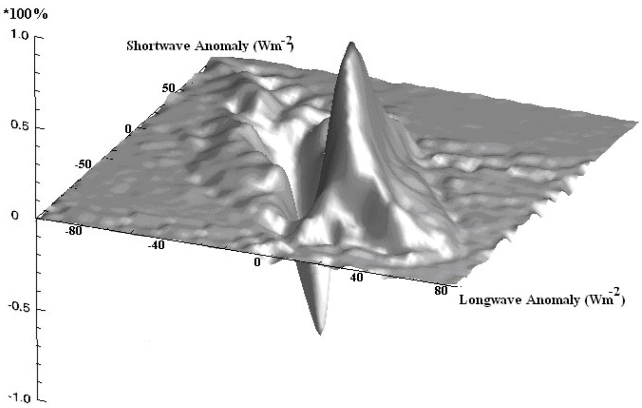

Figure 4. Correlation map for the first singular vector, explained most variance of two-dimensional histogram for outgoing LW and SW radiation anomalies.

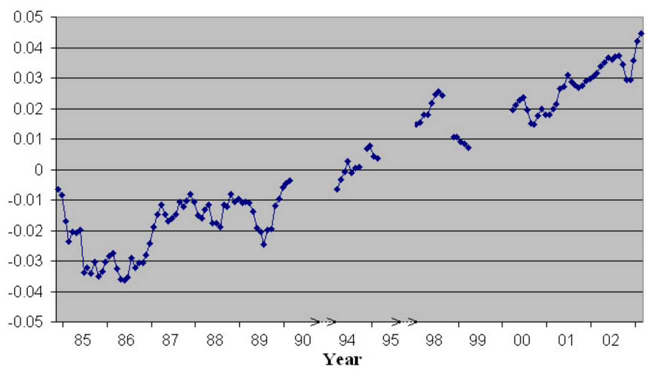

Figure 5. First principal component (time dependence), corresponding to the first singular vector, explained most variance of data (see Fig. 4).

3. MATHEMATICAL MODELING FOR SPATIAL&TEMPORAL VARIABILITY OF OUTGOING RADIATION FIELDS

Spatio-temporal statistical methods have been applied extensively in the climatological sciences. The climate system is composed of many processes that exhibit complicated variability over a vast range of spatial and temporal scales. Data sets of measurements collected on this system are typically very large and their analysis typically requires dimension reduction in space and/or time. Descriptive statistical techniques aid in the summary and interpretation of these data. The focus here is on a subset of two of the most useful methodologies: Multichannel Singular Spectrum Analysis (MSSA) and Principal Oscillation Pattern (POP) Analysis. Details of these statistical investigations may be found in the full text paper (Golovko, 2004).

3.1 Problem of Climate Signal Detection

The motivation for exploratory methods of data analysis in climate comes from the need to separate the climate "signals" from the background climate variability or "noise". This decomposition of the data is done with the hope of identifying the physical processes responsible for the generation of the signal. A fundamental characteristic of the statistical methods for signal detection is their ability to represent spatially distributed data in a compressed way such that the physical processes behind the data, or their effects, can be best visualized by the researcher. Signal detection in climate is useful to achieve four main goals in climate research: 1) to recognize the patterns of natural climate variability and distinguish them from presumed anthropogenic or other external effects, 2) to use the physical mechanisms inferred from the detected signals to construct numerical climate models, 3) to validate numerical climate models by comparing the fundamental characteristics of the modeled data with those of the observed data, and 4) to use the signals themselves to forecast the behavior of the system in the future. For all these reasons, the detection and description of climate signals represents a problem of increasing interest in the scientific community.

3.2 Multichannel Singular Spectrum Analysis (MSSA)

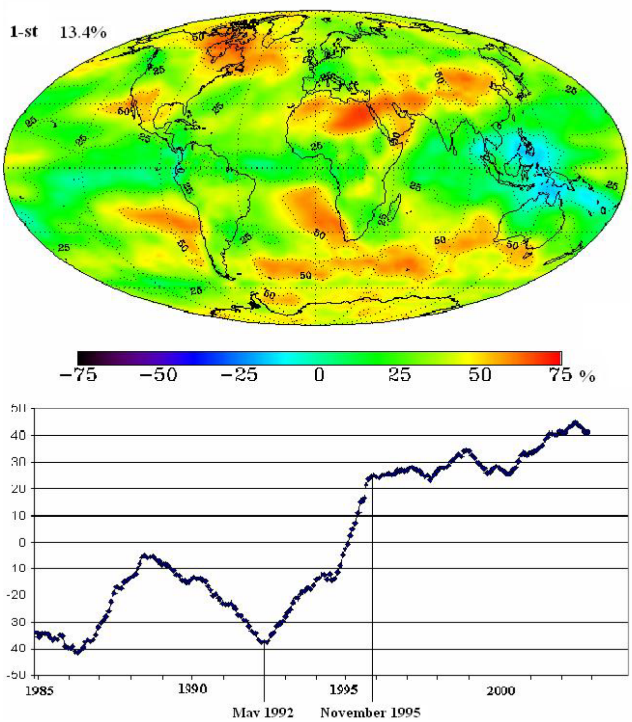

Figure 6. Correlation map for the first singular vector (spatial structure) and first principal component (time dependence), explained most (13,4%) variance of global outgoing LW radiation anomalies.

3.3 Principal Oscillation Pattern (POP) Analysis

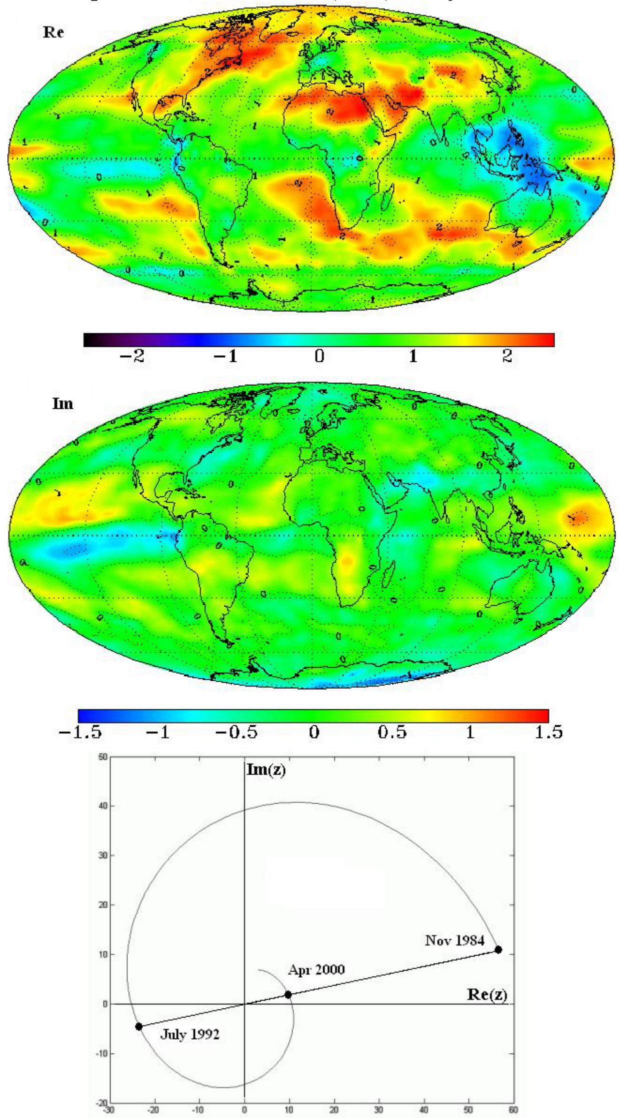

Figure 7. First principal oscillation pattern represented by real (top) and imaginary (middle) parts, as well as schematic diagram of the time evolution (bottom) for global outgoing LW radiation anomalies.

3.4 Forecast of outgoing radiation fields

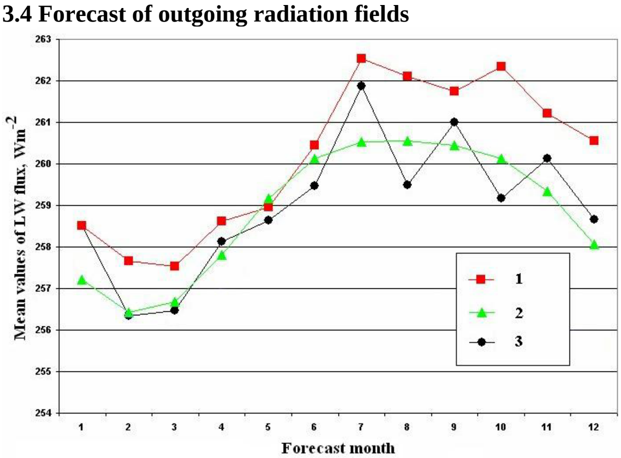

Figure 8. Quality of the forecasts for 12 months of OLR integral values for Tropics by two methods (MSSA-1, POP-2, observed - 3).

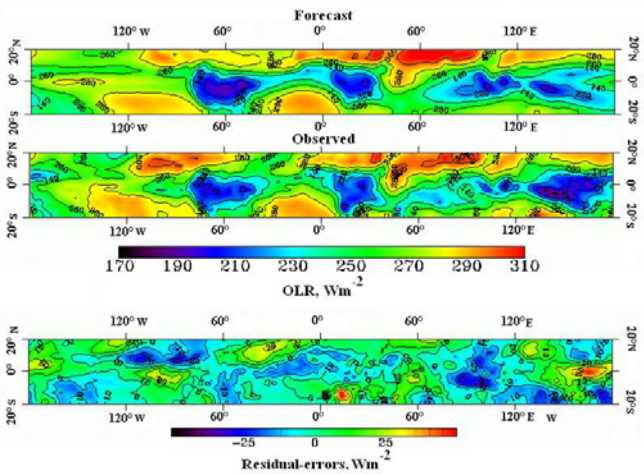

Figure 9. Forecast field (for 5 months) by POP predictive technique and observed OLR values for Tropics as well as residual-errors.

4. CONCLUSIONS

Time-series of global outgoing radiation fields have been reconstructed for the last 20 years using satellite observations from various space systems including some Russian systems. Observed data indicate that the energy components of the Earth radiation budget were varied substantially in the past two decades. It was detected that during the 1990s global outgoing long-wave radiation increased (considerably energy, emitted from the tropics and certain region of the northern hemisphere). The reflected solar radiation decreased by a smaller amount. Significance of the detected trends has been proved based on statistical tests. Time domain (1985-1986) for beginning of cardinal redistribution of global characteristics for outgoing long-wave and short-wave radiation has been established. The current investigations are critical for improving our scientific understanding whether these changes represent a long-term anomalous trend for climate system or are part of a climate natural fluctuation.

Based on time-series satellite observations of global outgoing longwave radiation (OLR) fields, statistical models have been elaborated for spatial and temporal variability of the main Earth Radiation Budget (ERB) component; the obtained results could reflect many characteristic features of the anomalous natural phenomena in the dynamically unstable climatic system. Typical temporal & spatial structures of the OLR anomalies describing dynamics of specific processes in the radiation field of the Earth have been identified while utilizing techniques of Multichannel Singular Spectrum Analysis (MSSA) and Principal Oscillation Patterns (POP) analysis. An opportunity has been used of medium range prediction for spatial distribution of OLR in different latitudinal zones while taking these structures into account.

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