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SHORT CONTRIBUTION

Meteosat data as an index of fluctuations in Earth radiation budget on weekly and monthly time scales

GARTH W. PALTRIDGE

CSIRO Division of Atmospheric Research, Aspendale, Victoria, 3195, Australia

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Studies of the overall thermodynamic and "chaotic" behaviour (Ruelle, 1985) of the Earth-atmosphere climate system require long time-series of the total solar radiation absorbed by the system and of the total infrared radiation emitted by the system. The series should extend for several years in order to examine fluctuations of net energy input on time scales of several days to several months. Such scales encompass the thermodynamic time constants (Lettau, 1954) of the atmosphere ($\sim$ 1 to 2 weeks) and the mixed layer of the oceans ($\sim$ 2 to 3 months). The Earth Radiation Budget Experiment (ERB-E) on polar-orbiting satellites (ERBE Science Team, 1986) can be expected to produce this sort of information. However, there are difficulties associated with calculating a consistent global-average ERB from the mosaic of measurements from satellites in low polar orbit (Paltridge, 1987) and it will be some time before suitable time-series are produced from their data. This note reports order-of-magnitude estimates of the natural variability of the ERB obtained from year-long time-series of visible and infrared radiance measurements by Meteosat - a geostationary satellite positioned permanently at 0° longitude over the equator at an altitude of 35,000 km.

These particular time-series are the first such series to be obtained as a by-product of the International Satellite Cloud Climatology Project (ISCCP - see, for instance, Schiffer and Roscow, 1983). Ultimately this project will yield 5 years of intercalibrated radiance data (and hence cloud cover information) from all five of the geostationary meteorological satellites. The ISCCP is relevant to studies of Earth Radiation Budget because fluctuations in cloud amount and cloud character are the major cause of fluctuations in net radiant energy input to the system. Note that "fluctuations" in the context of this work are internally generated variations in total radiant energy input and output of the system: They do not refer to the regular daily and seasonal cycles associated with the Earth's rotation and with the seasonal change in the declination of the Sun.

The raw data from Meteosat are of the reflected solar radiance between wavelengths of 0.4 and 0.7 μm in the visible region of the spectrum and of the emitted radiance between 10.5 and 12.5 μm in the far infrared region of the spectrum. The pair of time series examined here are of the full-Earth-disc spatial averages of these visible and infrared radiances obtained every day at noon GMT - that is, when the maximum area of the Earth's disc as viewed by Meteosat is sunlit. They are presented in

Fig. 1. Each series covers the 344 days from July 1, 1983 to June 8, 1984. The visible radiance is expressed as a reflectance (i.e., as a fraction of the annual mean incident solar flux density), and the infrared radiance is expressed in terms of its equivalent black body temperature.

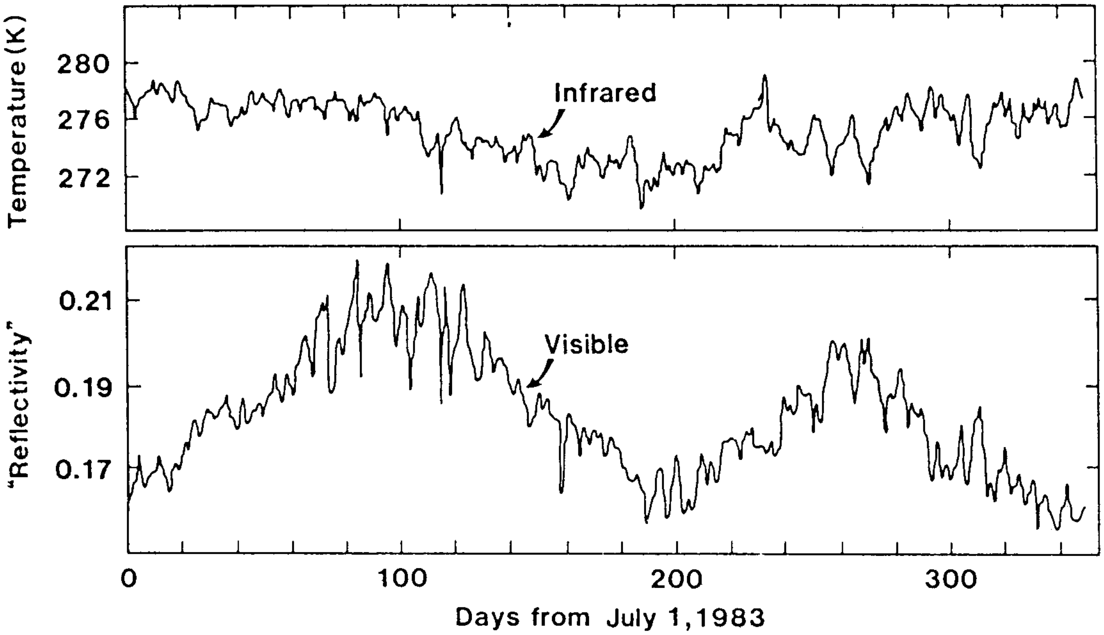

Fig. 1. The time-series obtained from Meteosat from July 1, 1983 to June 8, 1984. They are of full disc averages of noon GMT visible radiance (expressed as a reflectivity) and infrared radiance expressed as an equivalent black-body temperature. Five days of missing data have been replaced by the values of the previous day. The original pixel radiance values have 8-bit precision, and calibration consistency has been maintained by reference to underflights of the AVHRR instrument on the NOAA polar orbiters.

There is an obvious semi-annual cycle in the visible series which reflects the variation in total illuminated area of the Earth's disc as the Sun moves north and south. The annual variation in the infrared series with its minimum during the Northern Hemisphere winter reflects (presumably and among other things) the effect of solar declination on the daytime temperature of the major land masses. In any event these long-period cycles were filtered out of the data by a filtering procedure in the Fourier plane described later. This done, the r.m.s. deviation of fluctuations with periods shorter than 100 days is 0.0062 for the visible series and 1.12 degrees for the infrared series. A chi-squared test suggests (with 95% confidence) that the fluctuations are not normally distributed - the "mean fluctuation" does not appear as often as in a normal distribution. There is a small (0.25) but highly significant negative correlation between the filtered data of the two series, as is to be expected if the fluctuations derive primarily from cloud variability. (Thick cloud generally has high solar reflectivity and low top temperature - vice versa for thin cloud).

Standard fast-Fourier-transforms were performed on the data sets after the means and linear trends were removed. A high-pass filter was applied to the transforms (see caption to Fig. 2) to remove "power" at periods longer than 100 days. The data points in Fig. 2 are of the raw (but filtered) power spectrum of the infrared series and show highly variable power as a function of frequency. The raw "visible" power spectrum is similar. The curves in Fig. 2 are the smoothed power spectra of each of the data sets. The smoothing (of the filtered spectra) was performed only for the purpose of display in this figure so as to illustrate most easily the basic characteristics common to both the visible and infrared spectra; namely, a bunching of high-power spectral data points in bands centred (roughly) on periodicities of 50 days, 15 days, 10 days and 5 days. The significance of the 10- and 5-day periodicities is doubtful because (among other things) there are features of the spectra in that region which are not common to both the visible and infrared series. However, all these characteristic periods have been observed elsewhere in atmospheric behaviour and have been related in one way or another to dynamical processes in the system (Lau and Chan, 1985; Salby, 1984).

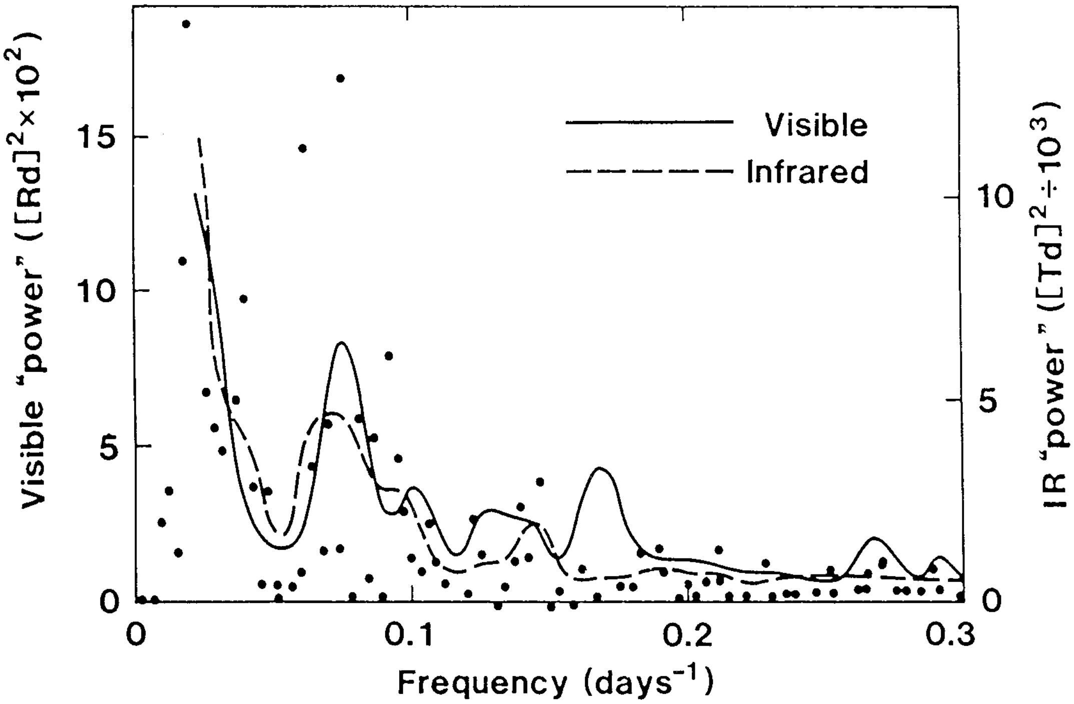

Fig. 2. Data points are of the "raw" power spectrum of the infrared series after application of a high pass filter to the Fourier transform. The filter had zero transmission at frequencies $\leq$ 0.0057 days^{-1}, and 100% transmission at frequencies $\geq$ 0.0115 days^{-1}. Tests showed that no significant noise was generated (in the real time plane) either by this filter or by mismatch of the end points of the series. The solid and dashed curves are of the smoothed power spectra of the visible and infrared time-series - smoothed by running a Spencer 15-point smoothing function through the filtered power spectra. R = "reflectivity", T = temperature, d = days.

It is therefore not surprising that they should appear in the present context since cloud cover is a function of atmospheric dynamics and modulates the radiation budget appropriately. Perhaps the safest comment is that both spectra display a significant lack of "power" in the 18 to 30 day region - this despite observations and theoretical studies of "vacillations" on this sort of time scale (Hunt, 1978).

A fundamental question about the climate system concerns whether there are more than one (and perhaps many) strange attractors for its short-term behaviour; and if so can the natural internally-generated fluctuations affect the energy input or output to an extent sufficient to force a change to another state or another attractor. Fig. 3 is relevant to this last. It provides an indication of the probability that a fluctuation exceeds a certain value for a certain time, and hence of the chance of a particular change-of-state in a system of finite heat capacity.

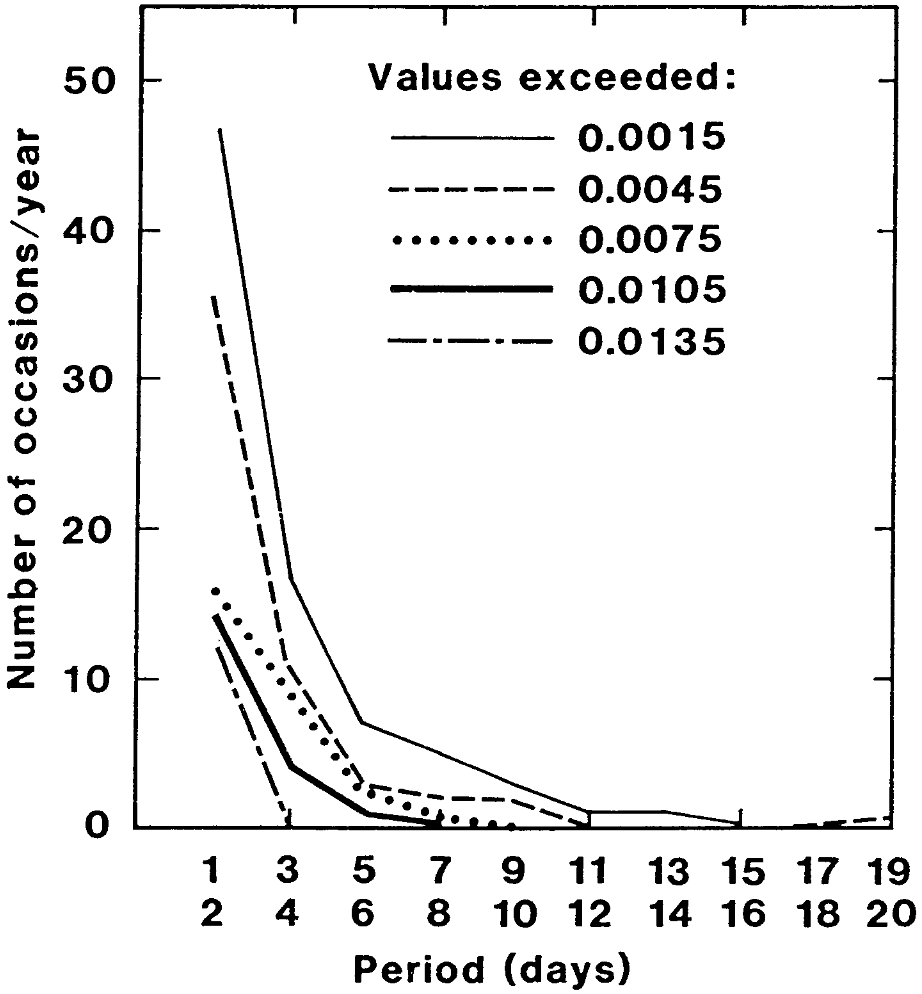

Fig. 3. For the "visible" time series, graphs of the number of occasions when fluctuations exceeded particular values for specific periods of time.

Interpretation of fluctuations in the present data as an index of the likely fluctuations in total ERB requires (at least) the following assumptions. It must be assumed that the radiances in the observed wavebands are proportional to the total spectrum (i.e. wavelength integrated) flux densities at the satellite. It must be assumed that these total flux densities are in turn proportional to the total fluxes radiating in all directions from the disc of the Earth viewed by Meteosat. Finally, it must be assumed that the noon measurements by Meteosat are an accurate representation of the 24-hour average fluxes reflected or emitted by the globe as a whole. With regard to this third assumption, it is probably true that the fluctuations averaged over the whole globe are less than those indicated by the restricted view (~ one-sixth of the globe) of one satellite. How much less cannot be established until the ERBE data are suitably analysed. In the meantime, the present figures may serve as an outside estimate.

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