Available online at www.sciencedirect.com
ScienceDirect
Agricultural and Forest Meteorology 145 (2007) 167–175
AGRICULTURAL AND FOREST METEOROLOGY
www.elsevier.com/locate/agrformet

Long-term changes to incoming solar energy on the Canadian Prairie

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Received 30 November 2006; received in revised form 12 April 2007; accepted 20 April 2007

Abstract

Many regions of the earth experienced a steady decline in solar radiation (global dimming) from the late 1950s to the late 1980s–early 1990s and a steady brightening thereafter. To determine trends in solar energy across the agricultural region of the Canadian Prairie, we analyzed incoming solar radiation, sunshine, and climate data gathered between 1951 and 2005 from 7 locations on the prairies. From the 1950s, there was a decreasing trend in annual average daily incoming solar radiation, no trend in annual average daily sunshine hours, and increasing trends in annual average daily temperature and in the annual number of precipitation/rain events. As well, we found the annual average daily incoming solar radiation decreased as the annual number of precipitation/rain events increased, but increased as the annual average precipitation intensity increased. We found the annual average daily sunshine hours decreased as the annual precipitation amount increased and as the annual average precipitation intensity increased. Thus, incoming solar radiation and sunshine responded differently to precipitation amount/events. Nevertheless, climate trends coupled with the relationship of solar radiation/sunshine to precipitation amount/events suggested that increased cloudiness played a key role in the extinction of solar radiation by the atmosphere over the past 50–60 years on the Canadian Prairie. Increasing greenhouse gas concentrations act to reduce cloudiness, whereas increasing aerosol concentrations often increase cloudiness. Specific to the Canadian Prairie, further research is needed to determine the influence of changing greenhouse gas and aerosol concentrations on cloudiness and cloud characteristics and the impact these changes would have on solar energy measured at the earth's surface.

Keywords: Global dimming/brightening; Incoming solar radiation; Bright sunshine; Climate trends; Precipitation events

1. Introduction

The sun provides the radiative energy that drives climate change. The output of energy from the sun has been increasing since about 1850 (Foukal and Lean, 1990; Francis and Hengeveld, 1998). About half of the warming of the earth's surface over the past century and a third of the warming since 1970 have been due to increased solar energy output (Francis and Hengeveld, 1998; Lean and Rind, 1998). Nature and human activities release atmospheric emissions that change the composition of the atmosphere and disrupt the balance between incoming and outgoing radiant energy thereby producing significant climate change (Karl et al., 1997; Liepert, 2002; Liepert and Tegen, 2002). Natural disruptions to the energy balance include volcanic emissions into the atmosphere resulting in global cooling, and changes in the earth's orbital path about the sun and the earth's rotational axis (Gullett and Skinner, 1992; Environment Canada, 1995). Industrial and agricultural emissions of greenhouse gases (such as

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doi:10.1016/j.agrformet.2007.04.011

CO_2, N_2O, CH_4) and refrigerants (such as chlorofluorocarbons and hydrochlorofluorocarbons) contribute to global warming by preventing long-wave radiation from escaping the earth's atmosphere into outer space. Other gas emissions (such as SO_2) and aerosols (such as soot) contribute to global cooling by blocking or reflecting incoming solar radiation back into outer space (Liepert, 2002; Pinker et al., 2005). Clouds are a very strong modifier of surface solar radiation (Liepert, 2002). Overall, increased cloudiness acts to reduce global warming. Increase in greenhouse gas concentrations leads to a reduction of cloudiness (Quaas et al., 2004) promoting global warming.

Many regions of the earth experienced a steady decline in global radiation from the late 1950s to the early 1990s, a phenomenon referred to as global dimming (Gilgen et al., 1998; Cutforth, 2000; Stanhill and Cohen, 2001; Liepert, 2002; Pinker et al., 2005). However, surface observations from the early 1990s to the present showed that the dimming had not continued but that a general brightening had occurred at several locations across the globe from the late 1980s-early 1990s to the present (Wild et al., 2005). From satellite records for 1983–2001, Pinker et al. (2005) found a slight dimming over land but a brightening trend over the oceans, which translated into an overall small increase in solar radiation at the earth's surface on a global scale. Further, from second-order analyses, Pinker et al. (2005) found that over land and oceans, there was a tendency for radiation to decrease from 1983 to the early 1990s and increase thereafter. Aerosols reduce solar energy reaching the earth's surface by scattering and absorbing sunlight in a cloud free atmosphere (the aerosol direct effect), and by modifying cloud properties to essentially increase cloud albedo (the aerosol indirect effect) (Quaas et al., 2004). Liepert (2002) suggested that the decline in surface solar radiation in the US prior to the early 1990s may be due to increased aerosol effects through increased air pollution and to changes in cloudiness and cloud characteristics through increased frequencies of overcast skies and increased cloud optical thickness at overcast conditions (i.e., increased cloud height and water content). Pinker et al. (2005) noted similar speculations but further suggested that global dimming had diminished since the early 1990s because of reduced levels of air pollution, especially noticeable over Germany and the eastern US. Wild et al. (2005) connected the transition from decreasing to increasing solar radiation with a similar shift in the transparency of the cloud-free atmosphere which, they suggest, may be related to a decrease in atmospheric aerosol content. Wild et al. (2005) further suggested that the decreased aerosol content may have been due to more effective clean-air regulations in industrialized regions or reduced air pollution in regions such as Eastern Europe where economies have declined as a result of political transition.

Several locations across the globe, including within the United States, Europe and Israel, have reported dimming and/or brightening trends in solar radiation and sunshine hours. To our knowledge, no study has addressed the long-term changes of solar energy on the Canadian Prairies. Thus, our objective with this study was to analyze long-term (1951 to 2005) meteorological records at several locations within the agricultural region of the Canadian Prairies for evidence of annual and seasonal trends in bright sunshine and in incoming global solar radiation.

2. Materials and methods

2.1. Historical weather data

The solar energy data used in this study were obtained from Meteorological Services of Canada, Environment Canada. From 1957 to 2005, incoming global solar radiation was measured at 7 weather-recording sites located within the agricultural region of the three prairie provinces (Alberta, Saskatchewan, and Manitoba) (Fig. 1 and Table 1). As well, sunshine hours were measured at 40 locations across the agricultural region of the Prairies (including the 7 locations where incoming global solar radiation was measured) between 1951 and 1999 (Fig. 1). Time periods over which incoming global solar radiation and sunshine measurements were taken varied with location (as evident for the 7 recording sites reported in Table 1). Only those stations with ≥25 years of record were included in the analysis (except Bad Lake-Outlook with approximately 24 years of solar radiation data). We analyzed annual and seasonal – January through April (JFMA), May through August (MJJA), September through December (SOND) – bright sunshine ($h\,d^{-1}$) and incoming solar radiation ($MJ\,m^{-2}\,d^{-1}$). MJJA corresponds to the growing season for annual crops grown on the Canadian Prairies. Quality control by Meteorological Services of Canada of hourly data to be archived included: missing hourly data were replaced with computer generated interpolated hourly data; hourly data that exceeded the theoretical maximum for that hour of that day by more than 15% were treated as missing, replaced and flagged. Daily incoming solar radiation ($MJ\,m^{-2}\,d^{-1}$) was totaled from hourly data. For a day when the majority