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Refining surface net radiation estimates in arid and semi-arid climates of Iran

Foroogh Golkar [a,b], William B. Rossow [c], Ali Akbar Sabziparvar [d,*]

[a] Agricultural Meteorology, Bu-Ali Sina University, Hamedan 65178, Iran
[b] NOAA-CREST Institute at City College of New York, NY, USA
[c] CREST Institute at City College of New York, NY, USA
[d] Meteorology, Bu-Ali Sina University, Faculty of Agriculture, Hamedan 65178, Iran

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Abstract

Although the downwelling fluxes exhibit space-time scales of dependency on characteristic of atmospheric variations, especially clouds, the upward fluxes and, hence the net radiation, depends on the variation of surface properties, particularly surface skin temperature and albedo. Evapotranspiration at the land surface depends on the properties of that surface and is determined primarily by the net surface radiation, mostly absorbed solar radiation. Thus, relatively high spatial resolution net radiation data are needed for evapotranspiration studies. Moreover, in more arid environments, the diurnal variations of surface (air and skin) temperature can be large so relatively high (sub-daily) time resolution net radiation is also needed. There are a variety of radiation and surface property products available but they differ in accuracy, space-time resolution and information content. This situation motivated the current study to evaluate multiple sources of information to obtain the best net radiation estimate with the highest space-time resolution from ISCCP FD dataset. This study investigates the accuracy of the ISCCP FD and AIRS surface air and skin temperatures, as well as the ISCCP FD and MODIS surface albedos and aerosol optical depths as the leading source of uncertainty in ISCCP FD dataset. The surface air temperatures, 10-cm soil temperatures and surface solar insolation from a number of surface sites are used to judge the best combinations of data products, especially on clear days. The corresponding surface skin temperatures in ISCCP FD, although they are known to be biased somewhat high, disagreed more with AIRS measurements because of the mismatch of spatial resolutions. The effect of spatial resolution on the comparisons was confirmed using the even higher resolution MODIS surface skin temperature values. The agreement of ISCCP FD surface solar insolation with surface measurements is good (within 2.4–9.1%), but the use of MODIS aerosol optical depths as an alternative was checked and found to not improve the agreement. The MODIS surface albedos differed from the ISCCP FD values by no more than 0.02–0.07, but because these differences are mostly at longer wavelengths, they did not change the net solar radiation very much. Therefore to obtain the best estimate of surface net radiation with the best combination of spatial and temporal resolution, we developed a method to adjust the ISCCP FD surface longwave fluxes using the AIRS surface air and skin temperatures to obtain the higher spatial resolution of the latter (45 km), while retaining the 3-h time intervals of the former. Overall, the refinements reduced the ISCCP FD longwave flux magnitudes by about 25.5–42.1 W/m^2 RMS (maximum difference −27.5 W/m^2 for incoming longwave radiation and −59 W/m^2 for outgoing longwave radiation) with the largest differences occurring at 9:00 and 12:00 UTC near local noon. Combining the ISCCP FD net shortwave radiation data and the AIRS-modified net longwave radiation data changed the total net radiation for summertime by 4.64 to 61.5 W/m^2 and for wintertime by 1.06 to 41.88 W/m^2 (about 11.1–39.2% of the daily mean).

Keywords: Net radiation flux; ISCCP FD dataset; AIRS; MODIS

* Corresponding author.
E-mail addresses: fgolkar@shirazu.ac.ir (F. Golkar), wbrossow@ccny.cuny.edu (W.B. Rossow), swsabzi@basu.ac.ir (A.A. Sabziparvar).

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1. Introduction

Land surface evapotranspiration (ET) models routinely use solar radiation directly or, in combination with long-wave radiation, the net radiation (Rn) to provide a measure of the net energy available to evaporate water (Boegh et al., 2002; Monteith, 1965; Nishida et al., 2003; Priestley and Taylor, 1972; Shuttleworth and Wallace, 1985; Su, 2002). Many of these ET models prefer knowledge of the diurnal cycle of net radiation at high spatial resolution.

Variation of the downwelling components of net radiation (Rn) is dominated by atmospheric variations, primarily clouds and temperature, but the upwelling components depend on the variation of surface properties. The advent of satellite measurements of atmosphere and surface properties has led to estimates of surface radiative fluxes that can cover this large range of space-time scales. However, the usefulness of these flux products is dependent on three issues: (1) the uncertainty of the calculated radiative fluxes as judged by comparison with more direct measurements, (2) the space-time scales available in these products, and (3) how much and by what means the flux products can be improved. (Zhang et al., 2004, 1995) estimated their overall surface flux uncertainty at about 10–15 W/m^2 for surface fluxes. More importantly, they conducted comprehensive sensitivity studies by varying the input data sets (and the radiative transfer model parameters) to quantify the uncertainties associated with each input quantity. The main conclusion was that the advent of extensive cloud data sets has reduced role of clouds as the main source of uncertainty in downwelling surface fluxes, making other uncertainty sources relatively more important. For surface radiative flux estimates, the accuracy of the near-surface atmospheric radiative properties (temperature, humidity and aerosol optical depth) are key for downwelling fluxes and the surface radiative properties (surface skin temperature and solar albedo) are key for upwelling fluxes (Zhang et al., 2007, 2006, 2004).

Our study area is the Fars Province in southern Iran (surface area of 122,608 km^2, one of the largest Iranian provinces), which is known for its semi-arid climate and flourishing agriculture. To study the effects of surface property variations and/or changes on the water budget in a semi-arid environment, evapotranspiration models, such as the Priestley-Taylor equation, can be used for this purpose if relatively high space-time resolution surface net radiation data can be obtained, but lack of sufficient ground- based data almost always is known as the main limitation. The radiation data from ISCCP FD dataset (Zhang et al., 2004) has the desired time resolution (3-h intervals) but the spatial resolution is coarse (280 km), providing only five values for the whole province. In order to improve the spatial resolution of surface radiative fluxes from ISCCP FD dataset, the pressing problem is evidently to improve the input data resolution as well as its accuracy. Our investigation of the accuracy of the ISCCP FD fluxes by comparisons with other satellite data products, as well as surface station measurements, shows that the fluxes are accurate enough that, rather than starting from the beginning to calculate new fluxes with better inputs, we can adjust the ISCCP FD fluxes directly based on alternate inputs. The additional benefit is to increase the spatial sampling interval to provide more detail, while no sufficient ground- based measurements is available for net flux in the study area. Thus, that is the main point of the current study to improve a method in refining spatial resolution as well as accuracy of the ISCCP FD fluxes, using satellite products, where in principle, provide the needed data for our study.

2. Data sets and methods

2.1. Study area and data

In the Fars Province 16 automatic weather stations (AWS) in 2009 are selected for this study because they have the most complete information and most nearly complete time records (Fig. 1). These stations record near-surface air temperature (T_a at 2 m height), soil temperature (T_{10} at 10 cm depth) and incoming shortwave radiation (SW) every 10 min. The selection of this kind of station is aimed at evaluating the data at the time of satellite overpass with maximum 5 min from the surface measurements.

The global radiation pyranometer with spectral range of 300–3000 nm is used in all AWS. We use these data to evaluate T_a and, indirectly, surface skin temperature (T_s) data from ISCCP FD, AIRS and T_s from MODIS – the main factors determining surface LW fluxes – and to evaluate the effects of surface albedo (A_s) and aerosol optical depth (AOD) on the SW fluxes from ISCCP FD. Note that the lack of direct surface measurements of T_s means that we can only check the qualitative consistency of the satellite values by comparison with the station soil temperature at 10 cm depth: the expectation is that during daytime, especially in summer, the value of T_s will generally be larger than both T_a and T_{10} and during nighttime, especially in winter, the value of T_s will generally be smaller than T_a and T_{10} (Arya, 2001). All data are from 2009 in this study.

The International Satellite Cloud Climatology Project (ISCCP) cloud data products (Rossow and Schiffer, 1991) describe the variations of the key physical attributes of the clouds, atmosphere and surface that affect the radiation balance. These observations are input to a radiative transfer model from the GISS GCM (revised) to calculate upwelling and downwelling, total shortwave (SW = 0.2–5 μm wavelength) and total longwave (LW = 5–200 μm wavelength) radiative fluxes at five levels: surface, 680 mb, 440 mb, 100 mb and top-of-atmosphere (http://isccp.giss.nasa.gov), every three hours over the whole globe on a 280 km equal-area global grid for July 1983 – December 2009 (Zhang et al., 2004). The ISCCP FD dataset also includes the values of T_a, T_s, A_s, and monthly AOD used to calculate the fluxes. There are five ISCCP FD grids