SOLAR COOKING IN THE SAHEL

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FIG. 1. A solar cooker in use in Chad. Foil glued to cardboard reflects energy onto a darkened cooking pot placed inside a clear plastic bag, cooking even dried food in around 3 h.

EXISTING USE OF SOLAR COOKERS IN THE SAHEL. Solar cookers cook food by focusing direct-beam solar energy. Figure 1 shows a simple cooker consisting of aluminum foil glued onto a cardboard panel and a dark cooking pot contained in a clear plastic bag to retain the warm air. Such a cooker can cook even dried food in less than three hours as long as sunshine is available, allowing morning cooking of the midday meal and afternoon cooking of the evening meal (which can be kept warm in simple thermos bags made from waste materials).

Agrometeorological Applications Associates and TchadSolaire (AAA/TS) have been training refugees and the indigenous population in Chad to use and manufacture solar cookers since 2005. In several camps, teams of refugee women now handle most of the maintenance and furnishing of cookers, training, and finance (including the impending contributions under the Carbon Credit scheme that will initially cover about 40,000 families). According to data from AAA/TS, wood is still needed for the early morning meal for children (about 12% of traditional daily energy needs) for about 20–30 days per year when dust prevents solar cooking, and for afternoon cooking during the rainy season (also about 20–30 days per year).

The program has support from the Government of Chad, in the context of its actions to preserve the environment. It has also found, gradually, total approval—and indeed, enthusiasm—from men. The sharing of knowledge with the surrounding population, and the distribution of cookers to them, has greatly reduced conflicts. Key to acceptance is that solar energy is freely and equitably distributed. The program has a positive effect on six of the eight UN millennium goals (www.un.org/millenniumgoals/) and is neutral for the other two. Solar cookers are therefore a cheap, practical tool for sustainable development, which can be built and main-

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tained without access to expensive tools or machinery. Planning of expansion of solar cooking to other regions in northern Africa would be facilitated by a more precise assessment of the availability of direct solar energy.

A CLIMATOLOGY FOR SOLAR COOKING.

Solar cookers require direct sunshine for effective cooking, so clouds or heavy atmospheric dust loads can slow down or prevent their use. Surface meteorological ("SYNOP") stations record the daily hours of direct sunshine (exceeding 120 W m^{-2}, with a resolution of 0.1 h) and were used to generate a climatology of days with greater than 6 h available for cooking ("cooking days"; locations of SYNOPs used are shown in supplementary Fig. ES1). SYNOP station records of sunshine hours are often made using Campbell-Stokes sunshine recorders. Scattered clouds can give errors of up to 20% for these data, and due to humidity the threshold for recording direct sunshine can vary from 70 to 280 W m^{-2}. However, in the dry areas suitable for solar cooking we do not expect large threshold variations, and we expect errors from dew and frost to be negligible.

The SYNOP dataset is very sparse in many parts of Africa and therefore is complemented by the use of geostationary satellite data. Various climatologies of surface solar radiation already exist (e.g., NASA GEWEX surface radiation budget data, ISCCP FD RadFlux and NASA/LaRC surface meteorology and solar energy data). However, these have a temporal resolution of at best three hours and extend, at present, only to June 2007 (at the latest). Higher temporal resolution surface insolation records are derived from SEVIRI (Spinning Enhanced Visible and Infrared Imager) on board the Meteosat Second Generation satellite series by EUMETSAT's Land Satellite Application Facility, but the approach uses a fixed aerosol climatology. Therefore, to obtain a climatology that accounts for subdaily variability in dust and cloud amount, we make use of a high temporal resolution record of aerosol optical depths (AODs) derived from SEVIRI.

Direct surface solar irradiance was derived using the Beer-Lambert law using AODs retrieved from SEVIRI. AOD retrievals are performed for land pixels designated as cloud-free, for solar zenith and view angles less than 70°, and were made available for this study for the period 2008–12, at a half-hourly time resolution between 0600 and 1600 UTC. The mean monthly percentages of "cooking days" were found from these data. Since SEVIRI AODs were only available between 0600 and 1600 UTC, there are some locations and periods that have solar zeniths less than 70° that are missing in the AOD record. Here, cooking hours were simply scaled to allow for these missing periods.

To assess the validity of the monthly-mean cooking days from SEVIRI, Fig. 2 shows a comparison with the SYNOP results with the best-fit straight line shown. Locations on coasts and rivers (where subpixel inhomogeneity is likely to be the cause of apparently excessive cloud flagging) and at high latitudes during December (where there are insufficient retrievals for good comparison) were excluded. Results from the two methods are reasonably well correlated (correlation coefficient of 0.52), but means from SEVIRI are lower than from surface observations, particularly for lower values. This systematic difference cannot be explained by typical errors in SYNOP data or SEVIRI AODs, and is likely mainly due to the cloud masking of SEVIRI; optically thin and partial cloud cover in the SEVIRI pixel is likely masked in the satellite data, while having minimal or no effect on the surface observations, and our analysis suggests some excessive cloud masking persists around areas such as coasts and rivers. SEVIRI AODs are also only retrieved for solar zeniths less than 70°, whereas surface observations are continuous. Figure 2 shows that although absolute values from SEVIRI are biased low, we expect SEVIRI to be valuable for examining spatial and temporal variations in cooking days.

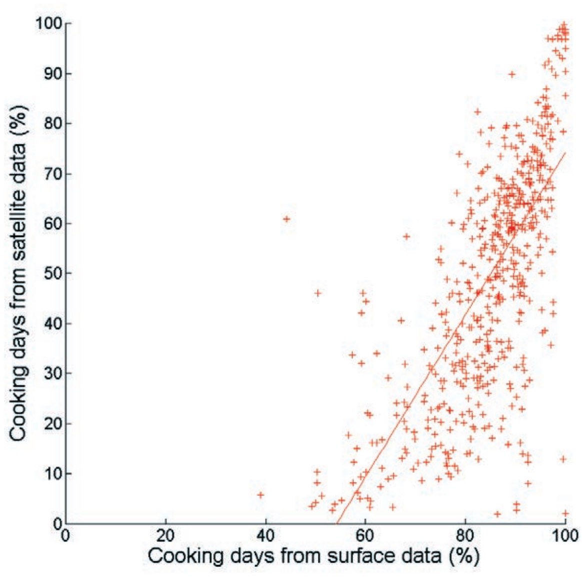

Fig. 2. Comparison of monthly means of the percentage of days with at least 6 h with > 120 W m^{-2} of direct solar irradiance ("cooking days") observed at surface stations and calculated from cloud-free SEVIRI AODs. As expected, SEVIRI gives lower values than the surface observations (see text).

Figure 3 shows the annual mean percentage of cooking days, along with monthly means from July and January, from both SEVIRI and surface observations in the Sahel (other months are shown in supplementary Figs. ES2–ES4). Consistent with the practical experience of AAA/TS, Fig. 3 shows 80% to almost 100% of days in northern Chad can be classified as "cooking days." Figures 3b, d, and f allow a station-by-station comparison of SEVIRI with SYNOP data. Consistent with Fig. 2, where SEVIRI reports low values, SYNOP values are significantly higher, but the spatial patterns are similar in each dataset. We note two additional caveats of SEVIRI. Validation indicates that its capabilities are strongest over drier and less vegetated surfaces such as those found in the Sahara and Sahel. Biomass-burning aerosol may be significant over the Sahel in winter, and SEVIRI AODs may miss this unless it is masked as cloud, although here SYNOP values are still greater than those from SEVIRI.

There are three main factors affecting whether cooking is possible: solar geometry, clouds, and dust. In boreal winter, the greater solar irradiance in lower latitudes is a strong control (Fig. 3e), whereas in boreal summer (Fig. 3c), clouds associated with the West African monsoon dominate and often prevent cooking in many regions south of 15°N. Summertime

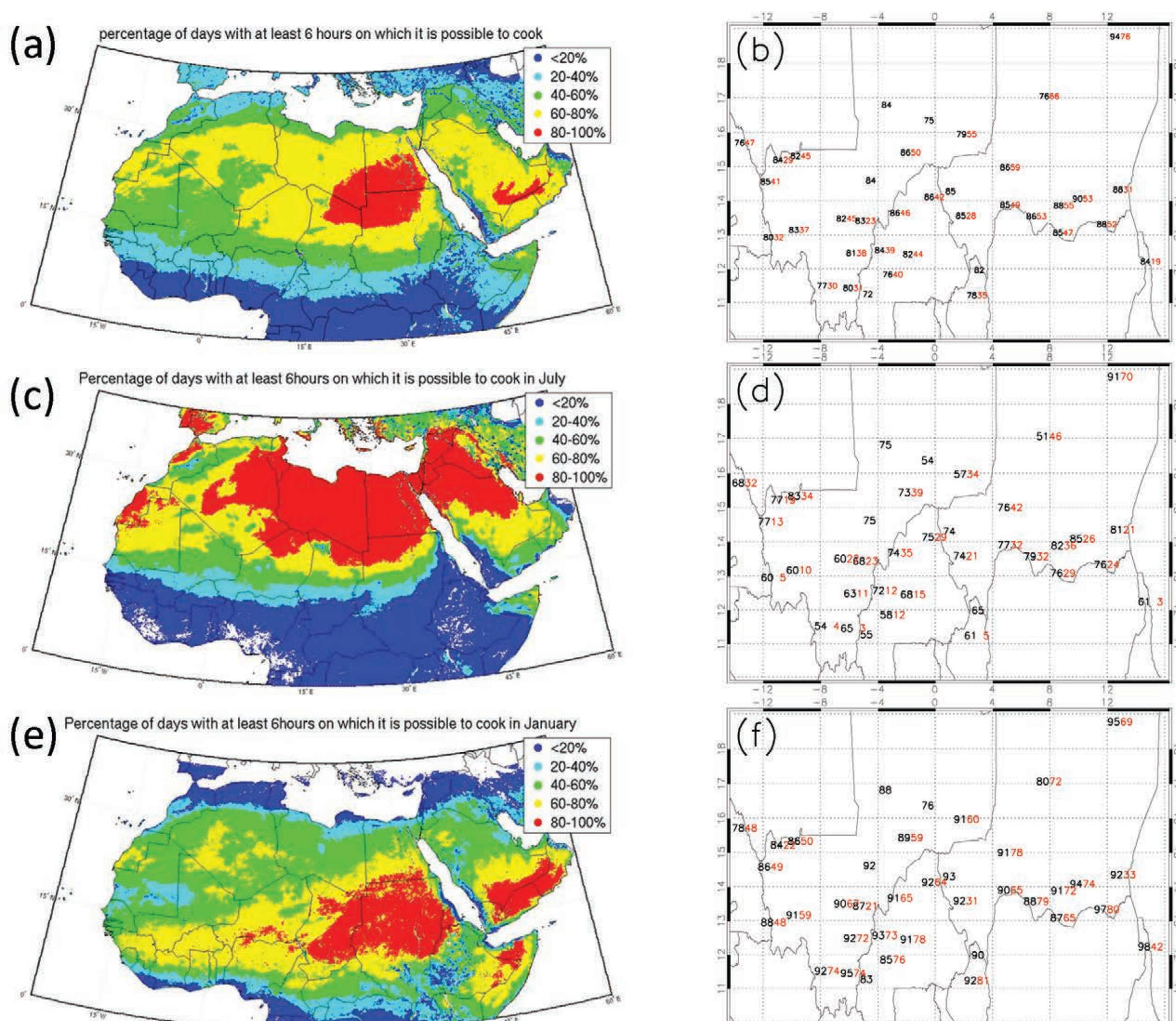

Fig. 3. Mean percentage of days with more than 6 h with direct solar irradiance >120 W m^{-2} ("cooking days") during (a,b) the whole year, (c,d) Jul, and (e,f) Jan. (a), (c), and (e) show results calculated from SEVIRI AODs and cloud mask. (b), (d), and (f) show results from surface observations (red) and closest SEVIRI pixel (black). Note that for clarity these only show surface stations in the Sahel area and not all the surface stations used in Fig. 2 (i.e., not those in Libya, Tunisia, Egypt, Chad, and Mauritania; see Fig. ES1 in online supplement).

clouds also affect cooking in the Atlas Mountains and around the coasts of the Arabian Peninsula (although many daylight hours were missing in Arabia, so the scaling correction there was significant). In January, clouds are mainly a problem close to the equator and the Intertropical Convergence Zone, in the Ethiopian highlands, and in Europe. Dust loads over Arabia and the Sahara are highest in summer (in the Sahara centered close to 0°W in July), and this reduces cooking days there. In winter, the Bodélé depression (around 17°N, 19°E) is more dominant, and downwind of this feature cooking hours in January are reduced (Fig. 3e). The cooking minimum in Mauritania (around 20°N, 10°W) is consistent with dust sources shown in Prospero et al. (2002). The Nile is easily identified in Egypt and Sudan in the SEVIRI plots; this is likely from persistent cloud-flagging errors as well as real clouds.

The annual mean in cooking days (Figs. 3a, b) reflects the balance between solar geometry, clouds, and dust. The maximum is located in the northeast Sahara away from monsoon and midlatitude clouds and the main dust maxima. Through the year, solar cookers can be used for at least 6 h (approximately two meals) for more than 80% of days over wide areas, and often more than 90% of days, although values are greatest in desert regions and the northern Sahel, where civil population densities are low. Values are lower where greater populations are made more viable by increased cloudiness and rain. However, many of the most vulnerable people are located close to the desert margins, where solar cooking is most practical (e.g., the refugee camps of northern Chad, where AAA/TS have ongoing projects). Furthermore, since in the Sahel cloudiness is maximized late in the day, 50% of days are "cooking days" even at 12°N in July (Fig. 3d).

CONCLUSIONS AND OUTLOOK. This first climatology of sunshine derived for solar cooking shows it can be the main cooking method for many vulnerable and other people and a useful method of cooking in areas such as the summertime Sahel, where clouds and dust reduce hours of direct sunshine. This climatology of sunshine from SEVIRI and SYNOPs has a number of practical implications beyond solar cooking—for example, it could be used to examine the feasibility of solar electricity generation.

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FOR FURTHER READING

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