Comparison of Broadband Solar Irradiances Measured on Fixed and Stabilized Platforms

Robert G. Ellingson, Ezra E. Takara and Gregory McDowall
Department of Meteorology, Florida State University, Tallahassee, FL 32306
Tim Tooman
Sandia National Laboratory, Livermore, CA

Introduction

There has been much debate over the past few decades over the magnitude of absorption of solar radiation by clouds. The debate intensified with the publication of the papers by Cess et al., 1995, Ramanathan et al. 1995, and Valero et al. 1995, as they observed solar absorption in amounts 40-100 W m^{-2} in excess of model predictions. Such excess absorption would indeed signal that our understanding of cloud radiative transfer is in need of a major revision. This set the stage for the ARM Enhanced Shortwave Experiments (ARESE I and II) during which cloud absorption was estimated by taking the differences of net radiation observed above and below a cloud layer by radiometers mounted on aircraft (ARESE I) or on aircraft and the ARM SGP site (ARESE II).

One problem in estimating absorption from such measurements is instrumental precision, particularly the correction factor that must be applied to the flux measurements to account for the orientation of the aircraft radiometer relative to the horizontal. Until the development of stabilized platforms, such corrections could only be approximated by using measurements of the aircraft pitch, roll and heading with known geometrical relations between the aircraft and earth horizontal planes for a given solar zenith angle. During the 2002 ARM-UAV Flight Series, the Proteus aircraft was equipped with two upward facing CM-22 radiometers, one mounted on a fixed plate and the other mounted on a stabilized platform. This arrangement allows for a comparison of downwelling fluxes determined with the geometrical corrections with those from the stabilized platform. The uncertainties of the fluxes so obtained allow us to estimate the uncertainties in absorption associated with the geometrical flux corrections.

Correcting the Fluxes

If the diffuse component is small, the downwelling solar flux as measured from the perspective of the horizontal on earth, F_e, is related to the flux on the aircraft F_a as

$$F_e = F_a (\cos \theta_e / \cos \theta_a) \quad (1)$$

Where θ is the solar zenith angle and subscripts a and e denote the aircraft and earth reference planes, respectively. θ_a is easily calculated from geometrical relationships using the known position of the aircraft and measurements of the aircraft pitch roll, and heading.

Complications arise, however, because the radiometer may not be perfectly level due to either imperfect preflight alignment or because of slight variations in the mounting due to contractions or expansions of the aircraft skin during the course of a flight. Because of the high sensitivity of the instruments, the offsets can usually be determined through a least squares analysis of constant data obtained from constant flight level legs towards and away from the sun, preferably before and after the experiment. The corrected values of F_e are usually then averaged over different time intervals for use in absorption estimates.

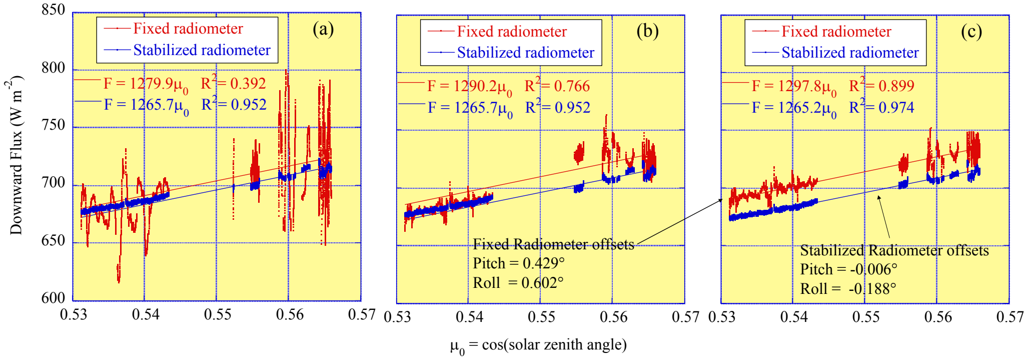

Figure 1. Fixed (red) and stabilized (blue) CM-22 radiometer downwelling shortwave fluxes on 15 November 2002 as measured on the Proteus. (a) Raw fluxes at 2-sec intervals. (b) Fixed radiometer fluxes at 2-sec intervals corrected for aircraft pitch, roll and heading as measured by the onboard navigation system. The raw stabilized platform fluxes are again shown in blue. (c) Fixed and stabilized platform fluxes each corrected for possible offsets that were determined for each instrument by minimizing the rms error of the equation F = A*cos(solar zenith angle). Note that the offsets for the fixed radiometer are significantly larger than the stabilized platform, resulting in a change in A from (b) to (c) of about 8 Wm^{-2}.

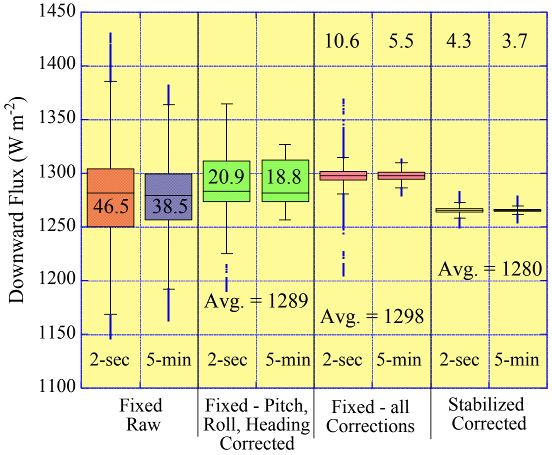

Figure 2. Box plots of the normalized flux distributions on 15 November 2002. The limits of the boxes show the 25 and 75 percentiles, and the horizontal lines in the boxes are the median values; The wiskers show the ranges, and other points are outliers. The standard deviations(in the box or at top) and 5-min average values are shown for some distributions.

Flux Analysis

In the analyses reported herein we correct the data in the following manner:

1. Interpolate aircraft navigation information to the flux observation times
2. Filter the data to remove data during turns or when the pitch and roll exceed 5°
3. Determine cos θ_a using aircraft navigation information
4. Make an initial correction using (1) above to determine F_e
5. Plot F_e verses cos θ_e
6. Determine the pitch and roll offsets necessary to minimize the rms error in the equation
   $F_e = A \cdot \cos \theta_e$
   where A is a regression coefficient for the assumed linear dependence on cos θ.

The data highlighted in this paper were obtained during a flight of the Proteus aircraft on 15 November 2002 at 14.5 km above the SGP site. Fig. 1a shows a comparison of the time series of the downwelling flux as measured by the CM-22 radiometers on the Fixed (red) and Stabilized (blue) platforms respectively. Note how the stabilized platform largely removes the major undulations caused by changes in the aircraft motion. It is quite clear that the stabilized platform fluxes are quite close to being linear in cos θ throughout this portion of the flight.

Figure 1b shows the comparison of the fixed and stabilized platform fluxes after the fixed platform fluxes have been corrected for the pitch, roll and heading of the aircraft. The corrections have removed the major undulations, but there are large differences between the observed fixed platform fluxes and the least squares linear fit (i.e., the explained variance of the linear fit is only about 0.39 for the fixed platform verses 0.95 for the stabilized platform). This indicates that there are significant offsets that must be determined.

The offsets were determined iteratively by adjusting the pitch and roll successively until the minimum rms error of the fit was found. Figure 1c shows a comparison of the final fit for both the fixed and stabilized platform radiometers. Note that the explained variance of the fixed platform fluxes has increased from 0.77 to almost 0.9 as a result of roll and pitch offsets of but 0.602° and 0.429°, respectively. The corrections to the stabilized platform are minor by comparison, amounting to but about 0.02 explained variance. Note also that the regression coefficient for the fixed platform has increased by 10 W m^{-2} relative to the value for the navigation corrected flux, or by about 1%! Clearly, small offsets are a major problem.

The distributions of the 2-sec and five-minute average normalized fixed and stabilized platform fluxes are shown in Fig. 2 (i.e., flux values divided by cos θ). Note that the navigation data decreases the standard deviation of the 5-minute average fluxes from 38.5 to 18.8 W m^{-2}, or about 20 Wm^{-2}. Correcting the fluxes for the offsets degreases the standard deviation from 18.8 to 5.5 W m^{-2}, and the average normalized flux increases by 9 W m^{-2} from 1289 to 1298 Wm^{-2}. Although there are substantial decreases in the standard deviation of the 5-miute averaged fluxes, these are still about 50% higher than the values obtained with the stabilized platform.

Summary and Conclusions

We have examined data from four different flights during the 2002 UAV flight series with similar results, namely:

1. Substantial offset corrections must be applied to fixed radiometers, the magnitude for which is order of 10 W m^{-2} to the average flux
2. The navigation and offset corrections reduce the standard deviation of the normalized, constant flight level, 5-minute average fluxes to about 6 W m^{-2}. These are about a factor of 2 higher than those for the stabilized platform fluxes

Estimating cloud absorption requires the differencing of upward and downward flux measurements made on platforms located above and below a cloud layer. Assuming the flux correction errors of the upwelling diffuse flux measurements to be negligible and the downwelling flux corrections to be random and of the same magnitude as those discussed above, we estimate that the uncertainty of cloud absorption due to the flux corrections to be the standard deviation of our 5-minute average fluxes times √2. For the data examined, these amount to 8.5 and 4.6 W m^{-2}, for the fixed and stabilized platforms radiometers, respectively. Although not negilible, the fixed platform errors are too small to account for the excess absorption found in pre-ARESE and ARESE I data.

Note that a major component of *the above correction assumes that the diffuse flux is small*. This is not the case for observations within or below cloud layers, and corrections for this effect add significant complexity to the procedure and uncertainty to the corrected, fixed platform fluxes, particularly so for the determination of the offsets. We have not attempted to estimate offsets with large diffuse fluxes, the flux uncertainties could easily amount to at least another 10 W m^{-2}, which in turn will lead to significant uncertainties in the estimated absorption.

Clearly, the use of a stabilized platform reduces the flux correction problem, and we urge use of such platforms in future cloud absorption experiments.