The Broadband Heating Rate Profile (BBHRP) VAP

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Motivation and Objectives of the BBHRP VAP

One of the greatest successes of the Atmospheric Radiation Measurement (ARM) Program has been the multi-year clear-sky spectral radiance intercomparisons (Tobin et al. 2002; Brown et al. 1998) between measurements of the atmospheric emitted radiation interferometer (AERI) (Revercomb et al. 1993) at the Central Facility (CF) of the Southern Great Plains (SGP) site and corresponding calculations of the Line-by-Line Radiative Transfer Model (LBLRTM) (Clough and Iacono 1995). This long time series radiative closure study, referred to as a Quality Measurement Experiment (QME), has led to numerous improvements in the specification of the atmospheric state in the radiating column, the AERI measurements, and the radiative transfer calculations. This study did not directly address the level of agreement between measurements and calculations of radiative flux, a quantity that must be computed accurately by models providing weather and climate predictions, diminishing its significance to global climate modelers. This shortcoming was remedied by the initiation of a second operational clear-sky radiative closure study, run in parallel to the AERI/LBLTM QME, which compared broadband measurements of surface radiative flux at the SGP CF by the precision infrared radiometer (PIR) (Clough et al. 2000) with corresponding calculations by the rapid radiation code RRTM_LW (Mlawer et al. 1997). Also included in this intercomparison were two sets of flux values obtained from the AERI-measured and LBLRTM-computed radiances through a conversion algorithm. This study also has been beneficial, articulating possible temperature-related issues with the PIR measurements and larger than expected differences between RRTM_LW and LBLRTM fluxes at low temperatures.

The productivity of these longwave (LW) studies, limited to the surface and clear-sky cases, has provided motivation to expand the scope of the operational measurement-model comparisons in multiple directions: shortwave (SW) radiation; clear and cloudy atmospheric conditions; and the analysis of radiative closure at the top of the atmosphere. The expansion of the existing clear-sky closure analyses to the SW is relatively straightforward, with suitable procedures having been developed for previous case studies at SGP (Halthore and Schwartz 2000; Mlawer et al. 2000) to deal with considerations such as aerosol properties and surface albedo. In contrast, the situation for investigating measurement-model agreement for cloudy conditions, in both the LW and SW, is far more challenging. Substantial progress in the ARM Program during the last few years with regards to the determination of cloud microphysical properties, most notably the active remote sensing cloud layer (ARSCL) VAP, (Clothiaux et al. 2000) has given confidence that this type of operational closure study can be attempted. However, substantive issues related to cloud imhomogeneity, temporal and spatial sampling, retrieval approaches, etc. are anticipated. Similarly, the expansion of these closure analyses to include measurements and calculations of top of the atmosphere (TOA) radiative fields, both for clear and cloudy conditions, will not be simple, with spatial sampling issues expected to be of crucial importance.

The extension of this type of closure analysis to a larger spatial scale is also of great importance to the Cloud Parameterization and Modeling (CPM) Working Group (see http://www.arm.gov/docs/documents/tech_reports/cloudparamod_wq2000.pdf - CPM vision document) of ARM, which has strongly expressed its desire for accurate measurement-based radiative heating rate profiles on the temporal and spatial scales typical of that in a single-column model (SCM) or general circulation model (GCM). Currently, the radiative heating rates driving the dynamics in a typical SCM are computed based on the atmospheric fields that have developed during the model run, rather than being grounded in the actual atmospheric conditions occurring at the time. Furthermore, the radiative transfer models used in some SCMs are not sufficiently accurate since they do not take advantages of recent advances in knowledge about gaseous sources of atmospheric absorption. Therefore, the CPM Working Group has proposed that the operational computation of radiative fields be expanded to include heating rates corresponding to the time step and grid cell size of a climate model, with the input to the radiative code being based directly on observations of the atmospheric state appropriate for that domain. The accuracy of these computed heating rates would be supported by the comparison of the corresponding calculated surface and TOA fluxes to direct measurements of these quantities. These heating rates would then be used in the SCMs to drive the evolution of model runs. The effect on the dynamics of using heating rates directly grounded in measurements and computed by a validated RT model can be ascertained.

These varied expansions to the existing measurement-model comparisons have been combined into a single product called the broadband heating rate profile (BBHRP) value-added product (VAP). Due to its comprehensive nature, the BBHRP VAP is a collaborative effort between all four of the Working Groups in ARM. The main purpose of this extended abstract is to provide a description of the structure of this undertaking, detailing the planned input sources and related algorithms, radiative transfer models, fields to be output and archives, radiation measurements, and scientific uses of the BBHRP VAP. In addition, the results from a very preliminary version of BBHRP will be shown for March 2000.

Components of BBHRP VAP

Due to the need for radiative closure analyses on two distinct temporal/spatial scales, the BBHRP VAP will have two corresponding input/output streams. First, a dataset associated with the SGP CF and distinct moments in time (corresponding to the launch times of radiosondes) will be developed, and will be associated with the expansion of the existing radiative closure studies to the SW and to cloudy conditions. This dataset will be referred to as ‘instantaneous’, and its input profiles and products will be termed ‘P_i’. The second dataset will correspond to a GCM grid cell and a three-hour average in time, and will be utilized for the SCM heating rate studies and TOA radiative closure analyses (using satellite data with large footprints).

Figure 1 presents a schematic overview of the BBHRP VAP, with each of its key components displayed in different color: input, models, output, and scientific uses. The ARM Working Group responsible for each piece of the product’s development is explicitly shown, indicating the collaborative nature of this effort.

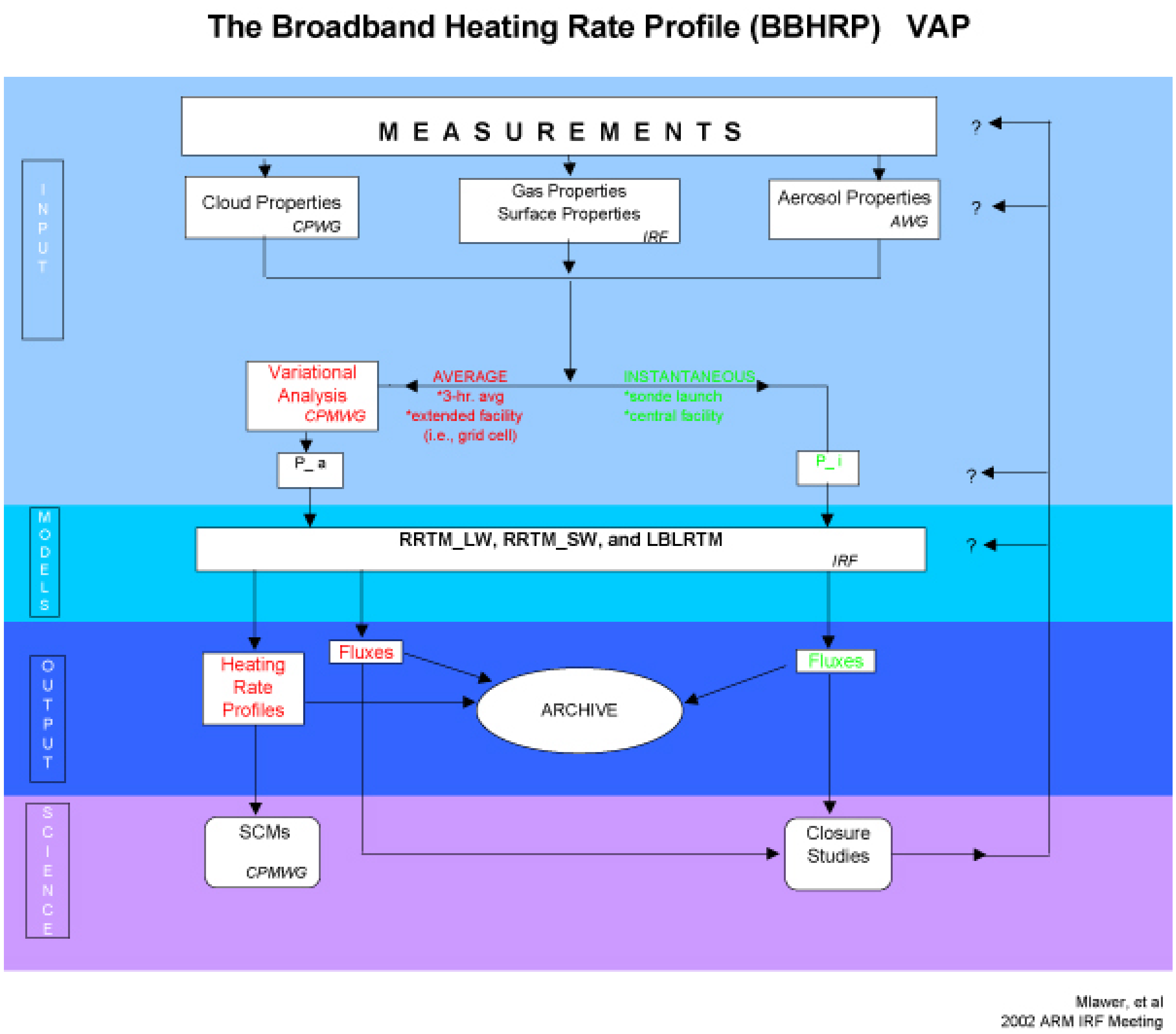

Figure 1. Schematic Overview of the BBHRP VAP

A. Input

As mentioned above there are two separate input streams, each corresponding to a different spatial/temporal scale.

1. P_i - for the CF and each sonde launch:

   a. Gas and temperature profiles—This information is the same as that needed for AERI/LBLRTM and Broadband QMEs, and the identical approach will be employed as in those efforts (as developed by the collaborative efforts of the Instantaneous Radiative Flux Working Group). In brief, the temperature field is given by radiosonde measurements (supplemented by U.S. Standard atmospheric temperatures at altitudes above the last radiosonde measurement). The relative water vapor column amounts are taken from radiosonde measurements, with the total column water vapor constrained to that retrieved from the co-located microwave radiometer. The total ozone column amount is taken from TOMS with the profile given by the U.S. Standard atmosphere.

   b. Cloud properties—The properties used will represent a 'best guess' by the Cloud Properties Working Group (Miller and Johnson 2002), with the goal being to characterize the cloud field impacting the radiometric measurements at the sonde launch time. Emphasis will be placed on the use of generally applicable retrieval approaches rather than special-case techniques. For the preliminary results shown below, 5-minute averages of ARSCL retrieved cloud properties are used, including layer cloud fraction, liquid water paths and effective particle size, and ice water path. For ice clouds, the parameterization of Ivanova et al. (2001) was used to obtain effective size from the temperature for each layer. (For later versions of BBHRP, it is planned to use a 20-minute average of ARSCL properties.)

   c. Aerosol properties—The properties used will be a measurement-based 'best guess' by the Aerosol Working Group as to the aerosols present over the Central Facility for both clear and cloudy conditions. For this preliminary adaptation of BBHRP, for clear skies the aerosol optical depth and single-scattering albedo are based on MFRSR measurements. The asymmetry parameter is set to 0.7. No aerosols are used in the cloudy sky calculations.

   d. Surface properties—Currently measurements at the Central Facility by the MFR and MFRSR are used, along with published natural spectral reflectances, to obtain the spectral surface albedos used in the calculation. A recent analysis (Michalsky et al. 2002) has shown that using local albedo measurements in a similar approach adequately represents the albedos needed to obtain accurate calculations of diffuse shortwave radiation at the surface.

2. P_a - for the grid cell corresponding to the Extended Facility and a 3-hour average

   a. Gas and temperature profiles—These profiles are derived from a variational analysis approach (Zhang et al. 2001; Zhang and Lin 1997) developed by the CPM Working Group.

b. Cloud properties—Based on a 3-hour average of ARSCL retrieved cloud properties, profiles are derived from a variational analysis approach developed by the CPM Working Group.

c. Aerosol properties - same method as for P_I

d. Surface properties—A method is being developed to use local surface type data determined by satellite measurements, in concert with published natural spectral reflectances, to derive a spectral surface albedo. Currently, surface albedos are used as in the P_i calculation.

B. Radiative Transfer Models

For the flux and heating rate calculations, the rapid radiation models RRTM_LW (Mlawer et al. 1997) and RRTM_SW (Mlawer and Clough 1998) will be used. Both of these correlated-k models reproduce the flux calculations of the line-by-line model LBLRTM (Clough and Iacono 1995) within 1.5 W/m^2 at all levels. For cooling rates, RRTM_LW and LBLRTM agree within 0.07 K/d in the troposphere and 0.6 K/d in the stratosphere. For the TOA comparisons, radiances will be computed by LBLRTM.

C. Output

For each input profile for both P_i and P_a, fluxes and heating rates computed by RRTM_LW and RRTM_SW will be stored at all vertical calculational levels. For P_a, spectral TOA radiances computed by LBLRTM will be summed and stored on a 10 cm-1 grid to enable comparisons to satellite observations from a number of different instruments. These datasets of modeled radiation (along with the corresponding input profiles and radiometric measurements) will be available at the ARM archive.

D. Science

The expected scientific uses of this VAP include:

1. Closure studies—As mentioned above, the P_i and P_a surface fluxes and P_a TOA radiances will be compared to corresponding measurements, enabling critical evaluation of measurements, models, and atmospheric specification, especially clouds. It is expected that temporal and spatial sampling will be an important cross-cutting issue for all cloudy sky calculations. The dataset will be of great utility in studies that validate GCM simulated radiative fluxes using observations (Wild et al. 1995).

2. SCM simulations—As discussed above, the effect on dynamics of using heating rates directly grounded in measurements and computed by a validated RT model will be investigated.

3. "Test suite" for possible improved parameterizations—The modular structure of the BBHRP VAP will encourage its use as a tool to evaluate new parameterizations, models, or input sources. A researcher would replace the corresponding existing approach by the trial one (whether meant to be generally applicable or for specific circumstances), the desired time period of the VAP

would be run, and the appropriate measurement-model differences would be compared to the ones from the standard runs. Improvements would be considered for implementation in a future version of BBHRP.

Preliminary Results

To illustrate the capabilities of the BBHRP VAP, the March 2000 IOP time period was analyzed with a preliminary version of the structure described above. Only the P_i profiles were used, with roughly half the cases missing due to temporary data gaps, and comparisons were made between the measured and calculated surface fluxes. It was expected that a variety of issues would arise in this initial set of comparisons. Figures 2a to 2d give the results of these comparisons for, respectively, the LW, SW diffuse, SW direct normal, and total SW fluxes. The top panel of each plot shows the measured and calculated fluxes, and the bottom panel shows the differences. Table 1 presents a statistical summary of these results.

As expected from previous closure studies, the clear-sky LW and SW differences are small. (The actual SW diffuse flux differences are much less than shown in Table 1 due to the use in this preliminary comparison of pyranometer measurements uncorrected for instrumental thermal effects.) The residuals for the direct beam for cloudy conditions are high since the cloud properties being used in the calculations, most notably the cloud fractions, are not taken from observations along the direct path to the sun. A close examination of the results for cloudy conditions indicates that there are issues related to ice water path amounts being too low to provide LW and SW radiative closure and that the cloud fractions determined from zenith radar measurements (i.e., ARSCL) do not represent those in the entire sky. These and other issues are currently being further examined.

Future Efforts

The large scope of this effort will necessitate a gradual evolution of the capabilities described above. Good agreement for P_i results is a prerequisite for success on the P_a profiles, so the initial focus will be on the improvement of the residuals from the 'instantaneous' profiles. The preliminary results shown above for March 2000 have identified a number of directions for this initial effort. After reasonable results for both P_i and P_a results are obtained for March 2000, the resulting calculated fluxes, radiances, and heating rates, along with the associated input profiles and radiometric measurements, will be archived and distributed to the community. The next goal of this effort will be to turn the BBHRP procedures into an operational VAP for SGP.

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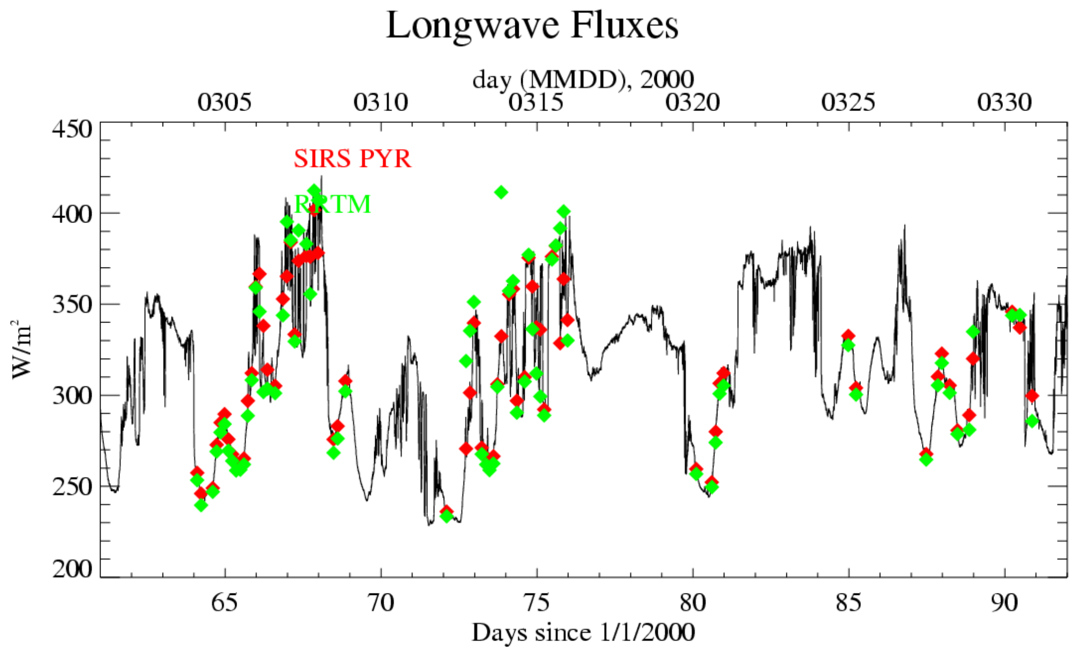
BBHRP Surface Fluxes



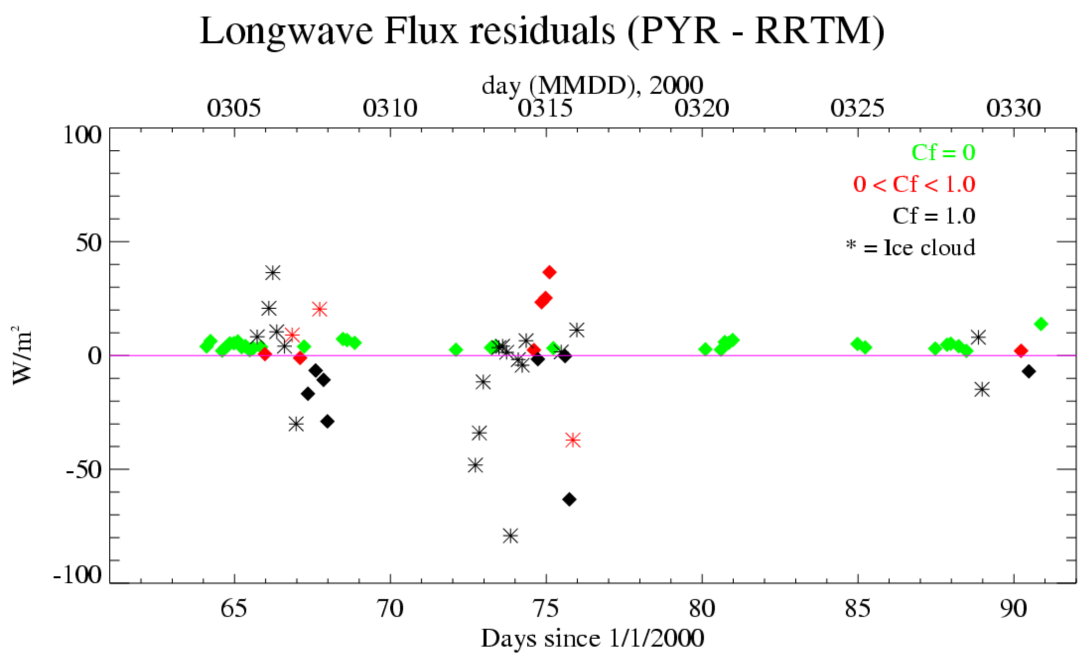


Figure 2a. Preliminary results of the BBHRP VAP for March 2000: Longwave total. The top panels of each plot show the measured (red) and calculated (green) irradiances corresponding to each sonde launch. Also shown are all the measured irradiances for the month (black). The bottom panel presents the differences between measured and calculated irradiances, with different colors and symbols used to indicate cloud cover (cf) and cloud type (liquid or ice), respectively.

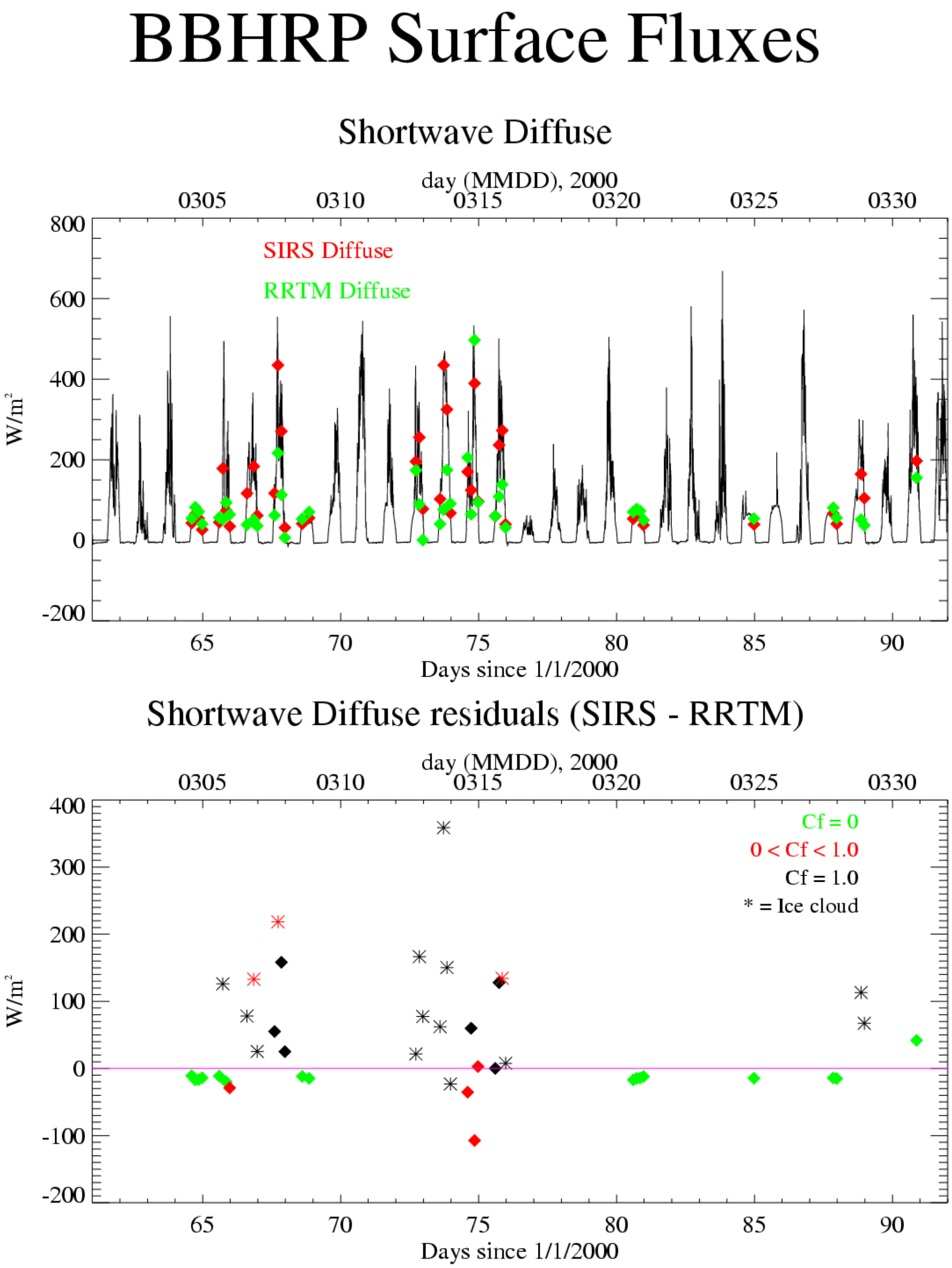


Figure 2b. Preliminary results of the BBHRP VAP for March 2000: Shortwave diffuse total. The top panels of each plot show the measured (red) and calculated (green) irradiances corresponding to each sonde launch. Also shown are all the measured irradiances for the month (black). The bottom panel presents the differences between measured and calculated irradiances, with different colors and symbols used to indicate cloud cover (cf) and cloud type (liquid or ice), respectively.

BBHRP Surface Fluxes

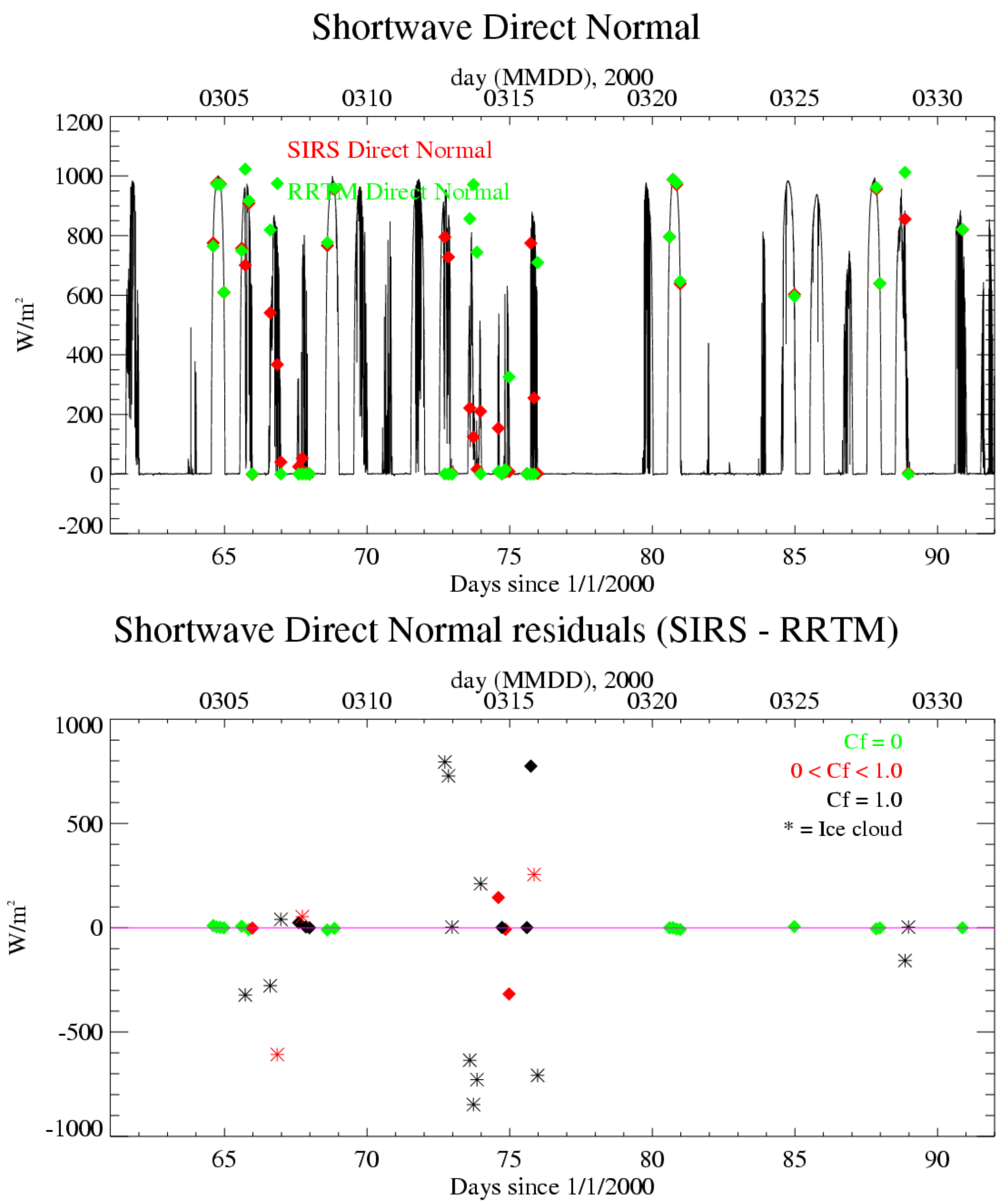


Figure 2c. Preliminary results of the BBHRP VAP for March 2000: Shortwave direct total. The top panels of each plot show the measured (red) and calculated (green) irradiances corresponding to each sonde launch. Also shown are all the measured irradiances for the month (black). The bottom panel presents the differences between measured and calculated irradiances, with different colors and symbols used to indicate cloud cover (cf) and cloud type (liquid or ice), respectively.

BBHRP Surface Fluxes

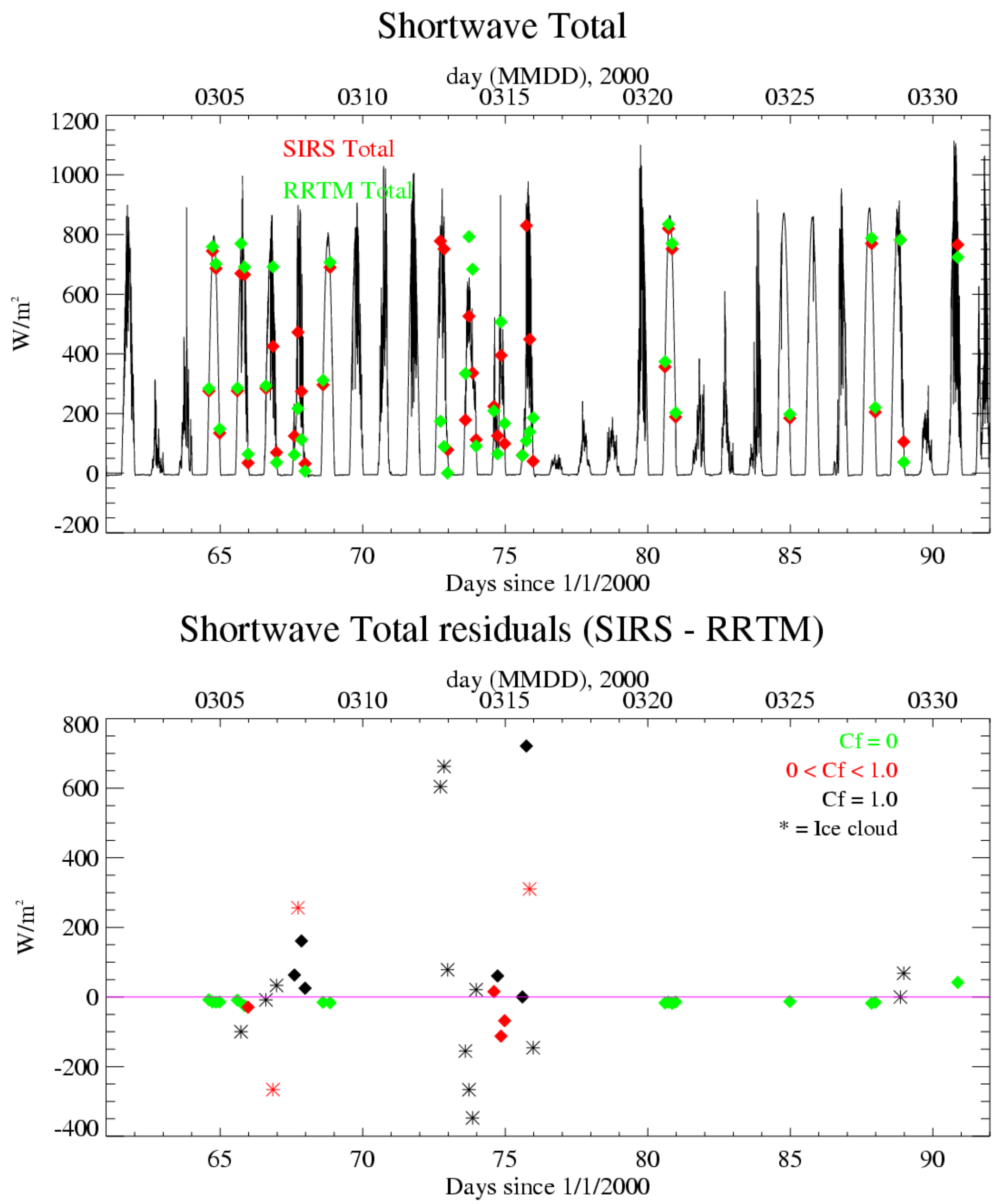


Figure 2d. Preliminary results of the BBHRP VAP for March 2000: Shortwave total. The top panels of each plot show the measured (red) and calculated (green) irradiances corresponding to each sonde launch. Also shown are all the measured irradiances for the month (black). The bottom panel presents the differences between measured and calculated irradiances, with different colors and symbols used to indicate cloud cover (cf) and cloud type (liquid or ice), respectively.

Table 1. March 2000 P_I Flux Differences, W/m^2 (Bias = SIRS – RRTM)

	# Cases	Bias	Avg (|Δ-Bias|)
Longwave	76		
Clear	34	4.1	1.2
Liquid Clouds	15	-3.5	16.8
Ice Clouds	27	-1.0	18.1
Shortwave Diffuse	42		
Clear	14	-14.5	1.9
Liquid Clouds	11	29.9	58.8
Ice Clouds	17	85.2	80.1
Shortwave Direct Normal	42		
Clear	14	-1.2	4.7
Liquid Clouds	11	56.8	146.6
Ice Clouds	17	-78.2	344.4

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