Recent Developments on the Broadband Heating Rate Profile Value-Added Product

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Objectives of the BBHRP VAP

The Atmospheric Radiation Measurement (ARM) broadband heating rate profile (BBHRP) value-added product (VAP) was initiated in order to build upon and broaden in a variety of directions the fruitful long-standing series of measurement-model comparisons of clear-sky spectral surface radiances at Southern Great Plains (SGP; Turner et al. 2003, Brown et al. 1998). The objectives of this effort are:

- Extend existing measurement-model closure studies to irradiance comparisons involving:
  - shortwave spectral region
  - cloudy conditions
  - the spatial and temporal scale corresponding to a General Circulation Model (GCM) ‘grid cell’ at SGP
  - top of the atmosphere (TOA) fluxes
- For use by single-column models (SCMs), compute heating rate profiles based on in situ measurements and using validated radiative transfer model

- Generate dataset of measured and modeled radiation for both Central and Extended Facilities at SGP and other ARM sites

- Provide a ‘test suite’ for researchers evaluating new parameterizations and data sources

The motivation and objectives of this project are described more fully in Mlawer et al. (2002).

Since this project involves radiative closure analyses on two distinct temporal/spatial scales, the BBHRP VAP has two corresponding input/output streams for SGP. First, a dataset associated with the SGP Central Facility (CF) and distinct moments in time (corresponding to the launch times of radiosondes) has been developed, and is referred to as ‘instantaneous’, and its input profiles and products are termed ‘P_i’. The second dataset corresponds 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 appropriately large footprints. This dataset is referred to as ‘average’, and its input profiles and products are termed ‘P_a’. This project, due to its large breadth, is designed to be a collaborative effort of all the Working Groups within ARM. An ARM Focus Group has been formed to provide a structure for the development and analysis associated with this project.

Current Status

There has been a great deal of progress made this year on the BBHRP VAP. The initial version (Version 1.0) has been completed for the March 2000 intensive operating period (IOP) for both P_i and P_a. A summary of the current status of and future plans for each dataset and its components is given in Table 1. Further details on the source of the input parameters used in the radiative calculations are given in Mlawer et al. (2002). More details on the approach used to retrieve cloud properties can be found in Miller et al. (2003).

P_i Version 1.0 Results

For both P_i and P_a, the atmospheric properties in Table 1 are input to the rapid radiation models RRTM_LW (Mlawer et al. 1997) and RRTM_SW (Mlawer and Clough 1998) for the computation of fluxes and cooling rates on an appropriate vertical grid. For March 2000, the results of the P_i comparisons with respect to surface irradiance measurements for the longwave, shortwave diffuse, shortwave direct normal, and total shortwave fluxes are shown in Figures 1a-1d, respectively. 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 selected results, with the results of the preliminary Version 0 of P_i presented for comparison.

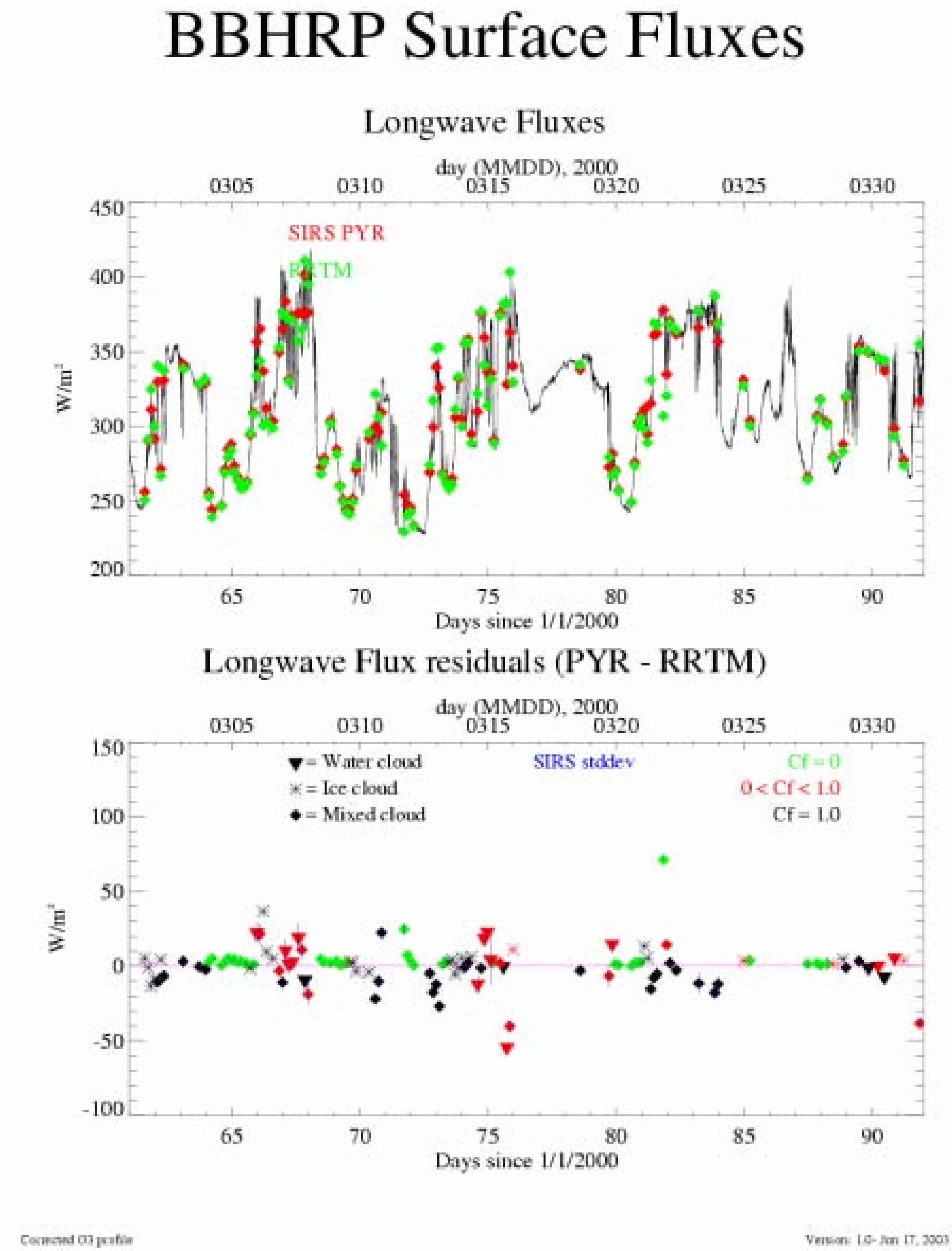
BBHRP Surface Fluxes
Longwave Fluxes
day (MMDD), 2000
0305
0310
0315
0320
0325
0330
SIRS PYR
RRTM
W/m²
450
400
350
300
250
200
65
70
75
80
85
90
Days since 1/1/2000
Longwave Flux residuals (PYR - RRTM)
▼ = Water cloud
⋇ = Ice cloud
◆ = Mixed cloud
SIRS stddev
Cf = 0
0 < Cf < 1.0
Cf = 1.0
150
100
50
0
-50
-100
Corrected O3 profile
Version: 1.0- Jun 17, 2003

Figure 1a.

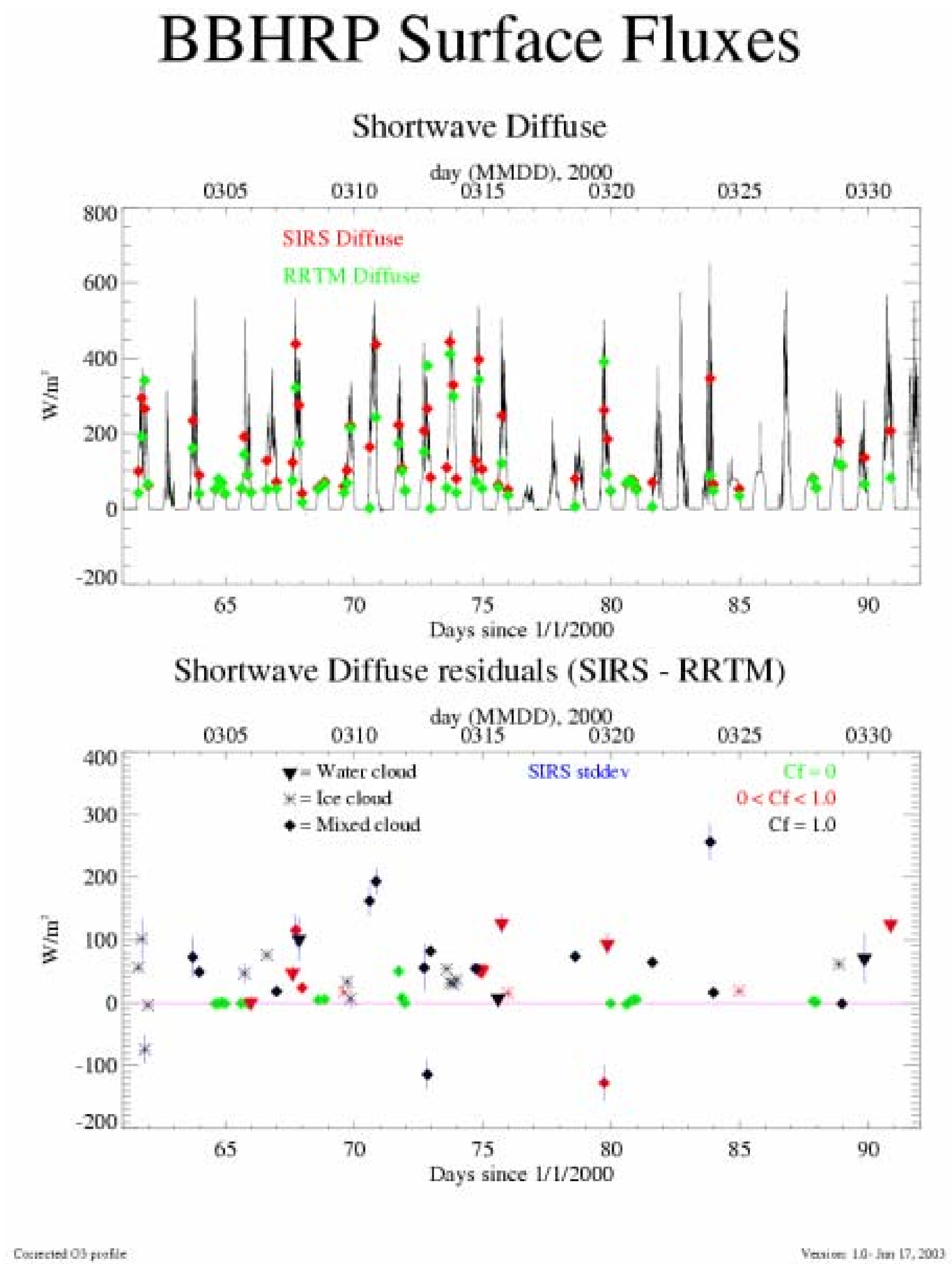
BBHRP Surface Fluxes
Shortwave Diffuse
day (MMDD), 2000
0305
0310
0315
0320
0325
0330
SIRS Diffuse
RRTM Diffuse
W/m²
800
600
400
200
0
-200
65
70
75
80
85
90
Days since 1/1/2000
Shortwave Diffuse residuals (SIRS - RRTM)
day (MMDD), 2000
▼= Water cloud
✳= Ice cloud
◆= Mixed cloud
SIRS stddev
Cf = 0
0 < Cf < 1.0
Cf = 1.0
400
300
100
-100
Corrected O3 profile
Version: 1.0 - Jun 17, 2003

Figure 1b.

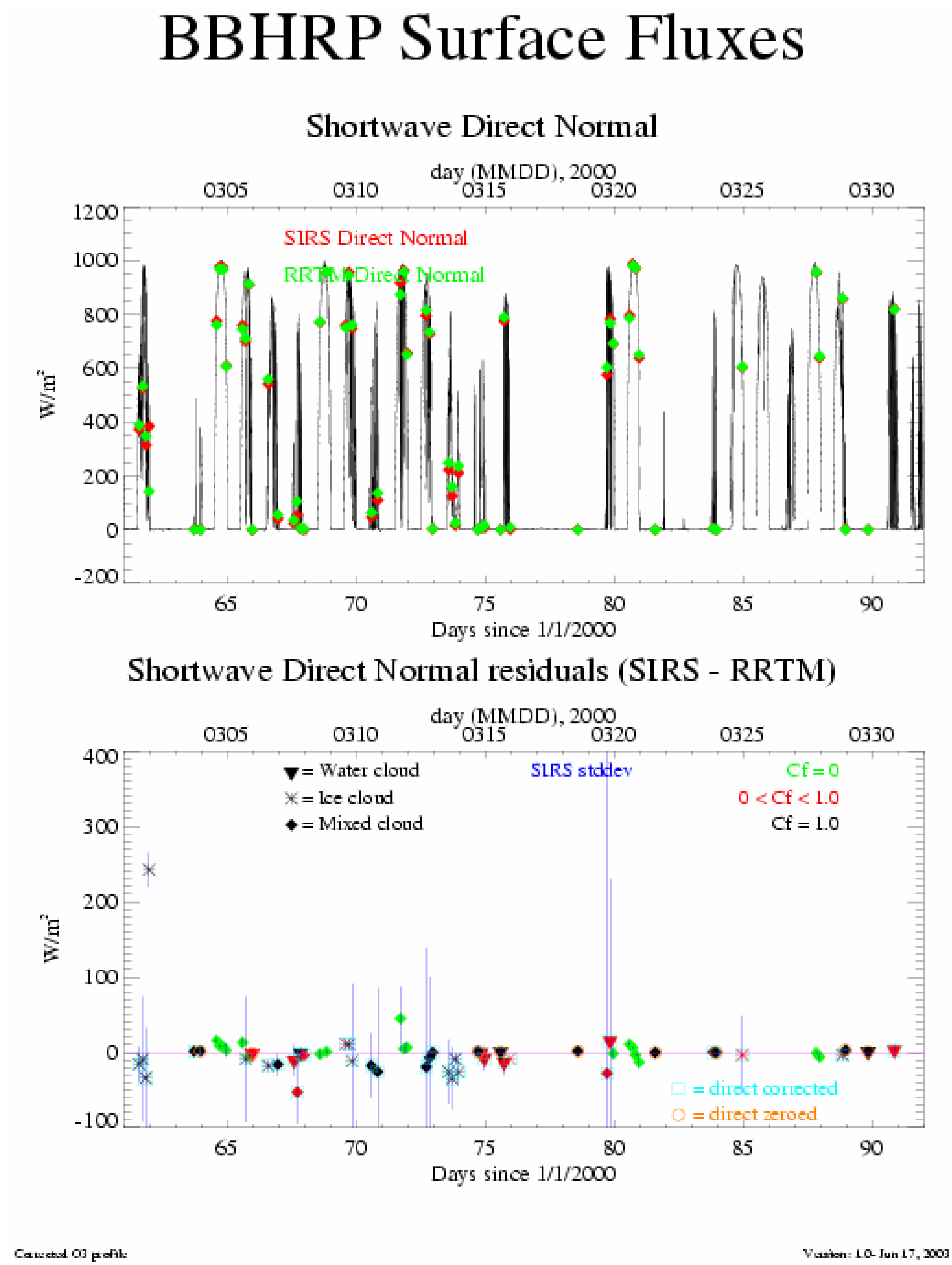
BBHRP Surface Fluxes
Shortwave Direct Normal
day (MMDD), 2000
0305
0310
0315
0320
0325
0330
SIRS Direct Normal
RRTM Direct Normal
W/m²
Days since 1/1/2000
Shortwave Direct Normal residuals (SIRS - RRTM)
▼= Water cloud
✳= Ice cloud
◆= Mixed cloud
SIRS stddev
Cf=0
0 < Cf < 1.0
Cf = 1.0
□ = direct corrected
○ = direct zeroed
Corrected O3 profile
Version: 1.0- Jun 17, 2003

Figure 1c.

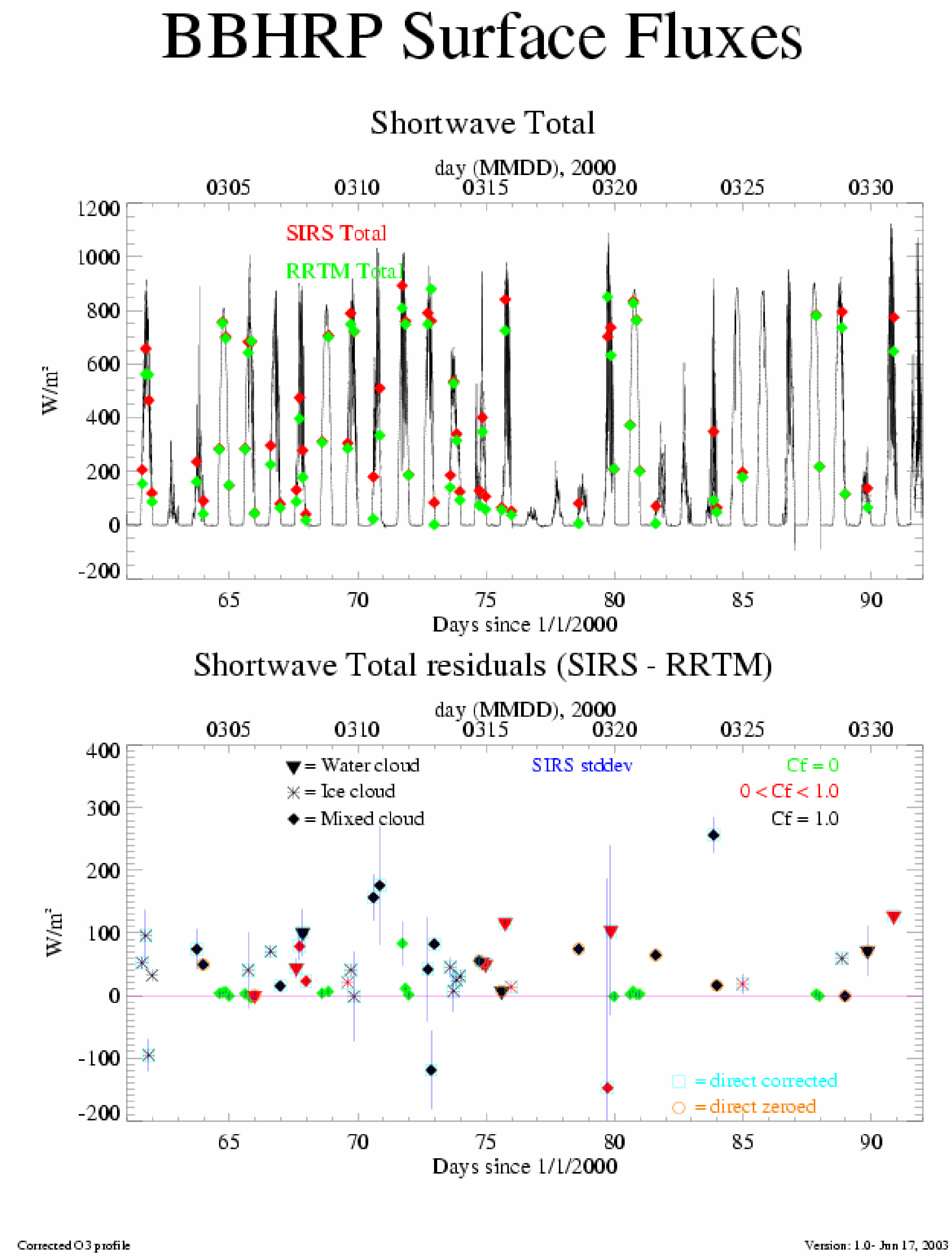
BBHRP Surface Fluxes
Shortwave Total
day (MMDD), 2000
0305
0310
0315
0320
0325
0330
SIRS Total
RRTM Total
W/m²
1200
1000
800
600
400
200
0
-200
65
70
75
80
85
90
Days since 1/1/2000
Shortwave Total residuals (SIRS - RRTM)
▼ = Water cloud
✳ = Ice cloud
◆ = Mixed cloud
SIRS stddev
Cf = 0
0 < Cf < 1.0
Cf = 1.0
□ = direct corrected
○ = direct zeroed
400
300
200
100
-100
Corrected O3 profile
Version: 1.0- Jun 17, 2003

Figure 1d.

Table 1. P_i and P_a status and future plans.

Component of BBHRP	Current Status	Near-term Plans
P_i	Version 1.0 ready	See entries in rows below
Gas and temperature properties	Same as for existing longwave Quality Measurement Experiments (QMEs)	Switch to physically retrieved water vapor column
Cloud properties	'Best guess' by Cloud Properties Working Group	Cloud cover needed, alternate microphysical retrieval schemes
Aerosol properties	For clear skies only; based on multi-filter rotating shadowband radiometer (MFRSR) measurements	Need for 'best guess' by Aerosol Working Group
Surface properties	Spectral albedos based upon CF's multi-filter radiometer (MFR), MFRSR	Sampling of a larger area
TOA comparisons	Informal Clouds and Earth's Radiant Energy System (CERES) comparisons encouraging	Need to incorporate into BBHRP framework
P_a	Version 1.0 ready	Analysis by Cloud Parameterization and Modeling Working Group
Gas and temperature properties	Variational analysis	Evaluate water vapor using P_i profile
Cloud properties	ARSCL cloud fractions scaled to geostationary operational environmental satellite (GOES) cloud cover	Evaluate
Aerosol properties	Same method as for P_i (interpolated in time)	Need for 'best guess' by Aerosol Working Group
Surface properties	Same method as for P_i	Sampling of a larger area, consider using downlooking at boundary sites
TOA comparisons	Ongoing	Consider adding spectral component

An overall improvement in the residuals has occurred relative to Version 0. Breaking down the results by atmospheric condition:

1. The clear-sky results show good agreement, with the longwave residuals consistent with existing longwave QMEs. A factor that increases the clear-sky residuals listed in Table 1 over their actual values is the misidentification of cloudy cases as clear, which can clearly be seen in Figure 1. It is clear from this and other results that the BBHRP VAP needs improvement with respect to quality control issues, including the use of back-up sources for input fields when the primary measuring instrument is not available.

2. The results for ice clouds have shown a great deal of improvement relative to Version 0 as a result of refinement and correction of the method utilized for retrieval of ice cloud microphysical properties. There is likely a remaining issue in that the retrieval yields ice clouds with too little optical depth (Haynes et al. 2003; Min and Joseph, 2003). In addition, part of the remaining residuals can be attributed to the lack of aerosols in cloudy sky calculations, resulting in an underestimation of the shortwave diffuse irradiance that cannot be eliminated by adjusting the cloud optical depth without harming the good measurement-model agreement in the longwave.

3. The liquid cloud results are not reliable due to problems the retrieval approach has distinguishing insects from liquid cloud particles in radar returns, resulting in clouds that are too optically thick. This also is the case for mixed phase clouds, the results of which are not presented in Table 2.

Table 2. March 2000 P_i Version 1.0 statistical summary (Bias = SIRS – RRTM, W/m^2).

	N	Version 0 Bias	Avg|Δ-Bias|	N	Version 1.0 Bias	Avg|Δ-Bias|
Longwave	76	0.8	-	117	0.7	7.9
Clear	34	4.1	1.2	38	4.8	4.7
Liquid	15	-3.5	16.8	17	2.2	11.8
Ice	27	-1.0	18.1	26	3.4	5.4
SW Diffuse	42	37.5	-	61	37.0	43.9
Clear	14	-14.5	1.9	18	4.2	5.9
Liquid	11	29.9	58.8	10	67.7	35.6
Ice	17	85.2	80.1	16	31.8	26.6
SW Direct-normal Clear	14	-1.2	4.7	18	5.1	8.1

An analysis of the shortwave clear-sky results indicates that the aerosol single-scattering albedo (SSA) needed for agreement with measured irradiances tend to be lower than the values both typically assumed and measured by in situ sampling techniques, consistent with previous shortwave radiative closure studies (Mlawer et al. 2000; Mlawer et al. 2001). Evidence can be seen for this in Figure 2, which plots in blue the aerosol SSA needed to obtain zero measurement-model residual for diffuse irradiance for each March 2000 P_i clear-sky case. The bars shown in blue are the SSA's needed to obtain measurement-model diffuse residuals of ±4 W/m^2 for these cases. The SSA used in the calculation, obtained by matching the calculated diffuse-to-direct ratio in the visible to a combination of this ratio in MFRSR visible channels, falls within this range for 12 out of the 16 clear-sky cases. (The number of clear-sky cases analyzed here differs from the number in Table 1 due to the misidentification of two cloudy cases as clear.) Also shown in this figure in the SSA values obtained for these times from the surface-based measurements of the aerosol observing system (AOS) (Sheridan et al. 2001), which can be seen to be generally higher than those needed for radiative closure. Although this analysis cannot be definitive due to the comparison of the surface-based AOS SSA measurements with the values needed for closure over the entire atmospheric column, they add to the motivation for aerosol absorption studies underway in the ARM Aerosol Working Group.

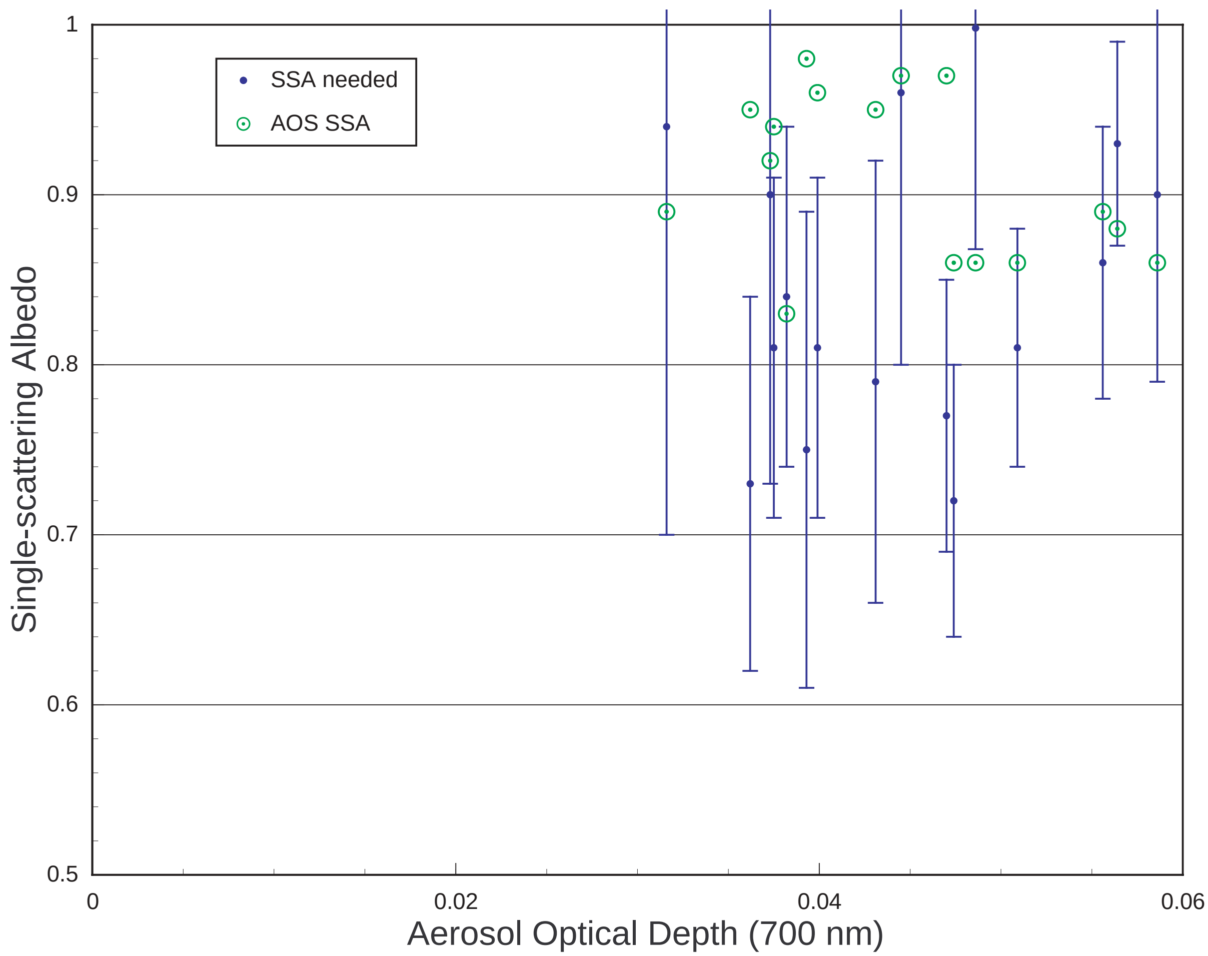

Figure 2.

P_a Version 1.0 Results

The P_a calculated surface irradiances are compared to a suitably weighted average of surface irradiance measurements distributed about the SGP Extended Facility (Zhang et al. 1997; Zhang et al. 2001), and the calculated TOA irradiances are compared to an appropriate average of GOES satellite measurements. The results for P_a Version 1.0 for March 2000 are shown in Figures 3a-3d, which present the results of the irradiance comparisons for longwave surface, longwave TOA, shortwave surface, and shortwave TOA net (i.e., down - up), respectively. The statistics associated with these results are given in Table 3. Broken down by atmospheric condition:

1. As in the P_i results, the clear-sky residuals are small, although the typical longwave surface residual is greater than in P_i. In addition, there is a possibly related negative residual of equal magnitude for the longwave TOA irradiance. There are some initial indications that the P_a water vapor column amount may be smaller than the P_i column amount for atmospheric profiles at corresponding times, which may explain these differences. This is currently being investigated.

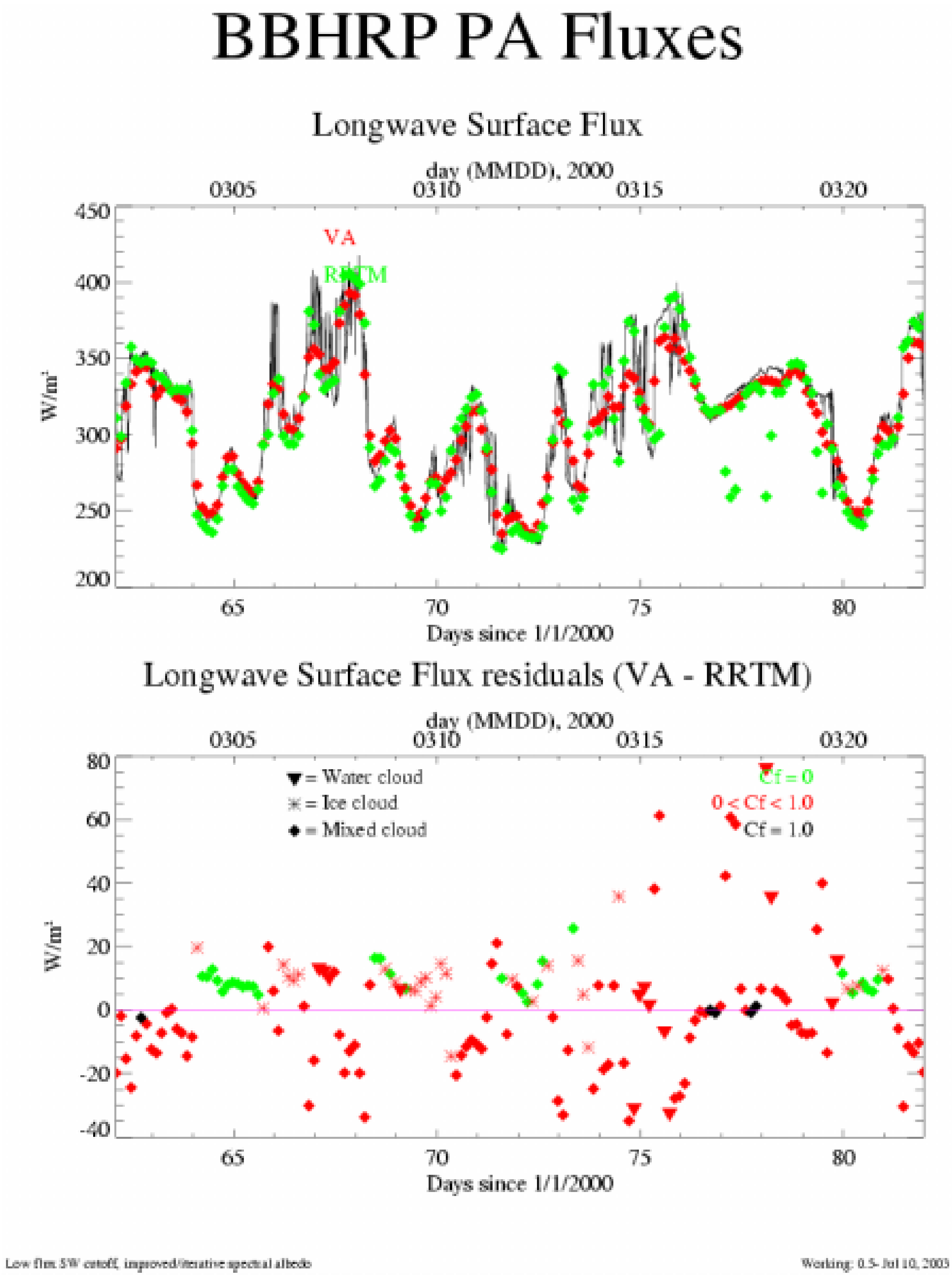
BBHRP PA Fluxes
Longwave Surface Flux
day (MMDD), 2000
0305
0310
0315
0320
VA
RRTM
W/m²
Days since 1/1/2000
Longwave Surface Flux residuals (VA - RRTM)
= Water cloud
= Ice cloud
= Mixed cloud
Cf = 0
0 < Cf < 1.0
Cf = 1.0
Low flux SW cutoff, improved/iterative spectral albedo
Working: 0.5- Jul 10, 2003

Figure 3a.

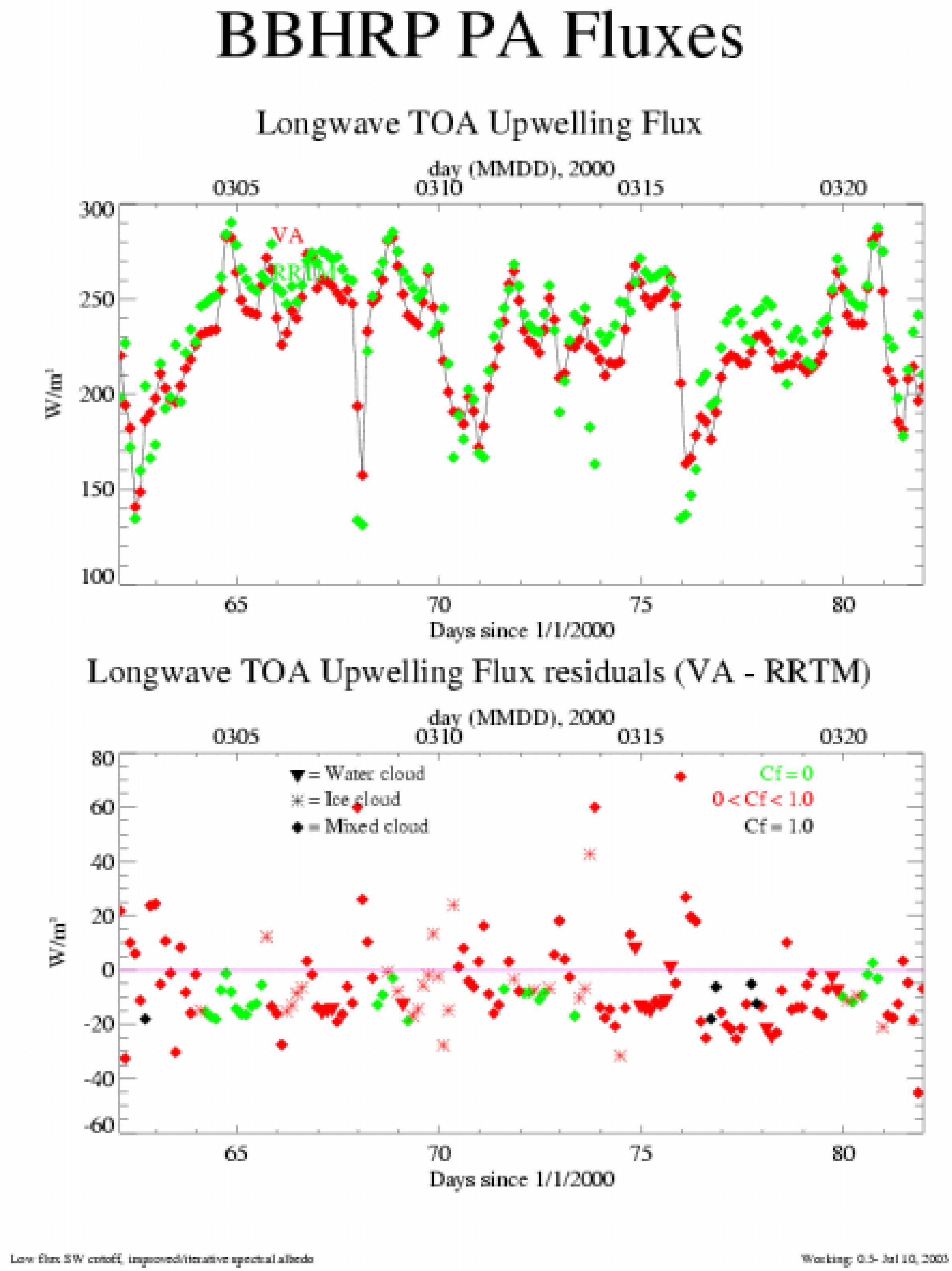
BBHRP PA Fluxes
Longwave TOA Upwelling Flux
day (MMDD), 2000
0305
0310
0315
0320
VA
RRTM
W/m²
300
250
200
150
100
65
70
75
80
Days since 1/1/2000
Longwave TOA Upwelling Flux residuals (VA - RRTM)
day (MMDD), 2000
0305
0310
0315
0320
▼ = Water cloud
✳ = Ice cloud
◆ = Mixed cloud
Cf = 0
0 < Cf < 1.0
Cf = 1.0
W/m²
80
60
40
20
0
-20
-40
-60
65
70
75
80
Days since 1/1/2000
Low flux SW cutoff, improved/iterative spectral albedo
Working: 0.5- Jul 10, 2003

Figure 3b.

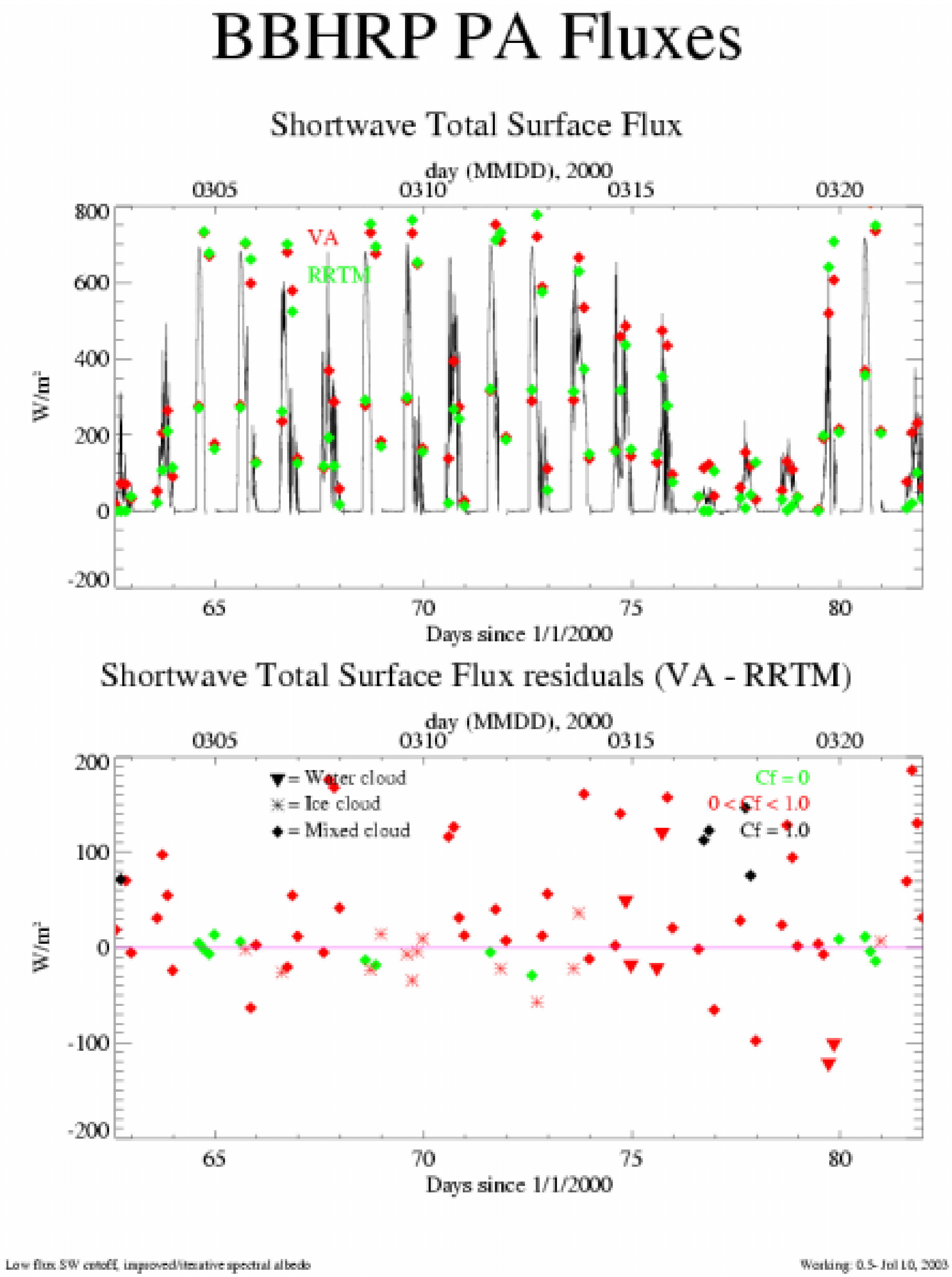
BBHRP PA Fluxes
Shortwave Total Surface Flux
day (MMDD), 2000
0305
0310
0315
0320
800
600
400
200
0
-200
VA
RRTM
W/m²
65
70
75
80
Days since 1/1/2000
Shortwave Total Surface Flux residuals (VA - RRTM)
day (MMDD), 2000
0305
0310
0315
0320
200
100
0
-100
-200
▼ = Water cloud
✳ = Ice cloud
◆ = Mixed cloud
Cf = 0
0 < Cf < 1.0
Cf = 1.0
W/m²
65
70
75
80
Days since 1/1/2000
Low flux SW cutoff, improved/iterative spectral albedo
Working: 0.5- Jul 10, 2003

Figure 3c.

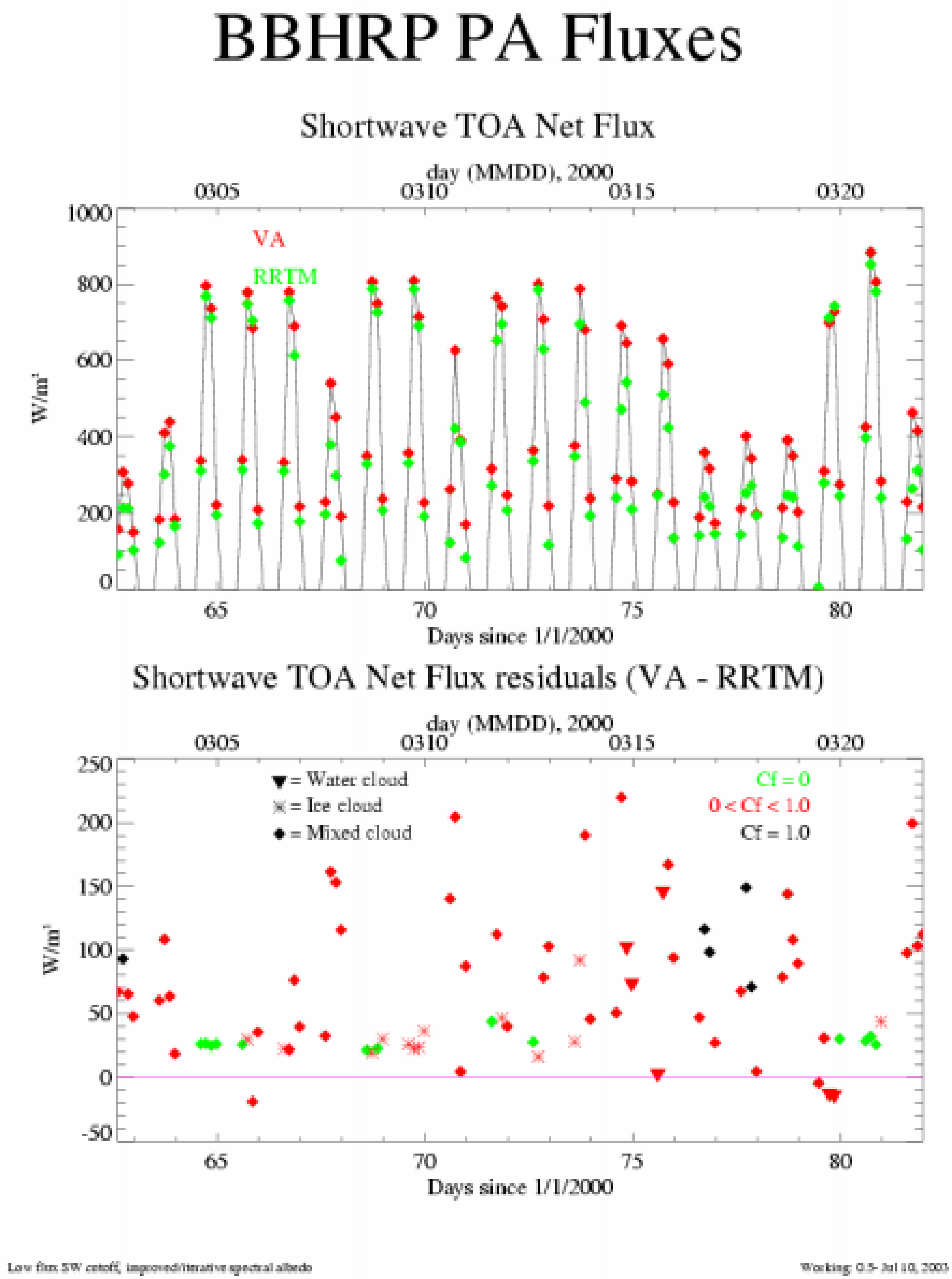
BBHRP PA Fluxes
Shortwave TOA Net Flux
day (MMDD), 2000
0305
0310
0315
0320
VA
RRTM
W/m²
Days since 1/1/2000
Shortwave TOA Net Flux residuals (VA - RRTM)
▼= Water cloud
⋇= Ice cloud
◆= Mixed cloud
Cf = 0
0 < Cf < 1.0
Cf = 1.0
Low flux SW cutoff, improved/iterative spectral albedo
Working: 0.5- Jul 10, 2003

Figure 3d.

Table 3. March 2000 P_a Version 1.0 statistical summary (Bias = measurement – RRTM, W/m^2).

	N	Bias	Avg|Δ-Bias|
Longwave surface	160	17.9	12.9
Clear	28	9.5	3.2
Liquid	14	8.4	16.3
Ice	27	8.6	6.0
Longwave TOA	160	-6.2	10.9
Clear	28	-10.1	4.5
Liquid	14	-10.8	6.3
Ice	27	-6.1	9.9
Shortwave surface	81	28.0	50.9
Clear	13	12.7	9.9
Liquid	6	-15.1	66.8
Ice	13	-10.1	19.1
Shortwave TOA	81	65.5	44.2
Clear	13	27.6	3.6
Liquid	6	49.8	57.8
Ice	13	33.5	13.0

2. The ice cloud residuals are consistent with the clear-sky residuals, as for P_i.

3. Due to the same issues as in P_i with the specification of liquid water clouds from the radar, the liquid and mixed phase clouds results are not encouraging.

Clearly noticeable in the shortwave TOA results, especially the clear-sky, is a positive bias, possible a result of a systematic issue with the P_a surface albedos, which are typically higher than the P_i values at corresponding times. This issue is currently being investigated.

Future Efforts

The BBHRP VAP is expected to have numerous scientific uses in closure studies, climate simulations, and the evaluation of improved physical parameterizations. The fulfillment of the multiple goals of this project will require the generation of a formal structure in which the data, both input and output are well organized and can be accessed and utilized by the community. Some of this has been accomplished this year, with a development of a system for evaluation of new approaches for possible inclusion in the VAP (i.e., an update to the algorithm with a new version number). For example, one such evaluation, referred to as ‘P_i Version 1.0 trial 1’, included aerosols in ice cloud cases using surface in situ aerosol measurements, did not show positive results and this approach was not adopted as an improved version of P_i. An expected milestone for this coming year will be Web access to the input rundecks, model output, and measured irradiances for both P_i and P_a.

The large scope of this effort will necessitate a gradual evolution of the project's capabilities. There are many specific advances that are expected in the next year. First, the heating rates computed by P_a Version 1.0 will be utilized by members of the Cloud Parameterization and Modeling Working Group in the manner discussed above. A detailed examination is planned of the P_a Version 1.0 residuals to resolve possible biases, with particular emphasis on the TOA residuals. The TOA boundary condition will also be included in the P_i analysis using CERES broadband data, with the possible use of spectral TOA satellite measurements (for P_a also) for probing of specific physical processes. Another area of improvement will be the use of different measurement sources for the specification of physical properties input to the radiative transfer models. One such change will be the development by the Aerosol Working Group of aerosol optical properties as a function of altitude for both clear and cloudy conditions. In addition, under development by members of the Instantaneous Radiative Flux Working Group is an approach to better specify the surface albedo needed for the P_i and P_a calculations by sampling a more appropriate surface area. Other expected areas of improvement are using the cloud liquid water determined by the Microwave Radiometer as a constraint on the radar-derived liquid column amounts, the determination of an appropriate total cloud cover to be used for P_i, and the evaluation of alternate cloud microphysical retrieval schemes. There are also plans to extend the temporal coverage of this VAP, running P_i at SGP from 2000 to the present and increasing the temporal frequency of the P_a calculations to once per hour. Also, the extension of the VAP to one or more additional ARM site is expected to begin development.

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