DRAFT!!!

Documentation and description of surface solar irradiance data sets produced for SeaWiFS

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INTRODUCTION

This is a description of two generations of modifications made to the Bishop and Rossow (1991) algorithm for surface solar irradiance. These modifications are currently implemented in the SeaWiFS production. Also described is the second generation data set (spanning 8 years) which is now in the archives at NCAR as well as a test version of third generation data set produced for SeaWiFS. Applications of the Bishop and Rossow data sets are found in papers by Mitchell et al. [1991], Liu et al. [1994], and Seager and Blumenthal [1994].

The modified Bishop and Rossow [1991] scheme uses C1 data (and will use higher resolution CX data) from the International Satellite Cloud Climatology Project. Briefly, ISCCP beginning in July 1983 combines data from multiple geostationary and polar orbiting meteorological satellites to provide a global view of the occurrence and optical properties of clouds [Schiffer and Rossow, 1983, 1985; Rossow et al., 1985; and Rossow and Schiffer, 1991]. The current ISCCP data production spans July 1983 - June 1991 but will extend indefinitely into the future, thus providing overlap with SeaWiFS.

This document will show that validation of satellite retrieved surface solar irradiance data sets using 5 ocean buoy datasets from BioWatt (34N 70W) and MLML (60N 21W) indicated a combined average bias of +5 W m^{-2} (range +20 to -10 W m^{-2}) and a worst case error of <7% of clear sky irradiance. These estimates ignored possible calibration errors of mooring data. Retrieved surface solar irradiance data showed excellent replication of the day-to-day variability of irradiance at the two mooring locations.

ISCCP C1 and CX Data:

The major input data set is the International Satellite Cloud Climatology Project C1 data, which contains, at nominal 280 km resolution and every 3 hours for the globe, information about clouds, the atmosphere, and surface [Rossow et al., 1988; Rossow and Schiffer, 1991]. Specific parameters used are: (1) solar zenith angle, (2) atmospheric ozone column abundance, total precipitable water, and surface pressure (daily for each 2.5 degree region on the globe; from TIROS Operational Vertical Sounder (TOVS) data), (3) surface visible (at 600 nm) reflectance (every 3 hours for each 2.5 degree region), and (4) cloud parameters for a single layer: cover fraction, and optical thickness (at 600 nm) (every 3 hours for each 2.5 degree region). A limitation is that visible radiative retrievals of cloud optical properties are performed only when the solar zenith angle is less than 78.5 degrees. Additional data sets employed are (5) land-water fraction, and (6) snow and sea ice cover (every 5 days for each 1 degree region). Although the ISCCP data are available eight times per day for most of the globe, regions not covered by geostationary satellite are observed less frequently by polar orbiters, leading to occasional gaps in the data.

The ISCCP CX data is the high-resolution (4-8 km pixel size, randomly subsampled at 30 km resolution) data set used to generate C1 data. CX data will be used to produce higher resolution surface solar irradiance fields as the next step in our SeaWiFS production.

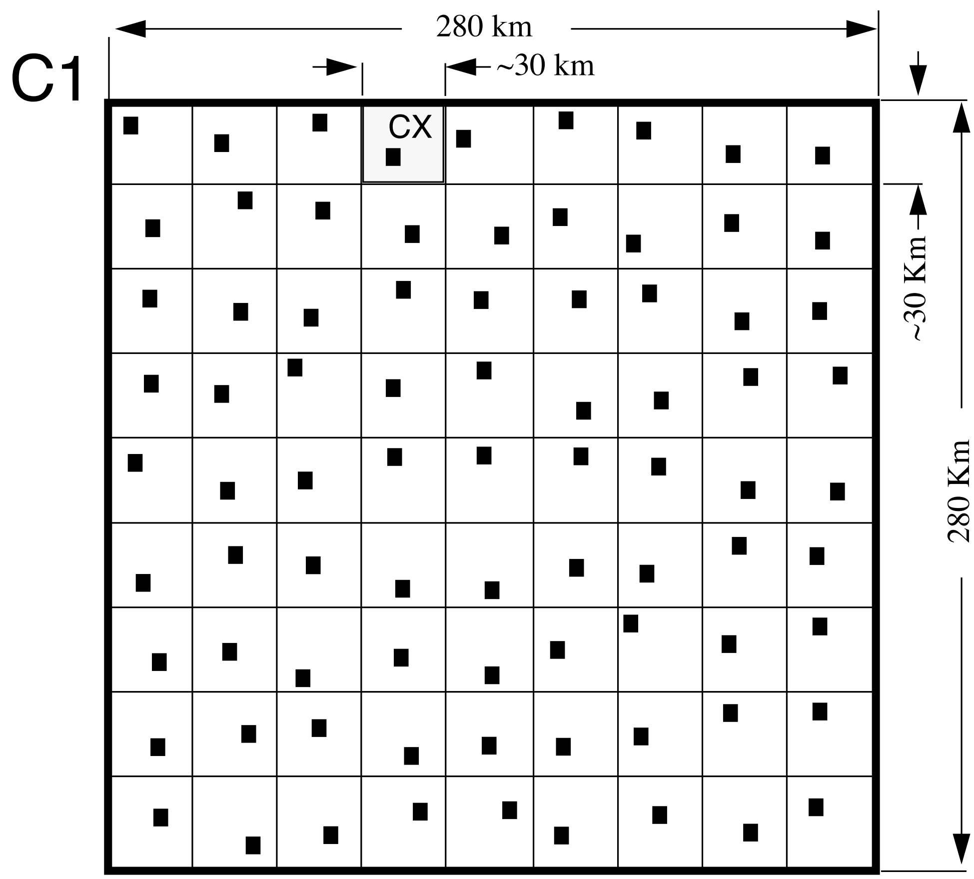

Figure 1. Schematic of ISCCP CX and C1 pixels. C1 pixels represent the average values of cloud properties in approximately 80 30km sized CX pixels. The CX pixel represents data ramdomly subsampled from a single 4-8 km area within that region.

The current span of ISCCP C1 and CX data is from July 1983 to June 1991, inclusive. ISCCP plans to begin production of a new but very similar product, denoted by D1 and DX. These data will eventually replace the 'C' data versions but priority will be to extend the 'C' time series forward in time and catch up with the earlier data later.

Although the Bishop and Rossow [1991] model has undergone two revisions. The fundamental approach has remained the same. Details of revisions are outlined below. Validation of data from these revisions are discussed in detail in a later section.

VERSION 2 PRODUCTION (Available from NCAR):

This revision to the Bishop and Rossow algorithm was focused primarily on issues of satellite sensor calibration, and data filling schemes necessary to implement production of global surface solar irradiance fields on 3 hour time steps as required by SeaWiFS. Changes are:

(1) Offsets in radiance calibrations from NOAA 7, 9, and 11 used in ISCCP cloud retrievals became apparent in EOF analyses of the seven year (1983-1990) Bishop and Rossow [1991] time series (see also Kelin and Hartmann, [1993]). To correct this, ISCCP C1 radiances were multiplied by 0.945 for data spanning July 1983 to January 1985 (NOAA 7), unaltered for February 1985 to October 1988 (NOAA 9) and multiplied by 1.119 for November 1988 to June 1991. ISCCP has a scheme to track sensor drift within the 3 periods and so no secondary drift correction was necessary. The adjusted radiances were subsequently used to derive cloud optical properties. Typical adjustments to total solar irradiances under cloudy conditions were of the order of +5 to +10 W m^{-2} and -10 to -20 W m^{-2} for NOAA 7 and NOAA 11 calibrated data sets, respectively. Cloud-free data were minimally affected because clear-sky radiances are computed by formula. After correction, NOAA satellite transitions were undetectable by EOF analysis of the data.

(2) All input data fields for each 3-hour ISCCP time step (surface pressure, ozone, precipitable water, surface reflectance, cloud fraction, and cloud optical thickness) were filled prior to performing the solar irradiance computations (see below). This eliminated the 'daily sampling correction factor' described by Bishop and Rossow [1991] and enabled production of irradiance fields on three hour time steps.

(3) Filling schemes:

a) Bad TOVS (surface pressure, ozone, precipitable water) data were trapped by referring TOVS surface pressure to Oort's monthly climatologies of surface pressure. Most data fields were complete. Ozone, water and surface pressure were retained from the last encountered good value at that location.

b) missing cloud fraction data are filled with a progressive scheme as outlined below:

1. a zonal (5 degrees of latitude) - surface type specific (land, ocean (Atlantic, Pacific, Indian), seas) averaged cloud fraction array was constructed and filled.
2. a 'day time' averaged cloud fraction (144x72) grid was computed from valid 'day' time cloud fraction data as defined by solar zenith angle less than 78.5 degrees.
3. a 24 hour averaged cloud fraction (144x72) grid was constructed and filled with the following precedence:
    - from neighboring points (+/- one pixel E/W) in longitude
    - from neighboring points (+/- one pixel N/S) in latitude
    - from averaged daily data from the previous day at the same location
    - from regional zonal means for that day (from 1).

4. missing data in each 3 hour cloud fraction array are filled from (2) if any daytime data are present or (3).

c) Missing cloud optical thickness data occur in cases where no cloud retrievals were performed due to missing data, or in cases of daylight and solar zenith angle >78.5 degrees. In these cases, each 3 hour data field is filled using the regional zonal means of cloud optical thickness over ocean or land binned as a function of cloud fraction and the corresponding cloud fraction value (from b).

The effectiveness of these steps was judged by animation of cloud fraction fields and spatial EOF analysis.

(4) Surface reflectance over the ocean was set to 0.06 as in the Version 1 [Bishop and Rossow, 1991] production. This was necessary to trap high ISCCP C1 surface reflectance values due to sun glint.

(5) The fraction of the day with unfilled data (weighted by irradiance) was introduced as a data quality indicator.

Availability of Version 2 production data:

Monthly averaged solar irradiance fields are available on line by:

```
anonymous ftp to nasagiss.giss.nasa.gov
login as "giss"
use your email address as password.
```

The entire Version 2 production at daily and monthly resolution (July 1983 to June 1991) are now in the archives at NCAR (October 1994).

The data set reference is ’`DS741.0 SURFACE SOLAR IRRADIANCE BY BISHOP`’.

Requests can be directed to:

```
NCAR Data Support Section, email: datahelp@ncar.ucar.edu, (303)-
   497-1219, or directly to
Dennis Joseph, email: joseph@ncar.ucar.edu. (303)-497-1216,
```

Data also can be directly accessed and browsed by:

```
ftp to ncardata.ucar.edu (128.117.8.111) or
WWW (MOSAIC) at "http://www.ucar.edu/dss".
```

Finally, selected daily time series of surface solar irradiance from the southern ocean in the proposed JGOFS study area are available on the US JGOFS data system. For those without the JGOFS data system software, access is possible via:

```
WWW (MOSAIC) at "http://lake.mit.edu/jgofs.html".
```

Version 2 Files:

There are seven classes of data files as defined below:

```
example filename: c1qcld19.8307in1b
                      name   yymm
```

yymm:		- year and month of data set.
name:	qcld	- daily: total solar irradiance including cloud effects
	qclr	- daily: clear-sky solar irradiance
	rati	- daily: fraction of day with unfilled data (quality parameter 5)

`aqcl`	- monthly: averaged total solar irradiance including cloud effects
`afrc`	- monthly: averaged cloud fraction.
`sqcl`	- standard deviation of qcld.
`rqcl`	- standard deviation of qcld/average of qcld.

Mapping is on a 144 x 72 (2.5 x 2.5 degree) rectangular grid, with:

```
[  1, 1]    centered on 178.75W 88.75S
[  1,72]    centered on   "     88.75N
[144, 1]             on 178.75E 88.75S
[144,72]             on    "    88.75N.
```

The files at daily resolution (qcld, qclr and rati) contain multiple sets of 72 x 144 (4 byte ascii integer) records with the number of sets corresponding to the number of days of the month. Note February data reflects leap years when they occur. The other files (aqcl, sqcl, rqcl, and afrc) contain a single set of 72 x 144 (4 byte ascii integer) records. All Irradiances are integer values of W m^{-2} multiplied by 10; all fractions are multiplied by 1000; missing data are denoted by values of -999.

For example, the 72nd record from the first day's data in c1qcld19.8307in1b is:

```
26412642264326432644264526462646264726482648264926502650265126522
53265326542654265526562656265733663366336633663366336733673367336
7
```

and would be translated into:

```
264.1 264.2 264.3 264.3 264.4 264.5 264.6 264.6 264.7 ... 263.9
264.0 264.1 W m-2.
```

VERSION 3 PRODUCTION: Full SeaWiFS implementation (test data set).

(1) NOAA satellite calibration corrections were retained from version 2.

(2) All data fields were filled as in version 2. Minor bugs found in TOVS ozone and precipitable water fields were repaired. Only 1-2% of pixels were affected by this cleanup (See, e.g. Figure 3).

(3) Filling schemes unchanged except for surface and total water, which was filled similarly to cloud fraction, from previous value,or from zonal or merid interpolation, or from zonal mean at the same latitude.

(4) Surface reflectance scheme was revised:

a) land/coastal points from C1 data were filled in cases of missing data or sun glint geometry.

b) ocean points are the sum of theoretical reflectance after Cox and Munk [1956] (function of zenith angle and cloud fraction) and irradiance back-scattered from below the surface, after Morel and Gentili [1991] (function of diffuse fraction of PAR using uniform backscattering parameters).

(5) A second quality parameter (fill method) was added:

fill codes are:

0	= normal (no data filled)
+10	= TOVS data filled (H_20, O_3)
+50	= glint or missing land reflectance
+100	= missing cloud opt thickness, cloud fraction data present.
+190	= missing cloud opt thickness, cloud fraction data filled.
255	= no daylight entire day

(6) Added:

a) all input data fields were saved.

b) Computed fields on 3hr time steps were saved as required by SeaWiFS.

c) Photosynthetically Active irRadiance (PAR) [350-700 nm] was added. PAR is computed using the Frouin et al. [1989] clear-sky formulation and the Bishop and Rossow [1991] approach.

d) Diffuse (vs. direct from sun) fraction of PAR was added.
The diffuse fraction of PAR including clouds is calculated from the parameterization of the clear sky formula, and assuming Rayleigh optical thicknesses [Hoyt, 1977] and a uniform aerosol optical thickness of 0.04.

(7) adopted NCSA's HDF Scientific Data Set format as required by SeaWiFS and the Goddard DAAC.

Differences between the original Bishop and Rossow (1991) production and SeaWiFS production for average surface solar irradiance for July 1993 are shown in Figure 2. The +5 to +10 W m^{-2} differences shown in the lower panel reflect primarily the effects of satellite calibration corrections applied in Version 2. Since radiances were adjusted downward, clouds became less optically dense, hence irradiance increased. Data in Figure 3 show less than +2 to -2 W m^{-2} differences between Production versions 2 and 3. Those differences that do exist occur mainly in non-oceanic regions. As a result of the completion of Version 2 production, Version 2 data will be used in the discussion of validation of data below.

Availability of Production version 3 data:

One month of test production data may be obtained by:

```
ftp to i0.giss.nasa.gov.  login as 'seawifs' password 'solar1'.
```

The data are readable using NCSA's HDF software (see Appendix 1 below) and may be displayed by NCSA's Collage (v1.3) and Spyglass.

Data format and description:

ISCCP C1 data source data is on an equal area grid with a an effective 280x280 km pixel size (with 2.5 degree latitude resolution). For SeaWiFS production, the data have been mapped on a 144 x 72 (2.5 x 2.5 degree) rectangular grid, with:

```
[  1, 1]    centered on 178.75W 88.75S
[  1,72]    centered on    "    88.75N
[144, 1]             on 178.75E 88.75S
[144,72]             on    "    88.75N.
```

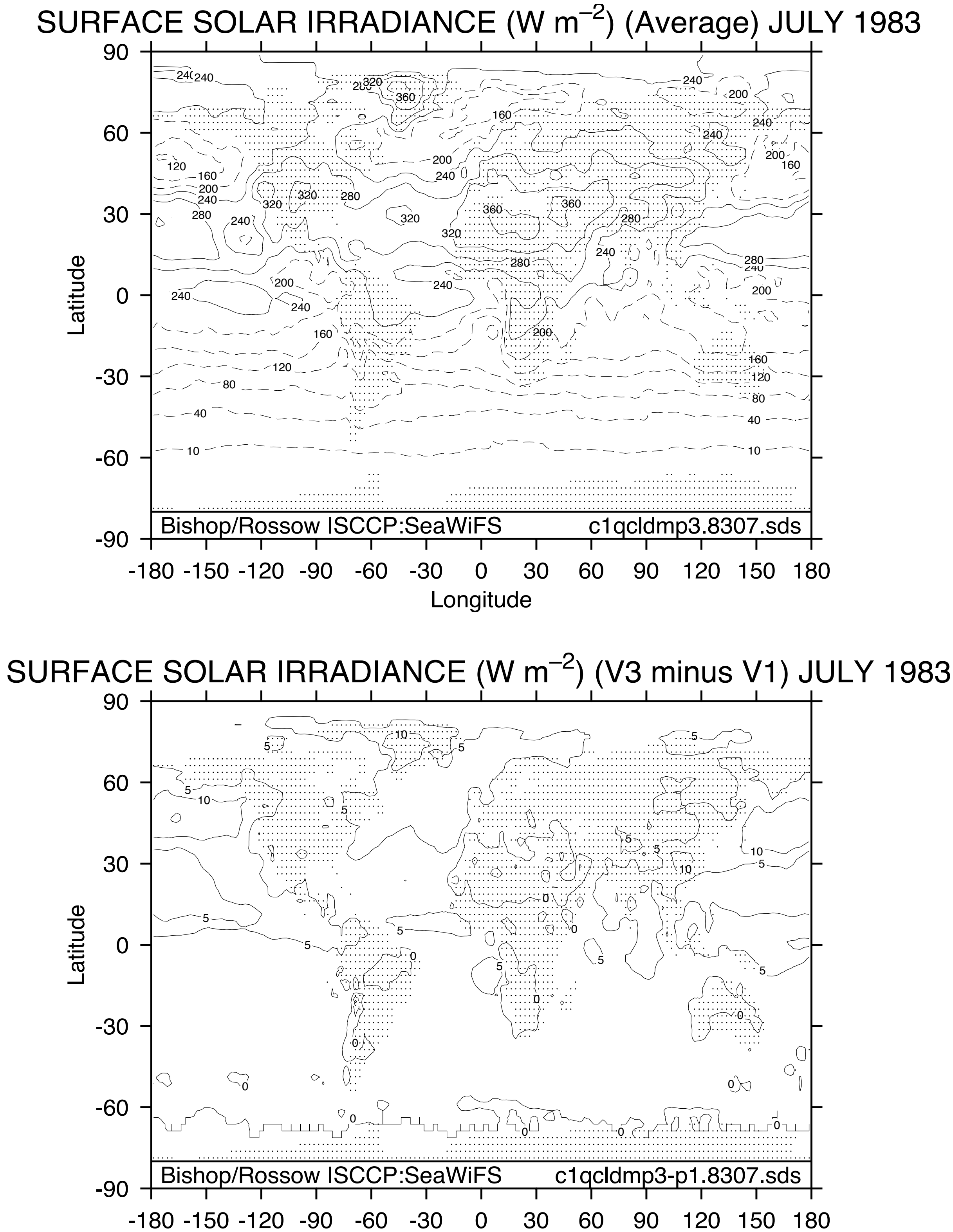

Figure 2. Top: Version 3 monthly averaged surface solar irradiance for July 1993: Bottom: difference between version 3 and data from Version 1 [Bishop and Rossow, 1991]

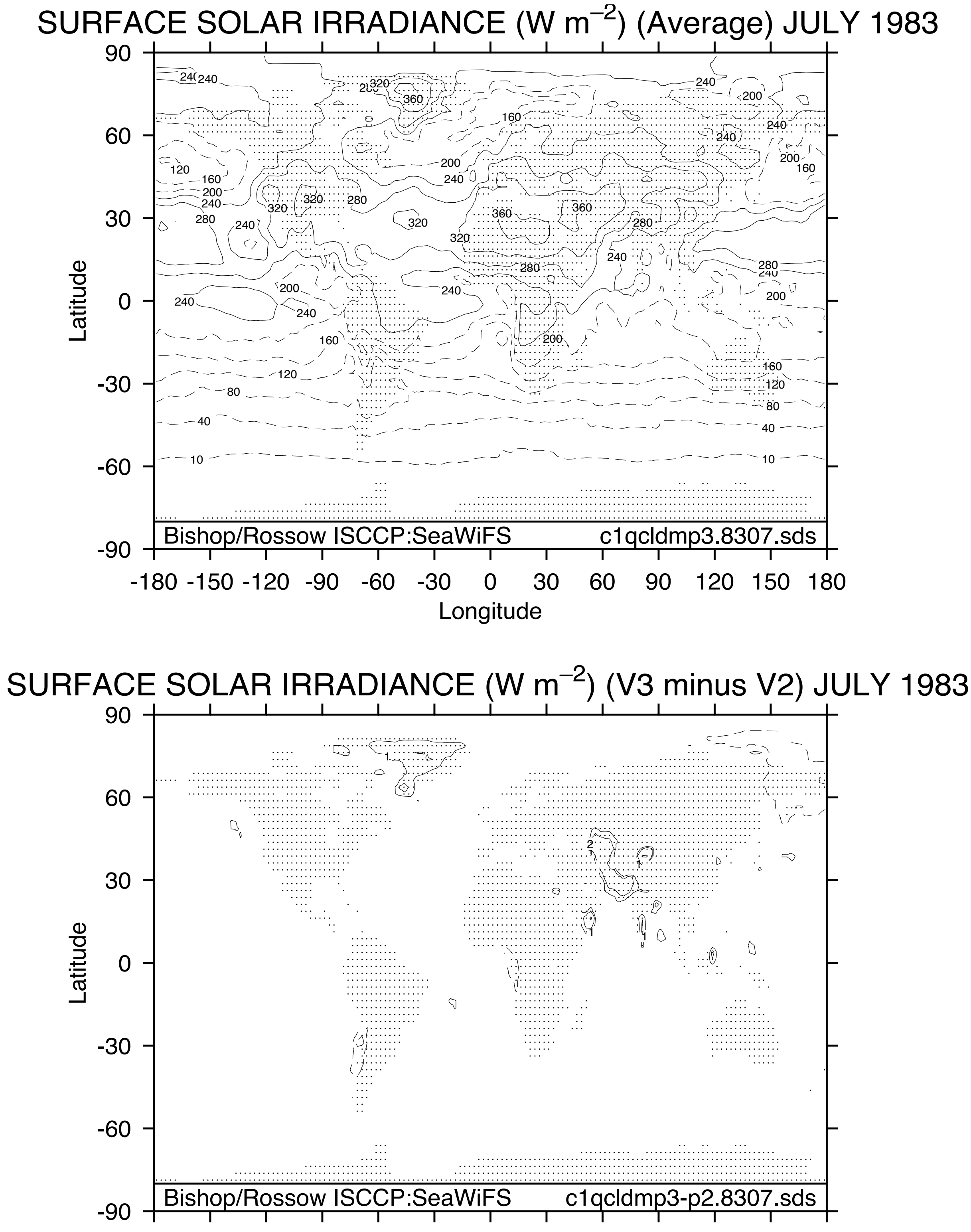

Figure 3. Top: Version 3 monthly averaged surface solar irradiance for July 1993: Bottom: difference between data from Version 3 and data from Version 2 described above.

Some variables are updated only once per day (e.g. 'TOVS' data for H_2O, O_3). Owing to sparseness of coverage, some of the C1 input variables were replaced with climatologies (e.g. surface pressure from NOAA GFDL monthly climatological data), with theoretical estimates (e.g. ocean surface reflectances, see above) or with bulk parameterizations (e.g. sulfate aerosols and visibilities were assumed constant). Total irradiance is given for both the full spectral range and for Photosynthetically Active Radiation (PAR, 350-700 nm). To correct to PAR [400-700 nm, typical of shipboard sensors] our calculated values should be multiplied by 0.97 (Ray Smith, personal communication). Standard deviations of total irradiance for both the full and PAR ranges are also included.

The model output consists of 3-hourly, averaged daily (over 24 hours), and averaged monthly arrays of clear-sky and total (i.e. including effects of clouds) irradiance. The 3 hourly data correspond to 3 hour periods centered on GMT's 0000, 0300, 0600, 0900, 1200, 1500, 1800, and 2100. Monthly and daily data are representative of the actual number of days of the month. February data represent 29 days in leap years.

The *NAMING SCHEME* for files is as follows:

```
example file name: c1qclddp3.8307.sds.
                     namex n yymm
```

where

`c1`: means ISCCP c1 data were used. (later versions will use cx,d1,dx etc.)

`name`: is the 4-letter code *NAME* for the variable (see Tables 1-4, below).

`x`: data *TYPE* is 8, d, or m - for 3-hourly, daily or monthly data, respectively. The three data types in uncompressed from occupy 5.16, 0.65, and 0.02 MB, respectively. The '8' and 'd' file sizes depend on the number of days in the month. (Note that the 3-hourly and daily data fall into two categories: for most fractional data and state variables, such as cloud cover and ozone, the data represents an average over the period in question; however for cumulative variables such as irradiance the 3-hourly data represent time-integrated averages. By contrast daily and monthly values always represent averages of 3 hourly and the daily data, respectively)

`p3`: means this is the 3rd version of the model. Bishop and Rossow (1991) describe version 1. Details of changes are described above.

`yymm`: is the month and year; all files for July 1983 are designated 8307

`sds`: identifies the data as being in HDF Scientific Data Set format

The four-letter variable code names and corresponding data descriptions are summarized in tables 1,2 and 3. Data sets listed in Table 3 are not currently intended for ingest into the SeaWiFS data archives. The main rationale for saving clear-sky (qclr) and input data fields is to permit recalculation of aerosol effects (now assumed constant) at a later date.

Table 1: Test C1 Output Variables and diagnostic quantities produced for SeaWiFS

name	type 'x'	multiplier	description	Units	Size* Mb

`cosz`	`8`
	`d`
	`m`
		1000
		1000
		1000
			cosine solar zenith angle - includes seasonal variation in earth - sun distance.	-	5.16
					0.65
					0.02

`qclr`	`8`
	`d`
	`m`
		1
		10
		10
			clear-sky irradiance (full spectrum)	W m^{-2}	5.16
					0.65
					0.02

`qcld`	`8`
	`d`
	`m`
		1
		10
		10
			irradiance including effects of clouds (full spectrum)	W m^{-2}	5.16
					0.65
					0.02

`qpar`	`8`
	`d`
	`m`
		1
		10
		10
			PAR [350-700 nm] including clouds (This may be changed to PAR [400-700 nm] in actual production). Use 0.97 to convert PAR [350-700] to PAR [400-700].	W m^{-2}	5.16
					0.65
					0.02

`dffr`	`8`
	`d`
	`m`
		1000
		1000
		1000
			Diffuse fraction PAR (including clouds)	-	5.16
					0.65
					0.02

`rati`	`d` `m`	1000 1000	daily/monthly sampling fraction	-	0.65 0.02
`fill`	`8` `d`	1 1	fill scheme mask	-	5.16 0.65
`sqcl`	`m`	10	std dev of daily `qcld` values over one month	W m^{-2}	0.021
`sqpa`	`m`	10	std dev of `qpar` including clouds	W m^{-2}	0.021

Table 2: Saved C1 and computed input variables

name	type 'x'	multiplier	description	Units	Size Mb
`psfc`	`m`	1	monthly climatological surface pressure	hPa	0.02
`aice`	`d` `m`	1000 1000	C1 snow and ice cover fraction	-	0.65 0.02
`wtot`	`d`	1000	C1 - filled total precipitable water	cm	0.65

Table 2: Saved C1 and computed input variables

name	type 'x'	multiplier	description	Units	Size Mb
`ozon`	`d`	1	C1 - filled total ozone	Dobson units	0.65

`rsfc`	`8`
	`d`
	`m`
		1000
		1000
		1000
			surface reflectance	-	5.16
					0.65
					0.02

`clfr`	`8`
	`d`
	`m`
		1000
		1000
		1000
			C1 - filled cloud fraction	-	5.16
					0.65
					0.02

`ctau`	`8`	100	C1 - filled cloud optical thickness		5.15
`aalb`	`m`	1000	computed diffuse cloud albedo	-	0.021
`lwco`	`m`	1	land water coast ocean mask -1 land 0 coast 1 non-ocean water (includes seas) 2 Atlantic 3 Indian 4 Pacific NOTE: This field never changes but is repeated in data to facilitate analysis.	-	0.02

Table 3: C1 Input variables saved for later use

name	type	multiplier	description	Units	Size Mb
`psfc`	`d`	1	C1 surface pressure	hPa	0.65
`wat1`	`d`	1000	C1 precipitable water 1000-800 mb	cm	0.65
`wat2`	`d`	1000	C1 precipitable water 800-680 mb	cm	0.65
`wat3`	`d`	1000	C1 precipitable water 680-560 mb	cm	0.65
`wat4`	`d`	1000	C1 precipitable water 560-440 mb	cm	0.65
`wat5`	`d`	1000	C1 precipitable water 440-310 mb	cm	0.65
`tsfc`	`d`	1000	C1 temperature at surface	K	0.65
`tmp1`	`d`	1000	C1 temperature at 900 mb	K	0.65
`tmp2`	`d`	1000	C1 temperature at 740 mb	K	0.65

Table 3: C1 Input variables saved for later use

name	type	multiplier	description	Units	Size Mb
`tmp3`	`d`	1000	C1 temperature at 620 mb	K	0.65
`tmp4`	`d`	1000	C1 temperature at 500 mb	K	0.65
`tmp5`	`d`	1000	C1 temperature at 375 mb	K	0.65

Table 4: PROPOSED CX Output Variables and diagnostic quantities produced for SeaWiFS

name	type 'x'	multiplier	description	Units	Size* Mb

`cosz`	`8`
	`d`
	`m`
		1000
		1000
		1000
			cosine solar zenith angle - includes seasonal variation in earth - sun distance.	-	413
					5.2
					1.6

`qclr`	`8`
	`d`
	`m`
		1
		10
		10
			clear-sky irradiance (full spectrum)	W m^{-2}	413
					5.2
					1.6

`qcld`	`8`
	`d`
	`m`
		1
		10
		10
			irradiance including effects of clouds (full spectrum)	W m^{-2}	413
					5.2
					1.6

`qpar`	`8`
	`d`
	`m`
		1
		10
		10
			PAR [350-700 nm] including clouds (This may be changed to PAR [400-700 nm] in actual production). Use 0.97 to convert PAR [350-700] to PAR [400-700].	W m^{-2}	413
					5.2
					1.6

`dffr`	`8`
	`d`
	`m`
		1000
		1000
		1000
			Diffuse fraction PAR (including clouds)	-	413
					5.2
					1.6

`rati`	`d` `m`	1000 1000	daily/monthly sampling fraction	-	5.2 1.6
`fill`	`8`	1	fill scheme mask	-	413
`sqcl`	`m`	10	std dev of daily `qcld` values over one month	W m^{-2}	1.6
`sqpa`	`m`	10	std dev of `qpar` including clouds	W m^{-2}	1.6

One month of compressed data (c1 or d1 based) occupies approximately 32 MB. Expanded volume totals approximately 62 MB (Tables 1 and 2) implying a data volume of approximately 0.738 GB/ year (uncompressed). One month of cx or dx based data for Table 4 parameters (yet to be produced) will be approximately 2.5 GBytes and will total approximately 30 GB/year (uncompressed).

File names and compressed file sizes of the SeaWiFS test data set follow references.

VALIDATION OF SURFACE SOLAR IRRADIANCE DATA

Several approaches (beyond those already taken by Bishop and Rossow [1991] have been taken to validate the quality of the data produced for SeaWiFS. All comparisons have been made using data from the existing eight year long time series (at NCAR) since differences between the SeaWiFS production data and the existing time series amount to less than 1-2 W m^{-2} (Figure 3), less than 1% of typical surface irradiances.

Ocean weather station climatology. Agreement between climatology from ocean weather stations A, I, J, P and Sable Island (1960's to early 1970's) and our existing (1983-1991) time series is depicted in Figure 4 and summarized by Tables 5 and 6.

Table 5: Ocean Station Climatology vs. Version 2 (1983-1991)

	OWS A (1961-1971)				OWS I (1957-1971)				OWS J (1958-1971)			
Month	Obs.	Int.	Pixel	s.d.	Obs.	Int.	Pixel	s.d.	Obs.	Int.	Pixel	s.d.
Jan.	6	3.2	3.9	0.4	12	7.8	8.2	0.9	21	15.9	13.4	1.7
Feb.	15	16.9	18.6	2.5	27	23.3	24.0	4.7	56	41.7	37.5	6.0
Mar.	49	56.1	59.5	4.5	53	66.2	67.0	4.1	92	91.4	87.0	5.2
Apr	83	114.0	116.0	9.8	105	124.0	125.2	13.3	126	148.5	148.1	10.5
May	111	166.0	161.5	15.9	153	182.6	183.6	9.4	181	194.2	187.9	10.4
June	96	188.4	178.3	13.7	163	207.1	208.5	16.3	191	208.6	208.8	4.2
July	156	170.8	165.6	17.1	168	177.5	178.1	13.2	178	192.0	189.2	11.6
Aug.	111	133.7	131.9	13.1	150	147.6	149.0	11.0	155	167.4	163.7	8.5
Sept.	78	77.7	79.6	8.2	84	91.5	92.3	7.9	109	119.2	112.7	9.7
Oct.	23	30.4	32.8	6.0	37	42.6	43.5	4.1	65	63.1	58.4	4.3
Nov.	8	7.8	9.2	0.7	16	13.0	13.3	2.2	31	24.6	21.2	3.4
Dec.	2	1.3	1.8	0.2	6	4.4	4.8	0.6	16	13.0	11.3	0.9
Average	61.5	80.5	79.9		81.2	90.6	91.4		101.8	106.6	103.3	

All values in W m^{-2}. Obs. - climatological (1970's) means for stations A, I, J, and Sable Island from Dobson and Smith [1988]; for B and P from Smith and Dobson [1984]. Int. - Version 2 data interpolated to location of the station. Pixel - values of data from pixel containing the station. s.d. - standard deviation of monthly irradiances over the 8 year time series.

Table 6: Ocean Station Climatology vs. Version 2 continued.

	OWS P (1959-1975)				Sable Island (1969-1980)			
month	Obs.	Int.	Pixel	s.d.	Obs.	Int.	Pixel	s.d.
Jan.	26.6	25.4	22.0	2.6	49	39.8	36.9	3.8
Feb.	52.7	54.2	50.8	5.1	81	75.5	71.7	3.6
Mar.	94.7	107.3	105.6	10.3	134	133.7	126.9	11.7
Apr.	151.7	174.9	172.2	11.4	172	184.7	180.2	21.5
May	186.0	204.7	205.2	10.8	222	232.9	228.3	21.4
June	187.2	202.0	201.0	17.1	237	246.6	241.9	17.9
July	172.9	182.3	185.9	10.1	236	246.0	246.5	16.4
Aug.	146.9	159.0	158.7	12.0	206	219.1	217.8	20.9
Sept.	114.3	124.1	120.6	6.4	165	166.7	165.6	9.0
Oct.	73.7	73.8	70.6	5.2	101	97.2	96.8	9.6
Nov.	36.7	35.3	32.5	4.4	56	48.9	48.2	4.4
Dec.	23.2	22.0	18.6	2.1	40	32.4	30.0	2.7
Average	105.5	113.8	112.0		141.6	143.6	140.9	

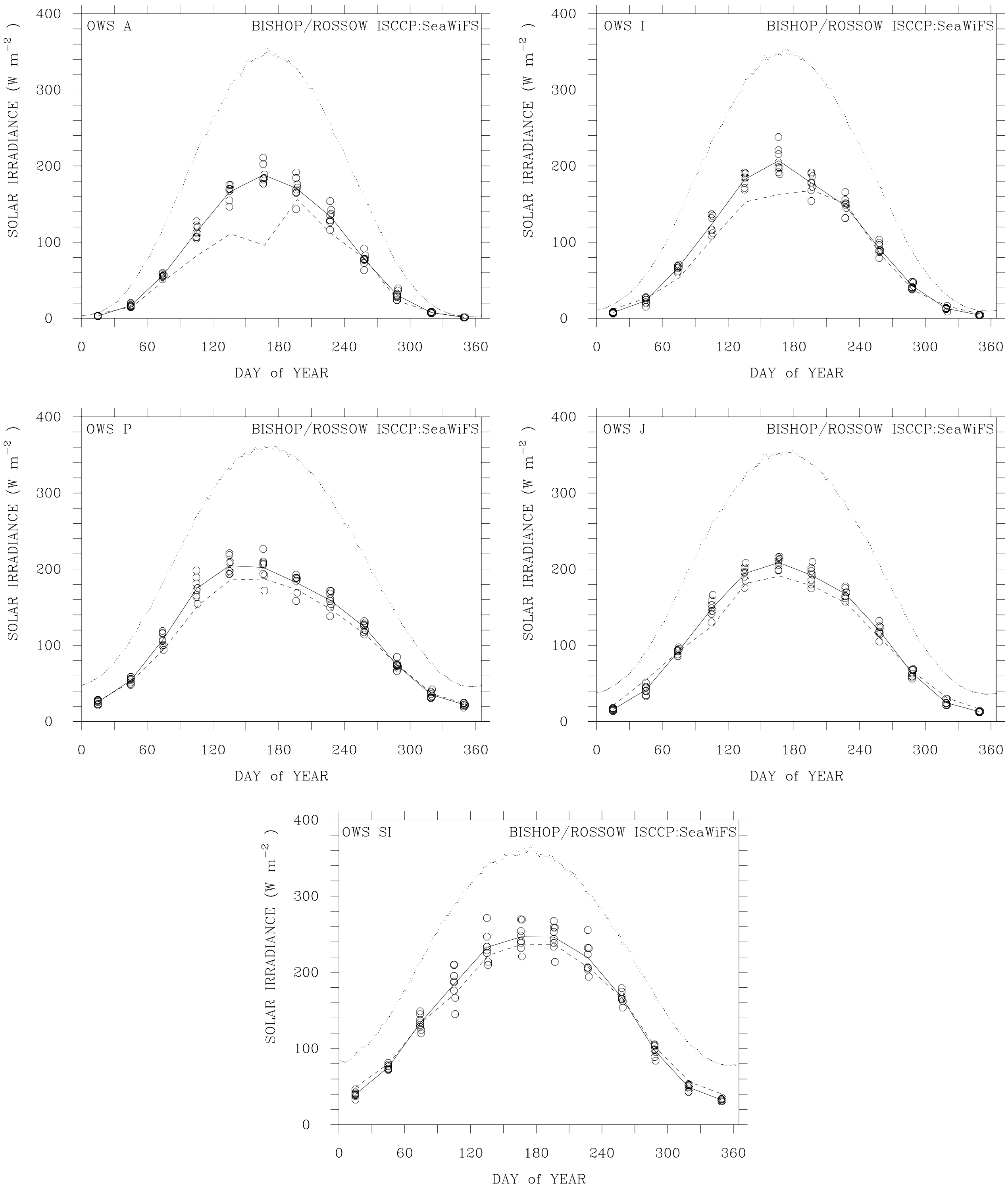

Figure 4. Comparison of surface solar irradiance from late 1960's to early 1970's climatoligy from ocean weather stations [Smith and Dobson, 1984; Dobson and Smith, 1988] and ISCCP Version 2 (July 1983 to June 1991). Climatological data for A (62N 33W), I (59N 19W), J (52.5N 20W), P (50N 145W) and Sable Island (44N 60W) are shown by dashed line; Version 2 8 year means are shown by solid line; Individual V2 months (o); V2 daily clear sky irradiance denote the upper envelope of the data.

Differences are greatest in the N Atlantic. Ocean weather station A, at 62 N, east of Greenland, shows differences of 50 and 80 W m^{-2} for the months of May and June and an annual average 18 W m^{-2} lower than version 2 data. Station I, at 59 N, south of Iceland, has 30 and 45 W m^{-2} differences for the same months and a 10 W m^{-2} difference in annual mean. Station J and Sable Island show differences in the summer months of less than 20 and 10 W m^{-2}, respectively, and almost no bias in annual mean due to compensating reverse differences in other seasons. Station P data tell a similar story with a bias below 9 m^{-2} in annual mean. The contemporaneous data comparison described below for the MLML site, almost at the location of OWS I, indicates little or no detectable bias between surface observations and those retrieved from ISCCP data. Furthermore, the decreasing amplitude of difference with latitude and the enhancement of differences in the N. Atlantic vs. the Pacific is consistent with patterns of shifts in climate between the two time periods compared [Deser and Blackmon, 1993; Levitus et al., 1994].

Contemporaneous comparisons at daily resolution. Bishop and Rossow [1991] reported on the results of spatial comparisons made using a 17 day time series of CX pixels and comparable array of ground sensors at a continental site and found a -4 W m^{-2} bias in the mean and 9 W m^{-2} standard error at daily resolution. No AVHRR calibration adjustments were needed for this 1986 time period and thus these comparisons may be applied to version 2 data..

Of more interest to the SeaWiFS group is the comparison to contemporaneous time series at daily resolution obtained as part of the ONR funded and BioWatt and MLML programs. The data were obtained from Dr. Malgorzata Stramska at USC. The time series comparison results are shown in Figures 5-9 and mean and standard deviation data are summarized in Table 7.

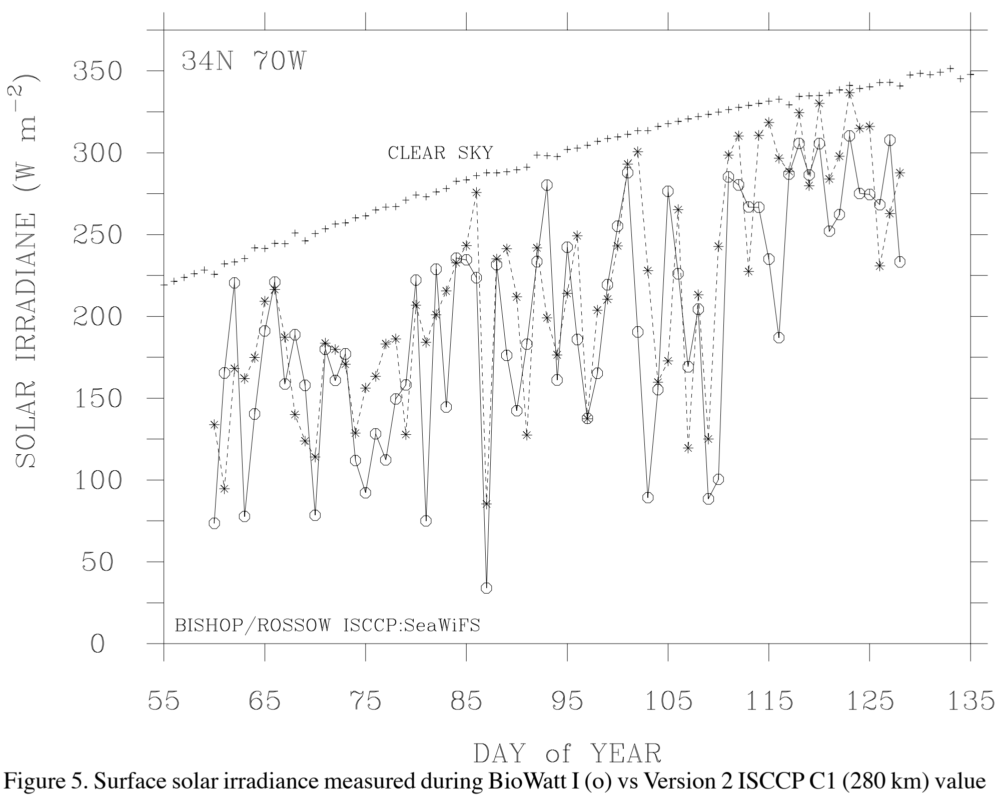

Figure 5. Surface solar irradiance measured during BioWatt I (o) vs Version 2 ISCCP C1 (280 km) value (*) in 1987.

Generally good agreement was found. Differences seen in the time series primarily reflect the mis-

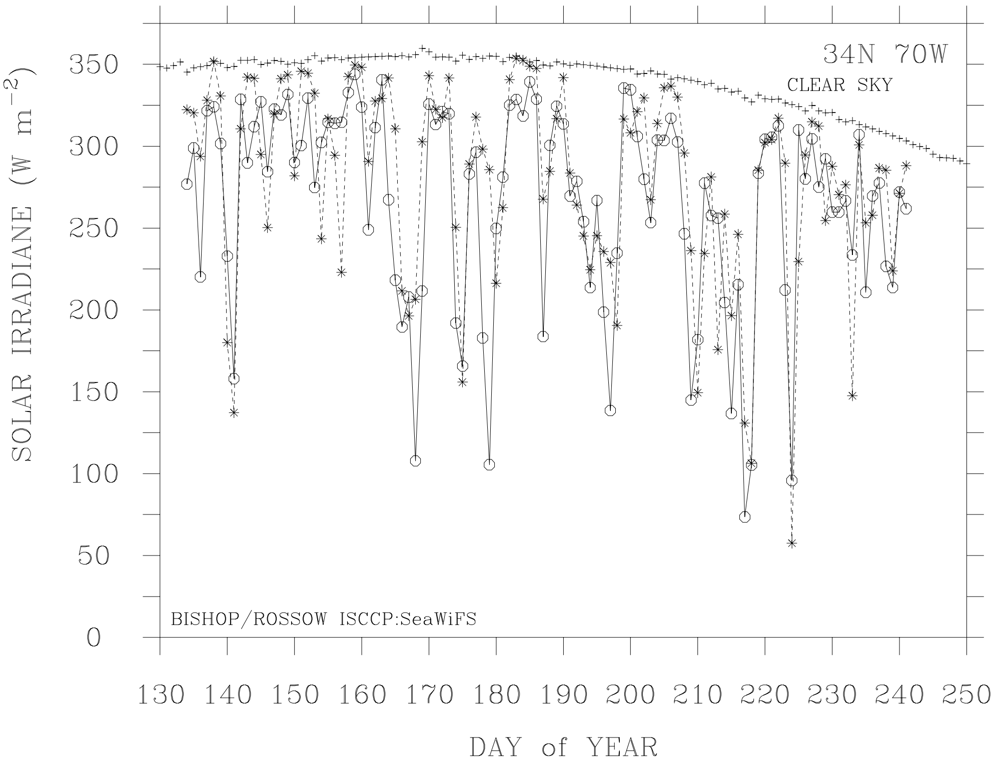

Figure 6. Surface solar irradiance measured during BioWatt II (o) vs Version 2 ISCCP C1 (280 km) value (*) in 1987.

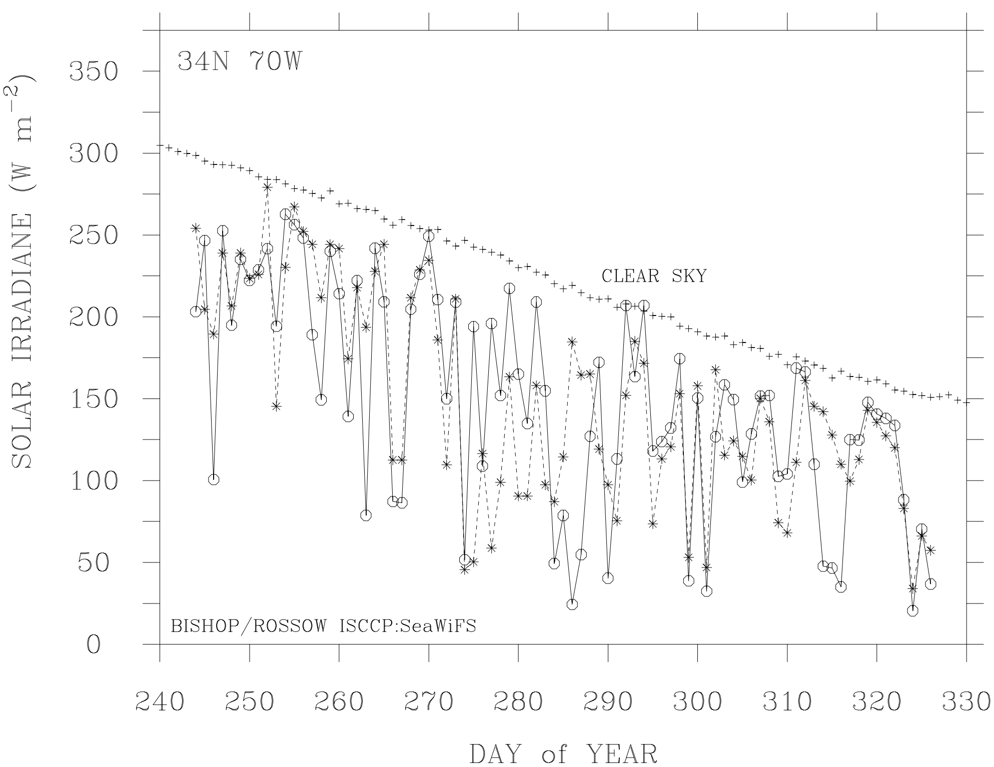

Figure 7. Surface solar irradiance measured during BioWatt III (o) vs Version 2 ISCCP C1 (280 km) value (*) in 1987.

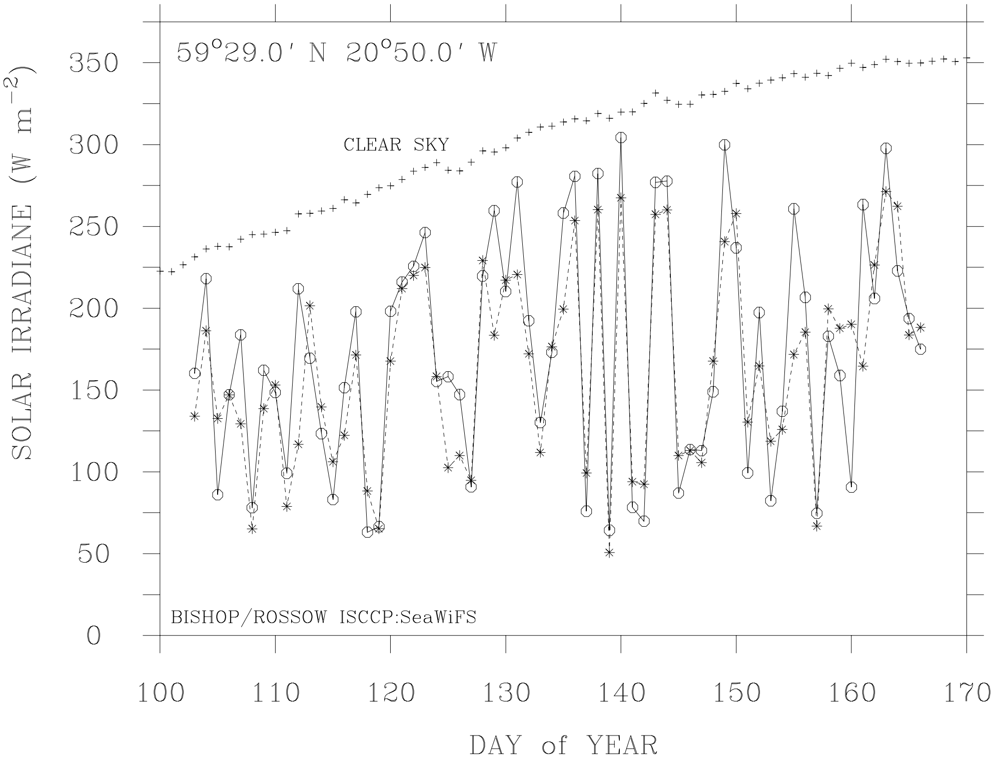

Figure 8. Surface solar irradiance measured during MLML (o) vs Version 2 ISCCP C1 (280 km) value (*) in 1989.

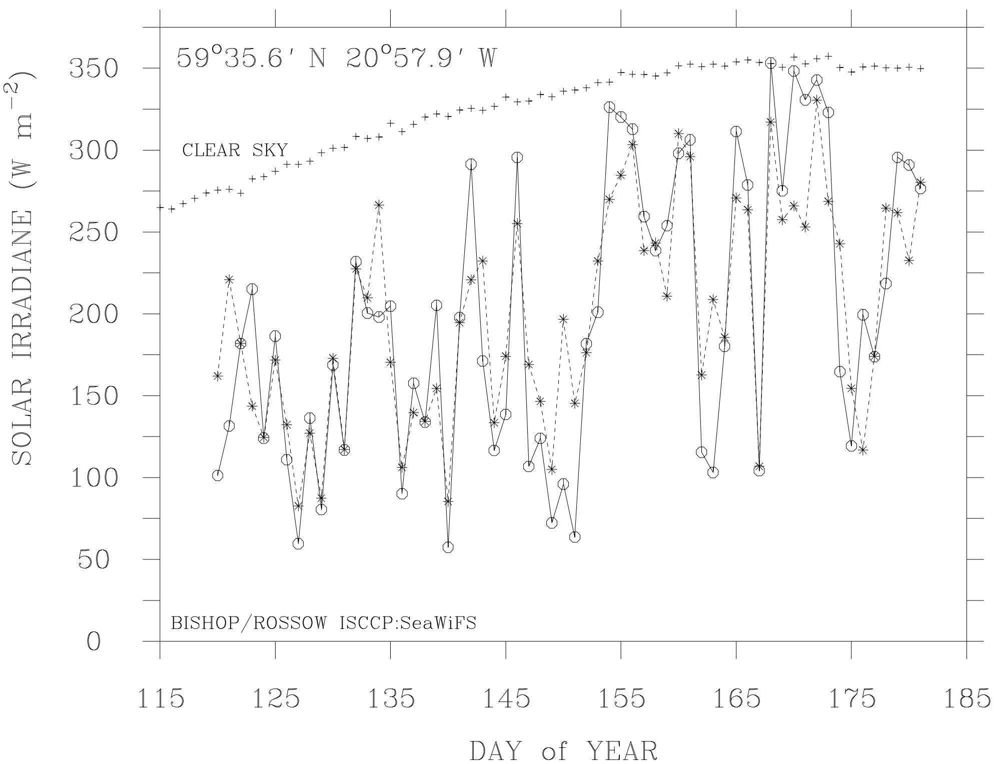

Figure 9. Surface solar irradiance measured during MLML (o) vs Version 2 ISCCP C1 (280 km) value (*) in 1991.

match of the 280 km spatial scale represented by the ISCCP C1 pixel and the point locations of the moorings. For example, scatter in Figure 10 is mostly due to temporal mismatches of the trends of

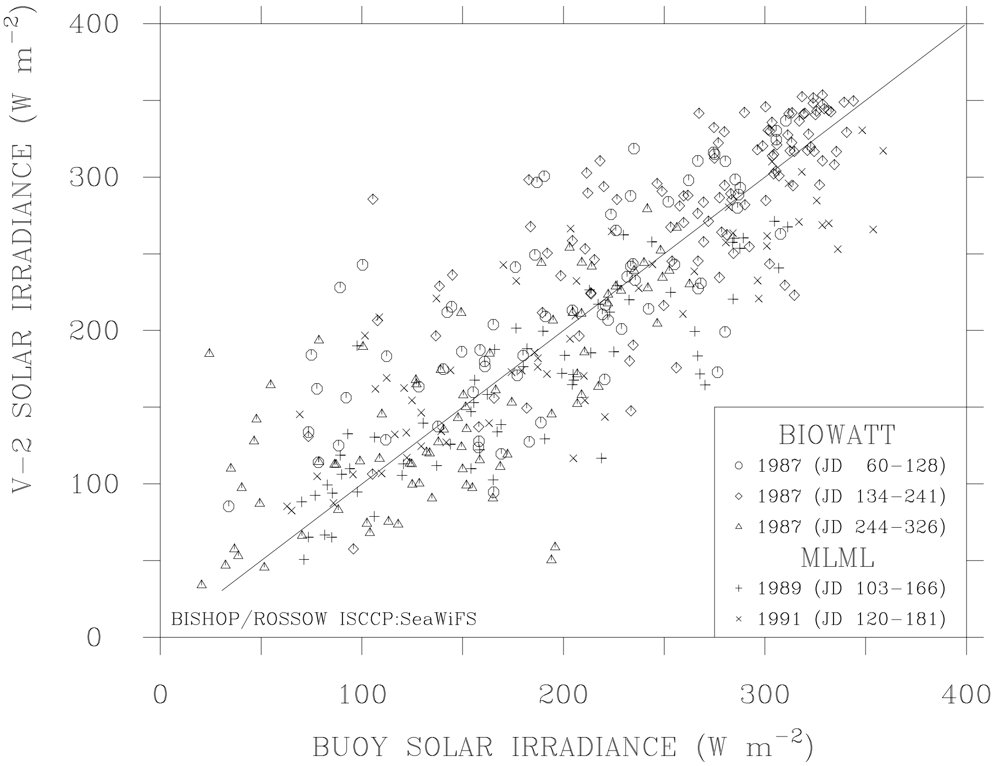

Figure 10. Correlation of Buoy and V-2 surface solar irradiance data on a daily basis. A major factor contributing to the scatter is the mismatch of spatial scales sampled by the two methods. A (1:1) line is drawn through the data.

the two data sets which results directly from the spatial mismatch and the fact that moving weather systems are sub grid scale for C1 pixels. The areal mismatch also is reflected in the standard deviations of the two data sets; the highs and lows of the Version 2 data sets are generally less extreme due to averaging of meteorological conditions over the 280 km sized pixel. The larger C1 pixel represents an area average of some 80 (4-8 km scale) pixels (Figure 1).

Areal differences, uncertainty of calibration of both data sets, and the assumption of globally uniform aerosols contribute to differences of the means. Biases of the 5 data sets combined, average

Table 7: Comparison of surface solar irradiance data from Biowatt and MLML moored surface buoys and those retrieved from Version 2 data ($W m^{-2}$)

Location	year (days)	Buoy mean $W m^{-2}$	Buoy s.d. $W m^{-2}$	Version 2 mean $W m^{-2}$	Version 2 s.d. $W m^{-2}$	Apparent Error V2-Buoy	Error % of Clear Sky
Biowatt I	1987 (60-128)	197.6	69.6	217.0	65.6	19.4	6.6
Biowatt II	1987 (134-241)	265.9	62.5	280.5	60.5	14.6	4.2
Biowatt III	1987 (244-326)	148.9	66.2	149.3	62.6	0.4	0.2
MLML I	1989 (103-166)	172.9	71.2	163.2	59.3	-9.7	3.2
MLML II	1991 (120-181)	197.9	86.4	199.6	65.4	1.7	0.5

+5 $W m^{-2}$, The worst case, if attributable solely to the Version 2 retrieved values, is less than 7% of irradiance under clear sky conditions.

We plan to repeat this comparion using the higher spatial resolution CX data set on both daily and 3 hourly time scales once CX based production is initiated since it will elucidate the contributions due to aerosol and areal differences to the observed variability. Access to other ocean mooring data sets would facilitate further comparisons of this kind.

SUMMARY

We have implemented and modified a fast computational scheme that reproduces the average and temporal fluctuations of surface solar irradiance and PAR on time scales relevant to marine phytoplankton physiology using ISCCP cloud data. Beyond the validation reported by Bishop and Rossow [1991], the data set has been tested against records from ocean weather station climatology and from the contemporaneous BioWatt and MLML optical moorings. More records of this kind are being sought. We are now ready to begin routine production of the ISCCP C1 product as soon as approved by the SeaWiFS project and data can be injested by the archives at Goddard. Until that time, an 8 year time series (at daily resolution) may be obtained from NCAR. Once C1 production is progressing smoothly, we will begin production of a 30km spatial resolution product based on ISCCP CX data.

References:

Bishop, J.K.B. and Rossow W.B., Spatial and temporal variability of global surface solar irradiance, J. Geophys. Res., 96, 16839-16858, 1991.

Cox, C. and W. Munk, Slopes of the sea surface deduced from photographs of sun glitter. Bull. Scripps Inst. Oceanogr., Univ. Calif, 6, 401-488, 1956.

Deser, C, and Blackman, M.L., Surface climate variations over the north Atlantic ocean during winter: 1900-1989. J. Climate, 6, 1743-1753. 1993

Frouin, R., D.W. Lingner, C. Gautier, K.S. Baker, and R.C. Smith, A simple analytical formula to compute clear sky total and photosynthetically available solar irradiance at the ocean surface, J. Geophys. Res., 94, 9731-9742, 1989.

Hoyt, D. V., A redetermination of the Rayleigh Optical Depth and its application to selected solar radiation problems. J. Appl. Meteorol, 16, 432-436, 1977.

Klein, S.A. and D.L. Hartmann, Spuriuos changes in the ISCCP dataset, Geophys. Res. Lett., 20, 455-458, 1993.

Levitus, S., J. I. Antonov, and T.P. Boyer, Interannual Variability of Temperature at a depth of 125 meters in the north Atlantic ocean. Science, 266, 96-99, 1994.

Liu, W.T., Zhang, A., and J.K.B. Bishop, (1994) Evaporation and solar irradiance as regulators of sea surface temperature in annual and inter annual changes. J.G.R. 99 (C6), 12623-12637.

Mitchell, B.G., E. Brody, O. Holm-Hansen, C. McClain, J.K.B. Bishop, (1991) Light limitation of phytoplankton biomass and macronutrient utilization in the Southern Ocean. Linmol. & Oceanogr. 36(8) 1662-1677.

Morel A. and B. Gentili, Diffuse reflectance of oceanic waters: its dependence on sun angle as influenced by the molectular scattering contribution. Appl. Opt, 30, 4427-4438, 1991

Rossow, W.B., and R.A. Schiffer, ISCCP cloud data products, Bull. Am. Meteorol. Soc., 72, 2-20, 1991. Rossow, W.B., et al., ISCCP cloud algorithm intercomparison, J. Clim. Appl. Meteorol., 24, 877-903, 1985.

Rossow, W.B., L.C. Garder, P-J. Lu, and A.W. Walker, International Satellite Cloud Climatology Project (ISCCP) documentation of cloud data. WMO/TD-No. 266, 78 pp. + 2 appendices, World Meteorol. Organ., Geneva, 1988.

Schiffer, R.A., and W.B. Rossow, The international satellite cloud climatology project (ISCCP): The first project of the World Climate Research Programme, Bull. Am. Meteorol. Soc., 64, 779-784, 1983.

Schiffer, R.A., and W.B. Rossow, ISCCP global radiance data set: A new resource for climate research, Bull. Am. Meteorol. Soc., 66, 1498-1505, 1985.

Seager, R. and M.B. Blumenthal, (1994) Modeling tropical Pacific sea surface temperature with satellite-derived solar radiative forcing. J. Climate (in press, Nov 1994 issue).

APPENDIX 1. HDF File Specifications:

All of the files are written using NCSA's HDF V3.3 (Hierarchical Data Format) as Scientific DataSets (SDS's). To read the data you must link to the HDF library when compiling, and use the following integer functions:

```
Fortran:
       parameter (im=144,jm=72,nd=2)
       integer dsgdata,dsgdast,dsgdims,dsgfill,dsgrang
       integer   rank, dims(nd), maxrank
       integer*2 idata(im,jm), fill, max, min
       character*60 label, unit, format, coordsys
c
c     here rank=2, dims=(144,72) always
c     maxrank(=2) is size of dims
c
              istat = dsgdims(filename,rank,dims,maxrank)
              istat = dsgdast(label,unit,format,coordsys)
c
c     label: describes data
c      unit: gives units, multipilcation factor
c    format: data type
c  coordsys: grd type
c
              istat = dsgdata(filename,rank,dims,idata)
c     idata: returns integer array each time called
c
              istat = dsgfill(fill)
c     fill: missing data value
c
              istat = dsgrang(max,min)
c     max: approximate upperlimit of data
c     min: approximate lowerlimit of data
```

Equivalent C functions are:

```
              DFSDgetdims(filename,rank,dims,maxrank)
              DFSDgetdata(filename,rank,dims,idata)
              DFSDgetdatstrs(label,unit,format,coordsys)
              DFSDgetfillvalue(fill)
              DFSDgetrange(max,min)
```

All functions return 0 on success and -1 on failure. The number type used for all files and variables is 16-bit signed integer (ntype=22). This may change on final production to include 8-bit unsigned integers. The fortran program 'sdsread.f' on i0.giss.nasa.gov is an example of a program which can read the produced data sets in sds format.

Listing of the current test production data files on i0.giss.nasa.gov:

```
      12948 Aug 14 15:31 c1aalbmp3.8307.sds.Z
      24337 Aug 14 15:32 c1aicedp3.8307.sds.Z
       2564 Aug 14 15:32 c1aicemp3.8307.sds.Z
    1772839 Aug 14 15:39 c1clfr8p3.8307.sds.Z
     368017 Aug 14 15:33 c1clfrdp3.8307.sds.Z
```

```
   14166 Aug 14 15:39 c1clfrmp3.8307.sds.Z
 1681363 Aug 14 15:46 c1cosz8p3.8307.sds.Z
   58057 Aug 14 15:40 c1coszdp3.8307.sds.Z
    3193 Aug 14 15:46 c1coszmp3.8307.sds.Z
 1973017 Aug 14 15:53 c1dffr8p3.8307.sds.Z
  393532 Aug 14 15:47 c1dffrdp3.8307.sds.Z
   14218 Aug 14 15:53 c1dffrmp3.8307.sds.Z
   26765 Sep 21 12:28 c1filldp3.8307.sds.Z
    1700 Aug 14 17:46 c1lwcodp3.8307.sds.Z
  174855 Aug 14 15:54 c1ozondp3.8307.sds.Z
    3689 Aug 14 15:54 c1psfcmp3.8307.sds.Z
 2113297 Aug 14 16:01 c1qcld8p3.8307.sds.Z
  512195 Aug 14 15:55 c1qclddp3.8307.sds.Z
   18224 Aug 14 16:01 c1qcldmp3.8307.sds.Z
 2050859 Aug 14 16:08 c1qclr8p3.8307.sds.Z
  452377 Aug 14 16:02 c1qclrdp3.8307.sds.Z
   16549 Aug 14 16:08 c1qclrmp3.8307.sds.Z
 1725547 Aug 14 16:16 c1qpar8p3.8307.sds.Z
  459027 Aug 14 16:09 c1qpardp3.8307.sds.Z
   15688 Aug 14 16:16 c1qparmp3.8307.sds.Z
  249809 Aug 14 16:16 c1ratidp3.8307.sds.Z
   12165 Aug 14 16:16 c1ratimp3.8307.sds.Z
 1131273 Aug 14 16:23 c1rsfc8p3.8307.sds.Z
  217361 Aug 14 16:17 c1rsfcdp3.8307.sds.Z
    8733 Aug 14 16:23 c1rsfcmp3.8307.sds.Z
   14631 Aug 14 16:24 c1sqclmp3.8307.sds.Z
   12634 Aug 14 16:24 c1sqpamp3.8307.sds.Z
  188619 Aug 14 16:24 c1tsfcdp3.8307.sds.Z
  195205 Aug 14 16:26 c1wsfcdp3.8307.sds.Z
  236591 Aug 22 10:04 c1wtotdp3.8307.sds.Z
```