Procedure for Generating Data Quality Reports for SIRS Radiometric Measurements

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Introduction

The Atmospheric Radiation Measurement (ARM) Program needs high-quality broadband shortwave (SW) (solar) and longwave (LW) irradiance information for the development and validation of atmospheric circulation and climate models. To this end, the National Renewable Energy Laboratory (NREL) performs a quality assessment of the data from 22 Solar Infrared Stations (SIRS) in the Southern Great Plains (SGP). Data quality reports (DQRs) are instrumental in passing the resultant information to the scientific community. The value of these reports depends on clear and consistent descriptions of the data quality, the source of any problems, and recommendations concerning use of the data.

Using our expertise with broadband SW radiation for renewable energy applications, our backgrounds in atmospheric physics and meteorology, and our prior experiences with SIRS data issues, we have created guidelines containing standardized language for writing DQRs. Our *DQR Guide* categorizes the most common problems we have encountered in the SIRS data and provides a standard procedure for preparing a DQR. We have also prepared flowcharts to aid in visualizing the data analysis and problem diagnosis processes. Descriptions of phenomena likely to be associated with each data problem are an important part of the *Guide*. Standardized language for the "Description" and "Suggestion" portions of the DQR are also available in the Guide. The DQR Guide will be updated to better meet the needs of the end-user and improve the DQR process as we expand our understanding of the SIRS and Atmosphere Radiation, and Cloud Stations (ARCS) measurement issues.

Approach

NREL has developed a system for SIRS data quality assessment based on *Augustyn + Company's* **Data Quality Management System, Version3** (**DQMS3**). Designed for solar and meteorological networks, **DQMS3** runs point-by-point tests on LW and downwelling SW irradiance data, assigning flags at each point indicating the test passed or failed, and the degree of failure. At present, upwelling SW radiometric data are visually inspected and any problems found in the data are reported. **DQMS3** includes several other features useful for data quality analysis: spreadsheet-style display of data and data quality flags; graphical display of the data trace or traces at several time resolutions; graphical representation of the data quality flags, concurrent with the data trace; and a graphical user interface for writing DQRs.

Data quality analysis (DQA) flowcharts are another important component of NREL's system for SIRS data quality assessment. After the data have been tested, problems are identified through the resultant data quality flags and/or by visual inspection of the daily trace. Evidence regarding conditions at the time of the dubious measurement is obtained through weather reports, Online Maintenance Information System (OMIS) reports, communications with scientists and technicians in the field, weekly SIRS SGP Data Quality Assessment Reports, etc. The flowcharts were developed to aid the investigator in visualizing the analysis procedure by logically stepping the user through the evidence. The result of this process is a number corresponding to a problem case described in NREL's *DQR Guide*.

First conceived of as an aid for the data quality analysis novice, NREL's *DQR Guide* provides a standard procedure for writing DQRs, including consistent language for the "Description" and "Suggestion" sections. The guide categorizes the most common problems we have encountered in the SIRS data, and includes detailed descriptions of these measurement problems. DQRs are composed in the **DQMS3** interface, and then saved to a file for later submission to ARM's MetaData Navigator (MDN) in a batch DQR. Since the implementation of our new data quality analysis system, over 200 DQRs for SIRS data have been prepared at NREL using this method.

The ice storm that struck much of the SGP can illustrate the effectiveness of the DQMS approach. Figure 1 illustrates the SIRS trace from E13 for January 20, 2002, the storm's first day. The MDN color flags seen in the flag bars at the bottom of the figure indicate where trouble may lie in the trace. Red flags result when a thick layer of ice on the unshaded pyranometer dome intermittently forces the global horizontal signal below daytime empirical limits. Yellow flags on the diffuse horizontal indicate that the signal is too low due to ice on the shaded pyranometer; an unknown electrical problem raises the global horizontal signal above nighttime empirical limits resulting in red flags. In the trace, we also notice that the LW components are in approximate equilibrium. This is due in large part to the heavily overcast skies, though the effect on the LW signals of ice covering the ground and downwelling precision infrared radiometer (PIR) dome are indistinguishable from those of overcast skies.

Our DQA Flowchart, shown in Figure 2, represents the next step in the data quality analysis process. Using the evidence gathered from the trace and flags (Figure 1) and from other sources listed above, we identify *DQR Guide* cases 1-3 (see Table 1) for the global horizontal data below daytime empirical limits. Similar analysis of the flags on the direct normal and diffuse horizontal (two-component test failure) leads to the Two-Component DQA Flowchart (Figure 3.)

In Figure 3, the Two-Component DQA Flowchart, analysis of the two-component failure of the direct normal and the diffuse horizontal irradiance data of Figure 1 suggests the problem continues. Following the yellow arrows, we find that the problem matches cases 2-4. Analysis of the January 30, 2002, SIRS data from E13 is complete when DQRs are written following the examples in Table 1.

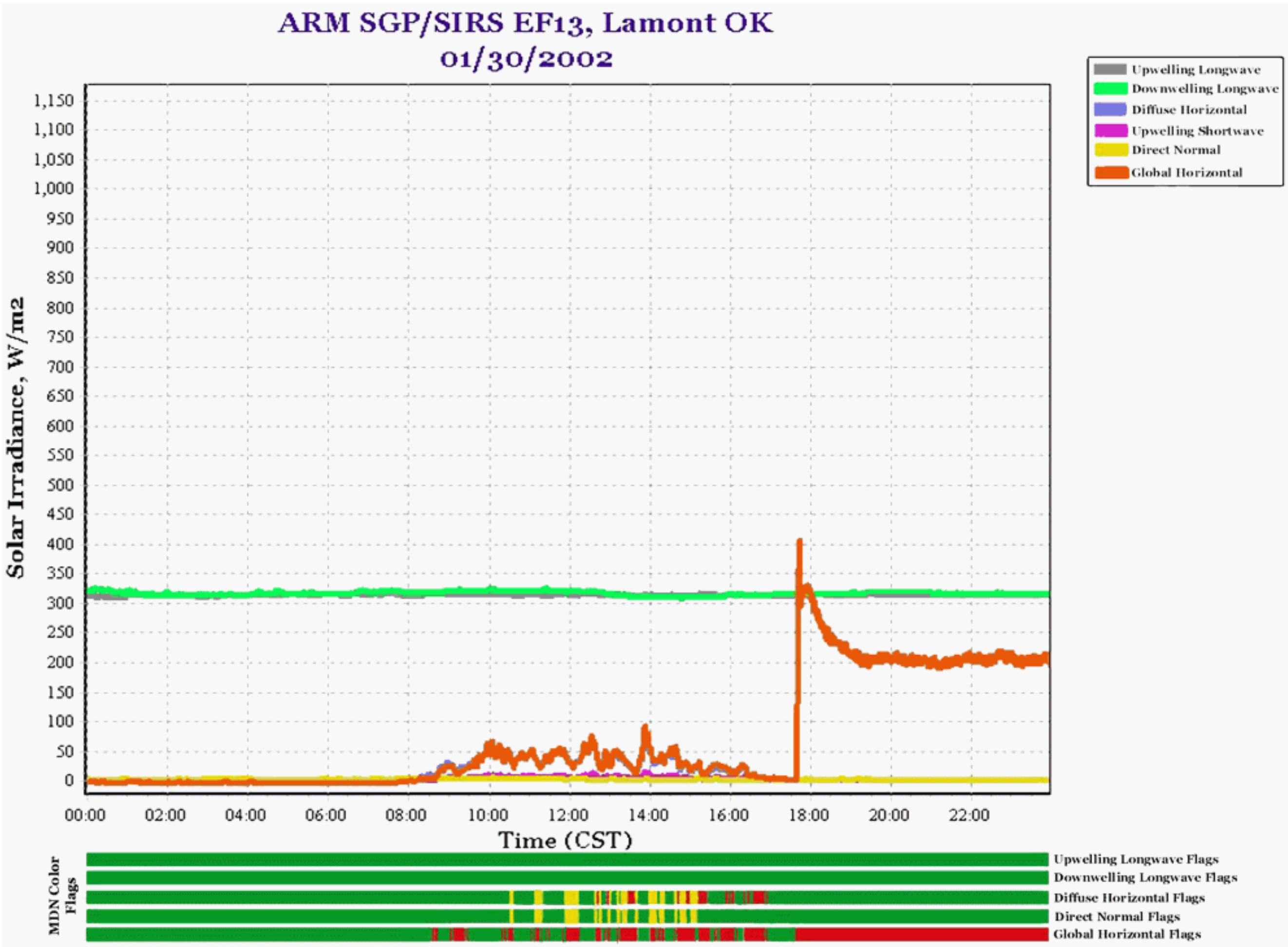

Figure 1. January 30, 2002. Beginning the previous evening and continuing throughout the next day, freezing rain hit the SGP site, coating instruments in a thick layer of ice. The LW and SW traces together indicate that the sky is overcast, a conclusion supported by the whole sky imager at C1.

Figure 4 presents the trace from E13 for February 1, 2002, two days after the ice storm. From a private e-mail communication with a technician at the SGP site, we know that the sky was clear and the ice had begun to melt (see Figure 5). Evidence of ice remaining on the instruments and ground is as follows:

- non-coincident dips in the global horizontal and diffuse horizontal
- an abnormally steep rise in the upwelling SW in the morning
- the LW signals are in approximate equilibrium in the morning at levels similar to those attained under heavily overcast skies.

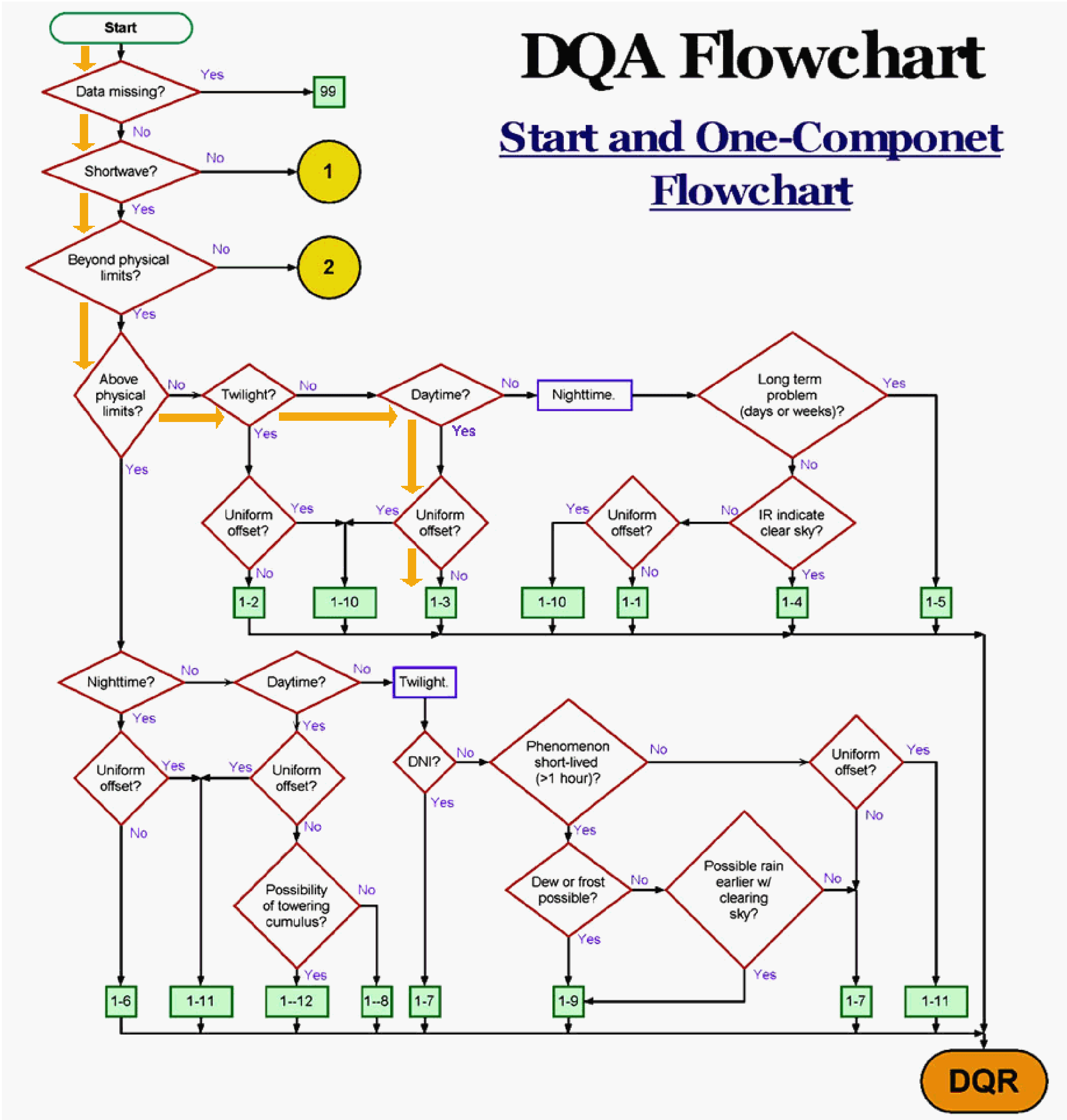

Figure 2. The DQA flowchart: start and one-component flowchart. The data quality flowcharts serve as an outline of the solar radiometric data quality analysis process, enabling one to quickly determine which DQR Guide case the problem at hand best fits.

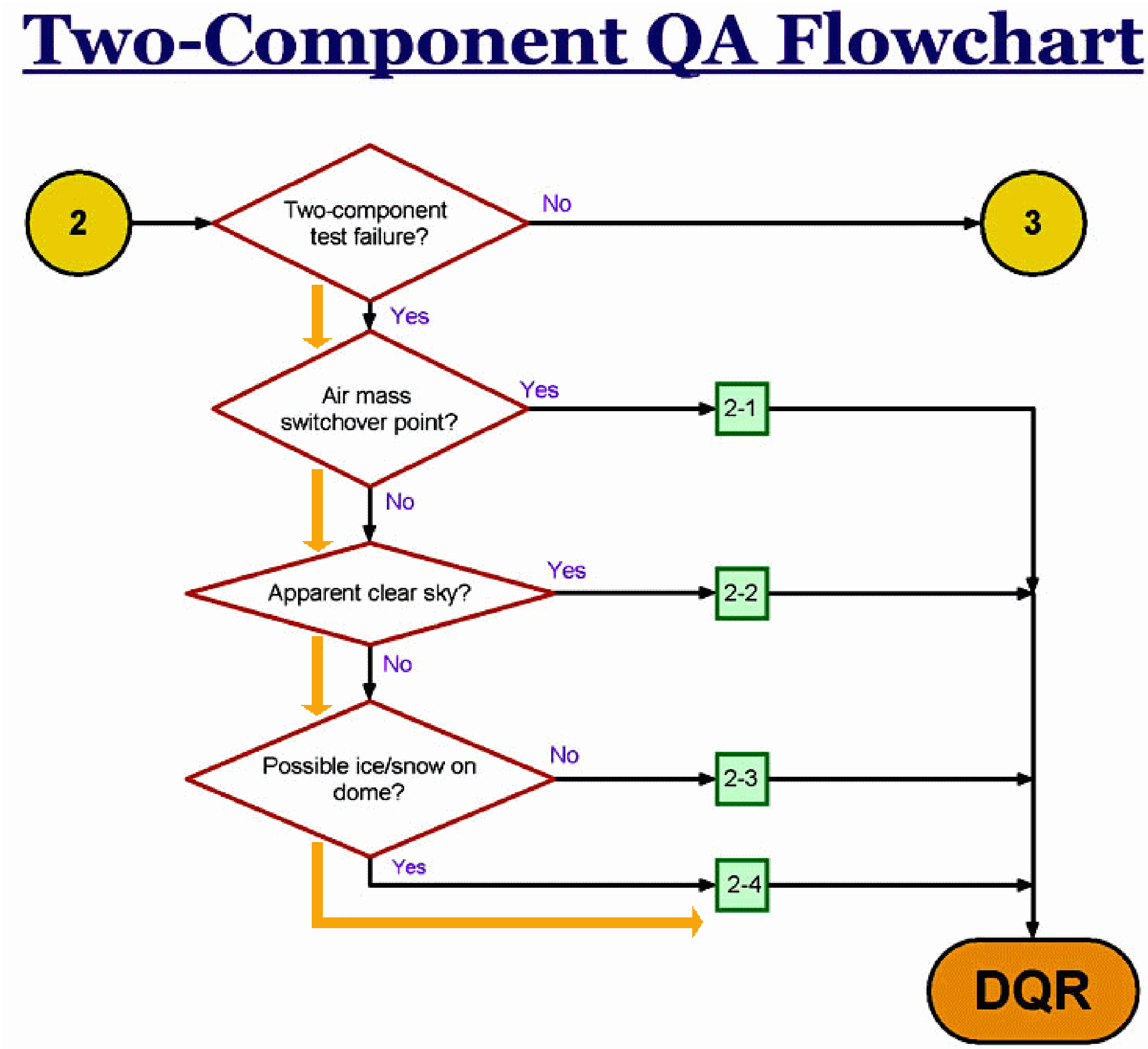

Figure 3. The two-component DQA flowchart. Analysis of the two-component failure of the direct normal and the diffuse horizontal in Figure 2 continues with this flowchart, following the yellow arrow.

In addition, the sun tracker has failed due to the AC power outage at the central facility (CF). As tracker failures do not normally generate flags indicating any error, they must be identified through visual inspection of the daily trace (see Table 2, DQR Guide case V-2.).

Table 1. Cases 1-3 and 2-4 from NREL's DQR Guide. The "Description" and "Suggestion" sections of the DQRs written for the January 30, 2002, global horizontal, diffuse horizontal and direct normal will follow the entries in the like-named columns found under the heading "DQR". Items in the "Action" column indicate whether or not the data should be repainted from the color assign by automatic testing in DQMS3.

Problem			DQR		
#	**Category**	**Description**	**Description**	**Action**	**Suggestion**
1-3	One-component test failure	**Global,** Diffuse or Direct below empirical limits. Daylight hours.	Data are below daytime empirical limits (Direct: -10 W/m^2; **Global: 5% of ETR**; Diffuse: 3% of ETR.)	No change.	Interpolation is not possible.
2-4	Two-component test failure	Global fails one-component test or is missing (See cases 99 and 1-3); **Direct** and **Diffuse** are suspect. LW and Upwelling SW suggest a **cloudy** or **overcast sky**. Possibility of ice or snow obscuring the PSP domes. Two DQRs:	Data (*Diffuse)* too high by two-component test (descriptions of testing criteria can be found at: http://rredc.nrel.gov/solar/pubs/seri_qc.) Possibly due to ice or snow obscuring the shaded PSP dome.	No change.	Interpolation is not possible.
			Data (*Direct)* too high by two-component test (descriptions of testing criteria can be found at http://rredc.nrel.gov/solar/pubs/seri_qc.) Visual inspection suggests the data are good.	Repaint data green.	

Quality assessment of the data in Figure 4 is complicated by having a number of problems occur concurrently. The unidentified electrical problem of January 30 persisted to February 1, raising the global horizontal signal above empirical limits for much of the day: DQR Guide cases 1-8 (see Table 2.). The direct and the diffuse are too low by the two-component test in a couple of instances, probably due to ice remaining on the shaded pyranometer dome: DQR Guide cases 2-4. Even three-component flags are seen for a few minutes late in the morning, indicating that the global horizontal is too high, or the direct or diffuse too low. We follow the yellow arrows through the flowchart in Figure 6 to arrive at cases 3-2; specifically, 3-2c, which describes snow, ice, or frost obscuring the pyranometer dome.

Examples of selected DQRs that will be written for the data from E13 for February 1, 2002, are shown in Table 2. In instances where more than one problem in a single component happens at the same time, a DQR will be composed drawing from all the relevant *DQR Guide* cases.

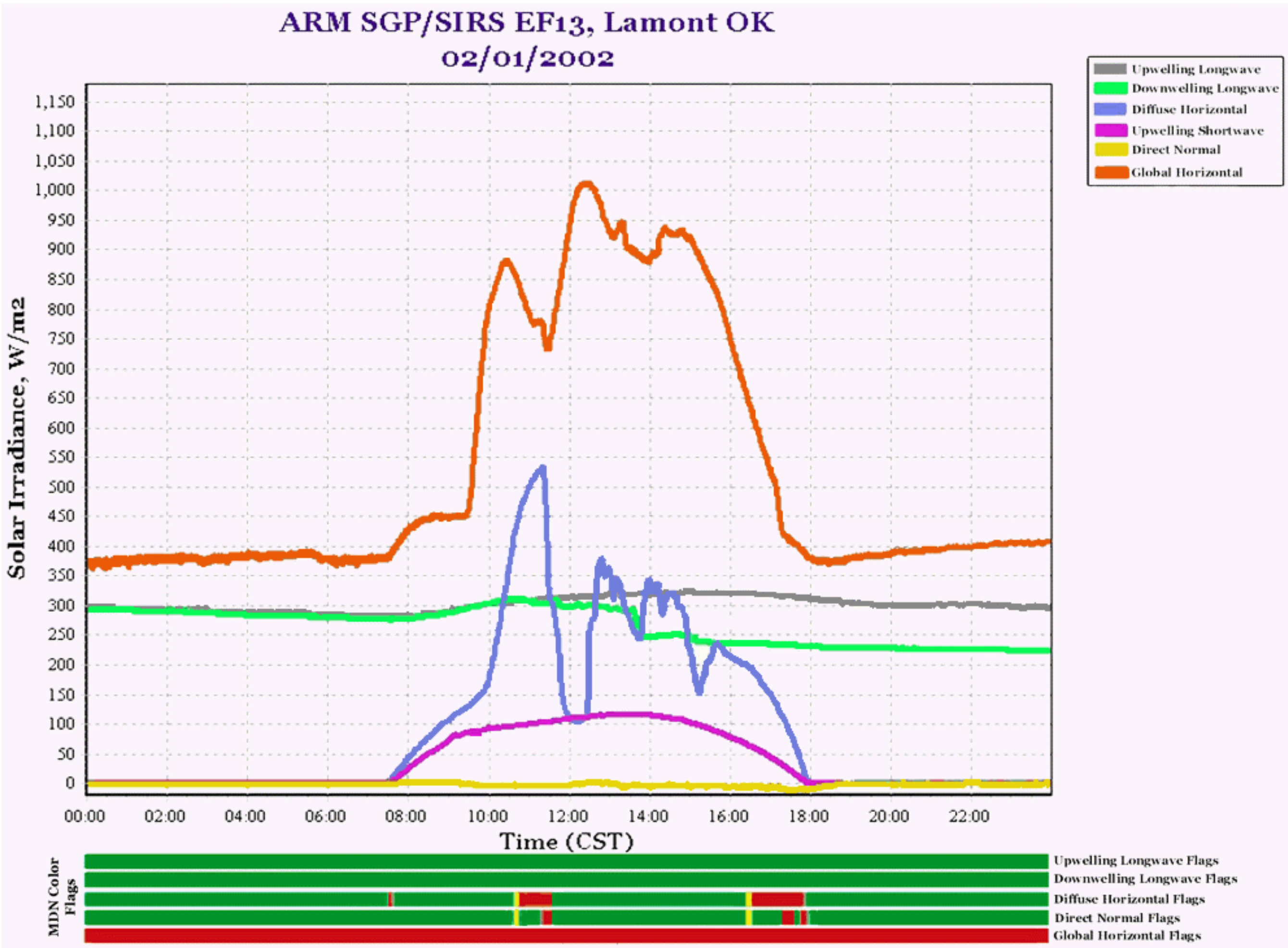

Figure 4. February 1, 2002: Two days after the ice storm the sky is apparently clear and the ice has begun to melt. This conclusion is supported by the photograph in Figure 1, taken on February 1 and by a private e-mail correspondence.

Conclusion

NREL has developed a standardized approach for SIRS data quality assessment that can be used by an expert or a novice solar radiometric data quality analyst. *Augustyn + Company's* **DQMS3** is an integral part of this system, providing automated data base management, point-by-point testing and flagging, spreadsheet-style data and flag display, graphical display of data and flags, and a user interface for composing DQRs. NREL's *DQR Guide*, while still under development, provides standard entries for the description and suggestion sections of the DQR, making DQRs more consistent from writer to writer, and over time.

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Figure 5. February 1, 2002. Ice coating radiometers at the CF in Lamont, Oklahoma, began melting under a clear-sky the second day after the ice storm. (Obtained from the ARM OMIS http://ops.sgp.arm.gov.)

Table 2. Cases 1-8, 3-2c and V-2 from NREL's DQR Guide. The "Description" and "Suggestion" sections of the DQRs written for the February 1, 2002, global horizontal, diffuse horizontal and direct normal will follow the entries in the like-named columns found under the heading "DQR." Items in the "Action" column indicate whether the data should be repainted from the color assign by automatic testing in DQMS3.

Problem			**DQR**		
#	**Category**	**Description**	**Description**	**Action**	**Suggestion**
1-8	One component test failure	**Global**, Diffuse or Direct above empirical limits. Daylight hours.	Data are above daytime empirical limits as determined by the Extra Terrestrial Radiation for the location and time. (See http://www.arm.gov/docs/instruments/statics/sirs.html.) Probable cause unknown.	No change.	Interpolation is not possible.
V-2	Visual inspection.	Global indicates a clear or mostly clear day, but Diffuse is matching Global, and Direct is near zero. Data is flagged good Two DQRs generated:	Data (*Direct*) too low by visual inspection. Downwelling and upwelling IR, global and upwelling SW all indicate clear or mostly clear-sky conditions during daylight hours, yet direct is near zero. Probable cause: sun tracker failure.	Repaint data red.	Interpolation is not possible.
Sun tracker failure.			Data (*Diffuset*) too high by visual inspection. Downwelling and upwelling IR, global and upwelling SW all indicate clear or mostly clear-sky conditions during daylight hours, yet diffuse matches global. Probable cause: sun tracker failure.	Repaint data red.	Interpolation is not possible.

Table 2. (contd)

Problem			DQR		
#	**Category**	**Description**	**Description**	**Action**	**Suggestion**
3-2c **Snow, ice, or frost on dome; obscuring.**	Three-component test failure	Global and **Diffuse** exhibit a dip or dips in the trace. Upwelling SW may be much higher than normal (300 + W/m^2); LW and perhaps Direct indicate a clear day. Winter, early Spring or late Fall. (See also U-1). SERI_QC flags indicate that the Global is too low and the Direct and Diffuse too high by the three-component test. Three DQRs generated:	Data (*Global*) too low by three-component test (internal consistency checks; descriptions of testing criteria can be found at: rredc.nrel.gov/solar/pubs/seri_qc.) Visual inspection suggests the data are below nor-mal values due to snow, ice, or frost on the unshaded pyranometer dome.	No change.	Interpolation may be possible for some applications.
			Automated testing has determined the data (***Direct***) are too high by three-component test (internal consistency checks; descriptions of testing criteria can be found at: rredc.nrel.gov/solar/pubs/seri_qc.) Visual inspection suggests the data are good.	Repaint data green.	
			Automated testing has determined the data (***Diffuse***) are too high by three-component test (internal consistency checks; descriptions of testing criteria can be found at: rredc.nrel.gov/solar/pubs/seri_qc.) Visual inspection suggests the data are below normal values due to snow, ice, or frost on the shaded pyranometer dome.	No change.	Interpolation may be possible for some applications.

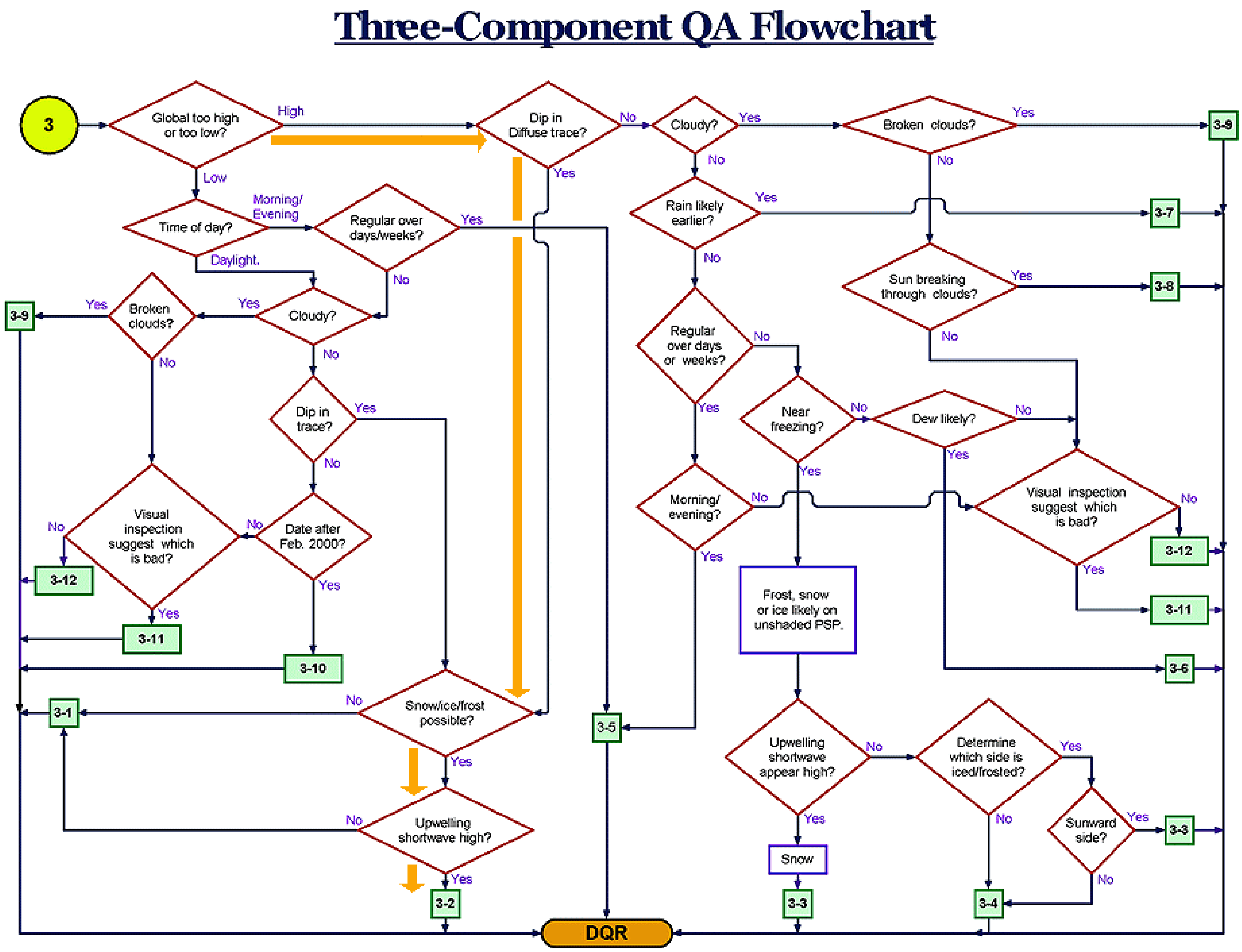

Figure 6. The three-component DQA flowchart. Analysis is not straightforward in the case of Figure 5 as several situations overlap one another: one-component, two-component, and three-component flags are all seen on all three downwelling SW signals at various point throughout the day.