ARM TR-017

Total Sky Imager
Handbook

June 2005

Atmospheric Radiation Measurement
Climate Research Facility
U.S. Department of Energy

Work supported by the U.S. Department of Energy
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Total Sky Imager (TSI) Handbook

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1. General Overview

The total sky imager (TSI) provides time series of hemispheric sky images during daylight hours and retrievals of fractional sky cover for periods when the solar elevation is greater than 10 degrees.

2. Contacts

2.1 Mentor

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2.2 Instrument Developer

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3. Deployment Locations and History

Table 1. Current Status and Locations

Serial Number	Property Number	Location	Installation Date	Status
660100	WD41403	PYE/MF1	2005/02/01	operational
880102	WD30270	TWP/CF1	2003/11/30	operational
880105	WD30880	TWP/CF3	2002/07/16	operational
880106	WD30881	SGP/CF1	2000/07/02	operational
880107	WD30882	TWP/CF2	2002/11/12	operational

4. Near-Real-Time Data Plots

Available at DQ HandS (Data Quality Health and Status).

5. Data Description and Examples

See YES Cloud Cover Products and YES Imaging Product Demos.

5.1 Data File Contents

The following datastreams produced by the TSI are available from the ARM Archive:

- **tsiskycover** – fractional sky cover and sun obscuration by cloud
- **tsiskyimage** – hemispheric sky image (JPEG)
- **tsimovie** – daily movie of hemispheric sky images (MPEG)
- **tsicldmask** – processed fractional sky cover image (PNG).

ARM netCDF file header descriptions may be found at TSI Data Object Design.

5.1.1 Primary Variables and Expected Uncertainty

Visual record of sky conditions.

Fractional sky cover (clear, thin, and opaque amounts).

Sun obscuration by cloud (sunshine meter).

Table 2. Primary Variables

Variable Name	Quantity Measured	Unit
percent.opaque	Percent opaque cloud	percent
percent.thin	Percentage thin cloud	percent
sunny	Sunshine meter	none

5.1.1.1 Definition of Uncertainty

See ARM Technical Report "Total Sky Imager Model 880 Status and Testing Results."

5.1.2 Secondary/Underlying Variables

Table 3. Secondary Variables

Variable Name	Quantity Measured	Unit
solar.altitude	Sun altitude above horizon	degrees
solar.azimuth	Solar azimuth angle	degrees
region.zenith.count.thin	Pixel count: number thin in zenith circle	pixels
region.zenith.count.opaque	Pixel count: number opaque in zenith circle	pixels
region.zenith.count	Pixel count: number total in zenith circle	pixels
region.sun.count.thin	Pixel count: number thin in sun circle	pixels
region.sun.count.opaque	Pixel count: number opaque in sun circle	pixels
region.sun.count	Pixel count: number total in sun circle	pixels
region.horizon.count.thin	Pixel count: number thin in horizon area	pixels
region.horizon.count.opaque	Pixel count: number opaque in horizon area	pixels
region.horizon.count	Pixel count: number total in horizon area	pixels
count.sub.proczen	Pixel count: number total between horizon and processed circle	pixels
count.opaque	Pixel count: number total opaque	pixels

Table 3. (cont'd)

Variable Name	Quantity Measured	Unit
count.thin	Pixel count: number total thin	pixels
count.box	Pixel count: box, outside mirror area	pixels
count.sky	Pixel count: number total in processed circle	pixels
count.unknown	Pixel count: number total indeterminant	pixels
count.mask	Pixel count: camera and sun strip mask	pixels
count.sub.horz	Pixel count: number below horizon in image	pixels

5.1.3 Diagnostic Variables

Table 4. Diagnostic Variables

Variable Name	Quantity Measured	Unit
time_offset	Time offset from base_time	seconds
sun.strength	Relative 'strength' of direct sun	none

5.1.4 Data Quality Flags

Most fields contain a corresponding, sample-by-sample, automated quality-check field in the b1 level datastreams. These flags are named **qc_<fieldname>**. For example, the **percent.opaque** field also has a companion **qc_ percent.opaque** field. Possible values for each sample of the **qc_<fieldname>** are shown in the table below.

Table 4. Data Quality Flags

Value	Definition
0	All QC checks passed
1	Sample contained 'missing data' value
2	Sample was less than prescribed minimum value
3	Sample failed both 'missing data' and minimum value checks
4	Sample greater than prescribed maximum value
5	Sample failed both minimum and maximum value checks (highly unlikely)
7	Sample failed minimum, maximum and missing value checks (highly unlikely)
8	Sample failed delta check (change between this sample and previous sample exceeds a prescribed value
9	Sample failed delta and missing data checks
10	Sample failed minimum and delta checks
11	Sample failed minimum, delta and missing value checks
12	Sample failed maximum and delta checks
14	Sample failed minimum, maximum and delta checks
15	Sample failed minimum, maximum, delta and missing value checks

The following are the current definitions for the minimum and maximum thresholds:

Table 5. Data Quality Thresholds

Field Name	Units	Min	Max
percent.opaque	percent	0	100
percent.thin	percent	0	100
sunny	none	0	1
sun.strength	none	-100	100
solar.altitude	degrees	-90	90
solar.azimuth	degrees	0	360
region.zenith.count.thin	pixels	0	101400
region.zenith.count.opaque	pixels	0	101400
region.zenith.count	pixels	0	101400
region.sun.count.thin	pixels	0	101400
region.sun.count.opaque	pixels	0	101400
region.sun.count	pixels	0	101400
region.horizon.count.thin	pixels	0	101400
region.horizon.count.opaque	pixels	0	101400
region.horizon.count	pixels	0	101400
count.sub.proczen	pixels	-1	101400
count.opaque	pixels	-1	101400
count.thin	pixels	-1	101400
count.box	pixels	-1	101400
count.sky	pixels	-1	101400
count.unknown	pixels	-1	101400
count.mask	pixels	-1	101400
count.sub.horz	pixels	-1	101400

5.1.5 Dimension Variables

Table 6. Dimension Variables

Variable Name	Quantity Measured	Unit
base_time	Base time in Epoch	seconds
lat	north latitude	Degrees
lon	east longitude	degrees
alt	altitude	meters above Mean Sea Level

5.2 Annotated Examples

This section is not applicable to this instrument.

5.3 User Notes and Known Problems

TSI retrievals of fractional sky cover are valid for solar elevation angles of 10 degrees or greater.

5.4 Frequently Asked Questions

See YES TSI FAQs.

6. Data Quality

6.1 Data Quality Health and Status

The following links go to current data quality health and status results:

- DQ HandS (Data Quality Health and Status)
- NCVweb for interactive data plotting using.

The tables and graphs shown contain the techniques used by ARM's data quality analysts, instrument mentors, and site scientists to monitor and diagnose data quality.

6.2 Data Reviews by Instrument Mentor

The system is frequently monitored for continued operation. Sky cover retrievals are monitored and spot checked by comparison of the sky images and their corresponding “cloud decision images.” This process cannot be automated. A visual inspection detects any periods that are not optimal, and these periods are reprocessed. Updated files are sent to the ARM Archive.

6.3 Data Assessments by Site Scientist/Data Quality Office

All DQ Office and most site scientist techniques for checking have been incorporated within DQ HandS and can be viewed there.

A comparison between the fractional sky cover data included in the Shortwave Flux Analysis Value-Added Product (VAP), derived from the broadband shortwave irradiance, and in the TSI-retrieved total sky cover is planned.

6.4 Value-Added Procedures and Quality Measurement Experiments

Many of the scientific needs of the ARM Program are met through the analysisby analyzing and processing of existing data products into “value-added” products or VAPs. Despite extensive instrumentation deployed at the ARM CART sites, there will always be quantities of interest that are either impractical or impossible to measure directly or routinely. Physical models using ARM instrument data as inputs are implemented as VAPs and can help fill some of the unmet measurement needs of the program. Conversely, ARM produces some VAPs not in order to fill unmet measurement needs, but instead to improve the quality of existing measurements. In addition, when more than one measurement is available, ARM also produces “best estimate” VAPs. A special class of VAP called a Quality Measurement Experiment (QME), which is a special class of VAP, does not output geophysical parameters of scientific interest. Rather, a QME adds value to the input datastreams by providing for continual quality assessments continuous assessment of the quality of the input data based on internal consistency checks, comparisons between independent similar measurements, or comparisons between

measurements with modeled results, and so forth. For more information see, the VAPs and QMEs web page.

In addition, VAP information is derived from inferred fractional sky cover and sunshine duration. A QME comparison with observer reports and with whole sky imager (WSI) sky cover retrievals are underway as part of the Southern Great Plains (SGP) Central Facility (CF) system evaluation.

7. Instrument Details

7.1 Detailed Description

7.1.1 List of Components

The YES Total Sky Imager Model TSI-660 is an automatic, full-color sky imager system that provides real-time processing and display of daytime sky conditions. An image-processing program running on a PC workstation captures images via TCP/IP at a 30-sec sampling interval and saves them to JPEG files that are analyzed to infer both fractional sky cover and sunshine duration.

For more information, visit YES Total Sky Imager.

7.1.2 System Configuration and Measurement Methods

Images from the sky are captured via a solid-state charge-coupled device looking downward onto a heated, rotating hemispherical mirror. A shadowband on the mirror blocks the intense direct-normal light from the sun, thereby protecting the imager optics. An image-processing algorithm captures and displays the images.

The TSI is a daytime imager. Once the sun rises above a user-selectable minimum solar zenith angle, image acquisition begins. The analysis step first masks out obstructions - the imager, its arm, and the sun-blocking band. Fractional sky cover is determined by a processing algorithm that examines the color relationships of the remaining image pixels to infer whether the pixel represents clear sky or thin or opaque cloud. In addition, the differential of brightness along the sun blocking band is analysed to infer if the sun is blocked by cloud or not, i.e., a sunshine meter.

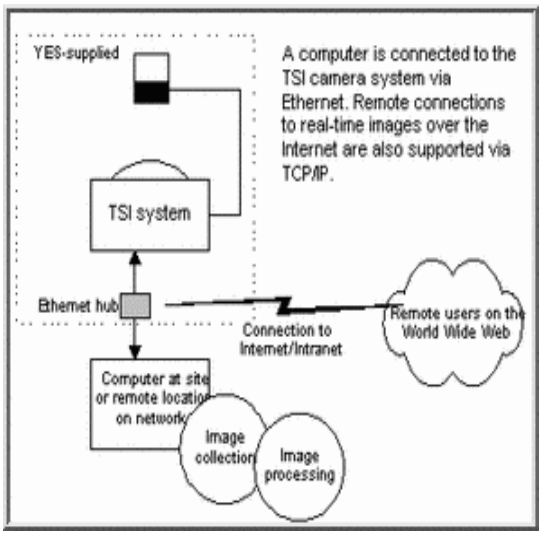

Figure 1. TSI Communications diagram

7.1.3 Specifications

Table 7. Instrument Specifications

Parameter	Value
Image Resolution:	352 x 288 color, 24-bit JPEG format
Sampling rate:	Variable, with max. of one image every 30 sec
Operating Temperature:	-40° C to +44° C
Weight/Size:	Approx.70 lbs.(32 kg); dims: 20.83”x18.78”; height is 34.19”; mounts on 16.75x12” 1/4-20 bolt square
Power Requirements:	115/230 VAC; mirror heater duty cycle varies with air temperature: 560W with heater on / 60W off
Software:	Image application supports MS-Windows®
Data Storage:	Local workstation disk
Communication:	10BaseT/RJ45 (15m)

7.2 Theory of Operation

Images from the sky are captured via a solid state CCD imaging camera that looks downward on a heated hemispherical mirror. The mirror images the hemisphere over the system into the lens, and has a solar-ephemeris guided shadowband to block the intense direct-normal radiation from the sun. An image-processing program running on a user-provided PC workstation captures images via TCP/IP at a user-defined sampling rate and saves them to JPEG files for analysis. The analysis software first masks out known obstructions -- the camera, its arm, and the sun-blocking shadowband. The raw color image is analyzed for fractional cloud cover, and both are stored as files.

7.3 Calibration

7.3.1 Theory

Sky cover processing limits are set by the instrument mentor, based on experience and tailored to human observations.

7.3.2 Procedures

This section is not applicable to this instrument.

7.3.3 History

This section is not applicable to this instrument.

7.4 Operation and Maintenance

7.4.1 User Manual

This section is not applicable to this instrument.

7.4.2 Routine and Corrective Maintenance Documentation

SGP Preventative Maintenance Procedure

TWP Operating Procedure

7.4.3 Software Documentation

YES TSI Manager

7.4.4 Additional Documentation

This section is not applicable to this instrument.

7.5 Glossary

Sky cover - The amount of the hemispheric field-of-view of the sky from the viewpoint of an observer standing on the surface that contains “cloud,” generally expressed in percent.

Also see ARM Glossary.

7.6 Acronyms

JPEG: Joint Photographic Experts Group compressed digital image format
PNG: Portable Network Graphics digital image format
TXT: ASCII text format
YES: Yankee Environmental Systems

Also see ARM Acronyms and Abbreviations.

7.7 Citable References

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