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Atmospheric Sounder Spectrometer for Infrared Spectral Technology (ASSIST) Instrument Handbook

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ARM CLIMATE RESEARCH FACILITY

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Office of Science, Office of Biological and Environmental Research

Acronyms and Abbreviations

AERI	Atmospheric Emitted Radiance Interferometer
ARM	Atmospheric Radiation Measurement
ASSIST	Atmospheric Sounder Spectrometer for Infrared Spectral Technology
FTIR	Fourier Transform Infrared
IR	infrared
LBLRTM	line-by-line radiative transfer model
SGP	Southern Great Plains
UTC	Universal Time Coordinates
VAP	value-added product

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Table 1. ASSIST Deployment 2

1.0 General Overview

The Atmospheric Sounder Spectrometer for Infrared Spectral Technology (ASSIST) measures the absolute infrared (IR) spectral radiance (watts per square meter per steradian per wavenumber) of the sky directly above the instrument. More information about the instrument can be found through the manufacturer's website.

The spectral measurement range of the instrument is 3300 to 520 wavenumbers (cm^{-1}) or 3-19.2 microns for the normal-range instruments and 3300 to 400 cm-1 or 3-25 microns, for the extended-range polar instruments. Spectral resolution is 1.0 cm^{-1}. Instrument field-of-view is 1.3 degrees. Calibrated sky radiance spectra are produced on cycle of about 141 seconds with a group of 6 radiance spectra zenith having dwell times of about 14 seconds each interspersed with 55 seconds of calibration and mirror motion.

The ASSIST data is comparable to the Atmospheric Emitted Radiance Interferometer (AERI) data and can be used for 1) evaluating line-by-line radiative transport codes, 2) detecting/quantifying cloud effects on ground-based measurements of infrared spectral radiance (and hence is valuable for cloud property retrievals), and 3) calculating vertical atmospheric profiles of temperature and water vapor and the detection of trace gases.

2.0 Contacts

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3.0 Deployment Locations and History

ASSIST instrument has been deployed with the AMF2 as noted in Table 1.

Table 1. ASSIST Deployment

Location	Date Installed	Date Removed	Status
SBS S1	Dec 2010	Apr 2011	Operational
GAN	Oct 2011	Feb 2012	Operational
MAG	Aug 2012	Jan 2013	Operational
SGP	March 2013	March 2013	Compare to AERI
MAG	May 2013	Sept 2013	Operational
TMP	Jan 2014	Sept 2014	Operational
SGP	June 2015	Nov 2015	Compare with AERI

The data collected during the operation of these facilities are available from the Atmospheric Radiation Measurement (ARM) Program's archive (http://www.archive.arm.gov/). However, there have been processing issues that have hindered autonomous processing of ASSIST data. These issues are not critical, meaning that ingest into netcdf is feasible, but the effort level involved and competition for staff resources has continued to delay final delivery.

4.0 Near-Real-Time Data Plots

Near-real-time plots of ASSIST zenith radiance spectra and diagnostic variables generated by the ARM Data Quality Office may be viewed via the Plot Browser. Select the site (PGH, GAN, MAG, or TMP) and scroll down the list datastreams to find _assist (where _ stands for the relevant site abbreviation above). Figure 1 and Figure 2 below shows hourly-averaged radiance from ASSIST ch 1and ch 2, respectively.

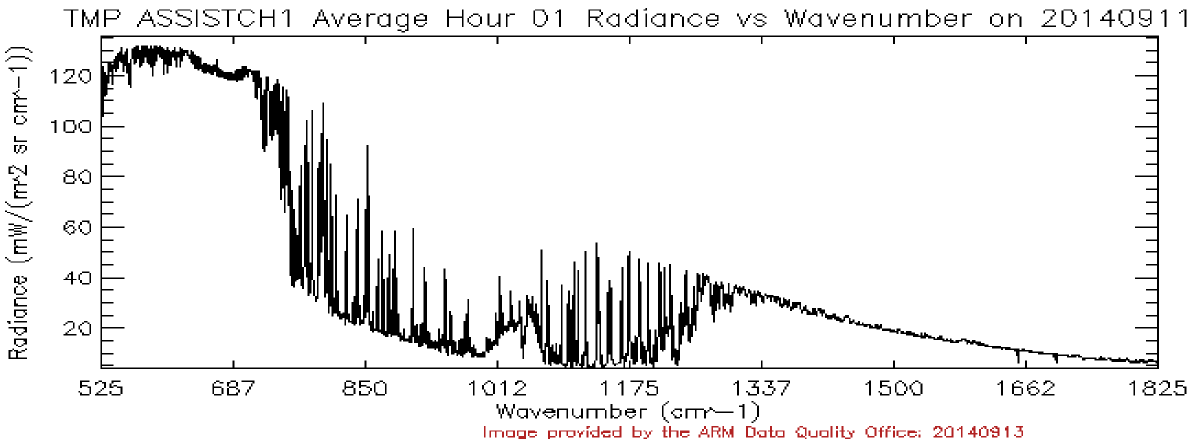


Figure 1. ASSIST MCT Channel 1 hourly-averaged zenith radiance for 2014-09-11.

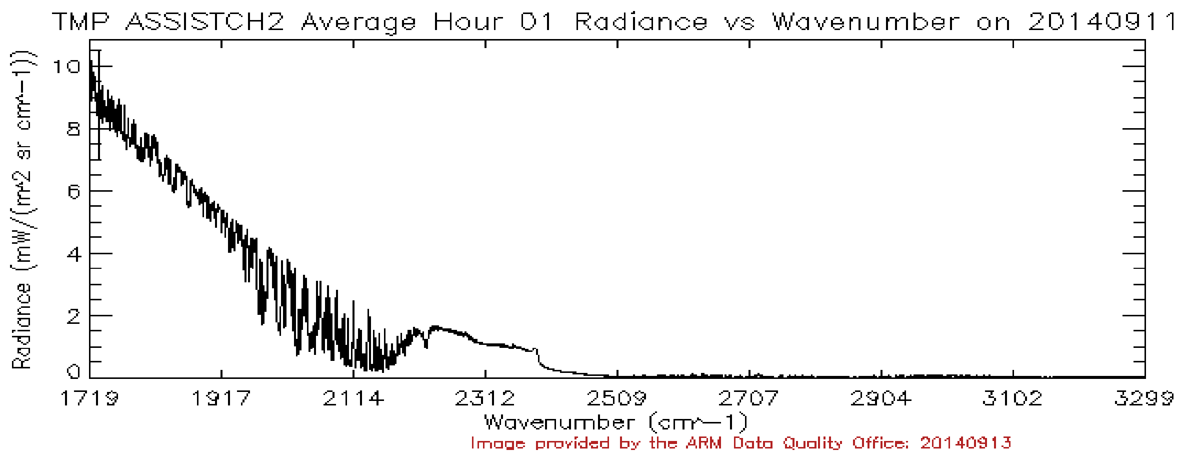


Figure 2. ASSIST InSb Channel 2 hourly-averaged zenith radiance for 2014-09-11.

5.0 Data Description and Examples

5.1 Data File Contents

The ASSIST data files are delivered by the instrument as both raw and calibrated files. The raw files include housekeeping fields, “annotator” files that provide essential context for processing, and raw mono-directional interferograms for both detector channels. The format of these files has not been rigidly constant, which has made reprocessing efforts especially laborious. The housekeeping files have been variously provided as asynchronous ASCII strings returned from one-wire sensors or more recently as column-separated ASCII files (better!). The annotator files were initially provided as Excel “xls” files but are now produced as ASCII comma-separated-variables “csv” files (better!). The interferograms have been provided as binary “igm” files, Matlab “mat” files, and now netcdf “nc” files (better!).

The calibrated data files have been patterned on products generated by the AERI. They were originally provided as Matlab "mat" files but are now generated as netcdf files by the instrument (better!). The calibrated files include the following, where X is channel A or channel B.

At full 1 wavenumber resolution
- Channel X sky radiance
- Channel X variance of complex Sky spectra
- Channel X variance of complex HBB spectra
- Channel X brightness temperature

At degraded 25 wavenumber resolution:
- Channel X sky radiance
- Channel X variance of complex Sky spectra
- Channel X variance of complex HBB spectra
- Channel X brightness temperature
- Channel X HBB noise equivalence radiance
- Channel X sky noise equivalence radiance
- Channel X real component of complex calibration responsivity
- Channel X imaginary component of complex calibration responsivity
- Channel X real component of complex calibration offset
- Channel X imaginary component of complex calibration offset

Selected Housekeeping files and annotator files necessary for processing and QA.

Sky radiance, brightness temperature, standard deviation, and imaginary component of sky radiance over an assortment of wavenumber ranges selected from transparent, semi-transparent, and opaque spectral regions.

ARM archives the raw data without change, and converts all of the calibrated data files into netCDF format patterned closely on the AERI datastreams.

5.1.1 Primary Variables and Expected Uncertainty

1. Absolute spectral radiance of the sky in units of watts per square meter per steradian per wavenumber.
2. Sky brightness temperature as a function of wavenumber in units of degrees Kelvin.

In addition, calculated quantities are also available:

1. Variance of sky infrared spectral radiance as a function of wavenumber.

5.1.1.1 Definition of Uncertainty

The operating specifications of the ASSIST were designed to match those of the AERI. The uncertainty in the primary and secondary quantities measured are discussed in detail in a review by Knuteson et al. (2004a).

5.1.2 Secondary/Underlying Variables

See above

5.1.3 Diagnostic Variables

The following variables reside in the .SUM files. They are critical variables. If they are flagged red, data quality will usually be compromised.

- Hatch Open - If this flags, the hatch is either closed or in an intermediate position. There is no sky data when the hatch is closed. There is still calibration data.
- Detector Temp - A warm detector means degraded data.
- LW HBB NEN - Noise-equivalent Radiance in Hot Blackbody at 1000 cm^{-1}) measures detector noise in the long wave. High values indicate degraded data.
- SW HBB NEN - Noise-equivalent Radiance in Hot Blackbody at 2500 cm^{-1}) measures detector noise in the shortwave. High values indicate degraded data.
- LW Responsivity - Characteristic value representing overall longwave channel responsivity). Measures the sensitivity of the detector. Low values indicate a problem; very low values affect data quality.
- SW Responsivity - Characteristic value representing overall shortwave channel responsivity. Measures the sensitivity of the detector. Low values indicate a problem; very low values affect data quality.
- Rain Intensity - if there is rain there should be no data. The rain sensor, when dirty, will flag under sunny skies. The sensor has an analog output. The rain sensor is located inside the hatch near the sky aperture and is used to flag the critical condition of rain falling on the sky aperture. If rain is detected, the scene mirror will be safe to the down-looking position. This rain sensor is not used to close the hatch; it could be viewed as an independent indicator of a situation where the hatch has not closed to protect the interferometer front end in the presence of rain.

5.1.4 Data Quality Flags

The following flags indicate that there was a problem in calibration because of a temperature or electronic instability of the ambient and hot blackbodies. Slight deviations from optimum values will not affect data quality. Larger deviations will cause more noise and can affect data quality for some uses but not for others. The significance of these deviations is noted by the mentor in Section 6.2, “Data Reviews by the Instrument Mentor.”

The difference in temperature between the ambient and hot blackbody temperatures provide the temperature calibration for the sky data. Larger differences between the ambient and hot blackbodies improve the calibration.

Diagnostic and Maintenance

These flags help us determine what may be causing a problem. Most are temperature and humidity problems. Some flags (noted) tell us a critical component is failing. This gives us warning to replace it before it fails. Some indicate when routine maintenance is required. I have included a description under the more important flags.

- Cooler Current - This flags when a cooler (or detector dewar) is beginning to fail. Immediate action is warranted. It can also lead to a warming of the detector, which will affect data quality.
- Cooler Expander Temp - If the expander gets too warm, the cooler cannot cool properly. The problem is caused by dirty cooling fins (or the cooling motor failed).
- Scene Mirror Temp - enclosure is too warm; usually flags with outside air.

The following flags indicate the instrument enclosure is too warm, which can affect how the instrument functions and cause components to fail.

- BB Support Struct. Temp
- Air Temp Near BBs
- Spare (Shelter) Temp
- Interfer. Window Temp
- Interfer. 2nd Port Temp
- Air Temp Near Interfer
- Rack Ambient Temp
- Computer Temp

The following indicate a component is overheating, probably leading to a failure:

- Cooler Comp. Temp
- Mirror Motor Temp
- ABB Controller Temp
- HBB Controller Temp
- Cooler Pwr Sup. Temp
- Motor Driver Temp

5.1.5 Dimension Variables

All ASSIST data files contain Universal Time Coordinates (UTC) time, date, longitude, latitude, and altitude.

5.2 Annotated Examples

See Section 4.0 on real-time data plots.

5.3 User Notes and Known Problems

The ASSIST has been collocated with the AERI at Southern Great Plains (SGP) two times. In neither instance where we able to demonstrate agreement to within one sigma of the quoted specifications, but generally the measurements agreed to within 2 sigma. This is not a catastrophe, but not ideal. We are currently exploring an element of the ASSIST structural design as a potential sources of measurement bias. Specifically, it was observed that the clear aperture of a fan module mounted over the scene mirror is just large enough to accommodate the design field of view. Even slight variations in mirror positioning might introduce artifacts in the measurement. We have collected clear sky at SGP with and without the fan module in place and will compare with the collocated AERI.

5.4 Frequently Asked Questions

Are data taken continuously?

Spectra are co-added and processed every 2 minutes.

Are data taken at night or on cloudy days?

Data are taken as long as the precipitation sensors on the instrument hatch are not triggered. This guards the steering mirror from water and snow that would obscure the optical throughput.

Are independently acquired data on temperature and water vapor profiles available for comparison? If so, from what source?

Radiosonde data (from weather balloon launches) are available in 3-hour time intervals. Other remote sensors provide profiles of water vapor and temperature (radio acoustic sounding system, Raman lidar, MWRP).

Are there any other references you can recommend?

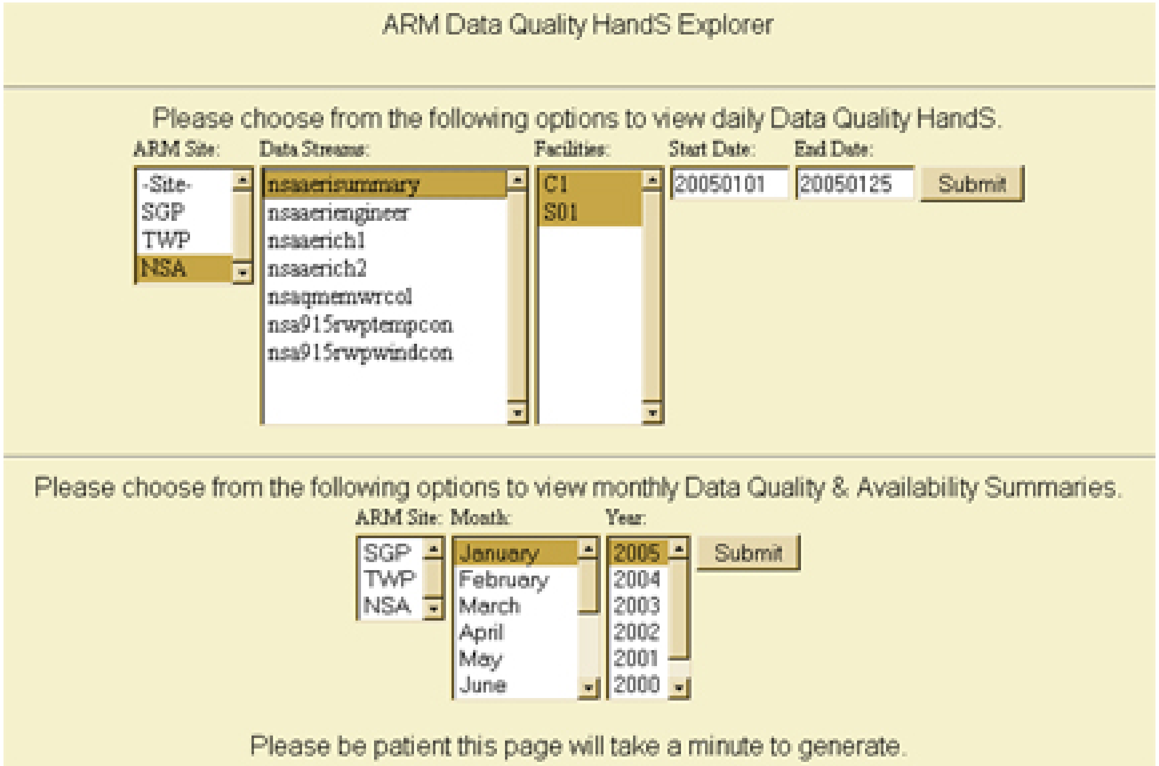
See the reference section at the bottom of this web page.

6.0 Data Quality

6.1 Data Quality Health and Status

Data quality for each spectrometer can be obtained from the Data Quality Office Health and Status web page.

A typical page is shown below.



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

- DQ HandS (http://dq.arm.gov/) for Data Quality Health and Status
- NCVweb (http://dq.arm.gov/ncvweb/ncvweb.cgi) for interactive data plotting.

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 Assessments by Site Scientist/Data Quality Office

This section is not applicable to this instrument.

6.3 Value-Added Procedures and Quality Measurement Experiments

No VAPS are currently run for the ASSIST but we intend to process ASSIST data with the PCA Noise Filter VAP developed for the AERI.

6.3.1 Examples of Data

See Section 4.0 on real-time data plots.

7.0 Instrument Details

7.1 Detailed Description

7.1.1 List of Components

The ASSIST radiometer is composed of six subsystems, which include the following: 1) the interferometer, 2) the detector; 3) the scene-scanning optics; 4) the calibration blackbodies with temperature controller; 5) a PC-based instrument control, data acquisition, data processing computer with custom software Edgar running under Windows, and 6) an automated viewport hatch, which serves to protect the front end optics in inclement weather.

The ASSIST is a commercial instrument with more information and details available via LR Tech.

7.1.2 System Configuration and Measurement Methods

The ASSIST has been deployed as part of the AMF2 mobile facility in a thru-wall configuration. The viewing mirror and the two calibration blackbodies are separated by a thermal barrier from the other half of the ASSIST, which consists of the interferometer and the data acquisition computer. The viewing mirror is at ambient temperature. The interferometer and computer are at room temperature in the trailer. The viewing mirror is rotated to view the sky and alternately the calibration sources.

7.1.3 Specifications

Resolution of instrument is one wavenumber (1/cm). Range of wavelengths is 520 to 3300 wavenumbers. The instrument views straight up into the atmosphere with a 1.3-degree field-of-view.

7.2 Theory of Operation

The IR spectra is gathered by the instrument and the operation of the interferometer follows. The Fourier Transform Infrared (FTIR) spectrometers measure light absorbed or emitted from a sample as a function of wavelength. They consist of an optical system for collecting light and concentrating it, an interferometer for algebraically combining the light from the two light paths, a detector to change the light intensity into an electrical signal, signal conditioning electronics, and a computer for extracting spectral data from the signal using FTIR methods.

In general, interferometers combine light from two light paths algebraically resulting in variations in light intensity across the aperture of the interferometer called interference fringes (for non-coincident or non-identical wavefronts). One light path is scanned to vary the optical path length. The other path is a reference path. Consider a Michelson interferometer looking at monochromatic light from a collimated expanded laser beam, in which the incident beam is split into two equal length paths by a beam-splitter. Also assume that each path ends in a plane front surface mirror, which is aligned such that the surfaces are normal to the beam.

If the mirrors are aligned exactly so that the distance traveled by light is point-for-point identical over the beam for the two paths, the observer will see a uniformly bright entrance aperture through the interferometer. If the paths differ by a half-wavelength, the observer will see a uniformly black aperture. For intermediate positions, the intensity will be proportional to the cosine of the phase angle (relative fraction of a half-wavelength path difference).

This observation is true only for monochromatic light. If a second monochromatic wavelength is added, the cross-section will have different intensity for each of the two wavelengths because the difference in path lengths between the two paths will be a different multiple (or fraction) of wavelengths for each wavelength. For additional wavelengths, intensity contributions are algebraically summed.

If light entering the interferometer is an unknown combination of wavelengths, like light from a source having a broadband spectrum, the result will be a complex combination of intensities due to the multiple wavelengths. As the optical path length of one path is slowly but uniformly changed, the difference in path length for each wavelength will change. Because the wavelengths are different, the path difference expressed as a factor of the wavelength will be different for each wavelength, and will change at a different rate. Path differences, resulting in a variation in output intensity, will change more quickly for short wavelengths than for long wavelengths. If a detector converts the intensity variations into electrical variations, temporal signal will be a superposition of cosines with periods representing the time variations in intensity. Analysis of this series into its component frequency components (with coefficients characteristic of the relative intensities of the individual wavelength components present in the incident light) is accomplished using a FTIR algorithm. The algorithm is ideally suited to breaking down signals comprising a series of sines or cosines, resulting in the electromagnetic spectrum of the incident light.

The function of the Helium Neon laser in a modern FTIR is often misunderstood. Its sole purpose is to measure the position(x) of the moving mirror, the so-called retardation distance. The helium neon laser is used in a separate interferometer, called the reference interferometer that shares the moving mirror with the IR interferometer. In this way, fringes are counted in the reference interferometer, which allows a precise measurement of the retardation position, x. With the interferogram, I(x), from the IR interferometer, and the retardation position, x, the spectra can be obtained by a fast fourier transform.

7.3 Calibration

7.3.1 Theory

Two blackbody sources, one at ambient temperature and the other at 330K are used to calibrate the instrument. The two sources are used to determine the slope and offset, which define the linear instrument response at each wavenumber (see Revercomb et al. 2004). The ASSIST views these two blackbodies every two minutes. Magnitude of the difference between these blackbody spectra is then formed to compute the responsivity and offset for the instrument.

After application of the responsivity and offset, the brightness temperature vs. wavenumber agrees with the known temperatures (290K and 330K) within 1 Kelvin. The residual error is thought to originate from two sources: angular dependence in the beam-splitter coatings and emission from the beam-splitter coatings. Of these two sources, the largest error appears to originate from emission in the beam-splitter (see Revercomb et al. 2004).

7.3.2 Procedures

Calibration procedures are performed automatically by the software. See Knuteson et al. (2004a, b) to see how calibration is automatically performed.

7.3.3 History

Because this instrument takes a calibration run every 2 minutes, the best history is to obtain views of the blackbody brightness temperature curves. Inspections of these curves by the mentor in the past has revealed no anomalies in calibration.

7.4 Operation and Maintenance

7.4.1 User Manual

There is no user manual for the ASSIST.

7.4.2 Routine and Corrective Maintenance Documentation

No routine or corrective procedures beyond routine cleaning of the scene mirror with distilled or de-ionized water. Because the ASSIST uses a first-surface gold mirror, no contact is allowed with the mirror during cleaning. Liquids or dry air only.

7.4.3 Software Documentation

The software for operating the instrument is called Edgar. A software manual is available on request.

7.4.4 Additional Documentation

The user may want to contact the instrument manufacturer, LR Tech, for additional information.

7.5 Glossary

HgCdTe - Mercury Cadmium Telluride Detector for long wavelength infrared detection (5 to 15 microns).

InSB - or “insbee” detector optimized for near-to-mid-infrared 1 to 5 microns.

Wavenumber - the inverse of the wavelength in centimeters. For example, one micron wavelength (.0001 cm, 1e^{-4}) becomes 10,000 wavenumbers when inverted. Wavenumber is useful because the photon energy is equal to the wavenumber times Planck’s constant times two pi (i.e., the wavenumber is proportional to the photon energy).

7.6 Citable References

Knuteson et al. 2004a, b, provide outstanding detail on the AERI, which also pertain to the ASSIST

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