Atmospheric Waves Experiment (AWE)
Calibration CALCON 2020

Joel Cardon, Harri Latvakoski, Greg Cantwell
Space Dynamics Laboratory, Utah State University
Atmospheric Waves Experiment (AWE)

AWE is the first dedicated NASA mission to investigate global gravity wave properties in the upper atmosphere and their impacts on the ionosphere-thermosphere-mesosphere (ITM) system.

**How does tropospheric weather influence space weather?**

- **PI:** Dr. Mike Taylor, USU
- **PM:** Burt Lamborn, SDL

**Global small scale GW measurements are essential but severely lacking**
AWE Mission on the ISS (2022-2024)

- Full coverage ±53° latitude every 4 days
- 1 image every second
- Large 600 km field-of-view
- Spatial resolution 8.5 x 4.2 km
- Comprehensive 30-300 km GW parameter measurements at ~87 km
- Two-year mission

First NASA Heliophysics instrument on the ISS
The AWE Advanced Mesospheric Temperature Mapper (AMTM)

ELC 1, site 8
Calibration Relationship with Science Measurements

- Gravity waves (visible in radiance images) perturb the temperature of the OH layer which is measured from
  \[ T = \frac{259.58}{\ln\left(\frac{2.644}{P_{12} - B}ight)} \]
  \[ \frac{P_{12}}{P_{14} - B} \]

  \( T \)  OH layer temperature
  \( P_{12} \)  Radiance in \( P_{1}(2) \) line
  \( P_{14} \)  Radiance in \( P_{1}(4) \) line
  \( B \)  Calibrated background radiance

- Calibrated background removes non-OH emission

- AWE calibration characterizes system-level instrument performance in expected on-orbit environment, and provides data products and associated uncertainties needed for on-orbit data processing and science analysis.
Instrument Radiometric Performance Model

- A detailed AMTM radiometric performance model was developed early in the program
  - Calculates expected instrument response using OH $P_1(2)$ and $P_1(4)$ radiances previously observed by ground-based AMTM instruments
  - Calculates all expected noise sources including photon shot and all detector noise contributions
  - Calculates measurement noise contributions due to non-linearity and response non-uniformity
  - Simulates absolute OH temperature measurements and OH temperature measurement precision
- Model was used to specify detector requirements for QE, dark current, total noise, full well, operating temperature, integration time, linearity, non-uniformity, etc.
- Model has been used to inform top-level science and instrument requirements
- Model is used to select calibration sources and develop calibration measurement plans

Radiometric performance model is an invaluable tool at all stages of the program
OH Radiance Calibration Equation

\[
L_{f,k,T_{\text{det}},T_{\text{opt}}}(\lambda_{OH_f}) = \frac{1}{R_f RSR_{f,T_{\text{opt}}}(\lambda_{OH_f})} \left[ F_{\text{lin}}(I_{f,k}) - F_{\text{lin}}\left(D_{f,k,T_{\text{det}},T_{\text{opt}}}ight) \right] FF_{f,k}
\]

where

- \(L_{f,k,T_{\text{det}},T_{\text{opt}}}(\lambda_{OH_f})\) = OH radiance in pixel k for filter f [(W/cm\(^2\)-sr)]
- \(T_{\text{det}}, T_{\text{opt}}\) = Detector and optics temperature
- \(f\) = Spectral filter \(P_1(2)\) or \(P_1(4)\)
- \(\lambda_{OH_f}\) = Wavelength of OH emission line for filter f
- \(RSR_{f,T_{\text{opt}}}(\lambda_{OH_f})\) = RSR for filter f and \(T_{\text{opt}}\) at wavelength \(\lambda_{OH_f}\)
- \(R_f\) = Peak radiance responsivity for filter f [DN/(W/cm\(^2\)-sr)]
- \(F_{\text{lin}}\) = Linearity correction function
- \(I_{f,k}\) = Signal in pixel k for filter f [DN]
- \(D_{f,k,T_{\text{det}},T_{\text{opt}}}\) = Darkfield in pixel k, for filter f, \(T_{\text{det}}\), and \(T_{\text{opt}}\) [DN]
- \(FF_{f,k}\) = Broadband flatfield for pixel k, filter f [unitless]

Notes:
1) Distortion and FPA co-alignment correction functions are applied to pixel coordinates during pixel geolocation.
2) Background channel calibration is similar but adjusted to \(P_1(2)\) and \(P_1(4)\) passbands before science processing.
### Calibration Planning – Test Matrix

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<td>OH absolute temperature and temperature precision</td>
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<td>Distortion</td>
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<td>Spatial resolution and temperature amplitude</td>
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<td>Linearity</td>
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<td>Absolute radiance responsivity</td>
<td>OH absolute temperature and temperature precision</td>
<td>40” Integrating sphere</td>
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<td>Spectral response</td>
<td>OH absolute temperature</td>
<td>MIC5 collimator with Fourier transform spectrometer for system-level; spectral filter vendor measurements for component level</td>
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The EM AMTM calibration will exercise a subset of the full FM calibration measurements.
Calibration Test Configurations

- AMTM is mounted on a two-axis rotation stage in THOR chamber for 90° field-of-view
- MIC5 collimator test configuration
  - Blackbody or FTS at entrance port
  - Cold shutter between THOR and MIC5 is used for dark noise and dark fields
- 40” integration sphere test configuration
  - 40” integrating sphere replaces MIC5
  - AMTM view integrating sphere through vacuum window
Darkfields and Dark Noise

- Masked pixels are used to provide measurements of dark current and any long-term drifts with each image
  - During ground calibration, AMTM will view a cold shroud in the THOR chamber with several permutations of FPA temperature, optics temperature, and integration time
  - Masked pixel measurements will be correlated with darkfields to provide darkfields for on-orbit calibration
- Range of ISS environment conditions drives a thermal design requiring relatively warm InGaAs FPA temp
- Accommodation on the ISS precludes planned deep space dark observations, but incidental dark measurements may be acquired during ISS maneuvers
- As a backup, AMTM filter wheel positioned in an intermediate position can provide additional on-orbit darks
Distortion, FPA Co-alignment, and Point Spread Function

- The MIC5 collimator produces a single spot on each FPA for each acquired image
- The two-axis stage is rotated over a regular grid of angles to cover the AMTM 90° FOV
- The individual images are combined to produce an image with a grid of spots
- If there were no distortion, the grid of spots would also be regular, but with expected “fish-eye” distortion, the grid of spots will not be regular
- The deviation between the measured grid of spots and a regular grid gives a measure of the optical distortion
- Mis-alignment of the FPAs will be evident as shifts or rotations from one combined image to the next
- The optical PSF can be measured by dithering the spots observed in selected regions of the FPAs
Absolute Radiance Responsivity and Flat Fields

- AMTM absolute response will be measured by viewing a calibrated integrating sphere through a large vacuum window.
- These measurements will be combined with AMTM RSR measurements to derive absolute response to OH emission features of interest.
- Two-axis stage will be rotated through a regular grid of angles covering the AMTM 90° FOV.
- Images acquired for each stage position will be combined to produce full-FPA flat fields.
- Ground flat fields will be compared with regularly updated on-orbit flat fields.
Relative Spectral Response

- AMTM spectral response is driven by the narrow spectral filters
- Transmission curves are provided by the vendor at several locations on the filters
  - Vendor curves are adjusted for 3.8° cone angle and expected on-orbit filter temperature
  - Small filter shifts due to filter temperature range on-orbit not expected to be a problem
- RSR will be measured at the system level to confirm component-level expectations
  - MIC5 collimator fed by a step-scan FTS
  - AMTM response images combined to produce temporal interferograms
  - Temporal interferograms are transformed to produce spectral response curves
Conclusions

• AWE is the first dedicated NASA mission to investigate global gravity wave properties in the upper atmosphere
• The ISS is a good platform for these measurements, providing good latitudinal and seasonal coverage during the two year mission
• ISS thermal environment and broad instrument accommodation mission drives certain aspects of the AMTM design, including ground and on-orbit calibration plans
• A detailed instrument radiometric performance model developed early in the program continues to be invaluable at all stages of the program, including during calibration measurement planning
• EM AMTM calibration is important to inform FM AMTM design and to exercise calibration equipment and procedures
• The comprehensive ground calibration will provide data products and instrument characterization needed for on-orbit data processing and science analysis