RAIDS Update

The Remote Atmospheric and Ionospheric Detection System aboard the ISS — *June 23, 2010*

S130E008968

Figure 1: Astronaut and Navy Captain Kay Hire on the STS-130 mission floats an NRL decal in front of the Japanese Experiment Module viewport with HICO-RAIDS Experiment Payload (HREP) visible in the background. Dr. Hire visited NRL in April 2010. (Photo credit: NASA)

RAIDS Science Operations Optimized

The Remote Atmospheric and Ionospheric Detection System (RAIDS) has completed eight months of science operations aboard the International Space Station (ISS). The experiment continues to obtain high-quality atmospheric measurements using the extreme-ultraviolet (EUV) spectrograph; mid-ultraviolet (MUV), near-ultraviolet (NUV), and near-infrared (NIR) spectrometers; and the 630-, 766-, and 777.4-nm photometers. Science data collection to address primary and secondary science objectives continues, and initial results publications are in preparation. Other on-going activities include sensitivity trending analysis for the sensors, analysis of attitude information from the ISS and the HREP star tracker, and calibration/validation support for the Special Sensor Ultraviolet Limb Imager (SSULI) aboard DMSP satellite *F18*.

Since December 2009 a number of improvements have been made to RAIDS ground planning and operations software, instrument observing modes, and access to NASA flight information. The mission operations improvements have streamlined mission planning and increased the collection efficiency of high-quality science data. The ISS pitch attitude variations remain the primary challenge for uniform collection of limb observations over the full range of target tangent altitudes. However, NASA has been very responsive to the RAIDS sensitivity to pitch orientation and is implementing ISS flight momentum controller modes that provide reduced pitch variation more suitable for limb observations.

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Sep-09																								000	000	07F	07F	07F	07F	07F		
Oct-09	07F	07F	07F	07F	140	100	038	03F	17F	1FF	0FF	180	180	180	1FF	1FF	1FF	000	000	000	000	17F	1BF	1BF	1BF	1BF	1BF	1BF	1BF	1BF	1BF	
Nov-09	1BF	1BF	1BF	1BF	1BF	1BF	1BF	1BF	1BF	1BF	1BF	1BF	000	000	000	000	1BF	180	180	1C0	1C0	1C0	1C0	1C0	1BF	1BF	1BF	1BF	1BF	1BF		STS-129 Nov 18-25
Dec-09	1BF	1BF	1BF	1FF	1BF	1BF	1BF	1BF	1BF	1BF	1BF	1BF	1BF	1BF	1BF	1BF	000	000	000	000	080	1FF	180	180	180	180	180	180	180	180	180	
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Feb-10	1FF	1FF	1FF	1FF	1FF	1FF	1FF	1FF	000	000	000	000	000	000	000	000	040	040	040	1FF	1FF	1FF	1FF	1FF	1FF	1FF	1FF	1FF				STS-130 Feb 10-20
Mar-10	1FF	1FF	1FF	1FF	1FF	1FF	1FF	1FF	1FF	1FF	1C0	000	000	000	000	000	1C0	1FF	1FF	1FF	1FF	1FF	1FF	1FF	1FF	1FF	1FF	1FF	1FF	1FF	1FF	
Apr-10	1FF	1C0	1C0	1C0	1C0	1C0	1C0	0C0	0C0	0C0	0C0	0C0	0C0	0C0	0C0	080	080	080	1FF	1FF	1C0	1C0	1C0	1C0	1C0	1FF	1FF	1FF	1FF	1C0		STS-131 April 7-17
May-10	1C0	1C0	1FF	1C0	1FF	1FF	1FF	1FF	1FF	1C0	1C0	1FF	1FF	0C0	0C0	0C0	0C0	0C0	000	000	0C0	0C0	0C0	1FF	1C0	1FF	1FF	1FF	1FF	1FF	1FF	STS-132 May 16-23
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Operating Modes	
Off	All off
Standby	FMP powered, Sensors off
Noise Trending	Sensors on, dust covers closed
Limb scan	Mode 1 or Free Limb Scan
Stepped Scan	Spectra at discrete altitudes
Mode 241	Interspersed limb scans & spectra
Stare	Spectra at fixed altitude
Holiday Safe	Visible/NIR sensors off
Sun Safe	Scanned onto disk/Sensors off

Bit Identification	
1xxxxxxxx	Platform moving
x1xxxxxxx	EUV on
xx1xxxxxx	FUV on
xxx1xxxxx	MUV on
xxxx1xxxx	NUV on
xxxxx1xxx	NIR on
xxxxxx1xx	765 on
xxxxxxx1x	630 on
xxxxxxxx1	777 on

Figure 2: RAIDS Data Collection Summary. The RAIDS data collection activity reflects the impact of space vehicle dockings, ISS construction, and Sun apparitions. The default operating mode transitioned from Mode 2 (Stepped Scans) to Mode 241 in January.

Data Collection

Our collection efficiency for high-quality data continues to be lower than is typical for free-flying satellites due to the impact of manned spaceflight operations upon ISS attitude. The dockings and departures of supply spacecraft introduce both transient perturbations and longer-term changes in station pitch that directly affect RAIDS limb scan pointing control.

The data collection summary (Fig. 2) reflects the heavy toll that Shuttle dockings have taken upon RAIDS observations during the first half of 2010. When the Shuttle is docked with the ISS, the space station pitches up to +16°, which points RAIDS downward onto the Earth disk for a period ranging from seven to ten days. The bright Rayleigh scattered continuum from the dayside atmosphere requires that all sensors except the EUV and FUV spectrographs must be shut down. We intentionally leave the EUV instrument powered to continue acquiring some limited science data. Several months will elapse before the next Shuttle mission in the fall, so we anticipate higher data collection efficiency in the near term.

Between January 4 and March 2, 2010 the fixed wavelength limb scans from all three spectrometers were acquired at wavelengths offset from the desired emission feature peaks due to a wavelength position reporting anomaly. This problem did not affect the spectral scan data acquired during that time period nor the EUV limb scans. Subsequently, limb scans for NO, O_2 Atmospheric (0-0), and N_2 2^{nd} Positive have been acquired at the optimal wavelengths and are better suited to science analyses.

A significant step toward improving data collection efficiency was made by gaining access to the Attitude Time Line (ATL) documents that described near-term ISS attitude and planned maneuvers. Prior to this, the RAIDS Team was routinely adjusting science operations in reaction to observed station attitude changes and the associated drops in data quality. This delayed-response naturally resulted in missed opportunities for high-quality observations. In April we gained web-access to NASA ISS flight operations information that enabled proactive planning of RAIDS operations in anticipation of ISS flight behavior. Using the ATL has significantly increased the fraction of observations acquired at desired tangent altitudes.

RAIDS Operating Modes

Mode 241. Since January 2010 most of the RAIDS data have been collected in a customized operating mode which intersperses discrete altitude, full spectrum scans with fixed-wavelength, continuous limb scans (Mode 241). The primary science focus remains retrieval of lower thermosphere temperature using the O_2 Atmospheric

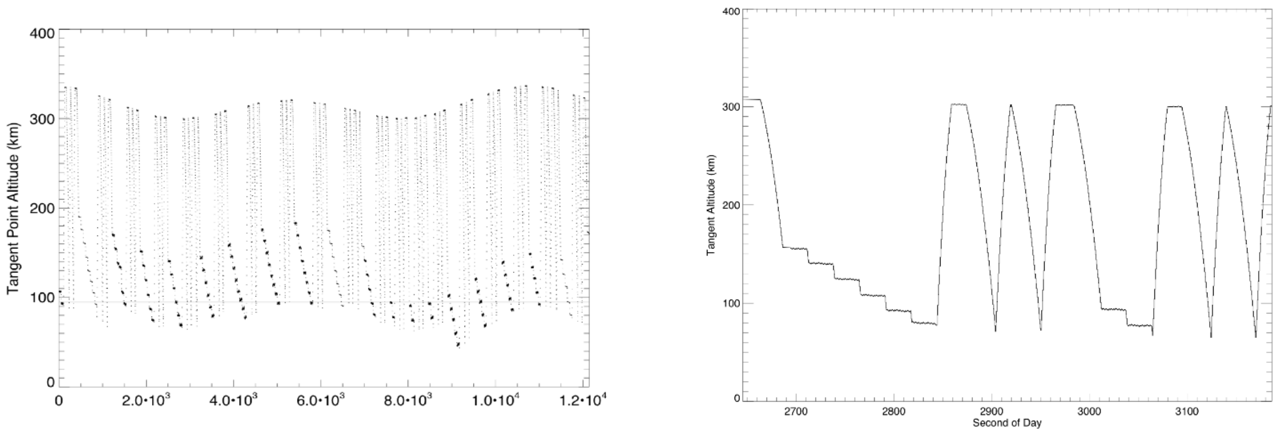

Figure 3: (Left) The tangent point altitudes for slightly more than one orbit plotted versus frame number show the variance of tangent altitude arising from ISS pitch wobble. (Right) The tangent altitudes for Mode 241 at the transition from day to night reflect the dwell altitudes where spectra are acquired followed by limb scans at fixed wavelengths. Dayside observations include more spectra at higher altitudes than at night, where the focus is the nightglow layer near 95 km.

band NIR emission. Comparison of RAIDS-derived temperatures with those from the SABER instrument aboard the NASA TIMED satellite is underway. The new mixed observing mode facilitates the secondary science objectives of thermospheric chemistry and composition studies, such as nitric oxide modeling using MUV spectra and limb scans, and atmospheric N_2 retrievals using 2^{nd} Positive emission in NUV spectra.

Mode 241 operates slightly differently on the dayside and nightside (Fig. 3), because most nightside airglow emissions tend to occur at lower altitudes. On the dayside the sequencer starts by initializing the spectrometers at high altitude, followed by five to eight consecutive spectra at fixed viewing angles (Mode 2). The spectrometers are set up to dwell at emission peak wavelengths 236.5, 337.1, and 760.5 nm at a fixed high altitude (Mode 4) for 0.5 secs, which is followed by a serendipitous limb scan at those wavelengths. Finally, the spectrometers are set to off-peak continuum wavelengths for a single limb scan (Mode 1) for background characterization. The pattern is similar on the nightside, except only two to four fixed altitude spectra are acquired and the spectrometers remain on emission peak wavelengths during the Mode 1 scan due to the lack of solar continuum. The overall cadence for the dayside sequence is 300-350 seconds, while the nightside sequence repeats every 220-270 seconds.

Holiday Safe Mode. Another common operating mode since December has been the “Holiday Safe” mode in which EUV limb scan data are acquired and all other sensors are powered off. Since the EUV spectrograph is blind to Rayleigh scattered light and therefore insensitive to changes in ISS pitch, RAIDS can operate safely and autonomously in this mode with no ground commanding. This mode was initially devised to accommodate staffing issues over the holidays, but the mode has been implemented subsequently when frequent ISS attitude changes are expected due to docking maneuvers.

Sun Safe Mode. During the three to four days when the Sun is expected to fall within the RAIDS field-of-regard (near zero Beta-angle) the scan platform is pointed down into the hard disk of the Earth a few degrees below the limb—depending upon ISS pitch—and all sensors are turned off. No science data is collected during Sun-safe mode, only experiment health and status.

Stare Mode. During Shuttle dockings, when RAIDS is pointed down 30° or more onto the Earth disk, most sensors are turned off, but the EUV and FUV sensors can safely remain powered to acquire disk spectra. In April and May when Sun apparitions coincided with Shuttle dockings, disk Stare Mode replaced Sun-safe mode.

Low Power Mode. In February and May HREP was required to enter a low power mode in which HREP was shutdown with the exception of survival heaters in order to accommodate ISS construction activity. No RAIDS data of any kind is acquired in this configuration.

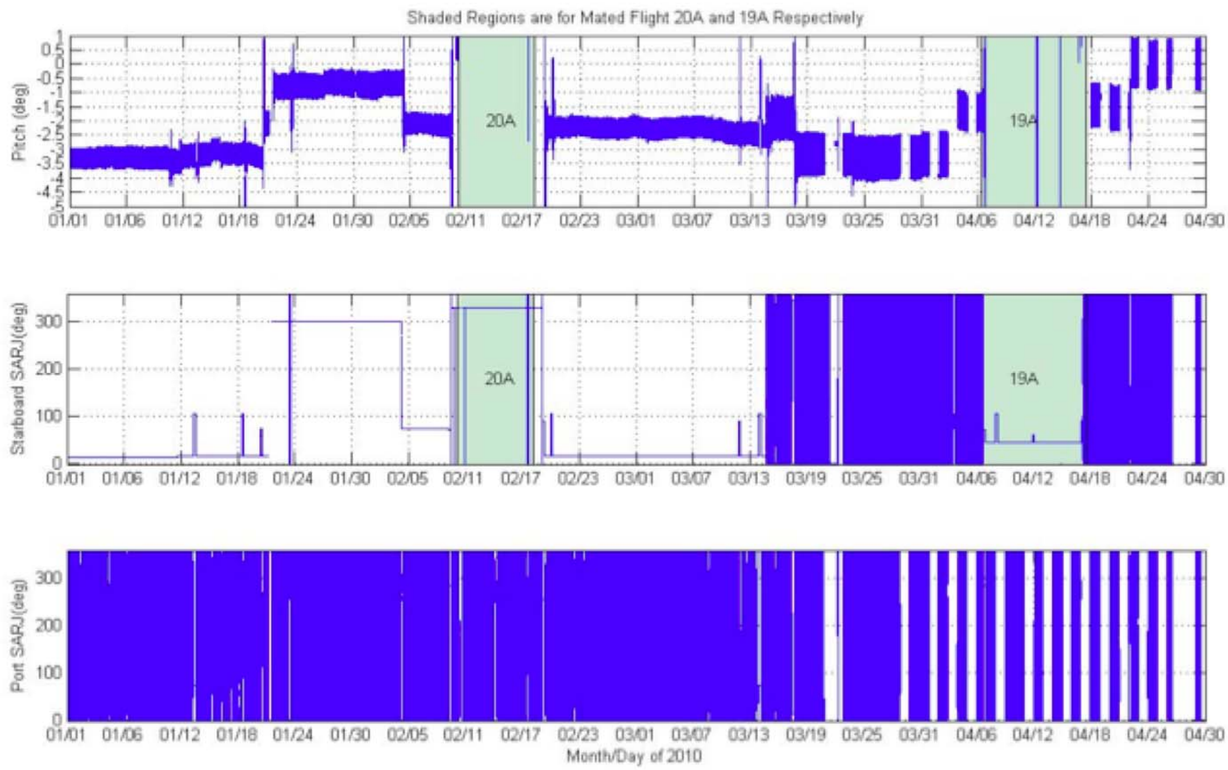

Figure 4: (Top) The ISS pitch value from January through April shows the unresolved pitch oscillation (blue band) increasing near March 15. The pitch value is off-scale during mated flight periods (green). (Middle) This event coincides with when the starboard solar array Solar Alpha Rotary Joint (SARJ) resumed sun-tracking rotation. The unresolved rotations appear as a blue band spanning 360°. (Bottom) The port SARJ was rotating throughout this period. (Plot provided by ISS GNC Team/Boeing)

ISS Attitude

At the time of the last *RAIDS Update* newsletter inaccessibility of accurate predictions of ISS attitude to the RAIDS Team and difficulty in correctly interpreting ISS attitude quaternions were identified as the most significant operational challenges. Although the application process took several months, in April 2010 the RAIDS team was granted access to an ISS mission operations website at Johnson Spaceflight Center that provides the Attitude Time Line documents for the ISS. Additionally, by early January we developed ground software to utilize the ISS attitude quaternions, which produced a continuous attitude data product by blending HREP Star Tracker and ISS attitude data.

In mid-March a new issue concerning ISS attitude arose when the magnitude of the station pitch oscillation increased from ±0.3° to ±0.75° (Fig. 4). This occurred when the second solar array resumed tracking the Sun, thereby increasing the increased angular momentum loading on the gyroscopic control system. The ISS momentum manager controller optimizes pitch oscillation against gyroscope loading within a dead-band. Unfortunately, while the lower amplitude pitch oscillation was within RAIDS observing mode margins, the new, higher amplitude pitch oscillation is not. To avoid saturating the RAIDS instruments when the ISS is at its high pitch value, the RAIDS viewing angles had to be restricted, and consequently RAIDS misses some of its target altitudes for the primary science objective. The total fraction of lost samples is not high (<7%), but the data loss disproportionately affects 45% of dayside airglow profiles; nightside observations are unaffected.

The RAIDS Team raised the concern about science data loss to the Space Test Program. Very quickly NASA scheduled a telecon to discuss the problem and explore mitigation strategies. In a follow-up telecon in early June, the ISS Guidance, Navigation, and Control (GNC) team identified several different low-impact mitigation strategies in which alternate momentum manager controllers might be implemented.

In the near term (July), RAIDS can request a two week observation period in which a previous momentum controller will be operated, providing a pitch stability of ±0.15°. The long term prospects for pitch stability are even better: the final ISS momentum controller may come on-line as early as September. The new controller has a Mixed/Blended Minimum Attitude & Momentum Oscillation mode which will provide continuous pitch stability to ±0.2°. The prospect of the new controller is very good news for future RAIDS limb observations. In the meantime, by carefully choosing two week periods for lower pitch oscillation between sun-safe events or docking activities, we can maximize high-quality observation periods until the new controller is fully implemented.

The lesson learned from this experience is twofold. First, during RAIDS preparation for the ISS mission, the GNC team provided a single number of ±3° for pitch oscillation. This information arrived too late in the RAIDS development cycle to implement changes to HREP and RAIDS mission operations. Moreover, the RAIDS Team did not know the right questions to ask about the meaning of this large value. In our recent discussions with the GNC team we identified the types of additional information concerning ISS flight characteristics that might prove more useful to future payload developers. Secondly, the implication of this ISS pitch oscillation is that future payloads should be prepared to implement actively-controlled pointing systems that utilize the ISS broadcast attitude information to achieve more precise pointing.

RAIDS Science Highlights

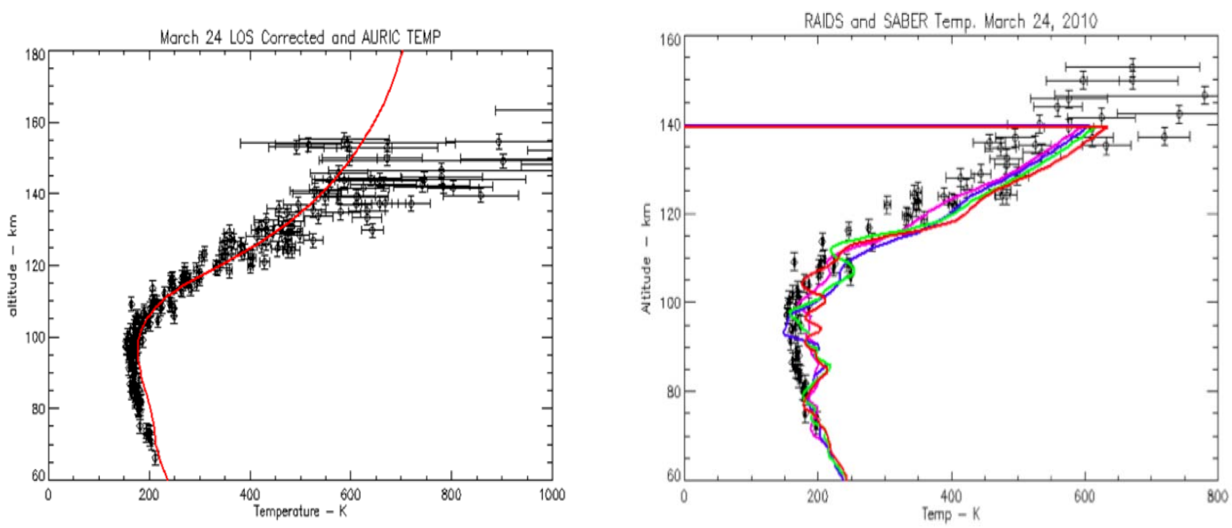

Figure 5: (Left) Thermospheric temperatures from O_2 Atmospheric (0-0) band emission (black) are plotted against the NRLMSISE-00 empirical model temperature profile (red) for March 24 solar activity conditions. (Right) The same RAIDS-derived temperatures are plotted against coincident TIMED SABER temperatures for the same date.

Temperature Sensing

Specification of the temperature of the lower thermosphere, especially at altitudes 100-200 km, is the Primary Science Objective of the RAIDS experiment. The main observable for measuring thermospheric temperature is the spectroscopic band shape of the O_2 Atmospheric (0-0) band emission at 760 nm using the NIR spectrometer and, potentially, the 765 nm photometer. Effective temperatures have been retrieved from the band profiles using two different algorithms yielding consistent values and uncertainties. These effective temperatures retrieved directly from the NIR spectra are line-of-sight corrected (to account for a bias due to airglow emission above the tangent point altitude along the lines-of-sight) to estimate the local temperatures at the tangent locations (Fig. 5). Temperature uncertainties are as low as a few Kelvin at low altitudes. Efforts are underway to evaluate and validate the RAIDS temperatures using coincident SABER data below 110 km. The variance of RAIDS temperatures near 110-120 km exceeds the statistical uncertainty of the retrieved values, and investigating this variability is a topic of particular interest. Scan-to-scan differences in temperature are observed which appear to be similar to variability present in the SABER data.

The altitude profile of O_2 emission for the (0-0) and (1-1) bands has been analyzed and found to be in good agreement with excitation models.

Reference:
A B Christensen, J H Hecht, R L Bishop,S A Budzien, A W Stephan, P R Straus, Z Van Epps, "Neutral Temperature Measurements in the Lower Thermosphere Utilizing the RAIDS Near Infrared Spectrometer" *C/NOFS Workshop*, May 18-20, 2010, Breckenridge, CO.

Dayside Ionosphere

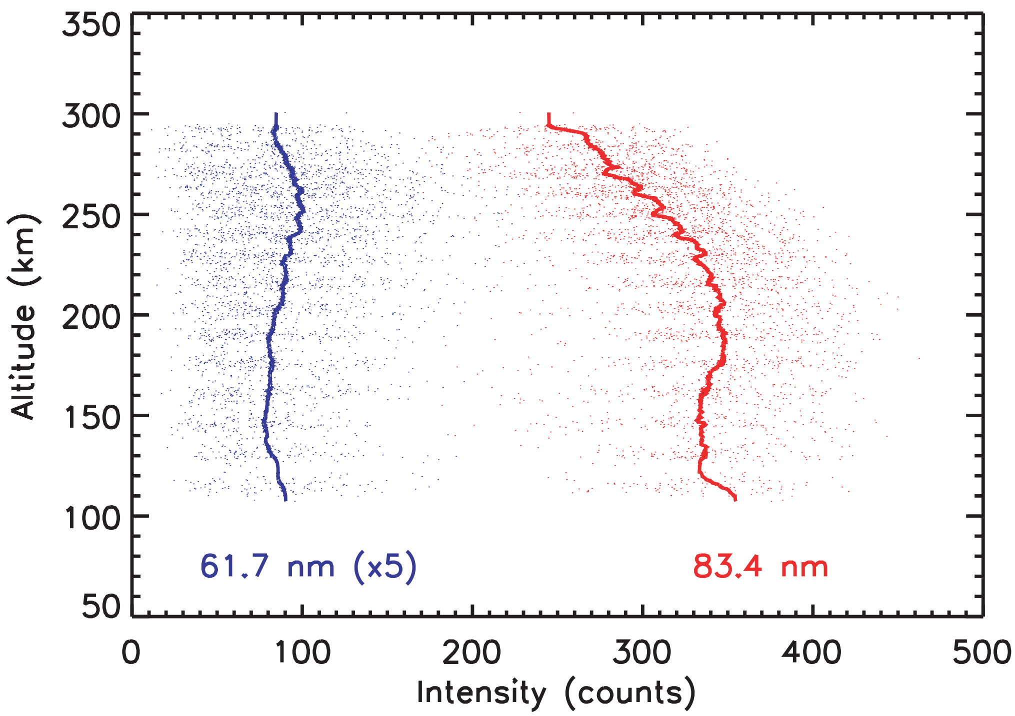

Figure 6: The signal-to-noise of 61.7 nm emission (blue) is quite low, but the averaged profile peaks above 200 km due to extinction as expected. The 83.4 nm profile (red) is significantly cleaner and peaks lower. The current low solar activity conditions may not permit effective retrieval of the initial source using 61.7 nm.

One of the Secondary Science Objectives is to obtain simultaneous O^+ 83.4 nm and 61.7nm emission profiles to observe the initial source excitation for O^+ using 61.7 nm along with the optically thick 83.4 nm scattering region of the F_2 ionosphere at higher altitudes. Initial analysis of limb scan spectra taken using the EUV spectrograph in short wavelength mode (55-85 nm) show that the emission profiles (Fig. 6) are consistent with model predictions. The weakness of the 61.7 nm emission feature and the current low solar activity conditions present significant challenges to validating the new 61.7/83.4 nm algorithm. Work on this problem continues, and we will periodically perform short passband observations as the solar activity picks up over the next year.

Reference:
R L Bishop, A W Stephan, S A Budzien, A B Christensen, P R Straus, J H Hecht, "Variability of Neutral and Ionized Species between 100-200 km as Measured by the RAIDS EUV Spectrometer" *C/NOFS Workshop*, May 18-20, 2010, Breckenridge, CO.

Nitric Oxide

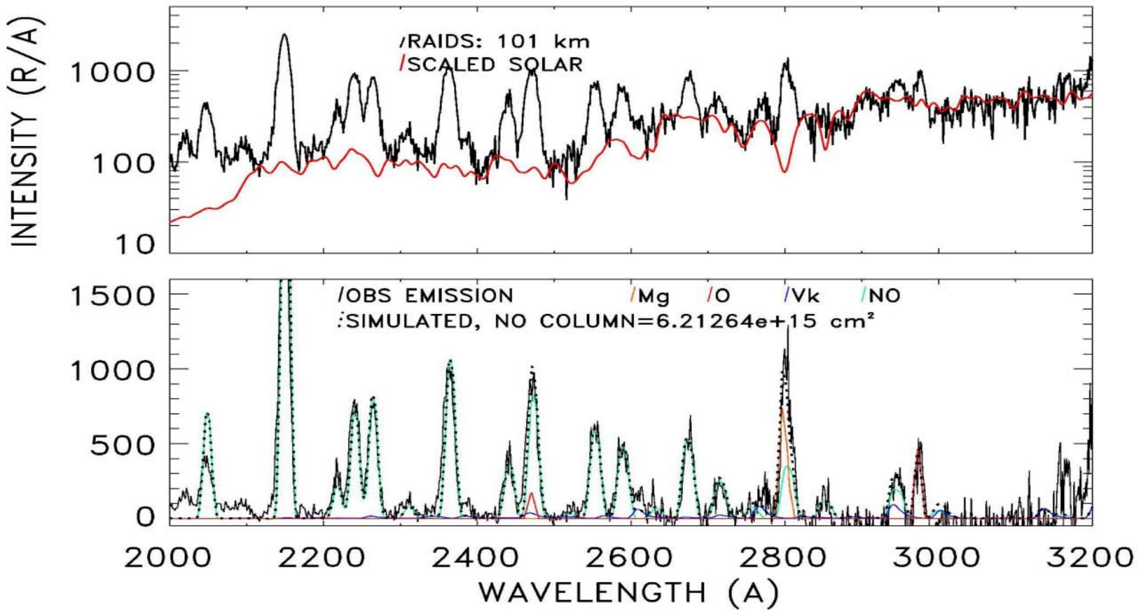

Figure 7: (Top) RAIDS MUV spectrum from Jan 15, 2010 at 101 km is fitted with a scattered solar continuum. (Bottom) After subtraction the emission features are well-fitted with synthetic spectra for NO, N_2, Mg, and O.

Good progress is being made in the analysis of MUV spectra (Fig. 7), with particular focus on nitric oxide modeling. This research supports the Secondary Science Objective for characterizing chemistry and composition of the thermosphere. Mid- and low-latitude NO serves as a useful tracer of transport and energetics in the thermosphere. RAIDS NO profiles have been modeled using 1-D chemistry with good results (Fig. 8) . Additionally, the latitudinal distribution of NO observed by RAIDS has been compared with that from an empirical models based upon SNOE data. Further work will examine NO diurnal variations , characterize NO as a function of soft X-ray energy input, and perform more detailed model comparisons.

Reference:
K Minschwaner, S Bailey, A Stephan, S Budzien, and R Bishop, "Nitric Oxide in the Equatorial Lower Thermosphere: New Observations from RAIDS on the ISS", *C/NOFS Workshop*, May 18-20, 2010, Breckenridge, CO.

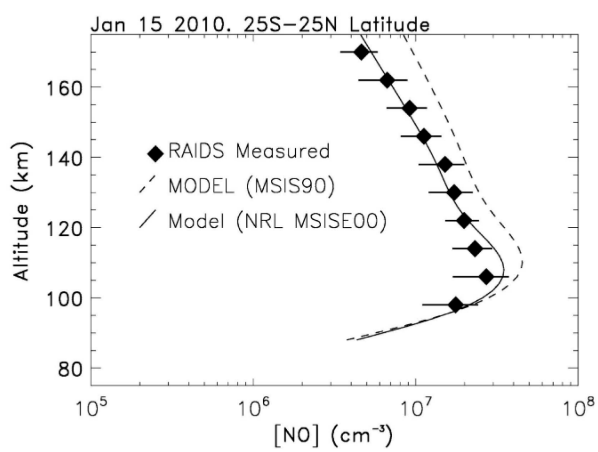

Figure 8: The NO profile of Jan 15 is fitted well using a 1-D chemistry model with composition provided by the NRLMSISE-00 empirical model.

Team News

Data Reduction and Distribution

We have successfully implemented mirrored RAIDS database systems at NRL and Aerospace. At the present time Level 0 HREP Health and Status data have been successfully ingested; Level 0 RAIDS science data has been partially ingested, and we are currently working on some software problems which have prevented certain days from loading. Unfortunately, at the present time we have no funds available for continued database development nor for making the RAIDS data publicly accessible over the internet.

Until data products are available from the database, an interim data reduction procedure has been standardized which generates limb scans, spectra, engineering data, and viewing geometry information and stores them as an IDL save set. Virginia Tech has successfully produced a number of these save set files and made them available to the Science Team via an FTP site.

Stellar Team Award

On April 30, 2010 the HICO-RAIDS Experiment Payload team received the Rotary National Award for Space Achievement Stellar Team Award. Led by Dr. Perry Ballard, Chief Engineer for the DoD Human Spaceflight Payloads Office in Houston, the international HREP team included the Department of State, the National Aeronautics and Space Administration, JAXA, NRL, The Aerospace Corporation, ONR, and the DoD STP. David Hess, Director, DoD Human Spaceflight Payloads, DoD Space Test Program (STP), and Dr. Ballard accepted the award on behalf of the HREP team. The award citation was for successful deployment of HREP, the first major Earth observing payload on the ISS and the first U.S. payload to fly on the Japanese Experiment Module Exposed Facility.

Figure 9: The Stellar Team Award trophy. (Photo courtesy of DoD STP)

Meetings

Recent:

- U*SAF Orbital Resources Ionosphere Conference*, Jan 12-14, 2010, Dayton, OH. (1 presentation)
- *American Meteorological Society, 90th Annual Meeting, Seventh Space Weather Symposium*, Jan 17-19, 2010, Atlanta, GA. (1 presentation)
- *Space Test Program, Space Experiments Review Board,* May 11, 2010, Arlington, VA. (1 presentation)
- *C/NOFS Workshop*, May 18-20, 2010, Breckenridge, CO (4 presentations)
- *Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) Workshop*, "Chemistry and Temperatures from the Upper Mesosphere to the Lower Thermosphere: Connecting satellite observations to ground-based measurement and model results", Jun 20-25, 2010. Boulder, CO (Workshop Session)

Upcoming:

- American Geophysical Union Fall Meeting, Dec 13-17, 2010, San Francisco, CA. (Special Session Proposed)

RAIDS Website and Wiki

We have a frequently-updated public website (https://raids.nrl.navy.mil/) with some information of a general nature about RAIDS. On this website is a "Team Member" area with restricted access for the RAIDS Instrument

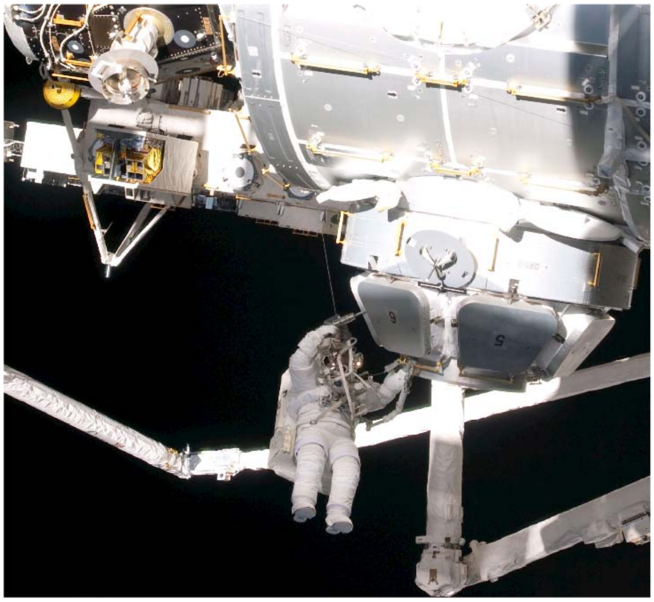

Figure 10: An astronaut works on cupola installation with HREP/RAIDS visible in the upper left. (Photo credit: NASA)

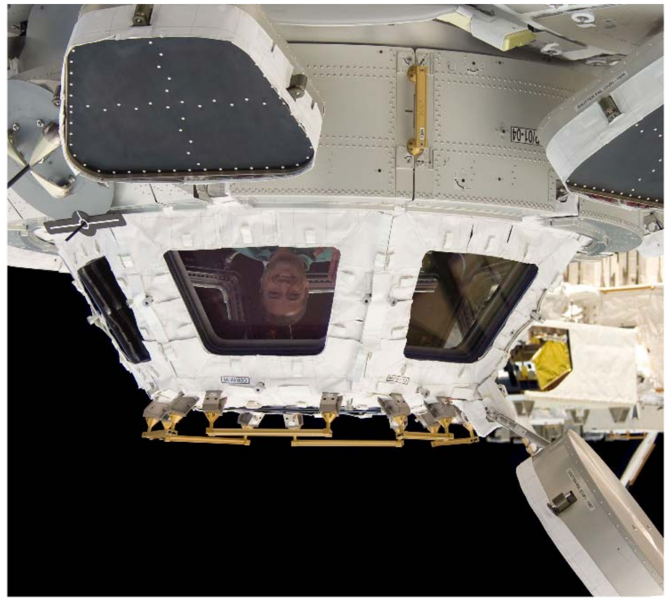

Figure 11: RAIDS stares down onto the disk in Sun-safe mode after cupola installation (Photo credit: NASA)

Team and RAIDS Science Team, including a Wiki. The Wiki includes a substantial amount of RAIDS documentation, papers, presentations, and mission operations information. Contact Scott Budzien for access.

New Team Members

Welcome to the following students who have joined the RAIDS Team!

- Cissi Lin, Virginia Tech (graduate student)
- Kenneth Bell, University of Maryland (NRL undergraduate intern)
- Ren Cashman, Boston University (graduate student)
- Ryan Agner, Embry Riddle Aeronautical University (graduate student)
- Kyle Jaffa, New Mexico Tech (undergraduate student)

RAIDS Instrument Team

Naval Research Lab, Washington, DC

- Scott Budzien, Principal Investigator
- Andy Stephan, Project Scientist
- Ken Wolfram, Electrical Engineer
- Don McMullin, System Engineer

The Aerospace Corporation, El Segundo, CA

- Rebecca Bishop, Aerospace Principal Investigator
- Andy Christensen, Senior Scientist
- Jim Hecht, Senior Scientist

RAIDS is a collaborative experiment built jointly by the NRL Space Science Division and The Aerospace Corporation. RAIDS/HICO is integrated and flown under the direction of DoD's Space Test Program. Support for RAIDS is provided by the Office of Naval Research and The Aerospace Corporation's Independent Research and Development program.