Design of an IR Ozone Retrieval Algorithm for NPOESS OMPS

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National Polar-orbiting Operational Environmental Satellite System

- Mission: Provide a national, operational, polar-orbiting, environmental remote-sensing capability
- Achieve cost-savings by merging the US operational weather satellite programs
  - Department of Defense and NOAA/Department of Commerce
  - Created "IPO" (Integrated Program Office)
- Competition for each of the sensor systems, and for the overall system responsibility
  - Redesign operational sensors to upgrade capabilities
  - Incorporate new technologies from NASA
- Shared System Performance Responsibility (SSPR)
  - Awarded to Northrop-Grumman (NGST); complete system integration (all sensors and algorithms)
- Program extends through 2018 with initial launch date of 2009

This Poster Focuses on OMPS and CrIS Ozone

- Ozone Mapping and Profiler Suite (OMPS)
  - Ball Aerospace team awarded contract May 1999
    - System management and sensor fabrication: Ball
    - UV/Vis/NIR algorithms: Raytheon (formerly Hughes STX)
    - IR algorithms: AER
    - Consultants: Don Heath (RSI), Kelly Chance (HS), Jim Russell (HU), Dave Flittner (UA)
  - Critical design review (CDR) completed
    - Sensor CDR in March 2002
    - Nadir algorithm CDR (IR and UV algorithms) in December 2002
    - Limb algorithm CDR in August 2003
- Cross-Track Infrared Sounder (CrIS)
  - ITT team awarded contract August 1999
    - AER, Boeing, Bomem (Quebec City), Ball
      - AER to provide Environmental Data Record (EDR) algorithms

Other NPOESS Sensors

- Advanced Technology Microwave Sounder (ATMS)
  - Provides AMSU-A/B and MHS capability
  - First-guess microwave for CrIS EDR algorithm
- Visible Infrared Imager/Radiometer Suite (VIIRS)
  - Will combine the radiometric accuracy of the Advanced Very High Resolution Radiometer (AVHRR) currently flown on the NOAA polar orbiters with the high (0.65 kilometer) spatial resolution of the Operational Linescan System (OLS) flown on DMSP
- Conical-Scanning Microwave Imager/Sounder (CMIS)
  - Similar to SSMI and SSMI/S
- Space Environmental Sensor Suite (SESS)
  - Multiple sensors to measure auroral characteristics, geomagnetic field, electron density profile, and total electron content
- Global Positioning System Occultation Sensor (GPSOS)
  - Multiple GPS receivers to measure electron density profile

OMPS System Architecture Derived from Data Requirements

- Ozone Environmental Data Record (EDR):
  - Total column: 24 hour revisit
  - Profile (tropopause-60 km): vertical resolution £ 5 km, 7 day revisit
  - Threshold coverage: £ 80 degree solar zenith angle
    - Objective: global coverage
- OMPS architecture: nadir sensor and limb sensor measure spectrum of backscattered / limb-scattered solar radiation
  - Nadir sensor: common telescope feeds two spectrometers
    - Total column spectrometer: 300-380 nm, 110 degree cross-track FOV
    - Nadir profile spectrometer: 250-310 nm, 16.7 degree cross-track FOV
  - Limb sensor: provides required vertical resolution
    - 290-1000 nm spectrometer fed by 3 vertical 2.3 deg FOVs (separated by 250 km at limb)
  - Each spectrometer registers the spectrum on a CCD
  - Long-term stability maintained on-orbit by use of solar diffusers

CrIS Ozone Emission Data Complements Core OMPS Capabilities

- Use of UV nadir sensor provides traceability to heritage data
  - Heritage: BUV, SBUV, TOMS, SBUV/2, GOME
  - TOMS v7 algorithm adapted to meet NPOESS threshold requirements
  - SBUV v6 algorithm adopted for nadir profile retrievals
- Solar scattering basis for UV/Vis/NIR limb sensor reduces systematic uncertainties in comparison with nadir data
  - Similar physics and calibration techniques
  - SOLSE/LORE algorithm adapted to meet NPOESS threshold requirements
- IR algorithm development by Ball team (AER) for retrieval of ozone from CrIS 9.6 micron radiances
  - Total column retrieved for all CrIS FOVs
  - Development focuses on polar nights in order to meet global coverage objective
    - Will also be effective in South Atlantic Anomaly (SAA) where high proton fluxes degrade the performance of the UV detectors (CCDs)

Algorithm Design Meets Strict Processing Requirements

- NPOESS requirement: demonstrate that algorithms can meet the requirements imposed by operational processing
  - Requirement: 20 minutes to process 1 orbit of data from raw data records (RDRs) through EDR output
    - Allow ~16 minutes for EDR algorithm
    - ~205,000 FOV per orbit requires processing ~214 retrievals/second

AER OMPS Responsibility: Use of CrIS for Ozone Sounding

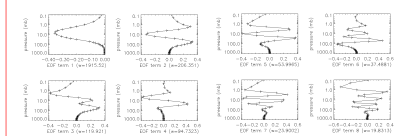
- CrIS EDRs:
  - Temperature profile, surface to 0.01 mb
    - Measurement uncertainty better than 1.5 K up to 1 mb
  - Moisture profile, surface to 100 mb
    - Measurement uncertainty better than 20% up to 300 mb
  - Pressure profile (derived)
- Sensor configuration
  - Cross-track scan with 3x3 array of ~14 km nadir FOV
  - 3 spectral bands
    - 650 - 1095 cm^{-1} @ 0.625 cm^{-1}
    - 1210 - 1750 cm^{-1} @ 1.25 cm^{-1}
    - 2155 - 2550 cm^{-1} @ 2.5 cm^{-1}
- Ozone derived from calibrated and geolocated spectral radiances in 950-1095 cm^{-1} band

OMPS-IR Algorithm Improves Upon Heritage Techniques

- Merges established techniques with state-of-art forward model
  - OSS forward model provides high accuracy with minimal computation
  - Retrieval performed using optimal estimation algorithm (e.g. Rodgers) using empirical orthogonal functions (EOFs) to improve retrieval stability
- Use CrIS EDRs (T, H_2O profiles) as first-guess for ozone retrieval
  - OMPS-IR algorithm will retrieve O3, T, H2O, and surface/cloud parameters using only the 950-1095 cm^{-1} CrIS channels
  - Savings of over 50% in processing time compared to full-band retrieval
    - Current timing 6400 retrievals in ~2.23 hours (~0.79 retrievals/second) with maximum 4 iterations per retrieval
    - I/O not optimized (time includes OSS initialization)
- Graceful degradation approach to processing
  - Will revert to NWP/climatology input if CrIS EDRs unavailable (assumes calibrated and geolocated spectral radiances available)

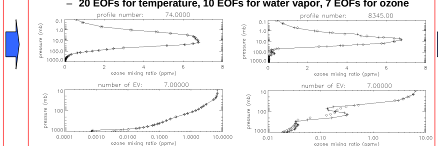
Ozone Retrieval Performed with EOFs to Reduce Instability

- Transformation from geophysical parameters into EOFs: first EOF is mean profile shape, subsequent EOFs provide more structure



EOF Representation Error

- Optimal number of EOFs depends on amount of representation error allowed, as well as the information content of the radiometric data
  - 20 EOFs for temperature, 10 EOFs for water vapor, 7 EOFs for ozone



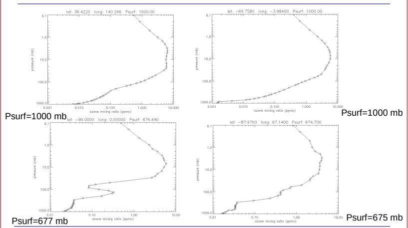
384 DU, 0.5 DU representation error

180 DU, 10 DU representation error

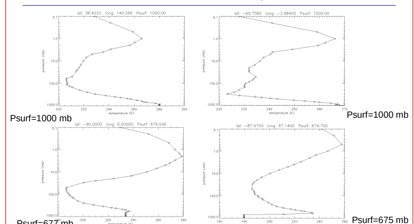
Databases for Algorithm Testing Must Capture Variability

- NOAA88 data supplied by IPO (8344 profiles)
  - Collection of temperature and moisture profiles used for testing of advanced sounder concepts
  - Includes nominal set of ozone profiles
    - Little variability and very few stressing profiles
- "AER Polar" data (120 profiles)
  - Merging of SAGE-2 and ozonesonde data with AER 2-d model output to provide robust set of temperature, water vapor, and ozone profiles
  - Selected only ozone-hole cases from October 1998
- "AER POAM" data (409 profiles)
  - Merging of POAM and ozonesonde data similar to "AER Polar"
    - Data provided by Eric Shettle and John Hornstein
    - Co-location to within ±15 hours
  - South Pole cases for Sept 1998, Mar & Sept 1999, Mar & Sept 2000
- AER database development emphasizes polar scenes

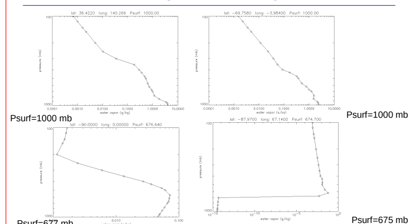
Database Contains Polar and Ozone-hole Profiles



Temperature Profiles Exhibit Global Variability



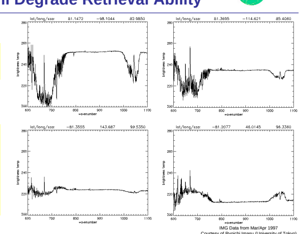
Water Vapor Profiles Range Exhibit Wide Range of Variability



Reduction in Radiometric Contrast Will Degrade Retrieval Ability

Scene variation between 83 deg and 100 deg SZA

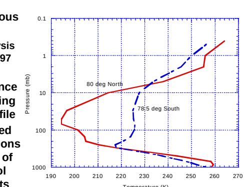
Decrease in contrast can occur due to shape of temperature profile or presence of clouds



IMG Data from March 1997
Courtesy of Ryoichi Imasu (University of Tokyo)

Temperature Profile Useful for Understanding Radiance Characteristics

- Corresponds to IMG measurements in previous slide
  - Data from NDSC analysis files from 22 March 1997
- A cloud at 200 mb will result in different radiance characteristics depending on the temperature profile
- Algorithm must be tested under stressing conditions to ensure development of adequate quality control for the retrieval products



Conclusions

- NPOESS will provide high-quality, high-spatial resolution total column ozone under Polar night conditions
- Clear sky retrieval simulations indicate ability to meet or exceed requirements under most conditions
  - Some cold, dry Polar profiles cause problems, and Q/C routines have been developed to flag these cases
- Implementation of cloudy retrieval capability nearly complete
  - Adopted cloud-clearing approach to treating these cases
  - Most stressing cases will be low clouds/ice fog
- Upcoming milestones
  - First test of algorithms will be using data from AIRS
  - NPP flight of CrIS in 2005
    - Platform for testing sensor and algorithms prior to operational use

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