6th Annual Symposium on Future National Operational Environmental Satellite Systems-NPOESS and GOES-R
Session 9 Calibration and Validation Plans for NPP/NPOESS and GOES-R - II

ORAL: NPOESS Preparatory Project Validation Program for the Ozone Mapping and Profiler Suite (OMPS)

L.E. Flynn, D. F. Rault, S. Janz, I. Petropavlovskikh, C. S. Long, S. K. Yang, and S. Farrow

Objectives: Provide an overview of the collaborative data, techniques, and team for the validation of the NPP OMPS environmental data products.

Pre-Launch Phase (L-24M to L)

- Improve Ground-based assets operations and access
- Develop Match-up and statistical analysis tools and readers
- Implement and exercise forward models for radiative transfer
- Create and manipulate sample, synthetic, and proxy SDR (Level 1), EDR DIP (Level 2) data sets
- Collect and exercise calibration parameters
- Implement alternative/heritage algorithms

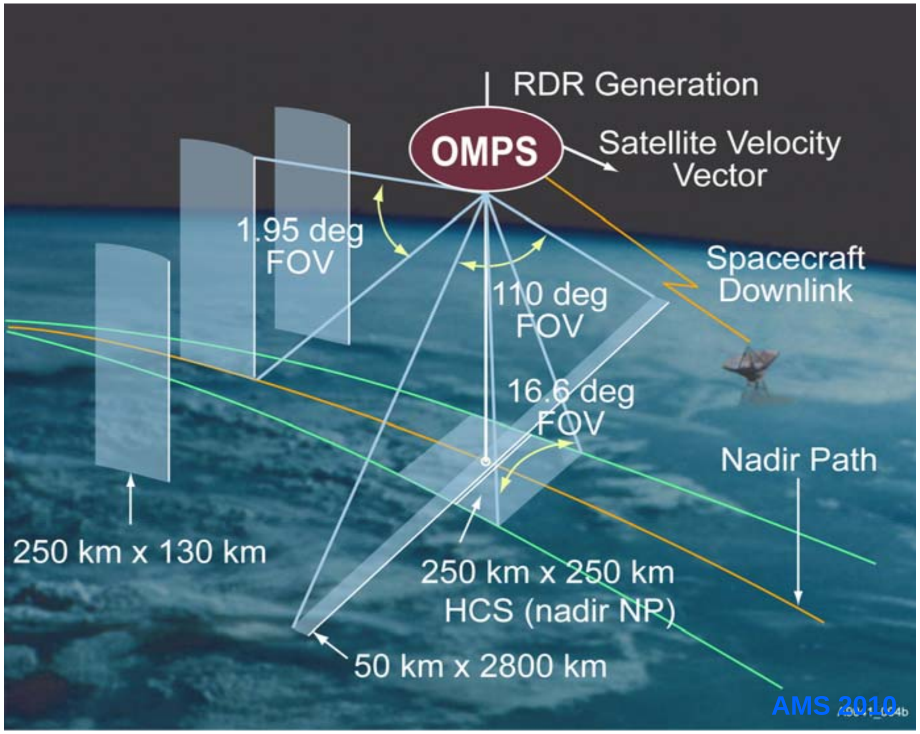
Early Orbit Check Out Phase (L to L+3M)

- Check parameters and instrument behavior
- Perform internal consistency checks
- Provide feedback to SDR Team
- Test tools and alternate algorithms with real data

Intensive Cal/Val Phase (L+3M to L+24M)

- Perform external comparisons to satellite products
- Perform sub-orbital comparison/validation
- Provide feedback to IPO and NGAS
- Evaluate product applications
- Begin trending and automated monitoring

Transition to regular operations & long-term monitoring



NPOESS Preparatory Project Validation Program for the Ozone Mapping and Profiler Suite

AMS 6th Annual Symposium on Future National Operational Environmental Satellite Systems-NPOESS and GOES-R
Session 9: Calibration and Validation Plans for NPP/NPOESS and GOES-R

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C. Long, S. Yang, and E. Beach
January 21, 2010
***NOAA/NESDIS/STAR**

Related Posters: #344, #345, #361, #362, and #379

Abstract

- The National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Program Office (IPO), in partnership with National Aeronautical Space Administration (NASA), will launch the NPOESS Preparatory Project (NPP), a risk reduction and data continuity mission, prior to the first operational NPOESS launch. The NPOESS Program, in partnership with Northrop Grumman Aerospace Systems (NGAS), will execute the NPP Calibration and Validation (Cal/Val) program to ensure the data products comply with the requirements of the sponsoring agencies. The Ozone Mapping and Profiler Suite (OMPS) consists of two telescopes feeding three detectors measuring solar radiance scattered by the Earth's atmosphere and solar irradiance by using diffusers. The measurements are used to generate estimates of total column ozone and vertical ozone profiles. The validation efforts will make use of external resources in the form of ground-based and satellite measurements for comparisons and internal consistency methods developed over the last thirty years. This presentation provides an overview of the collaborative data, techniques, and team for the validation of the NPP OMPS environmental data products.

Outline

- Short instrument/product overview
- Cal/Val Team and Others
- Cal/Val Plan Outline
- Progressive Analysis
  - In-orbit doors closed
  - First light solar
  - Earth-view
    - Orbit
    - Day
    - Week
    - Month
    - Year

OMPS
Instrument Design

Nadir Mapper

UV Backscatter, grating spectrometer, 2-D CCD

TOMS, SBUV(/2), GOME(-2), OMI

110 deg. cross track, 300 to 380 nm spectral, 1.1nm FWHM bandpass

Total Column Ozone, UV Effective Reflectivity, and Aerosol Index Daily Maps

Nadir Profiler

UV Backscatter, grating spectrometer, 2-D CCD

SBUV(/2), GOME(-2), OMI

Nadir view, 250 km cross track, 270 to 310 nm spectral, 1.1 nm FWHM bandpass

Ozone Vertical Profile, 7 to 10 KM resolution

Limb Profiler

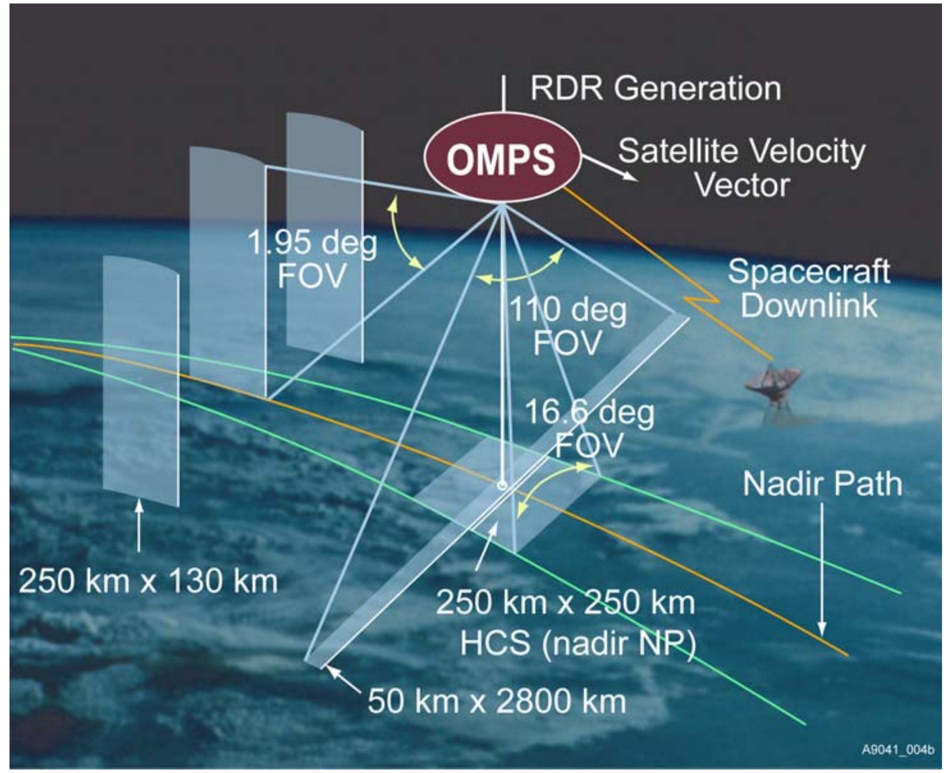
UV/Visible Limb Scatter, prism, 2-D CCD array

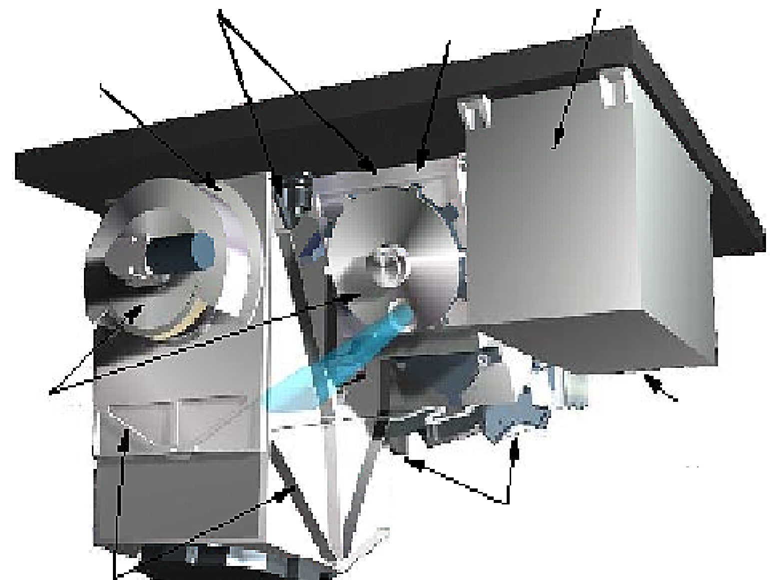
SOLSE/LORE, OSIRIS, SAGE III, SCIAMACHY

Three 100-KM vertical slits, 290 to 1000 nm spectral

Ozone Vertical Profile, 3 KM vertical resolution

The calibration concepts use working and reference solar diffusers.





Instrument and FOV Graphics from BATC

Ozone Calibration and Validation Team Members' Roles & Responsibilities

Area	Name	Organization	Funding Agency	Task
Validation and Comparisons	L. Flynn	NOAA/NESDIS	IPO	Internal and Satellites
Ground-based Data	I. Petropav-lovskikh	NOAA/ESRL	IPO	Dobson and Umkehr
Applications	C. Long J. Hornstein	NOAA/NCEP NRL	IPO/JCSDA NRL/IPO	Assimilation Trajectory
Limb	D. Rault	NASA LaRC	NASA NPP	R&D
Climate	R. McPeters L. Flynn	NASA GSFC NOAA/NESDIS	NASA NOAA/NCDC	CDR & Reprocessing
Instrument	S. Janz B. Sen	NASA GSFC NGAS	NASA/IPO IPO	RDR and SDR

Schedule of Major Task Categories

- Pre-Launch Phase (L-24M to L)
  - Improve Ground-based assets operations and access
  - Develop Match-up and statistical analysis tools and readers
  - Implement and exercise forward models for radiative transfer
  - Create and manipulate sample, synthetic, and proxy SDR (Level 1), EDR (Level 2), and DIP data sets
  - Collect and exercise calibration parameters and instrument models
  - Implement alternative/heritage algorithms
- Early Orbit Check Out Phase (L to L+3M)
  - Check parameters and instrument behavior
  - Perform internal consistency checks
  - Provide feedback to SDR Team
  - Test tools and alternate algorithms with real data
- Intensive Cal/Val Phase (L+3M to L+24M)
  - Perform external comparisons to satellite products
  - Perform sub-orbital comparison/validation
  - Provide feedback to IPO and NGAS
  - Evaluate product applications
  - Begin trending and automated monitoring
- Transition to regular operations and long-term monitoring

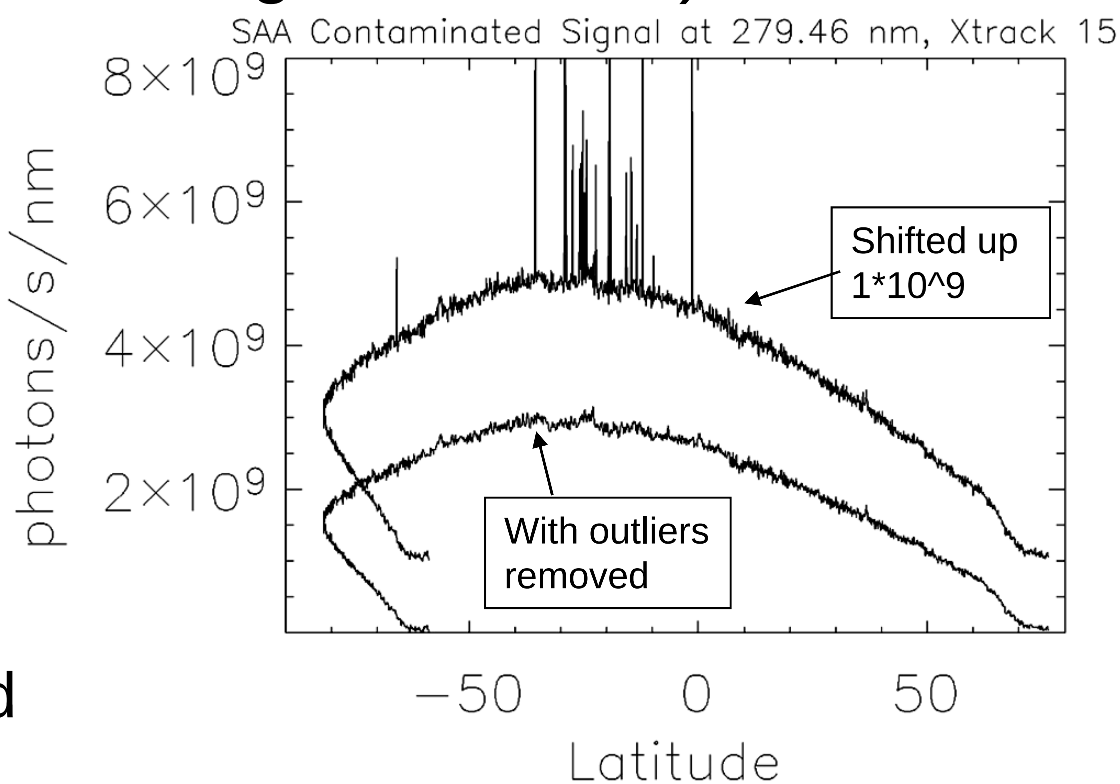
How much data do you need? What can it tell you? How can you accentuate different effects?

- Internal Measurements
  - Dark Current and non-Linearity estimates, and Charged Particle effects
- Single set of Solar measurements
  - Goniometry, Irradiance Calibration, Wavelength Scale, SNR, Flat Fielding, Bandpass check (Comparisons to reference, contemporaneous, and high-resolution spectra)
- Single Orbit of Earth-view data
  - Wavelength Scale variations, SNR, Rough Radiance/Irradiance Calibration, Triplet/Pair consistency (Absorbing, reflectivity, and aerosol channels), Cross-track consistency
- Single Day
  - Total Ozone versus other mappers, Zonal Means, Stray Light (Profile Wavelengths), better orbital analysis, and start of performance monitoring
- Single Week
  - Cross-track consistency, Absolute calibration of reflectivity channels, calibration biases compared to other space-based mappers and profilers – transfer, and better daily analysis.
- Single Month
  - Ground based total ozone validation data points (assisted by transfer), Starting points for trending of instrument degradation and solar diffuser changes, and better weekly analysis – trending of consistency results.
- Single Year
  - Ground-based ozone profile validation, evaluation of long-term characterization, better monthly analysis, and start of ice radiance trending.

Internal Instrument Measurements

Even before the instrument is open to external light, the SDR Team will be making measurements of Dark Current and of Linearity (by using an on-board LED and variable integration times).

We will also be able to investigate Charged Particle effects in the South Atlantic Anomaly. These are of concern for the OMPS Nadir Profiler. The Figure to the Right shows SAA contamination of OMI measurements and the results of a nearest-neighbor filtering program.



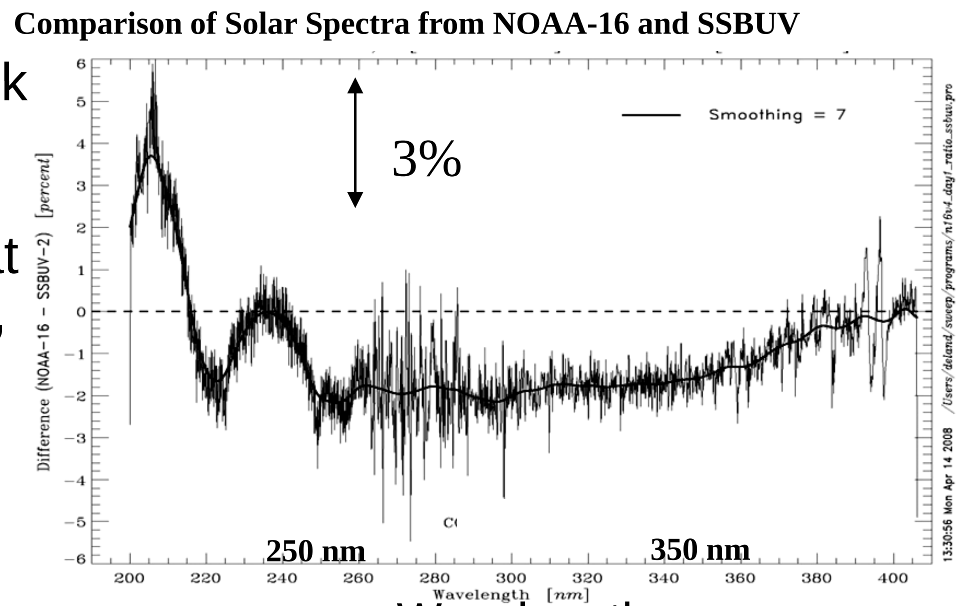
Outliers are identified by spectral, spatial, and temporal comparisons to nearest neighbors.

First Solar Measurements

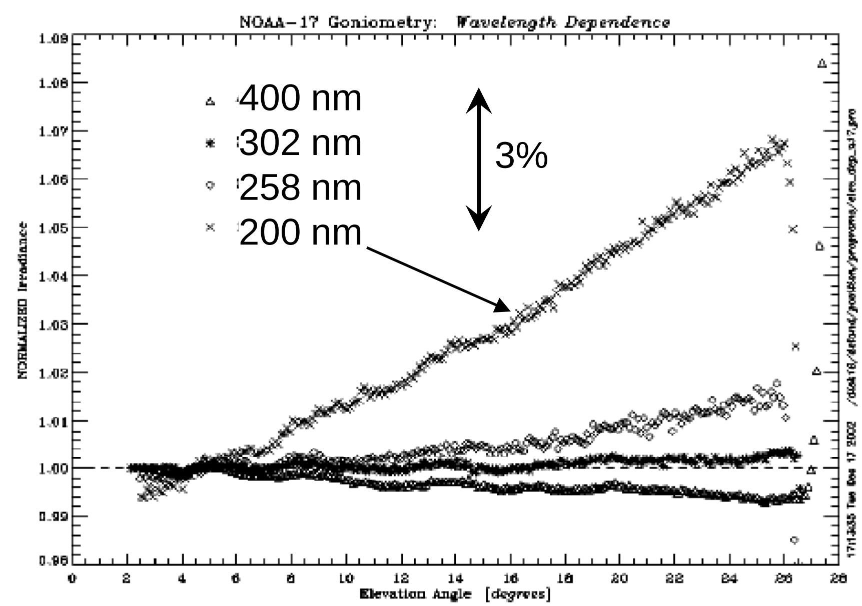
The first set of solar diffuser measurements will be used to check the Irradiance Calibration, Wavelength Scale, Goniometry Models, Signal-to-Noise Ratios, Flat Fielding/Pixel Response Uniformity, and Bandpass.

The top figure on the right shows the relative difference between a NOAA-16 SBUV/2 solar spectrum and an SSBUV reference spectrum.

The lower figure shows the changes in a set of solar diffuser measurements for NOAA-17 SBUV/2 as the solar angle varies from a reference elevation angle of 4 degrees. Since solar variations over the ten-minute measurement period are negligible, these changes are due to inaccurate goniometric corrections.



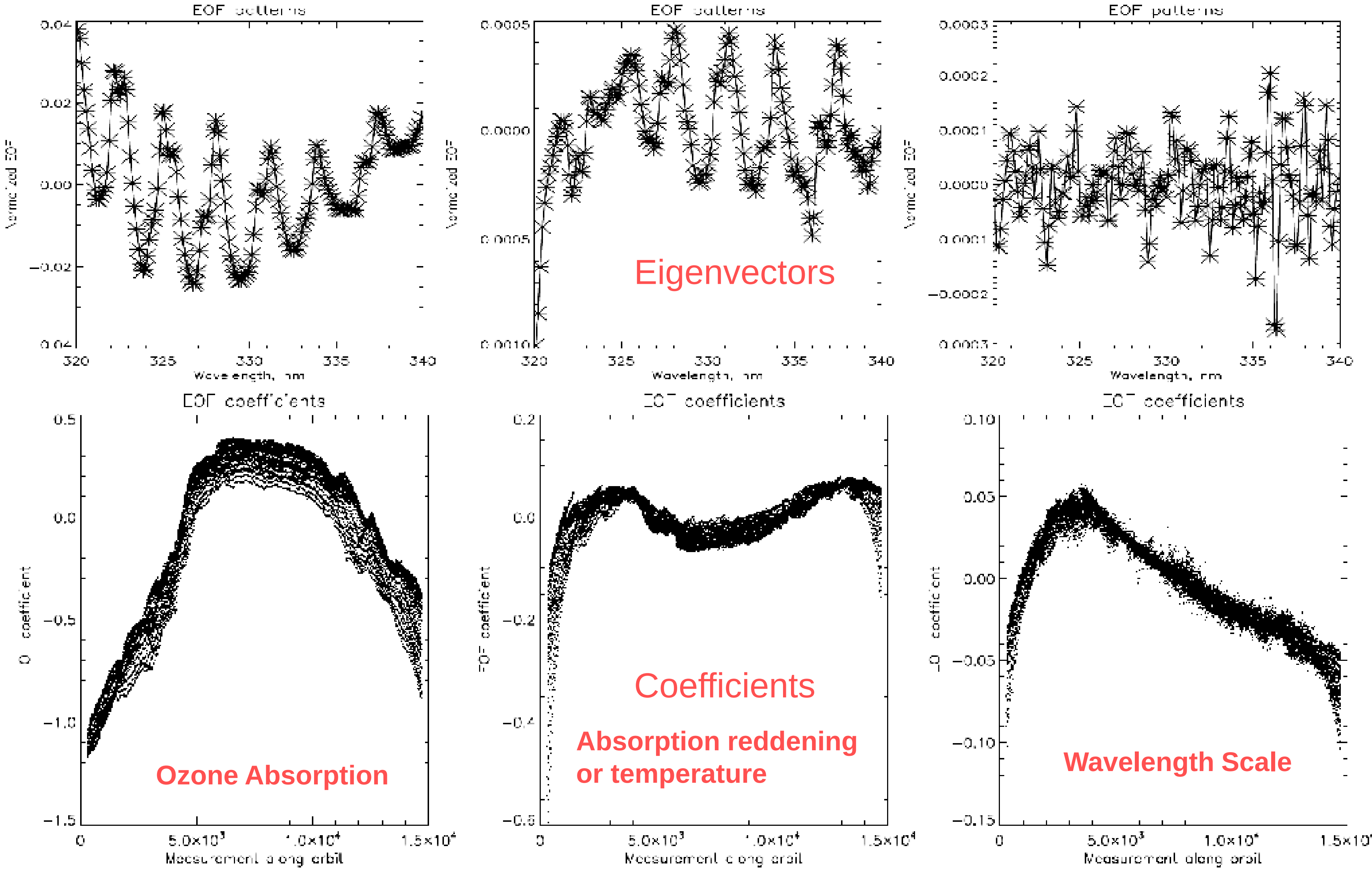
Wavelength



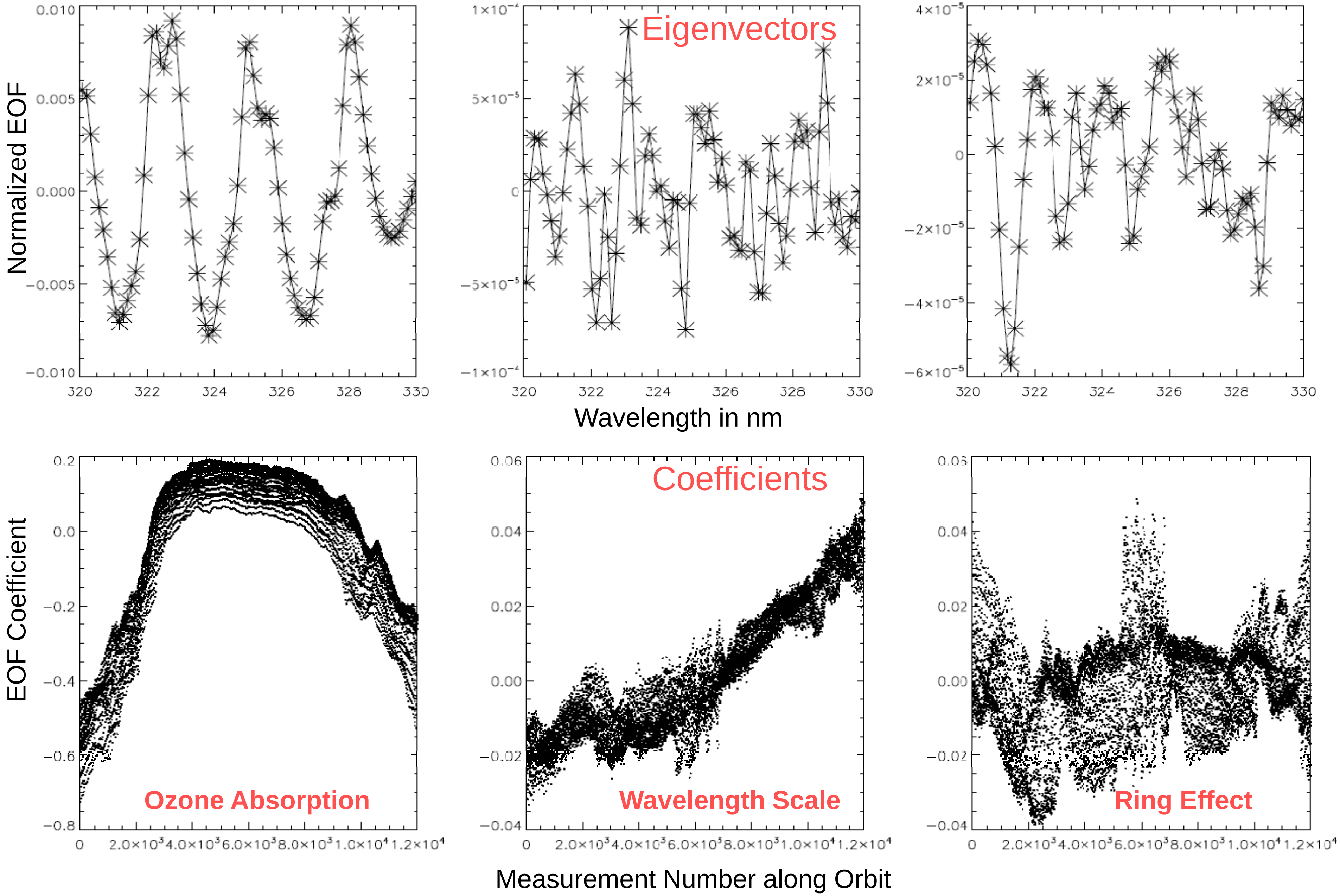
Figures from M. DeLand and L-K Huang of SSAI, Lanham MD.

Solar Elevation Angle, Degrees

Empirical Orthogonal Function Analysis of the Covariance Matrix
for a Single Orbit of GOME-2 Earth-view data



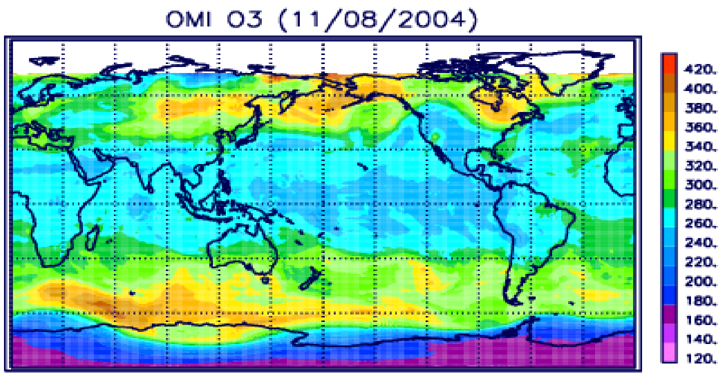
Empirical Orthogonal Function Analysis of the Covariance Matrix for a One Orbit of GOME-2 Earth-view data

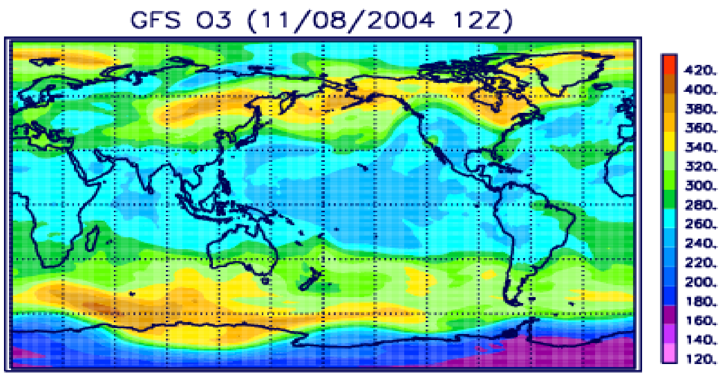


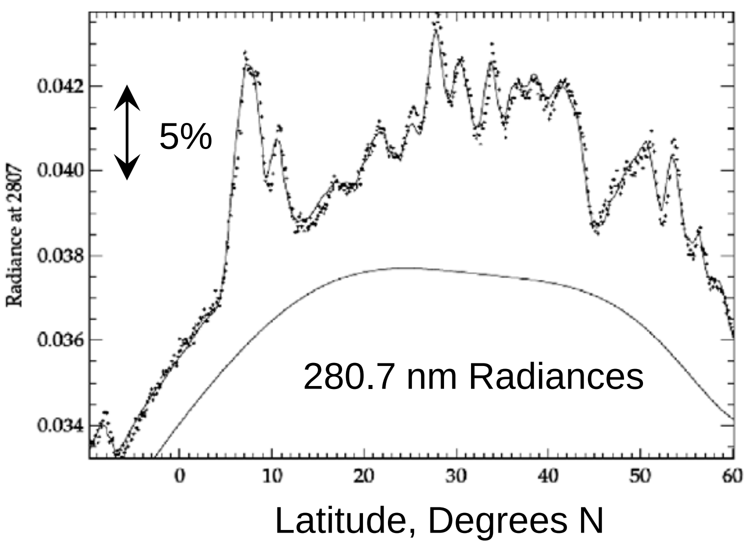
One day of data can be used to compare total ozone maps between two satellite instruments or with an assimilation product. The top two figures to the left give an example for EOS Aura OMI versus the Global Forecast System maps for a day.

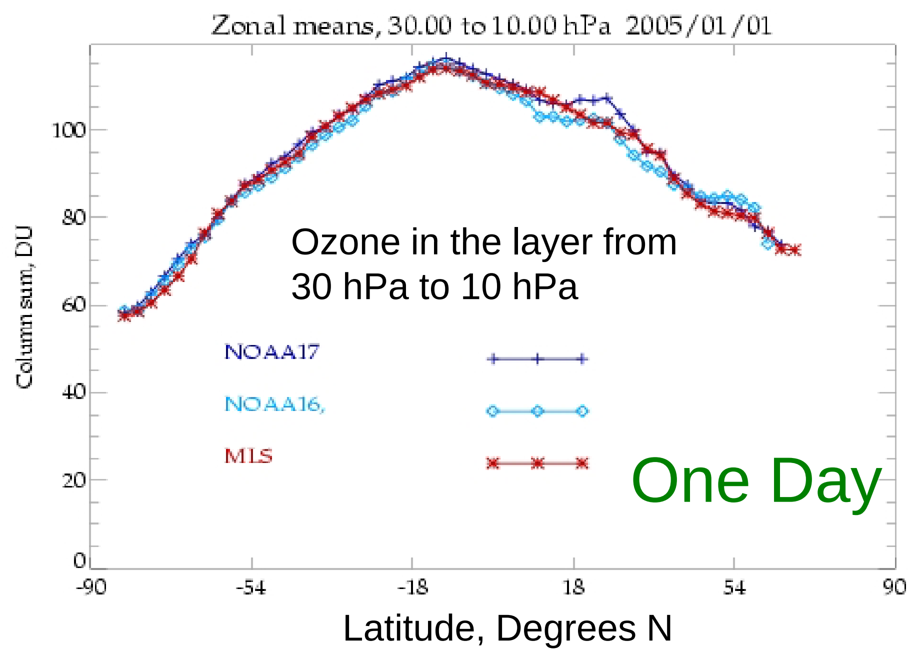
One day of OMPS Nadir Profiler measurements can be used to characterize stray light. The results for a simple one-channel source for a day of SBUV/2 data is shown in the figure on the lower left, that is, measurements with stray light over an orbit of position mode data for 280.7 nm for the SBUV/2 are compared to a model using scaled variations of the Photometer measurements at 380 nm. The solid line is the 280.7 nm data and the dots are the model.

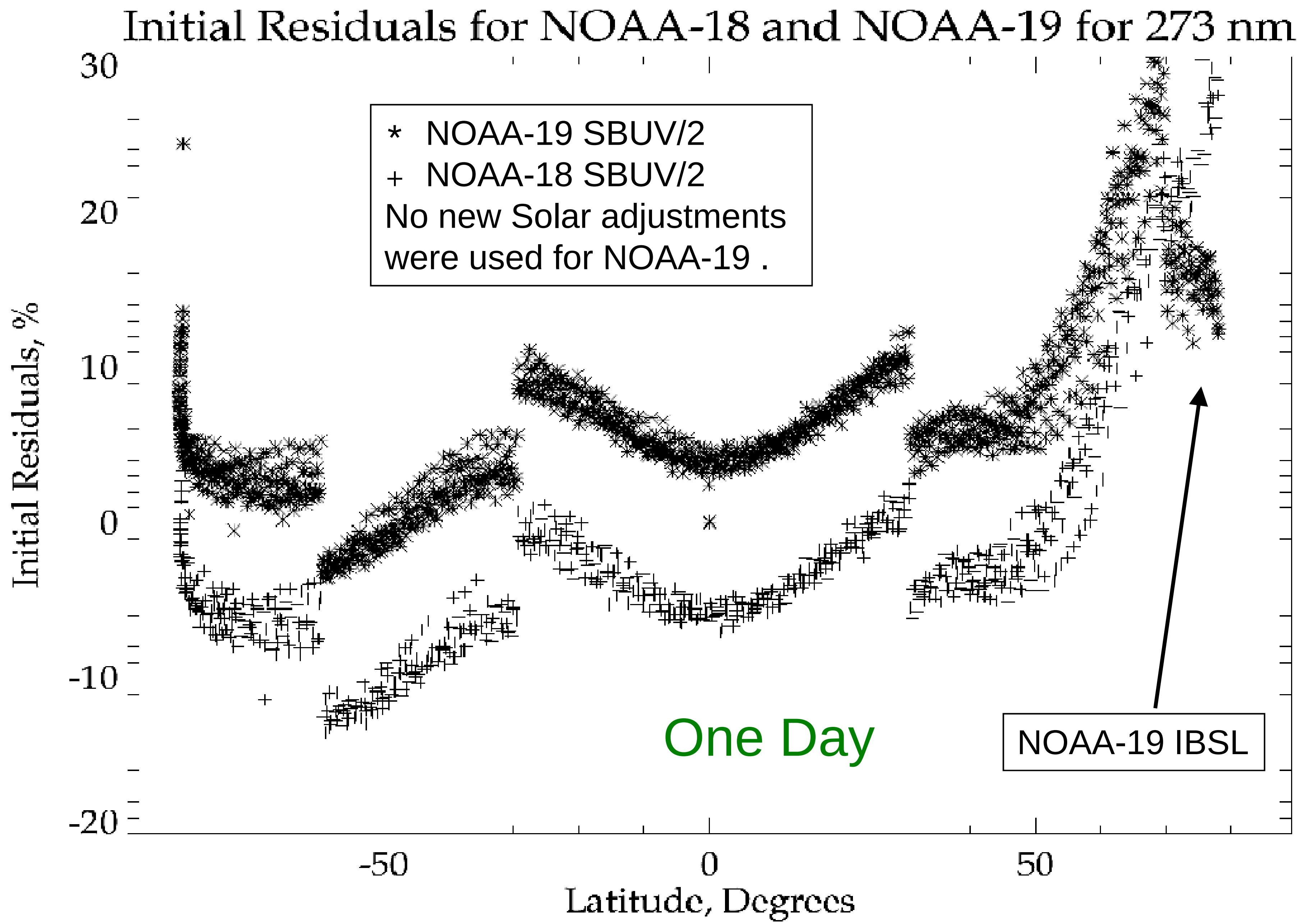
The final figure compares one day of zonal mean ozone profile estimates for NOAA-17 and NOAA-16 SBUV/2 with those from EOS Aura MLS.



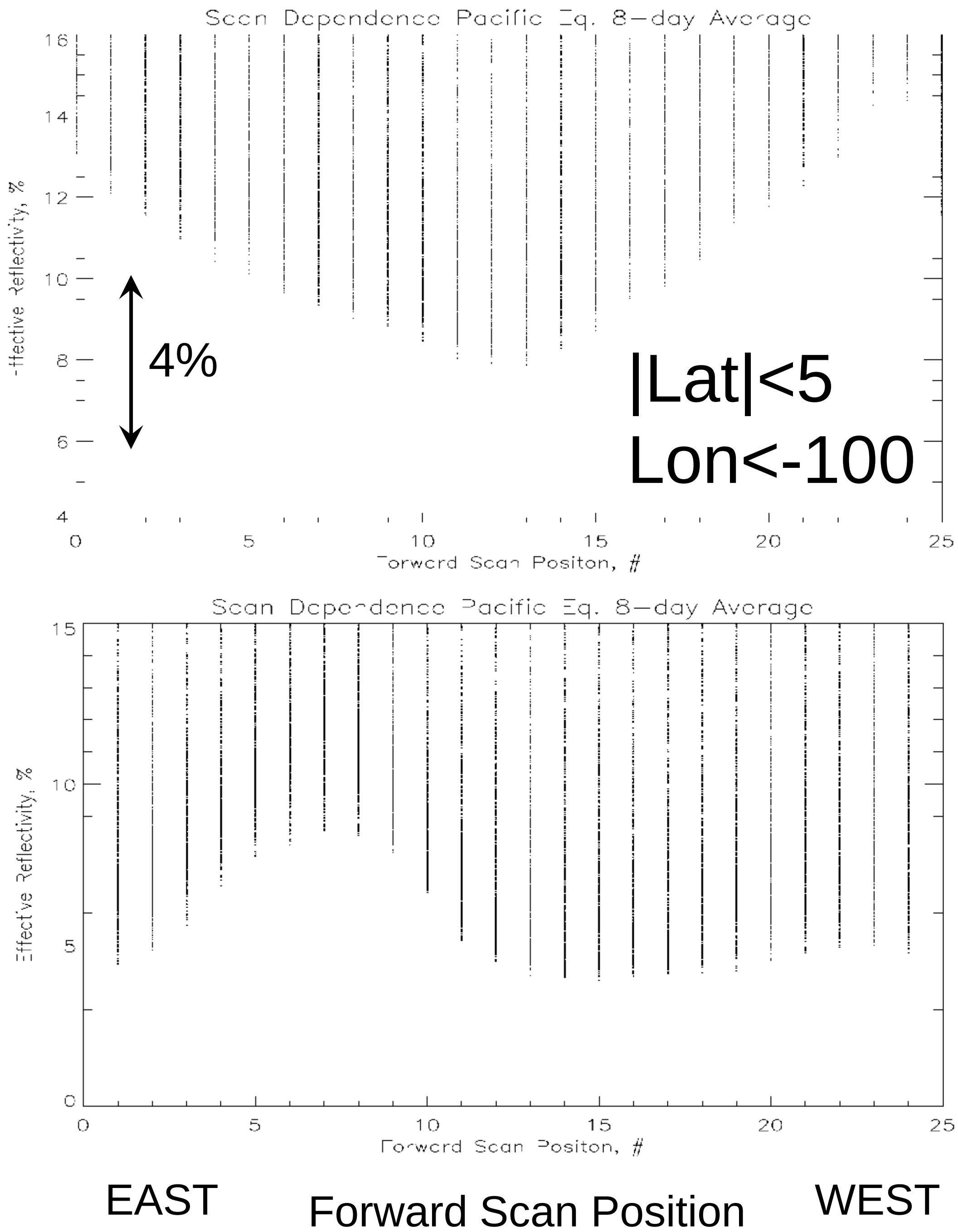








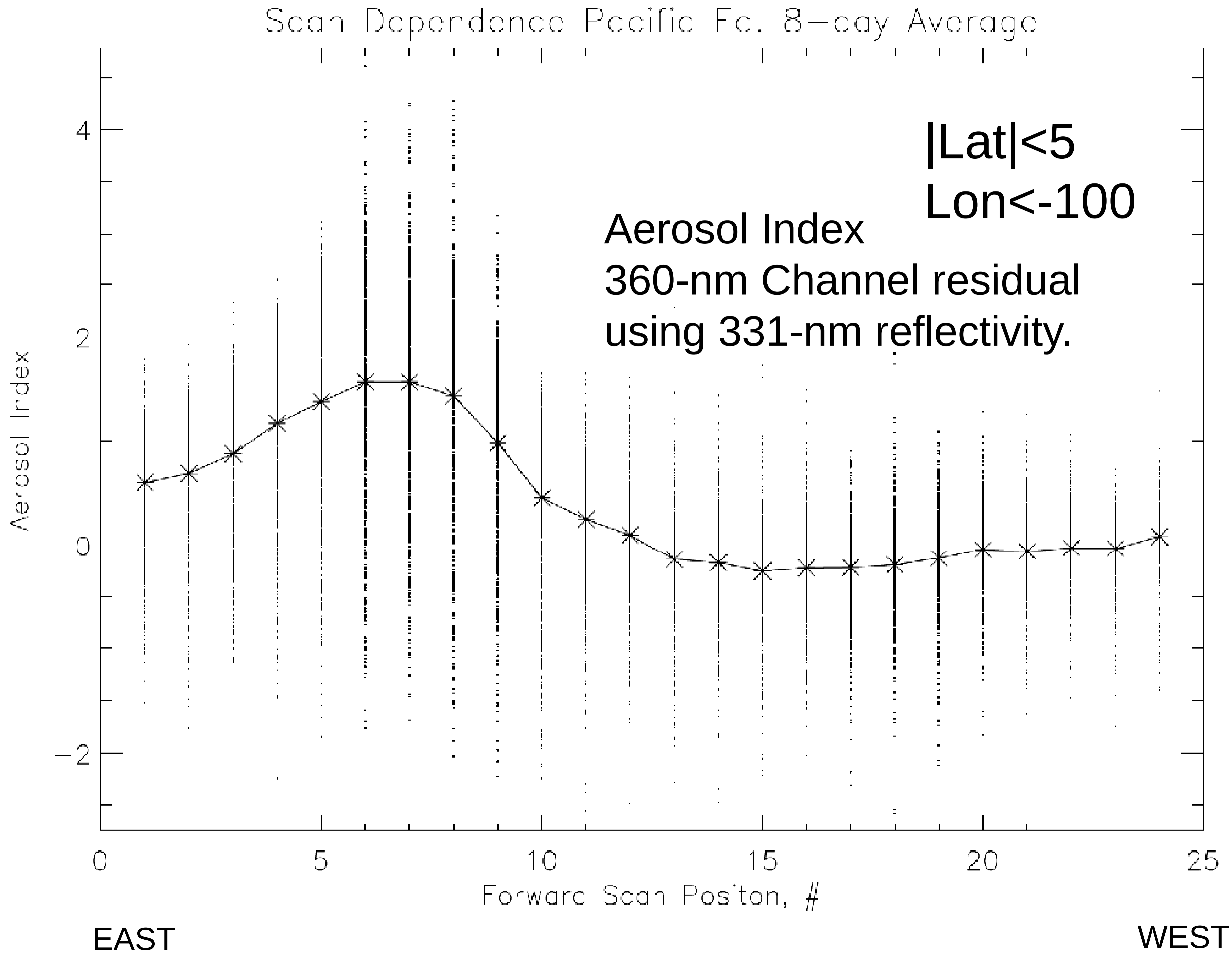
Initial Residuals for NOAA-18 and NOAA-19 for 273 nm
* NOAA-19 SBUV/2
+ NOAA-18 SBUV/2
No new Solar adjustments were used for NOAA-19 .
One Day
NOAA-19 IBSL
Initial Residuals, %
30
20
10
0
-10
-20
-50
0
50
Latitude, Degrees



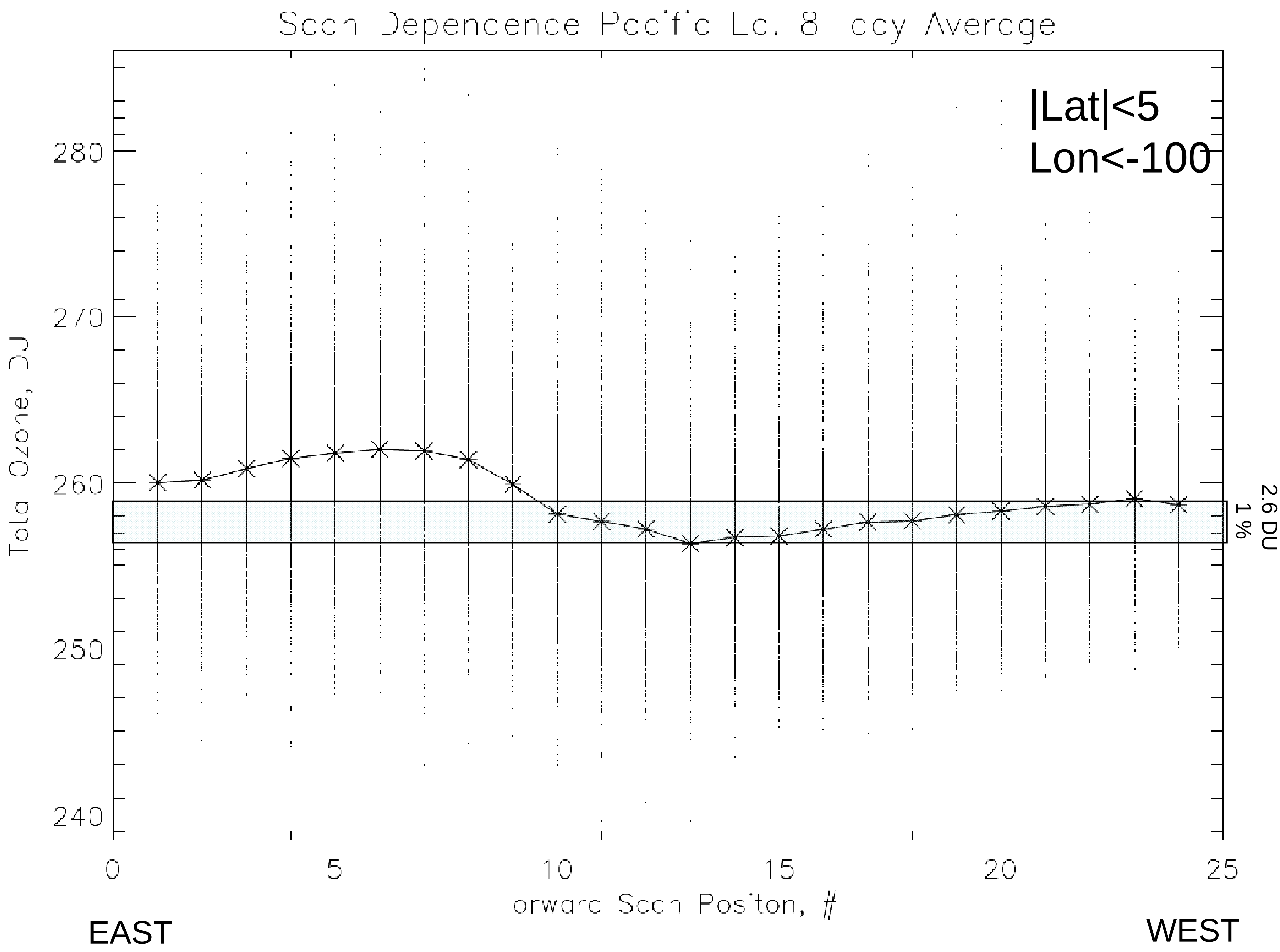
GOME-2 Version 8 331-nm Effective Reflectivity for a box in the Equatorial Pacific for eight days plotted versus satellite viewing angle positions.

The unadjusted values in the top plot reach a minimum of 8% (higher than expected for the open ocean) for the Nadir scan position.

A single calibration adjustment lowers this value to 4% and also flattens out the scan dependence for West-viewing positions. The East-viewing results are not as good probably due to sun glint.

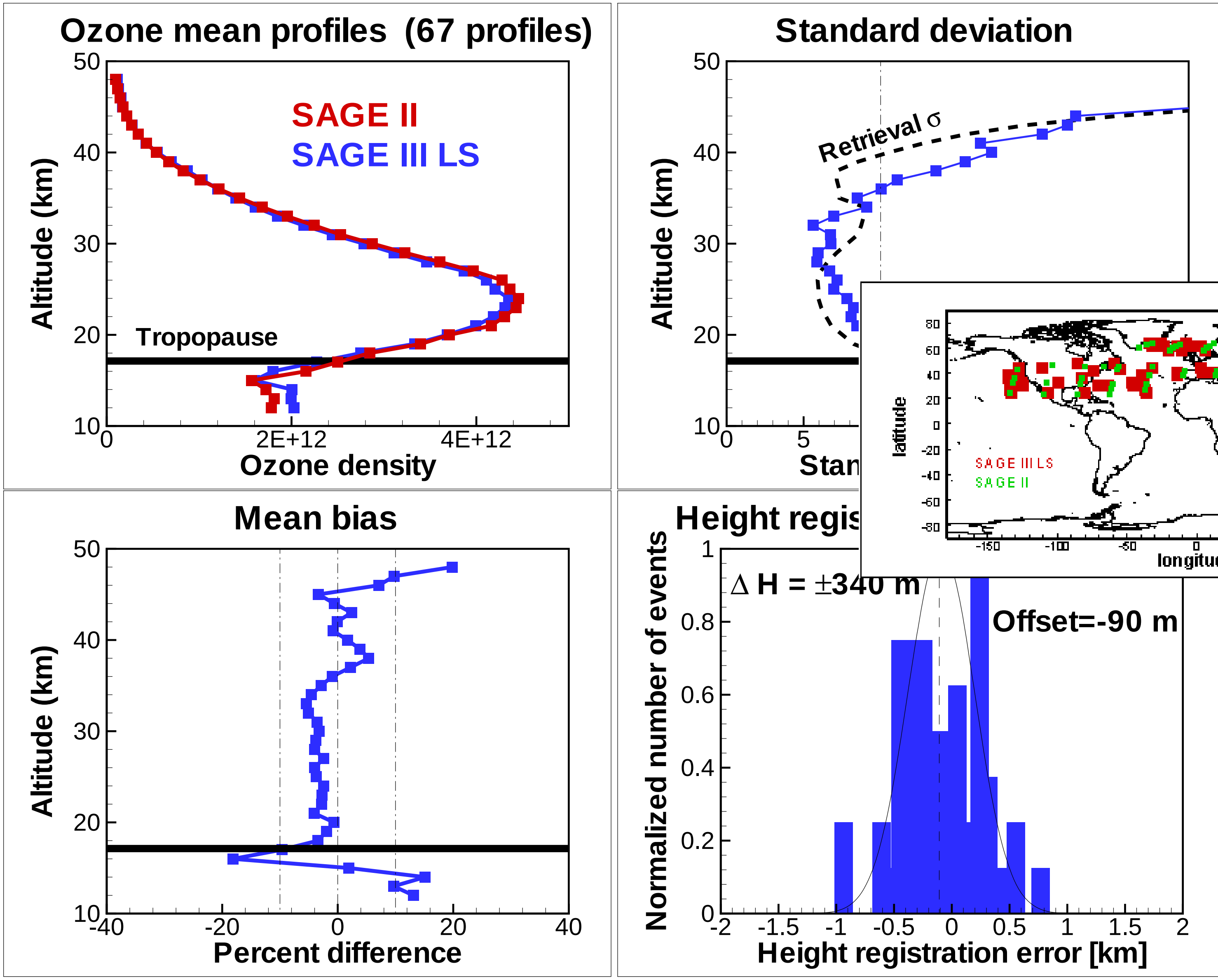


Scan Dependence Pacific Fc. 8-cay Average
|Lat|<5
Lon<-100
Aerosol Index
360-nm Channel residual
using 331-nm reflectivity.
Aerosol Index
4
2
0
−2
0
5
10
15
20
25
Forward Scan Position, #
EAST
WEST



Scan Dependence Pacific La. 8 day Average
|Lat|<5
Lon<-100
280
270
260
250
240
Total Ozone, DU
0
5
10
15
20
25
Forward Scan Position, #
2.6 DU
1 %
EAST
WEST

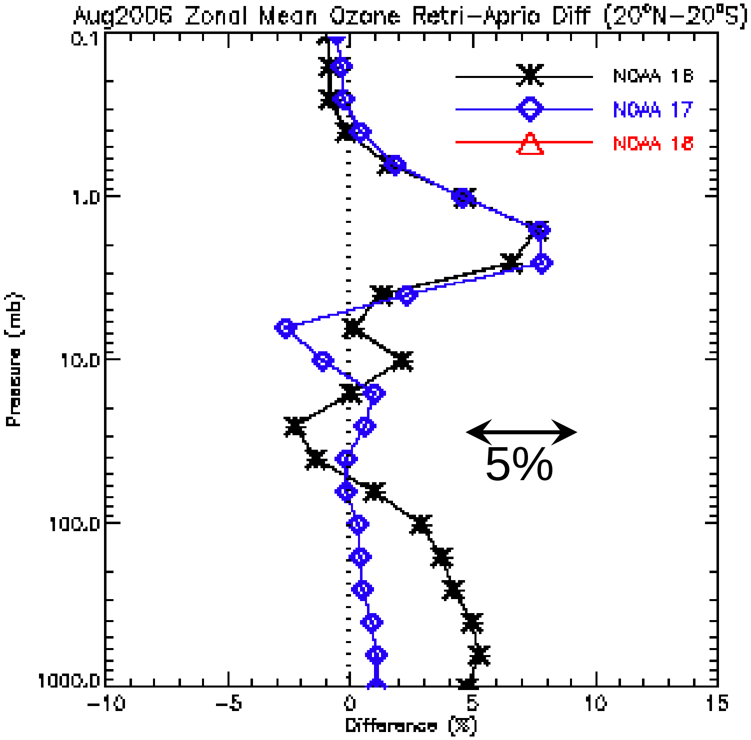
Comparison SAGE III LS versus SAGE II



Validation of the OMPS Limb Profiler ozone profiles will prove challenging as measurements with similar vertical resolution will be in short supply.

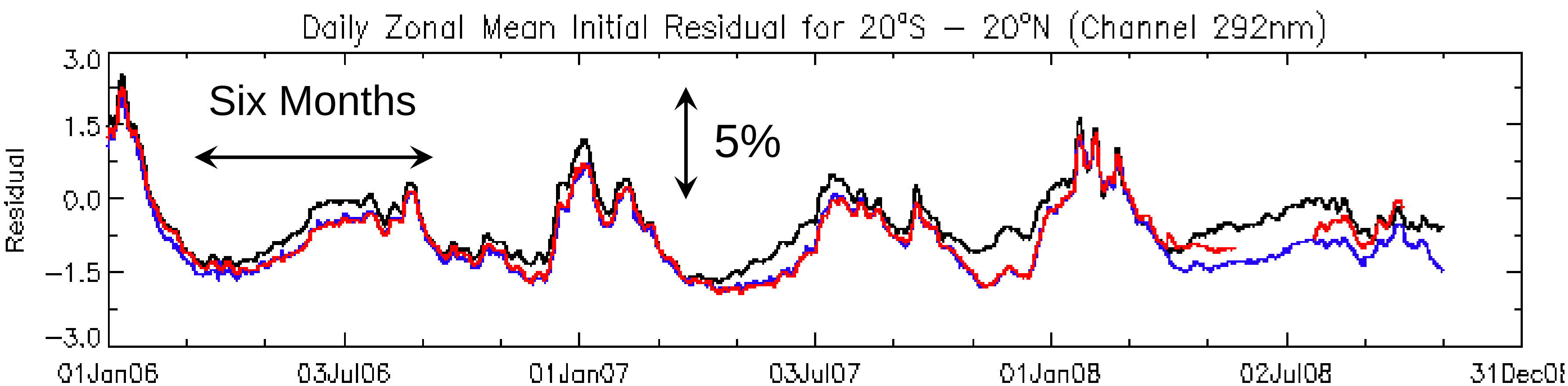
This slides demonstrates the use of SAGE II occultation measurements to validate the SAGE III Limb Scatter retrievals using coincident measurements over a two-week period.

Monthly Zonal Mean Profile Differences for SBUV/2

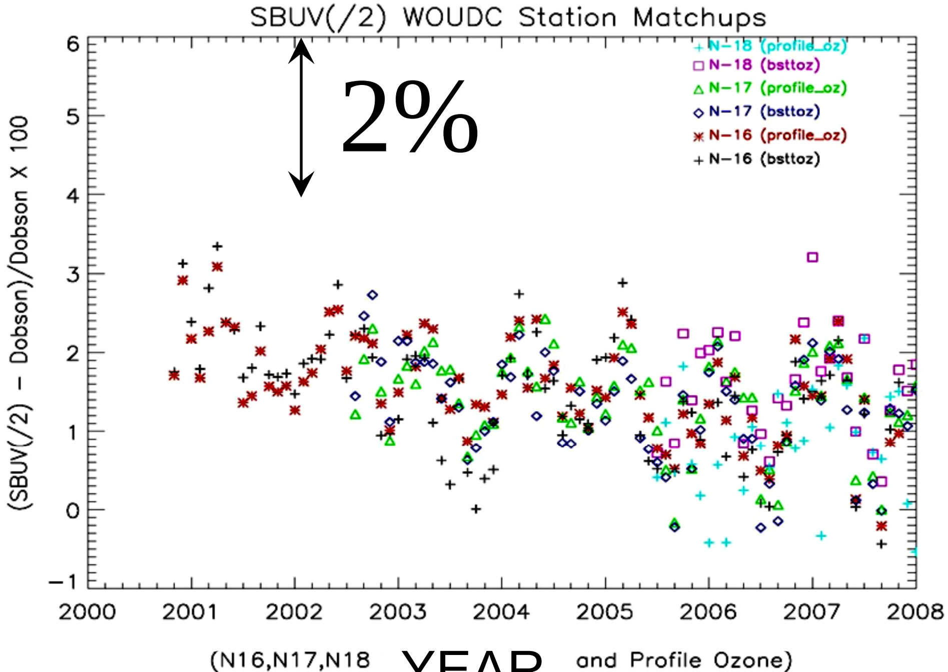


- The figure on the right compares monthly zonal means (for August 2006) for the NOAA-16 and NOAA-17 SBUV/2 profile retrievals. The lines show the differences between the retrieved profiles and the A Priori profiles for the Equatorial Zone (20S to 20N) as a function of atmospheric pressure.

The figure below tracks the average initial measurement residuals for the NOAA-16, NOAA-17 and NOAA-18 SBUV/2 instruments for the 292-nm channel. The curves connect the daily Equatorial Zonal Mean values for each instrument. The shared variations are due to real geophysical ozone changes from day to day. The divergent values are caused by differences in each instruments viewing conditions or calibration. The NOAA-16 has increasingly poorer viewing conditions as the record progresses.

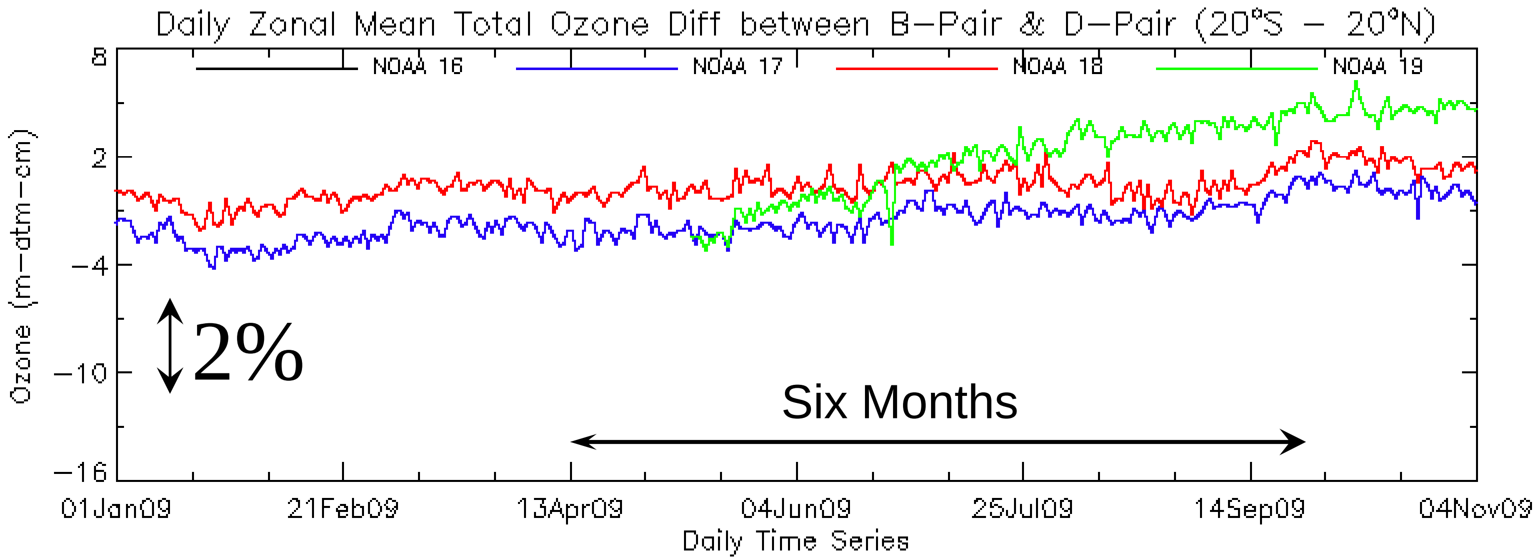


Total Ozone (Best and Profile) Comparisons
Reprocessed NOAA SBUV/2 and WOUDC Dobson



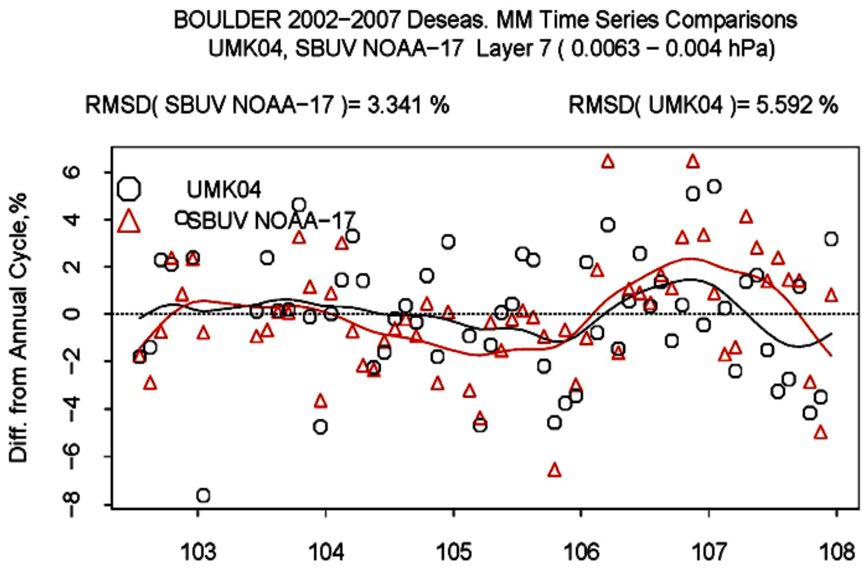
The figure to the left shows a time series of comparisons of match-up overpass total ozone values from SBUV/2 instruments with a collection of ground-based Dobson Stations. Each point is a monthly average percent difference for all of the comparisons. A station is included if it has at least five match-ups for a month.

The figure below is a check of the internal consistency of the total ozone estimates made for two different wavelength pairs for the SBUV/2 instruments, called the B-pair and D-pair. The D-pair estimates have much less sensitivity to time dependent calibration errors, but are only accurate at low solar zenith angles and low ozone column amounts. Notice the drift in the NOAA-18 SBUV/2 results.



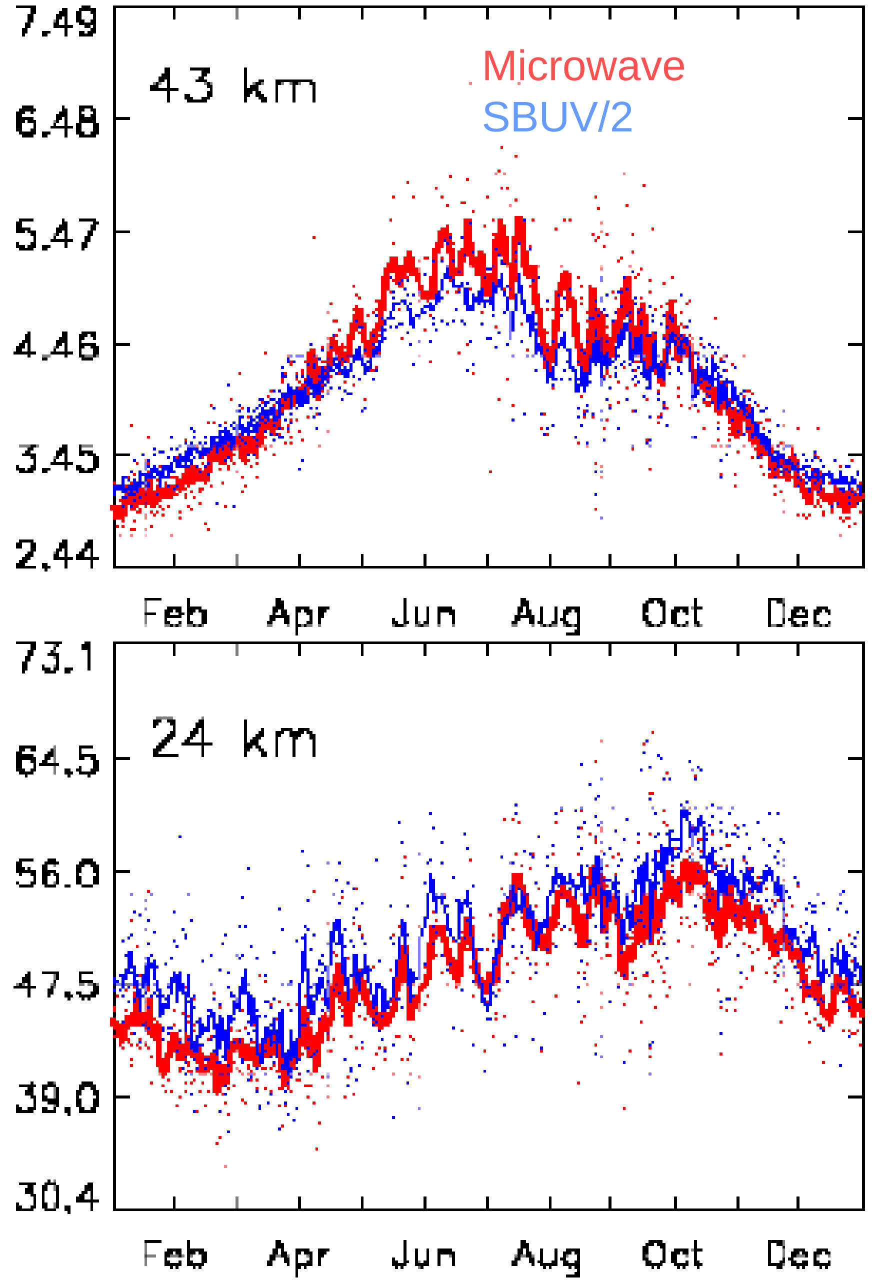
The figure to the right shows a comparison between ozone profile layer estimates from a ground-based microwave and match-up SBUV/2 overpass data. The dots are individual daily measurements and the curves are a seven-day moving average. The data are from a single year.

The figure below shows a multi-year comparison (2002 to 2007) between the ground-based Umkehr measurements for Boulder CO and the NOAA-17 SBUV/2 overpass values. The individual points are deseasonalized anomalies for the layer from 6.3 hPa to 4 hPa.



YEAR

Seasonal Variations of Layer Ozone over Lauder, New Zealand (45S, 170E)



Primary Reports

- **Cal/Val Plans –** Full plans will be cleared by the IPO for release soon.
- **Complete product evaluation reports –** These reports will be generated for the OMPS total column ozone product and OMPS ozone profile product approximately seven months into the ICV phase. They will summarize the results of the internal and external investigations, and quantify the product performance relative to the requirements with stratification as described. Reports will identify issues arising in meeting requirements created by measurement complications (*e.g.,* wavelength-scale variations or stray light signal contamination). The components of the studies used in these reports will be archived, *i.e.,* the tools, programs and data, and documentation on the procedures. Supplemental reports will be provided as results merit.
- **Open access Web pages –** Relevant information will be provided by creating Web pages for general access. They will be created and populated with graphs and statistical analysis pertinent to the OMPS data products. They will be designed for automated updates as products move into regular generation. The reference copy of the pages will live at the STAR domain, but mirrors can be placed at other locations as desired.
- **Overpass match-up data sets –** Data sets containing the OMPS products for the overpass match-up data sets will be available via anonymous *ftp* and on the GRAVITE system. These will be kept current with automated weekly updates from the latest OMPS processing. Over 100 stations have been identified as participants.
- **User-feedback reports –** Near the end of the ICV phase, we will report on the feedback obtained from assimilation users on the performance of the products, including biases in measurements *versus* forecast fields without the OMPS data sources, and identification of any difficulties in the application implementations.

Backup

Operational Mode – Calibration State

Nadir Calibration Period from ta to t1 where t1 = ta + 118sec + (47-15)sec + 100sec + 575sec

Sensor	Measurement	When Required	Window in Orbit	ta + Cal. Time Required
Total Column	Solar	Working Diffuser - Weekly Reference Diffuser - 6 mo.	Term* -10° to Term* +10°	118 seconds
	Dark Current	Weekly	Term*+10° to Term*+67°	100 seconds
	Linearity	Weekly		575 sec onds
Nadir Profile	Solar	Working Diffuser - Weekly Reference Diffuser - 6 mo.	At center TC diffuser position	47 seconds (15 second overlap with Total Column)
	Dark Current	Weekly	Term*+10° to Term*+67°	100 seconds
	Linearity	Weekly		575 seconds

* Term = Solar Illumination Terminator

Limb Calibration Period from tb to t2 where t2 = tb + 148sec + 100sec + 575sec

Sensor	Measurement	When Required	Window in orbit	tb + Length of Time
Limb Profile	Solar	Working Diffuser - Weekly Reference Diffuser - 6 mo.	Term*+17.1° to Term*+26.3°	148 seconds
	Dark Current	Weekly	Term*+26.3° to Term*+67°	100 seconds
	Linearity	Weekly		575 seconds

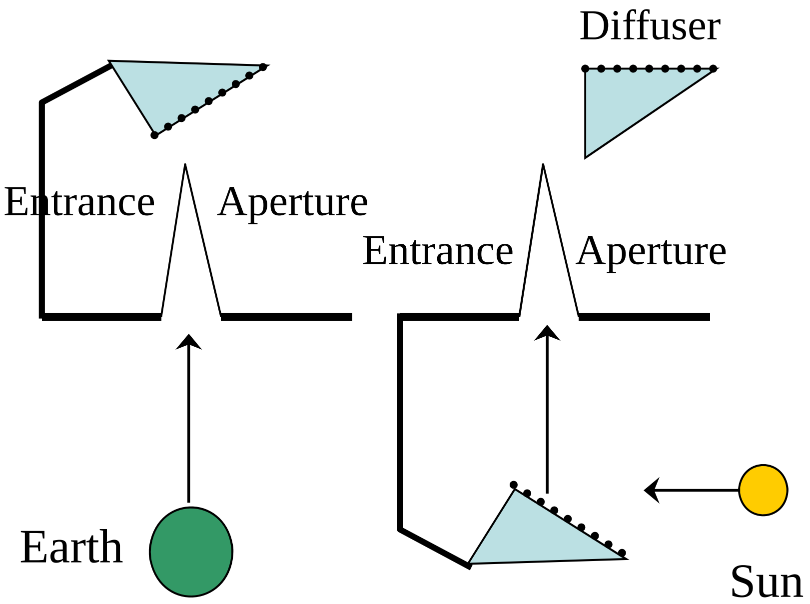
* Term = Solar Illumination Terminator

OMPS Nadir Design and Algorithms

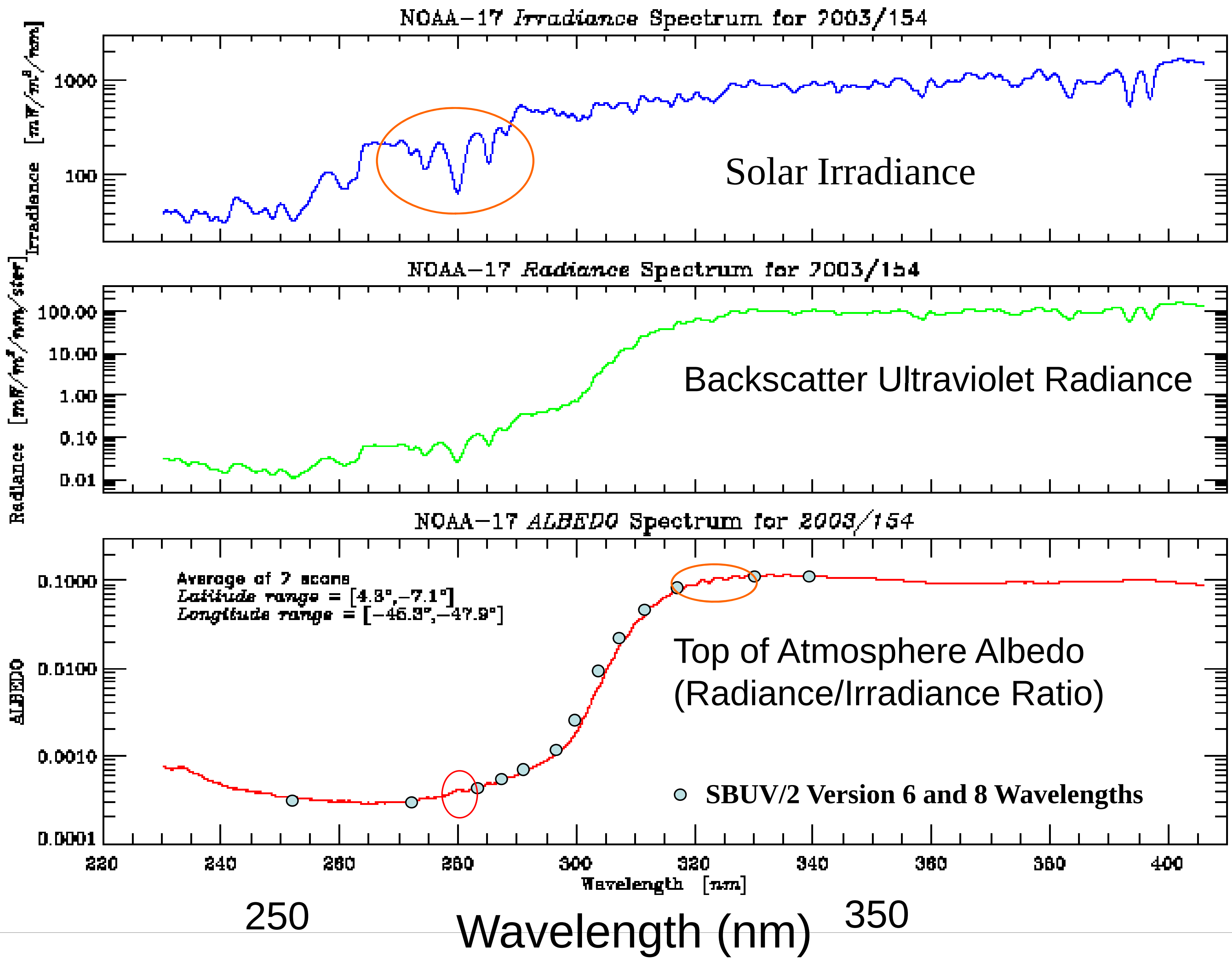
The OMPS NP ozone profile IP Algorithm is the Version 6 SBUV/2 algorithm. It is an Optimal Estimation retrieval using the radiance/ irradiance ratios from 12 wavelengths combined with a priori ozone profiles. A newer, Version 8 algorithm is in use at NOAA for the SBUV/2.

The OMPS NM total column ozone EDR Algorithm is a multiple triplet table look-up algorithm expanded from the Version 7 TOMS algorithm. Each triplet uses three radiance/irradiance ratios; one for a wavelength sensitive to the total column ozone, one at a nearby reflectivity channel, and the third at a longer wavelength reflectivity channel to determine first order wavelength-dependent reflectivity conditions.

The Nadir Mapper and Nadir Profiler share a telescope and two solar diffusers. One solar diffuser is used on a frequent basis to monitor instrument throughput changes, the other is used twice a year at repeated viewing conditions to monitor changes in the first diffuser.

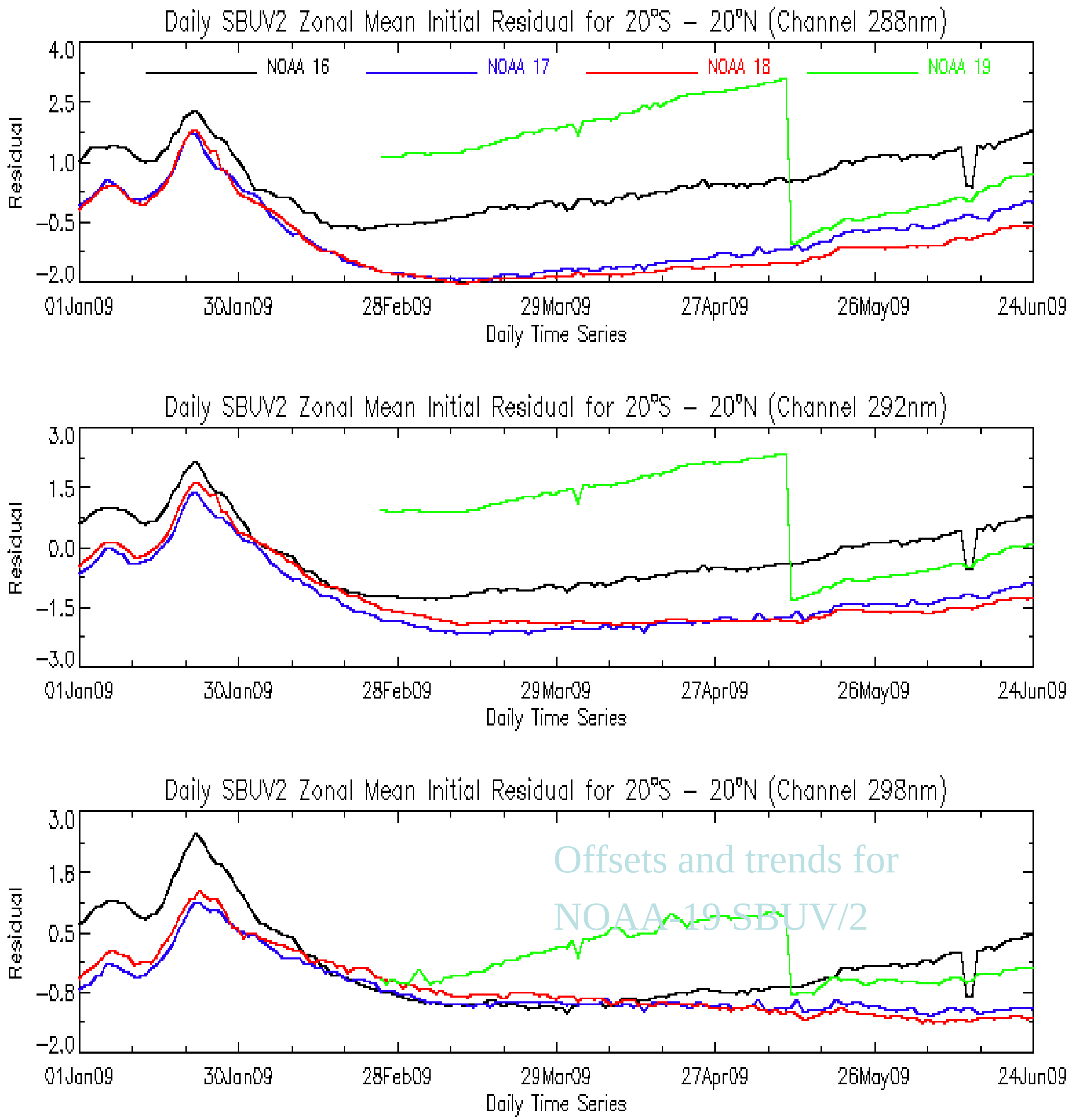


Measurements from NOAA-17 SBUV/2



Bundled Parameters for calibration, validation, tuning, diagnostics, trending, characterization, and QA/QC

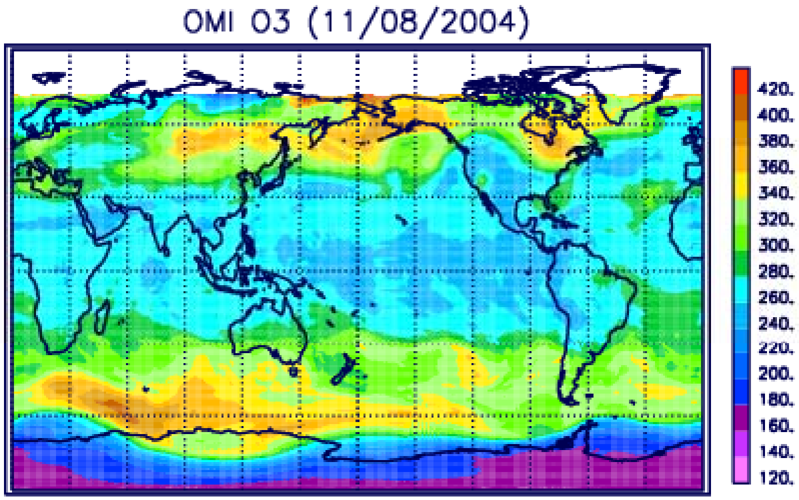
- Effective cloud fraction (TC,NP,LP)
- *Effective reflectivity (TC,NP,LP)
- Surface reflectivity (TC,NP,LP)
- Snow/Ice Coverage Flag (TC,NP,LP)
- Cloud Top Pressure (TC,NP,LP)
- Tropospheric ozone estimates (TC,NP,LP)
- Version 7 Total Ozone (TC)
- Neutral density profile (LP)
- Aerosol profile (LP)
- Nadir Ozone Profile (NP)
- *D-Pair Total Ozone estimate (NP)
- CrIS Cloud Fraction (IR)
- Calibrated measurement albedos (TC,NP,LP)
- *Final measurement residuals (TC,NP,LP)
- Bandpass centers (TC,NP,LP)
- Channel IDs (TC,NP,LP)
- SDR Calibration ID (TC,NP,LP)
- Solar Zenith Angle (TC,NP,LP)
- Solar Azimuth Angle (TC,LP)
- Spacecraft Roll Angle (TC)
- Height Scale and pointing adjustments (LP)
- Normalization radiances (LP)
- *Initial residuals for measurements (NP)
- Temperature Profile (TC,NP,LP)
- EDR Algorithm ID (TC,NP,LP)
- Latitude, Longitude (TC,NP,LP)
- GMT Time (TC,NP,LP)
- Ozone profile information (TC)
- Albedo Ozone Sensitivities (TC)
- Tropopause Height (LP)
- A Priori Aerosol Profile (LP)
- A Priori O3 Profile (NP,LP)
- Ancillary data use (TC,NP,LP)
- Eclipse (TC,NP,LP)
- South Atlantic Anomaly (TC,NP,LP,IR)
- Ascending/Descending (TC,NP,LP)
- *Aerosol Index (TC)
- Volcanic SO2 estimate (TC)
- SO2 Index (TC,NP)
- *Triplet consistency (TC)
- Sun Glint (TC,NP)
- Version 6 Flags (NP)

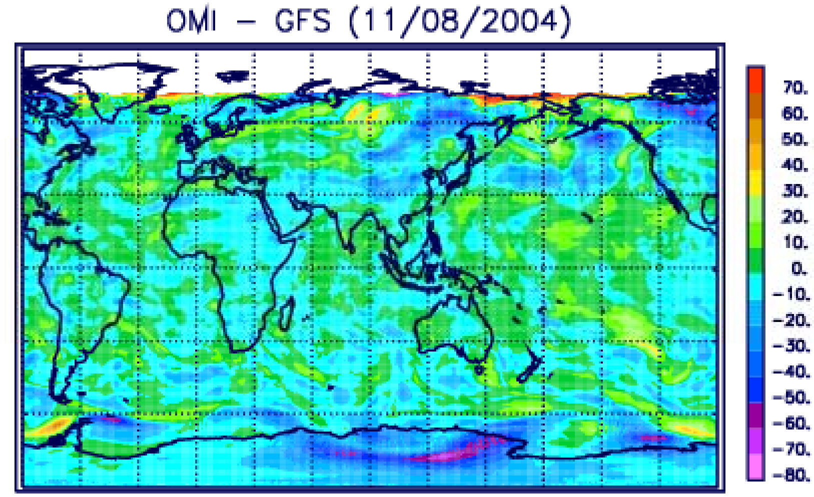


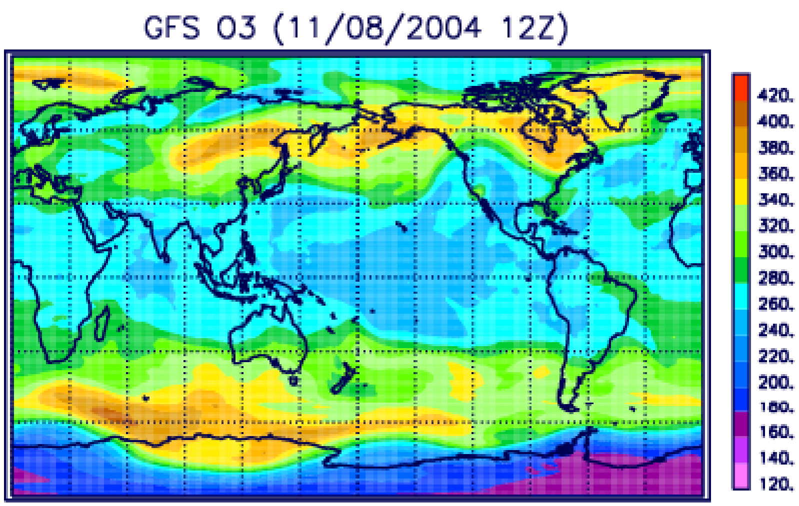
Tracking of Initial Residuals for SBUV/2 Instruments for 288, 292, and 296 nm Channels.

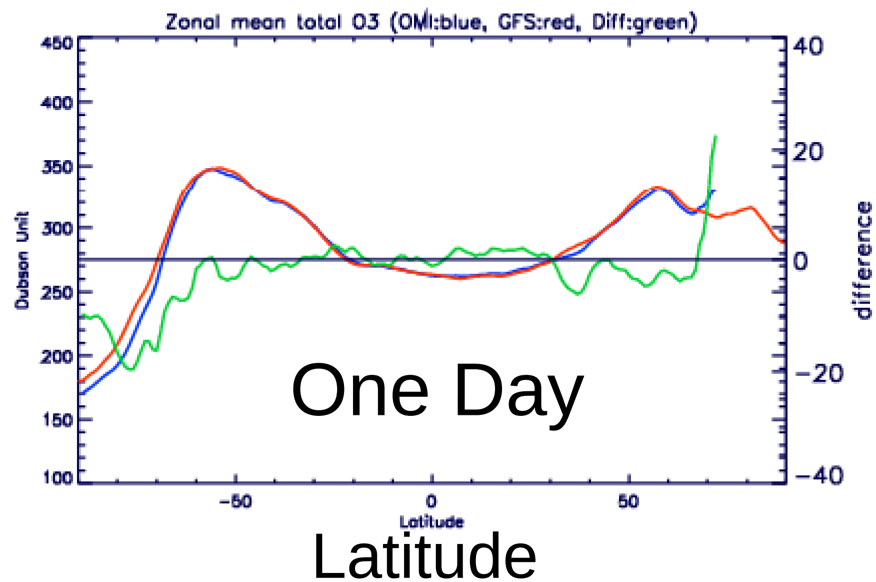
The Red and Blue are for NOAA-17 and NOAA-18 and track well. The Green is for NOAA-19 and the Black is for NOAA-16. The NOAA-19 data shows an offset and a trend relative to the others. Both were corrected and modeled by using the data from the OV tests. NOAA-16 results are produced at much different SZAs.

Comparison of OMI and GFS total O_3 (Nov. 8)

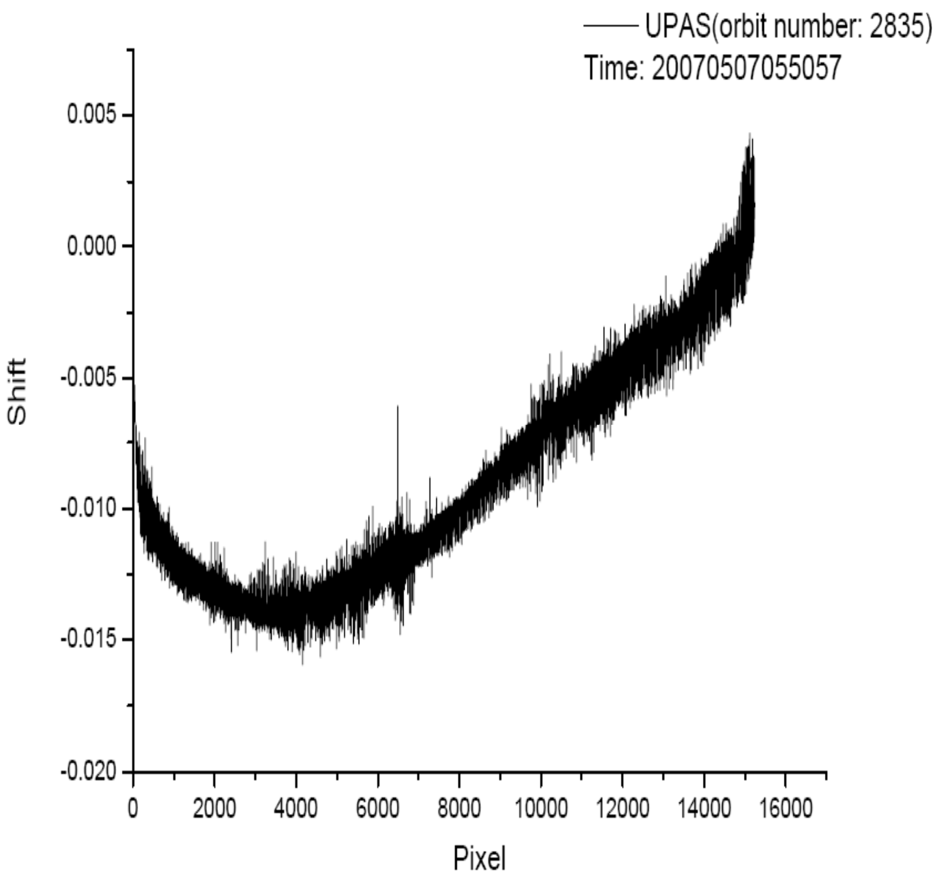




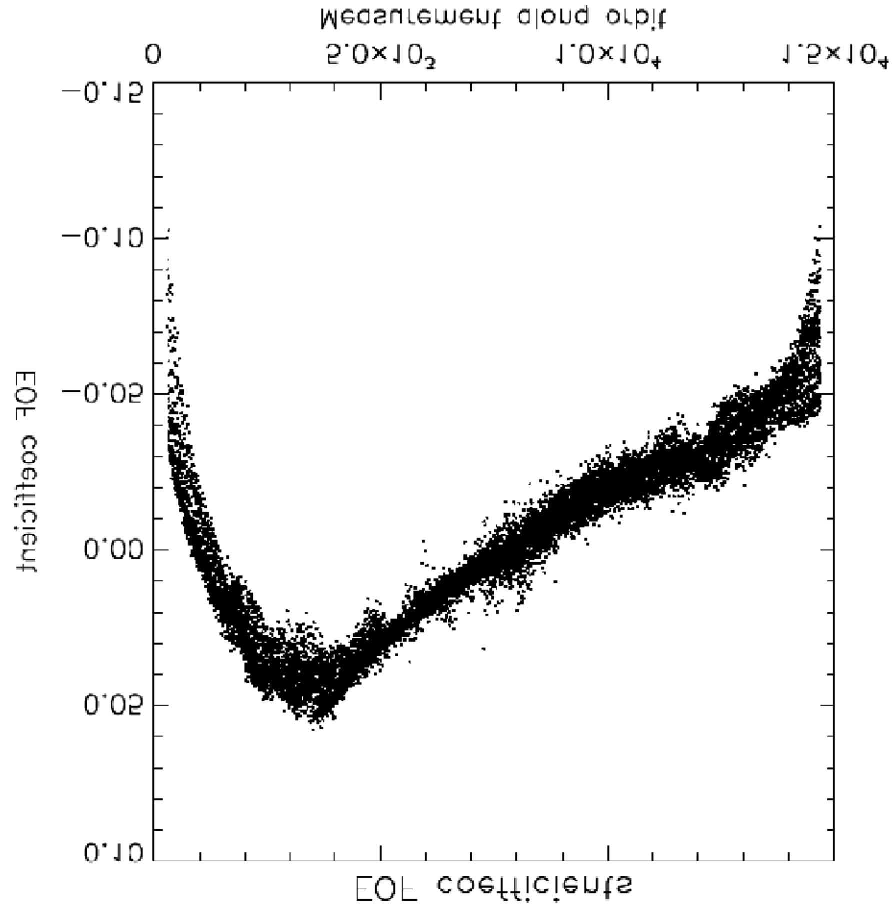




Comparison of Intra-orbit wavelength drift coefficients

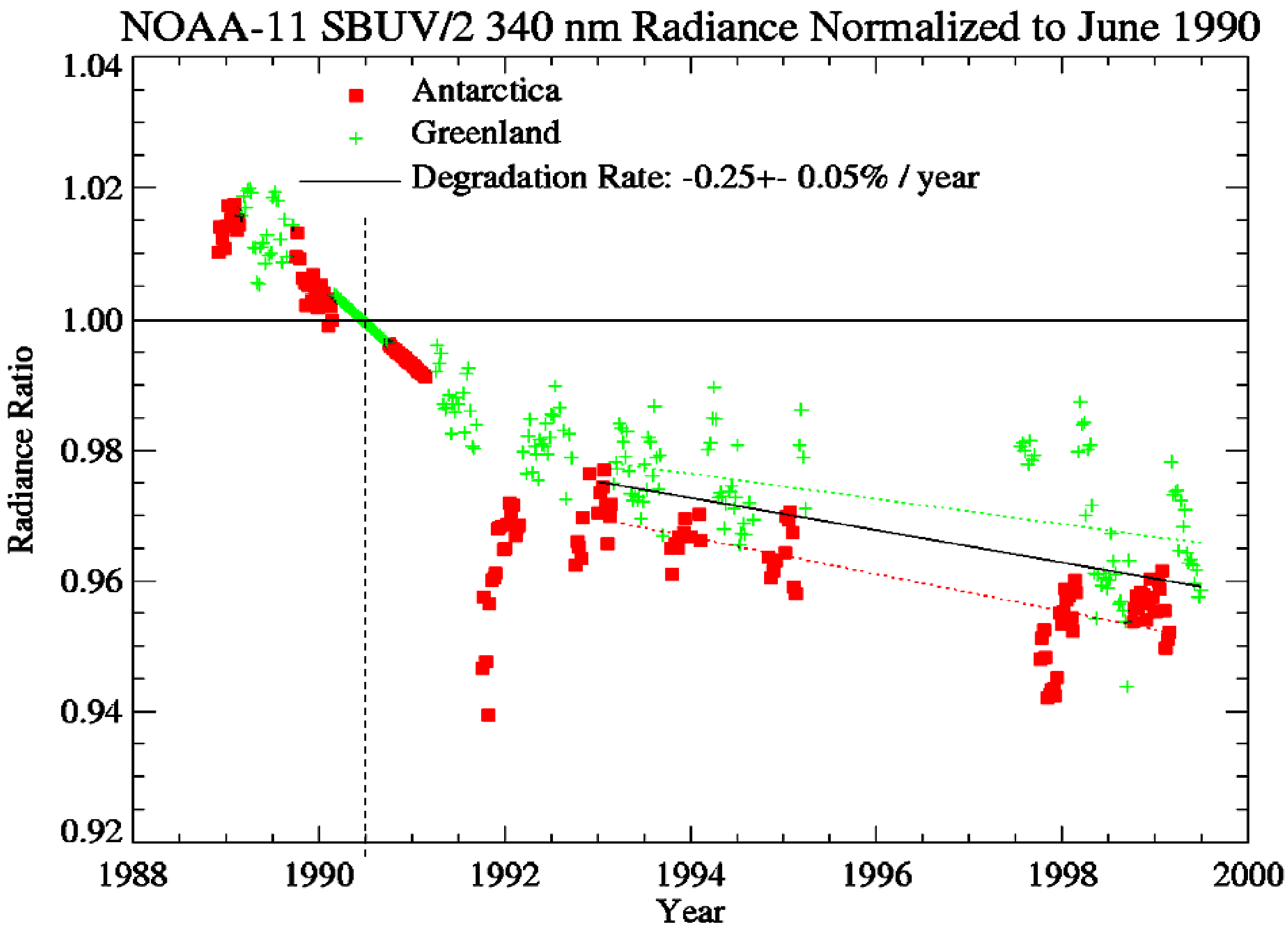


DOAS GOME-2
Wavelength Shift Coefficient using solar spectrum shift fit (From D. Loyola)



EOF GOME-2
Wavelength Shift Coefficient * (-1)

The hard calibration system is augmented by analysis and monitoring of the Earth albedo for reflectivity channels. Antarctica and Greenland have high surface reflectivity and year-to-year stability. This allows us to evaluate the absolute calibration and time-dependent drift. Solar zenith angle dependence also provides information about linearity.



Ice Radiances