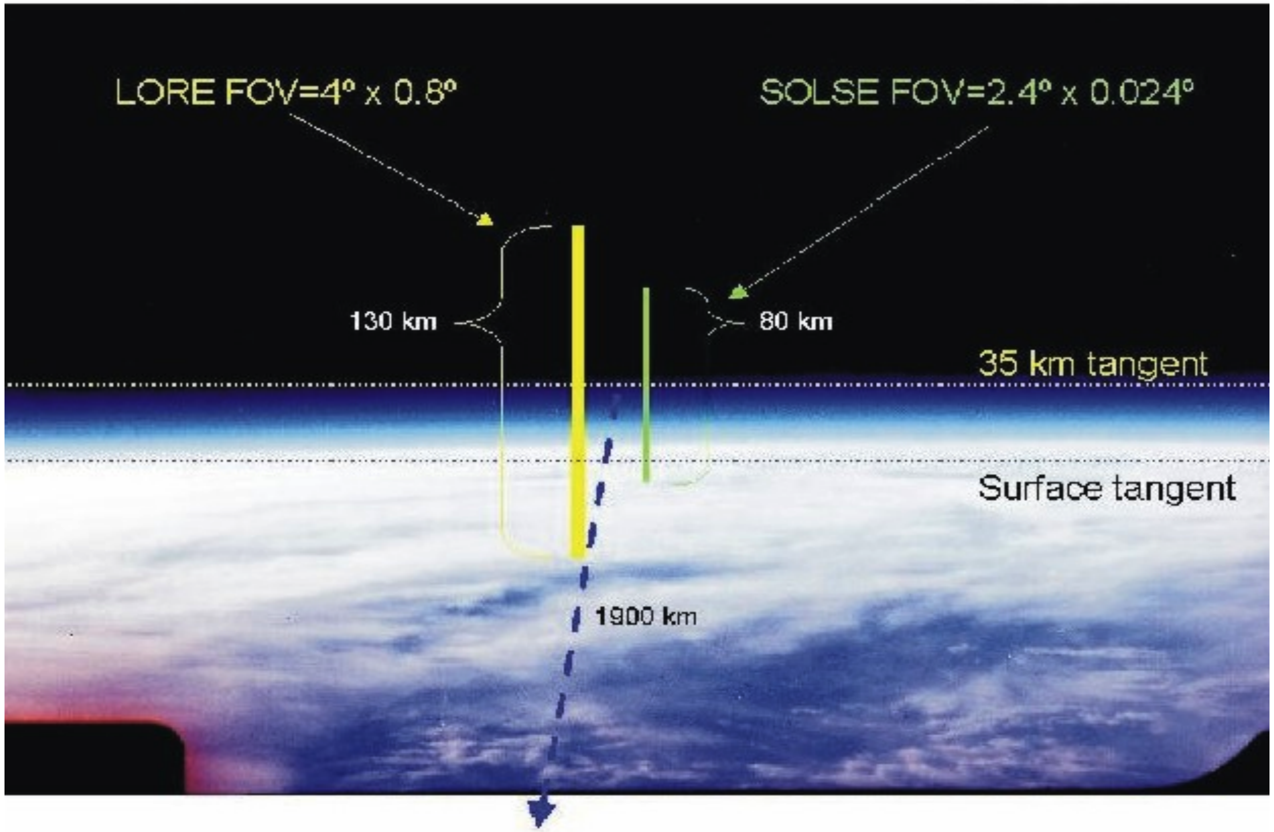
The OMPS Limb Profiler Ozone And Aerosol Profile Retrieval Algorithms



Space Shuttle limb view

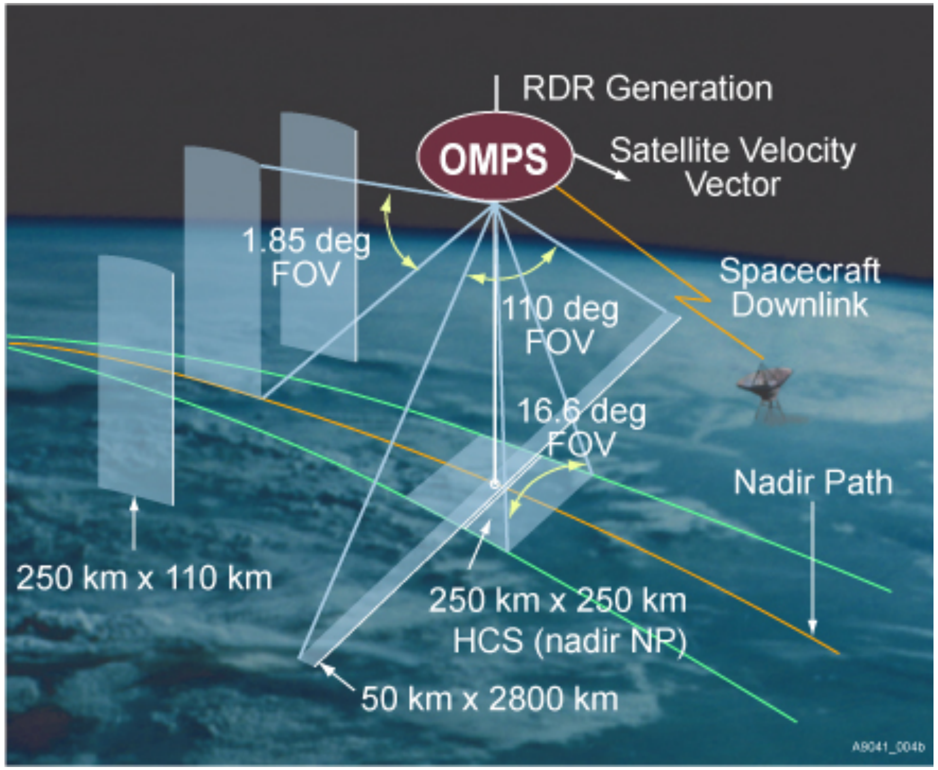
Robert Loughman, Didier Rault, Ghassan Taha, Jason Li, Tong Zhu and Adam Bourassa

Outline

- Brief OMPS Mission Review
- Measurement Sensitivity
- Retrieval Algorithm Status
  - Pointing
  - Cloud top height
  - Scene reflectivity
  - Aerosol
  - NO_2
  - Ozone
- Radiative Transfer Modeling Updates
- Conclusions and Future Plans

OMPS Mission

- The mission of OMPS is to continue the long-term ozone record for trend assessment
- All other retrievals are meant to improve the ozone retrieval performance
- NPP satellite, launch 2011

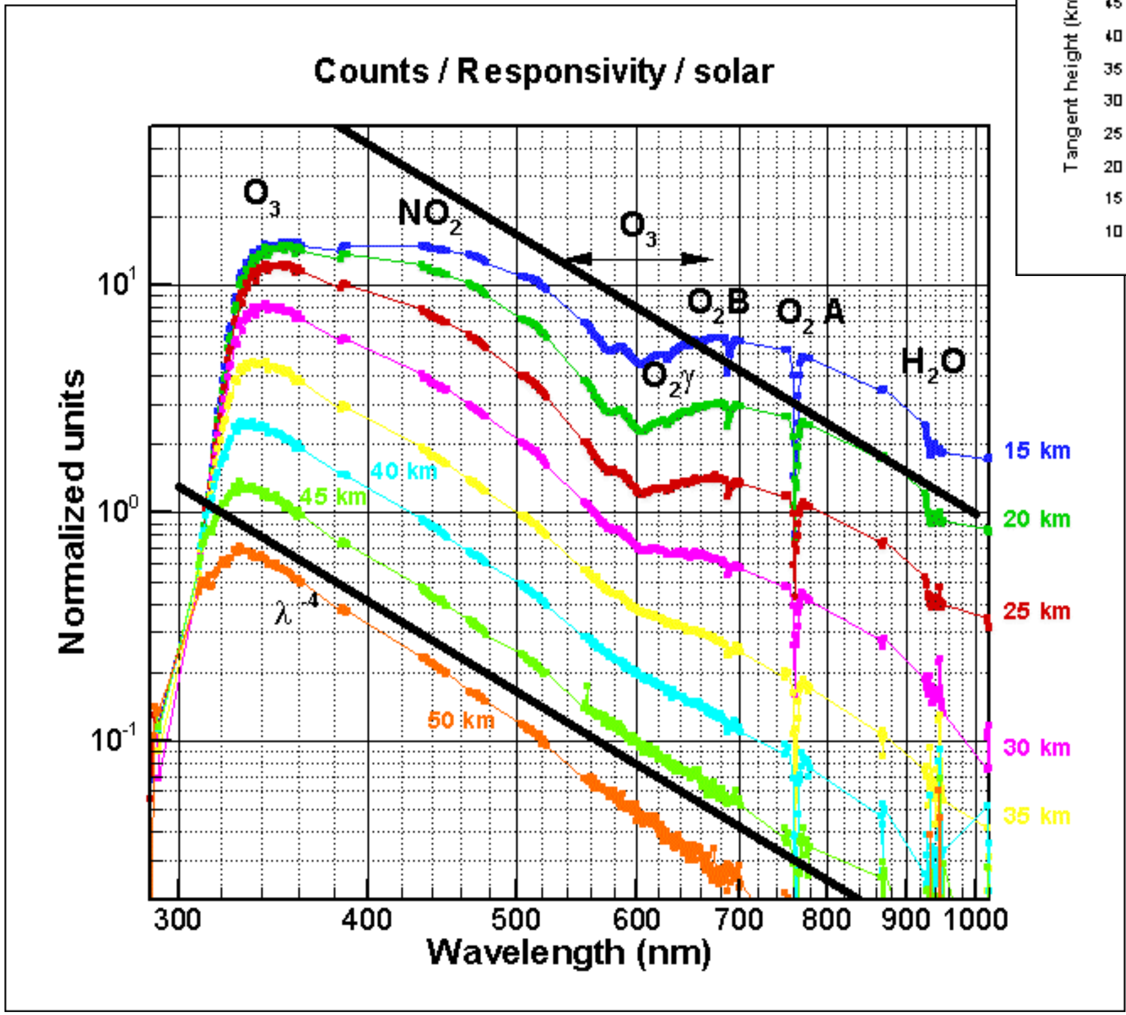


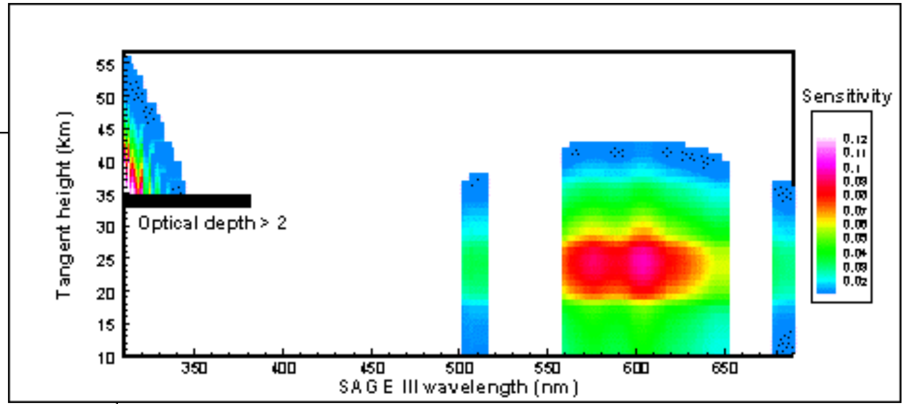
OMPS = Ozone Mapping and Profiler Suite

OMPS Ozone Profile Requirements:	
Accuracy:	10% (above 15 km)
Precision:	3% (15-50 km)
Stability:	2% (7 yrs)

LS Signal and Ozone Sensitivity

From Rault and Taha (2005)





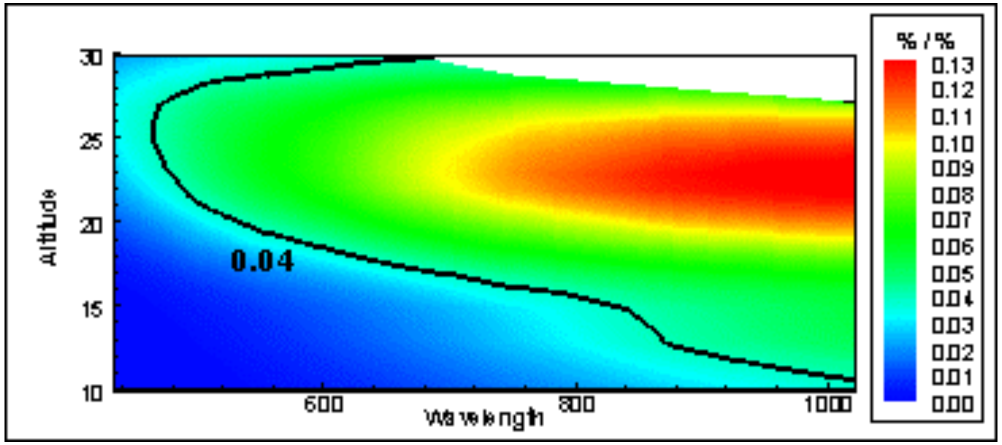
Vis: **lower stratosphere / upper troposphere**

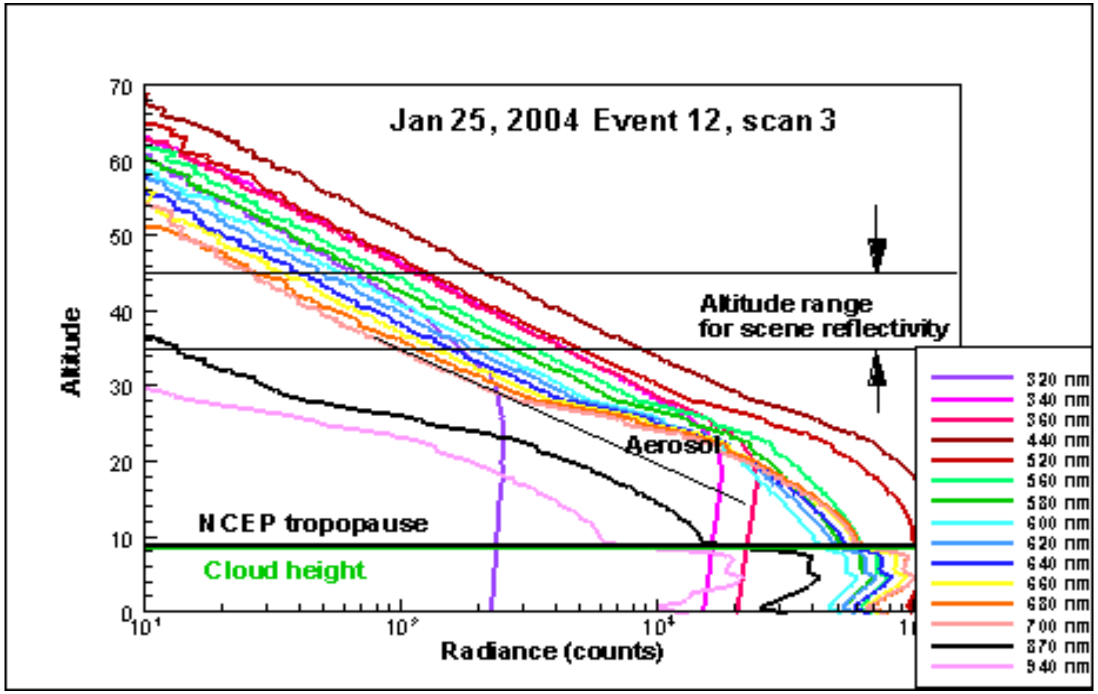
UV: **upper stratosphere**

Downlink 80 pixels for each scene

LS Signal and Aerosol Sensitivity

The magnitude of the aerosol sensitivity is similar to the ozone sensitivity, and a-priori aerosol knowledge is much poorer.





Therefore we need a good estimate of the aerosol profile to satisfy our ozone profile requirements.

From Rault and Taha (2005)

Current Retrieval Approach

RSAS #1 → Cloud Top Height → Effective Scene Reflectivity → Aerosol → RSAS #2 → Ozone (UV) → Ozone (visible)

This presentation describes the baseline "operational" algorithm

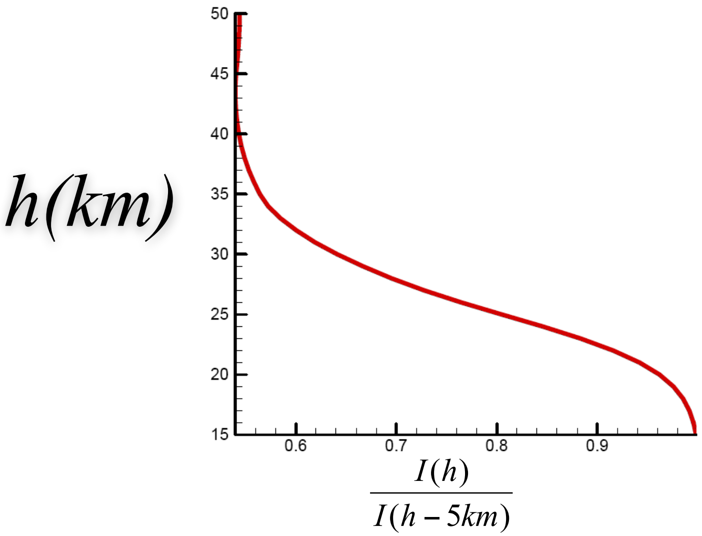
Each limb event is processed independently, then aggregated into a single HDF file containing retrieved profiles for the entire orbit (+ diagnostic pictures)

For alternative approaches, see D. Rault's presentation

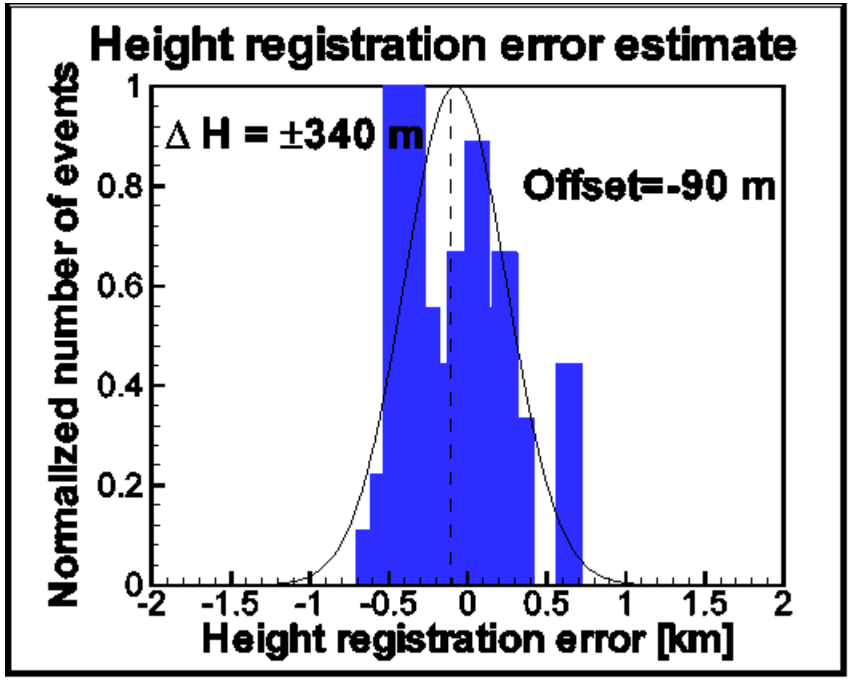
For testing and results, see G. Taha's presentation

Tangent Height Registration (RSAS)

- Named after the Rayleigh Scattering Attitude Sensor (RSAS) instrument (Janz et al., 1995) that tested the concept used
- Scattering (primarily by molecules) causes the radiance ratio at 350 nm to vary with altitude as shown
- This signal can be used to assign the tangent height scale to a measured radiance profile



RSAS accuracy is limited by T(z), p(z), aerosol(z) accuracy (normal NCEP errors lead to ± 250 m)



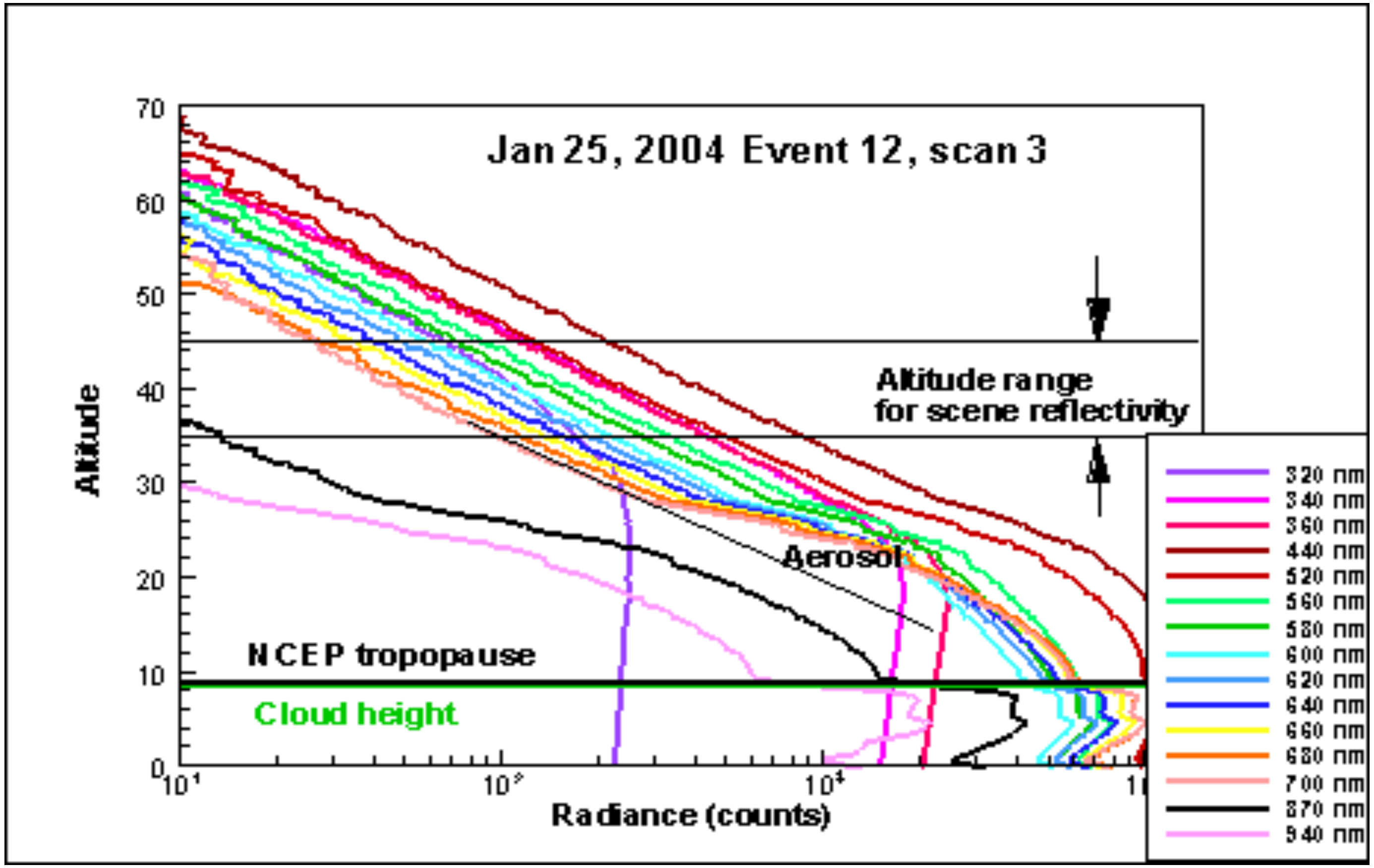
Cloud Top Height and Scene Reflectivity

Cloud top height – Abrupt, consistent change in slope of the radiance profile
– Cloud top is used as lower boundary for retrievals

Effective Scene Reflectivity

- Compare data vs model radiance above stratospheric aerosol layer (nominal altitudes = 35-45 km)

- Infer an effective Lambertian albedo at each wavelength

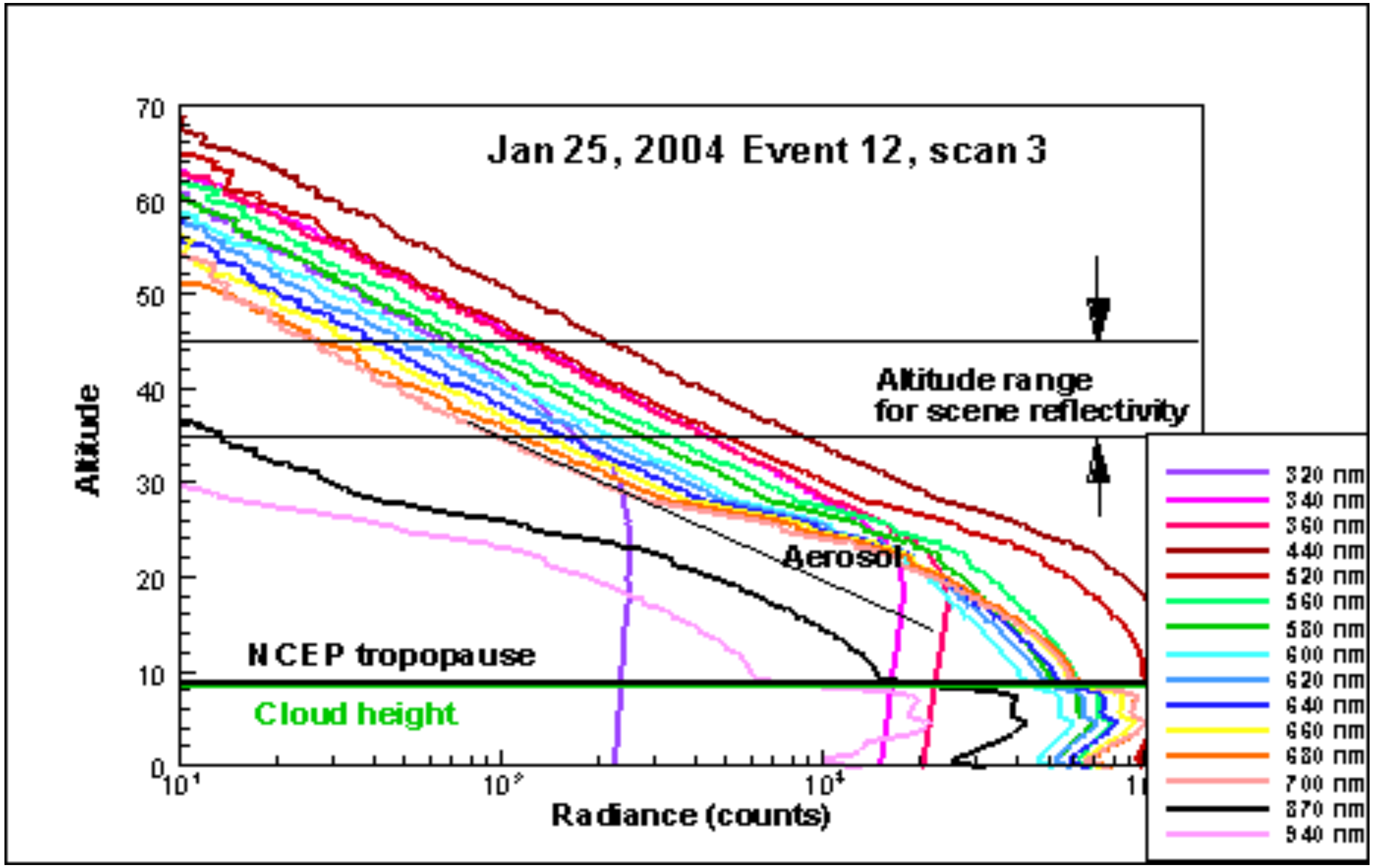


Aerosol Extinction Retrieval Algorithm

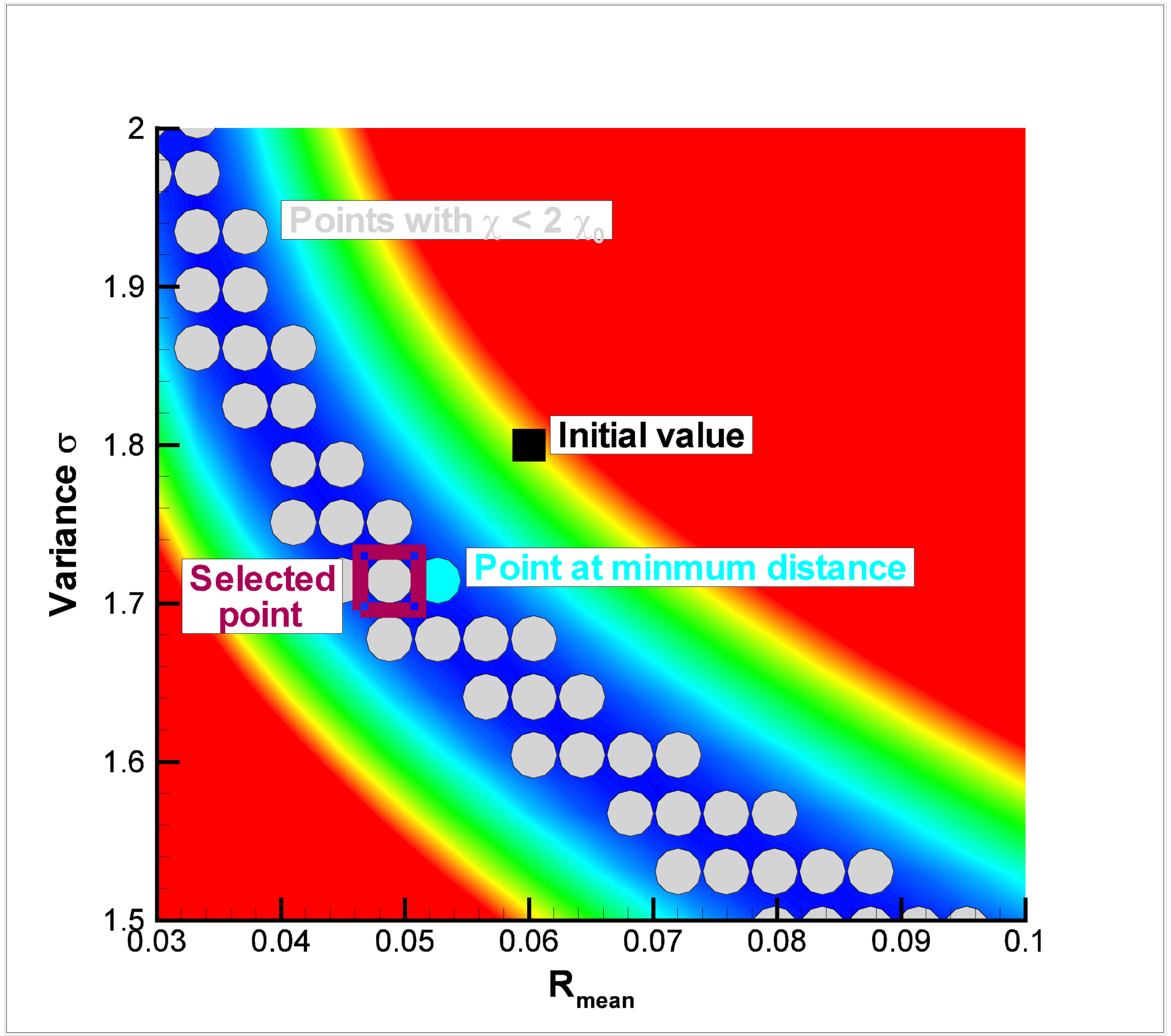
- Ozone profile & effective surface reflectivity are static
- Initially use an assumed aerosol size distribution (ASD) to solve for the aerosol extinction profile $\beta_a(z)$ at each wavelength independently

514, 677, 750, 870 nm

- Estimate aerosol effect across Chappuis
- Use longer λs for ASD estimate



Aerosol Size Distribution Retrieval



- Assume log-normal ASD
- Seek the (R_{mean}, σ) pair for which the aerosol extinction cross-section $C_a(\lambda)$ best matches the retrieved aerosol extinction coefficient $\beta_a(\lambda)$
- Many equally plausible candidates arise for the (R_{mean}, σ) pair
- Choose the best pair in the region near the initial ASD guess

Ozone and NO_2 Retrieval

- Normalize radiances from each channel to radiance at a reference altitude (reduces sensitivity to absolute calibration, surface brightness, polarization,…)
- Form wavelength pairs (UV) and triplets (vis) (reduces sensitivity to aerosol)
- Retrieve ozone profile using optimal estimation (Flittner et al., 2000)

- Separate UV and vis ozone retrievals (overlap = indication of quality)
- Use a range of altitudes for altitude normalization
- Use a range of wavelengths for insensitive wavelength of pair / triplet

NO_2 retrieval

- Our instrument does not resolve NO_2 lines well, so sensitivity is poor

- We are experimenting now to decide which produces better ozone retrievals: Our poor NO_2 retrieval, or using a seasonal climatology

Retrieval Algorithm Inputs (Databases and Ancillary Data)

- Rayleigh cross-sections and anisotropy (Bates, 1984)
- Ozone cross-sections (Bass and Paur, 1984; Molina and Molina, 1986; Burkholder and Talukdar, 1994) *Alternatives:* Bogumil et al., 2003; Brion et al., 1998; Malicet et al., 1995; Daumont et al., 1992.
- Nitrogen dioxide cross-sections (Harder et al., 1997)
- Solar spectrum (Rothman et al., 1992; Colina et al.,1996; Kurucz, 2005)

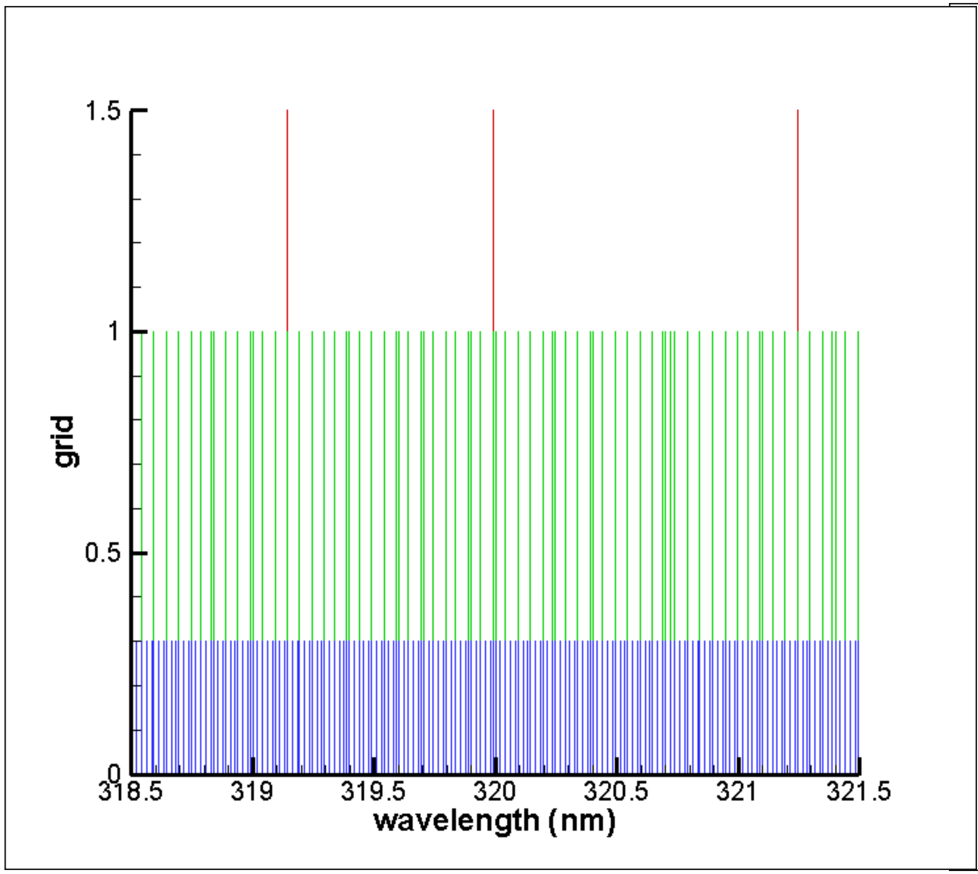
Ancillary Data:

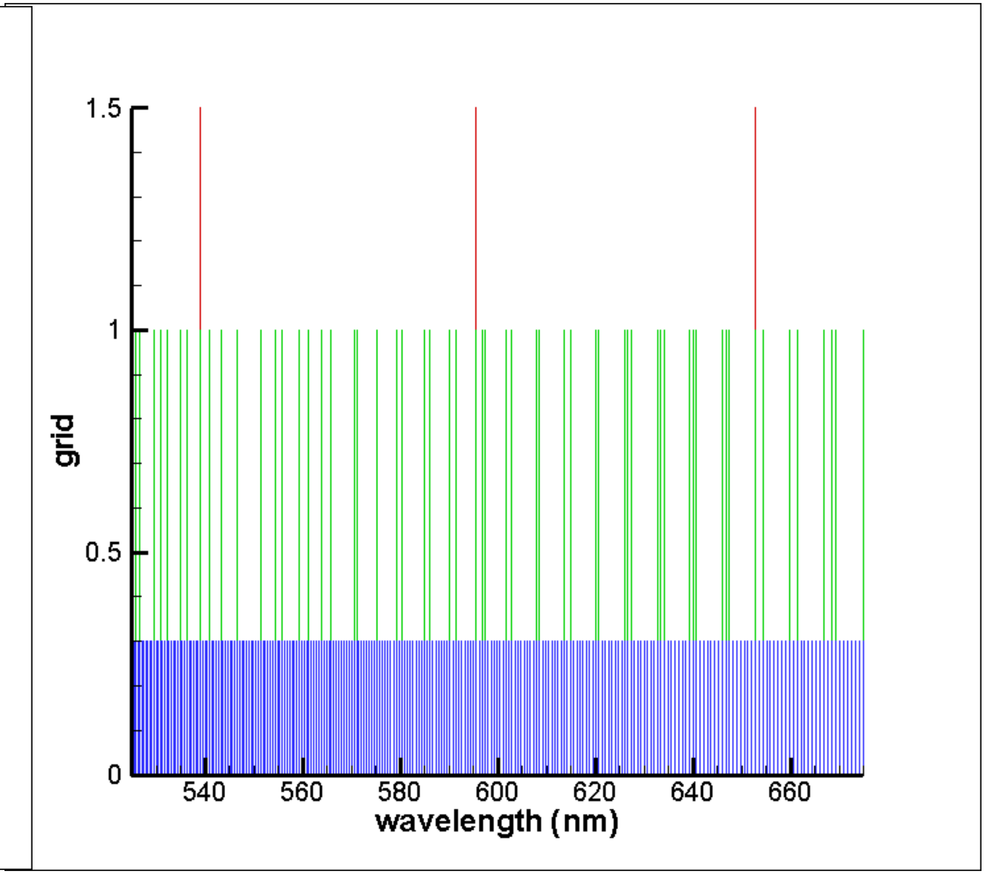
- p/T profiles (NCEP, Kalnay et al., 1996)
- Ozone (SAGE II monthly / latitude climatology, Anderson, 2000)
- Nitrogen dioxide (time-independent: HALOE, Anderson, 2000;
  time-dependent: PRATMO, McLinden et al., 2000)
- Aerosol (first guess) (latitude- and time-independent profiles based on SAGE III data)

Radiative Transfer Modeling

- Began with the Herman et al. (1994, 1995) model
- Benchmarked vs. existing models (Loughman et al., 2004)
- Imbedded *λ* grids increase efficiency: Solar/convolution (high res)
  SS (medium res)
  MS (low res)
- Loosen grids (especially MS grid) as much as possible without sacrificing ozone retrieval accuracy
- Now can convolve radiances directly (spatially and spectrally)
  -- Produces high-quality radiances at arbitrary (*λ, TH*)
  -- Eliminates need for look-up tables
- Modular F90/95 code (easier to maintain, better memory usage)
- Complete retrieval for one event requires ~100 sec

RT Grid Illustration





UV Grid Sample

Vis Grid Sample

Conclusions and Future Work

- The OMPS LP instrument and retrieval algorithms are on track to be completed and integrated before launch in 2011
- The primary product is the ozone profile, but useful secondary products should include aerosol extinction profile and ASD, cloud top height, …
- Continue to add realism to our simulations (true instrument characteristics, realistic measurement noise, real data, etc.)
- Add more diagnostic tools to assess the instrument and algorithm performance during the initial post-launch period
- Improve overall algorithm stability and robustness (to tolerate bad pixels, missing data, etc.)
- Continue to explore alternate algorithms as they are developed (inside or outside the OMPS team)

Acknowledgements

- David Flittner, for lots of help with the radiative transfer modeling (especially the aerosol kernel calculation)

- Mike Linda and the OMPS PEATE team, for incorporating our algorithm into an operational framework

- The OSIRIS, SCIAMACHY, SAGE II, and SAGE III research groups, for maintaining and sharing their high-quality data sets

- NASA, NOAA and IPO, for supporting LS research

- Darel Davidson, Jordan Foley and David Auslander for their help with refining the algorithms as summer students

Backup slides

OMPS Total Column (TC), Nadir Profiler (NP) and Limb Profiler (LP) Instruments

	TC	NP	LP
Pre-decessors	TOMS, SBUV, GOME, OMI, SCIAMACHY	SBUV, GOME, OMI, SCIAMACHY	SOLSE/LORE, OSIRIS, SAGE III, SCIAMACHY
Geometric Coverage	110° cross-track	Single nadir column	Three 100-km vertical cells
Spectral Coverage	300-380 nm	270-310 nm	290-1000 nm
Instrument design	UV backscatter, grating spectrometer, 2-D CCD detector array	UV backscatter, grating spectrometer, 2-D CCD detector array	UV/vis LS, prism, 2-D CCD array

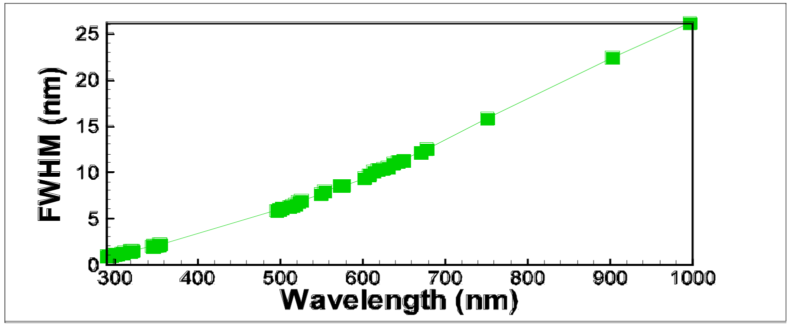
- 80 wavelength pixels will be downlinked for each scene
- Prism offers high res in UV, lower res in vis/NIR (optimized for ozone)

OMPS Ozone Profile Requirements:

Accuracy: 10% (above 15 km)

Precision: 3% (15-50 km)

Stability: 2% (7 yrs)



OMPS LP Heritage and Requirements

In the past decade, 4 instruments have made LS measurements from space:

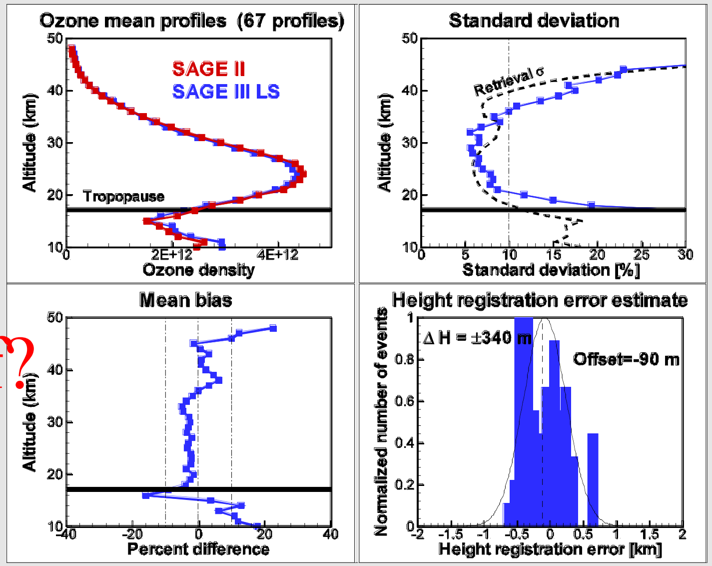
SOLSE-LORE, OSIRIS, SCIAMACHY, SAGE III

Next: OMPS LP, to launch on the NPP satellite in June 2010

OMPS Ozone Profile Requirements:

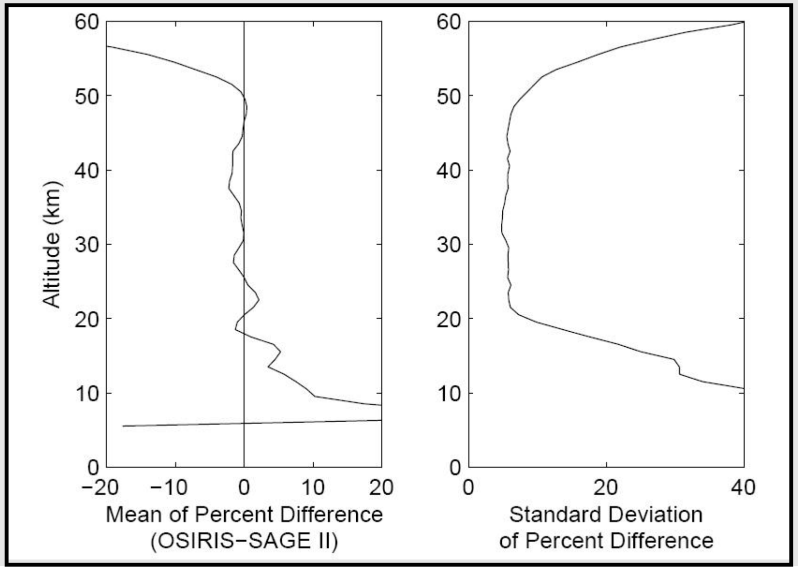
Accuracy:	10% (above 15 km)
Precision:	3% (15-50 km)
Stability:	2% (7 yrs)

SAGE III LS vs SAGE II



Ref?

OSIRIS vs SAGE II



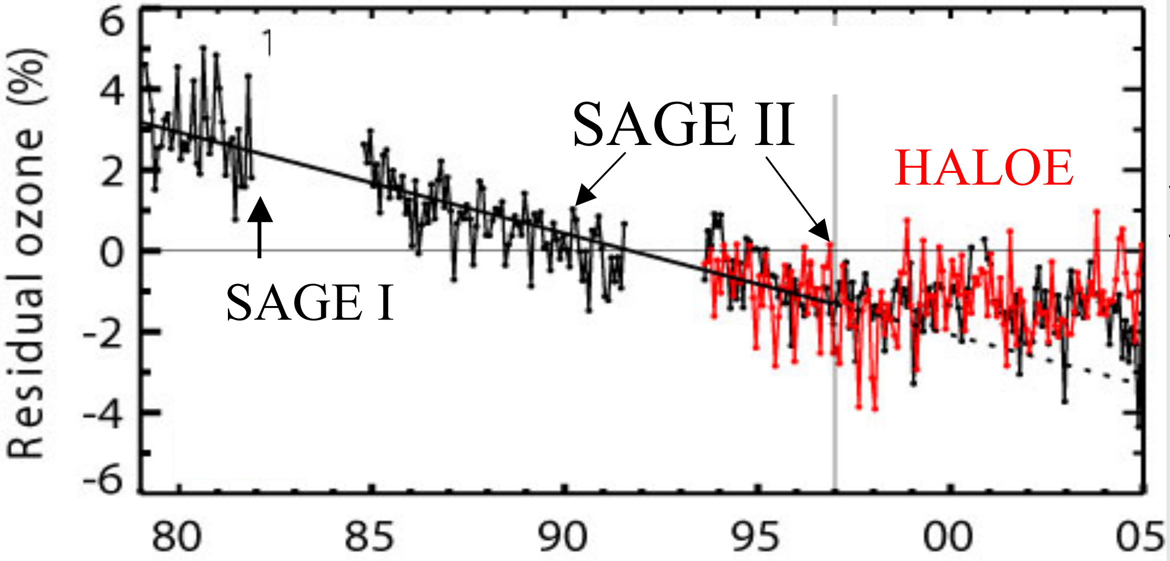
Ref?

Science background (2)

Need for continuation of ozone and aerosol monitoring

Limb Scatter has the *potential* to carry forward the long-term record of stratospheric *ozone* and *aerosol* begun by solar occultation sensors

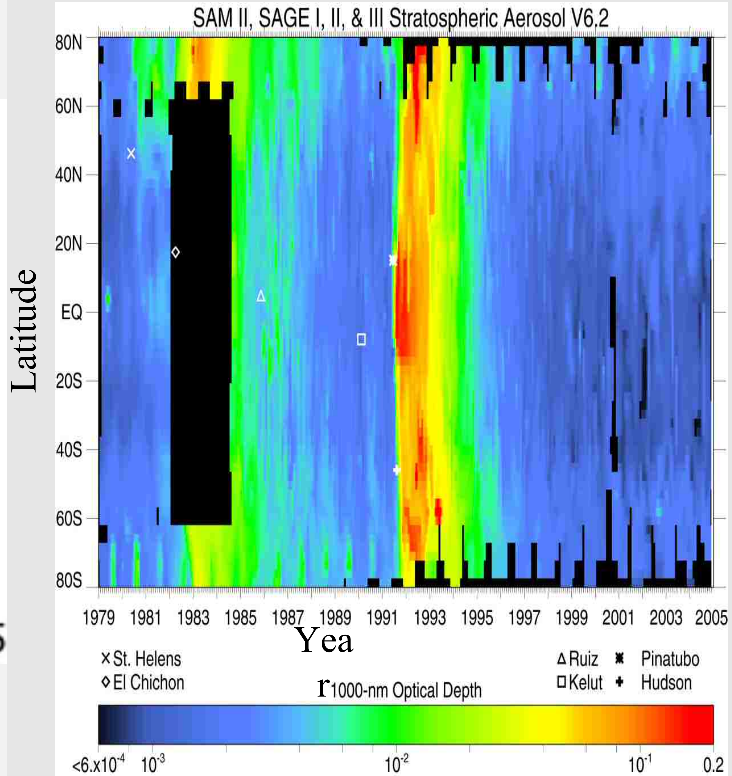
Ozone trends



YEAR

Ref?

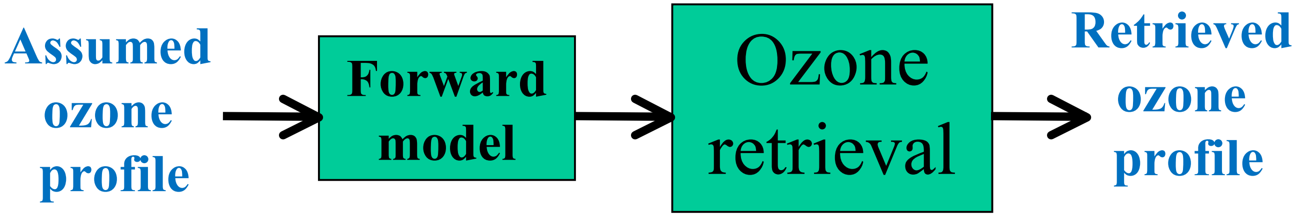
Stratospheric Aerosol

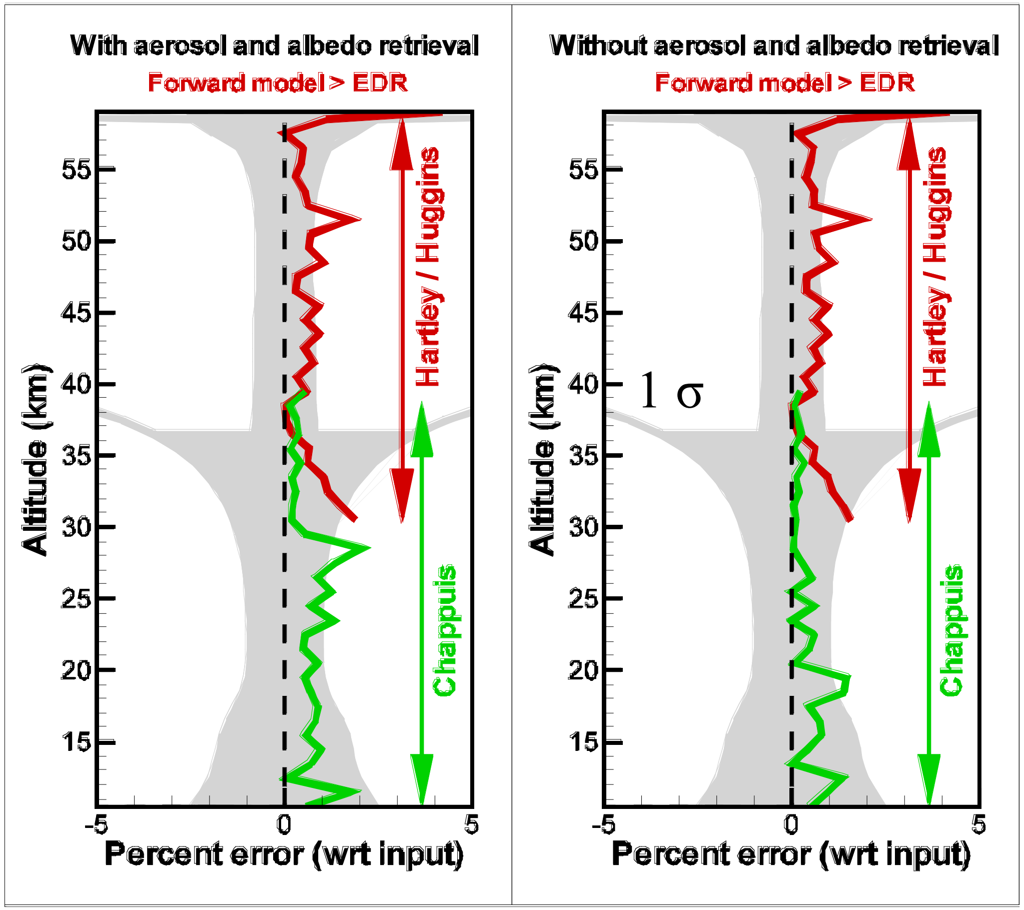


From L. Thomason LaRC

Ozone retrieval testing

(1) with synthetic data (forward model)

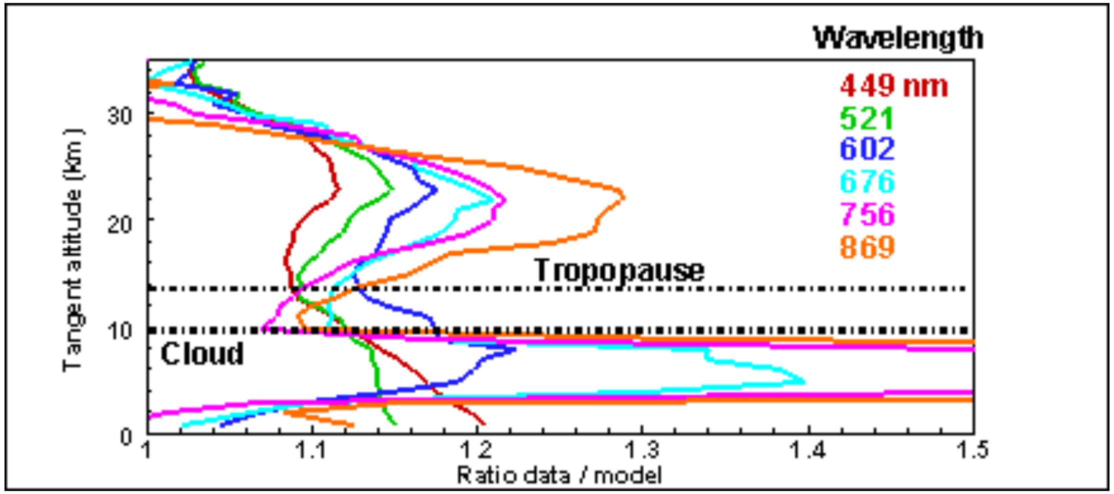




LS Aerosol Sensitivity

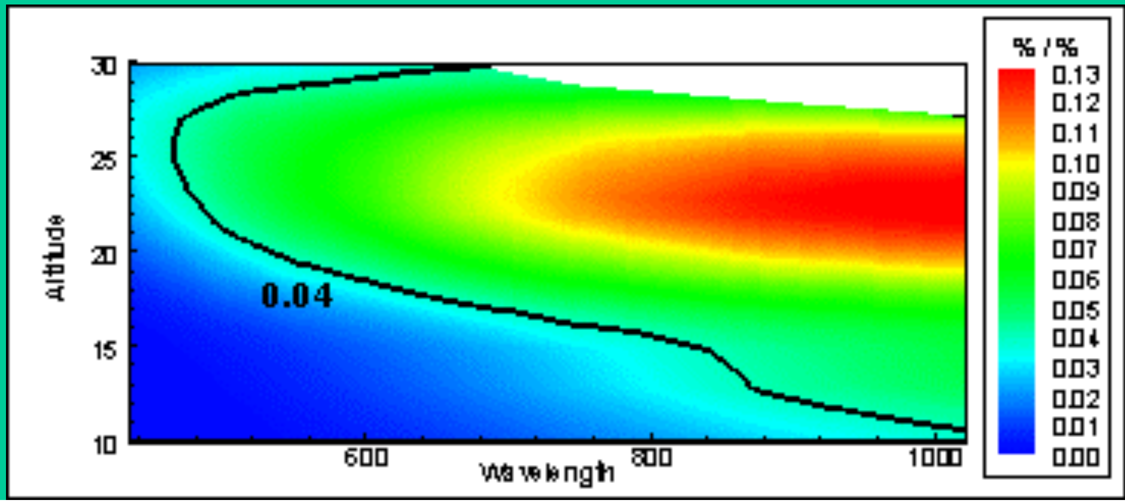
The range of heights with significant LS aerosol sensitivity is limited…

Ratio of data to model (No aerosol)



Sensitivity functions for aerosol retrieval: Dlog(I) / Dlog(β_a)

… especially at the shorter wavelengths



EDR development

Calibrated, [λ,TH] registered radiances

→

- Cloud height
- RSAS TH registration
- Surface reflectance
- Aerosol retrieval
- Ozone retrieval
- 1σ uncertainties
- Inline a-priori (O_3, NO_2, aerosol)

→

Ozone profiles
Aerosol profiles

↑

Temperature and pressure

Ozone Environmental Data Records (EDRs) Performance Requirements (→ Goals)

Table 1. Total Column Ozone EDR Performance.

Measurement Parameter	***Specification***
Horizontal Cell Size	50 KM @nadir
Range	50 DU to 650 DU
Accuracy	15 DU or better
Precision	3 DU + 0.5%
Long-term Stability	**1% over 7 years**

Table 2. Ozone Profile EDR Performance.

Measurement Parameter		***Specification***
Vertical Cell Size		**3 KM**
Vertical Coverage		Tropopause to 60 KM
Horizontal Cell Size		250 KM
Range		0.1 to 15 ppmv
Accuracy	Below 15 KM	Greater of 20% or 0.1 ppmv
	Above 15 KM	**Greater of 10% or 0.1 ppmv**
Precision	Below 15 KM	Greater of 10% or 0.1 ppmv
	15 to 50 KM	**Greater of 3% or 0.05 ppmv**
	50 to 60 KM	Greater of 10% or 0.1 ppmv
Long-term Stability		**2% over 7 years**

Science Team objectives:
Statement of work

- Produce an **operating algorithm** for the data products from the OMPS/LP instrument. The algorithm, at launch, will process **all the data** and the ozone data will be distributed to interested data users.
- **During early operation phase**, algorithm will be tuned (using a research stream developed by ST, as well as lessons learnt during CAL/VAL)
- The processing algorithm will then be **transferred to NOAA** to support operational users. (no earlier than one year after launch time)

Science Team composition

Roles and responsibilities

Science team is composed of two groups:

- **LaRC/HU:**
  - **D. Rault (LaRC), PI: SDR and EDR algorithms**
  - **R. Loughman (Hampton University), coI: EDR**
  - **D. Flittner (LaRC), coI: Data analysis**
- **GSFC/SSAI**
  - **R. McPeters (NASA, GSFC)**
  - **G. Jaross (SSAI), coI: SDR and instrument testing**
  - **G. Taha (SSAI), coI: OSIRIS/SCIA proxy testing, Validation**

Science team is being helped by the Ozone PEATE (GSFC):

Operational CPUs, Code testing, SDR+EDR integration, Integration to OMPS suite, Configuration control, Calibration trending, Operational data processing

Aerosol properties to retrieve:

- **Stratospheric aerosol extinction -- *f(λ, z)***
- **Stratospheric aerosol optical properties (complex index of refraction) – *f(λ, z)***
- **Stratospheric aerosol shape and size distribution – *f(z)***

This is a chronically underdetermined problem (since all can vary with altitude)

Initial SAGE III LS Aerosol Extinction Retrieval Method

- Ozone profile & effective surface reflectivity are static
- Compare I_d / I_n to I_c / I_n to solve for aerosol extinction at each tangent height:
  - I_d = measured radiance data
  - I_c = calculated radiance with latest aerosol extinction profile in the atmosphere (updated at each iteration)
  - I_n = calculated radiance, with no aerosol in the atmosphere
- Use assumed aerosol size distribution (ASD), shape (spherical), and index of refraction (1.448, 0) to solve for the extinction profile $\beta_a(z)$ at each wavelength independently

ASD Characterization

$$M_k = \int r^k N(r) dr$$

$$R_a = \frac{M_3}{M_2}$$ (area-weighted effective radius)

$$R_v = \frac{M_4}{M_3}$$ (volume-weighted effective radius)

For a single-mode, log-normal ASD:

$$R_a = r_0 \exp\left(\frac{5}{2} \ln^2 \sigma\right) \qquad R_v = r_0 \exp\left(\frac{7}{2} \ln^2 \sigma\right)$$

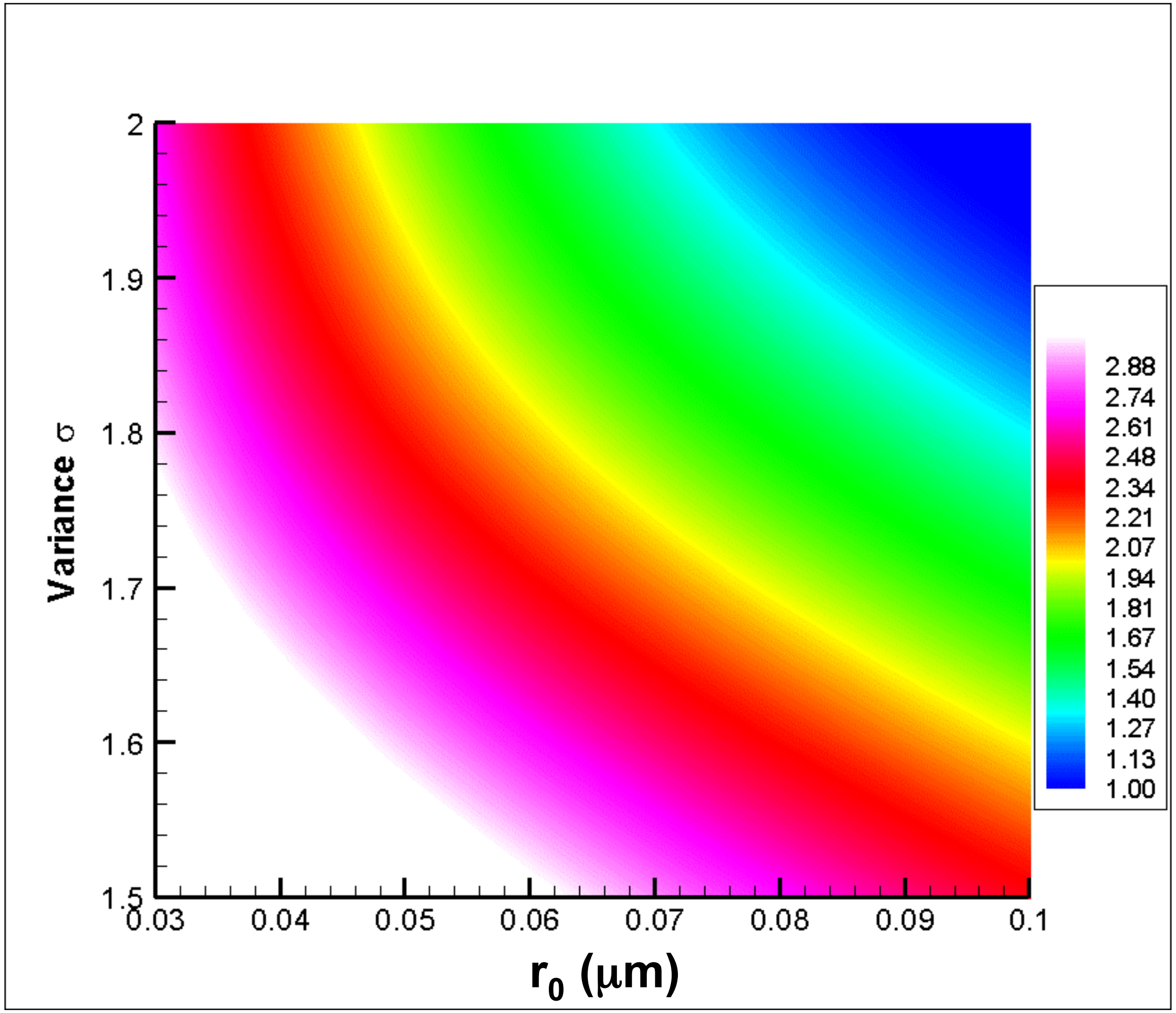
General effective radius: $r_0 \exp\left(\theta \ln^2 \sigma\right)$

We seek a single parameter to characterize the ASD, based on its moments $\boldsymbol{M_k}$.

Several authors (Hansen and Travis, 1974; Lenoble and Brogniez, 1984; Bauman et al., 2003) suggest $\boldsymbol{R_a}$ as a promising candidate.

(Shettle, 2006): For today's small stratospheric aerosol particles, $\boldsymbol{R_v}$ may be even better…

What can we learn about ASD?

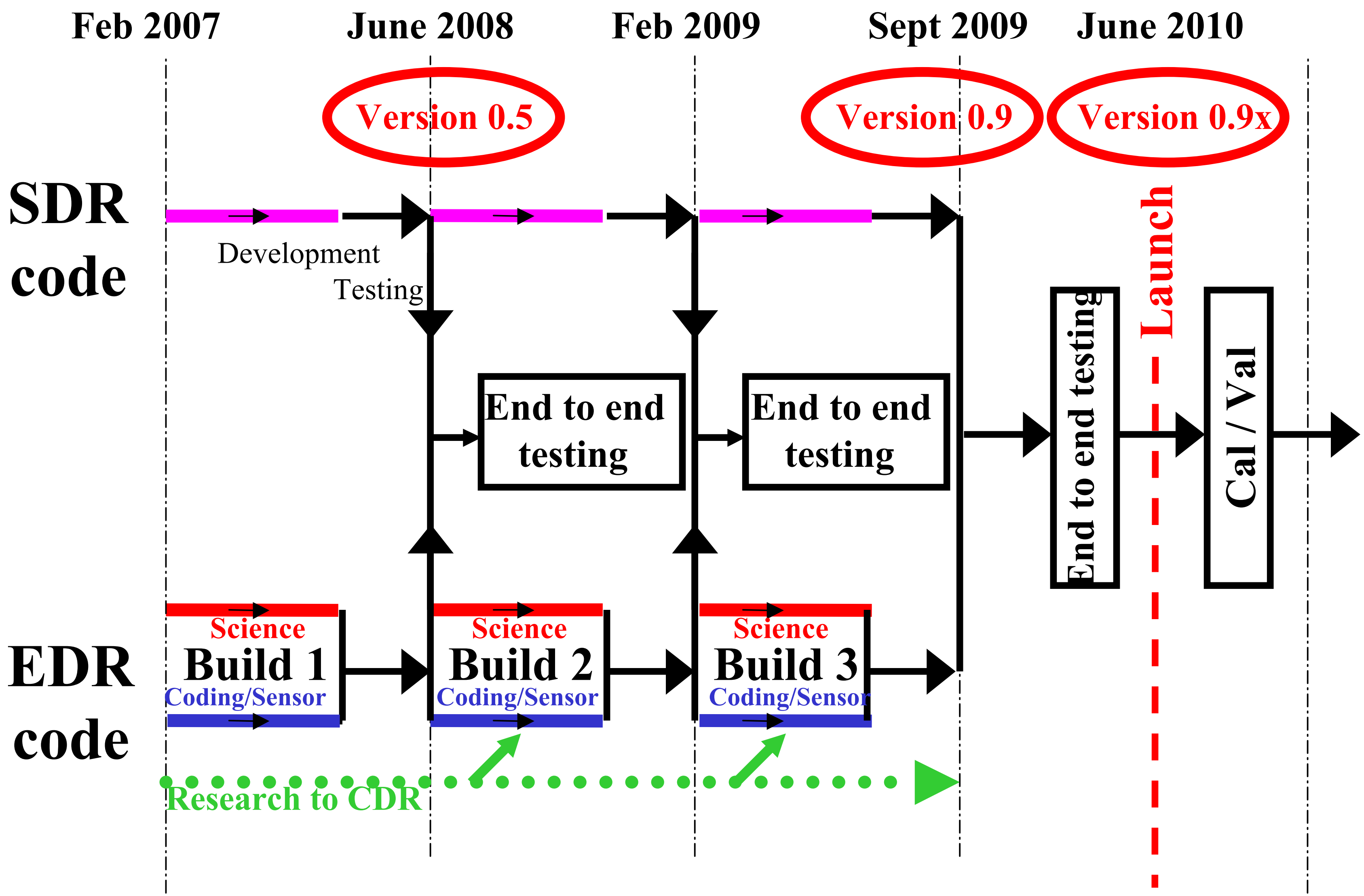


ASD retrieval seeks the (r_0, σ) pair for which the aerosol extinction cross-section $C_a(\lambda)$ best matches the retrieved aerosol extinction coefficient $\beta_a(\lambda)$.

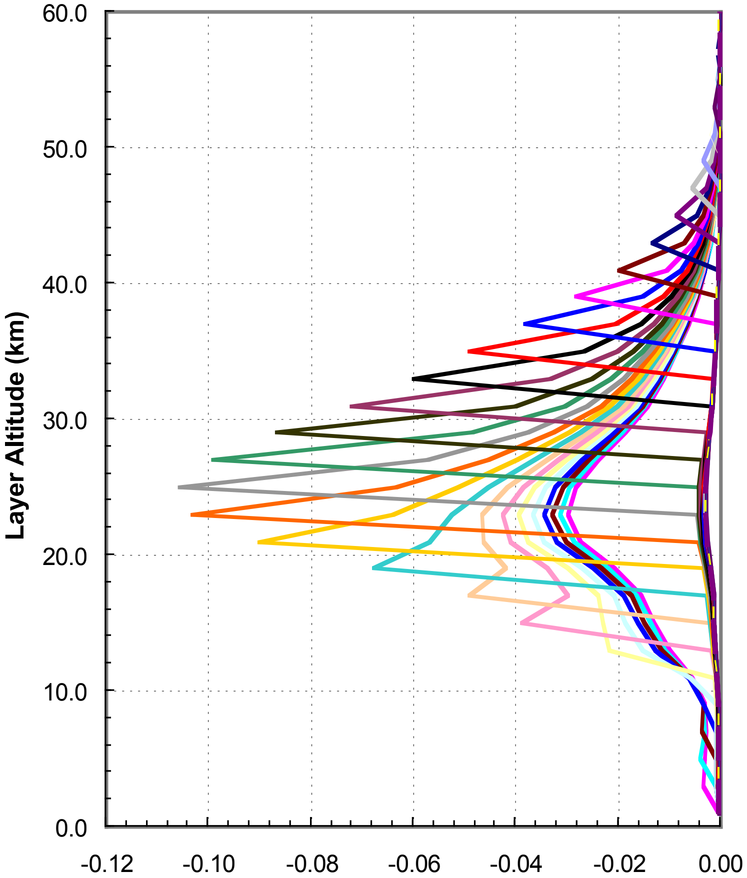
***Problem:* Many plausible (r_0, σ) pairs work equally well!**

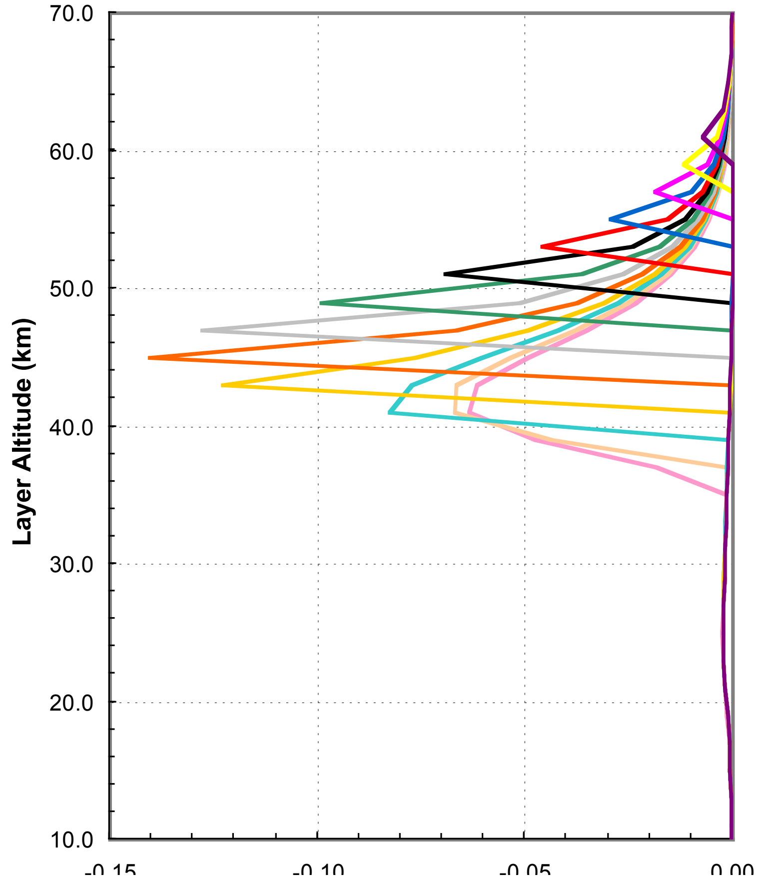
From Rault and Loughman (2007)

Science Team schedule (highlights)



Radiance Sensitivity to Ozone

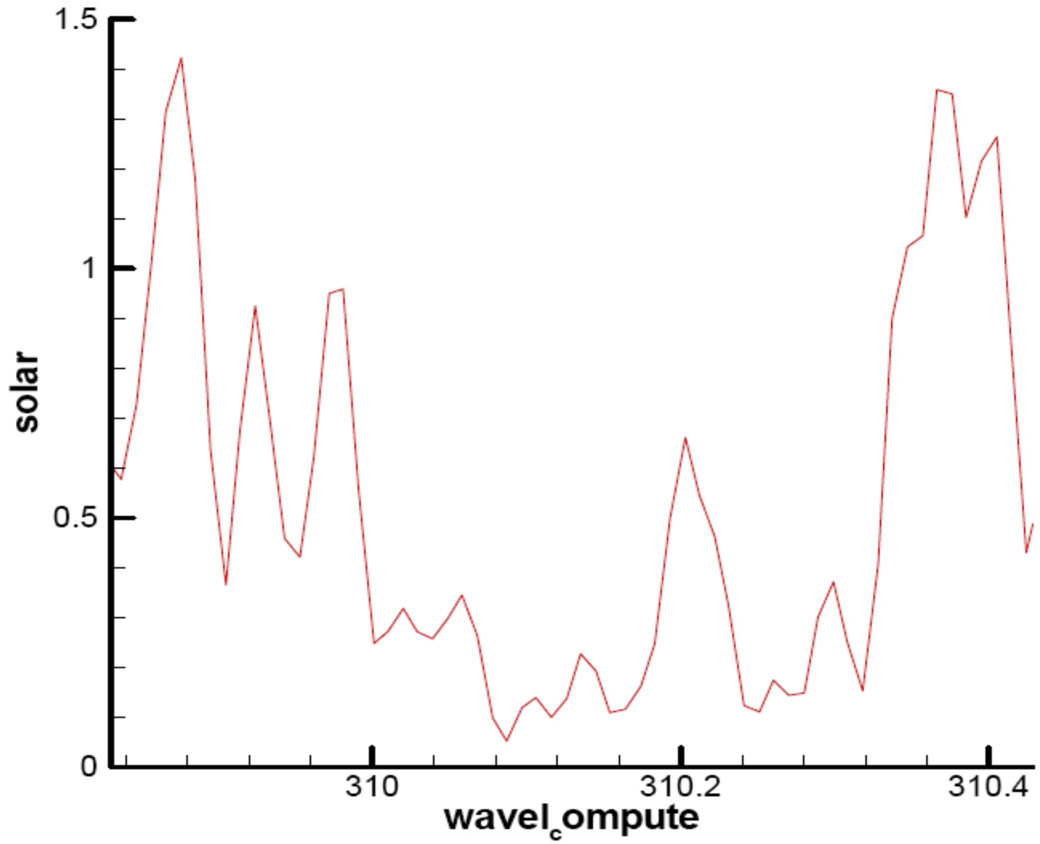




5) Ozone: Each curve shows the % change in radiance at a single tangent height due to a given perturbation in the ozone amount (for a 1-km layer) as a function of altitude.

The plots correspond to radiance at 600 nm (left) and 305 nm (right).

Sensitivity of solar grid



- Wild gyrations in solar irradiance on 1 Angstrom scales – stick with the native grid!

Radiative Transfer Modeling

Three concentric spectral grids are used for the RT calculation:

- Highest resolution = "0 grid" = "Convolution grid", used to apply the solar irradiance to calculated "albedos" (radiances with unit solar flux) & convolve them with the spectral slit functions.
- Middle resolution = "P grid" = "SS grid", sets the grid of wavelengths at which single-scattering radiance calculations are done in the RT model. This grid = a subset of the 0 grid, with points chosen near pixel centers, ozone absorption features, etc.
- Low resolution = "MS grid", used within the RT model for multiple-scattering, with interpolation using MS/SS ratios to fill in MS values between the nodes. This grid = a subset of the P grid, with points chosen as needed to maintain accuracy of better than 0.2% across the spectrum.
- **Run time breakdown:**

"Convolution grid"	**-- 1%**
"SS grid"	**-- 10%**
"MS grid"	**-- the rest!**

RT model setup: Theory

Nick-name	Purpose	Source	Fwd # of pts	Inv # of pts	Run-time Impact
0	Convolution	MODTRAN solar data	27000	27000	Negligible
P	Single Scatter	X-sect extrema	2750	500	Small
Q	Multiple Scatter	X-sect extrema	110	22	Large