OMPS Limb Profiler (LP) aerosol extinction algorithm development

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Abstract

This poster describes recent updates to the OMPS Limb Profiler (LP) aerosol extinction algorithm. The updated algorithm has been simplified, using assumed aerosol microphysical properties to infer the aerosol extinction at a single wavelength (676 nm) based on the limb scattered radiance. This retrieved aerosol extinction profile is then used to compute radiances across the OMPS LP spectrum, which can be compared to the OMPS LP measurements to assess the consistency of the assumed aerosol microphysical properties and retrieved extinction values. Initial assessment of the radiance residuals at several wavelengths will be presented.

OMPS LP Introduction

The Ozone Mapping and Profiler Suite (OMPS) Limb Profiler (LP) instrument measures the limb-scattered (LS) radiance through 3 slits, as shown in Fig. 1.

- Spectral coverage: 290 – 1000 nm
- Spectral resolution: 1.5 (UV) – 30 (NIR) nm
- Instantaneous Field of View (FOV): 1.85°
- Instantaneous Tangent Height Range: 110 km

OMPS LP is currently flying on the Suomi NPP satellite, with a subsequent flight scheduled for NOAA's Joint Polar Satellite System (JPSS)-2 (scheduled to launch in FY 2021).

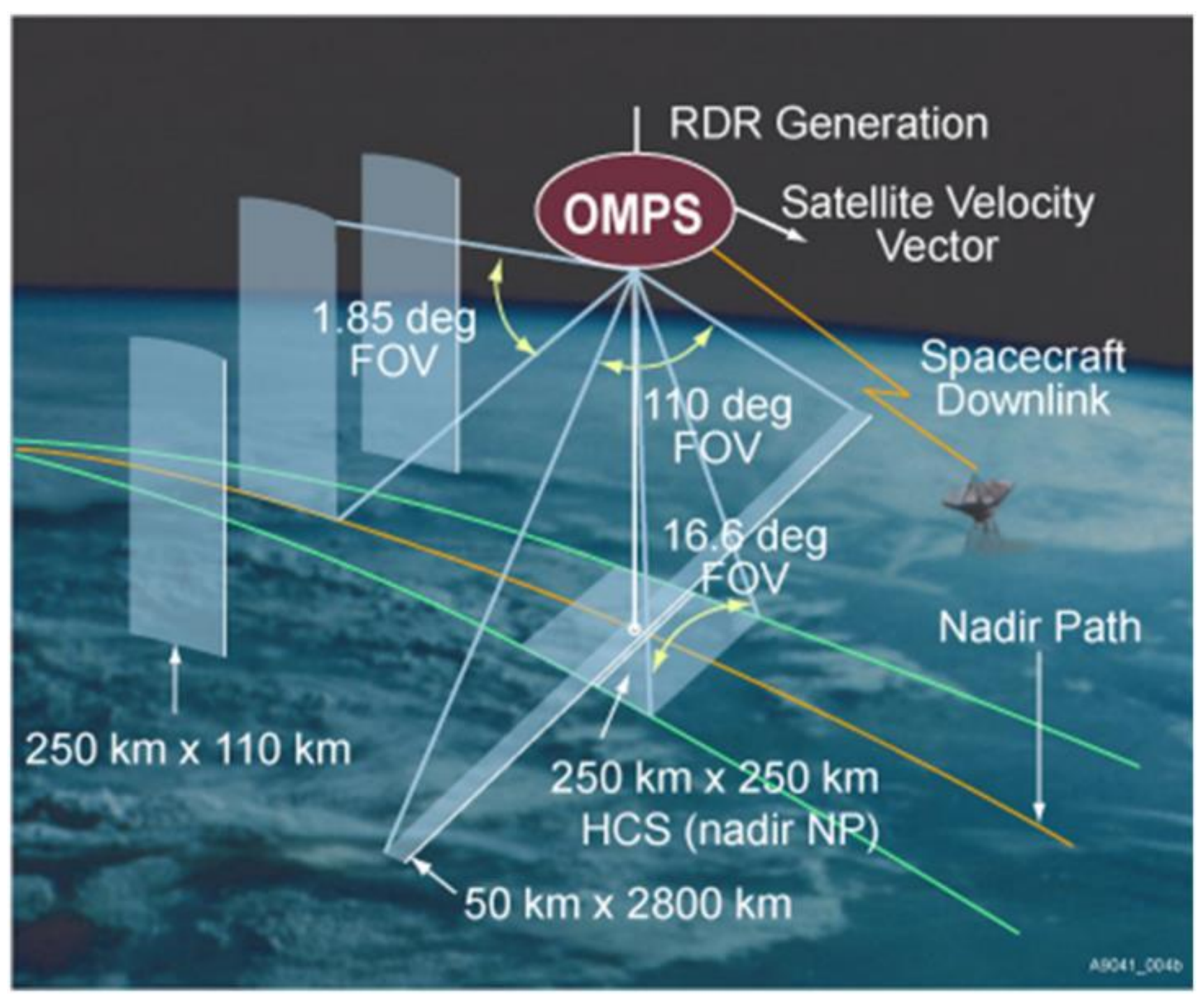


Fig. 1 – OMPS illustration. OMPS LP views the limb of the atmosphere through 3 thin vertical slits in the spacecraft aft direction, as shown. (Courtesy of Ball Aerospace)[1]

Why Retrieve Aerosol?

As its name suggests, the primary purpose of OMPS is to measure ozone. But we are also interested in retrieving aerosol extinction profiles, for 2 primary reasons:

1. The LS radiance *I* measured by OMPS LP is also influenced by interactions with aerosol, particularly the upper tropospheric / lower stratospheric (UT/LS) aerosols found along the line of sight (LOS, see Fig. 2). To maintain the desired ozone retrieval quality, the retrieval algorithm must account for interfering species such as aerosol.
2. UT/LS aerosol profiles are highly variable (in the vertical, horizontal and temporal dimensions), making measurements of the UT/LS aerosol properties inherently interesting due to their effects on the chemistry, dynamics, and radiation balance in that atmospheric region.

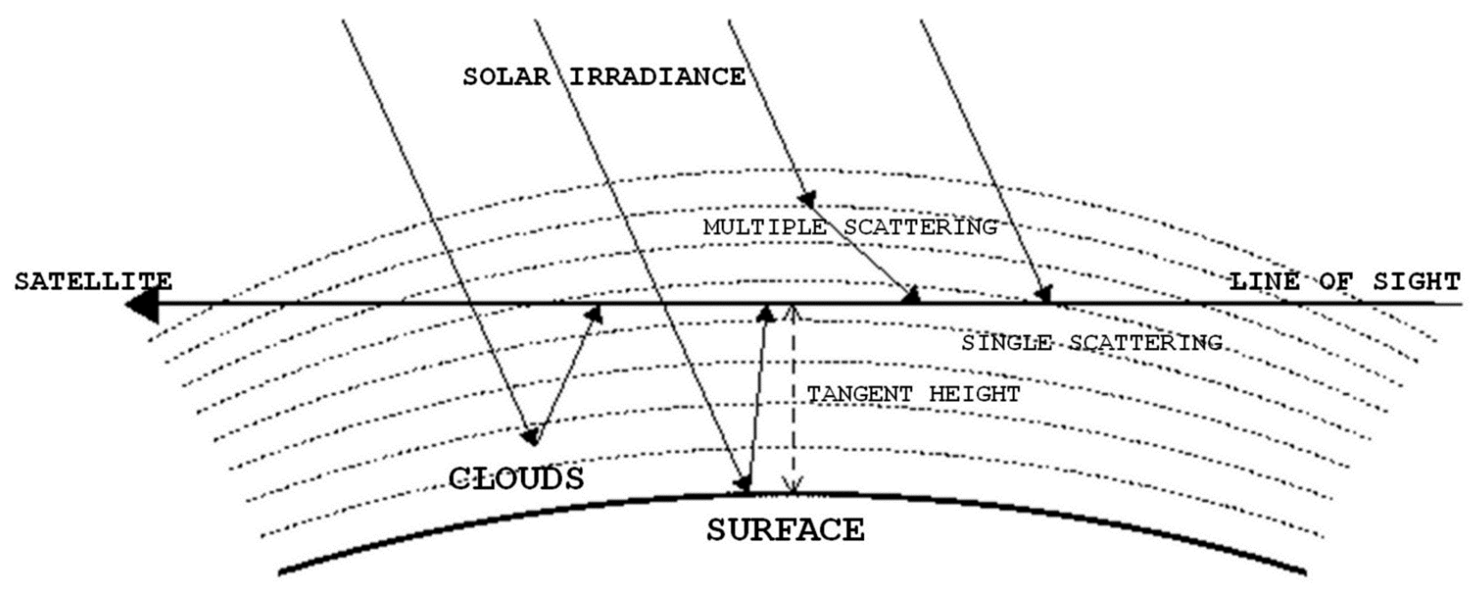


Fig. 2 – Illustration of the LS viewing geometry, including several possible mechanisms for scattered radiation to reach the satellite (single scattering, multiple scattering, surface and cloud reflection, etc.).[1]

Aerosol Wavelengths

The clearest aerosol signal is available at wavelengths λ with minimal interference by gaseous absorption. Our chosen wavelengths closely mimic the aerosol-sensitive channels used for solar occultation measurements by the Stratospheric Aerosol and Gas Experiment (SAGE) III team[2]:

385, 449, 521, 600, 676, 755, 868, 1020 nm

The OMPS LP instrument characterization is best at the wavelengths used for ozone retrieval (λ < 700 nm). To minimize molecular scattering, we therefore focus on the λ highlighted above.

Relevant Aerosol Properties

Two aerosol optical properties appear in the radiative transfer (RT) equation:

1. β_a = aerosol extinction coefficient (km^{-1}), signifies the rate at which radiation is lost due to aerosol per unit of path length
2. $P_a(\Theta)$ = aerosol scattering phase function, signifies the probability of scattering by aerosols into scattering angle Θ.

At a non-absorbing λ for which the atmosphere is optically thin and the corresponding molecular scattering properties [β_m and $P_m(\Theta)$] are well-known, these two properties (+ the surface reflectivity) are the primary variables that determine the LS radiance *I*.

Unfortunately, these aerosol optical properties depend upon several physical properties of the aerosol. These properties generally vary in time and space, and are imperfectly known:

1. Aerosol real and imaginary refractive index
2. Aerosol shape
3. Aerosol size distribution (ASD)

These properties cannot all be simultaneously determined from the OMPS LP measurements.

Current (V2) Aerosol Retrieval

The V2 aerosol retrieval[1] proceeds by estimating the 3 properties listed above by:

1. Assuming aerosols are sulfuric acid droplets with refractive index (1.448, 0).
2. Assuming spherical aerosols (Mie theory).
3. Beginning with an initial guess ASD (single-mode log-normal, with no altitude variation).

The algorithm retrieves $\beta_a(\lambda)$ based on these assumptions, then updates the ASD based on the wavelength-dependent radiance residual $R(\lambda)$, which is the difference between measured *I* and calculated *I* using retrieved $\beta_a(\lambda)$. The V2 algorithm was used to study the stratospheric remnants of the Chelyabinsk bolide[3].

Reasons for a New Algorithm

- The $R(\lambda)$ produced by the relatively complex V2 aerosol retrieval is difficult to interpret
- As shown in Figs. 3-4, the OMPS LP radiances are relatively insensitive to ASD for most of the orbit, making those ASD update highly sensitive to measurement noise, etc.
- While efforts to improve the OMPS LP radiance characterization (of stray light, etc.) proceed[4], it is best to focus on the longest λ < 700 nm for aerosol retrieval.

Updated Aerosol Retrieval

The updated aerosol retrieval proceeds like the V2 algorithm for items #1-2, then:

3. Uses a fixed ASD (again single-mode log-normal, with no altitude variation).

The algorithm retrieves β_a(676 nm) based on these assumptions. The wavelength-dependent radiance residual $R(\lambda)$ therefore contains ASD information entangled with measurement errors, instrument effects, etc. (to be refined later).

Chahine Algorithm

The updated algorithm also uses the Chahine[5] method to update the aerosol extinction profile $\beta_a(z)$, rather than the maximum likelihood method of Rodgers[6] that was used in V2. The Chahine method was chosen primarily because its solution is largely independent of the initial guess, while the V2 algorithm was sometimes affected by the relatively poor a-priori information available for $\beta_a(z)$ (e.g., see Fig. 6).

Updated RT model (ASD)

The updated algorithm also uses an updated RT model[7]. This model improves the accuracy of the calculated radiances (relative to the V2 algorithm's RT model), and also adds the possibility of varying ASD with altitude.

Stratospheric aerosol measurement campaigns clearly demonstrate that the ASD varies significantly with altitude (typically with smaller particles at higher altitudes)[8]. The RT model has been updated to allow the ASD [and therefore $P_a(\Theta)$] to vary with altitude. As a rough indication of the significance of this variation, the total radiance change at 345 and 600 nm is shown below for a simulated OMPS LP orbit in which the aerosol phase function differs, but all other quantities (including aerosol extinction coefficient) are fixed.

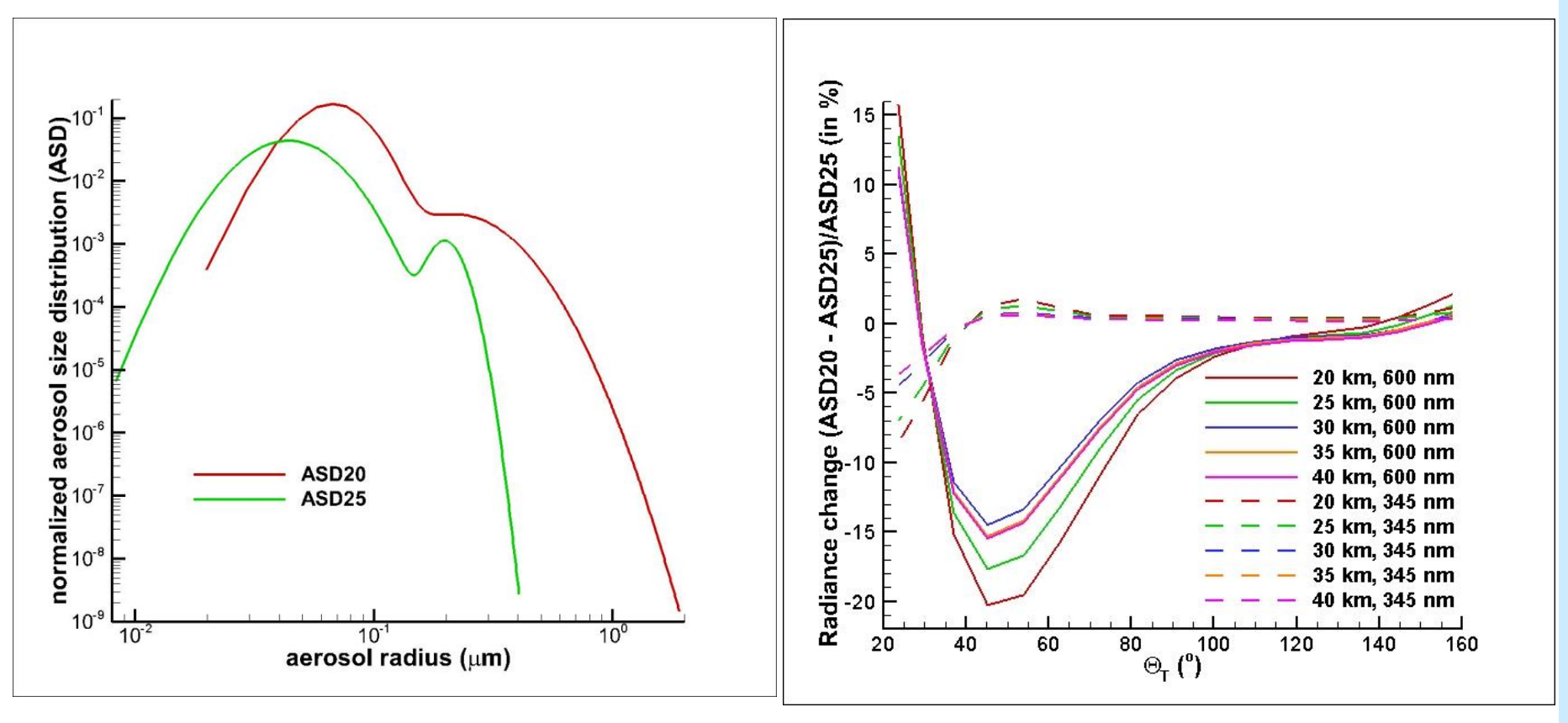


Fig. 3 – OMPS LP radiance sensitivity (right panel) to aerosol ASD (left panel). See below for further discussion.

ASD Sensitivity Discussion

The left panel of Fig. 3 shows bi-modal log-normal ASDs based on data for 6 balloon flights over Laramie, Wyoming during 2012, at 20 km and 25 km[9]. The right panel of Fig. 3 shows how *I* changes when each ASD is used (for the entire atmosphere), at *h* = 20, 25, 30, 35, 40 km. The magnitude of the radiance sensitivity to ASD suggests that over-simplified portrayal of the stratospheric ASD (e.g., excluding the phase function variation with altitude) may be a significant source of aerosol extinction retrieval error.

ASD or β_a?

Fig. 3 clearly shows that *I* is insensitive to ASD when Θ > 90° (which occurs in the Southern Hemisphere for OMPS LP). This is confirmed in Fig. 4 for a different comparison: When the ASD mode radius is perturbed by 5%, *I* is similarly unaffected when Θ > 90°. Furthermore, the pattern of $\Delta I(\lambda)$ along the orbit due to ASD perturbations resembles the spectral response change in $\Delta I(\lambda)$ due to $\beta_a(\lambda)$ perturbations, as determined by Mie theory. Only in the Northern Hemisphere (NH), when Θ < 90°, can the ASD effect be easily distinguished from the $\beta_a(\lambda)$ effect.

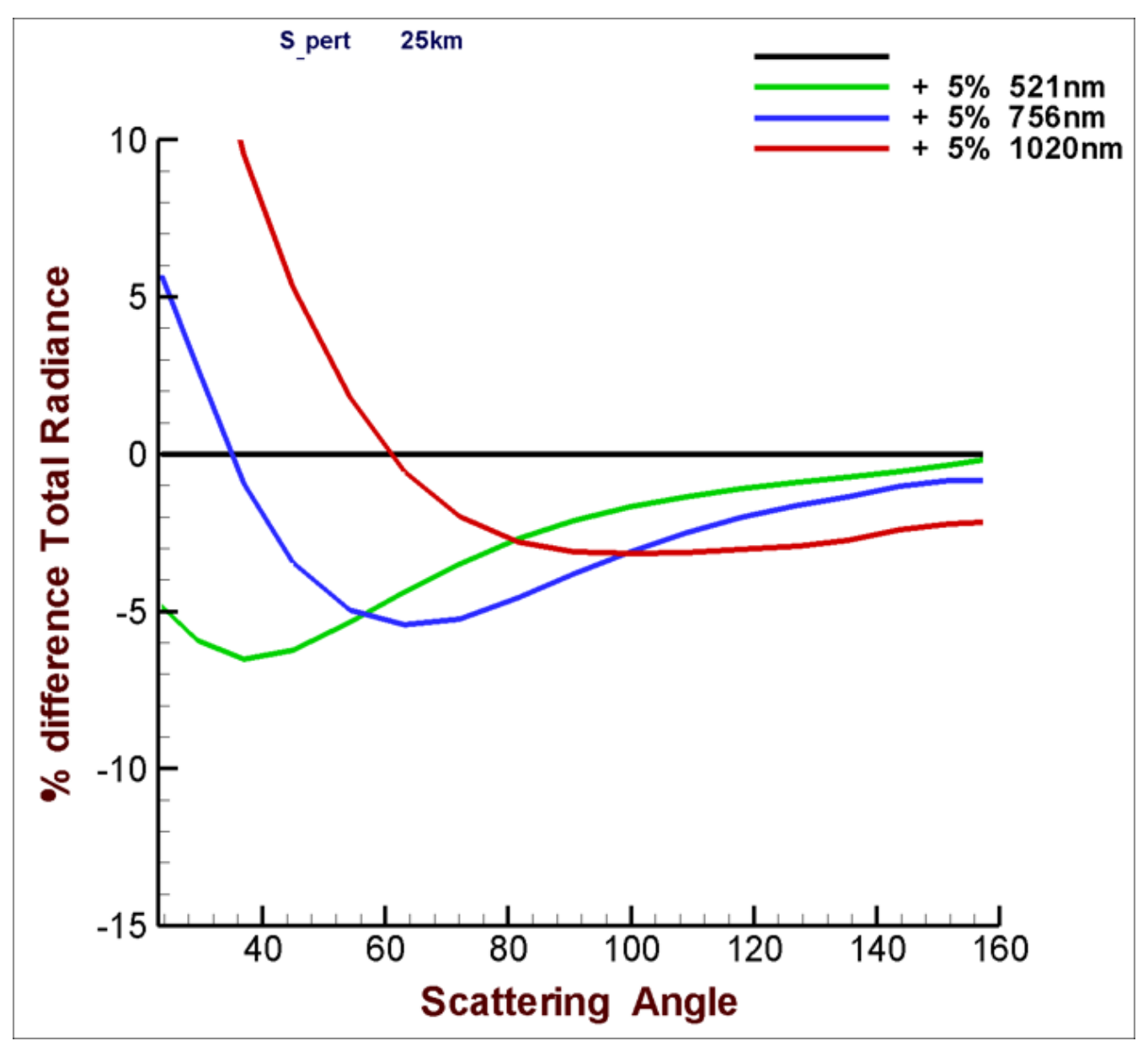


Fig. 4 – OMPS LP radiance sensitivity at z=25 km to a 5% perturbation in ASD mode radius at several wavelengths.

Residual Improvement

Fig. 5 shows the V2 aerosol retrieval algorithm radiance residuals *R*(676 nm) for an orbit of OMPS LP data. Large *R* values at the highest tangent heights are due to stray light in the measured *I*. The retrieval algorithm reports convergence at large frame numbers (> 140, which occur at the NH end of the orbit, with small Θ), but *R* > 20% for those cases. The updated algorithm reduces these residuals greatly, as shown in Figs. 6-7.

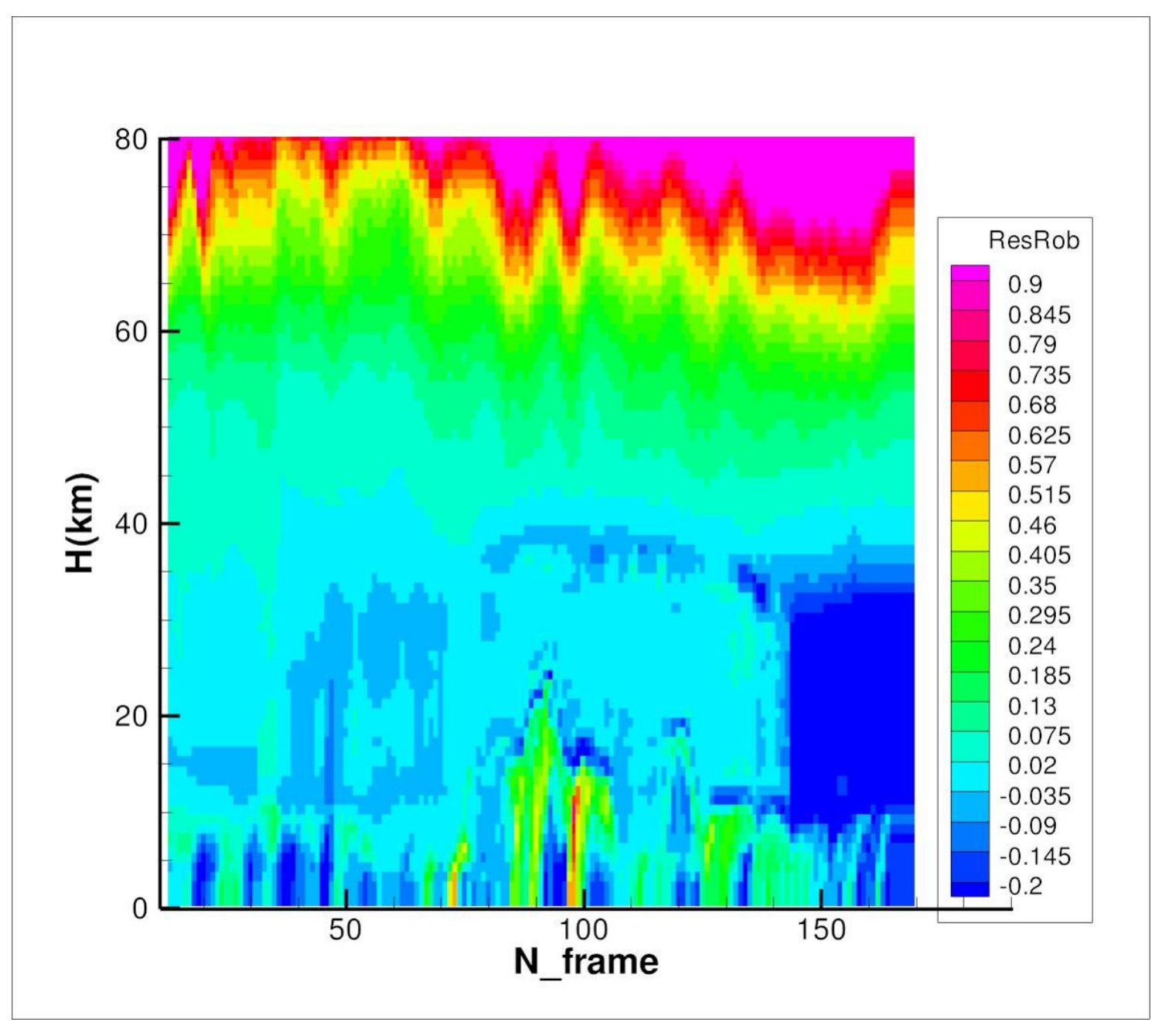


Fig. 5 – OMPS LP radiance residuals as a function of height and frame number.

Fig. 6 – A priori, V2, and Chahine β_a(676 nm) profiles, for frame 146.

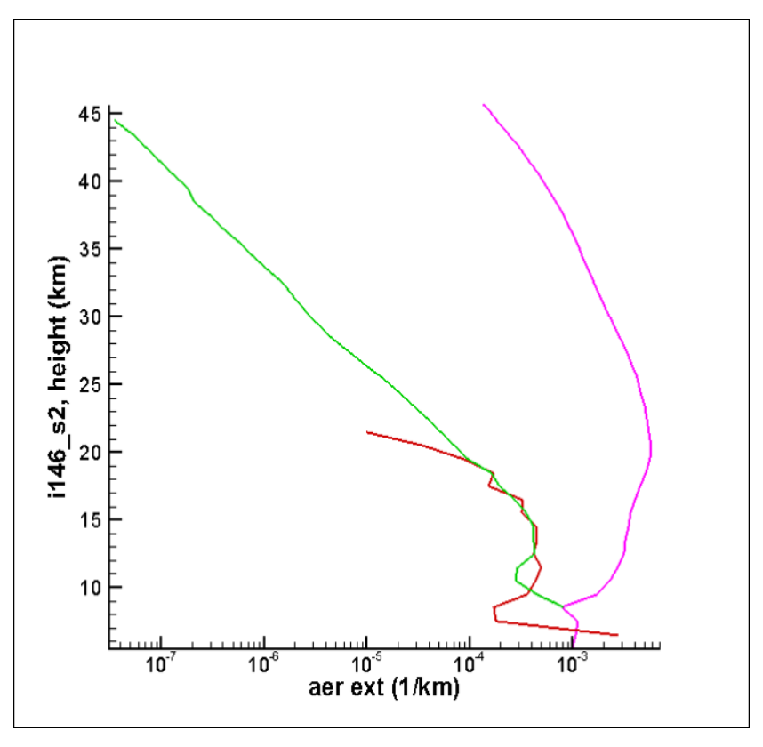
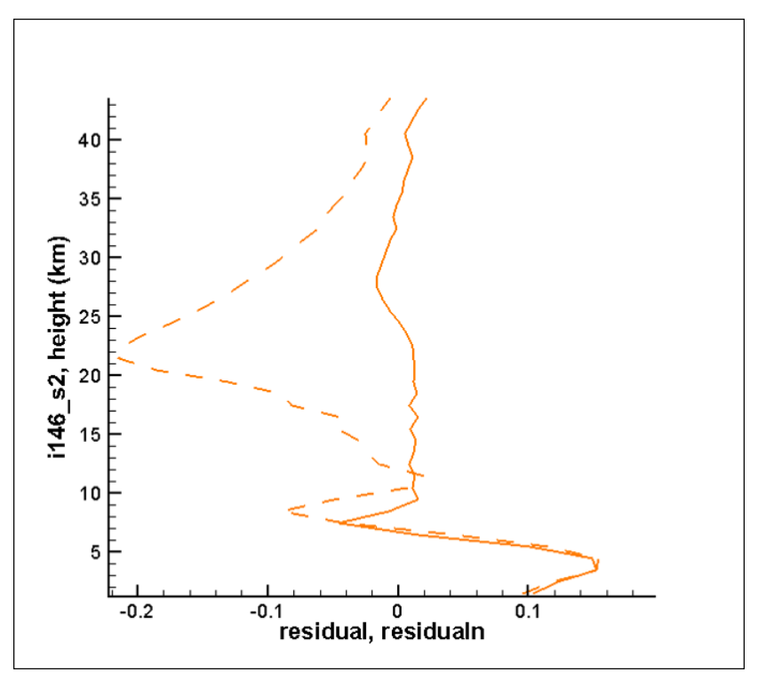


Fig. 7 - $R(\lambda)$ profiles, for V2 (dashed line) and Chahine (solid line) retrievals.



Summary

The OMPS LP aerosol retrieval algorithm has been updated, primarily to simplify it and make its radiance residuals easier to interpret. The algorithm updates also improve the convergence of the retrieval. As the OMPS LP radiance characterization improves, the information content of the longer wavelength radiances (λ > 700 nm) will yield additional aerosol information . The updated algorithm will prove particularly useful when stratospheric perturbations (such as volcanic eruptions) introduce aerosols that vary rapidly with space and time. Updating the retrieval algorithm to allow the ASD to vary with altitude is an ongoing project.

Acknowledgements

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References

1 - Rault and Loughman (2013), *IEEE Trans. on Geoscience and Remote Sensing*, doi:10.1109/TGRS.2012.2213093

2 – Thomason et al. (2007), *Atmos. Chem. Phys.,* doi:10.5194/acp-7-1423-2007

3 – Gorkavyi et al. (2013), *GRL*, doi:10.1002/grl.50788

4 – Jaross et al. (2014), *JGR*, doi:10.1002/2013JD020482

5 – Chahine (1968), *J. Opt. Soc. Am.,* 12, 1634-1637

6 – Rodgers, Inverse Methods for Atmospheric Sounding: Theory and Practice, (2000).

7 – Loughman et al. (2015), *Atmos. Chem. Phys.,* doi:10.5194/acp-15-3007-2015

8 - Deshler, T.D. et al. (2003), *JGR,* doi:10.1029/2002JD002514

9 - Deshler, T.D. et al. (2013), http://www-das.uwyo.edu/~deshler/Data/Aer_Meas_Wy_read_me.htm