ADM-AEOLUS VERTICAL SAMPLING

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Abstract

In 2012 the ESA Core Explorer Atmospheric Dynamics Mission, ADM-Aeolus, is due for launch. Scientific preparations are being made in the area of campaigns, Cal/Val, the development of an End-to-End simulator, E2S, and L1 and L2 wind profile processors. For ADM an advanced vertical sampling scenario needs to be elaborated due to the limited number of vertical range gates that are available in the Doppler Wind Lidar instrument. Issues of instrument wind calibration, wind variability climate, atmospheric optical and dynamical heterogeneity, expected beneficial impact, and data assimilation method are all at interplay in the optimisation of the vertical sampling. In this manuscript the focus will be on Aeolus performance in relation to atmospheric heterogeneities. Both in terms of processing and in terms of the distribution of vertical range gates (vertical processing levels) the characteristics of the atmosphere play an important role. High-resolution radiosondes, space lidar (CALIPSO), ECMWF model data and ground based measurement data sets are collocated to yield the combined optical and dynamical properties of the atmosphere that are relevant for Aeolus. Collocated CALIPSO and enhanced ECMWF data provide realistic test data to study Aeolus processing and sampling options. In a second step the sensitivity of data assimilation and NWP models to vertical sampling is investigated and some first results are shown in this paper. Tropospheric observations appear most relevant for defining both tropospheric and stratospheric flow.

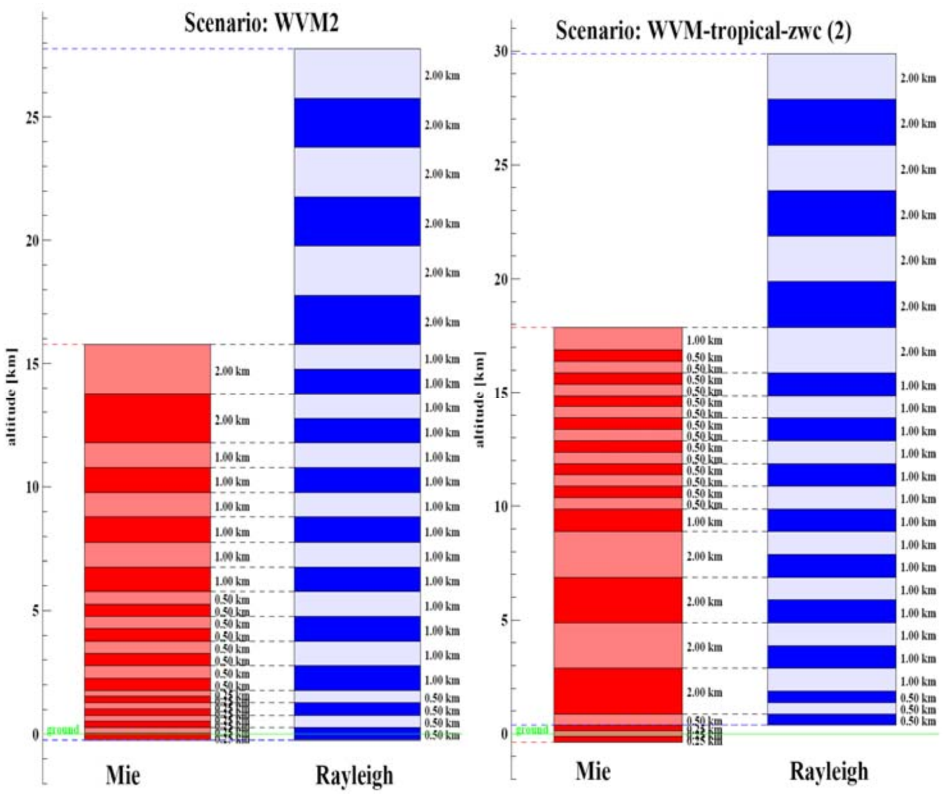

Figure 1: **Illustration of two possible Aeolus sampling modes with Mie particle and Rayleigh molecular sampling in resp. red and blue. The left mode focuses on the PBL, whereas the right mode details the tropical tropopause.**

1. INTRODUCTION

The Aeolus mission and the wind ground processor are further described in the 9th issue of the International Winds Workshop (IWW) Proceedings, resp. by Ingmann and Straume and Tan et al.; for more details see also Stoffelen et al. (2005) and www.esa.int/esaLP/LPadmaeolus.html. The atmospheric wind will be measured by a single payload onboard the Aeolus satellite, the Atmospheric LAser Doppler INstrument (ALADIN). This is a direct detection High Spectral Resolution Lidar (HSRL), operating in the ultra-violet spectral region. Its laser emits a short but powerful laser pulse toward the atmosphere, from which a small portion is scattered back by air molecules and cloud and aerosol particles. A telescope collects the backscattered light and directs it to optical receivers which measure the Doppler shift of the received signal. The ALADIN Doppler Wind Lidar (DWL) detects the backscattered light from Mie (particle backscatter) and Rayleigh (molecular backscatter) separately, on a Fizeau and Fabry-Perot receiver respectively, allowing for accurate particle and molecule backscatter and extinction products. The HSRL is, however, sensitive to cross-talk contamination (Tan et al., 2008) especially in the case of strong Mie-backscatter (e.g. from cirrus clouds). The cross-talk will be removed with care, with the help of appropriate instrument calibration. This cross-talk correction is dependent on a perfect vertical matching (one-to-one, one-to-two, etc. ratio of the bin thicknesses) of the Mie and Rayleigh sampling bins.

The Aeolus vertical sampling mode can be changed 8 times per orbit on average. However, the changes cannot be made weather dependent, since set more than two weeks in advance. A main limitation in the vertical bins is its number; only 24 Mie and 24 Rayleigh receiver bins are available. Moreover, the vertical bin size may be multiples of 250 m, but at maximum 2000 m. Other constraints are that Fizeau receiver bins should cover ground calibration over land (when possible), Fabry-Perot and Fizeau receiver bin winds should be cross calibrated which is most effective near 2-3 km height (the top of the PBL), Mie cross-talk correction is required on the Fabry-Perot measurements by using Fizeau measurements in the same height range (bin), where Mie contamination is infrequent in the stratosphere.

With these given constraints, it is thus relevant to investigate which vertical sampling schemes provide most wind information in the various geographical regions. This is the topic of the European Space Agency VAMP study: Vertical ADM-Aeolus Measurement Positioning. ADM-Aeolus will look into a both horizontally and vertically heterogeneous atmosphere, exhibiting aerosol stratification and moving clouds, complicating the interpretation and usefulness of the Aeolus observations. Combined wind and optical variability may cause height assignment errors within the bin, which, when accompanied with large vertical wind shear will be associated with large wind errors. Height assignment errors occur for example when only the lower half of a bin exhibits excessive UV extinction and most of the backscatter emerges from the top. Another relevant question lies in the usefulness or expected beneficial impact in the PBL, free troposphere, tropopause and stratosphere regions at different vertical sampling.

Other possible atmospheric complications exist in vertical atmospheric motion, since in data assimilation the Aeolus winds are represented by the horizontal wind vector due to lack of vertical wind representation in nowadays models. The Aeolus lidar hits the earth surface at an angle of about 37.5 degrees. In the 9th IWW proceedings Stoffelen et al. (2008) discusses the issue of vertical motion and concludes that the highest and potentially most detrimental vertical motion generally occurs below thick cloud and is not visible for Aeolus.

We discuss below the atmospheric wind heterogeneity, the atmospheric optical heterogeneity and the implications for Aeolus vertical measurement positioning. In a second step the sensitivity of data assimilation and NWP models to vertical sampling is investigated and some first results are shown in this paper.

2. OPTICAL ATMOSPHERE

Not many collocations of optical and dynamical measurement data exist. In order to build a set of climatologically representative scenes for ADM-Aeolus, we use available CALIOP data. The space-borne CALIPSO mission successfully acquires space-borne lidar data from the CALIOP instrument for almost 4 years, thereby covering all seasons. We collocate CALIOP data for all seasons with NWP model fields from ECMWF in order to acquire collocated atmospheric optical and dynamical data.

The CALIPSO level-2 aerosol product at 40 km horizontal resolution is rather coarse for the ADM-Aeolus basic sampling of 1-3.5 km. Therefore we use the CALIPSO level-1 product of attenuated backscatter (350 m horizontal resolution) at 532 nm wavelength and convert it to particle backscatter at 355 nm. To be compatible with the Aeolus sampling and to reduce instrument noise artifacts, we average to 3.5 km in the horizontal and 125 m in the vertical. To further suppress noise artifacts we only use night-time CALIPSO data. Figure 2 shows a typical result.

The derivation of optical properties starts with estimating the molecular backscatter and extinction from a given NWP temperature profile, followed by a cloud detection algorithm, and an aerosol detection step. The obtained molecular, aerosol and cloud optical properties at 532 nm are subsequently scaled to optical properties at 355 nm, thus enabling the computation of simulated UV attenuated backscatter profiles for both the ADM-Aeolus Mie and Rayleigh detection channels. The details of the retrieval will be reported elsewhere (Marseille et al., in preparation).

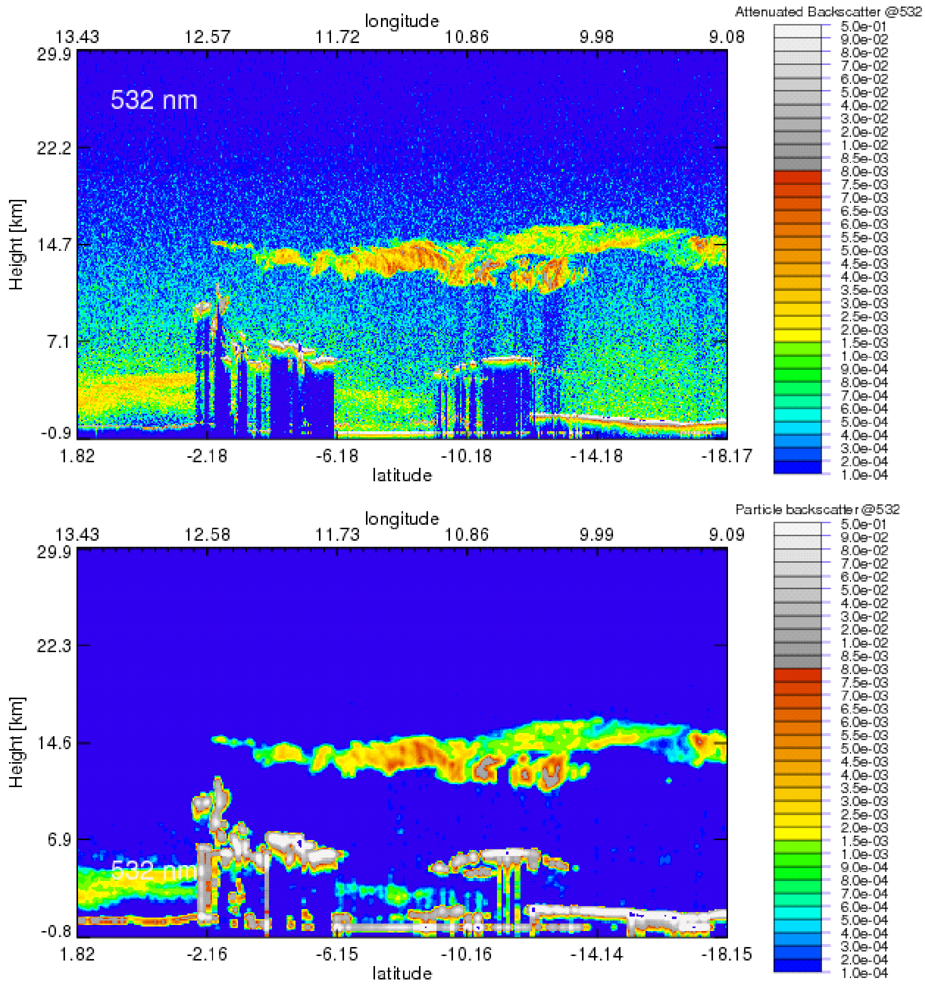

Figure 2: **CALIOP L1 attenuated backscatter (top) and KNMI derived particle backscatter at 3.5km horizontal and 125 m vertical sampling (bottom), both at 532 nm. While noise artifacts are suppressed, the main atmospheric structures as observed by CALIOP are still visible in the lower panel. Regions of spurious artifacts below dense clouds will not be observed by Aeolus.**

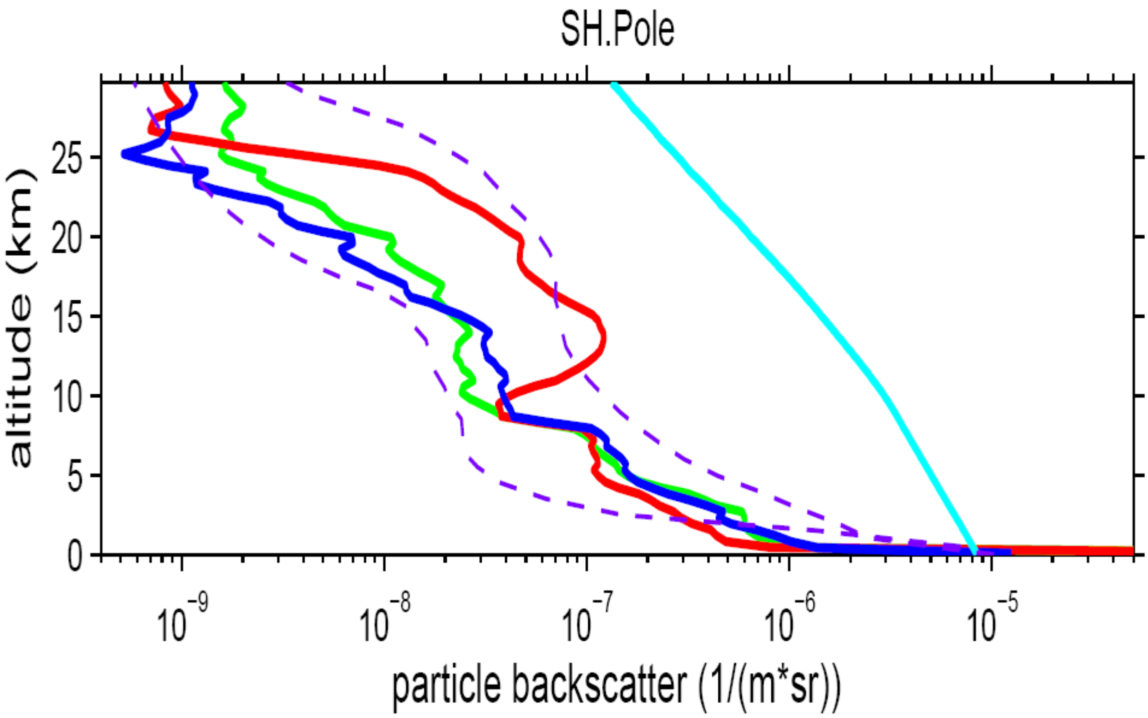

Figure 3 **Particle backscatter median below 70S at 355 nm as retrieved from CALIPSO night-time data, with April, August and October 2007 in resp. solid green, red and blue. Light blue solid is the molecular backscatter and purple dashed the Vaughan and LITE median, resp. left and right (see text). The KNMI-derived CALIPSO climate appears consistent with other climatologies with clear enhanced backscatter in August due to polar stratospheric clouds.**

Figure 3 shows, however, that the retrieval of optical properties by the KNMI algorithm on CALIPSO data is compatible with aerosol backscatter climatologies found earlier. These include an aircraft campaign by Vaughan et al. (Vaughan et al., 1995) in 1989, a relatively clean year, and the Space Shuttle data from LITE measured in 1994 (e.g., Marseille and Stoffelen, 2003), a relatively “dirty” year just after the Mnt. Pinatubo eruption in 1991. Moreover, the August backscatter in Figure 3 shows the expected enhanced backscatter due to polar stratospheric clouds (PSC). More in general, the KNMI-retrieved particle backscatter appears in line with the existing datasets on atmospheric backscatter. The CALIPSO-derived optical properties can be computed over a long period and thus provide an ideal basis for studying ADM-Aeolus processing by simulation.

3. DYNAMICS

At the 9th International Winds Workshop Stoffelen et al. (2008) compare collocated radiosonde and ECMWF winds and show that the effective vertical resolution of the ECMWF model is about 1.5-2 km. Stoffelen et al. (2010) show that the lack of vertical resolution is associated with a similar lack of wind variability in the horizontal below scales of 300 km. In fact, small-scale 3D wind structures are missed in the ECMWF model. The aspect ratio of these structures appears to be over a hundred, i.e., with a horizontal extent more than hundred times the vertical extent, as expected for atmospheric 3D turbulence. To obtain realistic wind variability on the ADM-Aeolus measurement scale, KNMI adds random wind variability to the ECMWF wind profiles on the smallest scales, i.e., below 2 km vertically. These “enhanced” ECMWF wind profiles, which are now compatible with the wind shear variability climate as observed in high-resolution radiosondes, are collocated with the CALIPSO-retrieved optical data outlined in section two, to obtain combined atmospheric optical and dynamical data with realistic variability.

At the 9th International Winds Workshop Stoffelen et al. (2008) showed that combined optical and dynamical gradients of particles may generate wind errors in ADM-Aeolus observations of a few m/s when the ECMWF model is used. After the above-mentioned wind variability enhancement, the number of cases with errors larger than a m/s increases about an order of magnitude as presented at the workshop. A point of further research is how to couple the added random wind variability to the high-resolution optical structures. For example, in cases of convection a correlation may be expected in small-scale wind and cloud particle density gradients. The current procedure ignores such correlation, which, when present, may further increase the expected wind errors of Aeolus. Due to the horizontal and vertical (Mie) oversampling of the atmosphere by ADM-Aeolus, such cases may be detected and subject to further quality control (QC).

4. WIND OBSERVATION SENSITIVITY

Marseille et al. (2008) use the ECMWF model adjoint in a sensitivity study to test the impact of prospective DWL missions on (past) forecasts of extreme weather. The adjoint code may also be used to test the evolution of initial stratospheric or tropospheric perturbations through the atmosphere that linearly transfer their energy to either the troposphere or stratosphere at the optimization time, e.g., after 5 days (figure 4). Below we report on the growth of so-called singular vectors in the ECMWF model. Typical examples are displayed in figure 5.

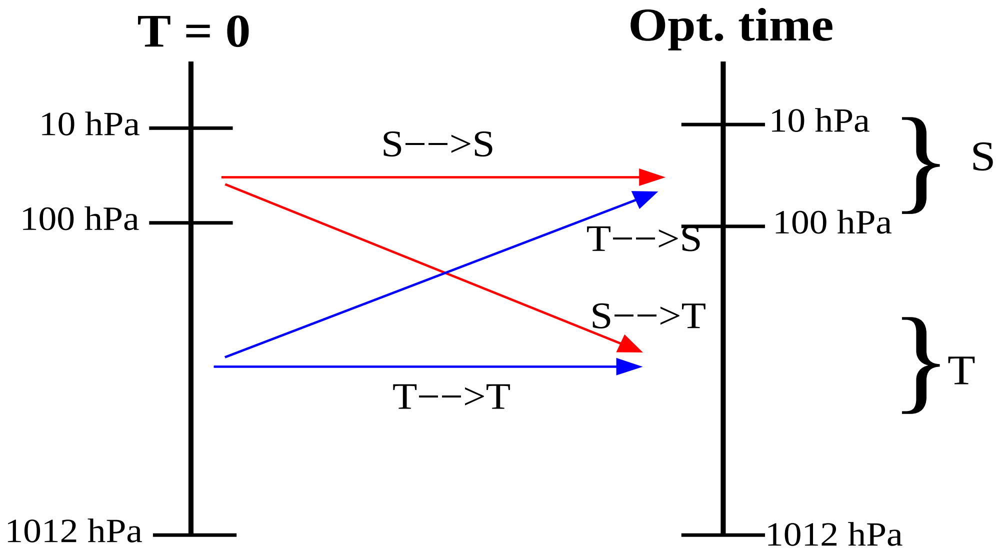

Figure 4: **Illustration of the sensitivity experiments to test the linear evolution of initial stratospheric (S) or tropospheric (T) perturbations to either the stratosphere (S) or troposphere (T) at the optimization time.**

Figure 6 shows the amplification of initial extra-tropical tropospheric or stratospheric singular vectors into the troposphere ranked by amplification factor. Initial combined tropospheric and stratospheric perturbations show identical growth to the tropospheric perturbations, since the initial stratospheric perturbations do not contribute much to the troposphere after 5 days.

Table 1 shows the amplification of initial extra-tropical tropospheric or stratospheric singular vectors into the troposphere or stratosphere for a 2 or 5 day optimization window. Initial tropospheric singular vectors show substantial growth both after 2 and 5 days in the troposphere, whereas stratospheric singular vector amplification is rather modest, both into the troposphere and stratosphere. This makes that the growth of initial stratospheric singular vectors into the troposphere is small with respect to the contribution of the initial tropospheric singular vectors. At the same time, the growth of initial tropospheric singular vectors into the stratosphere is important in relation to the contribution of the initial stratospheric singular vectors. This has not been tested yet for the 5-day optimization window though.

The tropical dynamics are less well represented in NWP models than the extra-tropical dynamics and moreover have different physical characteristics (Žagar et al., 2007). We did not study the tropics with the above method.

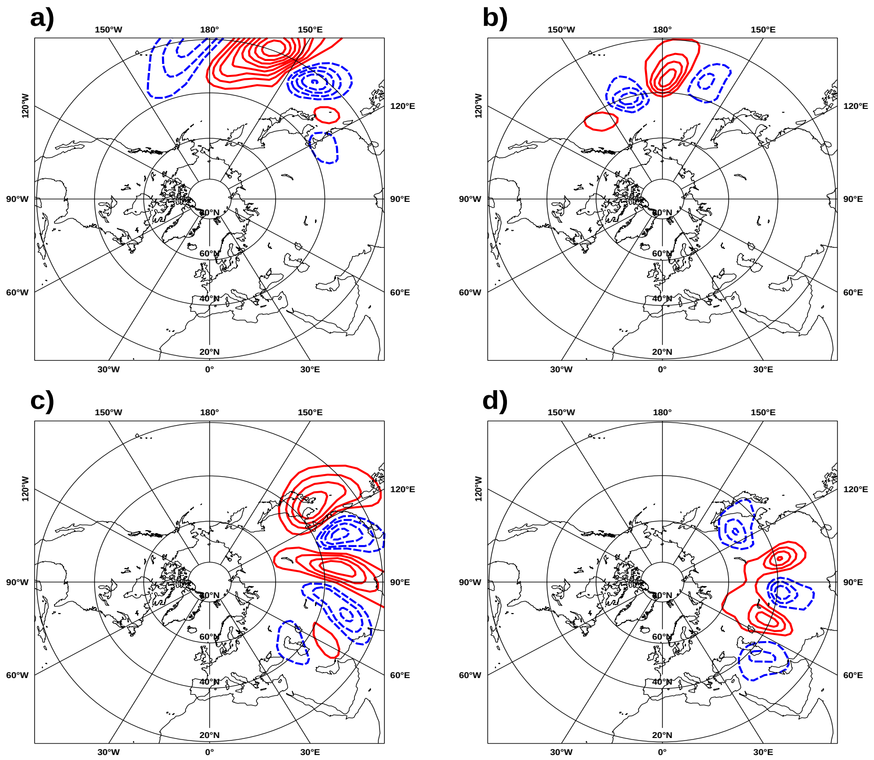

Figure 5: **Stream-function field of a typical individual stratosphere-to-troposphere singular vector initially at the 55 hPa pressure level (a and c) and after 5 days at the 500 hPa pressure level (resp. b and d).**

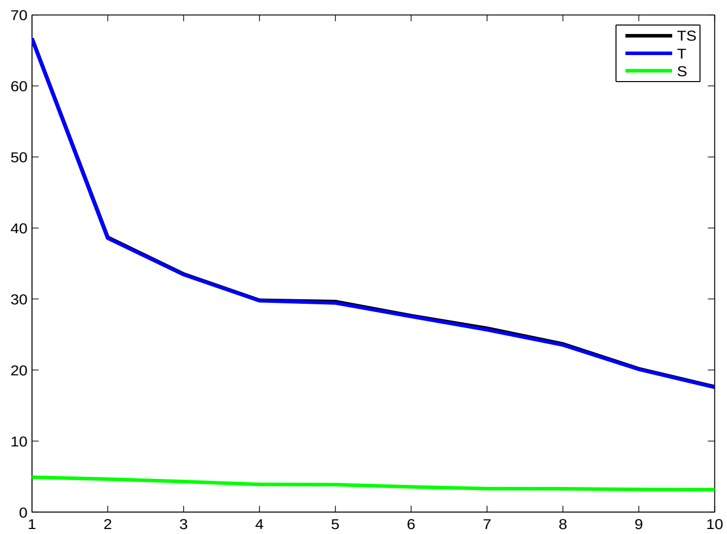

Figure 6: **Summer amplification (y-axis) of initial extra-tropical tropospheric (T) or stratospheric (S) perturbations (singular vectors) (x-axis) into the troposphere ranked by amplification factor. Initial combined tropospheric and stratospheric (T/S) perturbations show identical growth to the T perturbations (overlapping black and blue lines), since the initial S perturbations do not contribute.**

	2 days	5 days
T -> T	14	45
S -> S	4	6
S -> T	1	9
T -> S	1.5	-

Table 1: **Mean amplification over summer and winter of initial extra-tropical tropospheric (T) or stratospheric (S) perturbations (singular vectors) into the troposphere (-> T) or stratosphere (-> S) for an optimization time of 2 days or 5 days. Initial T perturbations show large growth into the T, whereas S shows modest growth in the S and T. T growth into S is sizable as compared to S -> S.**

In the ESA VAMP study further research is being conducted to test the impact of wind observation profiles in NWP. In a first study, the effectiveness of the wind observations to reduce common vertical background error structures, B, of NWP models is investigated. For example, since the depth of B structures varies in the vertical, one may expect that the optimal Aeolus receiver bins may also vary in the vertical. In a second study within VAMP, simulated Aeolus observations are assimilated in an ensemble of data assimilation experiments. The spread of the ensemble is used as a measure of observation impact. Different experiments with varying DWL scenarios could reveal sensitivity to Aeolus wind observation density in the troposphere or stratosphere. This is work in progress.

5 CONCLUSIONS

For ADM-Aeolus an advanced vertical sampling scenario needs to be elaborated due to the limited number of vertical range gates that are available in the Doppler Wind Lidar instrument. Issues of instrument wind calibration, zonal wind variability climate, atmospheric optical and dynamical heterogeneity, expected beneficial impact, and data assimilation method are all at interplay in the optimisation of the vertical sampling. Collocated CALIPSO and enhanced ECMWF data provide realistic test data to study Aeolus processing and sampling options.

In a sensitivity study using the ECMWF model, we found that tropospheric observations appear most relevant for defining both the tropospheric and stratospheric extra-tropical flow. Further sensitivity studies are underway.

The ADM-Aeolus satellite hardware is being tested progressively. The most challenging part is clearly in the laser system, where essential advances have been made over the last few years and the final tests are being prepared at ESA and industry. The Aeolus ground segment is forthcoming and provision of real-time wind profiles is being considered by EUMETSAT (Stoffelen, 2009).

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