CLOUD-AEROSOLS SPIN-OFF PRODUCTS RELEVANT TO CLIMATE MONITORING THAT COULD BE PROVIDED BY THE "ADM – ÆOLUS" ESA'S WIND MISSION: THE L2A DATA PROCESSOR AND NEW CONCEPT OF INTEGRATED TWO-WAY TRANSMISSION

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Abstract

The ADM-ÆOLUS Direct Detection Wind Lidar could provide spin-off products on aerosols and clouds. The L2A processor under study is presented with an emphasis on the retrieval technique used for molecular signals (Rayleigh channel). A concept of Integrated Two-Way Transmission is presented. The impact of complete or partial filling of range bins on L2A processor retrievals is analyzed.

1. ADM-ÆOLUS

The European Space Agency (ESA) is currently developing a Wind Lidar as "Atmospheric Dynamic Mission" (2nd Earth Explorer core mission selected in 1999). The general framework and status of ADM-ÆOLUS will be presented at the 23 ILRC.
In addition to wind information, ADM-ÆOLUS could also provide cloud-Aerosols spin-off products relevant to climate monitoring in the continuation of the joint NASA-CNES CALIPSO mission that has been successfully launched on 28 April 2006.
ADM-ÆOLUS is basically a direct Detection Wind Lidar designed as a High Spectral Resolution Lidar (HSRL). Fig. 1 displays a schematic of ADM-ÆOLUS and horizontal sampling strategy that results in a 25 % duty cycle. At receiver level it implements two spectrometers (a dual Fabry-Perot and a Fizeau interferometer) that provide molecular (Rayleigh) and particle (Mie) signals in two distinct channels (a key feature of HSRL). Based on Signal-to-Noise ratio consideration, the HSRL signals are accumulated in 25 range bins of various lengths i.e. 250 m, 500 m, 1000 m or 2000 m. The short bins will be used near the surface whereas the long bins will be used in the upper troposphere and lower stratosphere (notice that the final set up is still under study).
In the present paper we address the retrieval of the local optical depth (LOD) in the various range bins of the Rayleigh channel. Beforehand we derive the relevant equations to process the signals. For the sake of simplicity we do not consider here inherent cross talk between the two channels, but it is addressed in the study. Section 2 presents the spin-off products. Section 3 presents the accumulated Rayleigh signals. As said before, cloud and aerosol spin-off products will be retrieved at the same sampling mode as used for wind information. It is a new problem that requires a dedicated study. The Integrated Two-Way Trans-mission (ITWT) concept for the Rayleigh channel is presented in section 4. The ITWT equation is solved as an analytical explicit equation in order to retrieve the LOD. Complete or partial fillings of the range bin are studied. Section 5 presents the preliminary validation and discussion of the results.

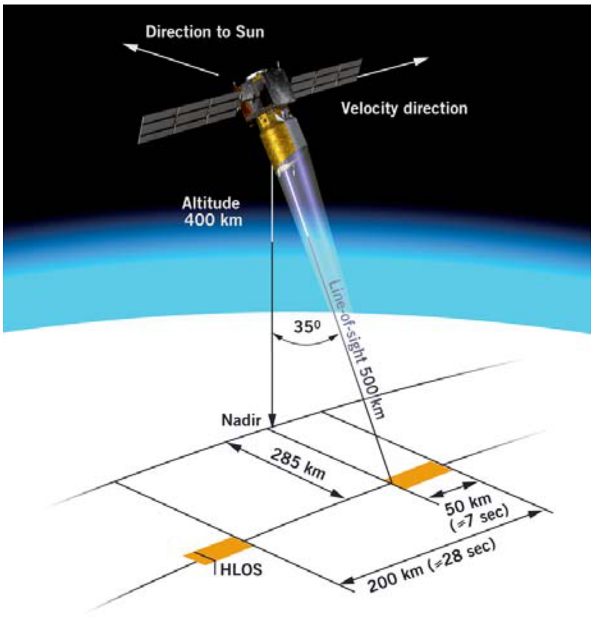

Fig. 1: ADM-ÆOLUS concept. It displays one single line-of-sight at 35° off nadir. The light scattered at 355 nm by molecules and particles is collected by a 1.5-m diameter telescope and accumulated in 25 vertical range bins. The HSRL duty cycle is 25 % i.e. 50 km (or 7 sec) every 200 km (28 sec).

2. Spin-off products

The relevant spin-off products into range bin (i,j) are the i) scattering ratio $(\beta_m + \beta_p)/\beta_m$, ii) particle LOD and iii) extinction-to-backscatter ratio. Fig. 2 displays the proposed L2A processor that implements i) a feature finder algorithm, the L1B data will be processed at 3.5 km horizontal resolution (index j) that results into 15 granularities

over the 50 km, ii) a scene classification algorithm to discriminate between aerosol layer, aerosols types, water and ice clouds, iii) various processing algorithms for Mie and Rayleigh channels. The Feature finder algorithm (step 1) is based on Mie channel signal processing to identify the presence of particles in a vertical range bin *i*. after horizontal accumulation on *j* (according to SNR test). The Rayleigh background in Mie channel is suitable to compute a 1st value for scattering ratio.
The scene classification will makes use of the full 50 km horizontal observation. Both, the scene classification and processing algorithms will make use of geophysical data provided by meteorological analyses at the best resolution. Look up tables of backscatter-to-extinction ratio $\beta_p(z) = k_p\,\alpha_p(z)$ are needed to process the Mie channel signals in order to retrieve the LOD. Combining the LOD retrievals in the two channels will enable to derive the backscatter-to-extinction ratio.
The LOD in range bin *i* is used to compute the 2-way particle transmission to the next range bin *i*-1 and so on down to the surface.
Iteration between step 3 and 2 will improve the scene classification.

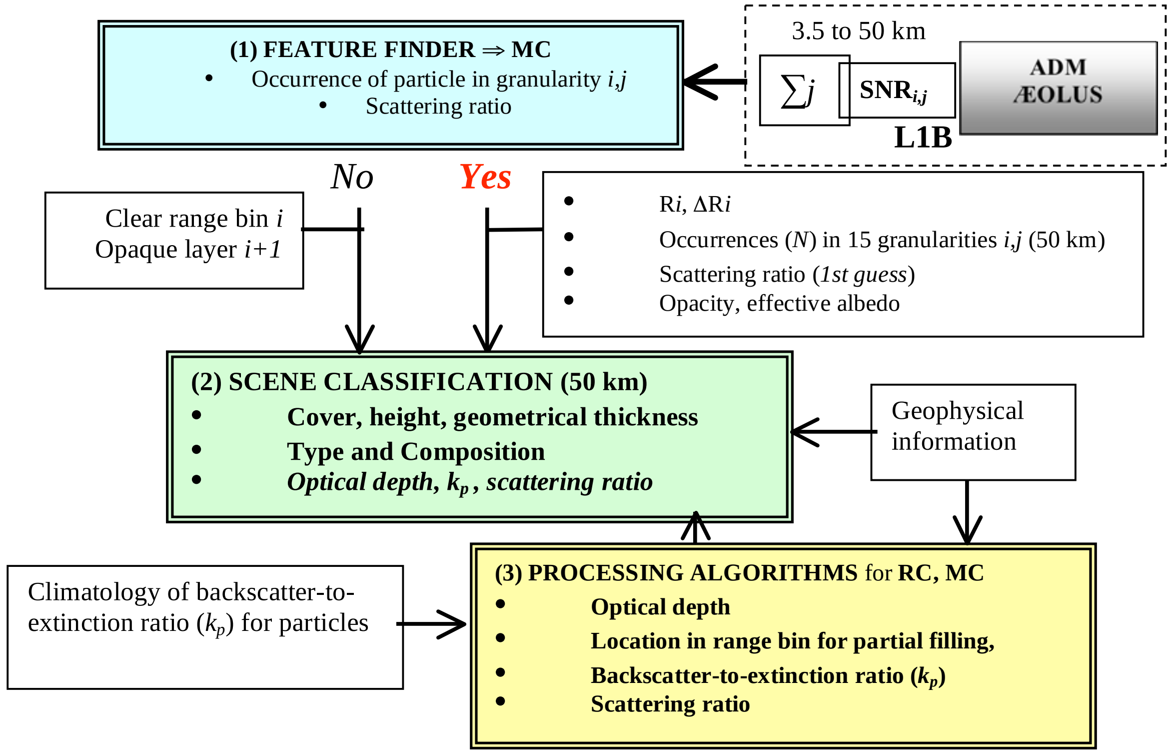

Fig.2: sketch of the L2A processor displaying the 3 steps to be used to derive the spin-off products from ADM-ÆOLUS L1B data with indices *i* in vertical and *j* in horizontal, respectively: 1) Feature Finder, 2) Scene Classification, 3) Processing Algorithms for Rayleigh (RC) and Mie channels (MC). If no Mie signal in range bin *i* can correspond to an opaque layer in range bin *i*+1or no particles in range bin *i*. Effective albedo is computed from MC

3. Accumulated signals

The Lidar signals at range (R) from the satellite in orbit and the geophysical variables are expressed in 2 different frameworks. So, the Lidar signals are converted in the atmospheric framework.
Considering no cross-talk between the 2 channels, the HSRL range resolved signals are written as

$$s_p(z)\left(R_0 - \frac{z}{\cos\theta}\right)^2 = K_p(\nu)\,\beta_p(z)\exp\left[-\frac{2}{\cos\theta}\int_z^{z_{\max}}\left[\alpha_m(y)+\alpha_p(y)\right]dy\right]$$

$$s_p(z)\left(R_0 - \frac{z}{\cos\theta}\right)^2 = K_p(\nu)\,\beta_p(z)\exp\left[-\frac{2}{\cos\theta}\int_z^{z_{\max}}\left[\alpha_m(y)+\alpha_p(y)\right]dy\right]$$

These equations could account for a cross-talk as well but at the cost of 2 new instrumental variables. It is not explicitly written here but it is addressed in the study.
The accumulated signals in the Rayleigh and Mie channels are

$$S_{m,i} = \int_{z_{i-1}}^{z_i} s_m(y)\,dy$$

$$S_{p,i} = \int_{z_{i-1}}^{z_i} s_p(y)\,dy$$

The full expression for the accumulated Rayleigh signal without cross-talk is presented below. This equation is used to derive the ITWT in a range bin and then used to build the RC processing algorithm that is presented in section 4.
The accumulated Rayleigh signal is

$$S_{m,i} = K_m(\nu)\left(T_{p,sat,i}\right)\left(T_{m,sat,i}\right)\int_{z_{i-1}}^{z_i} dy\,\frac{\beta_m(y)}{\left(R_0-\frac{y}{\cos\theta}\right)^2}\exp\left[-\frac{2}{\cos\theta}\int_{z_i-1}^{y}\left[\alpha_m(x)+\alpha_p(x)\right]dx\right]$$

Multiple scattering effects from cloud and aerosol layers are taken as negligible according to small receiver FOVs and laser footprint. Also, the number of speckle cells on the receiver is quite large so it results in weak signal fluctuation on a shot-to-shot basis that is further reduced by shot averaging.

The 2-ways transmissions from the satellite to z_i i.e. the upper boundary of the ith-layer are

$$T_{m,sat,i} = \exp\left[-\frac{2}{\cos\theta}\int_{z_i}^{z_{sat}}\alpha_m(y)\,dy\right]$$

and

$$T_{p,sat,i} = \exp\left[-\frac{2}{\cos\theta}\int_{z_i}^{z_{sat}}\alpha_p(y)\,dy\right]$$

for molecules and particles, respectively. Here, for the sake of simplicity the lowest range bin #1 does not contain a surface echo (it is an ideal situation). Example of particle extinction coefficient for cirrus cloud and atmospheric aerosols in the boundary layer is presented on Fig. 3. The optical depths are 0.13 and 0.22, respectively.

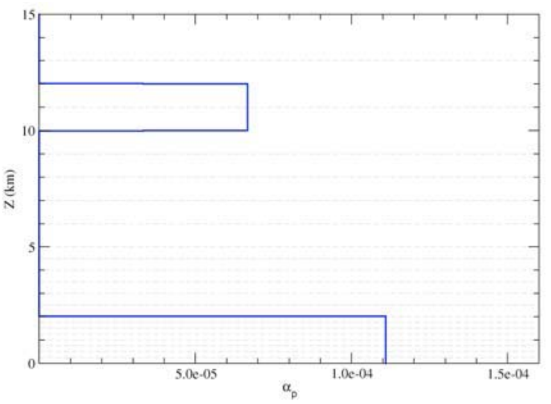

Fig. 3. Example of particle extinction coefficient for a cirrus layer (between 10-12 km) and atmospheric aerosols in the boundary layer (from 0 up to 2 km)

Fig. 4 presents the accumulated signals in the various range bins of the Rayleigh channel with a cirrus cloud (dotted red) and without cirrus cloud (dotted blue), and continuous range resolved signals for comparison (red and blue solid lines) for comparison. Notice the units are different for accumulated and range resolved signals.

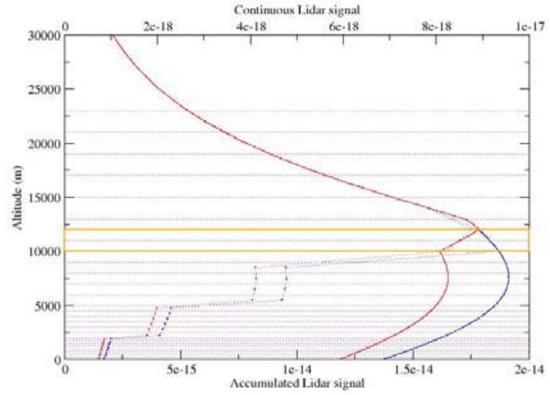

Fig. 4: i) Range resolved molecular signals at 355 nm (continuous lines) without (blue) and with (red) a cirrus cloud between 10-12 km, and ii) accumulated molecular signal in vertical range bin (dashed lines) without (blue) and with (red) a cirrus cloud. The yellow lines outline the cirrus layer between 10 and 12 km

4. Integrated 2-way transmission

Accumulated signals result in an Integrated 2-Way Transmission (ITWT) in a range bin. It is defined as the ratio of accumulated Rayleigh signals with and without particles $ITWT = S_{m,i}\big|_{obs} \big/ S_{m,i}\big|_{cal}$. The observation provides $S_{m,i}\big|_{obs}$ whereas $S_{m,i}\big|_{cal}$ is computed using geophysical information from meteorological analysis. The upper most range bin #25 is used for the purpose of background determination in the Mie channel (assuming no particle). A calibration of the Rayleigh channel is conducted in range bin#24. Then, the Lidar observations start at range bin #23. The ITWT is

$$\frac{S_{m,i}\big|_{obs}}{S_{m,i}\big|_{cal}} = \frac{K_m(\nu)}{K_m(\nu)}\frac{\left(T_{m,sat,i}\right)}{\left(T_{m,sat,i}\right)}\left(T_{p,sat,i}\right)\frac{\displaystyle\int_{z_{i-1}}^{z_i} dy\,\frac{\beta_m(y)}{\left(R_0-\frac{y}{\cos\theta_i}\right)^2}\exp\left[-\frac{2}{\cos\theta_i}\int_{z_i-1}^{y}\left[\alpha_m(x)+\alpha_p(x)\right]dx\right]}{\displaystyle\int_{z_{i-1}}^{z_i} dy\,\frac{\beta_m(y)}{\left(R_0-\frac{y}{\cos\theta_i}\right)^2}\exp\left[-\frac{2}{\cos\theta_i}\int_{z_i-1}^{y}\left[\alpha_m(x)\right]dx\right]}$$

The molecular backscatter, range-squared term and molecular transmission can be taken out of the integrals due to their slow variation over a range bin (at least in first approximation).

Then, the integral of the numerator can be solved for constant of extinction coefficient in the entire range bin (or for any simple analytical function). It can be written as an implicit equation

$$\frac{1}{\left(T_{p,sat,i}\right)}\frac{S_{m,i}\big|_{obs}}{S_{m,i}\big|_{cal}} - \frac{1}{2\,L_{p,i}}\left\{1-\exp\left(-2\,L_{p,i}\right)\right\} = 0$$

The particle slant local optical depth (SLOD) is

$$L_{p,i} = \frac{\alpha_{p,i}}{\cos\theta_i}\left(z_i - z_{i-1}\right)$$

the angle-off nadir θ_i is provided as L1B data. The ITWT is used to build a "Standard Correct Algorithm (SCA)". It is "correct" in a physical and mathematical sense, while "standard" means a range-by-range processing without iteration.

In practice, the difference is not strictly equal to zero. The residual term is made as small as possible according to an expected accuracy on $L_{p,i}$. In the case of a small optical depth, the residual term must be smaller than twice the accuracy. Positive or negative values of the residual term impact the SLOD and CC. The implications will be discussed during the presentation.

Similarly, it can be shown that inaccuracies on observation, simulated signal and particulate 2-way transmission from the satellite to the top of the range bin under study results into a bias equal to half the error.

For $\left(T_{p,sat,i}\right)^{-1}\left(S_{m,i}\big|_{obs} / S_{m,i}\big|_{cal}\right) \leq 1$, it is used as a "Credibility Criteria (CC)" to validate the retrieval of SLOD in range bin *i*.

The assumption of one single particle layer filling the entire range bin is too restrictive and will not be met in most practical situations. So the appropriate equation for partial filling by a single layer of constant extinction coefficient is presented below. The layer lower boundary is z_a and the upper boundary z_b

$$\frac{1}{\left(T_{p,sat,i}\right)}\left\{\frac{S_{m,i}\big|_{obs}}{S_{m,i}\big|_{cal}}\right\}_{a,b} - \frac{\left(z_i - z_b\right)}{\left(z_i - z_{i-1}\right)} + \frac{\left(z_b - z_a\right)}{\left(z_i - z_{i-1}\right)}\frac{1}{2\,L_{p,a,b}}\left(1-\exp\left[-2\,L_{p,a,b}\right]\right) + \frac{\left(z_a - z_{i-1}\right)}{\left(z_i - z_{i-1}\right)}\exp\left[-2\,L_{p,a,b}\right] = 0$$

As illustrative examples (see Fig. 5), analytical equations for various filling factors of the range bin: 1/2 (#2, 3) or 1/4 (#4, 5, 6, 7), have been studied. Given a SLOD, the ITWT are quite different depending on the filling factor and location of the layer in the range bin. A correct formulation of the problem enables to retrieve accurately $L_{p,i}$ in range bin *i*.

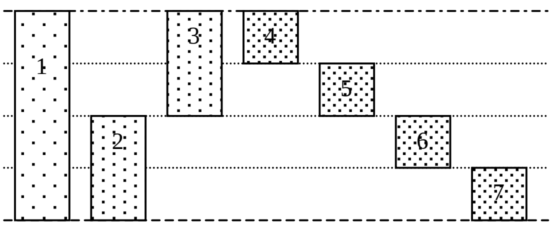

Fig. 5: total filling (#1) and various partial filling of range bin *i* by a single particle layer. For the sake of simplicity the filling factor is half or a quarter of the range gate *i*

However, for the location in the range bin is not known *a priori*, an "Iterative Correct Algorithm (ICA)" is proposed based on CC. The various solutions (see Fig. 5) can be processed in parallel.

5. Preliminary tests, validation and discussion

In addition, and for the purpose of comparison with a simple and pragmatic approach we consider a negative exponential law

$$\frac{1}{\left(T_{p,sat,i}\right)}\frac{S_{m,i}\big|_{obs}}{S_{m,i}\big|_{cal}} = \left\{\exp\left(-2\,L^*_{p,i}\right)\right\}$$

L^* stands for the SLOD solution of this simple equation. Despite that we know that it is incorrect, it is worth to study because this simple solution may come to some people mind. It is discussed as a "Simple Algorithm (SA)". Other simple solutions have been studied as well that are not reported here.

A direct comparison of the SCA and SA shows that the solutions are linked according to

$$\frac{1}{2\,L_{p,i}}\left\{1-\exp\left(-2\,L_{p,i}\right)\right\} = \exp\left(-2\,L^*_{p,i}\right)$$

For small SLOD it comes $L^*_{p,i} \cong \frac{L_{p,i}}{2}$, for large SLOD it is $L^*_{p,i} \cong \frac{1}{2}Ln\left\{2\,L_{p,i}\right\}$. The same reasoning starting from layer #23 shows that by no mean the two solutions can be identical or even close. Comparisons between total and partial fillings evidence the same basic discrepancies.

Preliminary numerical tests confirm the results of the analytical comparisons.

Also, they show that the proposed ICA with CC concept enables to retrieve accurately the optical depth and position of a particle layer in the case of partial filling.

More analytical and numerical results will be presented at the conference.

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