ESA CONTRACT REPORT

Technical Note to the European Space Agency

TN17.4: CCN6 results: further Chain-of-Processors testing of L2B results and of the CCN6 L2B processor algorithm updates

October 2017

Michael Rennie

Ref: AE-TN-ECMWF-GS-174

European Centre for Medium-Range Weather Forecasts
Europäisches Zentrum für mittelfristige Wettervorhersage
Centre européen pour les prévisions météorologiques à moyen terme

ECMWF

Series: ECMWF - ESA Contract Report

A full list of ECMWF Publications can be found on our web site under:
http://www.ecmwf.int/publications/

TN17.4

CCN6 results: further Chain-of-Processors testing of L2B results and testing of the CCN6 L2B processor algorithm updates

Authors

MICHAEL RENNIE
ECMWF

CHANGE LOG

Version	Date	Comment
1.0	17/02/2017	A first version.
1.1	30/08/2017	Incorporate CCN6 TN17.5 work into TN17.4 as agreed with ESA
1.2	23/10/2017	Update following review by Anne Grete Straume and Thomas Kanitz.

Contents

1 Introduction

This technical note reports on further end-to-end testing using the chain-of-processors for CCN6 (WP2810). It investigates the L2B product's robustness to new instrument features that are simulated in E2S and to algorithm tuning following the instrument on-ground characterization e.g. improved signal characterization (improved solar background modelling in E2S), and residual L1B systematic errors (WP2550). The verification of updates to the L2B algorithms as part of CCN6 was originally planned to be written in a separate TN17.5, however it has been agreed with ESA to merge that work into this TN17.4 to reduce duplication of effort preparing TNs.

In particular this TN17.4 includes:

- Testing of the new L2B processor Range Dependent Bias Correction (RDB) algorithm
- Testing of the effect on L2B winds of increased Solar background noise simulated in the recent E2S v3.07
- Testing the effect on L2B winds of a possible shift in the reference frequency between an ISR and an IRC (and the interaction with the Calibration Suite)
- Testing a refined vertical geolocation algorithm for the Rayleigh channel in the L2Bp
- Testing the effect of a change in Mie internal reference pupil inscription on the ACCD (an output of IFP testing) as simulated in the E2S v4.00
- Testing the effect on L2B winds of a more flexible scene classification algorithm: i.e. independent scattering ratio thresholds for the Mie and Rayleigh winds

The CCN6 technical proposal document requests that testing of the Optical Properties code to be included in this TN17.4, however this work has been included in a separate TN by Gert-Jan Marseille: AE-TN-KNMI-OPC_v2.0 (13 March 2017) entitled "TN on OPC: Implementation of OPC in the L2B and first test results on realistic atmospheric scenes".

The CCN6 technical proposal requested to test of the effect on L2B winds of changed parameters resulting from industry's IFP and TBTV testing of ALADIN. Due to long delays in receiving such inputs, the work has been de-scoped (following management discussions with ESA) to performing verification of L2B winds in realistic scenarios with the pre-launch processor delivery (Summer 2017), since the E2S v4.00 and L1Bp v7.01 did include some changes related to the IFP results i.e. the change in expected illumination of the Mie ACCD for the internal reference.

The ESA Change Request 6 Statement of Work requested the testing of improved Mie QC based on testing of the L2BP with A2D data from the WindVal campaign. The testing performed so far did not lead to recommendations for significant Mie QC improvements, which means that the planned testing is not needed.

1.1 *Documents*

1.1.1 Applicable documents

	Title	Ref	Ver.	Date
[AD1]	Change Request No: 6, Aeolus Level 2B/C Enhancements and Launch Extension of ESA Contract No: 4200018555/04/NL/MM Development and Production of Aeolus Wind Data Products		1.1	2015

1.1.2 Reference documents

	Title	Ref	Ver.	Date
[RD1]	Correcting winds measured with a Rayleigh Doppler lidar from pressure and temperature effects, Dabas et al.	Tellus A, 60(2), 206–215, 2008	N/A	2008
[RD2]	E2S Issue 4/00 Software Release Note	ADM-RN-52-2890	4/00	July 2017
[RD3]	E2S modelling	AE-TN-DLR-E2S-001	1.3	31/7/2012
[RD4]	End-to-end testing of the continuous mode L2B processor	AE-TN-ECMWF-GS-153	3.1	19/3/2014
[RD5]	ADM-Aeolus level-2B algorithm theoretical basis document	AE-TN-ECMWF-L2BP-0024	3.0	Aug 2017
[RD6]	B. Witschas, *'Analytical model for Rayleigh–Brillouin line shapes in air'* ,	APPLIED OPTICS / Vol. 50, No. 3 / 20 January 2011	N/A	2011
[RD7]	Generation and update of AUX_CSR	AE-TN-MFG-L2P-CAL-003	3.3	30/6/2016
[RD8]	Generation of the RBC Auxiliary file: Detailed Processing Model	AE-TN-MFG-GS-0001	3.2	15/12/2015
[RD9]	Advanced monitoring of Aeolus winds	AE-TN-ECMWF-GS-16	1.1	28/10/2015
[RD10]	Performance assessment of the Aeolus Doppler wind lidar prototype. PhD thesis by Ulrike Paffrath (DLR).		N/A	2006
[RD11]	Testing the behaviour of wind retrievals with new E2S simulation options	AE-TN-ECMWF-GS-173	1.1	6 Aug 2014
[RD12]	TN 2.1 Sensitivity Analysis	AE-TN-DLR-L1B-002		2007
[RD13]	The assimilation of horizontal line-of-sight wind information into the ECMWF data assimilation and forecasting system, part II: the impact of degraded wind observations. By András Horányi, Carla Cardinali, Michael Rennie and Lars Isaksen	Q.J.R. Meteorol. Soc., 141: 1233–1243. doi: 10.1002/qj.2551	N/A	2015
[RD14]	Witschas, B: Analytical model for Rayleigh–Brillouin line shapes in air	Applied Optics Vol. 50, No. 3, pp 267-270.	N/A	2011
[RD15]	Technical Note 51.2: Mie and Rayleigh Algorithm Performance Assessment (WP5100, Phase 2) by Karsten Schmidt, Oliver Reitebuch and Dorit Huber	AE.TN.DLR.5100.2.20161121	1.2	21/11/2016
[RD16]	Technical Note Enhanced Performance Simulations	AE-TN-DLR-L1B-003	1.1	2007
[RD17]	Assessment of Level-2B wind errors resulting from realistic simulation of ISR/IRC/AUX_RBC calibration chain	AE-TN-ECMWF-GS-171	1.2	16/01/2017
[RD18]	Level 1b Processor Detailed Processing Model	ADM-MA-52-1800	3/06	1/6/2016
[RD19]	O. Reitebuch, Anomaly Report AE-IPF-163 Background Modelling in the E2S, OR PM34 27 01 2015.pptx, L1B Progress Meeting PM 34, Schneefernerhaus, Germany, 27.01.2015			
[RD20]	E2S_background_OR_20141223.pdf. An attachment to Anomaly report.	AE-IPF-163		23/12/2014
[RD21]	Astrium document TN112 (pages 8-9) on "Determination of the atmospheric background"	AE.TN.ASF.AL.00112	02 Rev: 00	30/10/04
[RD22]	Aeolus Level-2B processing of A2D airborne campaign data	AE-TN-ECMWF-GS-83	1.6	18/3/2015
[RD23]	TN3.1a Test cases for the L2B processor	AE-TN-KNMI-GS-0031a	1.3	13/10/2017
[RD24]	Range Dependent Bias Characterisation	AE-TN-DLR-L1B-5300	1.0	3/1/2017
[RD25]	Use of Instrument Functional Performance Test (April 2016) in Instrument Spectral Registration mode and fit by the Corrected Spectral Registration algorithm	AE-TN-MFG-L2P-CAL-102-IFP-v2	2.0	2017

1.2 Acronyms

ACCD	Accumulation Charge Coupled Device
AOCS	Attitude and Orbit Control System
ALADIN	Atmospheric Laser Doppler Instrument
ATBD	Algorithm Theoretical Basis document
AUX	Auxiliary
BM	Burst mode
BRC	Basic Repeat Cycle
CM	Continuous mode
CoP	Chain-of-processors software
CSR	Corrected Spectral Registration
DA	Data assimilation
DEM	Digital Elevation Model
DWL	Doppler Wind Lidar
ECMWF	European Centre for Medium-Range Weather Forecasts
EGM	Earth Gravitational Model
ESTEC	European Space Research and Technology Centre (part of ESA)
FWHM	Full-width half maximum
HLOS	Horizontal Line Of Sight
IDL	Interactive Data Language
IFP	Instrument Functional Performance
IODD	Processor Input/Output Data Definitions Interface Control Document
IRC	Instrument Response Calibration
ISR	Instrument Spectral Registration
KNMI	Royal Netherlands Meteorological Institute
LITE	Lidar In-space Technology Experiment
LOS	Line of sight
L1B	Level-1B
L2B	Level-2B
L2Bp	L2B processor
LUT	Look-up table
N/A	Not applicable
NWP	Numerical weather prediction
PBL	Planetary Boundary Layer
PDGS	Payload Data Ground Segment
PRNU	Photo Response Non-Uniformity
QC	Quality control
RB	Rayleigh-Brillouin

RBC	Rayleigh-Brillouin correction
RMA	Reference model atmosphere
RR	Rayleigh response
RRC	Rayleigh response calibration
SNR	Signal to noise ratio
SRD	System requirements document
SZA	Solar zenith angle
TBD	To be determined
TBTV	Thermal balance, thermal vacuum
TN	Technical note
USR	Useful Spectral Range
VHAMP	Vertical and Horizontal Aeolus Measurement Positioning
WGS	World Geodetic System
WP	Work package
WVM	Wind velocity measurement[1]
XML	Extensible Markup Language
ZWC	Zero wind correction

[1] This is a misnomer as Aeolus measures a component of the wind velocity along the line of sight

2 Default Chain of Processors version used for testing

Unless specified otherwise, the testing that follows in the TN will use the following combination of processors in the Chain-of-Processors (CoP):

Table 1. CoP processor version combination used in sections following this one (unless specified otherwise)

Processor name	Processor version	Date of release
E2S	v3.07 + patch 1	June 2016, patch 1 released in November 2016
L1Bp	v6.06	June 2016
Calibration (CAL) suite	30 June 2016 + patch 1 to 3	Patch 3 provided in January 2017
L2Bp	v2.30 + developments	July 2016 + developments since then

Patch 1 of the E2S v3.07 was necessary to implement because it fixed a major problem with the range dependent bias simulation; which is tested in this TN. The L2B team discovered that the range values in the E2S simulation were incorrect and did not matching those in the L1Bp, meaning that the simulation of RDB was incorrect and hence the correction of the RDB in the L1B and L2B processors was not working properly. See Anomaly Report AE-IPF-290 for details.

If not specified we use the "perfect calibration" settings for the E2S, L1Bp and L2B as reported in the recent TN 17.1 i.e. [RD17].

3 Range Dependent Bias correction in the Level-2B processor

The L2B processor development code was modified (in late 2016) to include the Range Dependent Bias (RDB) correction (this was included in the L2Bp v3.00 delivery in September 2017). The new algorithm closely follows the equations specified in the L1B DPM document [RD18]. The L2B processor RDB correction is controlled (i.e. switched "on" or "off") via new switches in the AUX_PAR_2B file for each channel:

```
<RDB_Params>
    <Do_Mie_RDB_corr>True</Do_Mie_RDB_corr>
    <Do_Rayleigh_RDB_corr>True</Do_Rayleigh_RDB_corr>
</RDB_Params>
```

Setting the parameters to `False`, disables the RDB correction for the channel in question. The L2Bp ATBD and IODD documents (v3.00 release) have been updated to describe the new RDB correction algorithm and the format changes in the AUX_PAR_2B file to accommodate the switches. These RDB correction related modifications are part of the v3.00 L2Bp delivery (September 2017).

To test the L2B processor RDB correction, an E2S scenario was defined which has:

- Laser energy = 1000 mJ. A large energy value was chosen to reduce the effect of noise, therefore making the RDB more obvious.
- A 69 BRC scenario with some idealised clouds at a range of altitudes was chosen to get some Mie results at various satellite ranges. There is a sufficient amount of clear air to assess the Rayleigh RDB correction also. In fact, there is a much larger sample of clear air than cloudy.
- Input wind profiles are constant vertically but change every BRC to cover the HLOS wind range -50 to 50 m/s, to ensure RDB correction works over the dynamic range of HLOS wind values.

Control run of CoP:

- RDB simulation is switched "off" in the E2S and hence zero AUX_RDB_1B coefficients are applied in the L1Bp to match and hence the L2Bp RDB is effectively "off" (since the slope coefficients that are passed to the L2Bp via the L1B WVM file are set to zero).

Experiment run of CoP:

- E2S with RDB simulation "on" and RDB slope coefficients set to 10 times the default E2S values; so that the RDB is large and hence the effect of the correction is more obvious (as well as any possible residual RDB, left after an imperfect correction)
- L1Bp with RDB correction "on" with matching AUX_RDB_1B coefficients to the E2S RDB coefficients
- L2Bp with RDB correction "on" (applying the coefficients passed from the L1B WVM file) and a separate run with L2Bp RDB correction "off".
- Note that calibration files are not generated with RDB for consistency, because it is assumed that calibration files will be corrected for RDB for the Aeolus mission.

For the control run of the CoP, the verification results looked normal and hence are not shown here. For the experiment run of the CoP the results for the L2B Mie-cloudy HLOS winds are shown in Figure 1 and for the L2B Rayleigh-clear HLOS winds in Figure 2; both figures show the L2B HLOS wind bias without (a) and with (b) the L2Bp RDB correction applied. From this verification of the L2B wind results, it appears that the L2B RDB correction is working correctly in the sense that the bias after RDB correction is applied is very small for both channels. This implies that the mismatch between range values in the E2S and L1Bp has been fixed with Patch 1 to E2S v3.07 and also that the L2Bp RDB correction algorithm is doing the RDB correction properly. N.B. The use of a large laser pulse energy in the simulations helped detect the bug, of course for the real mission RDB correction this will not be possible.

In summary: It appears that despite the range value and hence the RDB varies across the extent of the range-bin of the Aeolus winds, that applying the RDB correction at the assigned altitude of the range-bin (typically half way up a range-bin) is sufficient to do the RDB correction without any obvious degradation.

However it should be made clear that this test only confirms that if the “truth” RDB coefficients are known, then it can be corrected in the L2B processor without degrading the L2B winds. In practice the “truth” RDB coefficients have to be determined by some calibration procedure during the mission. It is a work package for the L1B team [RD24] to investigate how well the RDB coefficients can be determined from a ground return calibration procedure.

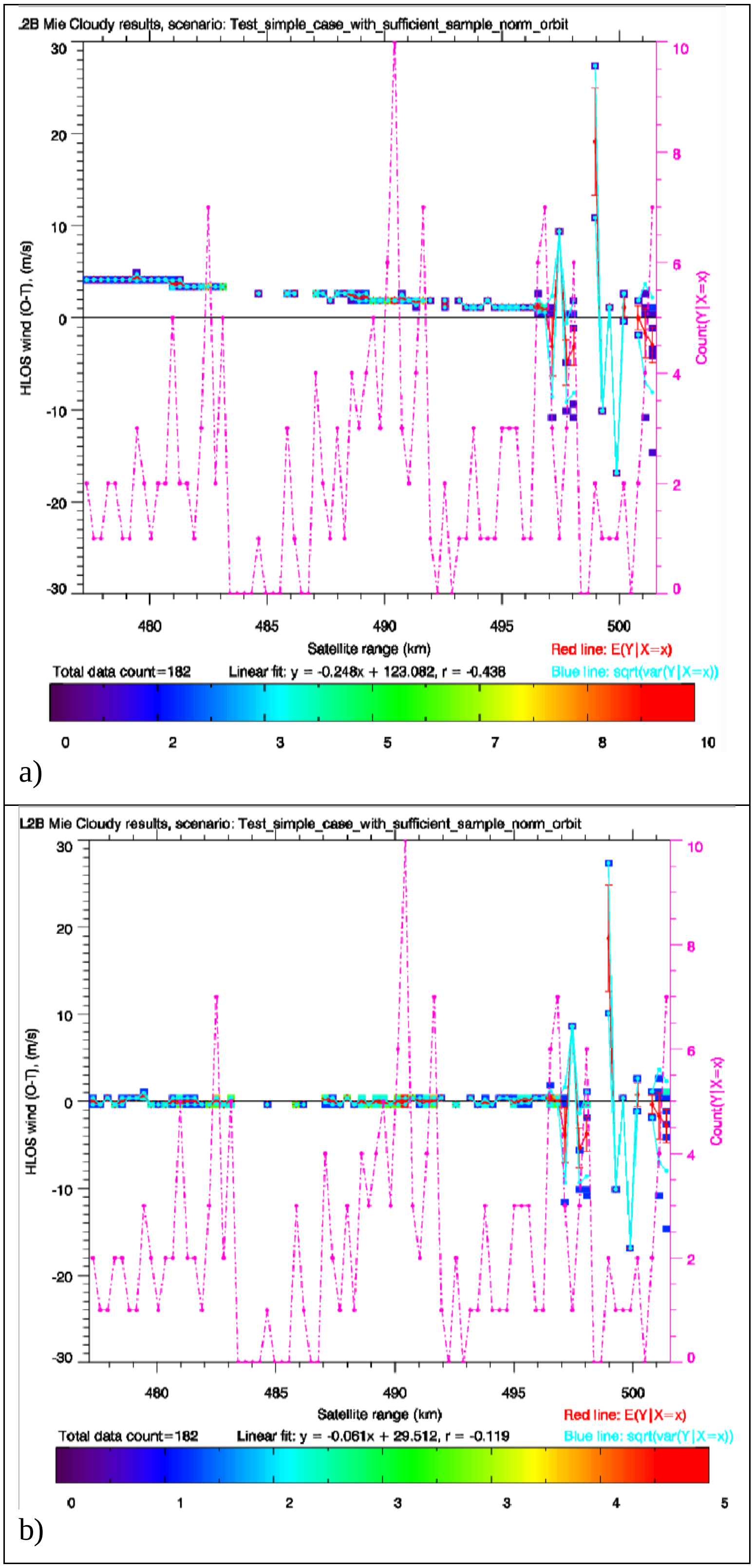


Figure 1. Dependence of L2B Mie-cloudy HLOS wind error (observation (O) minus truth (T)) upon satellite range. For a) with RDB simulation (10x default) in the E2S, but with the RDB correction "off" in the L2Bp and b) with RDB simulation (10x default) in the E2S, but with RDB correction "on" in the L2Bp.

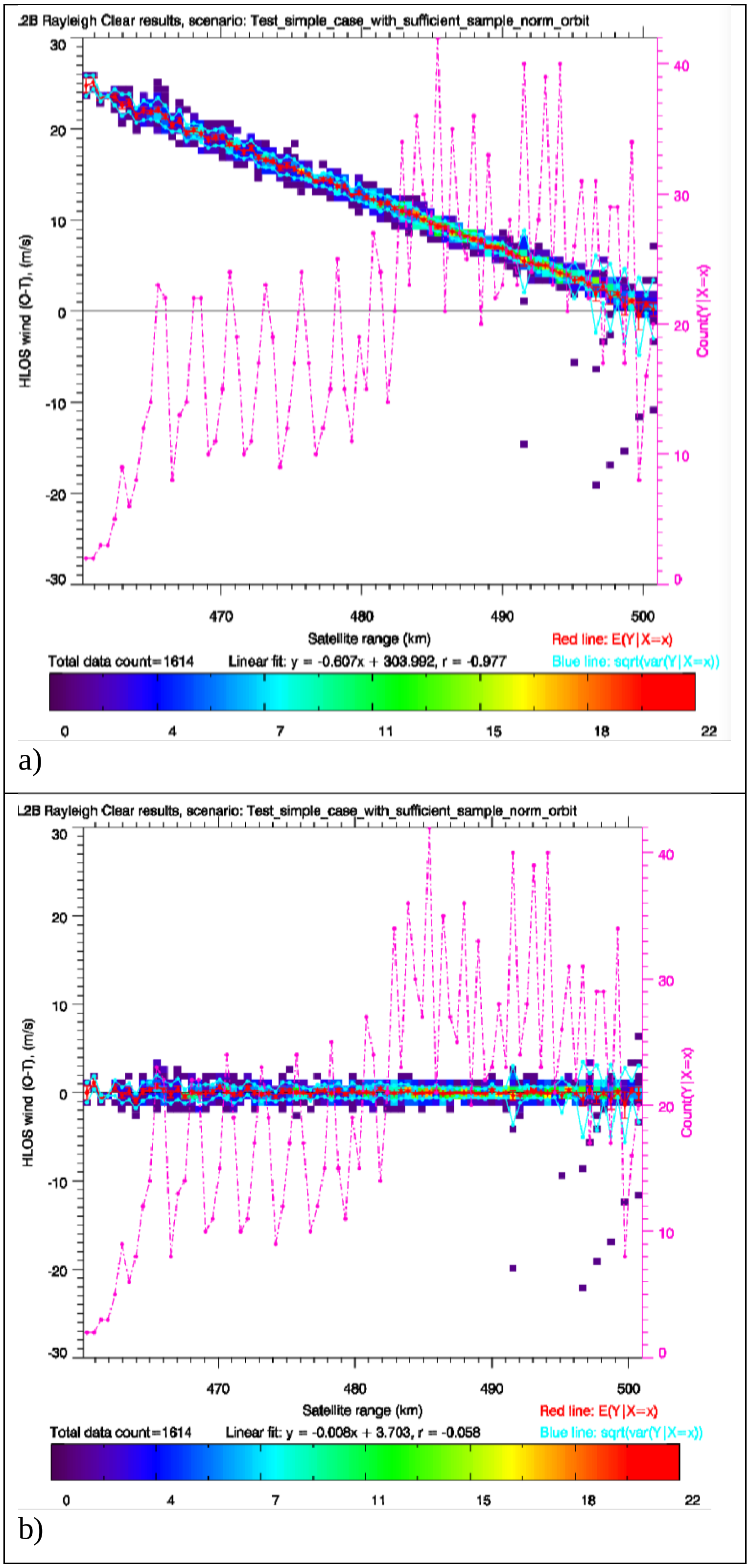


Figure 2. Dependence of L2B Rayleigh clear HLOS wind error (observation (O) minus truth (T)) upon satellite range. For a) with RDB simulation (10x default) in the E2S, but with the RDB correction "off" in the L2Bp and b) with RDB simulation (10x default) in the E2S, but with RDB correction "on" in the L2Bp.

4 Solar background noise and the effect on L2B wind errors

An updated solar background model was implemented in E2S v3.07 as proposed by Oliver Reitebuch (L1 team); see [RD19] and [RD20]. The new model is more realistic than the earlier E2S implementation and leads to a significant increase in solar background noise level (by around factor 100). However the new solar background model is still a very simplified model e.g. it does not account for the variation of solar zenith angle for the particular geolocation of the observation and it does not take into account the varying effective albedo due to clouds and ground conditions.

The new model is characterized by the following items (see [11]).

- Use of a solar spectral irradiance with an E2S default value of 1100 W/($m^2\mu m$)
- Use of a background effective albedo (to account for cloud and ground reflectance and transmission in the atmosphere). The default value is set to 0.8
- Use of a solar zenith angle (SZA) with a default value of 75 degrees (which is expected to give radiance values typical of day-time conditions for Aeolus' orbit). The solar background model spectral radiance formula retains the *cos*(SZA) dependence.

A variation of SZA from 59.5° to 90° is the expected range to be encountered by Aeolus. To simulate night-time conditions, the SZA value can be set to 90°, which leads to zero solar background radiance. With Aeolus flying its terminator orbit and with an inclination of 97°, the worst case solar background noise is encountered as the satellite passes near to the pole at summer solstice; see [RD21] and Figure 3, for which the SZA is 59.5°. At solar equinox the worst case SZA is 83°.

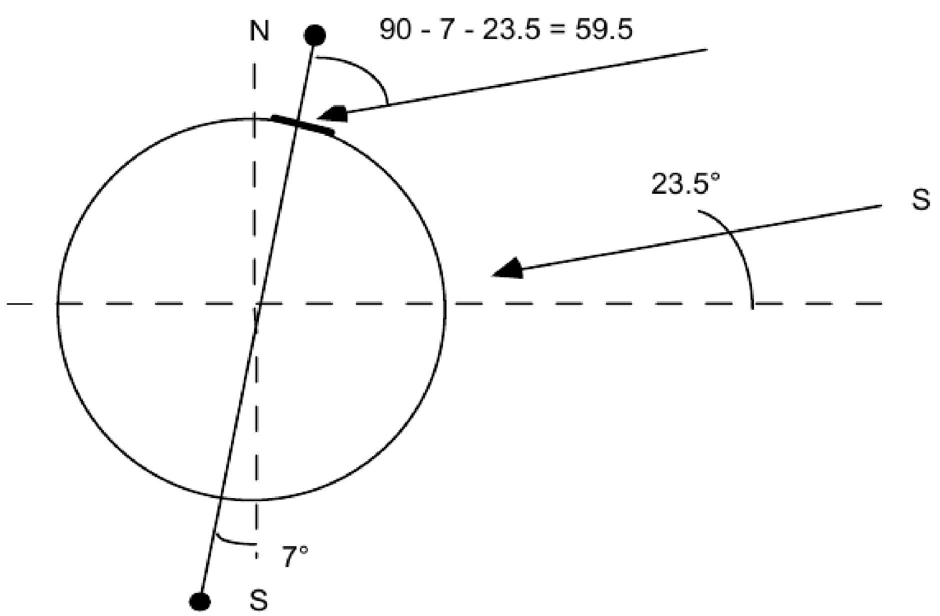


Figure 3. Configuration for worst case solar background, copied from [RD21]

It is useful to understand how the quality of the L2B HLOS winds vary with solar background noise - including the effect on the calibration chain i.e. the IRC and its error propagation to the MRC and AUX_RBC_L2 files and hence to the L2B winds.

Section 8 of [RD15] investigated the effect of varying the SZA on the L1B processor wind observation errors; it showed a marked increase in random error for the Rayleigh winds particularly at higher altitudes (e.g. doubling the error standard deviation at 25 km altitude) when going from no solar background to the worst case (they used SZA=60° and background effective albedo 0.8), however the Mie winds did not show an increase in noise with the worst background noise conditions. The systematic errors in WVM were not affected for either channel, however the [RD15] study did not assess increased noise during the IRC and this method of propagation to wind errors.

Since we cannot easily simulate the realistically varying solar background conditions with the E2S we instead focus on comparing the extremes of solar background radiance values using simulations with constant solar conditions over many orbits, whereas in reality the conditions will vary along the orbit.

4.1 Sensitivity of L2B error statistics to solar zenith angle

Three solar zenith angle are assessed: 59.5°, 75° and 90°. The change in the L2B HLOS wind error statistics when altering the solar background levels in the E2S WVM simulations with "perfect" calibration files was investigated. The three WVM runs used the *ECMWF_TcO_1279_2015* E2S scenario which is described in [RD17]; this uses ECMWF model fields of temperature, pressure, wind and clouds to define the E2S scenario optical properties over 5.5 orbits to get a large sample of winds. Other than the changes in solar background, the default E2S noise settings were used. The L2B processor maximum group size was set to 100 km for both Rayleigh and Mie HLOS winds.

During testing it was found to be difficult to make meaningful comparisons of the errors of the different solar background conditions with the "nominal" Advanced Monitoring QC settings and statistical metrics; see [RD9]. This is because the "nominal" QC rejects outliers based on the estimated L2B HLOS wind standard error exceeding a threshold. However the L2B error estimate is itself a function of the solar background level detected in processing, hence the QC needs some retuning for different levels of solar background to reject outliers effectively and so not to damage the non-robust statistics like mean error and standard deviation of error, which are very sensitive to outliers.

To get around this we decided to not apply the "nominal" QC on the HLOS wind results, but instead to use robust statistical metrics i.e. median error and median absolute deviation (instead of mean error and standard deviation of the error) to compare the HLOS wind errors for the different levels of solar background. With no QC (and hence using all the data) the new statistics highlight a large number of poor quality Rayleigh winds in the lower troposphere due to the presence of cloud induced attenuation and also possibly errors in the L2B classification of measurements into clear and cloudy using noisy measurement-level scattering ratios. Note that the "nominal" QC with an 8 m/s threshold can remove the vast majority of these poor quality observations for use in NWP for the E2S default settings and hence they are not a major concern.

4.1.1 E2S v3.07 default solar background settings

One run used SZA=75°, which is the default value used in E2S v3.07 along with a background effective albedo of 0.8. This should represent typical day-time solar background conditions at solstice.

4.1.2 Worst case solar background settings

The Astrium TN 112 [RD21] estimates the worst case solar background radiance to be 154 W/m^2/sr/µm which occurs near the pole in the daylight of summer solstice. To achieve an equivalent level of radiance to this in the E2S simulation it was necessary to modify an input parameter in the E2S solar background model formula which is:

$$M_\lambda = L_\lambda \frac{\rho_{eff}}{\pi} \cos(SZA)$$

The E2S default spectral irradiance of L_λ=1100 W/ m^2/µm is thought to be a correct value hence it is not changed. With SZA set to 59.5 degrees, the parameter to be modified to match the Astrium worst case radiance of 154 W/m^2/sr/µm is the effective albedo; it needs to be set to 0.87 (rather than the default of 0.8 in E2S). The background effective albedo is controlled via the E2S input file lidarInstrumentLinkParameters.xml, in particular: `<BackgroundEffectiveAlbedo>`

Therefore for the worst case scenario the E2S background effective albedo will be set to 0.87 in combination with SZA=59.5 degrees.

4.1.3 Best case solar background settings

The best case scenario for the solar background is in night-time conditions. This is achieved by setting SZA=90° due to the cosine dependence in the formula, leading to zero solar radiance.

4.1.4 Results with the three solar background conditions for WVM

The L2B HLOS error statistics for the three levels of solar background have been superimposed onto one plot for comparison[2]. The Rayleigh-clear is shown in part a) and the Mie-cloudy in part b) of Figure 4.

[2] It is not yet an option to plot three outcomes of the CoP on one plot with the current monitoring tools. Hence they were superimposed using the Linux convert command. Unfortunately it is not easy to distinguish the three results (apart from where they differ a lot).

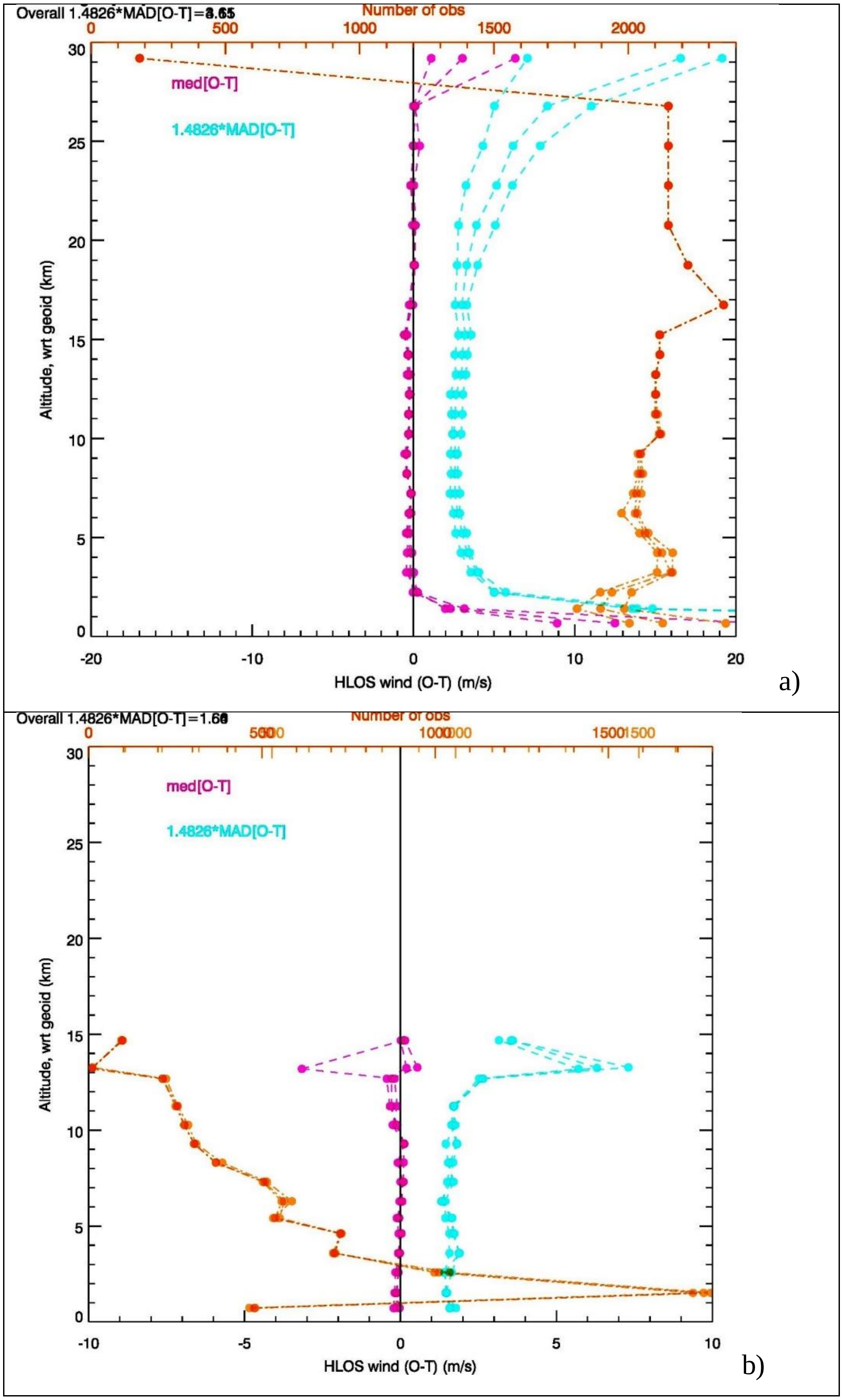


Figure 4. L2B HLOS wind error statistics as a function of altitude for the three levels of solar background tested superimposed on one plot. a) Rayleigh-clear results, b) Mie-cloudy results. The pink line shows the median error (observation minus truth) and the blue line shows the median absolute deviation of the error (times a factor 1.4826 to

make it comparable to standard deviation are outliers are removed). The number of observations entering the statistics is shown in orange (to go with top axis).

The median errors (the superimposed pink lines) do not change very much for the different levels of solar background i.e. the bias is not particularly sensitive to the level of solar background light for both the Rayleigh (a) and Mie (b) results. There is some variation of bias for at the lowest altitudes for the Rayleigh results, but here the number of observations (orange lines) produced by the L2B processor varies with more observations produced for the best case solar background and the least for the worst case. Looking at the data in more detail (via cross-sectional lidar plots, not shown), the extra observations are very low information content observations with positive bias and large random errors. The very low signal levels are related to attenuation from clouds above. It is not clear why the "no solar background" case leads to more of these poor quality observations.

Interesting behaviour is seen in the random errors as measured by the median absolute deviation (blue lines) (times a factor 1.4826 to make it comparable to standard deviation). There is a notable divergence in the random errors above 15 km for the Rayleigh winds with the "no solar background" having the lowest errors and the "worst case solar background" having the largest random errors as one would expect. The E2S default solar background lies in between but closer to the worst case results. **At an altitude of 27 km, with the best case solar background noise the Rayleigh HLOS wind has random error (approximately equal to standard deviation) of 5 m/s whereas with the worst case it has 11 m/s** i.e. more than double the standard deviation**. At 5-10 km the worst case solar background has noise around 0.5 -1.0 m/s larger standard deviation than the best case**.

According to the Aeolus Mission Requirements: For the precision of the HLOS wind observations it is desirable to achieve a precision of 3-5 m/s between 20 and 30 km. Clearly this desired precision in being compromised in the wort case solar background noise conditions.

For the Mie-cloudy results the small differences in random error between worst and best case appear to be just sampling noise i.e. no solar background sensitivity for the Mie channel. The results for both channels are very similar to those reported by the L1B team investigation [RD15] by Karsten Schmidt.

The increase in noise for the Rayleigh in worst case day-time conditions, particularly in the stratosphere, is sufficiently large to expect a detectable reduction in NWP impact in such conditions relative to the night-time conditions. This Rayleigh noise level will vary along the orbit and with the seasons. Thankfully the L2B estimated errors account for the solar background induced noise (via the L1B measurement-bin SNR values) meaning that appropriate weighting of the observations in data assimilation should be possible using the L2B estimated error (or even just rejection of the very noisy data). However the stratosphere is very poorly observed by winds in the current observing system, hence even rather noisy winds (with continuous sampling along track of Aeolus) will be of use it is expected. Longer horizontal averaging may be considered to try to mitigate the noise if the results no longer represent sensible wind values.

4.2 Sensitivity of L2B calibration chain to worst case solar background noise

IRCs with étendue on were simulated in the E2S, with the worst and best case solar background conditions. The IRCs are done with a realistic atmosphere scenario from ECMWF derived meteorological properties i.e. model clouds, winds, temperature, pressure and orography over Antarctica. Antarctica is chosen because this is a likely area for real mission IRCs to be performed given the large albedo of ice. The model data is from an arbitrary date in April 2011. The E2S scenario also uses the ADAM albedo maps for realistic ground returns. The same Antarctic IRC scenario has already been used and described in section 4.2.2 of TN17.1 [RD17]; it was used in Mie calibration testing.

It is assessed if the L2B HLOS wind systematic errors are larger with the worst case solar background noise compared to night-time conditions. This calibration testing follows the methods applied in TN17.1 i.e. [RD17]. However, note that this Antarctic IRC scenario was used only for testing the Mie response calibration in TN17.1; here will also test it in the CSR updater and hence the AUX_RBC_L2 Rayleigh calibration processing, which according to the previous section should be more sensitive to solar background noise than the MRC.

The E2S IRC runs have default noise apart from the modification to the solar background. The IRC, CSR updater and GENRBC have been run ten times for both solar background conditions (worst case day and night). The results for the CSR updater stage are given in the following tables.

The truth étendue parameters are: width=500 MHz and tilt = 1.0.

Table 2. Results of the CSR updater with worst case solar background IRC

Run number	Width (MHz)	Width error (MHz)	Tilt	Tilt error	Distance	Comment
1	452	-48	1.2	0.2	0.001092	A modified ISR matching actual RRC has been found
2	530	30	1.0	0.0	0.001254	“”
3	735	235	0.8	-0.2	0.001490	“”
4	728	228	0.8	-0.2	0.001261	“”
5	574	74	0.9	-0.1	0.001584	“”
6	517	17	1.0	0.0	0.001308	“”
7	492	-8	1.1	0.1	0.001438	“”
8	534	34	1.0	0.0	0.001266	“”
9	637	137	0.9	-0.1	0.001260	“”
10	612	112	0.9	-0.1	0.001215	“”
	Mean(absolute (value))	92		0.1		

Table 3. Results of the CSR updater with best case solar background in IRC

Run number	Width (MHz)	Width error (MHz)	Tilt	Tilt error	Distance	Comment
1	673	179	0.8	-0.2	0.001327	A modified ISR matching actual RRC has been found
2	562	62	1.0	0.0	0.000948	“”
3	611	111	0.9	-0.1	0.000985	“”
4	580	80	0.9	-0.1	0.001347	“”
5	630	130	0.9	-0.1	0.001016	“”
6	669	169	0.8	-0.2	0.000951	“”

7	608	108	0.9	-0.1	0.001016	“”
8	567	67	1.0	0.0	0.001290	“”
9	661	161	0.8	-0.2	0.001341	“”
10	618	118	0.9	-0.1	0.000957	“”
	Mean(absolute (value))	119		0.1		

Based on the CSR updater results alone it would appear that the worst case solar background noise does not have a worse CSR updater performance compared to the best cases solar conditions. This must be because the Rayleigh signal is not affected too much by increased solar background noise between the IRC RRC range of 6 and 16 km. Presumably by chance i.e. sampling error, the best case solar background conditions étendue width error is on average worse than the worst case solar background. The overall performance of the CSR updater in the Antarctic scenario is similar to the performance found in other cloudy IRC scenarios in TN17.1 [RD17].

In summary, the solar background noise conditions do not seem to have a noticeable effect on the L2 Rayleigh calibration systematic errors.

4.3 Summary of effect of solar background noise on L2B winds

The Rayleigh winds are significantly noisier above ~15 km due to solar background noise compared to night-time conditions, but the bias is not affected. The Mie winds are unaffected, both in terms of random and systematic errors.

The systematic errors from increased noise in L2 Rayleigh calibration chain do not seem to be effected by the levels of solar background noise in the IRC 6-16 km vertical range

5 Effect on the L2B Rayleigh calibration of a drift in laser reference frequency between the ISR and the IRC

For the Aeolus response calibrations, the reference value of the frequency offset, i.e. the zero on the frequency offset axis, does not correspond to a fixed absolute frequency. The nominal ALADIN laser frequency is expected to drift with time by up to 60 MHz[3]. Hence because the ISR and IRC are performed at different times the nominal laser frequency may have drifted and therefore the frequency offset axes are not with respect to the same absolute frequency. This feature was noticed as being a potential problem for the L2B Rayleigh calibration strategy during testing of A2D data and resulted in the following recommendation (from TN8.3 see [RD22])

> *"A recommendation for the ALADIN calibration suite is that the consequences of an absolute frequency drift between ISR and IRC (e.g. by 25 MHz, up to 60 MHz) should be investigated and that strategies need to be developed to cope with it. If uncorrected, this will lead to significant biases for winds produced by the L2B Rayleigh calibration strategy (i.e. the Rayleigh-Brillouin correction method)."*

The CAL suite has since this recommendation been modified to include an algorithm to estimate the absolute frequency drift between the ISR and the IRC by use of the internal reference calibrations. With an estimate of the frequency drift it is easy to account for it in the CSR updater i.e. to map the RRC frequency offset axis to that which is consistent with the ISR reference frequency offset. Section 8.3.1 of [RD7] explains how the CSR updater estimates the frequency drift between the ISR and IRC using the internal responses (either the Mie or the Rayleigh internal calibrations can be used).

It is important to test how well the CSR updater can estimate the frequency drift with realistic i.e. noisy calibration data. If it is doing a good job then it will lead to negligible additional L2B Rayleigh HLOS wind bias. If the frequency drift estimate is too inaccurate then it could lead to significant bias in the updated CSR and hence in the AUX_RBC_L2 file and the L2B Rayleigh winds. The L2B Mie winds are unaffected because they use the MRC data (via the L1B WVM files) and usually the WVM mode is performed soon enough after an IRC (MRC) for the calibration to be valid i.e. the nominal laser frequency should not have drifted significantly (e.g. with weekly IRCs)

According to [RD7] the resultant AUX_RBC_L2 calibration file (for use in L2B Rayleigh winds) provides the Rayleigh response curves with respect to the ISR frequency offset axis rather than alternatively with respect to the IRC frequency offset axis. However this should not matter for L2B winds as long as the internal and atmospheric response curves are both with respect to the same frequency offset axis as illustrated in Figure 5.

---

[3] Thomas Kanitz (ESA) reports: To compensate it would be centered on weekly basis, if the drift is larger than 25 MHz as determined with the Fizeau.

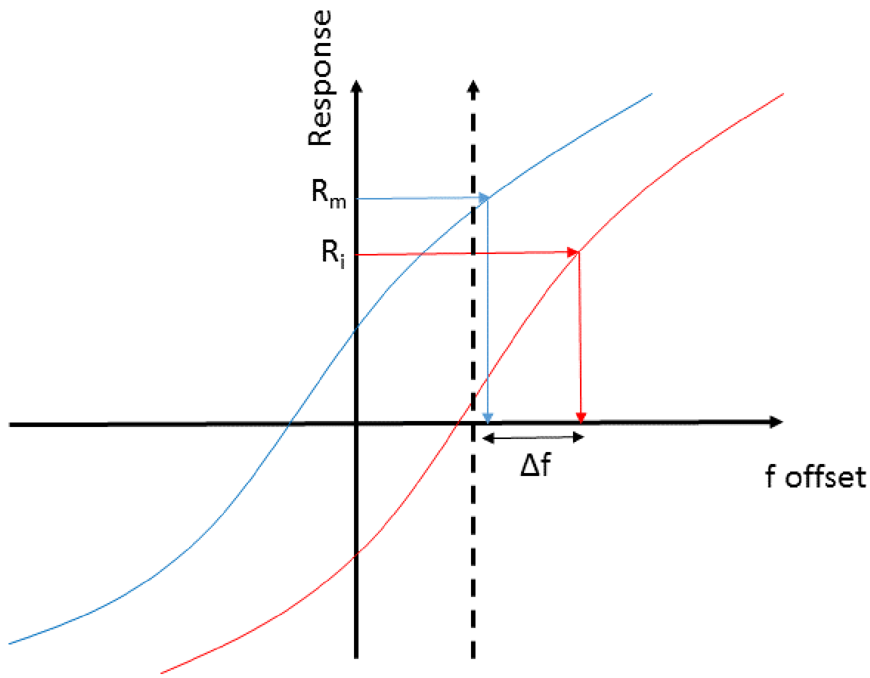


Figure 5. Example of how the frequency offset axis does not affect the Doppler shift detection (Δf) in the resultant AUX_RBC_L2 file if the atmospheric (m) and internal (i) response calibrations are provided with respect to the same frequency offset axis i.e. it would not matter if both curves were shifted along the f offset axis by the same amount.

The L1B team tested the frequency offset detection, as was presented by Alain Dabas' at L1B Progress Meeting number 36. It was reported:

The validation of the scheme was carried out on IRC data generated with a slightly modified laserWavelength in lidarInstrumentLinkParameters.xml E2S parameter file: From laserWavelength=354.8 nm to laserWavelength=354.80001 nm, which is equivalent to a frequency offset of $\delta f = 25\,MHz$

- *The results are good when the scheme is applied to Rayleigh responses.*
- *The result is wrong when the scheme is applied to Mie responses. The examination of* MRC_ISR *and* MRC_IRC *internal show both curves are identical in spite of the modification of the laser wavelength i.e. there is a limitation in the E2S simulation of the Mie channel.*
- *Question: is the frequency drift information to be passed to other processors?*

The last point, about whether the frequency drift information should be passed to other processors, raised by Alain, should not be a problem as illustrated in Figure 5. The issue regarding the simulated Mie calibration not altering with a change in laser frequency has since been addressed with an update to the E2S in v3.07 (i.e. the E2S version applied in this TN's testing). This allows the Mie ACCD centre column to be assigned a wavelength value rather than simply shifting it to be the laser wavelength (see Markus Meringer's (L1 team) presentation at L1B PM 38).

The CAL suite has been tested with a range of frequency drifts from 0 MHz to 60 MHz, as recommended in TN8.3 [RD22]. To determine the wavelength change for a given frequency change, we use the following formula:

$$\Delta\lambda = -\frac{\lambda^2}{c}\Delta f$$

Table 4. The corresponding change in wavelength for a change in frequency relative to the baseline of λ=354.8 nm

Δf (MHz)	Δλ (nm)
-60	2.52E-05
0	0
60	-2.52E-05

The tests were performed with default noise "on" in the E2S for both the ISR and the IRC for realism. Since the CSR updater method of determining the frequency drift value uses only the internal reference signals, then it is not necessary to run the IRC with realistic atmospheres, hence a simple atmosphere IRC is used with no clouds and horizontally constant atmospheric conditions and with étendue on (width=500 MHz, tilt=1.0). For the first tests the CSR updater is set to use the internal RRC rather than MRC to detect the frequency shift which is the default in the AUX_PAR_CS file i.e.

```
<Frequency_Drift_Reference>RRC</Frequency_Drift_Reference>
```

Control case settings:

Noisy ISR, noisy IRC with simple atmosphere with étendue on. No modification in laser wavelength in IRC relative to ISR. N.B. the CSR updater detected a frequency drift by small amount (even though there is none)

Experiment case settings:

Control + E2S defined laser wavelength modified in IRC step. The CSR updater reported the detected frequency drift. Each frequency shift value the ISR, IRC, CSR updater and RBC generation step was run ten times to get a sample of results, which is necessary given the random noise. The results for the detected laser frequency drift are presented in the following tables.

Table 5. Results of CSR updater for IRC with modified laser wavelength to 354.8000252 nm (or -60 MHz shift)

Run number	Detected laser frequency drift (MHz)
1	-121.9957
2	-121.8280
3	-121.8404
4	-121.1118
5	-121.5024
6	-121.7589
7	-121.6308
8	-121.5392
9	-122.0690
10	-121.3922

	Mean = -121.67 MHz, St.dev = 0.29 MHz

Table 6. Results of CSR updater for IRC without modifying the laser wavelength (i.e. 354.8 nm) i.e. the control case

Run number	Detected laser frequency drift (MHz)
1	0.2876
2	-0.5191
3	0.1259
4	-0.5304
5	-0.4990
6	0.1002
7	0.2691
8	-0.0006
9	-0.0805
10	-0.1209
	Mean =-0.10, St.dev = 0.32 MHz

Table 7. Results of CSR updater for IRC with modified laser wavelength to 354. 7999748 nm (or +60 MHz shift)

Run number	Detected laser frequency drift (MHz)
1	122.4259
2	122.6228
3	122.3355
4	122.4664
5	122.6921
6	122.6405
7	122.6835
8	122.8193
9	122.4508
10	122.5273
	Mean =122.57 MHz, St.dev = 0.15 MHz

The laser frequency drift detected by the CSR updater, from making a comparison to the ISR derived internal Rayleigh response and the RRC internal response, is a factor of two too large i.e. 120 MHz rather than 60 MHz in magnitude. Plotting the ISR derived and IRC internal Rayleigh response functions for an example run with the modified laser wavelength to 354.7999748nm (equivalent to +60 MHz frequency shift) in the IRC leads to the response calibration results of Figure 6. It is evident in plot a) that the RRC internal calibration is indeed shifted by ~120 MHz relative to the ISR derived one (compare blue and red lines); however in plot b) the frequency shift for the MRC is closer to ~60 MHz, which is the correct value.

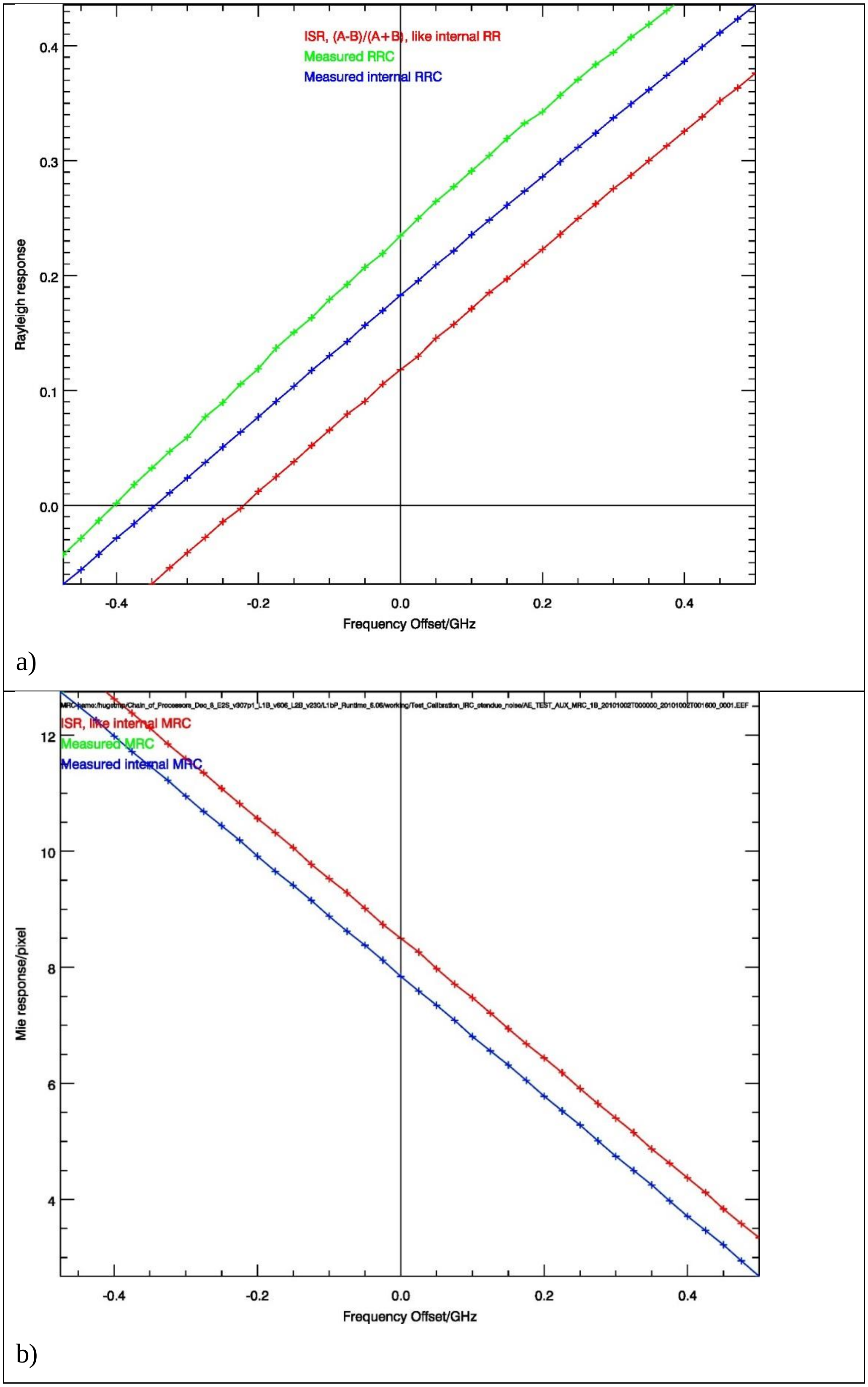


Figure 6. Comparison of ISR and IRC response calibrations for a) Rayleigh response versus offset frequency b) Mie response versus offset frequency. It appears that something was not quite right in the E2S simulation of the RRC in

terms of the wavelength modifications. The issue was reported to the L1B team and Dorit Huber quickly found a problem in SLS_LidarSimulator.m for which a fix was provided.

The test cases were run again following the fix to E2S v3.07 via Patch 1. The updated results are provided in the following tables:

Table 8. Results of CSR updater for IRC with modified laser wavelength to 354.8000252 nm (or -60.01 MHz shift)

Run number	Detected laser frequency drift (MHz)
1	-59.8096
2	-59.7342
3	-59.6002
4	-59.9034
5	-59.5902
6	-59.3425
7	-59.8766
8	-59.5046
9	-59.6860
10	-59.4641
	Mean = -59.65 MHz, Mean error = 0.36 MHz St.dev = 0.18 MHz

Table 9. Results of CSR updater for IRC without modifying the laser wavelength (i.e. 354.8 nm) i.e. the control case

Run number	Detected laser frequency drift (MHz)
1	0.0106
2	-0.0758
3	-0.3532
4	0.1918
5	-0.4082
6	-0.0440
7	-0.1343
8	-0.0800
9	0.2039
10	-0.1233
	Mean =-0.08 MHz, Mean error = -0.08 MHz St.dev = 0.20 MHz

Table 10. Results of CSR updater for IRC with modified laser wavelength to 354. 7999748 nm (or +60.01 MHz shift)

Run number	Detected laser frequency drift (MHz)
1	60.0190
2	59.5687

3	59.5613
4	59.8247
5	59.8111
6	59.3177
7	59.8423
8	59.9609
9	59.7912
10	60.4453
	Mean =59.81 MHz, Mean error = -0.2 MHz St.dev = 0.30 MHz

The E2S simulation appears to be working correctly with Patch 1 as the CSR updater reported frequency shifts are close to the expected value; this is also confirmed in the plot of the Rayleigh responses in Figure 7. Due to noise, the estimates vary somewhat with both mean and standard deviation of errors on the order of 0.3 MHz. The worst case is around 0.7 MHz for an individual run, which corresponds to an error in HLOS wind space of 0.2 m/s, which is a small error, so this is good news for the L2B Calibration chain

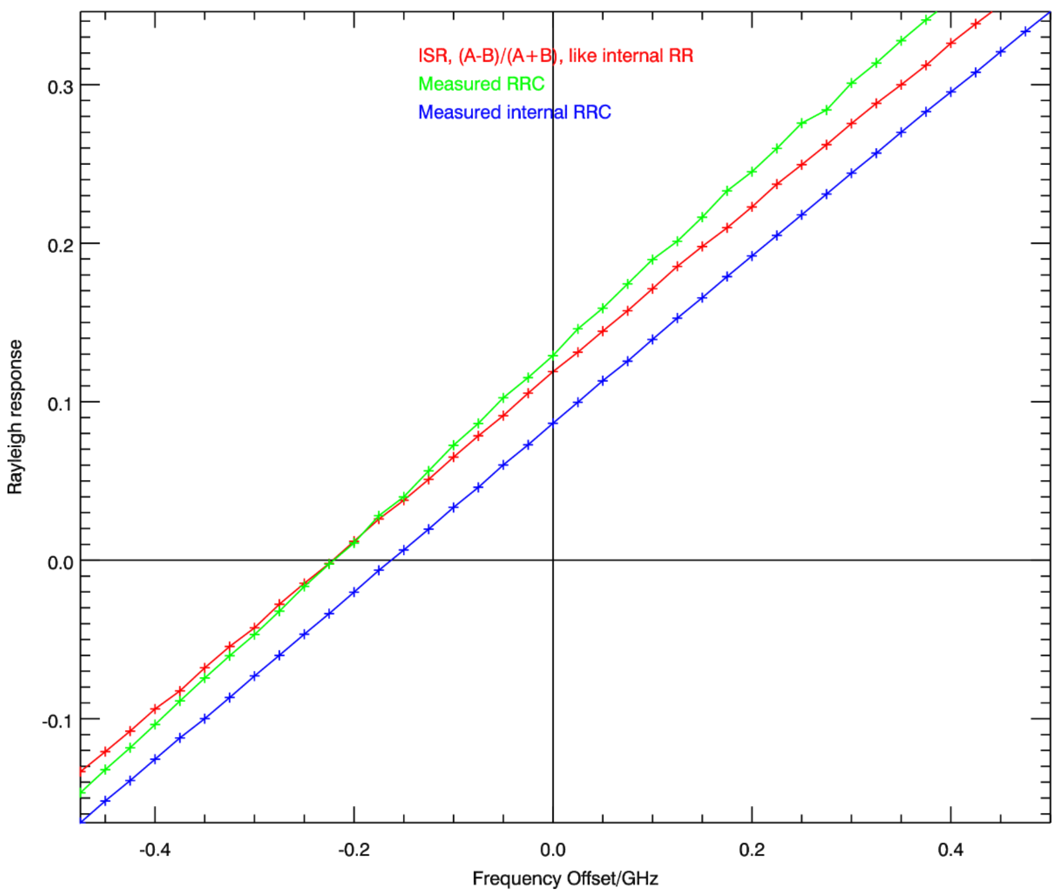


Figure 7. The ISR and IRC response calibrations compared for the Rayleigh response versus offset frequency after the fix to the E2S. This can be compared to Figure 6a) in which the RRC curves were shifted by 60 MHz too much relative to the ISR.

The effects on the L2B Rayleigh wind biases may be more complicated; in terms of how the frequency shift detection error interacts with the CSR updater process. For test run number 6 of Table 10, which had a frequency shift error of ~0.7 MHz the CSR updater still determined the étendue parameters rather well i.e. tilt=548 MHz and tilt=1.0, therefore the resultant L2B Rayleigh wind systematic error are expected to be small. Comparing the systematic error of L2B Rayleigh-clear HLOS winds for a "perfect" calibration case to that using the AUX_RBC_L2 generated from test run number 6, the bias difference is 0.15 m/s. This bias is also a function of the CSR updater performance with noise "on" in the E2S and not just the frequency shift determination. This level of bias is typical of that encountered when ISR noise is switched on in Section 4.3.2 of [RD17], therefore is not attributable to the error in frequency shift determination.

In summary: It is concluded that the errors in the CSR frequency shift detection are not causing any significant additional L2B Rayleigh wind bias. Also, it does not seem to be necessary to pass information on the ISR to IRC frequency drift to the L2B processor as long as the internal and atmospheric calibration is provided with respect to the same frequency offset axis.

6 Dynamic Rayleigh wind height assignment

One of the changes included in the L2B processor as part of CCN6 was the option to calculate more representative Rayleigh height assignment accounting for the weighting of molecular scattering attenuated backscatter within the range-bin. Previously a fixed height assignment option has been used with the setting of 0.49 i.e. just less than half-way through the range-bin to account for attenuated molecular backscatter typically being slightly higher in the lower part of the bin due to density decreasing with height (this value was justified in TN15.3 [RD4]). The new method uses the a priori estimates of pressure and temperature from the AUX_MET_12 file to do a dynamic calculation appropriate for the given range-bin at a given time. The settings in the AUX_PAR_2B file needed to use the dynamic estimate of Rayleigh height or the fixed estimate are described in the ATBD v3.00 [RD5]. Some testing has been done to see the effect on the L2B Rayleigh winds as follows.

The table below lists the value of weight given to the upper range-bin height as a function of pressure and temperature values encountered in a realistic simulation (ECMWF temperature, pressure) scenario as output from the L2B processor with the dynamic weighting switched on:

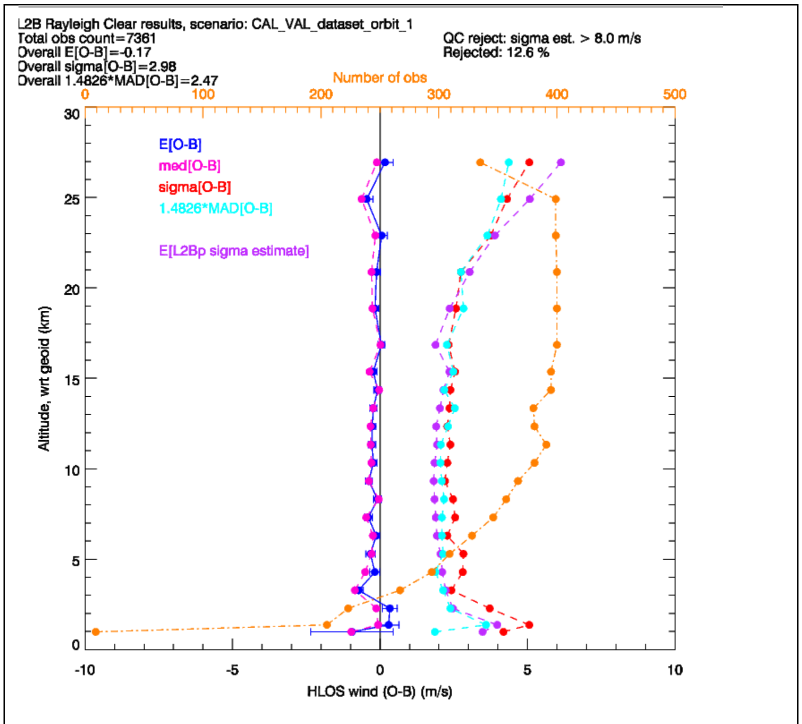
Table 11. Example of how the Rayleigh height assignment varies in example L2B profile

Assigned Rayleigh altitude (km)	Pressure (hPa)	Temperature (K)	Weight to upper bin
26.94	19.12	223.26	0.4797
24.92	25.98	219.26	0.4780
22.90	35.68	213.58	0.4804
20.88	49.23	210.56	0.4809
18.87	68.65	201.83	0.4818
15.36	96.44	195.25	0.4921
14.35	148.84	205.34	0.4925
13.35	175.27	213.33	0.4929
12.34	205.11	222.36	0.4933
11.33	238.53	230.78	0.4938
10.32	275.96	239.27	0.4943
9.31	317.68	247.03	0.4948
8.31	364.21	254.69	0.4954
7.30	415.93	259.96	0.4961
6.29	473.91	265.56	0.4969
5.28	538.32	271.32	0.4977
4.23	609.84	277.21	0.4986
3.27	689.04	283.06	0.4996

2.26	776.40	288.62	0.5007
1.51	847.93	290.61	0.5008
1.00	898.91	292.61	0.5011
0.50	952.58	294.72	0.5015

One can see that the suggested average value of 0.49 is not too bad as an overall compromise. Note that the thinner the range-bins i.e. those nearer the surface, the less important is the deviation of the weight given to upper bin value from 0.5.

The effect of the dynamic weight compared to the fixed weight has been tested for one orbit of realistically varying winds (from ECMWF TCo1279 L137 simulation (~9 km grid spacing horizontally, 137 levels in the vertical)). Verification statistics for such a case with dynamic weight to the upper bin (a) and fixed weight of 0.49 (b) are given in Figure 8 below.



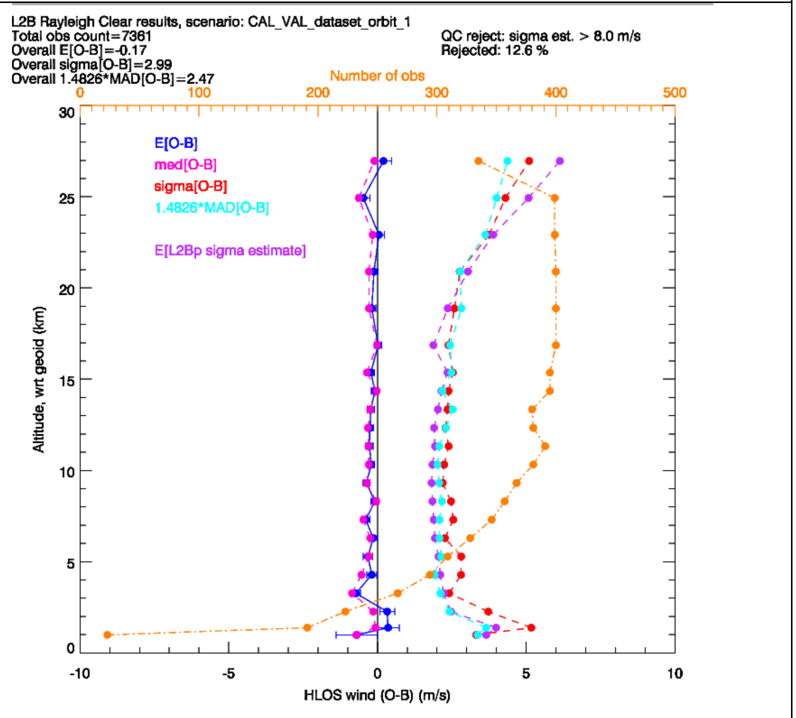
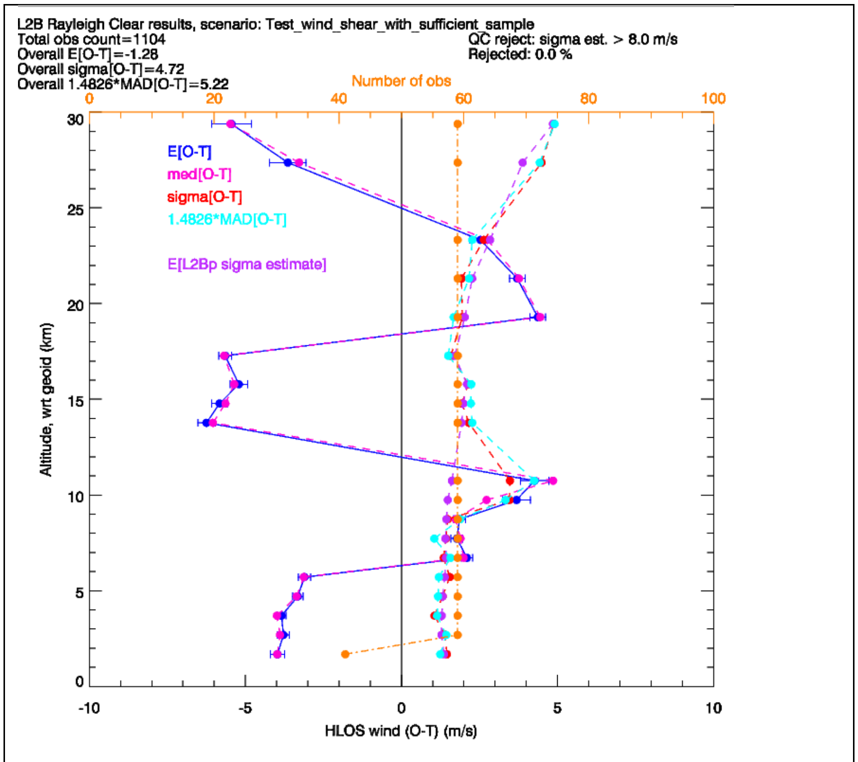


Figure 8. Aeolus L2B Rayleigh-clear verification statistics shown with varying altitude for a) with dynamic p, T derived altitudes and b) with fixed height = 0.49. Simulation is one orbit of 320 km realistic ECMWF model derived E2S inputs.

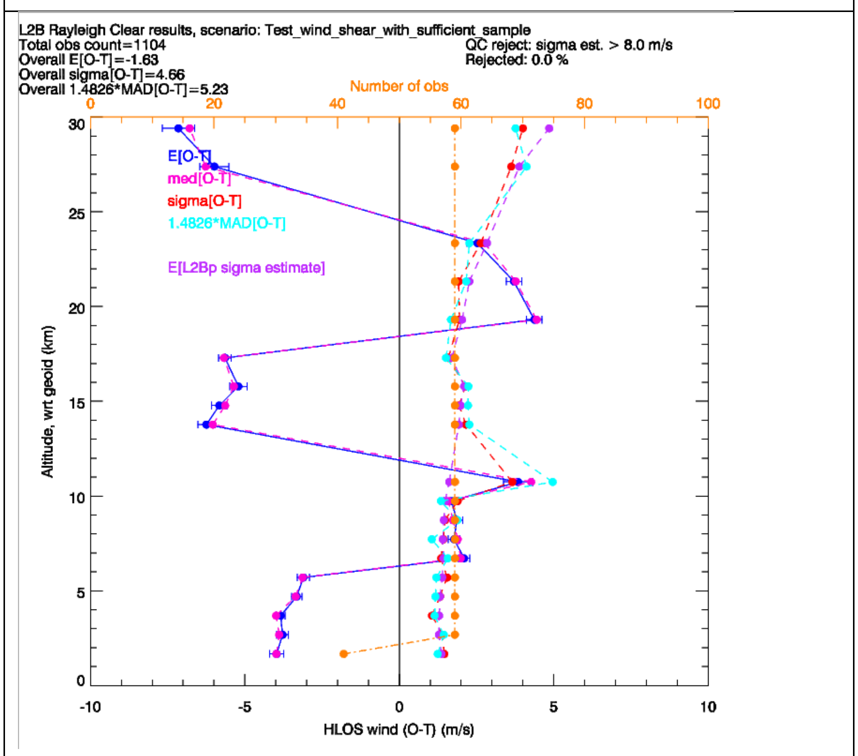
Figure 8 shows there is hardly any change in the error statistics when using the dynamic weight compared to the fixed weight (0.49) for the upper bin. The dynamic weight has a better standard deviation, but by only 0.01 m/s.

So why does the dynamic weight apparently not give much improvement over the fixed weight? Height assignment is most important for thicker range-bins combined with strong vertical HLOS wind shear. If HLOS vertical wind shear is at an extreme value of 50 m/s/km (or 0.05 s^{-1}), then the difference between the fixed weight on upper bin and the dynamic weight for one of the uppermost range-bins is according to Table 11; 0.4900-0.4797=0.0103, which for a 2 km thick range-bin corresponds to a 2000*0.103 =20.6 m vertical misplacement. This would give an effective bias of with strong wind shear of 50 m/s/km *0.0206 km = 1.03 m/s which is a fairly large bias. However, if the vertical wind shear is more moderate level of 10 m/s/km of then an effective bias of 0.2 m/s would occur; which is not particularly noticeable compared to more significant biases coming from other sources. So it seems that with the more moderate wind shear levels, as encountered in the ECMWF model for this simulation, then the change to dynamic weight leads to little difference in the error statistics because the effect is expected to be small.

Doing a simulation with the extreme vertical wind shear; varying linearly with altitude from -150 m/s to 150 m/s repeatedly with 50 m/s/km vertical wind shear throughout the profile gives the following results. The scenario contains 59 BRCs with the conditions not varying in the horizontal. There is some aerosol via the RMA profile for mid-latitude winter, however the atmosphere is predominantly clear air to focus on the Rayleigh results.



a)



b)

Figure 9. Aeolus L2B Rayleigh-clear verification statistics for a) with p, T derived dynamic weight to upper bin and b) with fixed weight = 0.49 to upper bin. Simulation is for 59 BRCs.

In both dynamic and fixed weight cases there are large HLOS wind biases of the order 5 m/s, even at lower range-bins i.e. larger than would be expected due to height assignment issues. There is a marginal improvement in bias for the upper altitude range-bins with dynamic weight compared to the fixed weight, however there is a much larger bias overall. This larger bias seems to be not related to the assignment of the altitude dynamically (which should improve bias by 1 m/s).

A possible hypothesis for the large biases is due to the Rayleigh signal in extreme vertical wind shear being in effect a superposition of many Rayleigh-Brillouin spectra which over a 2 km range-bin will have 100 m/s variation in HLOS wind speed. Such a "blurred-out" in frequency line-shape will then have a rather different Rayleigh response versus frequency than if the Doppler shift is constant. Our Aeolus calibration strategy (RBC look-up table) is only designed to work on fixed HLOS wind speeds (Doppler shifts) within the range-bin and not on such high wind variability scenarios. If this is true then is a fundamental problem for Aeolus wind retrievals in strong wind shear with thicker range-bins.

In summary: the dynamic Rayleigh height assignment has been technically demonstrated to work, however it leads to very modest improvements in the L2B Rayleigh wind error statistics compared to the fixed weight approach in the scenarios tested.

7 An update in the Chain of Processors default version used for testing

Unless specified otherwise, the testing that follows this section will use the following combination of processors in the Chain-of-Processors (CoP):

Table 12. CoP processor version combination used in sections following this one (unless specified otherwise)

Processor name	Processor version	Date of release
E2S	v4.01	July 2017
L1Bp	v7.01	August 2017
Calibration (CAL) suite	v4.00	July 2017
L2Bp	v3.00	September 2017

If not specified we use the “perfect calibration” settings for the E2S, L1Bp and L2B as reported in the recent TN 17.1 i.e. [RD17].

The above chain-of-processors combination was set-up for testing as part of the L2BP v3.00 processor delivery scheduled for September 2017.

8 Effect of Instrument Functional Performance (IFP) related modifications to the chain-of-processors on L2B winds

The CCN6 work package 2810 has a sub-task to test the "sensitivity of L2B winds to updated instrument parameters emerging from the on-ground IFP test …". A number of changes to the simulation of Aeolus have been made in E2S v4.00 which are also present in the latest (at time of writing) E2S: E2S v4.01. A few of these changes have come about as a result of the IFP testing of Aeolus e.g.:

- Fizeau transmission and reflection model of the internal path
- Radiometric gain model[4]

The first one has most significance for L2B winds. It will have a direct effect on the Mie results by the resultant different Mie response curves for the internal and atmospheric paths.

However it can also effect the Rayleigh L2B results via the calibration chain. This is because the ISR is created using internal signal and hence for the Rayleigh transmission curves it shows the effect of the internal path Fizeau reflection, whereas the RRC is performed using atmospheric signal and will show the effect of the atmospheric path Fizeau reflection. The Calibration suite CSR updater compares the RRC to the ISR to obtain the étendue parameters. Because of the mismatch of the ISR and RRC Fizeau reflection function this may cause discrepancies in the atmospheric RR curves that are written to the AUX_RBC_L2 file and hence lead to L2B Rayleigh biases. Therefore we should verify if the L2B Rayleigh wind biases in the latest CoP are noticeably worse.

To test the effect of changes to the E2S/L1Bp parameters related to IFP results we shall perform runs of the CoP for realistic scenarios and qualitatively compare the verification results to those of past CoP results.

8.1 Calibration chain processing

Five AUX_RBC_L2 files were generated via repeated runs of: noisy ISR, CSR generation, noisy IRC, CSR updater and RBC generation using standard E2S noise settings with realistic atmospheric (ECMWF input) for the IRC. The E2S was run with étendue on with a top hat width of 500 MHz and a tilt of 1.0.

The CSR updater results were:

Width (MHz)	Tilt	Distance
459	1.2	0.001033
533	1.0	0.000998
570	0.9	0.001145
559	1.0	0.000991
352	1.5	0.001131

[4] Thomas Kanitz (ESA) reported: After some library work, I presented the available numbers and the "design idea" to DH and OR. Based on that it was implemented in E2S. It has nothing to do with IFP.

The results look reasonable apart from the last run which is an outlier.

8.2 WVM processing chain

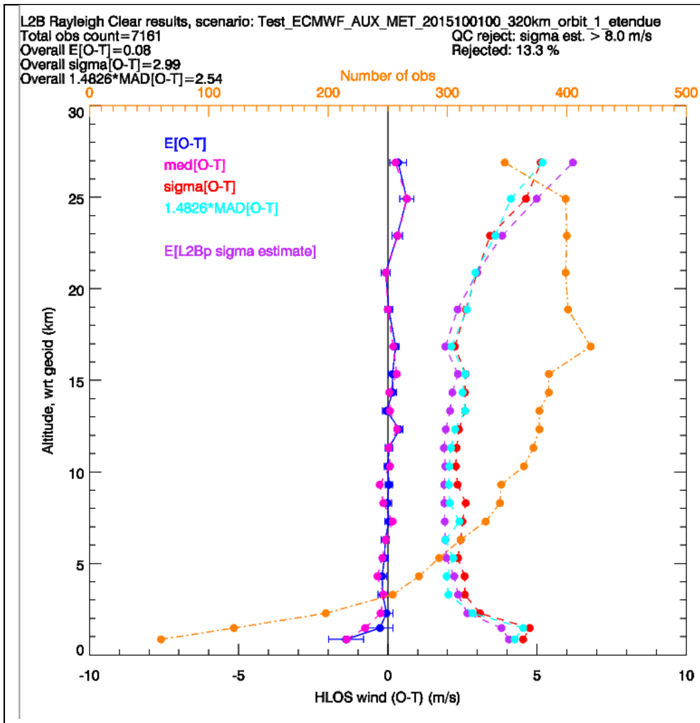
A realistic EMCWF scenario of one orbit (lower orbit of 320 km) with the étendue on and the same parameters as above was run. The resultant L1B WVM file was then processed multiple times to the L2B product using the different AUX_RBC_L2 files produced in the previous section.

The L2B winds were produced with the settings:

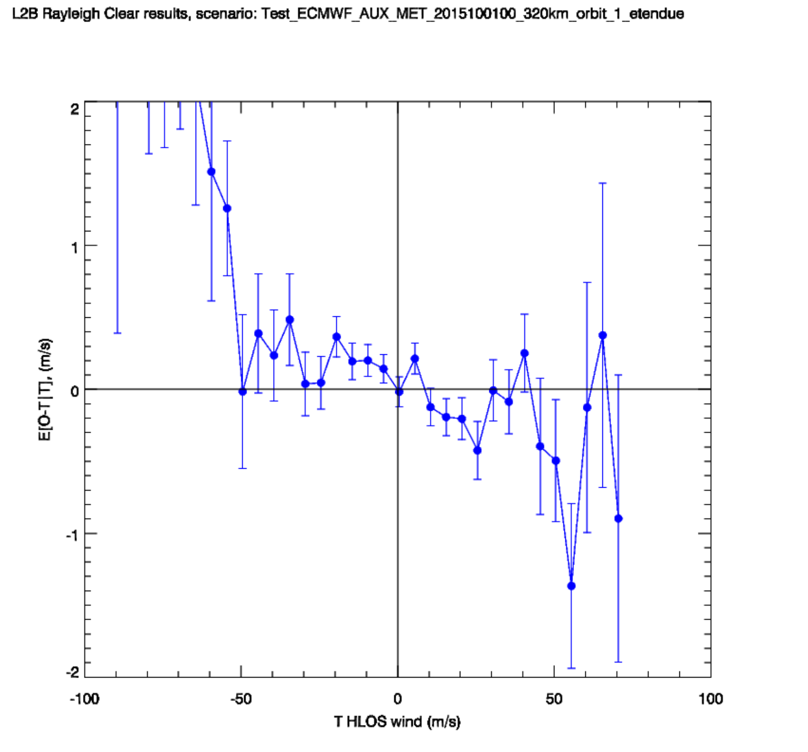
- Rayleigh grouping of 100 km, Mie of 20 km
- Scattering ratio threshold of 1.25 for both Rayleigh and Mie measurement-bin classification.
- The AUX_MRC_1B data used for the L2B Mie winds came from an idealistic simulation of the IRC (no noise).

For the different AUX_RBC_L2 files it was found that the L2B Rayleigh-clear wind verification did not vary significantly (even for the fifth AUX_RBC_L2 file with apparently dubious étendue results); an example of the verification produced with one of the AUX_RBC_L2 files is shown in Figure 10.

The levels of bias is fairly similar to that found in previous CoP versions and the HLOS dependence of the bias looks similar also; compare to results in TN17.1 [RD17]. One clear difference is the improvement in Rayleigh-clear HLOS wind error standard deviation. This is because of the lower orbit (320 km) simulated by default in the latest CoP compared to the higher orbit in the older CoP.



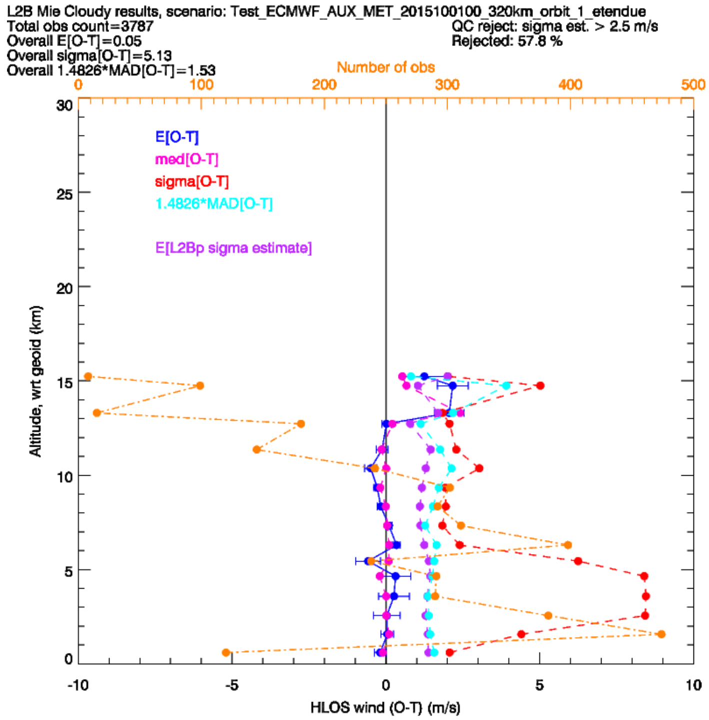
a)



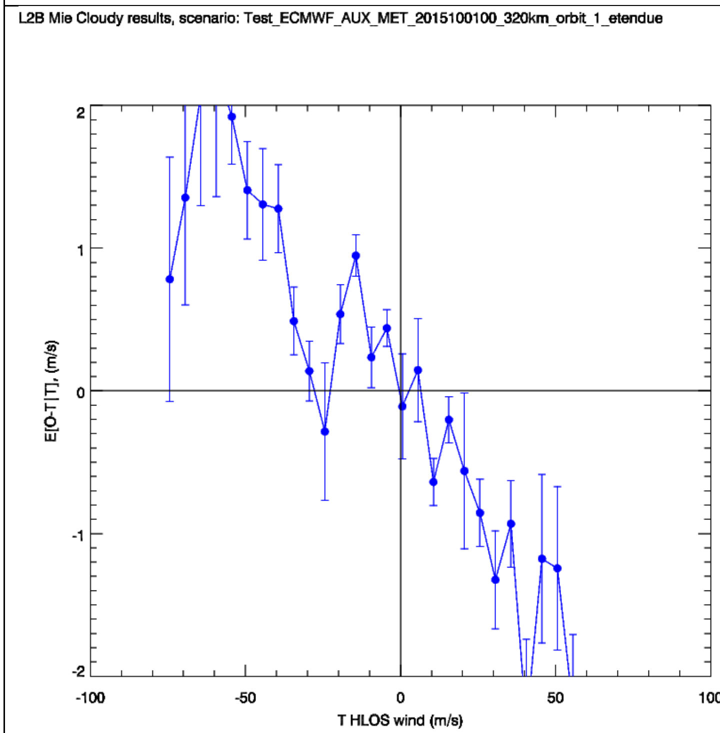
b)

Figure 10. L2B Rayleigh-clear verification using one of the AUX_RBC_L2 files generated. a) Verification statistics as a function of altitude (O=observation, T=truth) b) This plot shows the dependence of the mean error (in observation (O) minus truth (T)) upon the truth (T) HLOS wind values.

The L2B Mie-cloudy wind verification is shown in Figure 11. The robust statistic (scaled Median Absolute Deviation) random error level looks as to be at the expected levels for the Mie results (1-2 m/s). The standard deviation is affected by outliers and some refinement of the classification scattering ratio threshold and L2B wind error estimate QC threshold can be tuned to remove these (as has been done on previous CoP versions). The Mie-cloudy HLOS wind dependent bias (slope error), as shown in b) of Figure 11, looks large, as was noticed in previous investigations, and is believed to be because of vertical wind shear dependency of the bias for the Mie (see TN17.1 [RD17], height assignment issues with clouds in strong vertical wind shear and thick range-bins). Also, this could be exacerbated by the outliers in the statistics.



a)



b)

Figure 11. L2B Mie-cloudy verification. a) Verification statistics as a function of altitude (O=observation, T=truth) b) This plot shows the dependence of the mean error (in observation (O) minus truth (T)) upon the truth (T) HLOS wind values.

In summary: The L2B HLOS wind error statistics do not look worse than those of the older chain-of-processors as provided in TN17.1 [RD17] with the latest CoP. Therefore it appears that there are no obvious bad side effects for L2B winds of the IFP related changes to the E2S.

These results are in agreement with Thomas Flament's note [RD25], that the main impact of the Fizeau internal/atmospheric path illumination change is on the AUX_CAL only.

N.B. The first time this new CoP combination was tested, the L2B Mie-cloudy HLOS winds suffered from an overall -2 m/s bias. After some investigation it was discovered to be a bug in the L2B processor. The L2B processor had assumed the Mie calibration information from the AUX_MRC_1B to be referenced across the whole ACCD from pixels 1 to 20 i.e. including the detection chain offset (DCO) pixels. However the MRC (and L1B processor) has pixel numbering referenced only for the sixteen useful signal pixels i.e. pixel 3 to 18. This small bug (with large consequences) was fixed and the overall bias was reduced to be close to zero. The bias did not exist in previous CoP because the MRC internal and measurement responses were almost identical linear curves, whereas they now have different slopes/intercepts following the IFP changes. When the internal and atmospheric response curves are the same and nearly linear, then it does not matter where along the pixel axis the response value lies i.e. it doesn't matter if the L2B used pixel values are too big by 2 pixels if this is consistent in the internal and atmospheric responses.

9 Testing of the new flexible L2B scattering ratio thresholds for classification

CCN6 WP2550 has a sub-task to: "Implement flexible and independent scattering ratio thresholds (in the AUX_PAR_2B) for the Rayleigh and Mie channel classification algorithms and perform scientific testing to verify behaviour". This technical change has been implemented in L2Bp v3.00. In this section we report on the chain-of-processor verification of this change to show that the new code options works as expected and discuss the recommended scattering ratio thresholds determined using ECMWF's verification tools for simulated data

9.1 The ECMWF derived "realistic" scenario with cloud optical properties

Some tests have been done with an ECMWF "realistic" scenario (i.e. realistic wind, temperature and cloud variation, but no aerosols) for one orbit of data (actually this is the first orbit of the CAL/VAL rehearsal dataset). The best wind results with regards to the more accurate L2B HLOS wind observation types i.e. Rayleigh-clear and Mie-cloudy are found when using fairly conservative, but different scattering ratio thresholds for the Mie and Rayleigh.

- The best results obtained in this scenario for the **Rayleigh-clear HLOS winds are with a scattering ratio threshold of 1.25** (not varying with altitude). This threshold limits the genuinely "cloud" contaminated measurement-bins from entering into the Rayleigh-clear winds (which can lead to biases) and the threshold also accounts for the roughly 10-20% positive bias for the lowest values of L1B refined scattering ratio; see Figure 12.
- The best results obtained in this scenario for the **Mie-cloudy HLOS winds are with a scattering ratio threshold of 1.5** (not varying with altitude). Therefore rejecting measurement-bins with relatively low levels of particulate backscatter and with the aim of avoiding too many genuinely "clear" measurement-bins with noisy scattering ratio estimates entering the retrieval. This may have some cost in regards to missing measurement-bins with aerosol i.e. they will end up in the Mie-clear wind results, rather than the better quality Mie-cloudy wind results. **The next sub-section addresses appropriate Mie SR thresholds for aerosol conditions.** N.B. These results used a 20 km group size for the Mie winds, much smaller than is sensible for the Rayleigh, which is possible due to the good SNR conditions from cloud backscatter for the Mie.

Note that different scattering ratio thresholds were applied for the Mie and Rayleigh results in this test. The L2Bp algorithms seemed to work as expected and hence we have practically tested the algorithm as was requested in CCN6.

Since these results are based on simulated Aeolus data, then the recommended scattering ratio thresholds may not apply to real Aeolus data which could have different SNR properties. It will be a Commissioning Phase task to tune these parameters.

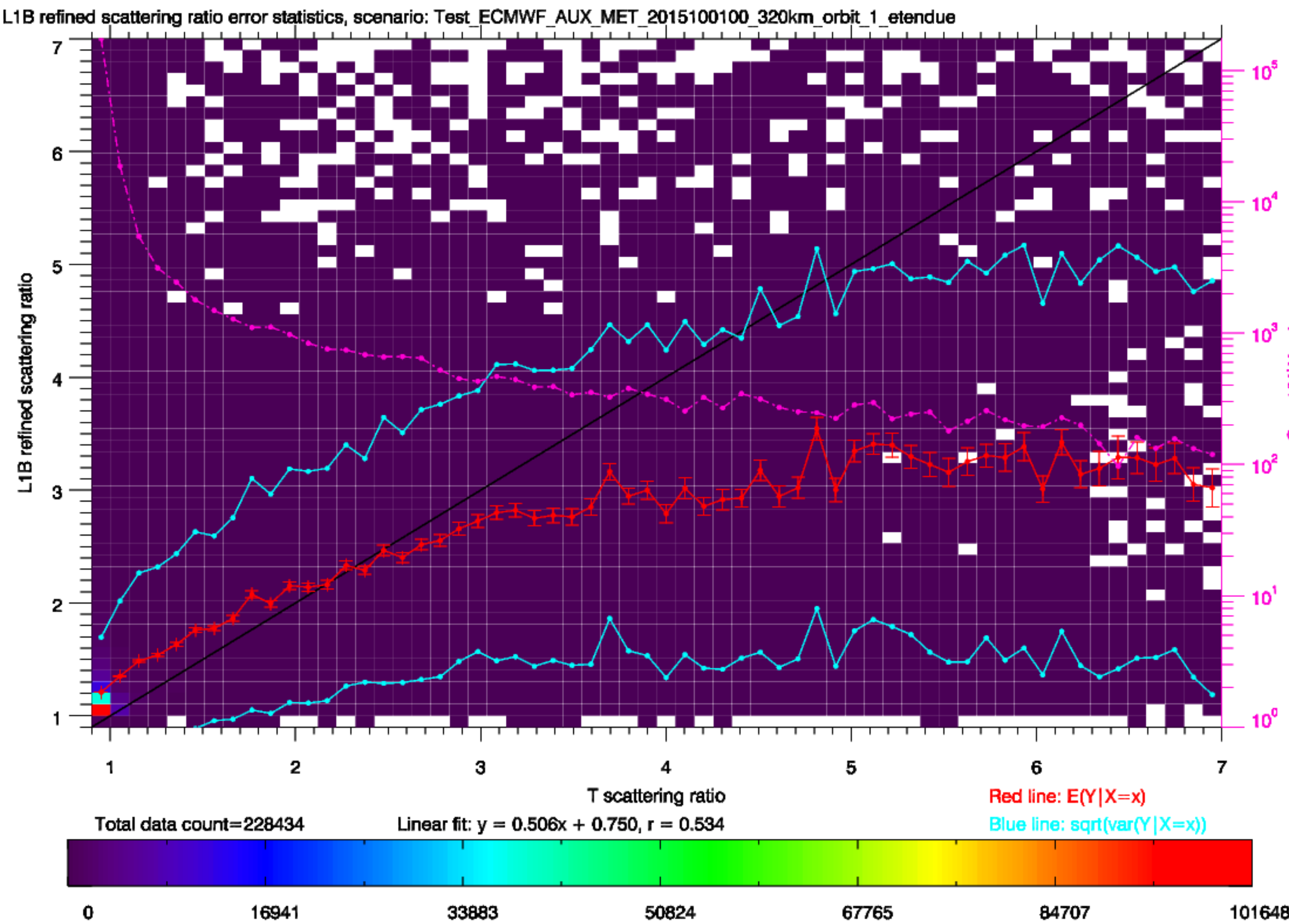


Figure 12. Comparison of the L1B refined scattering ratio to the "truth" (T) scattering ratio for the ECMWF derived cloudy scenario (red line). Pink line: number of observations with a given true or estimated scattering ratio. Black line: 1:1 comparison. Blue lines: 1 sigma standard deviation. A positive bias in the L1B SR is evident for SR < 2.3 and a negative bias for SR > 2.3. The bias at small SR is more a concern for L2B classification.

Figure 13 a) shows the "true" SR (input to E2S) interpolated onto the Mie measurement-bins and b) the resultant L1B refined scattering ratio. It is clear that the L1B measurement-bin scattering ratio values can be rather noisy (blue lines show standard deviation around the mean red line in Figure 12) and that there is limited information (lots of missing values) below optically thick clouds. If one uses the L1B scattering ratio for classification, then there is 63% success rate with a SR threshold of 1.25 as compared to the ideal classification (using the "truth" SR) based on the same threshold i.e. see Figure 14. This seems to capture the majority of the truly "clear" measurement-bins without too much contamination by incorrectly classified measurement-bins i.e. those that actually are "cloudy" but are assigned as "clear".

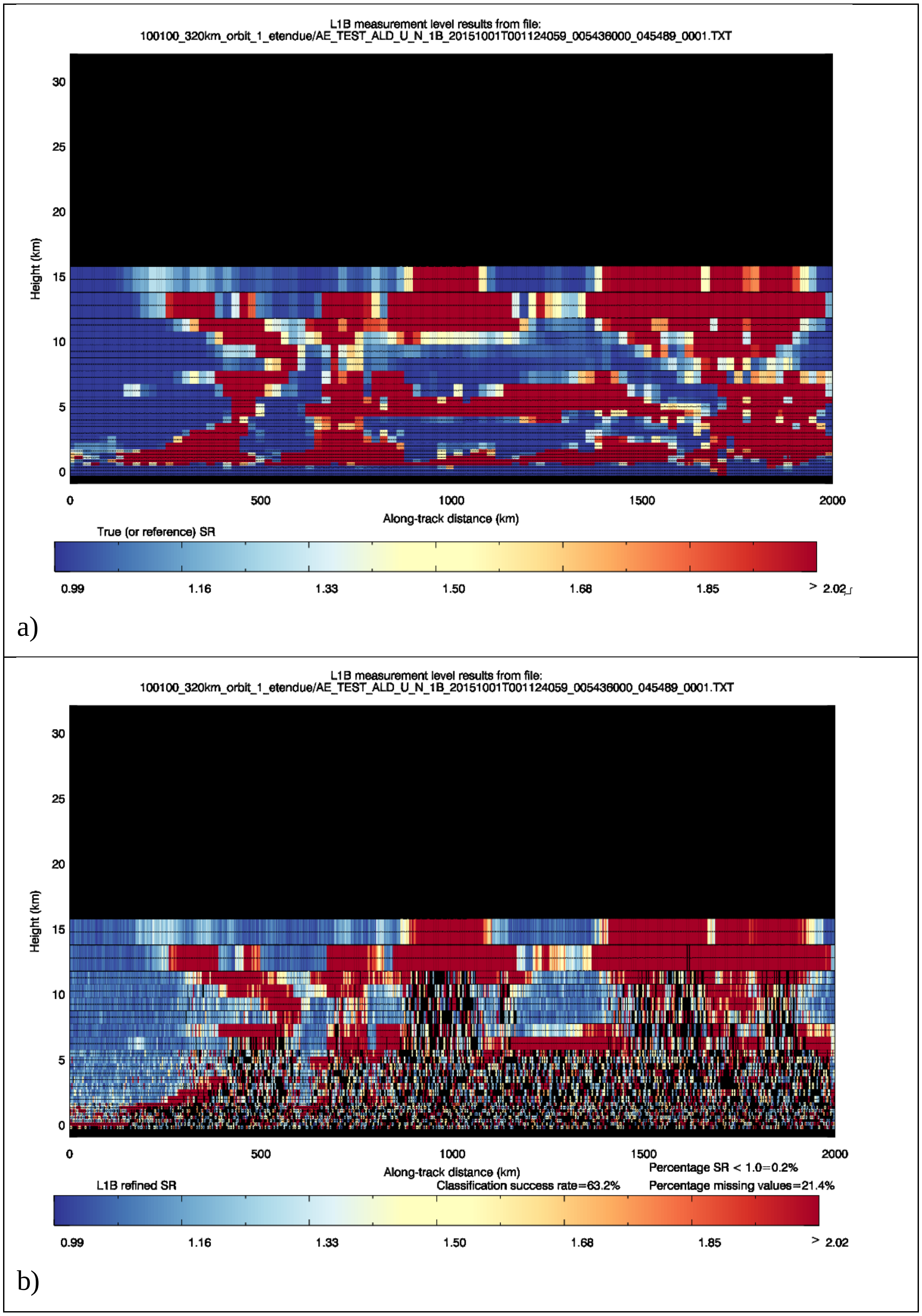


Figure 13. a) "Truth" scattering ratio on Mie measurement-bins b) L1B measurement-bin scattering ratio, for the first 2000 km of the 1 orbit ECMWF scenario.

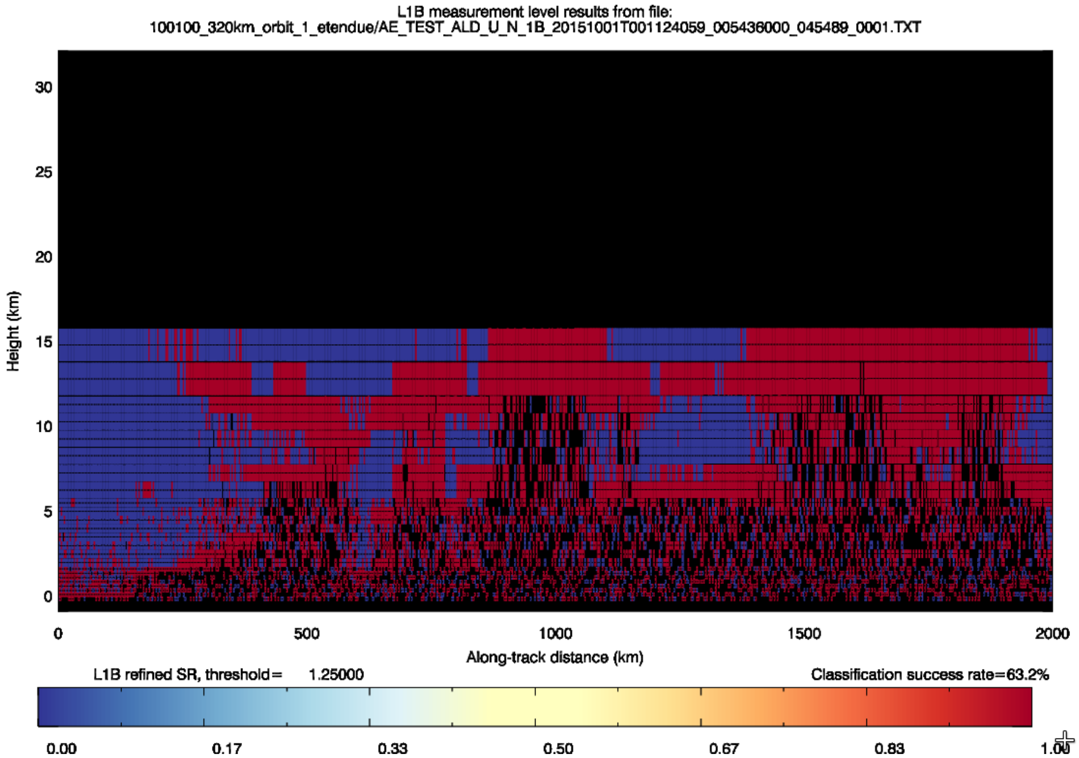


Figure 14. Plot showing the classification decision: cloudy (red) or clear (blue) with a scattering ratio threshold of 1.25 applied to the L1B refined scattering ratio of Figure 13 b). With a scattering ratio threshold of 1.25 then the classification is successful 63% of the time using the L1B refined scattering ratio.

9.2 LITE Scene B with aerosol optical properties

Given that the ECMWF "realistic" scenario does not contain particulate backscatter and extinction related to aerosol (only to clouds) then it was thought to be useful to test a scenario with aerosol. One such scenario is LITE Scene B with profiles every 0.5 km (Indonesian cirrus case part 2, 10-Sep-1994 between 20:02:04h and 20:04:03h). It is characterized by an optically thin cirrus layer at 15 km altitude and elevated aerosol layers up to 3 km (see TN3.1a [RD23]). It also has low levels of aerosol in the stratosphere.

With this scenario, it was found that to get reasonable quality Mie-cloudy results from aerosol regions it was necessary to decrease the scattering ratio threshold from 1.5 to 1.2. This is because aerosol often has true scattering ratio values in the range 1.1 to 1.4 (see Figure 15 and Figure 16), however with the positive bias in the L1B refined scattering we need to increase the SR threshold above 1.1.

However, a Mie SR threshold of 1.2 leads to more outlier (gross error) wind results, due to measurement-bins with no true Mie signal, but detected as having scattering ratio greater than 1.2 due to noise (the noise is evident in Figure 17). One can use the Mie HLOS wind estimated standard error values to try to QC the outliers (however this is imperfect). Another possibility to avoid too much contamination of good Mie results with outliers would be to introduce a new class for the L2B Mie results: **Mie_low_SR** in a future L2B processor version**. This could be for winds derived from measurement-bins with scattering ratios between e.g. 1.1 and 1.5** - scattering ratio values which seem to be more typical values for aerosol loaded areas and optically thin clouds. **Mie_high_SR would then**

be for scattering ratios > 1.5 and hence would still remain free of most of the possible outliers due to errors in classification. N.B. Some cirrus clouds and polar stratospheric clouds will fall into this low range of scattering ratios. In fact, Figure 18 shows histograms of the L1B refined SR and the E2S input truth SR (derived from ECMWF model fields - clouds only). There are actually quite a large fraction of measurement-bins with 1.0 < SR < 1.5 from the ECMWF model fields, therefore this range is not just reserved for aerosols. It is seen how relatively few of the L1B refined SR values are clear (SR=1.0) compared to the truth. There are many more L1B SR values assigned low but > 1.0 SR values due to the noise and positive bias. These SR threshold issues will have to be investigated carefully with real Aeolus data when available.

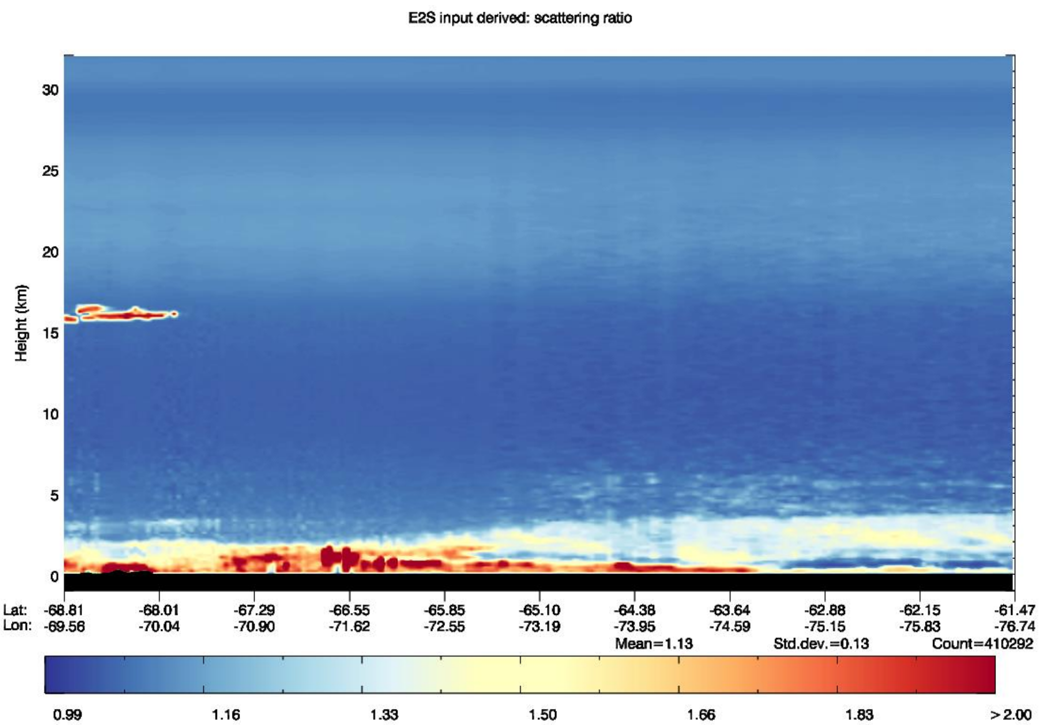


Figure 15. E2S inputs converted to scattering ratio for LITE scene B: 10-Sep-1994 between 20:02:04h and 20:04:03h near Indonesia.

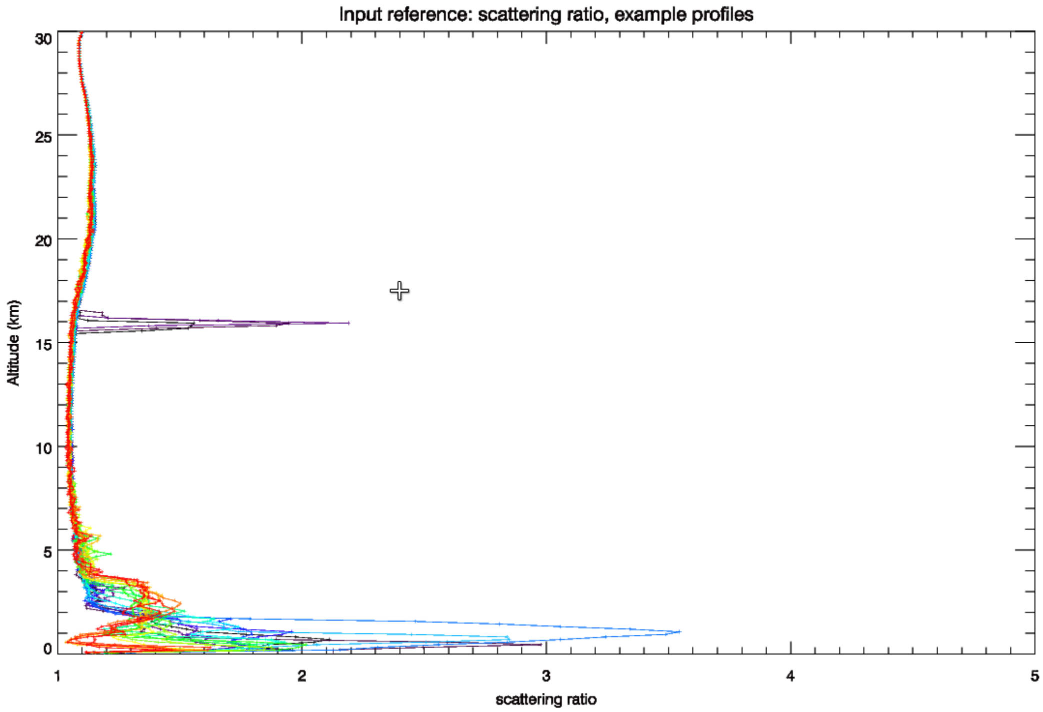


Figure 16. E2S inputs converted to scattering ratio at various positions during the scenario (as shown in Figure 15). Different colour for each profile (first= dark blue, last = dark red).

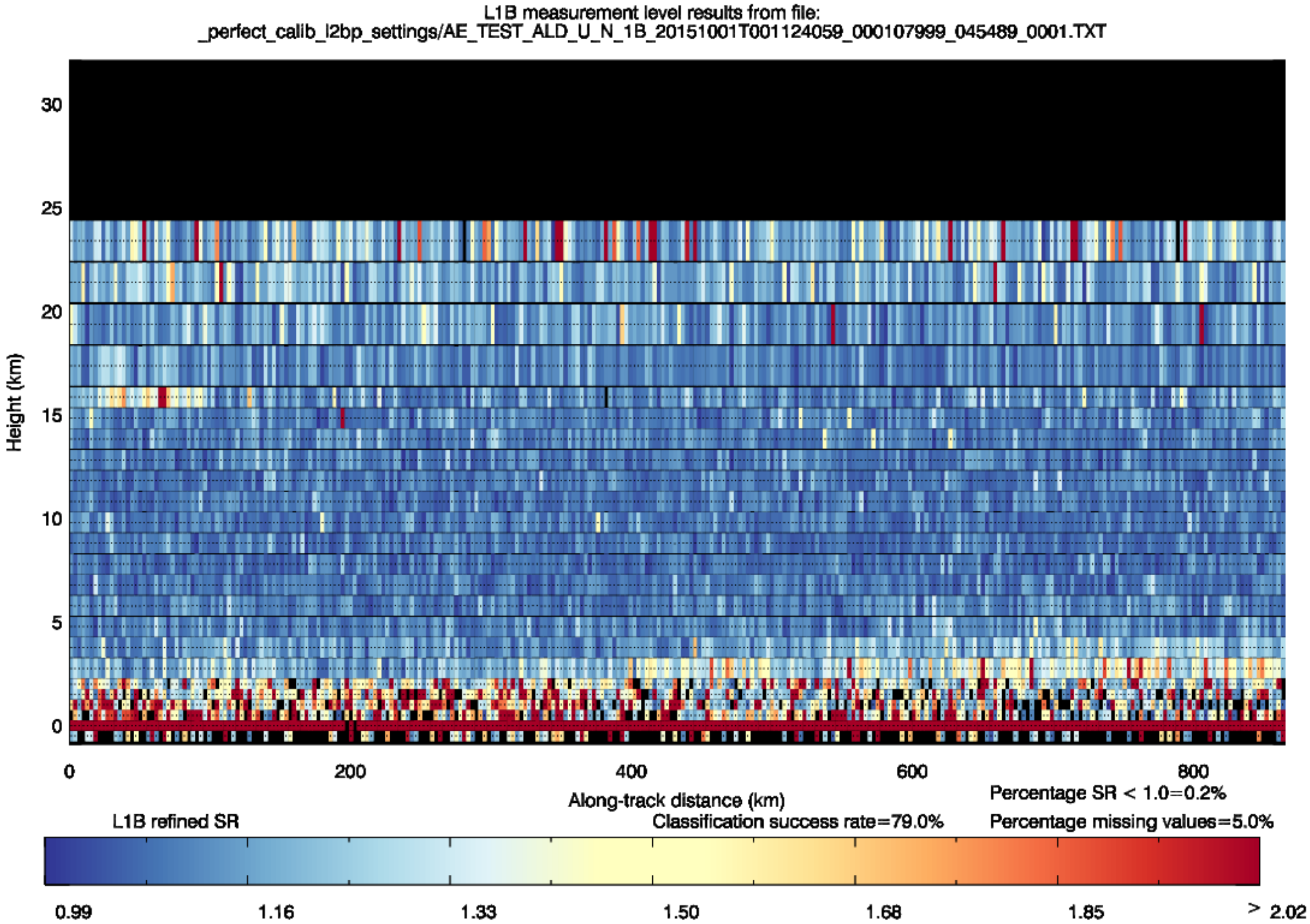


Figure 17. L1B refined scattering as reported on Mie measurement-bins for LITE scene B. Compare to the “truth” SR as shown in Figure 15.

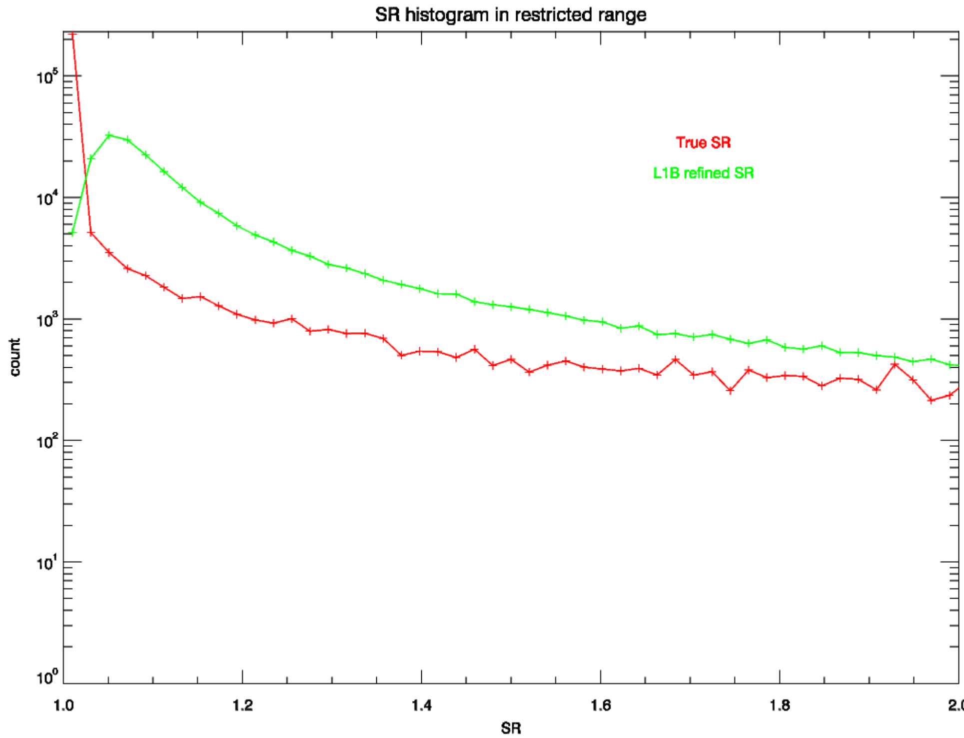


Figure 18. Histogram of true scattering ratio and L1B refined scattering ratio on measurement-bins for an ECMWF TCo1279 case with particulate backscatter from clouds only (no aerosol). Notice the log scale on the count axis.

In summary: The testing of this section was sufficient to show that the new flexible Mie and Rayleigh scattering ratio thresholds in the L2B processor worked as expected. Some suggestions for classification scattering ratio thresholds for optimising the quality of Rayleigh-clear and Mie-cloudy results were given.

10 Conclusions

This technical note has investigated the effect of several changes in the E2S and L1B products upon the L2B results. Some of the main findings:

- The Rayleigh winds are significantly noisier above 15 km altitude due to conditions with solar background noise (day) compared to night-time conditions, but the systematic error is not affected. This means the desired noise levels of the Aeolus mission requirements above 20 km altitude cannot be met in day-time conditions. The Mie winds are unaffected, both in terms of random and systematic errors. The systematic errors from increased noise in the L2 Rayleigh calibration chain do not seem to be effected by the levels of solar background noise, since it uses the RRC in the 6-16 km altitude range
- It was concluded that the errors in the CSR frequency shift detection (to detect frequency shift between the ISR and IRC) are not causing any significant additional L2B Rayleigh wind bias. Also, it does not seem to be necessary to pass information on the ISR to IRC frequency drift to the L2B processor as long as the internal and atmospheric calibration information is provided with respect to the same meaning frequency offset axis.
- The L2B HLOS wind error statistics are not noticeably worse with the new Chain-of-Processors (details of new CoP in section 7) compared to the older chain-of-processors as provided in TN17.1 [RD17]. Therefore it appears that there are no obvious bad side effects for L2B winds of the IFP related changes to the E2S, which is a good result.

This technical note has also investigated technical changes to the L2B processor algorithms implemented as part of CCN6, the conclusions of the testing of which are:

- Applying the RDB correction at the assigned altitude of the range-bin (typically half way up a range-bin) is sufficient to do the RDB correction without any obvious degradation. This investigation was aided by simulations using high laser pulse energy.
- The dynamic Rayleigh observation height assignment has been technically demonstrated to work, however it leads to very modest improvements in the L2B Rayleigh wind error statistics compared to the fixed weight approach in the simulated scenarios tested. This will be investigated further in the Commissioning Phase with real Aeolus data.
- It was shown that the new independent Mie and Rayleigh scattering ratio thresholds for classification in the L2B processor worked as expected. Some suggestions for the scattering ratio thresholds for optimising the quality of Rayleigh-clear and Mie-cloudy results were given (i.e. 1.5 for partitioning Rayleigh clear and cloudy), and 1.2 for partitioning Mie clear and cloudy) to optimise current L2B results (from simulations). It was suggested that a new classification of Mie_low_SR and Mie_high_SR might be useful to avoid contaminating the current Mie-cloudy type with too many outliers.