The Wind Lidar Mission ADM-Aeolus

Data Processing

David Tan

Research Department

ECMWF

Acknowledgements:

ESA (Mission Science & Aeolus project team)

Aeolus Mission Advisory Group

Level-1B/2A/2B Development Teams

Contents

- Summary on 2 Slides
- Background
- Data Processing
  - Assimilation of Level-2B hlos wind
    - Simulations of Level-2B hlos wind data
    - Assimilation impact study
  - Level-2B processor development
    - How to make operational Level-2B hlos
    - Algorithms & rationale
    - Validation
- Conclusions

Summary of ECMWF activities for ADM-Aeolus

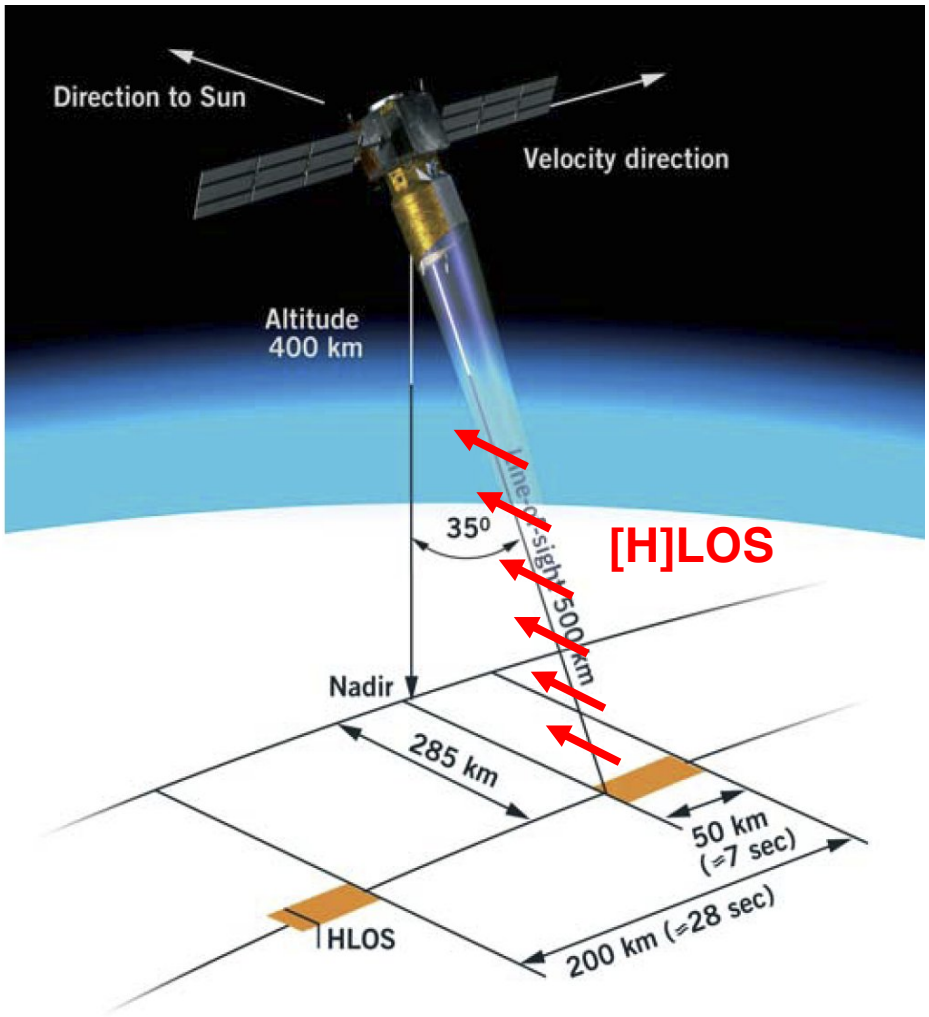
- Prepared for assimilating L2B hlos wind
  - 2002-04, example for other centres
- Developing Level-2B processor
  - ECMWF is lead institute, 5 sub-contractors
  - 2004-present
- Other ongoing work/operational phase
  - MAG, GSOV, Cal/Val, In-orbit commissioning
  - ECMWF to generate operational L2B/L2C products, monitor & assimilate Aeolus data, assess impact on NWP
  - Maintain, develop & distribute L2B processor
    - ➔ On behalf of ESA, using NWP-SAF approach

Status summary: Day-1 system on track

1. Level-2B hlos winds – primary product for assimilation
   a. Account for more effects than L1B products
   b. Will be generated in several environments
   c. Motivated strategy to distribute source code
2. Main algorithm components developed & validated
   a. Release 1.33 available – development/beta-testing
   b. Documentation and Installation Tests
   c. Portable – tested on several Linux platforms
3. Ongoing scientific and technical development
   a. Sensitivity to inputs, QC/screening, weighting options
4. Contact points – ESA and/or ECMWF

Contents

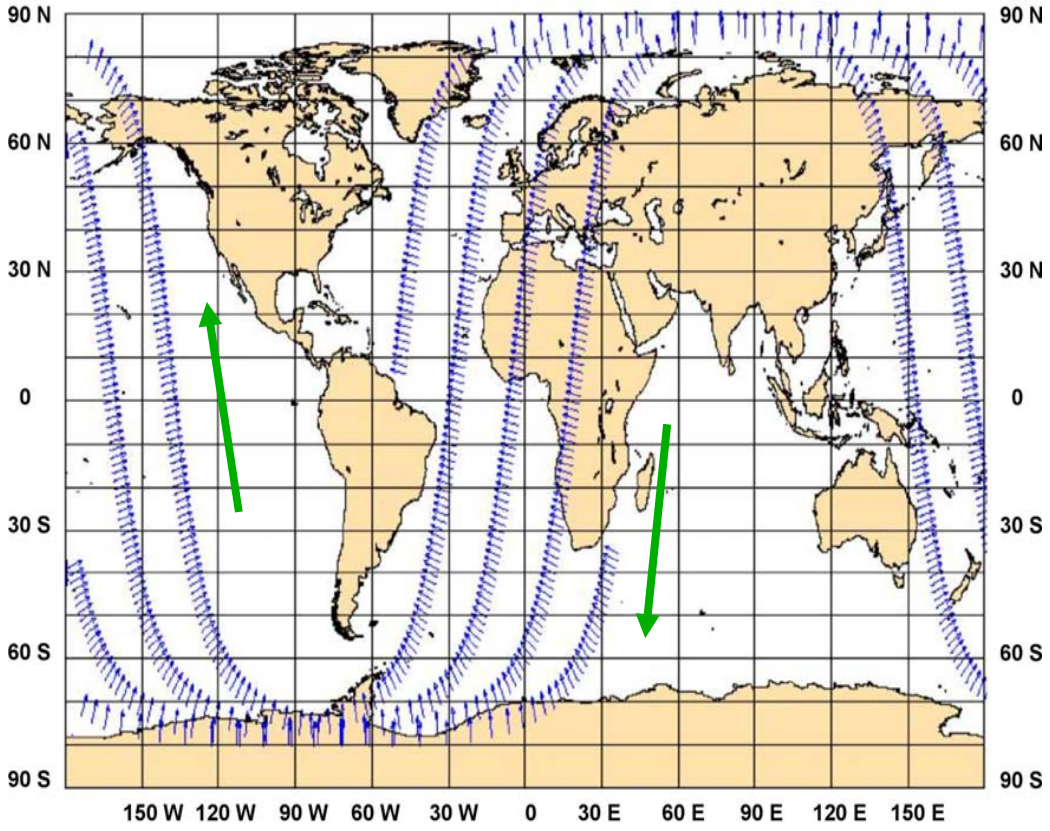
Atmospheric Dynamics Mission ADM-Aeolus



ADM-Aeolus with single payload
Atmospheric LAser Doppler INstrument
ALADIN

- Observations of Line-of-Sight LOS wind profiles in **troposphere to lower stratosphere up to 30 km** with **vertical resolution from 250 m - 2 km**
- horizontal averages over **50 km every 200 km** (measurements downlinked at 1km scale)
- Vertical sampling with **25 range gates** can be varied up to 8 times during one orbit
- High requirement on **random error** of HLOS
  <1 m/s (z=0-2 km, for Δz=0.5 km)
  <2 m/s (z=2-16 km, for Δz= 1 km),
  unknown bias <0.4 m/s and linearity error <0.7 % of actual wind speed; HLOS: projection on horizontal of LOS => LOS accuracy = 0.6*HLOS
- Operating @ **355 nm** with spectrometers for molecular Rayleigh and aerosol/cloud Mie backscatter
- First **wind lidar** and first High Spectral Resolution Lidar **HSRL** in space to obtain aerosol/cloud optical properties (backscatter and extinction coefficients)

ADM-Aeolus Coverage and Data Availability



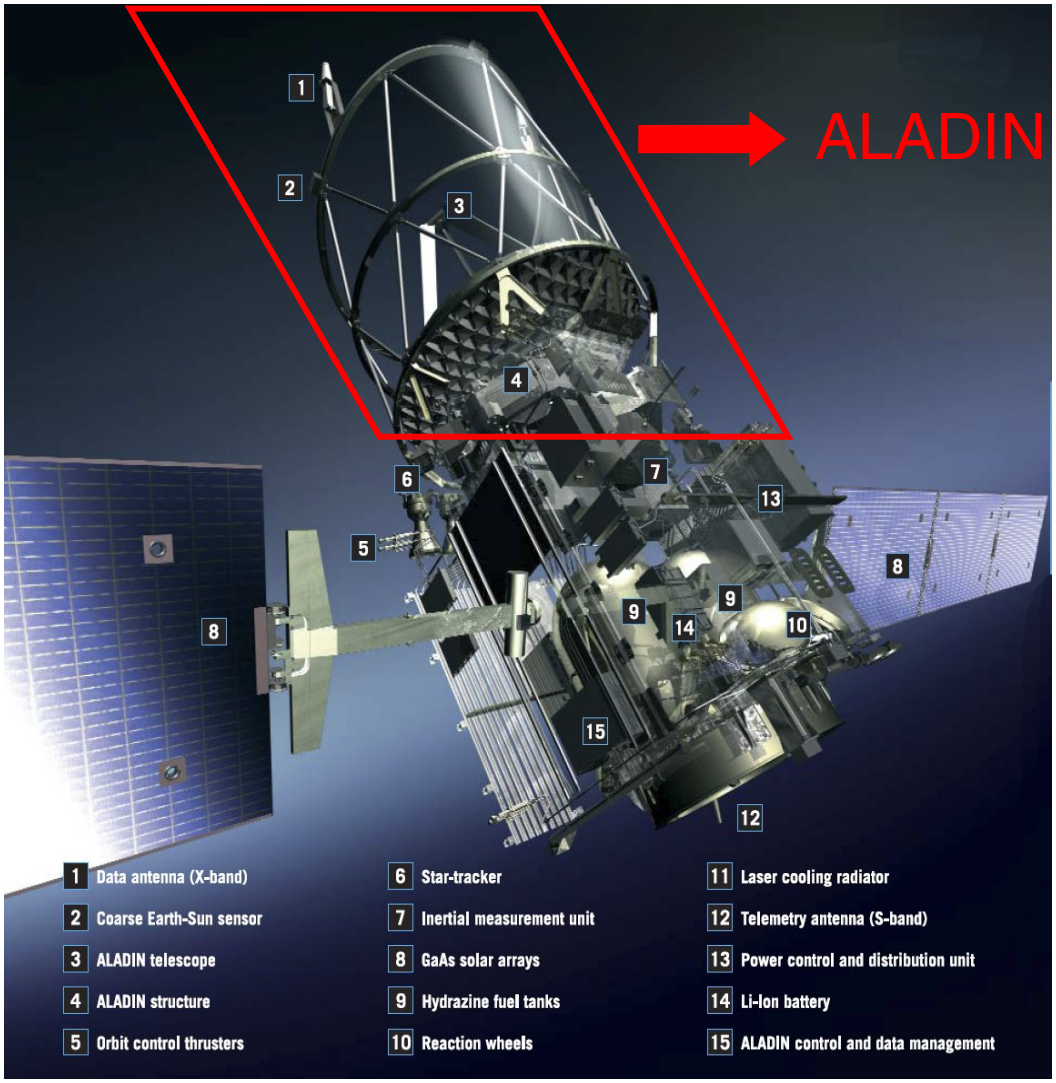
50 km observations during 6 hour period

- **3200 wind profiles per day**: about factor 3 more than radiosondes
- **3 hour data availability** after observation (NRT-Service) => 1 data-downlink per orbit; 30 minutes data availability for parts of orbit (QRT-Service with late start of downlink)
- **launch date May 2010** (consolidated launch date prediction in some months expected)
- **mission lifetime 39 months**: observations from 2010-2012

ADM-Aeolus Science Report
(ESA publication SP-1311, 2008)

TELLUS 60A(2), Mar 2008 special issue on ADM-Aeolus workshop 2006

Satellite and Instrument ALADIN



Mass and Power Budgets

mass: 1100 kg dry +116-266 kg fuel
power: 1.4 kW avg. (solar array 2.4 kW peak)
mass instrument: 470 kg
power instrument: avg. 840 W (laser 510 W)
Volume: 4.3 m x 2.0 m x 1.9 m

Doppler Lidar Instrument ALADIN

Nd:YAG laser in burst mode operation
(120 mJ @ 355 nm, 100 Hz)
1.5 m Cassegrain telescope
Dual-Channel-Receiver with ACCD detector
(Accumulation Charge Coupled Device)

Orbit

polar, sun-synchronous, dawn-dusk (6 pm LTAN),
97° inclination; height 410 km (395-425 km),
7 days orbit repeat cycle (109 orbits);
92.5 min orbit duration

Pointing and Orbit Control

GPS, Star-Tracker, Inertial Measurement Unit,
Yaw steering to compensate for earth rotation

Launcher tbd 2008

Rockot (Russia), Dnepr (Russia) or Vega (ESA)

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Comparison of Power-Aperture Products of Space Lidars

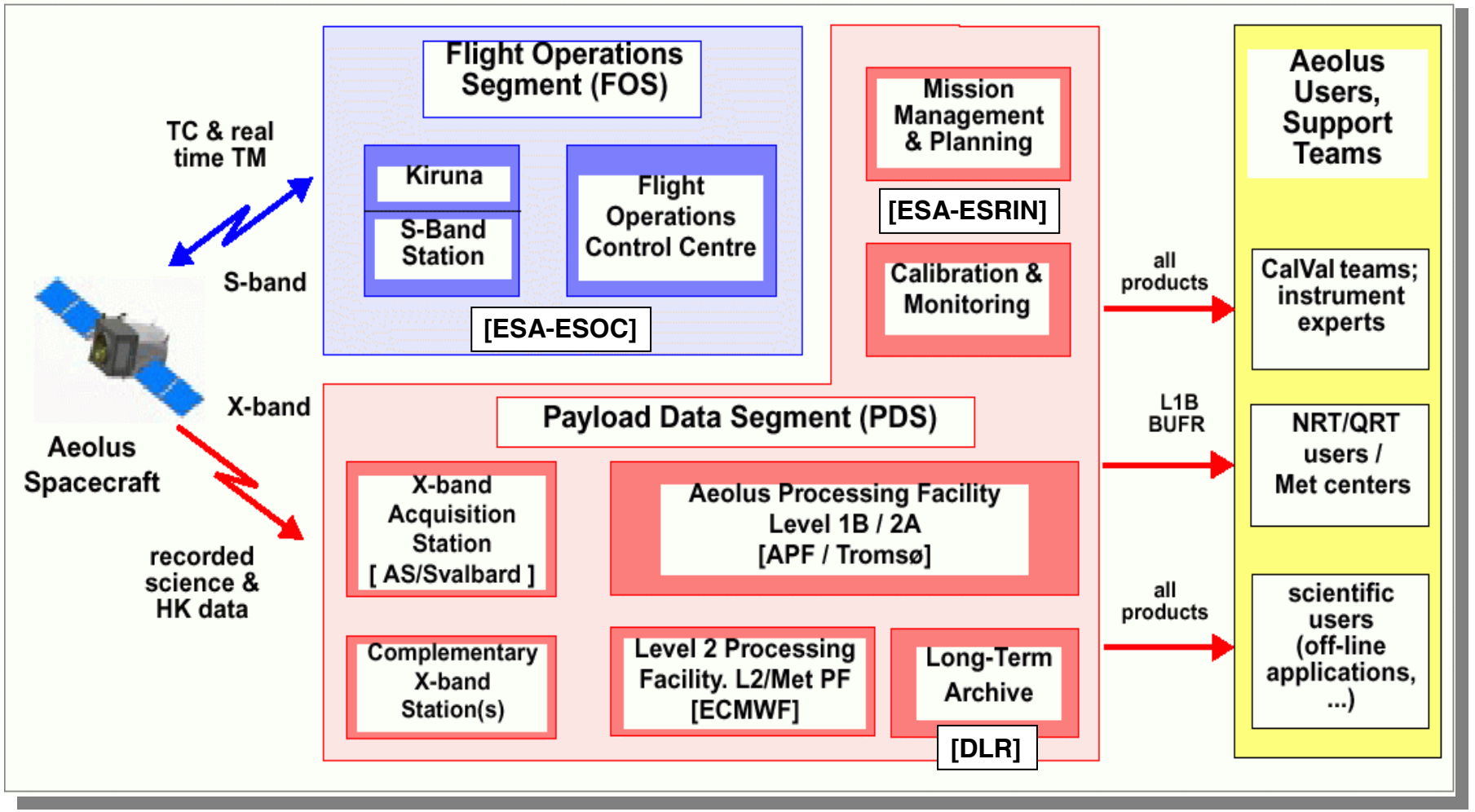
Lidar	Lidar altitude	Pulse energy	Pulse rep. rate	Mirror diameter	Power-aperture product PAP, range-cor.
LITE (532 nm)	250 km	560 mJ	10 Hz	1.0 m	$7.0\ 10^{-11}$ W
GLAS (532 nm)	600 km	35 mJ	40 Hz	0.9 m	$0.25\ 10^{-11}$ W
CALIOP (532 nm)	700 km	110 mJ	20 Hz	1.0 m	$0.35\ 10^{-11}$ W
ALADIN (355 nm)	410 km	150 mJ	100 Hz	1.5 m	$15.8\ 10^{-11}$ W
ATLID (355 nm)	450 km	20 mJ	100 Hz	0.6 m	$0.28\ 10^{-11}$ W

Factor 45

Factor 56

adapted from A. Ansmann 2006

ADM-Aeolus Ground Segment



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Ground Segment - Svalbard Satellite Reception Station

Data-downlink with 5 Mbit/s with X-Band to 2.4 m antenna to Svalbard, Norway (78°15'N)

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ADM-Aeolus Data Products

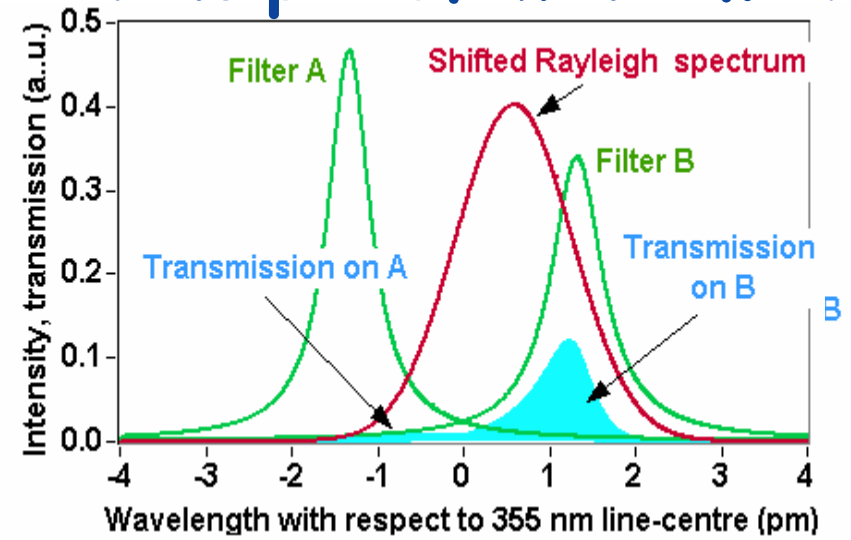
Product	Contents	Processor developer and location	Size in MByte/orbit
Level 0	Time ordered source packets with ALADIN measurement & housekeeping data	MDA (Canada) Tromsø (Norway)	47
Level 1b	*Geo-located, calibrated observational data* ▪ preliminary HLOS wind profiles (standard atmosphere used in Rayleigh processing) – not suitable for assimilation ▪ spectrometer readouts at "measurement" scale (1-5 km) – input for Level 2a/b processing ▪ viewing geometry & scene geo-location data	MDA (Canada) Tromsø (Norway)	10-15 (BUFR) + 22 (EE XML Format)
Level 2a	*Supplementary product* ▪ Cloud profiles, coverage, cloud top heights ▪ Aerosol extinction and backscatter profiles, ground reflectance, optical depth	DLR-IMF (Germany) Tromsø (Norway)	12
Level 2b	*Meteorologically representative HLOS wind observations* HLOS wind profiles at "observation" scale (~ 50 km) suitable for assimilation - temperature T and pressure p (Rayleigh-Brillouin) correction applied with ECMWF (or other) model T and p	ECMWF Reading (UK) (and other NWP/research centres)	18
Level 2c	*Aeolus assisted wind vector product* Vertical wind profiles (u and v component); NWP model output after assimilation of Aeolus HLOS wind	ECMWF Reading (UK)	22

Ongoing ADM-Aeolus Scientific Studies

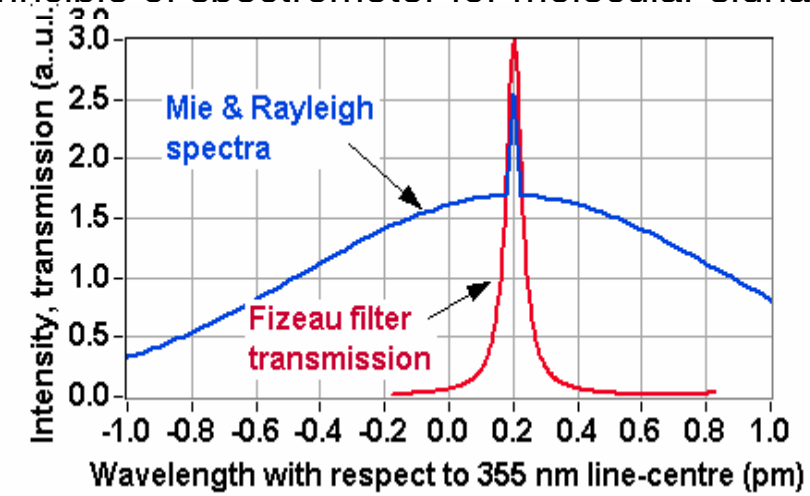
Title	Team
Consolidation of ADM-Aeolus Ground Processing including L2A Products	**DLR** Germany Météo-France, KNMI, IPSL, PSol
Development and Production of Aeolus Wind Data Products	**ECMWF** UK Météo-France, KNMI, IPSL, DLR, DoRIT
ADM-Aeolus Campaigns	**DLR** Germany Météo-France, KNMI, IPSL, DWD, MIM
Optimisation of spatial and temporal sampling	**KNMI** Netherlands
Tropical dynamics and equatorial waves	**MISU** Sweden
Rayleigh-Brillouin Scattering Experiment	tbd

ESA plans an Announcement of Opportunity AO for ADM-Aeolus scientific use of data for late 2008 – distinct from the AO for Cal/Val

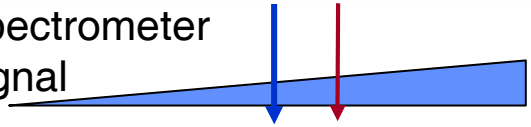
Principle of wind measurement with ALADIN



Principle of spectrometer for molecular signal



principle of spectrometer for aerosol signal



Atmospheric LAser Doppler INstrument ALADIN

- Direct-Detection Doppler Lidar at 355 nm with 2 spectrometers to analyse backscatter signal from molecules (Rayleigh) and aerosol/clouds (Mie)
- Double edge technique for spectrally broad molecular return, e.g. NASA GLOW instrument (Gentry et al. 2000), but sequential implementation
- Fizeau spectrometer for spectrally small aerosol/cloud return
- Uses Accumulation CCD as detector => high quantum efficiency >0.8 and quasi-photon counting mode
- ALADIN is a High-Spectral Resolution Lidar HSRL with 3 channels: 2 for molecular signal, 1 for aerosol/cloud signal => retrieval of profiles of aerosol/cloud optical properties possible

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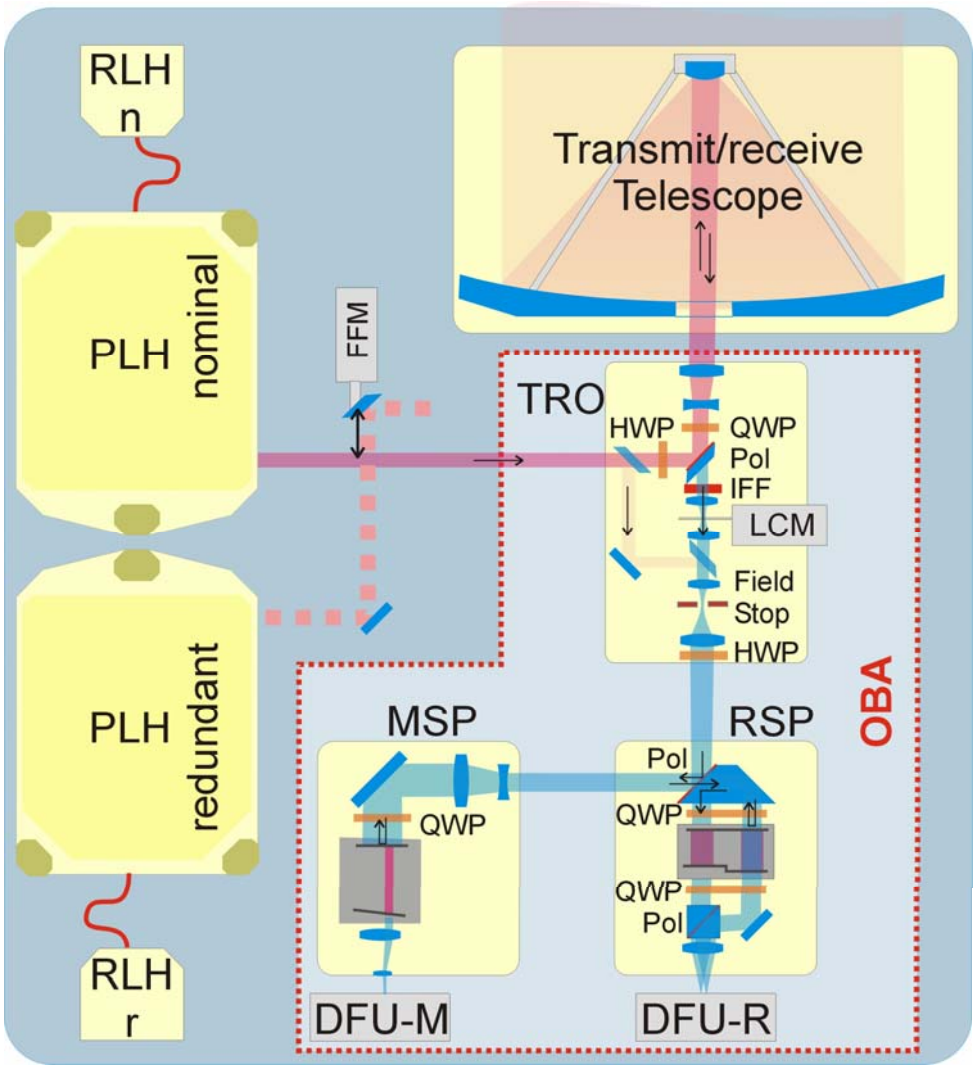
Fig. U. Paffrath

ALADIN Optical Layout

Transmitter laser assembly:
Reference Laser Head with stabilized tunable MISER lasers seeding the Power Laser Head with low power oscillator, two amplifiers and tripling stage two redundant laser assemblies in ALADIN

Mie receiver:
Fizeau interferometer, thermally stable, fringe imaged on single accumulation CCD



Telescope:
1.5 m diameter, Cassegrain, SiC lightweight structure, afocal, thermally focused

Transmit/receive optics:
polarizer as T/R switch, Laser Chopper mechanism, 1 focus as field stop, interference filter and prism for broad-band rejection of solar background

Rayleigh receiver:
Double edge Fabry-Perot interferometer, sequentially illuminated, temperature tunable Outputs focused on single accumulation CCD

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    - → Simulations of Level-2B hlos wind data
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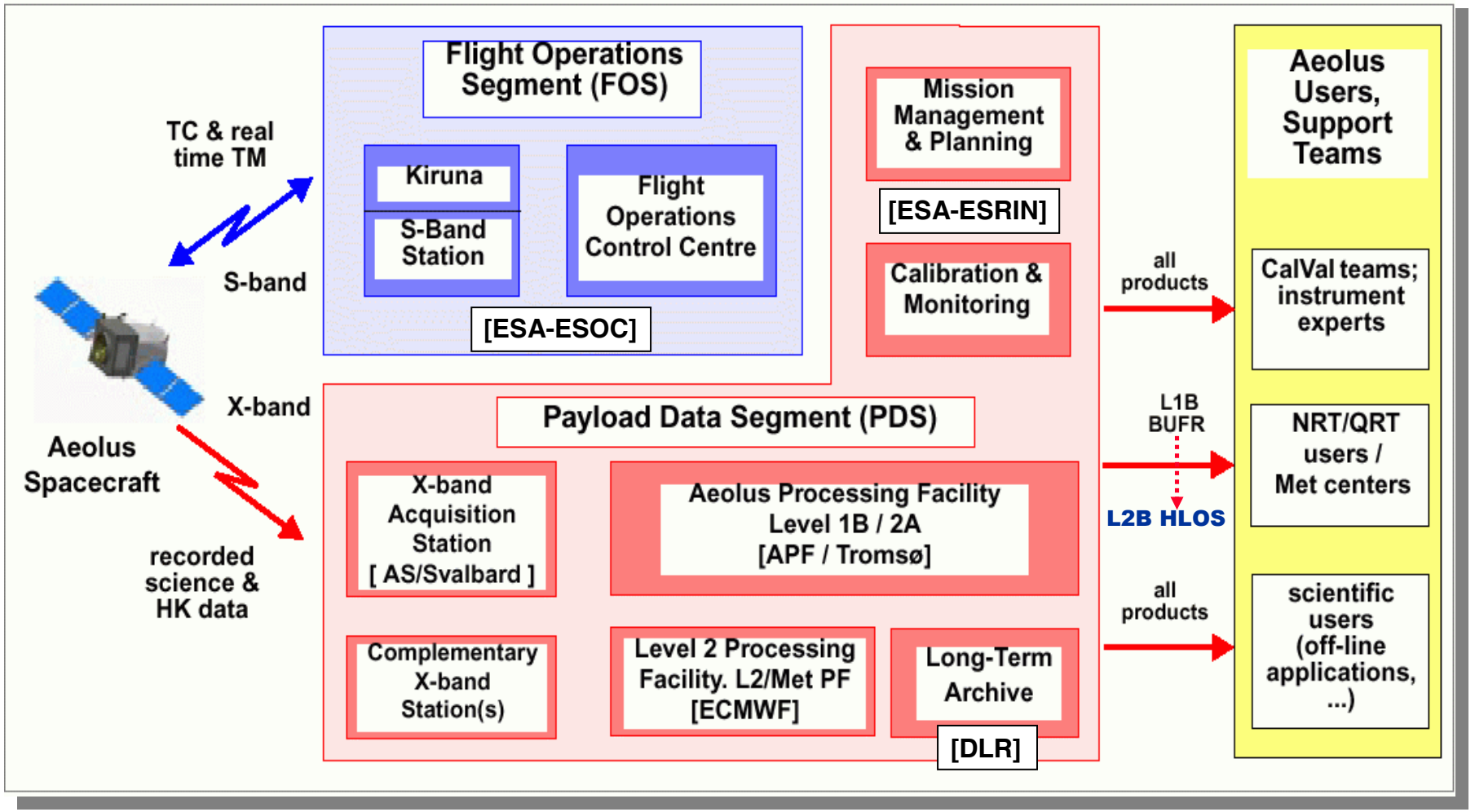
ADM-Aeolus Ground Segment



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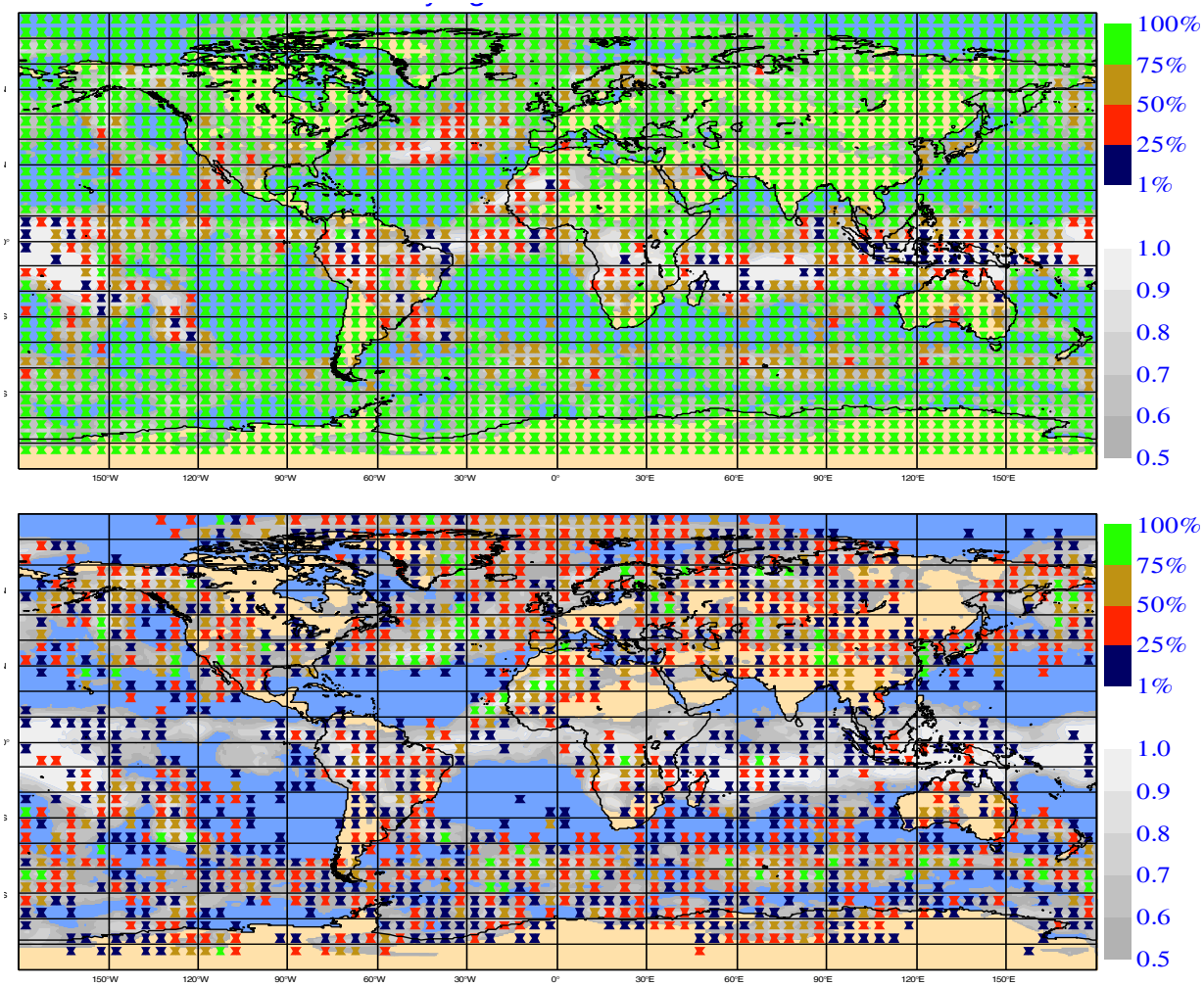
L2B data simulated using ECMWF clouds …

- 90% of Rayleigh data have accuracy better than 2 m/s
- In priority areas (filling data gaps in tropics & over oceans)
- Complemented by good Mie data from cloud-tops/cirrus (5 to 10%)
- Tan & Andersson QJRMS 2005

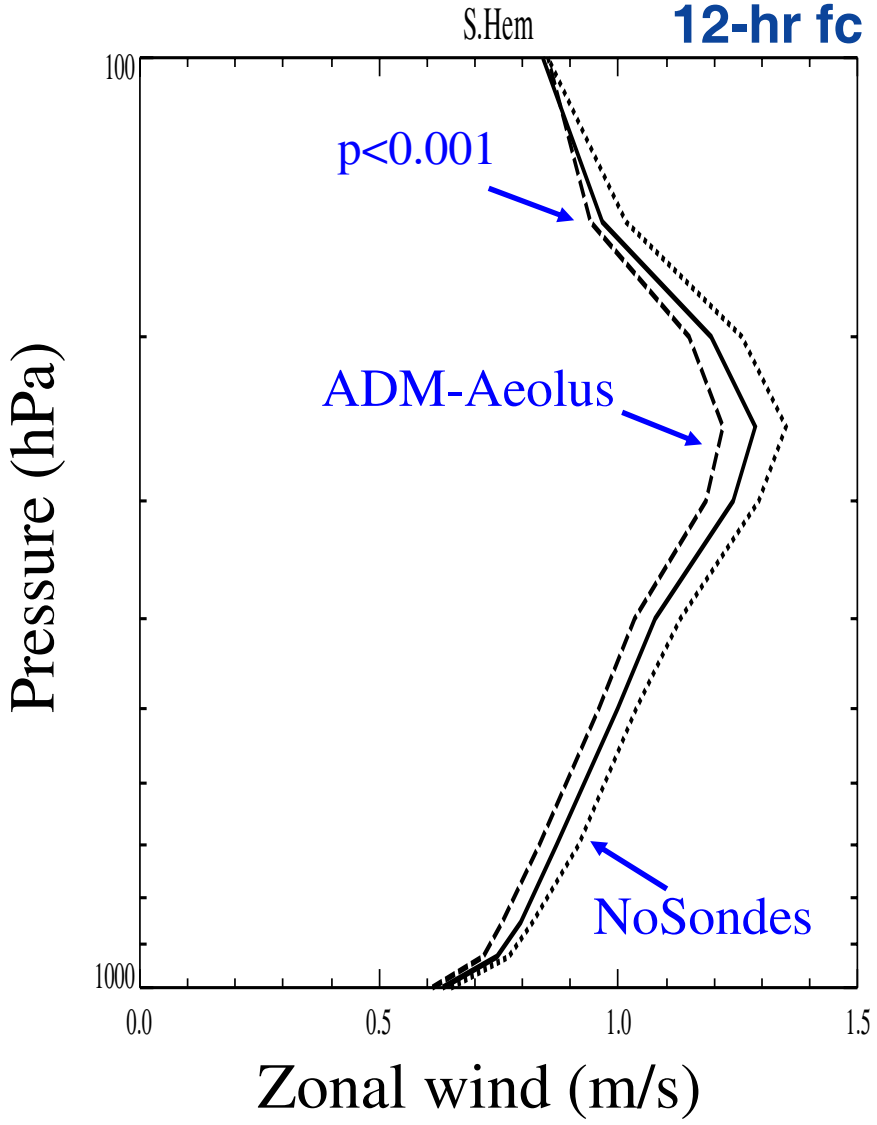
Yield (data meeting mission requirements in % terms) at 10 km



LIPAS-simulated HLOS data – operational processors later

ECMWF

… & impact studied via assimilation ensembles



Spread in zonal wind (U, m/s)

Scaling factor ~ 2 for wind error

Tropics, N. & S. Hem all similar

Simulated DWL adds value at all altitudes and in longer-range forecasts (T+48,T+120)

Differences significant (T-test)

Supported by information content diagnostics

Cheaper than OSSEs

ECMWF

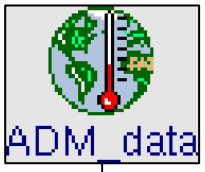
Global information content - consistent

- Mike Fisher for Entropy Reduction & DFS
  - $S \sim \log(\det(P^A))$
    $\sim \mathrm{tr} (\log (J'' {}^{-1}))$
  - J'' = 4d-var Hessian
  - P^A = analysis error covar.
- DWL data are accurate and fill data gaps
  - subject to usual caveats about simulated data

	TEMP/PILOT	Simulated DWL
Data considered	u,v to 55 hPa	HLOS
Entropy_Reduction ("Info bits")	4830	3123
Deg_Free_Sig	3707	2743
N_Obs	90688	50278
Info bits per obs	0.053	0.062
N_Obs/Deg_Free_Sig	24.5	18.3
Redundancy		2 — 3 %

Assimilation of prototype ADM-Aeolus data

2003/4: introduced L2B hlos as new observed quantity in 4d-Var



Prototype Level-2B (LIPAS simulation, includes representativeness error)

Observation Processing

Data Flow at ECMWF

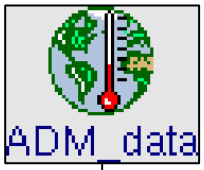
Non-IFS processing	"Bufr2ODB" Convert BUFR to ODB format Recognize HLOS as new known observable
Observation Screening	IFS "Screening Job" Check completeness of report, blacklisting Background Quality Control
Assimilation Algorithm	IFS "4D-VAR" Implement HLOS in FWD, TL & ADJ Codes Variational Quality Control
Diagnostic post-processing	"Obstat" etc (Lars Isaksen) Recognize HLOS for statistics Rms, bias, histograms

→ *Analysis*

ECMWF

Assimilation of prototype ADM-Aeolus data

2004-: Receive L1B data & L2B processing at NWP centres



Level-1B data

(67 1-km measurements)

Observation Processing

Data Flow at ECMWF

Non-IFS processing	"Bufr2ODB" Convert BUFR to ODB format Recognize HLOS as new known observable
L2BP (1 50-km observation) Observation Screening	IFS "Screening Job" Check completeness of report, blacklisting Background Quality Control
Assimilation Algorithm	IFS "4D-VAR" Implement HLOS in FWD, TL & ADJ Codes Variational Quality Control
Diagnostic post-processing	"Obstat" etc (Lars Isaksen) Recognize HLOS for statistics Rms, bias, histograms

Analysis

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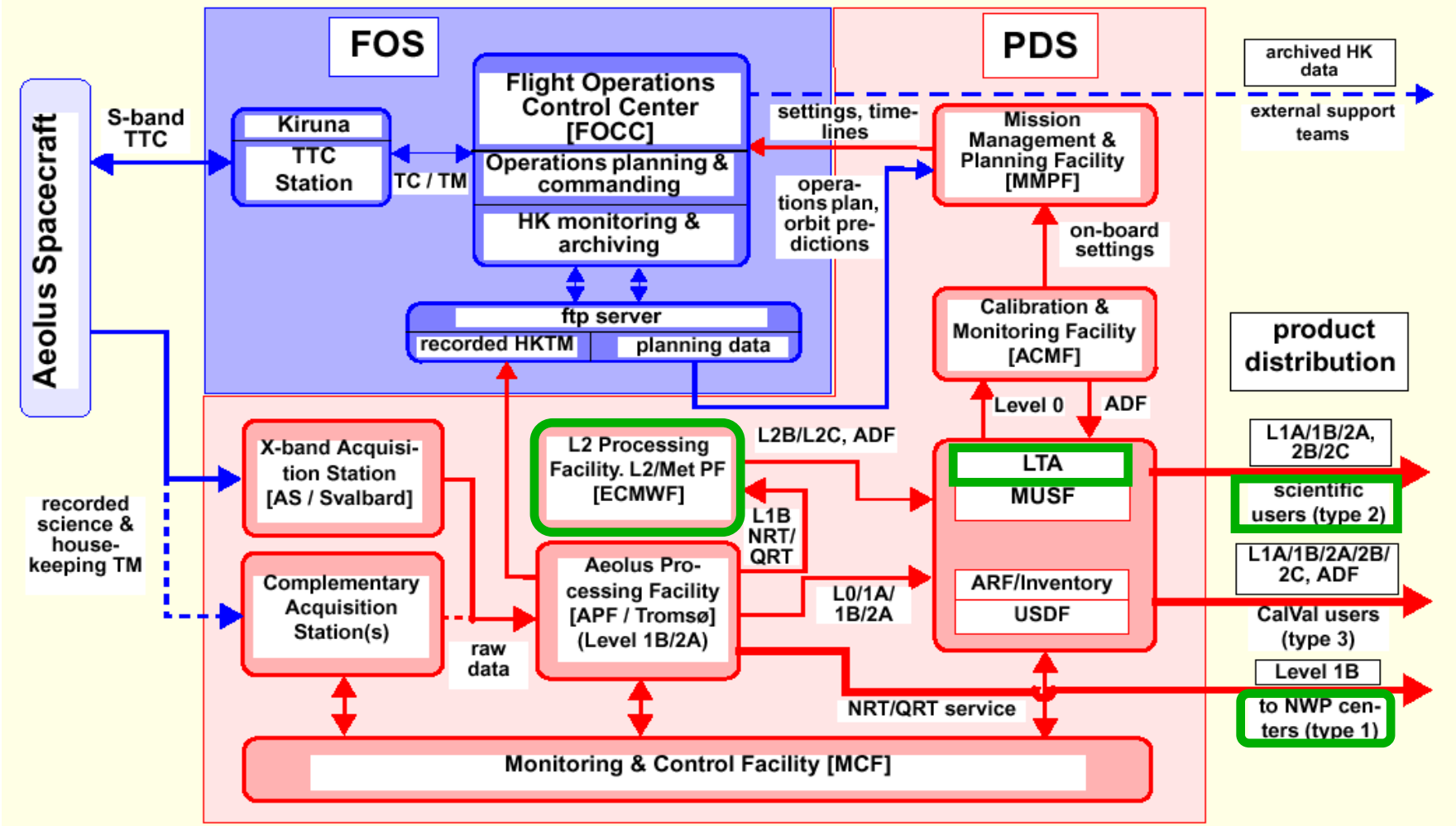
Level-2B processor will run in different environments

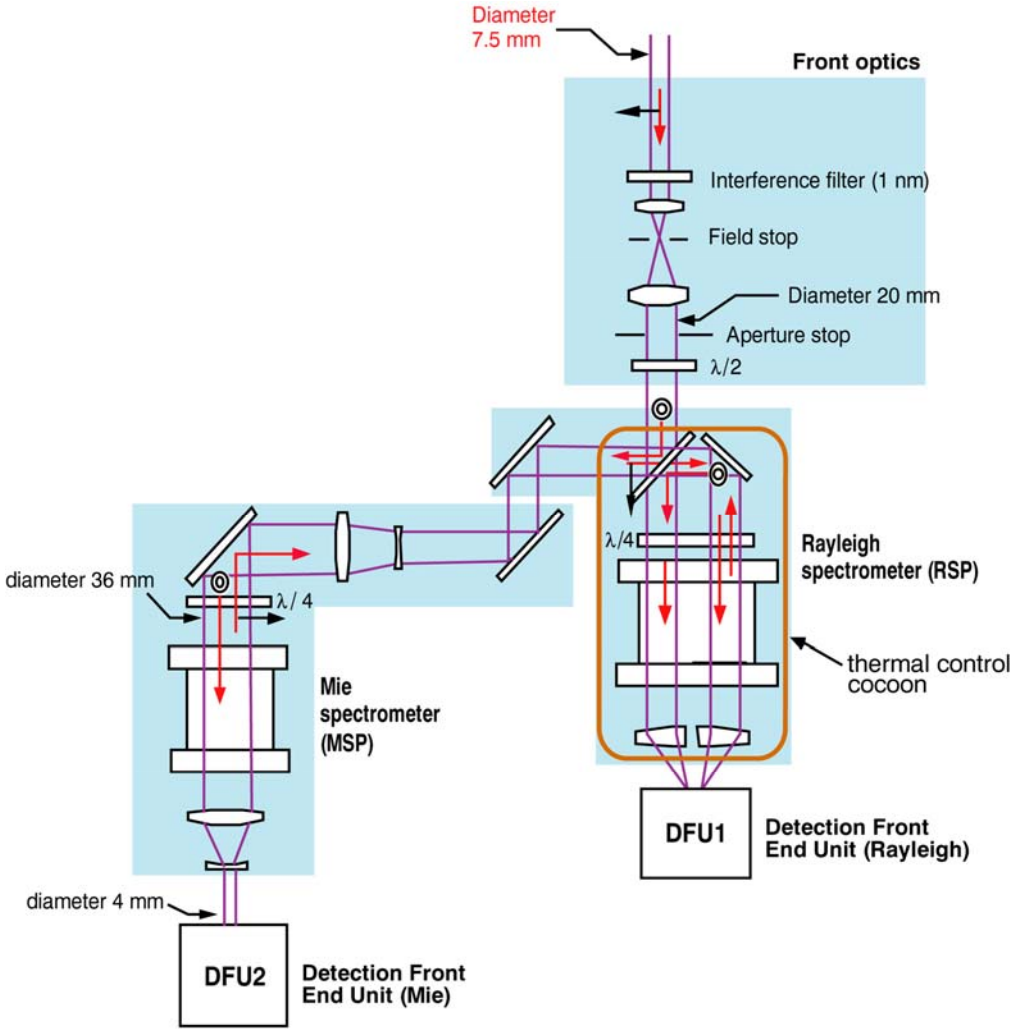
ECMWF will supply source code - use as standalone or callable subroutine

Aeolus Ground Segment & Data Flows - schematic view



ECMWF

Retrievals account for receiver properties …



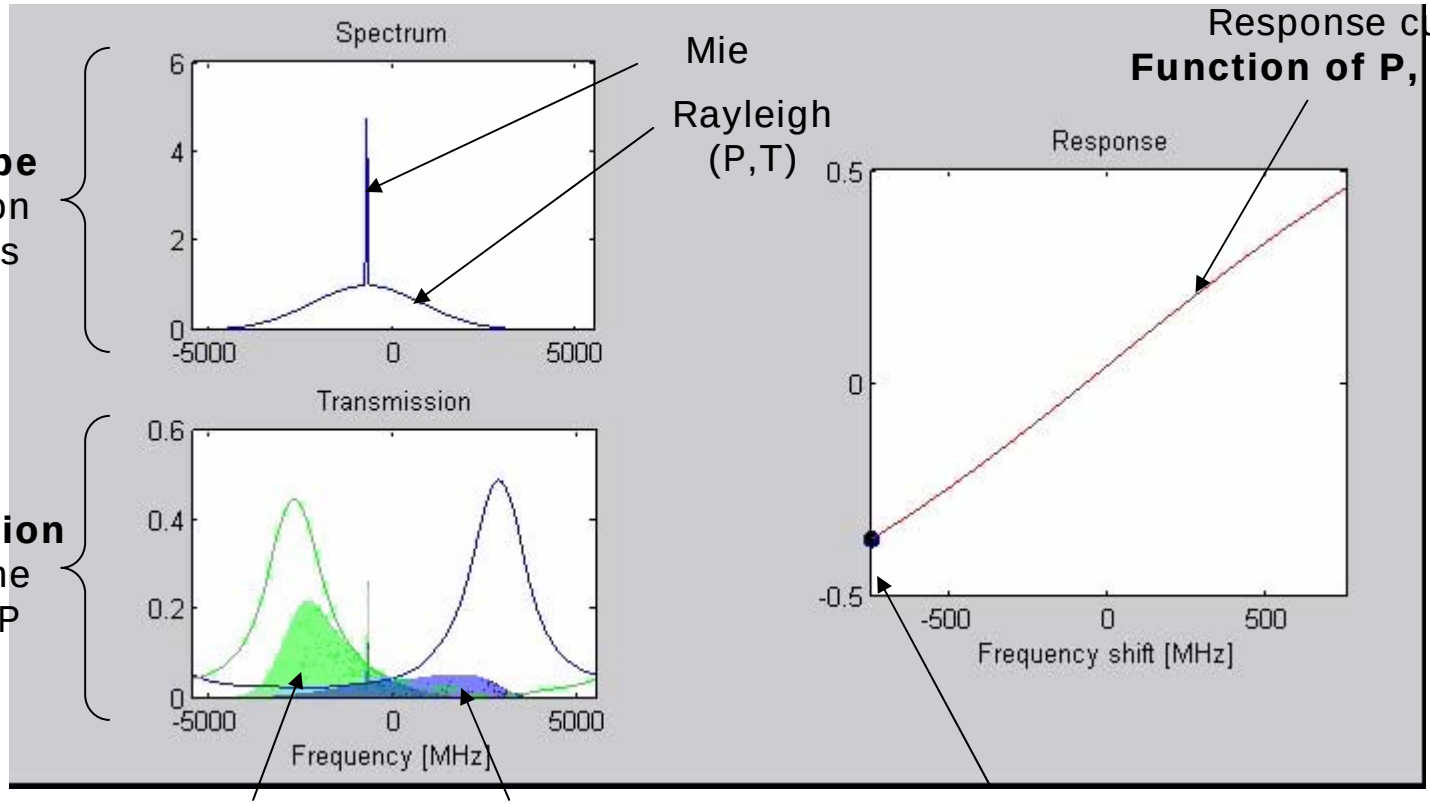
ADM-Aeolus Optical Receiver - Astrium Satellites

- Tan et al Tellus 60A(2) 2008
- Dabas et al same issue
- Mie light reflected into Rayleigh channel
- Rayleigh wind algorithm includes correction term involving scattering ratio (s)

ECMWF

… and for atmospheric scattering properties

ILIAD – Impact of P & T and backscatter ratio on Rayleigh Responses - Dabas Meteo-France, Flamant IPSL



Line shape
Depends on
P, T and s

Transmission
through the
Double FP

Light transmitted through T_A and T_B

Response (function of f_D)

- **1km-scale spectra are selectively averaged**
  - *Account for atmospheric variability - improve SNR*

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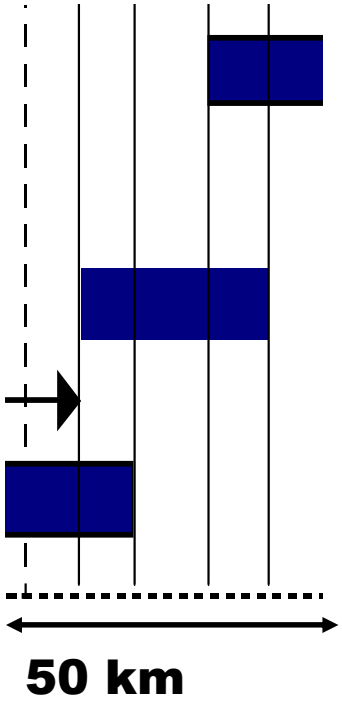
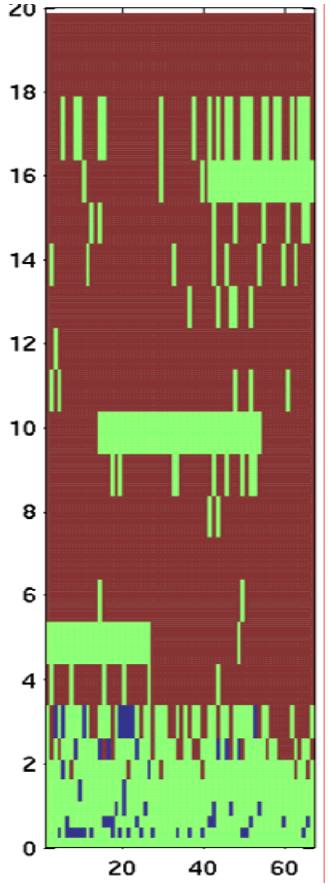
Retrievals validated for idealized broken multi-layer clouds – E2S simulator + operational processing chain

Specified cloud layers

Retrieved clouds and aerosol



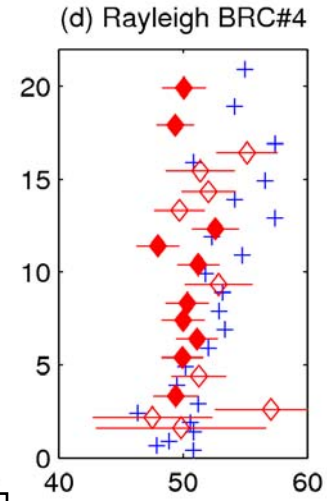


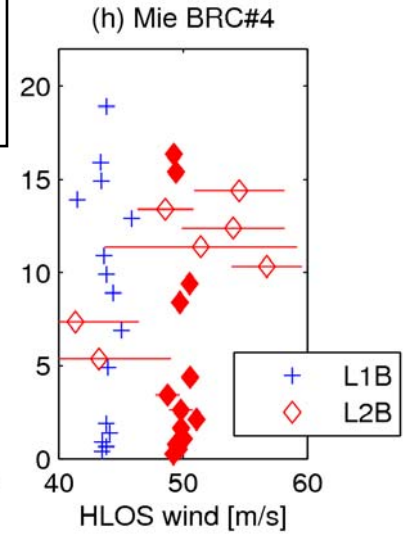
Specified wind=50 m/s

Retrieved Rayleigh winds are accurate in non-cloudy air

Classify scene (threshold) then average cloudy/non-cloudy regions separately

Retrieved Mie winds are accurate in cloud and aerosol layers





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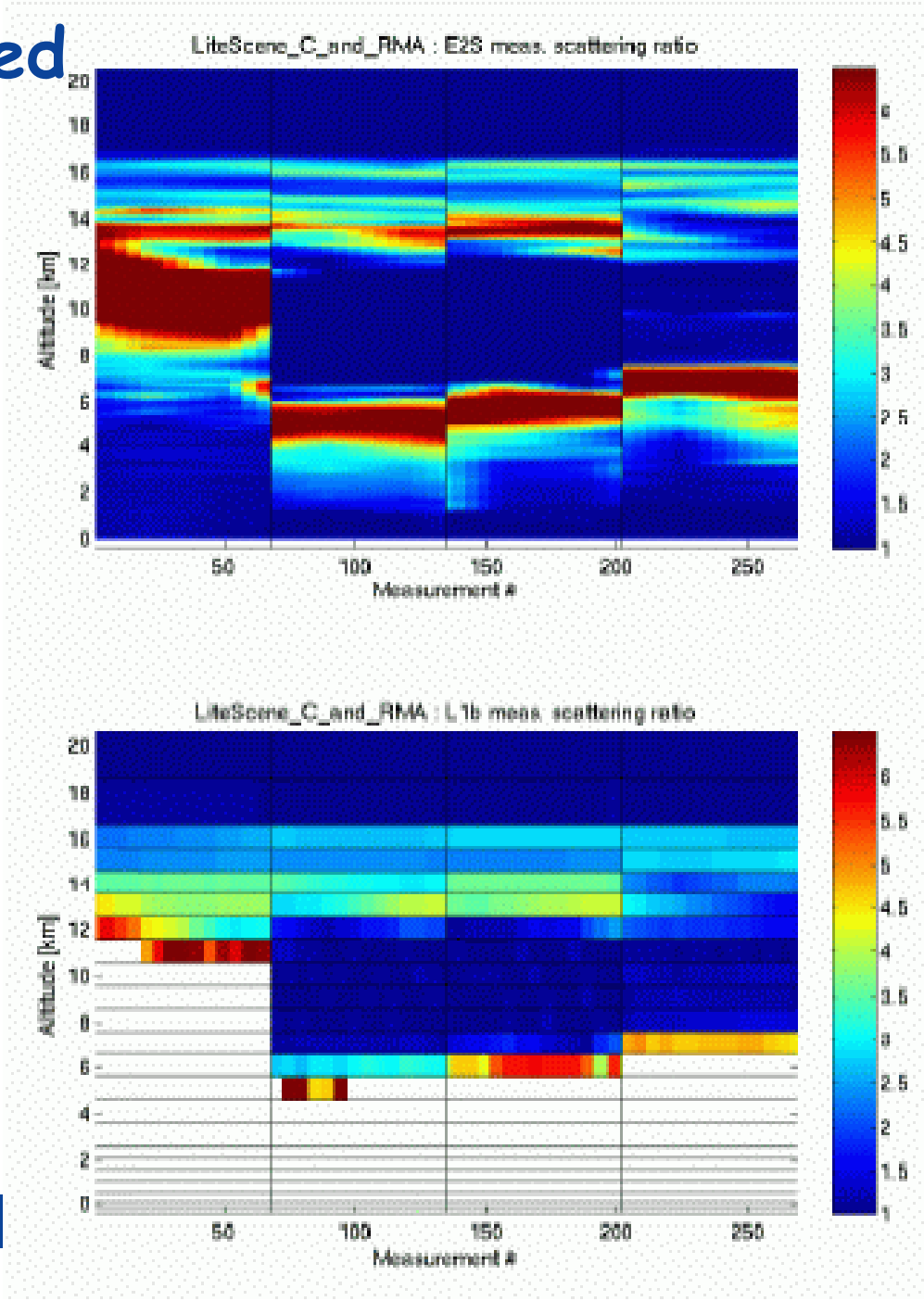
Realistic scenes simulated

- Real scattering measurements obtained from the LITE and Calipso missions

  ESA's software (E2S) is used to simulate what ADM-Aeolus would 'see'

- The L1B software retrieves scattering ratio at the 1 km measurement resolution

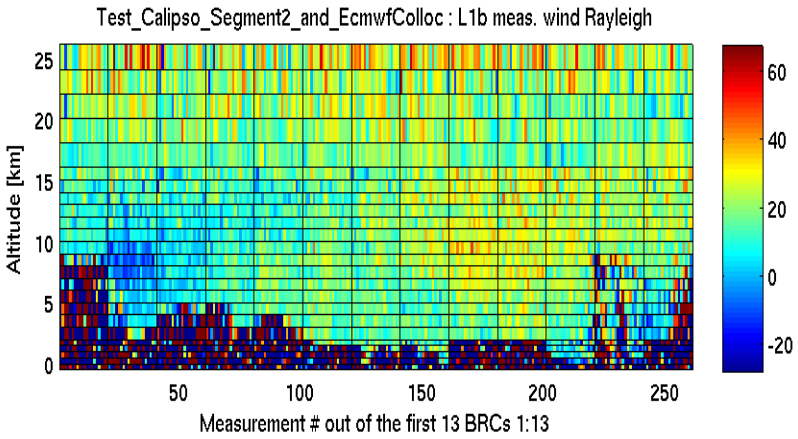
  Our input not perfect



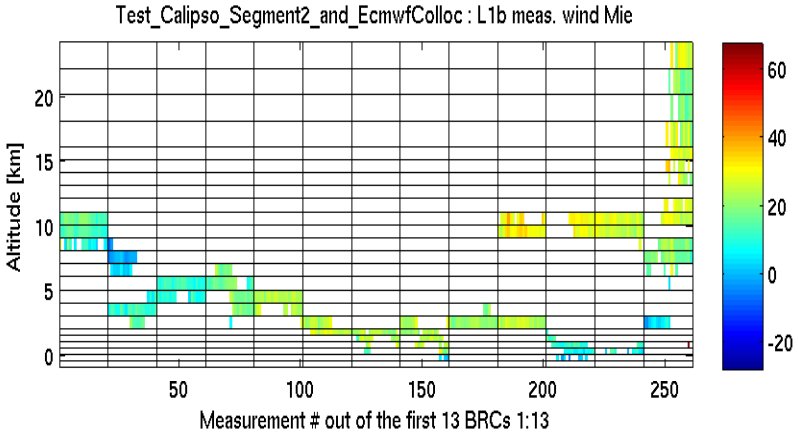
Wind retrieval validated in the presence of heterogeneous clouds and wind – E2S simulation

Level-1B

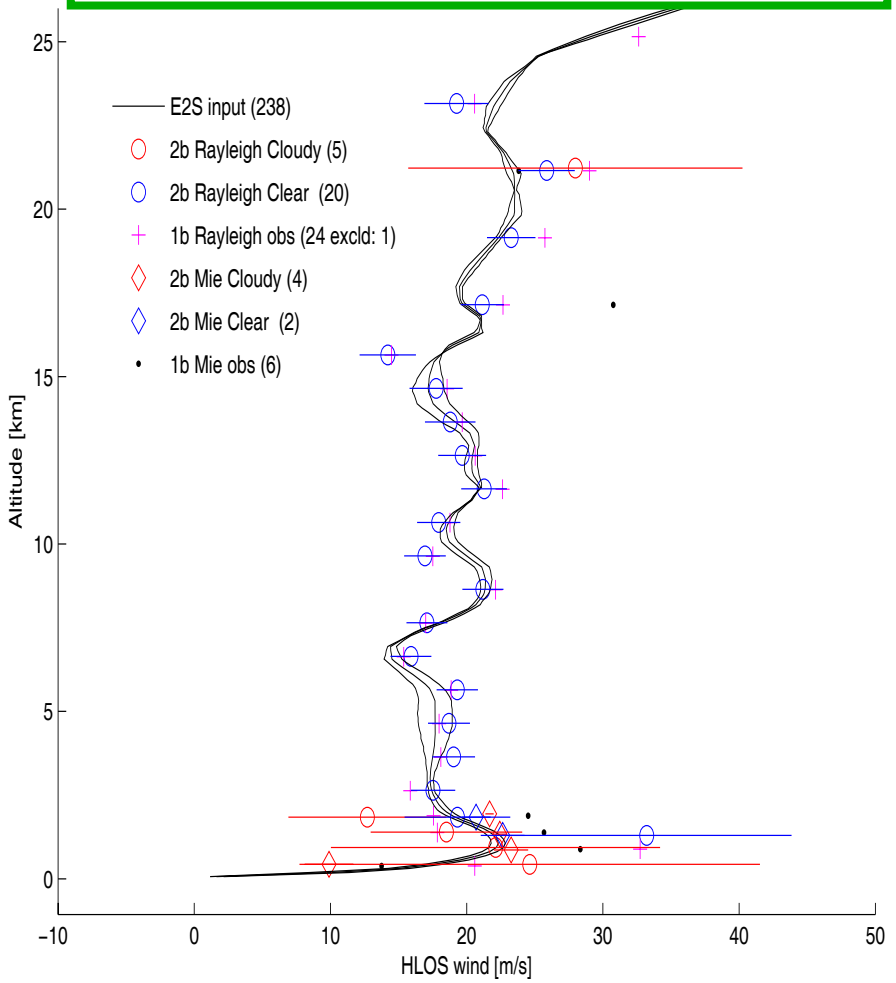
Rayleigh molecular



Mie particles



Retrievals fairly accurate



Backscatter from Calipso

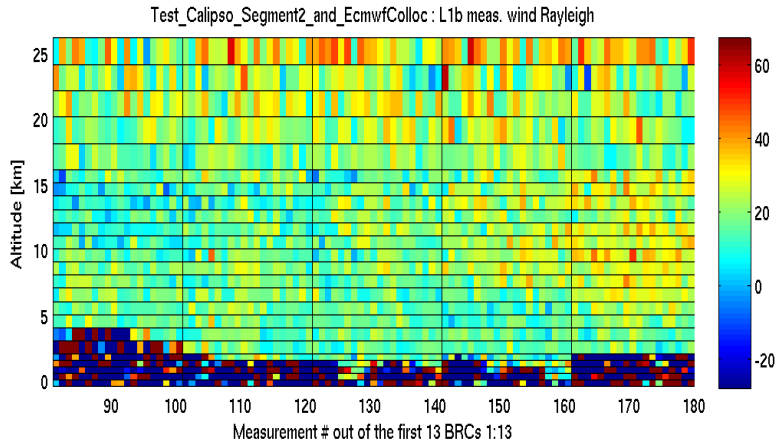
Outliers being examined

ECMWF

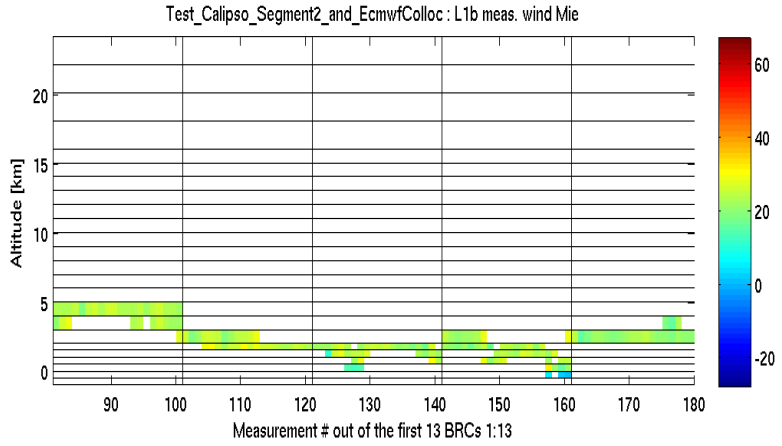
Wind retrieval validated in the presence of heterogeneous clouds and wind – E2S simulation

Level-1B

Rayleigh molecular



Mie particles



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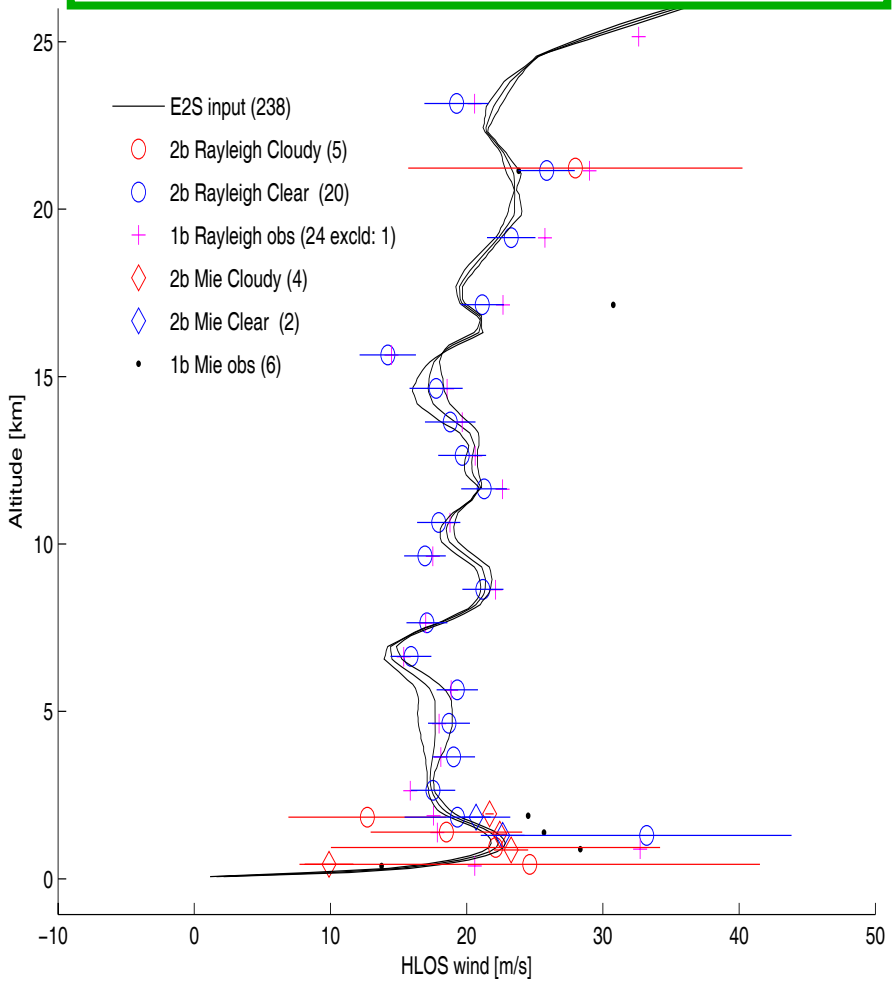


Backscatter from Calipso

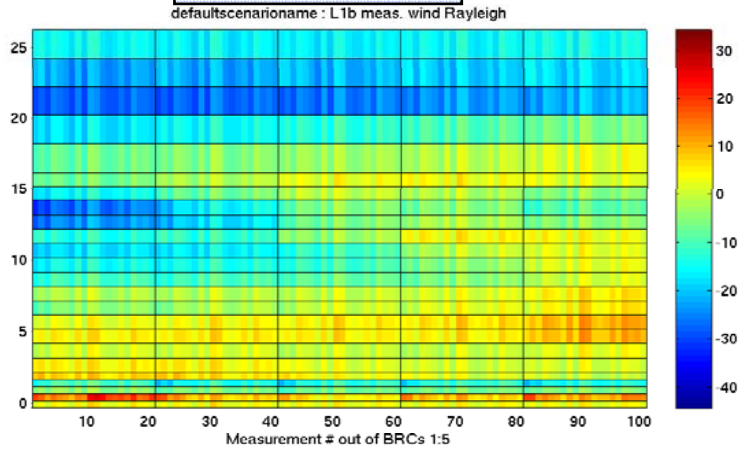
Outliers being examined

ECMWF

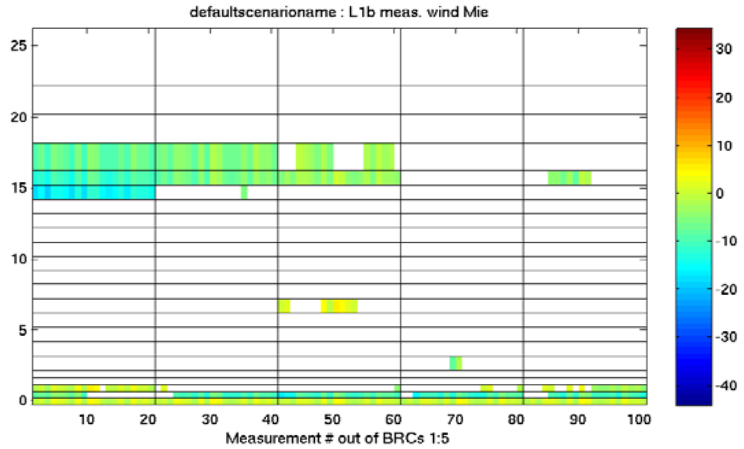
… but only after bugs were fixed in earlier versions of the L1B processor

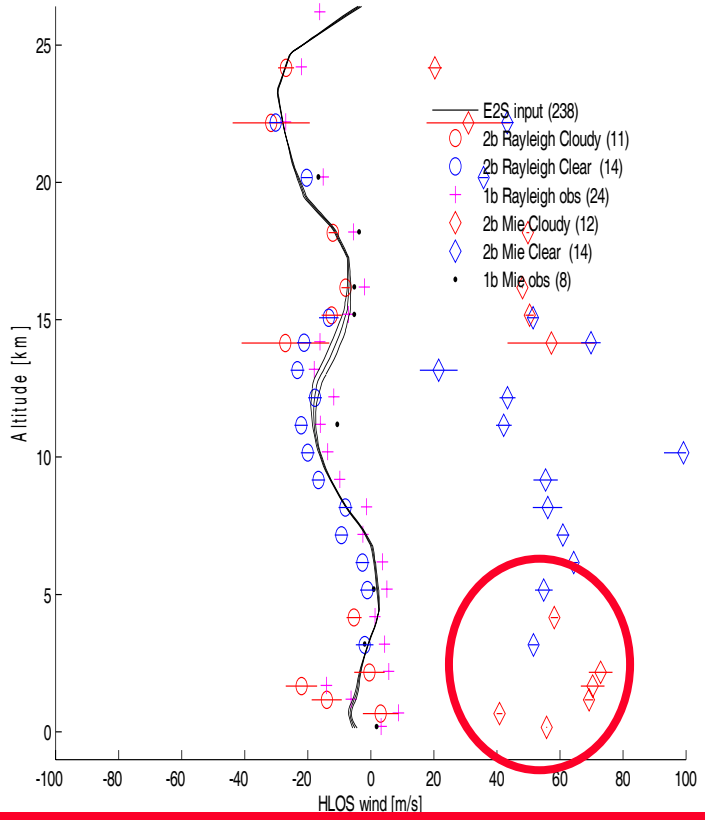
Level-1B

Rayleigh molecular



Mie particles

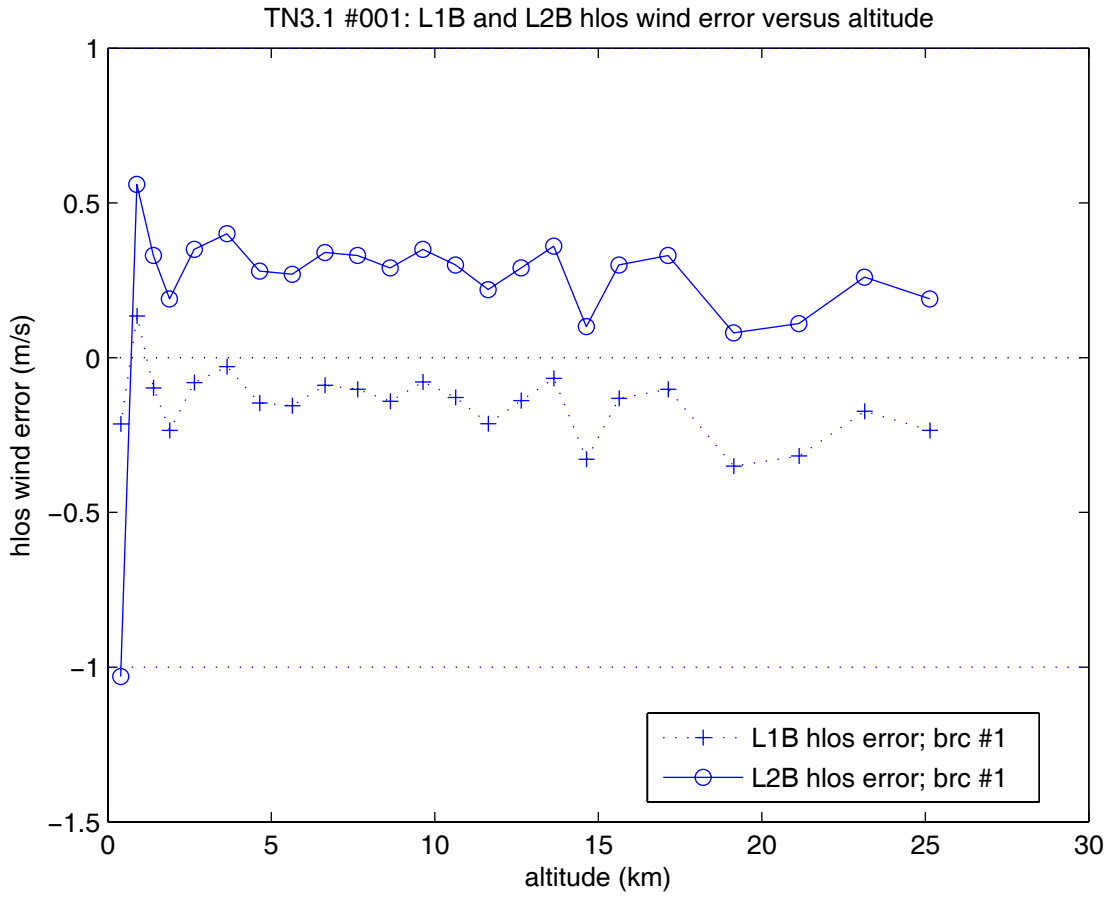




Retrieved Mie winds revealed systematic error in L1B input

ECMWF

Wind retrieval error from ACCD digitization - theory confirmed by E2S simulation



Photon noise will dominate

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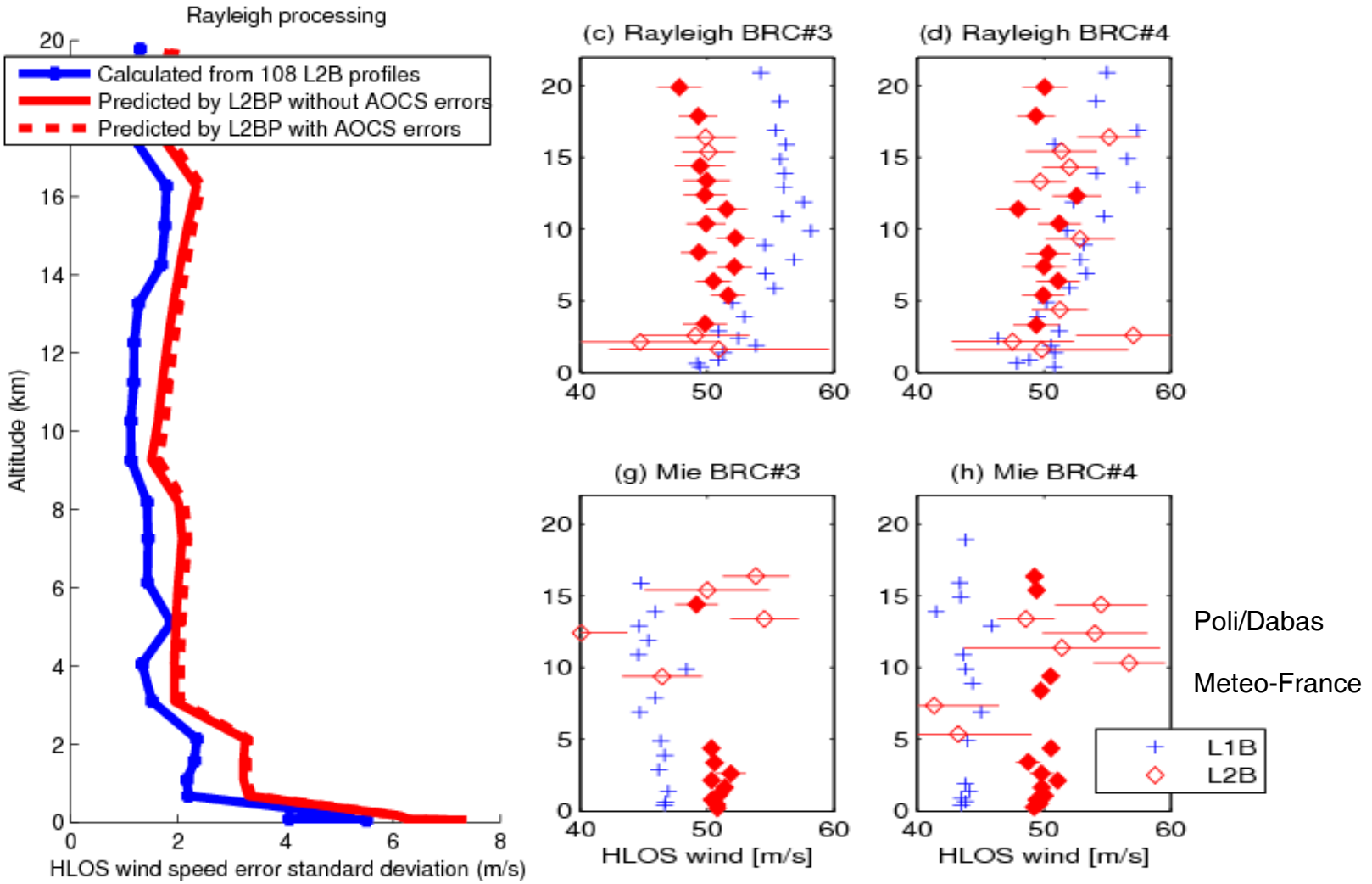
Level-2B hlos error estimates – reqts met



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Conclusions – Day-1 system on track

1. Level-2B hlos winds – primary product for assimilation
   a. Account for more effects than L1B products
   b. Will be generated in several environments
   c. Motivated strategy to distribute source code
2. Main algorithm components developed & validated
   a. Release 1.33 available – development/beta-testing
   b. Documentation and Installation Tests
   c. Portable – tested on several Linux platforms
3. Ongoing scientific and technical development
   a. Sensitivity to inputs, QC/screening, weighting options
4. Contact points – ESA and/or ECMWF

Key references

- Baker et al 1995, BAMS
- ESA 1999 Report for Assessment (Stoffelen et al 2005, BAMS) and 2008 Science Report
- Weissman and Cardinali 2006, QJRMS
- N. Zagar & co-authors, QJRMS & Tellus A
- Tan & Andersson 2005, QJRMS
- Tan et al 2007, QJRMS
- Tan et al 2008, Tellus A (Special Issue on ADM-Aeolus)

5.2 Key assimilation operators

- Tan 2008 ECMWF Seminar Proceedings
- HLOS, TL and AD
  - $H = -u \sin\varphi - v \cos\varphi$
  - $dH = -du \sin\varphi - dv \cos\varphi$
  - $dH^* = (-dy \sin\varphi, -dy \cos\varphi)^T$
  - Generalize to layer averages later
- Background error
  - Same as for u and v (assuming isotropy)
- Persistence and/or representativeness error
- Prototype quality control
  - Adapt local practice for u and v

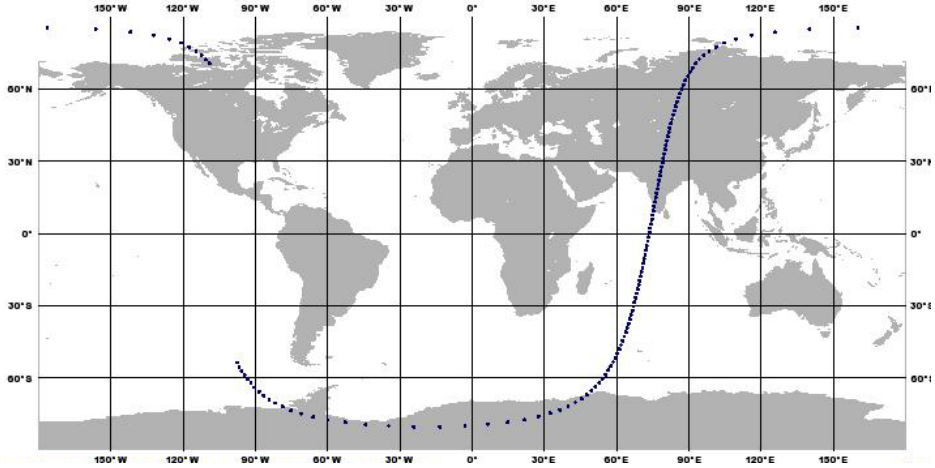
Background for ADM-Aeolus
Observational Requirements

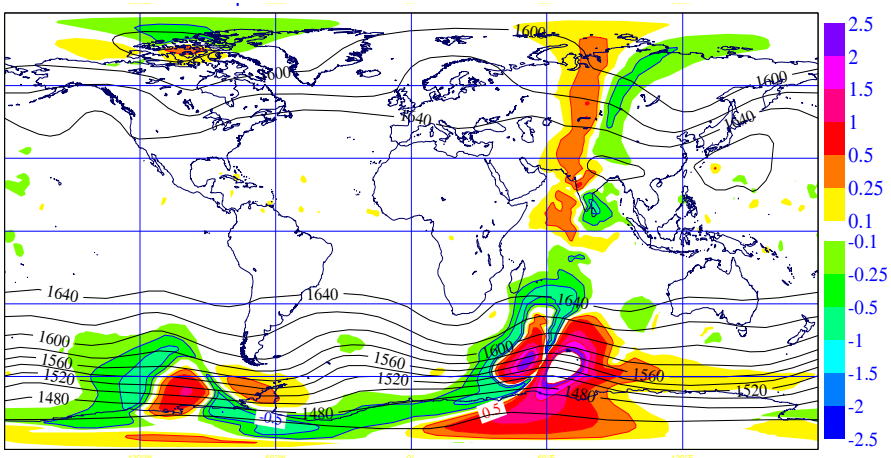
		PBL	Troposph.	Stratosph.
Vertical Domain	[km]	0-2	2-16	16-20
Vertical Resolution	[km]	0.5	1.0	2.0
Horizontal Domain			global	
Number of Profiles	[hour^{-1}]		> 100	
Profile Separation	[km]		> 200	
Horizontal Integration Length	[km]		50	
Accuracy (HLOS Component)	[m/s]	1	2	3
Data Availability	[hour]		3	
Length of Observational Data Set	[yr]		3	

➔ **Most important requirements - accuracy & vertical resolution**

5.1 Prototype Level-2C Processing

- ✓ Ingestion of L1B.bufr into the assimilation system
  - ♦ L1B obs locations within ODB (internal Observation DataBase)
- ✓ Assimilation of HLOS observations (L1B/L2B)
  - ♦ Corresponding analysis increments (Z100)





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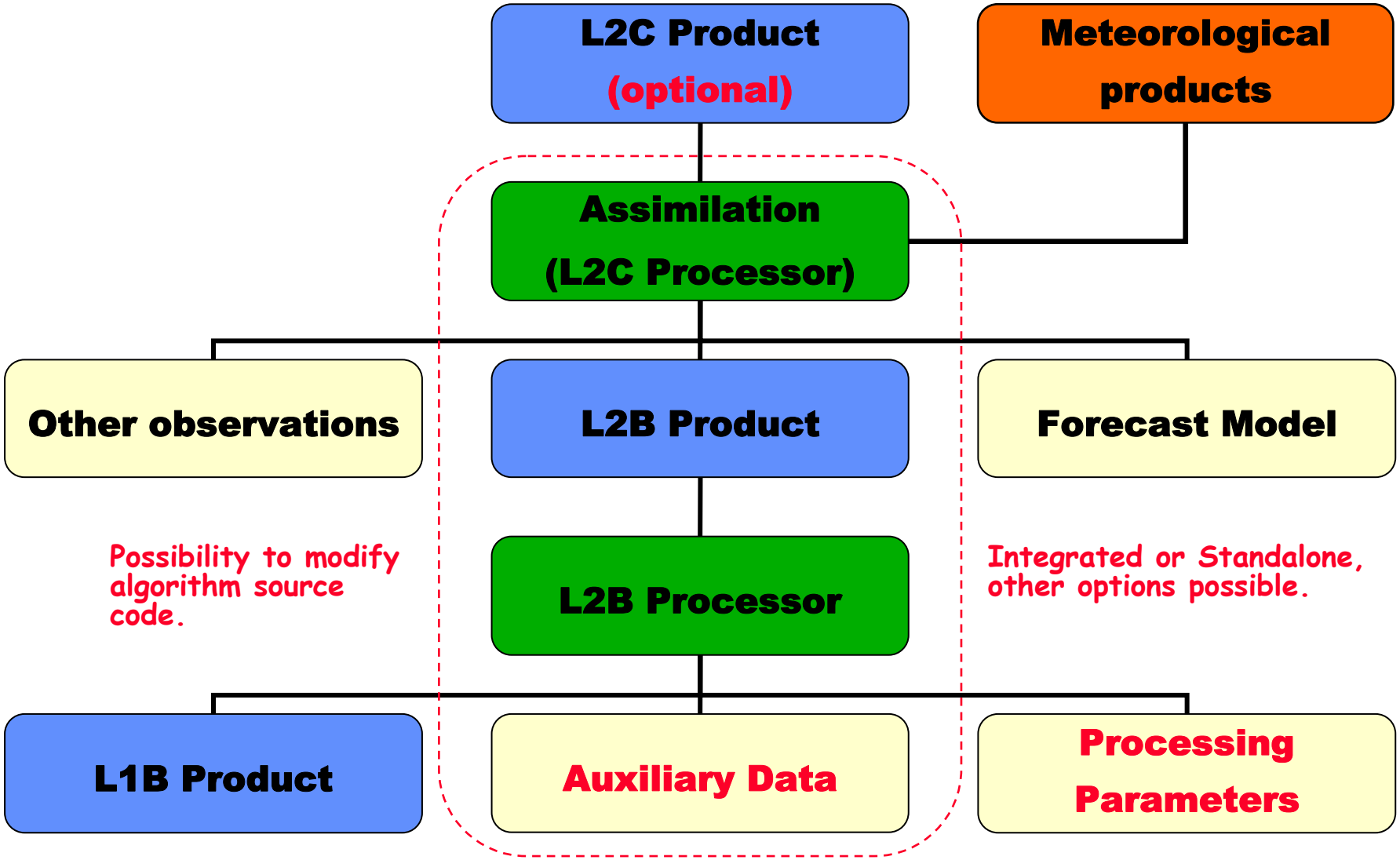
2a-4. Other NWP configurations



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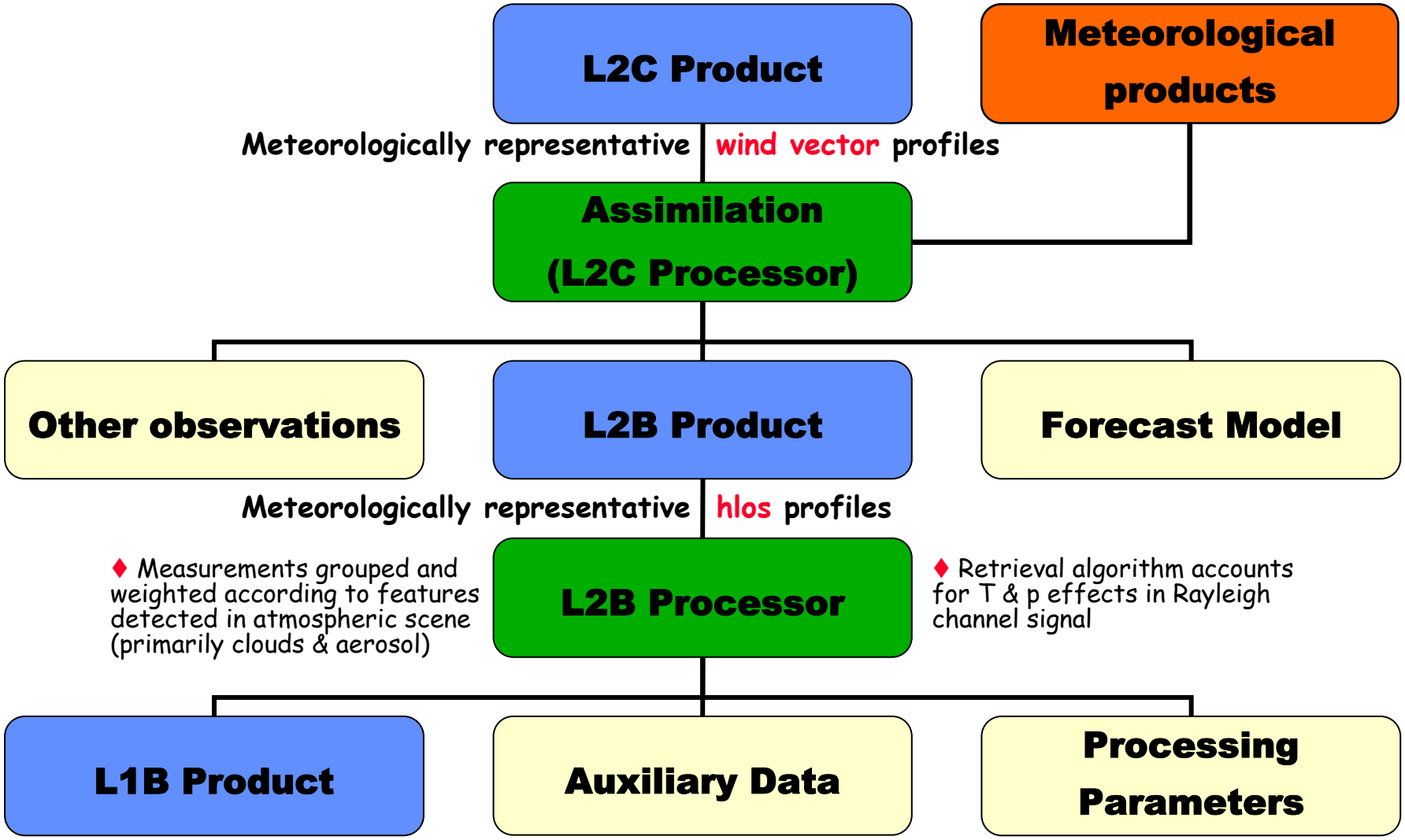
1a/b. What are Level-2B/2C Products?



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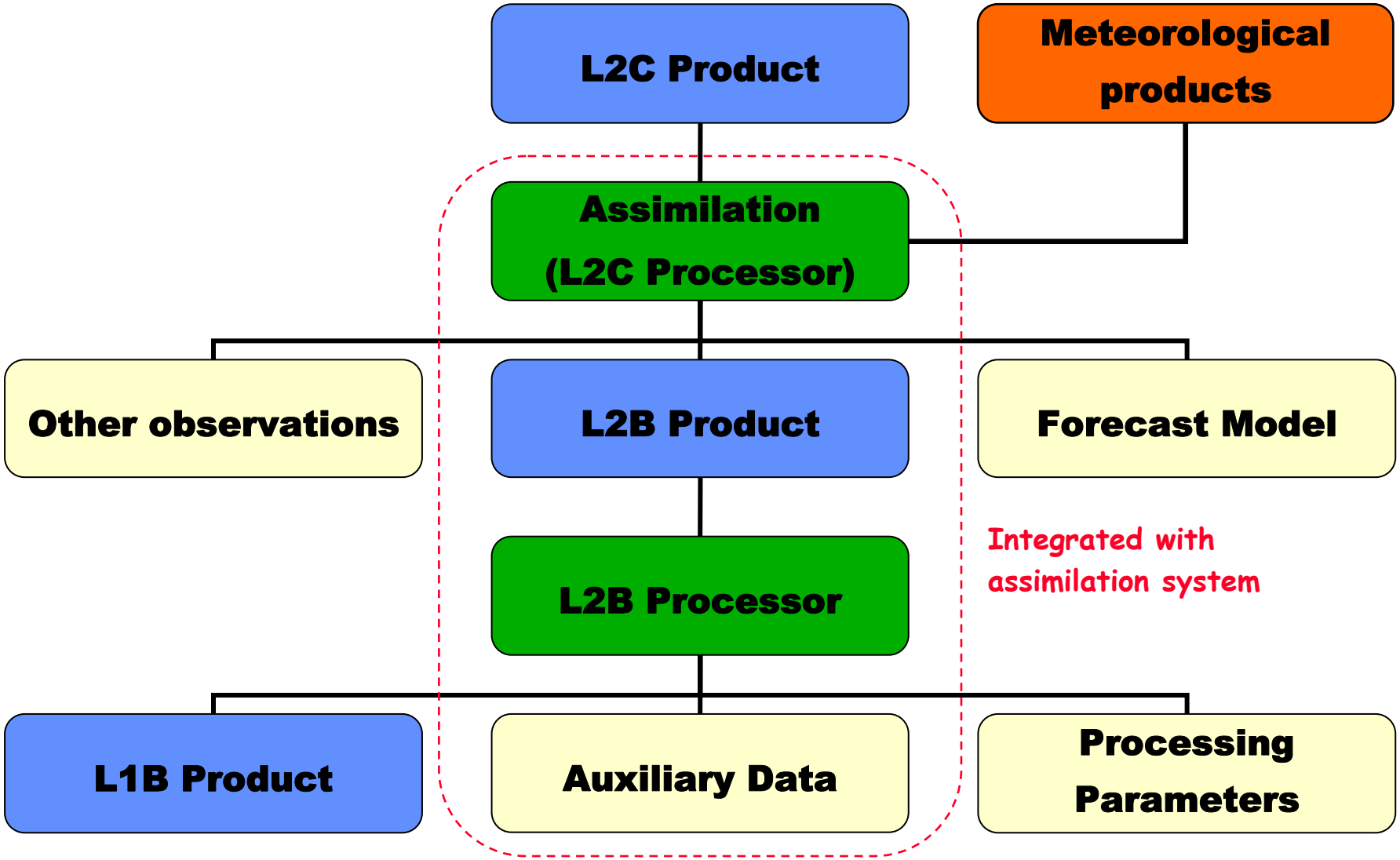
2a-1. ECMWF "operational" configuration



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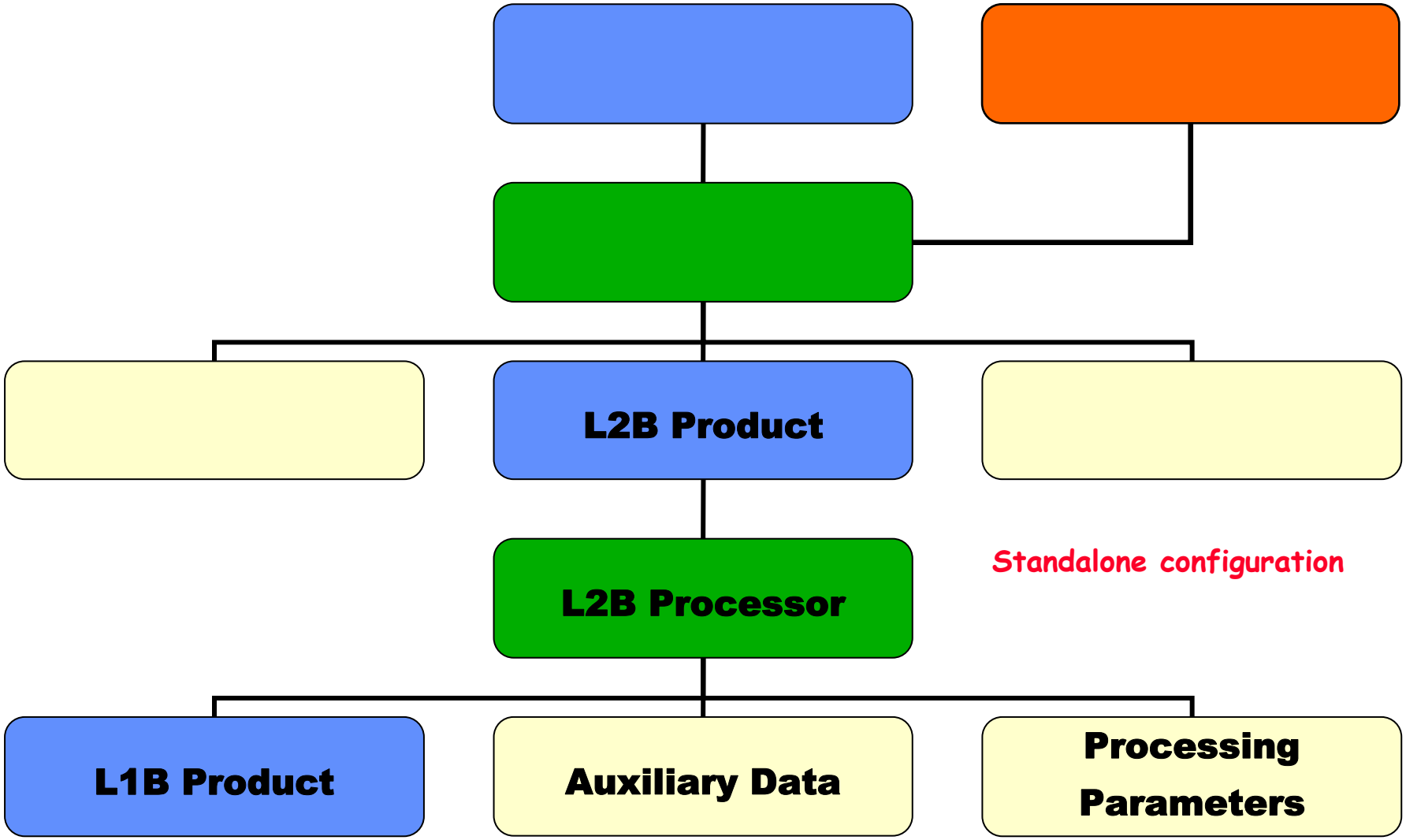
2a-2. ESA-LTA late- and re-processing



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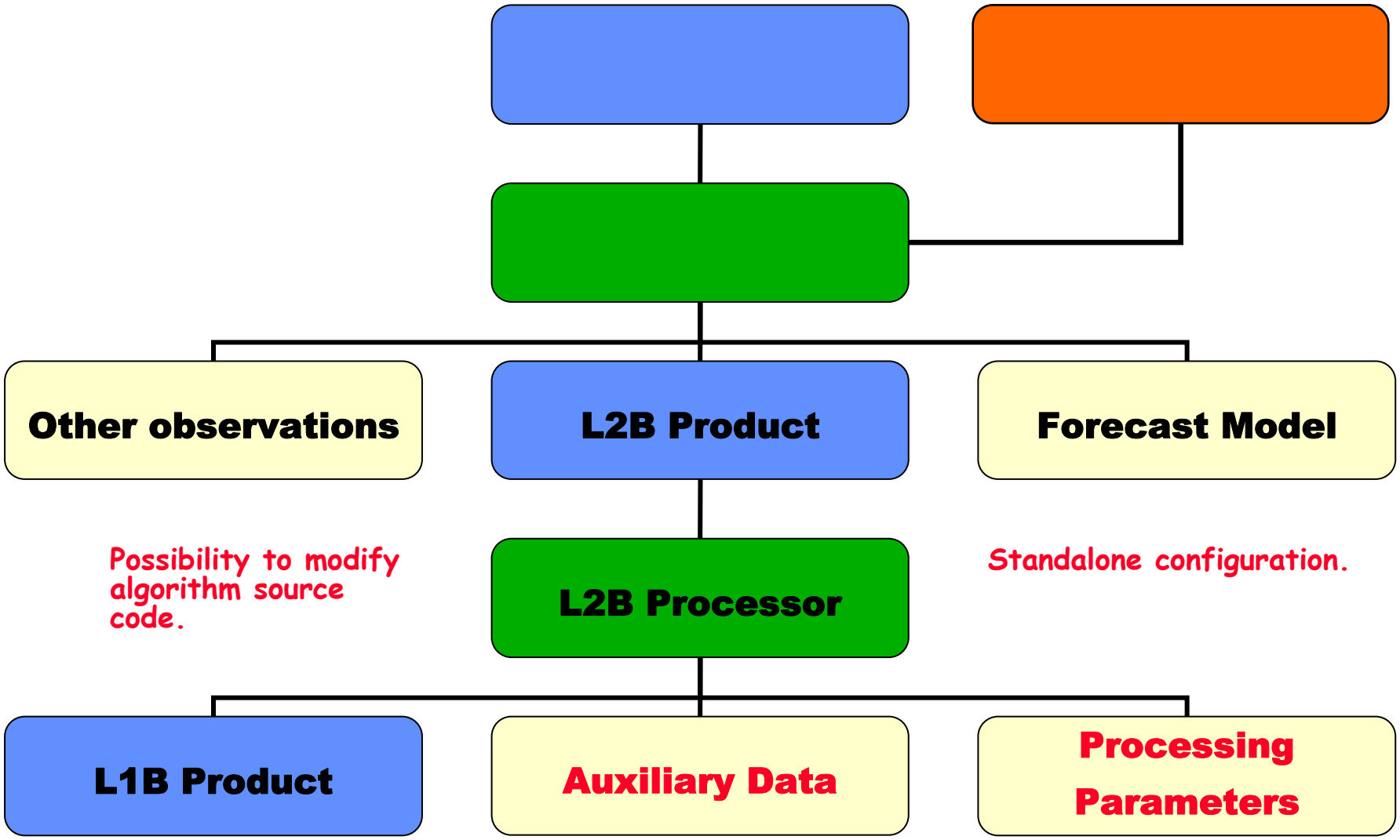
2a-3. Research/general scientific use



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