ADM-Aeolus wind retrievals for NWP

DGH Tan
ECMWF

Acknowledgments:

ESA (Mission Experts Division & Aeolus project team)

Aeolus Mission Advisory Group

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

Overview – almost ready for launch

- ECMWF preparations 2002-2004
  - Example for other NWP centres
- Level-2B processor development
  - ECMWF is lead institute, 5 sub-contractors
  - 2004-present
- Other ongoing work/operational phase
  - 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

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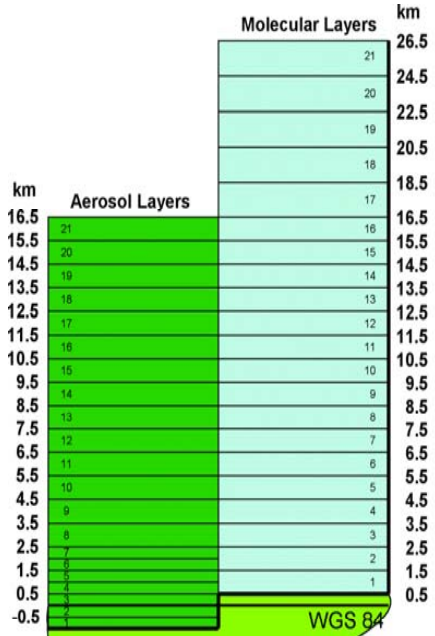
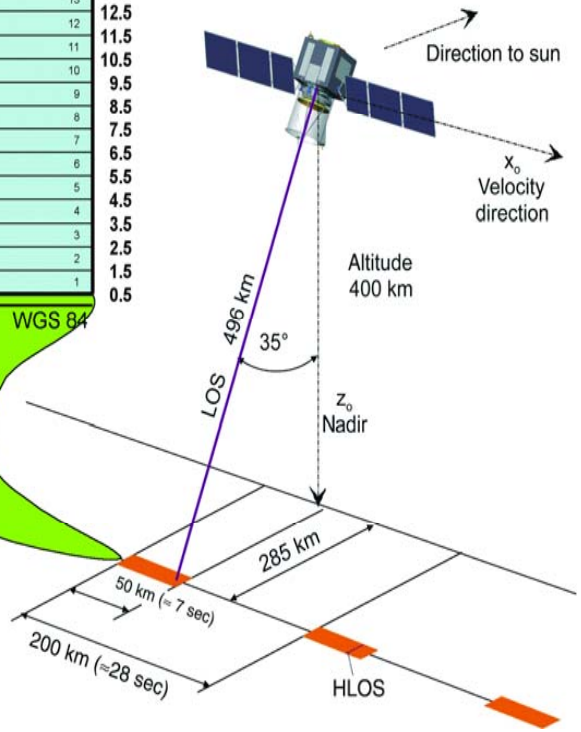
Product for assimilation – L2B 50km hlos wind

ADM-Aeolus Baseline



L2C – adds along-track wind component after data assimilation



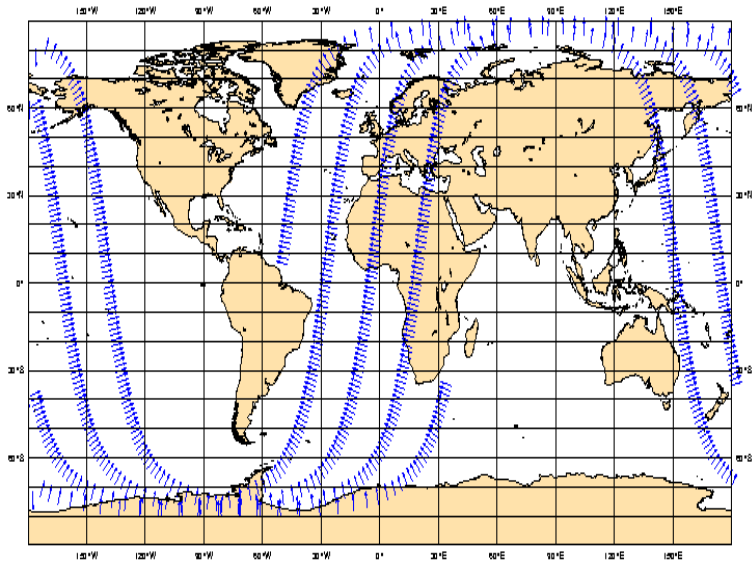
Burst mode
1 obs ~ 50 meas
Scalable system

UV lidar (355 nm) with two receivers

- Mie (aerosol), Rayleigh (molecules)
- both use direct detection

Wind profiles from surface to 30 km with resolution varying from 0.5 to 2 km

- vertical bins configurable in flight
- HLOS component only
- direction 7° from zonal at equator
- 6 hour coverage shown



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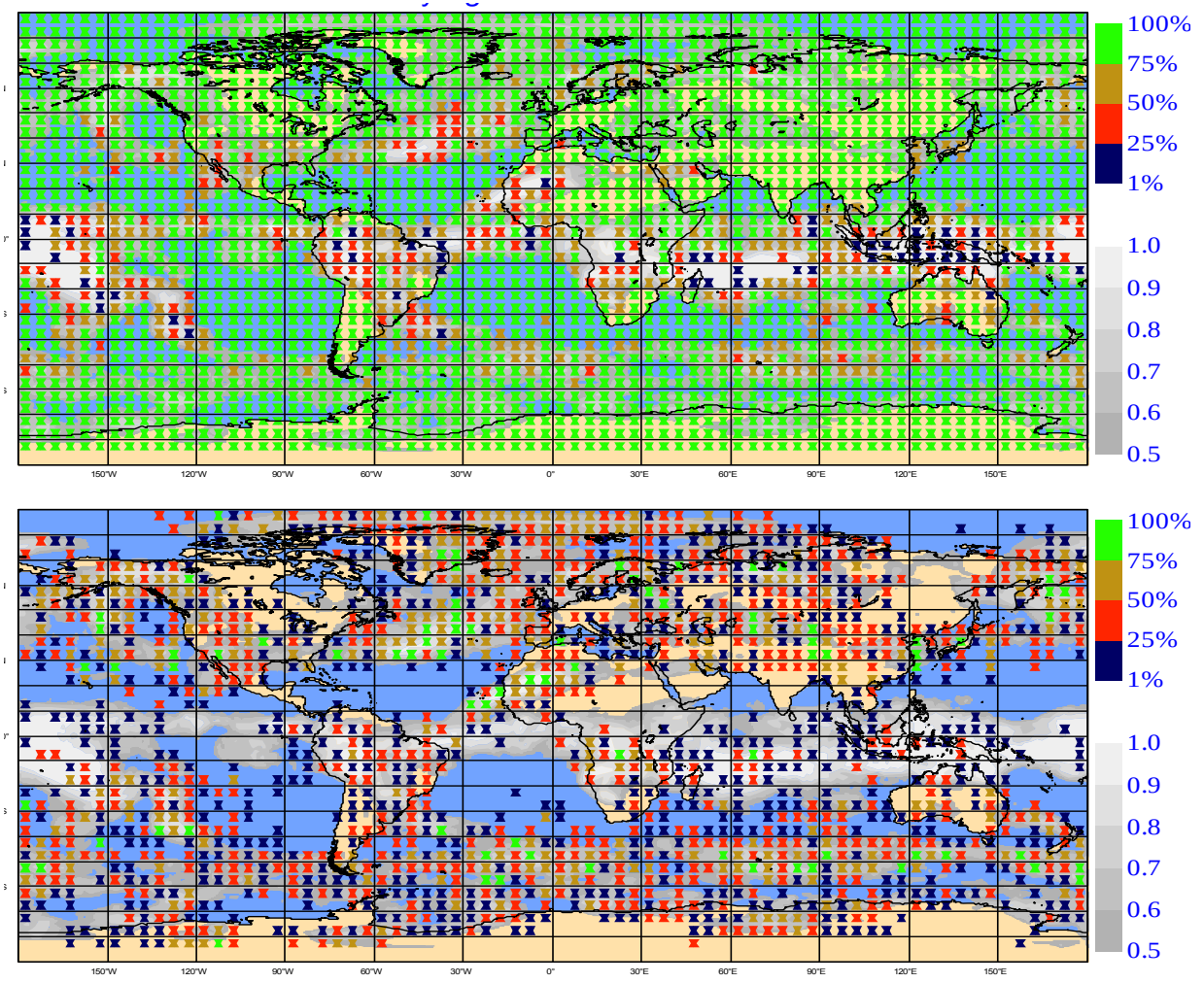
L2B data simulated using ECMWF clouds …

- 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

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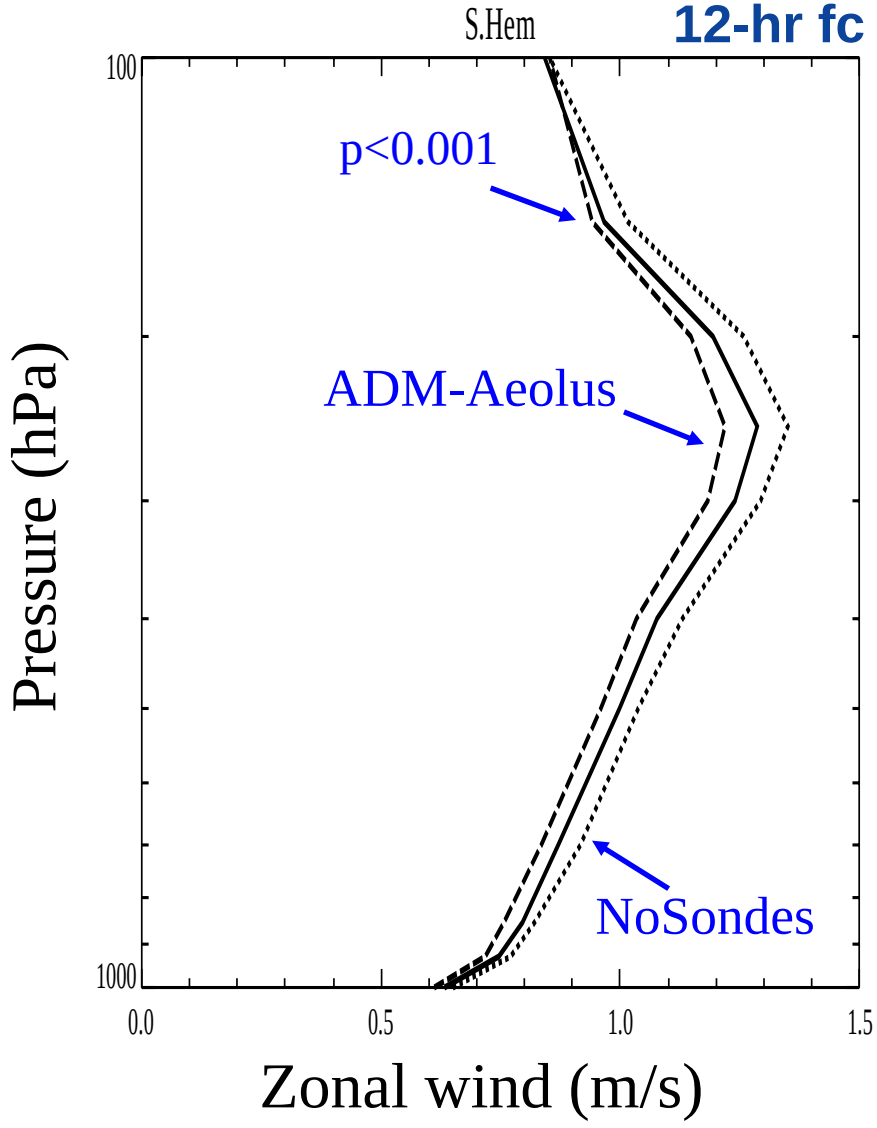
… & impact studied via assimilation ensembles



12-hr fc impact **(Tan et al QJRMS 2007)**

- 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

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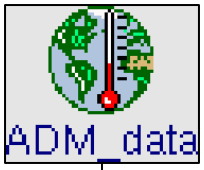
Global information content - consistent

- 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

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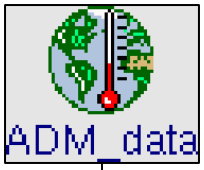
Assimilation of prototype ADM-Aeolus data

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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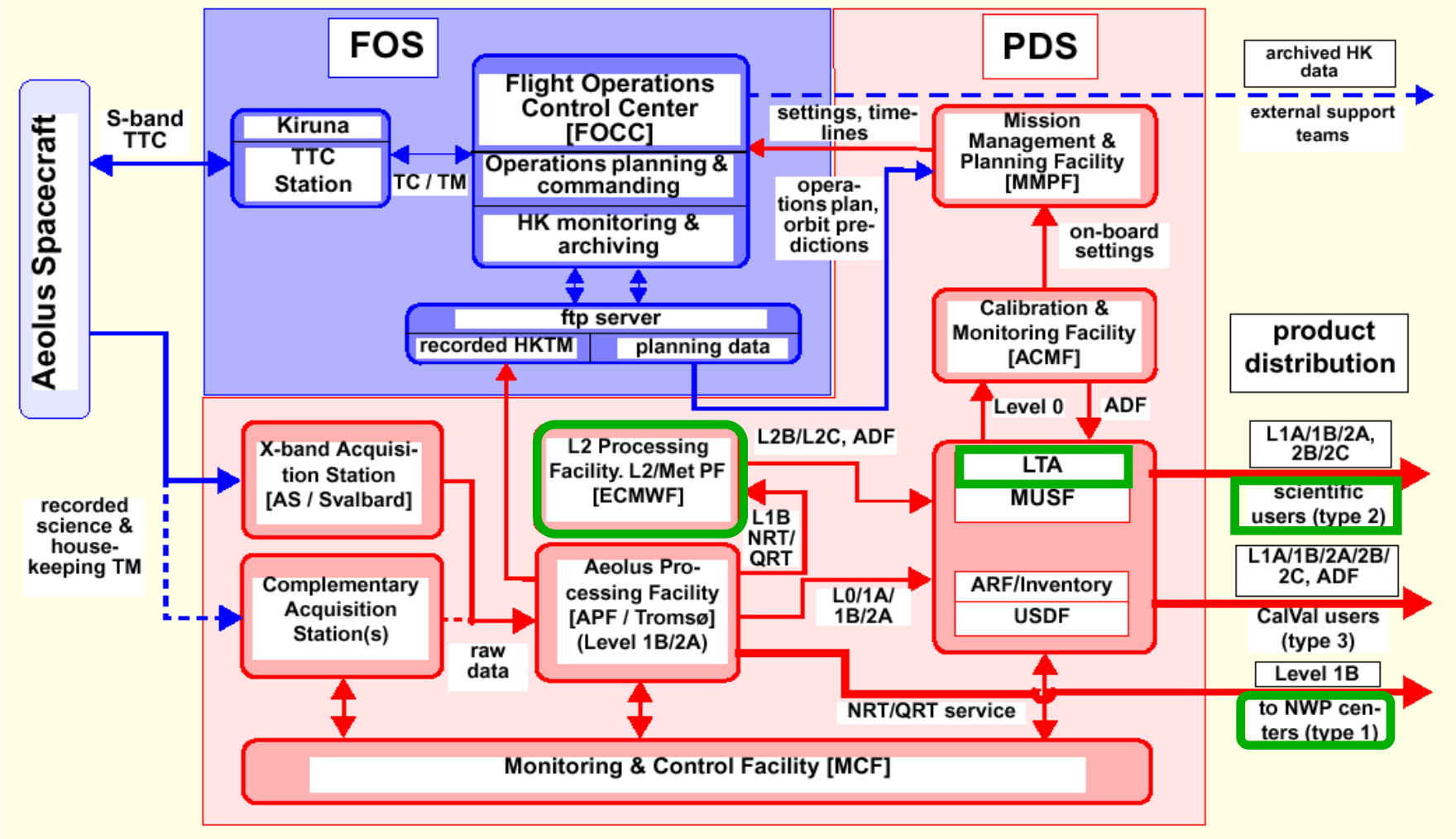
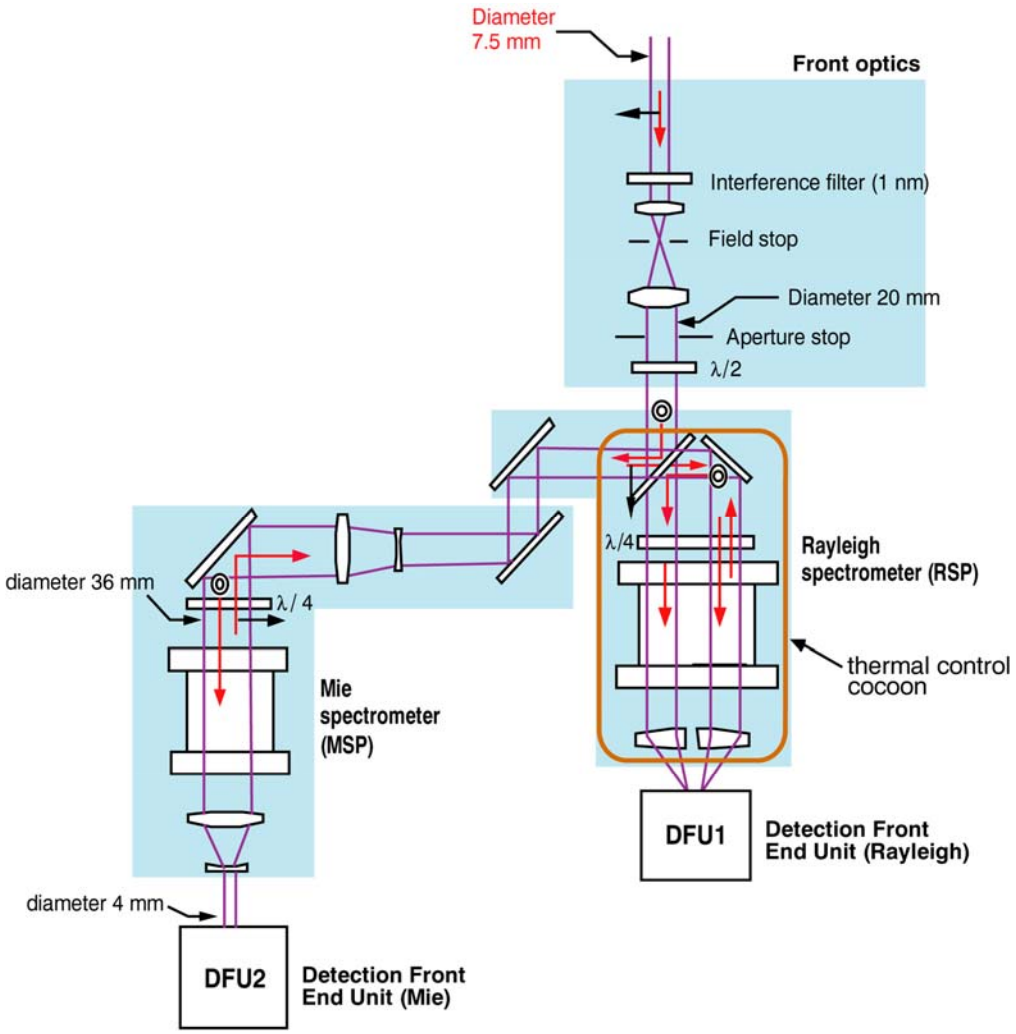
Level-2B processor will run in different environments

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

Aeolus Ground Segment & Data Flows - schematic view



Retrievals account for receiver properties …

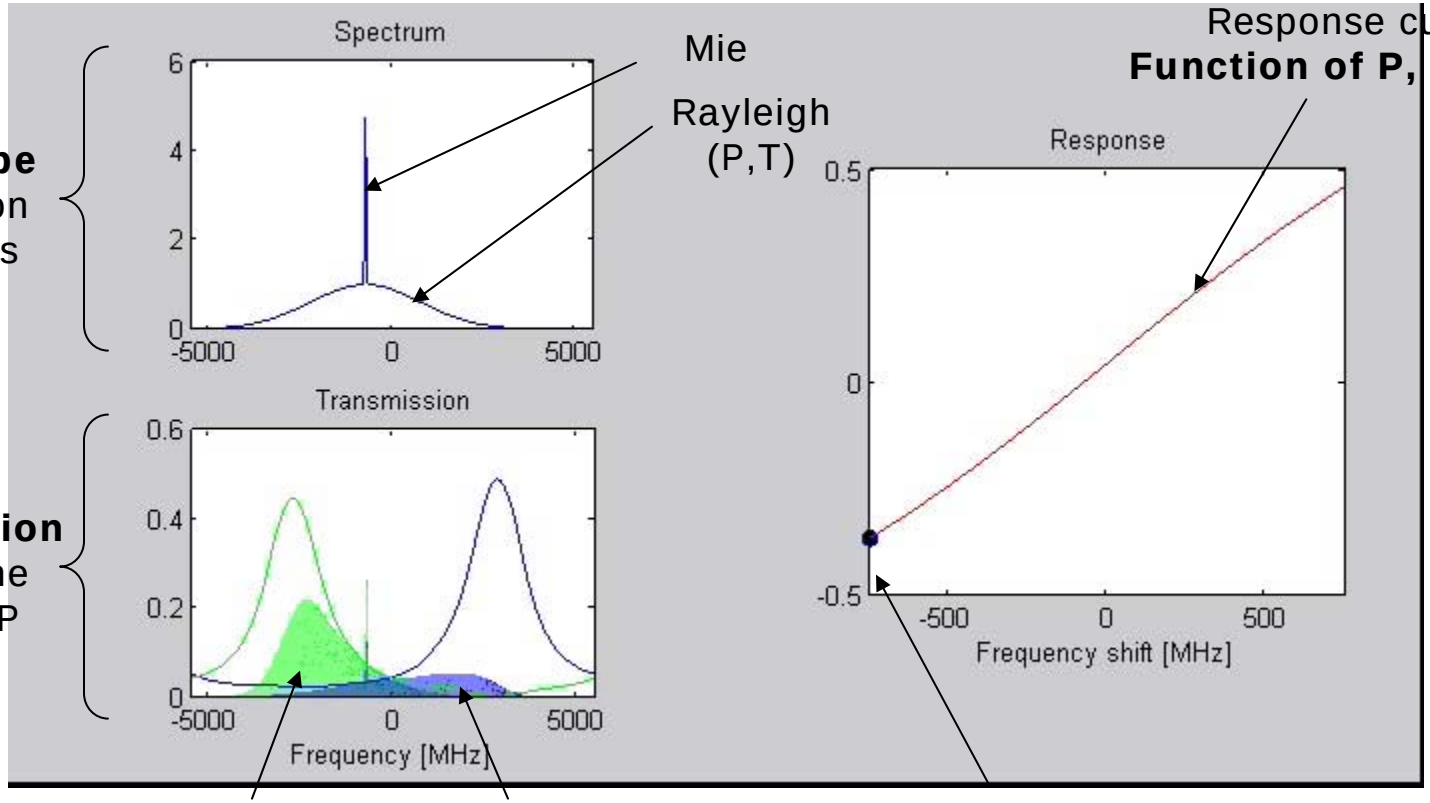


ADM-Aeolus Optical Receiver - Astrium Satellites

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

… and for atmospheric scattering properties

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



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

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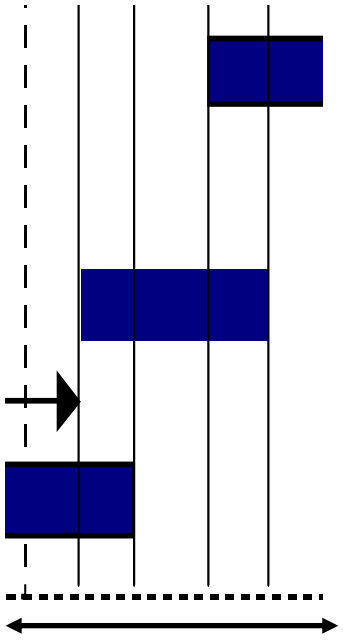
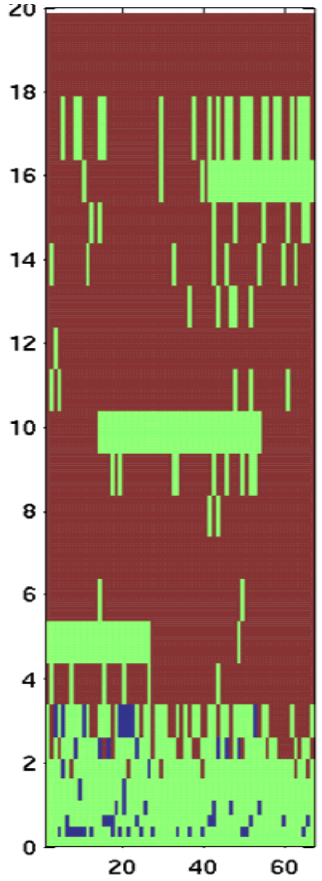
Retrievals validated for idealized broken multi-layer clouds – E2S simulator + operational processing chain

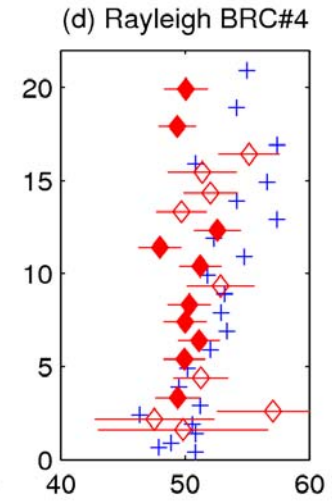
Specified cloud layers	Retrieved clouds and aerosol



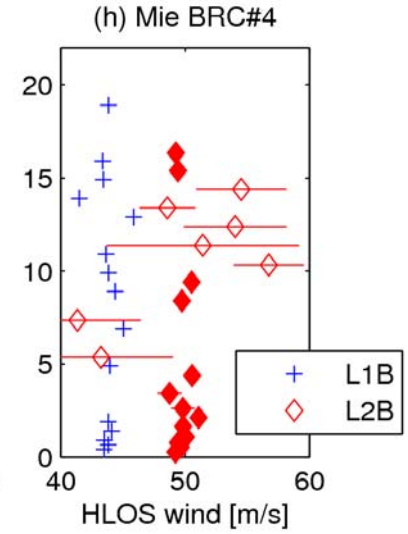


Specified wind=50 m/s

Retrieved Rayleigh winds are accurate in non-cloudy air



Retrieved Mie winds are accurate in cloud and aerosol layers



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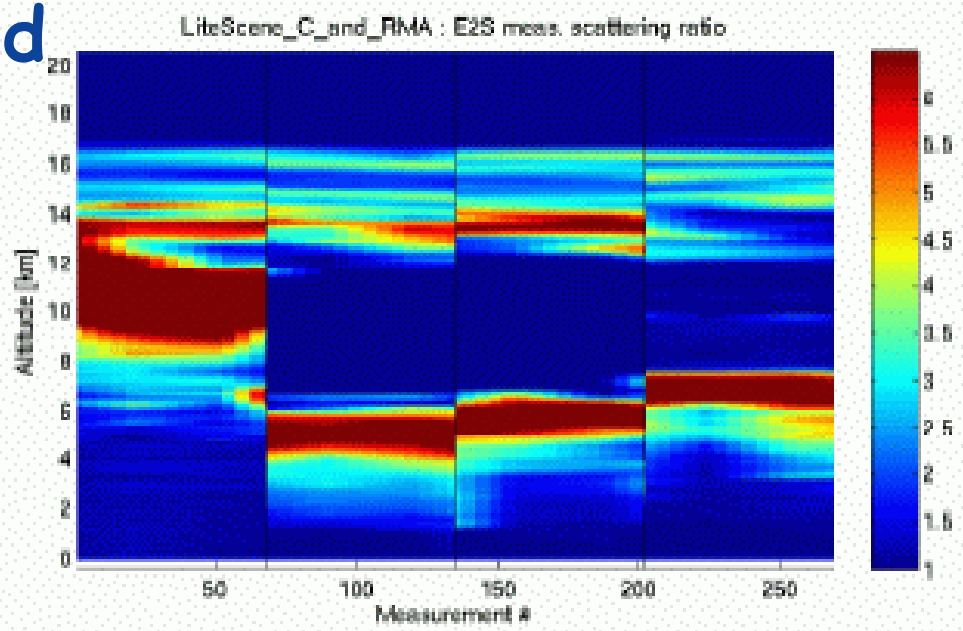
Realistic scenes simulated

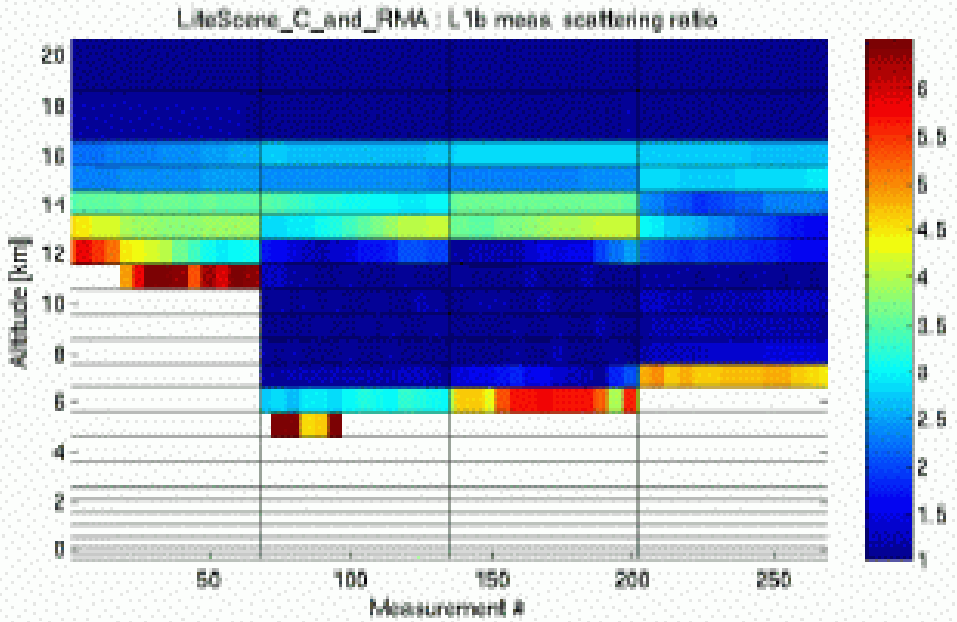
- Real scattering measurements obtained from the LITE mission

  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

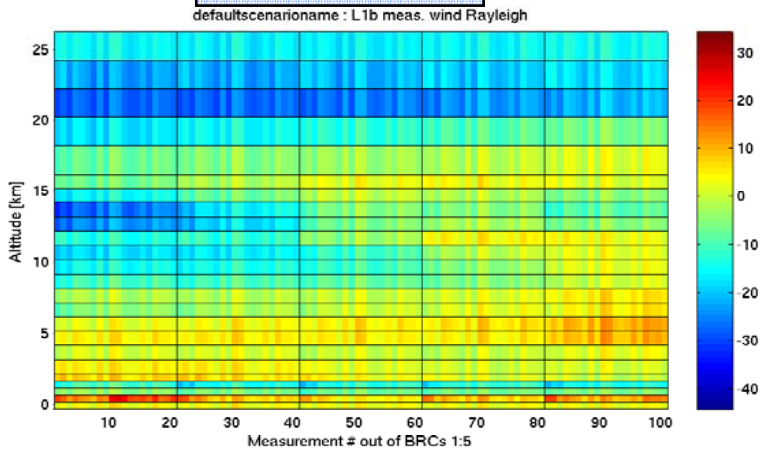




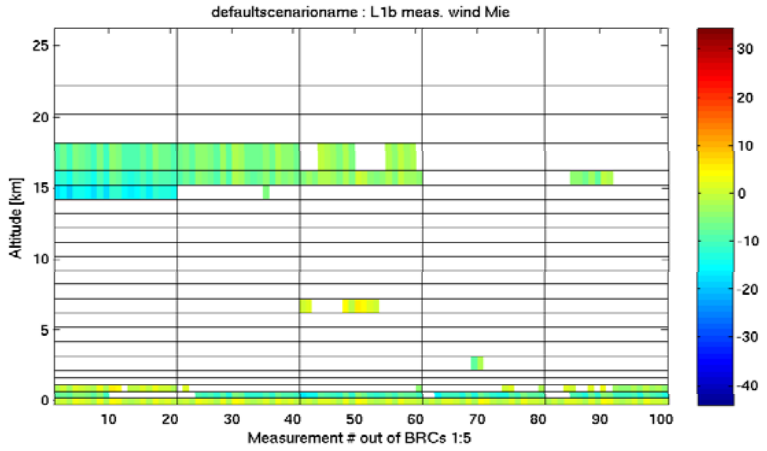
Wind retrieval validated in the presence of heterogeneous clouds and wind – E2S simulation

Level-1B

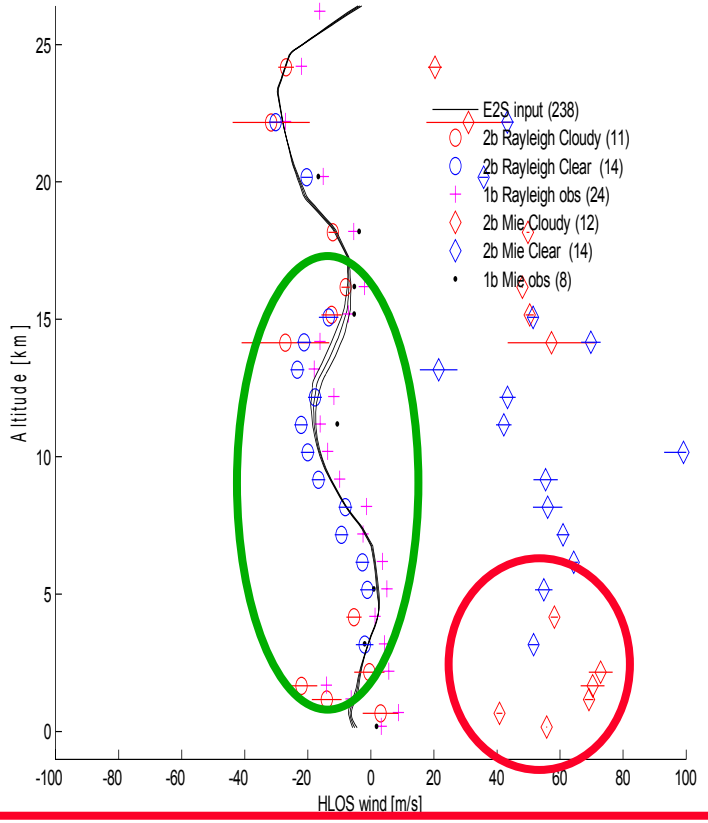
Rayleigh molecular



Mie particles



Retrieved Rayleigh winds are accurate – being refined



Retrieved Mie winds revealed systematic error in L1B input

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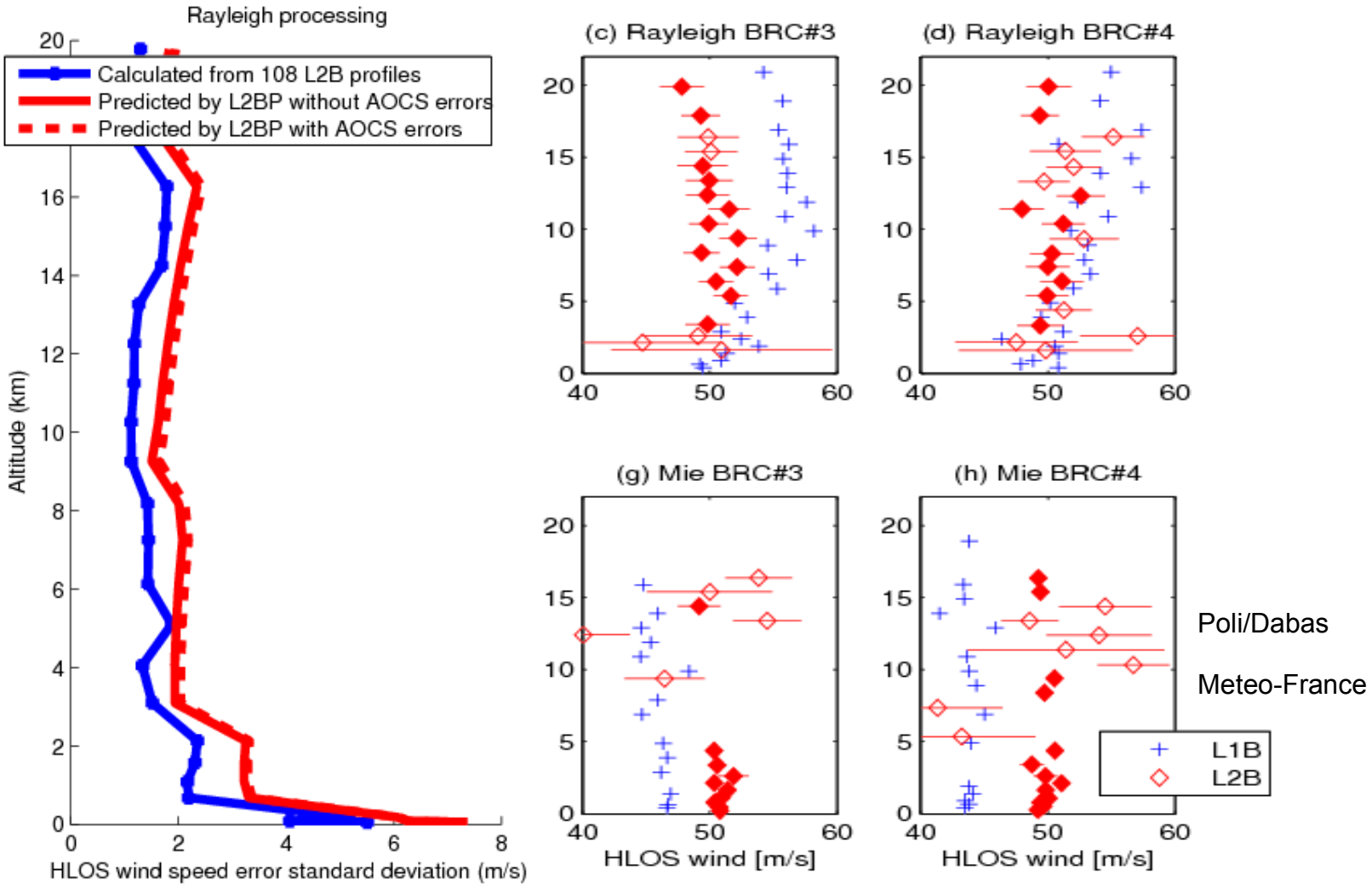
Summary – Day-1 system on track

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

Level-2B hlos error estimates – reqts met



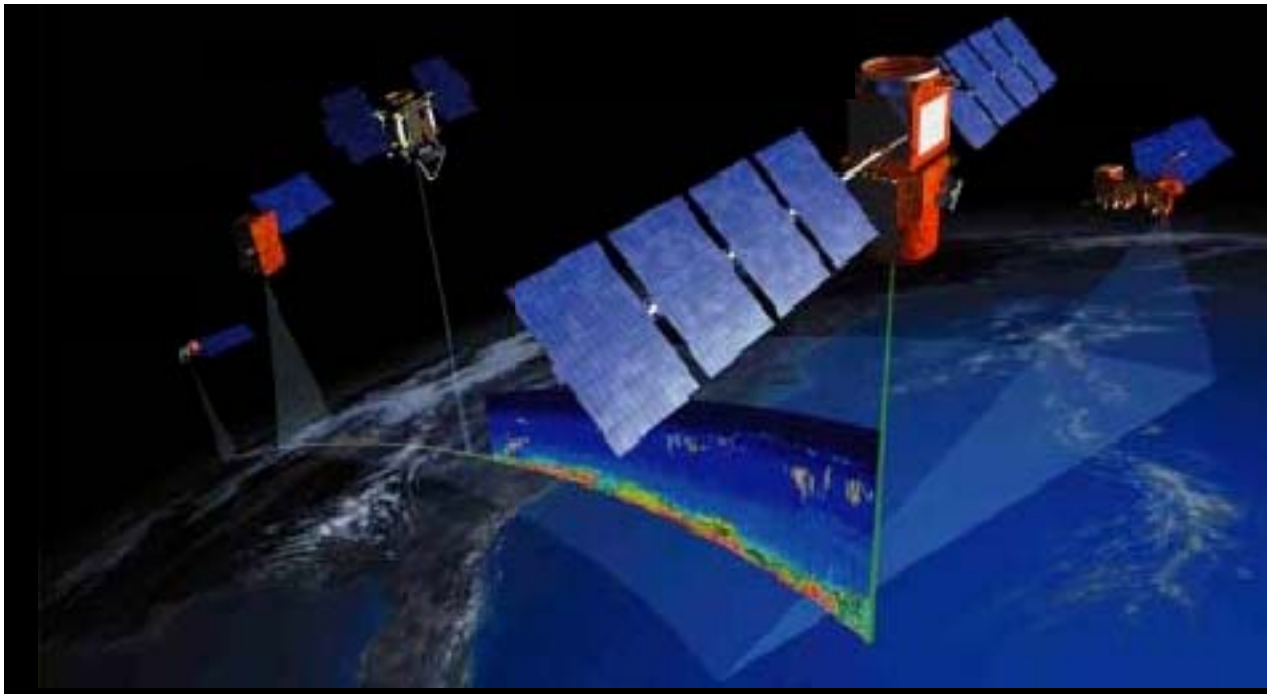
Overview – why expectations are so high

- ADM-Aeolus addresses key observational needs
  - Objectives, wind observation requirements, DWL instrument, viewing geometry
- Implementation well-advanced for launch in 2009
  - Space and ground segments
  - HLOS wind product (L2B data, algorithm, portable s-ware)
  - Cloud and aerosol products (L2A data)
  - Experimental campaigns and calibration/validation
- Studies with wind lidar data support theoretical expectations
  - Data simulations, NWP data impact studies (assimilation ensembles as alternative to OSSEs, + information content)
  - Airborne DWL (Weissman). Tropical assimilation (Zagar).

Key references

- Baker et al 1995, BAMS
- ESA 1999 Report for Assessment (Stoffelen et al 2005, BAMS) and 2007/8 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)

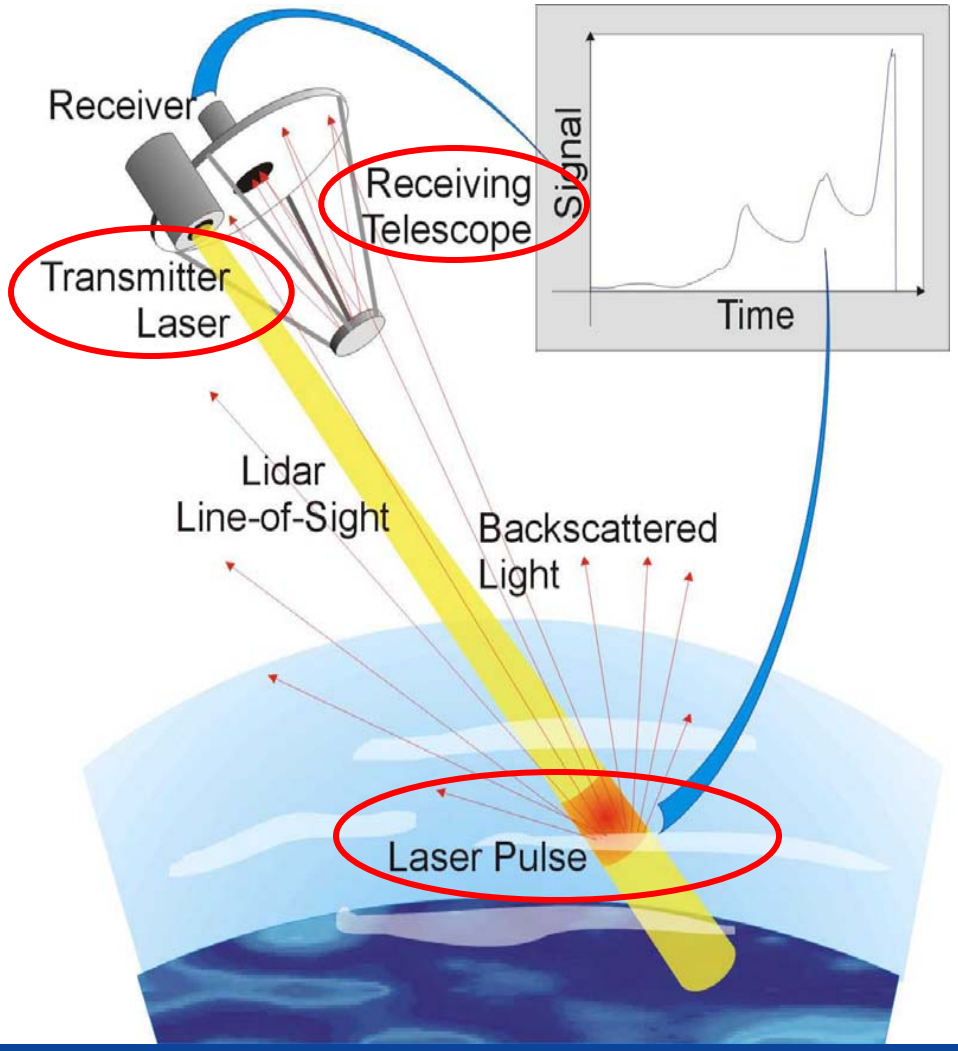
Background for ADM-Aeolus
Measurement Concept



CALIPSO lidar – vertical cross sections of backscatter

- Backscatter signal
- Aeolus winds are derived from Doppler shift of aerosols **and** molecules along lidar line-of-sight
- Error estimates, cloud & aerosol properties derived from signal strength

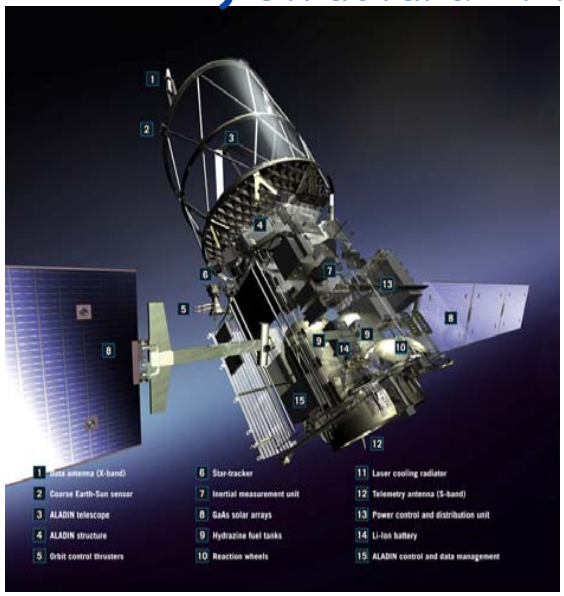
Background for ADM-Aeolus
Measurement Concept

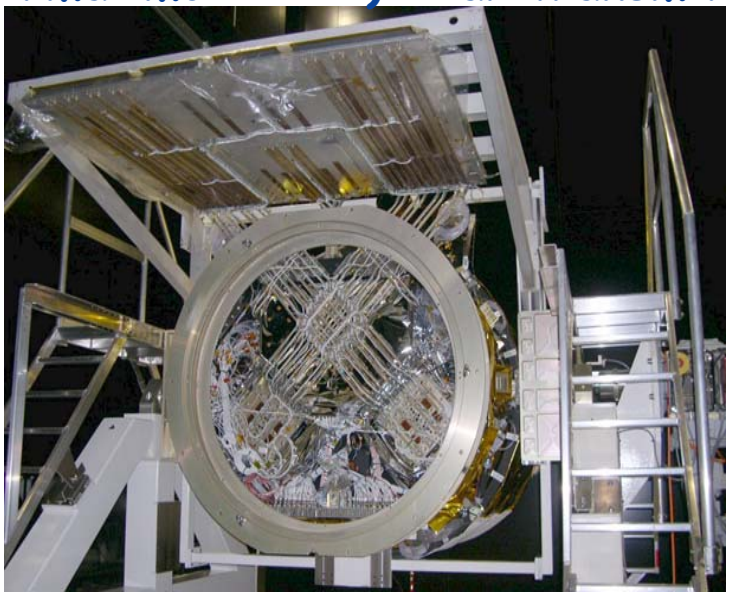


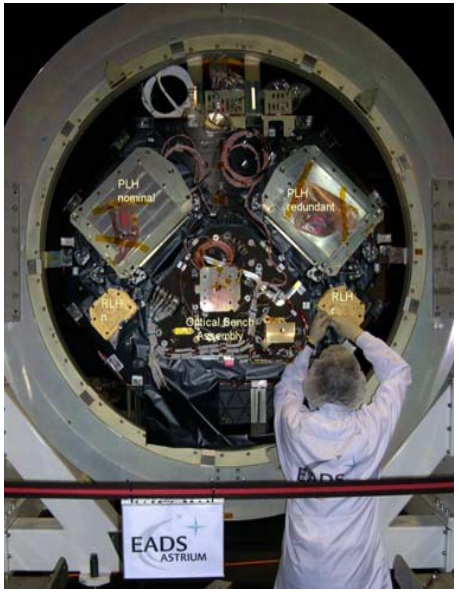
- Backscatter signal
- Winds are derived from Doppler shift of aerosols **and** molecules along lidar line-of-sight
- Error estimates, cloud & aerosol properties derived from signal strength

ADM-Aeolus Space Segment – preparation/testing of

1) structural-thermal model 2) lidar transmitter/receiver







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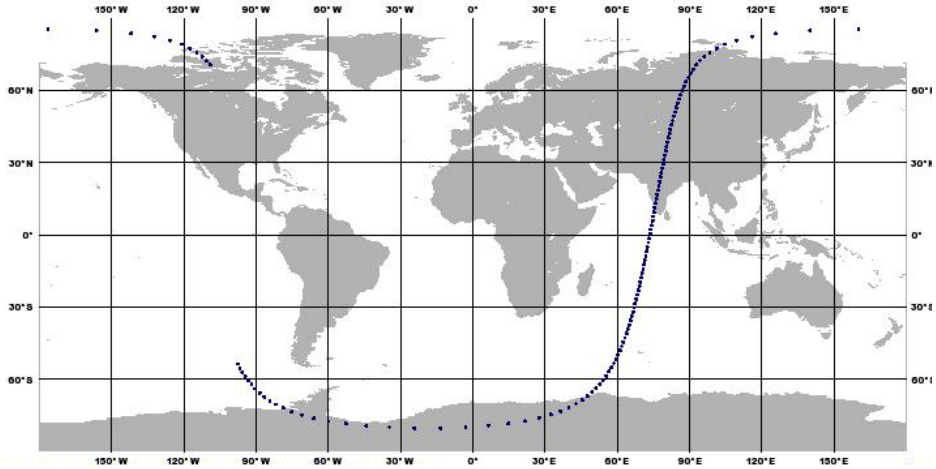
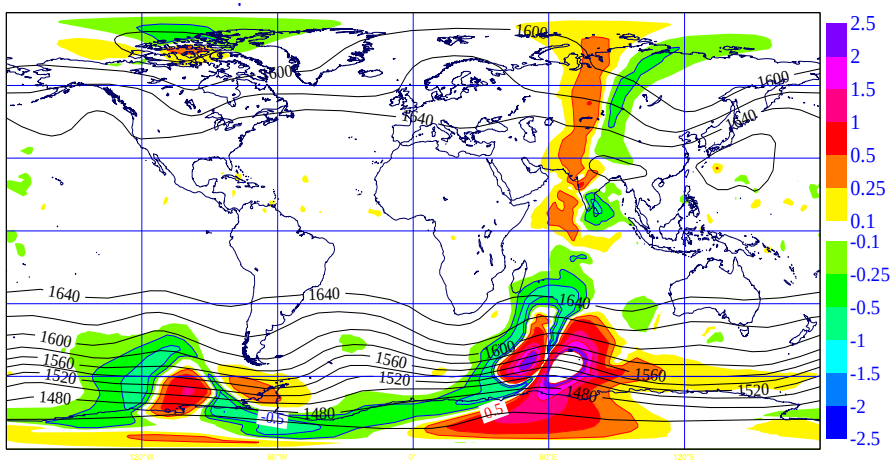
5.1 Prototype Level-2C Processing

- ✓ 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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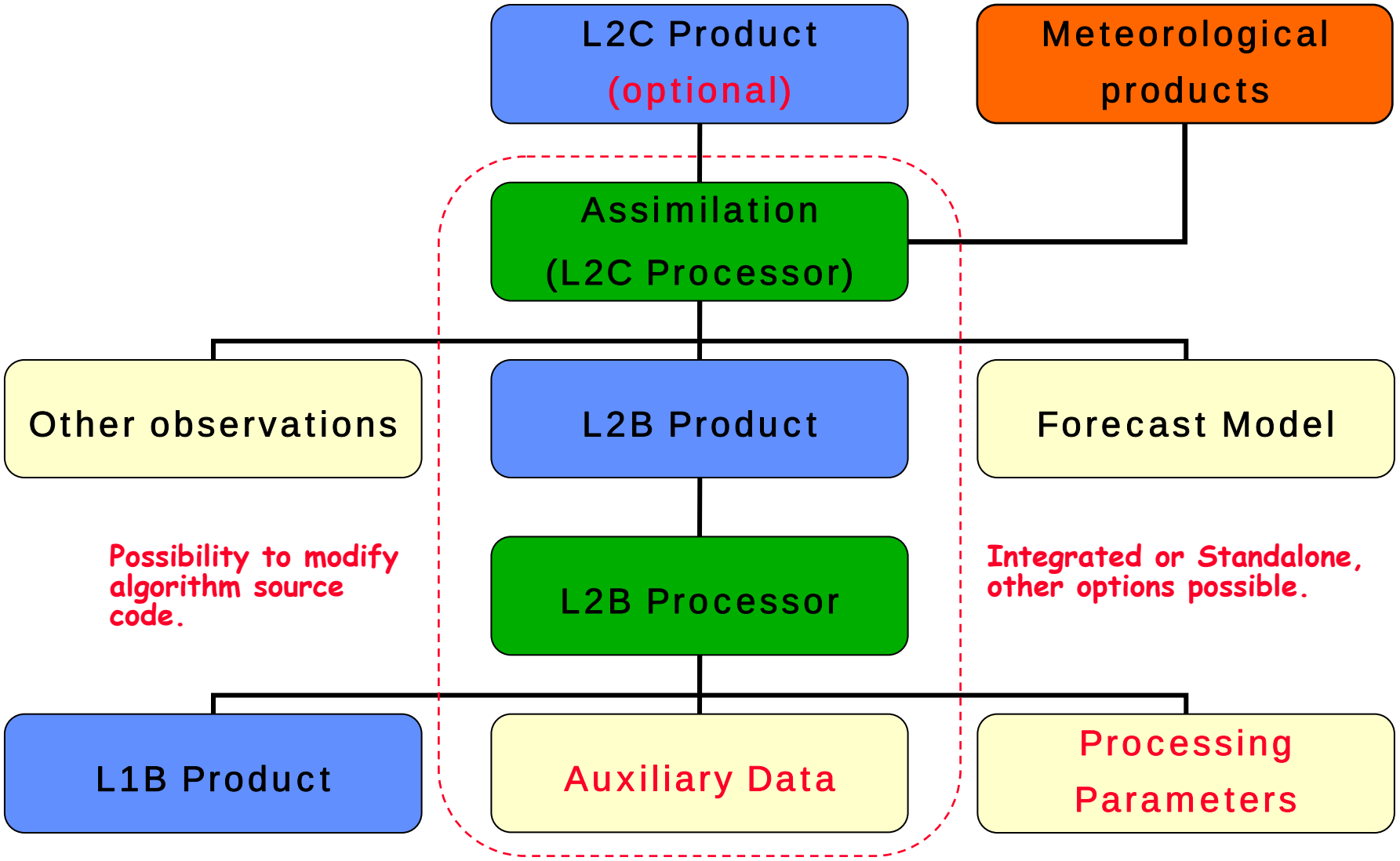
5.2 Key assimilation operators

- 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

2a-4. Other NWP configurations



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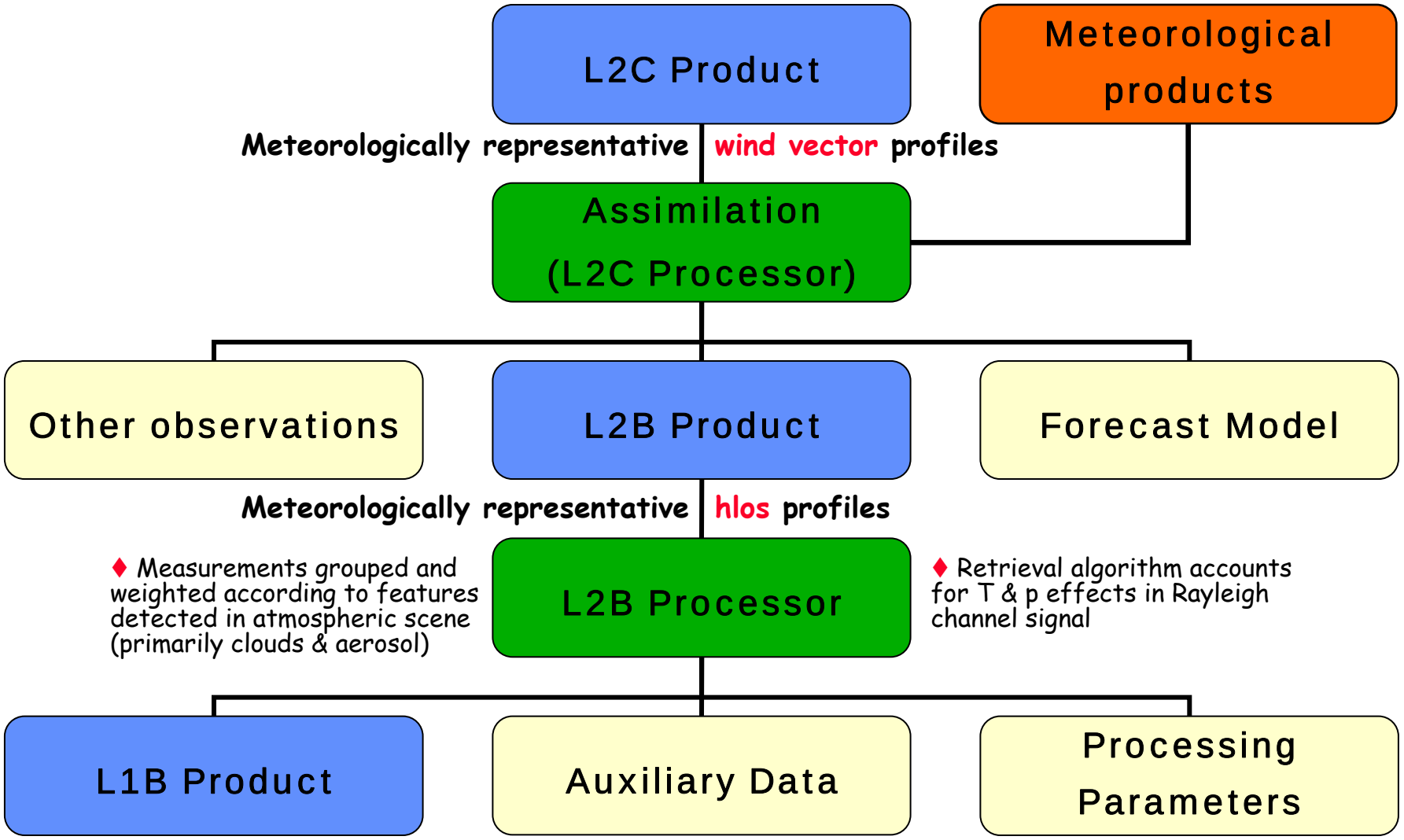
1a/b. What are Level-2B/2C Products?



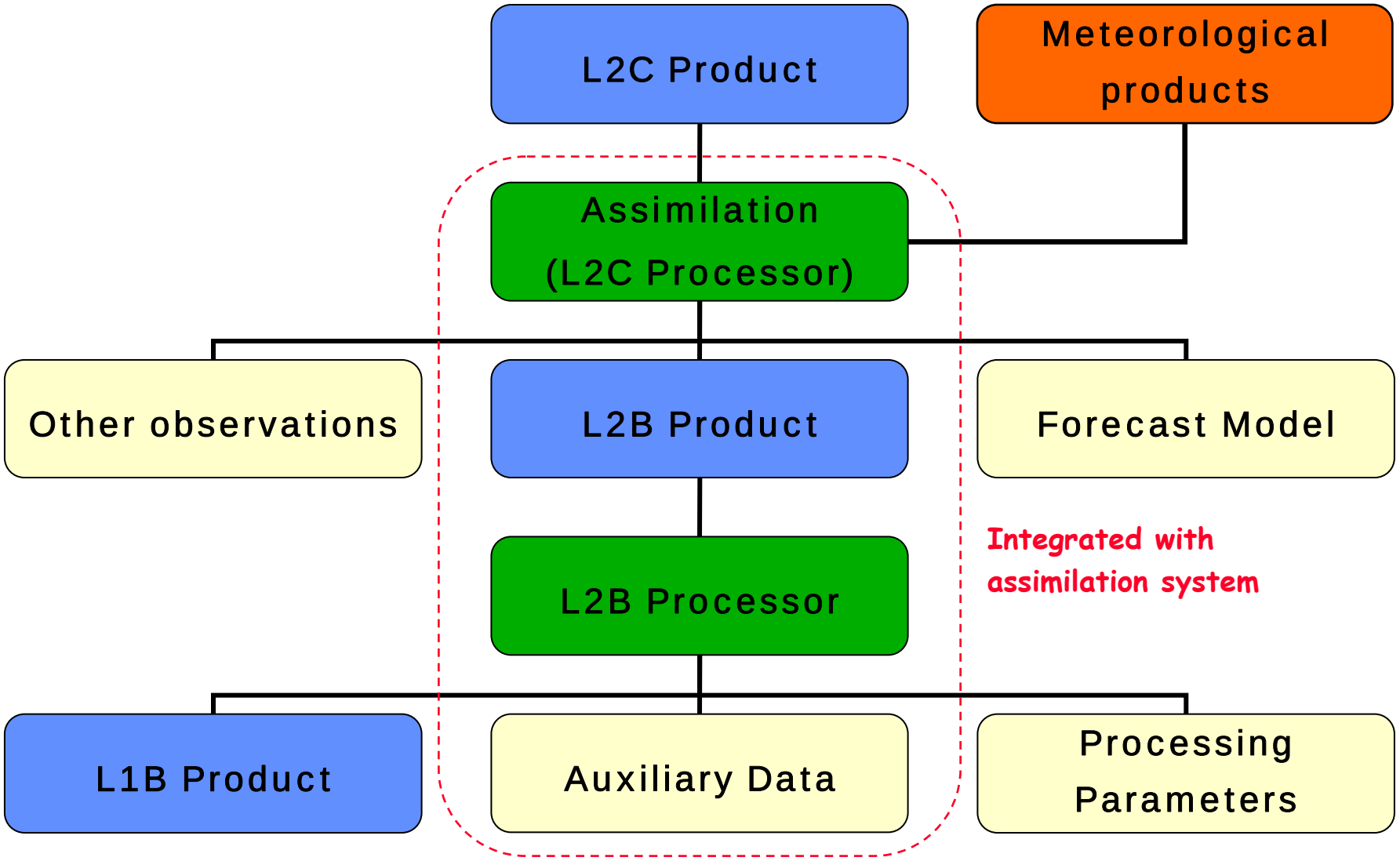
1a/b. What are Level-2B/2C Products?

- 2B: Meteorologically representative HLOS profiles
  - retrieval algs applied to Level-1B data, 2B-output suitable as input to data assimilation
    - auxiliary input data: T & p, Rayleigh-Brillouin response data, etc
- 2C: Meteorologically representative wind vector profiles
  - result of a data assimilation algorithm, combining Level-2B with other data/weather forecast model
- How do they differ from Level-1B Products?
  - Rayleigh channel retrieval accounts for T & p effects
  - measurements grouped/weighted by features detected in the atmospheric scene (primarily clouds & aerosol)

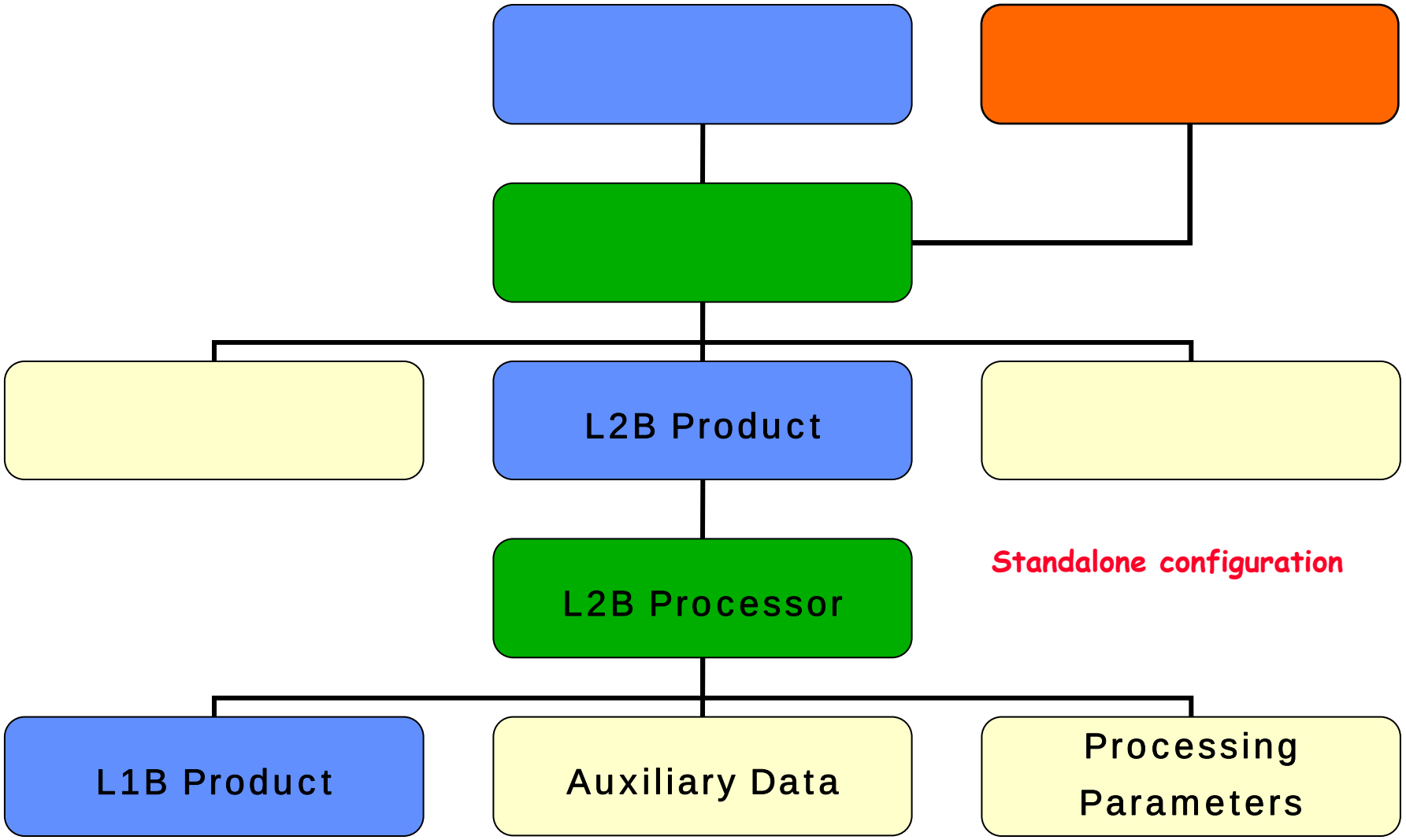
2a. Who will make Level-2B/2C Products?

- ECMWF for "operational" Level-2B/2C products
  - Processing integrated with data assimilation system
  - Products in ESA's Earth Explorer file format available from ESA (Long-Term Archive)
- ESA LTA for Level-2B late- & re-processing
  - Level-1B missing ECMWF's operational schedule
  - New processing parameters/auxiliary inputs
- Other Numerical Weather Prediction centres
  - Different operational schedule/assimilation strategy
  - Different processing params/aux inputs/algorithms
- Research institutes & general scientific users
  - Different processing params/aux inputs/algorithms

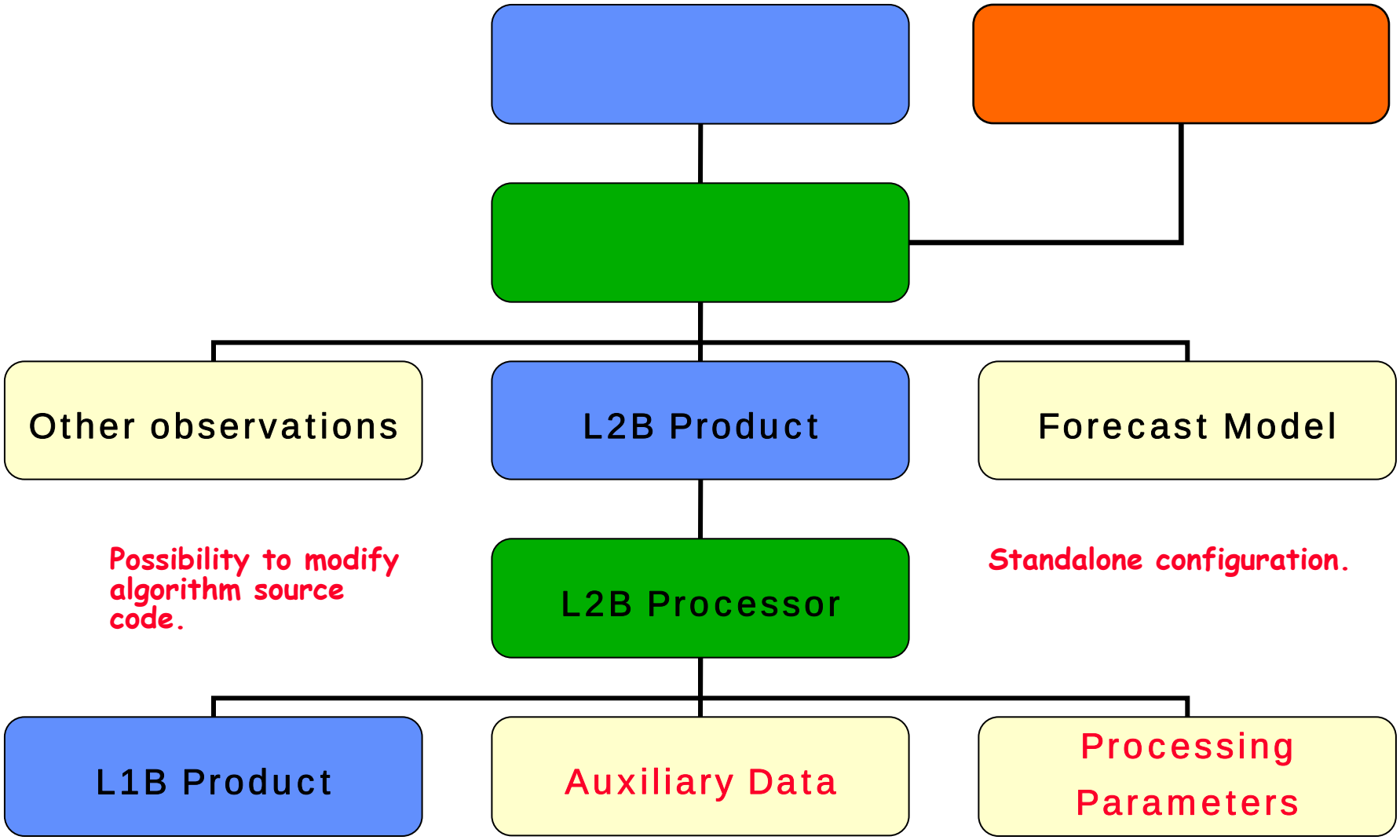
2a-1. ECMWF "operational" configuration



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



2a-3. Research/general scientific use



2b. Why distribute L2BP Source Code?

- **Distribution of executable binaries only permits**
  - **limited number of computing platforms**
  - **different settings in processing parameters input file**
    - thresholds for QC, cloud detection
  - **different auxiliary inputs**
    - option to use own meteorological data (T & p) in place of ECMWF aux met data (available from LTA)
- **Provide maximum flexibility for other centres/institutes to generate their own products**
  - **different operational schedule/assimilation strategy**
  - **scope to improve algorithms**
    - feed into new releases of the operational processor

3a. How it works – Tan et al *Tellus A* 2008

- Rayleigh channel HLOS retrieval – Dabas et al, Tellus A
  - R = (A-B) / (A+B) and HLOS = F^{-1} (R;T,p,s)
  - T and p are auxiliary inputs
  - correction for Mie contamination, using estimate of scattering ratio s
- Mie channel HLOS retrieval
  - peak-finding algorithm (4-parameter fit as per L1B)
- Retrieval inputs are scene-weighted
  - ACCD = Σ $ACCD_m$ W_m, W_m between 0 and 1
- Error estimate provided for every Rayleigh & Mie hlos
  - dominant contributions are SNR in each channel

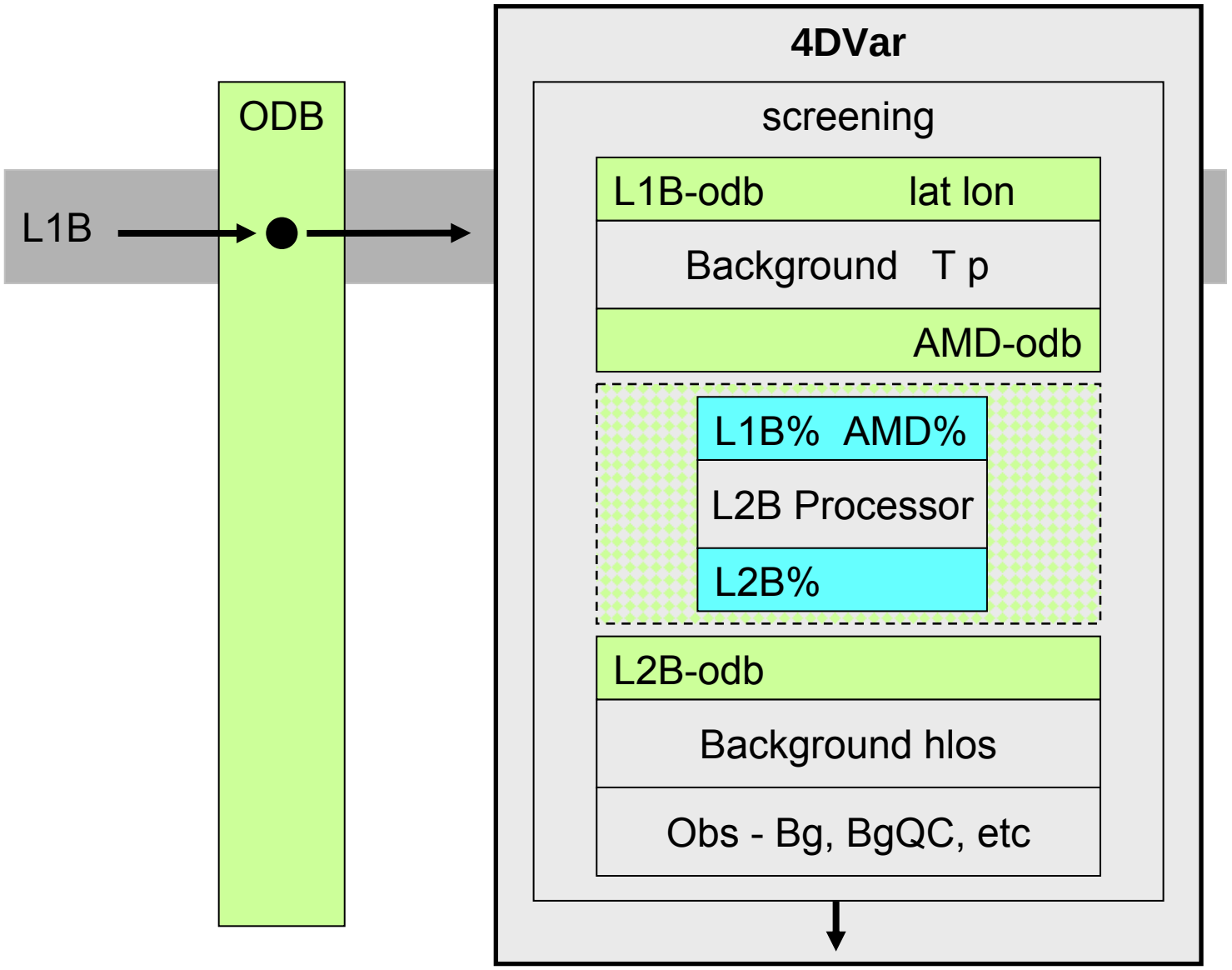
4. Distribution of L2BP software

- **Software releases issued by ECMWF/ESA**
  - **Details & timings to be determined**
  - **Probably via registration with ECMWF and/or ESA**
  - **Source code and scripts for installation**
    - Fortran90, some C support
    - Developed/tested under several compilers
  - **Suite of unit tests with expected test output**
  - **Documentation**
    - Software Release Note
    - Software Users' Manual
    - Definitions of file formats (IODD), ATBD, etc.

Conclusions

- **Expectations for ADM-Aeolus are high**
  - **On track for producing major benefits in NWP**
    - Meeting the mission requirements for vertical resolution & accuracy
    - Extending to stratosphere, re-analysis
    - Our software available to NWP/science community
  - **Combine with other observations**
    - Height assignment for AMVs
    - Complement other cloud/aerosol missions
  - **Related research**
    - Background error specification

5.3 L2BP integration within an assimilation system



Wrapper module copies "odb" variables to & from % data structures (hidden from screening)

C.f. RTTOV + SSMI TCWV

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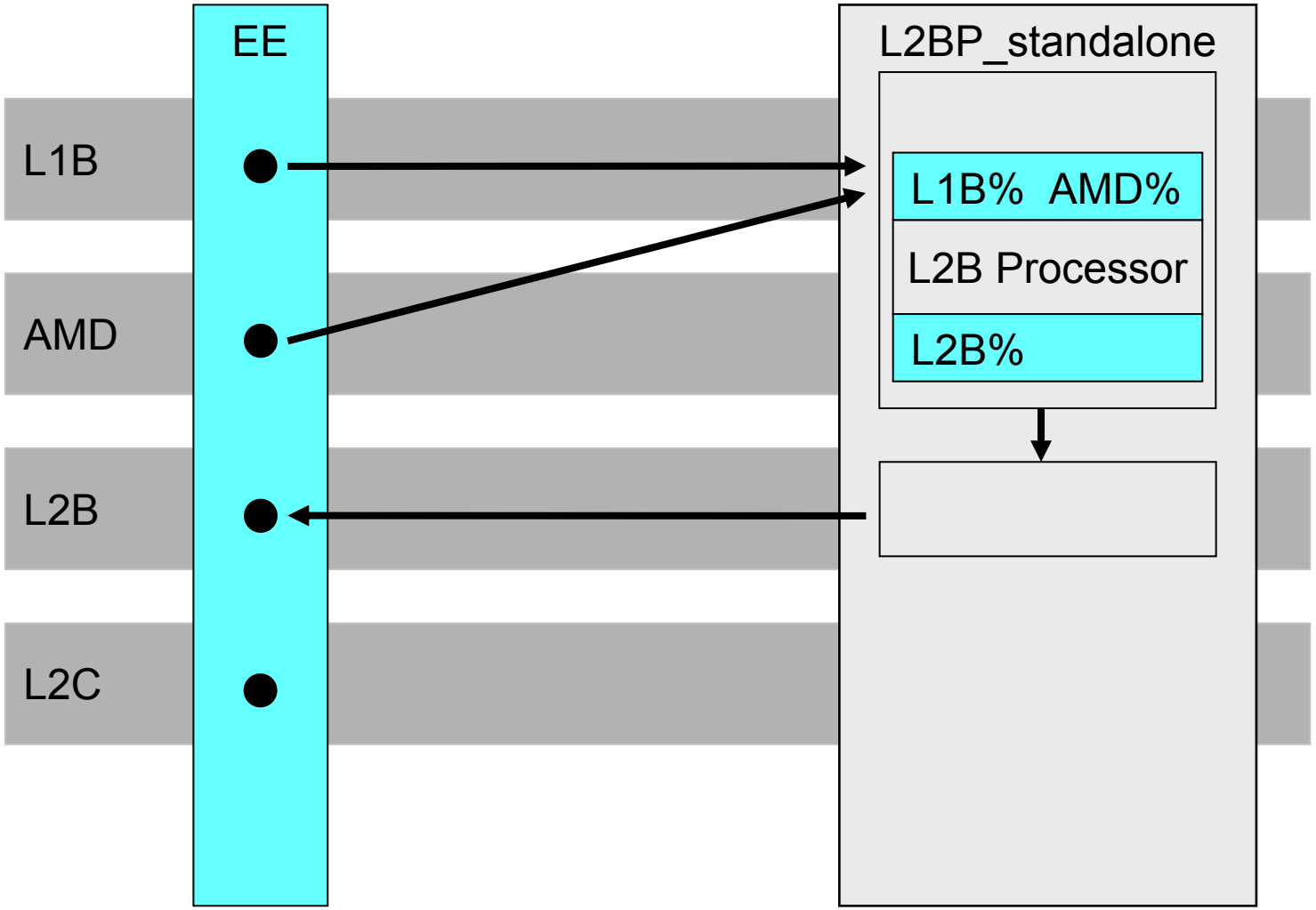
5.4 Overview data flow – standalone mode



5.5 Principal Guidance to Met Centres

1. How to install and test the standalone version
   - Source code, documentation, unix scripts and test data (EE format) supplied
   - Useful tool for inter-comparison purposes
2. Interface requirements for integrated-assimilation mode
   - Generation of auxiliary meteorological data
   - Wrapper module between "odb" and L2B processor used as a callable subroutine within assimilation.x
   - Both to occur during Screening
   - Facilitates assimilation of Aeolus data
   - Assimilation outputs at discretion of each met centre