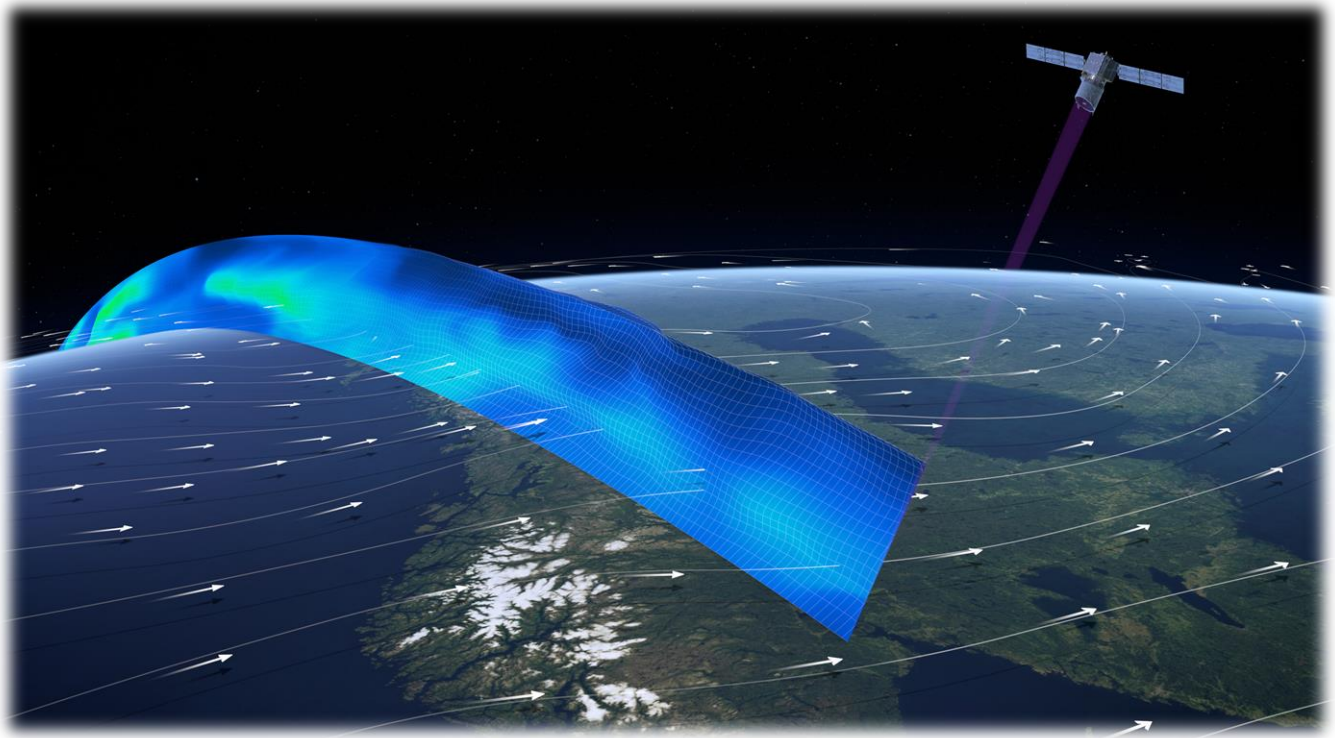
The Aeolus Level-2B processor and the Meteorological Processing Facility at ECMWF

by Michael Rennie (ECMWF)

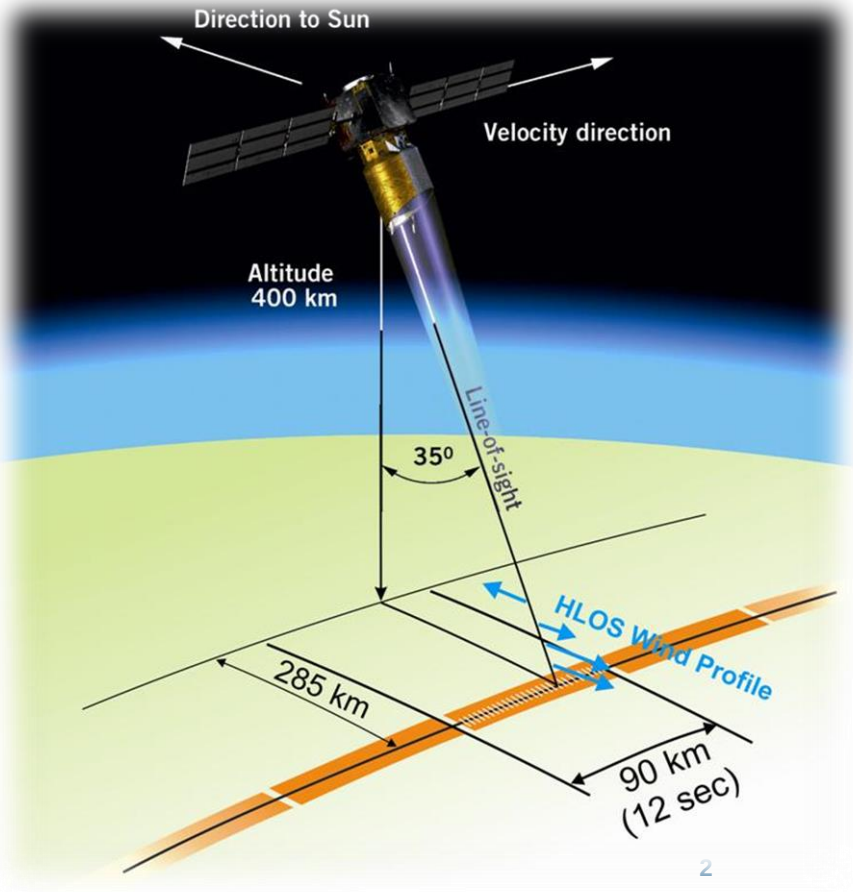
ECMWF/ESA Workshop: Tropical modelling, observations and assimilation

8 November 2016

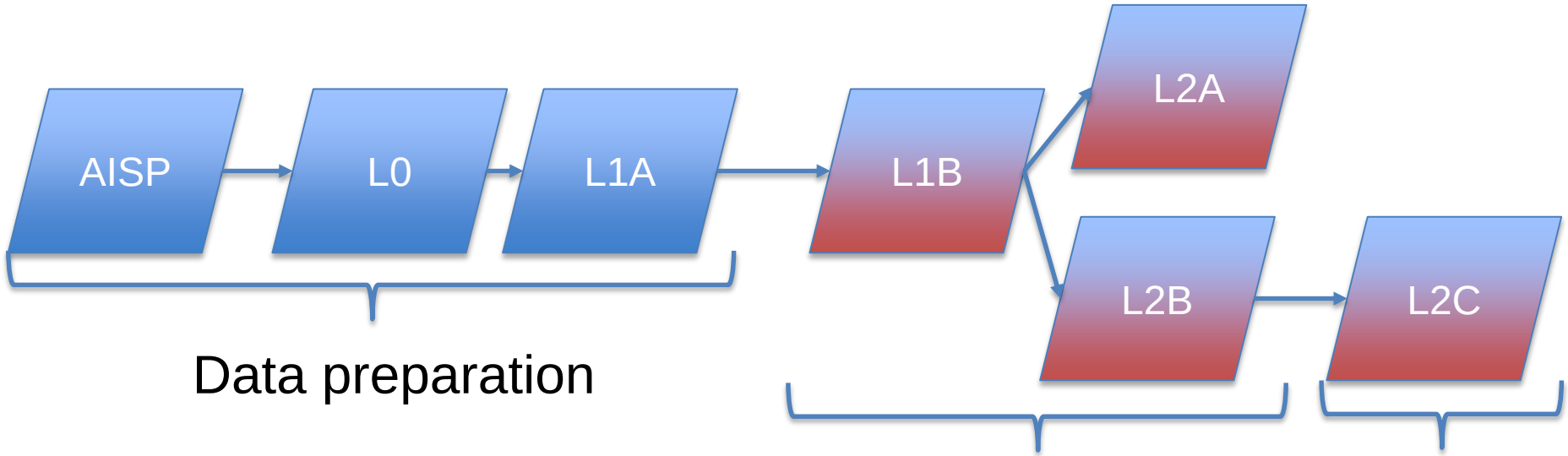


Outline

- Aeolus Level-2B wind observations and production at ECMWF
- What Aeolus provides in the tropics
- Aeolus data assimilation at ECMWF



Aeolus instrument data processing levels



Aeolus data processing levels

- Level-1B product
  - **Measurement-level** Mie & Rayleigh useful signal data with a number of corrections/calibrations applied
  - Uncorrected (H)LOS wind observations
- Level-2A product
  - Supplementary aerosol and cloud product
- Level-2B product
  - **(H)LOS wind** observations suitable for NWP data assimilation
- *Level-2C product*
  - *Vector winds from the ECMWF analysis after the assimilation of L2B winds*

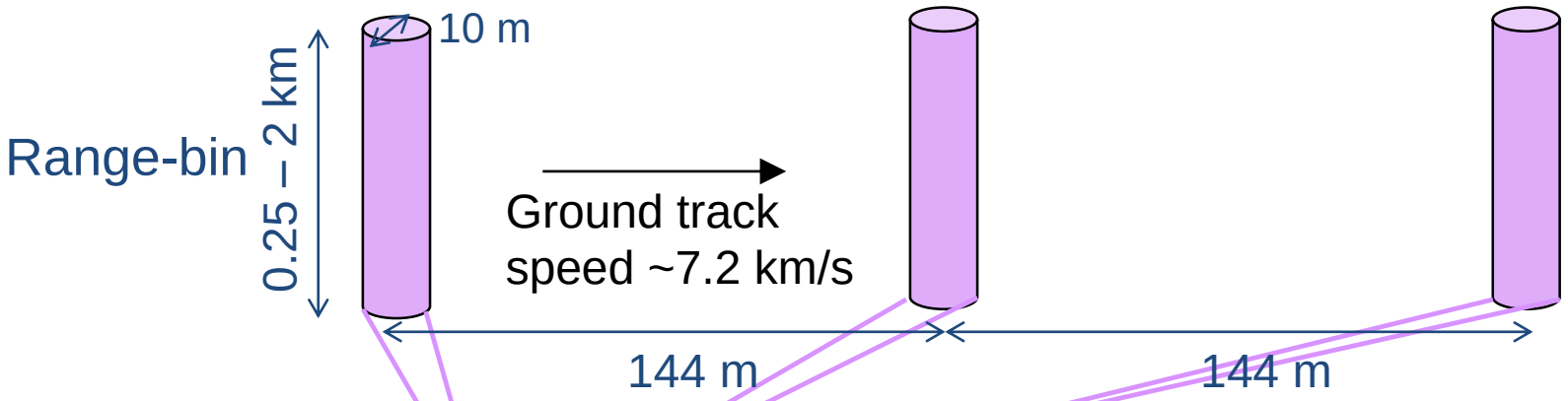
Level-2B wind processing

- Processor developed over past decade by ECMWF, KNMI, MF for ESA
- Output: Line-of-sight (LOS) or Horizontal LOS (HLOS) wind component observations
- **Rayleigh** channel corrected for temperature, pressure dependence and Mie contamination (not done for L1B)
  - using *a priori* information (from short-range NWP)
- Each observation (Mie or Rayleigh):
  - Classified into a type: **cloudy** or **clear**
  - Uncertainty estimates for each wind result, quality flags
- Flexible control of processing options
- L2Bp software and documentation can be downloaded from:

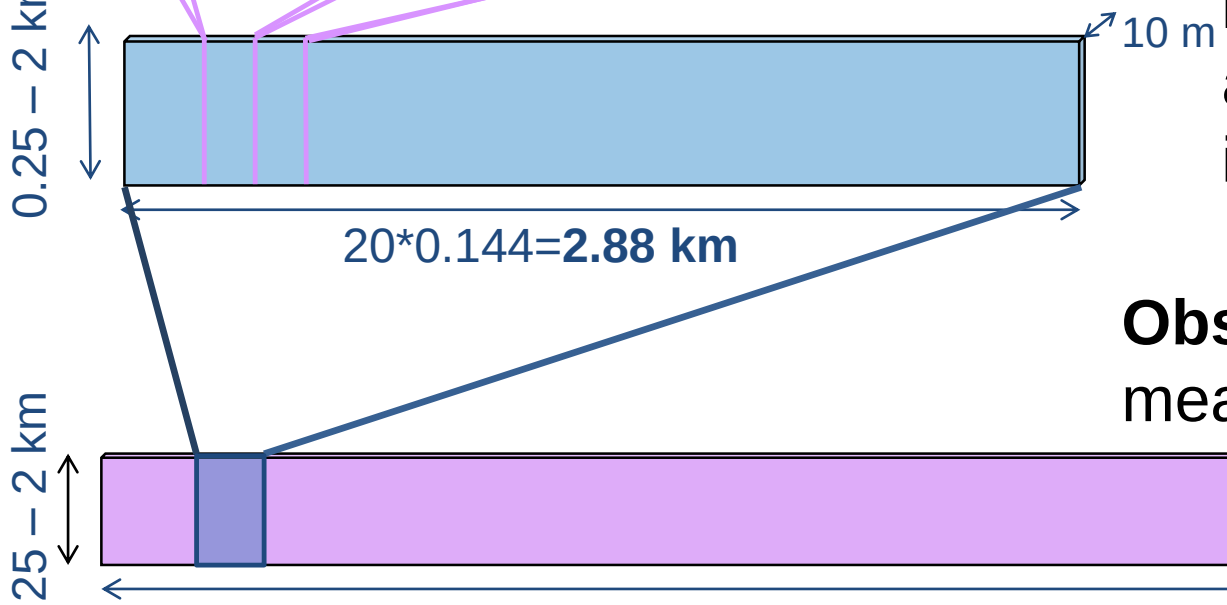
https://software.ecmwf.int/wiki/display/AEOL/ADM-Aeolus+Level-2B+Processor+Package

- L2Bp portable and easy to install by users

L2B wind “observations” constructed horizontally from small-scale measurements



Laser pulses

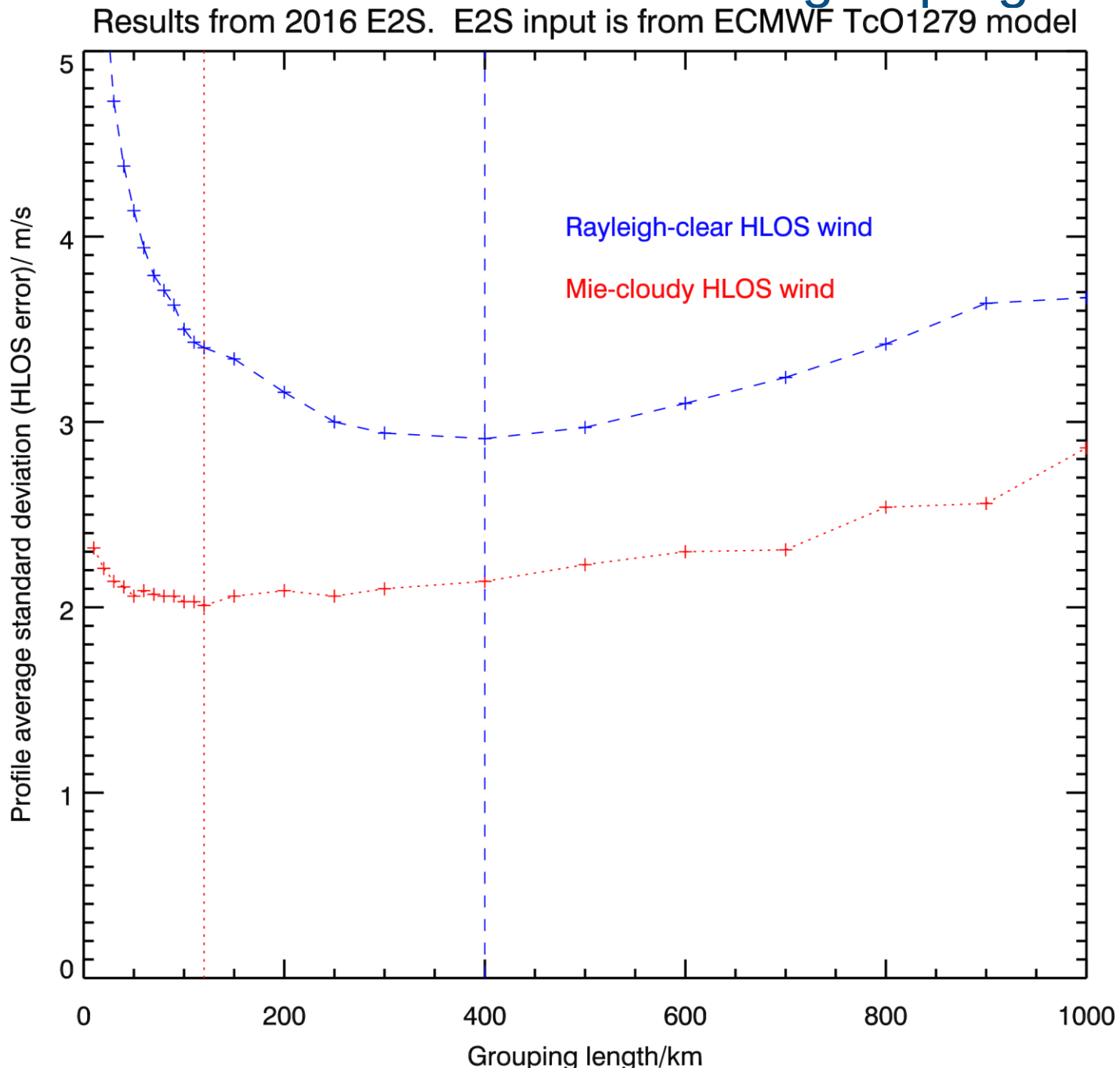


Measurement = accumulation of 20 pulses on instrument

Observation = average of e.g. 30 measurements

Flexible L2Bp algorithm to produce varying horizontal averaging

L2B wind error st. dev. vs. L2B grouping length



ECMWF will produce Aeolus L2B products in the L2 Meteorological Processing Facility

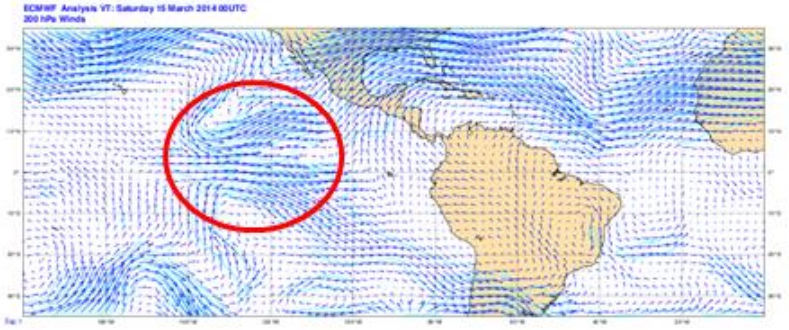
- ECMWF will operationally produce L2B products in Near Real Time
  - **Format:** either Earth Explorer or L2B WMO approved BUFR
  - Made available to public via ESA and EUMETCAST
  - Processor settings will be optimised for global NWP use
- Users can run their own L2B processor at their facility
  - L1B data will be provided in NRT via ESA
  - Why?
    - Try out own settings
    - Get involved in research to improve the wind products
    - Improvements can be fed back to L2B team (aeolus@ecmwf.int)

Aeolus L2B winds in the tropics (*simulation*)

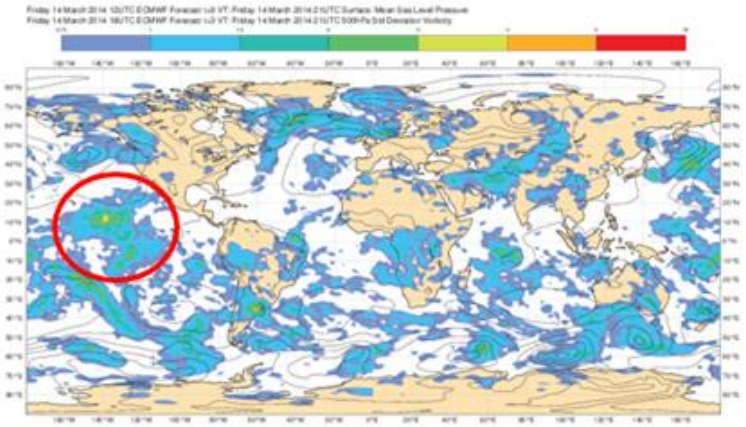
ECMWF

An interesting tropical scenario

200 hPa winds on the 15 March

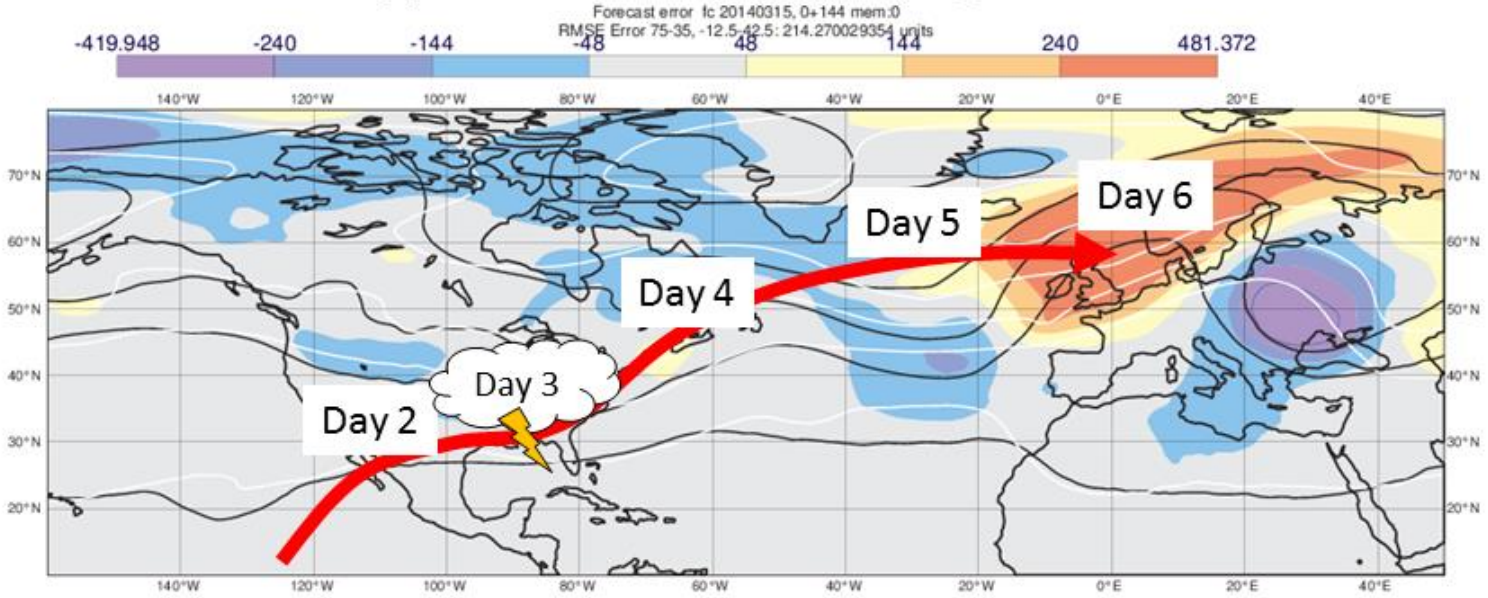


Vo500 EDA spread for 14 March 12z



Courtesy: Linus Magnusson

Approximated error propagation



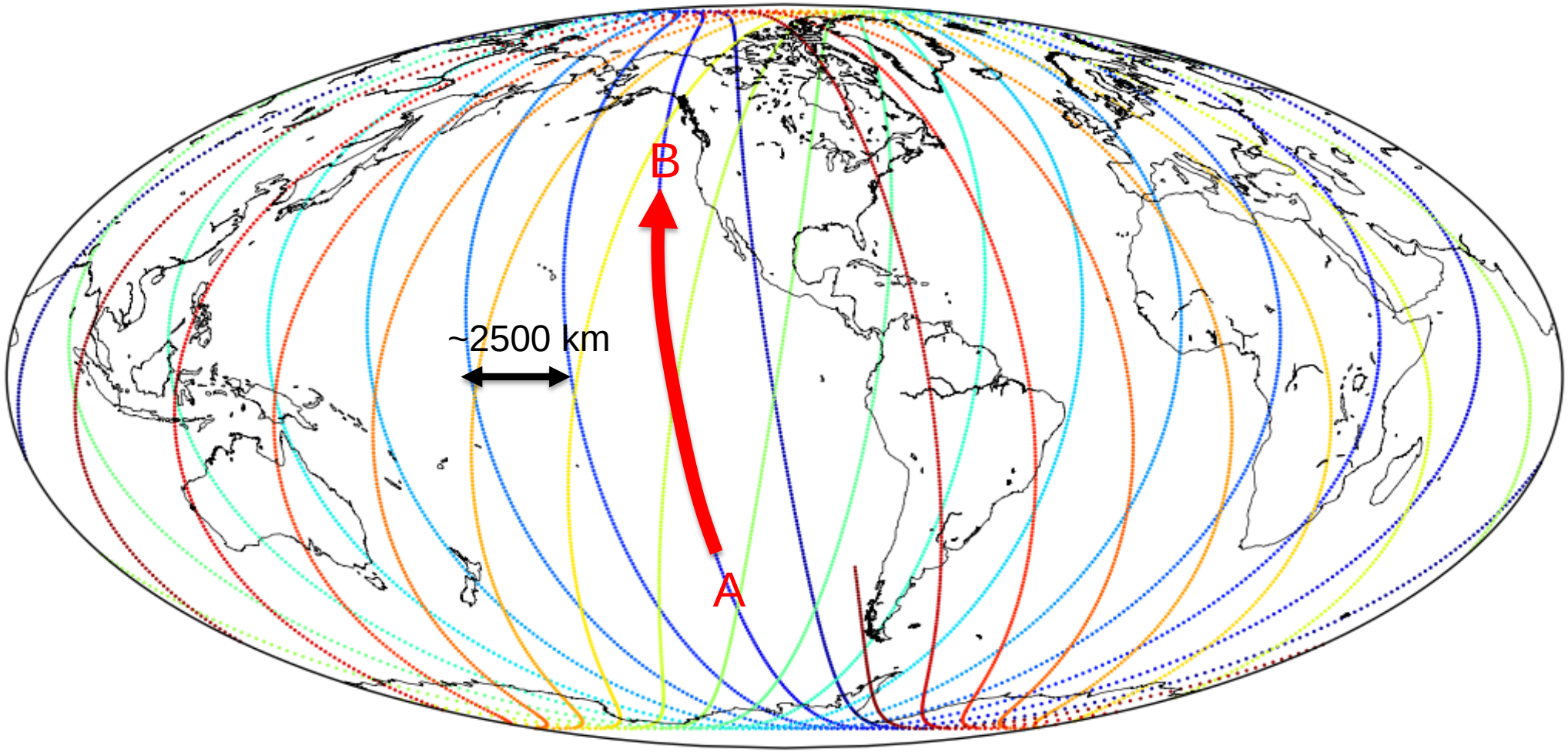
Major six day forecast bust over Europe in March 2014

Sensitive to initial conditions in east tropical Pacific;

- strong westerly winds in upper troposphere (“Pacific westerly duct”)
- Projects onto 1st Rossby mode + Kelvin wave

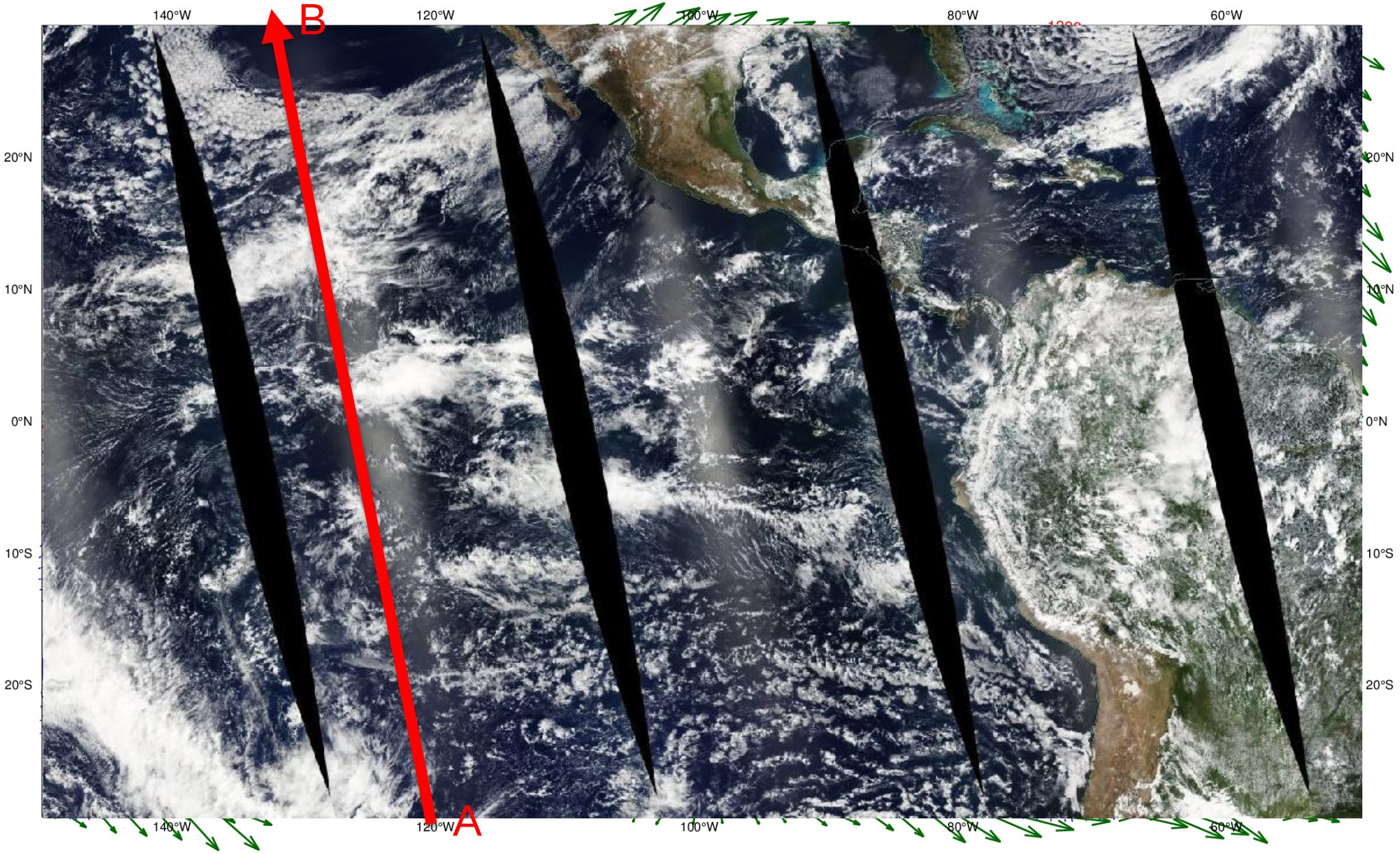
What would Aeolus observe in such a case?

Example global horizontal coverage of Aeolus in 24 hours

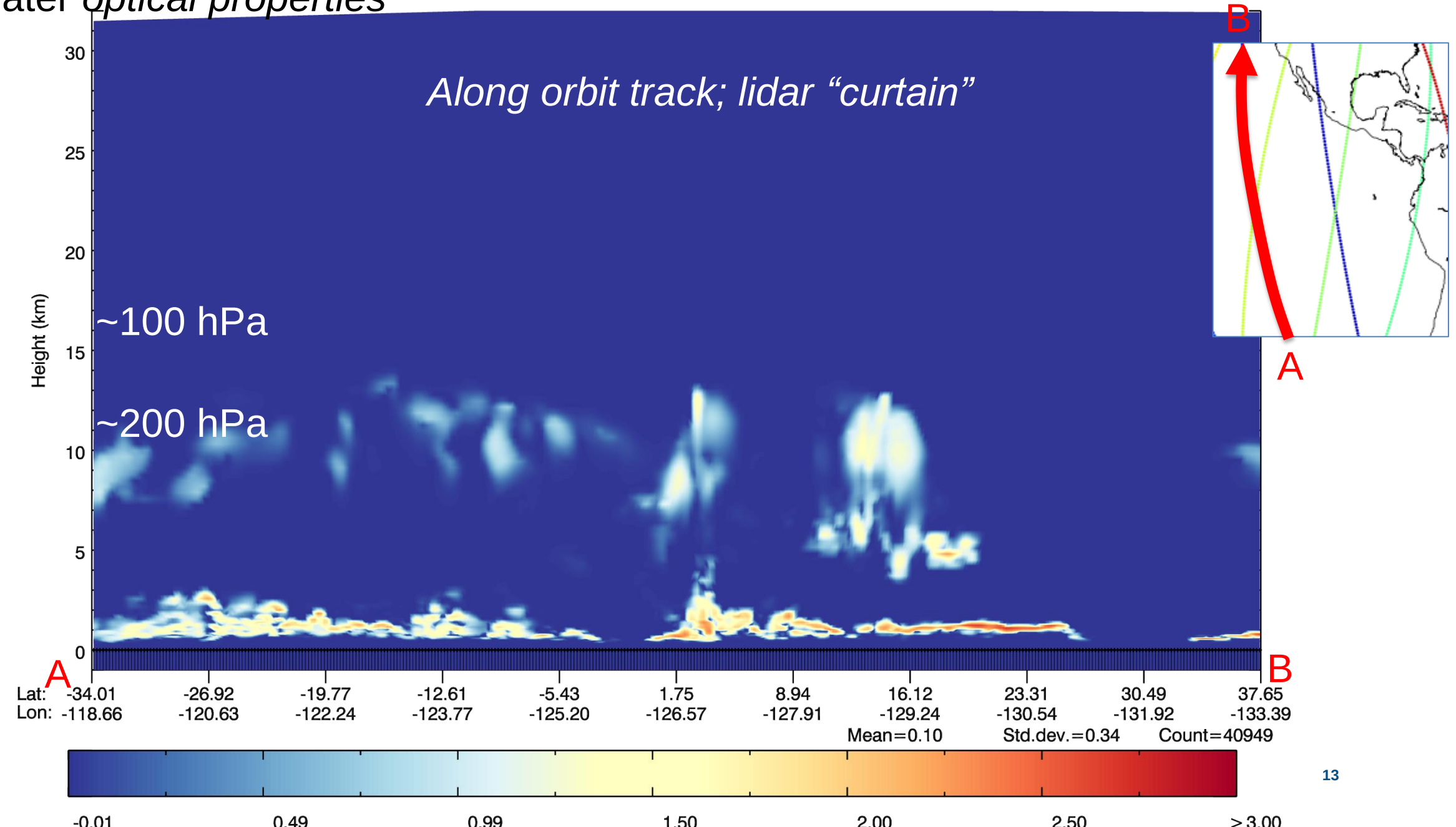


Simulate Aeolus using ECMWF short-range forecast fields from analysis prior to forecast bust

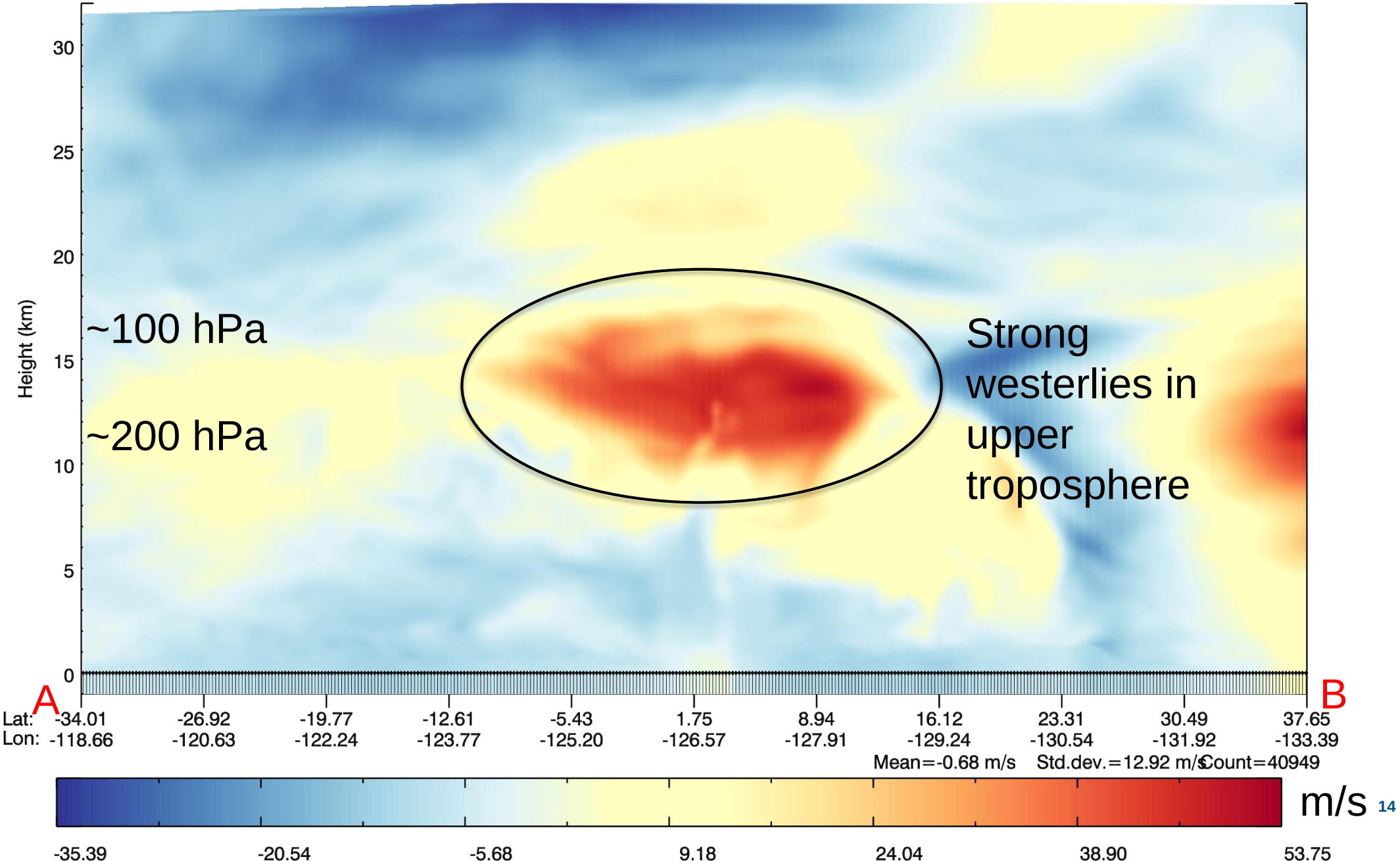
Aqua MODIS image ~21 UTC 2014/03/14



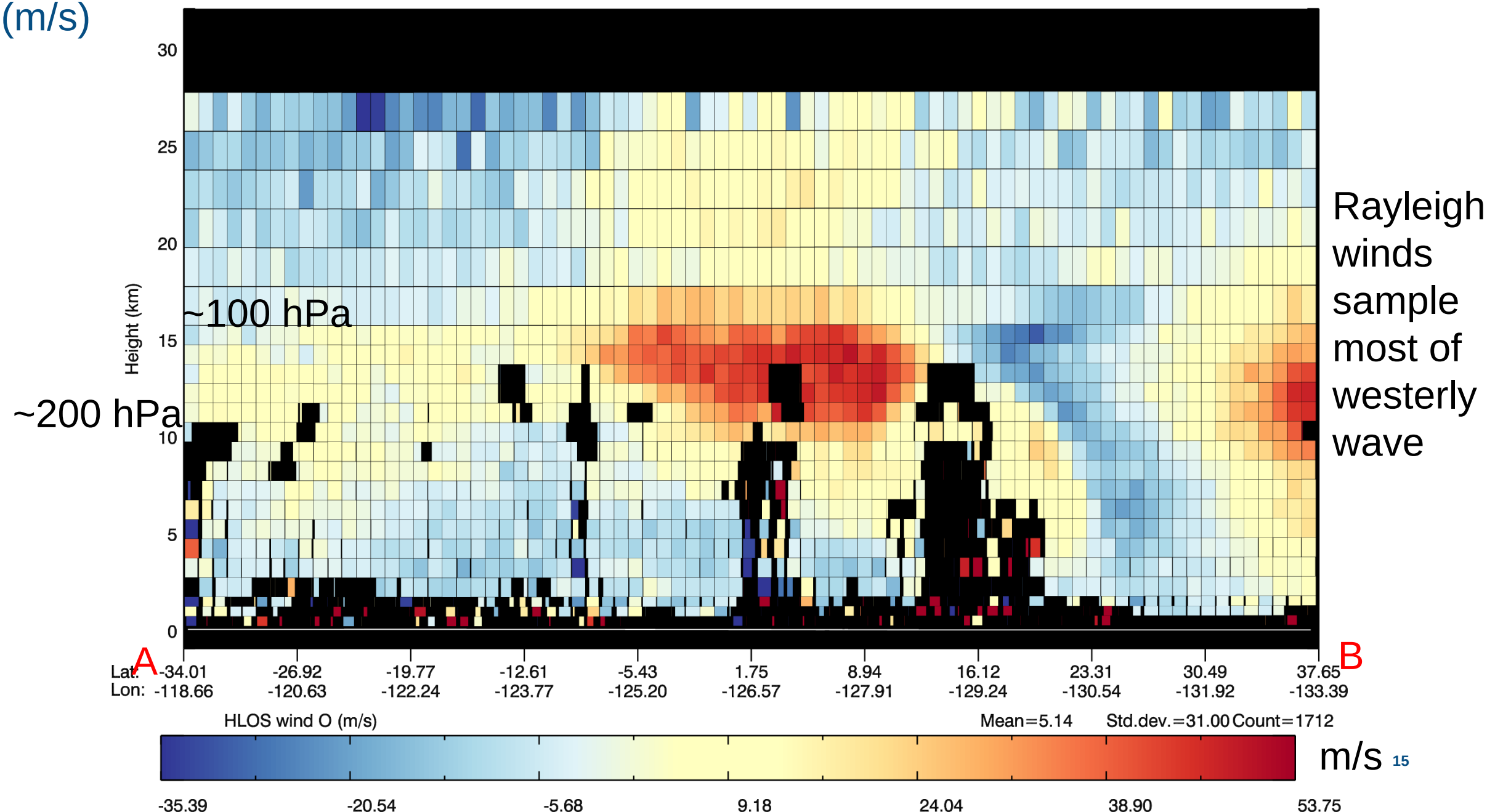
Aeolus simulator input: $\log_{10}(\text{scattering ratio}=1+\beta_p/\beta_m)$ i.e. related to cloud ice/water *optical properties*



Aeolus simulator input: HLOS wind (m/s) ~u-wind component

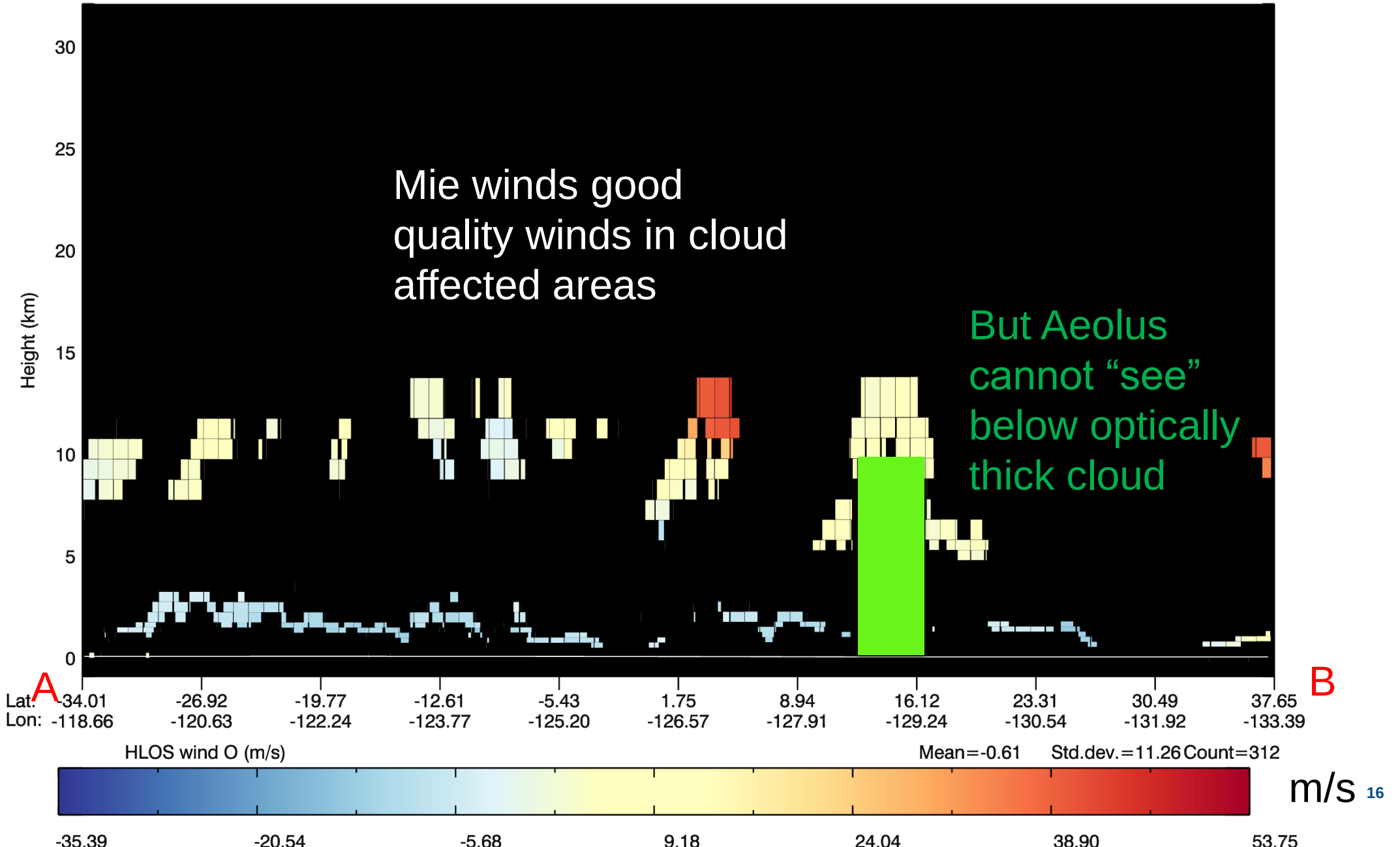


What Aeolus would observe; simulated observations: L2B Rayleigh HLOS wind (m/s)

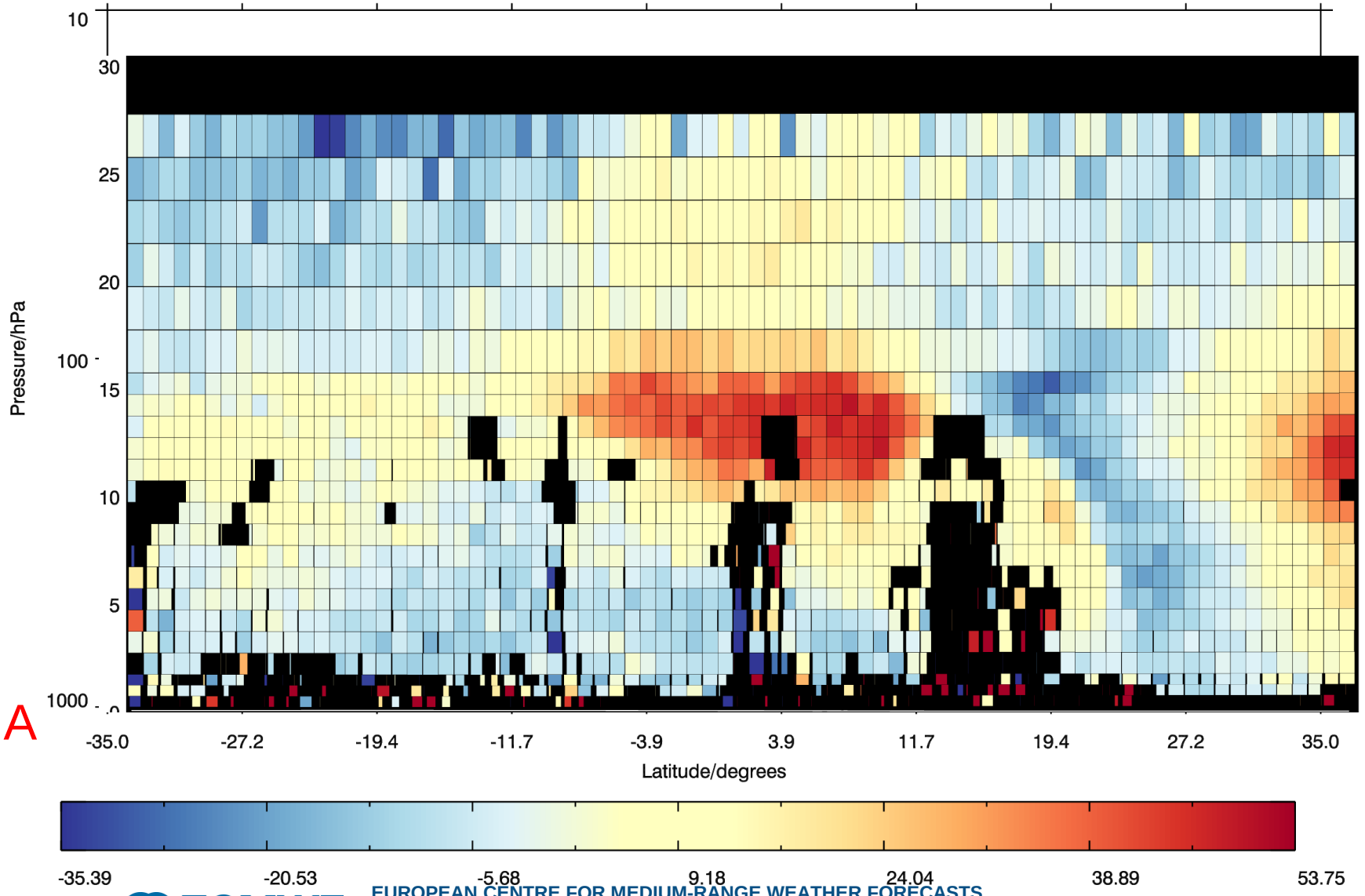


Rayleigh winds sample most of westerly wave

What Aeolus should observe; simulated observations: L2B Mie HLOS wind (m/s)



Wind observations **actively assimilated at ECWMF** in 00 UTC 15/3/2016 analysis – u wind (m/s) zonal average



A

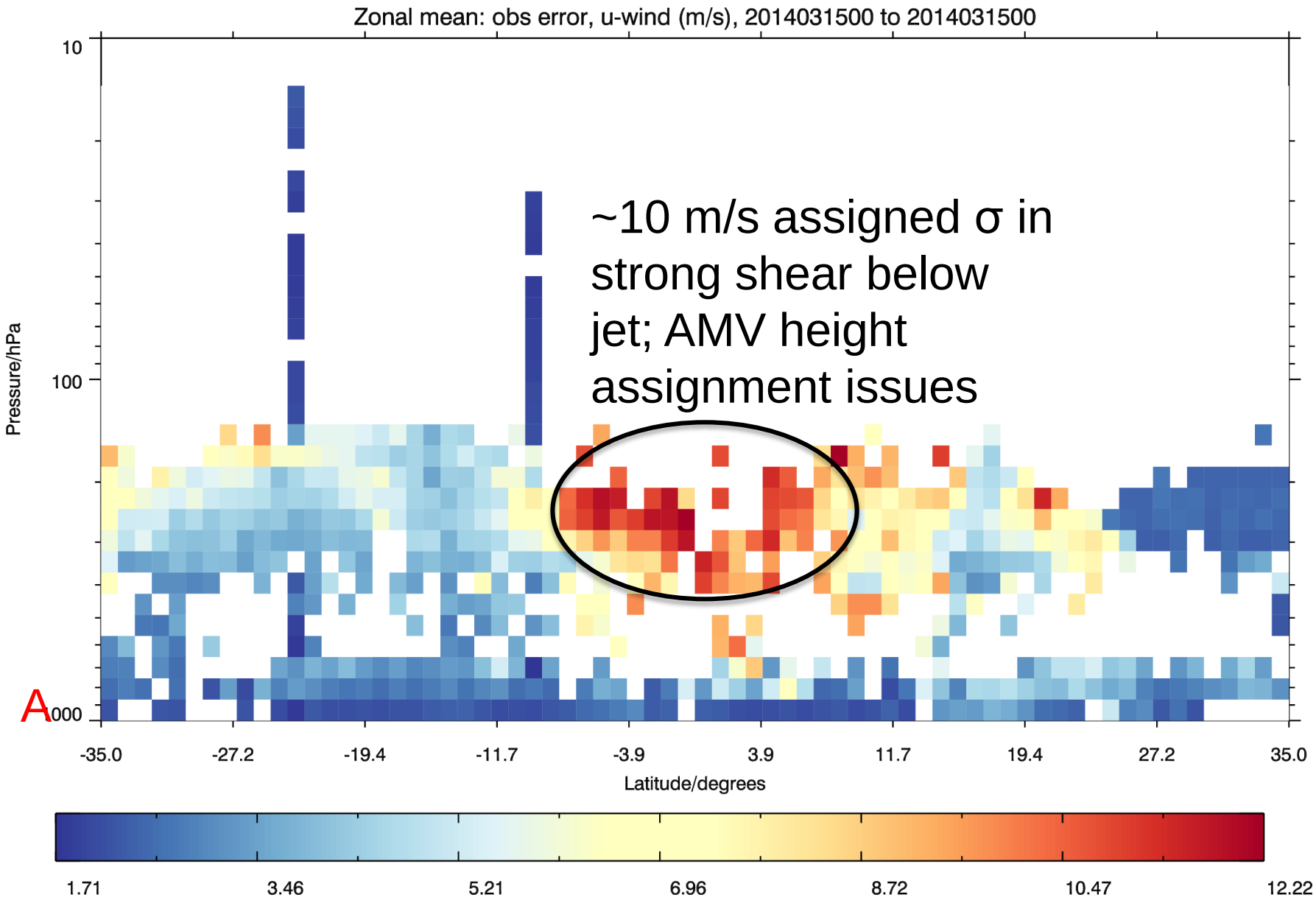
B

m/s

Real obs available in *140°W -120°W*, count ~**3700**
Mostly **AMVs**

Compare:
Aeolus Ray HLOS winds, count ~**2000**

u-wind assigned error of **actively assimilated** observations



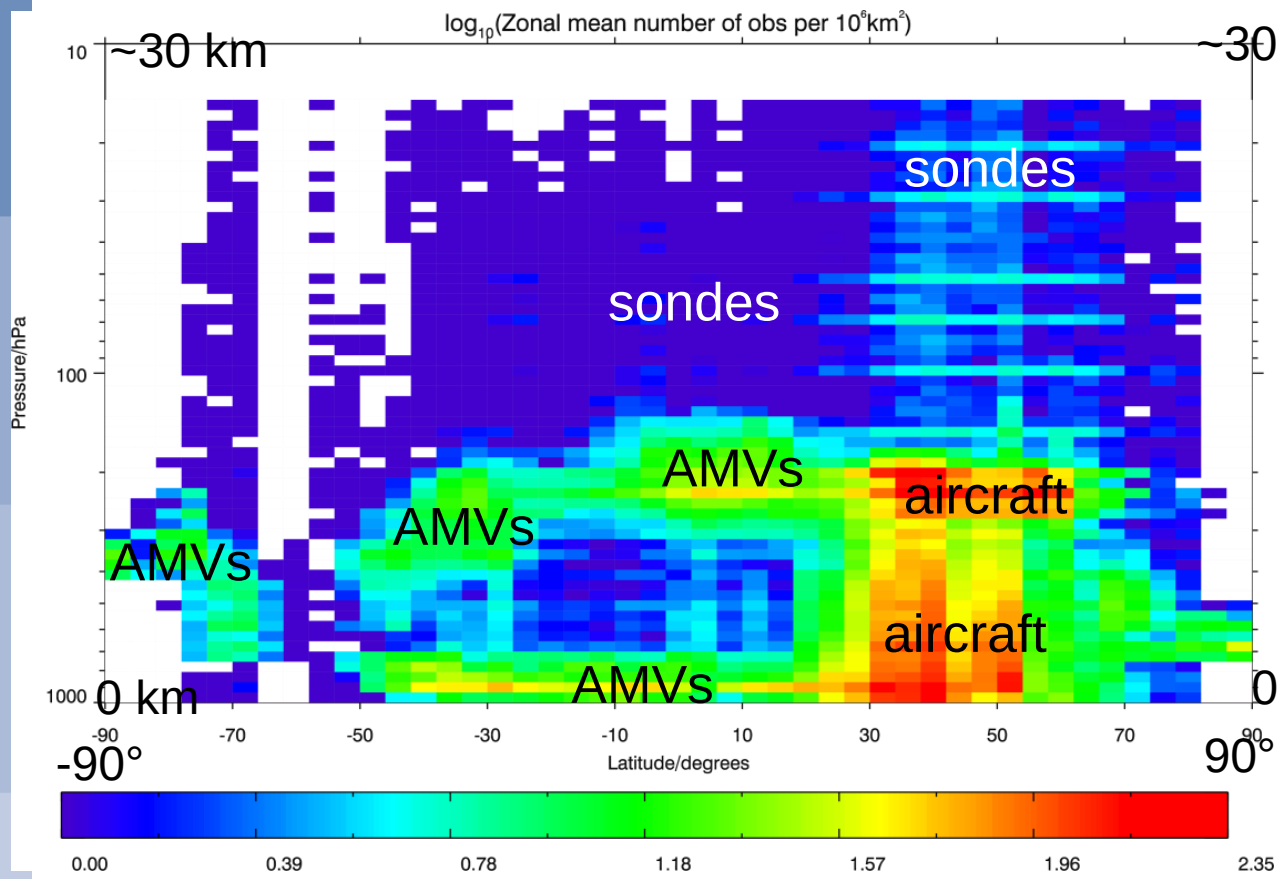
Compare Aeolus:

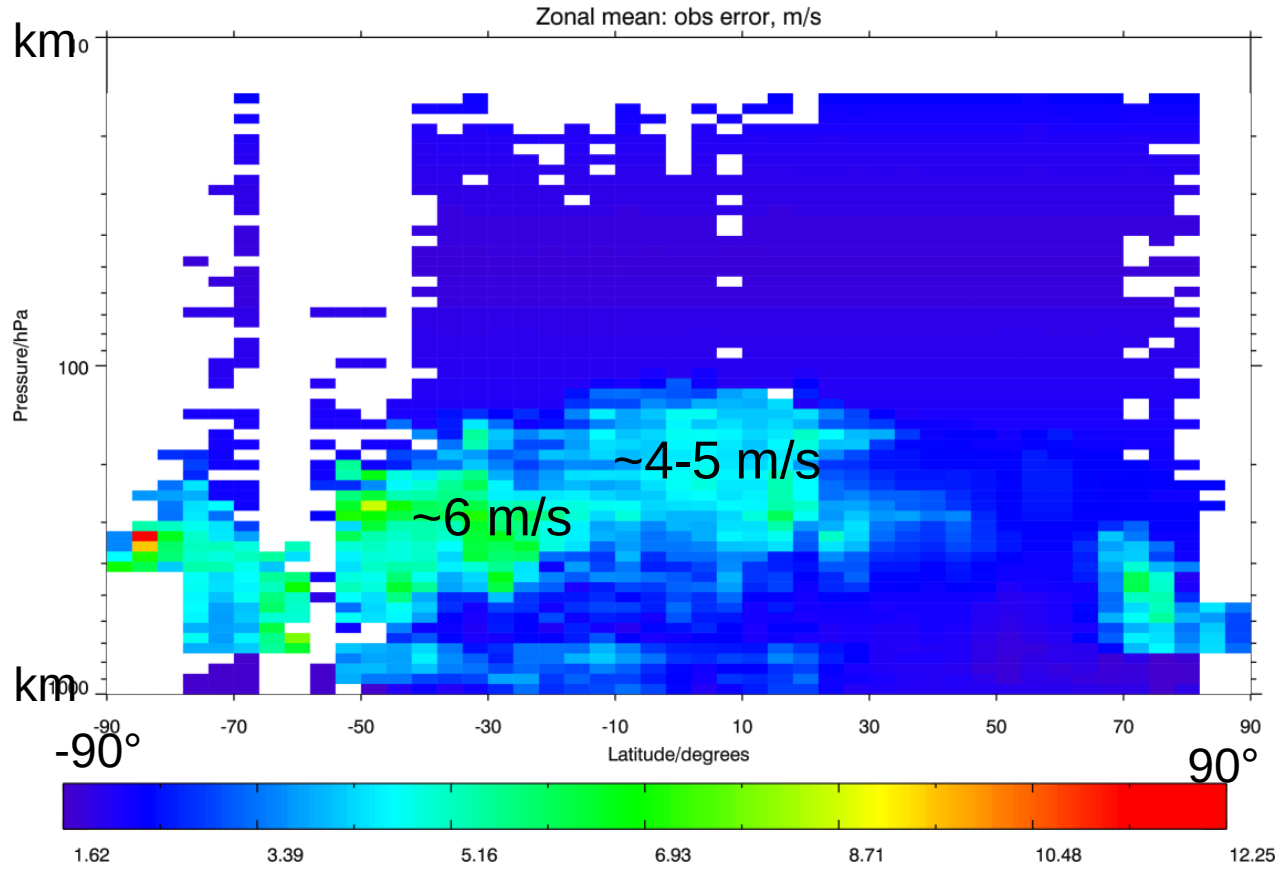
- Ray σ~3 m/s
- Mie σ~2 m/s

Global picture: ECMWF assimilated wind obs coverage and assigned errors

Zonal mean: $\log_{10}$(number of obs per area)

Zonal mean: assigned obs error (m/s)



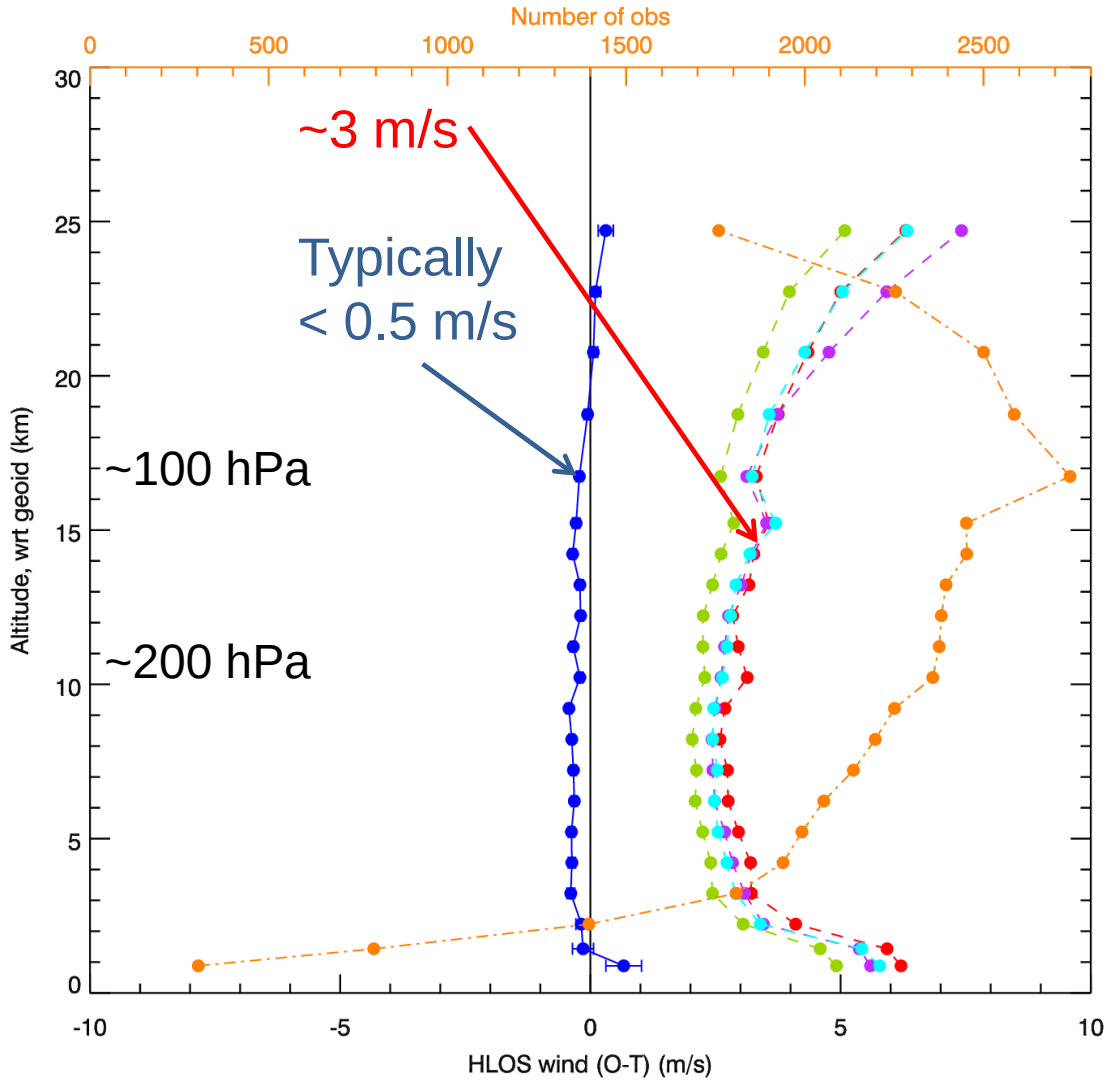


Aeolus wind errors are larger than conventional and scatterometer, but mostly smaller than AMVs

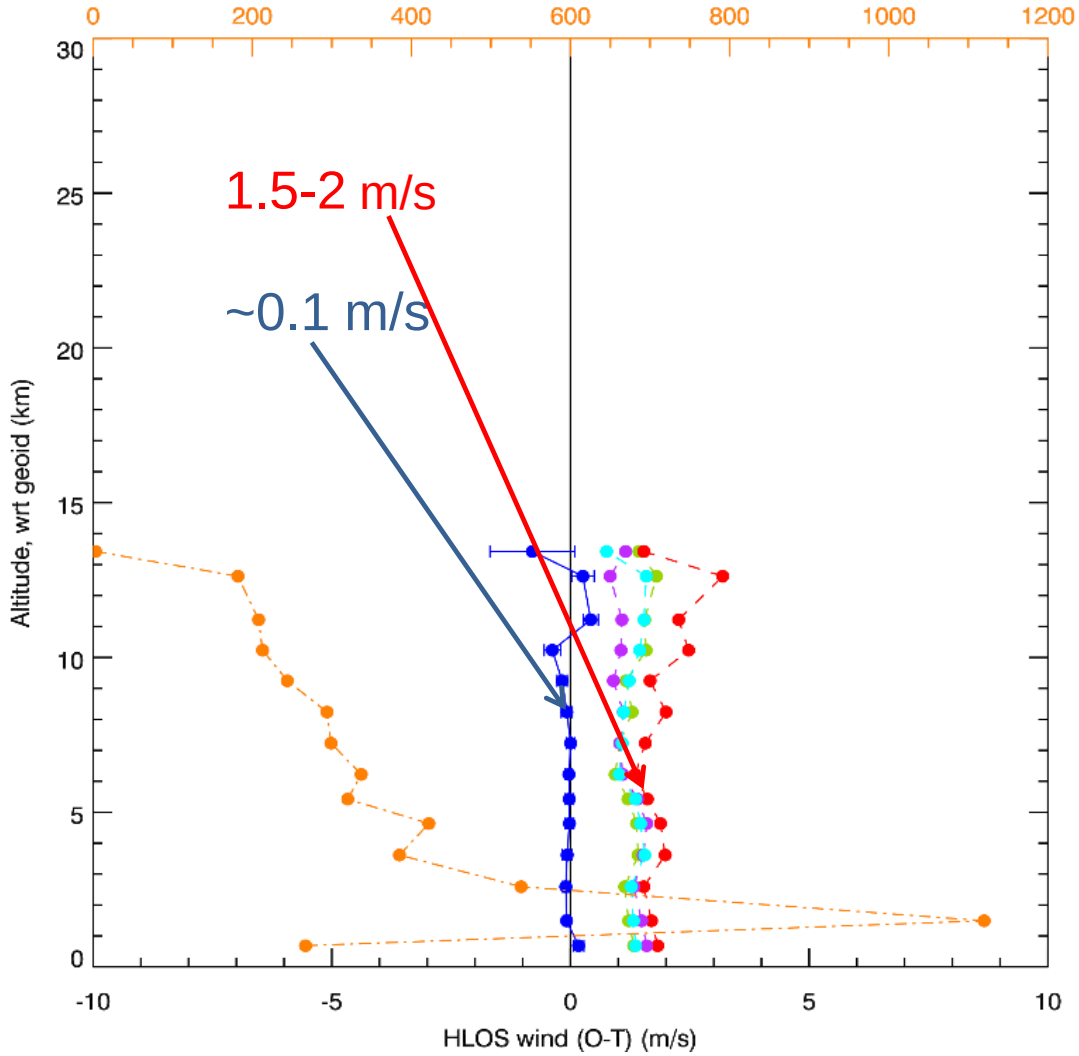
Global L2B HLOS wind error statistics. Simulator input: ECMWF TcO1279

St. dev.(error)
Mean(error)
Number of obs

Rayleigh-clear (typical solar conditions)



Mie-cloudy

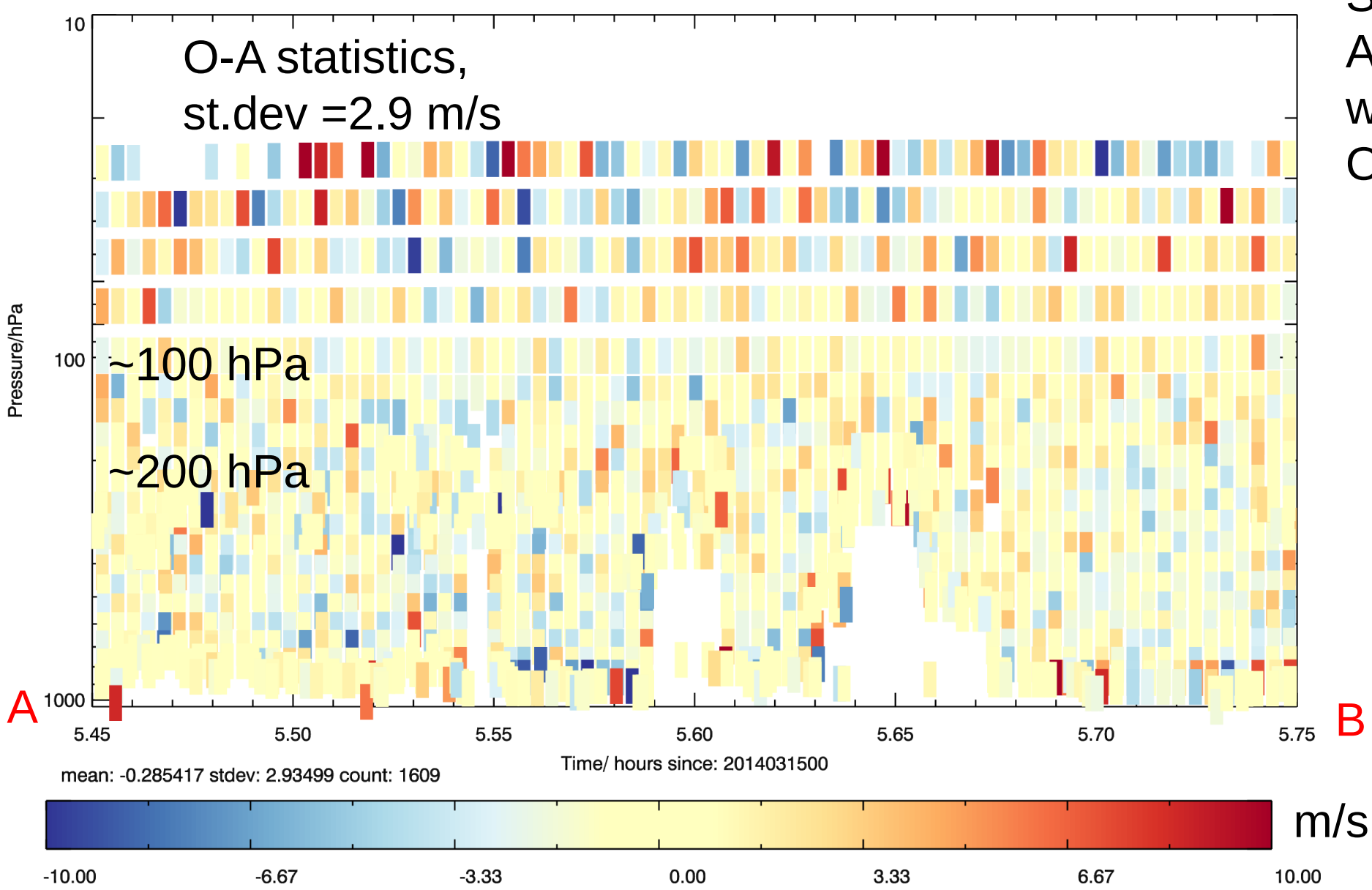


Example of Aeolus L2B HLOS wind assimilation in the tropics

Analysis increments from “simulated” Aeolus L2B winds **in the tropics**

- Use “simulated” L2B winds from forecast bust case shown earlier (March 2014)
  - simulated from full observing system background
- Assimilate L2B winds in “poor” observation system run:
  - using only conventional and GPSRO obs; cycled for a week prior to generate dynamically possible differences to “reality”
  - assimilate simulated L2B winds in “forecast” bust analysis cycle
- 4D-Var increments
  - an impression of possible Aeolus increments in the tropics
- N.B. Aeolus HLOS near equator is ~10 degrees off zonal
  - 85% zonal component, 15% meridional component

Example of assimilating “simulated” Aeolus L2B for the interesting tropical case (15th March 2014)

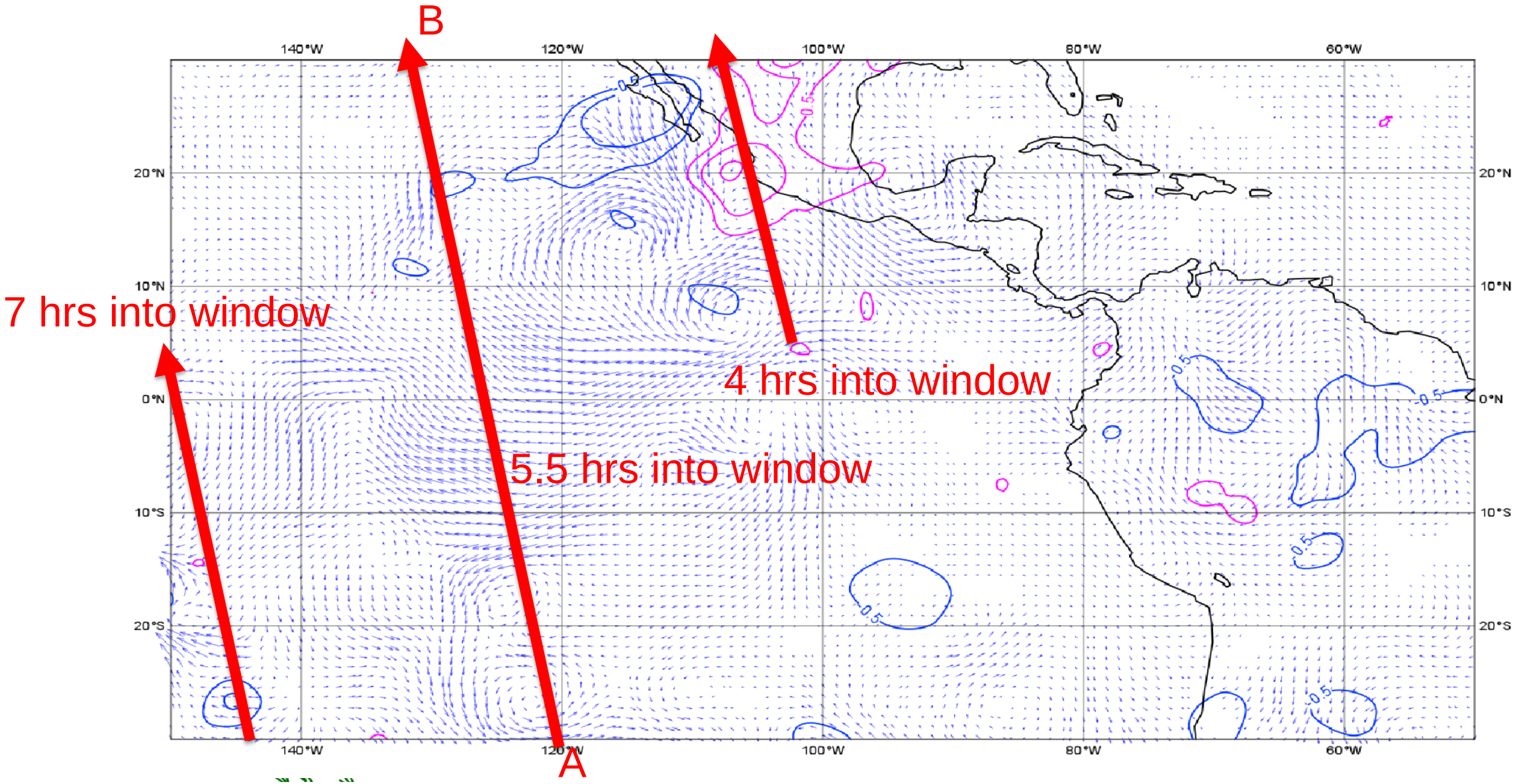


Simulated Aeolus HLOS winds from full OS forecast

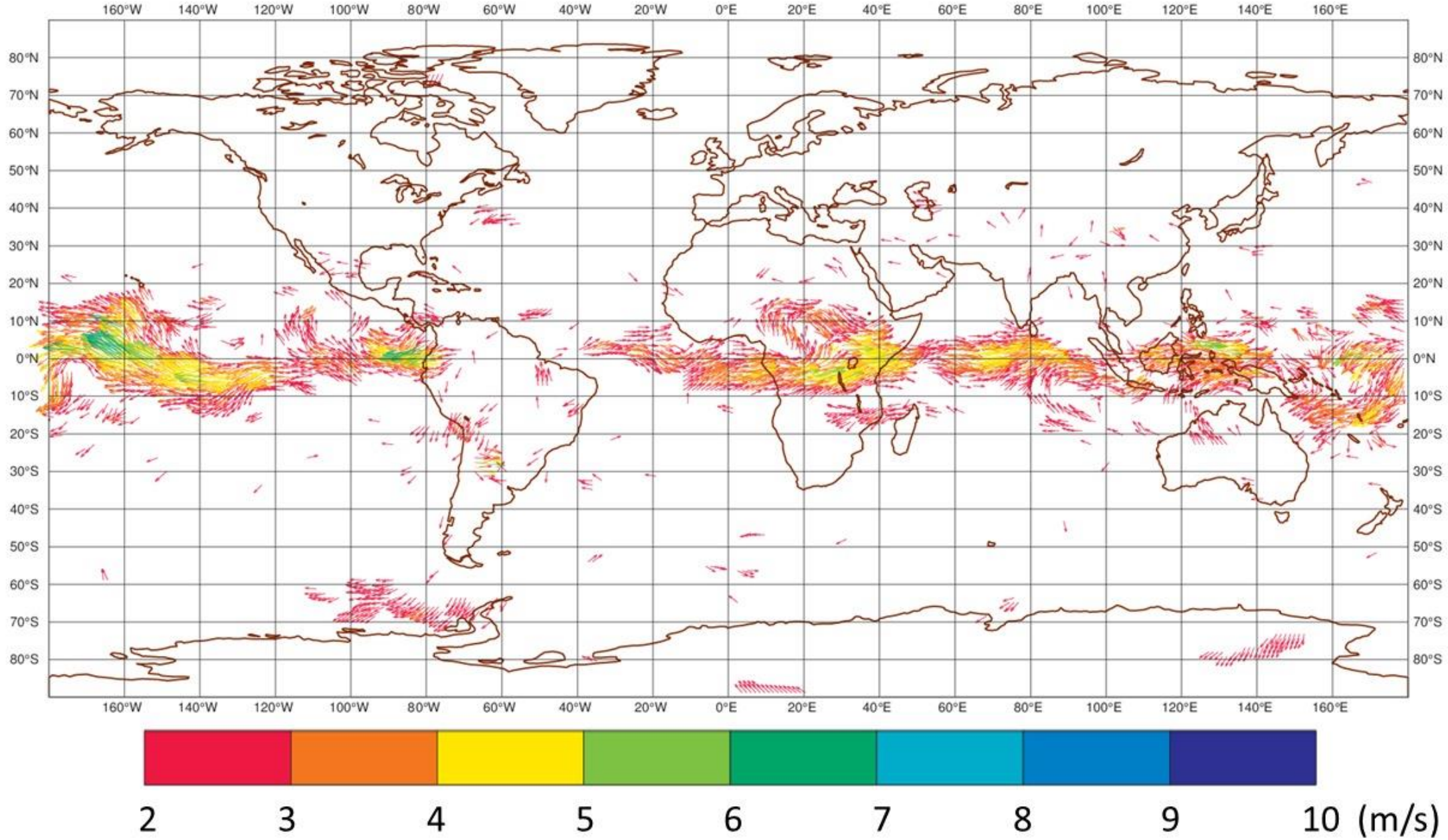
4D-Var increments at 200 hPa from simulated Aeolus (at start of 12 hour window)

Background wind field

Wind and temperature increments



100 hPa, mean(ECMWF analysis) - mean(Met Office analysis) from 1-7 May 2015



Summary

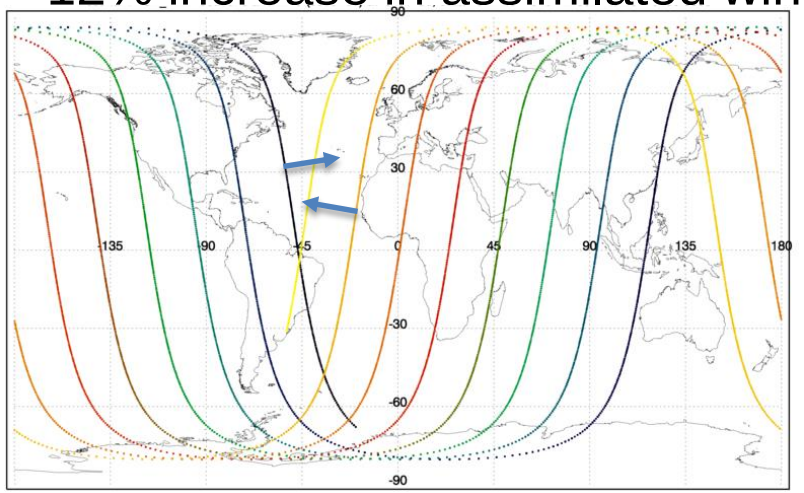
- ECMWF will operationally produce Aeolus Level-2B winds during the mission for ESA
  - Made available in NRT to the community
  - Main application: global NWP
- Aeolus winds will provide a significant boost in number of good quality wind obs in tropical UTLS
  - An area where global NWP wind analyses disagree most
- ECMWF intend to operationally assimilate Aeolus L2B winds as soon as possible after launch

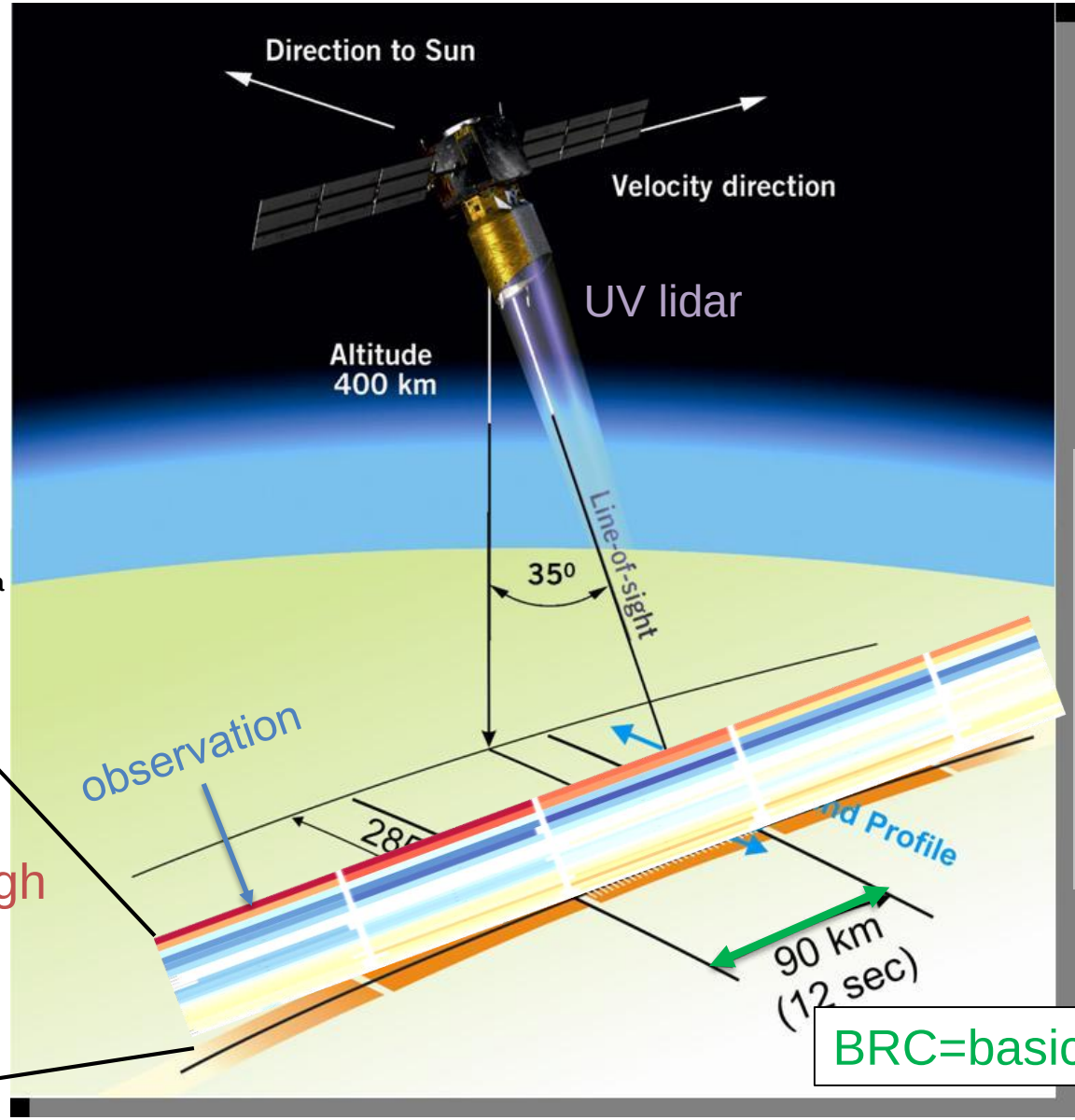
Any questions?

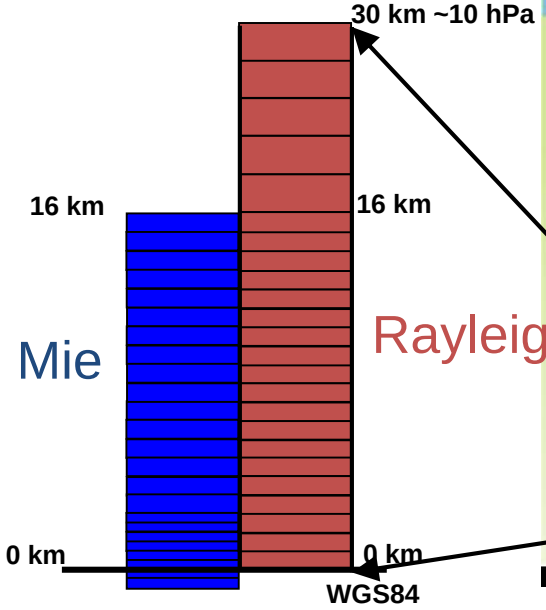
Spare slides

Aeolus wind observation sampling

12 hrs coverage; ~72K “good” winds;
~12% increase in assimilated wind obs







Example Aeolus vertical sampling (24 bins)

Mie

Rayleigh

With polar orbit, Line-Of-Sight provides mostly zonal component of horizontal wind

BRC=basic repeat cycle

ECMWF

Continuous coverage along-track

L2B processor

- Software developed over past decade by ECMWF, KNMI + for ESA
- Main steps in wind retrieval:
  - Input Screening of L1B data e.g. range checks
  - Match AUX_MET (*T*,*p*) data to measurements (used for Rayleigh T, p correction)
  - *Optional:* Optical properties
    - Estimates of measurement-level particulate backscatter/extinction; scattering ratio
  - Horizontal grouping of measurements
  - Classification (clear/cloud) of measurements
    - **Default:** using threshold on L1B scattering ratio
    - **Optional:** using threshold on L2B optical properties
  - Accumulation of measurement signals
  - Mie channel wind retrieval
  - Rayleigh channel wind retrieval (with Rayleigh-Brillouin correction)
  - Error quantifier estimation
- Additional tools: L2B EE to BUFR converter, various ASCII dump tools, etc.

ADM-Aeolus operational L2B (winds) processing at ECMWF

- ECMWF funded by ESA to operationally process and monitor L2B winds during mission
- L2B processing will run as part of operational observation pre-processing:

  Data driven: process each L1B product as it arrives from ESA's PDGS

  Hence ECMWF will perform **Near-Real-Time L2B processing**

Benefits:

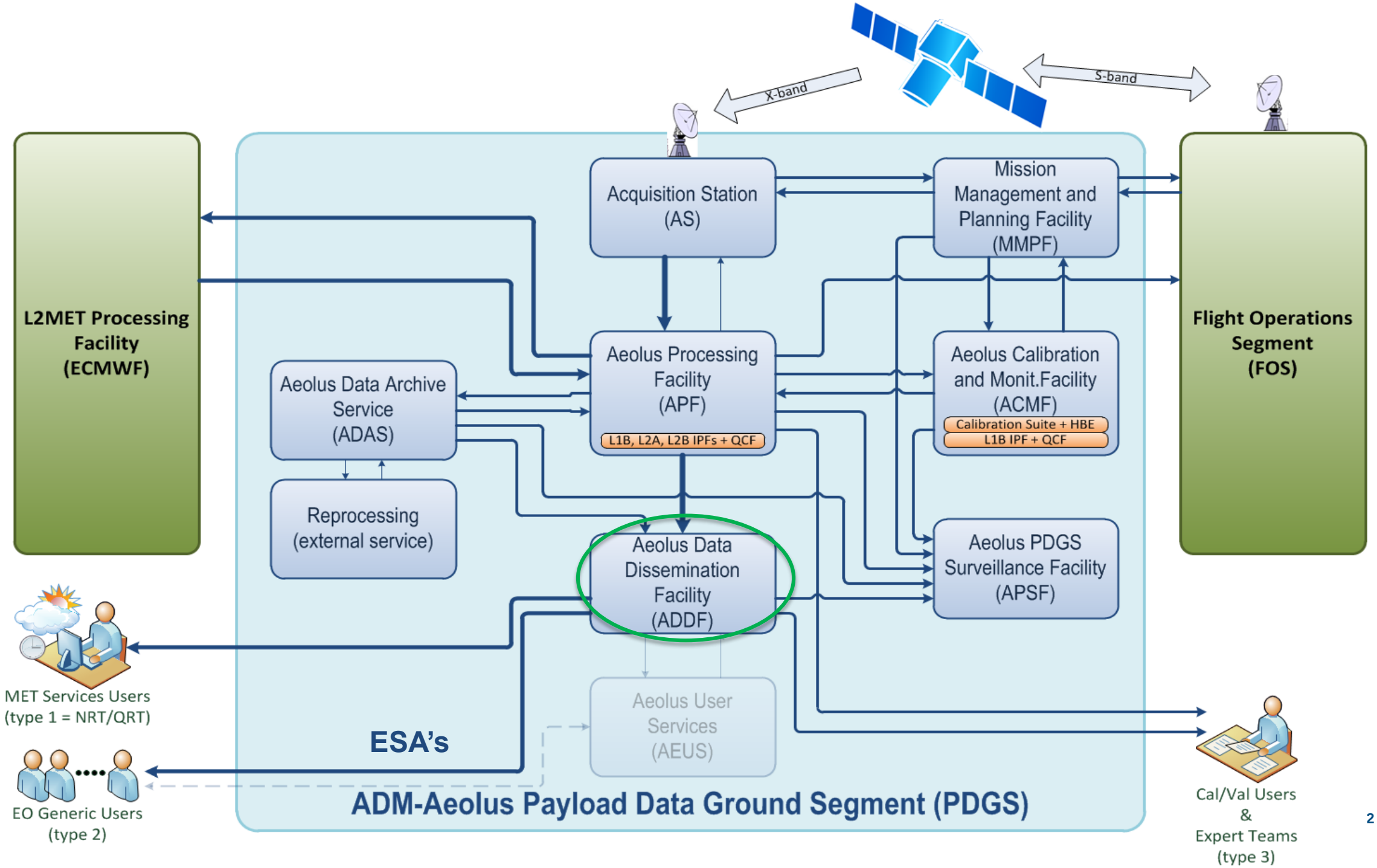
Reduced complication compared to having L2Bp as part of the data assimilation suite(s).

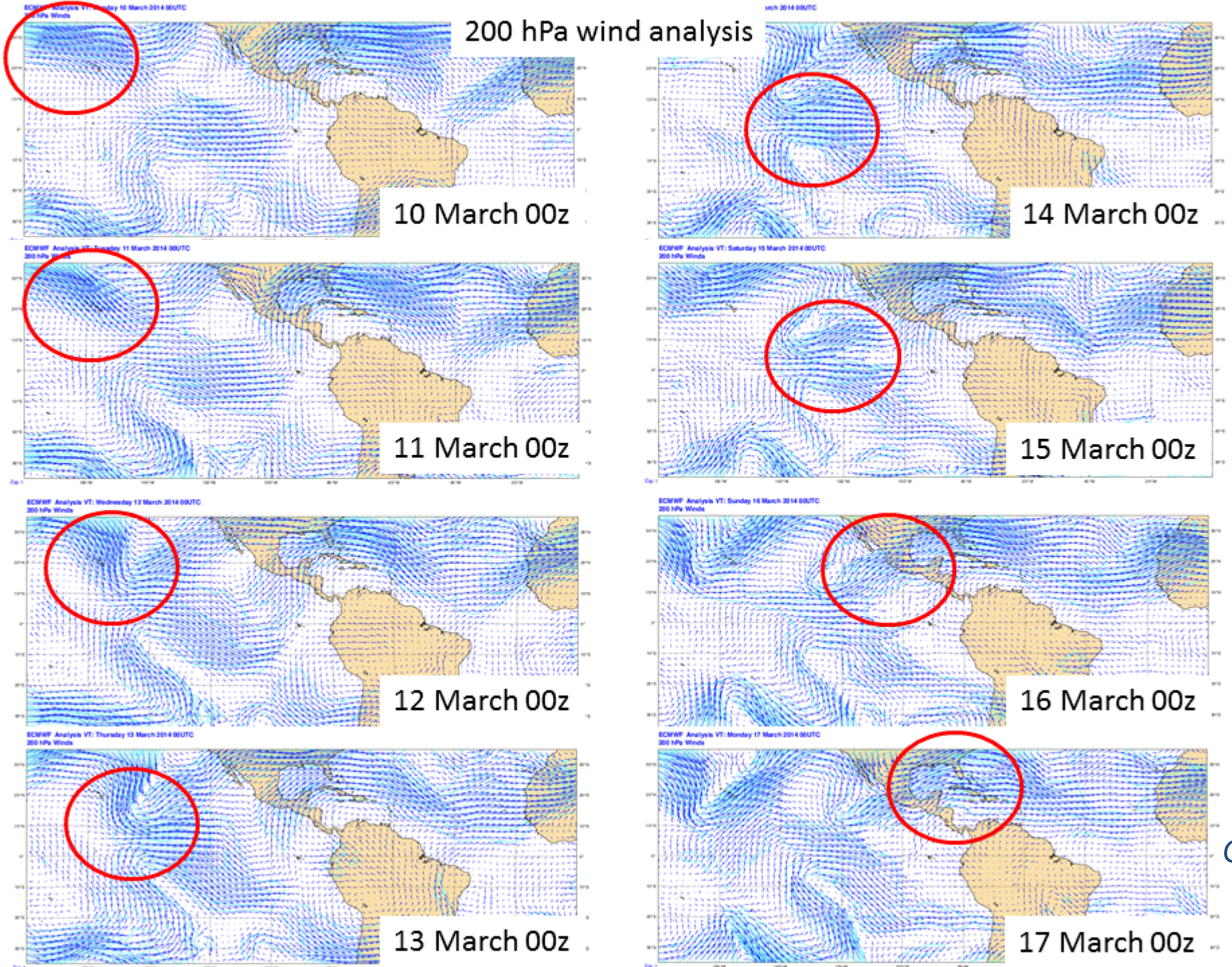
Will allow more Aeolus L2B data into early delivery data assimilation suite.

Member states and other users will have access to Aeolus L2B BUFR sooner.

- To achieve this, the forecast background used in the processing ("AUX_MET") will be based on our early delivery forecast (up to 19 h forecast) and predicted orbits.

ECMWF

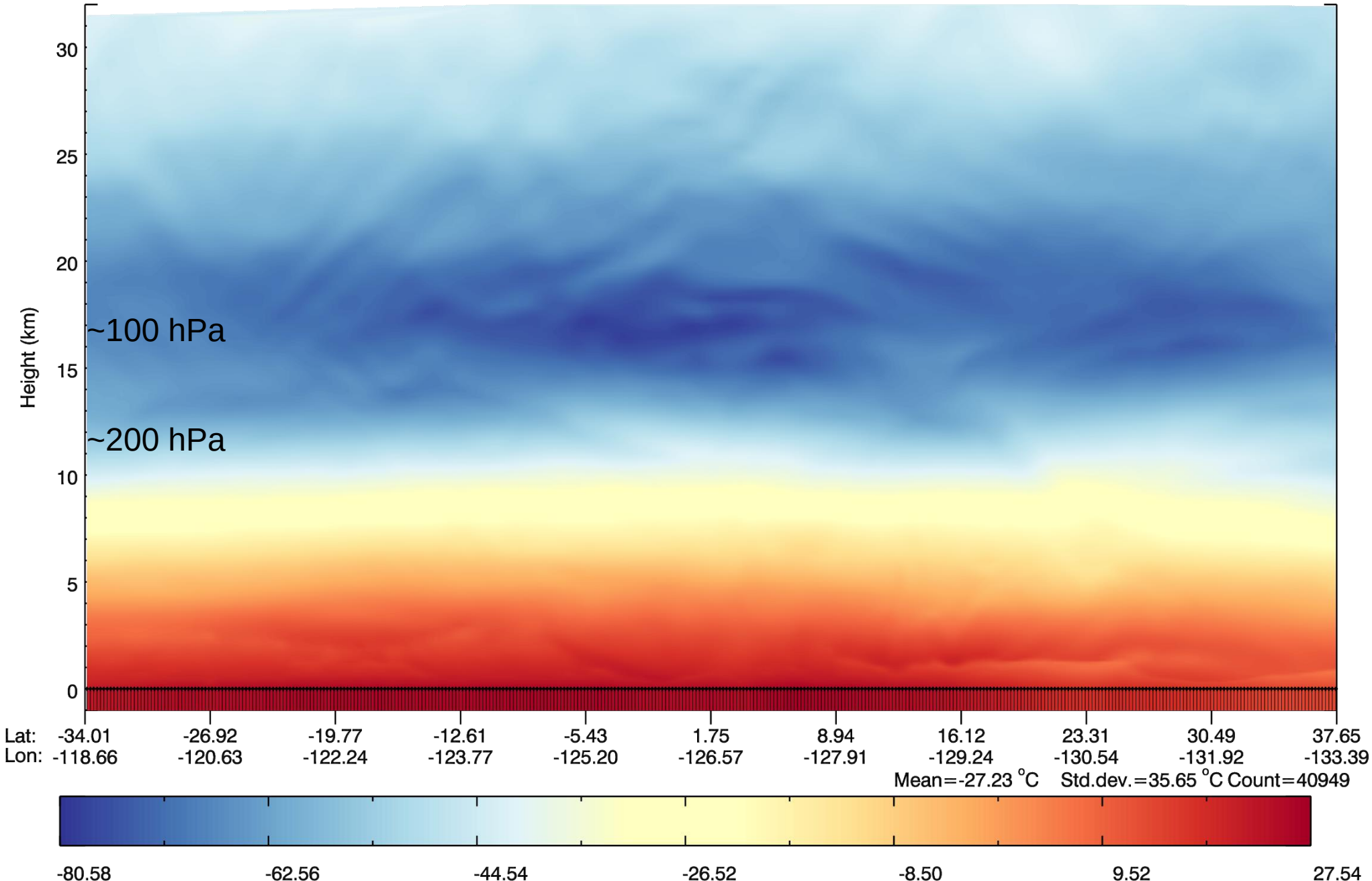

X-band
S-band
L2MET Processing Facility (ECMWF)
Acquisition Station (AS)
Mission Management and Planning Facility (MMPF)
Flight Operations Segment (FOS)
Aeolus Processing Facility (APF)
L1B, L2A, L2B IPFs + QCF
Aeolus Data Archive Service (ADAS)
Reprocessing (external service)
Aeolus Calibration and Monit.Facility (ACMF)
Calibration Suite + HBE
L1B IPF + QCF
Aeolus PDGS Surveillance Facility (APSF)
Aeolus Data Dissemination Facility (ADDF)
Aeolus User Services (AEUS)
ESA's
ADM-Aeolus Payload Data Ground Segment (PDGS)
MET Services Users (type 1 = NRT/QRT)
EO Generic Users (type 2)
Cal/Val Users & Expert Teams (type 3)



Strong winds in tropical upper troposphere – emanating from extratropical disturbance

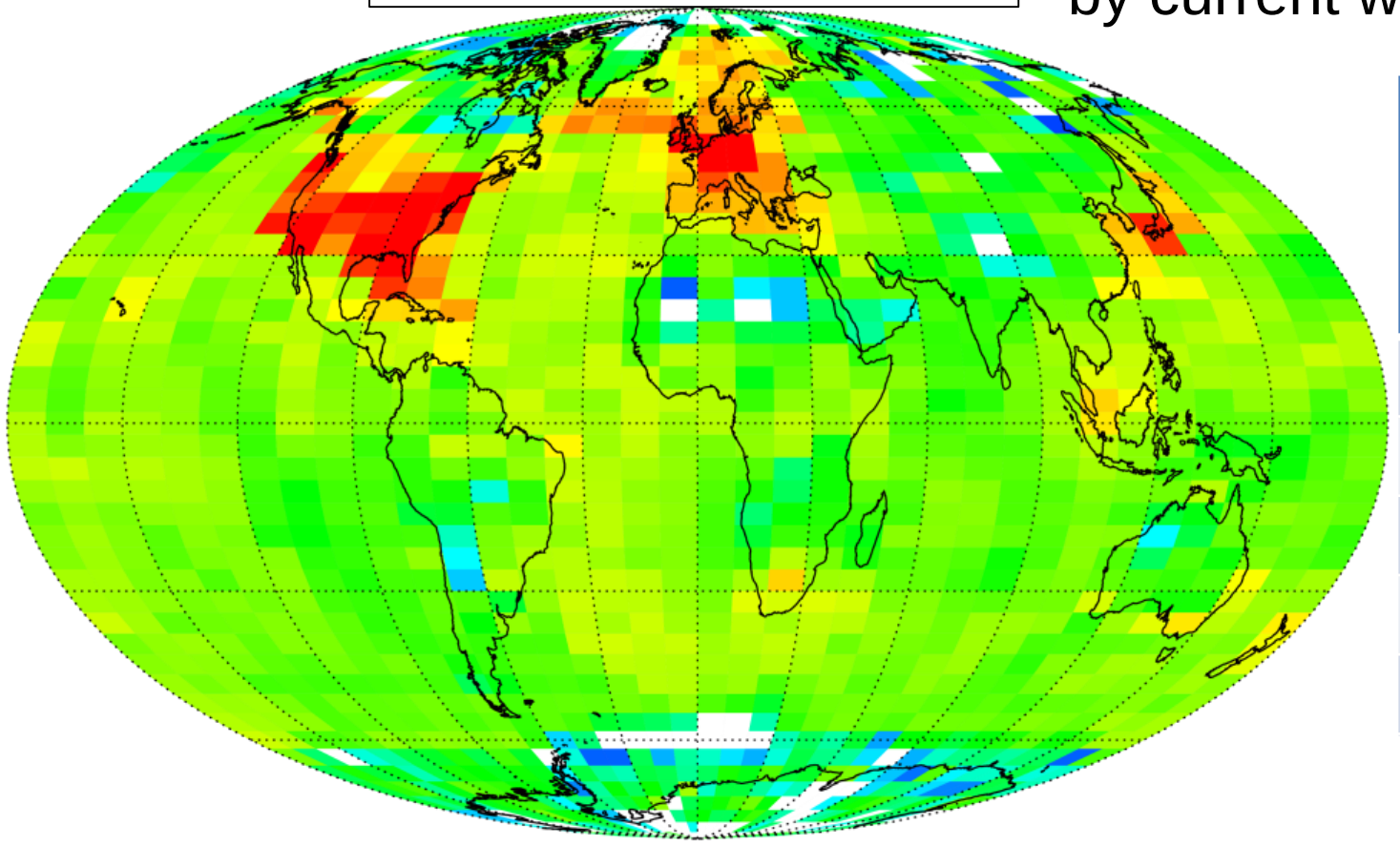
Courtesy: Linus Magnusson

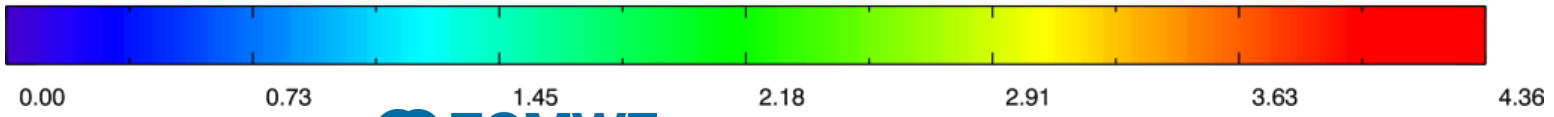
Aeolus simulator input: temperature (°C)



Global observed wind distribution in a recent ECMWF cycle

$\log_{10}$(number obs/area)

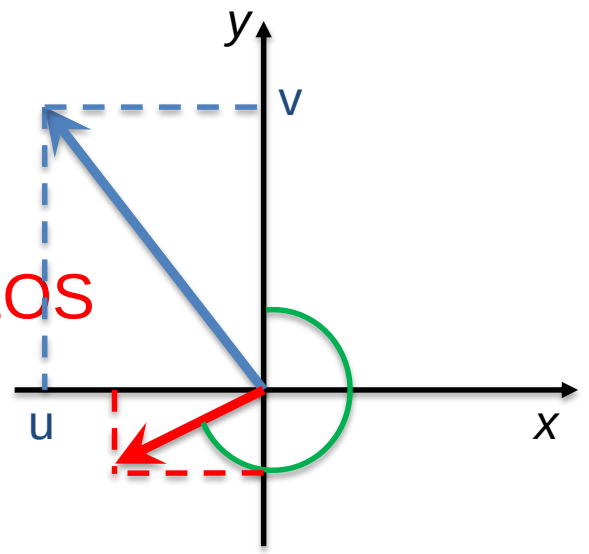




Generally tropics relatively poorly sampled by current wind OS

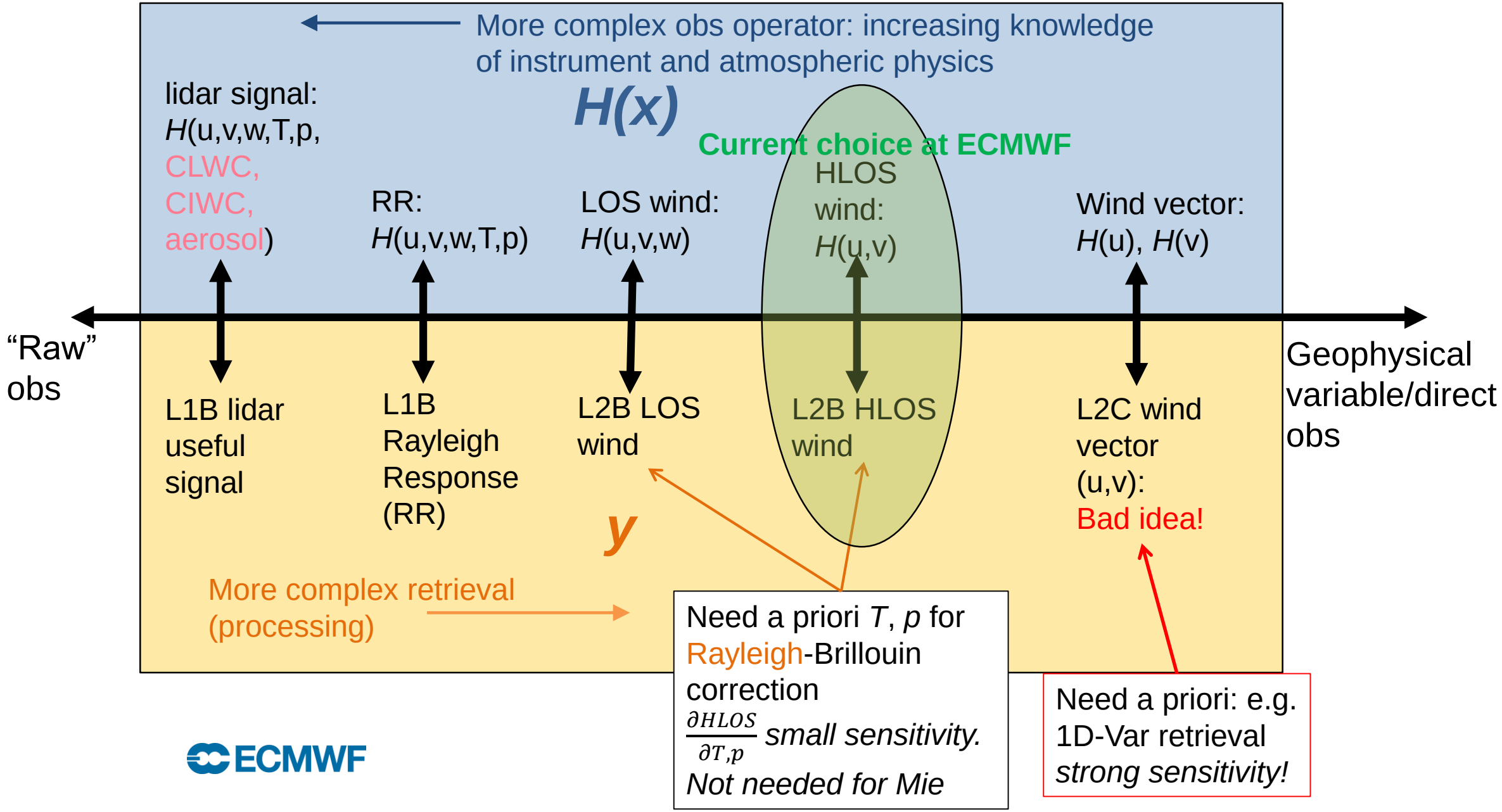
Obs type	% of total count	Mean assigned u-wind error (m/s)
AMVs	47	4.6
Scatterometer	23	1.5
Radiosondes	11	2.0
Wind profilers	10	1.8
Aircraft	9	2.4

L2B **HLOS wind** assimilation at ECMWF



- Observation operator: HLOS wind operator (*point-wind version)*
  - Interpolation of model wind to obs geolocation **point**
  - HLOS wind = Dot product of model wind vector with laser HLOS unit vector (azimuth angle)
- Weaknesses:
  - Assume point obs rather true spatial average
    - OK if model effective resolution is 4-8 times the grid (~36-72 km horizontally)
  - Ignore vertical wind component *w (diagnostic variable in IFS)*
  - L2B Rayleigh wind retrieval uses *a priori* knowledge of *T, p* (a small correlation of observation error with background error)
    - but can be accounted for in obs operator
  - **R** will be based on L2B standard error estimates + extra terms/inflation if necessary

Choosing the Aeolus product level to assimilate at ECMWF



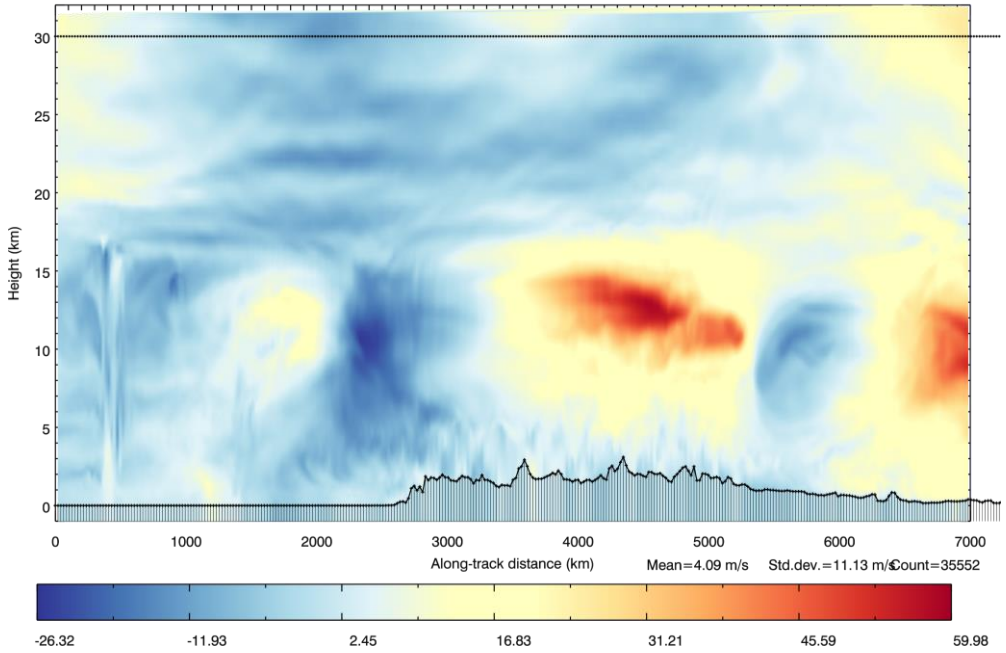
ECMWF

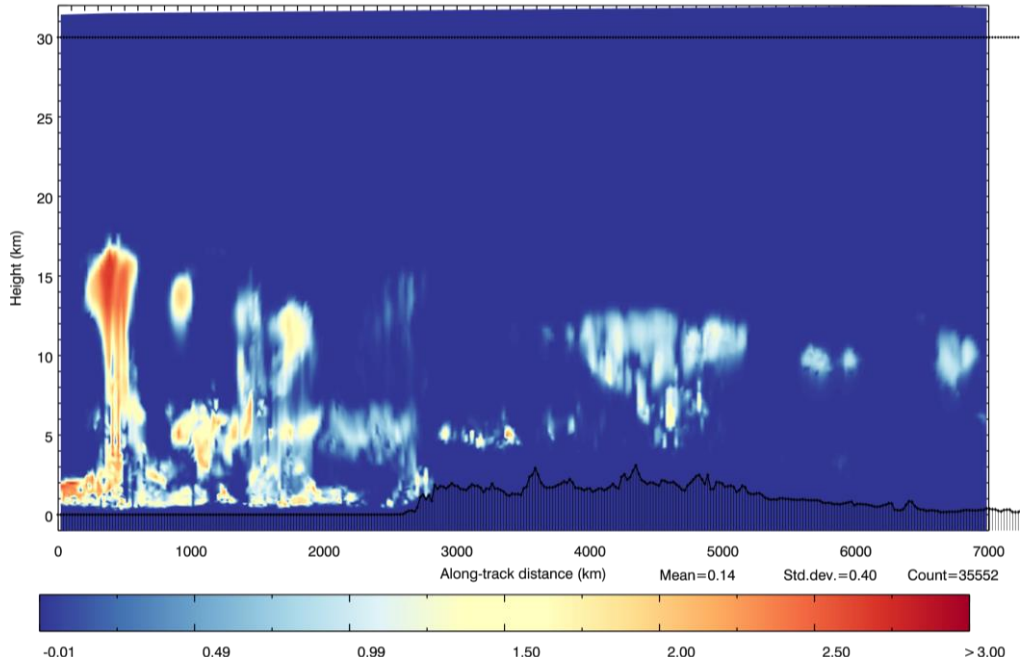
Assessing appropriate averaging length scale

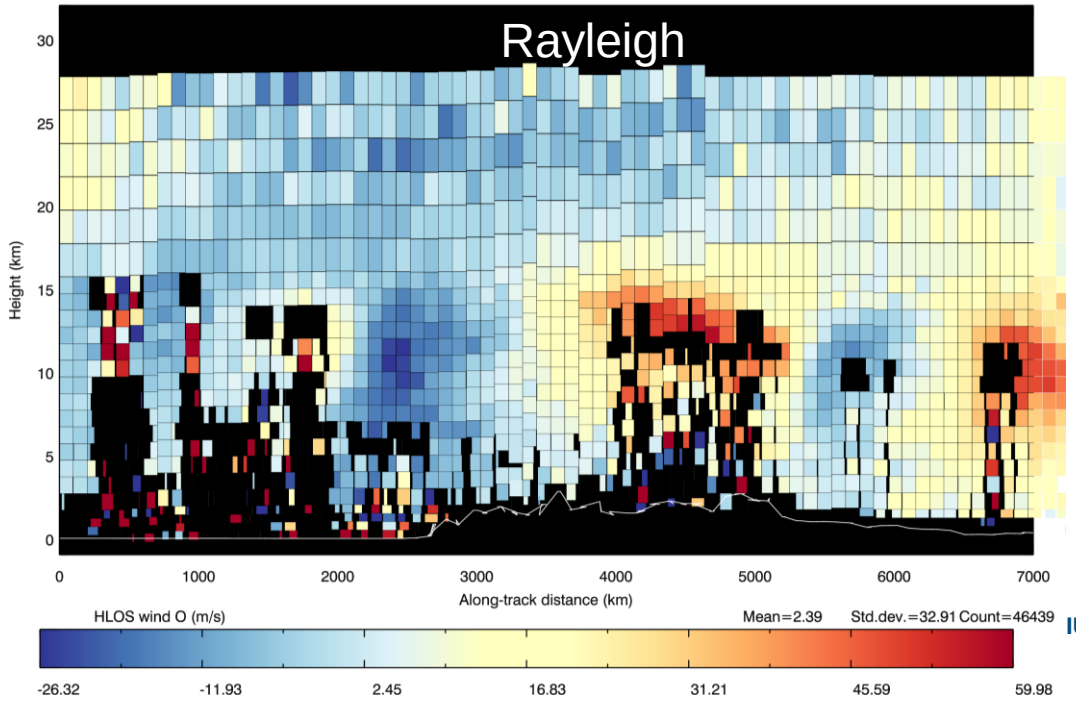
- Investigate **horizontal** averaging lengths in the L2B processor
  - see how the (L2B wind – “true” wind) errors vary
  - truth wind defined as point wind from model

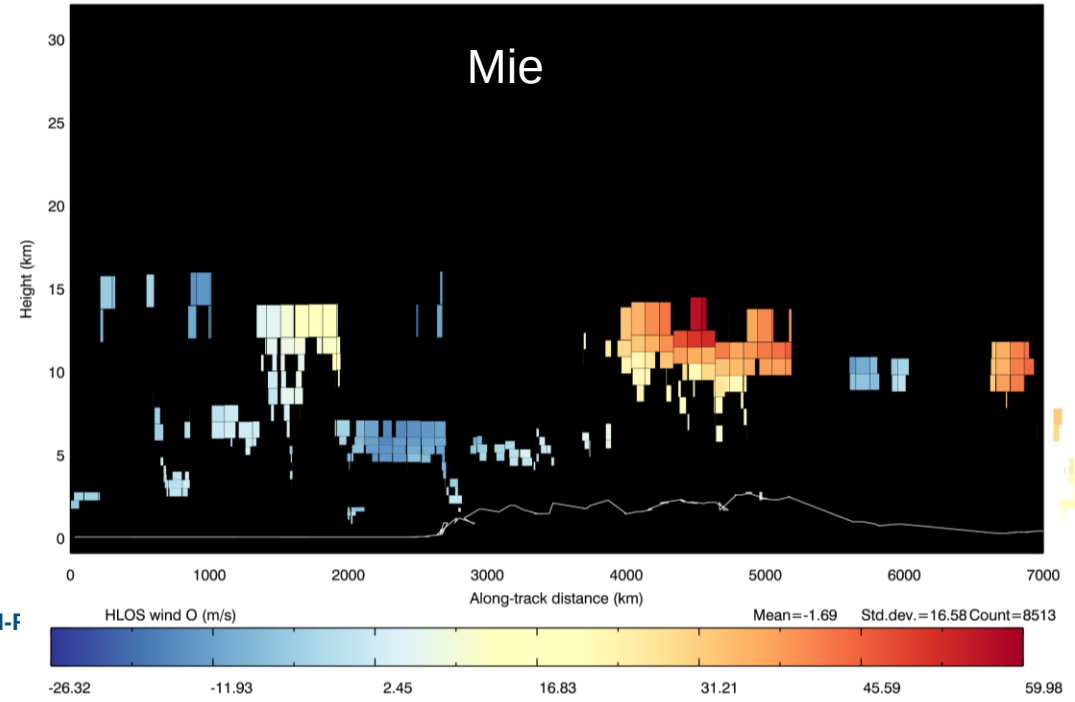
- **Test scenario:**

ECMWF TcO1279 (~9 km grid) as input “truth” meteorological data i.e. HLOS, T, p, ice/water clouds


Height (km)
Along-track distance (km)
Mean=4.09 m/s
Std.dev.=11.13 m/s
Count=35552
-26.32
-11.93
2.45
16.83
31.21
45.59
59.98


Height (km)
Along-track distance (km)
Mean=0.14
Std.dev.=0.40
Count=35552
-0.01
0.49
0.99
1.50
2.00
2.50
>3.00


Rayleigh
Height (km)
Along-track distance (km)
HLOS wind O (m/s)
Mean=2.39
Std.dev.=32.91
Count=46439
-26.32
-11.93
2.45
16.83
31.21
45.59
59.98


Mie
Height (km)
Along-track distance (km)
HLOS wind O (m/s)
Mean=-1.69
Std.dev.=16.58
Count=8513
-26.32
-11.93
2.45
16.83
31.21
45.59
59.98