Prospects for wind lidar assimilation

by Michael Rennie, ECMWF

ECMWF seminar: Use of satellite observations in NWP

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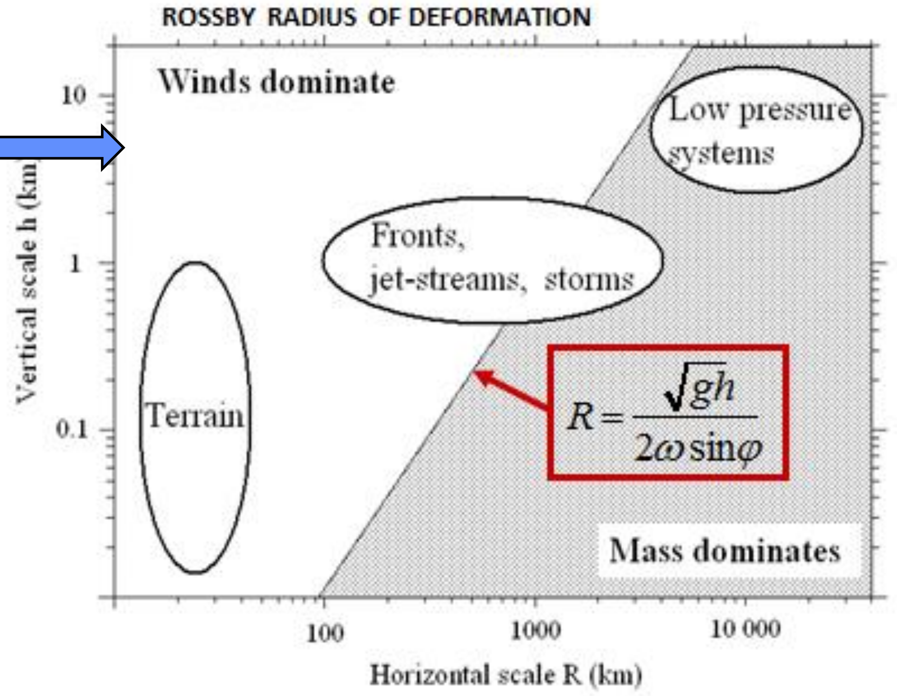
Outline

1. Importance of wind for NWP
2. Doppler wind lidar
3. The Aeolus DWL mission
4. Expectations for Aeolus NWP impact

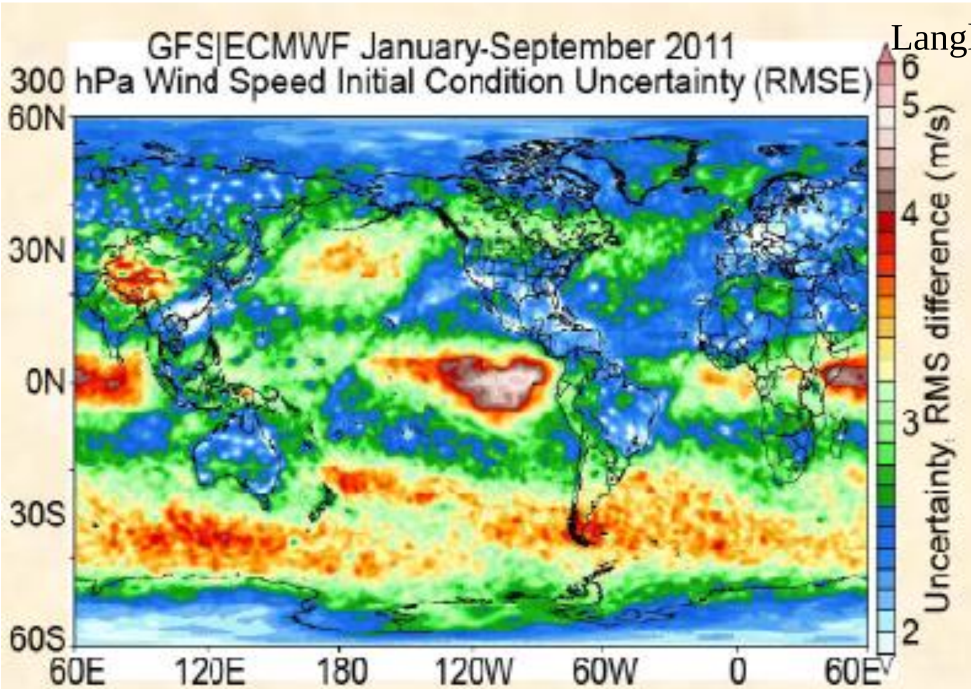
Importance of wind observations for NWP

- **<u>Extratropics:</u>**
  - Geostrophic adjustment theory
- **<u>Tropics</u>:**
  - wind more efficient at recovering equatorial waves than mass (e.g. Žagar et al. 2004)



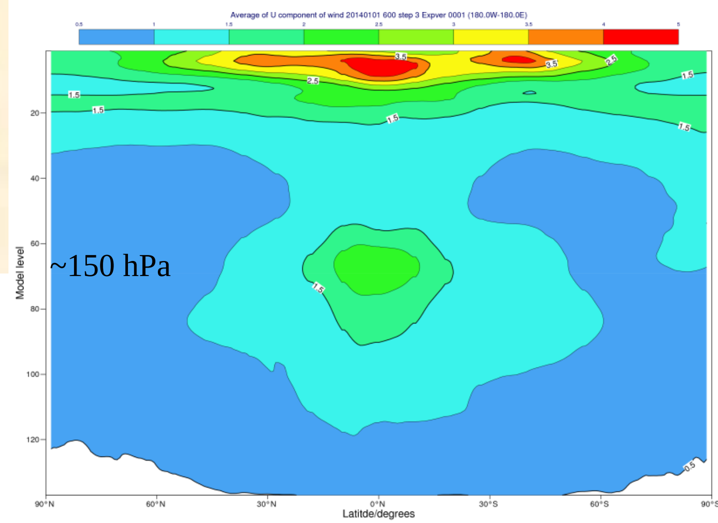
- **Wind from model dynamical adjustment (4D-Var) to other variables important too**
  - Mass sampled in time (e.g. Talagrand 1981)
  - Humidity tracer advection (e.g. Peubey and McNally 2009)
  - But wind more efficiently determined with <u>direct</u> wind obs

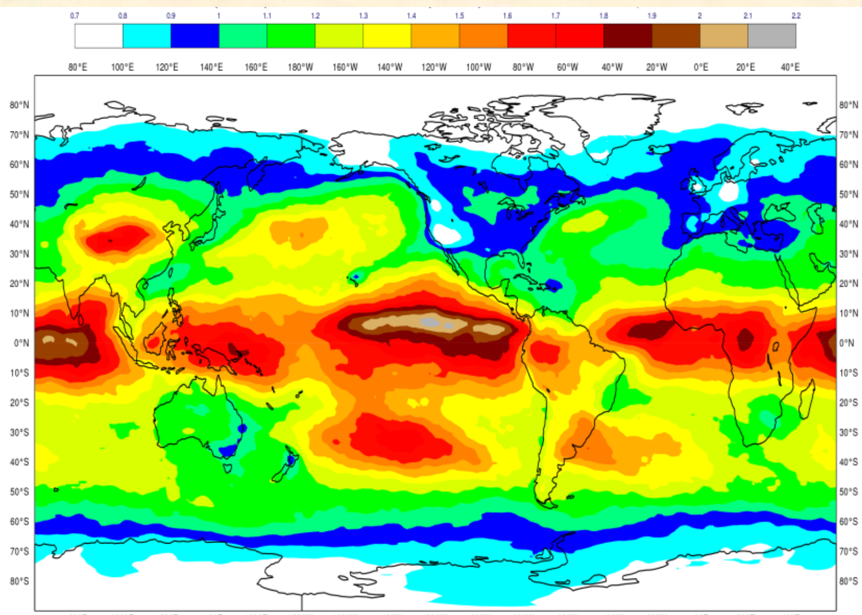
How accurate are global wind analyses?



Langland and Maue (2012)

- e.g. 300 hPa wind speed RMS difference between GFS and ECMWF
- Largest uncertainties in poorly observed areas

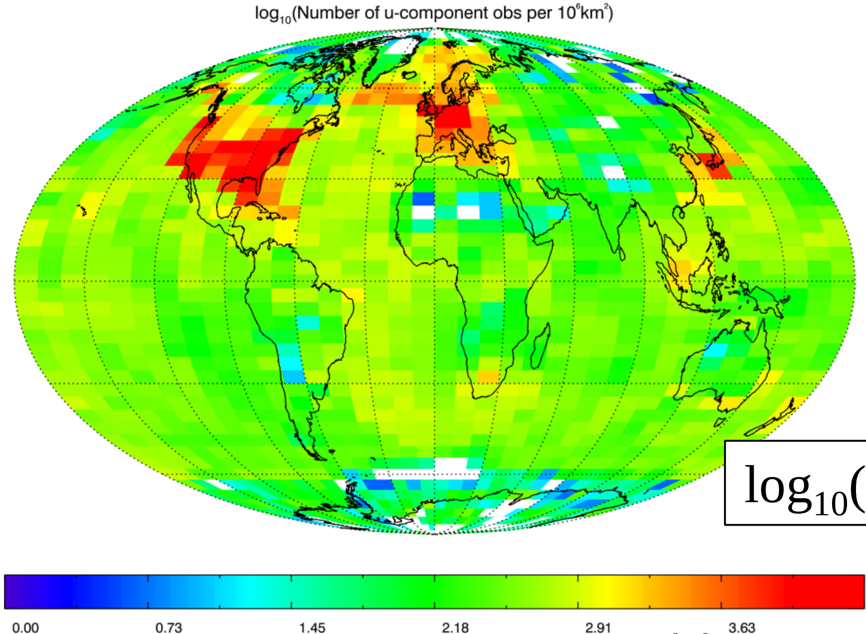


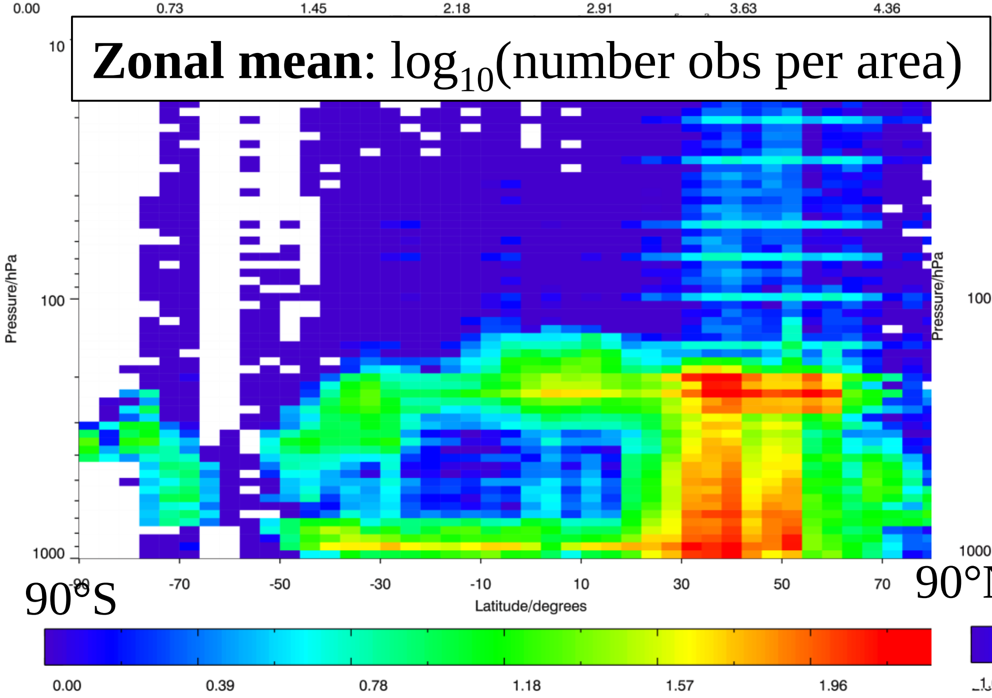


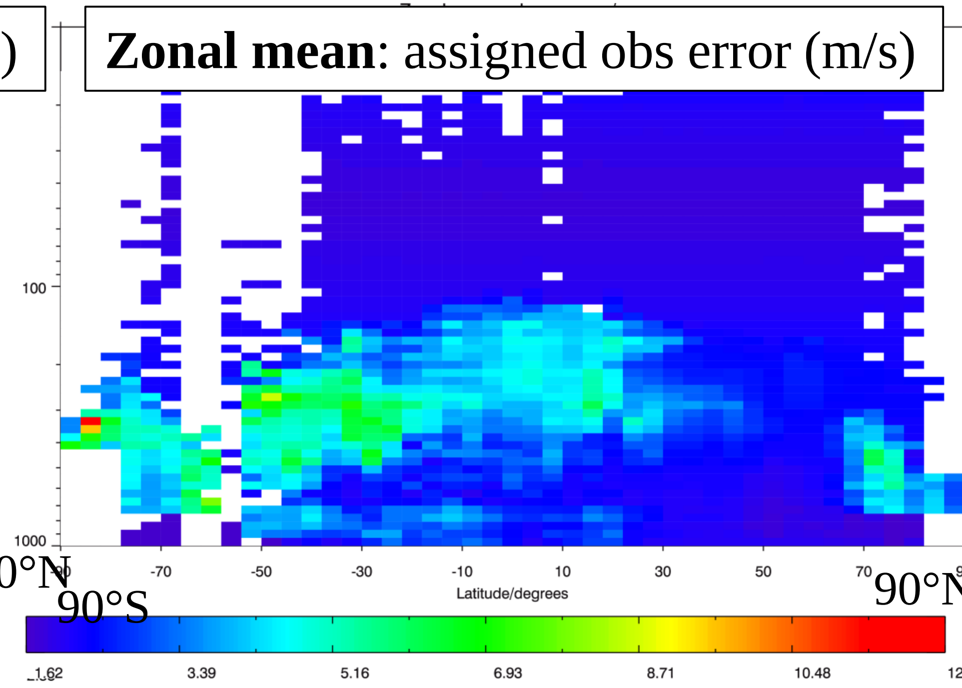
Similar structures in ECMWF Ensemble of Data Assimilation (EDA) spread, 12-h FC 300 hPa zonal wind, mean Jan-Sep <u>2014</u>

Winds assimilated in an ECMWF cycle

- Very uneven distribution
- AMV coverage good in tropics, but obs errors large
- Stratosphere poorly sampled







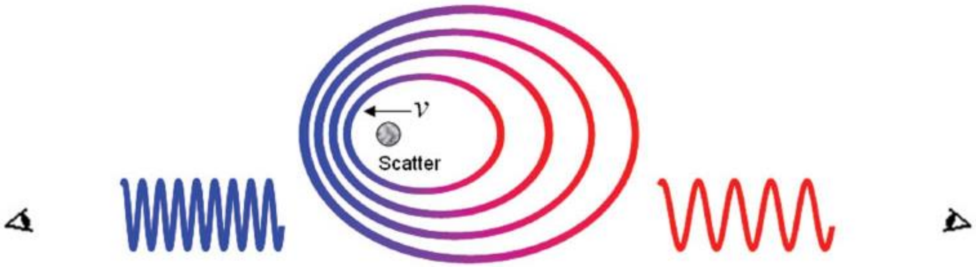
- Any hope for filling the gaps?
- Aeolus Doppler wind lidar (DWL) should help the vertical sampling:
  - ESA Earth Explorer Core Mission, chosen in 1999
  - Technology demonstration, ~3 years
  - Will be first European lidar and first wind lidar in space
  - Launch 2016
    - Long delays due to technical difficulties, but now on track

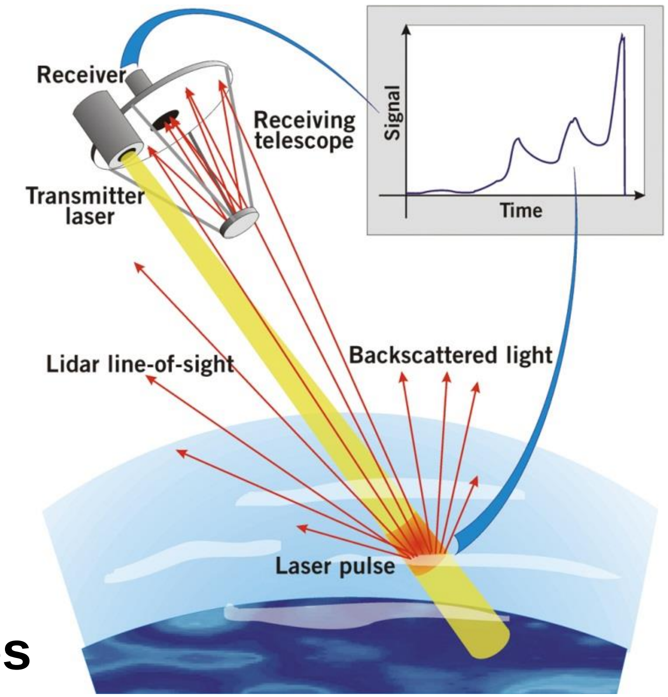
aeolus
because wind matters

esa

Doppler wind lidar

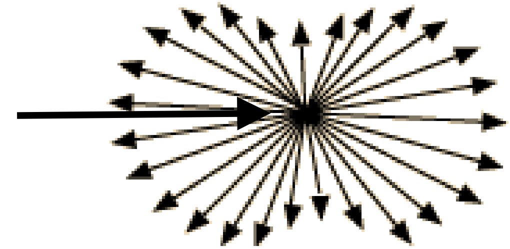
- **DWL measures Doppler frequency shift of backscattered light**



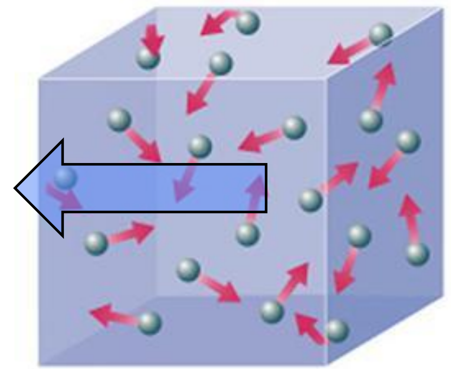


  - **Doppler shift,** $\Delta f = 2 f_0 v_{LOS} / c$
  - **<u>Scattering from:</u>**
    - **air molecules (clear air) and particles (aerosol/cloud)**
    - **Wind = Average molecules/particle movement in volume of air**

Clear air winds: Rayleigh scattering

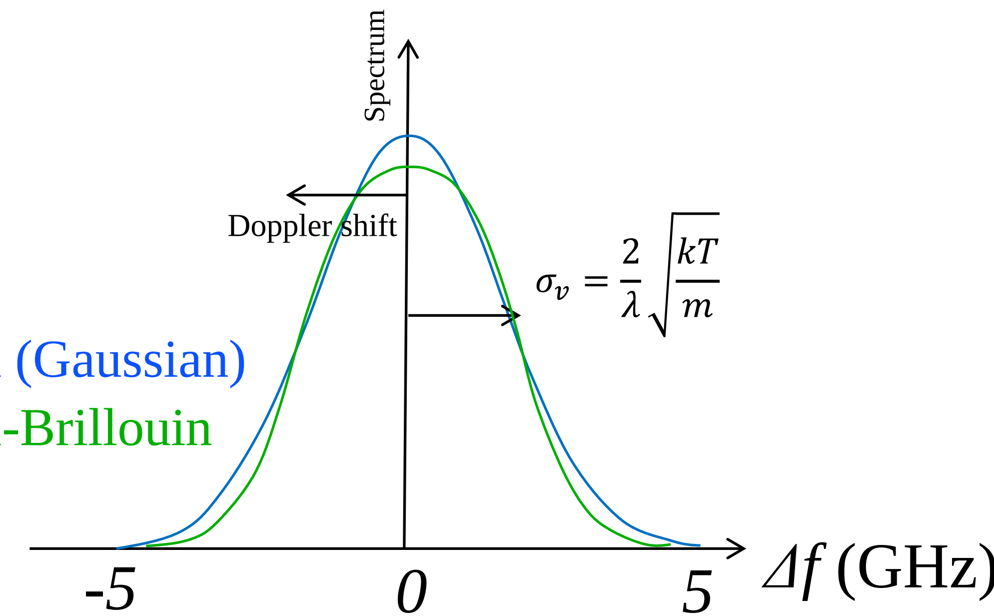


- $I \propto \lambda^{-4}$; scatterer size < $\frac{\lambda}{10}$, air molecules → ultra-violet
- Thermal motion → Doppler broadening
  - e.g. 459 m/s for T=15 °C
  - Brillouin scattering effect due to acoustic waves (at high pressure) has to be considered



- Wind measured as shift in

mean of distribution



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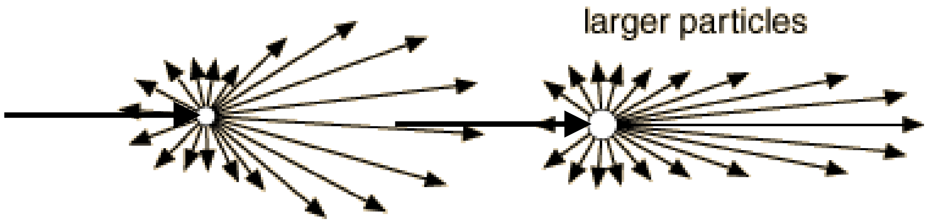
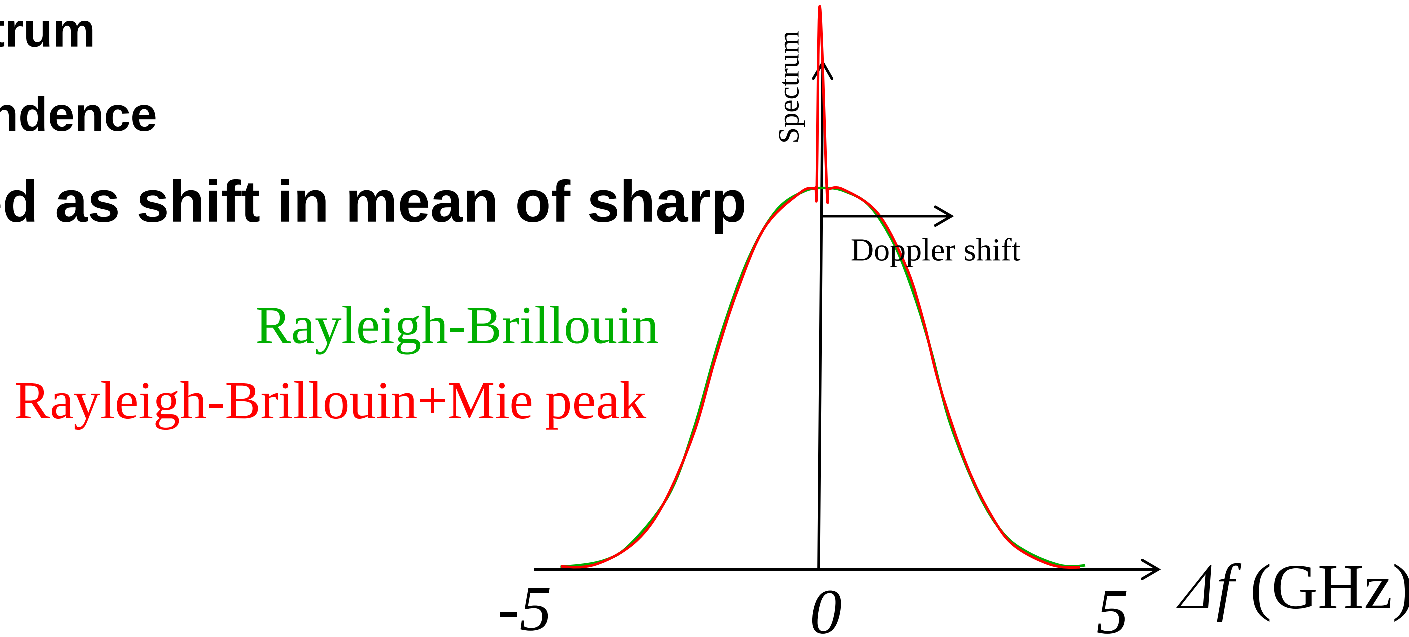
Cloud/aerosol winds: Mie scattering



- Particle sizes > λ; intensity not strongly λ dependent
- Doppler broadening negligible (particles heavy)
  - Narrow spectrum
  - No T, p dependence
- <u>Wind</u> measured as shift in mean of sharp Mie peak



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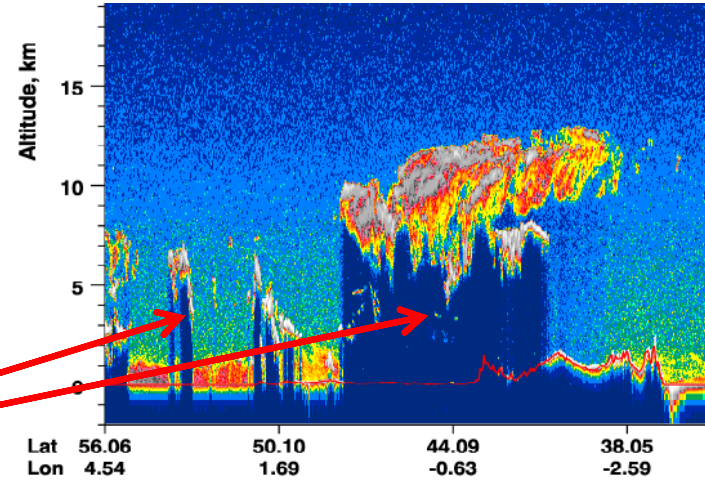
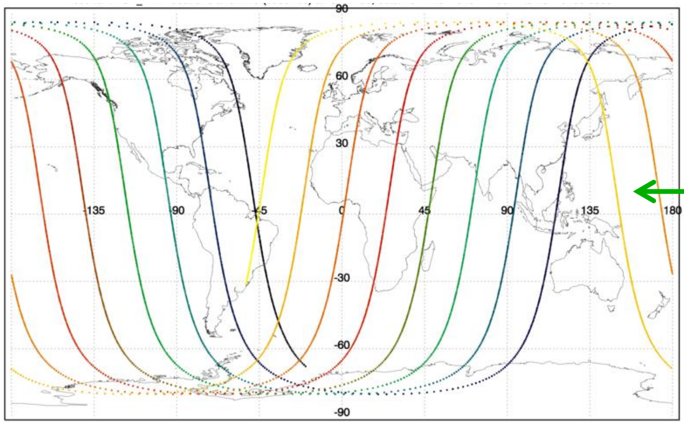
DWL features

- **Advantages:**
  - High resolution and accuracy possible
  - Measurement closely linked to wind
- **Disadvantages:**
  - No transmission through thick cloud
  - Space-borne DWL limitations:
    - Complex technology (but ground/air based works fine!)
    - Obtaining <u>vector wind</u> not easy
    - Limited sampling across-track (e.g. sub-satellite “curtain”) from one satellite
    - Low signals at ~400 km range

e.g. CALIPSO total attenuated backscatter



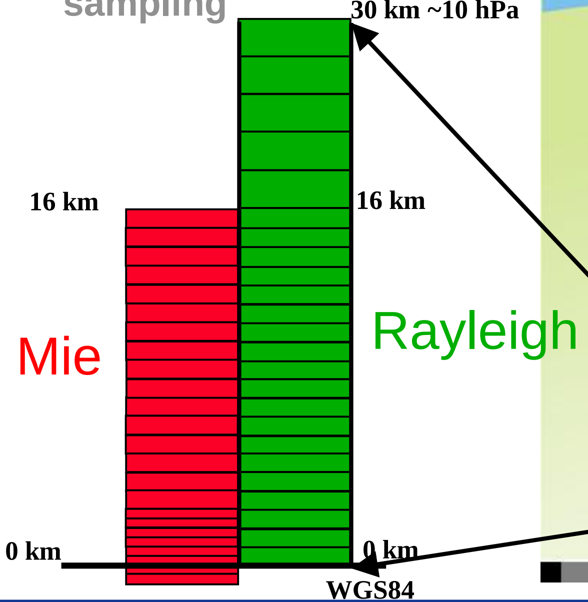
Aeolus DWL



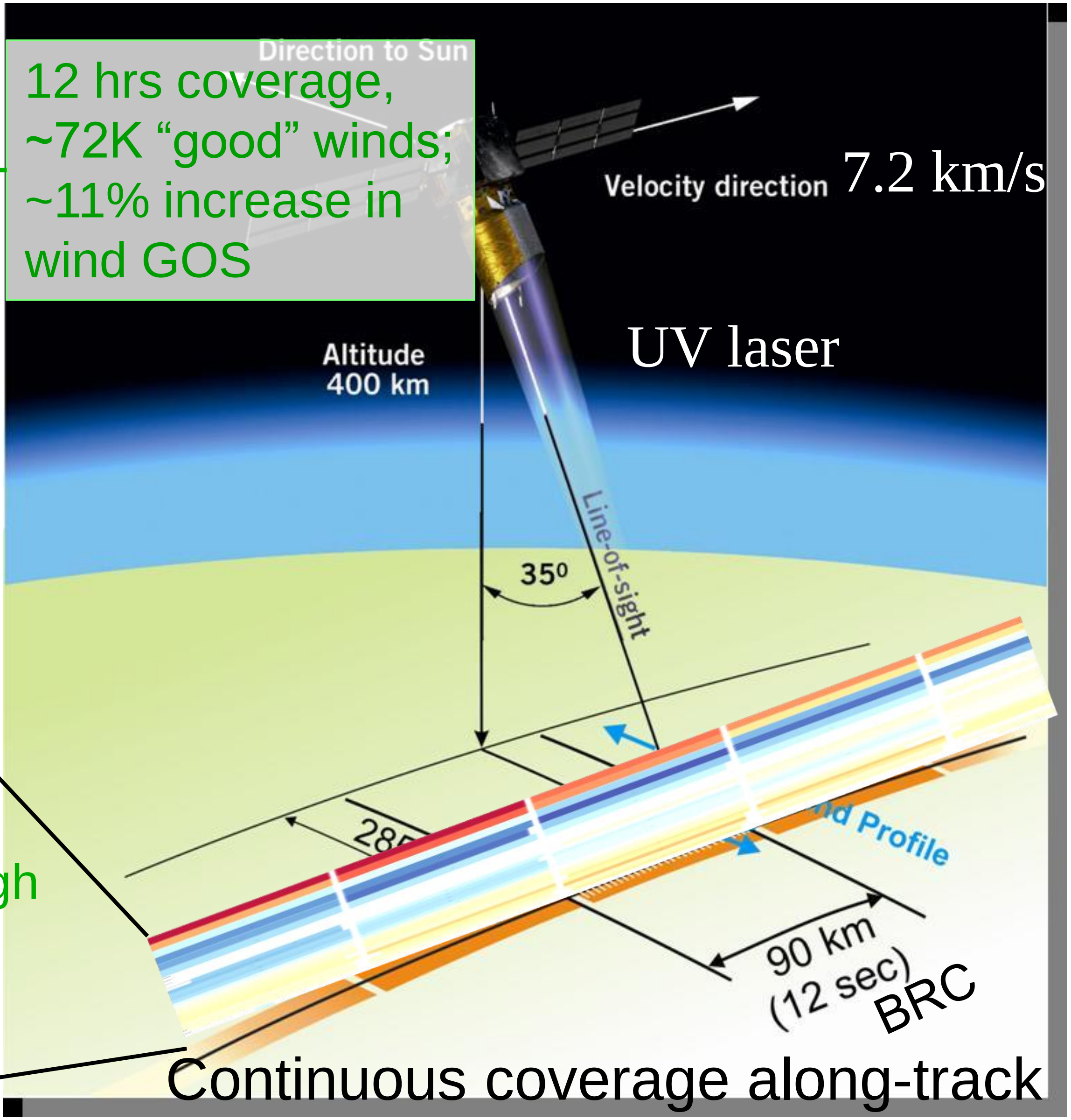
Mostly zonal component of wind

Coverage up to 83 °N/S

Example of Aeolus vertical sampling

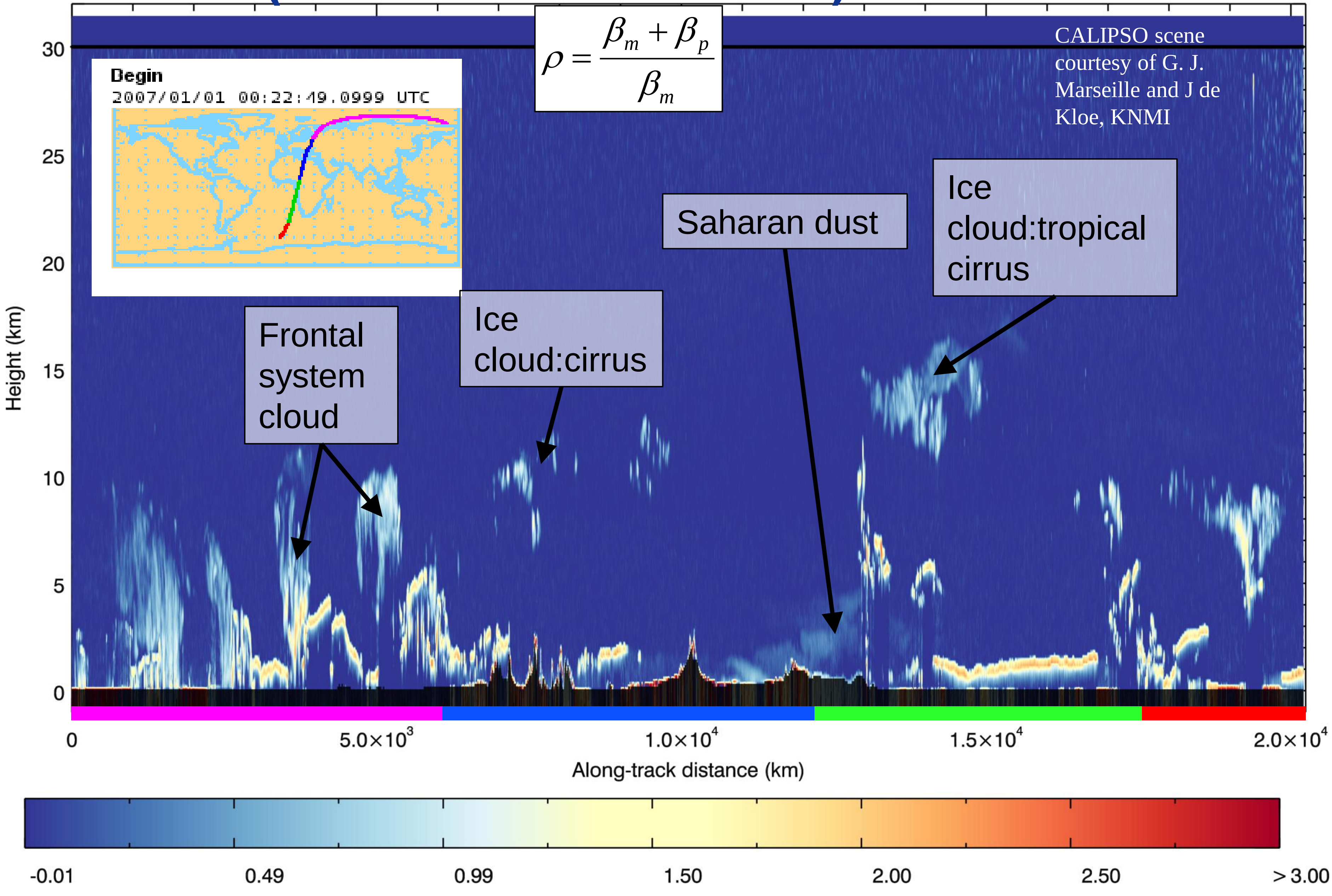


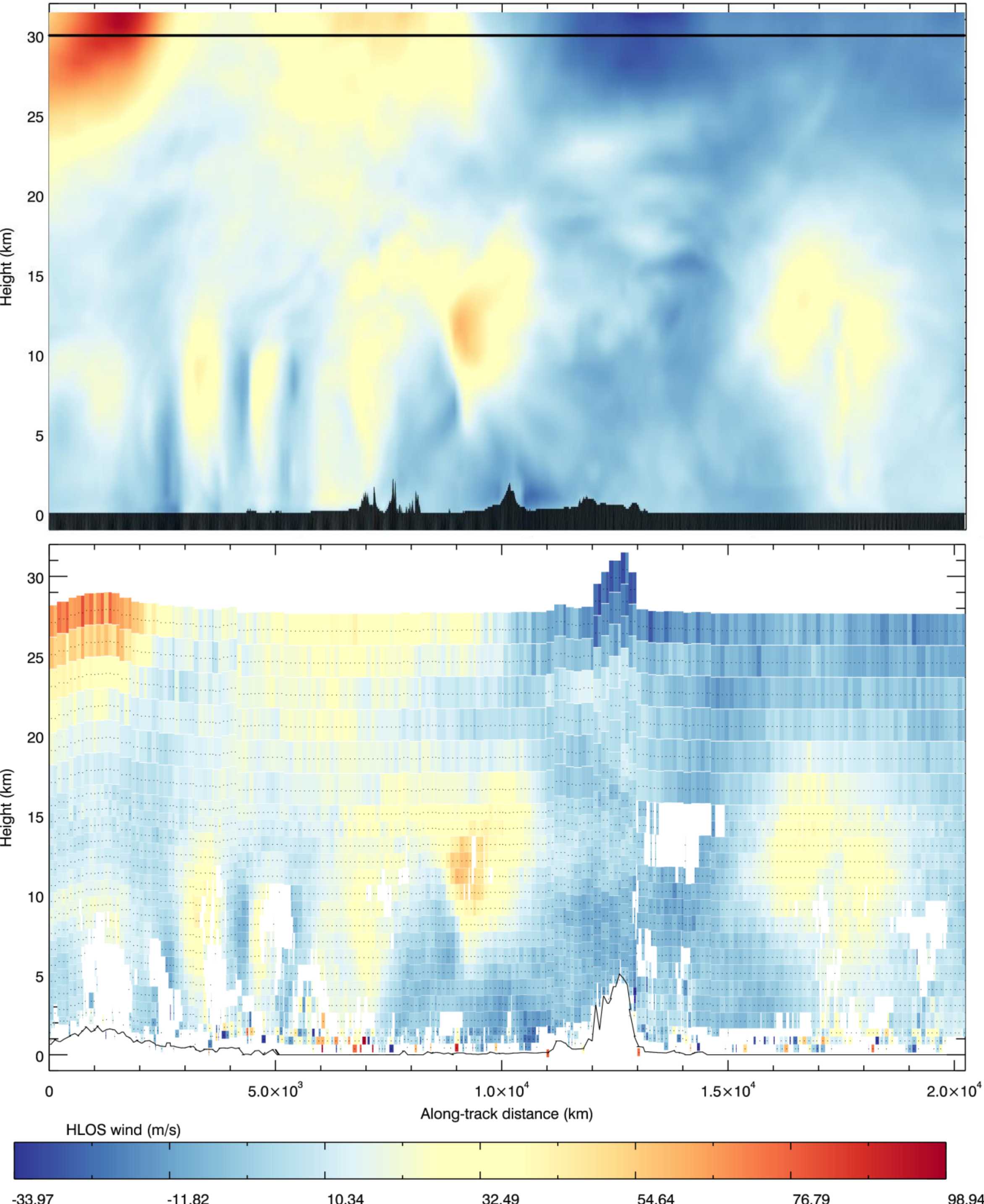
12 hrs coverage, ~72K "good" winds; ~11% increase in wind GOS



What might Aeolus winds look like?

Example simulator input: $\log_{10}$(scattering ratio) at 355 nm (derived from CALIPSO)

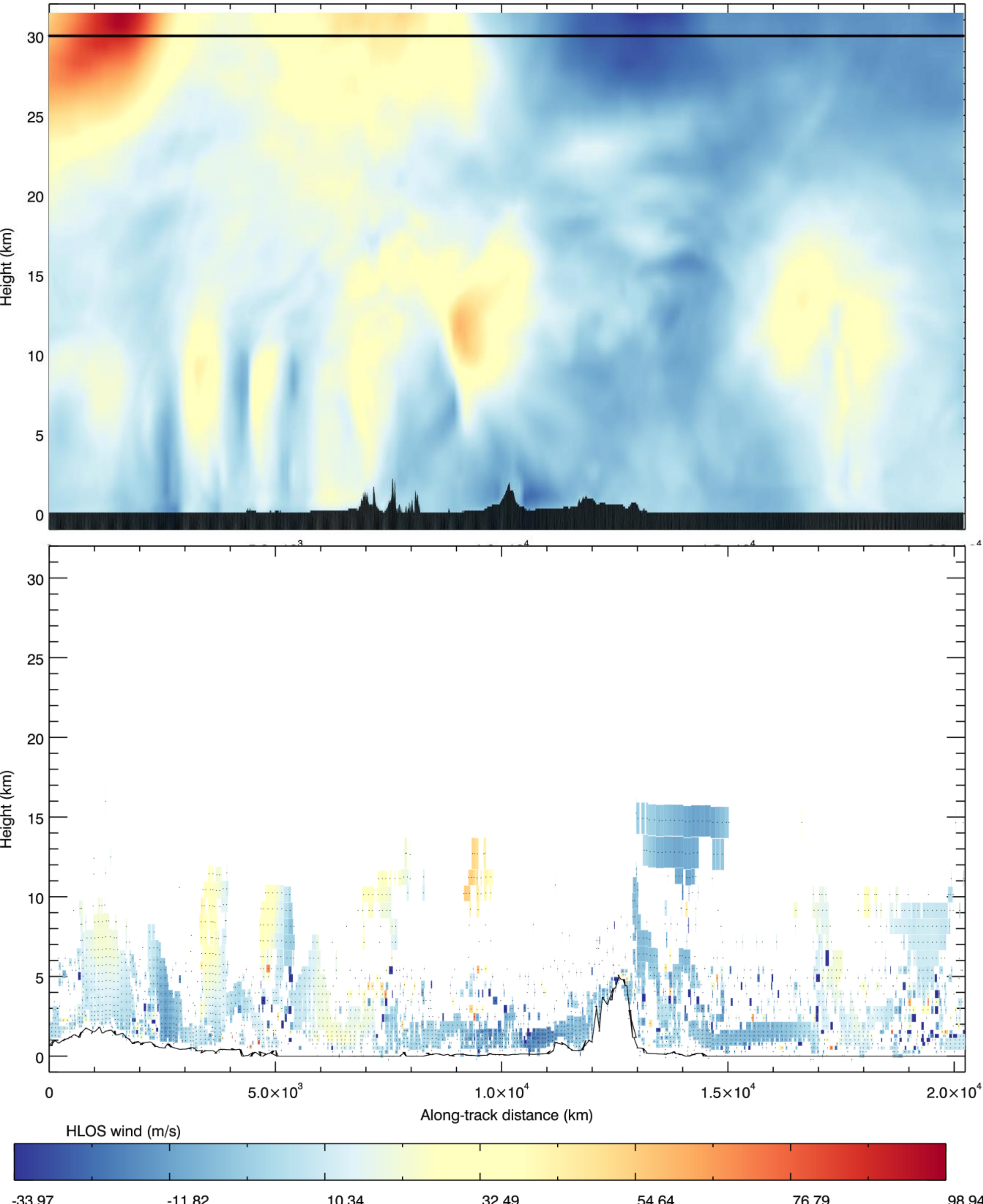




Simulator input: “True” HLOS wind (ECMWF)

Output: Level-2B processed “**clear-Rayleigh**” HLOS wind i.e. what the winds should look like

ECMWF



Simulator input: "True" HLOS wind (ECMWF)

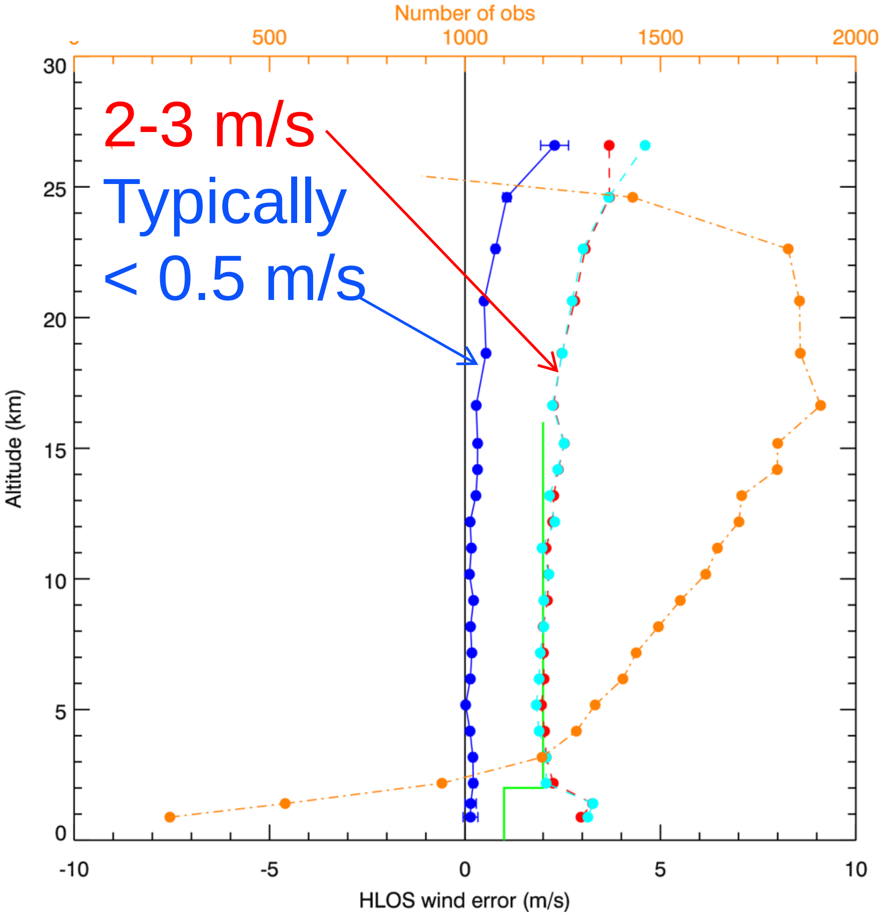
Output: Level-2B processed "**cloudy-Mie**" HLOS wind

Simulated L2B HLOS wind error statistics

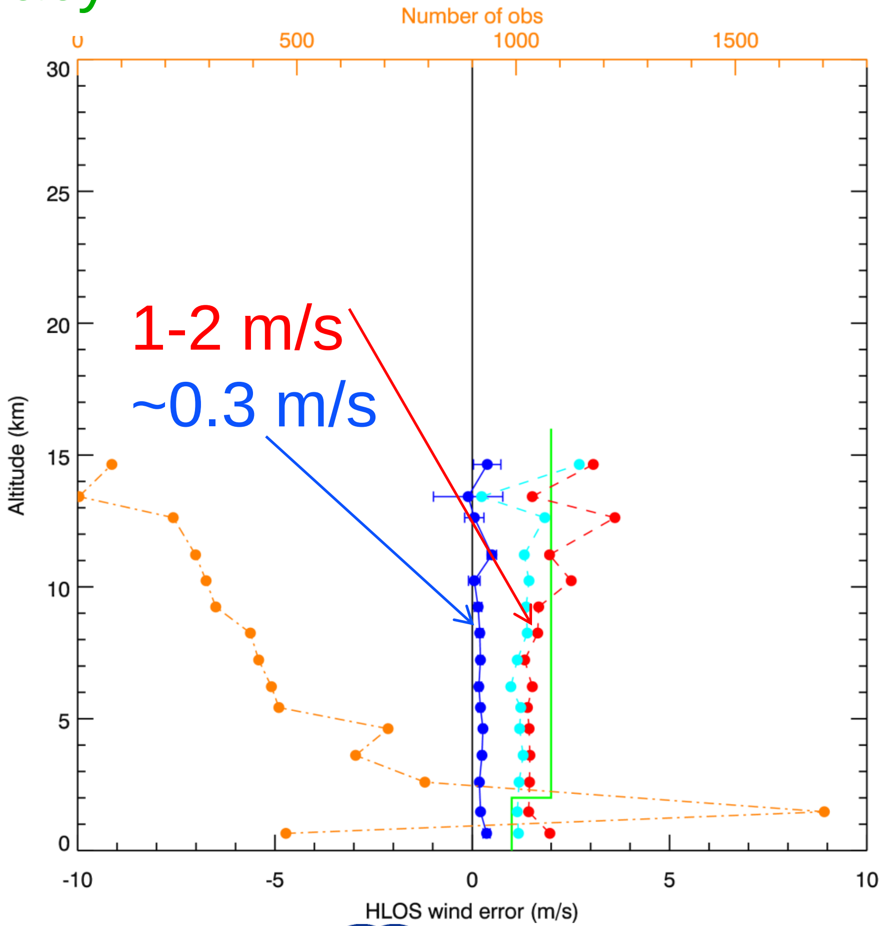
Stdev(error)
Mean(error)
Number of obs
ESA required accuracy

Rayleigh and Mie are complementary

Rayleigh-clear



Mie-cloudy



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Error sources for Aeolus HLOS winds

- **Instrument errors:**
  - e.g. readout noise, dark-current noise, laser frequency stability
  - Pointing/spectrometer alignment errors
    - improved by ground returns (zero wind reference)
- **Unwanted signals:**
  - Aeolus measures photon counts from interferometers.
    - Shot noise: SNR ~√N, main error source
  - Solar background light
  - Sampling error: wind/backscatter variability

  - Vertical wind
  - Rayleigh winds *f*(*T*, *p*) of atmosphere
- **Errors during calibration lead to systematic errors**

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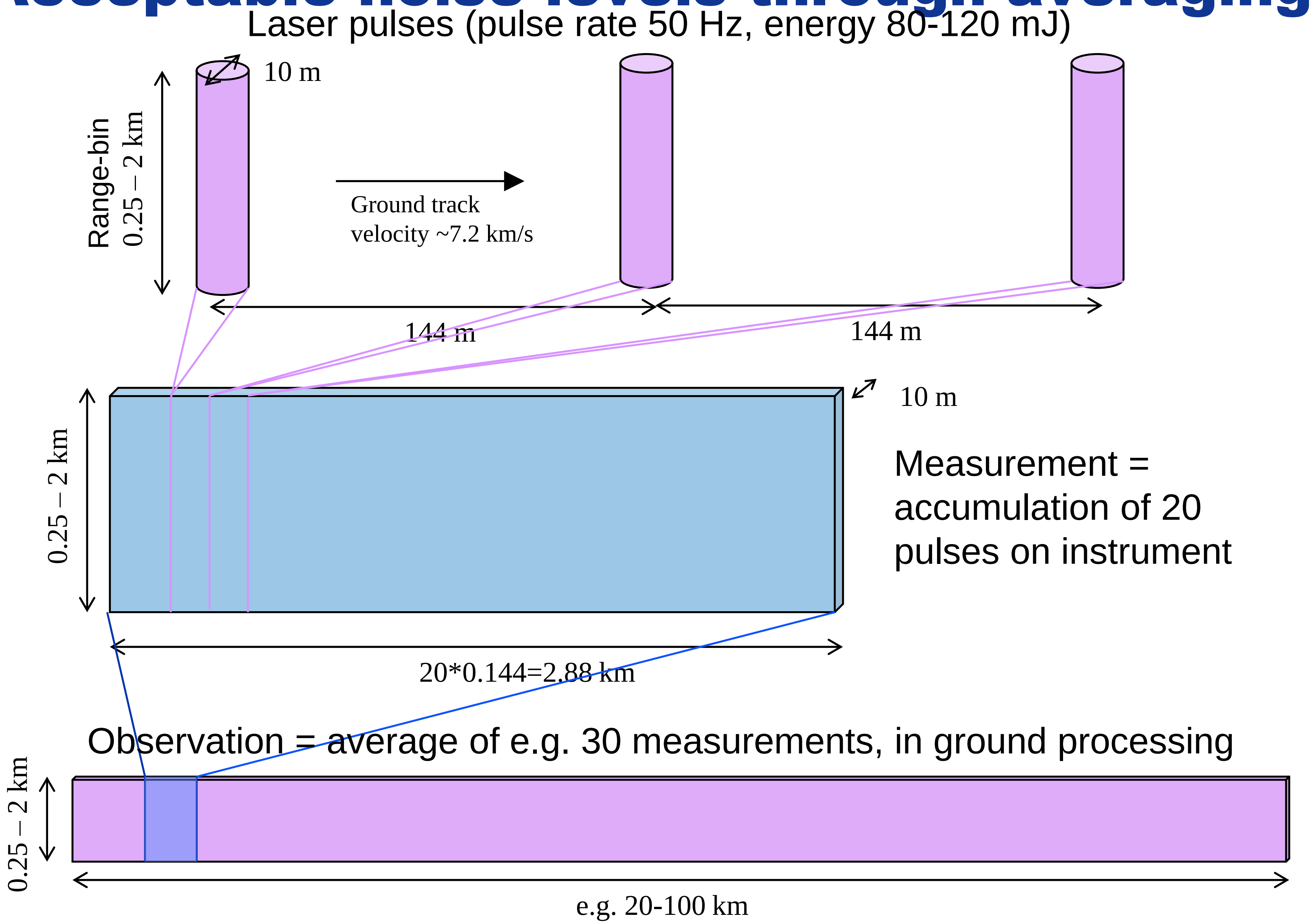
Acceptable noise levels through averaging



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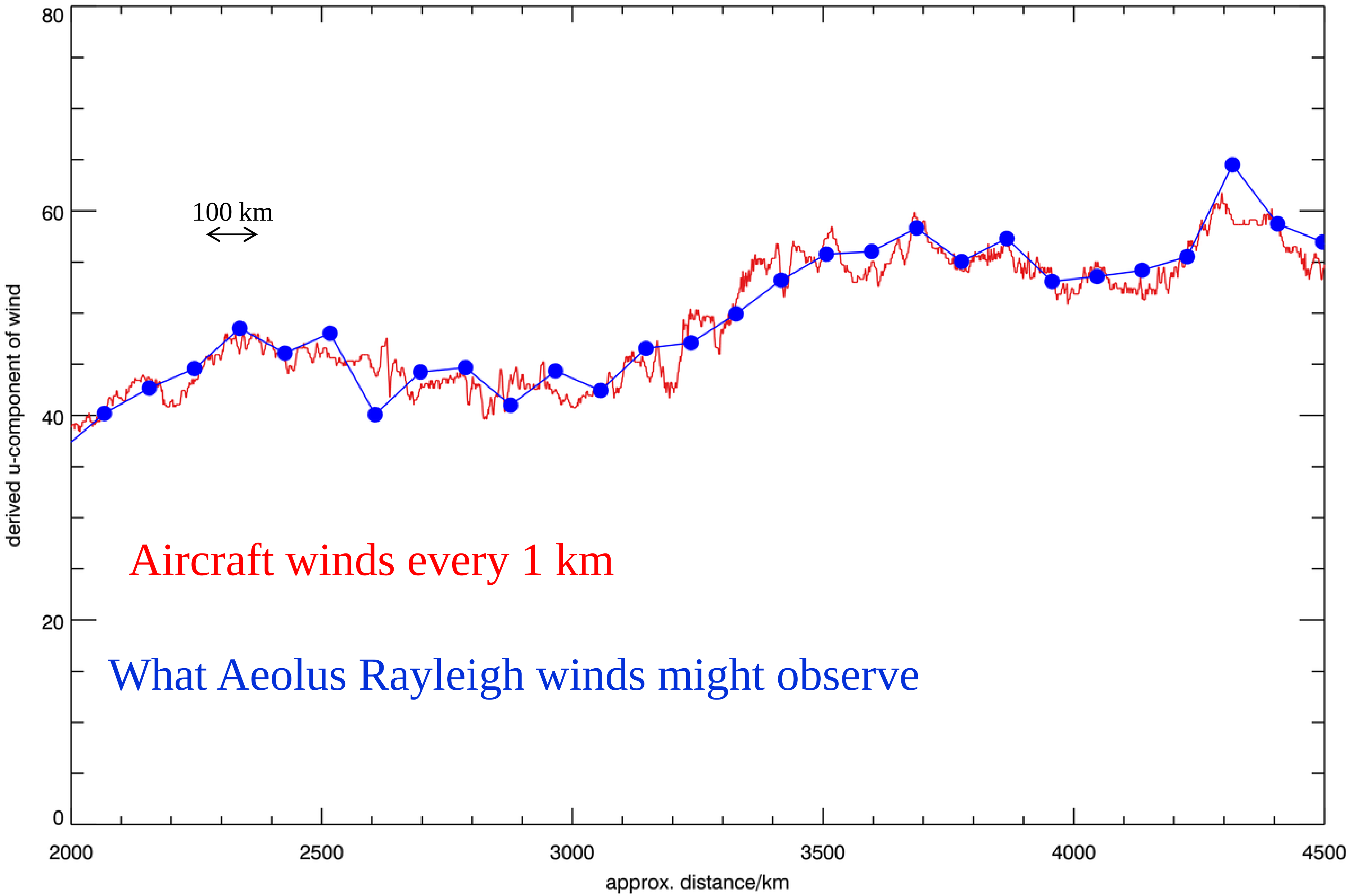
80
60
40
20
0
100 km
derived u-component of wind
Aircraft winds every 1 km
What Aeolus Rayleigh winds might observe
2000
2500
3000
3500
4000
4500
approx. distance/km

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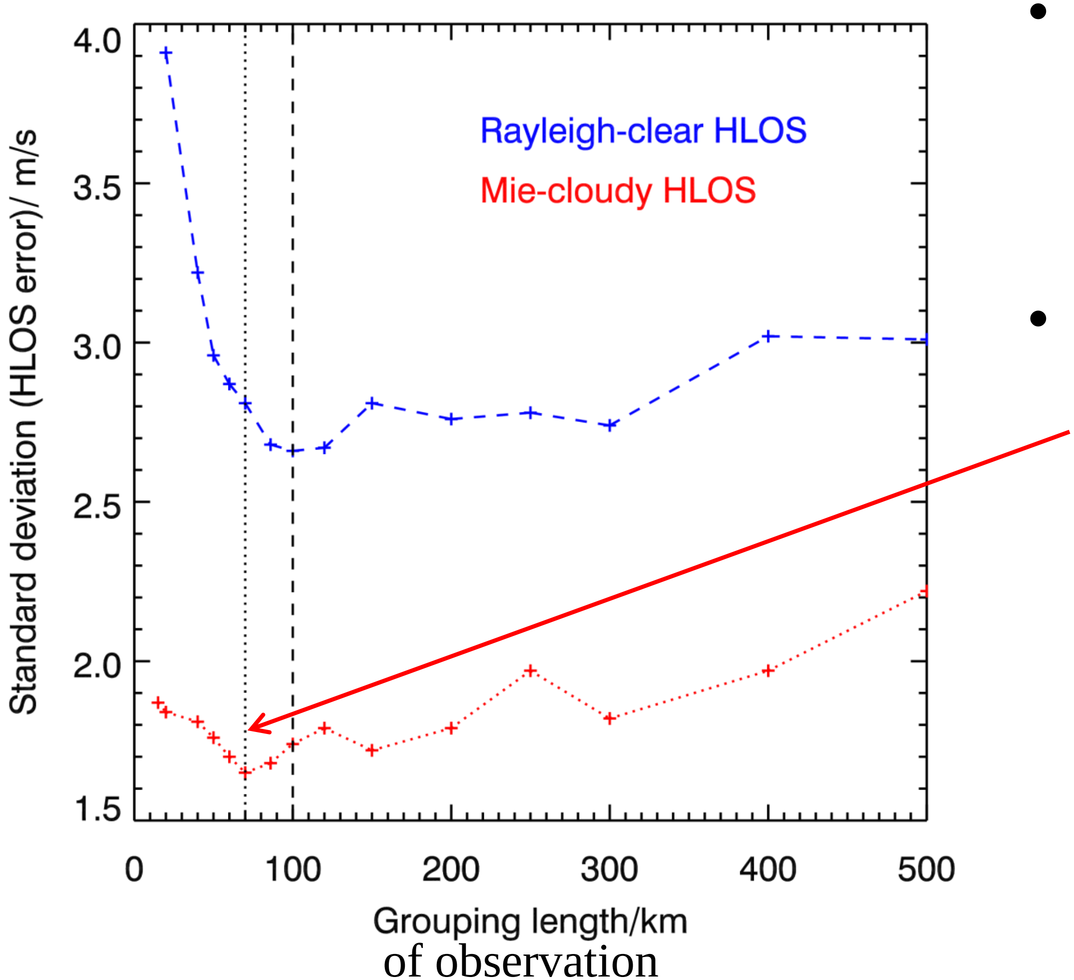
Wind error vs. averaging length *Simulation!*



- Comparing L2B winds to "point-wind" from ECMWF T1279 model
- Can achieve better accuracy at **small-scales with Mie** compared to Rayleigh

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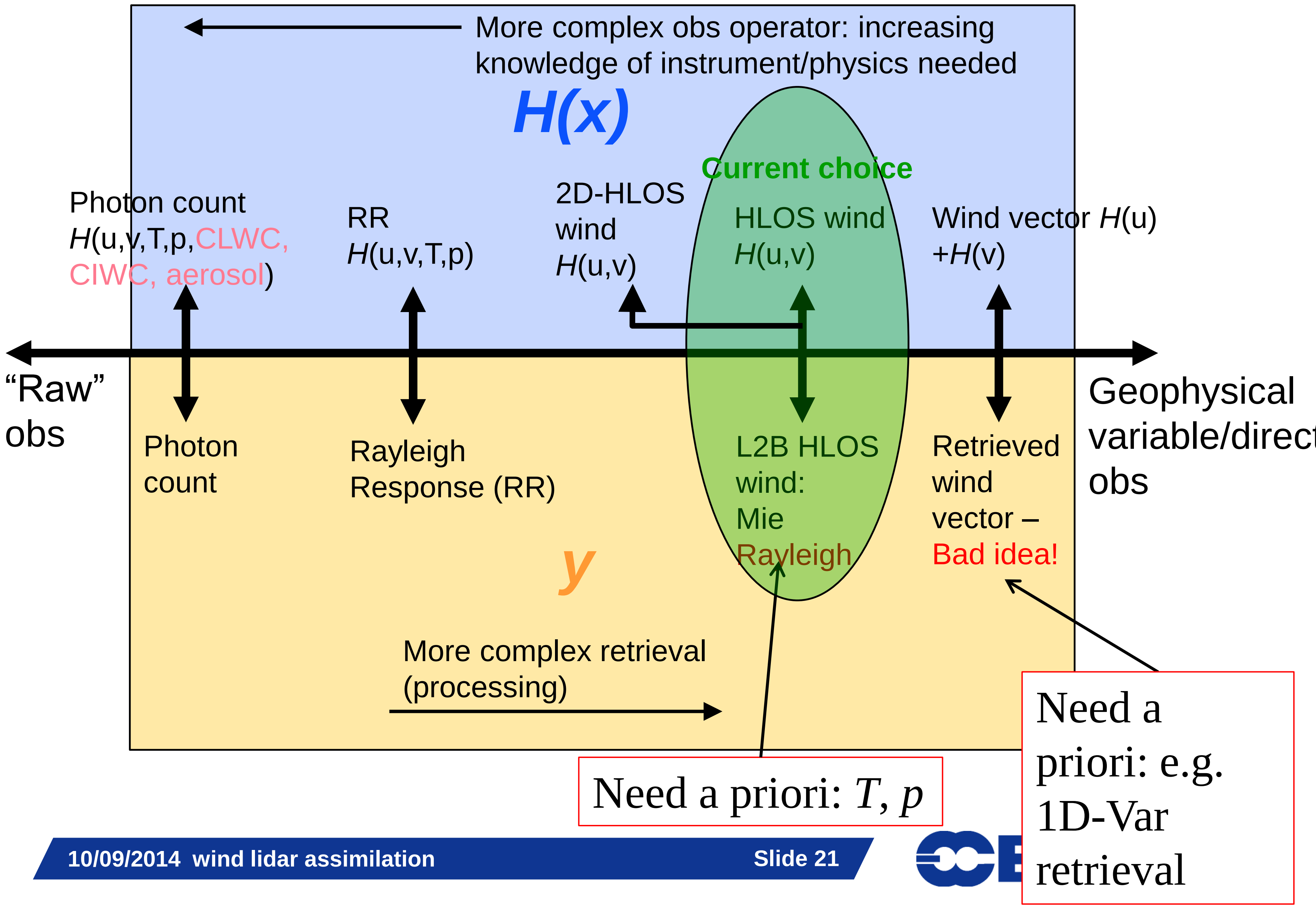
What to assimilate for Aeolus?



Aeolus winds for NWP: L2B

- Level-2B processor* provides
  - Retrieval of HLOS winds
    - Geolocated – geometric height, lat, lon, azimuth angle, time
    - Error estimates for each wind, quality flags
  - Flexible classification into wind types – *cloudy or clear (currently)*
  - Flexible horizontal averaging of spectrometer counts
    - Some control of noise and representativity of observations
  - Rayleigh winds corrected for temperature, pressure and Mie cross-talk
  - In future: estimates of optical properties
  - Many processing options controllable from settings file
- Research mission; encourage users to play with L2B processor
    - http://www.ecmwf.int/en/research/projects/aeolus

* developed by ECMWF, KNMI, Météo-France, DLR. See e.g. Tan et al. (2007)

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Expectations for Aeolus NWP impact

Recent assessments relevant to Aeolus:

1. **EDA spread experiments using ECMWF model**

   L. Megner (MISU), H. Körnich (SHMI), G. Marseille (KNMI) –method of D. Tan (2007) - but with new instrument config.

2. **Recent OSSE with DWL (Zaizhong et al., 2013) by JCSDA**
3. **ECMWF OSEs using available in situ wind observations**

1. and 3. were financially supported by ESA

Aeolus EDA experiments

- **Reduction in ensemble spread → positive impact**
- **Accurately simulated Aeolus obs**
- **ECMWF, T399 (wind impact for small-scales could be underestimated)**
- **Impact *similar to radiosonde network*:**
  - **Largest at ~200 hPa, tropical oceans and winter poles**
  - **~5 % improvement short-range – could lead to 1-3 hrs impact**

Global mean 12 hr EDA spread of zonal wind

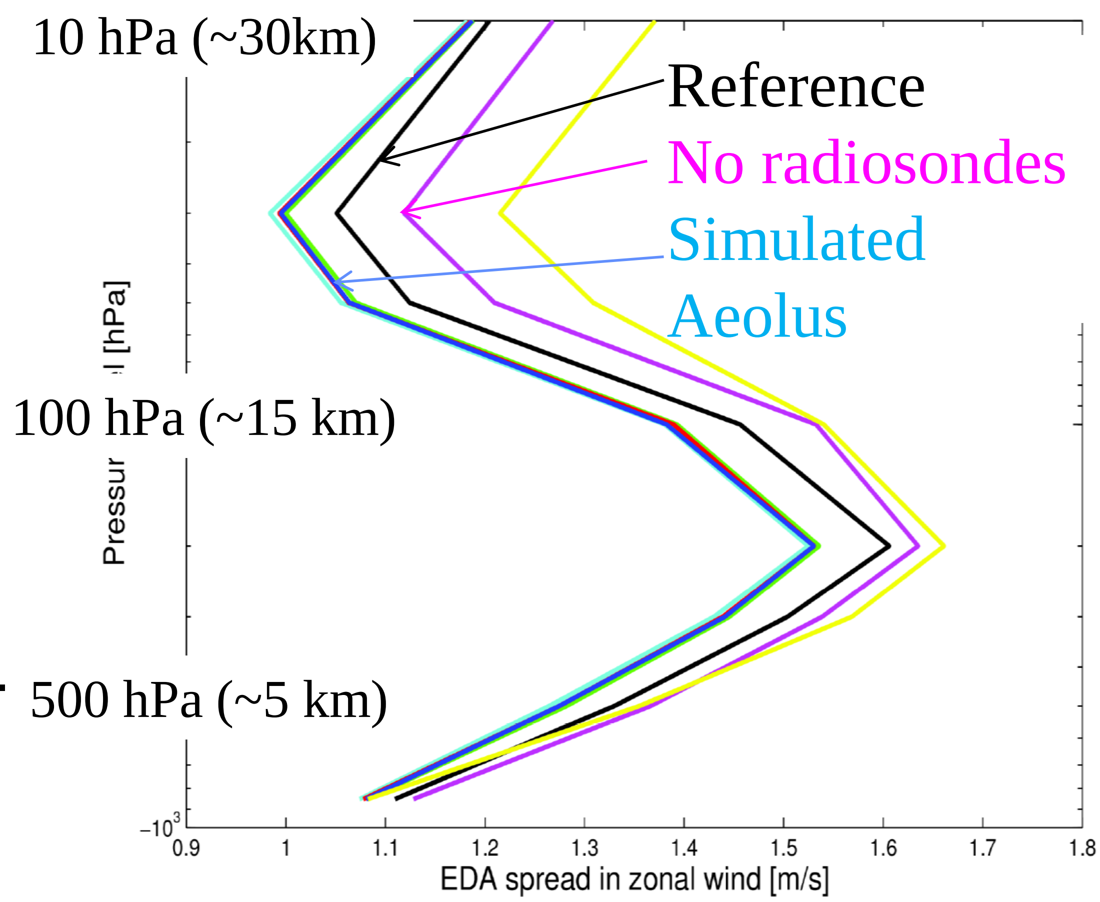
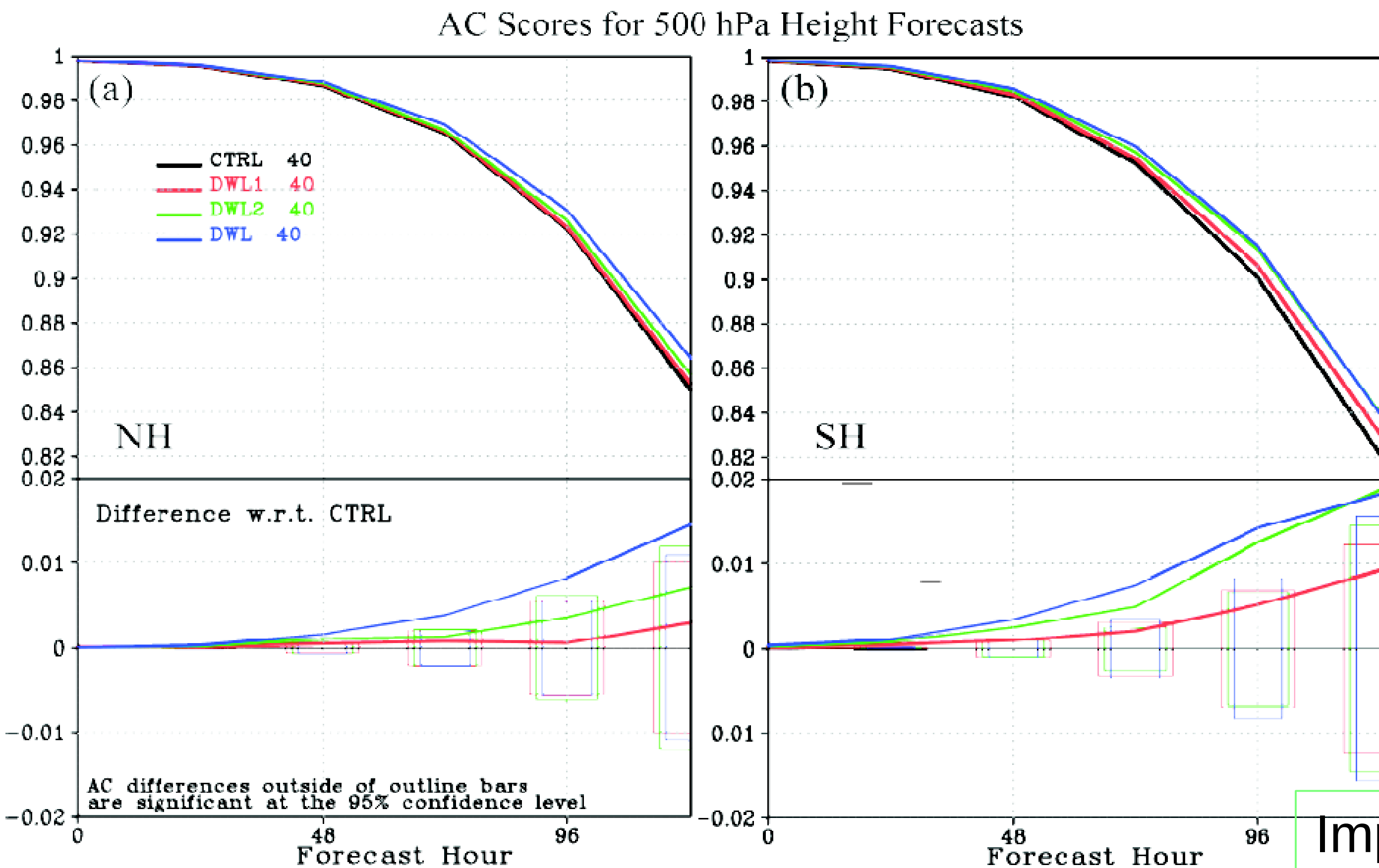


Image courtesy of ESA VHAMP project

OSSE by JCSDA

Images courtesy JCSDA



- NCEP GSI/GFS system, 2009
- Different DWL satellite configurations tested

NH impact 500 hPa Z:

4-look DWL, ~5 hrs

1-look DWL, ~ 1 hr

SH impact 500 hPa Z:

4-look DWL, ~6 hrs

1-look DWL, ~ 3 hrs

Impact on tropical winds; 15% reduction in RMSE (1-look), short-range at 200 hPa, but lost after 5 days (NCEP system?)

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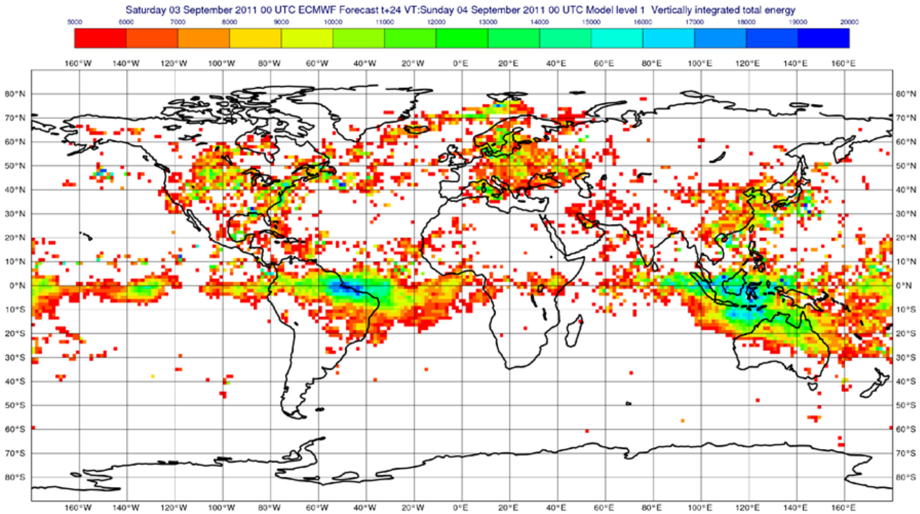
HLOS impact in ECMWF system

by A. Horányi , C. Cardinali, M. Rennie and L. Isaksen (QJRMS, 2014)

- **OSEs using *in situ* observations:**
  - **aircraft; radiosondes; PILOT and wind profilers**
- **Assessed impact of assimilation of HLOS winds**
  - **convert (u, v) → HLOS wind**
  - **can real single-component wind obs give useful impact?**
    - **Yes, ~70% impact of vector wind**
  - **Typical impact of zonal HLOS : 2-5 hrs in NH extratropics**
  - **Large impacts in tropics despite very few obs**



Decrease of error in total energy of the 24h forecast error

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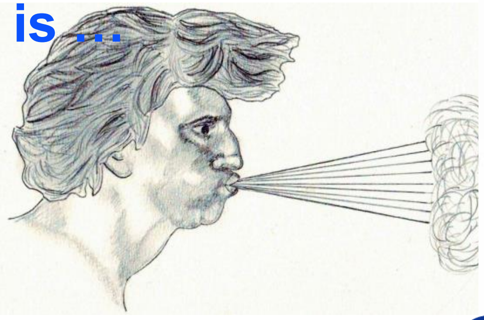
Finally: *Tentative* expected impact for Aeolus

- ***If*** **mission error specifications are met:**
  - **Extratropics:**
    - **500 hPa geopotential: ~3 hrs, SH, 2-5% analysis improvement:**
      - **Difficult for any one observation type to show "large" impact on top of full OS**
    - **Expect similar impact for wind**
  - **Tropics:**
    - **Evidence of locally large impacts, e.g. up to 15% improvements in upper tropospheric winds**
  - **But the proof of the pudding is …**



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http://www.esa.int/esaLP/LPadmaeolus.html

Thanks for listening.
Any questions?

Aeolus L2B processing software available to download:

http://www.ecmwf.int/en/research/projects/aeolus