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Sampling Aeolus Winds for Data Assimilation

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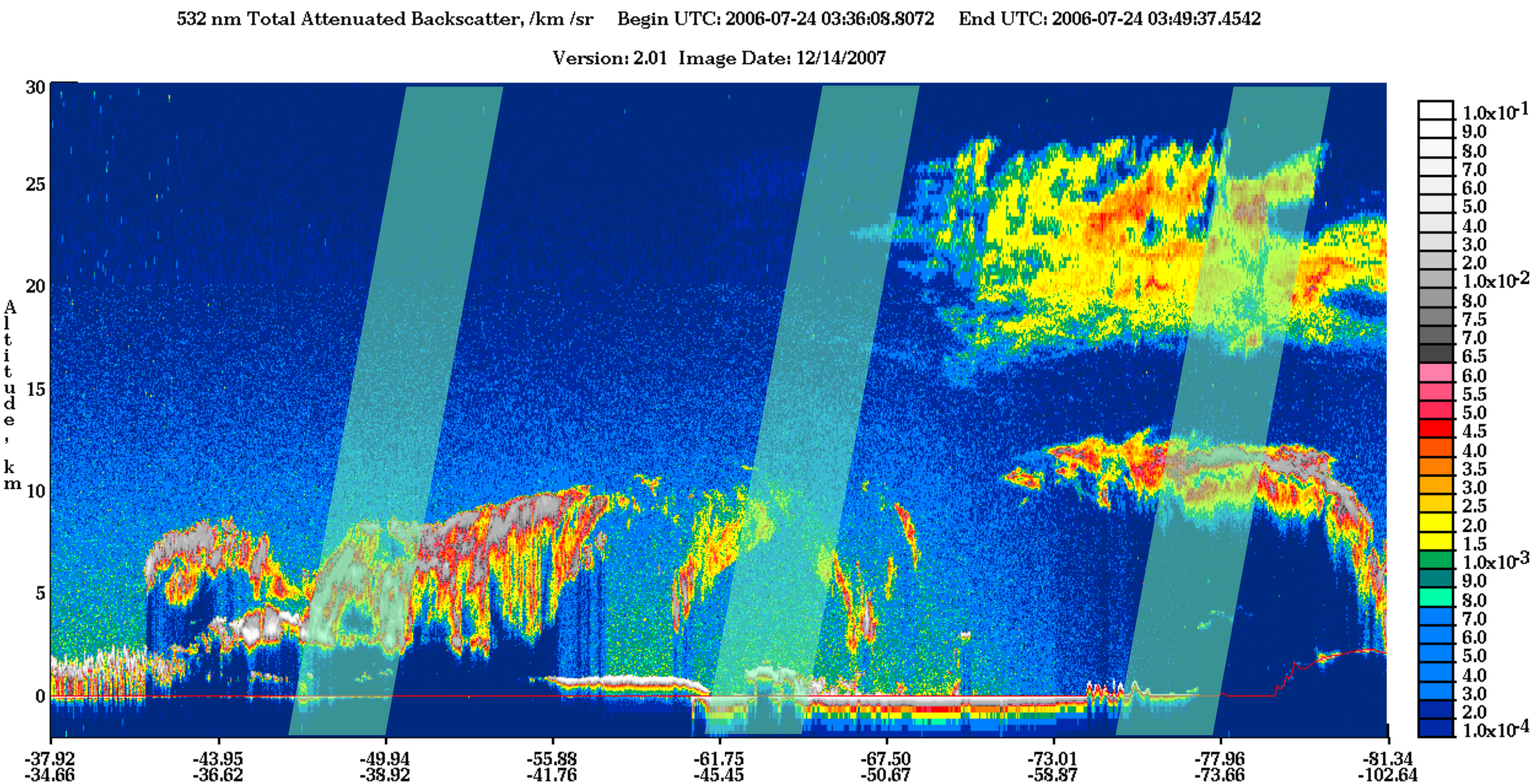
Aeolus Continuous versus Burst Mode



- CM has a 2D plane of observations rather than snapshots in BM

Winds from Continuous Mode

- Rayleigh performance specification over 50 km is not met any more since less signal is available (50 Hz rather than 100 Hz)
- The 50-km performance spec. is now met over 100 km
- Two independent 100-km observations now appear over a 200-km track rather than one 50-km observation in burst mode, i.e., more information content
- No physical observation boundaries exist any more (i.e., adjacent BRCs now) and more flexibility in cloud classification and measurement grouping appears – 2D plane of observations
- How to exploit Continuous Mode ?
  - Spatial aggregation & representation error
  - Thinning or more smart exploitation ?
  - How to set vertical and horizontal sampling in CM 2D plane ? (VHAMP)
- What are the relevant spatial scales

Data assimilation

- $o = x + \delta o$ observation
- $b = x + \delta b$ background (prior)
- $a = b + W(o - b)$ analysis

x : state variable, spatial average over the true weather, due to limitations in the NWP model

δo : random observation error, contains representation error, spatially correlated, since the (spatial) context of o is generally different from x

δb : random background error, spatially correlated

W : weight, depends on "average" covariances of δo in a matrix R=O+F and δb in a matrix B; O for observation error and R for representation error

Scales < B scales in o-b are generally removed in DAS (low pass filter)

➢ B, O and F, variances and correlation, are essential in data assimilation

Inertial range turbulence

- Kolmogorov (1941)
- Distribution of kinetic energy density among wave number scales

$$E(k) = C\,\varepsilon^{2/3} k^{-5/3}$$

C=0.5 is the universal Kolmogorov constant,

ε the energy dissipation rate; troposphere mean: 7.76 10^{-5} $m^2 s^{-3}$

k is the wave number in m^{-1}

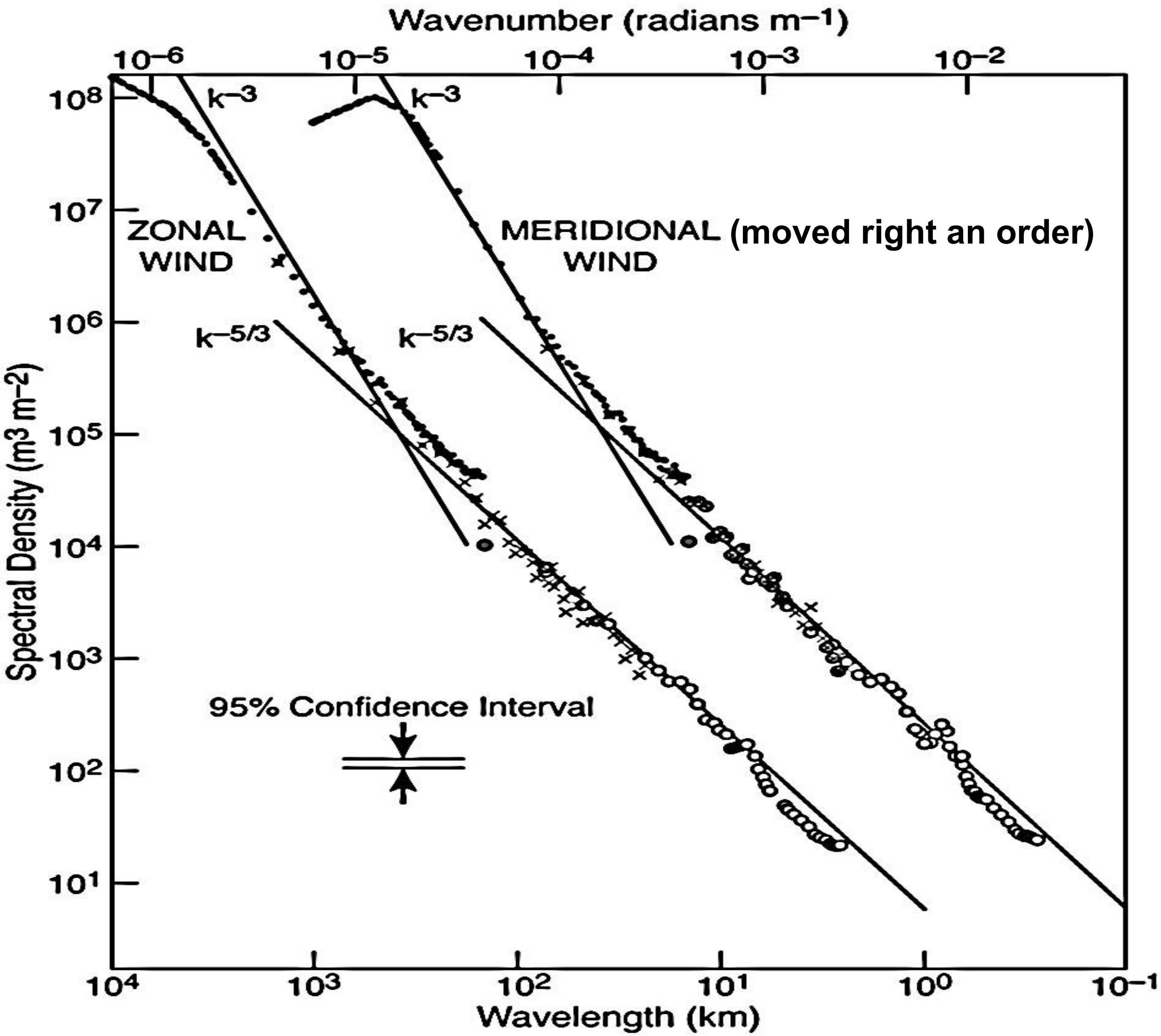
- Integrated variance and spatial structure function

$$e(r) = 3/2\ C\,\varepsilon^{2/3} r^{2/3}$$

➢ Representation error for point observation

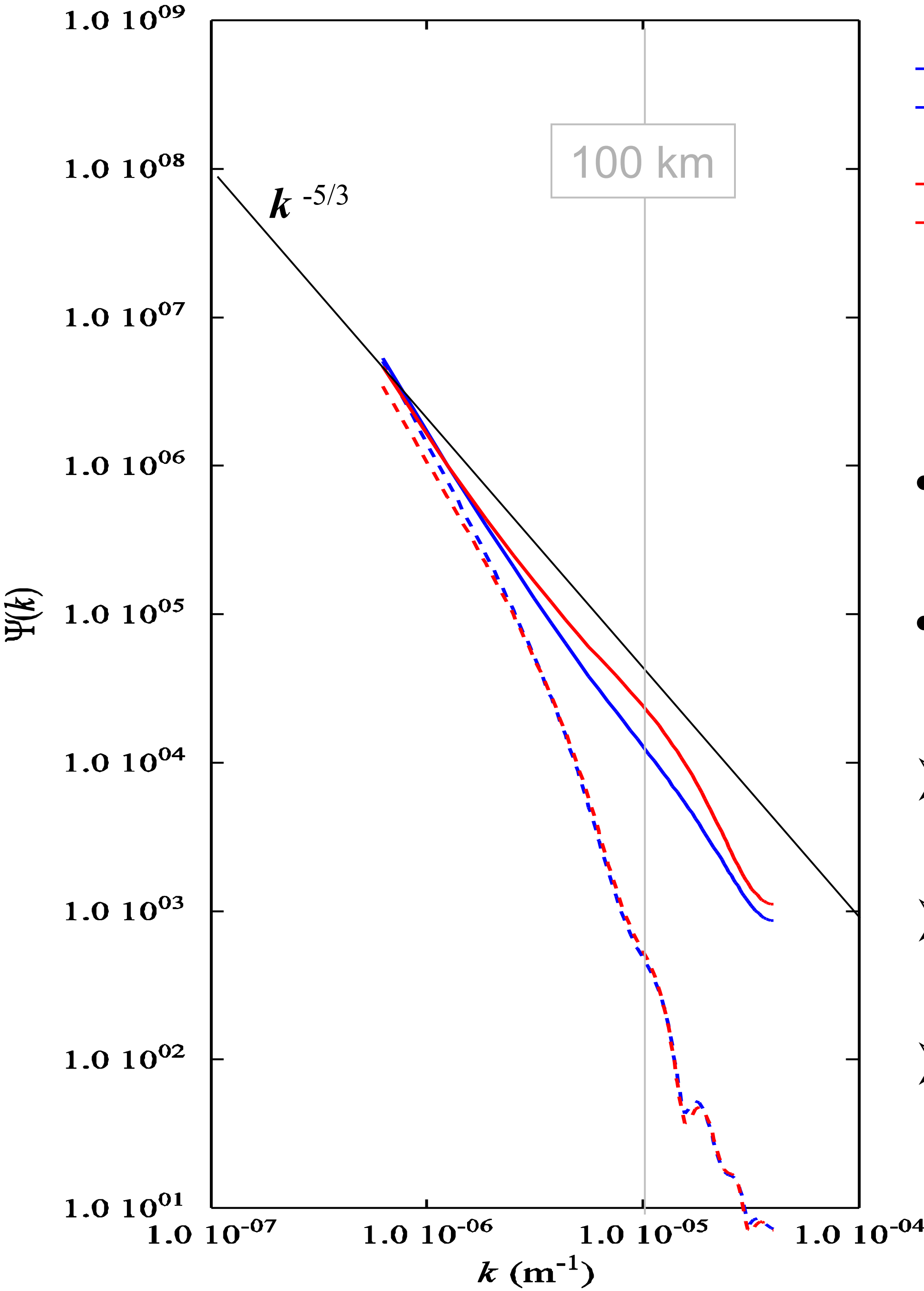
Mathieu & Scott (2000); Lindborg (1999); Nastrom & Gage (1987)

Nastrom & Gage Spectrum



- Tropospheric spectra are close to $k^{-5/3}$ below 500 km
- 3D turbulence
- L/H ~ 100
- SD(log spectral density) = 0.4

Nastrom and Gage (1985), Lindborg, (1999), …



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NWP deficit over the ocean

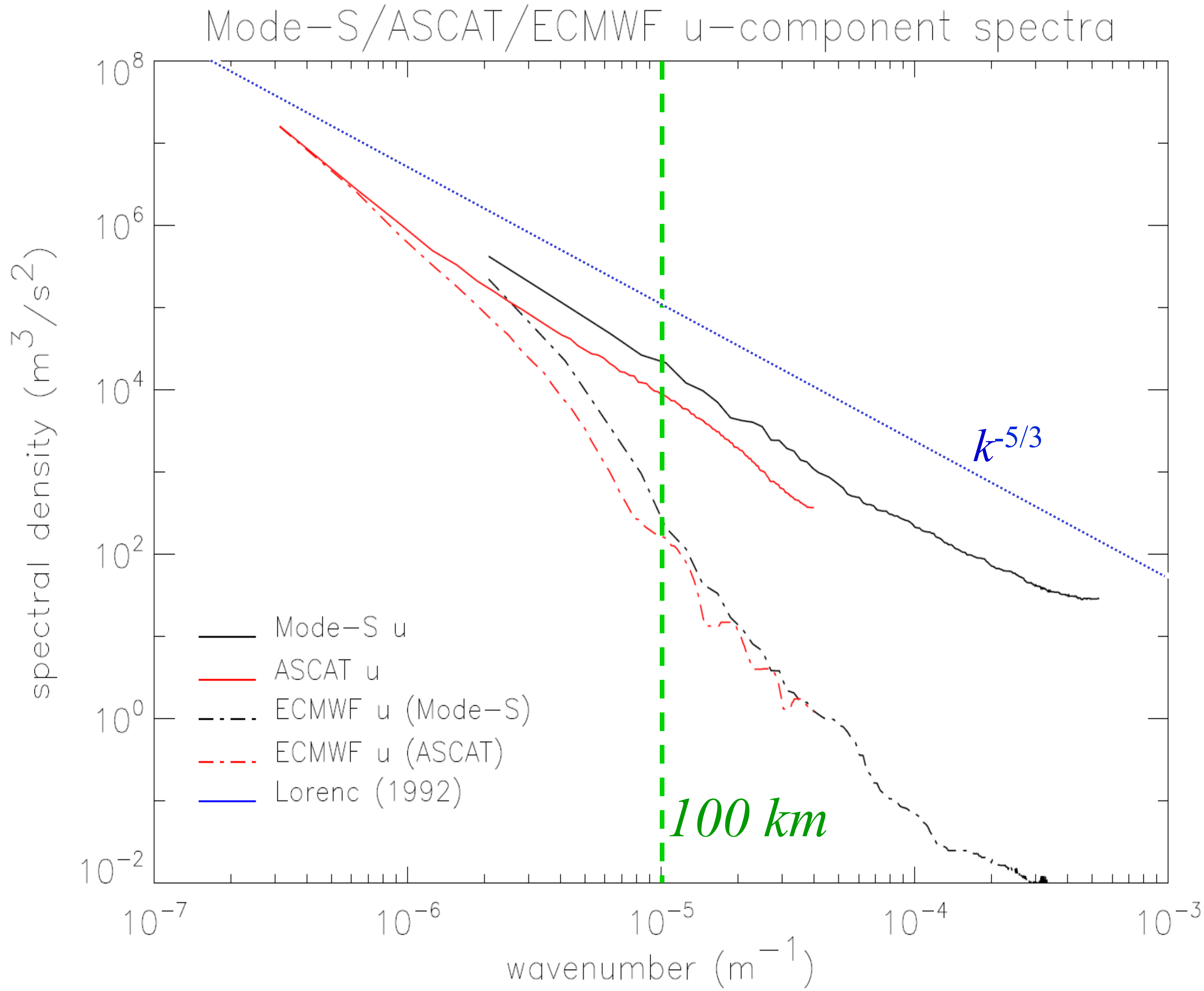
- ASCAT contains small scales down to 25 km, close to $k^{-5/3}$
- ECMWF maintains ~ k^{-3} (2D turb.)

➢ Order of magnitude deficit at 100-km scale

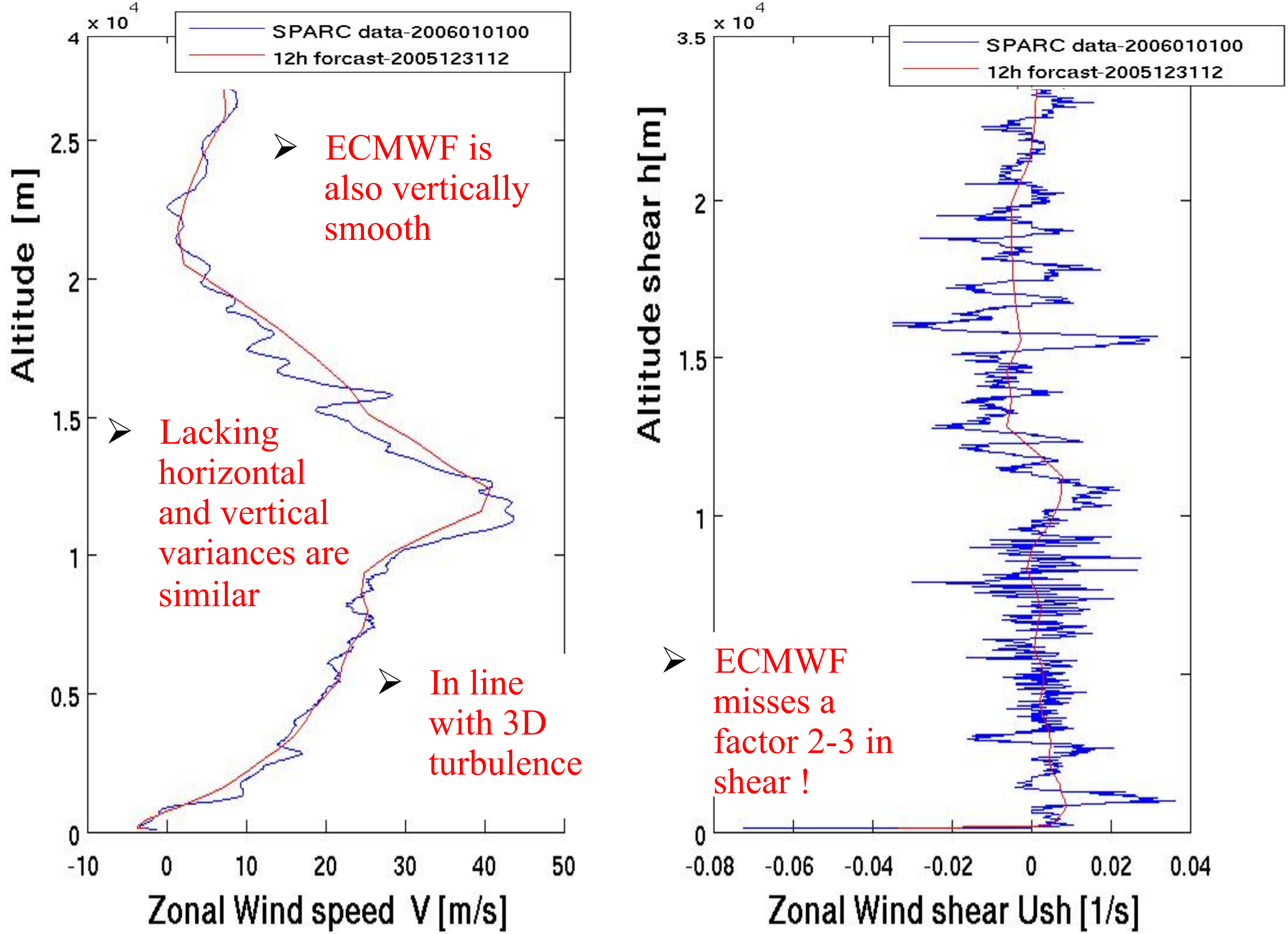
➢ It appears no problem to average Aeolus to 100 km for global NWP

➢ Height dependent ?

ASCAT/Mode-S/ECMWF spectra u-component



- "Dutch" spectra at 11km height are more energetic than global surface wind spectra, as anticipated
- "Dutch" Mode-S aircraft spectra show some red noise below 10km scale
- ECMWF spectra behave very similar w.r.t. Mode-S and ASCAT observations
- Effective ECMWF model resolution may be rather uniform with height



Houchi et al., 2010

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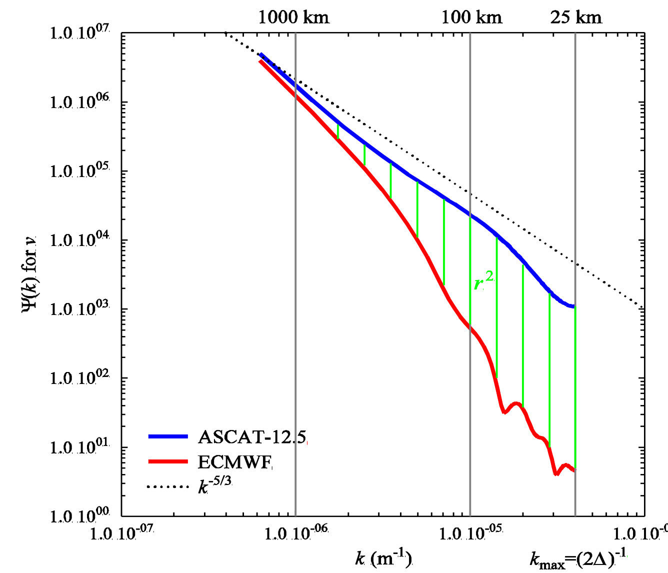
Triple collocation result

	u	v
Bias ASCAT (m/s)	0.15	-0.02
Bias ECMWF (m/s)	0.28	0.08
Trend ASCAT	1.01	1.01
Trend ECMWF	1.03	1.04
σ ASCAT (m/s)	1.05	1.29
σ ECMWF (m/s)	1.28	1.14
Representation error	0.79	1.00



Representation error from spectrum difference integrated from k^{-1}=25 km to k^{-1}=800 km included in scat

- Wind representation error is substantial
- Wind representation error is spatially correlated
- Needs to be accounted for in data assimilation

How to determine B and R from (o-b)?

Lorenc (1986): "*t* is the vector of coefficients obtained by projecting the true state of the atmosphere onto the model basis"

➢ ***t*, *b* and *a* have similar spectra**

- Separate *o* error and *b* error from (o-b) statistics

$$\langle o_{\text{data}} - b \rangle^2 = \langle (o_{\text{data}} - t) - (b - t) \rangle^2$$

$$= \langle o_{\text{data}} - t \rangle^2 + \langle b - t \rangle^2 - 2\langle o_{\text{data}} - t \rangle \langle b - t \rangle$$

$$= \langle o_{\text{data}} - o_s \rangle^2 + \langle o_s - t \rangle^2 + \langle b - t \rangle^2 - 2\langle o_{\text{data}} - t \rangle \langle b - t \rangle + 2\langle o_{\text{data}} - o_s \rangle \langle o_s - t \rangle$$

o_s is the spatial average of *o* along the track

$$= \langle o_{\text{data}} - o_s \rangle^2 + \langle o_s - t \rangle^2 + \langle b - t \rangle^2$$

instrument error variance (white noise)

representativeness error variance ("small" scales in o_s not in *t*)

background error variance (large scales in both *b* and *t*)

- Random instrument error is independent from random representativeness error, since the latter represents by definition unobserved scales
- Random observation error is independent from model error as the model error is specified on NWP model resolved scales only and observation error on smaller scales

➢ Random instrument errors should not be correlated on model scales (e.g., by air mass)

Suitable "uncorrelated " obervations

$$\langle o_{\text{data}} - b \rangle^2 = \langle o_{\text{data}} - o_s \rangle^2 + \langle o_s - t \rangle^2 + \langle b - t \rangle^2$$

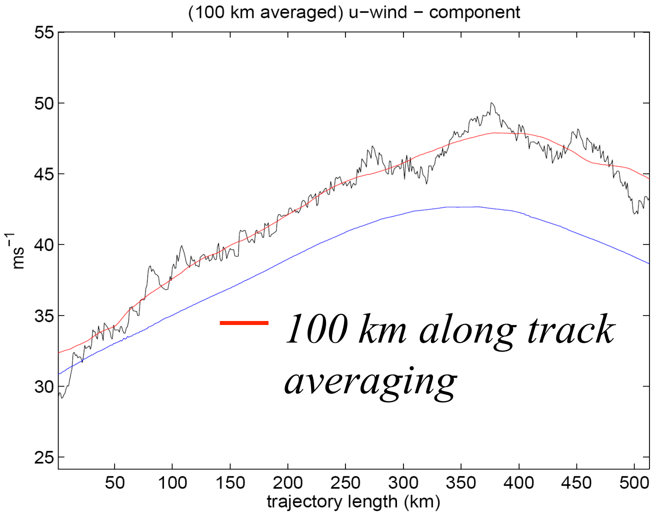
O: instrument error variance (white noise)

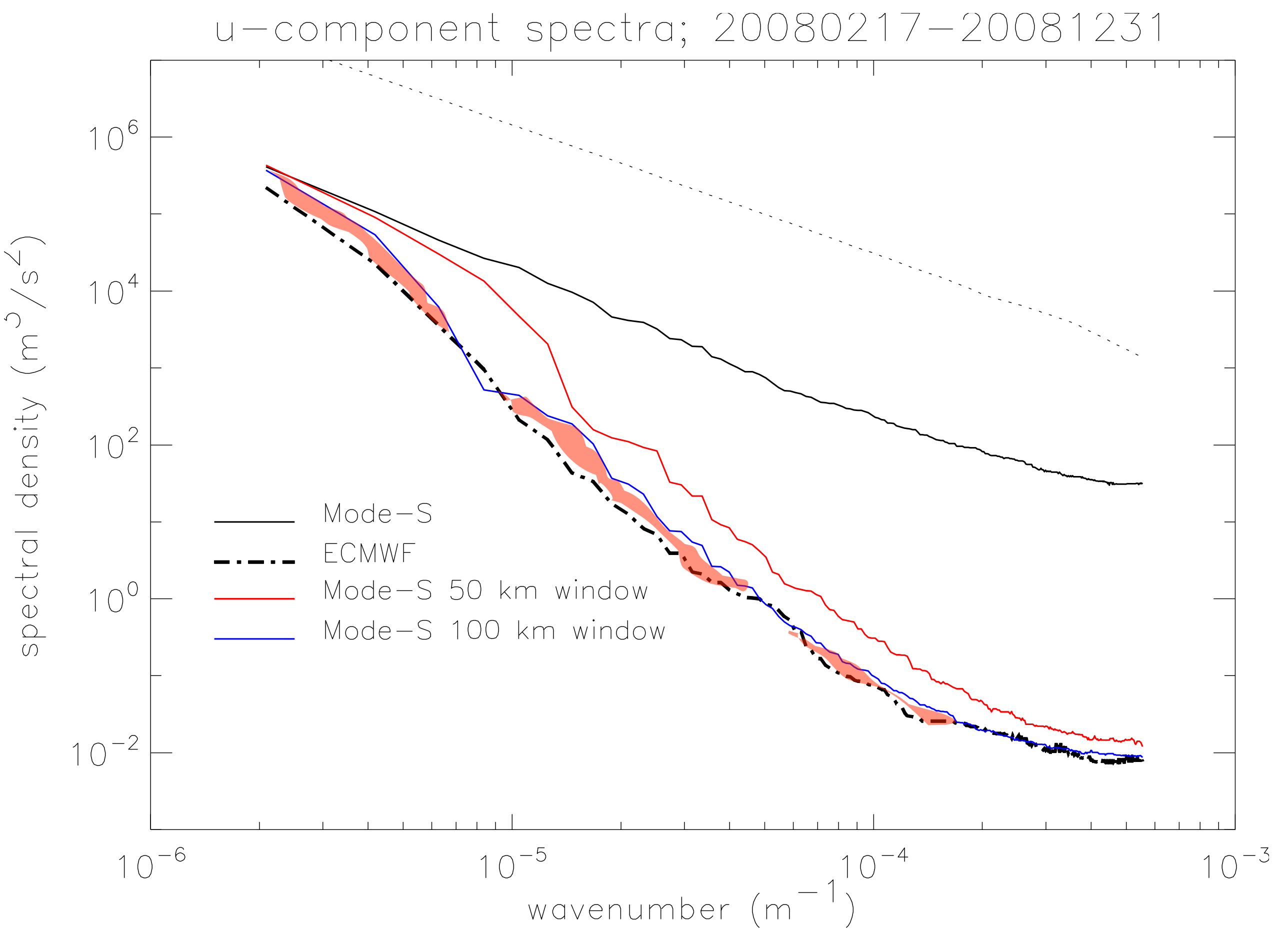
F: representativeness error variance ("small" scales in o_s not in t)

B: background error variance (large scales in both b and t)

- ➢ We need them both vertically and horizontally
- (o-b) from high-resolution aircraft (Mode-S), scatterometer, high-resolution radiosonde, ECMWF, HiRLAM
- Main challenge: how to determine the characteristics of *t (model basis true state)* ?
- If *t* is known than the correlation lengths scales of ***R=O+F*** and ***B*** can be determined.

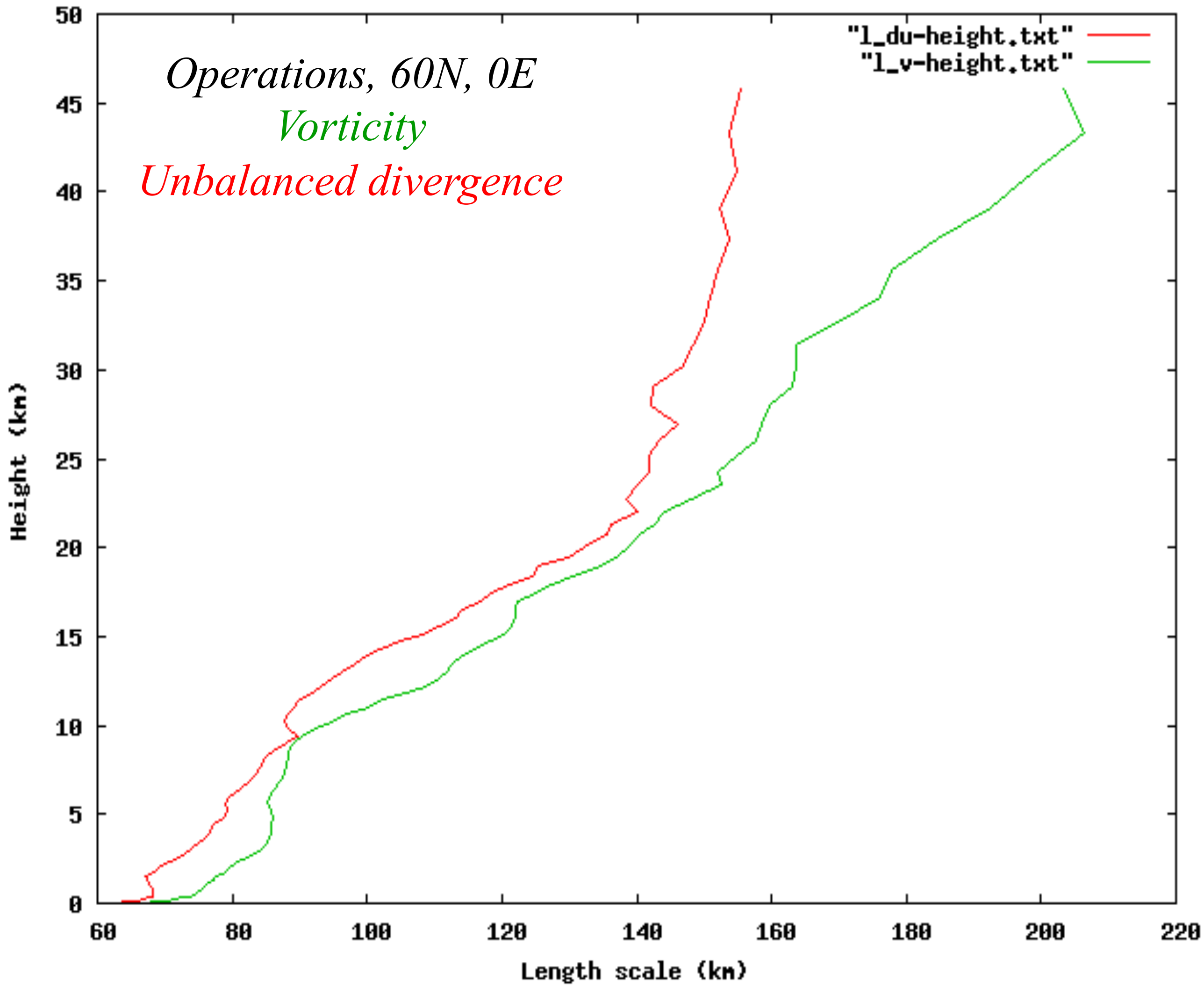
Atmosphere accumulation over 100 km





- ➢ **Along-track averaging over > 100 km closely simulates the model truth spectrum**
- ➢ **100-km averaging would reduce the representativeness error variance (F) and the observation error (O), thus R**

ECMWF horizontal length scales in B



- Synthetic
- Both similar
- Height dependent

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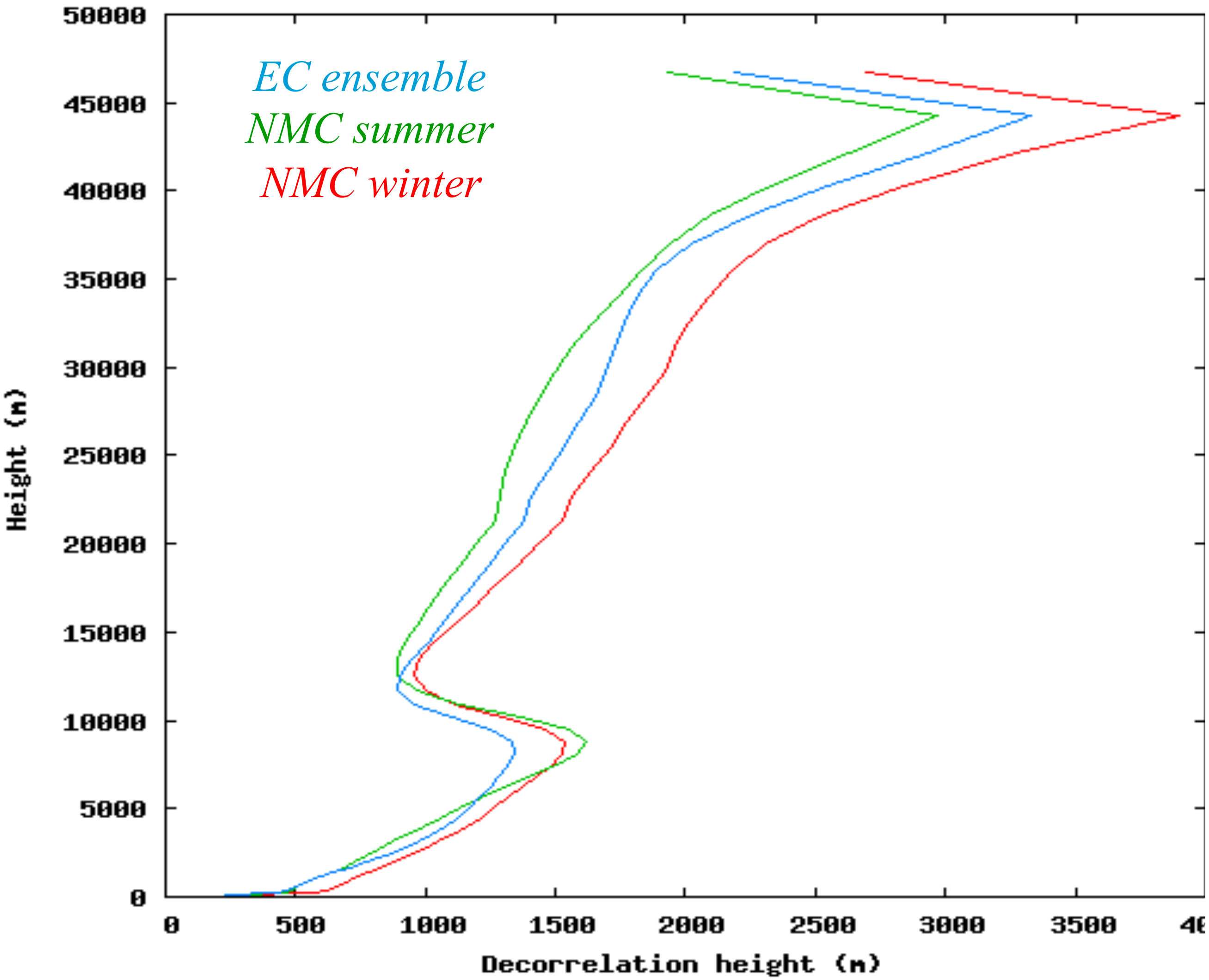
Preliminary

Depth scales in B



- Synthetic
- All similar
- Height dependent

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Summary

- Although CM is really different from BM and does not meet the current Aeolus wind performance specification, the CM provides more flexibility (no BRC boundaries) in data processing and assimilation; we need to investigate the potential benefits
- CM mission exploitation requires new research on data assimilation and impact in both regional and global NWP models
- Study items for regional and global models
  - Spatial representativeness errors
  - B scales, L(h), D(h)
  - Assimilate spatially irregular and correlated data (in a 2D plane)
  - Impact (OSSE, SOSE, EnDA)
- Investigate more fundamental L2B software updates with flexibility in QC and spatial processing
- Work in progress in Aeolus VHAMP, L2Bp and ECMWF impact projects

THANKS !

Comparison of SeaWinds with ECMWF and buoys

All triple collocation data from January 2008

	SDP at 25 km		SDP at 100 km	
	σ_u (m/s)	σ_v (m/s)	σ_u (m/s)	σ_v (m/s)
ECMWF	1.87	1.83 >	1.57	1.48
Buoys	1.79	1.88 <	2.17	2.06

When going to coarser resolution

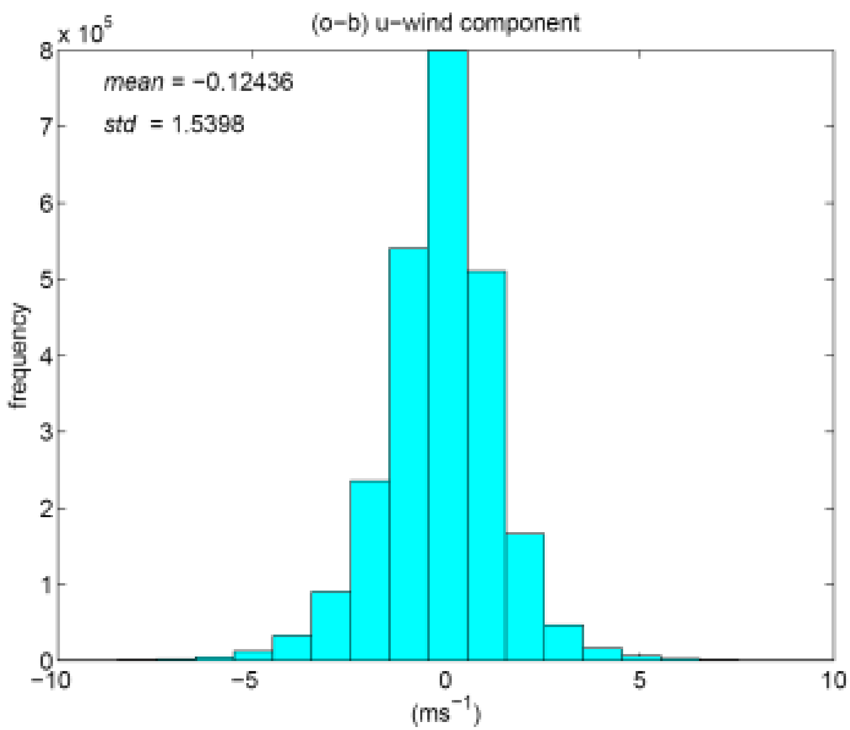
⇒ *Agreement with model increases by 2,19 m2/s2 for wind vector*

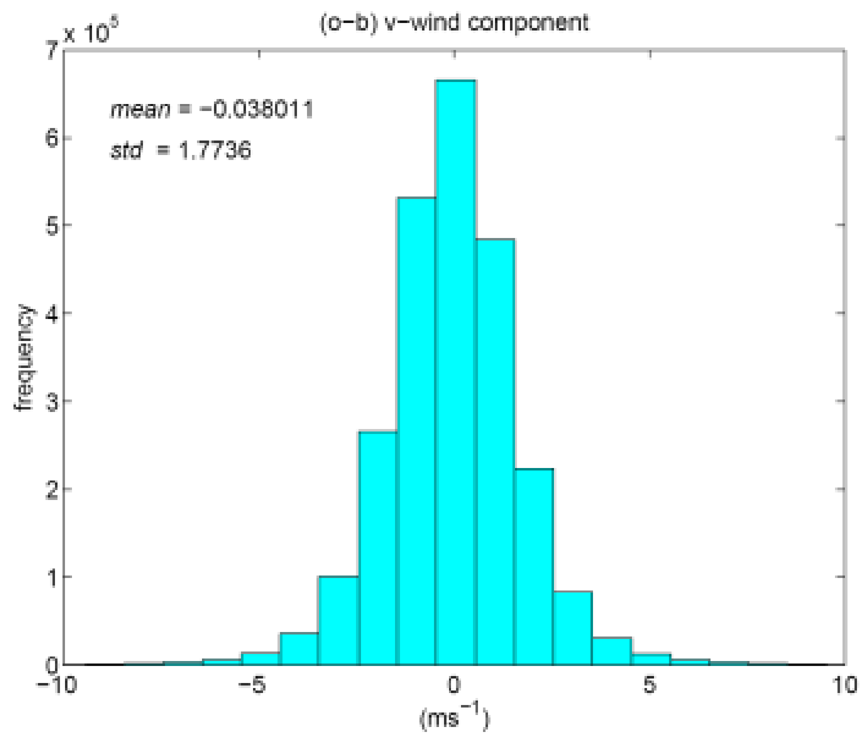
⇒ *Agreement with buoys decreases by 2,21 m2/s2 for wind vector*

⇒ *In line with spectral analysis*

Application to ASCAT

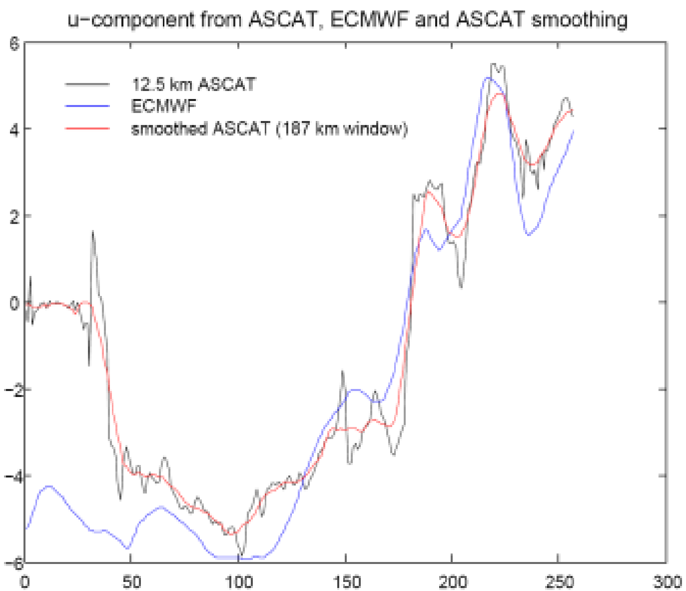
- 3 month ASCAT/ECMWF data: 1/10/2008 – 31/12-2008
- (o-b) statistics for u and v wind components; global coverage

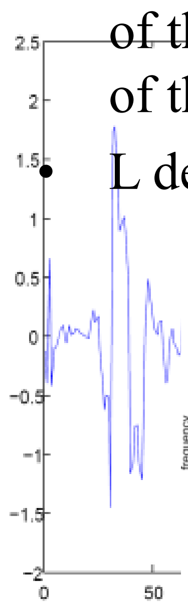


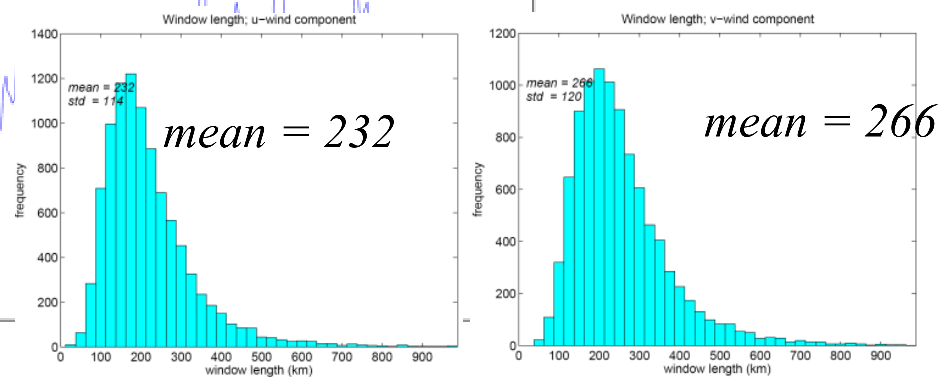


Proxy truth

- Data averaging along a satellite track
  - Window length (L) is such that the spectrum of the averaged data is close to the spectrum of the corresponding model data
  - L depends on local atmospheric conditions







Mean averaging for u/v of 232/266 km is larger than nominal Aeolus averaging of 100 (troposphere)-140 (stratosphere) km

➢ Aeolus CM contains scales not represented by the model ⇒ representativeness error

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Aeolus CM wind sampling

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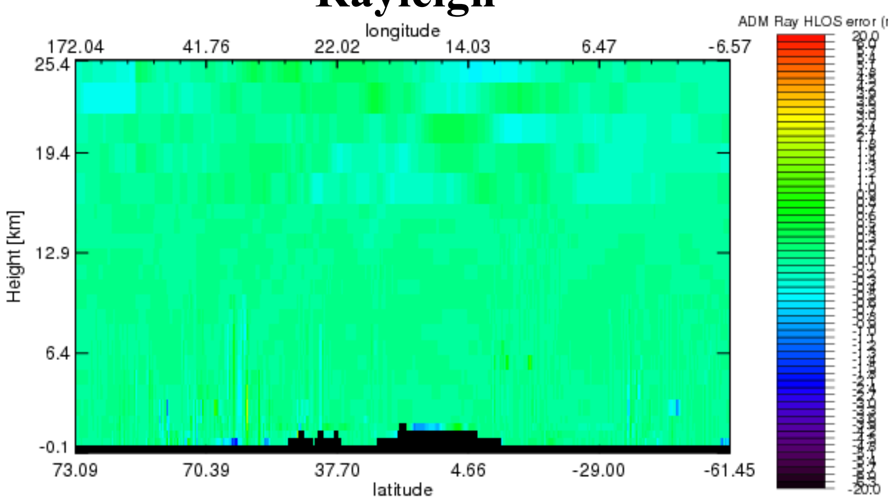
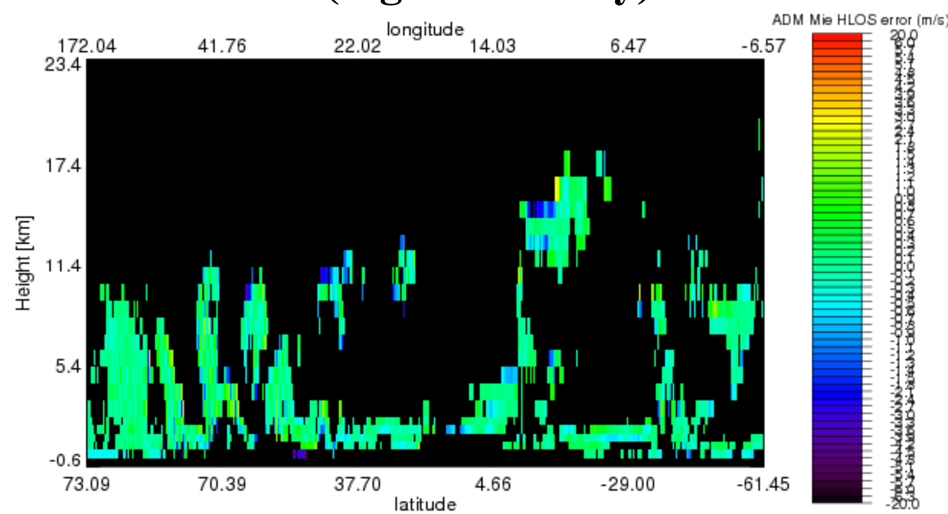
- The Rayleigh molecular channel is the Aeolus work horse: it provides rather continous sampling of the atmosphere with rather homogeneous error (but for sensitivity to particle contamination lower down)
- The Mie particle channel provides good signal in the PBL and also on cloud and aerosol elsewhere but this is relatively sparse (concerns exist for cloud-associated dynamics and optical heterogeneity)
- How to combine both channels is TBD in the Aeolus L2B project

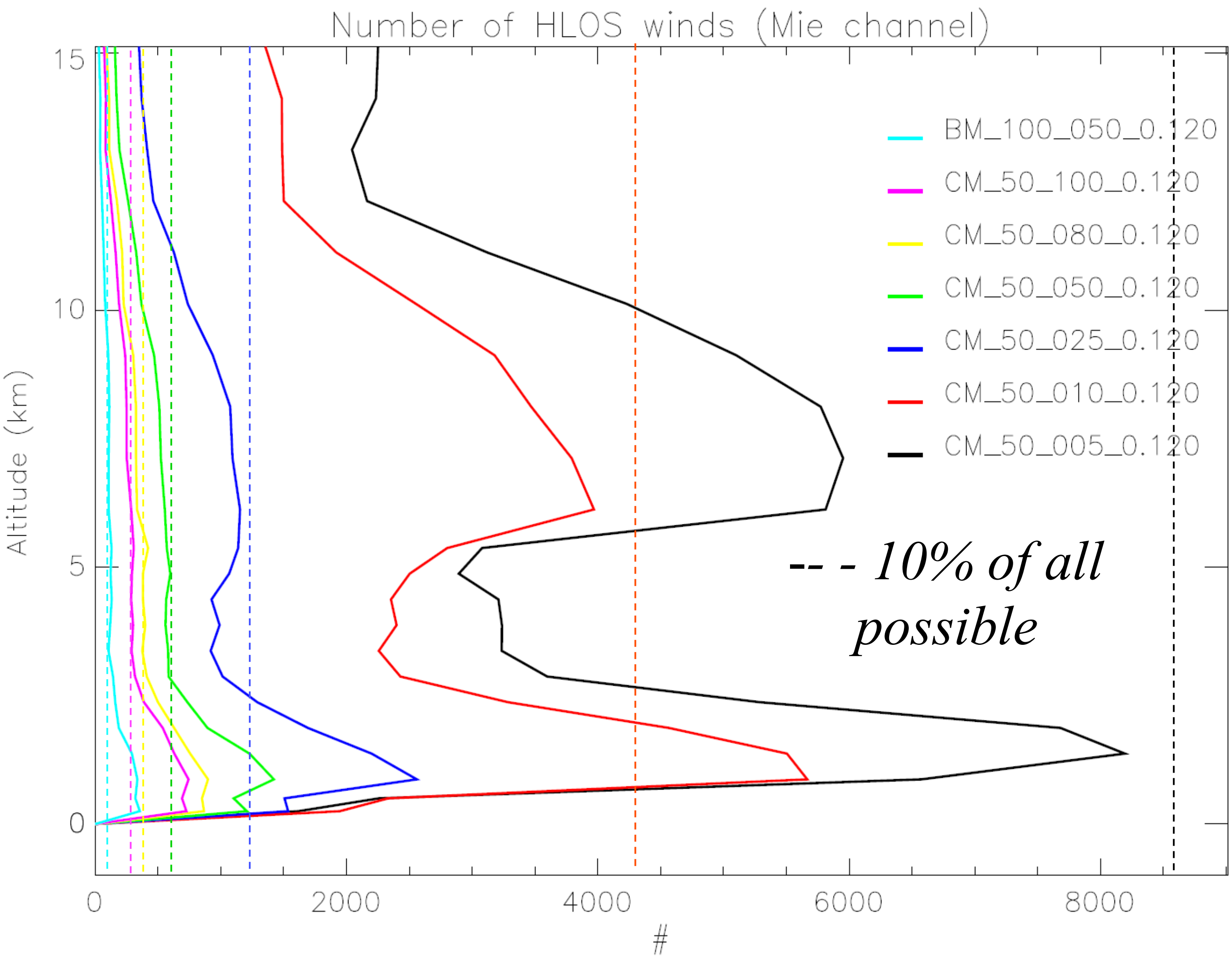
Rayleigh



Mie (high SNR only)

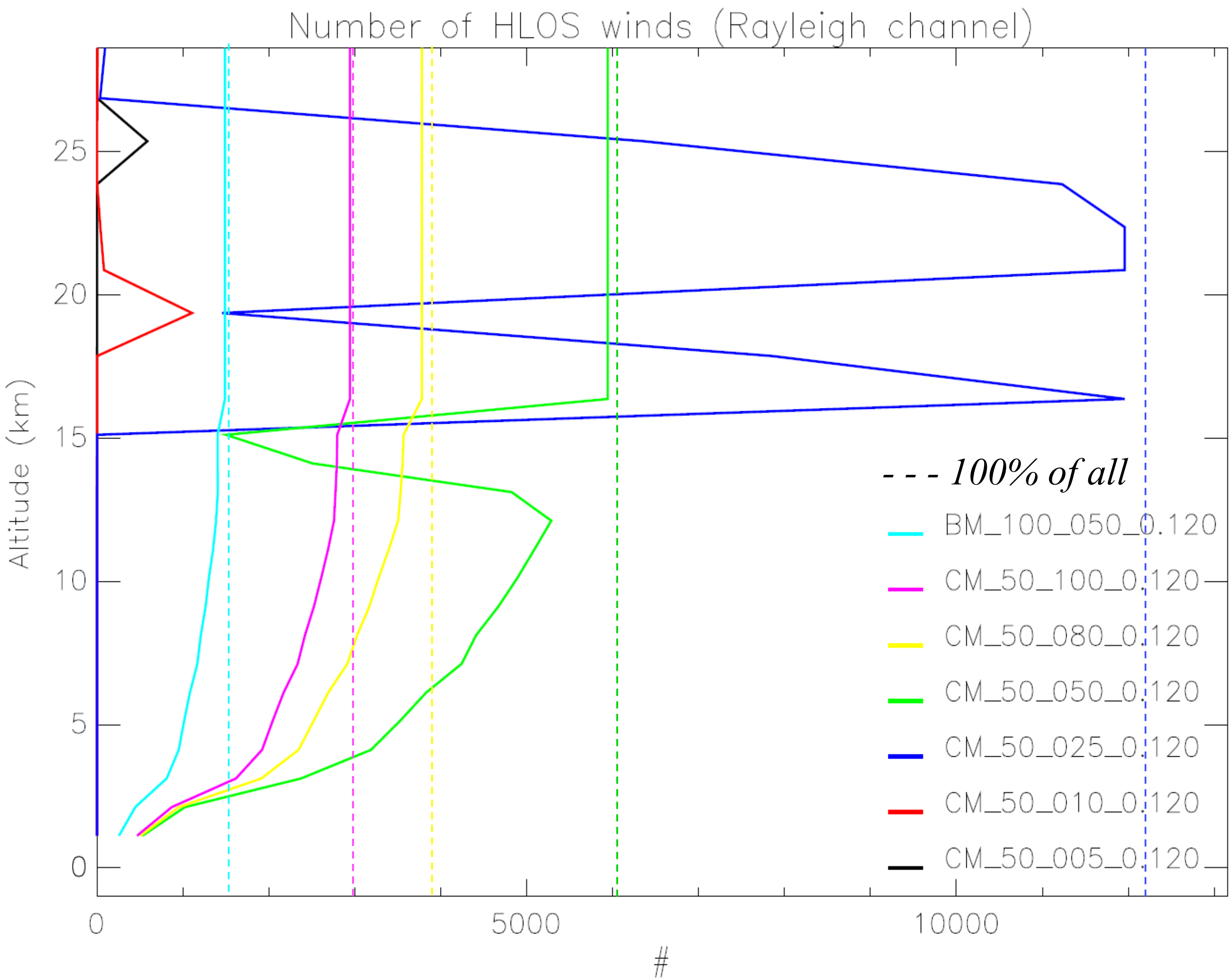


Mie wind coverage



- *Mie in ~10% of cases in Upper Trop.*
- *At each UT level 90% of scenes has no Mie wind*
- *Mie provides no full profiles generally*
- *CM yields substantially more Mie winds than BM*
- *3.5 km accumulation is often sufficient to get a good quality Mie wind.*

Rayleigh winds



- *High percentage of winds*
- *For the sampling scenario used, at least 80 km accumulation is needed for good quality*
- *Depends on laser energy*

Aeolus sampling

- Model error vertical correlation length and depth scales are guiding in the horizontal and vertical positioning of the Aeolus bins, e.g.,
    - Denser vertical sampling at levels where the B-matrix vertical depth scales are small and horizontal length scales are large (UTLS, stratosphere)
    - Accumulation length and depth variation may be a function of height
- Spatial representativeness error is important, particularly its spatial extent
- Observed wind data may be spatially irregular due to varying aggregation at different heights; is this problematic ?

➢ VHAMP and Aeolus wind processor studies ongoing to further investigate this.

Preliminary CM Conclusions

- CM does not meet the Aeolus specifications
- CM however offers more flexibility for spatial processing and QC and its potential needs scientific elaboration
- Aeolus CM characteristics have been briefly studied
  - Rayleigh winds are everywhere, but essentially SNR driven
  - Mie winds are sparse (at 10% level), but potentially dense in cloudy layers
- Laser power degradation (33%) would severely compromise the quality of Rayleigh winds and the number of Mie winds
- Mie winds are potentially available on small scales and rather heterogeneous
- NWP data assimilation of CM offers some challenges since adjacent observations can no longer be assumed independent:
  - 3D representativeness error correlation
  - How to assimilate dense wind observations of rather homogeneous quality in a 2D plane ?
- Few studies exists on spatial aggregation and data assimilation.