Sampling Aeolus Winds for Data Assimilation

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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

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

\( \delta b \) : random background error, spatially correlated

\( W \) : weight, depends on “average” covariances of \( \delta o \) in a matrix \( R=O+F \) and \( \delta b \) 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,
\( \varepsilon \) the energy dissipation rate; troposphere mean: \( 7.76 \times 10^{-5} \text{ m}^2\text{s}^{-3} \)
\( k \) is the wave number in \( \text{m}^{-1} \)
- Integrated variance and spatial structure function
  \[ e(r) = \frac{3}{2} C \varepsilon^{2/3} r^{2/3} \]

➢ Representation error for point observation
  Mathieu & Scott (2000); Lindborg (1999); Nastrom & Gage (1987)
Tropospheric spectra are close to $k^{-5/3}$ below 500 km

- 3D turbulence
- $L/H \sim 100$
- SD(log spectral density) = 0.4

Nastrom and Gage (1985), Lindborg, (1999), ...
NWP deficit over the ocean

- ASCAT contains small scales down to 25 km, close to $k^{-5/3}$
- ECMWF maintains $\sim k^{-3}$ (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
ECMWF is also vertically smooth.

In line with 3D turbulence.

ECMWF misses a factor 2-3 in shear!

Lacking horizontal and vertical variances are similar.

Houchi et al., 2010
## Triple collocation result

<table>
<thead>
<tr>
<th></th>
<th>$u$</th>
<th>$v$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bias ASCAT (m/s)</td>
<td>0.15</td>
<td>-0.02</td>
</tr>
<tr>
<td>Bias ECMWF (m/s)</td>
<td>0.28</td>
<td>0.08</td>
</tr>
<tr>
<td>Trend ASCAT</td>
<td>1.01</td>
<td>1.01</td>
</tr>
<tr>
<td>Trend ECMWF</td>
<td>1.03</td>
<td>1.04</td>
</tr>
<tr>
<td>$\sigma$ ASCAT (m/s)</td>
<td>1.05</td>
<td>1.29</td>
</tr>
<tr>
<td>$\sigma$ ECMWF (m/s)</td>
<td>1.28</td>
<td>1.14</td>
</tr>
<tr>
<td>Representation error</td>
<td>0.79</td>
<td>1.00</td>
</tr>
</tbody>
</table>

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

Representation error from spectrum difference integrated from $k^{-1}=25$ km to $k^{-1}=800$ km included in scat
How to determine B and R from (o-b)?

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

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

\[
= \langle o_{data} - t \rangle^2 + \langle b - t \rangle^2 - 2 \langle o_{data} - t \rangle \langle b - t \rangle \\
= \langle o_{data} - o_s \rangle^2 + \langle o_s - t \rangle^2 + \langle b - t \rangle^2 - 2 \langle o_{data} - t \rangle \langle b - t \rangle + 2 \langle o_{data} - o_s \rangle \langle o_s - t \rangle
\]

- 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)

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

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

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 $t$)
Suitable “uncorrelated “ observations

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

- 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 \(t\))

- 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.


- 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

Operations, 60N, 0E

Vorticity
Unbalanced divergence

Harald Schyberg, MetNo
Preliminary
Depth scales in B

- Synthetic
- All similar
- Height dependent

Harald Schyberg, MetNo
Preliminary
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

<table>
<thead>
<tr>
<th></th>
<th>SDP at 25 km</th>
<th>SDP at 100 km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\sigma_u$ (m/s)</td>
<td>$\sigma_v$ (m/s)</td>
</tr>
<tr>
<td>ECMWF</td>
<td>1.87</td>
<td>1.83</td>
</tr>
<tr>
<td>Buoys</td>
<td>1.79</td>
<td>1.88</td>
</tr>
</tbody>
</table>

When going to coarser resolution

- Agreement with model increases by 2.19 m$^2$/s$^2$ for wind vector
- Agreement with buoys decreases by 2.21 m$^2$/s$^2$ 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
The Rayleigh molecular channel is the Aeolus work horse: it provides rather continuous 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
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.