Spectral correction to recover full 10min variability from hourly mesoscale data

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Motivation

Mesoscale models play increasing role in resource assessment
But mesoscale data are NOT measured 10min data
Can mesoscale data be used as is directly in energy assessments?
Contents

- Intro - Spectrum of wind variability
- Problem - too smooth mesoscale data
- Solution - correct and extrapolate spectrum
- Results
- Conclusion
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Spectrum of wind variability

Wind varies on a wide range of spatial and temporal scales

- Wind data: 10min averages

From: [http://apollo.lsc.vsc.edu/classes/met130/](http://apollo.lsc.vsc.edu/classes/met130/)
Wind varies on a wide range of spatial and temporal scales

- Wind data: 10min averages
- Main scales 10min - 1 year:
  - Global scale \((7 - 365\) days)
  - Synoptic scale \((2 - 7\) days)
  - Mesoscale \((\frac{1}{24} - 2\) days)
  - (Microscale) \((< \frac{1}{24} \) days)

Stull (2000) and Fiedler (1970)

From: http://apollo.lsc.vsc.edu/classes/met130/
Why is the wind variance important?

- Wind power is proportional to wind speed cubed: \( P \propto u^3 \)
- Increased variance means more power (at same average wind speed)
- Mean wind speed is also important – but not the focus of this study
What does a wind speed spectrum look like?
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- Wind measurements - Cabauw mast (3 years, 80m agl):
- “Raw” FFT (variance contribution of each frequency bin)
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- “Raw” FFT (variance contribution of each frequency bin)
What does a wind speed spectrum look like?

- Wind measurements - Cabauw mast (3 years, 80m agl):
- “Smoothed” FFT
What does a wind speed spectrum look like?

- Wind measurements - Cabauw mast (3 years, 80m agl):
- Linear trend (log-log), $f > 1$ days$^{-1}$

\[
\alpha \approx -\frac{5}{3}
\]

\[\text{e.g. Xiaoli (2012)}\]
Spectrum of wind variability

Relation between spectrum and variance?

- Variance = integral of $S(f)$ for all $f$

\[ \sigma^2 = \int_{f_{\text{min}}}^{f_{\text{max}}} S(f) df \]
Relation between spectrum and variance?

- Variance = integral of $S(f)$ for all $f$
  \[ \sigma^2 = \int_{f_{\text{min}}}^{f_{\text{max}}} S(f) df \]
- Cumulative Spectrum = integral of $S(f)$ up to $f_0$
  \[ \sigma_{\text{cum}}^2 (f_0) = \int_{f_{\text{min}}}^{f_0} S(f) df \]

Spectrum of wind variability
Spectrum of wind variability

Relation between spectrum and variance?

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\[
\sigma_{cum}^2 (f_0) = \int_{f_{min}}^{f_0} S(f) df
\]
Spectrum of wind variability

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\[ \sigma_{\text{cum}}^2(f_0) = \int_{f_{\text{min}}}^{f_0} S(f) df \]

Note: No smoothing applied!
Just integration
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The problem

Mesoscale model problems – time domain

- Model data too smooth compared to measurements
The problem

Mesoscale model problems – time domain

- Model data too smooth compared to measurements
- Model data (often) sampled hourly, but measurements 10min
The problem

Mesoscale model problems – frequency domain (spectrum)

- Problem 1: Spectrum may have too high damping at high frequencies
Mesoscale model problems – frequency domain (spectrum)

- Problem 1: Spectrum may have too high damping at high frequencies
- Problem 2: Spectrum does not cover highest frequencies (if hourly sampled)
Mesoscale model problems – frequency domain (spectrum)

- Problem 1: Spectrum may have too high damping at high frequencies
- Problem 2: Spectrum does not cover highest frequencies (if hourly sampled)
- Problem 3: Spectrum may have errors in ‘main ranges’ (meso, synoptic, global)
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The solution

Solution 1: Correct damping of highest frequencies

- Apply ‘inverse’ damping filter’
  (Note: not required for all mesoscale data/models, e.g. ‘EMD-WRF EUR+ (ERA5)’)
The solution

Solution 1: Correct damping of highest frequencies
Solution 2: Extrapolate spectrum to recover high frequencies
  ▪ Utilize linear nature (in log-log) to extrapolate to 10min
The solution

Solution 1: Correct damping of highest frequencies
Solution 2: Extrapolate spectrum to recover high frequencies
Solution 3: Correct shape of spectrum in main ranges
  ▪ Correct the amount of variance in each main range
The solution

Example (time domain)

- Obs: Cabauw  Vs  Mod: EMD-WRF Europe+  Vs  Mod+Cor. 2+3 (cor. 1 not needed)
Example (time domain)

- **Obs: Cabauw** Vs **Mod: EMD-WRF Europe+** Vs **Mod+Cor. 2+3 (cor. 1 not needed)**

The solution
The solution

Example (cumulative spectrum)

- **Obs: Cabauw**  Vs  **Mod: EMD-WRF Europe+**  Vs  **Mod+Cor. 2+3 (cor. 1 not needed)**
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What is the effect of spectral correction?

- 8 masts from 100km offshore to 100km onshore (2-8 years)
- Errors quantified relative to corrected data to focus on spectral effects
- Hence, errors on mean wind speed are avoided
What is the effect of spectral correction?

- Error on total variance (if uncorrected):
What is the effect of spectral correction?

- Error on total variance (if uncorrected):

- Ca. -5% offshore
- Up to +28% onshore
What is the effect of spectral correction?

- Error on total energy $\langle u^3 \rangle$ (if uncorrected):

```plaintext
<table>
<thead>
<tr>
<th>Offshore</th>
<th>Distance to coast [km]</th>
<th>Onshore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error if uncorrected [%]</td>
<td>0</td>
<td>50</td>
</tr>
</tbody>
</table>
```

Results
What is the effect of spectral correction?

- Error on total energy $\langle u^3 \rangle$ (if uncorrected):
  
  AEP error ca. 20-50% of total energy error

- Total energy $\langle u^3 \rangle$ error:
  - Ca. -3% offshore
  - Up to +10% onshore

- AEP error:
  - Ca. 1% offshore
  - Up to 5% onshore
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Conclusion

Spectrum of mesoscale data - summary

Problems:
- 1) Mesoscale data may be dampened too much for $f > 1 \text{ day}^{-1}$
- 2) Mesoscale data mostly sampled hourly
- 3) Mesoscale data may have erroneous variance in ‘main ranges’
Spectrum of mesoscale data - summary

Problems:
- 1) Mesoscale data may be dampened too much for $f > 1 \text{ day}^{-1}$
- 2) Mesoscale data mostly sampled hourly
- 3) Mesoscale data may have erroneous variance in ‘main ranges’

Presented solutions:
- 1) Correct damping by applying ‘inverse damping filter’
- 2) 10min samples recovered by extrapolating spectrum (linear in log-log)
- 3) Re-shape amount of variance in main ranges

Conclusion
Conclusion

So can mesoscale model data be used as is for AEP?
Conclusion

So can mesoscale model data be used \textit{as is} for AEP?

- \textbf{onshore}:
  - \textbf{No} - spectral errors result in up to 28% error on variance and up to 5% on AEP
  - Full spectral correction recommended
So can mesoscale model data be used as is for AEP?

- **onshore:**
  - No - spectral errors result in up to 28% error on variance and up to 5% on AEP
  - Full spectral correction recommended

- **offshore:**
  - Yes – spectral errors result in up to 5% error on variance and up to 1% on AEP
  - But solution 2 is recommended to recover 10min data for consistency with 10min measurements
Thanks for the attention!

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