Evaluation of the WRF Stochastic Kinetic Energy Backscatter scheme for wind resource assessment

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Motivation

• Investigate new methods for generating long-term reference time series for wind resource assessment.
• Can the uncertainty in mesoscale-model-based reference time series be significantly reduced using ensemble methods?
GL GH Virtual Met Data (VMD) system

- **WRF Model**: The cornerstone of VMD.
- High-resolution long-term reference data sets for any location in the world.
- VMD incorporates both deterministic (standard) and ensemble downscaling capabilities.
  - Stochastic kinetic energy backscatter
  - Multiphysics
  - Analog ensemble

VMD simulation for 1300 UTC 30 June 2007
New high-resolution inputs to VMD

Measurement-based inputs continuously steer the model analyses toward the true state of the atmosphere.

- MERRA (~50 km)
- Sea surface temp
- Snow cover / sea ice
- Soil moisture
- Terrain elevation
- Land cover
- Soil temperature
- MERRA (~50 km)
- Sea surface temp
- Snow cover / sea ice
- Soil moisture
- Terrain elevation
- Land cover
- Soil temperature
Stochastic kinetic-energy backscatter ensemble (SKEB)

**Underlying principle:**
Multiple possible states of the unresolved scales corresponding to a given state of the resolved variables; each unresolved state may feed back differently to the resolved scales.

**GOAL:** Account for energy at unresolved scales

Inject KE into simulation from unresolved scales

11 parallel WRF Model forecasts executed, each perturbed by SKEB

- Original 60 h fcst
- Single SKEB perturbation
- Original fcst minus SKEB fcst

- Random perturbations introduced from a prescribed KE spectrum, consistent with the flow-dependent structure of resolved features. Introduced at every time step to $u$, $v$, $T$ fields.

Source: National Geographic

Underlying principle:
Multiple possible states of the unresolved scales corresponding to a given state of the resolved variables; each unresolved state may feed back differently to the resolved scales.
Key tuning parameters for SKEB

• Perturbation strength (energy “feedback” from unresolved scales)
  ▪ Backscattered energy rate for u,v (tot_backscat_psi)
  ▪ Backscattered energy rate for T (tot_backscat_t)

• Choosing the appropriate perturbation strengths
  ▪ **GOAL**: Achieve a “reasonable” ensemble spread while minimizing the RMSE of the individual ensemble members.
  ▪ Default settings (WRF 3.4.1) appear to have little impact on small scale variations for winds and temperature at hub height on ~2 km grids (about an order of magnitude too small).
Evaluation of SKEB relative to a well-established method

**Multiphysics ensemble:** Run WRF with different physics suites

**Stochastic kinetic energy backscatter ensemble:** Inject kinetic energy into simulation from unresolved scales.

**GOAL:** Account for energy at unresolved scales
# Multiphysics ensemble members

Approximate intersection of Hacker et al. (2011, Tellus) and Lee et al. (2012, MWR)

<table>
<thead>
<tr>
<th>Member</th>
<th>Land Surface</th>
<th>Surface layer</th>
<th>PBL</th>
<th>Microphysics</th>
<th>Cumulus</th>
<th>Long-wave</th>
<th>Short-wave</th>
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<td>Grell</td>
<td>RRTMG</td>
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</tr>
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</table>
Performance of the ensemble methods

• Evaluation at 2 complex sites, each having several masts with high quality instruments at 60 or 80 m AGL.
  ▪ California.
    o Highly complex wind regime and very complex terrain.
  ▪ Northeast U.S.
    o Complex terrain and forested.

• Simulation details.
  ▪ Nested 10 km – 2 km grid configuration.
  ▪ A complete 2-year time series.

• Demonstrate improvements by calibrating output to site data using an optimized ensemble combination technique.
Site specific examples
Mast 1: California

- **Standard VMD**: $R^2 = 0.82$
- **Stochastic backscatter uncalibrated**: $R^2 = 0.85$
- **Multiphysics calibrated**: $R^2 = 0.88$
- **Stochastic backscatter calibrated**: $R^2 = 0.88$

Calibration applied to non-training data

Year 2 daily mean wind speeds
**Mast 1: California**

\[
GFE = \frac{1}{nbins} \sum \left| \frac{% \text{simulated} - % \text{observed}}{% \text{observed}} \right|
\]

Year 2 daily mean wind speeds

- **GFE = 64 %**
  - MEASURED
  - MERRA
- **GFE = 29 %**
  - MEASURED
  - Standard VMD
- **GFE = 27 %**
  - MEASURED
  - Multiphysics
- **GFE = 37 %**
  - MEASURED
  - Stochastic Backscatter

Calibration applied to non-training data
**Mast 2: Northeast U.S.**

<table>
<thead>
<tr>
<th>Measurements</th>
<th>R²</th>
<th>Measurements</th>
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<tbody>
<tr>
<td>Standard VMD</td>
<td>0.82</td>
<td>Stochastic backscatter</td>
</tr>
<tr>
<td>Multiphysics calibrated</td>
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Calibration applied to non-training data

Year 2 daily mean wind speeds
Mast 2: Northeast U.S.

$$GFE = \frac{1}{nbins} \sum \left| \frac{\% \text{ simulated} - \% \text{ observed}}{\% \text{ observed}} \right|$$

Year 2 daily mean wind speeds

Calibration applied to non-training data
Overall results for ensemble methods

Improvement over standard VMD

Year 2 daily mean wind speeds

Calibration applied to non-training data
Overall results for ensemble methods

Improvement over standard VMD

Year 2 daily mean wind speeds

Calibration applied to non-training data
Concluding remarks and next steps

- Both ensemble methods decrease uncertainty in the downscaling results, in terms of improving the goodness-of-fit to site data, with a slight edge to multiphysics.
- In terms of RMSE, multiphysics ensemble appears to outperform SKEB at these 11 sites,
  - Our choice of SKEB tuning parameters may need refinement.
- SKEB-based ensemble system may be easier to maintain.

**Next steps**

- Actively testing a new computationally efficient analog ensemble method (Delle Monache et al, 2011; 2013).
- Develop and implement ensemble variance calibration to provide statistically reliable confidence intervals.
Thank you

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Example improvements to the virtual time series

- Ensemble Members
- Uncalibrated ensemble mean
- Calibrated ensemble means
- Measurements

N = 11 members

Stochastic backscatter

Multiphysics

Calibration applied to non-training data
Example improvements to the virtual time series

N = 11 members

Wind Speed

Ensemble Members  Uncalibrated ensemble mean  Calibrated ensemble means  Measurements

Stochastic backscatter

Multiphysics

Calibration applied to non-training data
Why use MERRA as the basis for downscaling?

• Five-fold increase in resolution over NCEP-NCAR (R-1) and NCEP-DOE (R-2).
  ▪ Horizontal resolution: ~50 km (R-1/R-2: 250 km).
  ▪ Vertical resolution: 72 vertical levels (R-1/R2: 28 levels).

• GL GH thoroughly understands its quality and suitability for bankable wind resource assessments.

• Substantially higher $R^2$ in most locations compared to R-1/R-2; superior starting point for mesoscale downscaling.

• One of only two reanalyses that provide hourly output.

• Output reliably updated to be within 30 days of real time.