Updated Wind Resource Assessment for the Outer Continental Shelf off the Coast of California

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Background

1. A new wind resource data set for the Outer Continental Shelf (OCS) off the coast of California has been produced by NREL

2. This data set, called CA20, replaces NREL’s 2013 WIND Toolkit (WTK) for this region

3. Both data sets were produced using the Weather Research and Forecasting (WRF) numerical weather prediction model

4. CA20 is being used by NREL to update its floating offshore wind cost analysis for the OCS

5. CA20 leverages extensive R&D advancements over the last 7 years, extends the period of record to a full 20 years (2000-2019), and includes uncertainty information for 100-m wind speeds
New Data Set

- Highest wind resource in the northern OCS, consistent with WTK
New Data Set shows an Increase in Modeled Resource

Comparison of Mean 100-m Wind Speeds from Both Data Sets

<table>
<thead>
<tr>
<th>Call Area</th>
<th>Mean Wind Speed (m·s⁻¹)</th>
<th>Change (m·s⁻¹)</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WIND Toolkit</td>
<td>Updated Data Set</td>
<td></td>
</tr>
<tr>
<td>Humboldt</td>
<td>9.41</td>
<td>10.41</td>
<td>1.00</td>
</tr>
<tr>
<td>Morro Bay</td>
<td>8.20</td>
<td>9.52</td>
<td>1.32</td>
</tr>
<tr>
<td>Diablo Canyon</td>
<td>7.70</td>
<td>9.18</td>
<td>1.48</td>
</tr>
</tbody>
</table>
Mean 100-m Uncertainties

Annual Average

Hourly Average

Model Sensitivity [%]

Median hourly 100-m wind speed uncertainty (%)

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Key Questions

• What validation was performed?

• What is leading to the increased modeled wind resource in CA20?

• How did we determine uncertainty metrics?

• How is the data set made available to the public?
Validation
Observation stations

- Mostly buoy measurements below 5 meters
- Some coastal radar 150 m and above
- No floating lidar

Offshore floating lidar data from NYSERDA was used
WRF Setups or “Ensemble Members”

Atmospheric forcing
- ERA-5
- MERRA-2

Planetary Boundary Layer (PBL) scheme
- MYNN
- YSU

Sea surface temperature
- NCEP RTG
- Default in reanalysis product

Land surface Model (LSM)
- NOAH
- NOAH-MP

16 ensemble members
Bias

Average across all sites

- ERA5_OSTIA_MYNN_NOAH
- ERA5_OSTIA_YSU_NOAH
- ERA5_OSTIA_MYNN_NOAHMP
- ERA5_OSTIA_YSU_NOAHMP
- ERA5_NCEP_MYNN_NOAH
- ERA5_NCEP_YSU_NOAH
- ERA5_NCEP_MYNN_NOAHMP
- ERA5_NCEP_YSU_NOAHMP
- MERRA2_OSTIA_MYNN_NOAH
- MERRA2_OSTIA_YSU_NOAH
- MERRA2_OSTIA_MYNN_NOAHMP
- MERRA2_OSTIA_YSU_NOAHMP
- MERRA2_NCEP_MYNN_NOAH
- MERRA2_NCEP_YSU_NOAH
- MERRA2_NCEP_MYNN_NOAHMP
- MERRA2_NCEP_YSU_NOAHMP

Unbiased RMSE (ms⁻¹)
Earth Mover’s Distance

Average across all sites

- ERA5_OSTIA_MYNN_NOAH
- ERA5_OSTIA_YSU_NOAH
- ERA5_OSTIA_MYNN_NOAHMP
- ERA5_OSTIA_YSU_NOAHMP
- ERA5_NCEP_MYNN_NOAH
- ERA5_NCEP_YSU_NOAH
- ERA5_NCEP_MYNN_NOAHMP
- ERA5_NCEP_YSU_NOAHMP
- MERRA2_OSTIA_MYNN_NOAH
- MERRA2_OSTIA_YSU_NOAH
- MERRA2_OSTIA_MYNN_NOAHMP
- MERRA2_OSTIA_YSU_NOAHMP
- MERRA2_NCEP_MYNN_NOAH
- MERRA2_NCEP_YSU_NOAH
- MERRA2_NCEP_MYNN_NOAHMP
- MERRA2_NCEP_YSU_NOAHMP

EMD (ms⁻¹)
## Validation Conclusions

### Final WRF Component Selection for New 20-Year Wind Resource Data Set for the OCS

<table>
<thead>
<tr>
<th>Model Component</th>
<th>Selection for New 20-Year Data Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reanalysis product</td>
<td>ERA5</td>
</tr>
<tr>
<td>PBL scheme</td>
<td>MYNN</td>
</tr>
<tr>
<td>SST product</td>
<td>OSTIA</td>
</tr>
<tr>
<td>LSM</td>
<td>Noah</td>
</tr>
</tbody>
</table>
Explaining the Increased Modeled Wind Resource
Factors affecting increase in wind resource

<table>
<thead>
<tr>
<th>PBL Scheme</th>
<th>Reanalysis Product</th>
<th>SST Product</th>
<th>Time Period</th>
<th>WRF Version</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIND Toolkit</td>
<td>YSU</td>
<td>ERA-interim</td>
<td>NCEP RTG 1/12 degree</td>
<td>7 years (2007-2013)</td>
</tr>
<tr>
<td>BOEM 20-year</td>
<td>MYNN</td>
<td>ERA-5</td>
<td>OSTIA 0.25 degree (pre-2007) HadISST2 0.25 degree (post-2007)</td>
<td>20 years (2000-2019)</td>
</tr>
</tbody>
</table>

*PBL - Planetary Boundary Layer

**PBL Scheme is critical in influencing modeled wind profiles**
Example: Hot Summer Day

- Surface heats up
- Lower warmer air **less dense** than upper colder air
- Warmer air moves up aloft
- Colder air comes down to replace it
- Cycle results in strong large-scale vertical convection
- Termed ‘**unstable**’ conditions
- Effect is to mix high momentum air aloft (i.e., high wind speeds) down to the surface
- Leads to even distribution of momentum in column, i.e., similar wind speeds or **low shear**
Example: Following Summer Night

- Now surface cools
- Lower colder air *more dense* than upper warmer air
- Vertical mixing is now *suppressed*
- Termed ‘*stable*’ conditions
- Effect is to keep high momentum air aloft (i.e., high wind speeds)
- Leads to uneven distribution of momentum in column, i.e., *high shear*

[Link to image](http://ww2010.atmos.uiuc.edu/(Gh)/wwhlpr/fcst_temps_winds.rxml)
[Link to additional resources](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/wind-profiles)
Summary on Stability Regimes

https://www.researchgate.net/figure/a-Wind-profiles-for-neutral-unstable-and-stable-conditions-according-to-Eq-2-The_fig3_242639903
Role of PBL Schemes

• This vertical mixing is a form of **turbulence**
• Turbulence: unsteady, chaotic movement of a fluid
• **Too computationally expensive** to model directly in WRF
• Rather, models like WRF **parameterize** that mixing in terms of measurable quantities (e.g., wind shear)
• Such parameterizations are called PBL schemes, and WRF currently has **9 of them**!
PBL Schemes

Two most popular schemes:
  • **YSU** (simple, fast), used in WIND Toolkit
  • **MYNN** (more complex, expensive), used in new 20-year data set
    • Becoming global standard
    • Used in operational weather prediction models
    • Used by wind industry consultants
    • Focus of previous and ongoing research (A2e’s Wind Forecast Improvement Projects)
    • New European Wind Atlas

For offshore California, they produce VERY different results
Direct MYNN vs YSU Comparison, 2017
Other Factors Affecting the Increase

- WRF Version, reanalysis product, SST product and time period do not significantly change the modeled wind resource between WTK and CA20
- PBL scheme is by far the largest driver
- But still a lot of the increase is left unexplained:
Other Factors Affecting the Increase

• Other differences that might explain the increase include
  o Different domain sizes (WTK was run for the whole U.S.)
  o Updated terrain and land use data

• More analysis is required to fully account for differences
Interannual Variability (IAV) Comparison:

IAV = expected variability in annual mean wind resource from year to year

CA20 has significantly higher IAV values. Why?
IAV Comparison:

2007-2013 WTK period just happened to be very consistent in many parts of the OCS

Annual 100m wind speeds at Buoy 46014

WIND Toolkit period

Difference, BOEM20 - WTK [%]
Uncertainty Metric Approach
Use of Ensembles

- Recall the 16 WRF model setups used in the validation analysis
- We can quantify sensitivity in WRF model by exploring spread between those “ensemble members”

Snapshot of 100-m wind speeds for all 16 ensembles (blue) in OCS location over 4-day event
Specifying an Uncertainty Metric

- Running 16 different simulations for 20 years is too computationally expensive.
- Instead we run them for the 2017 year only.
- Quantify uncertainty at each time step as the standard deviation divided by the mean, i.e., the coefficient of variation, or CoV.
- Focus only on the 100-m wind speeds.
Extrapolating Uncertainty

- Train a machine learning model to predict uncertainty (grey) from atmospheric variables in 20-year run (orange)
- Apply that model to full 20-year run to extrapolate uncertainty to full 20-year period
How are We Sharing the Data?
Wind Prospector

Wind Resource Data Download (Point)
Download resource data from the Wind Integration National Dataset (WIND) Toolkit, Western Wind Dataset or Eastern Wind Dataset (where available) by point. This tool will return data for the station closest to the point drawn.

Wind Resource Data Download (Box)
Download resource data from the Wind Integration National Dataset (WIND) Toolkit, Western Wind Dataset or Eastern Wind Dataset (where available) by box. This tool will return data for all stations falling within the drawn region.

Wind Power Analysis
Run an analysis on the amount of yield that can be produced in a specific area.
• Ideal for downloading data at a single location
Python-based API

- Need Python familiarity
- Better for downloading regions of data and applying any processing (e.g., monthly means)

```python
# Extract time-series data for a single site
import h5pyd
import pandas as pd

# Open .h5 file
with h5pyd.File('/nrel/wtk/conus/wtk_conus_2010.h5', mode='r') as f:
    # Extract time_index and convert to datetime
    # NOTE: time_index is saved as byte-strings and must be decoded
    time_index = pd.to_datetime(f['time_index'][...].astype(str))
    # Initialize DataFrame to store time-series data
    time_series = pd.DataFrame(index=time_index)
    # Extract 100m wind speed, wind direction, temperature, and pressure
    for var in ['windspeed_100m', 'winddirection_100m', 'temperature_100m', 'pressure_100m']:
        # Get dataset
        ds = f[var]
        # Extract scale factor
        scale_factor = ds.attrs['scale_factor']
        # Extract site 100 and add to DataFrame
        time_series[var] = ds[:, 100] / scale_factor
```

https://github.com/NREL/hsds-examples