NREL Transforming ENERGY

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

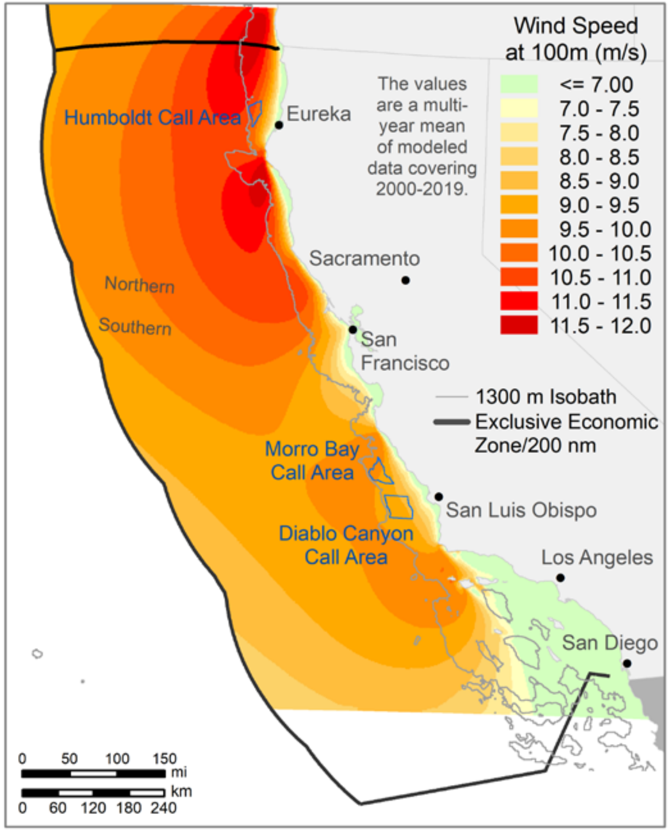
2. This data set, called CA20, replaces NREL's 2013 WIND Toolkit (WTK) for this region

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

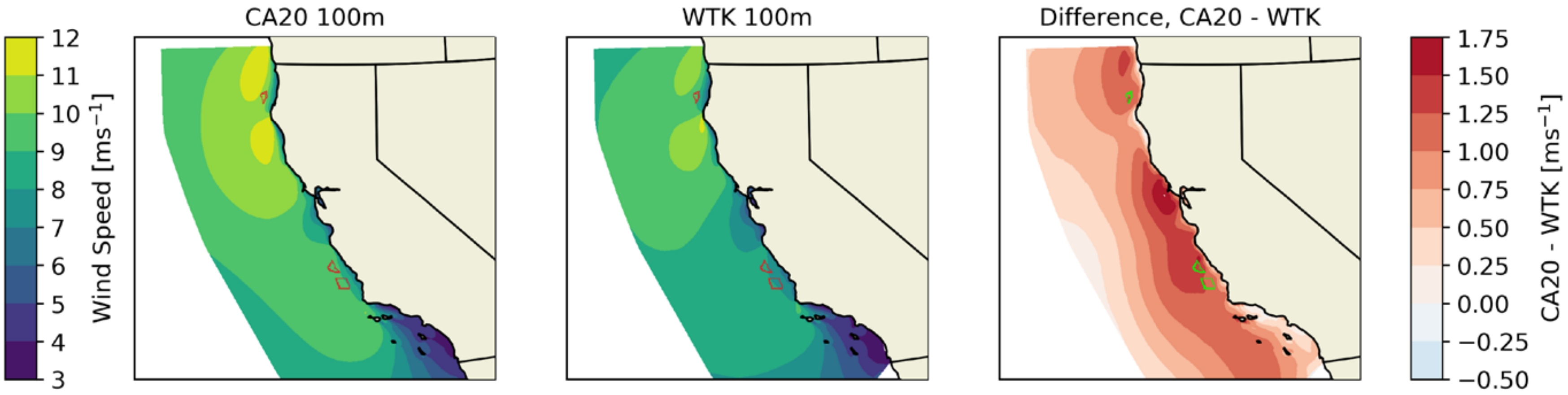


Mean annual wind resource for the OCS based on the new 20-year data set

- Highest wind resource in the northern OCS, consistent with WTK

New Data Set shows an Increase in Modeled Resource

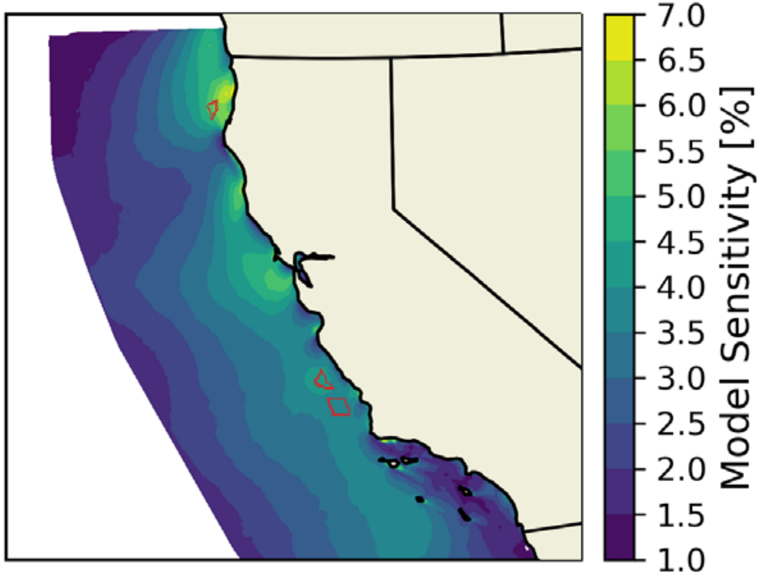
Comparison of Mean 100-m Wind Speeds from Both Data Sets



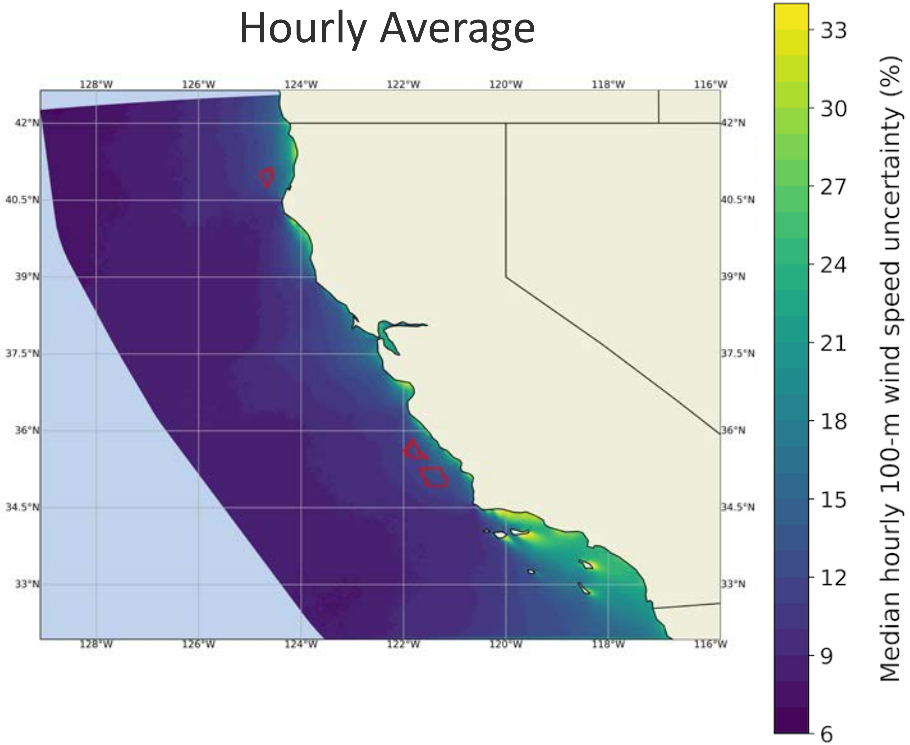
Call Area	Mean Wind Speed (m·s^{-1}) WIND Toolkit	Mean Wind Speed (m·s^{-1}) Updated Data Set	Change (m·s^{-1})	Change (%)
Humboldt	9.41	10.41	1.00	10.6
Morro Bay	8.20	9.52	1.32	16.1
Diablo Canyon	7.70	9.18	1.48	19.2

Mean 100-m Uncertainties

Annual Average



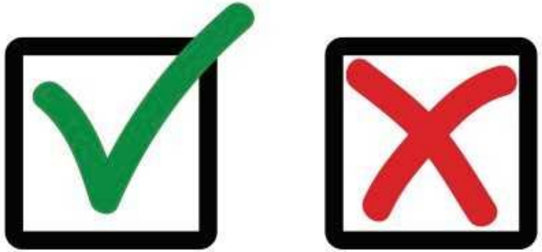
Hourly Average



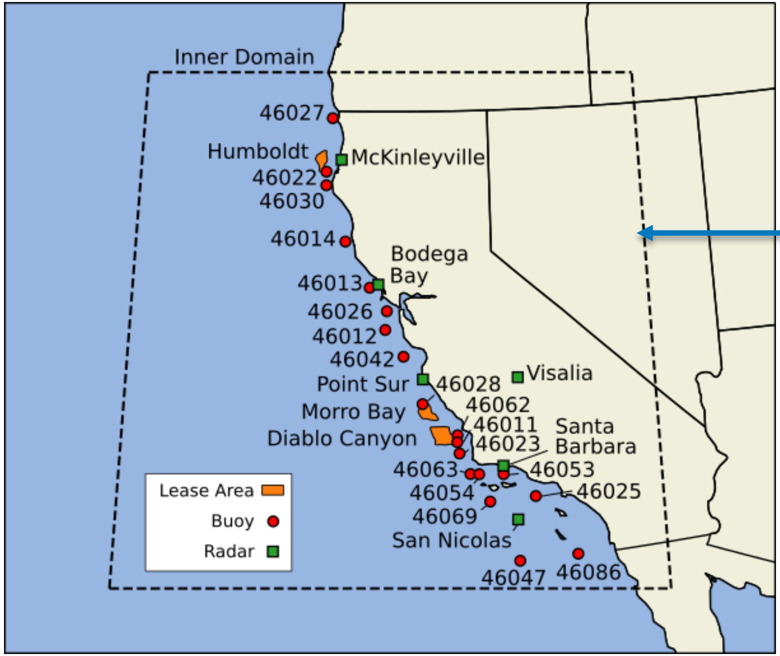
Key Questions

- 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

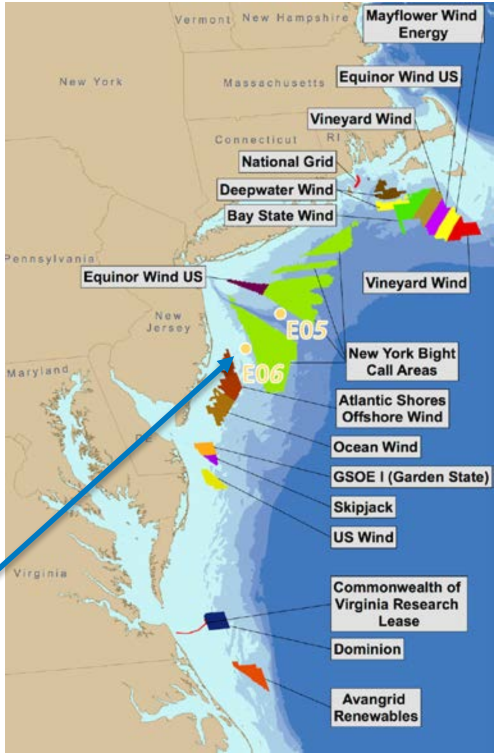


Mostly buoy measurements below 5 meters

Some coastal radar 150 m and above

No floating lidar

Offshore floating lidar data from NYSERDA was used



WRF Setups or "Ensemble Members"

16 ensemble members

Atmospheric forcing

- ERA-5
- MERRA-2

Sea surface temperature

- NCEP RTG
- Default in reanalysis product

Planetary Boundary Layer (PBL) scheme

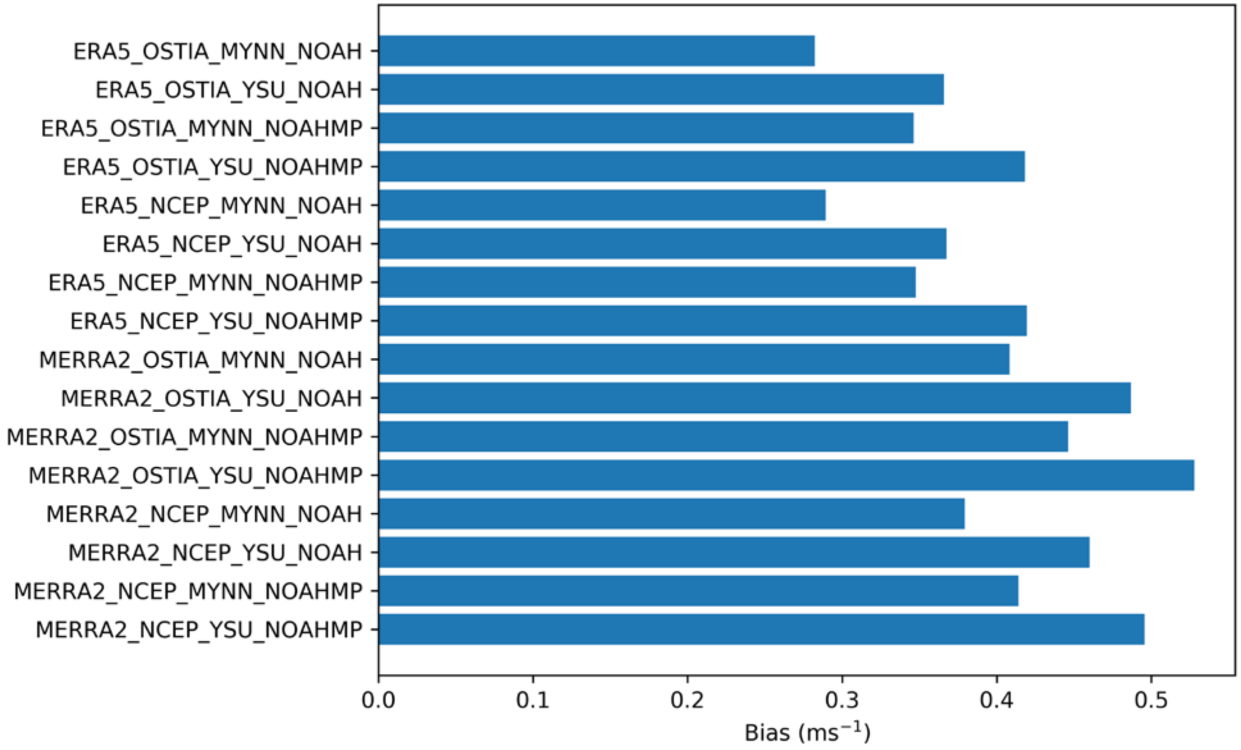
- MYNN
- YSU

Land surface Model (LSM)

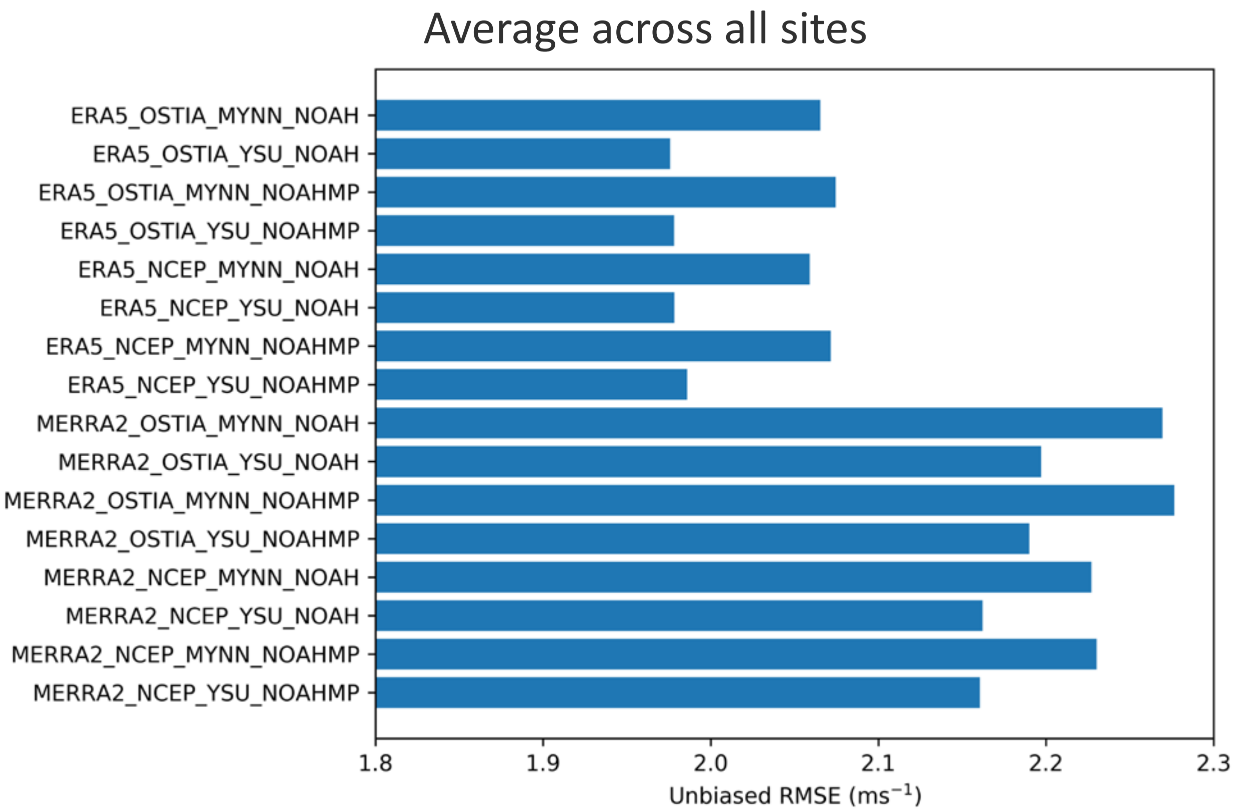
- NOAH
- NOAH-MP

Unbiased Root-Mean-Squared-Error (RMSE)

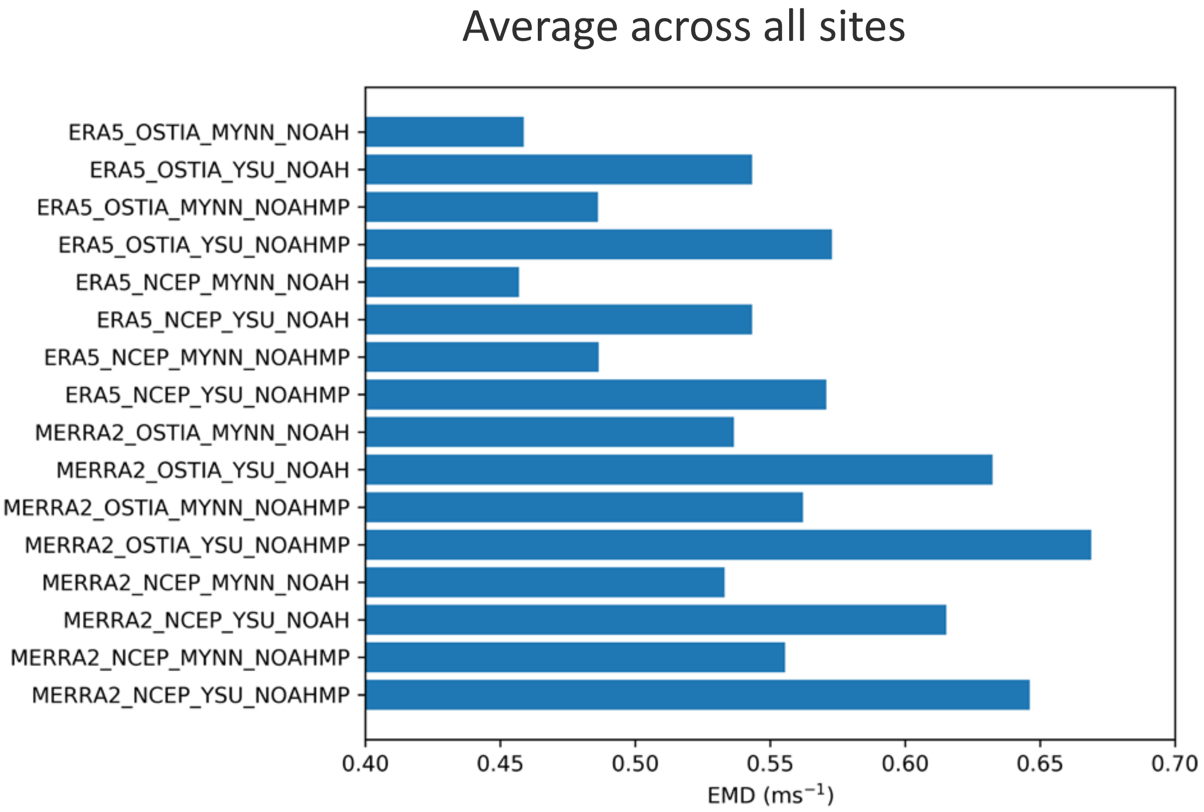
Average across all sites



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
1.8
1.9
2.0
2.1
2.2
2.3
Unbiased RMSE (ms^{-1})

Earth Mover's Distance

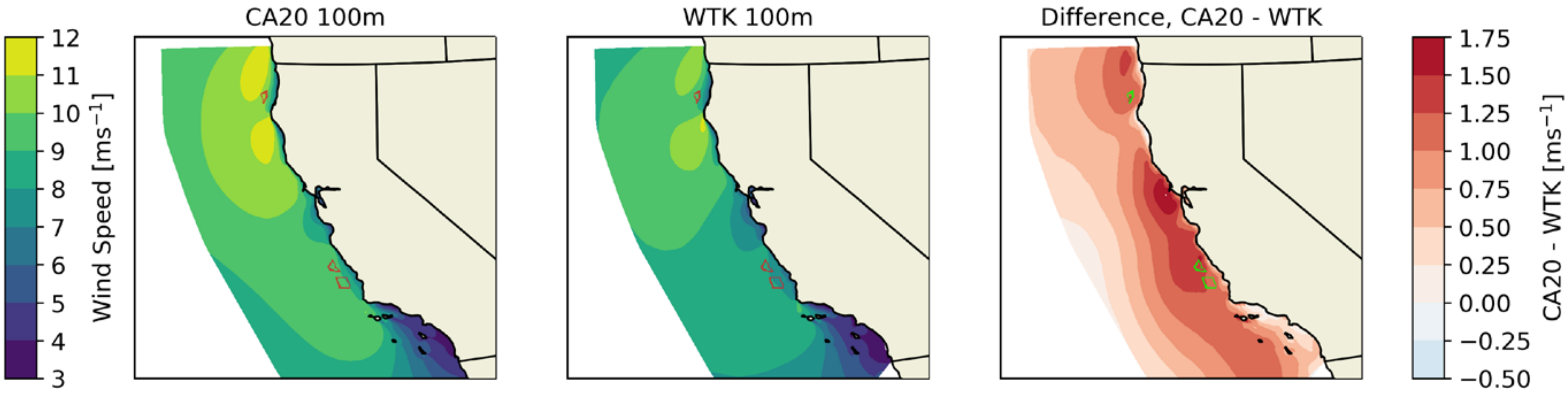


Validation Conclusions

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

Model Component	Selection for New 20-Year Data Set
Reanalysis product	ERA5
PBL scheme	MYNN
SST product	OSTIA
LSM	Noah

Explaining the Increased Modeled Wind Resource



Factors affecting increase in wind resource

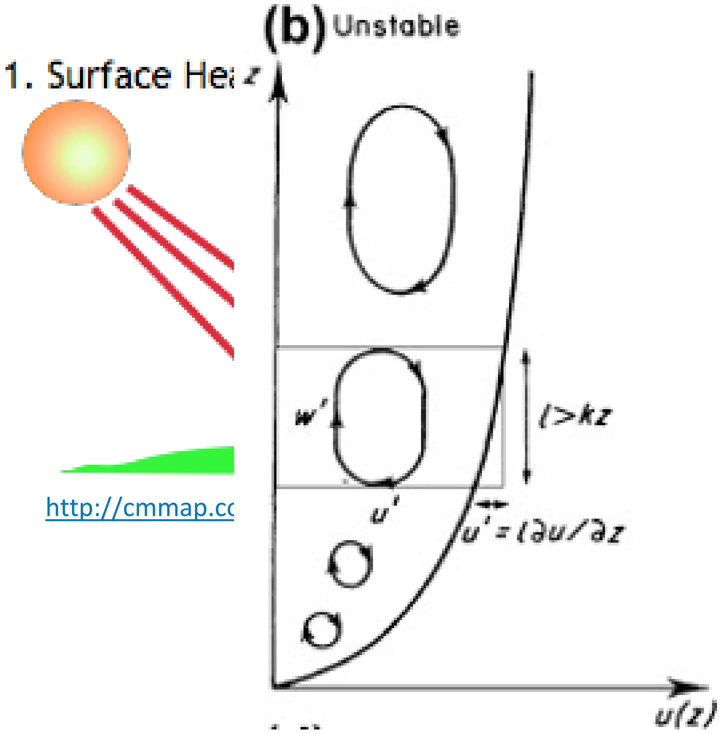
	PBL* Scheme	Reanalysis Product	SST Product	Time Period	WRF Version
WIND Toolkit	YSU	ERA-interim	NCEP RTG 1/12 degree	7 years (2007-2013)	3.4
BOEM 20-year	MYNN	ERA-5	OSTIA 0.25 degree (pre-2007) HadISST2 0.25 degree (post-2007)	20 years (2000-2019)	4.1

*PBL - Planetary Boundary Layer

PBL Scheme is critical in influencing modeled wind profiles

Example: Hot Summer Day

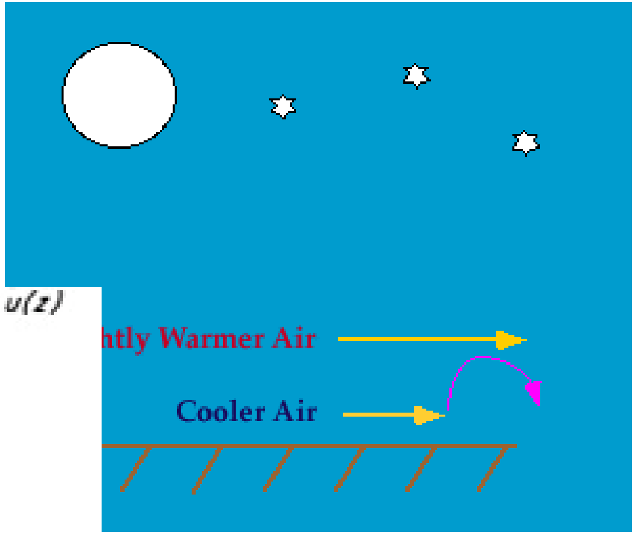
- Surface heats up
- Lower warmer air ***less dense*** than upper colder air
- Warmer air moves up aloft
- Colder air comes down to replace it
- Cycle results in strong large-scale vertical convection
- Termed **‘unstable’ conditions**
- Effect is to mix high momentum air aloft (i.e., high wind speeds)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



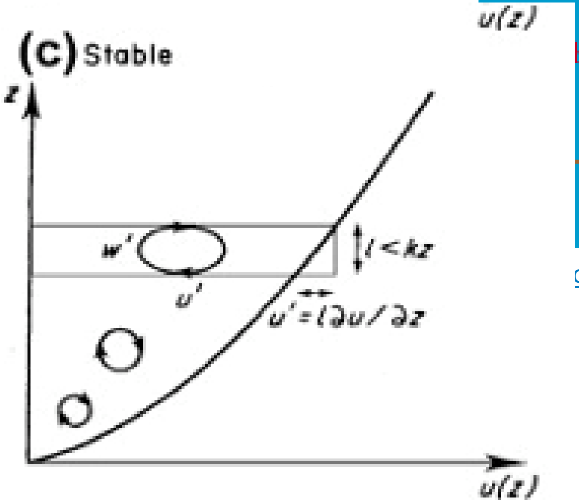
https://www.sciencedirect.com/topics/earth-and-planetary-sciences/wind-profiles

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**



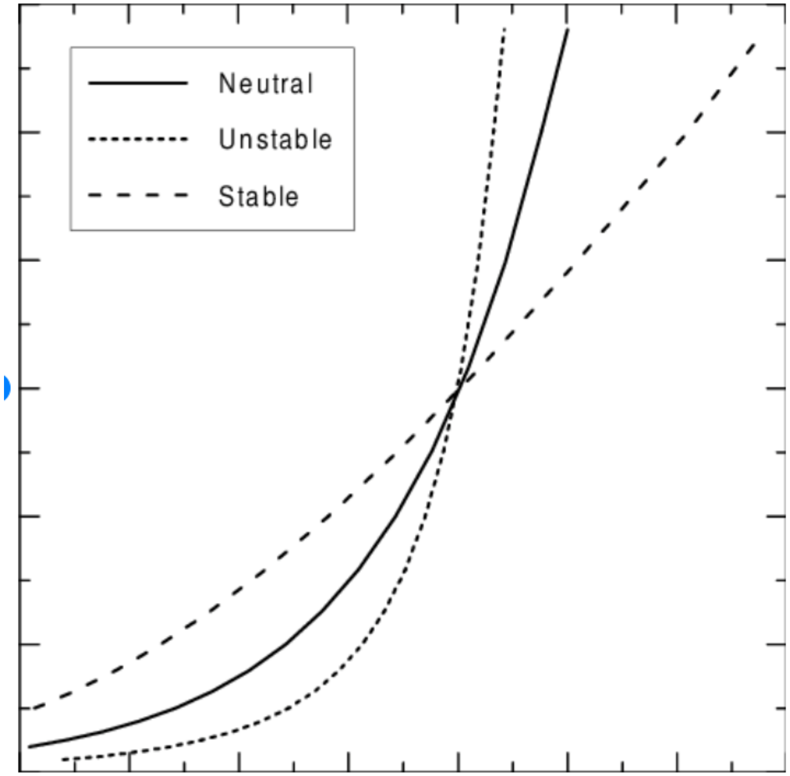
os.uiuc.edu/(Gh)/wwhlpr/fcst_temps_winds.rxml



https://www.sciencedirect.com/topics/earth-and-planetary-sciences/wind-profiles

Summary on Stability Regimes

Height



Wind Speed

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

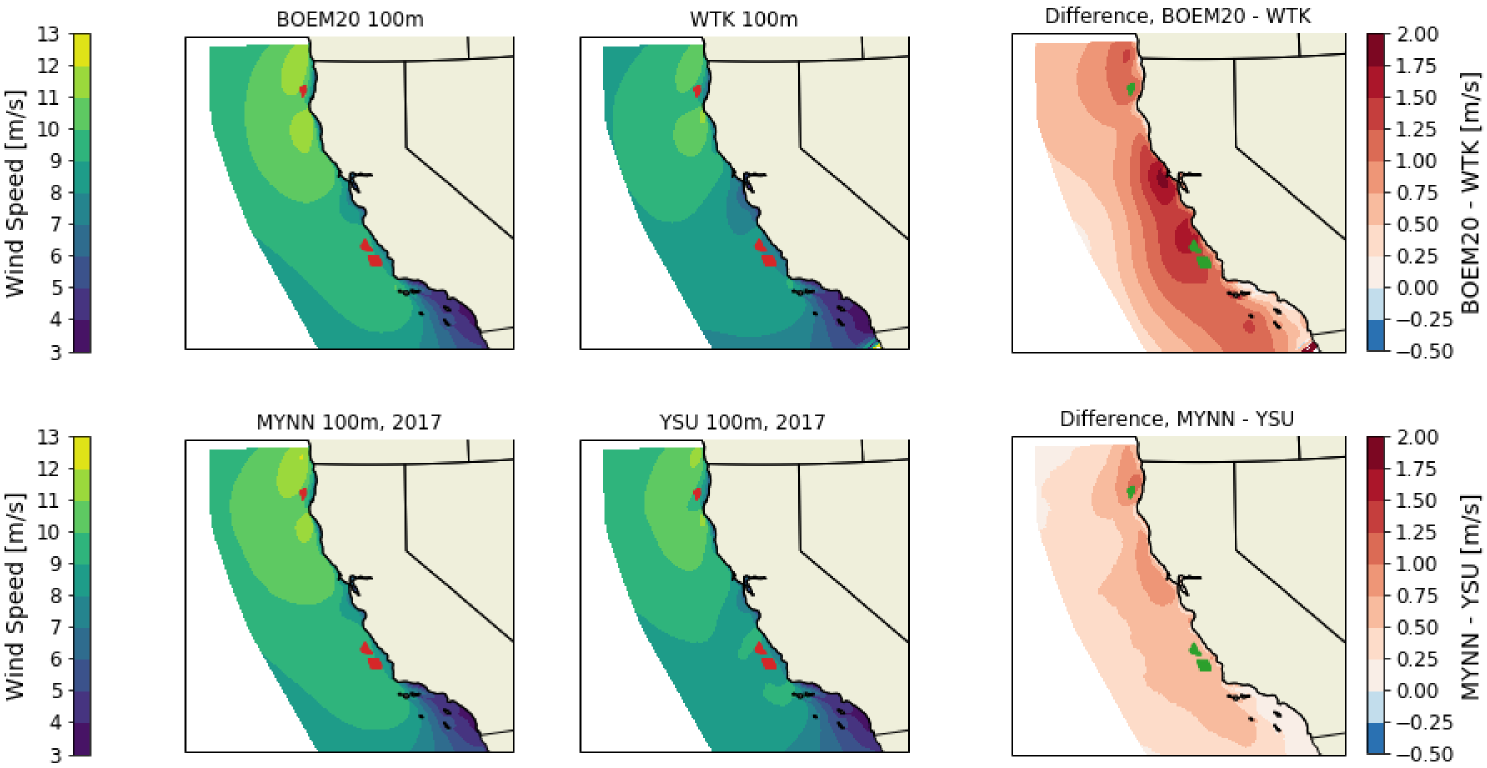
Two most popular schemes:

- **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

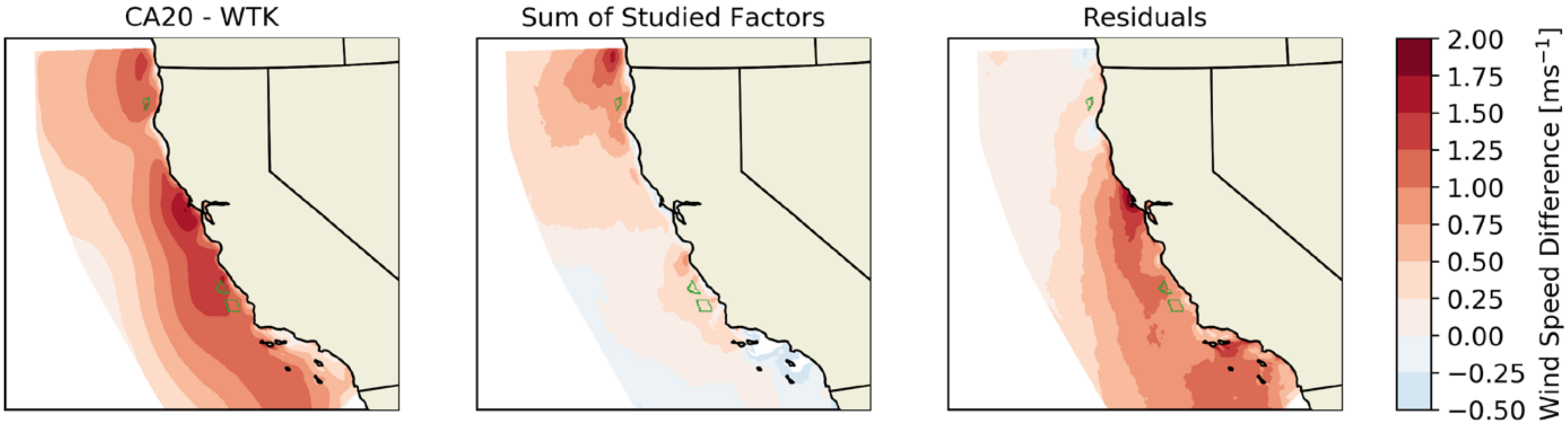
For offshore California, they produce VERY different results

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:



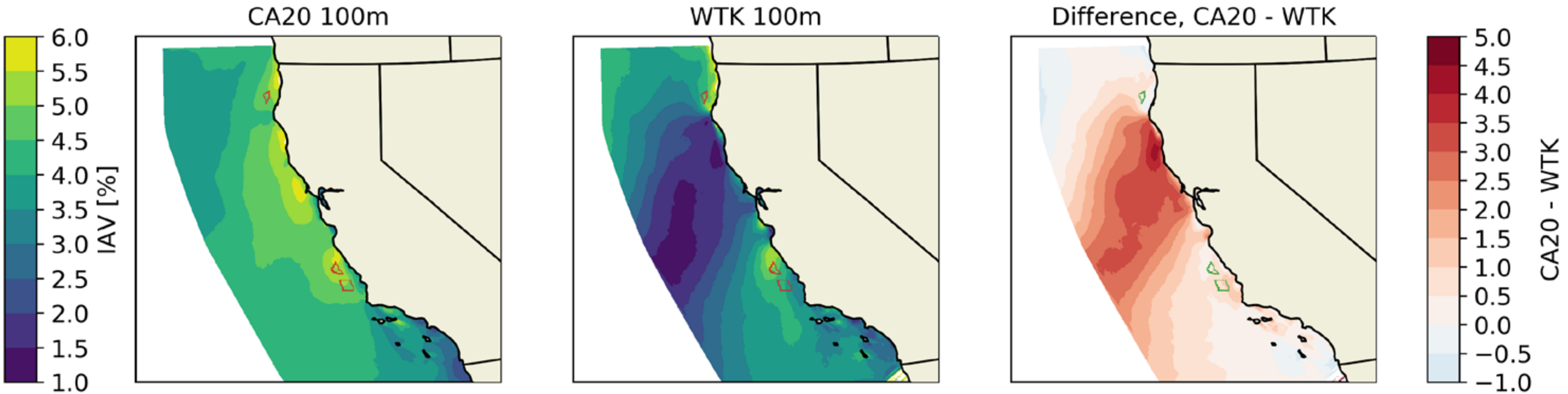
Other Factors Affecting the Increase

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

- More analysis is required to fully account for differences

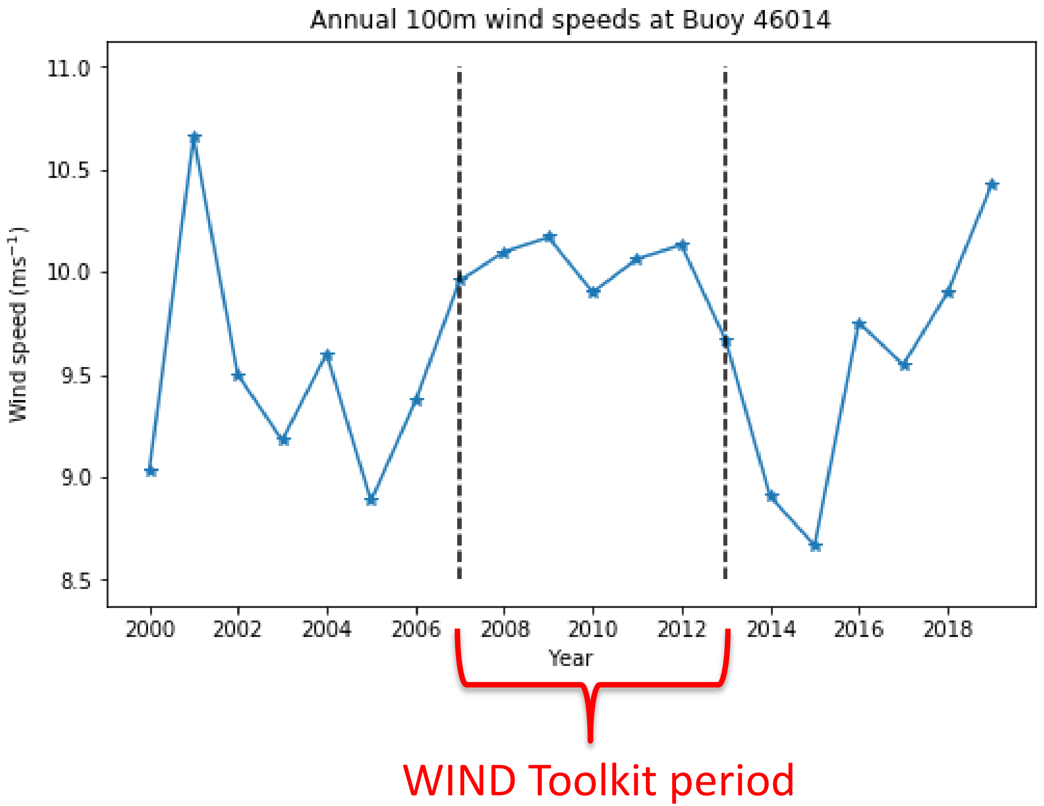
Interannual Variability (IAV) Comparison:

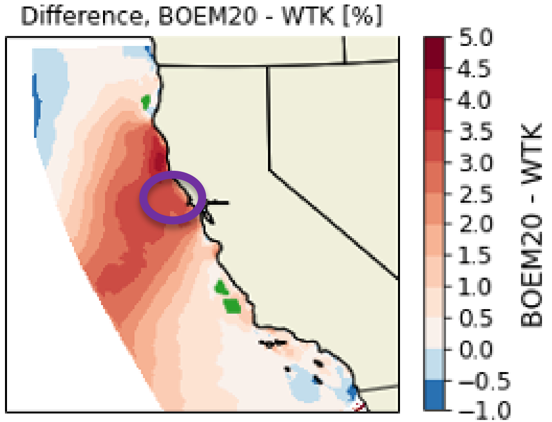
IAV = expected variability in annual mean wind resource from year to year



CA20 has significantly higher IAV values. Why?

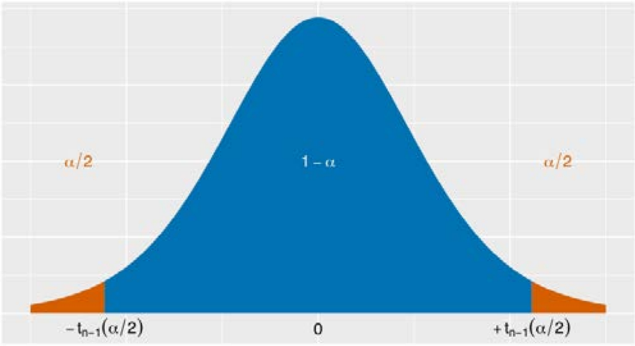
IAV Comparison:





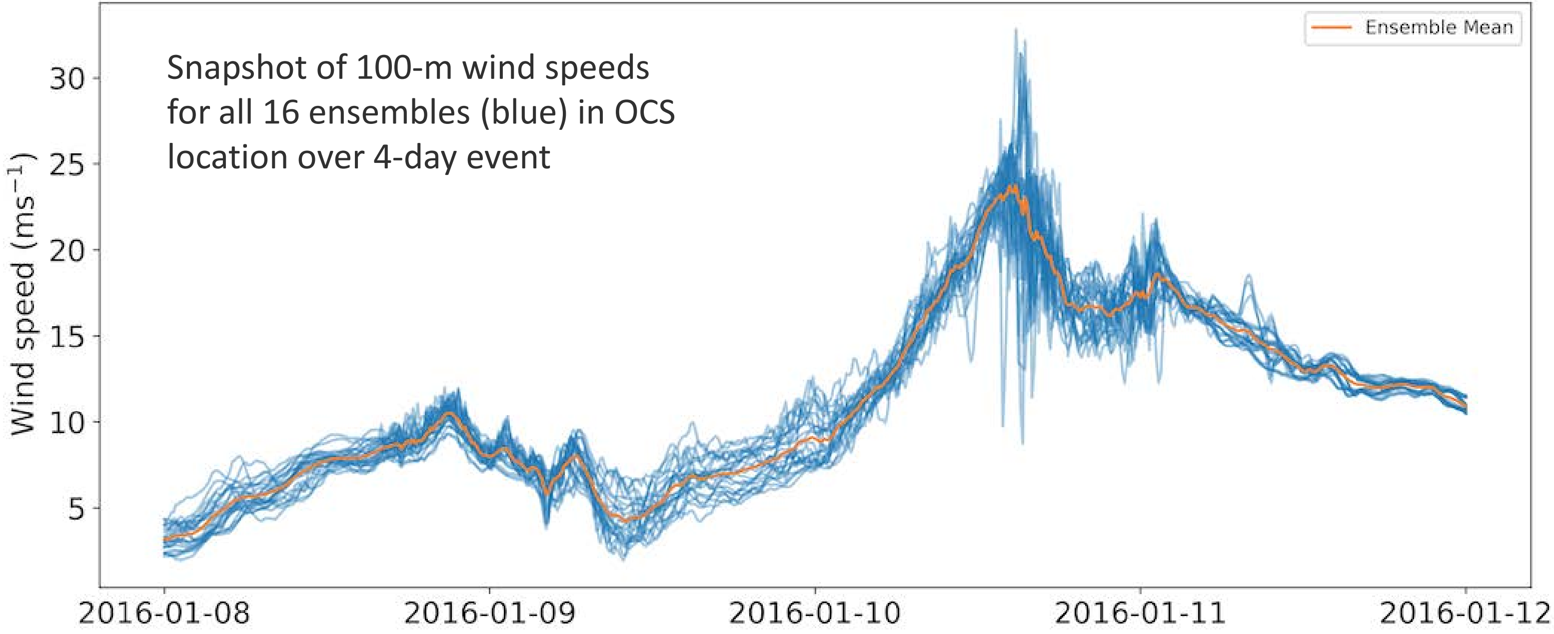
2007-2013 WTK period just happened to be very consistent in many parts of the OCS

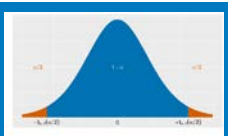
Uncertainty Metric Approach



Use of Ensembles

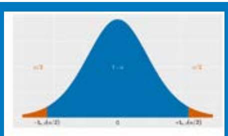
- Recall the 16 WRF model setups used in the validation analysis
- We can quantify sensitivity in WRF model by exploring spread between those “ensemble members”





Specifying an Uncertainty Metric

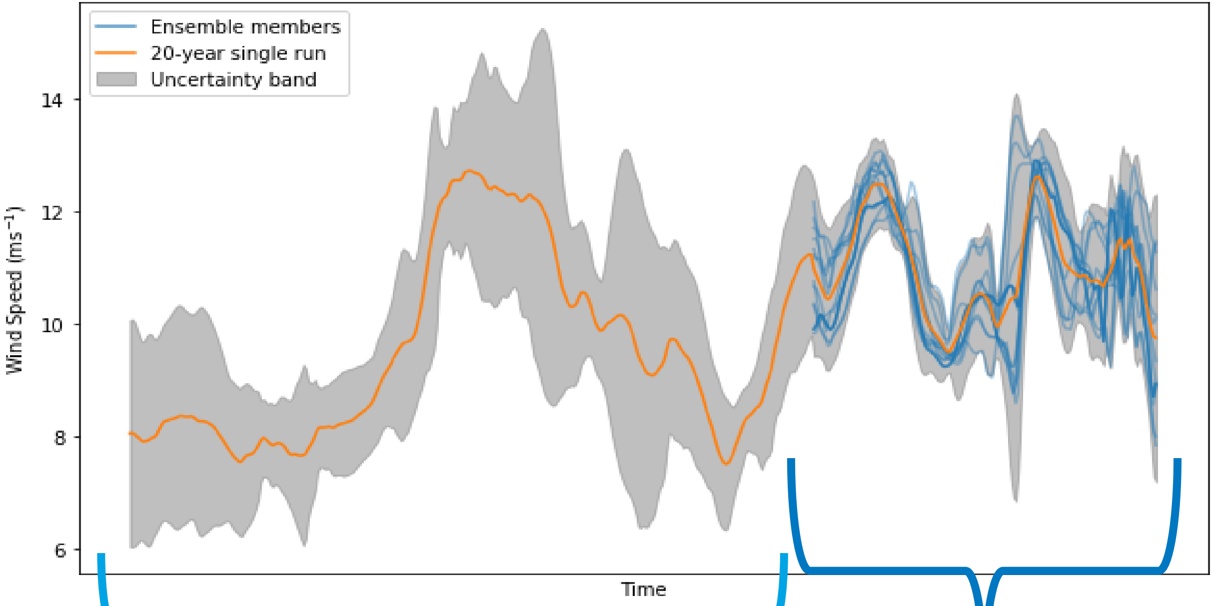
- Running 16 different simulations for 20 years is too computationally expensive
- Instead we run them for the 2017 year only
- Quantify uncertainty at each time step as the standard deviation divided by the mean, i.e., the coefficient of variation, or CoV
- Focus only on the 100-m wind speeds



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

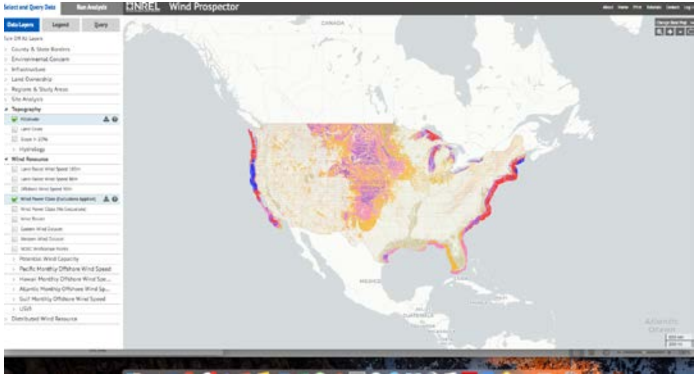


Extrapolate uncertainty to 20-year single model run

Machine Learning

Calculate uncertainty from ensemble spread over subset of data (1 year)

How are We Sharing the Data?



Wind Prospector

Select and Query Data | **Download Data**

Wind Resource Data Download (Point)

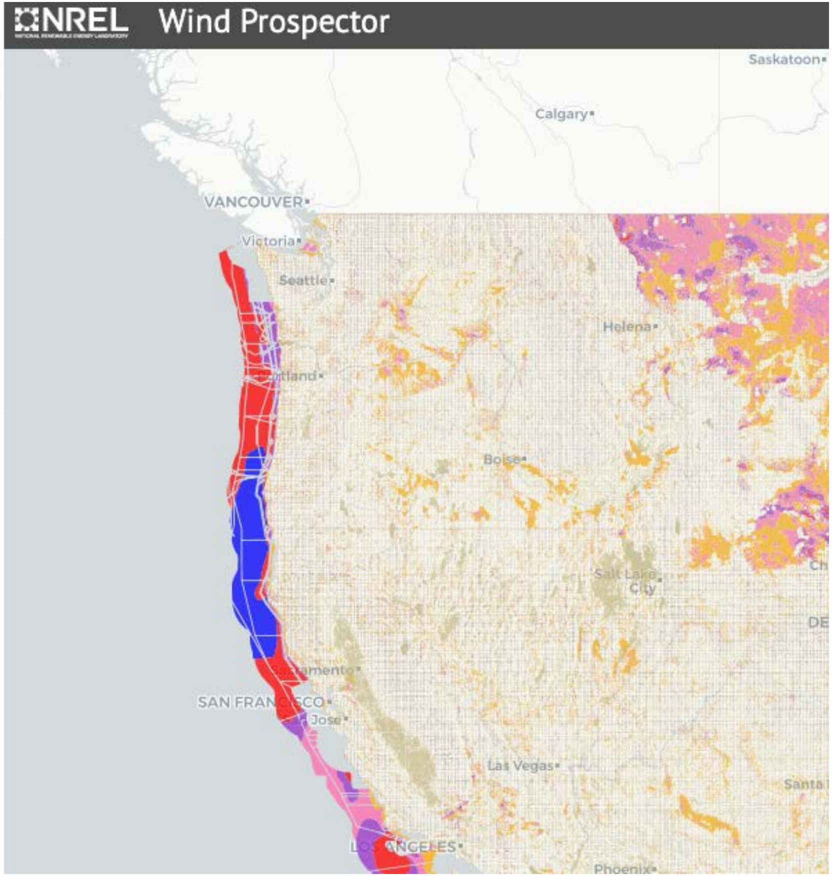
Download resource data from the Wind Integration National Dataset (WIND) Toolkit, Western Wind Dataset or Eastern Wind Dataset (where available) by point. This tool will return data for the station closest to the point drawn.

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.

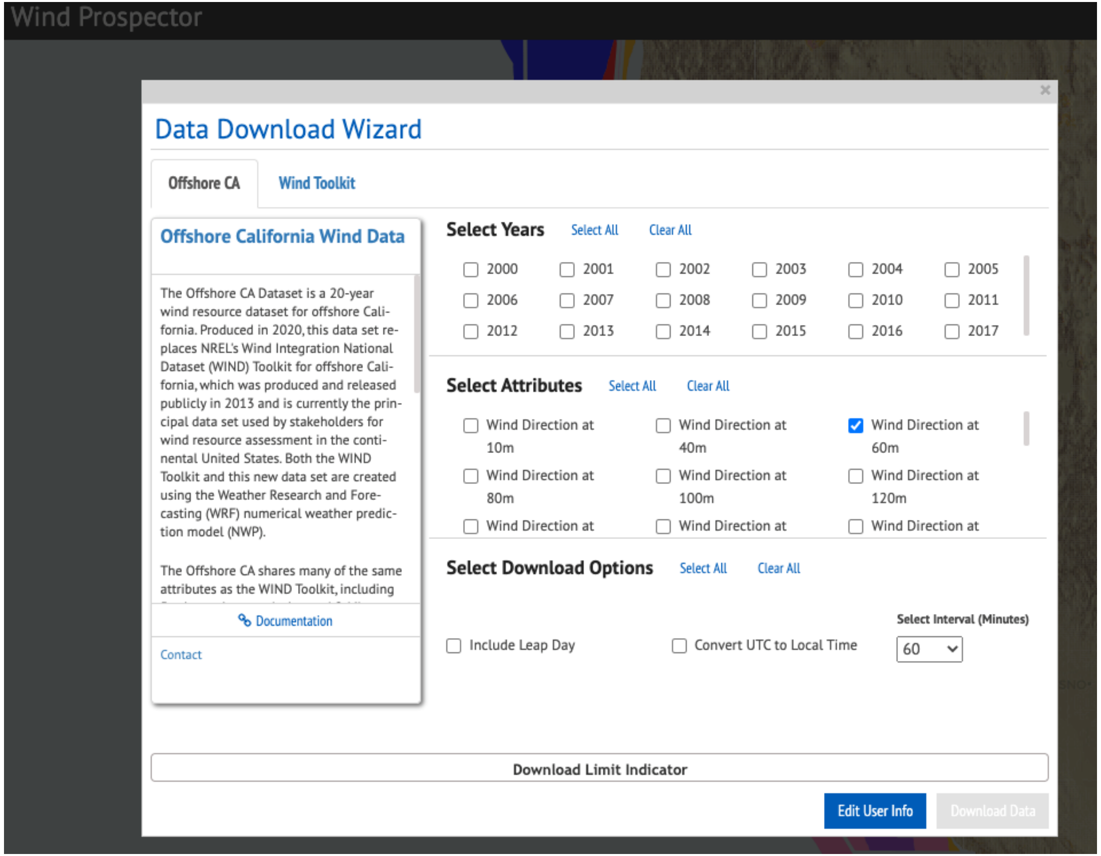
Wind Power Analysis

Run an analysis on the amount of yield that can be produced in a specific area



Wind Prospector

- 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)

```
# 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

Thanks!

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