Toward an Estimate of Wind Resource Offshore North Carolina

Evaluation of a Stability-Based Extrapolation Scheme

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Offshore wind resource assessments over the continental shelf off North Carolina have suggested that tens of gigawatts of power generation potential are possible from wind farms. An initial assessment undertaken by the University of North Carolina at Chapel Hill (UNC) took advantage of a variety of in-situ historical observations and employed simple extrapolation schemes (a power law and log-layer formulation) to estimate turbine-height winds and power potential. Subsequent work has investigated a variety of more sophisticated extrapolation schemes and established that 10-meter satellite Advanced Scatterometer (ASCAT) winds estimated by the European Organization for the Exploitation of Meteorological Satellites (2008 to present) are consistent with buoy-based winds. Here we describe work toward implementation and evaluation of a stability-based extrapolation scheme applied to the ASCAT winds to broaden the spatial coverage of the study.

Motivation for this re-examination came from the influence of oceanography offshore of North Carolina on atmospheric conditions. Large spatial changes in average sea surface temperature due to the poleward flow of the Gulf Stream and equatorward flow on the mid-Atlantic shelf produce strong variations in static stability of the overlying lower atmosphere. We seek to clarify the dependence of turbine-height winds (30 to 150 meters above sea level) off North Carolina on atmospheric stability and to document the sign and strength of the change in wind speed relative to neutral conditions, as well as how it varies along and across shore and over time.

Formulations

Two simplifying assumptions made in an earlier UNC study were temporally fixed variations in roughness length (i.e., only accounting for changes in roughness over land with no wind-speed dependence) and no accounting for atmospheric stability. Both assumptions can be relaxed through use of existing bulk formulae that are commonly used in oceanography when the necessary ancillary measurements are available.

Surface roughness over water, typically represented as a quadratic drag law with multiple contributions, increases...
with wind speed due to the growth of the wave field. These schemes, referred to as neutral stability schemes, are relatively simple to implement because they require only wind observations at a specified height above the sea surface. A limitation in these formulations is that the wave field can be represented by the wind speed alone, which introduces uncertainty in the application of these simple schemes from a lack of dependence on wave age, especially in shallow waters and fetch-limited settings.

Atmospheric stability also impacts the vertical profile of wind speed. Unstable conditions are associated with convection, enhanced near-surface fluxes and reduced shear aloft, whereas stable conditions are associated with reduced near-surface fluxes and increased vertical shear aloft. 

Monin-Obukhov Similarity (MOS) scaling, with some modifications to improve its application over the oceans (including variations in surface roughness), has been found to adequately represent the variations in surface fluxes and wind shear in a number of settings. Implementations of MOS scaling have found wide application and continue to be refined.

However, use of these formulations requires a number of variables in addition to wind speed to be measured simultaneously [surface air temperature (SAT), relative humidity, sea surface temperature (SST), downwelled short- and long-wave radiation and barometric pressure]. A commonly available implementation of the Coupled Ocean-Atmospheric Response Experiment bulk algorithm (COAREV2.0), includes allowances for some missing variables (specifically downwelled short- and long-wave radiation). The challenge to this stability-based extrapolation scheme is to find appro-
priate sources of ancillary data on the same time and space scales as the ASCAT winds.

**ASCAT, NARR, AVHRR-OI**

The ASCAT product used provided daily estimates of wind speed on a 25-kilometer spatial grid starting in January 2008. After exploring possible sources for surface sea and air temperature, relative humidity and barometric pressure, we found that the North American Regional Reanalysis (NARR) product from the National Centers for Environmental Prediction was largely compatible in spatial resolution with the ASCAT winds. We then evaluated the NARR fields.

For this, note we limit the time frame of interest to 2009. We first examined the NARR wind field through a comparison with the buoy-based winds and found the annually averaged wind speed to be biased low relative to buoy-based wind observations by 1 to 2 meters per second. This 20 percent bias in speed can lead to a 50 percent error in wind power, given the cubic relationship between the two quantities. Because the NARR winds fail to correctly capture the 10-meter wind field, we evaluate the NARR representation of the ancillary fields needed for the stability-based extrapolation scheme of the ASCAT winds.

The annual mean difference between NARR and buoy-measured SST in 2009 for stations on the shelf was typically more than 2° C and exhibits a strong seasonal pattern of large differences (up to 5° C) in winter and small differences (less than 1° C) in summer, with NARR SST always greater. It is clear that the SST in NARR fails to capture low SST nearshore and north of Cape Hatteras during cooler months.

A substitute SST product was sought. A number of daily products are now available that utilize optimal interpolation (OI) and a blend of infrared and microwave radiometers and in-situ observations. All are global products but at varying spatial resolution. The 25-kilometer resolution National Climate Data Center optimally interpolated Advanced Very High Resolution Radiometer (AVHRR-OI) was found to best represent SST along the North Carolina coast relative to buoy-based observations. The other products, though available at finer spatial resolution, often fail to accurately capture the cooler nearshore waters in winter and north of Cape Hatteras.

The annual mean difference between NARR and buoy-measured SAT in 2009 for stations on the shelf was typically about 1° C and exhibits a seasonal pattern of larger differences (up to 5° C) in winter and negligible differences in summer, with NARR SAT typically greater. The largest annual mean difference (2° C) was observed on the shelf north of Cape Hatteras at the same location as the largest mean difference in SST (3.4° C).

The sea-air temperature difference (as SST-SAT) is a critical component of the MOS extrapolation scheme. A comparison of the difference using NARR and using buoy observations reveals that NARR overestimates the difference such that unstable conditions persist over the entire area of interest, even in winter. The buoy-based difference indicates stable conditions on the shelf north of Cape Hatteras and in the nearshore waters south of Cape Hatteras during winter and early spring. When the AVHRR-OI SST product is used in combination with the NARR SAT, the difference exhibits periods of stable conditions in the same locations as the buoy observations but is biased toward greater stability and weaker unstable conditions.
Conclusion

The COARE V2.0 stability-based extrapolation scheme has been implemented to estimate winds at 80 meters above sea level, making use of the ASCAT 10-meter winds, the AVHRR-OL SST and the NARR SAT, relative humidity and air pressure. A neutral stability extrapolation is also formed as a reference. The smallest temporal resolution possible is daily, set by the availability of the satellite products. The daily values have then been averaged over varying time periods to estimate mean differences and uncertainties between the two extrapolation schemes.

Monthly average winds at 80 meters for 2009 exhibit significant departures from neutral stability that vary systematically with geographic location and time of year. Unstable conditions (SST>SAT) dominate over the Gulf Stream, in the Sargasso Sea and over the outer shelf south of 35° N throughout most of the year. In these regions, the stability-based monthly mean winds at 80 meters are typically 0.5 to 1 meters per second less than expected, assuming neutral conditions, a result of enhanced vertical mixing of momentum. In winter (January to March), stable conditions, produced by cool water nearshore, extend along the length of North Carolina and 25 to 50 kilometers offshore. In spring (April to June), stable conditions are found only north of Cape Hatteras but have expanded across the shelf, with the last remnant in June associated with the shelfbreak. In the regions of stable conditions, the stability-based winds at 80 meters are significantly greater than expected when neutral stability is assumed. The validity of the speed estimate in the stable regions is difficult to assess because the highly sheared stable layer grows quite slowly. The growth in the thickness of the stable layer is proportional to the square root of downstream horizontal distance from nonstable conditions and may take several tens of kilometers for the layer to impact the winds at 80 meters. Therefore, the study results identify regions of uncertainty in the winds where there may potentially be a greater wind resource than predicted using neutral extrapolation of low-level winds. Further study will be required to firm up speed estimates.

Additional studies will include measurement of the wind profile over the lower 200 meters of the atmosphere in regions with stable stratification and more sophisticated model approaches. Several offshore platforms that can host an mast profiler exist off North Carolina, and negotiations to deploy a profiler are underway. Nested fine-scale atmospheric modeling, with 2-kilometer horizontal resolution and nine vertical levels under 200 meters, by WeatherFlow (Scotts Valley, California) is ongoing and may provide an improved estimate of average winds over regions of stable atmospheric conditions if sufficiently validated. A final synthesis that considers these sources of information is anticipated to be completed in the next one to two years.

References

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