# Improving the Prediction of Hub Height Winds Using Flux Gradient Techniques

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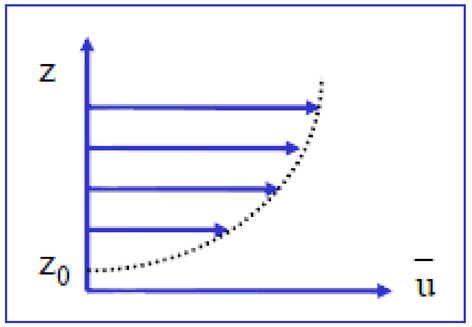



## Science Questions

(1) Can the forecast of wind turbine hub-height wind speeds be improved through inclusion of near-neutral and unstable flux-gradient wind modeling techniques?

(2) What is the uncertainty associated with high resolution WRF mesoscale in both now-cast and forecast of winds at 10 m and hub-height?

(3) Does assimilation of surface energy flux measurements (heat flux, shear stress, surface roughness, displacement height, and mixed layer height) improve mesoscale forecasts through mesoscale model and surface exchange methodologies?

(4) What is the impact of spatial variability in surface energy-balance on forecasted gradient winds at 10m and hub-height?

## Boundary-Layer Velocity Gradients Program

**Phase one** is an evaluation of the flux gradient velocity profile technique based on directly measured surface energy balances.

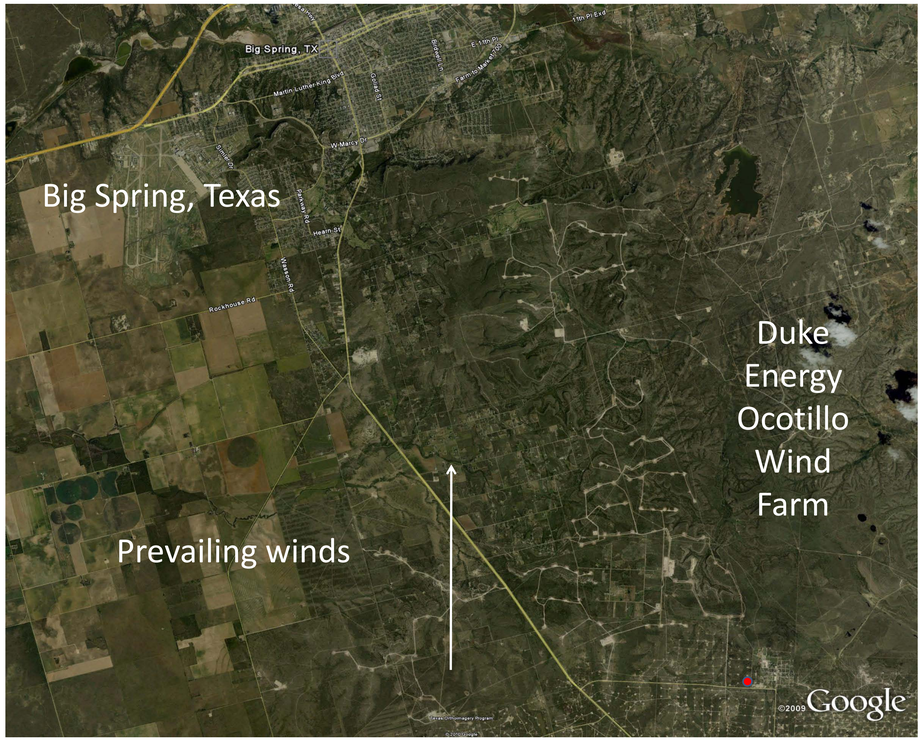
**Phase two** is an evaluation of results from Phase one as implemented in the WRF model through alternative land use model parameterizations.

## Collaborations

ARL has a three-year Cooperative Research And Development Agreement with Duke Energy Generation Services, Inc.
ARL has partnered with Earth Systems Research Laboratory (ESRL), the U.S. Dept. of Energy's Energy Efficiency and Renewable Energy (EERE) office, AWS Truepower, and WindLogics to improve short-term wind forecasts for wind energy production.

## Future Directions

Determine a modified non-dimensional wind gradient relationship that allows for more accurate extrapolation of near surface winds to wind turbine hub height. (see Garratt, 1992).
In partnership with ESRL, conduct a field experiment to improve short-term wind forecasts from the High-Resolution Rapid Refresh (HRRR) model for wind energy production.
Using WRF, test the potential for improvement in hub-height wind forecasts using the site-specific surface layer profile model.




**Wind Flux Profiling Tower**

Acquired Observations

15, 30, 60 minute output
u, v, w, ws, wd
$\sigma_u$, $\sigma_v$, $\sigma_w$, u'v', u'w', v'w', T, $T'^2$, w'T', $u'^2$, $v'^2$, $w'^2$, urun, vrun, wrun

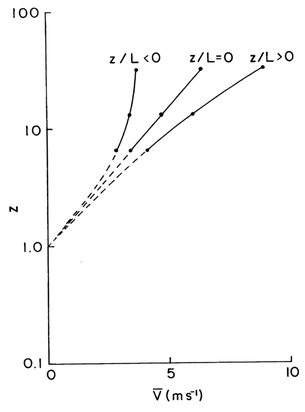
**Surface Energy Balance System**

15, 30, 60 minute output
u, v, w, ws, wd
$\sigma_u$, $\sigma_v$, $\sigma_w$, u'v', u'w', v'w', T, $T'^2$, w'T', $u'^2$, $v'^2$, $w'^2$, urun, vrun, wrun, soil temperature (5 levels), soil moisture, solar energy components, surface temperature, $CO_2$/$H_2O$

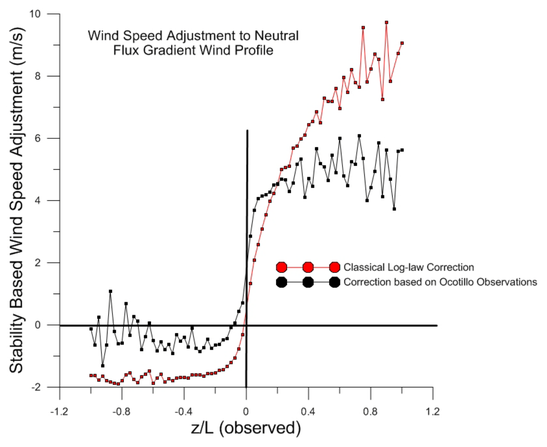
## Flux Gradient Profile Measurements

**$u_*$, $z_0$, d, z/L, w't'**

$$u_z = \frac{u_*}{k}\left[ln\left(\frac{z-d}{z_0}\right) - \psi\left(\frac{z}{L}\right)\right]$$




## Gradient Profile Stability Adjustment




## Gradient Wind Profile Prediction versus Observed Hub Height Winds