Mechanisms of Low-Level Jet Formation in the U.S. Mid-Atlantic Offshore

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Contents

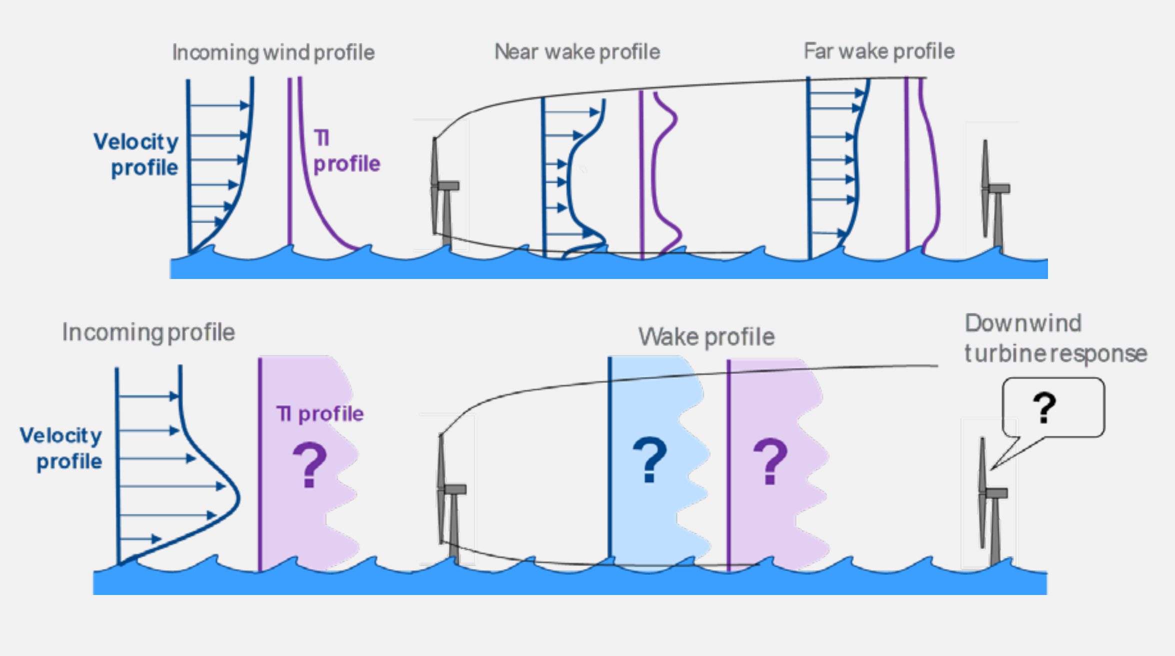
Low Level Jets

Local maximum in the wind speed near the surface

Implications for wind energy:

- Increased loads
- Increased shear
- Negative shear
- Wake recovery

*Mid-Atlantic offshore LLJs are *not diurnal*



What atmospheric conditions lead to mid-Atlantic LLJS?

LLJ Mechanisms – Inertial Oscillation

$$\frac{DU}{Dt} = fV - \frac{1}{\rho}\frac{\partial P}{\partial x} - \frac{\partial}{\partial z}\left(\frac{\tau_x}{\rho}\right)$$

$$\frac{DV}{Dt} = -fU - \frac{1}{\rho}\frac{\partial P}{\partial y} - \frac{\partial}{\partial z}\left(\frac{\tau_y}{\rho}\right)$$

$$0 = fV_g - \frac{1}{\rho}\frac{\partial P}{\partial x}$$

$$0 = -fU_g - \frac{1}{\rho}\frac{\partial P}{\partial y}$$

Geostrophic Balance

$$\frac{\partial(U - U_g)}{\partial t} = f\left(V - V_g\right) - F_x$$

$$\frac{\partial(V - V_g)}{\partial t} = -f\left(U - U_g\right) - F_y$$

Inertial Oscillation

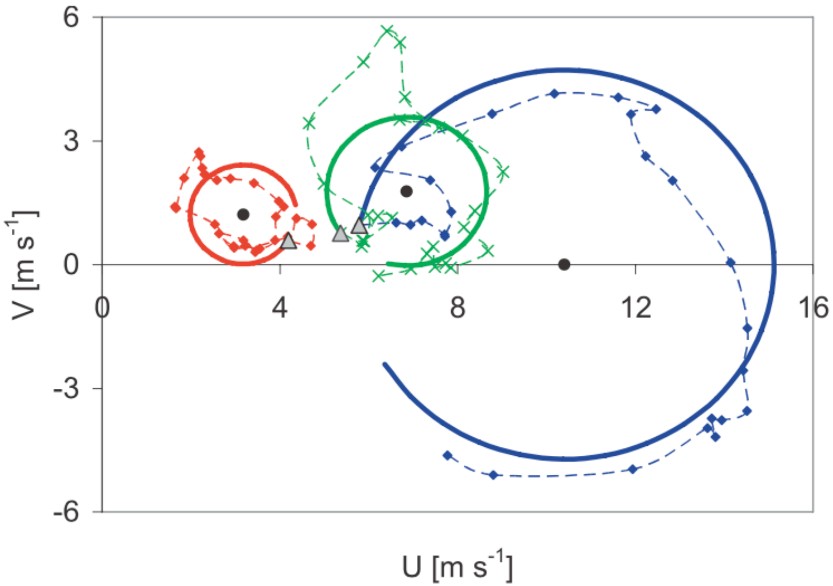
$$U(z,t) = U_{eq}(z) + \left(V_0(z) - V_{eq}(z)\right)\sin ft + \left(U_0(z) - U_{eq}(z)\right)\cos ft$$

LLJ Mechanisms – Inertial Oscillation

$$\frac{DU}{Dt} = fV - \frac{1}{\rho}\nabla P - \frac{\partial}{\partial z}\left(\frac{\tau_x}{\rho}\right)$$

$$0 = fV_g - \frac{1}{\rho}\frac{\partial P}{\partial x}$$

$$\frac{\partial(U - U_g)}{\partial t} = f\left(V - V_g\right) - F_x$$



[Fig 8] Wiel et al, *Journal of Atmospheric Sciences 67*(8), 2010

Inertial Oscillation

$$U(z,t) = U_{eq}(z) + \left(V_0(z) - V_{eq}(z)\right)\sin ft + \left(U_0(z) - U_{eq}(z)\right)\cos ft$$

LLJ Mechanisms – Triggers

Frictional Decoupling – Blackadar 57

$$\frac{\partial(U - U_g)}{\partial t} = f\left(V - V_g\right) - F_x$$

- Nocturnal stability triggers decrease in friction/vertical eddy diffusivity

Differential Heating or Sloped Terrain

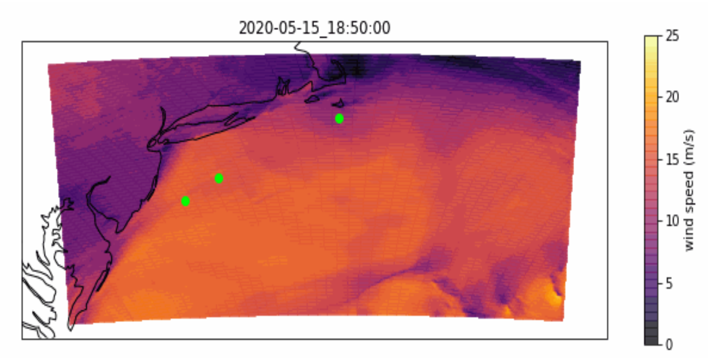
$$\partial_z U_g = -\frac{g}{fT}\,\partial_y T$$

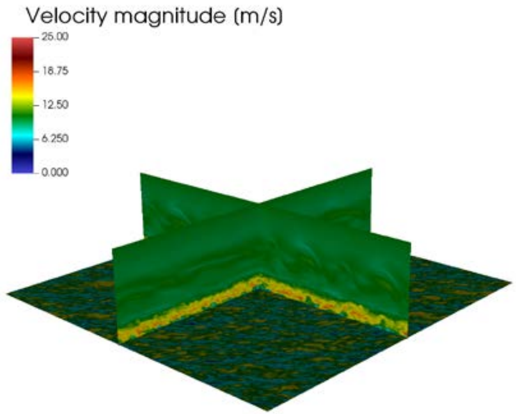
$$\partial_z V_g = \frac{g}{fT}\,\partial_x T$$

- Horizontal temperature gradients (**baroclinicity**) lead to vertical variations in geostrophic wind

Which, if any, of these mechanisms are responsible for US Atlantic LLJs?

Data and Simulation Resources





Floating LiDAR Buoy

- Identify observed low-level jet events
- Wind speed, direction
- SST, waves, temperature, etc.

Weather Research & Forecasting Model (WRF)

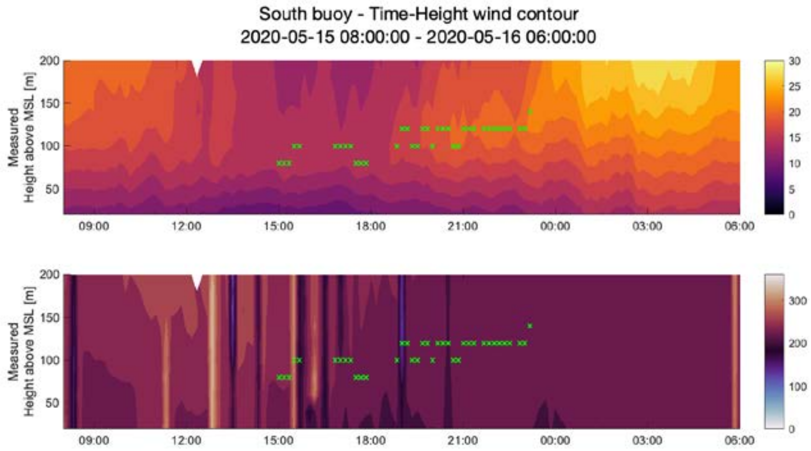
- Mesoscale: simulate mid-Atlantic region
- T, P, velocity fields
- Energy fluxes

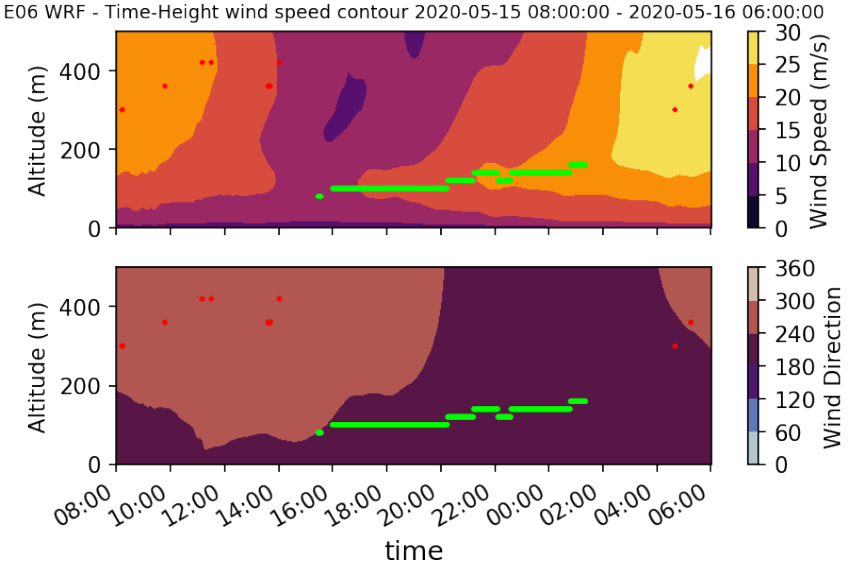
AMR-Wind (Large Eddy Simulation)

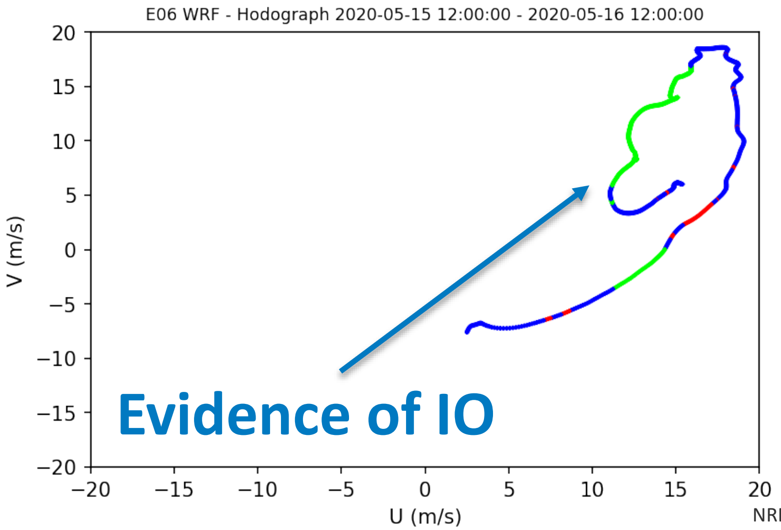
- Resolve turbulence & microscale features of the LLJ event
- Turbine impacts

Mesoscale Characteristics of the May 15, 2020 LLJ

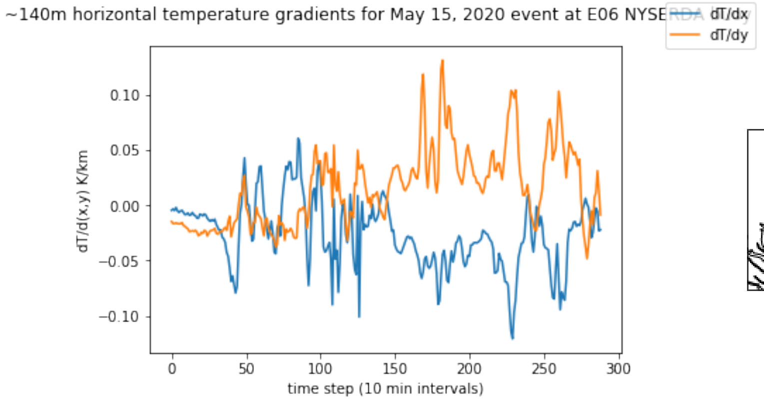
- Persistent LLJ at 1600 UTC
- Consistent SSW wind direction
- Rising jet nose, winds > 25 m/s

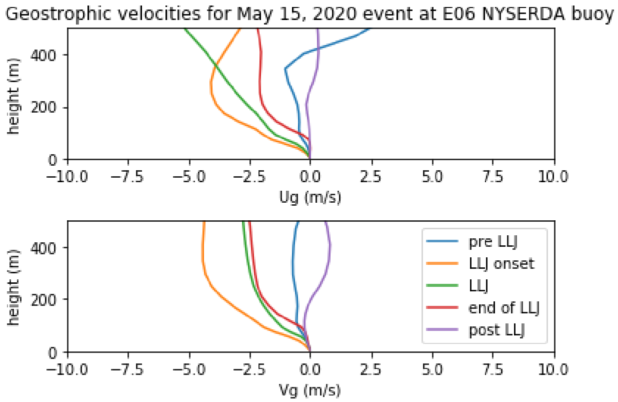


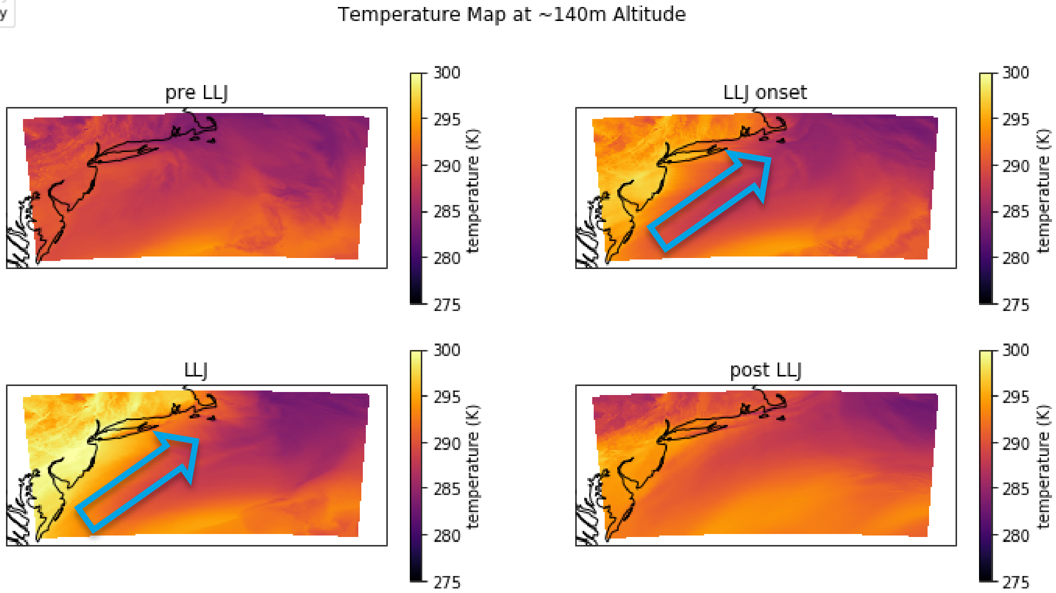




Mesoscale Characteristics of the May 15, 2020 LLJ

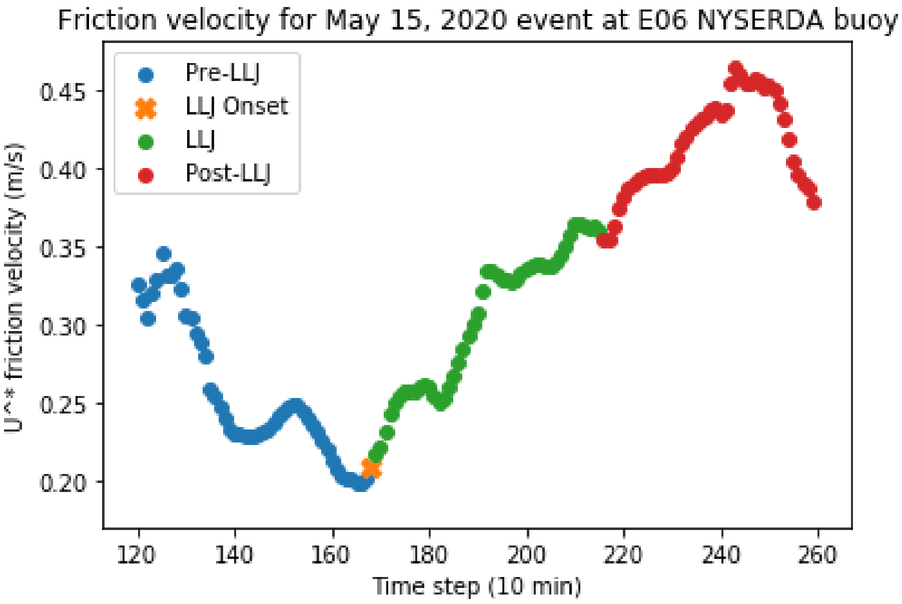


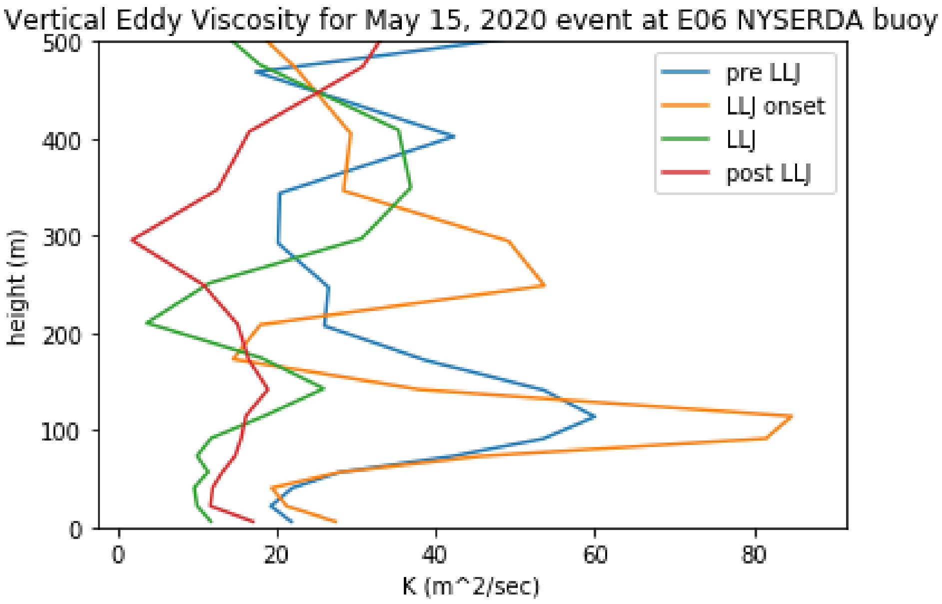




Evidence of baroclinicity

Mesoscale Characteristics of the May 15, 2020 LLJ





Evidence of frictional decoupling

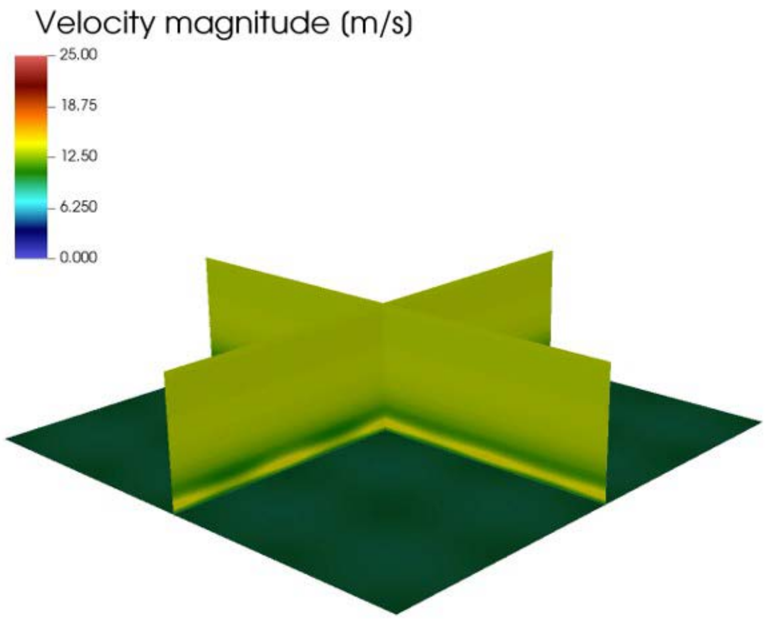
All three mechanisms contribute to the formation of mid-Atlantic LLJs…

But what are the necessary and *sufficient* conditions?

- Too complex for the simple 1-D system of equations to capture LLJ formation and dissipation.

Ongoing Work:

- Single-Column Model
  - Simplify horizontal gradients
  - More realistic stability and forcing than analytic models



- Microscale LES
  - Resolve turbulent structures and ABL
  - Drive turbine simulations

- LLJs impact turbines
- Mid-Atlantic LLJs correlate with:
    - Inertial Oscillation
    - Baroclinicity
    - Frictional Decoupling
- Ongoing work to disentangle competing effects

Questions?

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