NREL
Transforming ENERGY

Understanding Low Level Jets in the US Atlantic Offshore

Emily de Jong, Eliot Quon, Shashank Yellapantula

Rocky Mountain Fluid Mechanics

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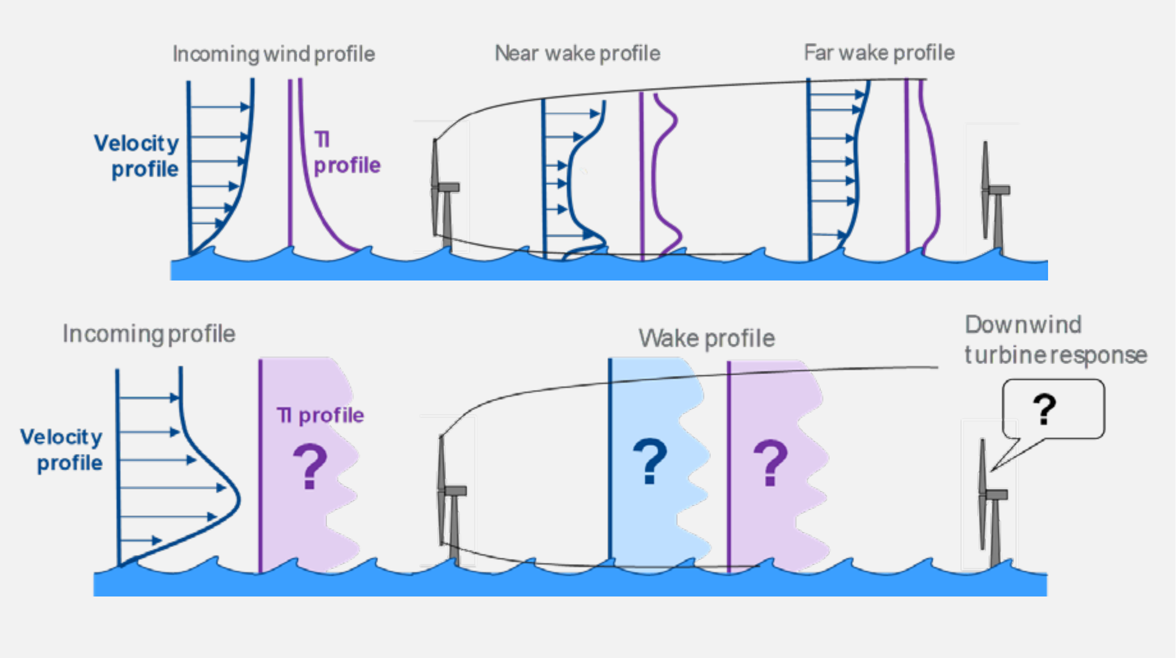
Low Level Jets

Local maximum in the wind speed near the surface

Implications for wind energy:

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

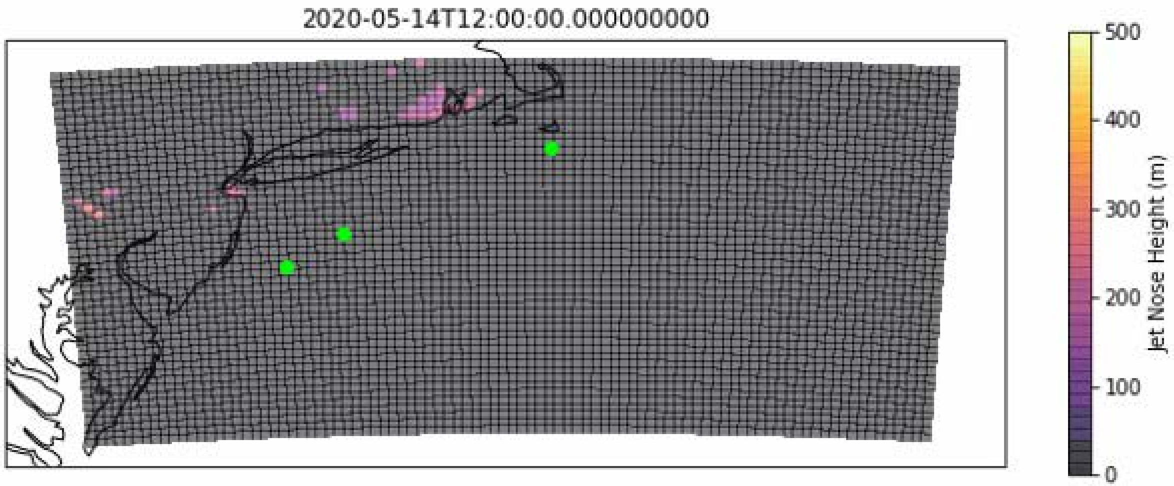


Graphic courtesy of Jing Li and GE Research/NREL LLJ team.

LLJs in the US Mid-Atlantic

LLJs are found in:

- Great Plains
- California Coast
- North Sea
- Antarctic peninsula
- …
- *USA mid-Atlantic*



A. NYSERDA E06 South Buoy
B. NYSERDA E05 North Buoy
C. MassCEC ASIT & lidar buoy

What atmospheric conditions lead to mid-Atlantic LLJS?

LLJ Mechanisms – Inertial Oscillation

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

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

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

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

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

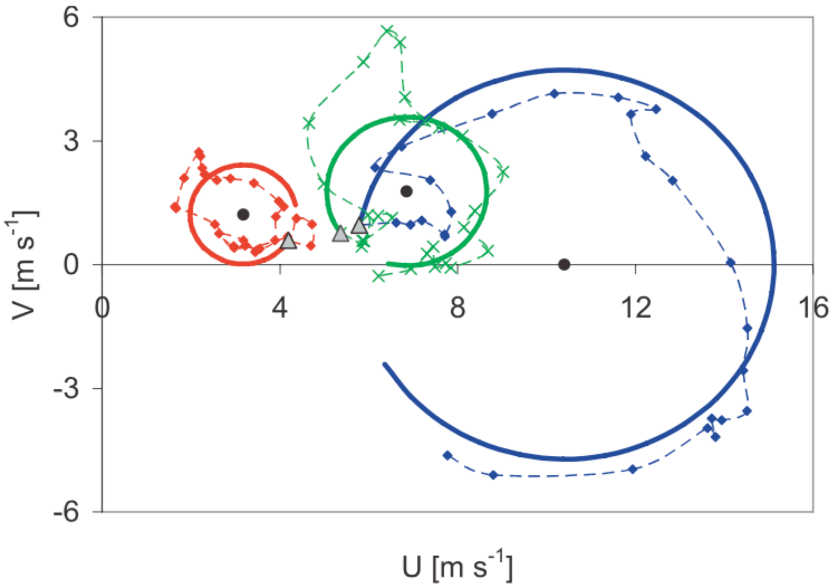
$$U(z,t) = U_{eq}(z) + \left(V_0(z) - V_{eq}(z)\right)\sin ft + \left(U_0(z) - U_{eq}(z)\right)\cos ft$$

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

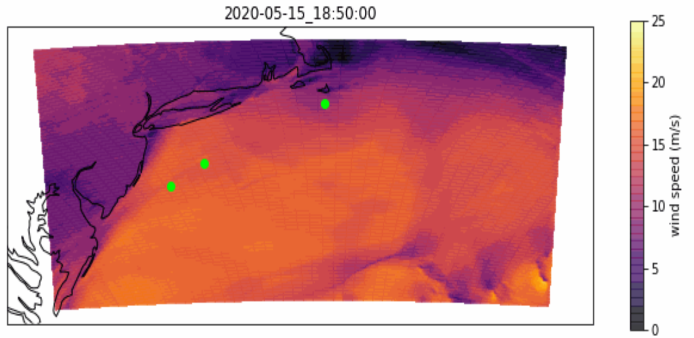
$$\partial_z U_g = -\frac{g}{fT}\,\partial_y T$$

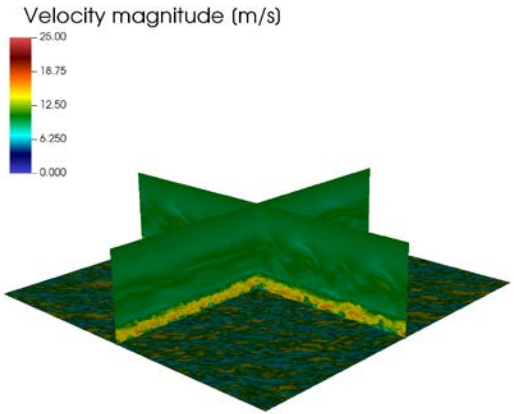
$$\partial_z V_g = \frac{g}{fT}\,\partial_x T$$

- 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



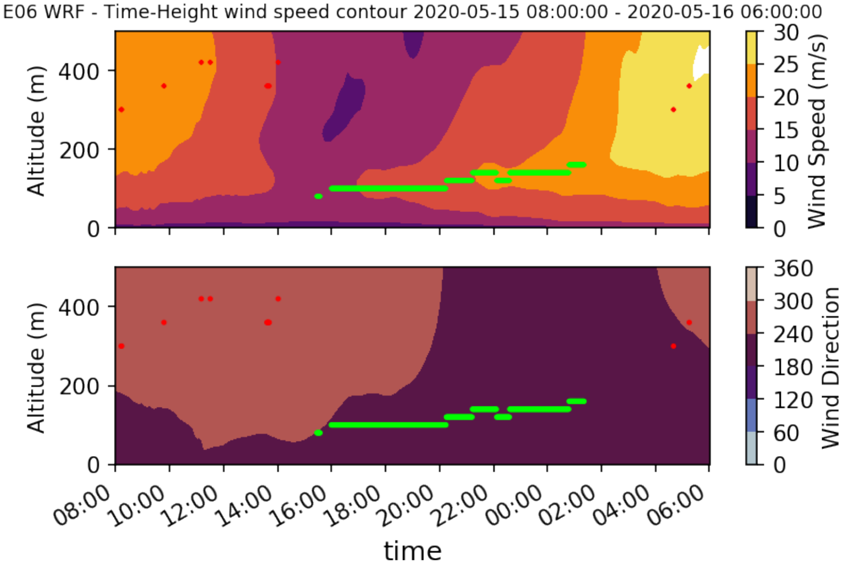


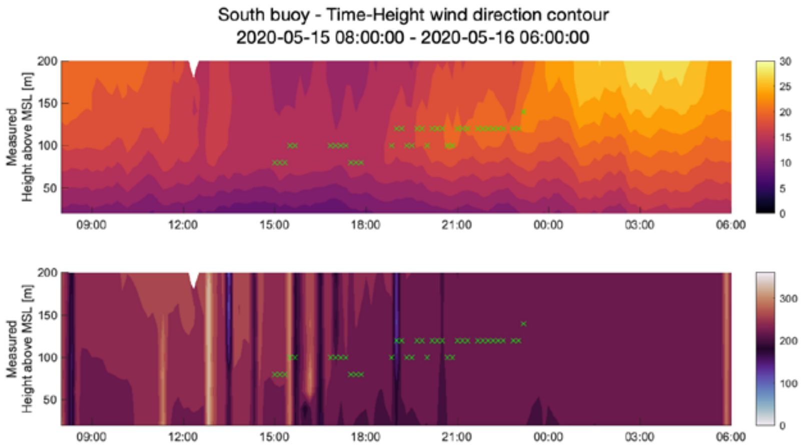
Floating Lidar Buoy
- Identify observed low-level jet events
- Wind speed, direction
- SST, waves, temperature, …

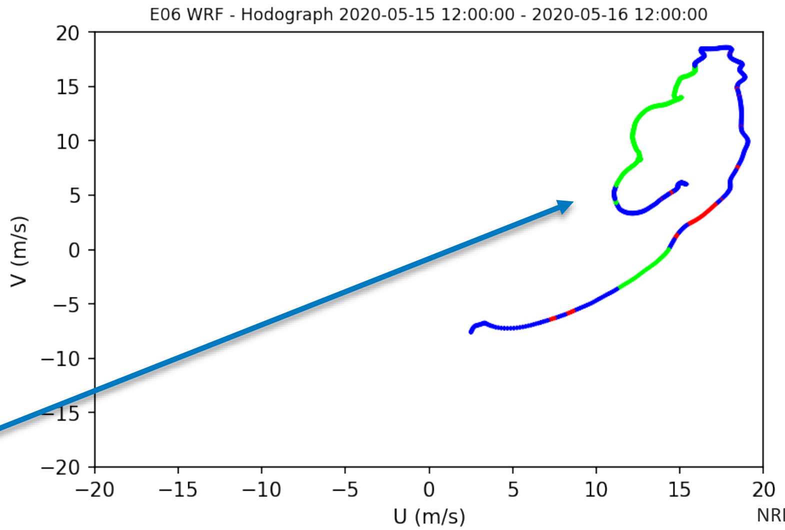
Weather Research & Forecasting Model (WRF)
- Simulate mid-Atlantic region during LLJ event
- T, P, velocity fields
- Energy fluxes

AMR-Wind (Large Eddy Simulation)
- Resolve microscale features of the LLJ event

Mesoscale Characteristics of the May 15, 2020 LLJ

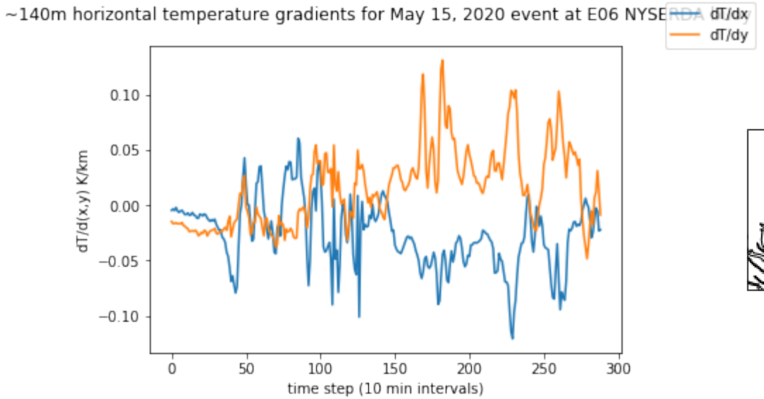


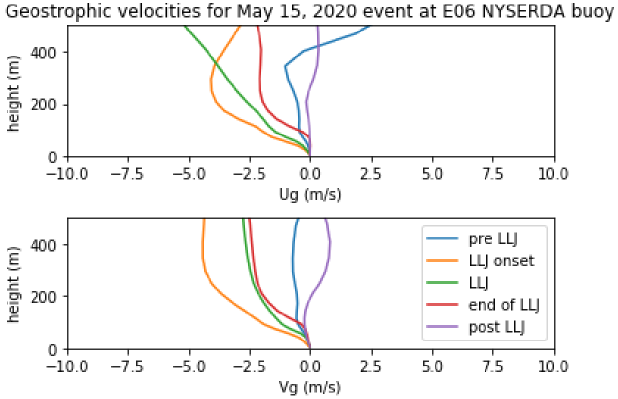


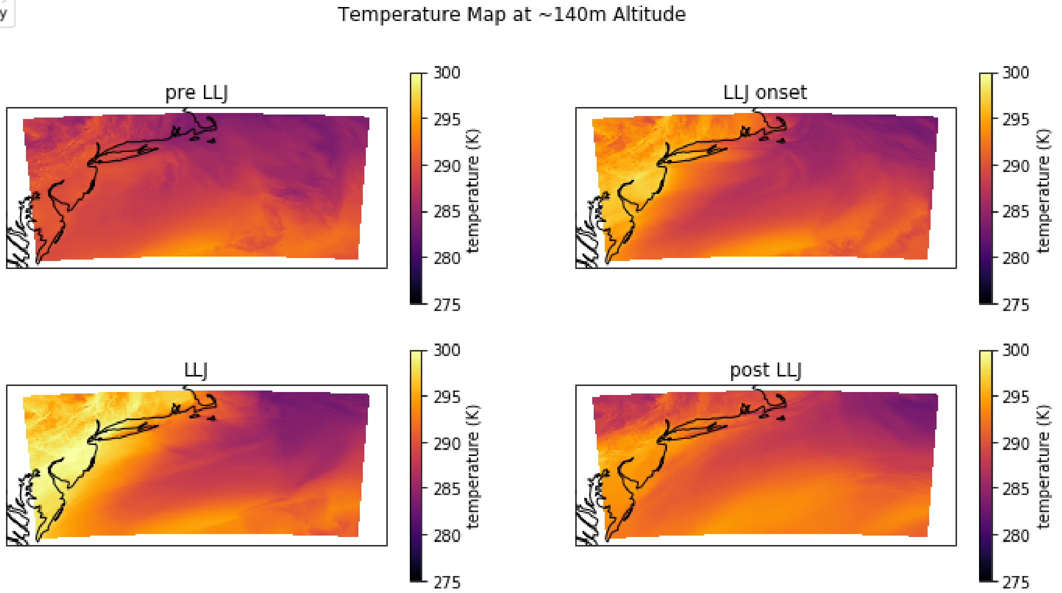


Evidence of IO

Mesoscale Characteristics of the May 15, 2020 LLJ

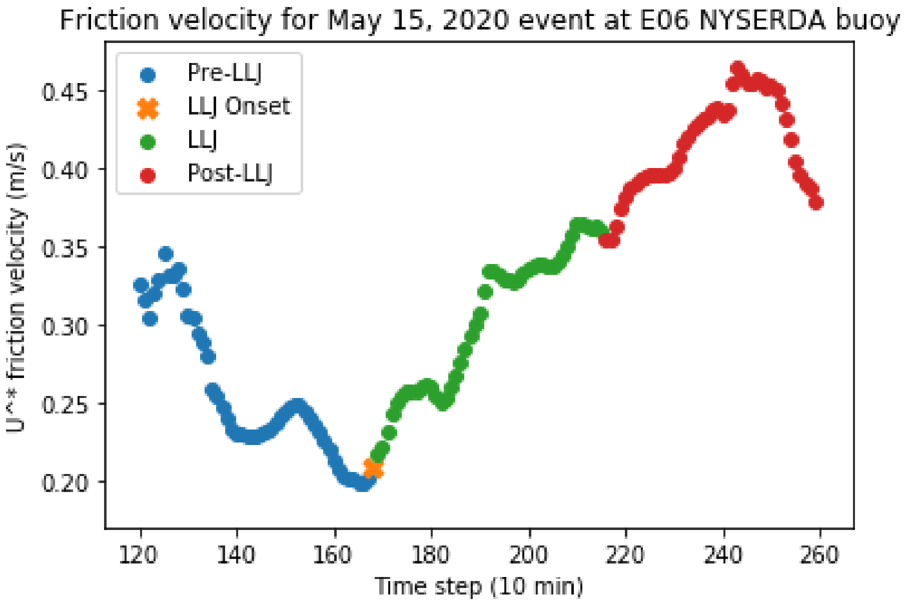


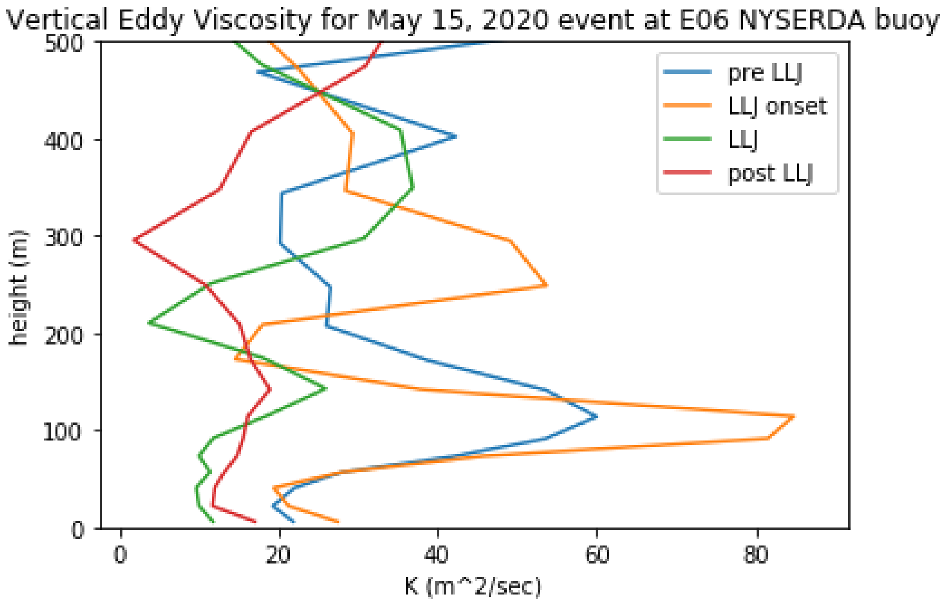




Evidence of baroclinicity

Mesoscale Characteristics of the May 15, 2020 LLJ





Evidence of frictional decoupling

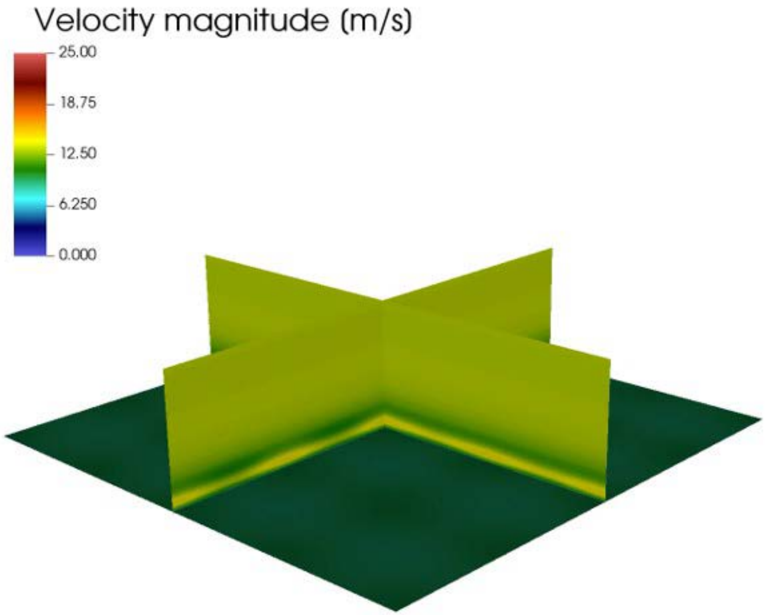
All three mechanisms contribute to the formation of mid-Atlantic LLJs…

But what are the <u>necessary</u> and <u>*sufficient*</u> conditions?

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

Next steps:

- Microscale LES
  - Resolve turbulent structures and ABL
  - Detail about near-surface friction and shear
  - Drive turbine simulations



- Single-Column Model
  - More detail (ex. stability) than the simple system

Questions?

www.nrel.gov

edejong@caltech.edu. / emily.dejong@nrel.gov

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