Summer Experience

- EPFL in Lausanne, Switzerland
  - Dr. Fernando Porté-Agel
- July 17th - September 1st
- Surface Flow Convergence
How?

• Emailed Dr. Porté-Agel
  – Followed up on Skype
  – Offered to host me (easy part)

• Visa process (nightmare)
  – Work Visa
  – 3 month process
  – Traveled to Chicago and DC
  – Received visa 5 days before I left
Switzerland
Lausanne

- Population: 146,372 (4th in Switzerland)
- Northernmost shore on Lake Geneva
- Smallest city in world w/ rapid transit system
- Olympic Capital
Lausanne

Summer 2015
Travels

Summer 2015
Surface Flow Convergence

- **Observed**: Flow *veers* as it travels through a wind farm.

- Near-ground measurements show **surface flow convergence**.

- **Hypothesis**: pressure gradient imposed by turbines responsible.
Surface Flow Convergence: How?

- Pressure drops across turbine
  - Recovers far downstream

- Complete pressure recovery may not be possible with closely spaced turbines

Increasing pressure deficit in deep arrays
Surface Flow Convergence: Data

Surface flow veering observations (courtesy Prof. Eugene Takle; ISU)
Computational Analysis

- RANS + Actuator Disk
- OpenFOAM
- Validation:
  - 1-D Momentum Theory
  - Risø (Tellus) turbine
- Infinite array
  - Angled Inflow
  - Uniform & Neutral B.L.
- Story County Wind Farm
  - Crop/Wind-Energy Experiment (CWEX)
RANS Results

Semi-infinite wind farm at Hub Height (Uniform):

Compounding pressure drops

Flow Angle Change of $\approx 4^\circ$
Semi-infinite wind farm at surface (Neutral ABL):

Compounding pressure drops

Flow Angle Change of $\approx 8^\circ$... Much Higher!

Balance between static and dynamic pressure
Large Eddy Simulation

• How do unsteady phenomena affect SFC?
  – Atmospheric Stability and Turbulence
  – Wake Rotation
  – Coriolis Force?

• Implementation: SOWFA
  – OpenFOAM
  – Actuator Line Model
Domain

- Turbine: NREL 5MW Ref x10
  - D = 126 m
- Boundary Conditions (Uniform):
  - N-S: Periodic (Semi-infinite wind farm)
  - W-E: Inflow/Outflow
  - Top-Bottom: Slip

\[ U = 8 \text{ m/s} \]

\[ 15D \quad 10D \]

\[ 5D \quad 70D \]
Uniform Results: Pressure
Uniform Results: Flow Angle
Uniform Results: Normalize Power

![Graph showing normalized power vs turbine number with an annotation highlighting a particular point.](image-url)
QUESTIONS?