

U.S. DEPARTMENT OF  
**ENERGY**

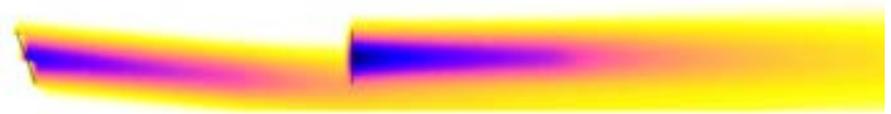
Office of  
**ENERGY EFFICIENCY &  
RENEWABLE ENERGY**

# Advanced Flow Control Science for Wind Plants

## Project ID #T8

Paul Fleming

National Renewable Energy Laboratory



# FY17-FY18 Wind Office Project Organization

“Enabling Wind Energy Options Nationwide”

Technology Development

Market Acceleration & Deployment

Atmosphere to Electrons

Stakeholder Engagement, Workforce Development, and Human Use Considerations

Offshore Wind

Environmental Research

Distributed Wind

Grid Integration

Testing Infrastructure

Regulatory and Siting

Standards Support and International Engagement

Advanced Components, Reliability, and Manufacturing

Analysis and Modeling (cross-cutting)

# Project Overview

## T8: Advanced Flow Control Science for Wind Plants

### Project Summary

- Research the science of wind farm control to produce methods and strategies to design and analyze wind farm controllers.

### Project Objective & Impact

- Coordinating the control of turbines within a wind farm to substantially improve the performance of existing and new wind farms, increasing power production, reducing turbine loads, and providing grid services. Research in advanced flow control science provides the methods and strategies for realizing significant improvements over existing technology approaches. This research will increase the value of wind energy, while reducing the cost for both land-based and offshore deployments.

### Project Attributes

Project Principal Investigator(s)

Paul Fleming

DOE Lead

Mike Derby

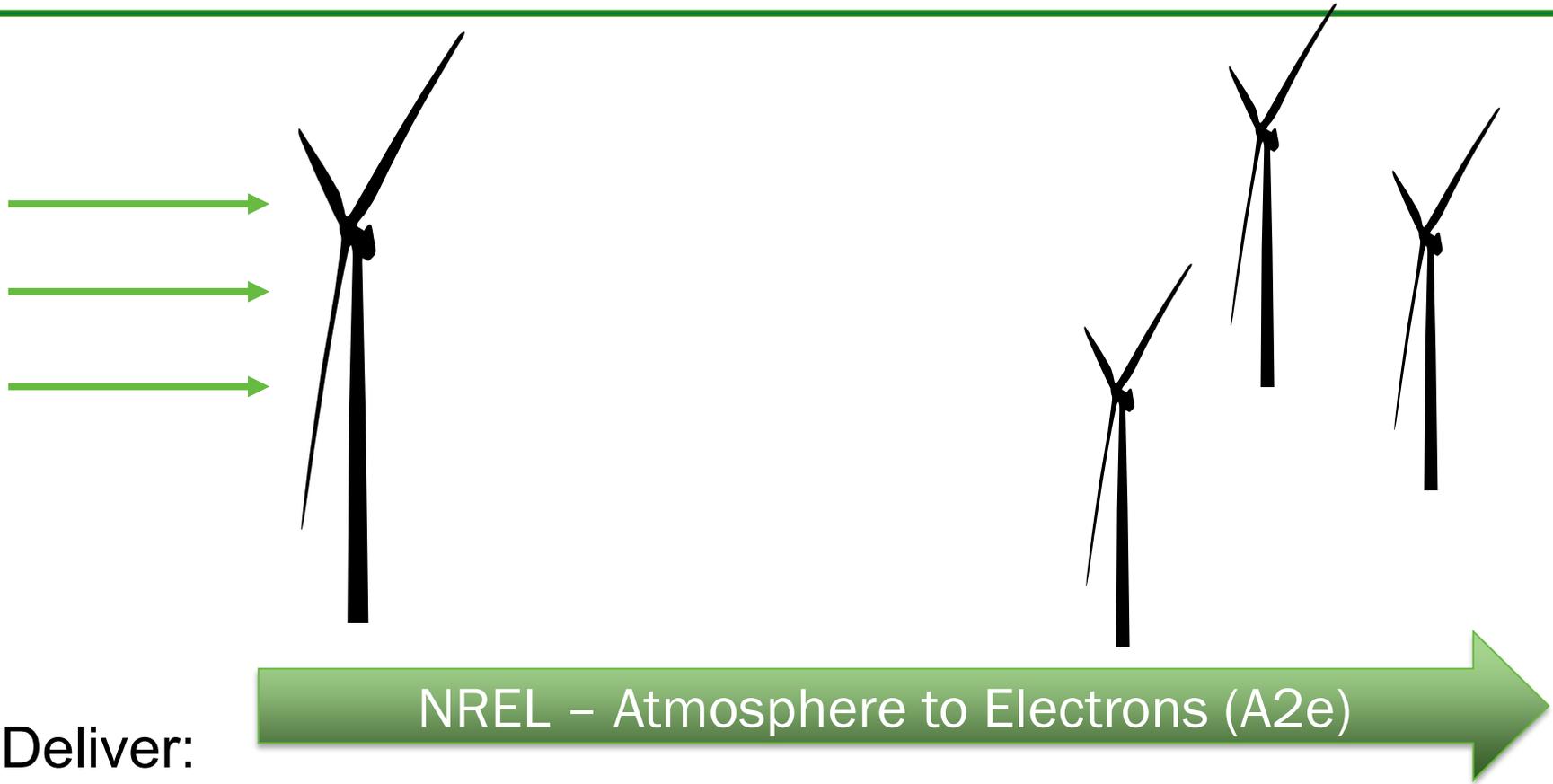
Project Partners/Subs

CU Bolder  
Colorado School of Mines  
TU DELFT

Project Duration

5 years - October 2013 -  
Ongoing

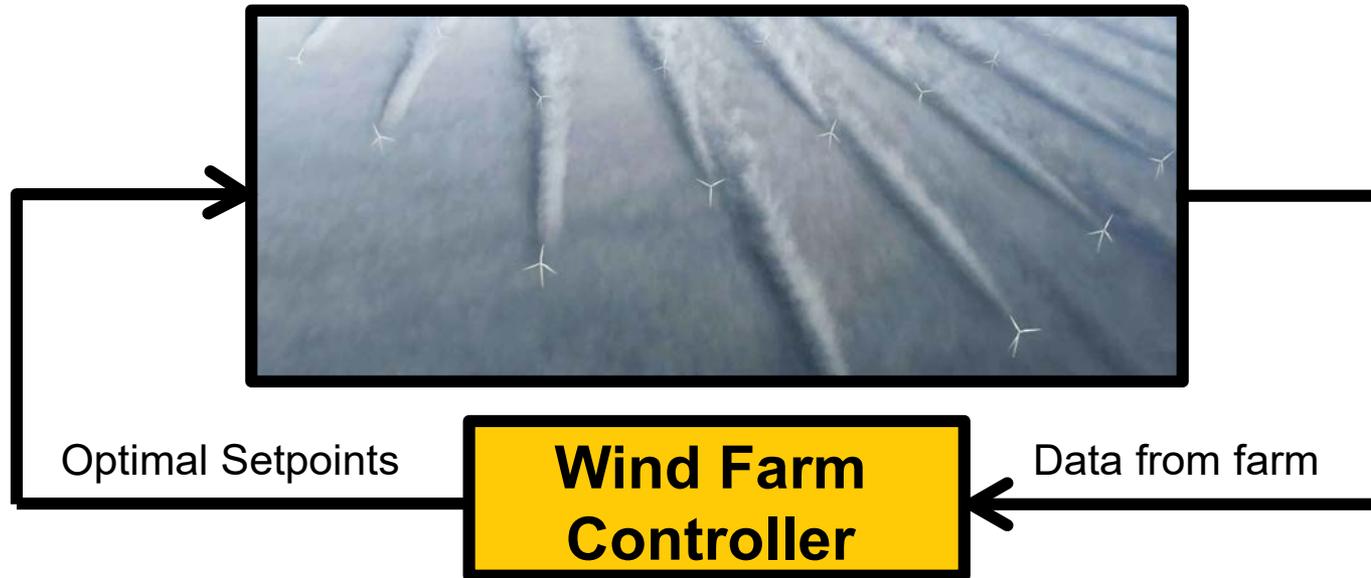
# Technical Merit and Relevance



Deliver:

- Increased energy production
- Reduced loads
- Higher value to the grid
- Increased certainty over production

# Technical Merit and Relevance



*For a 300MW plant, 2% AEP improvement can add **\$1M/year** in revenue*

## Value Proposition

### Increase Production

MWh up to 2%  
\$1M per year

### Less Maintenance

O&M cost down 10%  
\$1M per year

### Extend Project Life

30 years & Beyond  
+5 years = \$150M

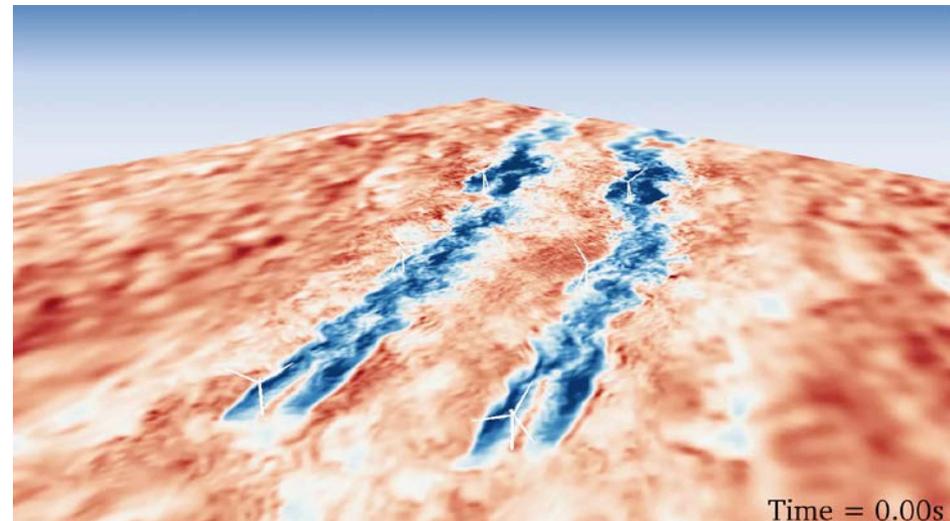
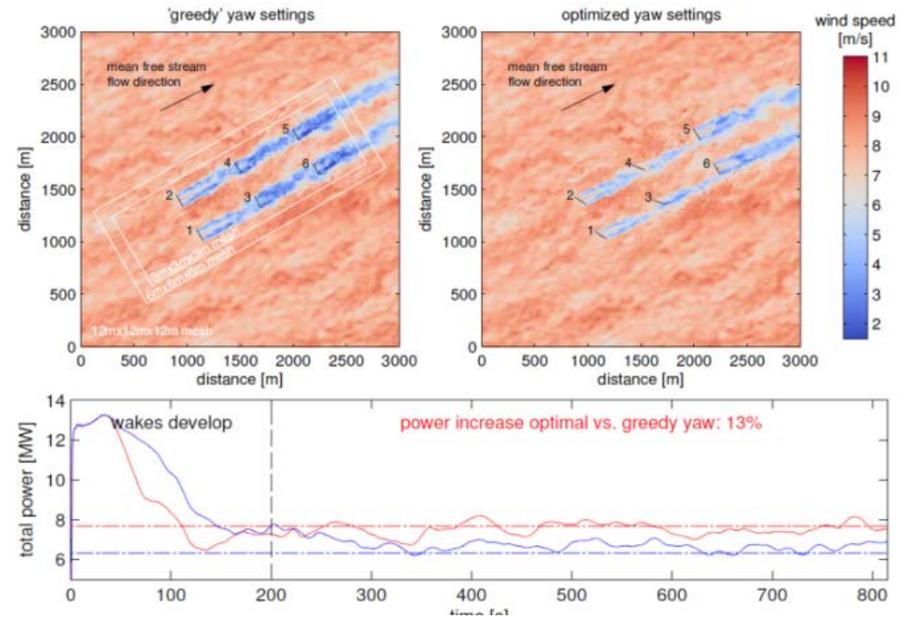
# Approach and Methodology

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# Approach and Methodology

- FLORIS: Key open source wind farm control tool
  - Developed with TU DELFT
  - Control-oriented wake model
- Today, contains 4 separate models of wakes which can be selected/defined by user
- **Critical and central to all wind farm controls research**
- Has an active and growing user base, we've been in touch with many manufacturers and developers on their progress using FLORIS



# Accomplishments and Progress

## Control-Oriented Modeling

- Added turbulence models and advanced physics
- Validated using lidar data
- Inclusion of loads, tilting and pitch angle
- Software overhaul for open source

## Controller Design

- Designed controllers for field validation campaigns
- Created tools for controlling floating controllers
- Initial generic offshore controller report
- Designed controllers for loads reduction

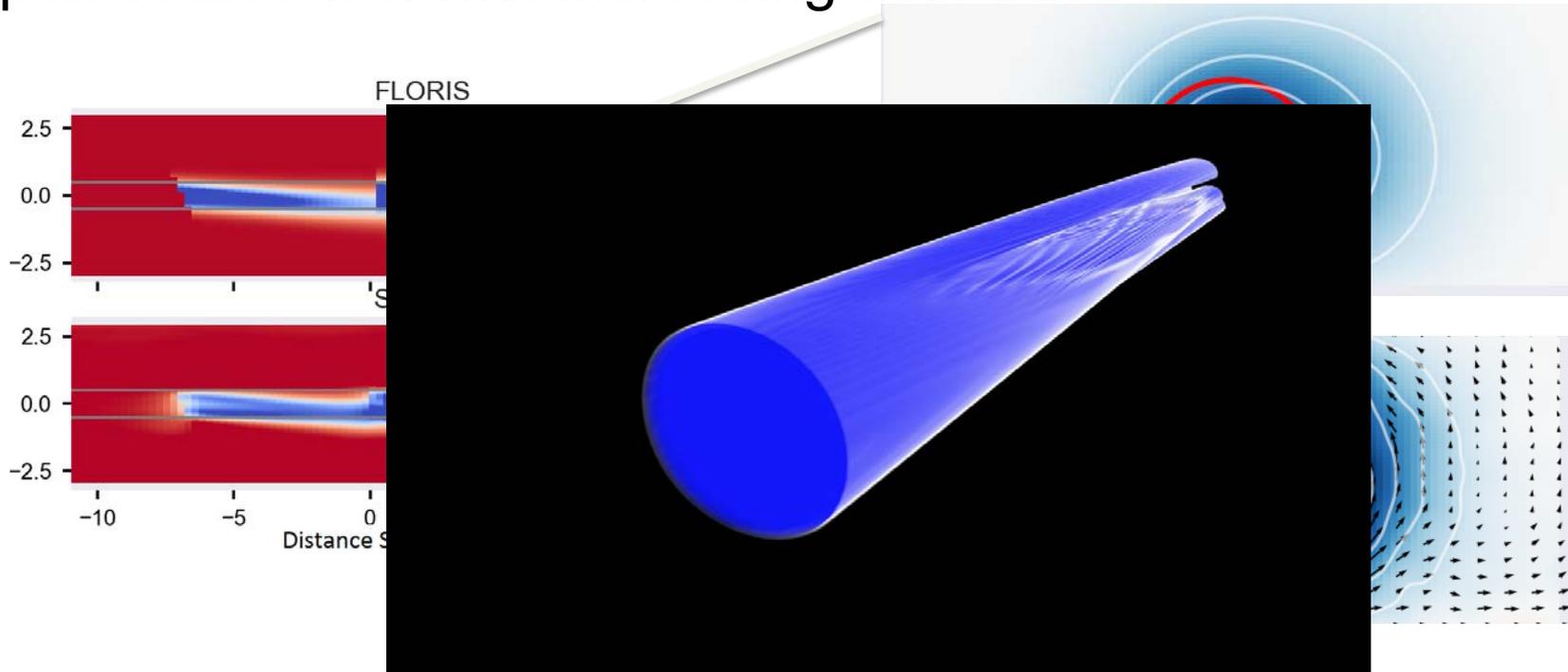
## Control Validation

- Completed several LES-based validation studies of wind farm control concepts
- Two lidar-based validation campaigns
- Began full-scale commercial field campaign

# Accomplishments and Progress

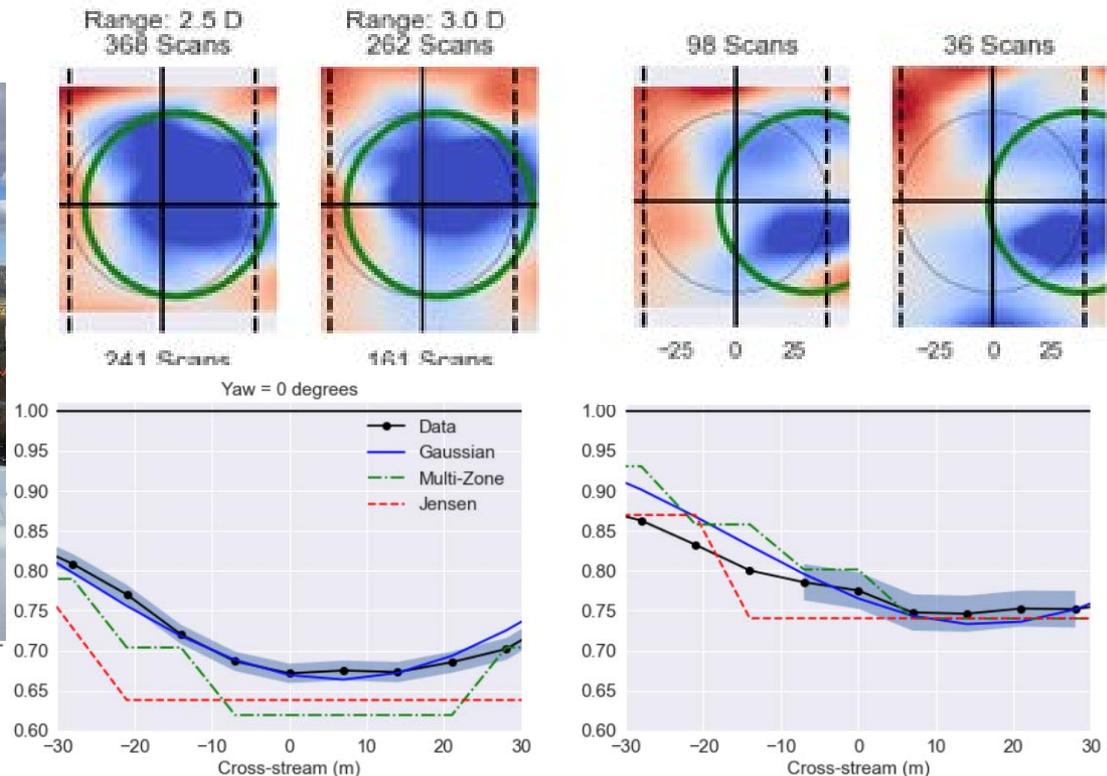
Controls model FLORIS substantially improved to include new physics and capabilities

Open source tool with increasing user base



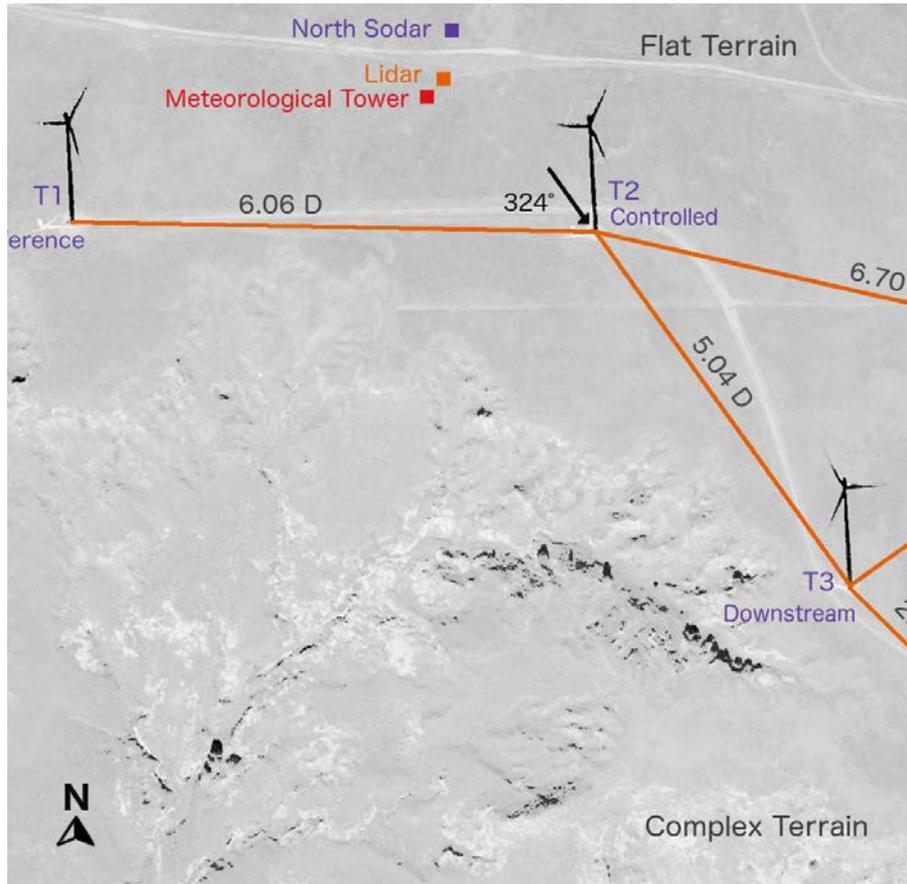
# Accomplishments and Progress

In connection with wake dynamics group, completed test of wake steering on single turbine using lidar to validate FLORIS-based prediction of wake steering.



# Accomplishments and Progress

Field validation builds on HFM research and demonstrates that wake steering gains are achievable



# Accomplishments and Progress



Offshore wind energy represents an important opportunity for US wind energy and a domain where the application of wind farm control can be more significantly impactful

Important control challenges to solve, due to hydrodynamic interactions and increased degrees of freedom

Controls project successfully developed control models of floating systems to be used in systematic controller design

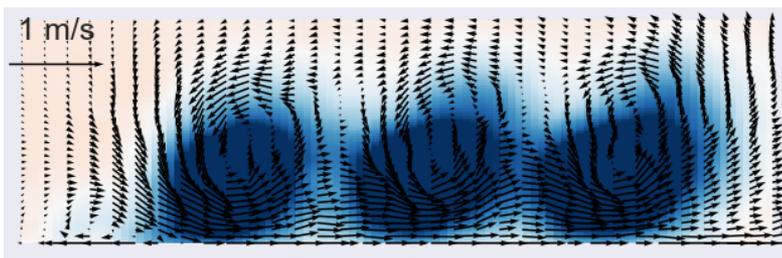
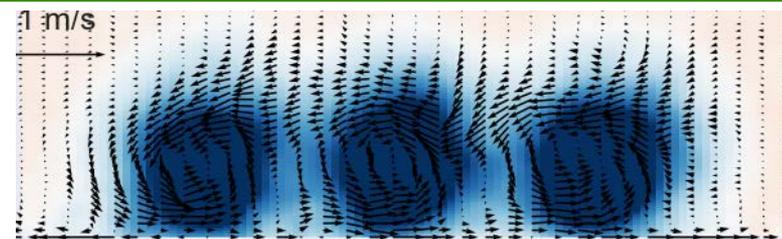
# Communication, Coordination, and Commercialization

- Internal collaboration
  - Extensive collaboration with other A2e projects wake dynamics, HFM and ISDA
- External collaboration
  - Cooperative research agreements in place with international universities
  - Strategic collaboration with industrial partners
  - Advisory role in relevant EU funded projects
- Open source
  - FLORIS is open source, open development and used by people throughout research community and industry
- Publications
  - 7 journal publications in FY17-18
  - Organized sessions at Torque and American Control Conference while providing numerous conference papers

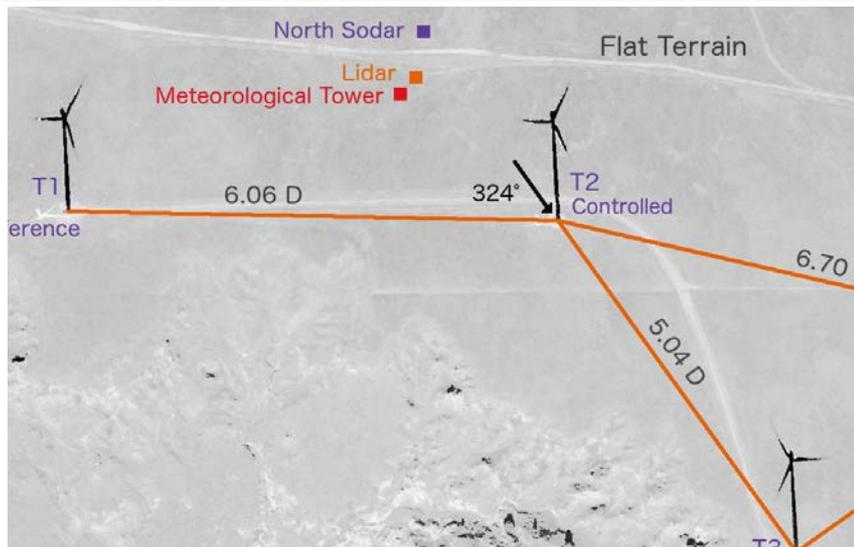
# Upcoming Project Activities



Plant Controllers



Physics



Validation



Offshore