SAND2015-4259PE

Overview of Planned DOE Wind Program Validation Experiments

A2e Wind Plant Physics and Modeling Planning Meeting

February 25, 2015

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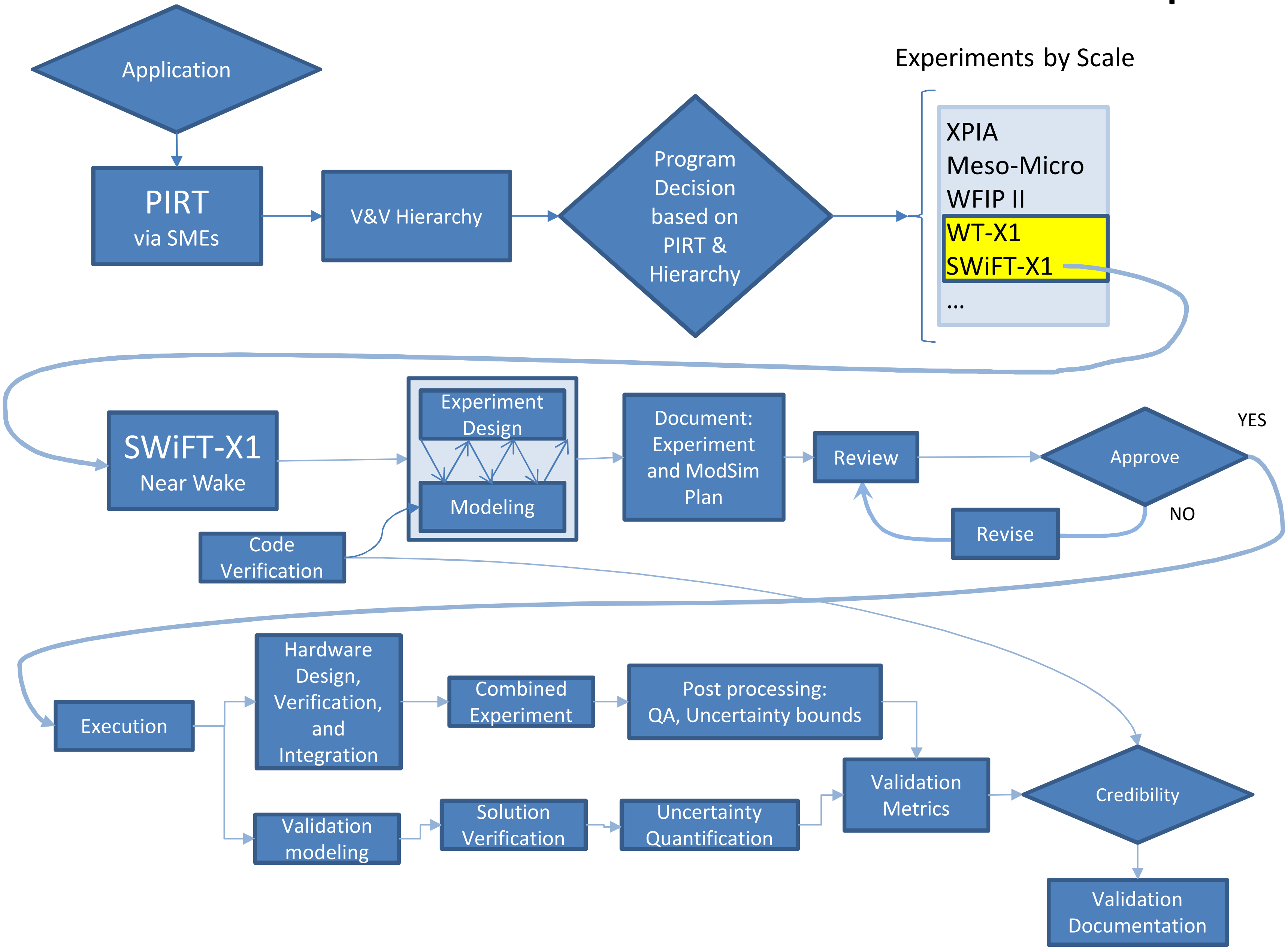
Overview of Planned DOE Wind Program Validation Experiments

- Short summary presentations on each of the planned validation experiments
- Desired outcomes of presentations and breakouts:
  - Guidance/suggestions for experimental campaigns currently in the FY2015-16 operating plan.
  - Define and prioritize the next experimental campaigns.

Verification and Validation Process Example



Definition of a Modeling Campaign:

1.) What is to be predicted?
2.) Under what scenario?
3.) Impact of the model results on final design decisions?

Definition of an Experimental Campaign:

1.) **Objective**: What will be validated and what are the test conditions?
2.) **Method**: How will this data be gathered? What is the setup and instrumentation?
3.) **Environment/Requirements**: What are the requirements and constraints on the test campaigns? What is the required resolution/accuracy/time-scale?
4.) **Desired Outcome**: What will success mean? How will it be quantified?

Near Term Planned Experiments

- **XPIA: Plant Inflow and Meso-micro Coupling**
- **Mesoscale-Microscale Coupling**
- **WFIP 2: Plant Boundary and Intra-plant Flow**
- **Wind Tunnel: Scaled rotor(s) with inflow control.**
- **SWiFT Experiment 1: Near Wake validation**

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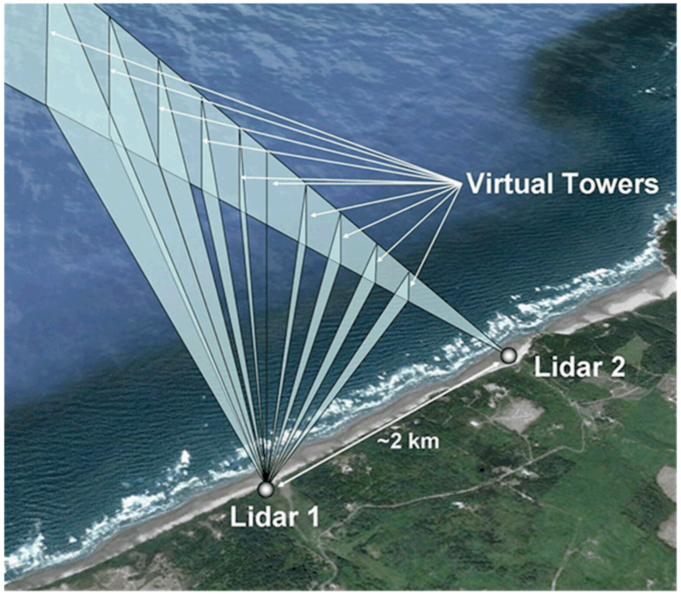
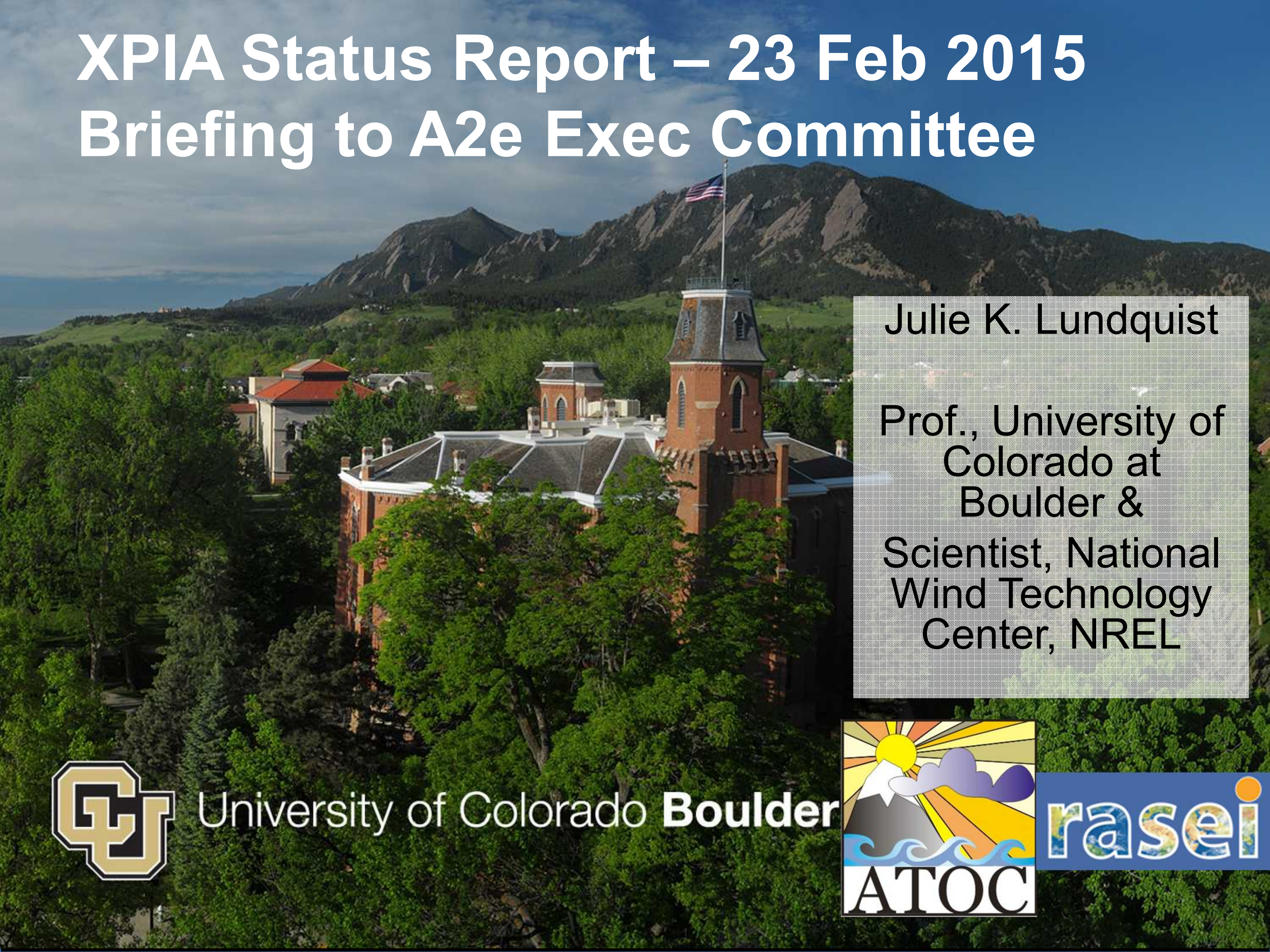


XPIA Status Report – 23 Feb 2015
Briefing to A2e Exec Committee



Julie K. Lundquist

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Scientist, National Wind Technology Center, NREL

University of Colorado **Boulder**

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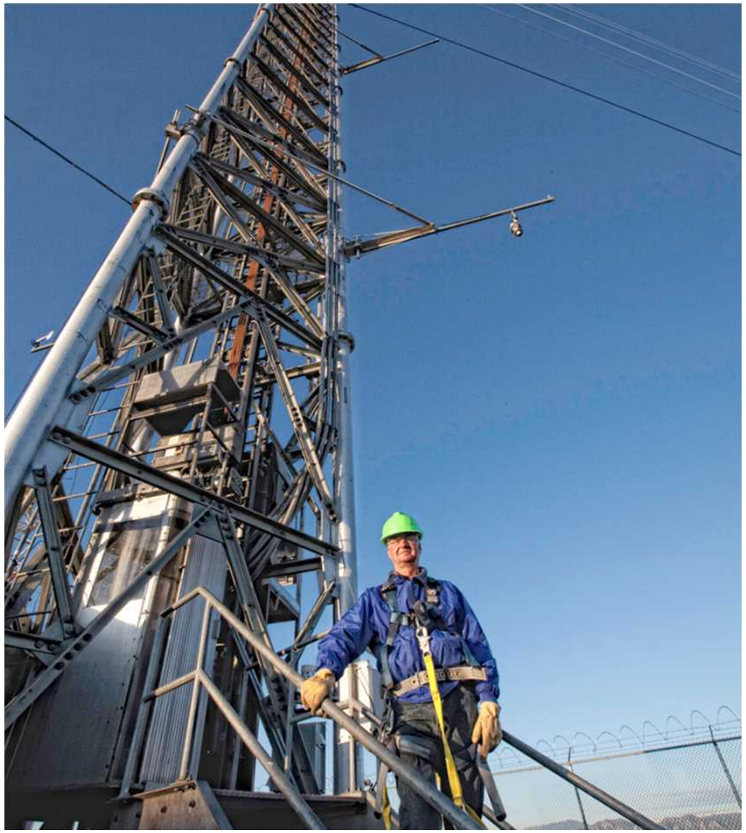
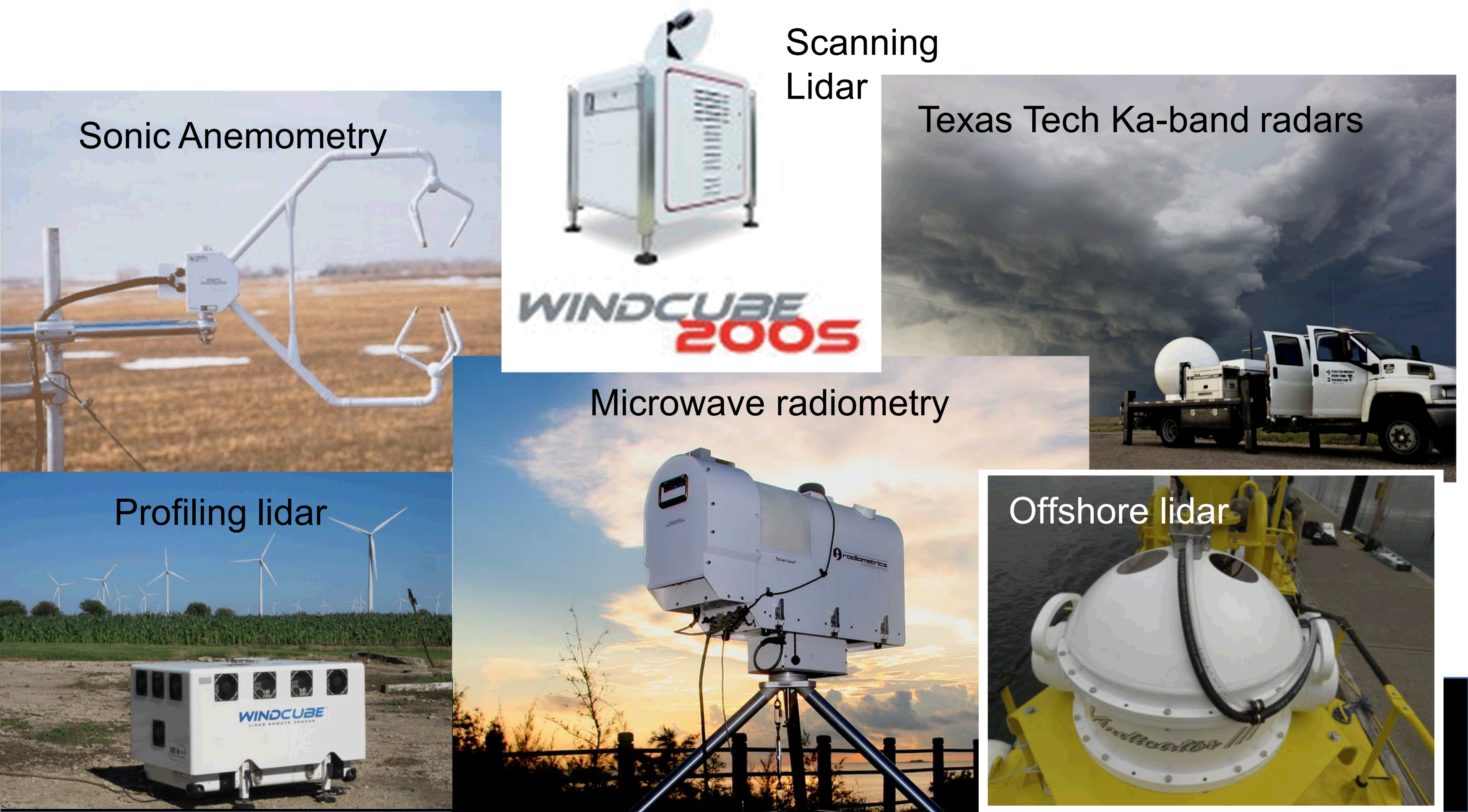
XPIA: **X**MC **P**lanetary boundary layer **I**nstrumentation **A**ssessment

- **GOAL:** to assess existing instrumentation for their temporal and spatial resolution capability to capture PBL and intra-array wind plant flow characteristics **for validation and verification of wind plant flow models**
- **PLAN:** detailed field experiment 2 March – 10 Apr at Boulder Atmospheric Observatory in Boulder, Colorado
- **ARCHIVE:** A2e data archive will receive data by 30 Sept 2015



300 m meteorological tower, http://www.esrl.noaa.gov/psd/technology/bao/

XPIA includes the current state-of-the-art in planetary boundary layer instrumentation



XPIA will test meteorological instrumentation for collecting data for validating mesoscale and LES models

Mesoscale (~ 1km resolution)

- Winds (lidars, radars, radar wind profiler, tower)
- Temperature (radiometer, soundings, tower)
- Turbulence (radar wind profiler)
- Boundary-layer height (soundings, radar wind profiler, lidar)

Large-Eddy Simulation Scale (~ 10 m resolution)

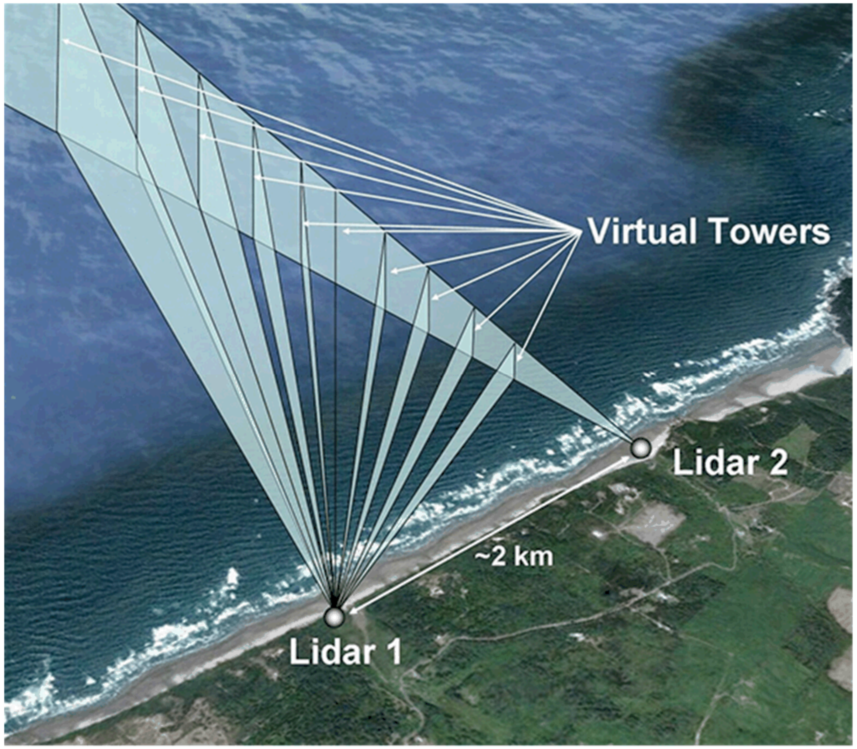
- Winds (DBS; dual- and triple-Doppler lidar)
- Turbulence (DBS; dual- and triple-Doppler lidar, radar)

Data collected specifically at the request of modelers from our V&V meeting:

- **radiosonde profiles**
- **surface flux measurements**
- **multiple temperature profiles**

XPIA will test existing meteorological instrumentation in a range of air quality conditions and operational modalities

- Texas Tech Ka-band radars in dual-Doppler mode
- Leosphere 200S scanning lidars (NOAA, U Texas-Dallas, U Maryland Baltimore County) in dual-, triple-, and quadruple-Doppler mode
- NOAA High Resolution Doppler lidar
- Profiling lidars
  - Windcube v1 lidars
  - Halo in profiling mode
- Profiling lidars with motion compensation on motion table
  - AXYS Vindicator
  - Windcube v2



Schematic of dual-Doppler lidar

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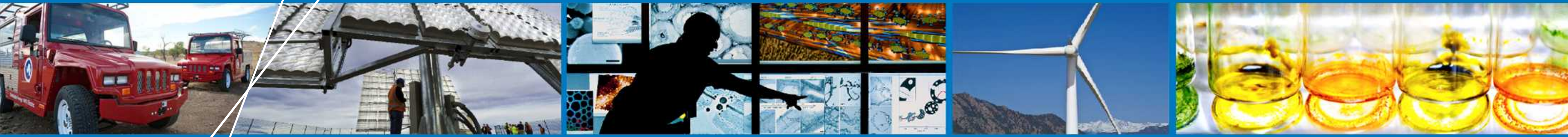

A2e High Fidelity Mesoscale-Microscale Coupling Project

Pat Moriarty

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Meso-Micro and Wind Plant Physics Approach

- **Systematic comparison and improvement of tools and methods for modeling across the mesoscale microscale interface that will enable better prediction of**
  - Wind
  - Turbulence

  That influence
  - Wind power
  - Wind turbine structural loads
- **Over a range of atmospheric and terrain conditions**
- **Transfer methods and best practices to industry**
- **Open source data and simulation tools**
- **Will inform future observation campaigns and model development**
- **Success will be matured models and quantified uncertainty bounds for metrics to include**
  - Wind speed and direction profiles
  - Temperature profiles, heat flux
  - Turbulence – TKE profiles, coherence, spectra

First Benchmark

- **SWiFT/Reese site near Lubbock, TX**
  - TTU 200m tower
    - Observations at 10 heights
    - Sonics and temperatures – 50 Hz
  - 2 x 60 m towers upwind
  - Radar Profiler
  - Site of future A2e turbine to turbine interaction studies
  - Further instrumentation may be added
- **3 Conditions**
  - Unstable, Stable and Near Neutral within 2 years of data
- **Sensitivity studies**
  - Models – WRF-LES, WRF-OpenFOAM
  - Mesoscale fixed
  - Atmospheric conditions
    - Surface roughness
    - Heat flux
    - Geostrophic winds
  - Setup – grid resolution, turbulence model
  - Meso-micro coupling methodology

Participants and timeline

- **Simulations**
  - NREL (WRF-OpenFOAM- LES), LLNL (WRF-LES), PNNL (WRF), NCAR (WRF-LES), CENER (WRF-OpenFOAM-RANS), +2 other DOE labs
  - NCAR – Arbiter of results
  - International benchmark through IEA Task 31 – all participants welcome
- **Observations and Data Analysis**
  - Sandia/TTU – SWiFT/Reese site data
- **January 2015**
  - Project kickoff and initial planning
- **March 2015**
  - Release of validation cases and metrics to international community
- **March +**
  - Weekly iterations and model comparisons between team members
  - Long term integrated strategy development
- **September 2015**
  - Workshop for exercise participants including external partners
  - Formal initial summary to DOE by NCAR and labs

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Wind Forecasting Improvement Project 2: WFIP 2

WFIP2 Motivation

- Complex topography can amplify errors in the synoptic scale forecast and produce phenomena that are poorly represented in NWP models due to limitations in either resolution or model physics.

WFIP2 Goals

- Advance wind energy forecasting in complex terrain through investigation of physical phenomena associated with large forecast errors.
- Develop new and improved model physics.
- Complete an 18-month observational field campaign centered in the Columbia River region in Oregon and Washington states.

Wind Forecasting Improvement Project 2: WFIP 2

Key phenomena of interest:

- frontal passages with mix-out of cold pools
- gap flows
- mountain waves
- mesoscale topographic wakes
- convective outflows
- marine pushes
- land-sea breezes
- slope and drainage flows
- low-level jets

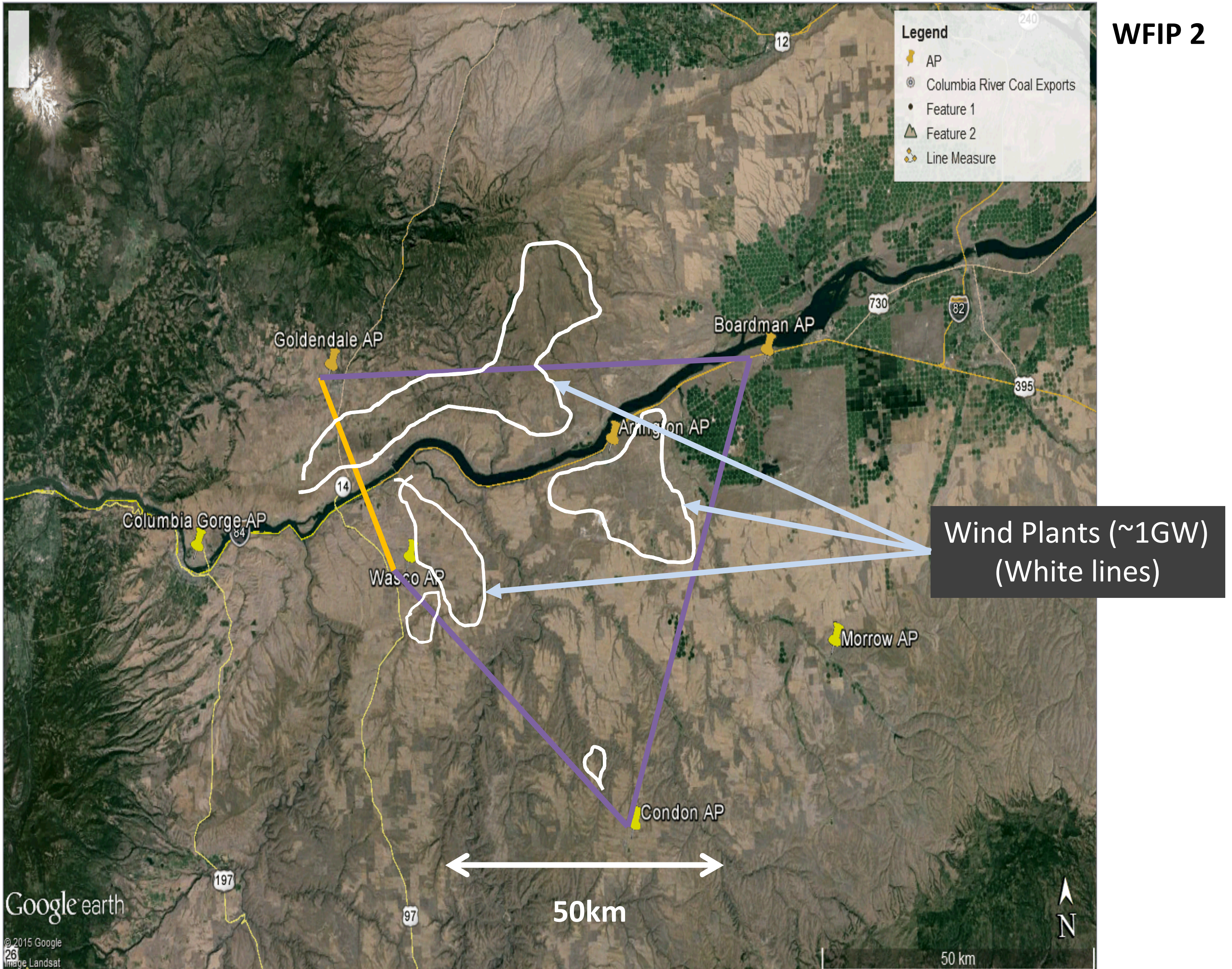
WFIP2 Instrument List

- Wind Profiling Radars (8 + 3)
- Radiometers (3-4)
- Sodars (18)
- Profiling lidars (5)
- Scanning lidars (3-4)
- Radiosondes (1)
- Ceilometer (1)
- Energy balance system (1)
- Surface fluxes: H, LE, U* (2)
- Sonic anemometers (~16)
- Surface met (~15)
- Solar and net radiation (~10)
- Tall Towers fixed (~40)
- Microbarographs (10)

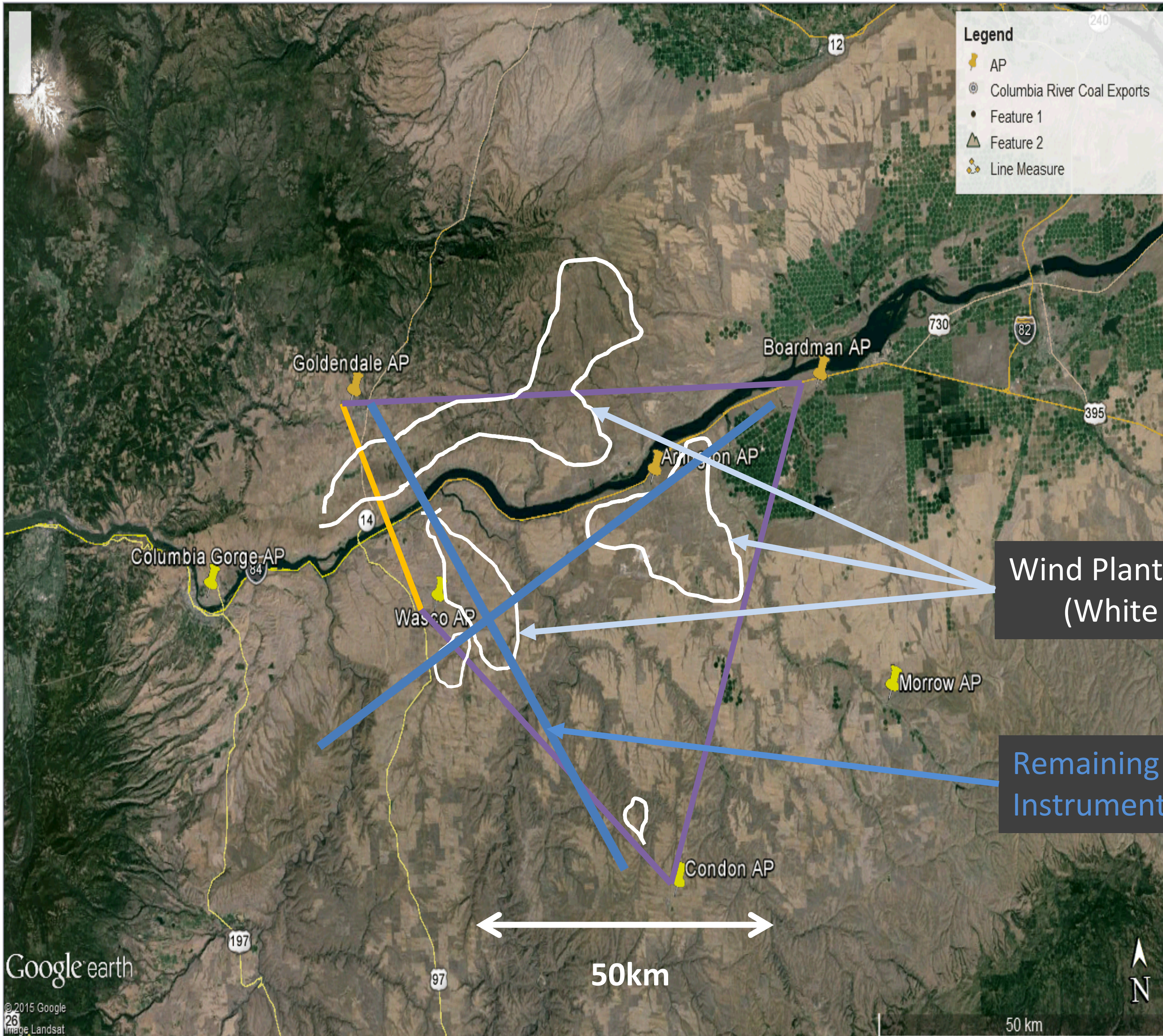
WFIP 2


Wind Profiling Radar Locations
Forks WA
Astoria, OR
Troutdale STP
Yakima AP
Walla Walla AP
Goldendale AP
Boardman AP
Wasco AP
Condon AP
Prinville AP
Coos Bay, OR
100 km
200 km
N
© 2015 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat

WFIP 2

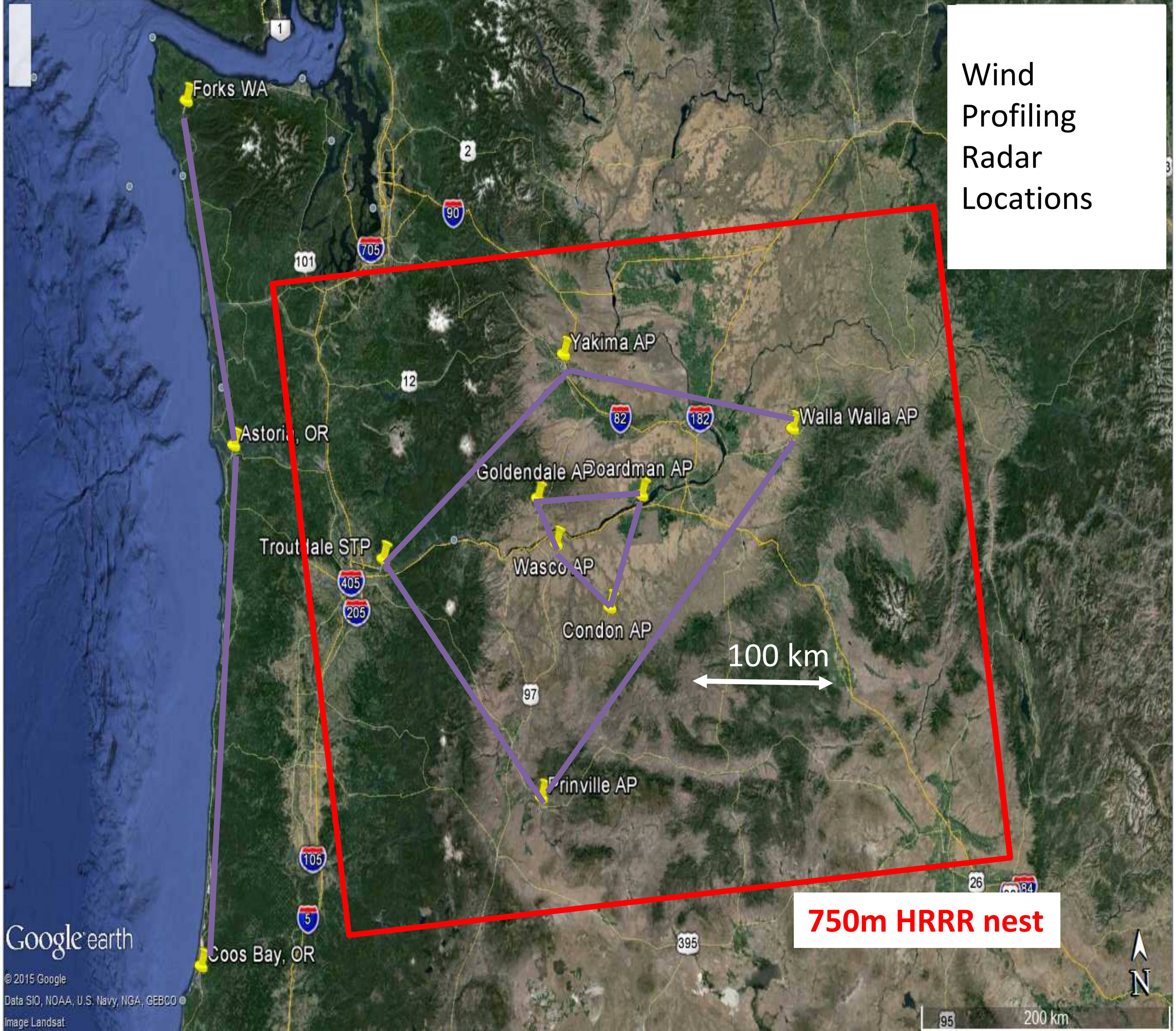

Legend
AP
Columbia River Coal Exports
Feature 1
Feature 2
Line Measure
Goldendale AP
Boardman AP
Columbia Gorge AP
Wasco AP
Morrow AP
Condon AP
Wind Plants (~1GW)
(White lines)
50km
50 km
Google earth
© 2015 Google
Image Landsat

WFIP 2



Legend
AP
Columbia River Coal Exports
Feature 1
Feature 2
Line Measure
Goldendale AP
Boardman AP
Arlington AP
Columbia Gorge AP
Wasco AP
Morrow AP
Condon AP
12
730
82
395
14
84
197
97
240
50km
50 km
N
Google earth
© 2015 Google
Image Landsat
Wind Plants (~1GW)
(White lines)
Remaining
Instrumentation

WFIP 2



Wind Profiling Radar Locations
750m HRRR nest
100 km
Forks WA
Astoria, OR
Yakima AP
Walla Walla AP
Goldendale AP
Boardman AP
Troutdale STP
Wasco AP
Condon AP
Prinville AP
Coos Bay, OR
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Image Landsat
200 km
N

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Turbine Scale Experiment Objectives

- Guided by verification & validation framework …
- Plan and execute wind tunnel experiments …
- Complete data reduction and quality control …
- Provide measured data for A2e HFM validation …
- First in ABL tunnel, then large aerospace tunnel

PIRT Dictates Target Measurements

Inflow conditions
- "Laminar" baseline
- Turbulence level(s)

Blade boundary layer
- Laminar/turbulent
- Crucial for low Re

Blade aerodynamics
- Dynamic stall
- Other flow fields

Wake development
- Skew/meander
- Tip vortex kinematics

Grid turbulence and inflow measurements

Visualization / shear stress measurements

Unsteady surface pressure measurements

Visualization / 3-D time resolved velocity data

Potential Experimental Conditions

- **Inflow condition**
  - Laminar
  - Turbulent
- **Blade rotation**
  - Parked
  - Operating
- **Rotor alignment**
  - Axisymmetric
  - Yawed
- **Region 2 - 3**
  - Tip speed ratio
  - Blade pitch angle
- **Dynamic events**
  - Wind speed ramps
  - Yaw sweeps
- **Wake impingement**
  - Circular cylinder
  - Porous disk

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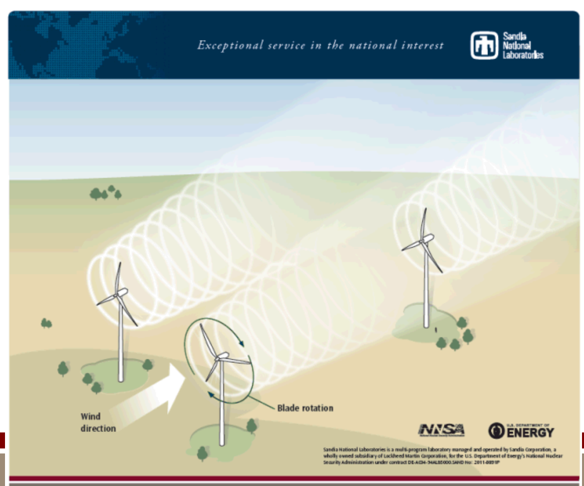
SWiFT site layout and capabilities

DOE/SNL Scaled Wind Farm Technology (SWiFT) facility
hosted by Texas Tech University (TTU)

SWiFT exists to:

- Reduce turbine-turbine interaction and wind plant underperformance
- Public, open-source validation data
- Advance wind turbine technology



Facilities:

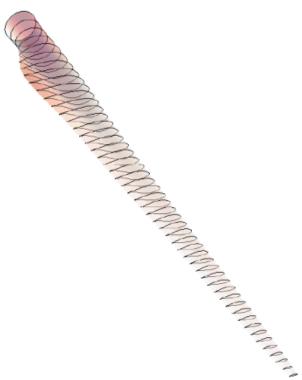
- Three variable-speed variable-pitch modified wind turbines with full power conversion and extensive sensor suite
- Two heavily instrumented inflow anemometer towers
- Site-wide time-synchronized data collection

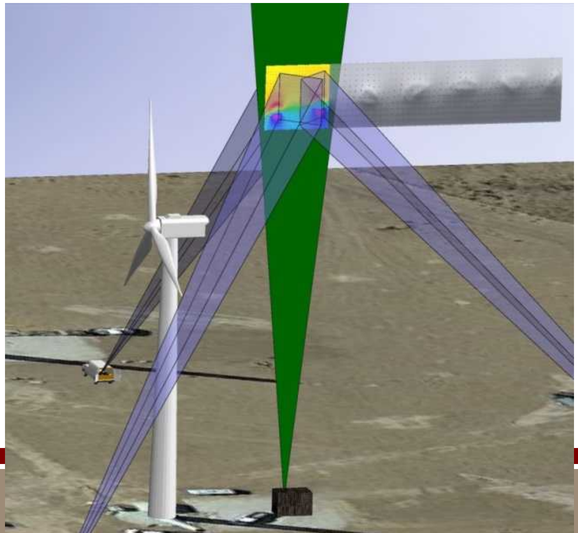
SWiFT-X1: Near Wake Validation

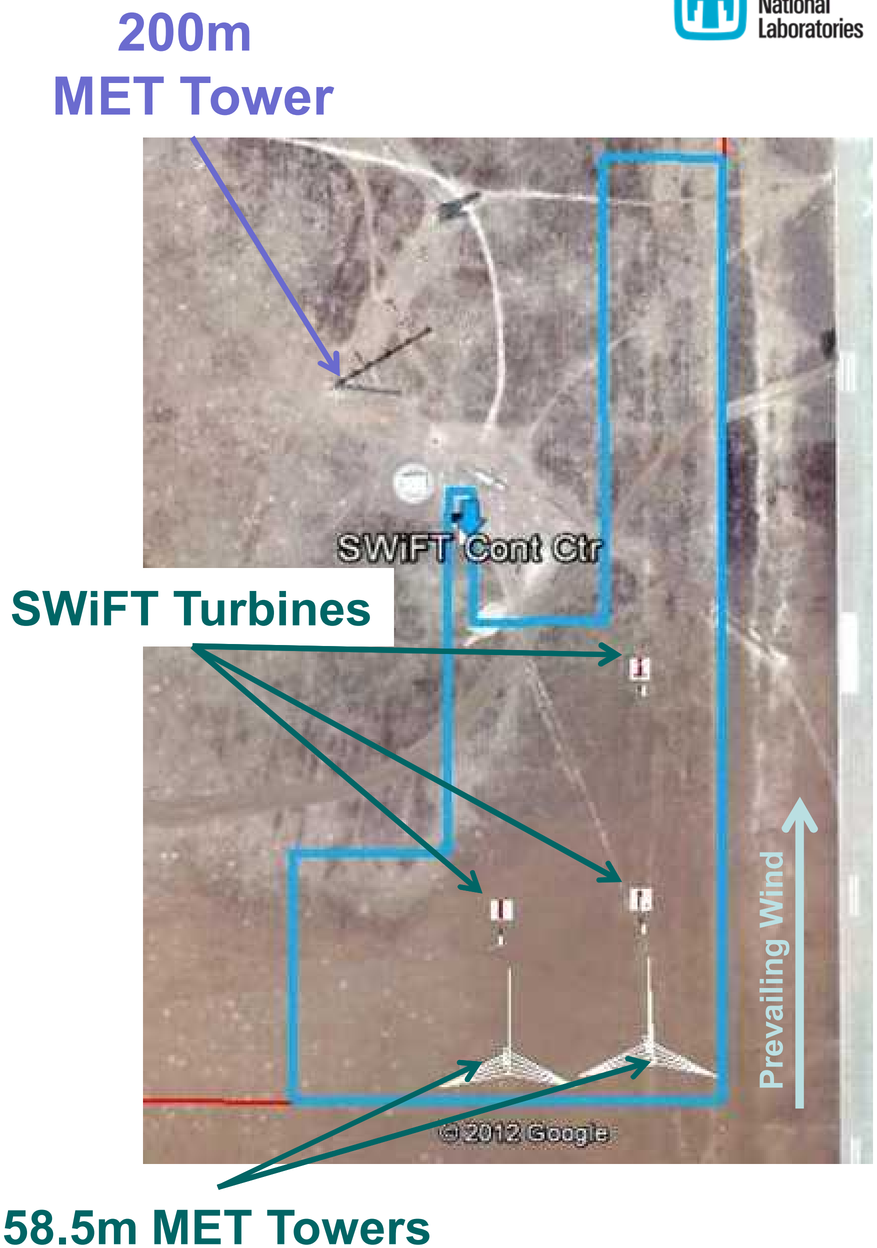
Goal: Validate HFM ability to predict blade loading and near wake structure given MET tower inflow measurements.

Measurements:

- ABL Condtions:
  200m MET, Sodar, and Radar Profiler
- Inflow: Dual 58.5m MET towers
- Rotor and Tower Strains and Accels.
- Rotor spanwise loading: Pressure taps and/or distributed strain measurements
- New rotors functionally scaled from utility turbine
- Near Wake Flow Diagnostic: SWIS





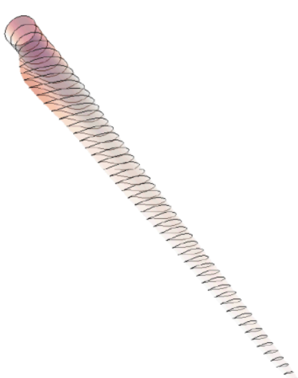


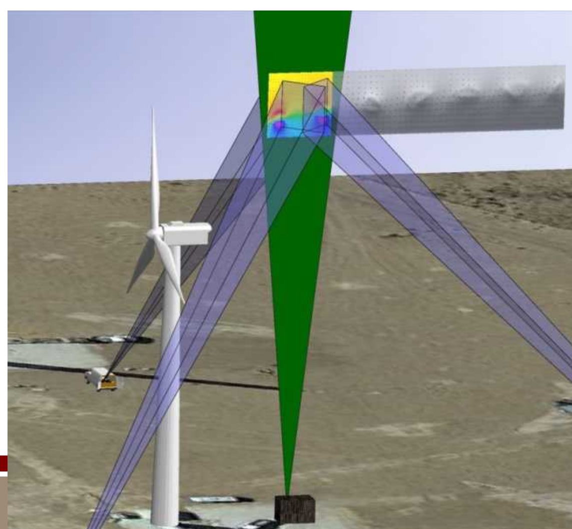
SWiFT-X2+: Wake Meandering and Turbine-Turbine Interaction

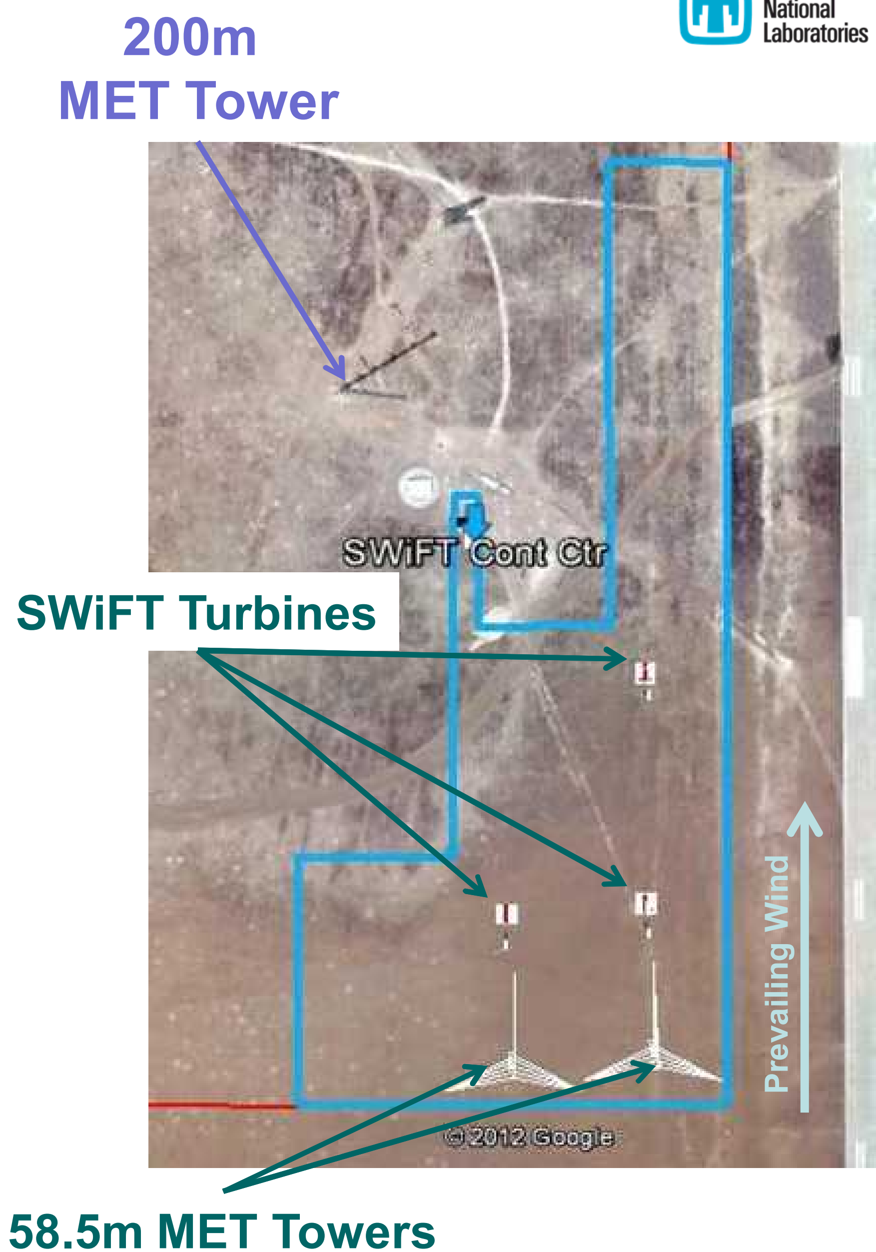
Goal: Validate HFM ability to predict blade loading and near wake structure given MET tower inflow measurements.

Measurements:

- Far Wake:
  - Re-deployable MET tower
  - Scanning Lidar
  - TTU Ka-band mobile Doppler radars
  - Flow-angle sensors on downstream turbine
- Downstream turbine loads
- Correlation with ABL observations







Validation data request

- Structure of a Validation Data requirement:
  - Objective
  - Method
  - Environment
  - Success criteria
- An example Validation Data requirement:
  - Objective: quantify distribution of blade spanwise load
  - Method: surface pressure measurements and/or spanwise strain measurements
  - Environment: clean uniform inflow, turbulent inflow with quantified turbulence character and shear character
  - Success criteria: measurement data available with quantified inflow including uncertainty bounds.

Questions for Breakouts

- What experiments are missing?
- What measurements are missing?
- How should the data be processed?
- What are the quantities of interest?
- What interactions between scales are required to measure?

Questions for modelers

- Dual-Doppler or triple-Doppler retrievals for validating flow models within a wind farm:
  - How frequently should they be collected?
  - What vertical resolution is required?
  - Over what horizontal extent should data be collected?
  - Given that uncertainty in any measurement is a function of dwell time, how should the trade-offs be weighed between reduced uncertainty of any individual measurement and increased revisit time to that point/volume?
- XPIA will collect data in a range of air quality conditions (clean → dirty), which will affect the horizontal coverage of data collected. How useful are instruments which require specific air quality conditions?
- Temperature profiles currently available from remote sensing are ~ 50m resolution near the surface. Are such profiles useful?

Questions for modelers

- What are highest priority phenomena to capture in benchmarks?
- What metrics are most relevant for wind energy applications?
- What are current and preferred/acceptable levels of uncertainty?

SWiFT test requirements schema

- Design of new test hardware for SWiFT could be done based on known operational envelopes and using standard rotor design practices and standard farm flow measurements.
- At the same time, design of a V&V test campaign begins with the PIRT process, which determines a test campaign specification, which leads to a test procedure.
- Interdependency 1: The test campaign specification drives aspects of test hardware and test instrumentation.
- Interdependency 2: The hardware operational requirements drives aspects of the V&V test procedure.

- This is all documented in detail in the SWiFT-X1 requirements document at Sandia.