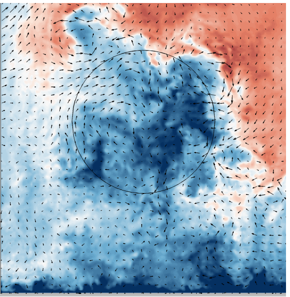
SAND2017-12647PE

Sandia Wind Energy Uncertainty Quantification Applications



David Maniaci, Thomas Herges, Chris Kelley, and Brandon Ennis

Wind Energy Technologies Department
Sandia National Laboratories

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V&V Framework

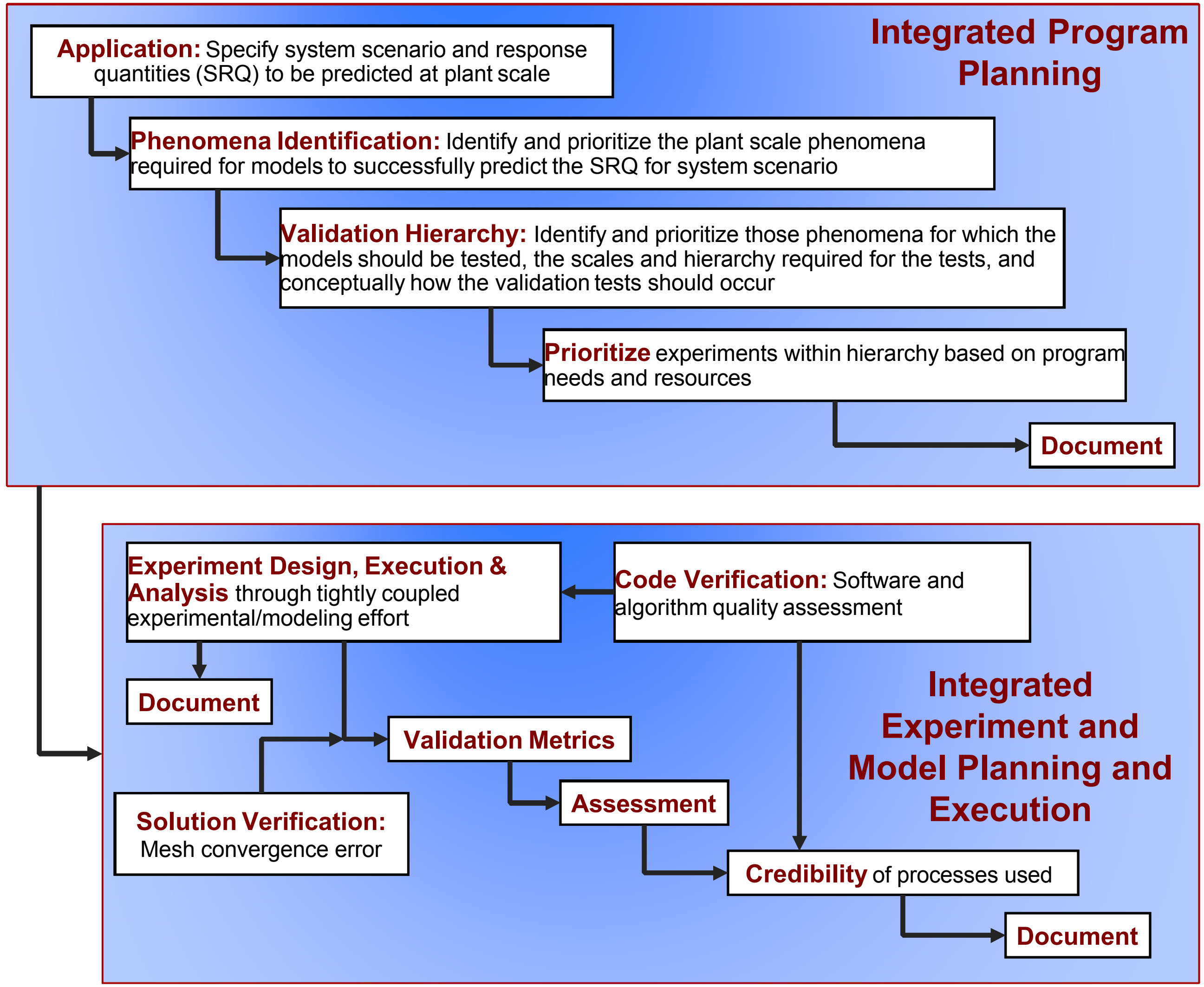
(2015 Hills, Maniaci, Naughton)

Integrated Planning

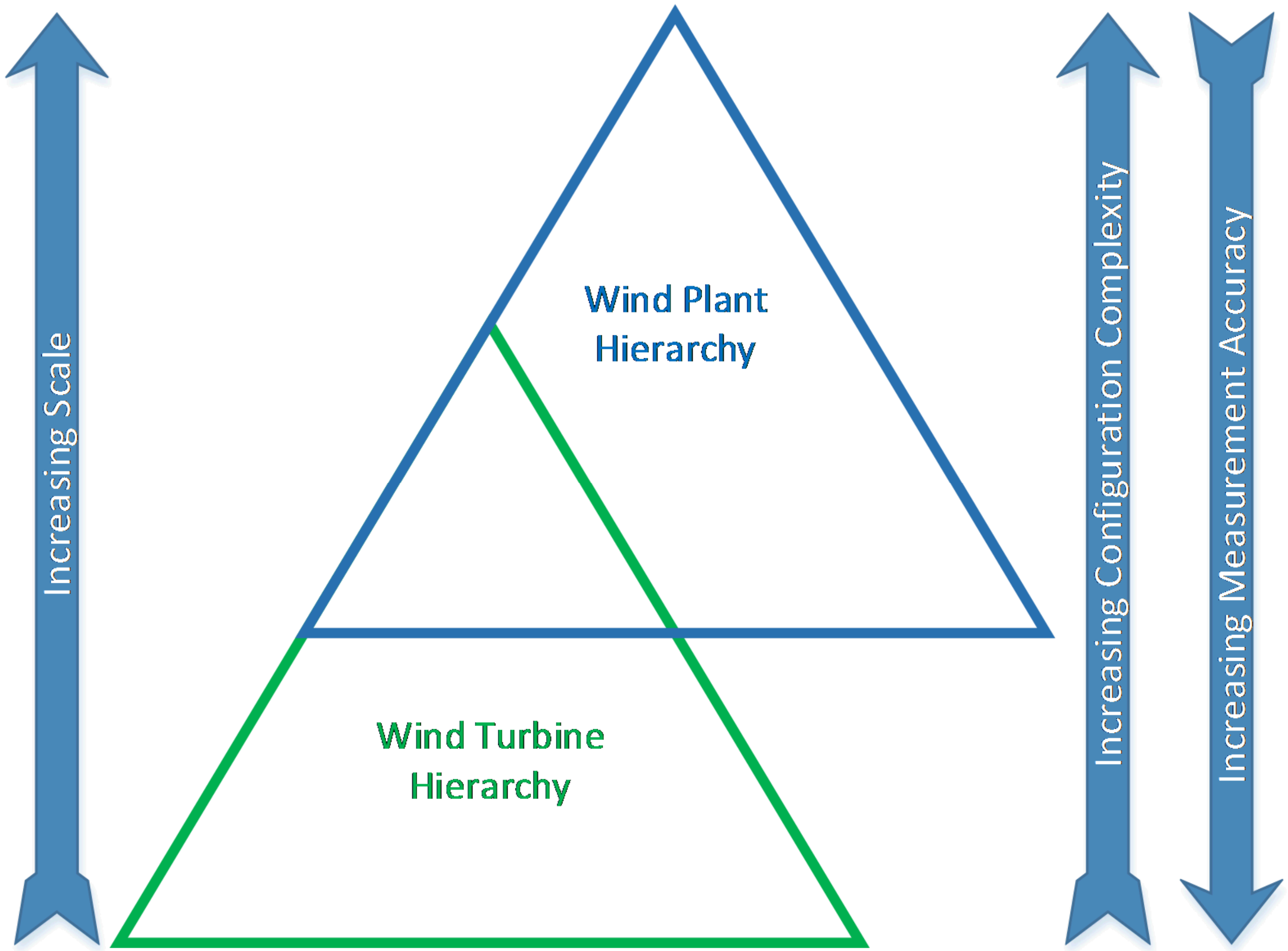
- Program leaders, modelers, software developers, experimentalists, V&V specialists

Validation Planning

- Domain specific program leaders, modelers, experimentalists, V&V specialists, data acquisition specialists

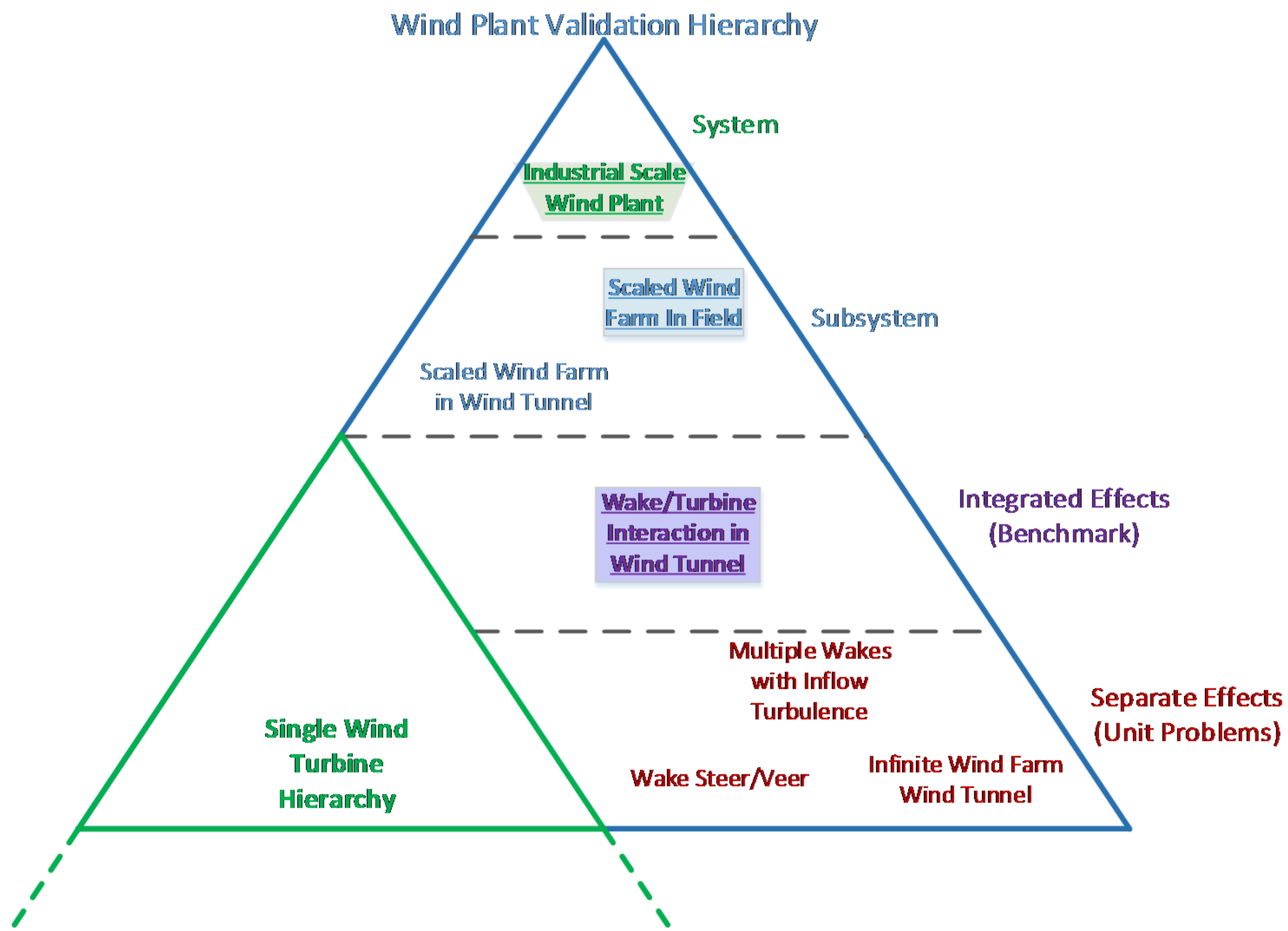


Validation Hierarchy



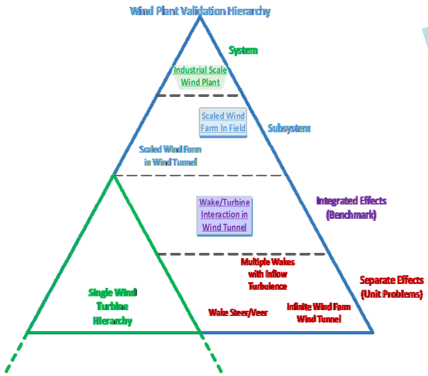
MDC4

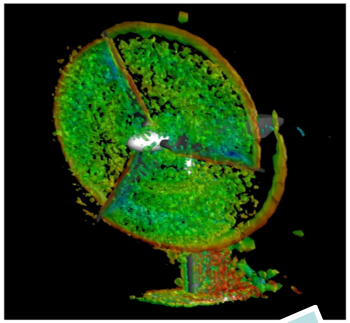
Wind Plant Validation Hierarchy



Slide 4

MDC4 SWiFT is one assesst within many that will be utilized to build confidence in Nalu's predictive capability.
Maniaci, David Charles, 4/19/2017





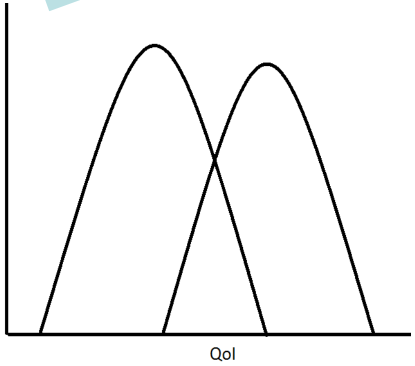
Virtuous Cycle

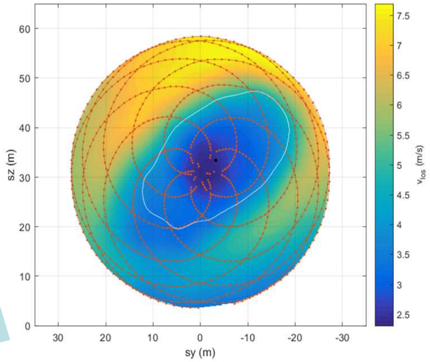
Validation

Model Development

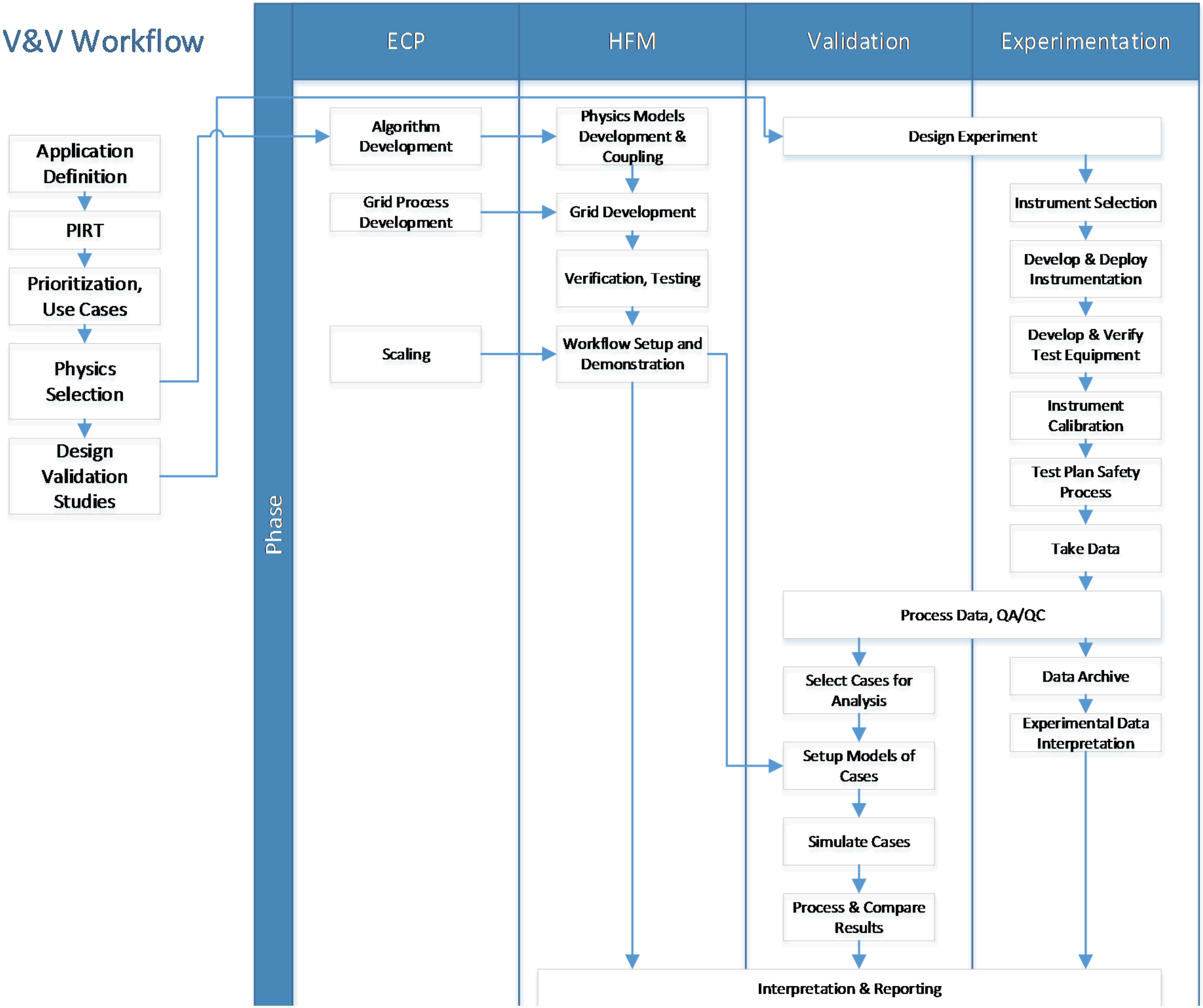
Experimentation

Uncertainty Quantification





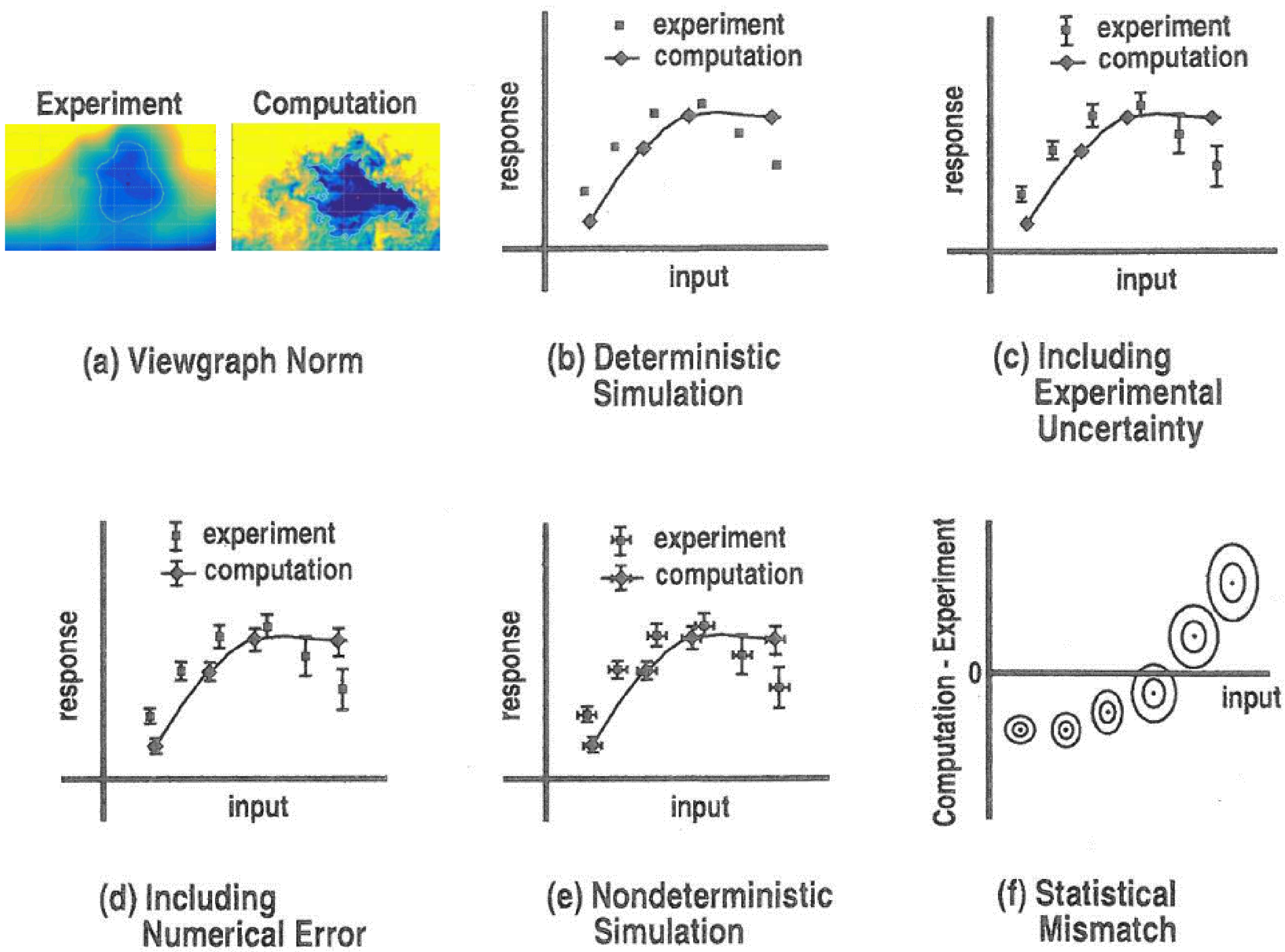
V&V Workflow


ECP
HFM
Validation
Experimentation
Phase
Application Definition
PIRT
Prioritization, Use Cases
Physics Selection
Design Validation Studies
Algorithm Development
Grid Process Development
Scaling
Physics Models Development & Coupling
Grid Development
Verification, Testing
Workflow Setup and Demonstration
Design Experiment
Instrument Selection
Develop & Deploy Instrumentation
Develop & Verify Test Equipment
Instrument Calibration
Test Plan Safety Process
Take Data
Process Data, QA/QC
Select Cases for Analysis
Setup Models of Cases
Simulate Cases
Process & Compare Results
Data Archive
Experimental Data Interpretation
Interpretation & Reporting

MDC2

Uncertainty Quantification

Levels of Precision



Modified from Oberkamf and Roy, 2012

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MDC2 Maniaci, David Charles, 4/17/2017

Projects

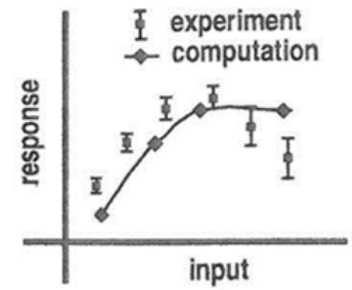
- SWiFT Site Experimental Uncertainty Quantification
  - Inflow, Turbine Loads and Acceleration, Wake Measurement
- DTU Spinner Lidar Wake Tracking Uncertainty
- Multi-level Uncertainty Quantification with LES
- V&V Framework and application to wind energy
- Wakebench (IEA Task 31): VV&UQ Framework and User Guidelines
  - 1. Validation framework for wind energy applications
  - 2. Uncertainty quantification procedures using subscale wake testing
  - 3. Uncertainty quantification procedures using lidar experiments
  - 4. Framework for wind plant uncertainty quantification

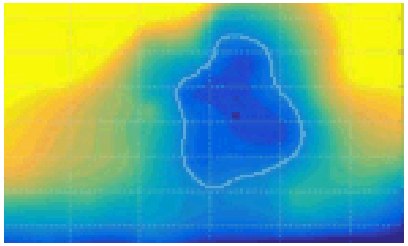
SWiFT Site Experimental Uncertainty Quantification

- Inflow Measurements
  - α
  - ρ
  - p
  - RH
  - T
  - TI (sonic)
  - U_∞ (sonic)
  - U (sonic)
  - V (sonic)
  - U_∞ (cup)
  - U_∞ (nacelle)
  - Vr (sonic)
  - WD (sonic)
  - WD (vane)

- Turbine Measurements
  - Aerodynamic power
  - Rotor speed
  - Aerodynamic torque
  - Rotor thrust
  - Individual blade root loads (instantaneous)
  - Individual blade loading profile (instantaneous)
  - Nacelle measured wind direction
  - Nacelle measured wind speed
  - Yaw heading
  - Yaw misalignment
  - Blade pitch
  - Rotor azimuth
  - Nacelle acceleration

- Wake Measurements
  - DTU Spinner Lidar
  - Wake identification and tracking
  - Turbulence estimators





SWiFT Met Tower Uncertainty

Table 3.1. SWIFT METEOROLOGICAL TOWER UNCERTAINTY SUMMARY

Measurand	units	δ	δ/mean (%)	mean
α	—	1.88×10^{-3}	0.89	0.21
ρ	kg/m^3	7.9×10^{-4}	0.0731	1.08
p	Pa	1.53	1.71×10^{-3}	89500
RH	%	2.01	4.49	46.8
T	K	0.212	0.0733	289
TI (sonic)	—	1.23×10^{-3}	1.02	0.12
U_∞ (sonic)	m/s	0.0439	0.207	6.82
U (sonic)	m/s	0.01	0.207	4.82
V (sonic)	m/s	0.01	0.207	4.82
U_∞ (cup)	m/s	0.20	2.93	6.82
U_∞ (nacelle)	m/s	0.50	7.33	6.82
Vr (sonic)	°	1.73	86	2.0
WD (sonic)	°	1.22	0.69	176
WD (vane)	°	1.20	0.68	176

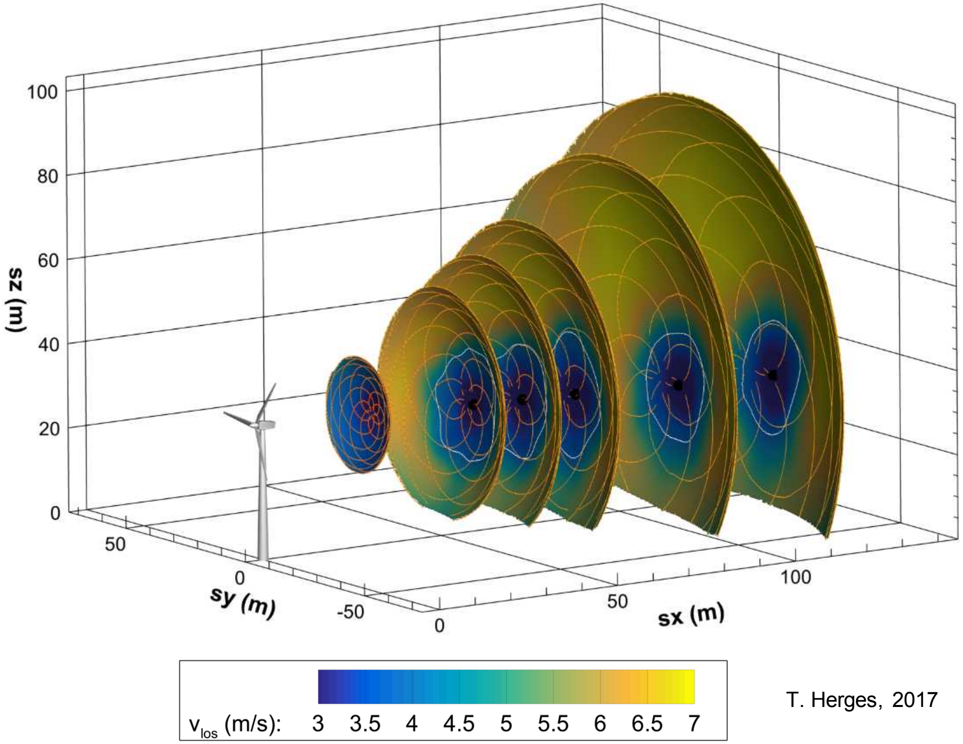
Five inflow quantities have uncertainties above 1% of their mean values: veer (86%), nacelle wind speed (7.3%), relative humidity (4.5%), and cup anemometer wind speed (2.9%).

The nacelle wind speed, humidity, and cup anemometer uncertainty are all dominated by low manufacturer specified accuracies. Therefore all of these uncertainties could be reduced by purchasing higher accuracy sensors.

SWiFT Wake Measurements

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

Objective: Assess the ability of models to predict ***wake shape, strength, and deflection***.



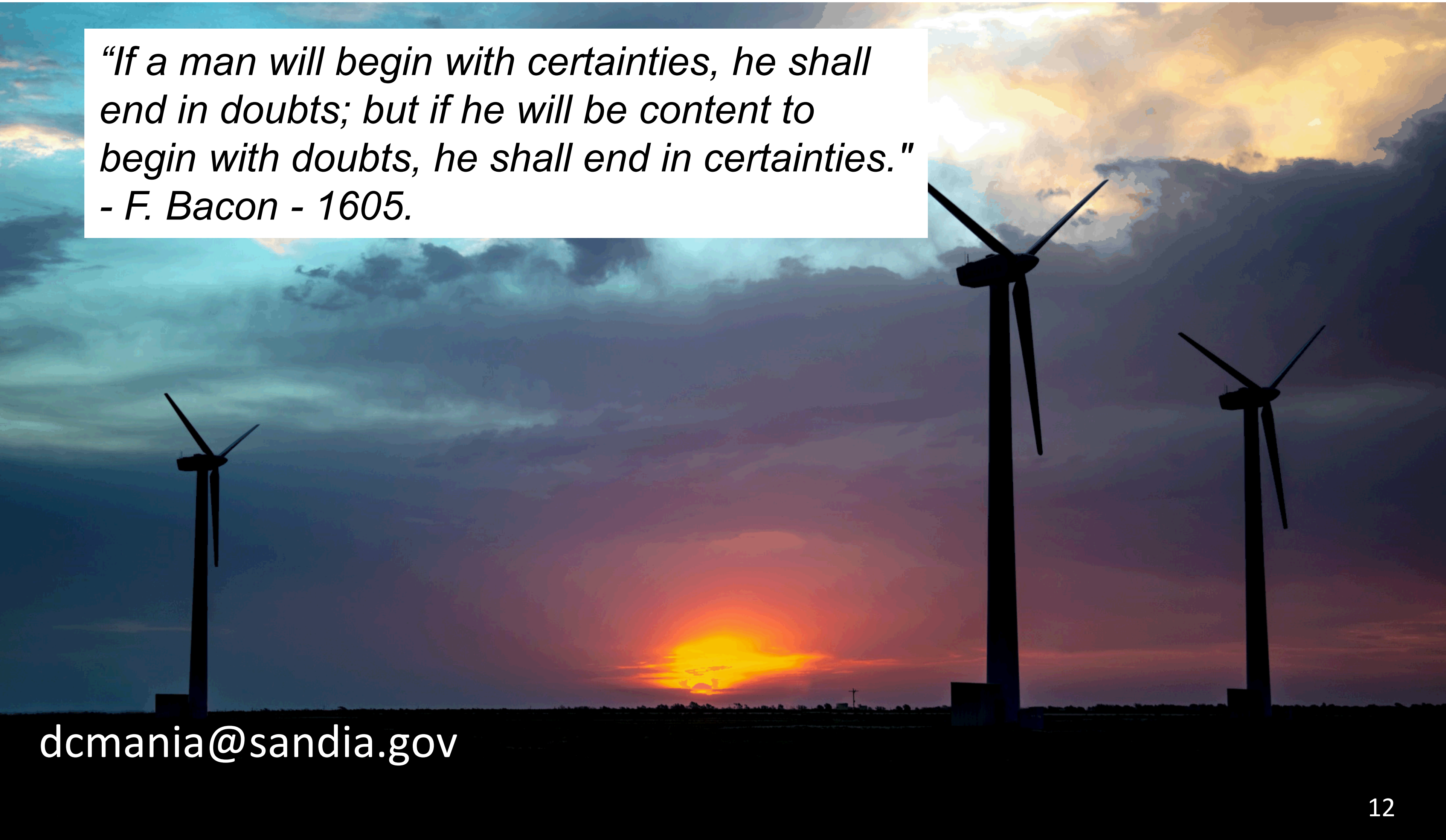
T. Herges, 2017

Slide 11

MDC11 Build from validation using a few datasets to looking at ensembles of data.

Maniaci, David Charles, 8/30/2017

Thank you



"If a man will begin with certainties, he shall end in doubts; but if he will be content to begin with doubts, he shall end in certainties."
- F. Bacon - 1605.

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Multi-level Uncertainty Quantification with LES

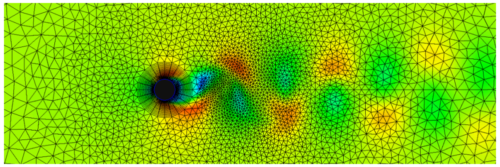
Sandia National Laboratories

Demonstrated an order of magnitude reduction in computational cost for a cylinder flow problem by coupling Nalu (CFD) to DAKOTA (UQ) and using a multilevel UQ approach.

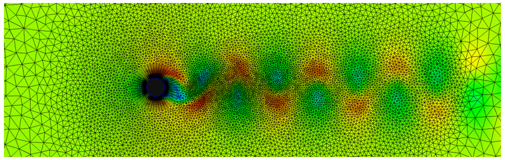
Problem description

- (Laminar) Flow over a cylinder (Re=10-750)
- Input parameters: Density and Viscosity
- QoI: Coefficient of Drag
- 4 levels of mesh resolution

Coarse Mesh: 10 minute time to soln.

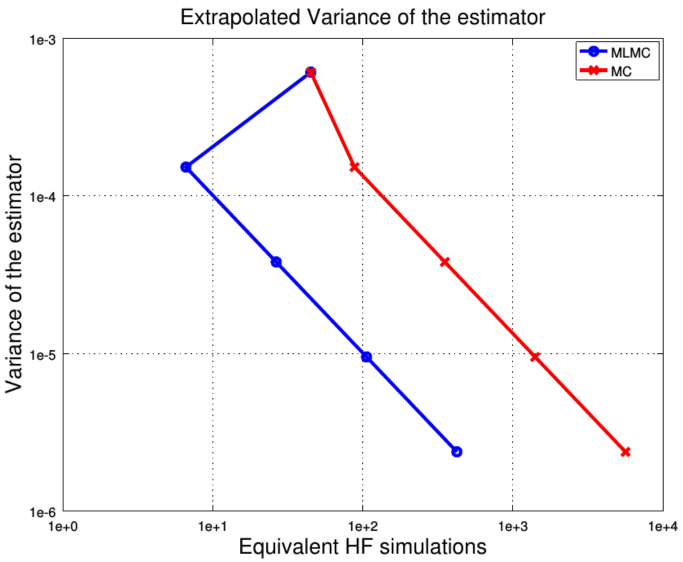


Medium Mesh: 4 hours time to soln.



UQ approach

- Multilevel sampling-based estimator to accelerate convergence



Impact

- Sampling methods are well suited for UQ problems with extremely high dimensionality (such as wind farm LES)
- Convergence is guaranteed for non smooth QoIs
- Demonstrated order of magnitude improvement in accuracy/cost of Multilevel estimators (MLMC) relative to conventional Monte Carlo (MC) for the cylinder problem

*G. Geraci, M. Ebeida, M. Eldred; SNL