

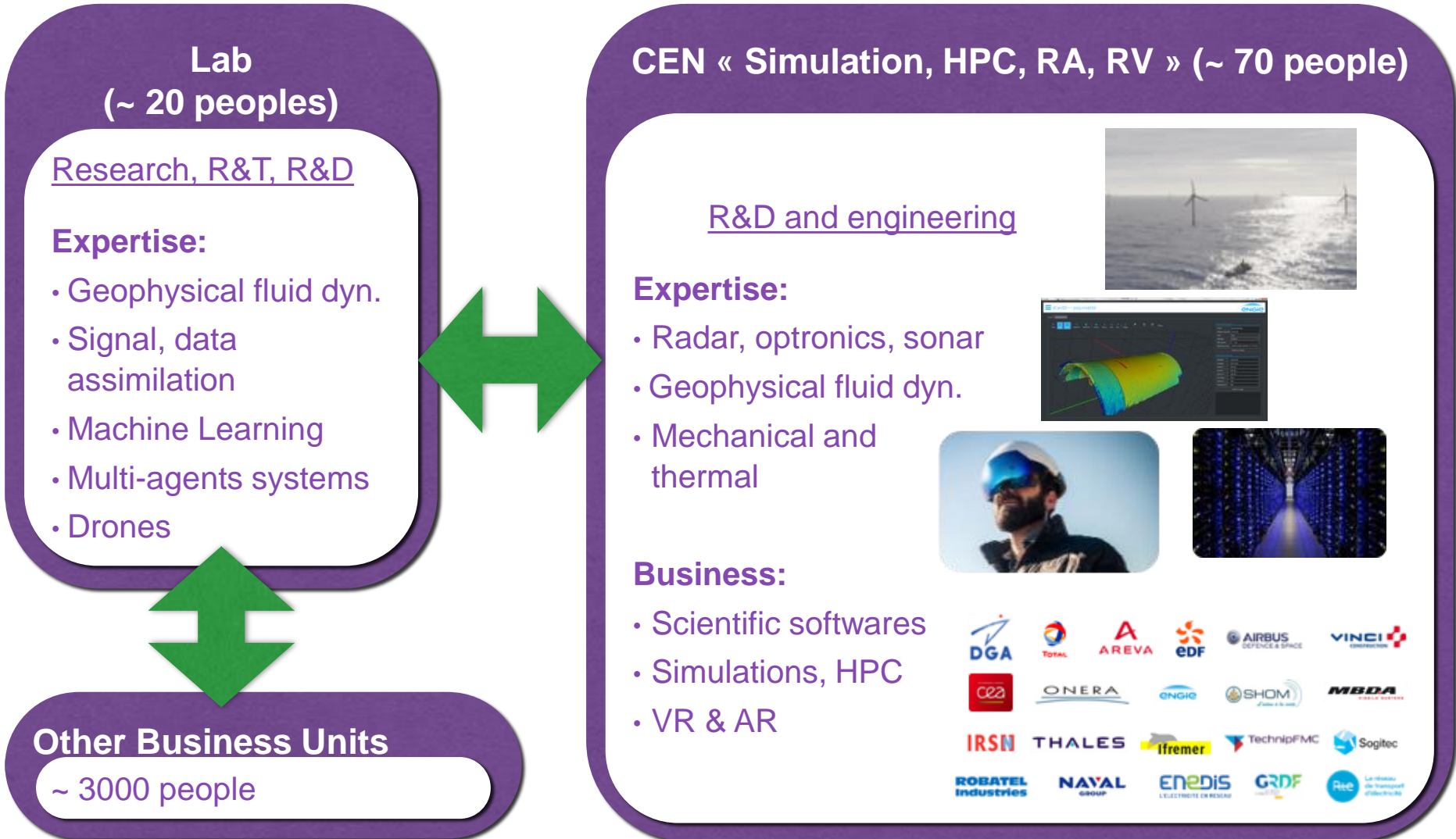
# Reducing wind energy costs by improving control loops and real-time unsteady air flow prediction



**Valentin Resseguier, SCALIAN DS**

## Content

1. Wind turbine context
2. Our approach
3. Results



# PART I - WIND TURBINE CONTEXT

## Wind turbine applications

- Lower wind turbine maintenance costs
- Higher wind farm power
- Longer wind turbine life cycle
- Quantifying actual gain due to control systems

How ? Active control loops with robust and fast aerodynamic short-time prediction to reduces :

- Reduce blade lift variation
  - Reduce wake effects within wind farm
  - Real-time simulations
-

## Wind turbine applications at the blade scale

- Lower wind turbine maintenance costs
- Higher wind farm power
- Longer wind turbine life cycle
- Quantifying actual gain due to control systems

**How ? Active control loops with robust and fast aerodynamic short-time prediction to reduces :**

- Reduce blade lift variation
- Reduce wake effects within wind farm
- Real-time simulations



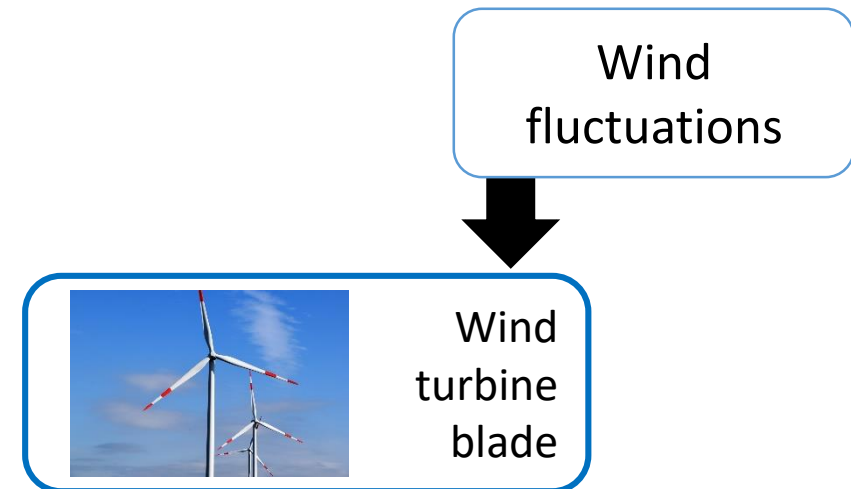
Wind  
turbine  
blade

## Wind turbine applications at the blade scale

- Lower wind turbine maintenance costs
- Higher wind farm power
- Longer wind turbine life cycle
- Quantifying actual gain due to control systems

**How ? Active control loops with robust and fast aerodynamic short-time prediction to reduces :**

- Reduce blade lift variation
- Reduce wake effects within wind farm
- Real-time simulations

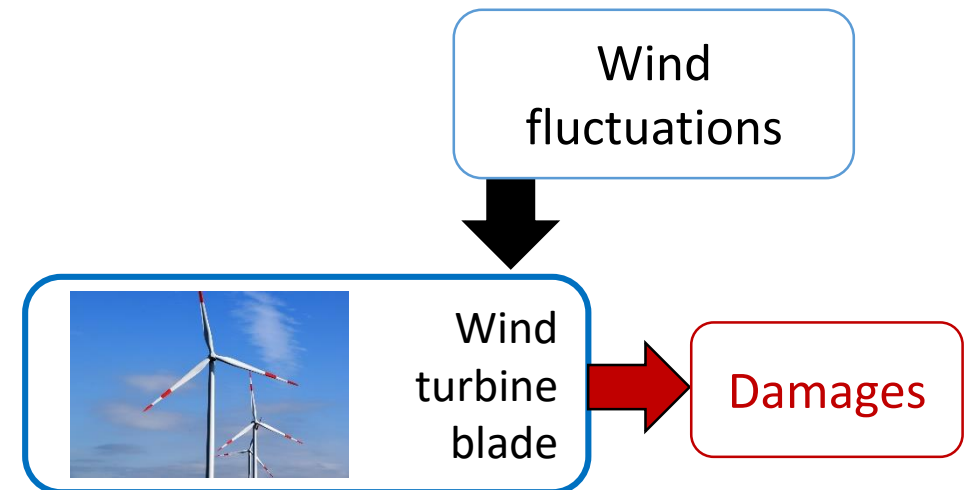


## Wind turbine applications at the blade scale

- Lower wind turbine maintenance costs
- Higher wind farm power
- Longer wind turbine life cycle
- Quantifying actual gain due to control systems

**How ? Active control loops with robust and fast aerodynamic short-time prediction to reduces :**

- Reduce blade lift variation
- Reduce wake effects within wind farm
- Real-time simulations



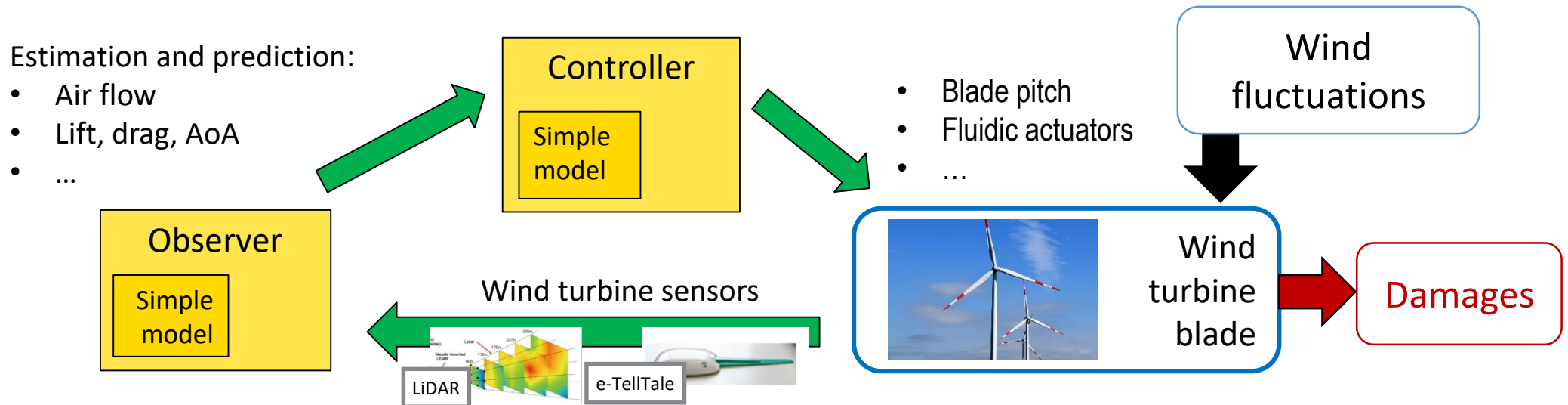


# Wind turbine applications at the blade scale

- Lower wind turbine maintenance costs
- Higher wind farm power
- Longer wind turbine life cycle
- Quantifying actual gain due to control systems

**How ? Active control loops with robust and fast aerodynamic short-time prediction to reduces :**

- Reduce blade lift variation
- Reduce wake effects within wind farm
- Real-time simulations

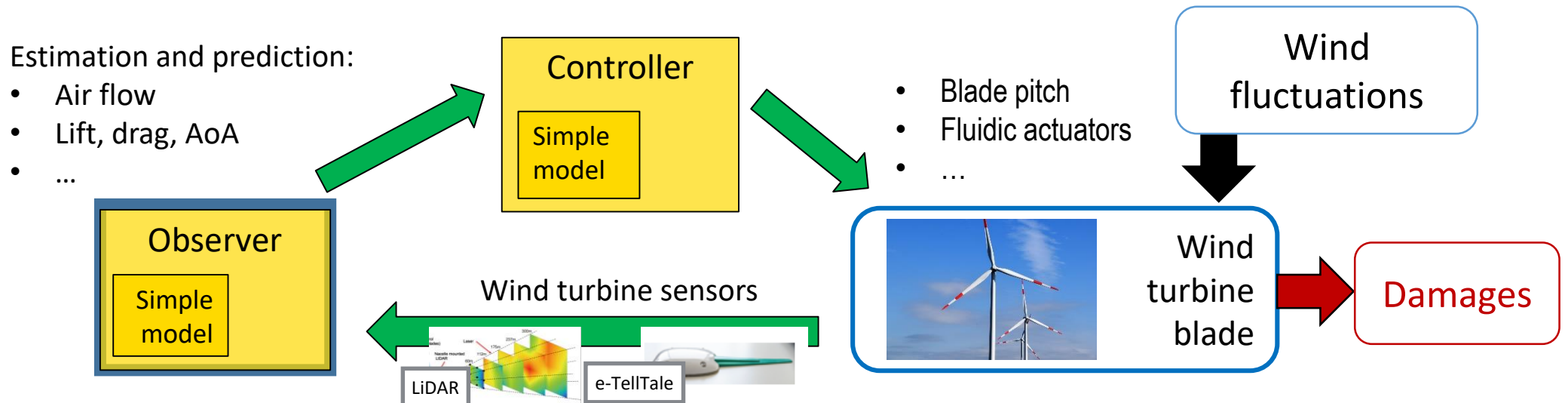


# Wind turbine applications at the blade scale

- Lower wind turbine maintenance costs
- Higher wind farm power
- Longer wind turbine life cycle
- Quantifying actual gain due to control systems

**How ? Active control loops with robust and fast aerodynamic short-time prediction to reduces :**

- Reduce blade lift variation
- Reduce wake effects within wind farm
- Real-time simulations

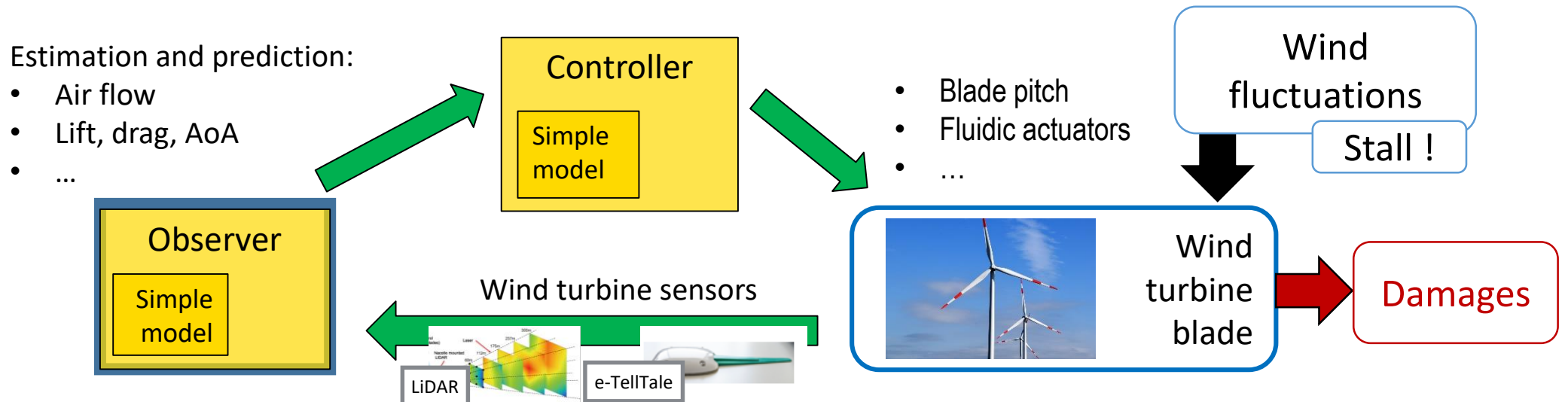


# Wind turbine applications at the blade scale

- Lower wind turbine maintenance costs
- Higher wind farm power
- Longer wind turbine life cycle
- Quantifying actual gain due to control systems

**How ? Active control loops with robust and fast aerodynamic short-time prediction to reduces :**

- Reduce blade lift variation
- Reduce wake effects within wind farm
- Real-time simulations

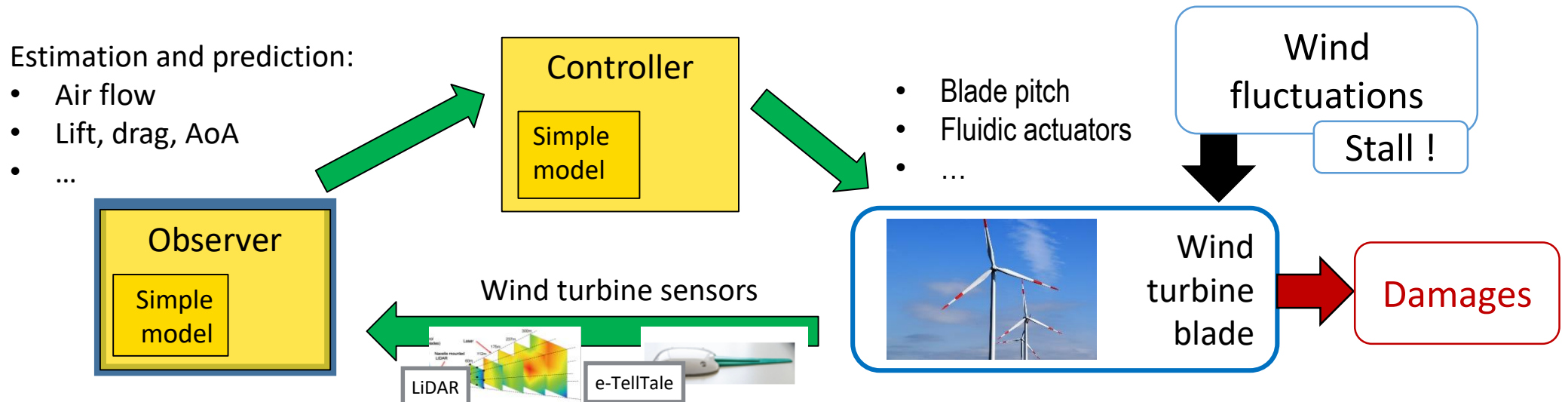


# Wind turbine applications at the blade scale

- Lower wind turbine maintenance costs
- Higher wind farm power
- Longer wind turbine life cycle
- Quantifying actual gain due to control systems

**How ? Active control loops with robust and fast aerodynamic short-time prediction to reduces :**

- Reduce blade lift variation
- Reduce wake effects within wind farm
- Real-time simulations



Which simple model? How to combine model & measurements?

## Wind turbine applications at the farm scale

- Lower wind turbine maintenance costs
- Higher wind farm power
- Longer wind turbine life cycle
- Quantifying actual gain due to control systems

**How ? Active control loops with robust and fast aerodynamic short-time prediction to reduces :**

- Reduce blade lift variation
- Reduce wake effects within wind farm
- Real-time simulations



## Wind turbine applications at the farm scale

- Lower wind turbine maintenance costs
- Higher wind farm power
- Longer wind turbine life cycle
- Quantifying actual gain due to control systems

**How ? Active control loops with robust and fast aerodynamic short-time prediction to reduces :**

- Reduce blade lift variation
- Reduce wake effects within wind farm
- Real-time simulations

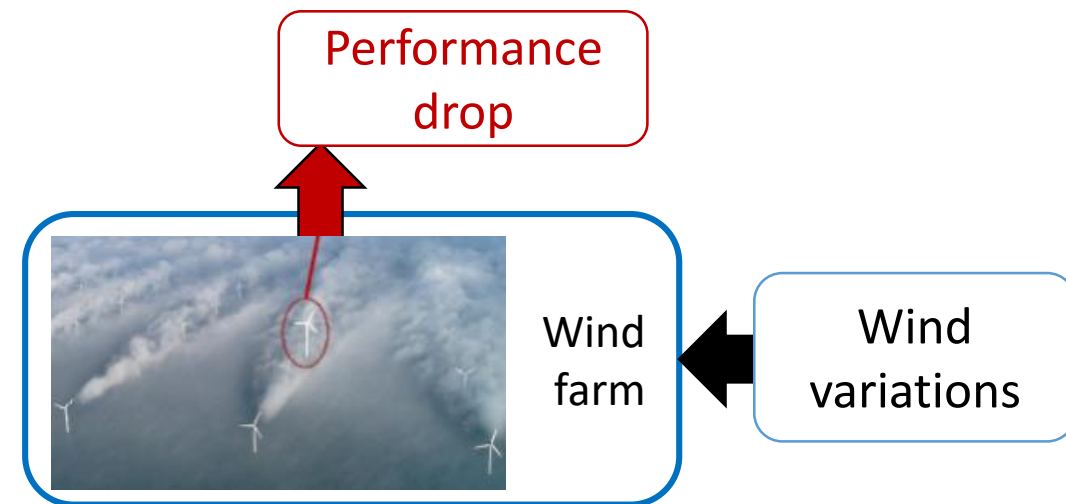


## Wind turbine applications at the farm scale

- Lower wind turbine maintenance costs
- Higher wind farm power
- Longer wind turbine life cycle
- Quantifying actual gain due to control systems

**How ? Active control loops with robust and fast aerodynamic short-time prediction to reduces :**

- Reduce blade lift variation
- Reduce wake effects within wind farm
- Real-time simulations

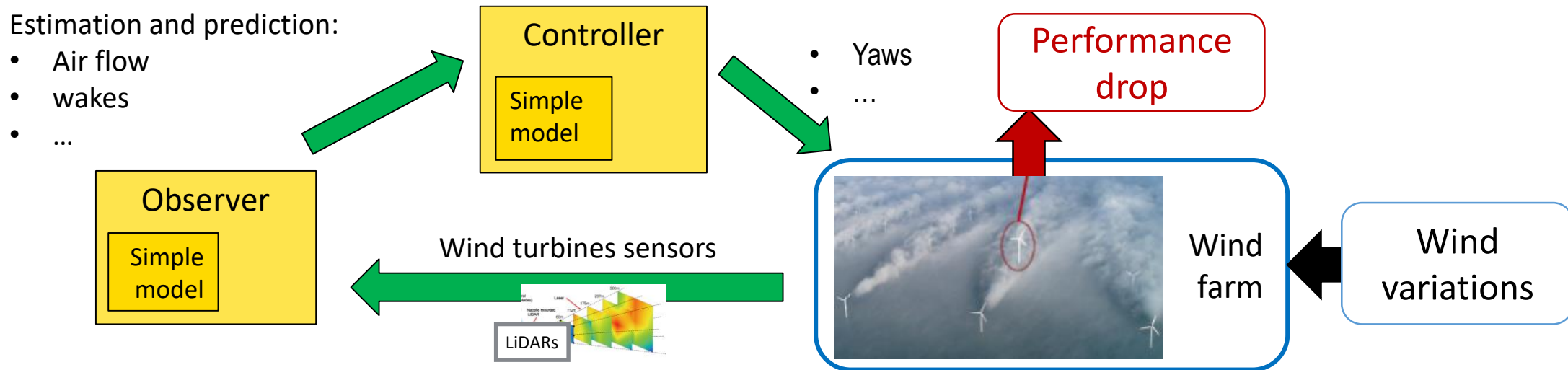


# Wind turbine applications at the farm scale

- Lower wind turbine maintenance costs
- Higher wind farm power
- Longer wind turbine life cycle
- Quantifying actual gain due to control systems

**How ? Active control loops with robust and fast aerodynamic short-time prediction to reduces :**

- Reduce blade lift variation
- Reduce wake effects within wind farm
- Real-time simulations



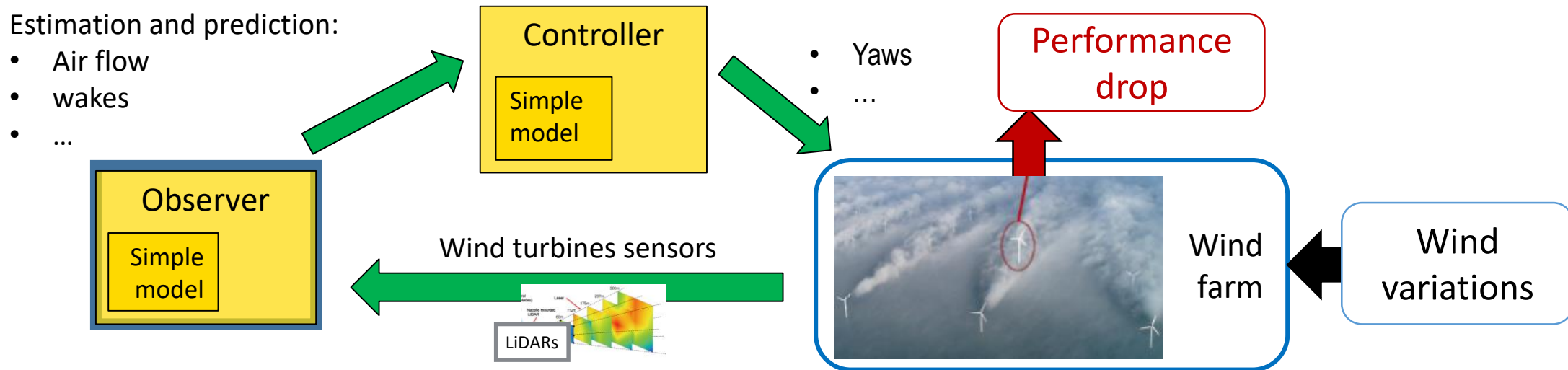


# Wind turbine applications at the farm scale

- Lower wind turbine maintenance costs
- Higher wind farm power
- Longer wind turbine life cycle
- Quantifying actual gain due to control systems

**How ? Active control loops with robust and fast aerodynamic short-time prediction to reduces :**

- Reduce blade lift variation
- Reduce wake effects within wind farm
- Real-time simulations

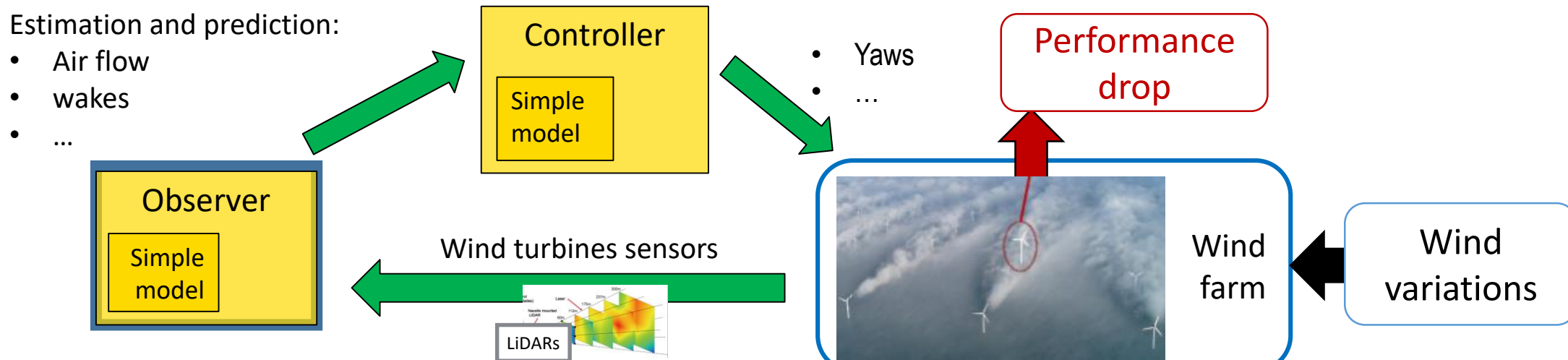


# Wind turbine applications at the farm scale

- Lower wind turbine maintenance costs
- Higher wind farm power
- Longer wind turbine life cycle
- Quantifying actual gain due to control systems

**How ? Active control loops with robust and fast aerodynamic short-time prediction to reduces :**

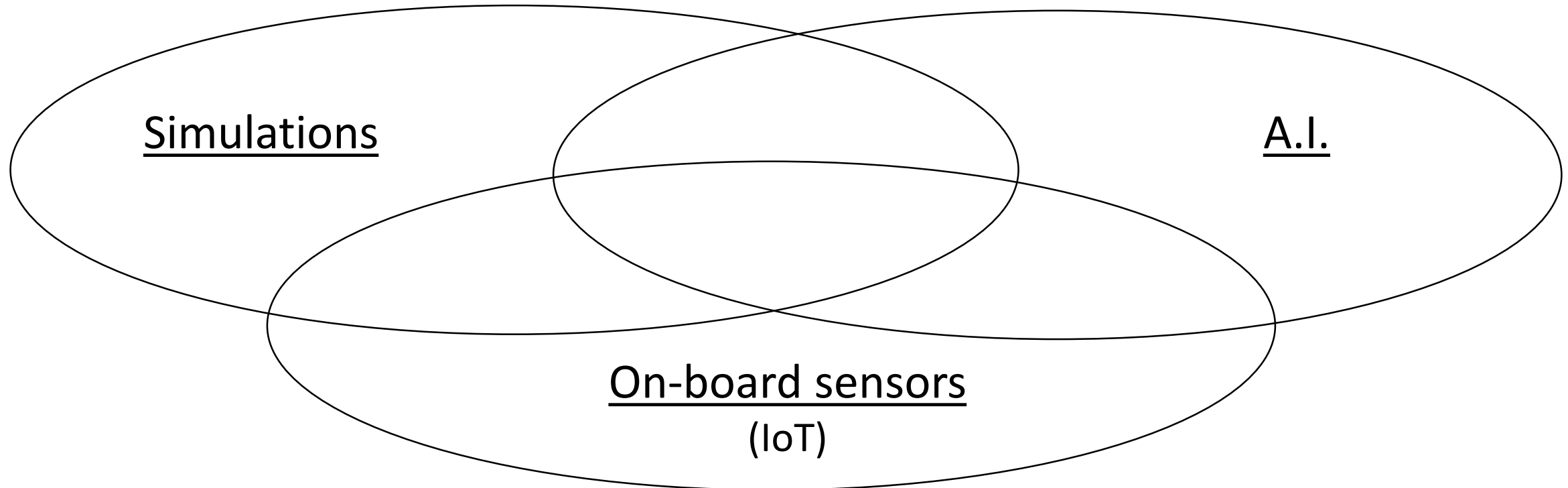
- Reduce blade lift variation
- Reduce wake effects within wind farm
- Real-time simulations



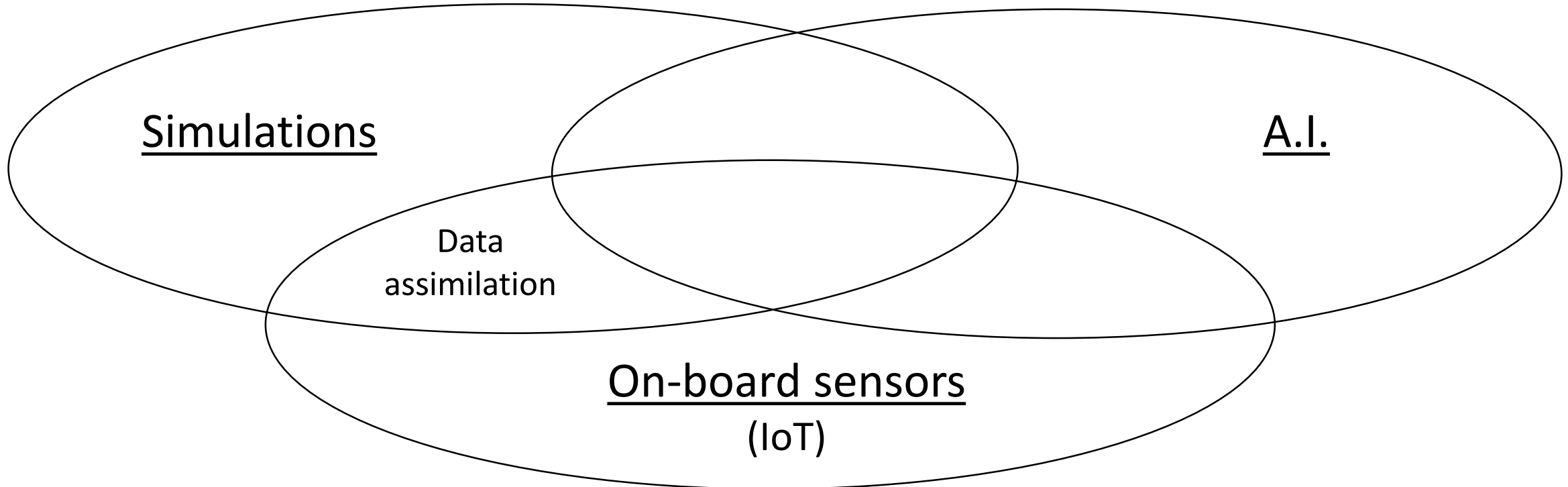
Which simple model? How to combine model & measurements?

## **PART II - OUR APPROACH**

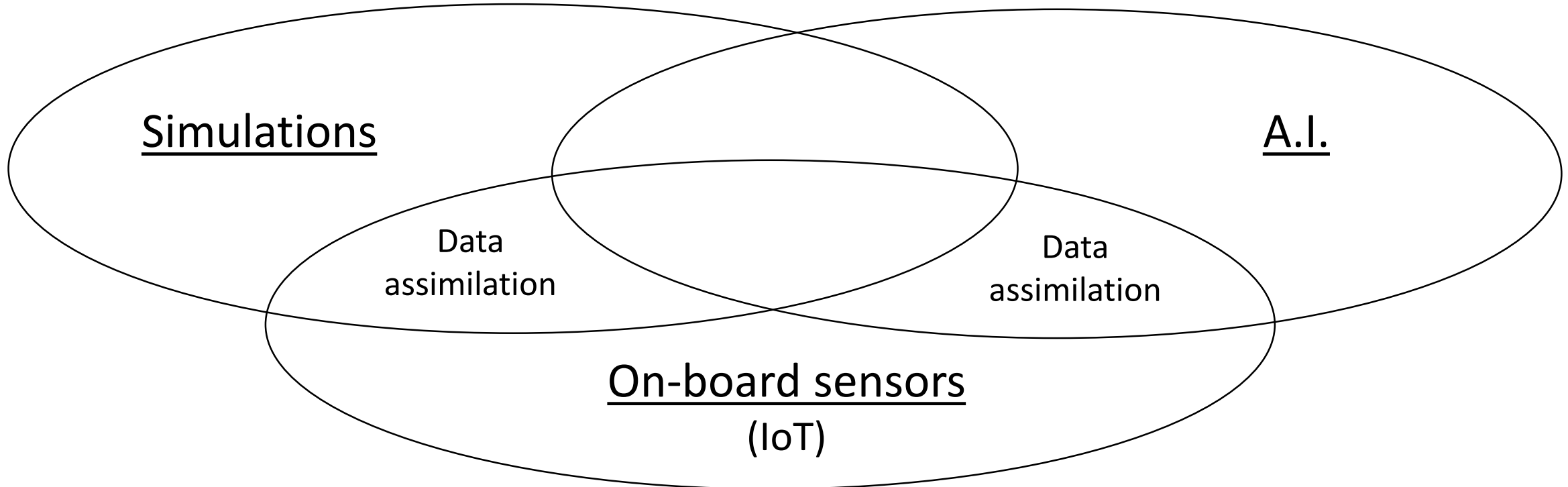
# A New Methodology



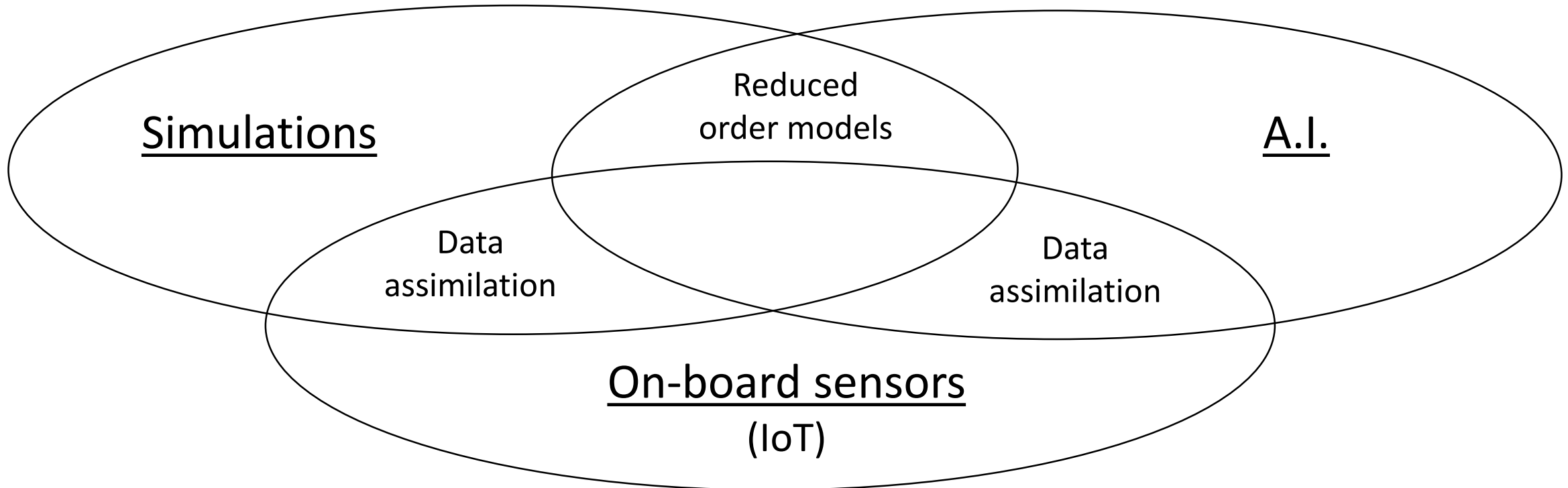
# A New Methodology



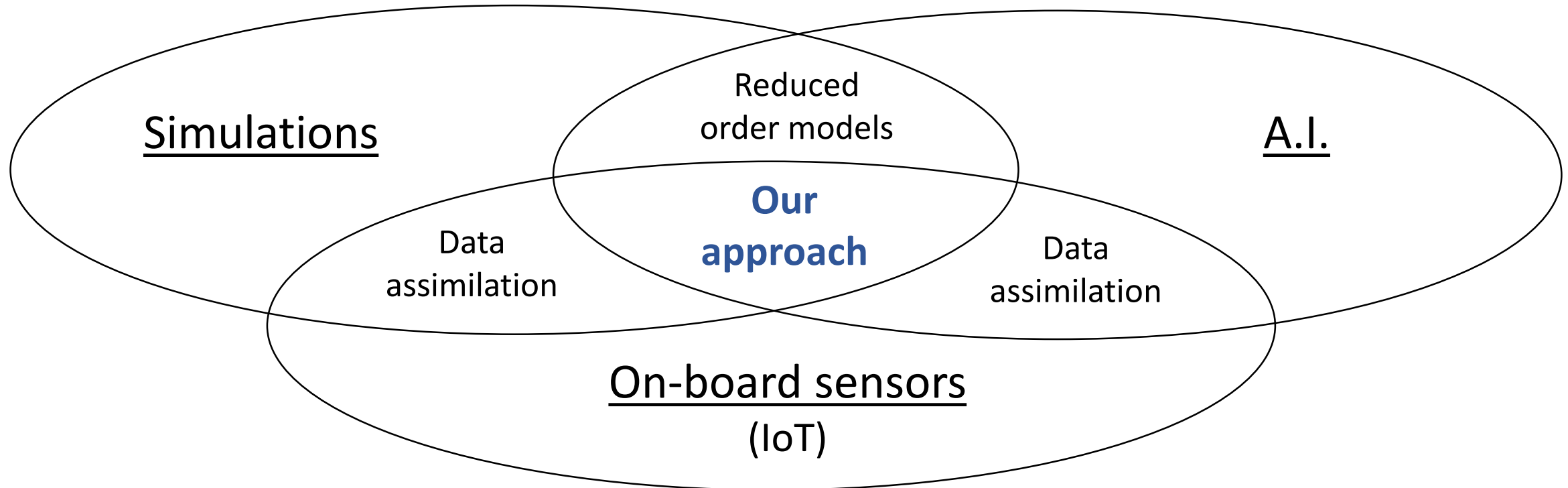
# A New Methodology



# A New Methodology



# A New Methodology

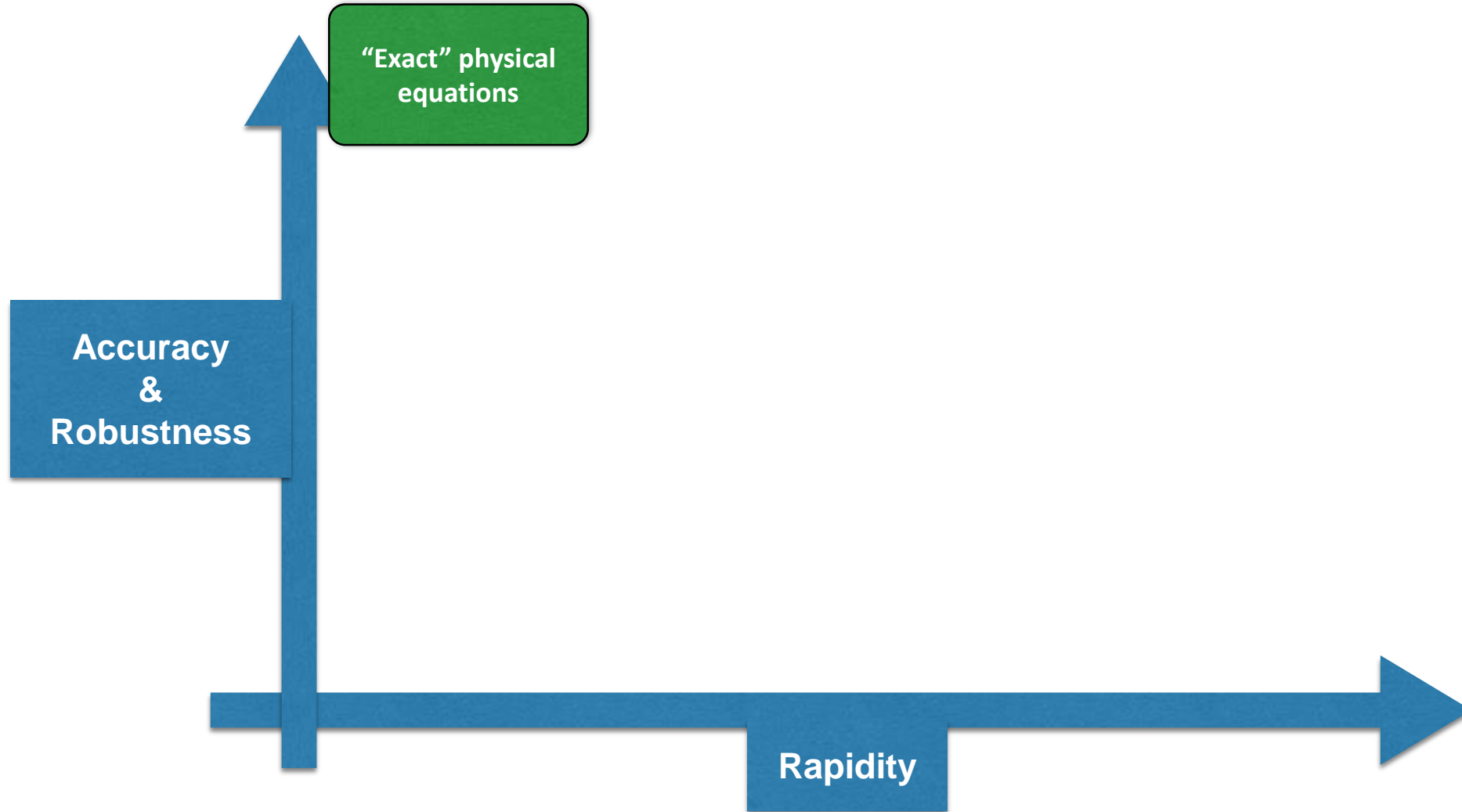




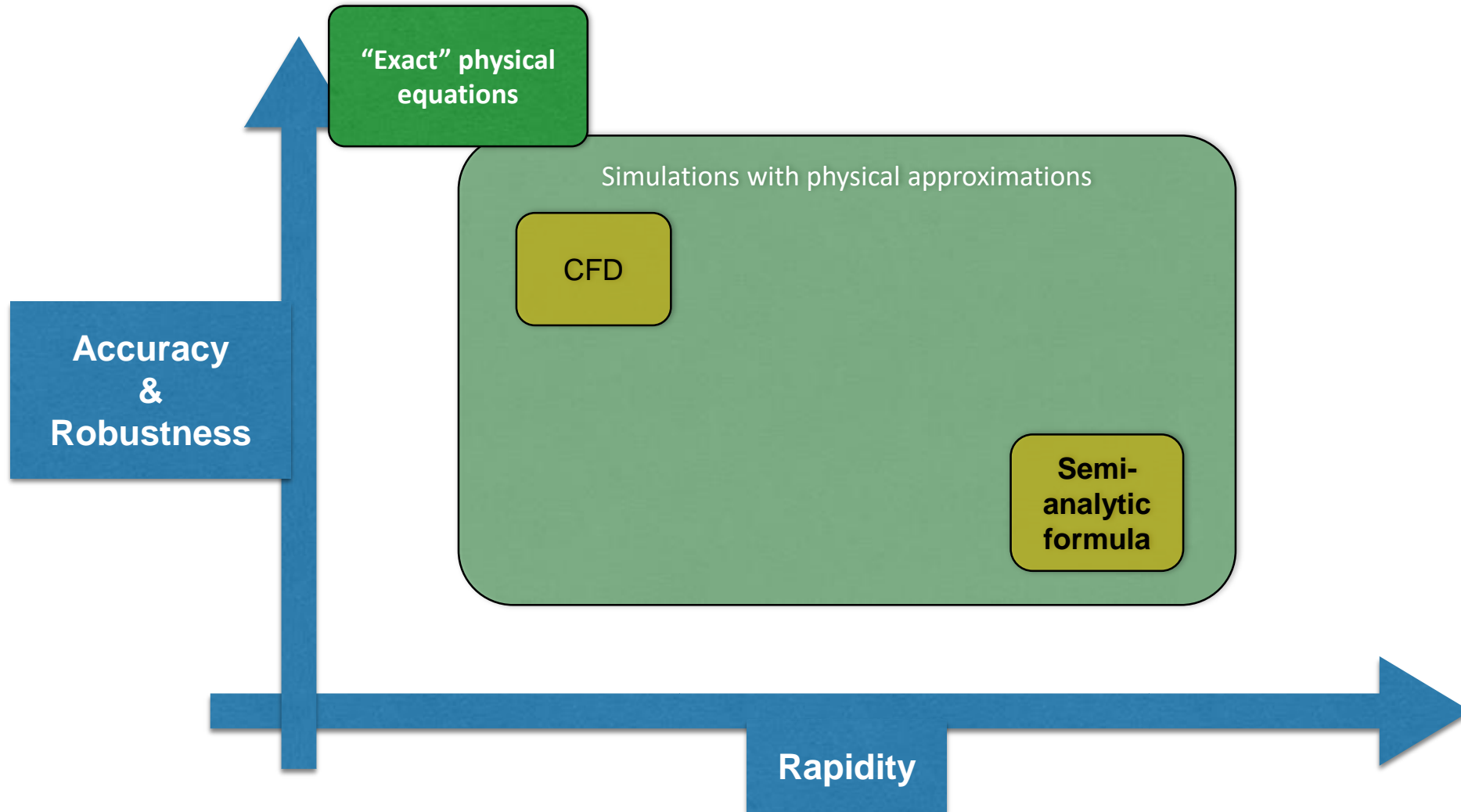
# Tradeoff accuracy / rapidity



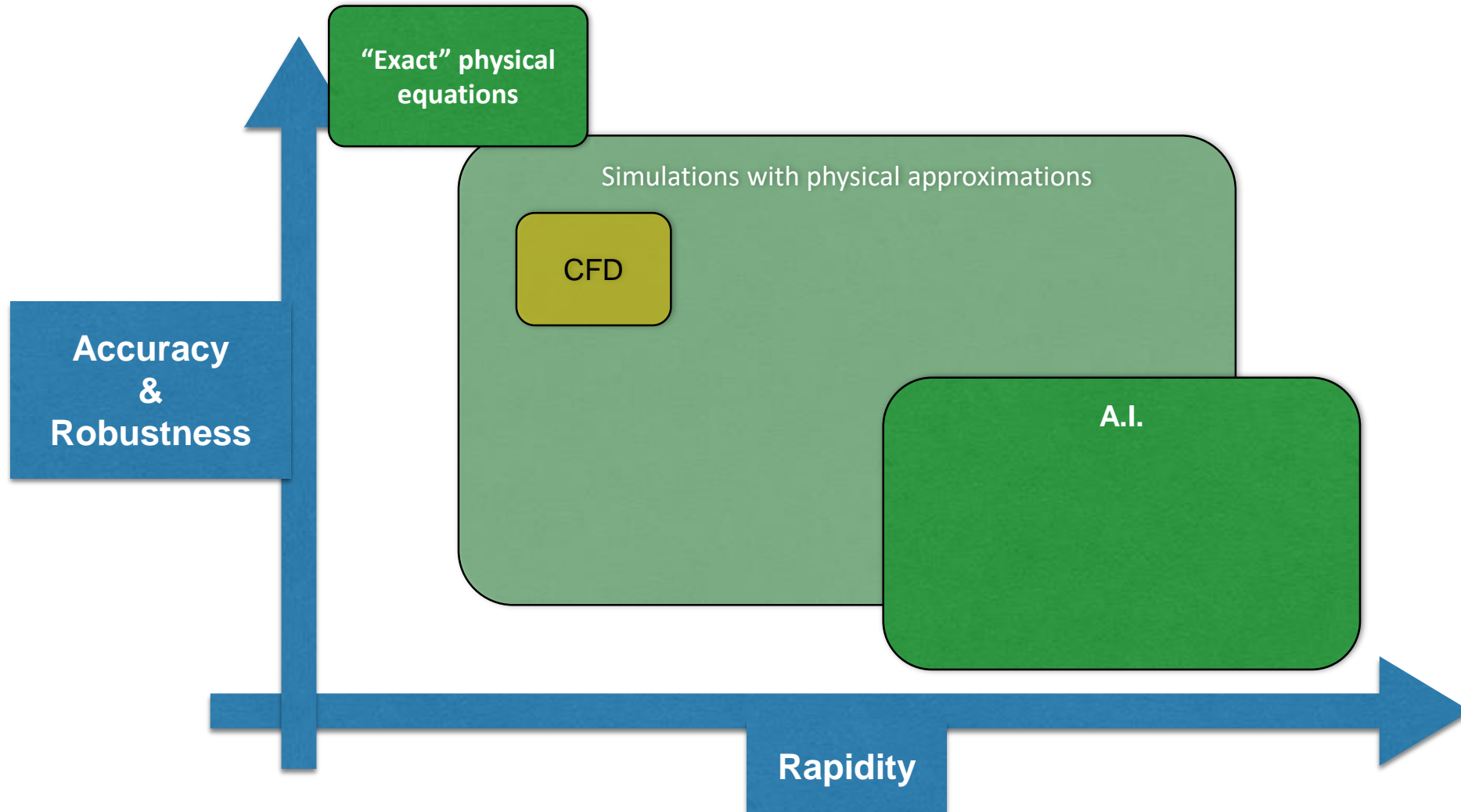
# Tradeoff accuracy / rapidity



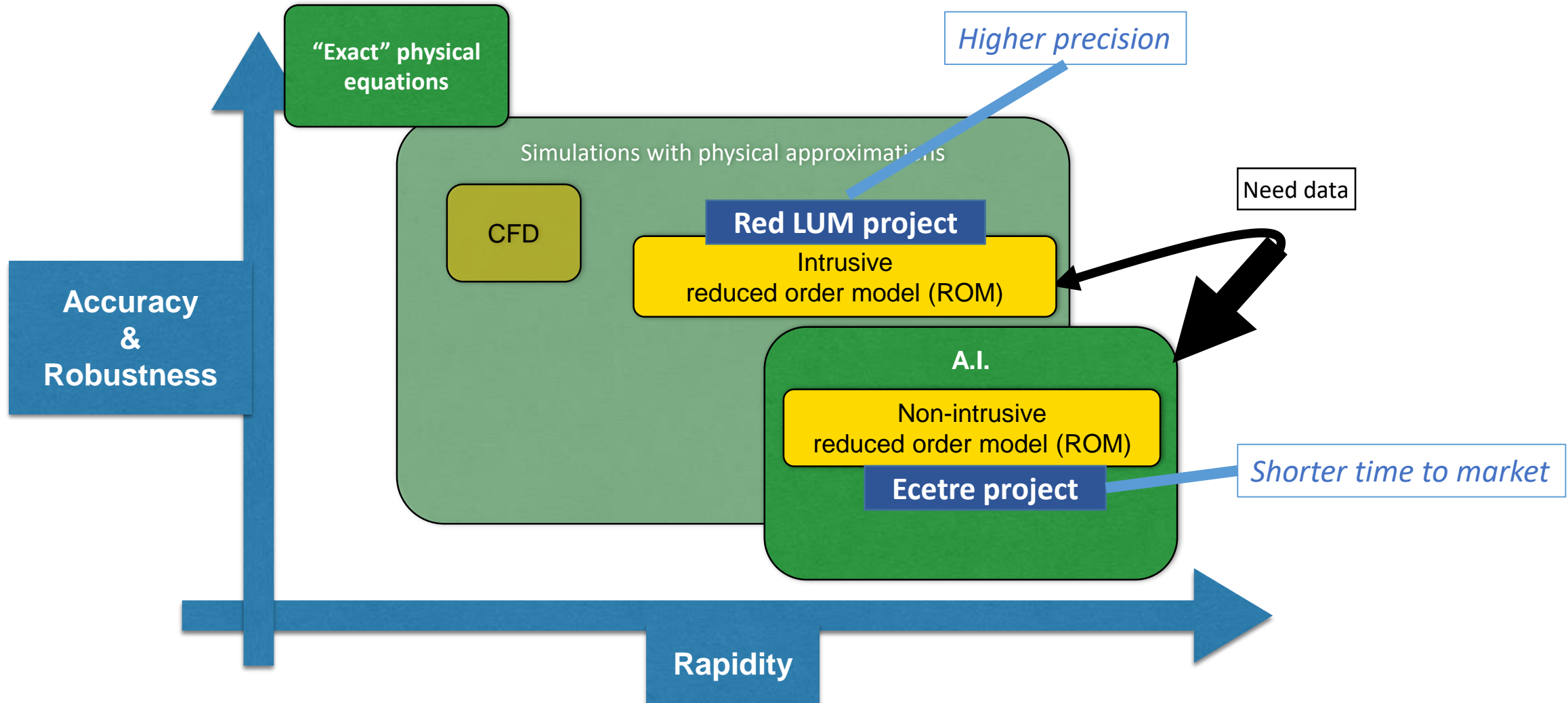
# Tradeoff accuracy / rapidity



# Tradeoff accuracy / rapidity

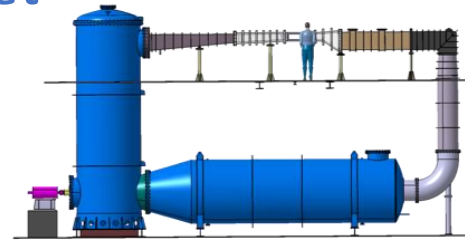


# Tradeoff accuracy / rapidity



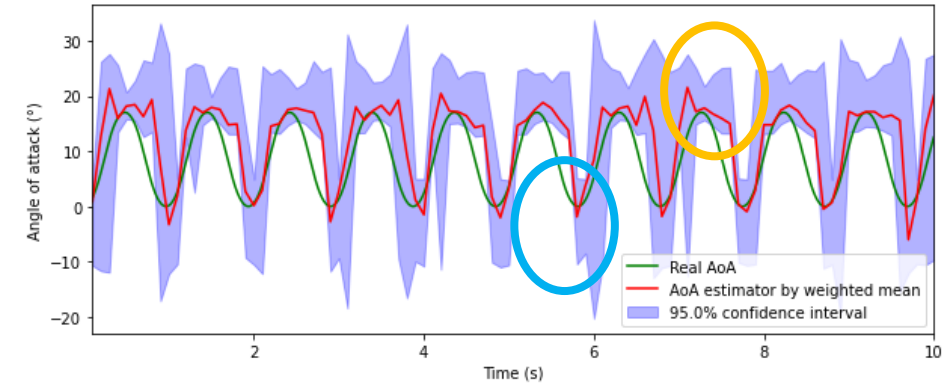
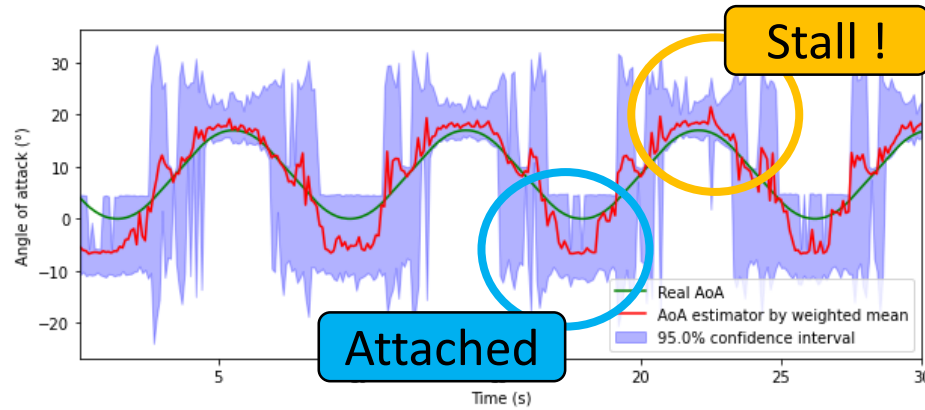
## PART III - RESULTS

# Ecetre experimental results : Fast Observer of AoA & Lift

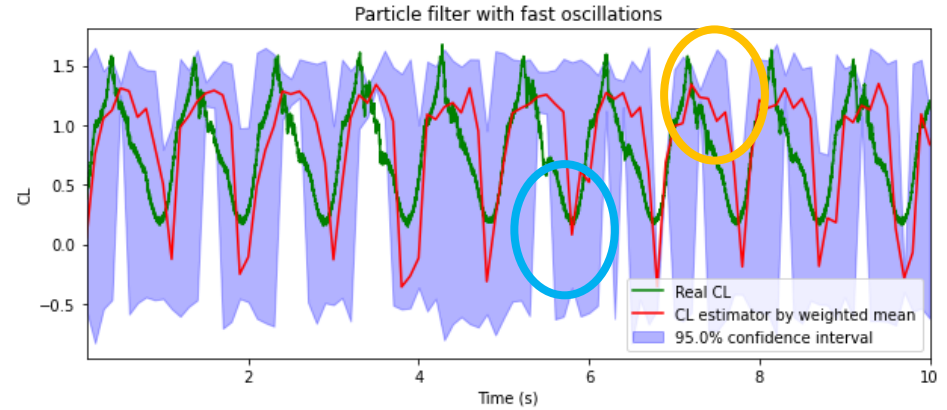
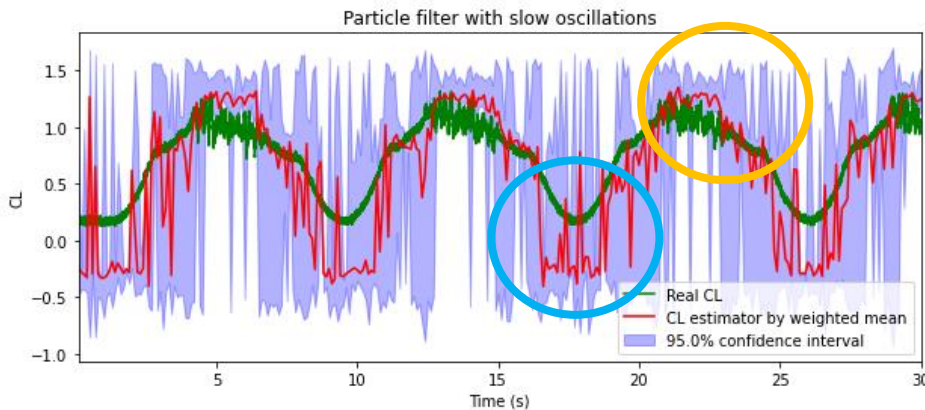


Reynolds ~ 10<sup>6</sup>

AoA estimation



Lift estimation



0.1 Hz AoA variations

1 Hz AoA variations

# First Red LUM Numerical results : Fast Observer of the whole 3D flow

Reduced order models with 8 degrees of freedom  
➤ Measurement : (blurred & noisy) velocity at a single spatial point only

## Reference :

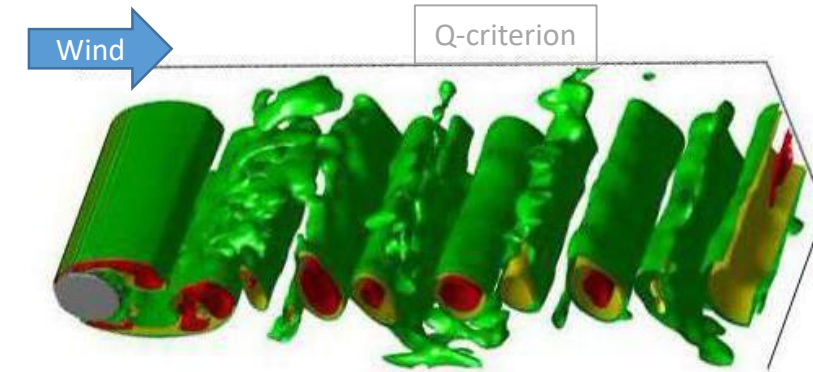
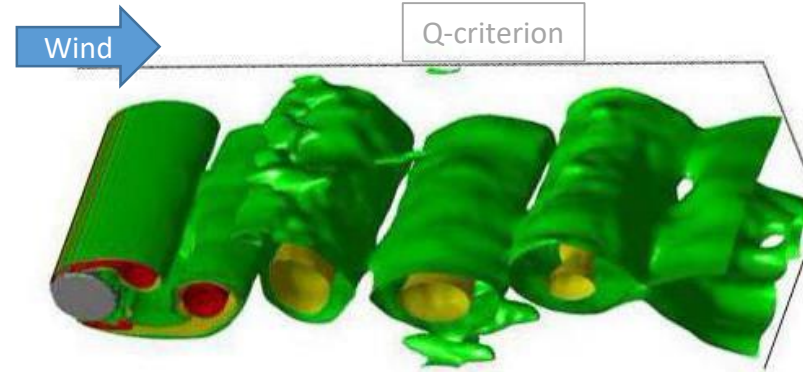
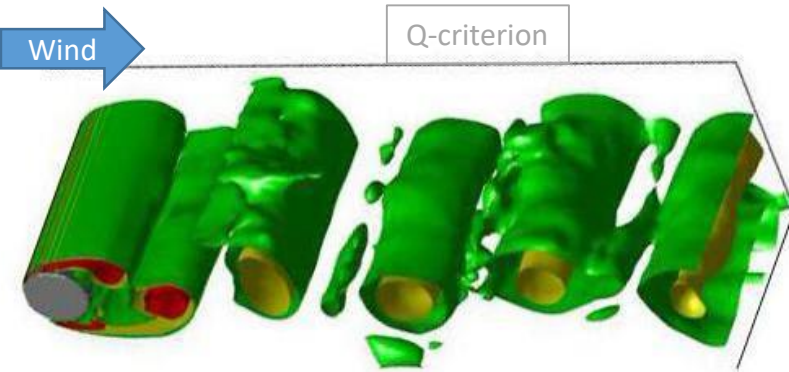
PCA-projection of the  
"true" simulation ( $10^7$ -dof DNS)  
(Optimal from 8-dof linear decomposition)

## Our method :

POD-Galerkin with  
randomized Navier-Stokes

## State-of-the-art :

POD-Galerkin with Navier-Stokes + optimally tuned eddy viscosity & additive noise



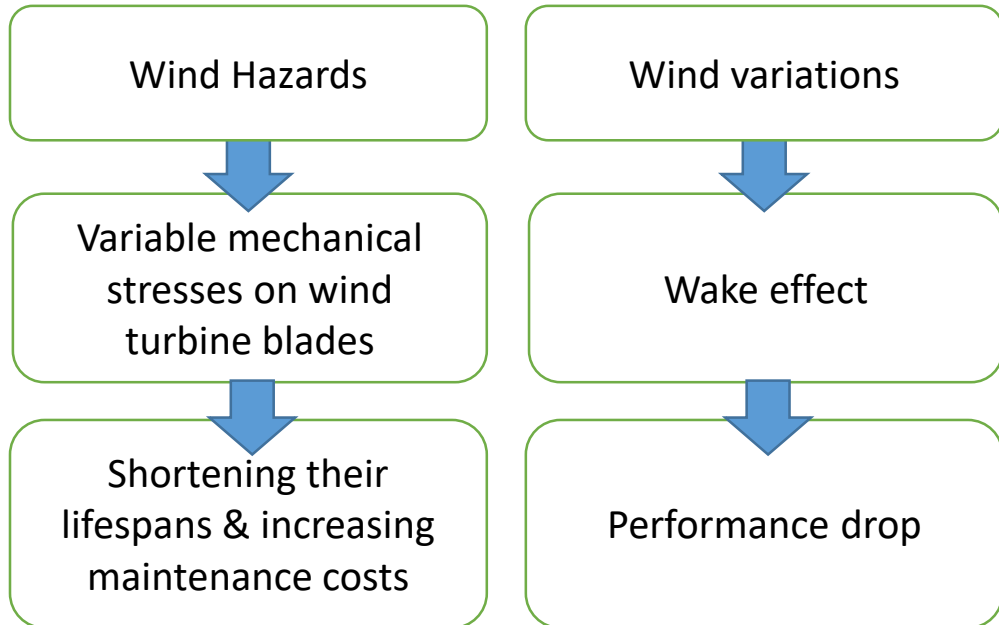


# CONCLUSION



## Conclusion

- Problems :
  - Mechanical fatigue of wind turbine blades



### ▶ Solution :

- Estimation / short-time prediction from :
  - Incomplete measurements (eTellTale, LiDAR)
  - Very fast simulation of fluid mechanics (reduced order models)
    - **Ecetre project :**  
Shorter time to market
    - **Red LUM project :**  
Very innovative / dynamic / higher precision
  - Coupling with
    - Data assimilation
- For better control loop and prevent damages