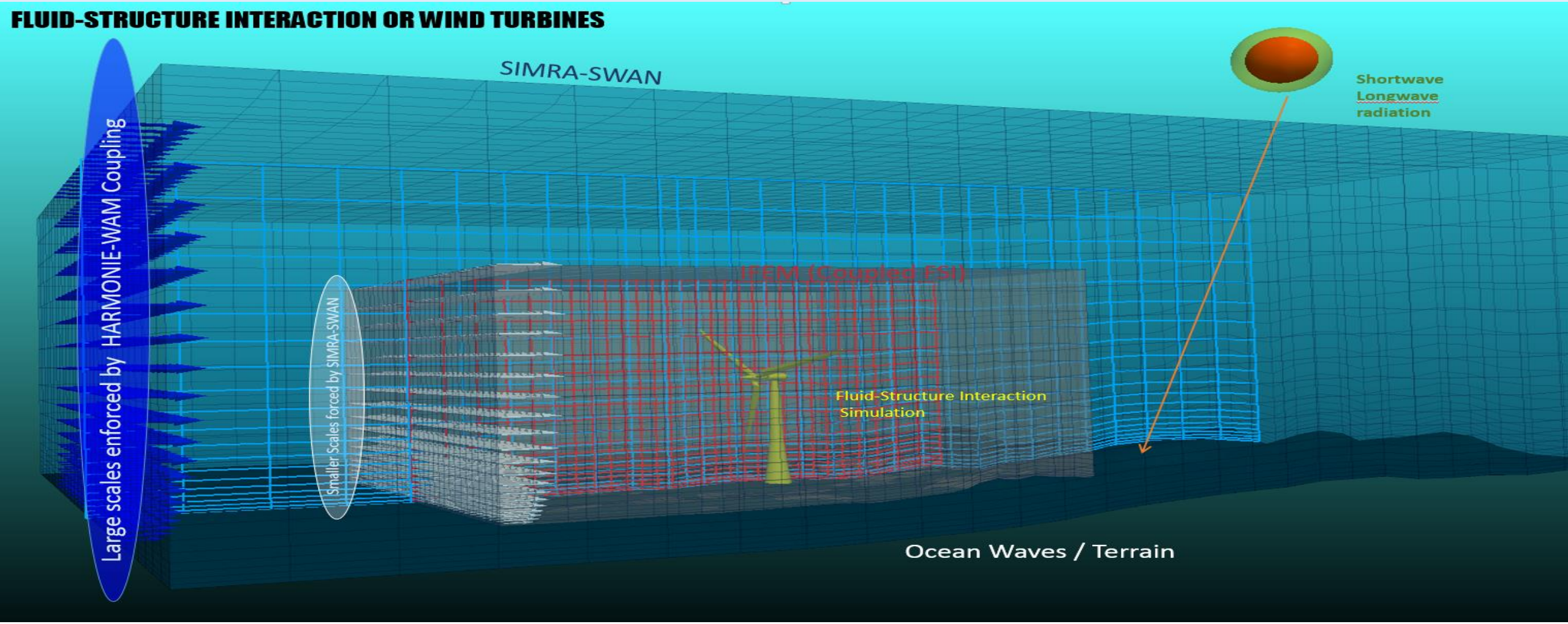
A Comprehensive Multiscale Numerical Framework For Wind Energy Modelling

FLUID-STRUCTURE INTERACTION FOR WIND TURBINES (FSI-WT project 2012 - 2017)



SINTEF DIGITAL (Formerly ICT), MATHEMATICS AND CYBERNETICS DEPARTMENT.

ADIL RASHEED , MANDAR TABIB, TROND KVAMSDAL, KARL MERZ, JOHN TANDE.

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  - APPROACH AND TOOLS USED/DEVELOPED
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  - BESSAKER ONSHORE WIND FARM
  - MET-OCEAN INTERACTION FOR OFFSHORE WIND FARM
- FUTURE WORK TOWARDS ROMs (OPWIND)

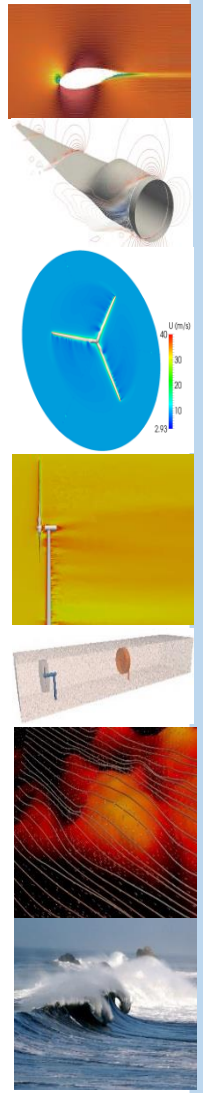
MOTIVATION

- Develop efficient methods for real-time simulation for industrial needs.
  - Approach - From High-fidelity simulation to faster reduced order methods.

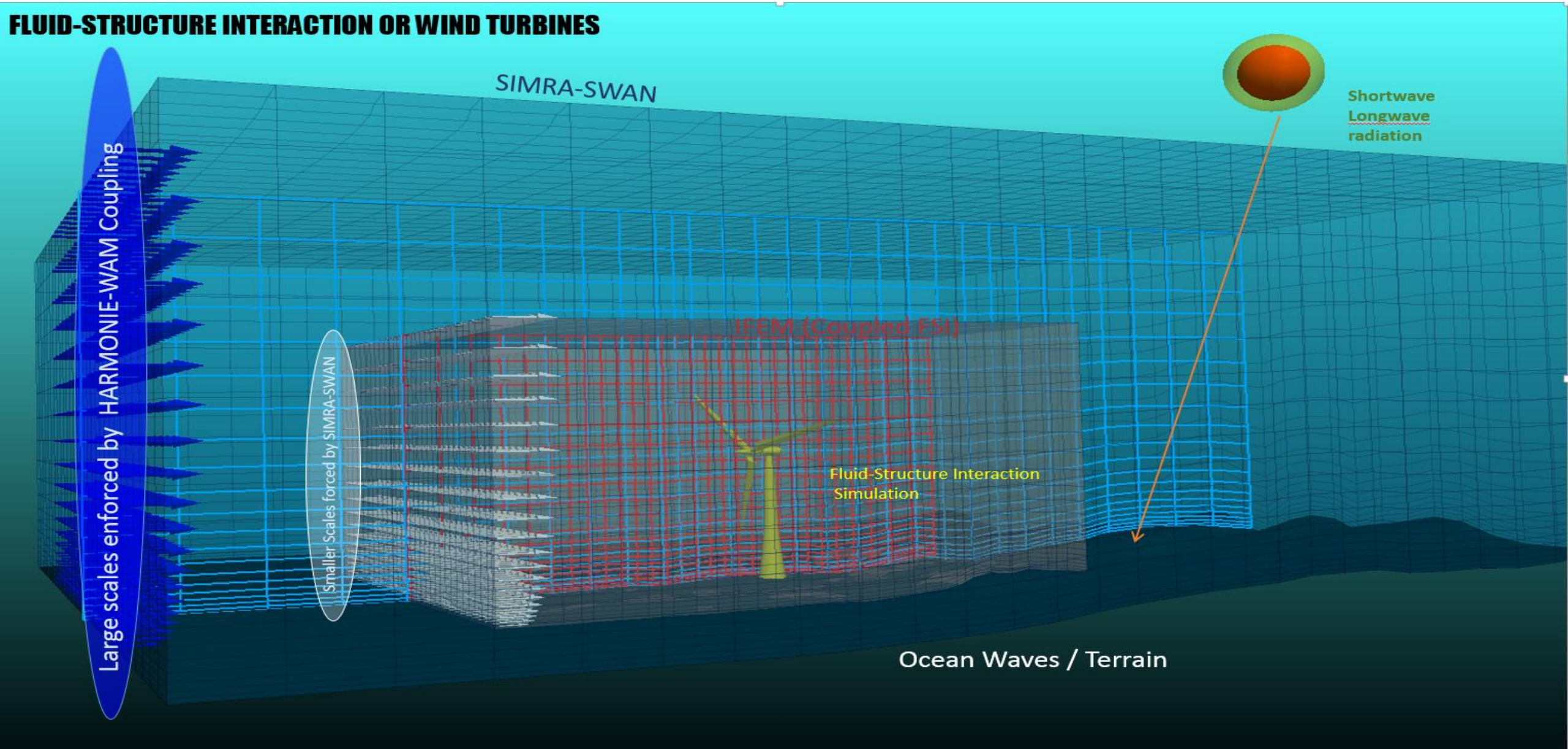
- Aim of FSI-WT project – High fidelity tools in a multi-scale framework in order to resolve wide-range of spatio-temporal scales and to accurately determine influence of key variables on wind-farm performance (onshore and offshore).
    - Meso-scale atmospheric phenomena and stratification – Marine and Atmospheric boundary layer.
    - Ocean-atmospheric interactions for offshore wind farms
    - Terrain influence on wind
    - Influence of blade geometry
    - Wake dynamics.
  - **A single model cannot resolve all the spatio-temporal scales and hence need to embed several models in a multi-scale framework.**
  - These hi-fidelity models can be used later to develop reduced order models for faster simulation.

TOOLS USED/DEVELOPED FOR MULTISCALE MODEL

Physics	Tool Coupling and Resolution of use
Mesoscale atmospheric flow.	Mesoscale weather forcasting model - **HARMONIE - 1 Km x 1 Km** resolution.
Microscale wind model with terrain impact.	**SIMRA (inhouse code)** – **50 m x 50 m** resolution.
Supermicroscale - Wind Farm resolved with Turbine model Influence of wake with terrain features and stratification.	**SIMRAFOAM** with Actuator line method (SIMRA + SOWFA). Finest mesh resolution – **3m x 3m x 3m** = (*Turbine diameter/20*) . Turbine not explicitly resolved and needs turbine data.
Turbine blade resolving models	Turbine geometry resolved. Mesh resolution in *μm* to *mm* near boundary of turbine. **Flow over airofoil (IFEM), Sliding mesh and MRF.**
Ocean Wave models	WAM and SWAN.

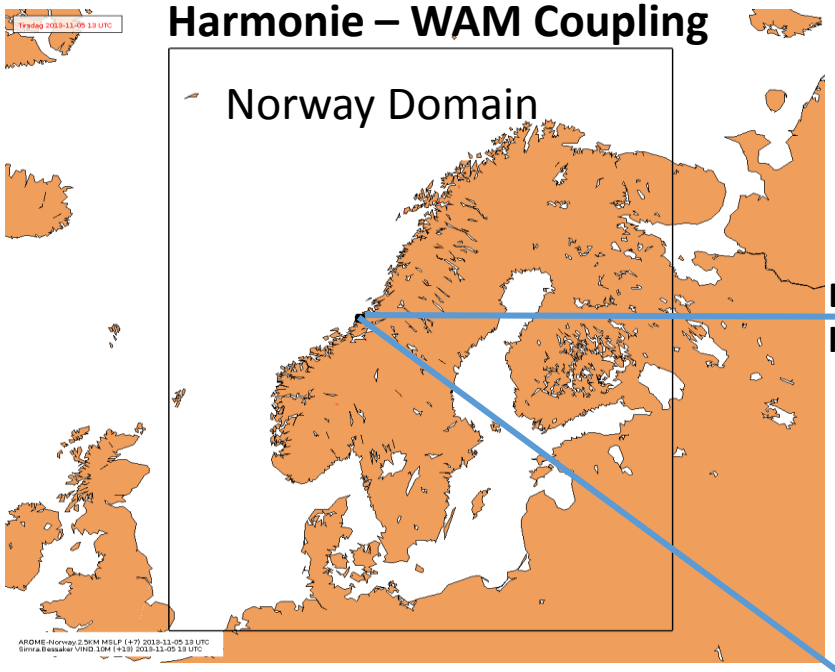


MULTI-SCALE COUPLING - OFFSHORE



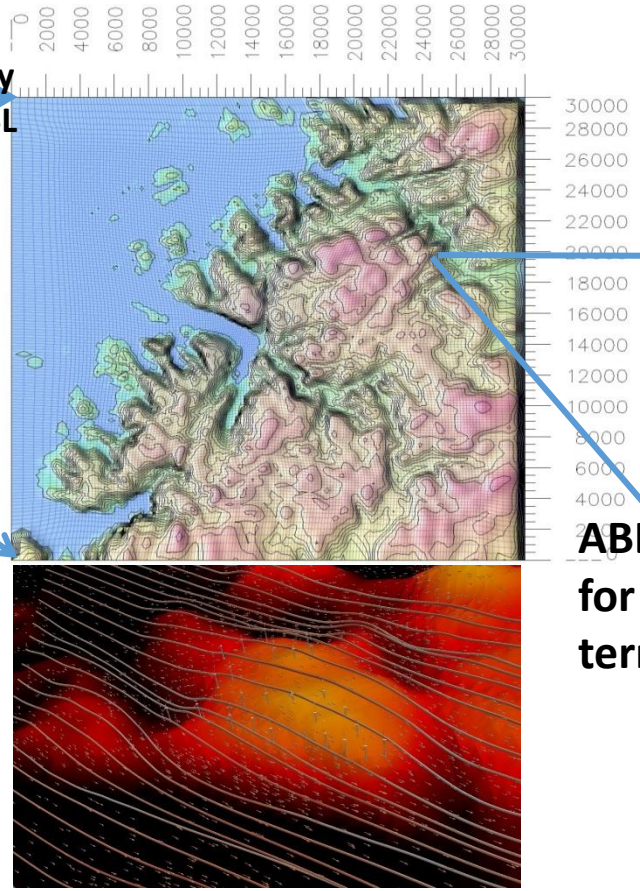
MULTI-SCALE COUPLING - ONSHORE

Harmonie – WAM Coupling

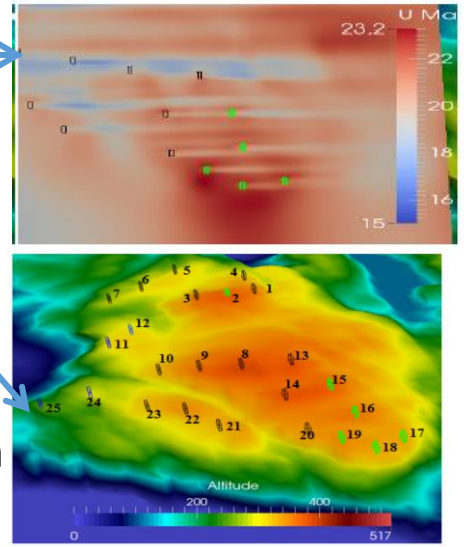


Boundary layer MBL

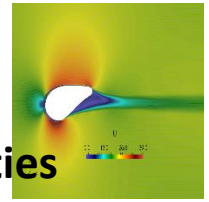
SIMRA – Microscale model.



SIMRAFOAM

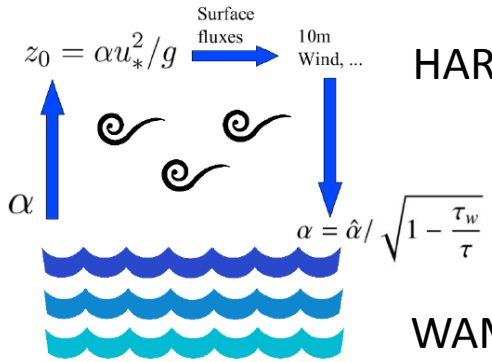


Airofoil and blade geometry



Airfoil properties

ABL for terrain

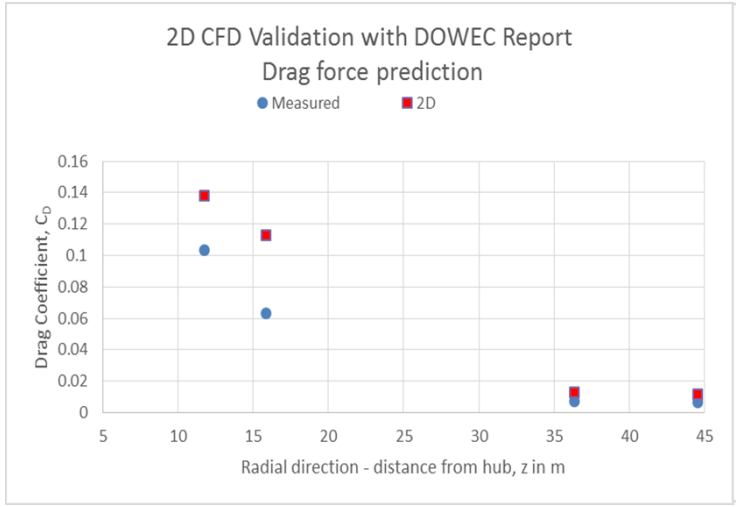


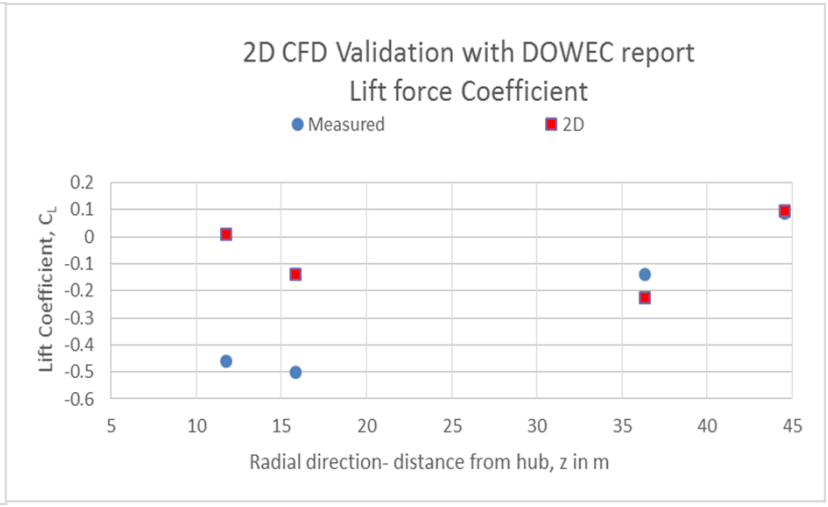
HARMONIE

WAM

CASE STUDY AND VALIDATION EXAMPLE

NREL 5 MW FOR TESTING - 2D Vs Q3D Vs 3D Blade Models. Flow At Different Sections.





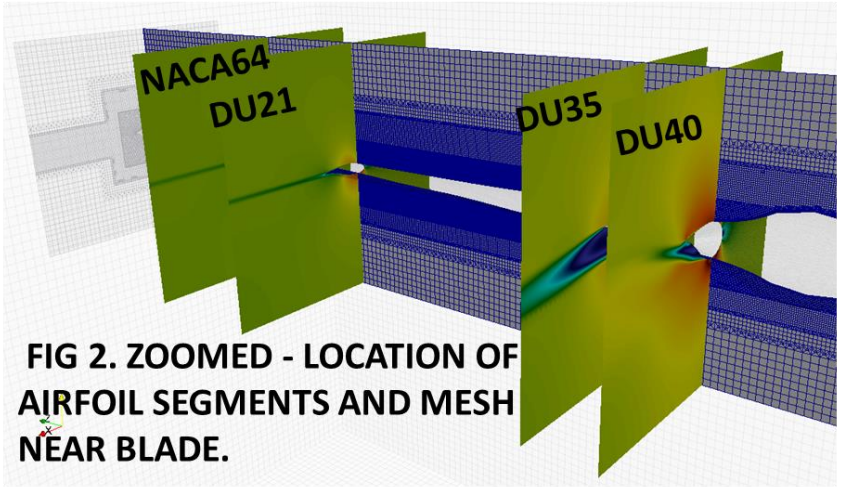
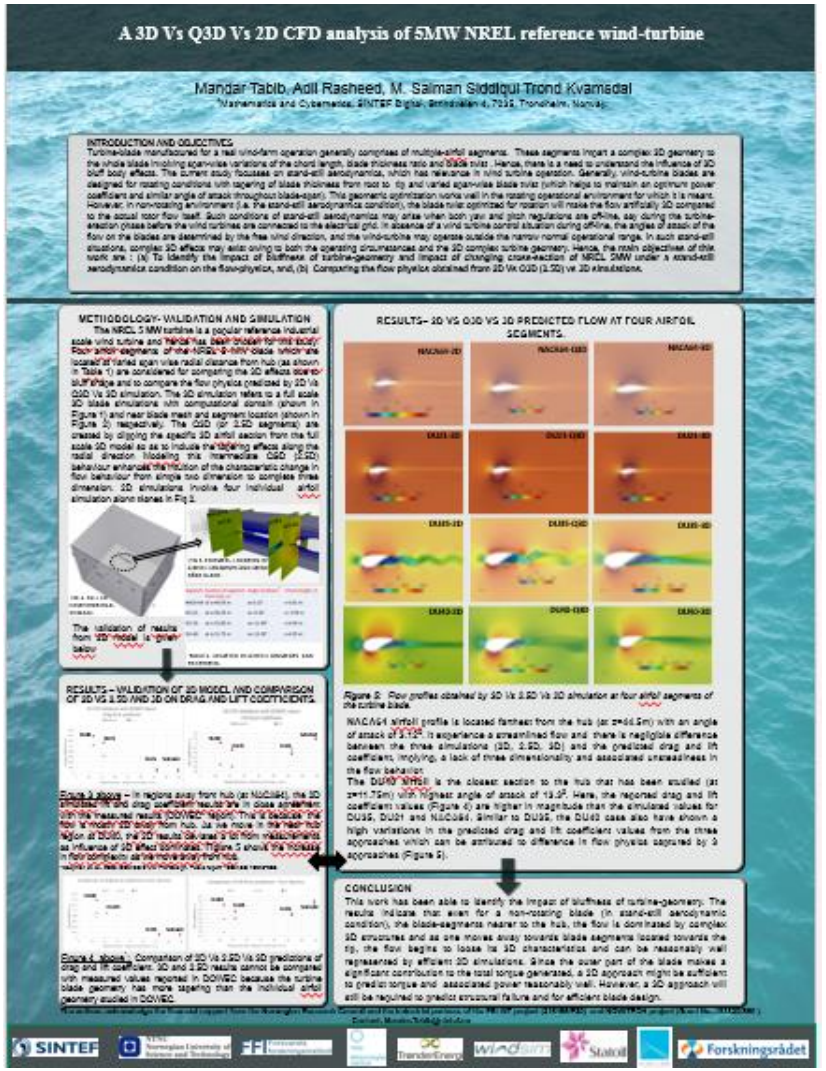


FIG 2. ZOOMED - LOCATION OF AIRFOIL SEGMENTS AND MESH NEAR BLADE.

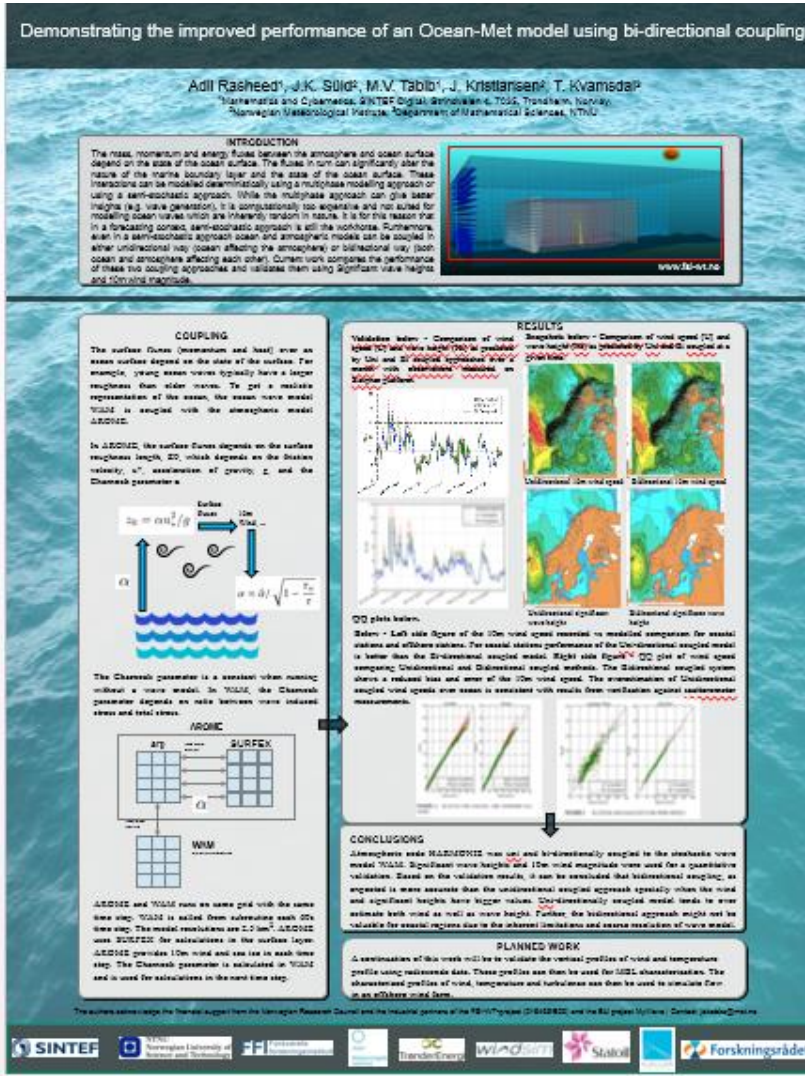
As one moves away from hub towards the tip, the flow begins to loose its 3D characteristics and can be reasonably well represented by efficient 2D simulations.



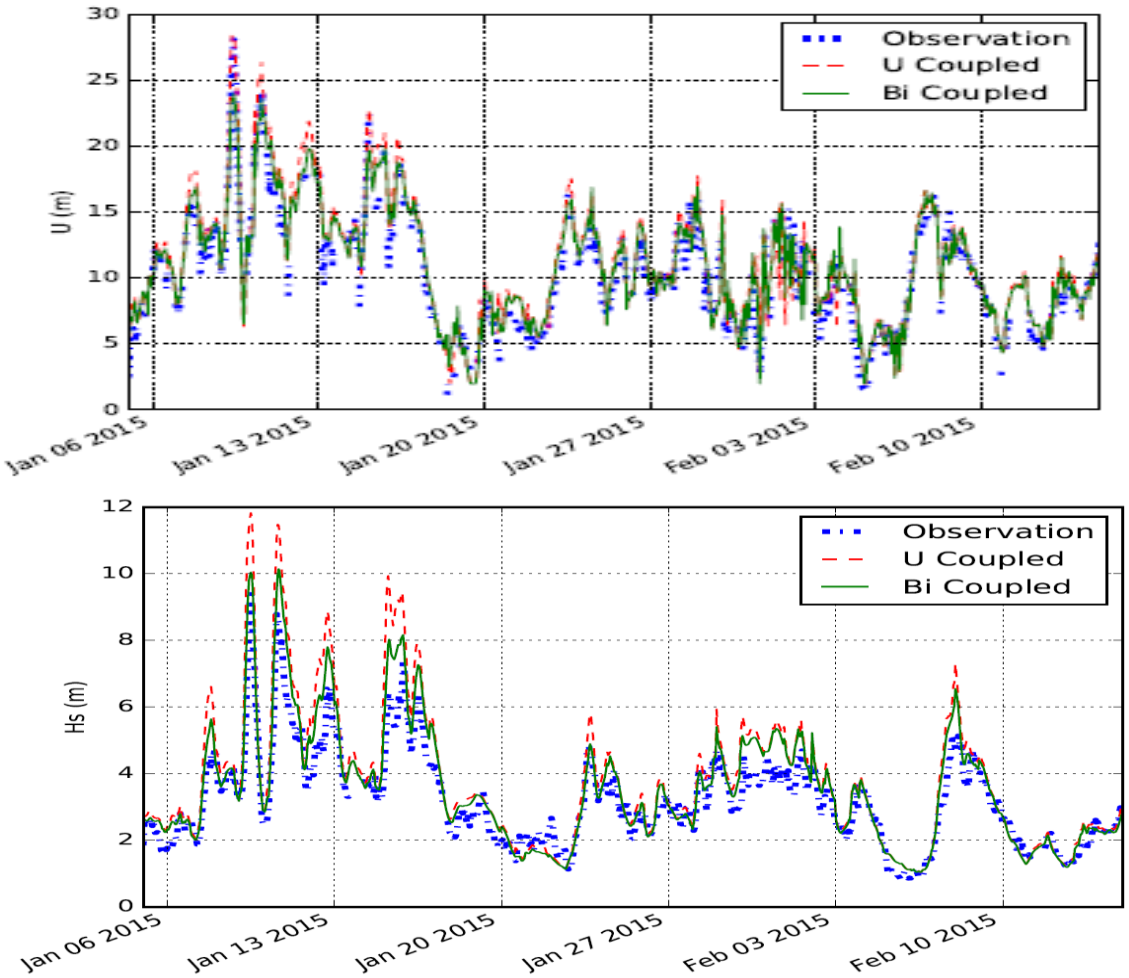
VALIDATION OF MULTISCALE FRAMEWORK FOR OFFSHORE CONDITIONS – WAM-HARMONIE AND SIMRA-SWAN.

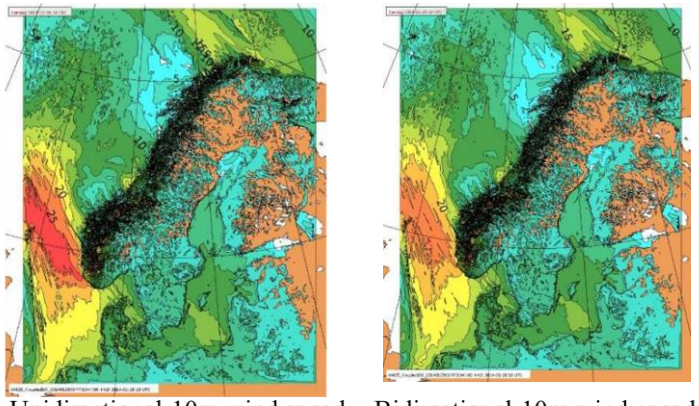
MET OCEAN INTERACTIONS

HARMONIE-WAM	SIMRA-SWAN
Resolution ~1km	Resolution ~50m for air flow, 5m for wave modeling
Unsteady mode	Steady mode
Accounts for sensible and latent heat flux	Accounts for only sensible heat flux
Not good close to the coast in shallow water	Idea for shallow water and close to the coast



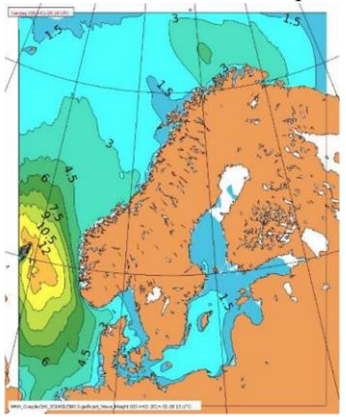
CONTINUED … VALIDATION OF MULTISCALE FRAMEWORK FOR OFFSHORE CONDITIONS – WAM-HARMONIE.



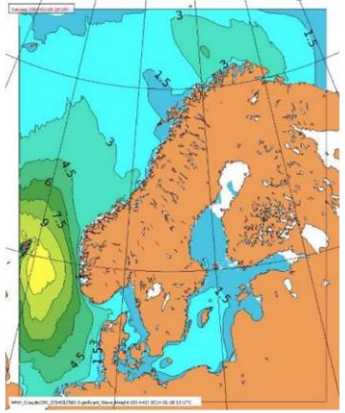


Unidirectional 10m wind speed

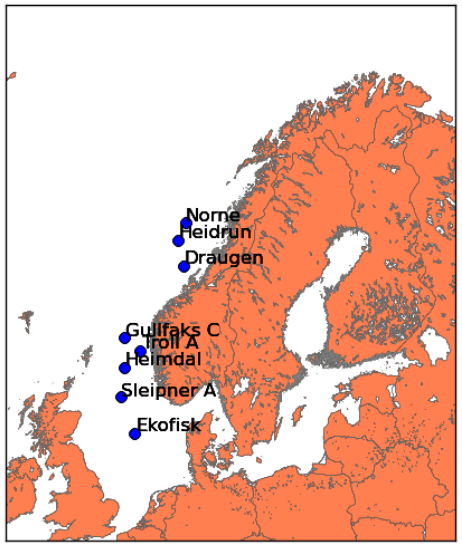
Bidirectional 10m wind speed



Unidirectional significant wave height

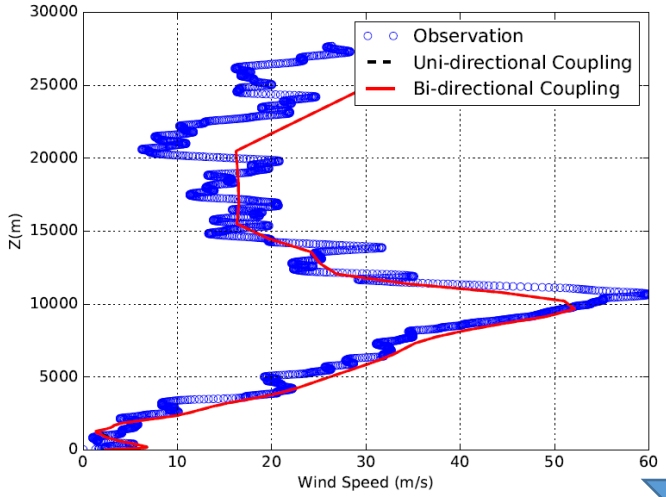


Bidirectional significant wave height

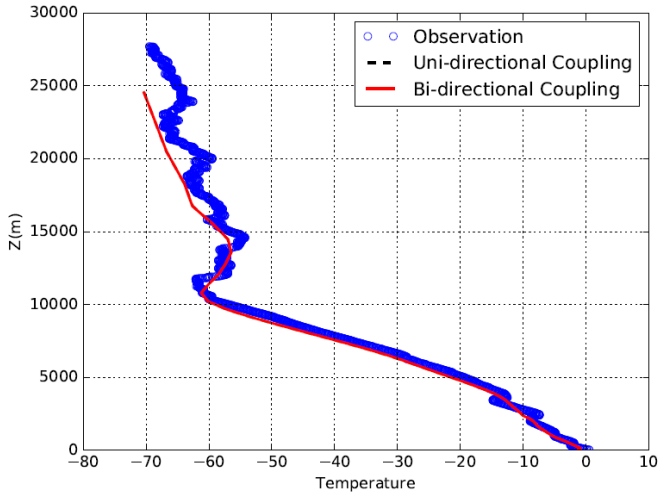


Comparison of wind speed (U) and wave height (Hs) as predicted by Uni and Bi coupled approaches over a month with observations measured on Sleipner platform.

CONTINUED … VALIDATION OF MULTISCALE FRAMEWORK FOR OFFSHORE CONDITIONS – WAM-HARMONIE

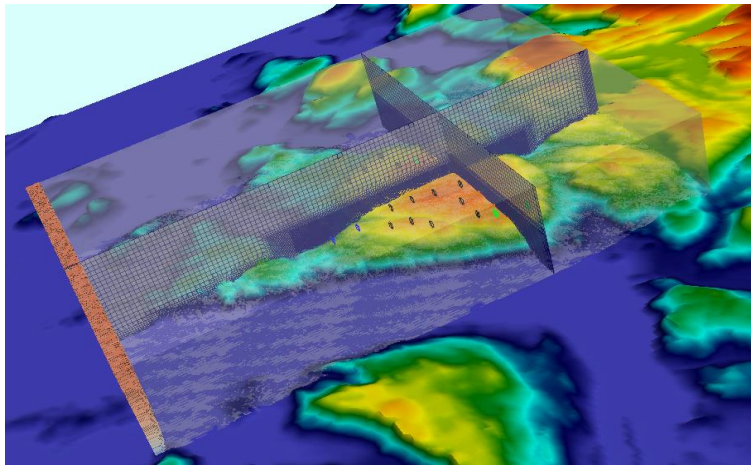


(a) WIND PROFILE

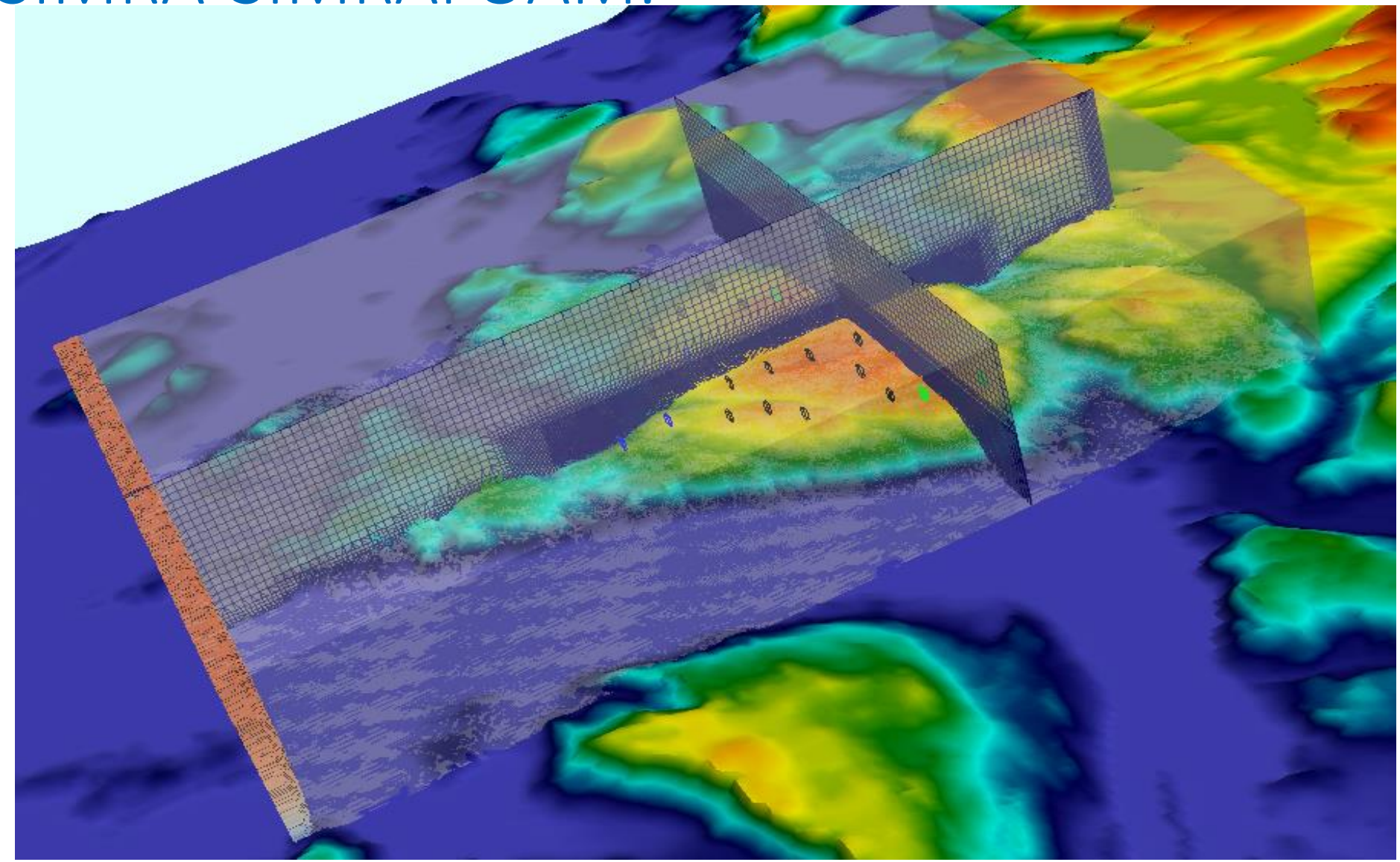


(b) TEMPERATURE PROFILE

MBL AS INPUT TO SIMRA/ SIMRAFOAM for wind-farm.



CONTINUED … VALIDATION OF MULTISCALE FRAMEWORK FOR ONSHORE BESAKKER WIND FARM – HARMONIE-WAM-SIMRA-SIMRAFOAM.



25 Turbine farm

Altitude - Sea-level to 400 m.

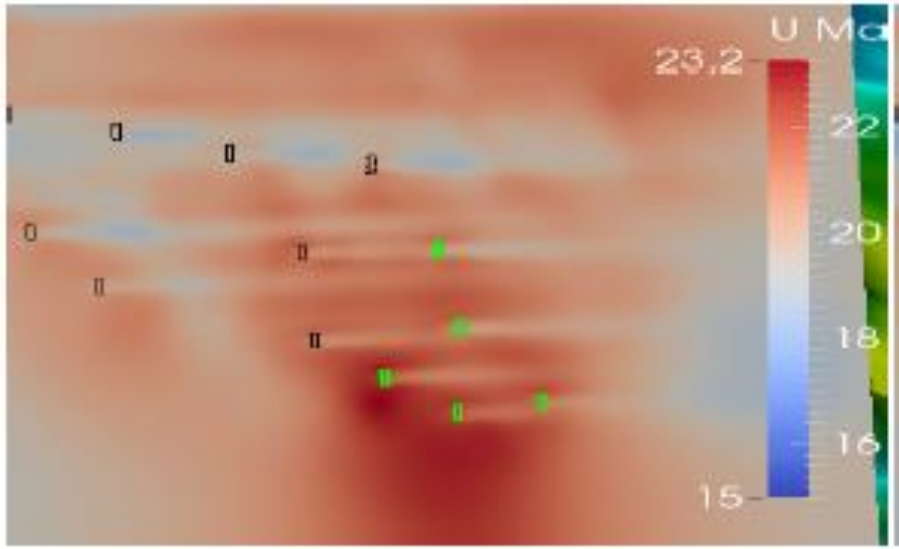
Domain:
6.8km X 4.5 km X 1.5km

Boundary condition from the coupled **HARMONIE-SIMRA** provided to **SIMRAFOAM.**

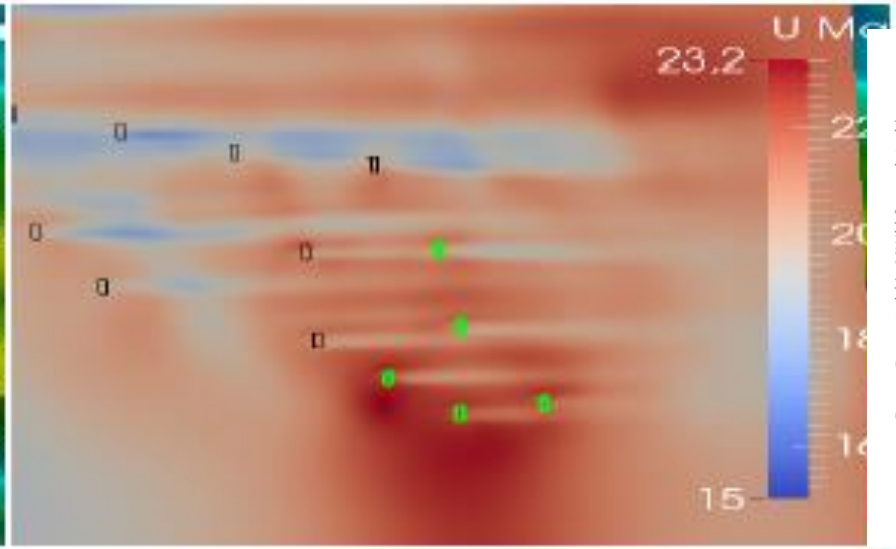
Mesh: 13 million grid cell with 3m resolution close to the TURBINE location

CONTINUED … VALIDATION OF MULTISCALE FRAMEWORK FOR ONSHORE BESAKKER WIND FARM – STRATIFICATION INFLUENCE AND TERRAIN INFLUENCE.

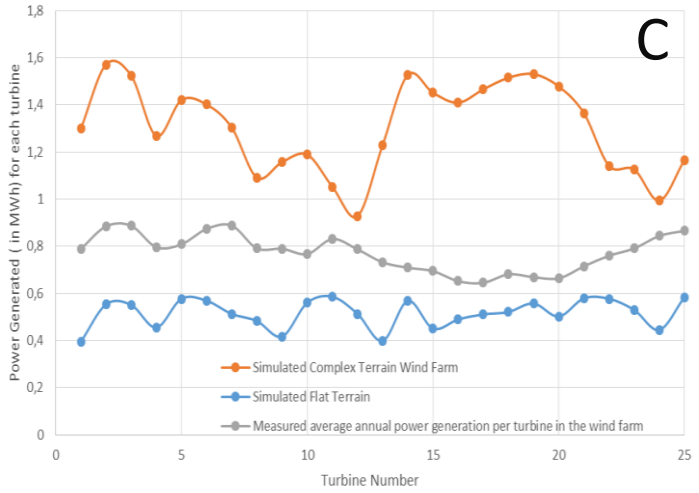
Velocity in Neutral condition



Velocity in Stable stratification

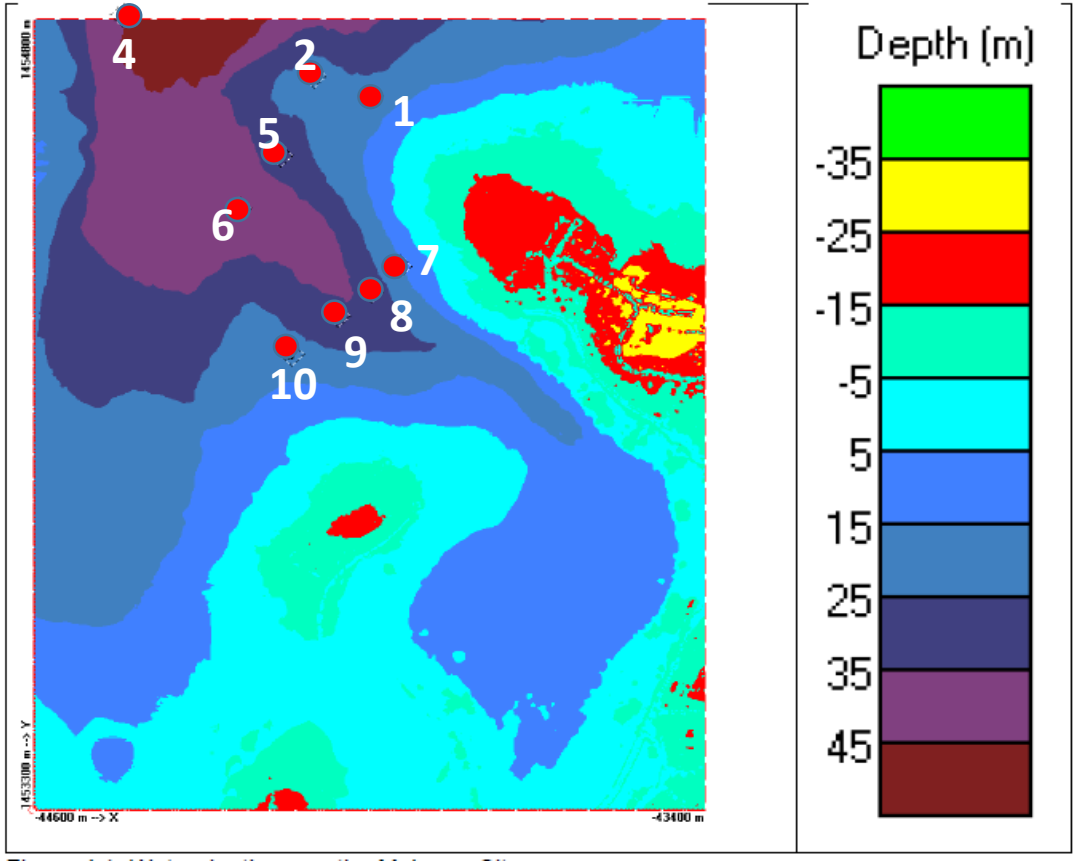


Terrain Influence. Flat and Complex Terrain with neutral flow.



CONTINUED … VALIDATION OF MULTISCALE FRAMEWORK FOR OFFSHORE CONDITIONS – SIMRA-SWAN.

Location	Obs Hs (m)	Standalone Model Hs (m)	Coupled Model Hs (m)
1	4.16	4.30	4.27
2	4.54	4.80	4.87
5	4.17	4.59	4.5
6	4.01	4.06	4.00
7	2.13	2.40	2.45
8	2.03	2.60	2.60
9	2.57	2.80	2.85
10	2.68	2.90	2.92

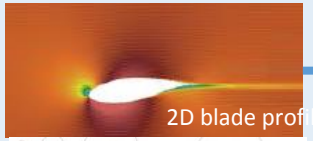


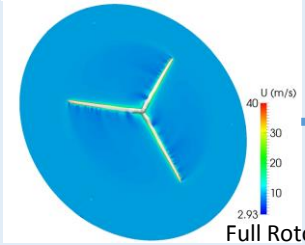
Flow accelerates in the fjord due to channeling effect as a result of which the source term (wind induced) increases which in turn results in an increased significant wave height in the coupled model.

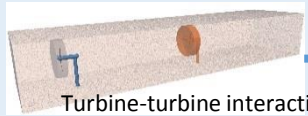
FSI-WT MULTISCALE (2012-2017)

2017 – 2020 OPWIND

An array of high fidelity numerical simulation tools







Building Database For ROM.

Subgrid parameterizations

New Chosen Input Parameters (tip speed ratio, yaw, pitch, turbine geometry)

Input parameters to construct the reduced order basis

Model Order Reduction

ROM

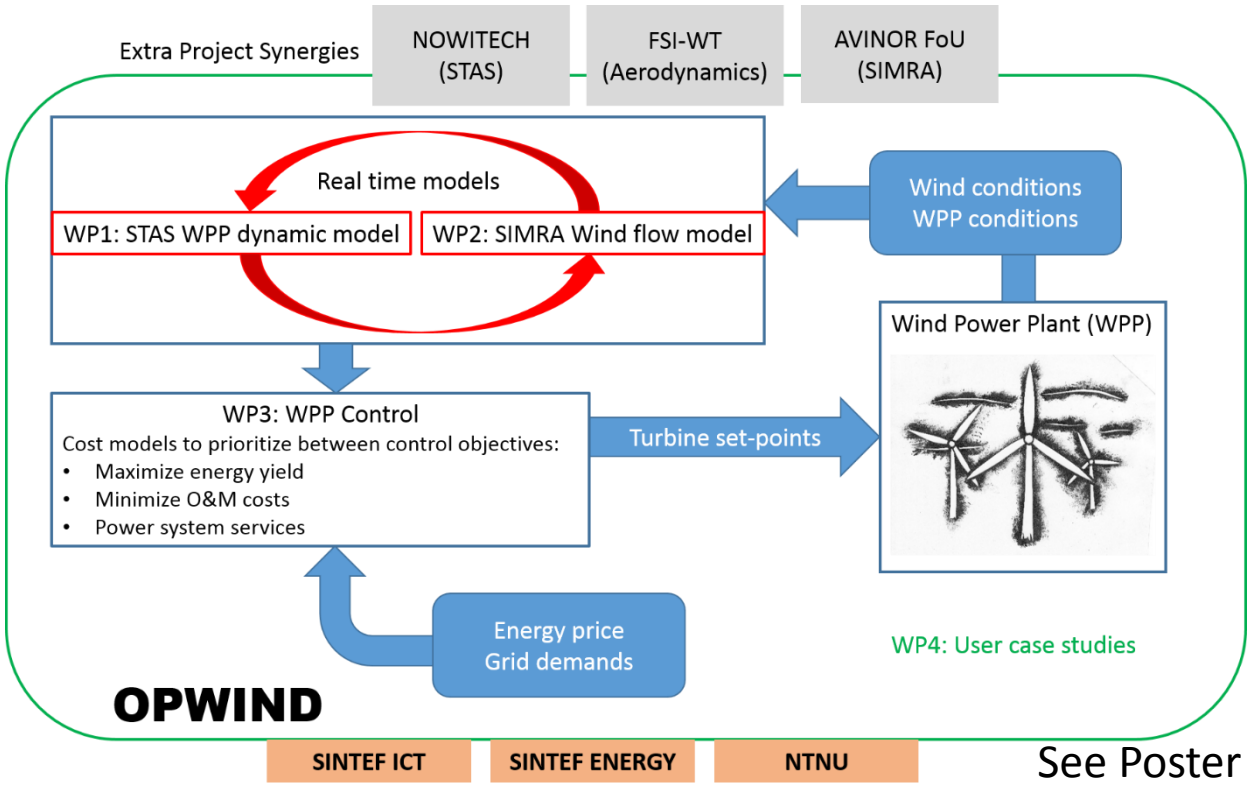
Output (Power, Loadin

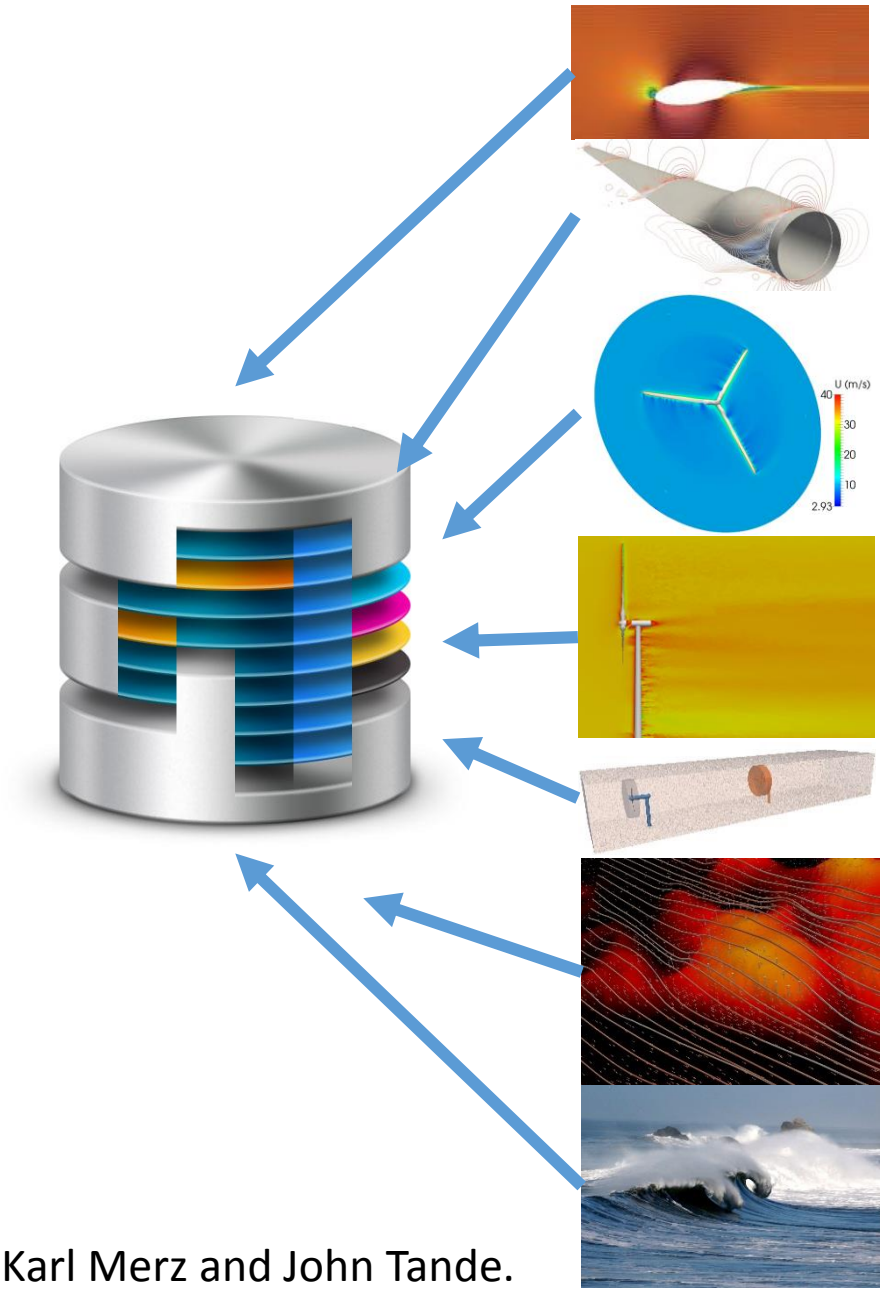
New Operating Condition (stability parameter, wind profiles, wind shear, turbulence)

Statistical reduction

FUTURE WORK - 2017 – 2020 WITH OPWIND (SINTEF Energy)

- ROM MODEL DEVELOPMENT FOR INDUSTRY.
  - GENERATE DATABASE
  - Generate Reduced order model





See Poster by Karl Merz and John Tande.

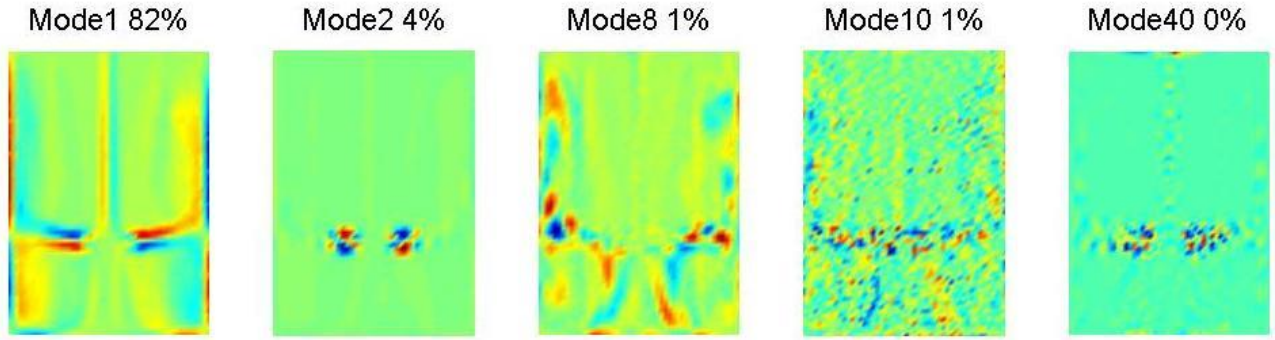
Demonstration of Usability of ROMS

Analysis of dominant flow structures and their flow dynamics in chemical process equipment using snapshot proper orthogonal decomposition technique. M. V. Tabib and J. B. Joshi. Chemical Engineering Science, 63 (14), 2008, 3695-3715.

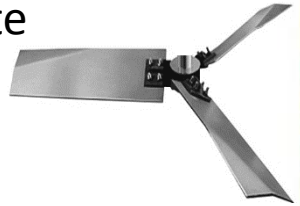
Proper Orthogonal Decomposition

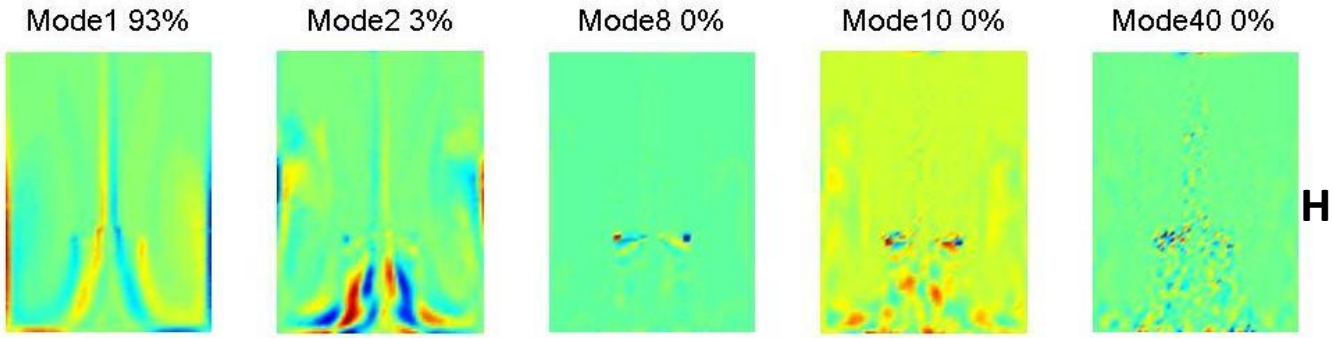
Energy Distribution as a function of modes for different kinds of rotating machinery. It is clear that only first 4-5 modes contribute most of the energy.

μ can be any parameter like pitch, yaw, angle of attack, surface roughnes, scales of turbine

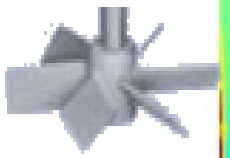


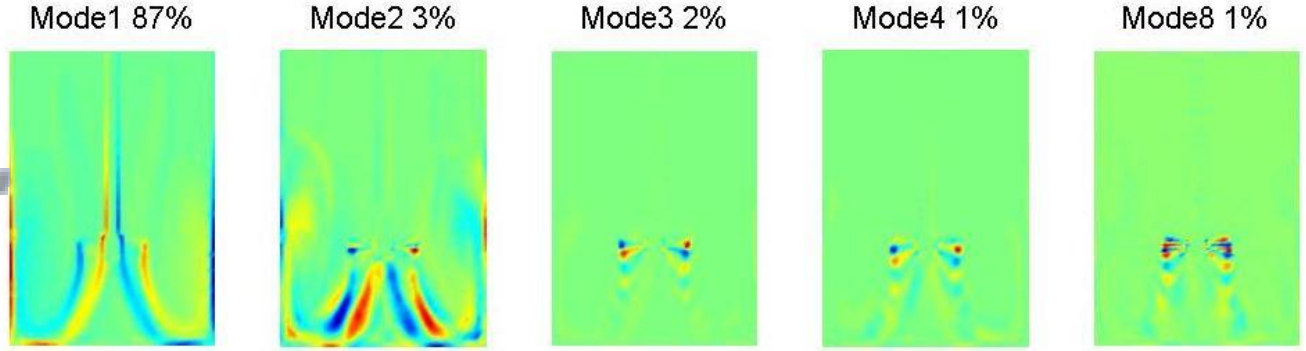
Disc Turbine (Radial Flow)





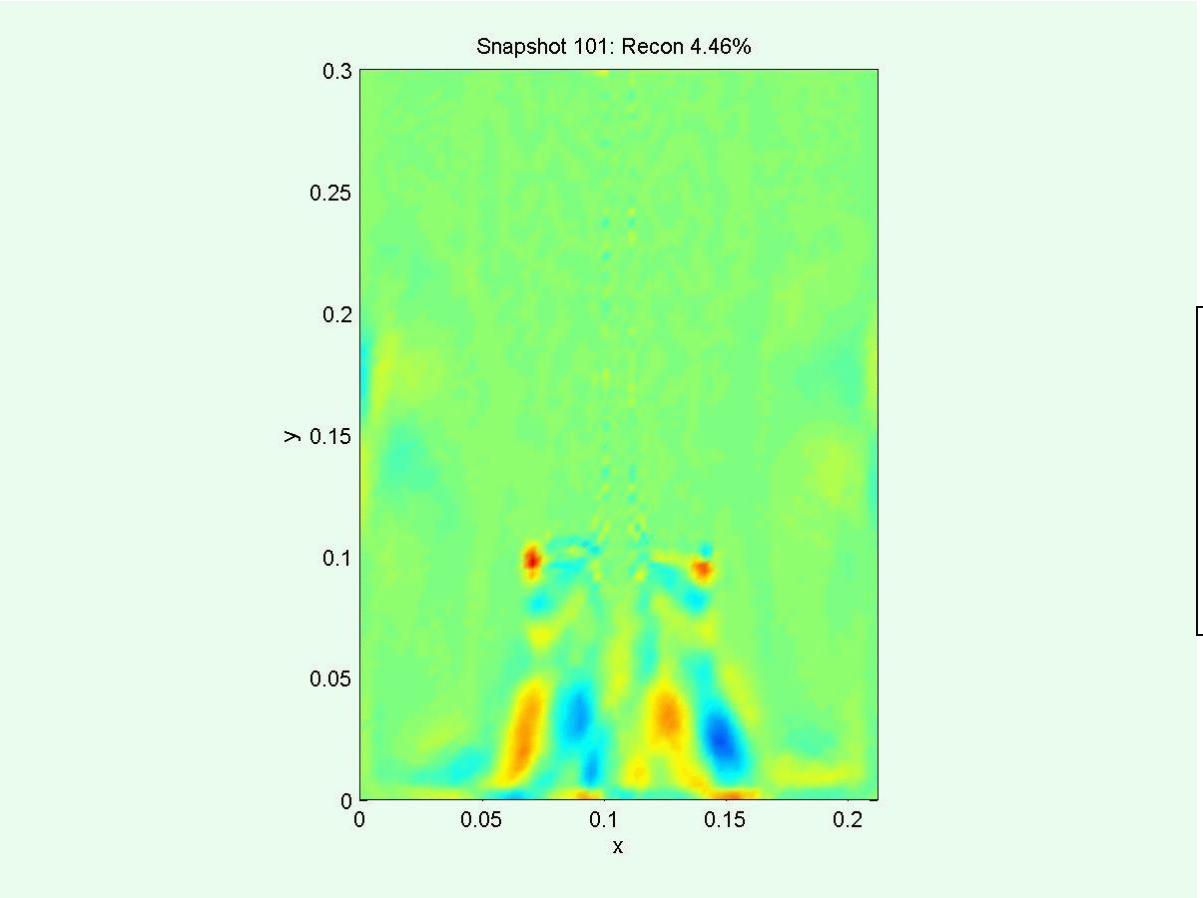
HE3





PBDT

APPLICATION TO RECONSTRUCT WAKE.



Rolling off blade tip vortices is seen

ACKNOWLEDGEMENTS

- Financial support from the Norwegian Research Council and support from the industrial partners of the FSI-WT (http://www.fsi-wt.no) project (Kjeller Vindteknikk, Statoil, Trønder Energi AS and WindSim).

THANK YOU
Queries?

MULTISCALE APPROACHES

MULTDOMAIN

EMBEDDED –

DOWNSCALING AND UPSCALING.

PARALLEL MULTISCALE

SERIAL

SIMPLIFICATION

TRANSFORMATION

ONE WAY COUPLING.