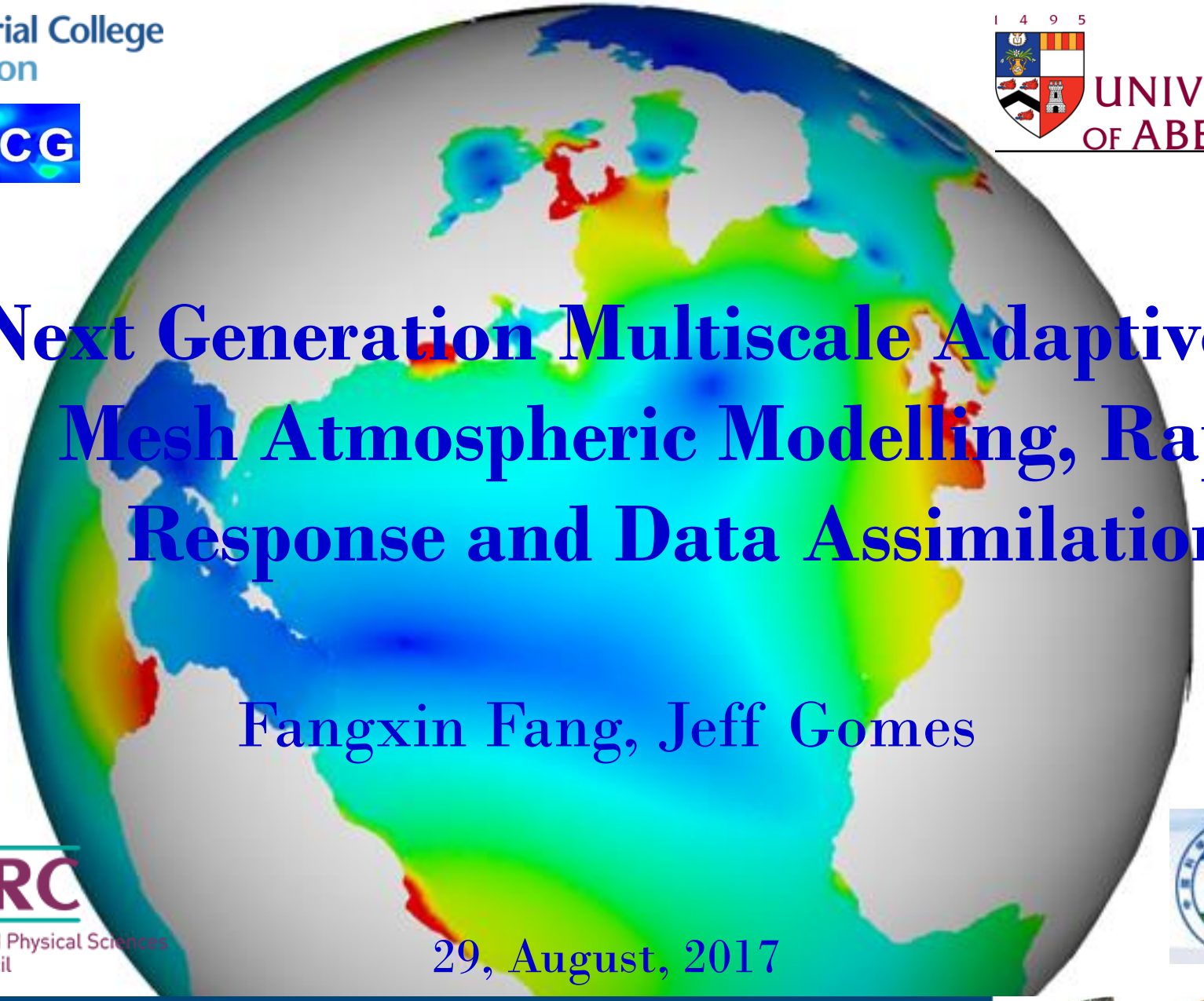
Imperial College London

AMCG

1 4 9 5 UNIVERSITY OF ABERDEEN



Next Generation Multiscale Adaptive Mesh Atmospheric Modelling, Rapid Response and Data Assimilation

Fangxin Fang, Jeff Gomes

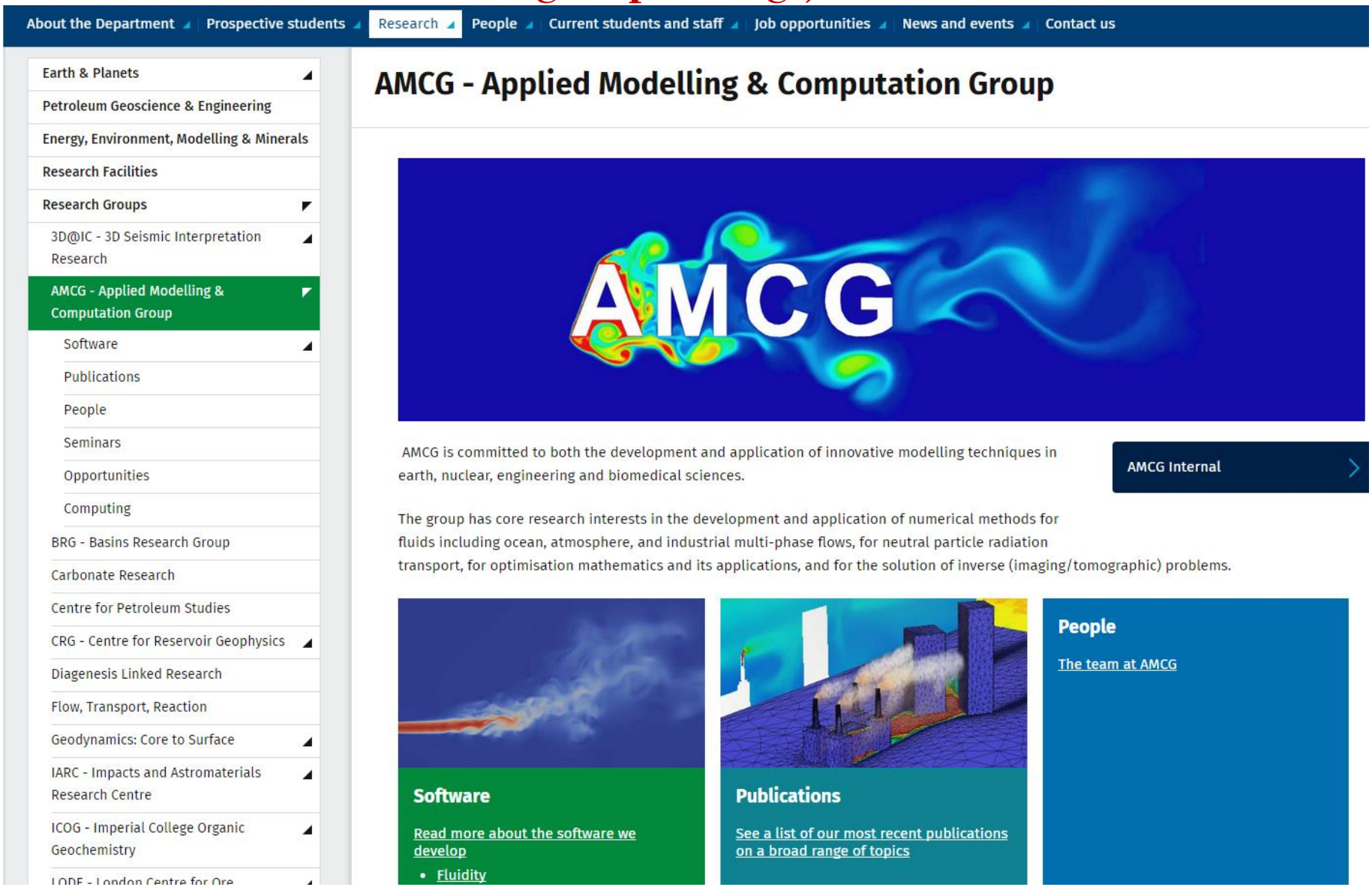
EPSRC Engineering and Physical Sciences Research Council

29, August, 2017

IAP CAS

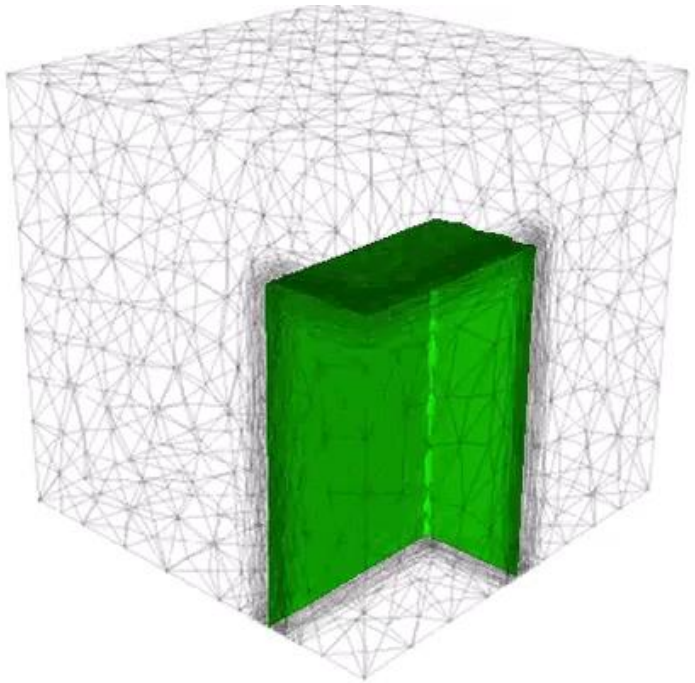
DEPARTMENT OF EARTH SCIENCE AND ENGINEERING

AMCG website (http://www.imperial.ac.uk/earth-science/research/research-groups/amcg/)

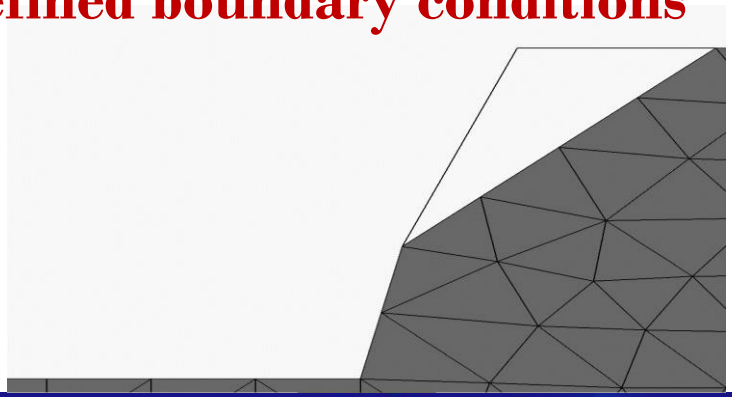


Fluidity

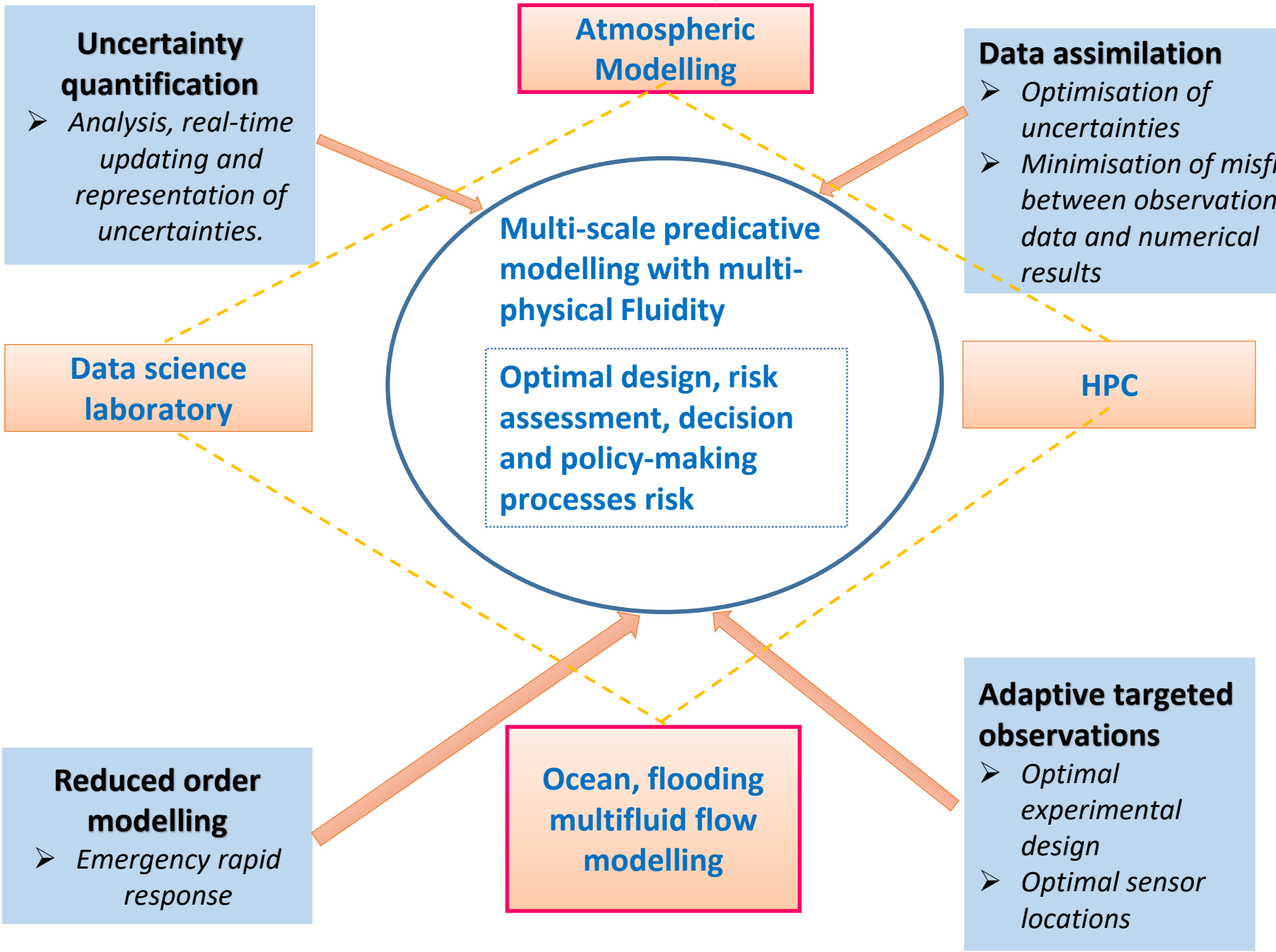
- Open Source Model Software for Multiphysics Problems
- Unstructured FEM Meshes
- Anisotropic Adaptive Mesh technology



- User-friendly GUI
- Python interface to calculate diagnostic fields, to set prescribed fields and user-defined boundary conditions

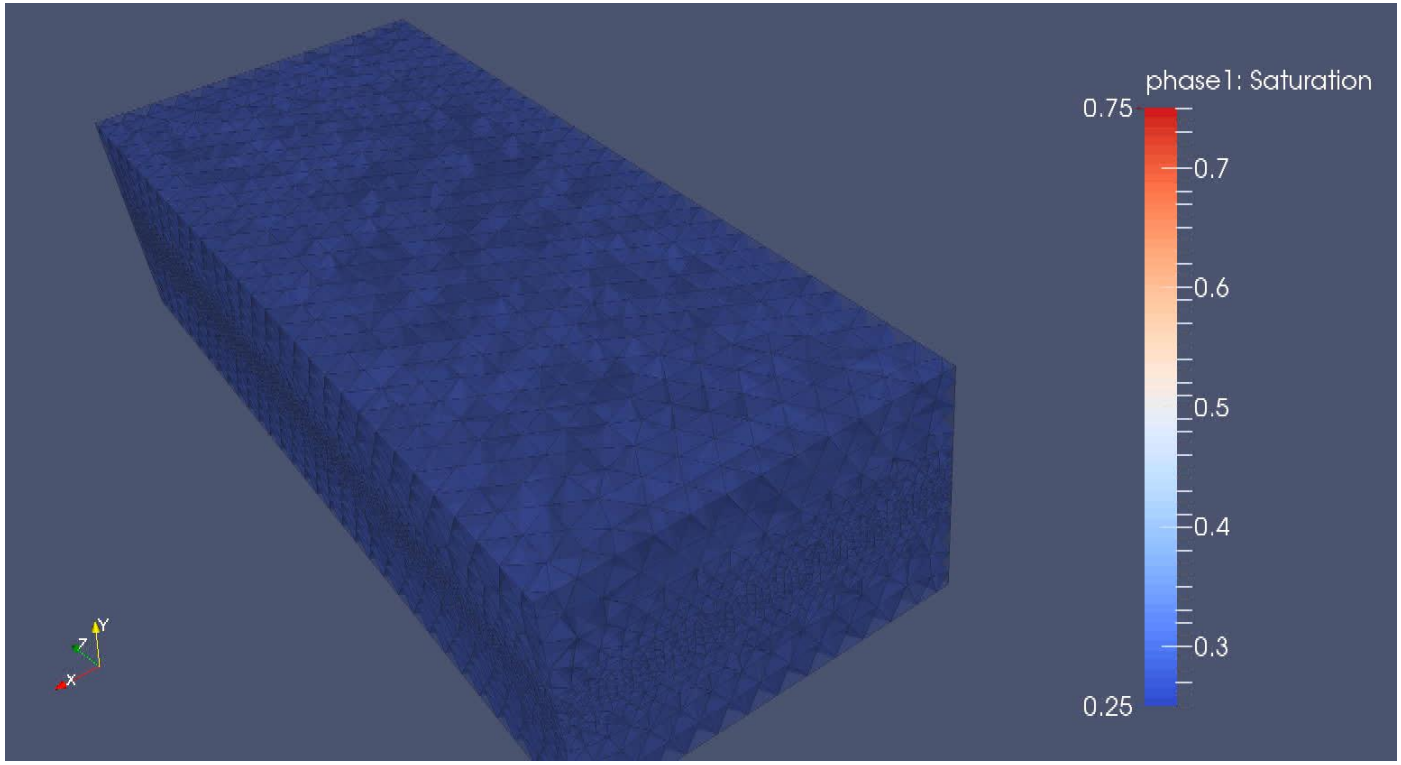


Predictive and Uncertainty Model Framework



Computational Multi-Fluid Flow Dynamic Model

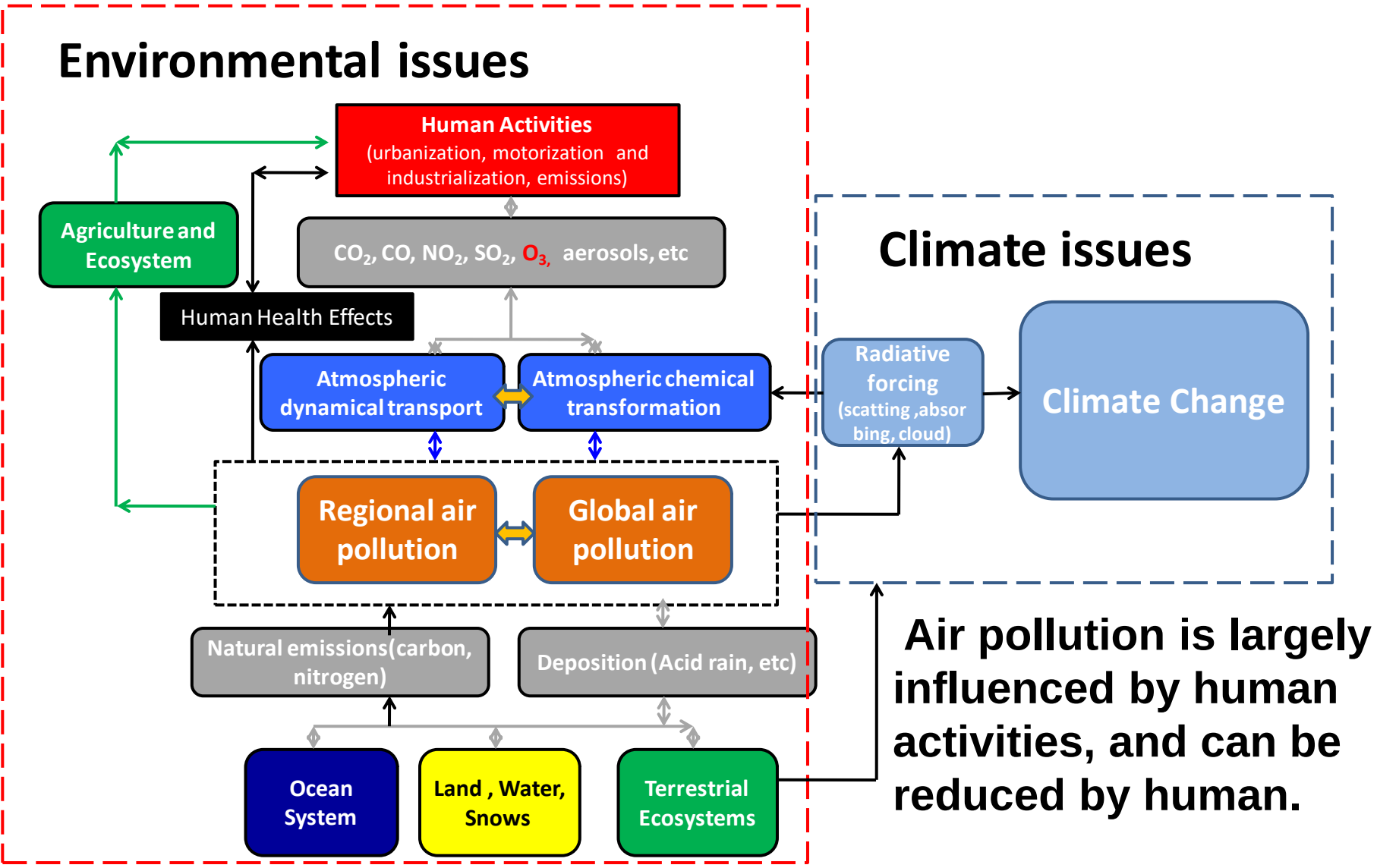
- Porous media model embedded in Fluidity are based on:
  - new family of FE element-pairs (P_nDG-P_m and P_nDG-P_mDG) and
  - numerical formulation (overlapping CVFEM) that ensures high-order accuracy on the solution fields (i.e., pressure, velocity, saturation, temperature etc)
- The model has been used on transport of contaminant in subsurface media (mining spillage), oil and gas production, nuclear waste repository etc;



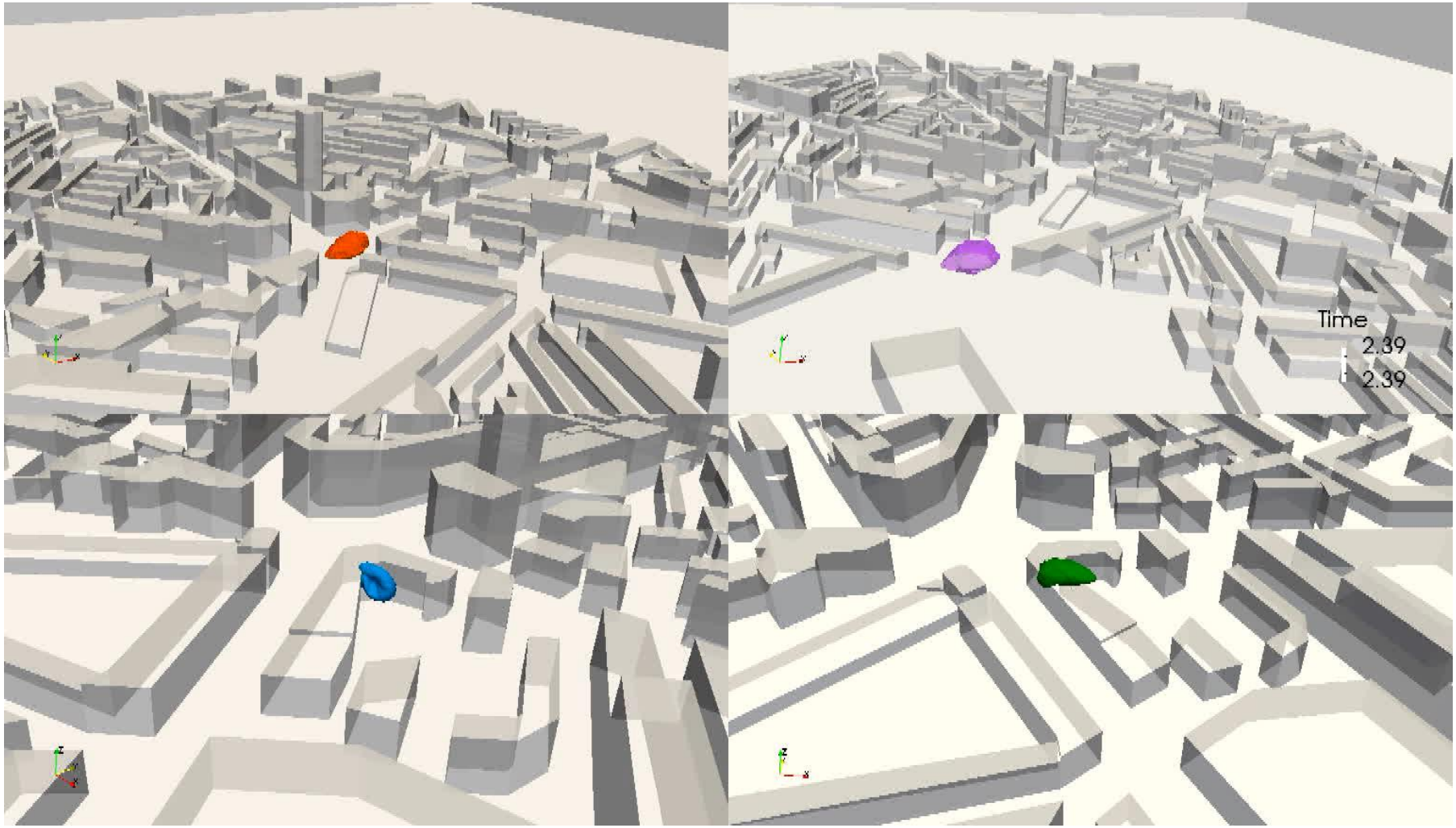
Atmospheric Environmental Model: Critical bridge between human activities and environmental change (IAP)

Beijing, Olympic site

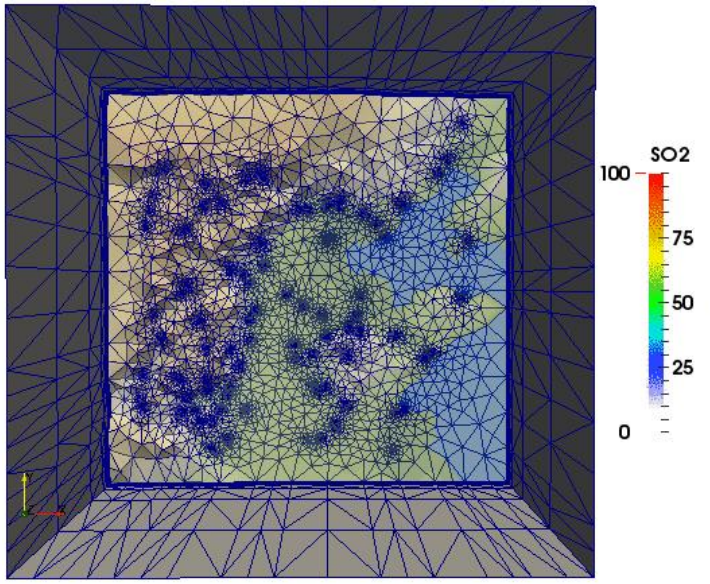
Atmospheric Environmental Model: Critical bridge between human activities and environmental change (IAP)



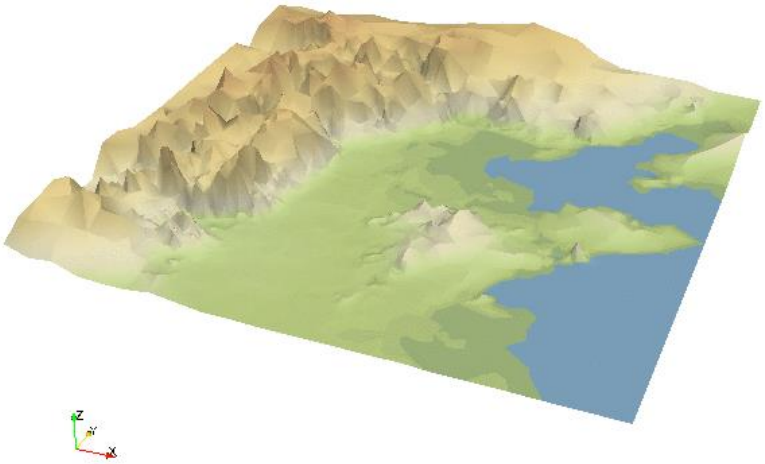
Urban Air Pollution Modelling
(MAGIC, supported by EPSRC) @Elephant Castle, London



Air Pollutant Modelling
(IAP-ICL, supported by NSFC/ EPSRC)

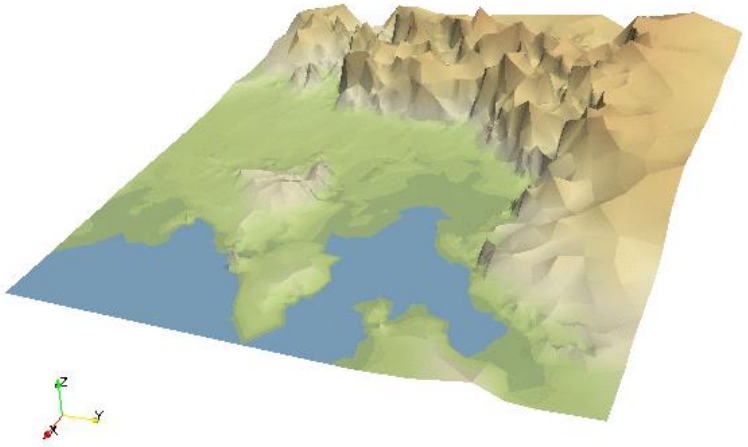


View1: SE-NW

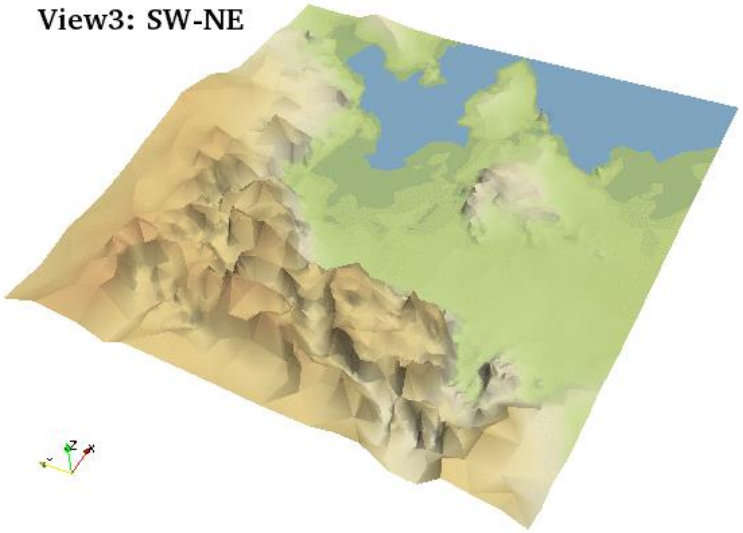


SO_2 released from over 100 power plants (over Beijing and 55 cities)

View2: NE-SW

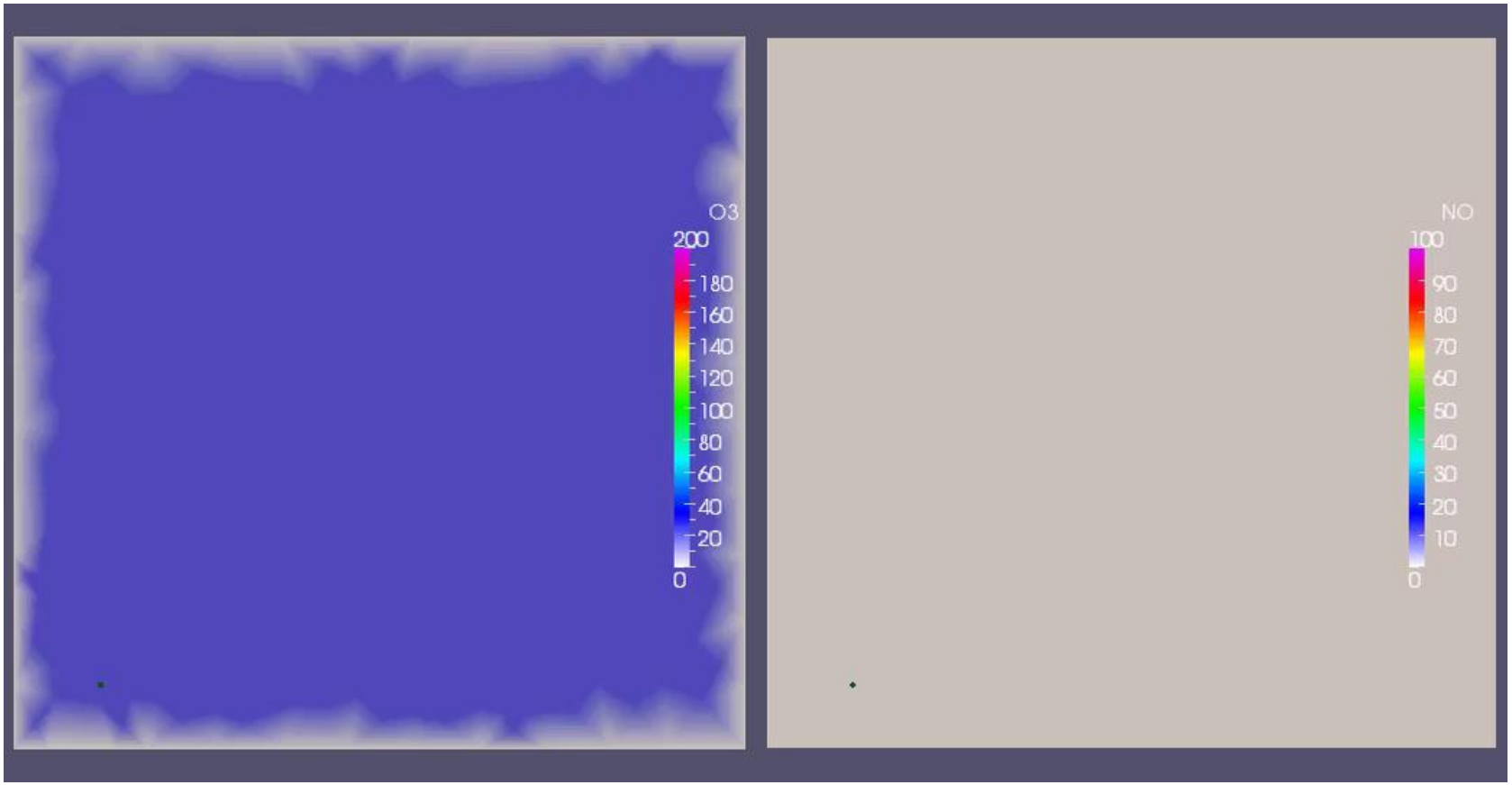


View3: SW-NE



Chemical modelling (IAP-ICL, Zheng etc.)

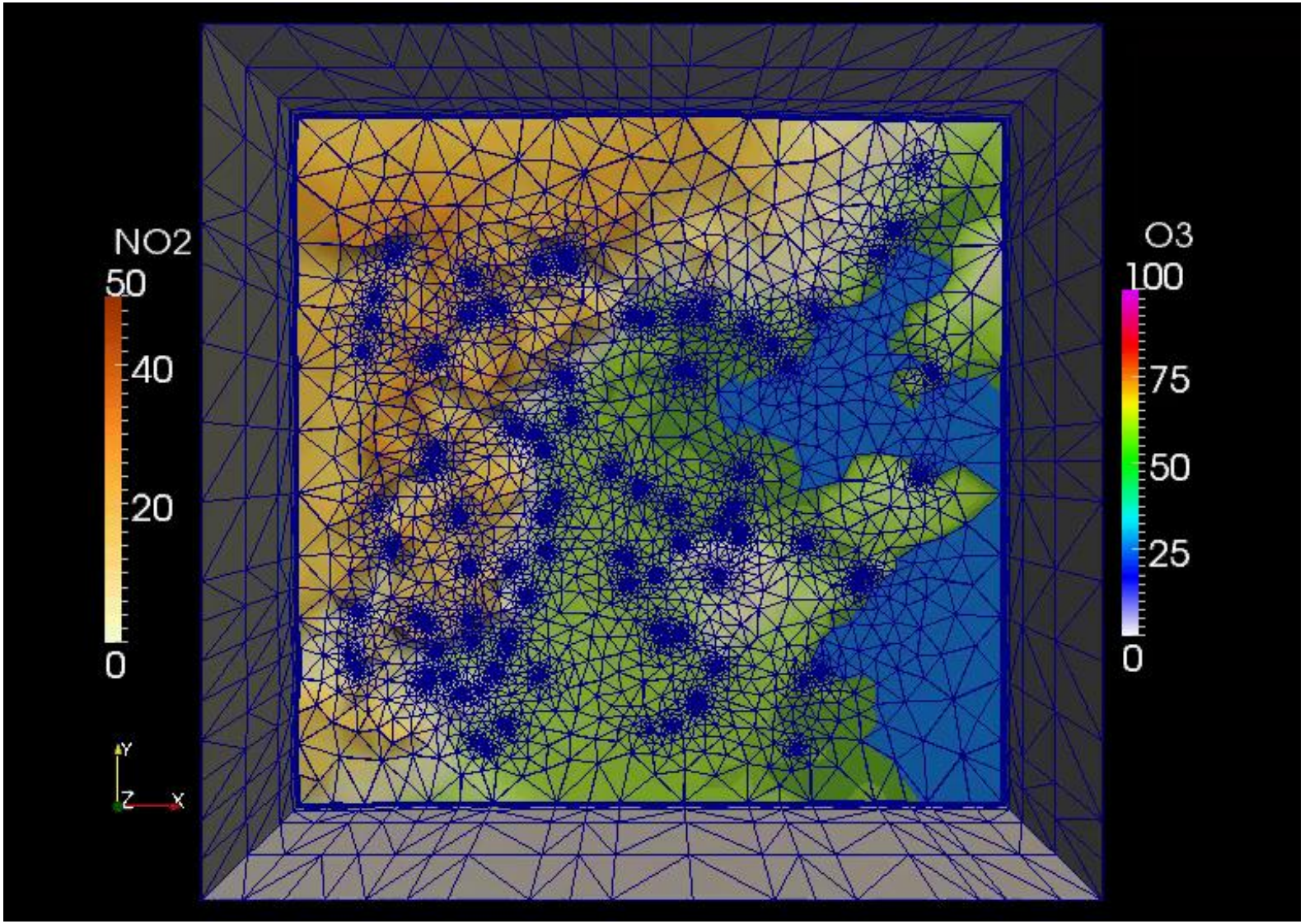
(NO and NO2 released from over 100 power plants)



Continuous formation/consumption of NOx and Ozone over 5 days.

3D chemical modelling (IAP-ICL, Zheng etc.)

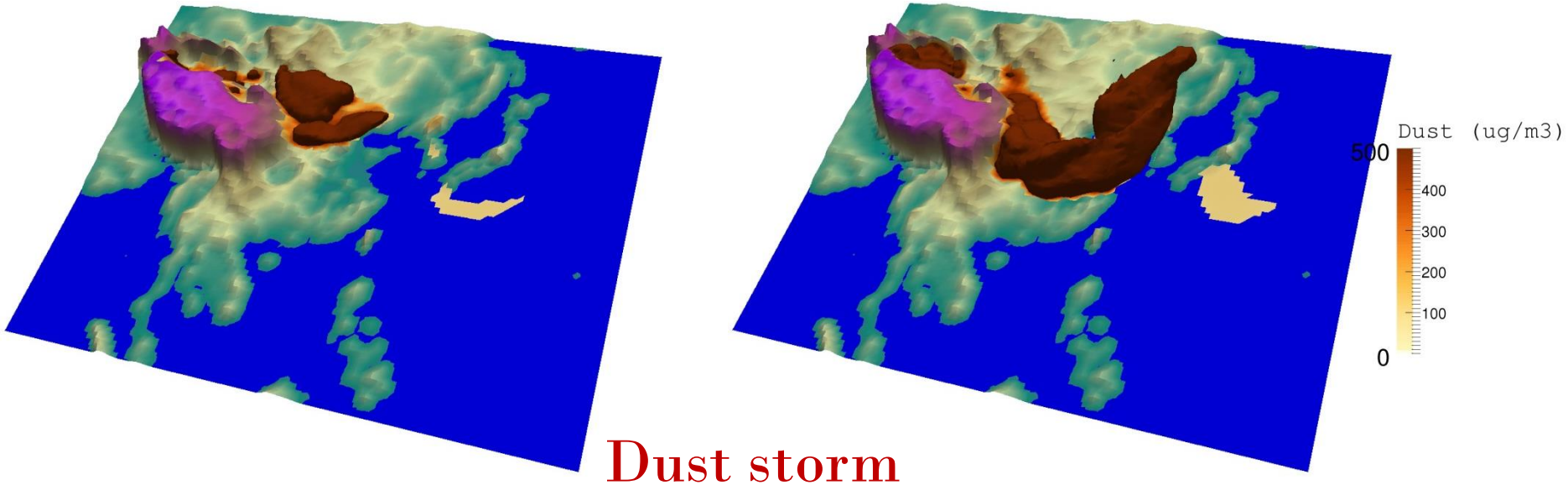
(NO and NO2 released from over 100 power plants)



1 day

2010-03-19_04

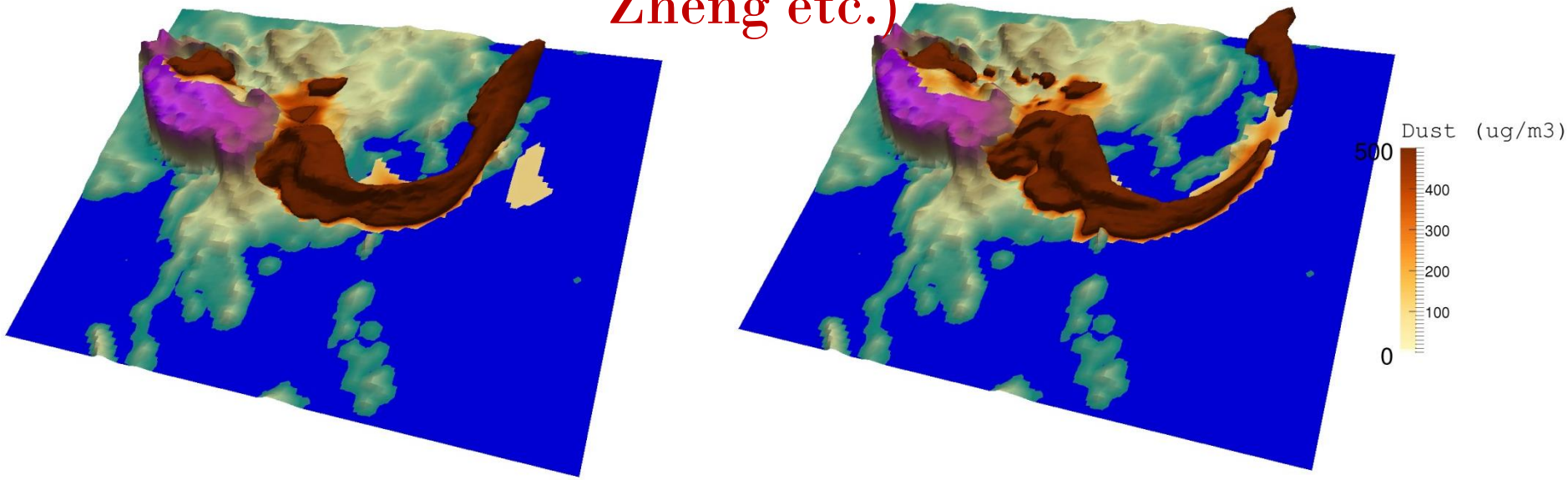
2010-03-20_04

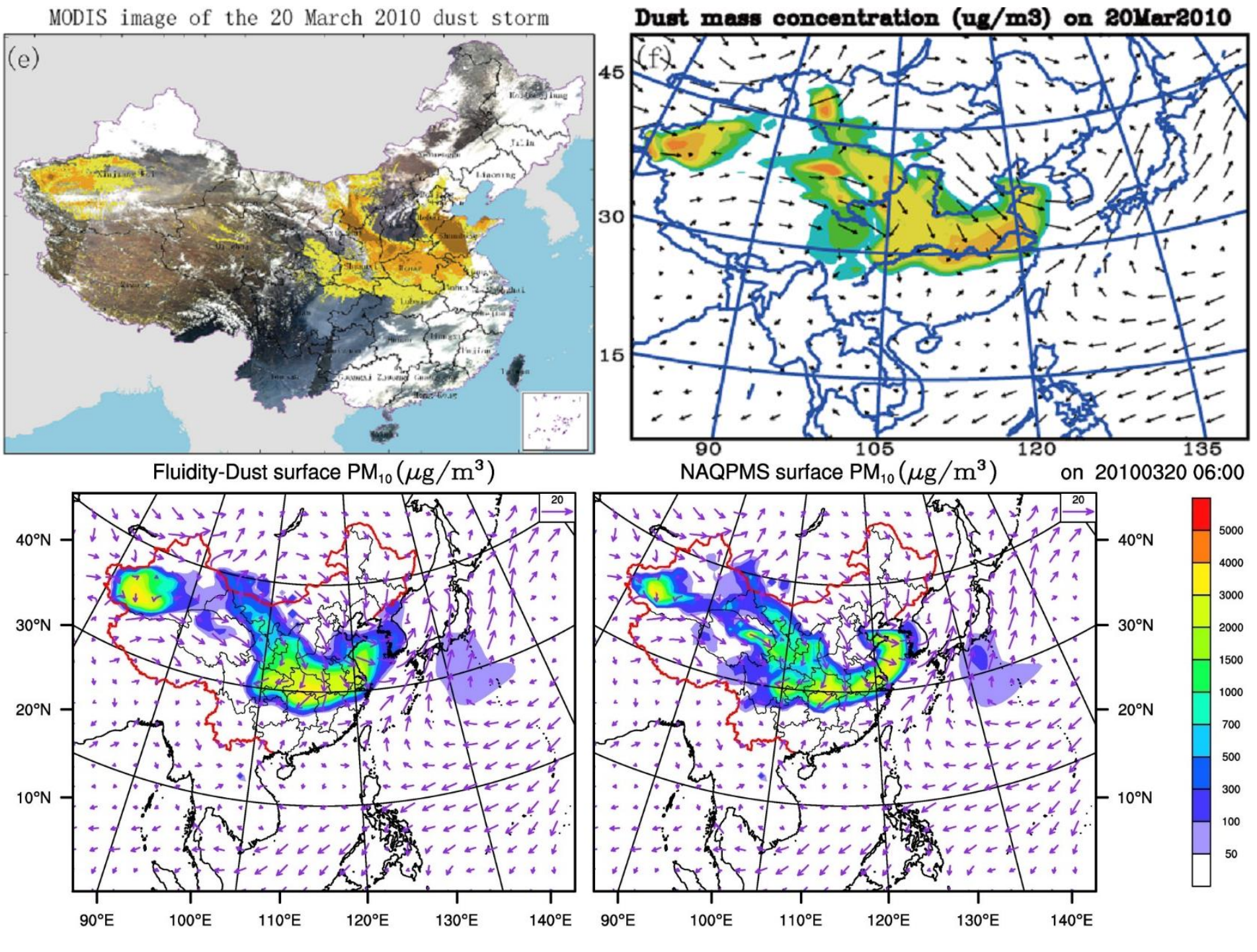


Dust storm (IAP-ICL, Zheng etc.)

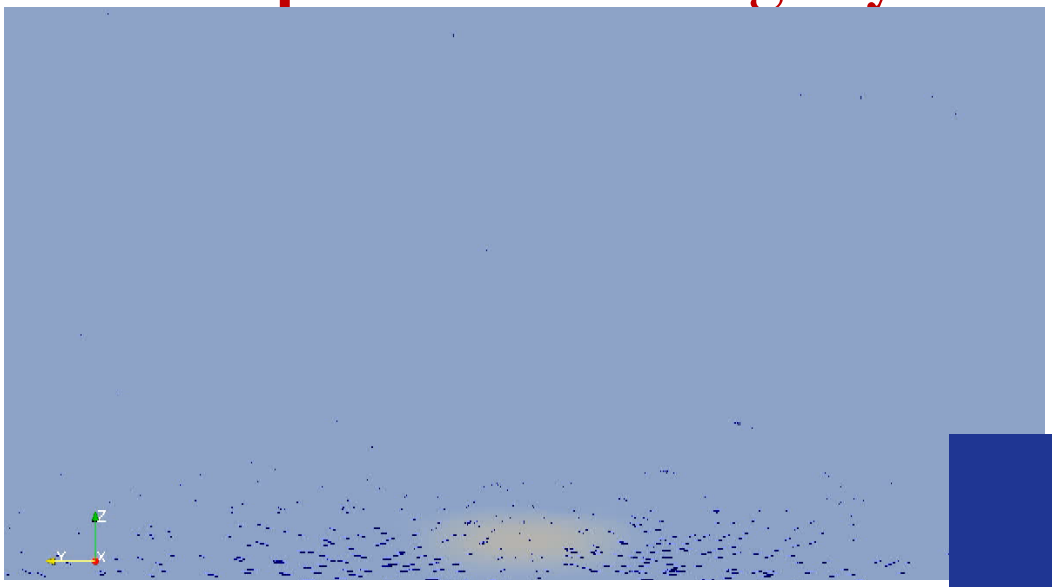
2010-03-20_18

2010-03-21_04

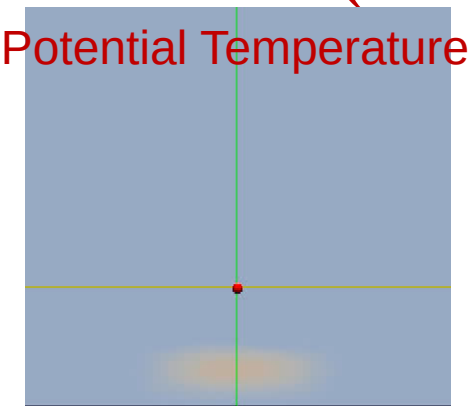



MODIS image of the 20 March 2010 dust storm
(e)
Dust mass concentration (ug/m3) on 20Mar2010
(f)
45
30
15
90
105
120
135
Fluidity-Dust surface PM10 (μg/m3)
NAQPMS surface PM10 (μg/m3)
on 20100320 06:00
20
40°N
30°N
20°N
10°N
90°E
100°E
110°E
120°E
130°E
140°E
5000
4000
3000
2000
1500
1000
700
500
300
100
50

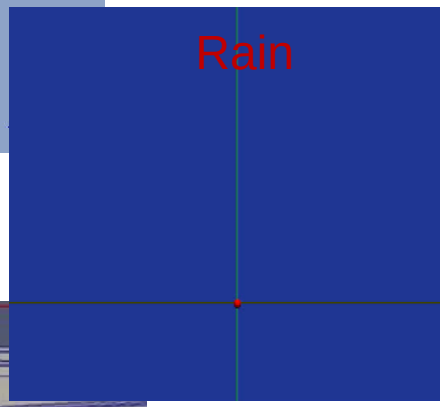
3D Atmospheric Modelling: Cyclone 3D Simulation (IAP-ICL)



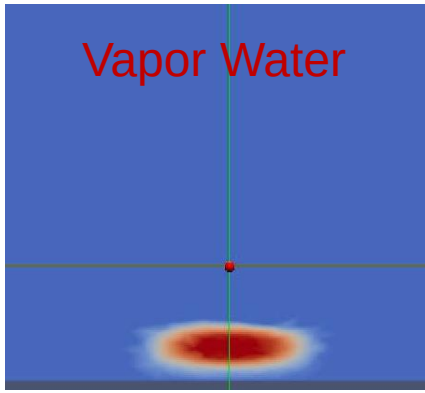
Velocity Vector



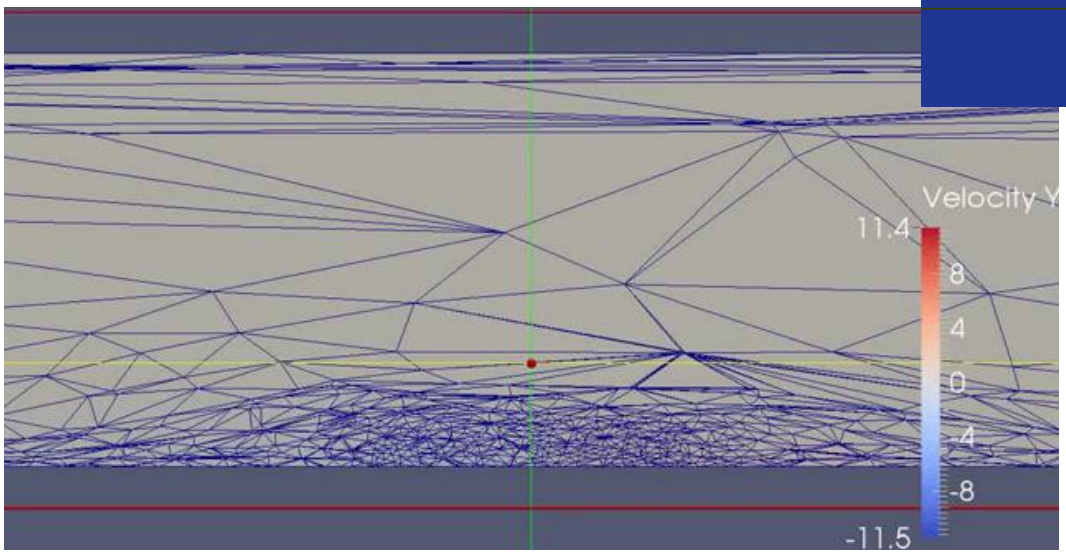
Potential Temperature



Rain



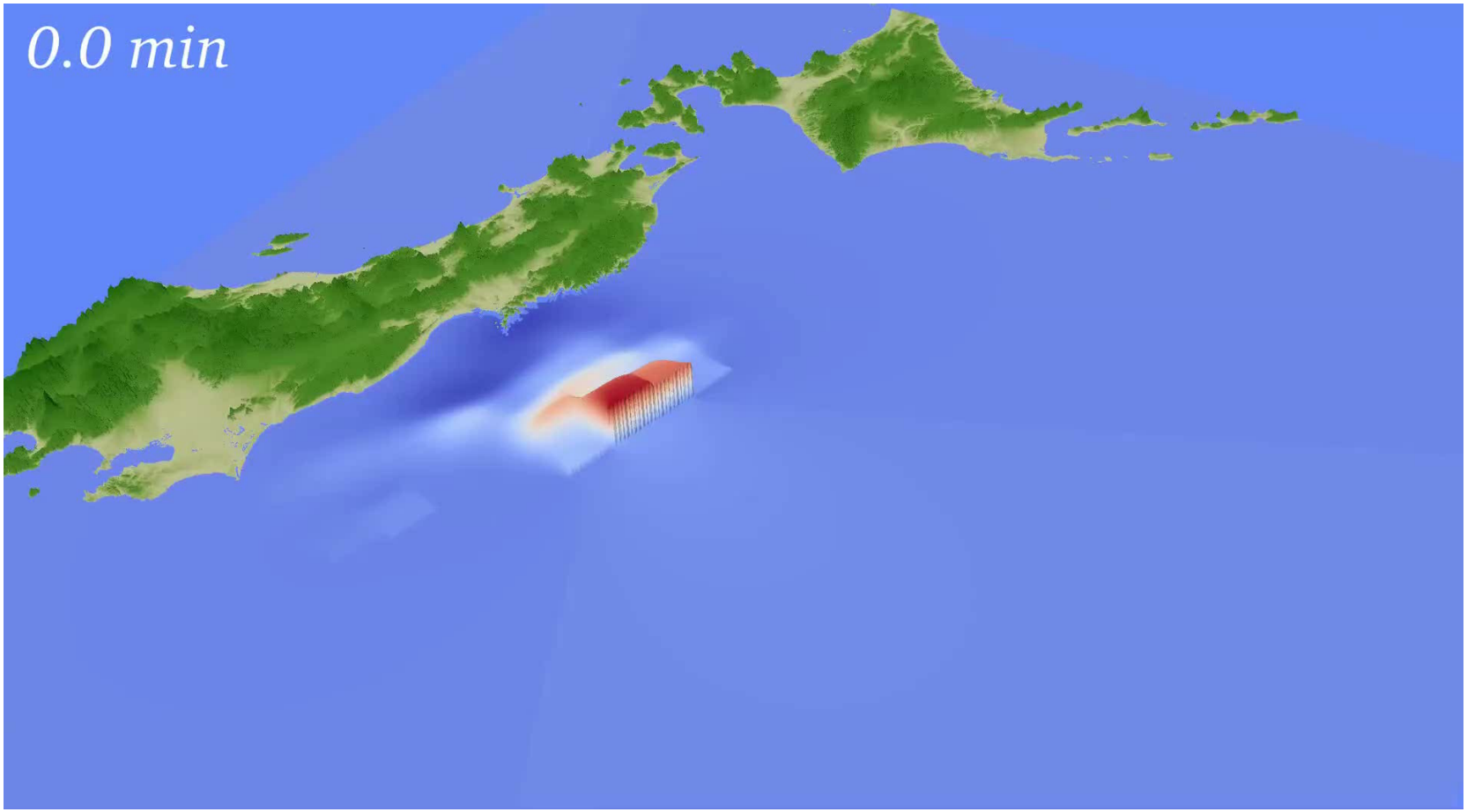
Vapor Water



Adaptive mesh

Cloud

Tohoku event from 2011
(Visiting PhD student from Japan)



Natural Disaster: Simulating Flooding – Denmark (R. Hu etc. supported by the EU PEARL project)

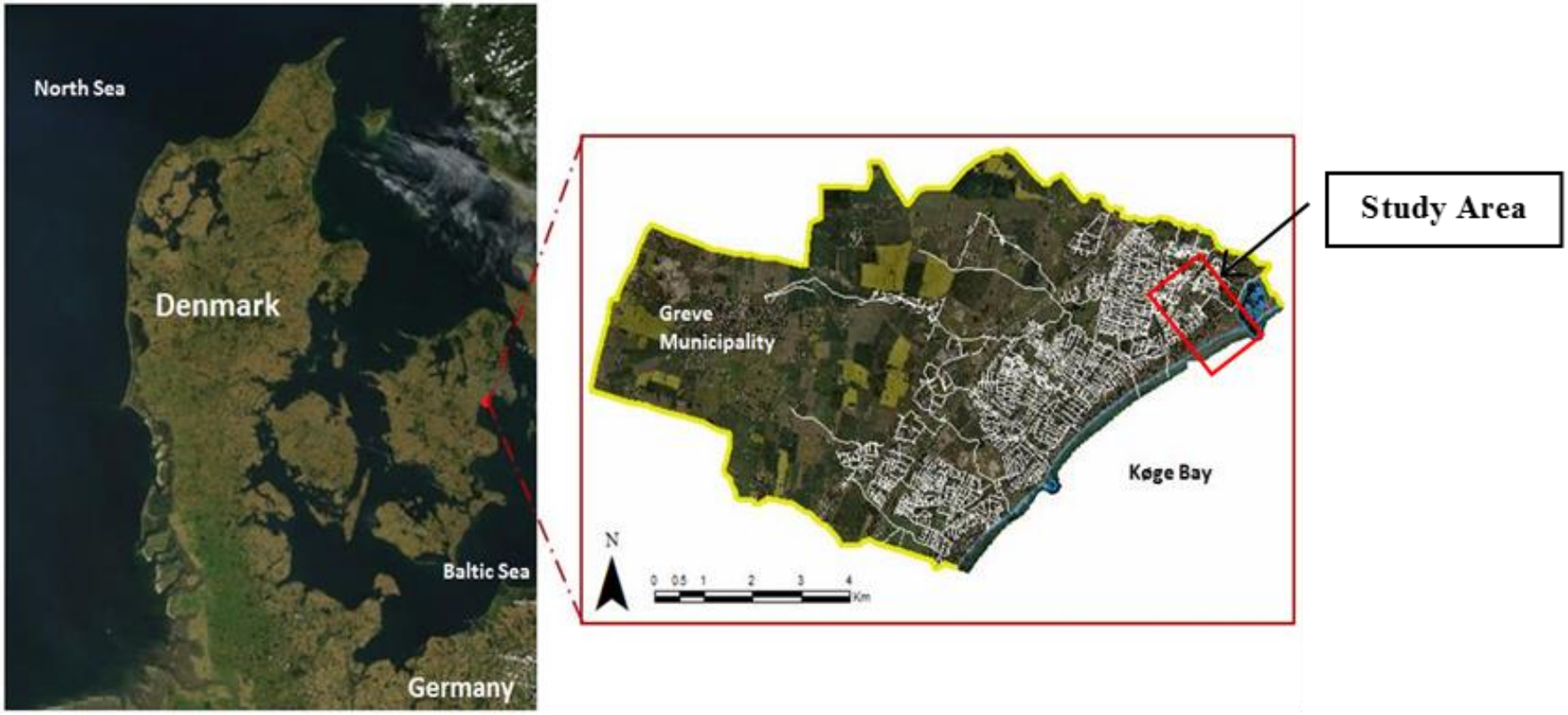
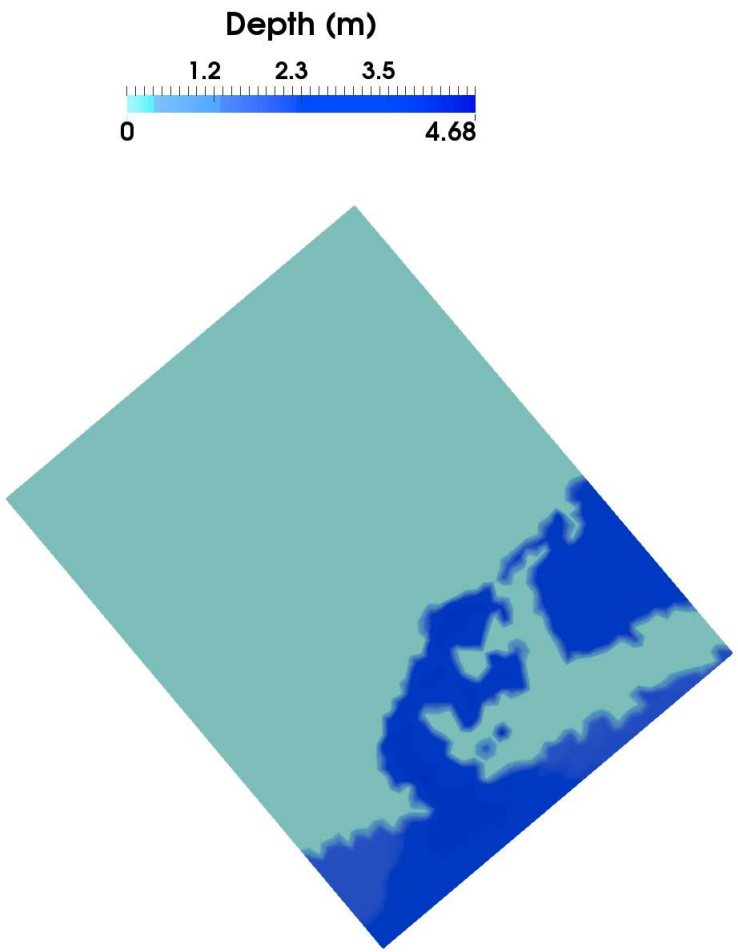
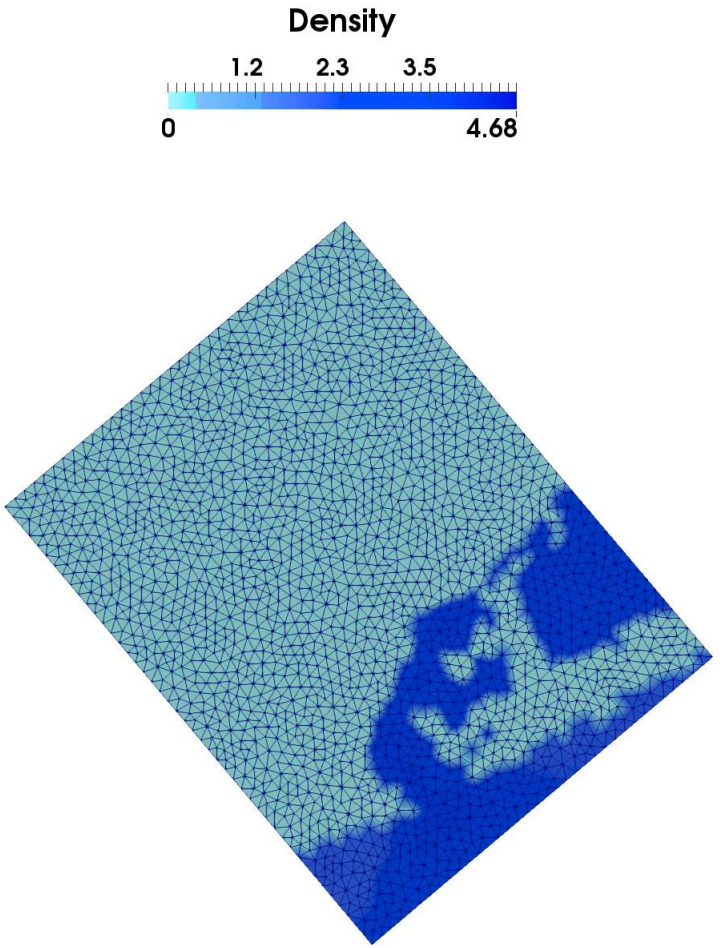


Fig. 11. Situation of Study Area in Greve, Municipality of Denmark, see Soledad (2014)

Natural Disaster: Simulating Flooding – Denmark (R. Hu etc. supported by the EU PEARL project)

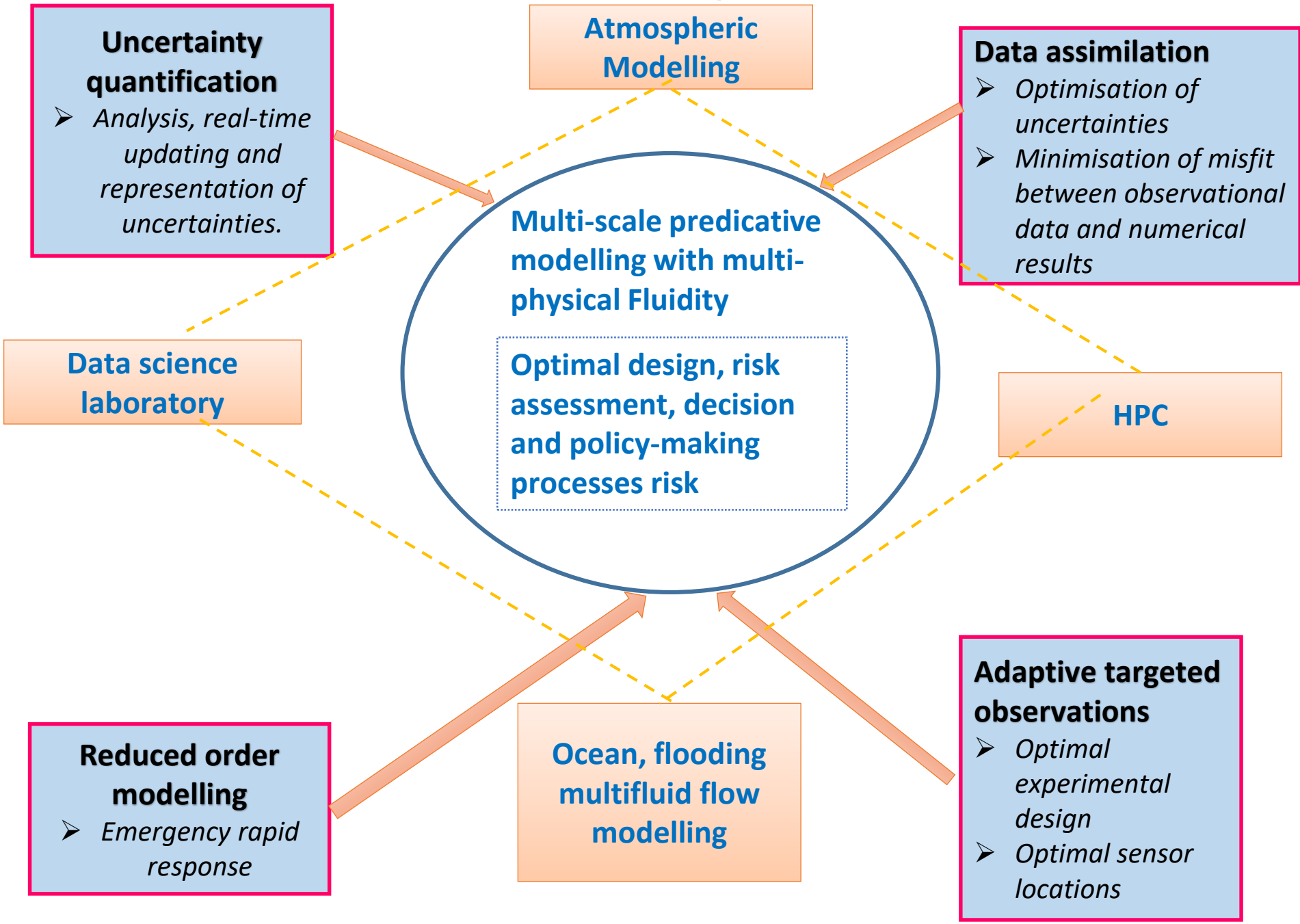


Surface



Surface with mesh

Predictive and Uncertainty Model Framework



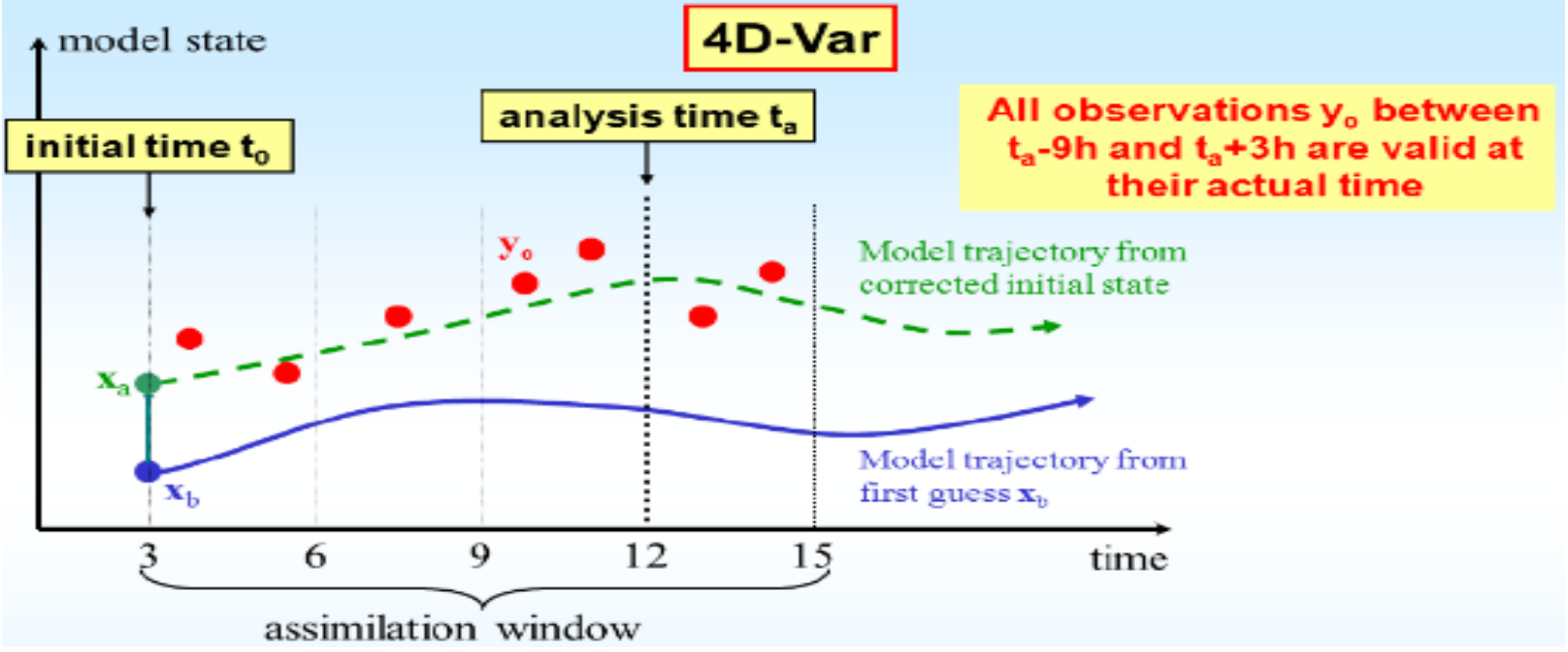
Data Assimilation (DA)

DA methods:

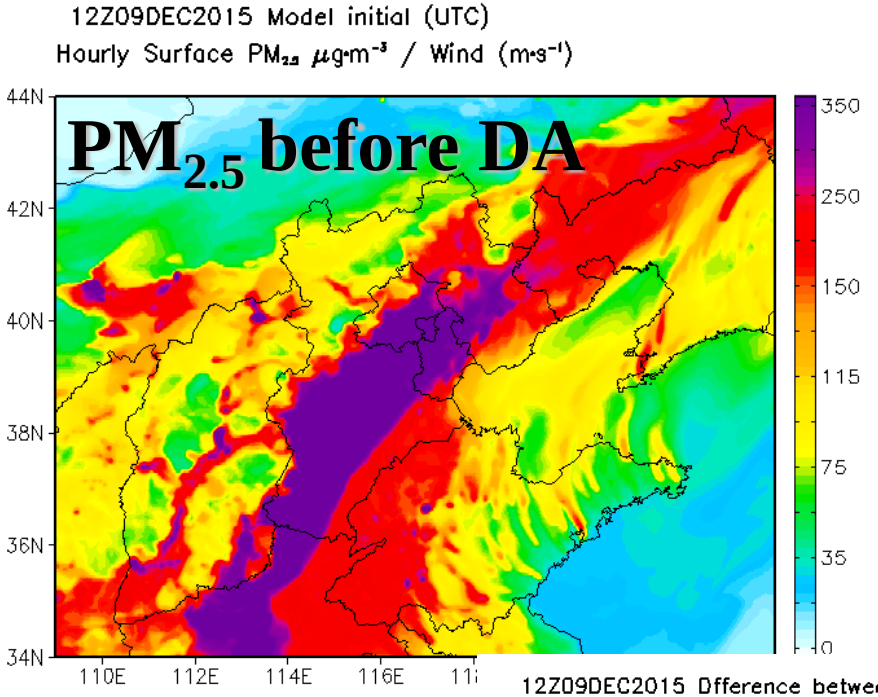
- Optimal interpolation;
- Nudging;
- 3D-Var;
- 4D-Var (Adjoint);
- Ensemble KF

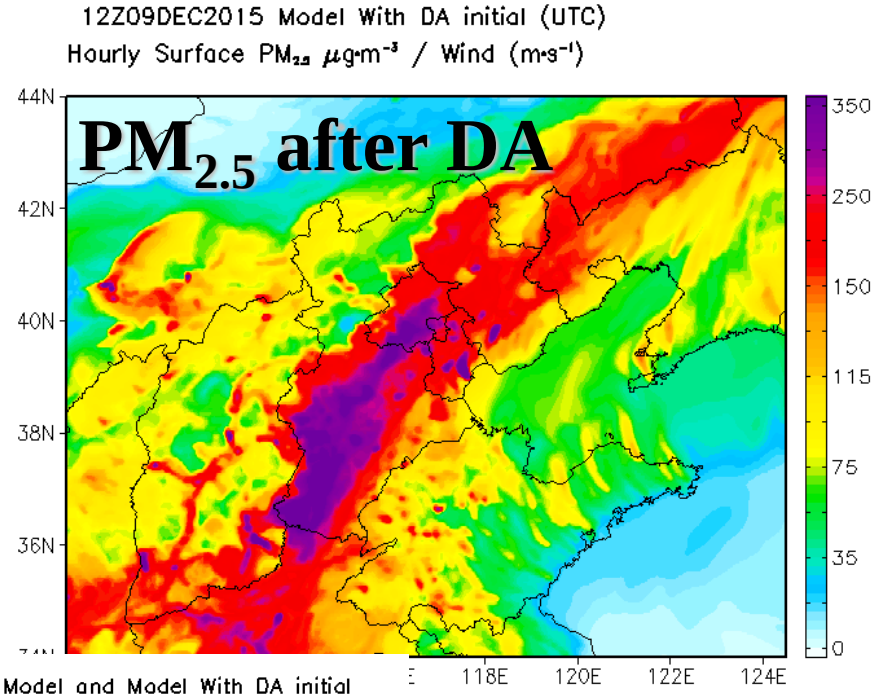
Motivation for DA:

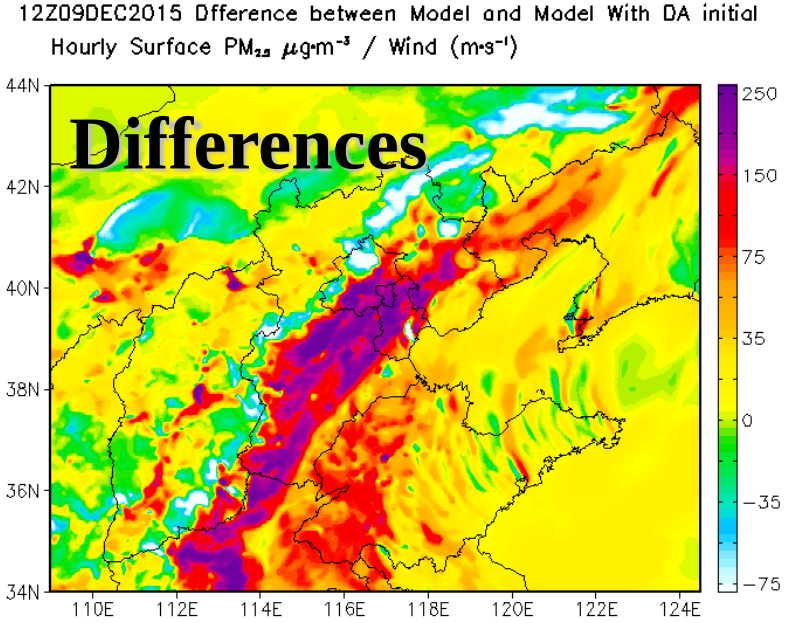
- To improve the predictability of numerical models;
- Uncertainty sensitivity analysis;
- Optimisation of uncertainties in models;
- Goal-based error measure and mesh adaptivity;
- Design optimisation;
- Adaptive observation (Optimisation of sensors locations).



Work from Institute of Atmospheric and Physics, China

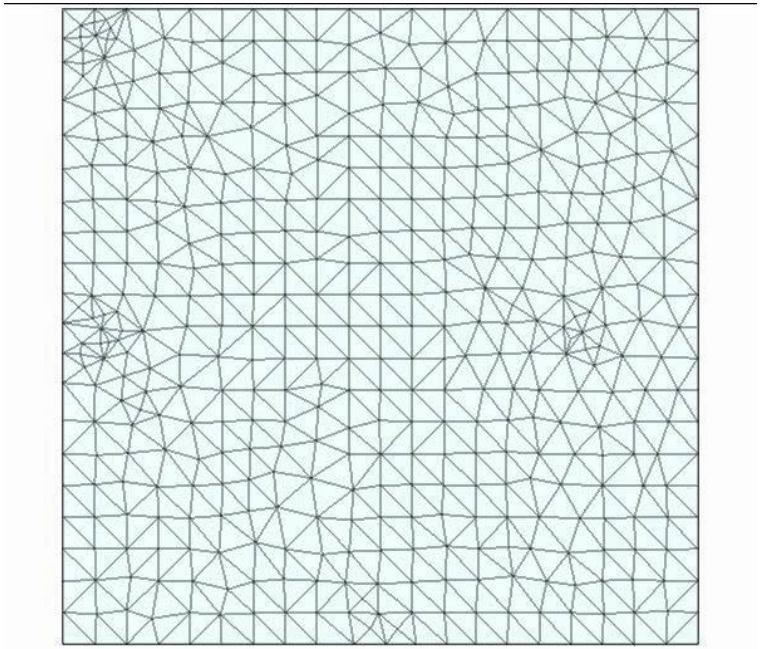


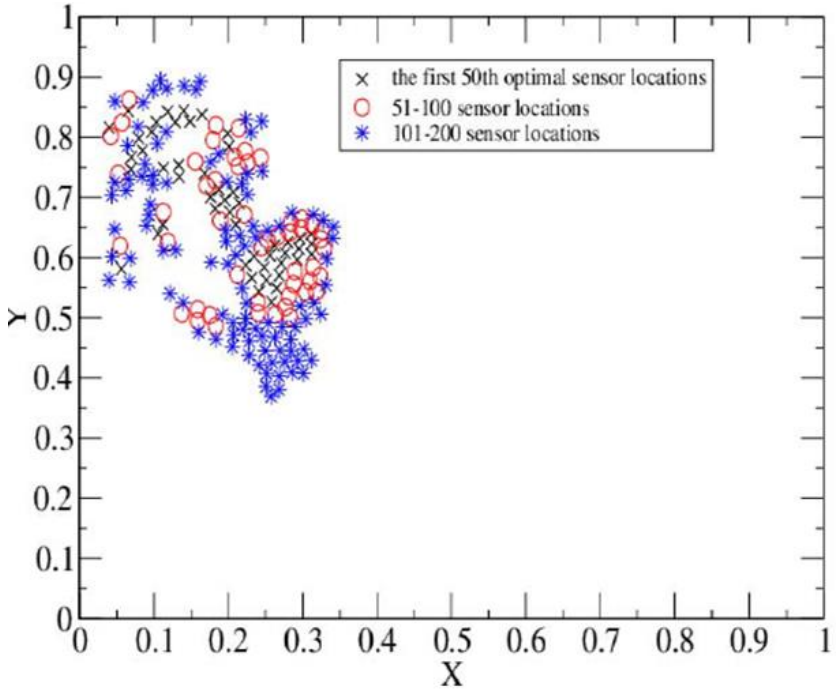


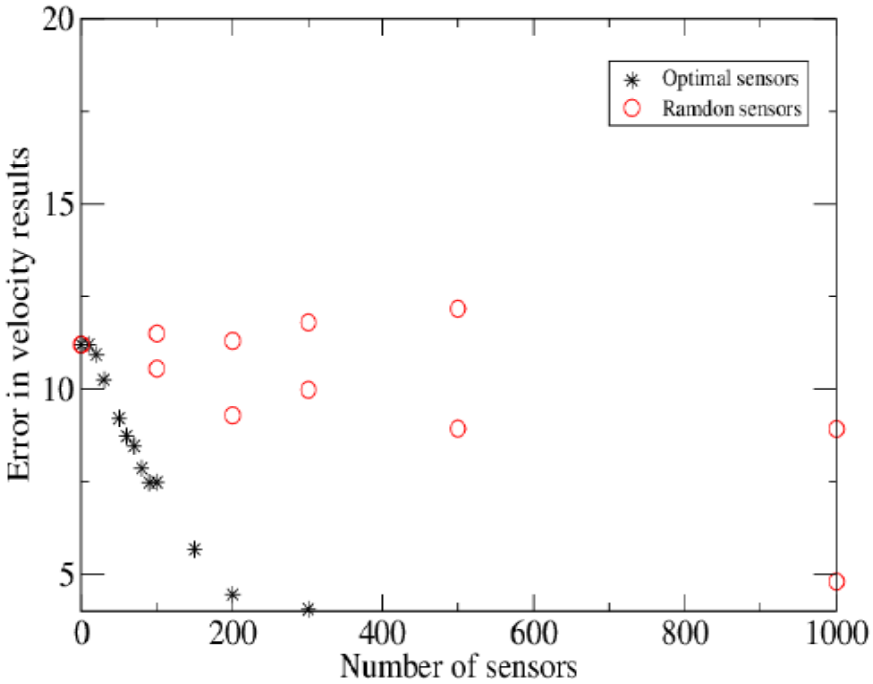


Sources: CNEMC IAP

DA: Optimal sensor location







Reduced Order Modelling

Navier-Stokes Equations:

$$\rho_0\left(\frac{\partial \vec{u}}{\partial t}+\vec{u}\cdot\nabla\vec{u}\right)-\nabla\cdot\mu\nabla\vec{u}+\nabla\bar{p}=-(\rho'+\rho_0)g\vec{n}_g, \quad (1)$$

$$\nabla\cdot\vec{u}=0, \quad (2)$$

Discretising equations (1) and (2)

Full discretised system (high dimensional):

$$\begin{bmatrix} B & C \\ C^T & 0 \end{bmatrix}\begin{bmatrix} \mathbf{u}^{n+1} \\ p^{n+1} \end{bmatrix}=\begin{bmatrix} B' & 0 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} \mathbf{u}^{n} \\ p^{n} \end{bmatrix}+\begin{bmatrix} s \\ 0 \end{bmatrix}$$

Projecting onto the reduced space using SVD/POD

$$\begin{bmatrix} B^{POD} & C^{POD} \\ (C^{POD})^T & 0 \end{bmatrix}\begin{bmatrix} \alpha^{u,n+1} \\ \alpha^{p,n+1} \end{bmatrix}=\begin{bmatrix} B'^{POD} & 0 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} \alpha^{u,n} \\ \alpha^{p,t} \end{bmatrix}+\begin{bmatrix} s^{POD} \\ 0 \end{bmatrix}$$

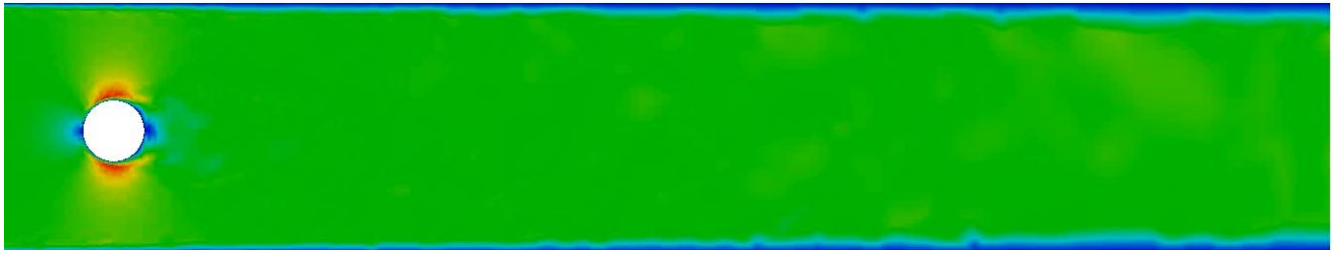
Wring the reduced order model in a general form

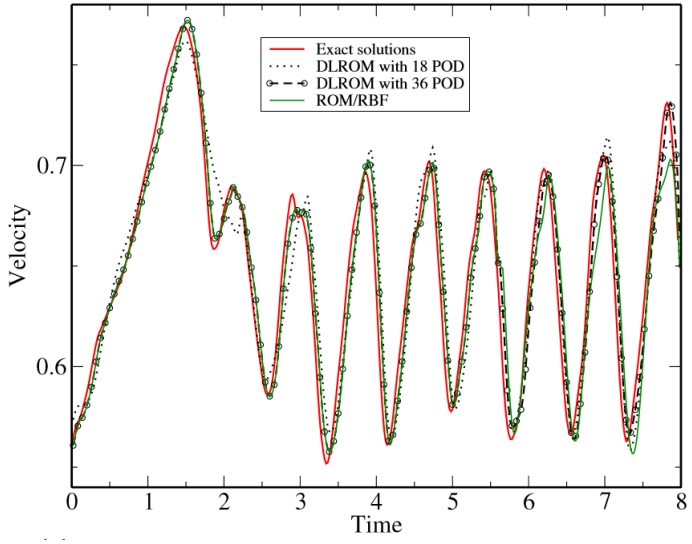
$$\alpha_i^n=f_i(\boldsymbol{\alpha}^{n-1}),\quad n\in\{1,2,\ldots,N_t\},$$

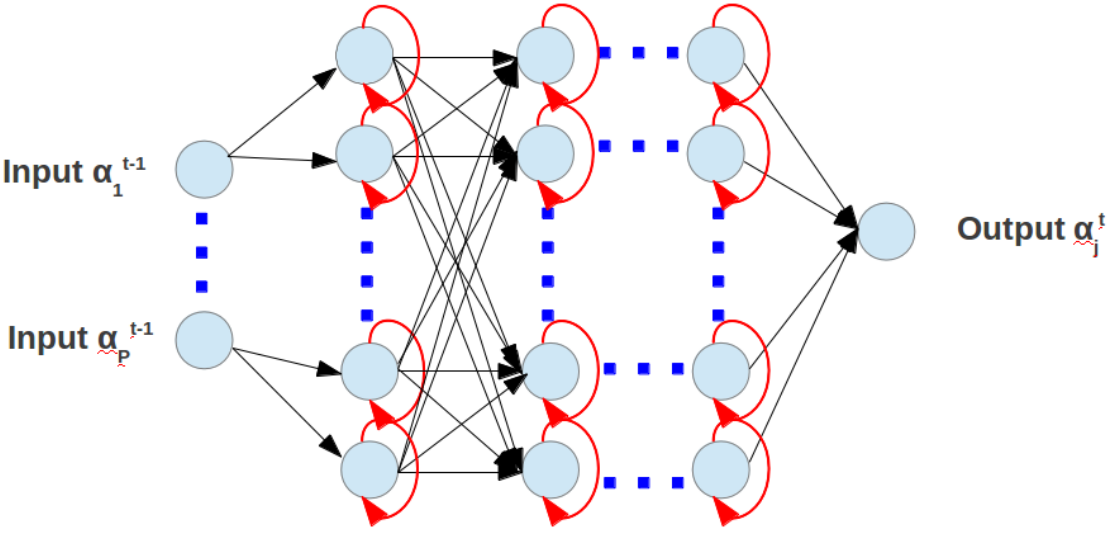
The function f is represented by deep learning

Reduced Order Modelling (POD) and Deep Learning (Xiao etc)

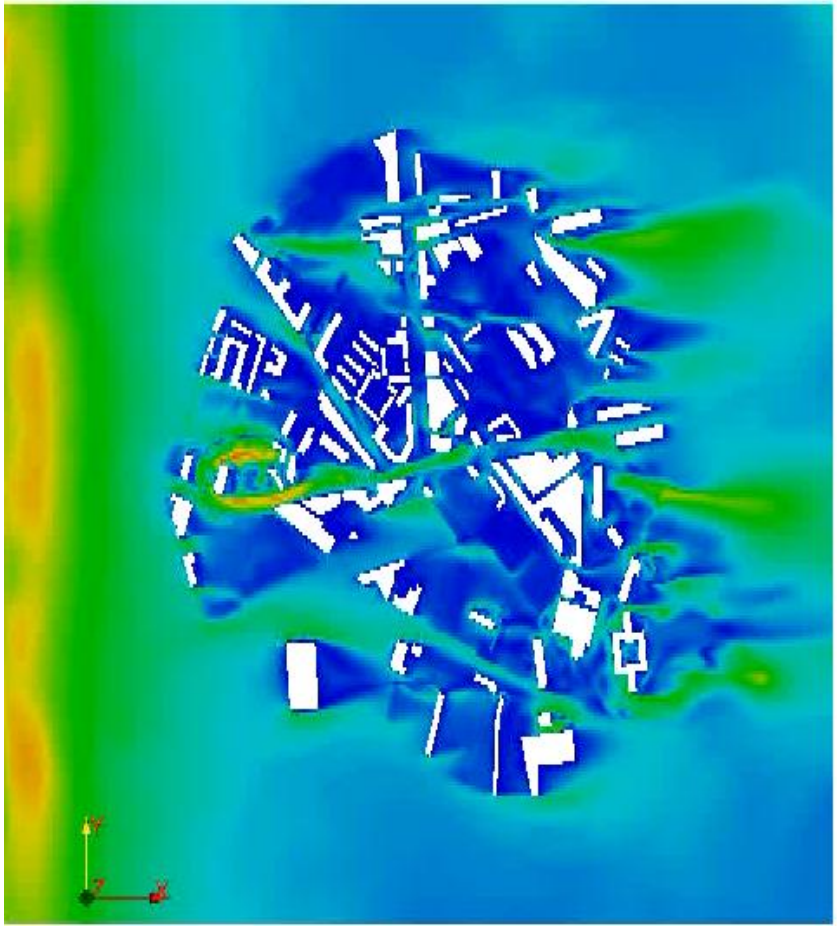
Top panel: Full modelling

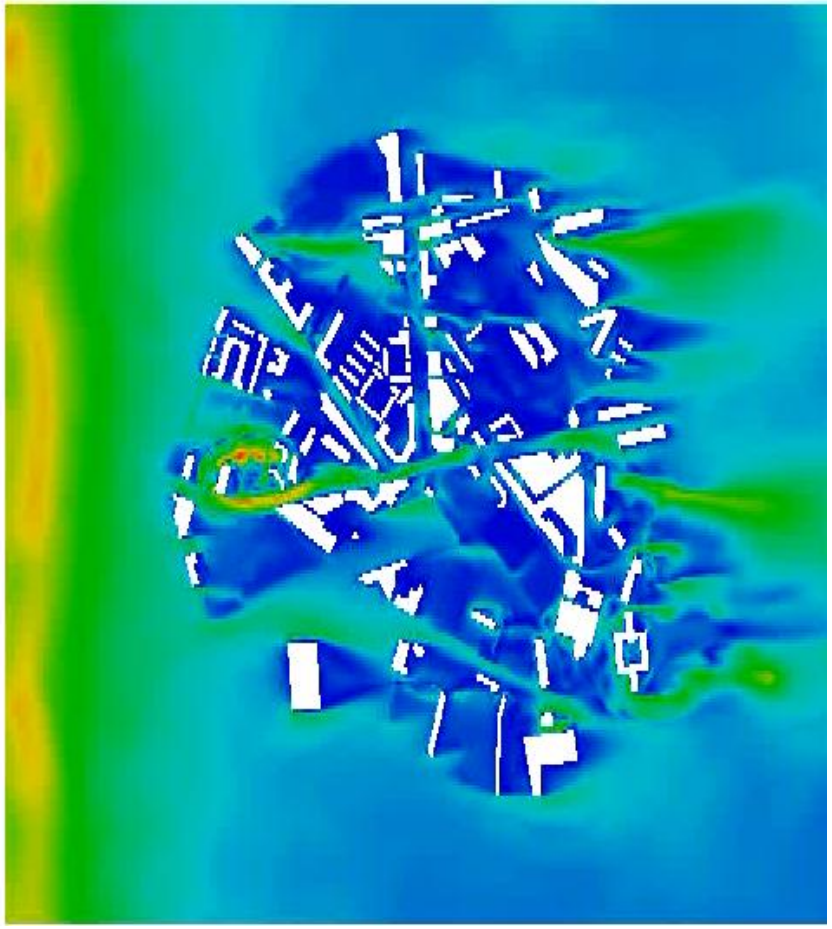






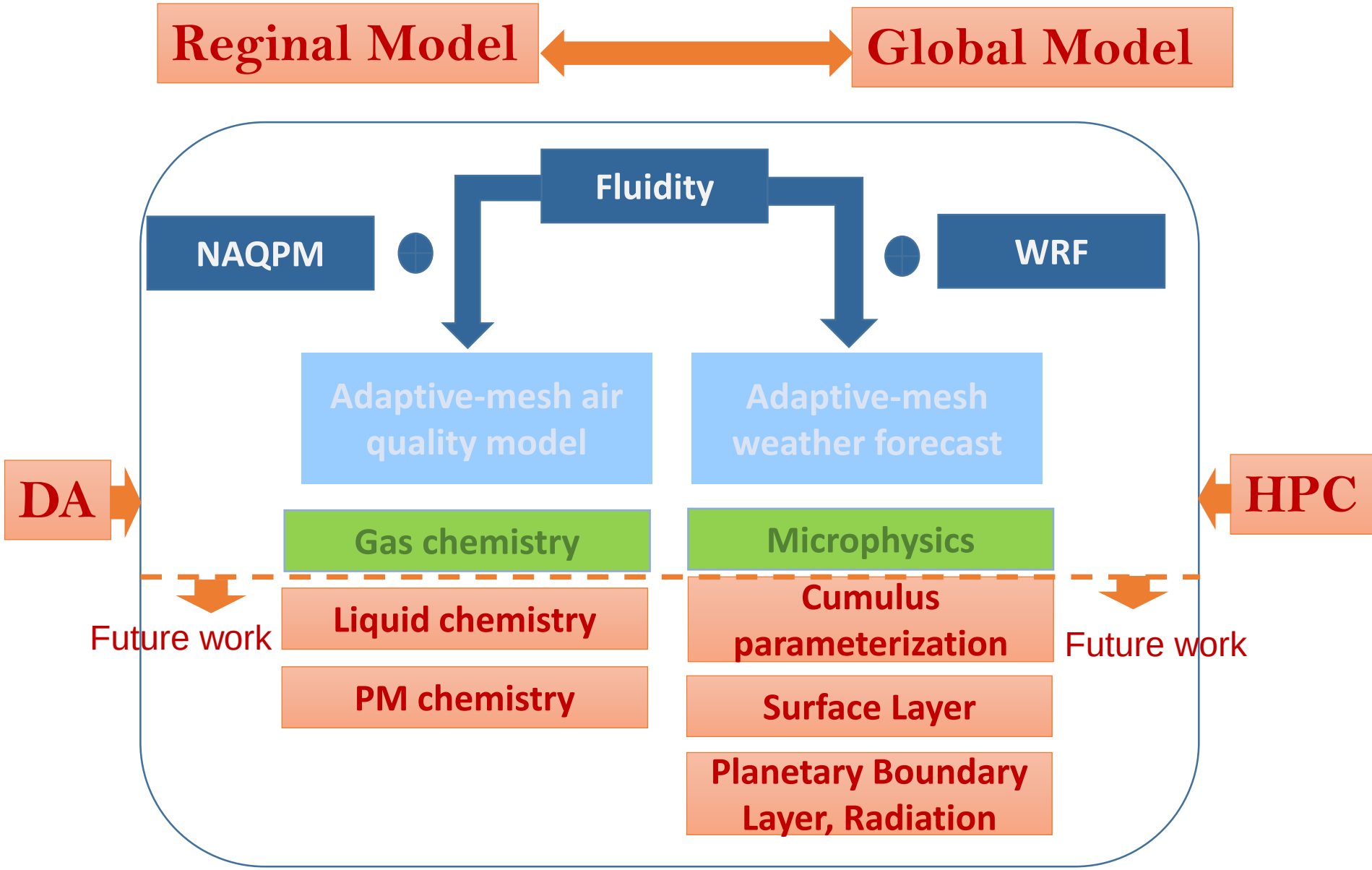
Rapid modelling: Air flow (Elephant Castle London)
(Xiao etc. supported by MAGIC –EPSRC)
Left: reduced order modelling; right: high fidelity modelling





CPU time: seconds (Reduced order model); 3 hours (10 cores, Full fidelity model)

Future work


Reginal Model
Global Model
Fluidity
NAQPM
WRF
Adaptive-mesh air quality model
Adaptive-mesh weather forecast
DA
HPC
Gas chemistry
Microphysics
Liquid chemistry
Cumulus parameterization
PM chemistry
Surface Layer
Planetary Boundary Layer, Radiation
Future work
Future work

Thanks

Rapid modelling: Flow past two buildings

Top: reduced order modelling; bottom: high fidelity modelling