NCAR

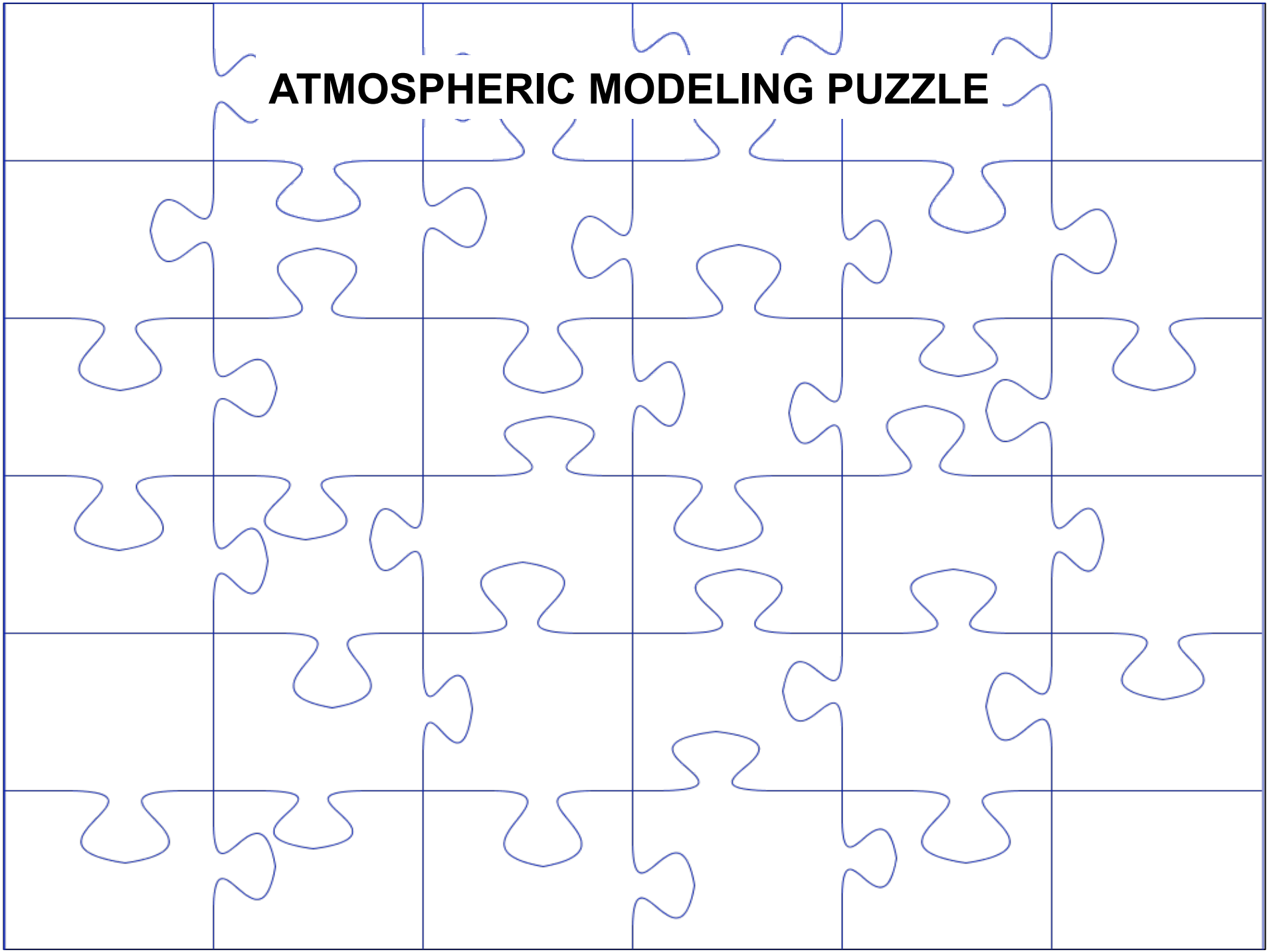
Toward Multiscale Simulations of Flows in Heterogeneous Atmospheric Boundary Layers

Branko Kosović

Acknowledgments:
Katherine A. Lundquist, Jeffrey D. Mirocha (LLNL), and John Clyne (NCAR)

National Center for Atmospheric Research

ATMOSPHERIC MODELING PUZZLE



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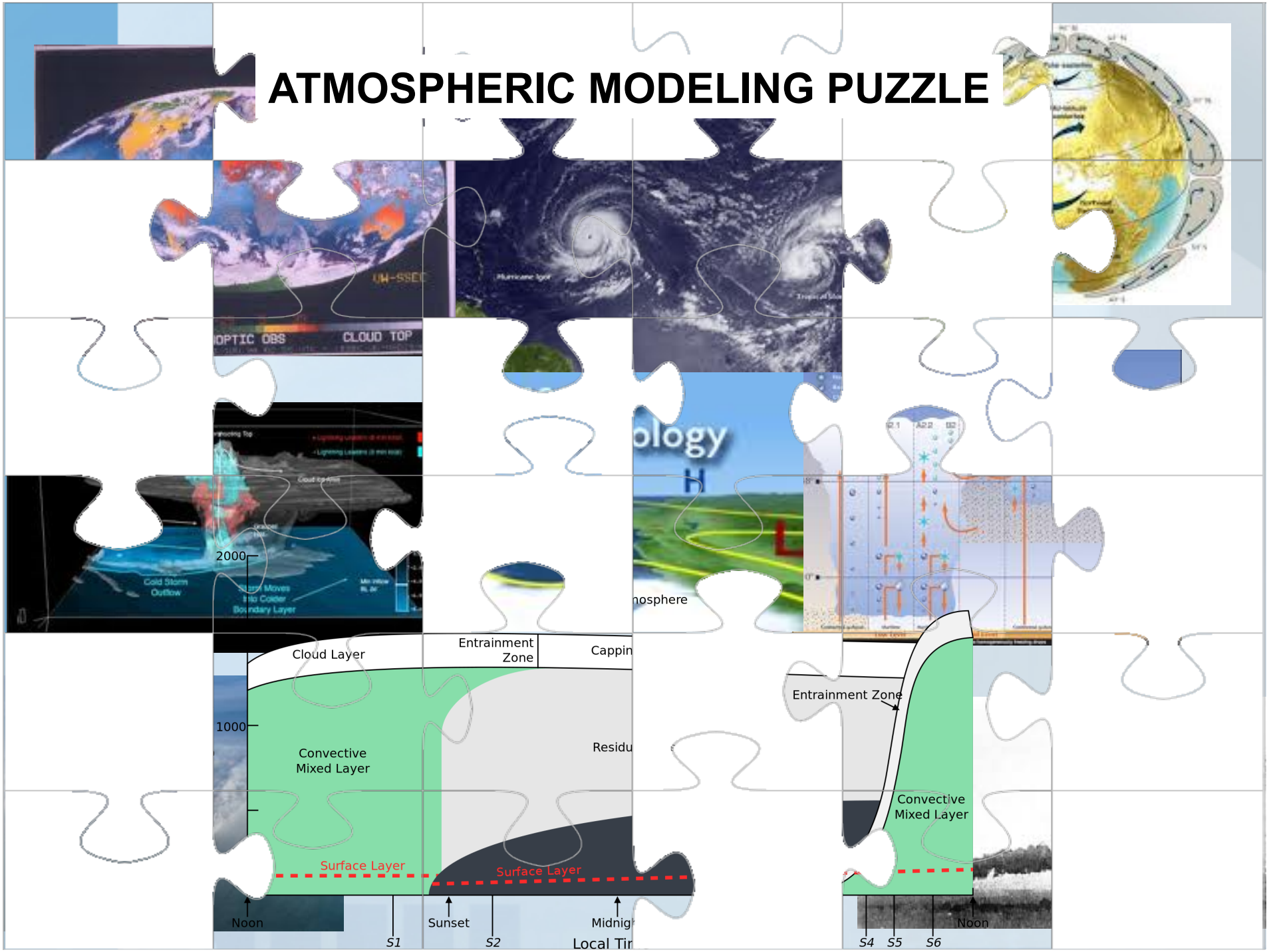

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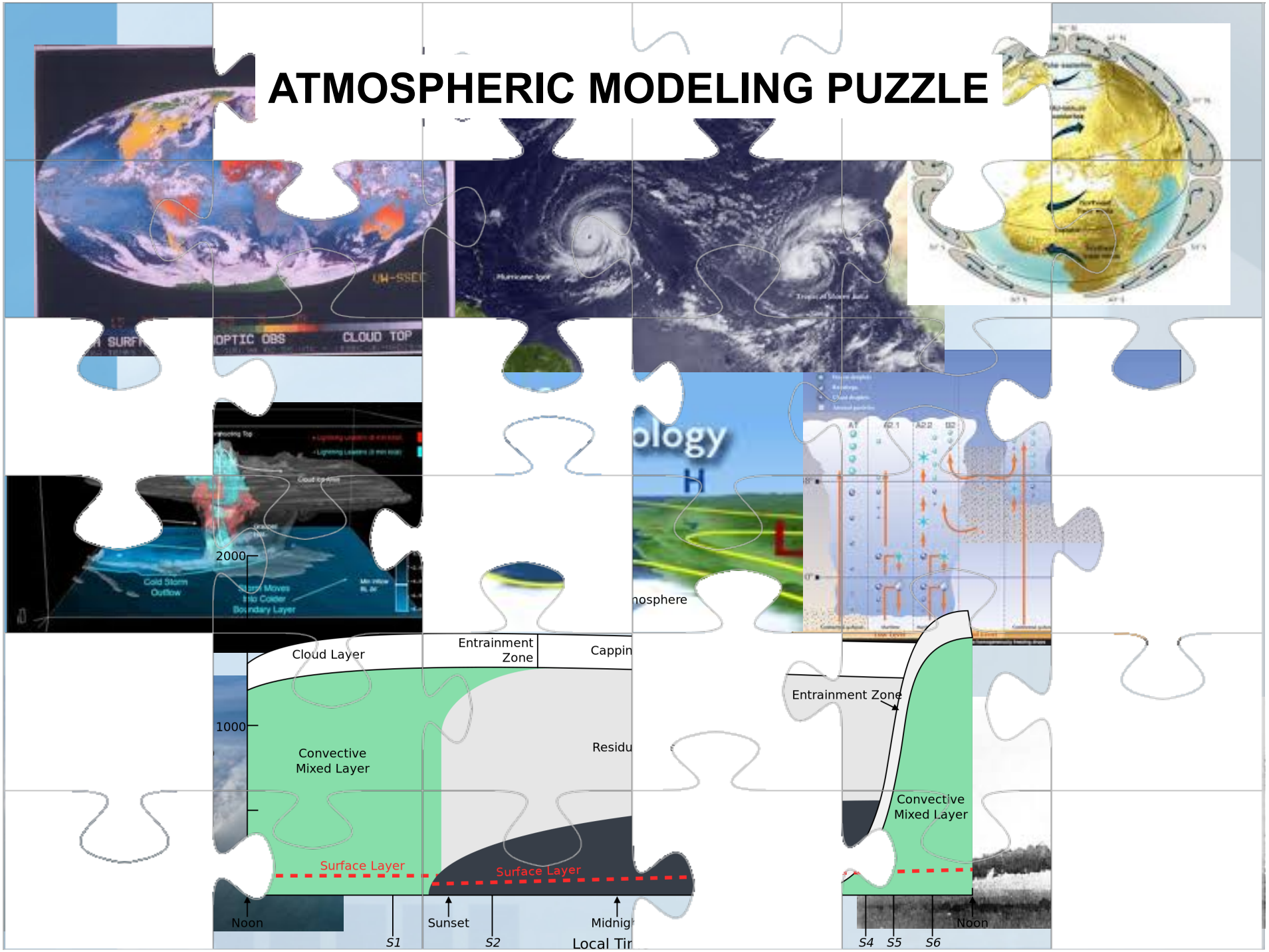

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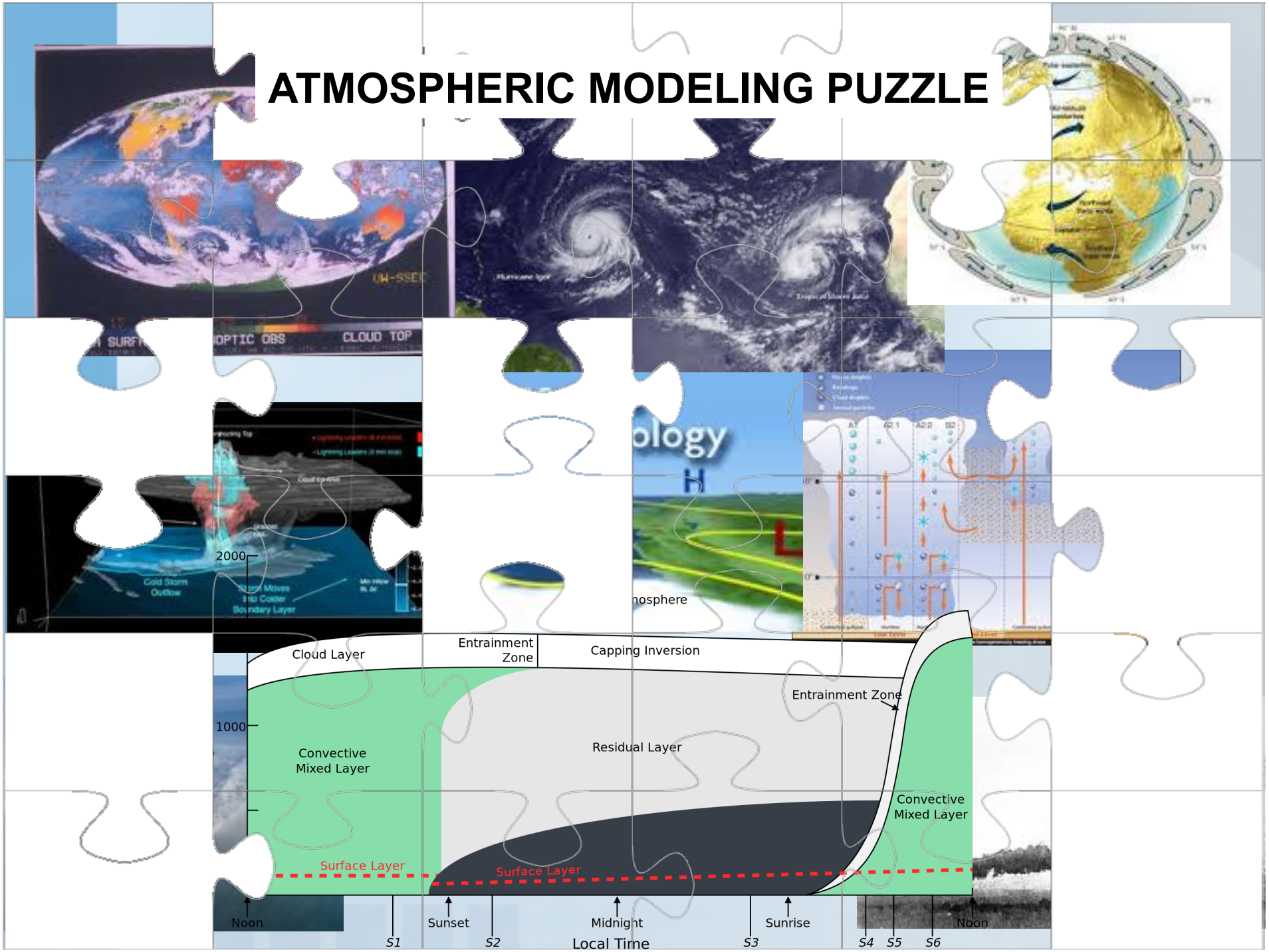

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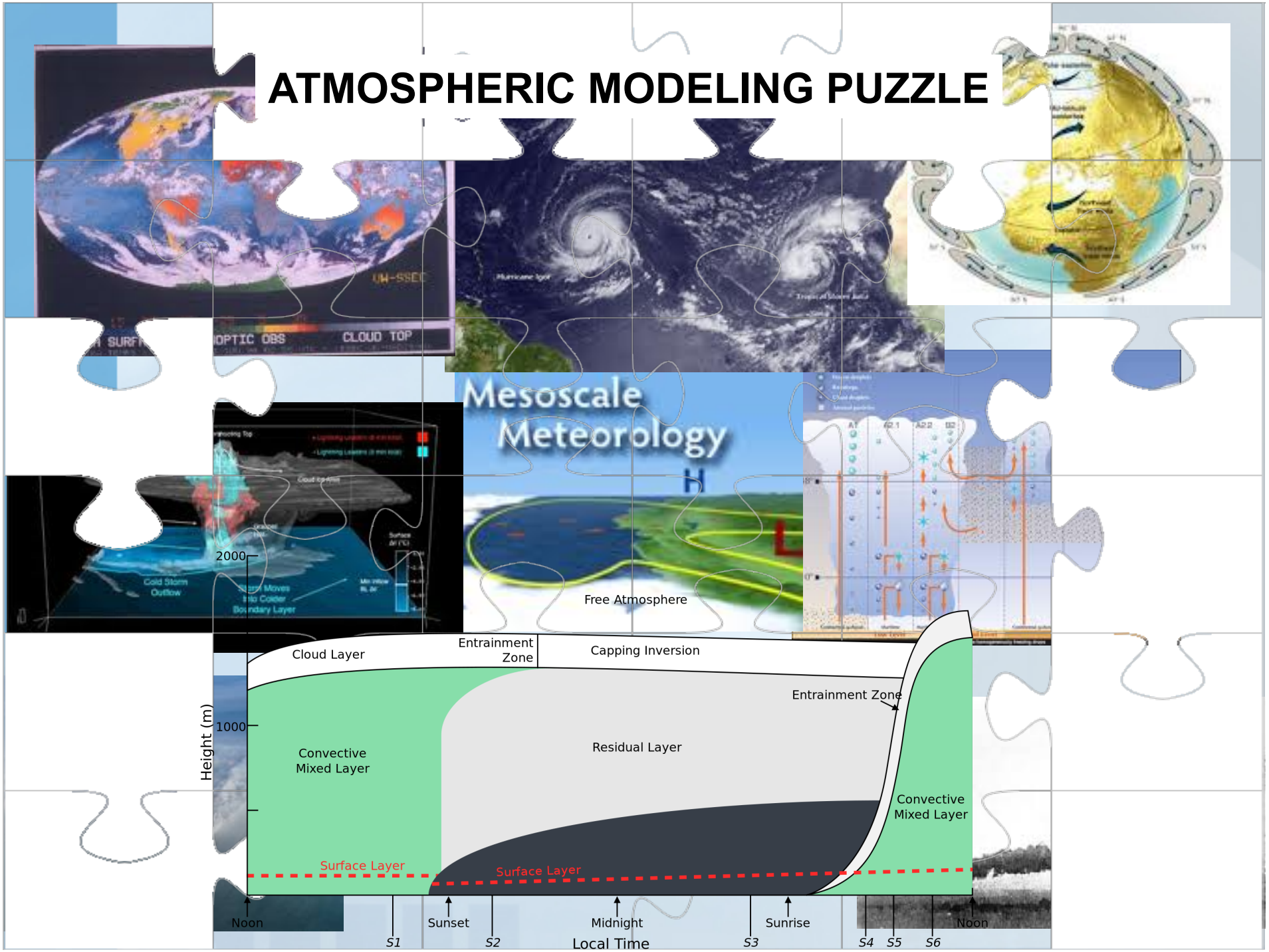

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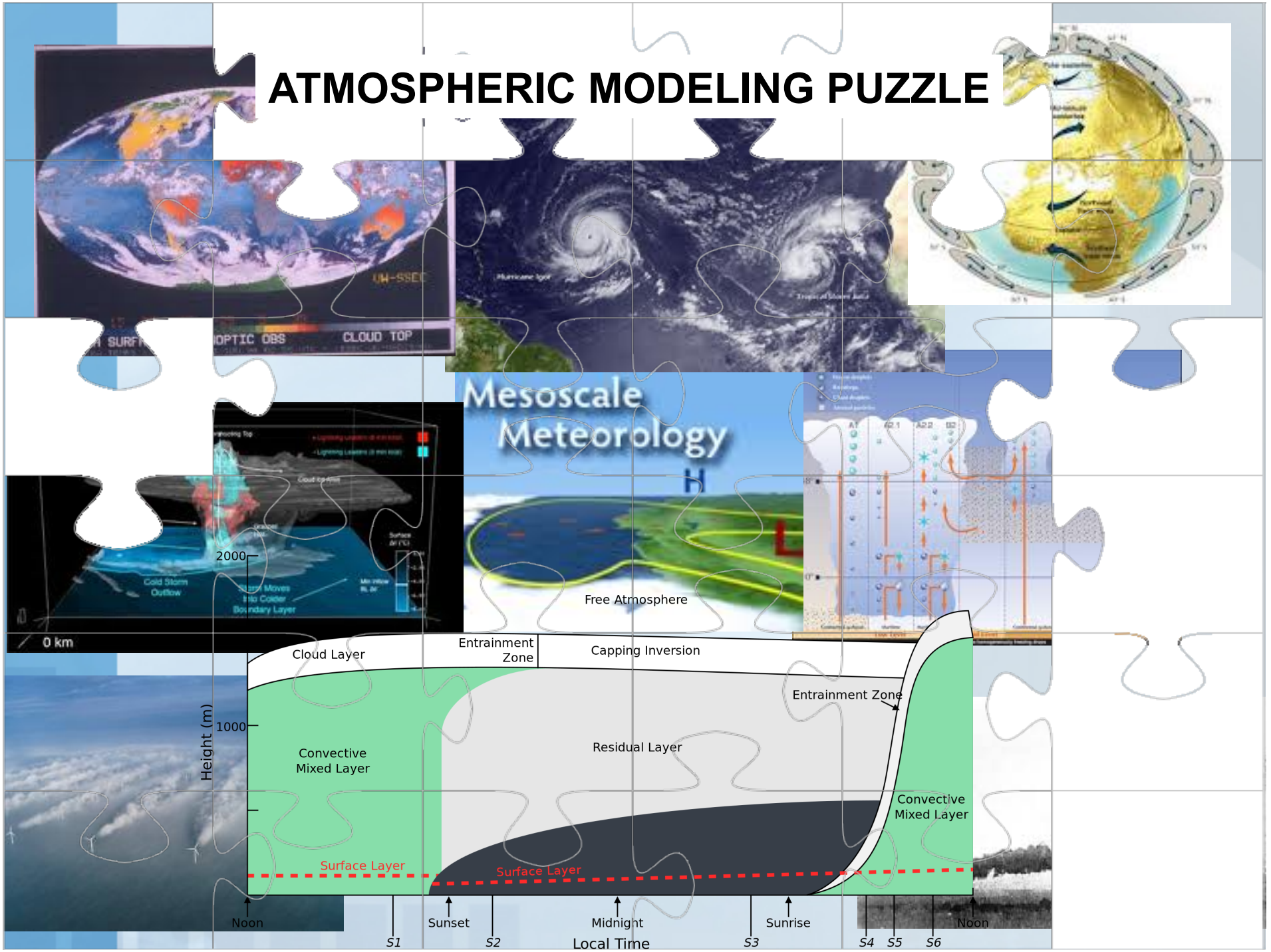

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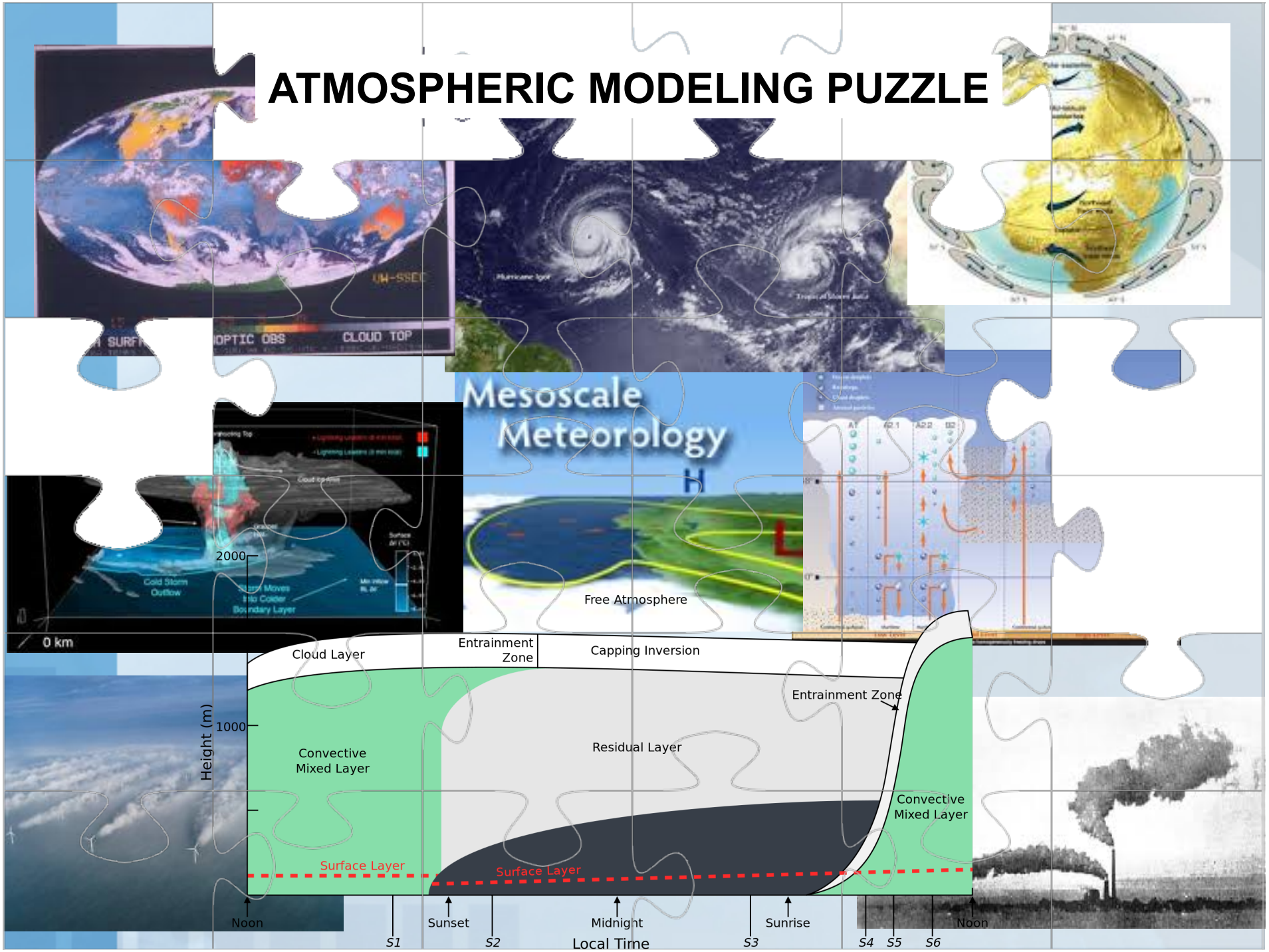

We Validated WRF's LES Capability for Simulation of Flows Over Complex Terrain

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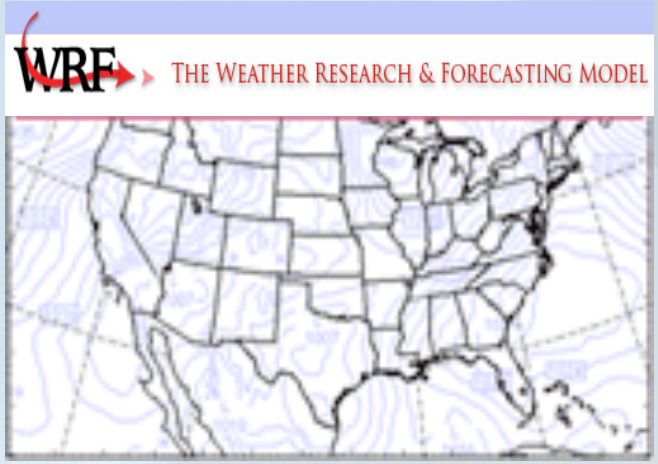
- **Weather Research and Forecasting (WRF) model is developed by community and has a wide user base**
- **WRF model includes advanced LES capabilities**



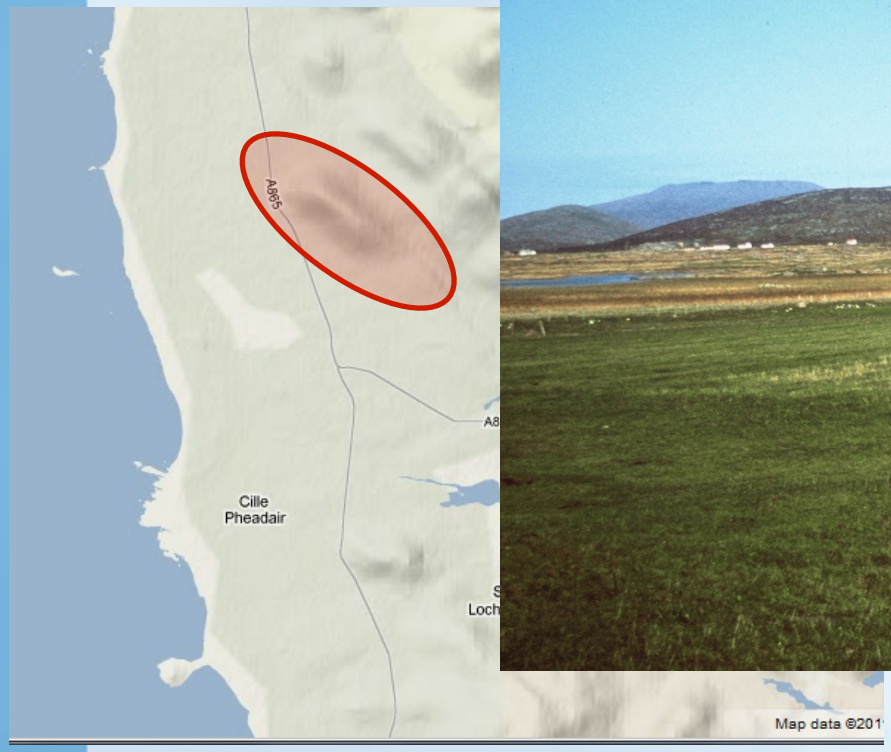
$$\tau_{ij} \approx M_{ij} = -(C_s l)^2 \Big\{ 2\big(2\tilde{S}_{mn}\tilde{S}_{mn}\big)^{\frac{1}{2}}\tilde{S}_{ij} \Big\}$$ **Smagorinsky**

$$+C_1\left(\tilde{S}_{ik}\tilde{S}_{kj} - \frac{1}{3}\tilde{S}_{mn}\tilde{S}_{mn}\delta_{ij}\right) + C_2\left(\tilde{S}_{ik}\tilde{R}_{kj} - \tilde{R}_{ik}\tilde{S}_{kj}\right) \Big\}$$ **NBA**

$$C_1 = C_2 = \frac{960^{\frac{1}{2}} C_b}{7(1+C_b)S_k} \qquad \tilde{S}_{ij} = \frac{1}{2}\left(\frac{\partial \tilde{u}_i}{\partial x_j} + \frac{\partial \tilde{u}_j}{\partial x_i}\right) \qquad \tilde{R}_{ij} = \frac{1}{2}\left(\frac{\partial \tilde{u}_i}{\partial x_j} - \frac{\partial \tilde{u}_j}{\partial x_i}\right)$$

(Kosovic, JFM 1997; Mirocha et al., MWR 2010)

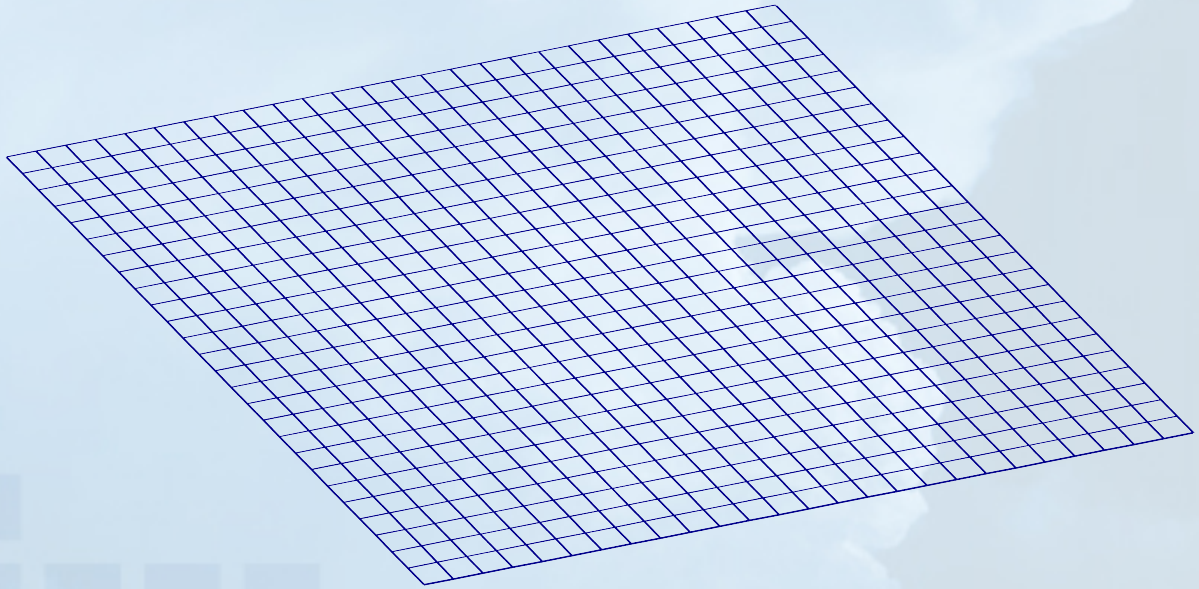
Askervein Hill Experiment Was Used for Validation of WRF



Askervein Hill experiment took place on the West side of South Uist island (Scotland) in 1983 (Taylor and Teunnisen, BLM 1987). Measurements were taken using cup anemometers mounted at 10m above the ground on 50 towers.

One Way Nesting Is Used for LES Over A Wind Turbine Array

- Periodic boundary conditions are used on the outer domain to spin up realistic turbulent inflow
- Outer domain had 240x160x60 grid cells with grid cell size 30 m in horizontal direction and 10 m in vertical



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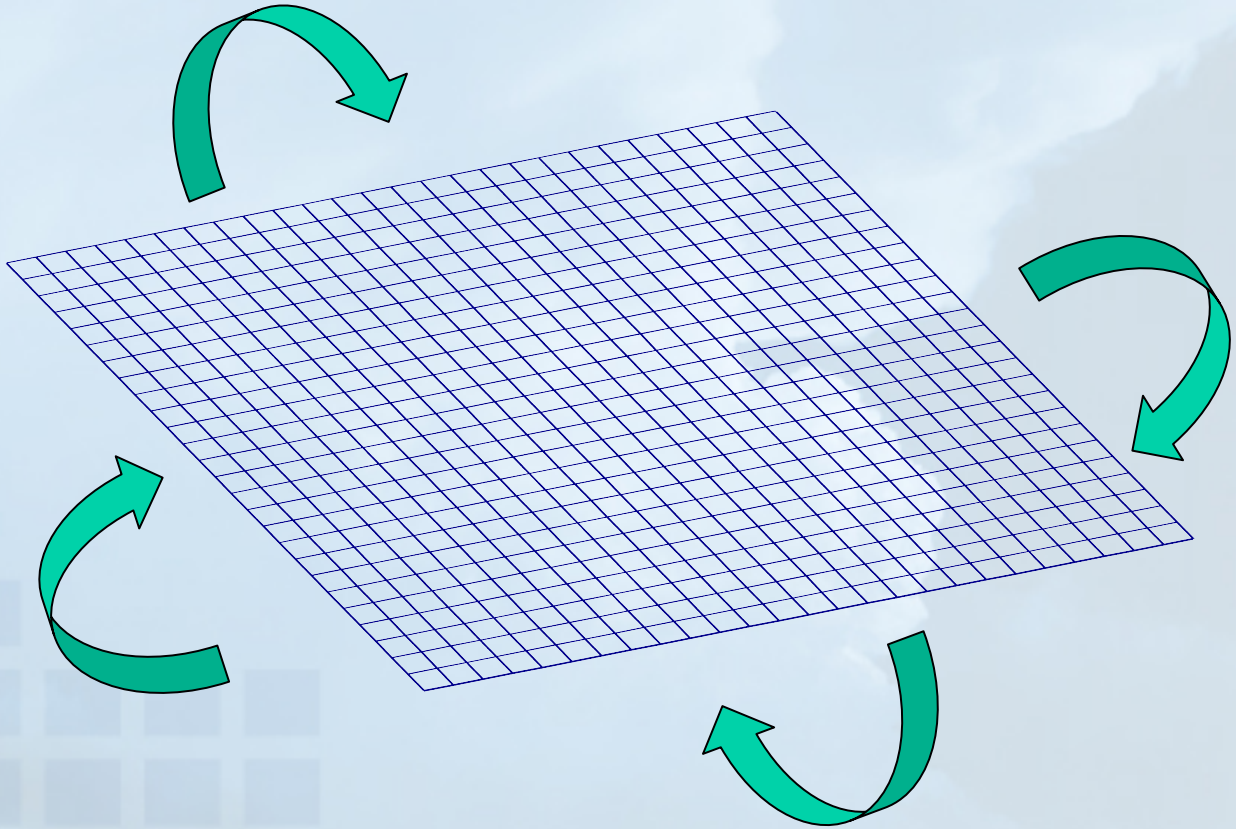
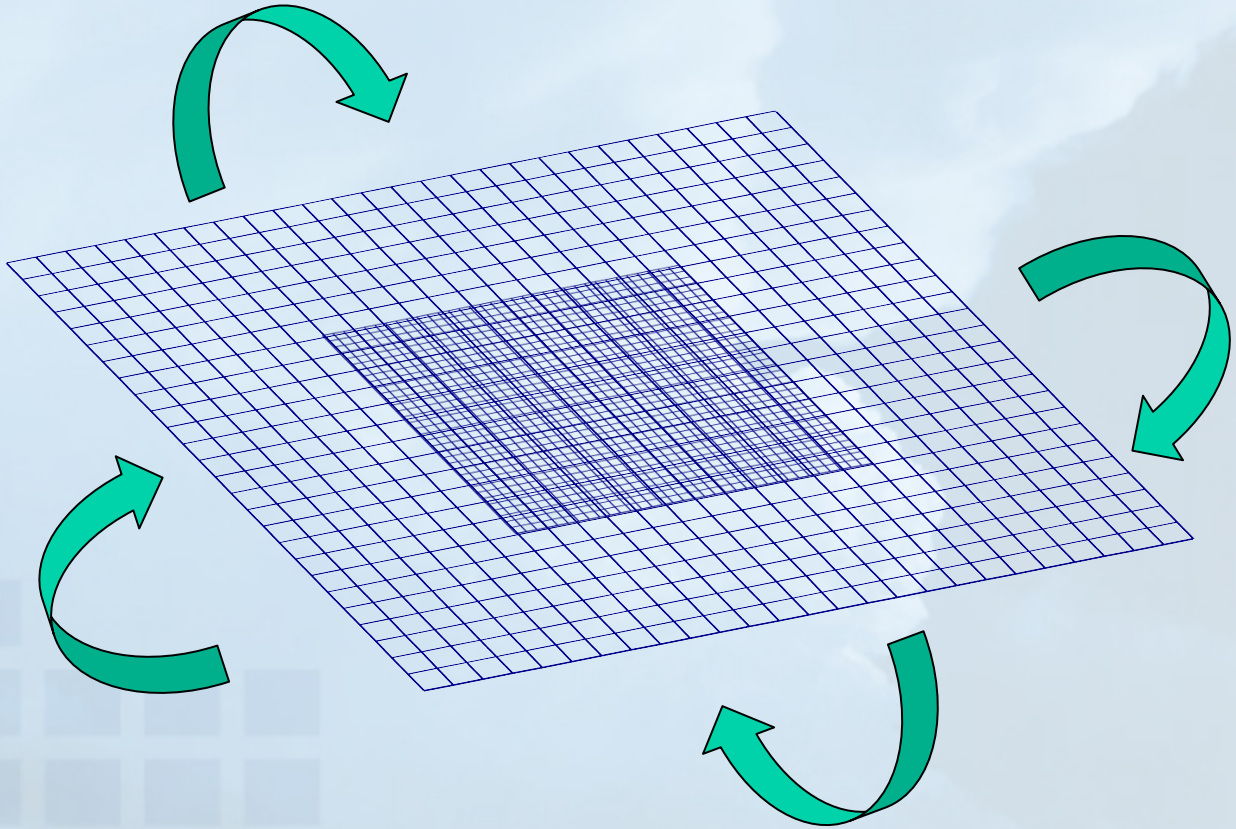


One Way Nesting Is Used for LES Over A Wind Turbine Array

- **Inner domain had 440x250x60 grid cells with grid cell size 10 m in both horizontal and vertical directions**



One Way Nesting Is Used for LES Over Complex or Heterogeneous Terrain

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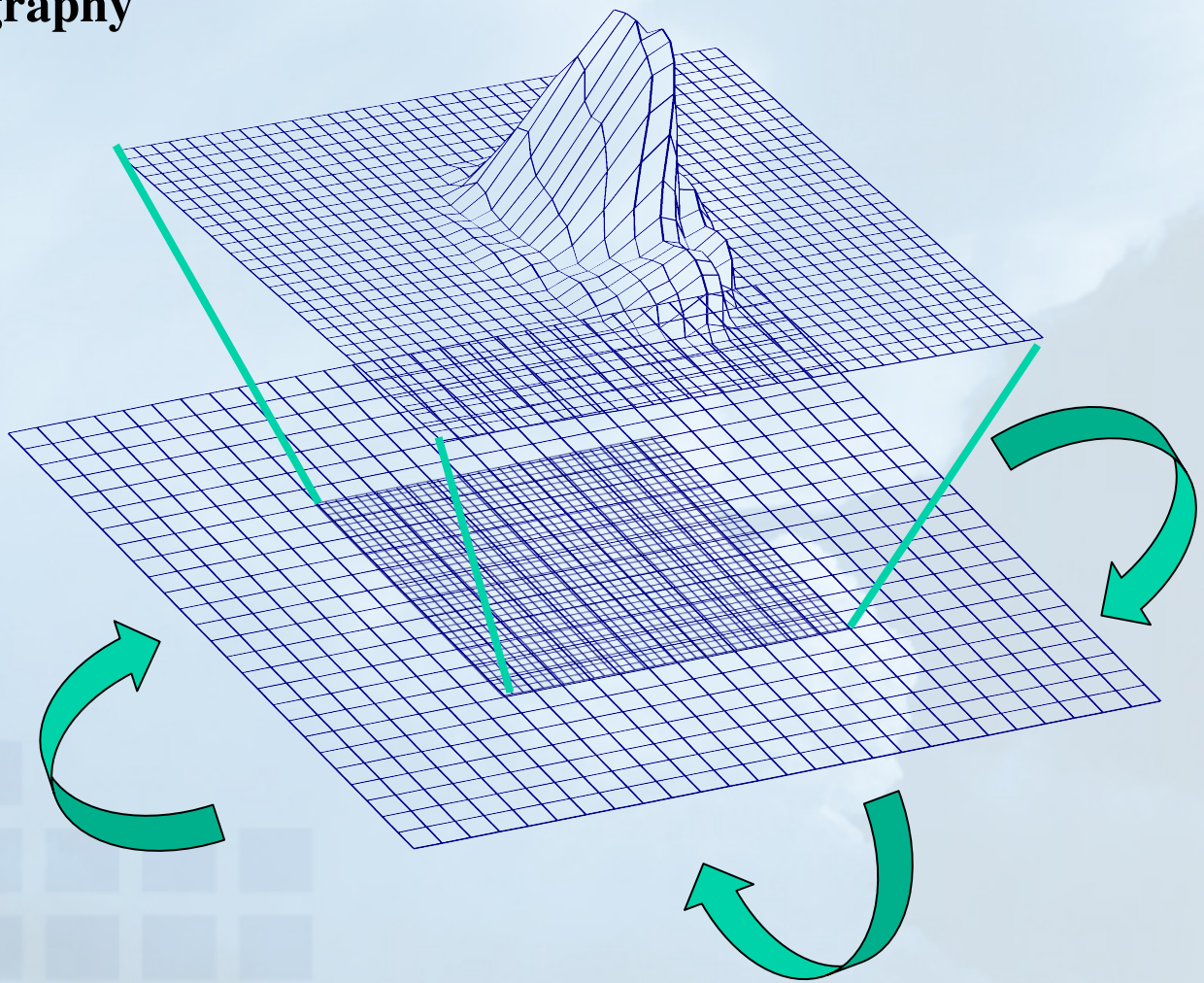
- **Only inner domain includes represenation of the Askervein Hill topography**



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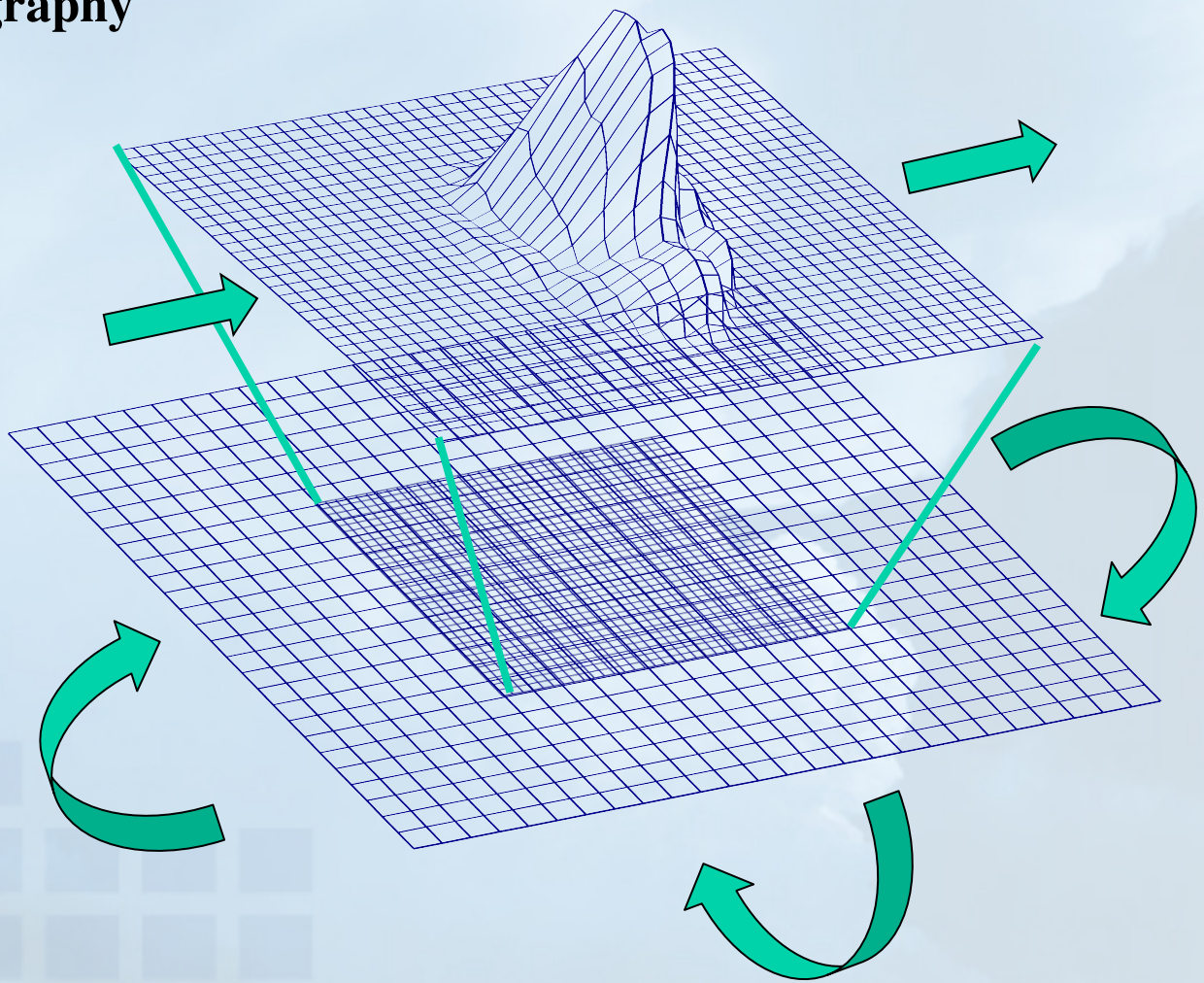
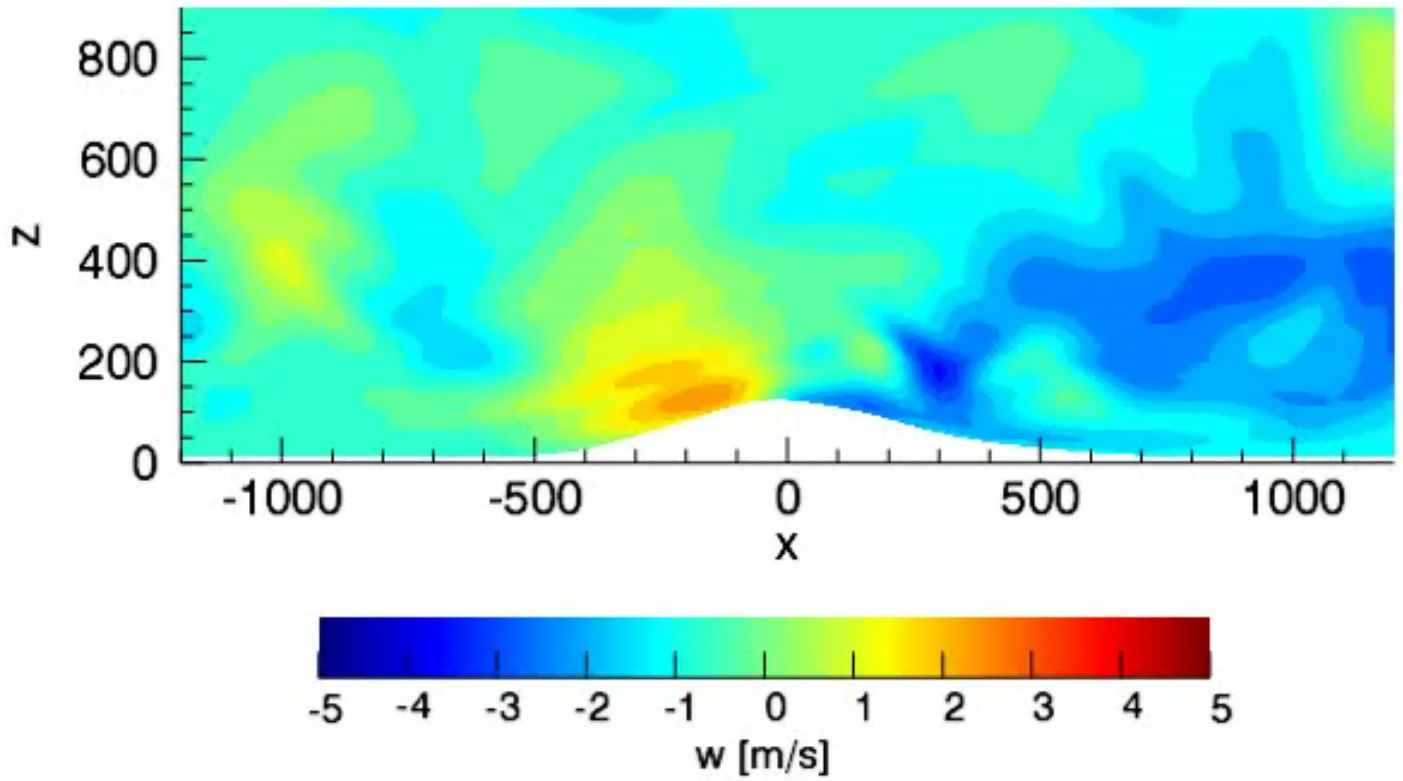
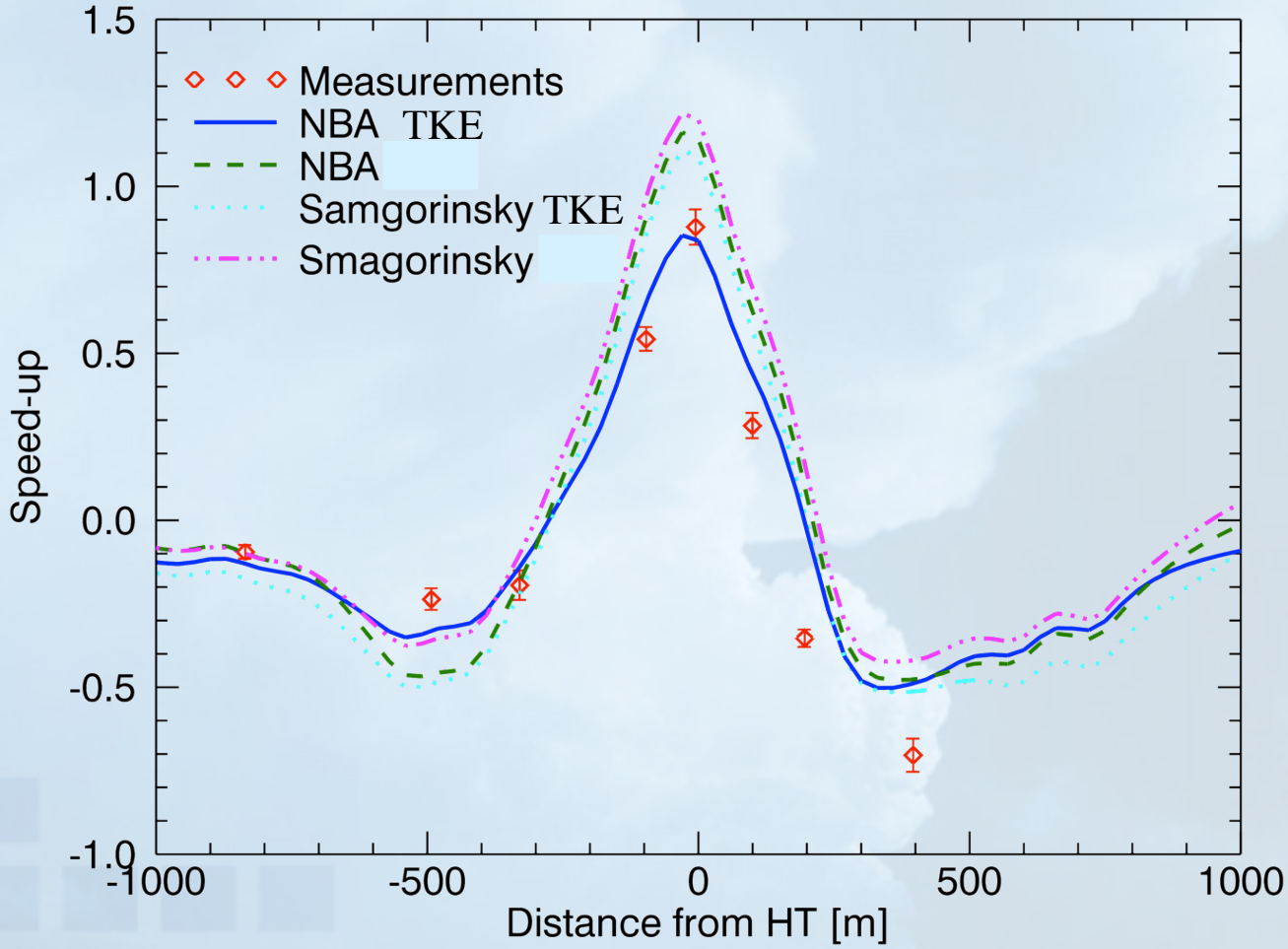


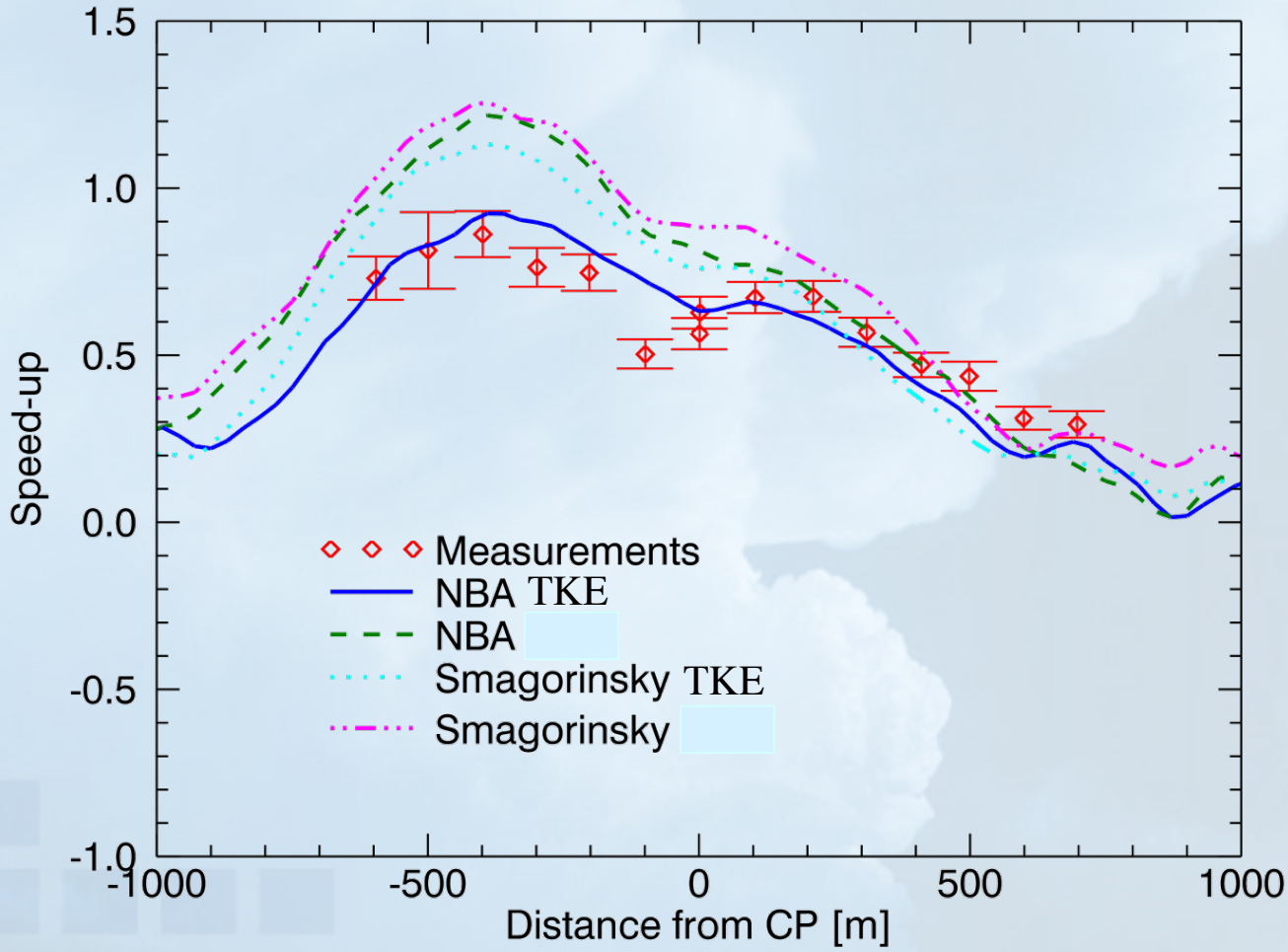
Vertical Velocity



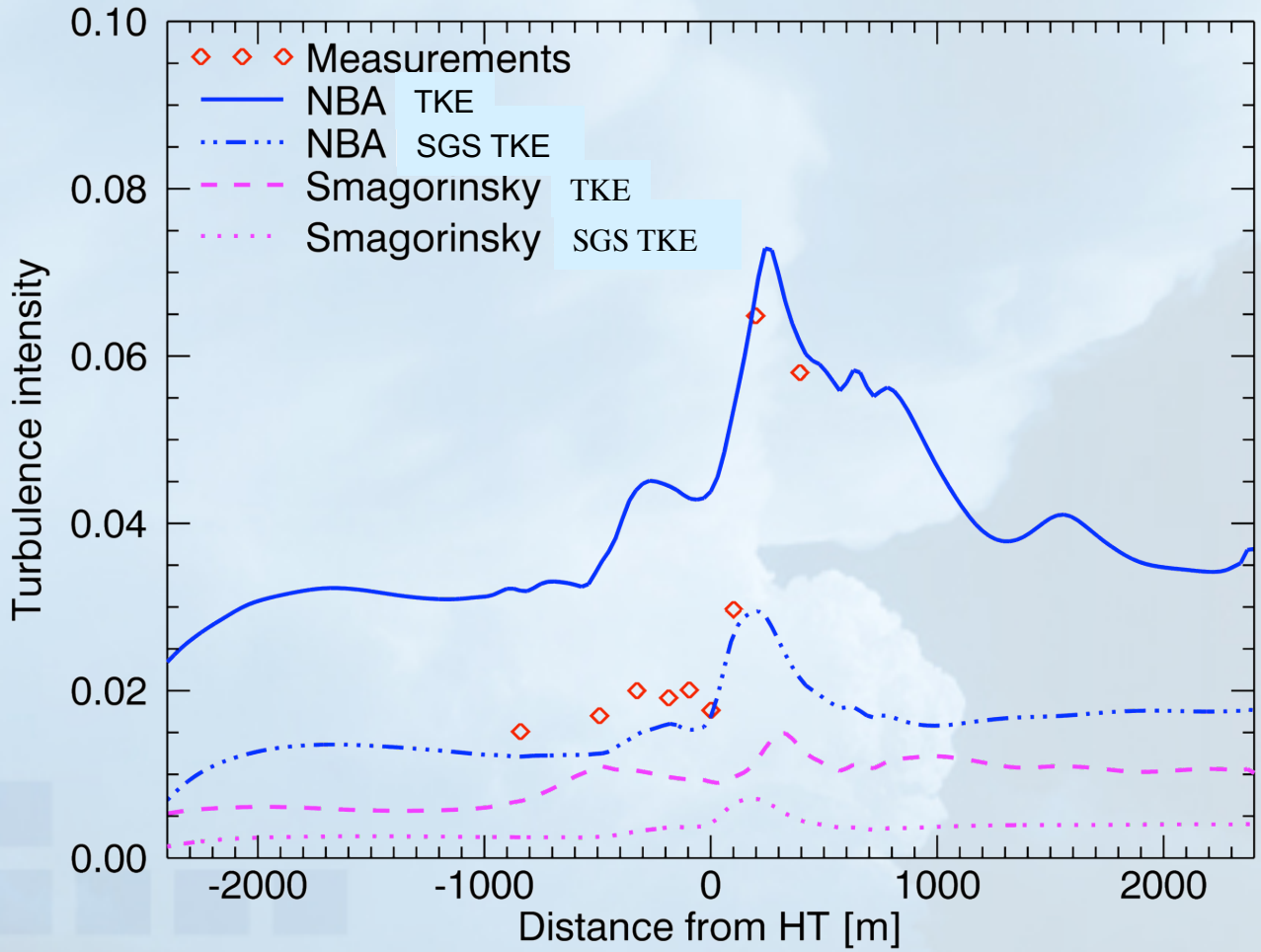
Speed-up along Line A



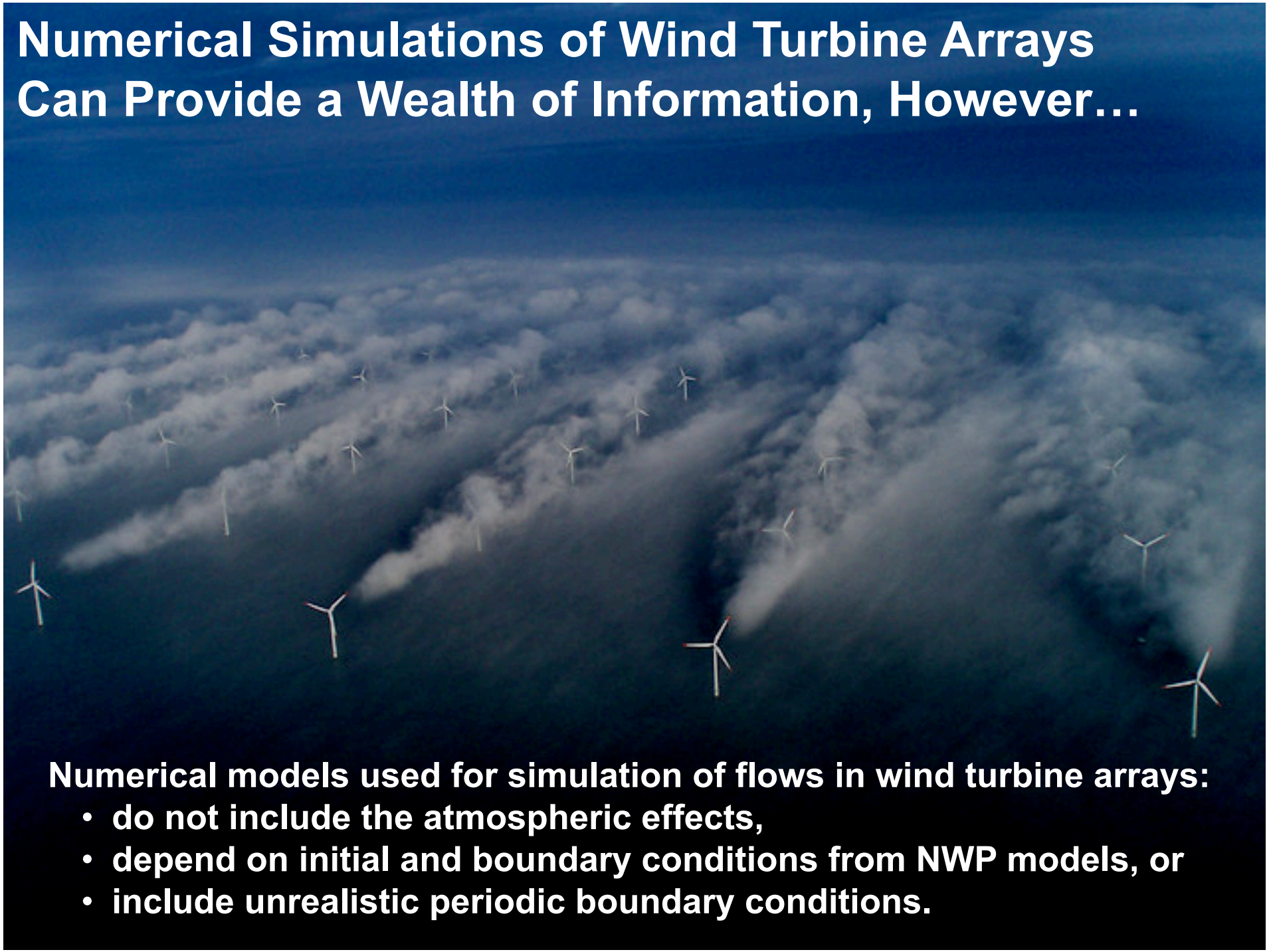
Speed-up Along Line B



Turbulence Intensity along Line A



Numerical Simulations of Wind Turbine Arrays Can Provide a Wealth of Information, However…



Numerical models used for simulation of flows in wind turbine arrays:

- **do not include the atmospheric effects,**
- **depend on initial and boundary conditions from NWP models, or**
- **include unrealistic periodic boundary conditions.**

We Implemented Generalized Actuator Disk Model in WRF

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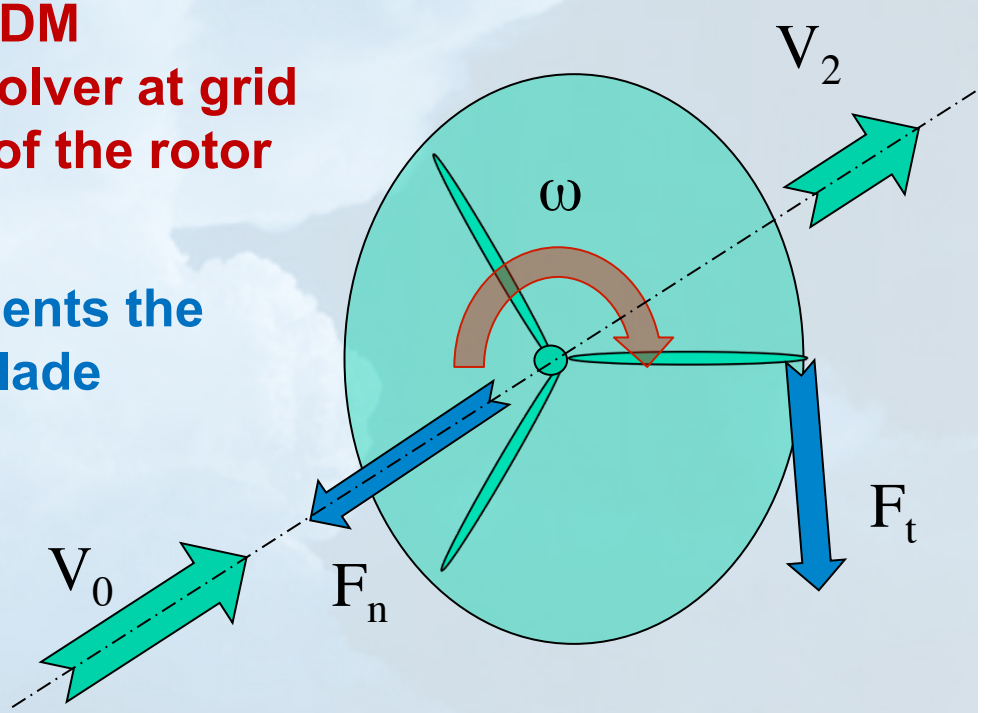
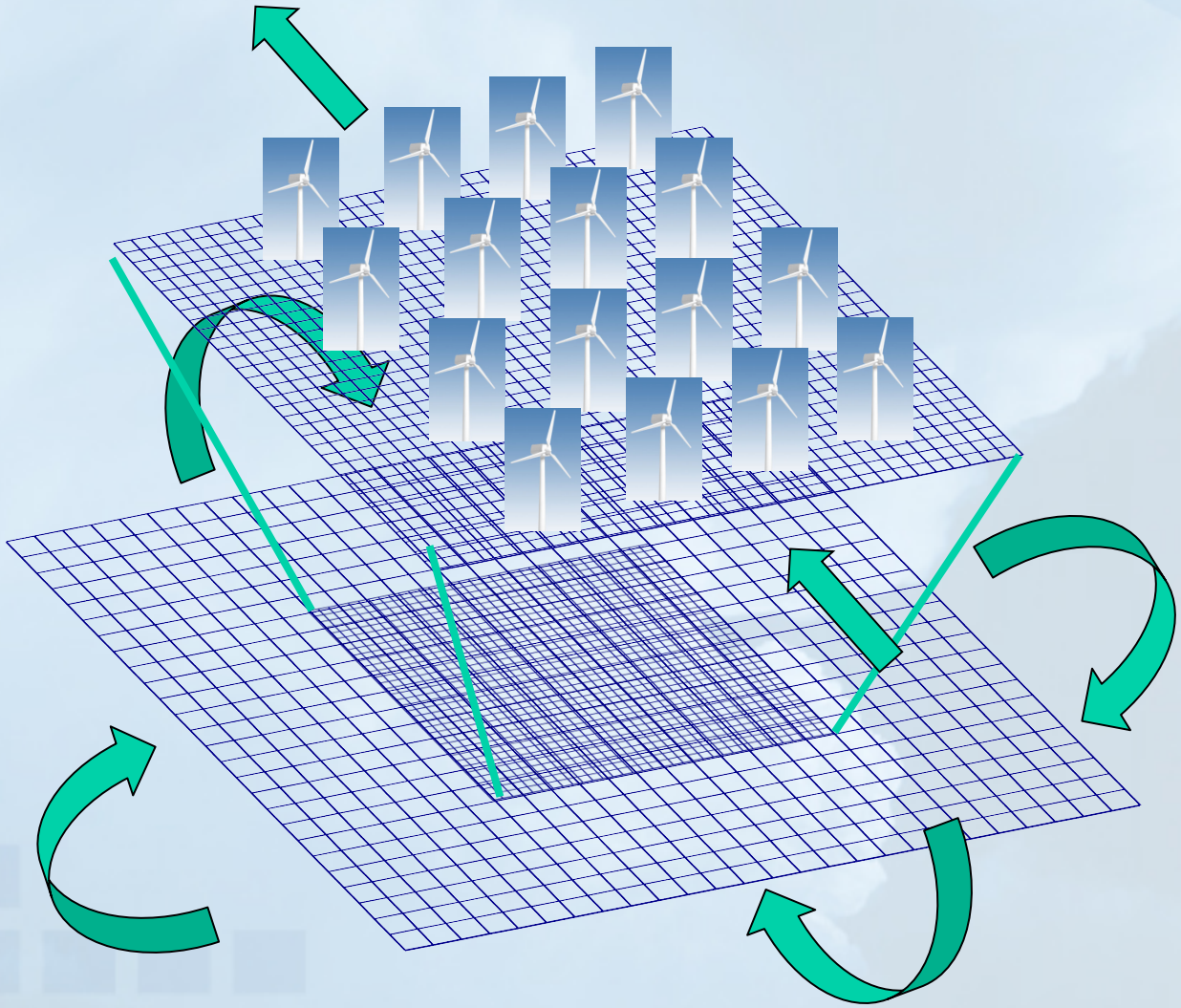
- Wind turbine impacts the flow through thrust and torque
- Actuator Disk Model (ADM) represents the effects of the rotor as a porous rotating disk
- Forces are computed using Blade Element Theory
- Generalized ADM is a full ADM implemented in a 3D flow solver at grid points on or in the vicinity of the rotor (Mikkelsen, 2003)
- Actuator Line Model represents the effects of each individual blade



One Way Nesting Is Used for LES Over A Wind Turbine Array



Only inner domain includes the wind turbine array

Wake Effects of an Array of Wind Turbines

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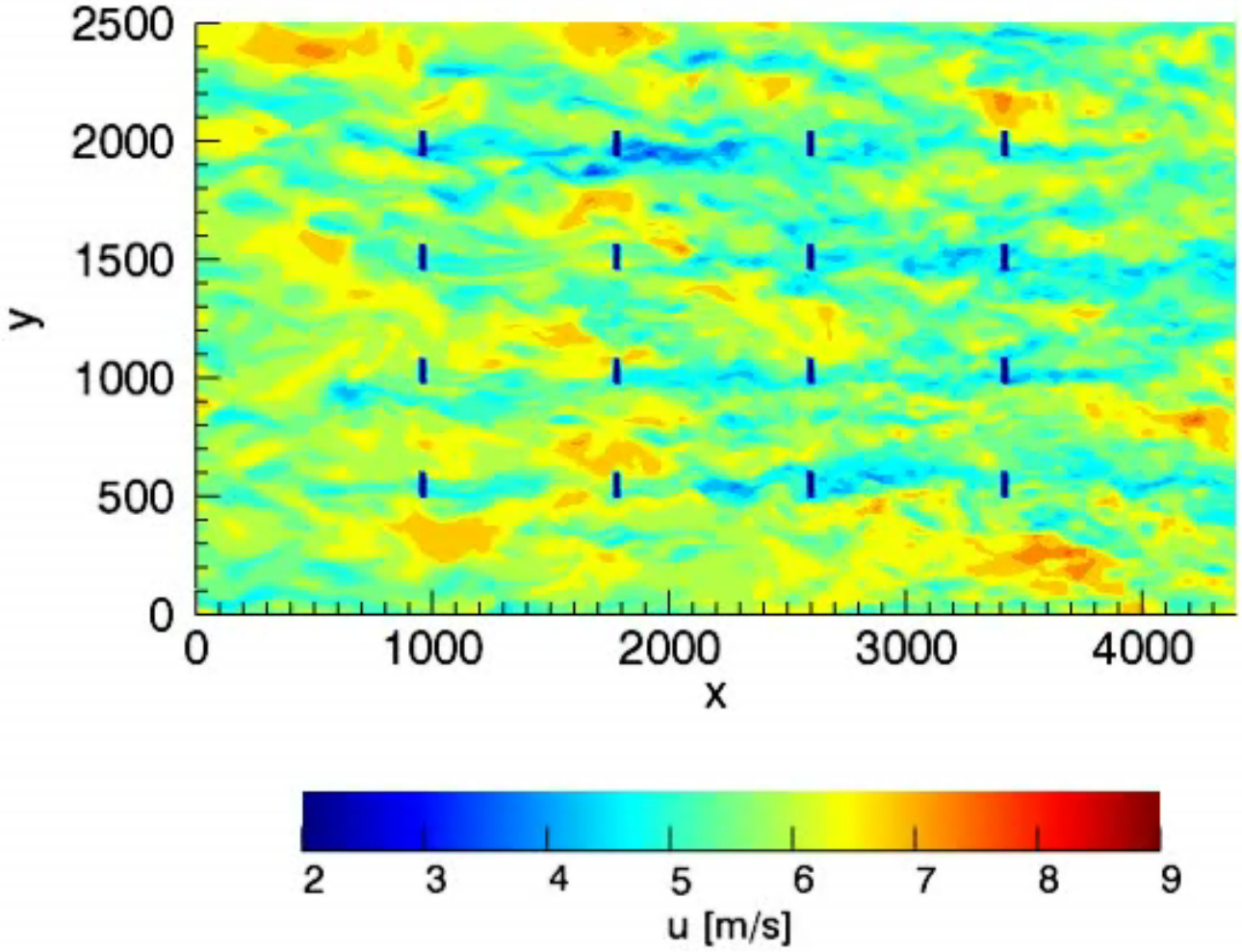
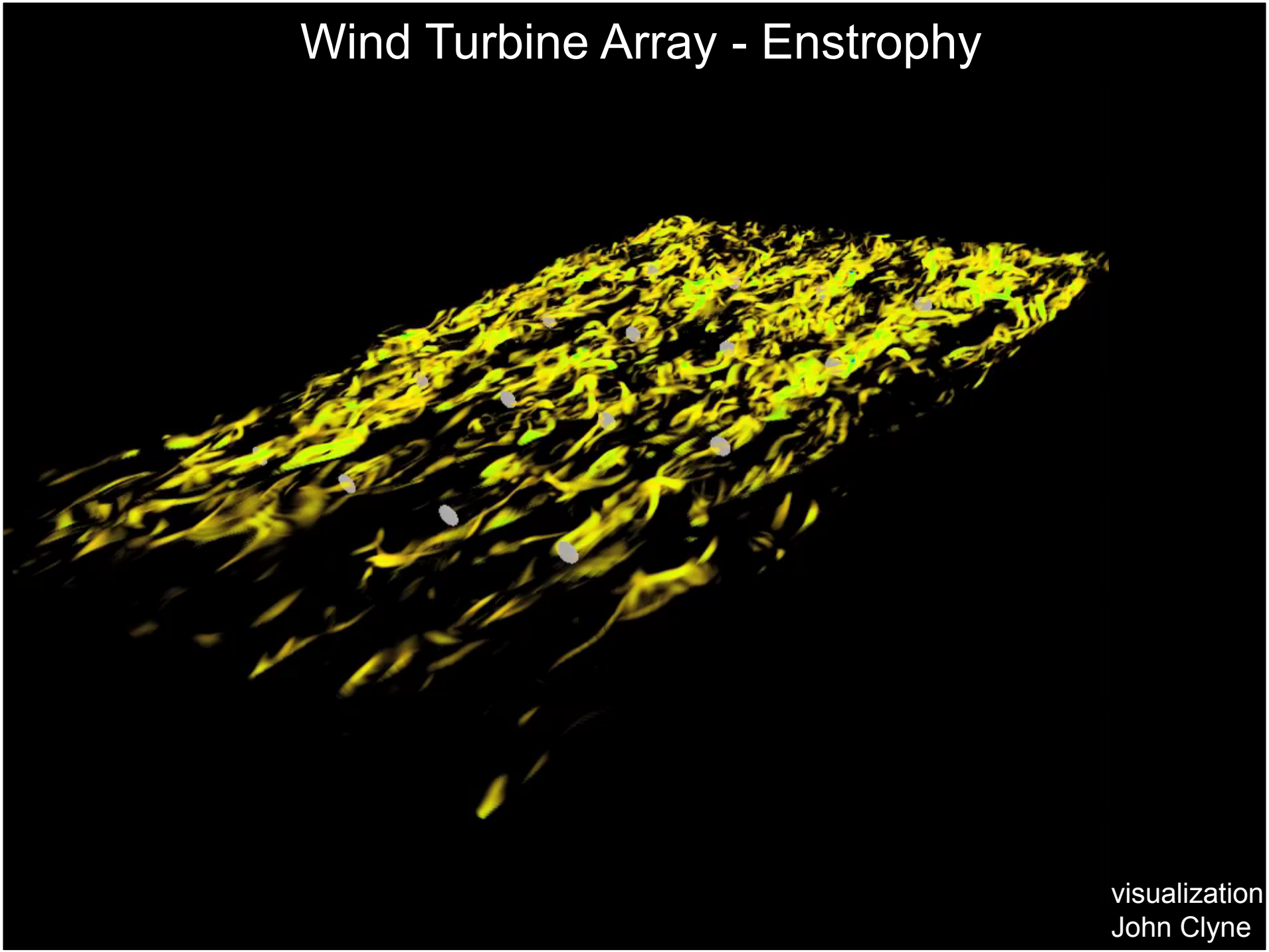


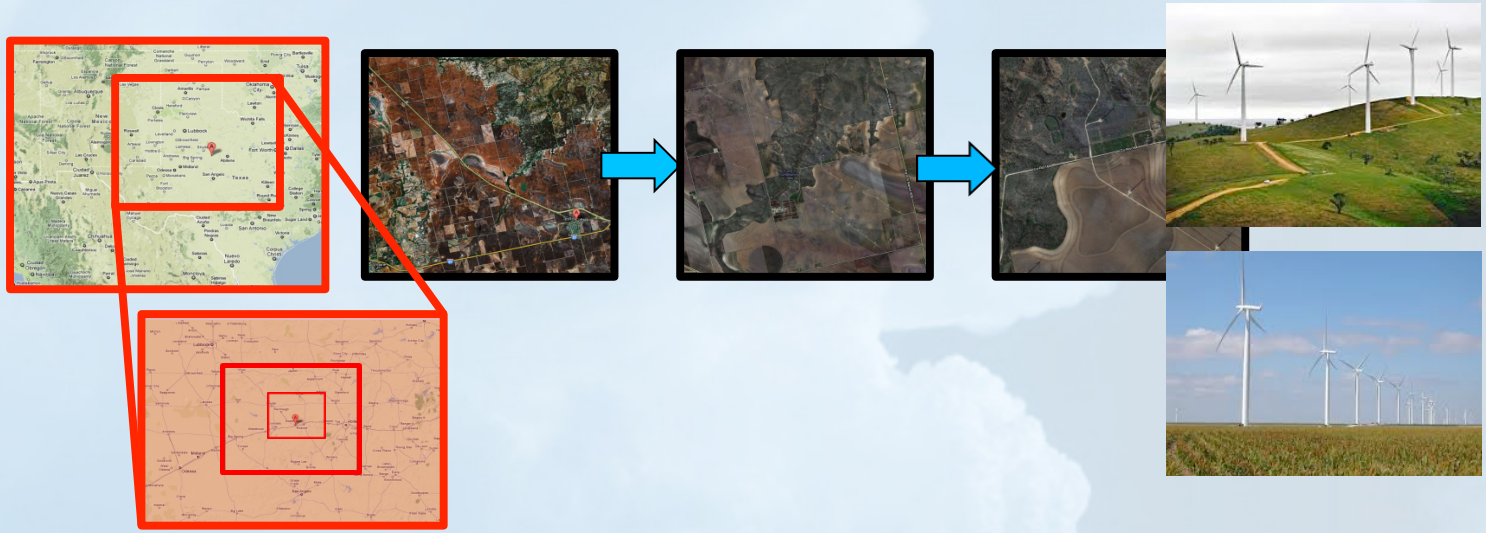
Wind Turbine Array - Enstrophy



visualization
John Clyne

Summary

- We are developing a multiscale modeling capability using WRF
- We validated WRF-LES using Askervein Hill experiment data
- We implemented Generalized Actuator Disk Model in WRF



Developing multi-scale modeling capability requires:

- Effective nesting of LES within mesoscale simulation (turbulence parameterizations are based on different assumptions)
- Lower boundary conditions for LES over heterogeneous terrain

Wind Turbine Array – Streamwise Velocity

visualization
John Clyne