Turbulence and Lagrangian transport in the hurricane boundary layer

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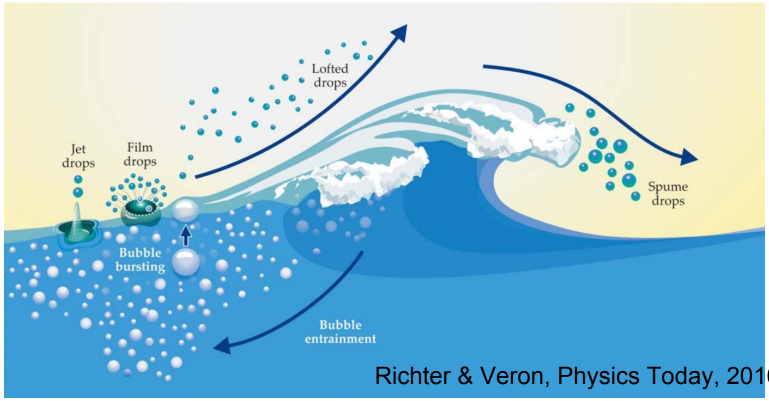
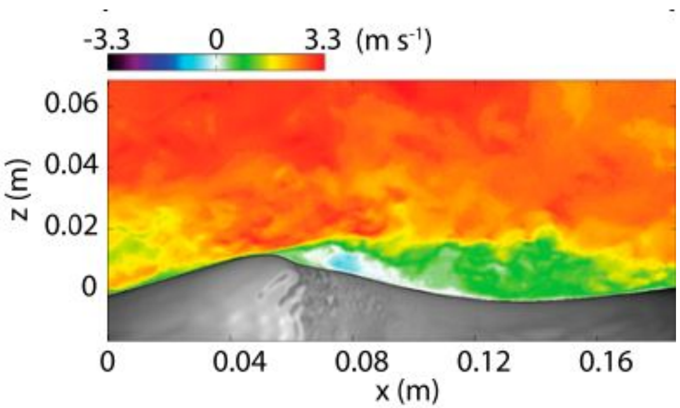
How do processes at the air-sea interface…

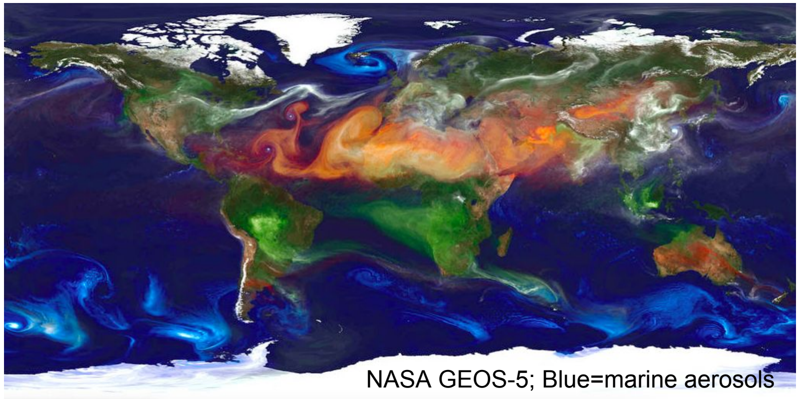
…affect large-scale transport and dynamics?



Richter & Veron, Physics Today, 2016

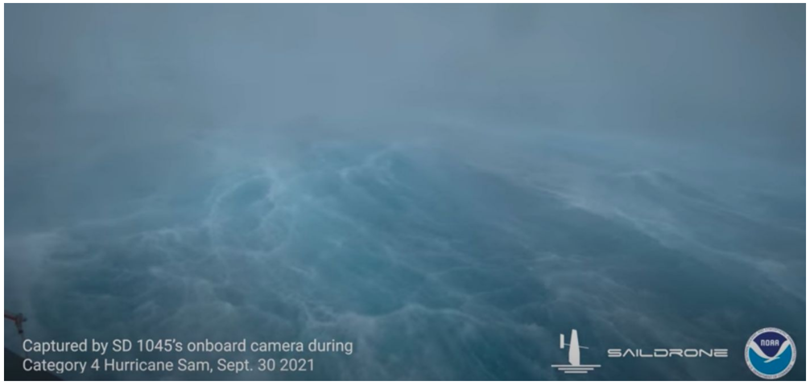


Buckley & Veron, JPO, 2016



NASA GEOS-5; Blue=marine aerosols

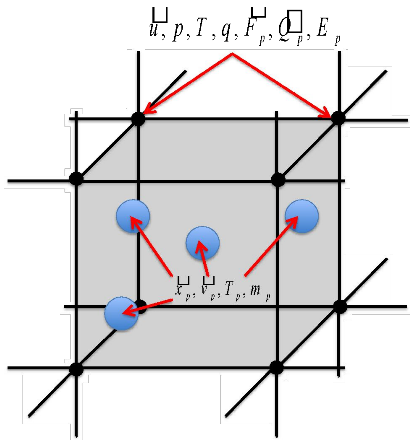
Climate?



Hurricanes?

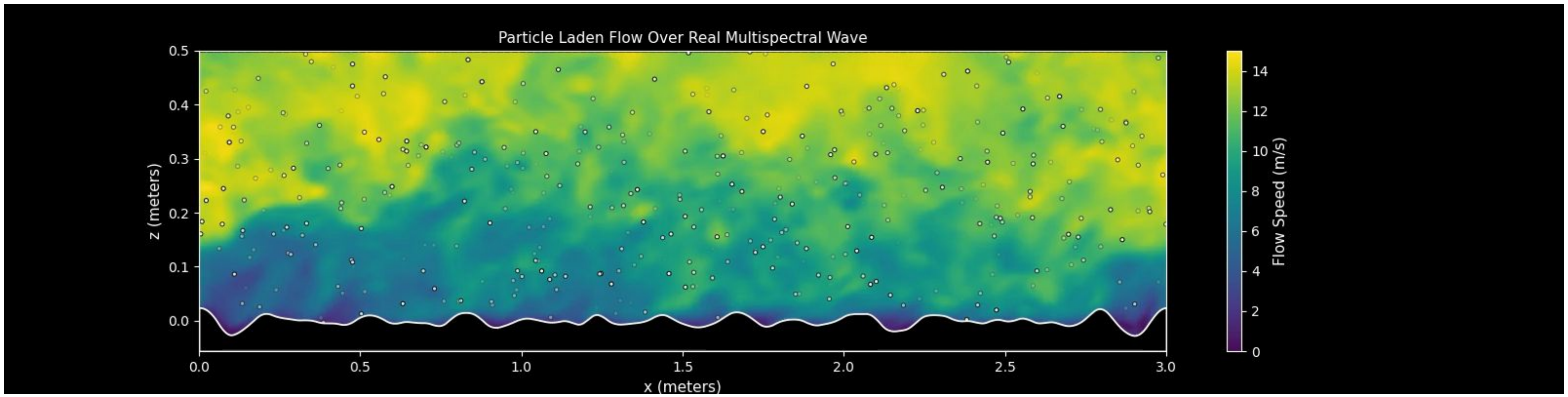
Numerical method: Large-eddy simulation with Lagrangian droplets

- State-of-the-art "Lagrangian cloud model", but including spray origins as well



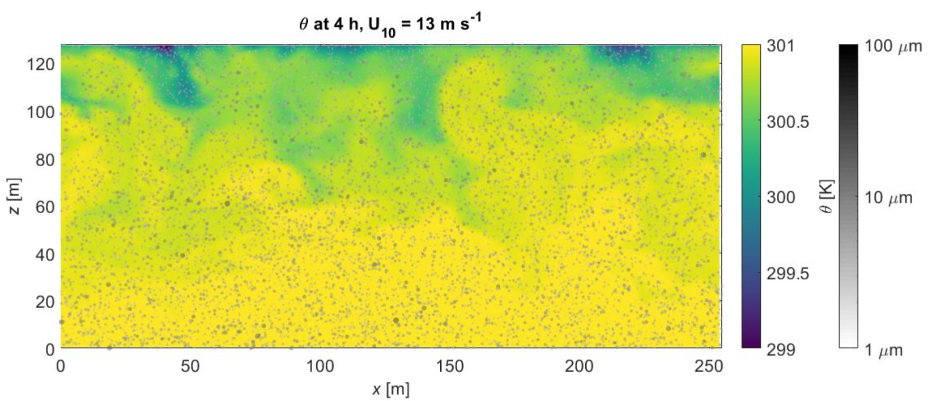
- Water phase represented by Lagrangian parcels with its own properties (velocity, size, temp, multiplicity, composition, etc.)
- Air flow solved using traditional LES methods
- Phases fully two-way coupled

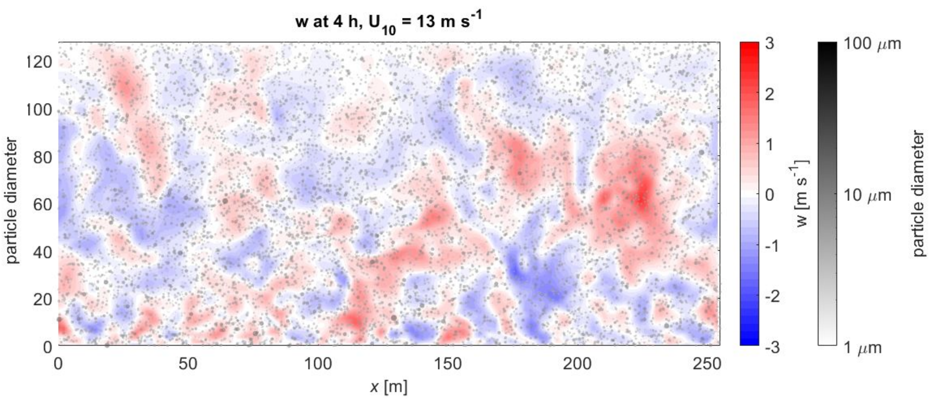
- MAJOR WEAKNESS: Many, many particles needed for resolved spray/cloud phase



Scientific questions:

- How do coherent turbulent structures affect spray/droplet transport?
  - Roll structures in particular (Lorsolo et al. 2008, Wang & Jiang 2017, etc.)
  - One- and two-point correlations to quantify coherence
- Do droplets modify fluxes, temperature, humidity in the hurricane boundary layer?
  - Long-standing question!
  - Depends heavily on droplet abundance and transport
  - LCM ideally suited for answering this question

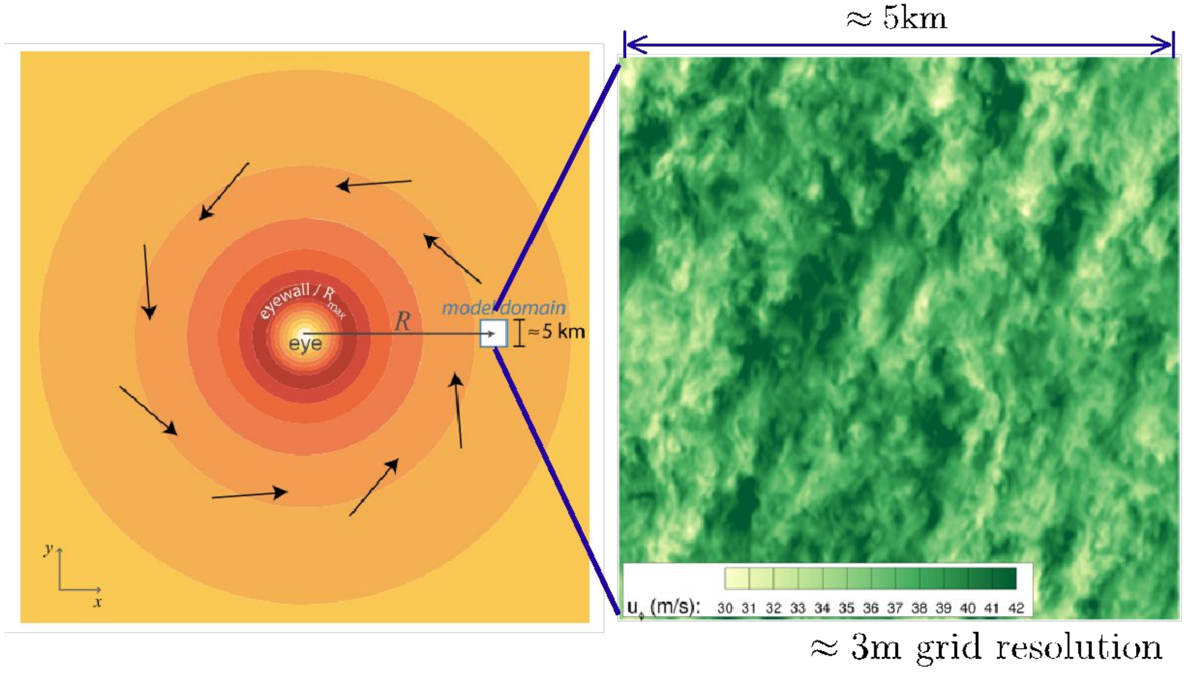




Preliminary simulations of the ASD configuration: temperature and vertical velocity in the hurricane boundary layer; spray droplets are colored by their size

Enter ASD project: Allow GPUs to accelerate the flow and droplet solvers

- Apply to the LES of the spray-laden hurricane boundary layer
  - A complex case with a known proliferation of spray
- High grid resolution (10 meter), O(10^9) droplets



Droplet/turbulence interaction and feedback as a function of:

- Radius relative to eye
- Surface roughness
- Gradient wind forcing

Computational characteristics of ASD project

- Utilize Cloud Model version 1 (CM1)
  - Fortran code MPI + OpenMP
  - Augment with Langrangian transport capability
  - GPU enablement through OpenACC directives
- Explore several different parameter settings of
  - Radius from hurricane center
  - Drag coefficient
- Resource requirements
  - 90K GPU-hours
  - 72 TB Campaign Storage

Computational characteristics of ASD project (con't)

- Why did we choose to use GPU nodes on Derecho
  - Large per device problem size offers significant per device parallelism
  - Straight forward OpenMP version of the code already existed
- Computational characteristics
  - Resolution: (2048 x 2048 x 1024)
  - Grid spacing (2.5m x 2.5m x 2.5m)
  - Droplets (10^5 – 10^9)
  - 6 hours of model time
  - 16-32 GPU nodes of Derecho
- Performance comparison
  - 4 V100 NVIDIA GPU
  - 4 Cheyenne CPU nodes
  - **~4.4x reduction in execution time versus CPU nodes**

Questions?

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