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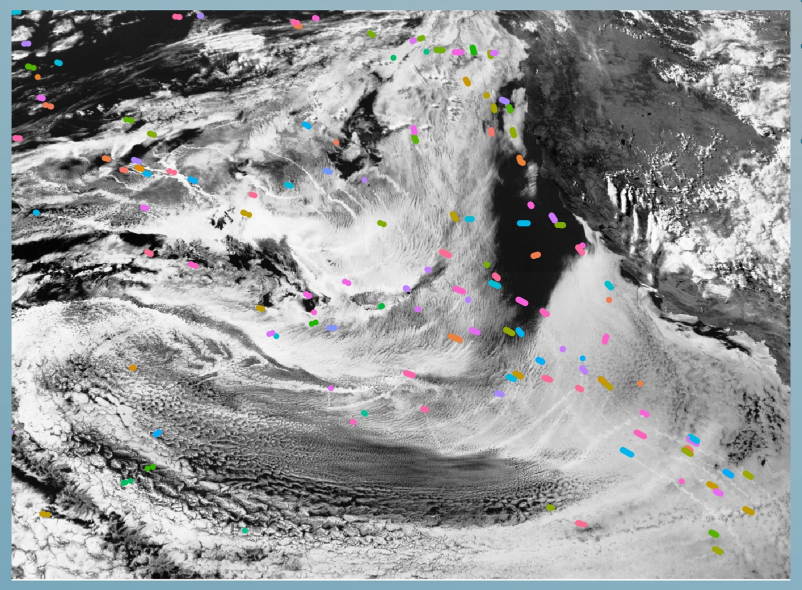
A NOVEL STOCHASTIC PARAMETERIZATION FOR LAGRANGIAN MODELING OF ATMOSPHERIC AEROSOL TRANSPORT

Abstract

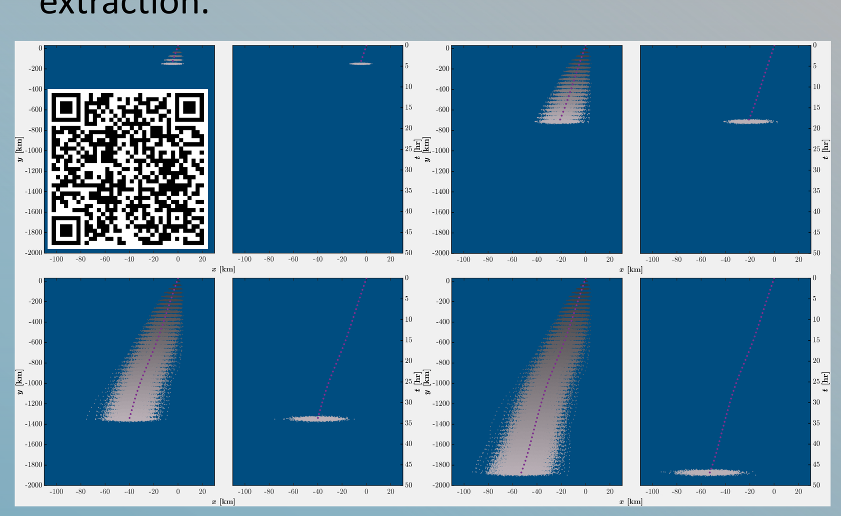
- Our climate is changing—this may get unpleasant.
- **Global climate models are**:
  - Critical to understanding these changes.
  - The best option to study dramatic intervention strategies.
    - E.g., stratospheric aerosol injection and/or marine cloud brightening.
  - Known to be imperfect.
- ***"The effect of anthropogenic aerosols on cloud droplet concentrations and radiative properties is the source of one of the largest uncertainties in the radiative forcing of climate over the industrial period."*** [Carslaw, Nature, 2013]
- **Goal:** Gain a better understanding of how injections of aerosols behave at fine scales.
  - Characterize the sub-grid dynamics of aerosol plume transport/mixing/spreading.

Ok, sounds good—How?

- Lagrangian (particle) model for aerosol transport. *(Schmidt, Patel, Bosler, UW Team)*
  - Stochastic wind parameterization.
  - Resolves sub-grid turbulent effects that drive plume spreading.



- Data sources:
  - LES results *(Blossey, Wood, McMichael—UW)*
  - Fog chambers *(Pattyn, Zenker, Wright, Sanchez)*
  - Satellite imagery of ship tracks
    - Temporary cloud trails from ship exhaust cloud seeding.
    - Actual example of anthropogenic MCB.
    - Apply ML model to generate parameterizations. *(Patel, Shand, Shuler, Warburton)*
    - Automated image recognition and feature extraction.



Mathematical Model

- We consider a conservative tracer transported via turbulent atmospheric flow according to the advection-diffusion equation

$$\begin{aligned} \frac{\partial q}{\partial t} &= -\nabla \cdot (q\boldsymbol{v}), & q(\boldsymbol{x},0) &= g(0;\boldsymbol{\mu}=\boldsymbol{x}_0,\boldsymbol{\sigma}_0),\\ \boldsymbol{v}(\boldsymbol{x},t) &= f(\boldsymbol{x},t), & \boldsymbol{v}(\boldsymbol{x},0) &= f(\boldsymbol{x},0),\\ \boldsymbol{x} &\in \mathbb{R}^d, & t &> 0. \end{aligned}$$

- The tracer mass is divided among particles with (a.s.) distinct positions and masses

$$\boldsymbol{x}_i(t),\ i=1,\dots,N_p, \qquad m_{\mathrm{TOT}} = \sum_{j=1}^{N_p} m_j(t).$$

such that the concentration field may be recovered as

$$\begin{aligned} q(\boldsymbol{x},t) &= \int_{\mathbb{R}^d} \sum_{j=1}^{N} m_j \phi(\boldsymbol{x}-\boldsymbol{z})\delta(\boldsymbol{z}-\boldsymbol{x}_j)d\boldsymbol{z}\\ &= \sum_{j=1}^{N} m_j \phi(\boldsymbol{x}-\boldsymbol{x}_j)\\ &:= \sum_{j=1}^{N} m_j \delta(\boldsymbol{x}-\boldsymbol{x}_j). \end{aligned}$$

- The particles move under the influence of wind, and particle positions evolve according to

$$\frac{d\boldsymbol{x}_i}{dt} = \boldsymbol{v}_i^*(t).$$

- We impose a stochastic parameterization for wind velocity

$$\mathrm{d}\boldsymbol{v}_i^*(t) = \frac{\overline{\boldsymbol{v}} - \boldsymbol{v}_i^*(t)}{T_\ell}\mathrm{dt} + \sqrt{\frac{2\boldsymbol{\eta}}{\mathrm{T}_\ell}}\mathrm{d}\boldsymbol{W}(\mathrm{t}),$$

and integrate in time as

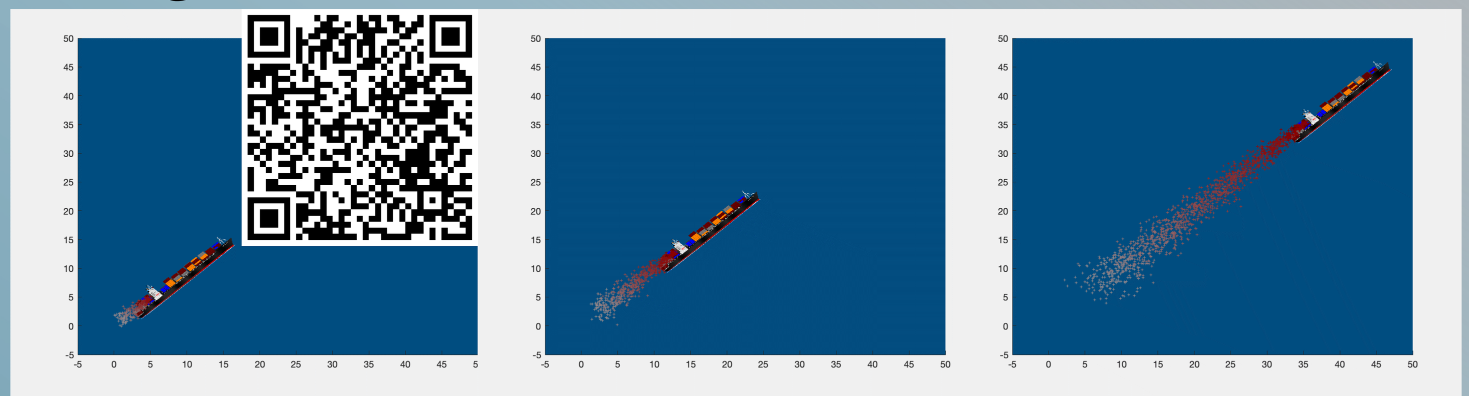
$$\boldsymbol{v}_i^*(t+\Delta t) = \boldsymbol{v}_i^*(t) + \frac{\left[\overline{\boldsymbol{v}} - \boldsymbol{v}_i^*(t)\right]\Delta t}{T_\ell} + \sqrt{\frac{2\boldsymbol{\eta}\Delta t}{T_\ell}}\mathrm{d}\boldsymbol{W}(\mathrm{t}).$$

In collaboration with:

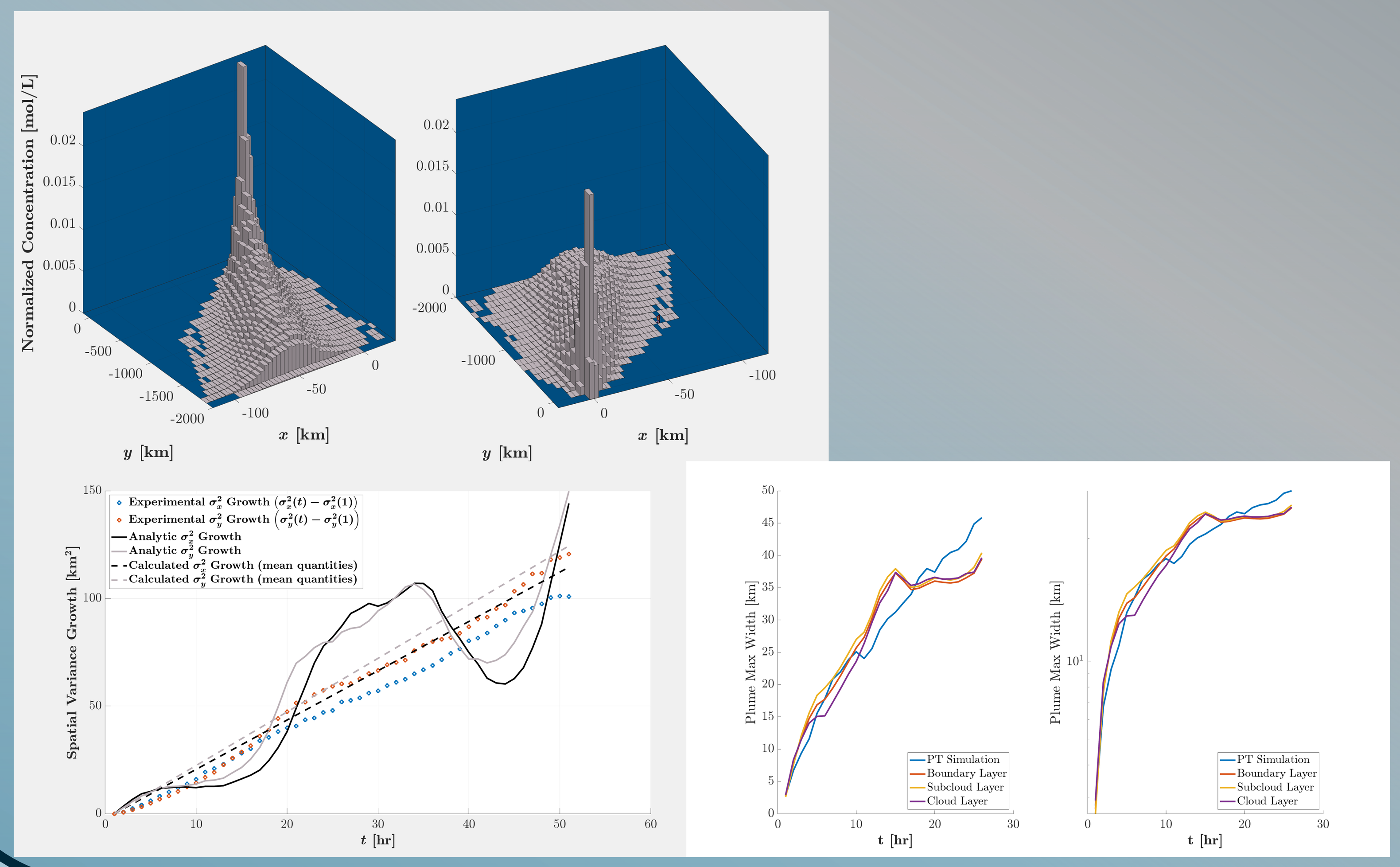
Lekha Patel[1], Peter Bosler[1], Lucas McMichael[2], Peter Blossey[2], Robert Wood[2]
[1]Sandia National Laboratories, [2]University of Washington

Test Problem Setup

- A traveling ship emits discretized packets of aerosols.
- We begin tracking this packet in the xy-plane when it becomes visible and continue this for 48 hours.
- While under observation, the particles are transported according to the stochastic wind model.
- The physical parameters are chosen to be Lagrangian analogues of those used in the LES simulations.



Results



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