Overview of the Puff-Particle Model (PPM)

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Acknowledgement

- The PPM was developed by Dr. Peter de Haan as part of his Ph.D thesis at the Swiss Federal Institute of Technology in Zurich, Switzerland. This presentation is based on a summary of his work as presented in the following references:

. de Haan, P., J.S. Scire, D.G. Strimaitis and M.W. Rotach, 1999: Introduction of a Puff-Particle approach for near-source dispersion into the CALPUFF model. 23rd NATO/CCMS ITM, Bulgaria. Air pollution Modeling and Its Application XIII, S.-E. Gryning and E. Batchvarova (eds.), Plenum Press, New York

de Haan, P. and J.S. Scire, 1999: Prediction of higher moments of near-source concentration by simulating the meandering of pollutant puffs. Preprints 13th Conference Boundary Layers and Turbulence, 10-15 Jan 1999, Dallas, TX. American Meteorological Society.

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Overview

- Puff-Particle Model (PPM) is a module introduced into the CALPUFF Lagrangian puff dispersion model to provide a more detailed treatment of near-field dispersion
- PPM combines the advantages of both puff and particle dispersion models
- Allows the model to predict both the mean concentration as well as the concentration distribution about the mean (higher moments of the probability density function)

Introduction

- Puff models such as CALPUFF offer advantages over steady-state plume models such as:
  - Accounting for spatial variability of meteorological and dispersion conditions, causality effects, low wind speed dispersion, memory of previous hour's emissions, spatial variability in dispersion rates, etc.
- Lagrangian stochastic particle models are:
  - State-of-the-science approach, especially for simulation of inhomogenous (convective) turbulence
  - Computationally demanding
  - More difficult to deal with wet and dry deposition, chemistry

Puff Models Types

- Ensemble average puff model
  - Puff consists of a center of mass and a 3-D distribution of total mass around the center
  - Represents the ensemble average of the concentration distribution belong to a “piece” of the pollutant release
- Cluster dispersion puff model
  - Puff is a physical cluster of particles
  - “Relative” dispersion (due to turbulent eddies smaller than the puff) contribute to puff cluster growth
  - Larger eddies move puff as a whole without changing the relative separation of particles within the cluster (meander component)

Puff-Particle Model

- Instantaneous puff releases require use of relative dispersion but update frequency of flow field is too low to resolve turbulent eddies not covered by relative dispersion concept
- PPM uses a full stochastic Lagrangian particle dispersion model to determine the puff trajectory
- Kinematic turbulent energy associated with eddies smaller than the puff size are removed since they are already accounted for the in relative dispersion
- Every puff carries along it position along with the position and turbulent velocity components of the stochastic particle to which it belongs

Puff-Particle Model

- Effect of meandering caused by turbulent eddies larger than the puff but not resolved by the flow is simulated by the puff center trajectories
- Two contributions of dispersion process:
  - Relative dispersion (small eddies)
  - Meander (large eddies)
- Stochastic path artificially produces the meandering behavior, but it is necessary to account for the spatial and temporal correlation of turbulence
  - Neighboring puffs should show similar meandering

Implementation of PPM into CALPUFF

- To every newly released puff a “mirror ensemble” is attached. This mirror ensemble consists of a user-defined number of puff-particles.
- Time step broken into sub-steps (sampling steps) in CALPUFF. For each sub-step the mirror ensemble is advected with a PPM time step (~1-10 seconds). For every PPM time step, new particle trajectories are computed, from which the puff trajectories are derived.
- At end of sampling step, mirror ensemble’s first and second moments of mass distribution are used to compute the parent puff’s size and position and then handed back to main CALPUFF routine

Implementation of PPM into CALPUFF

- CALPUFF then computes any physical process changing the puff's mass or chemical composition (but not its size or location)
- At some point, the size of the particle-puffs in the mirror ensemble will be large enough so that most of the energy spectrum will be within the puff-particle
  - Relative dispersion ~ same as absolute dispersion
  - Parent puff location and size is recomputed, the mirror ensemble is deleted and the parent puff is restored
  - Parent puff treated in normal CALPUFF way using absolute dispersion

Testing and Evaluation

- The PPM was evaluated using measurements from three tracer experiments.
  - Copenhagen
    - 9 hours measurements under convective conditions
    - 115m release height, suburban area
  - Lillestrom
    - 8 observations, 15-minute averaging times
    - Strongly stable winter conditions
    - 36m release height, suburban area
  - Kincaid
    - Mostly convective conditions
    - 171 hours of measurements
    - 187m power plant stack, rural environment
- Datasets are “reference datasets” developed as part of European short-range dispersion model harmonization workshops

Description of Evaluation Results

- Copenhagen
  - Good agreement of arcwise maximum concentrations with little overall bias and nearly all data points within factor of two of observations
  - Some underprediction of cross-wind integrated concentration (CIC)
  - Very similar results to those obtained with a full Lagrangian particle dispersion model (LPFM)
- Lillestrom
  - Generally good prediction of arc-maximum concentrations
  - Some displacement of location of peak concentrations
- Kincaid
  - Used QI=3 (highest quality) data
  - Agreement between predicted and observed arc-maximum concentrations was very good, with s light tendency toward overprediction of the highest concentration values