Shield - A system for urban emergency response modeling

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**Objectives:** To predict the transport of hazardous materials that are released into the atmosphere in urban areas. Provide results to other systems that protect building occupants.

**Method:** Accurately characterize the flow in urban areas from the metropolitan scale down to the individual buildings. Detect hazardous releases. Model transport and dispersion of hazardous materials.
Requirements

- Cover ~10x10 km domain
- Model resolution ~10m
- Account for 3D wind variability over whole domain
- Update wind analysis every 5-10 minutes
- Track plumes for several kilometers from release
- Produce 30 minute plume prediction in ~90s
Multiple Scales – Multiple Models

- NWP Model
- Radar Wind Analysis
- Lidar Wind Analysis

- Chem-Bio Sensors
- Cloud Detection

- Control GUI Display

- Quic-Urb

- Decision Support Systems
Multiple Scales – Multiple Models

- Diverse data sources
- Wide range of resolutions and domains
- How to merge into a multi-scale product suitable for T&D applications?

**Mesoscale**

**City**

**Neighborhood**

**Building**

**Grid Increment**

<table>
<thead>
<tr>
<th>Grid Increment</th>
<th>Model Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2 km</td>
<td>0-200 km</td>
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<tr>
<td>1/2 km</td>
<td>0-50 km</td>
</tr>
<tr>
<td>100 m</td>
<td>0-5 km</td>
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<tr>
<td>10 m</td>
<td>0-1 km</td>
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</tbody>
</table>
Meso Scale

Models
1. **MESO**: Mesoscale-model data-assimilation and forecast system (WRF)

3-D winds product interval
1. 12 hour forecast every hour

Grid Increment: 1-2 km
Model Coverage: 0-200 km
Meso Scale

RT-FDDA

- Full physics weather forecast model (WRF)
- Assimilates wide range of observations
- Metropolitan coverage
- New 12 h Domain 4 (85x85 km, 1.5km \(\Delta x\)) forecast every hour using real-time observations

**Observations**

**Forecast**

- LIDAR
- TAMDAR
- SATELLITE
- RADAR
- QUICKSCAT scatterometer
- UPPER AIR
City Scale

Models
1. **MESO**: Mesoscale-model data-assimilation and forecast system (WRF)
2. **CITY**: Doppler-radar assimilation system (VDRAS)

3-D winds product interval
1. 12-36 hour forecast every hour
2. Doppler-radar wind analyses every 6 minutes
Variational Assimilation Systems

VDRAS - Variational Doppler Radar Assimilation System
VLAS – Variational Lidar Assimilation System

- Simplified model and adjoint for assimilating radial wind and backscatter observations
- Provide analysis and short term forecast of wind, temperature, and other variables using single Doppler radar or lidar observations
- VDRAS typically run at a resolution ~1km over a domain of ~100-1000 square kilometers
- VLAS typically run at a resolution ~100m over a domain of ~10-100 square kilometers

Data Ingest
- Rawinsondes
- Profilers
- Mesonet
- Doppler data

Data Preprocessing
- Quality control
- Interpolation
- Background analysis
- First Guess

4DVAR Assimilation
- Cloud-scale model
- Adjoint model
- Cost function
- Weighting specification
- Minimization
VDRAS

- Most accurate wind solution when domain filled with radar returns - precipitation days or warm season
- Domain
  - 60 x 60 km domain
  - 250 meter horizontal resolution
  - 150 meter vertical resolution
  - Lowest level at 150 meters AGL
- Input
  - Background wind field (RTFDDA)
  - Radial wind measurements (Doppler Radar)
    - 1 NEXRAD 0.5° lowest elevation
    - 4 TDWR 0.0° lowest elevation
Neighborhood Scale Models

1. **MESO**: Mesoscale-model data-assimilation and forecast system (WRF)
2. **CITY**: Doppler-radar assimilation system (VDRAS)
3. **NEIGHBORHOOD**: Doppler-lidar assimilation system (VLAS)

3-D winds product interval

1. 12-36 hour forecast every hour
2. Doppler-radar wind analyses every 6 minutes
3. Doppler-lidar wind analyses every 6 minutes
VLAS

- Most accurate wind solution when domain filled with lidar returns - clear days
- Domain
  - 6 x 6 km domain
  - 100 m horizontal resolution
  - 50 meter vertical resolution
  - Lowest level at 25 meters AGL
- Input
  - Background wind field
    - RTFDDA, VDRAS
  - Radial wind measurements
    - WindTracer Doppler lidar
WindBlender

- Use diagnostic wind model to blend data from various wind models
  - RTFDDA
  - VDRAS
  - VLAS

- Provides
  - Common operating picture
  - Data redundancy
  - Completes areal coverage

- Domain
  - 20 x 20 km domain
  - 100 m horizontal resolution
  - 50 meter vertical resolution
  - Lowest level at 25 meters AGL
Building Scale

Models
1. MESO: Mesoscale-model data-assimilation and forecast system (WRF)
2. CITY: Doppler-radar assimilation system (VDRAS)
3. NEIGHBORHOOD: Doppler-lidar assimilation system (VLAS)
4. BUILDING: Diagnostic CFD model (QUICUrb, LANL)

3-D winds product interval
1. 12-36 hour forecast every hour
2. Doppler-radar wind analyses every 6 minutes
3. Doppler-lidar wind analyses every 6 minutes
4. CFD wind analyses for every lidar analysis of skimming-flow winds
Tiled QUIC-Urb Domain

- Diagnostic model, Röckle empirical formulation

- Overall area of interest too large to run a single QUIC-Urb domain: $O(10^7)$ grid points

- Large number of buildings requires automated process to generate building database: $O(10^4)$ buildings, $O(10^5)$ building elements

- QUIC-Urb tile issues:
  - Optimum solution that minimizes errors while providing a timely large domain QUIC-Urb wind map
  - How should the tiles be configured?
  - What amount of tile overlap will be required?
  - What are the wind solution errors associated with this solution?
Tiled QUIC-Urb Domain

- Generation of the QUIC-Urb compatible building database is a non-trivial task
  - Automated and manual quality control required
  - ~100,000 building elements
  - The large number of buildings requires automated processing
  - Algorithm based upon PFGA task loading

Building Shape Files
Urban Shield

• Current configuration contains 4 overlapping QUIC-Urb tiles
  – Each 6km square
  – 200 meter overlap
  – 20m horizontal resolution

• Tiles run in parallel on separate cores within a single CPU

• ~4 minutes to complete and merge
Urban Shield

- Location of QUIC-Plume domain determined by prevailing winds at release location
- T&D domain able to span multiple QUIC-Urb tiles
Urban Shield

Threat zones
Inverse modeling application
Used for operational situational awareness

Moving point releases
Dense gas effects
Variety of source terms
Fast building-aware simulations and intuitive displays allow for:

- Evacuate vs shelter-in-place decisions
- Location of command posts in safe zones
- Establishment of evacuation routes
- Defining areas requiring decontamination
- Definition of threat zones
- Adjustment of HVAC systems
GPU Computing

1 M particles on NVIDIA GPU, real time animation
GPU Computing

Supercomputer performance at low/no cost
Developed by:
Eric Pardyjak, University of Utah
Pete Willemsen, University of Minnesota
Multiple Scales – Multiple Models

- NWP Model
- Radar Wind Analysis
- Lidar Wind Analysis

- Chem-Bio Sensors
- Cloud Detection
- Control GUI Display

- Blended Wind Field
- QUIC-Urb
- QUIC-Plume

- Decision Support Systems

- Non-building Aware Model
- Process Algorithm
- Building Aware Model
- Sensor
QUESTIONS?