Atmospheric Transport and Dispersion: Research Needs and Priorities

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A Multiscale Environment

- **Micrometeorology is a mixture of large and small scale forcing**
  - **The large scale synoptic forcing determines the overall stability and wind field**
  - **The local geometric (mechanical) forcing modifies the wind field**
  - **The local land-use (thermal) forcing also modifies the wind field**
  - **The local modifications may trigger instability**
- **Atmospheric dispersion of contaminants depends on the details**
  - **Advection is driven by the *total* wind field (large & small scale)**
  - **Vertical transport in the micrometeorology system is a mixture of *implicit* mixing dominated by the increased turbulence of the non-uniform surface properties and *explicit* lofting due to mechanically or thermally driven vertical wind**

All Scales are Involved

- Synoptic scale (0.01 mb/km)
  - Duration of incoming weather
- Mesoscale (hydrostatic) (0.10 mb/km)
  - Large scale forcing (or lack thereof)
- Microscale (non-hydrostatic) (1 mb/km)
  - Terrain forcing (or lack thereof)
- Urban scale (10 mb/km)
  (also applies to extended military facilities)
  - Building & Thermal forcing

A Hierarchy of Atmospheric Forcing

Scenario	Pressure Change (mb)	Horizontal Scale (km)	Pressure Gradient (mb / km)
Synoptic (meso-α)	10	1000	0.01
Mesoscale (meso-β)	10	100	0.10
Urban Scale – Mechanical Light Wind (2 kt)	0.006	0.05	0.12
Cloud Scale (meso-g)	2	4	0.50
Land / Sea Boundary	1	1	1.00
Urban Scale – Thermal 2 K Urban Heat Island	24	20	1.20
Urban Scale – Mechanical Strong Wind (10 kt)	0.16	0.05	3.20
Terrain Elevation 5 % Grade	5	1	5.00

All Weather Phenomena are Involved

- All synoptic conditions must be considered
  - Strong forcing (large air-mass interaction)
  - Weak forcing (local thermally driven circulations)
- Dispersion depends on much more
  - Weak forced situations create substantially worse hazards
  - Overcast situations depress the UV degradation of bio agents
  - Moisture hydrolyzes many chemical agents
  - OH- oxidizes many chemical agents
  - Precipitation scavenges chemical & biological agents

Scale Interaction is Critical

- **From 1000 km to 1 m (10^6) / From 3 days to 5 min (10^3)**
  - **Downscale interaction is evident**
  - **Upscale interactions include:**
    - **MCCs**
    - **CBs**
    - **Orographic & Land / Sea circulations**
    - **Urban heat island**
- **This is a stiff problem mathematically if treated exactly**
  - **Timestep & memory limits**
  - **All operational weather forecast system are scale specific**

The combination of weak forcing and multi-scale problems is especially difficult due to the "stiffness" of the exact system which leads to the current limits of our physical understanding, physical modeling, and computational ability

Urban Parameterization

$$\frac{DU}{Dt} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + fV - \frac{\partial < uu_j >}{\partial x_j} - f_{urb} C_d a(z) U|U|$$

← Drag

$$\frac{Dtke}{Dt} = \delta_{i3}\frac{g}{\Theta} < u_i\theta > - < u_i u_j > \frac{\partial U_i}{\partial x_j} - \frac{\partial < u_j \cdot tke >}{\partial x_j}$$

$$-\frac{1}{\rho}\frac{\partial < u_i p >}{\partial x_i} - \varepsilon + f_{urb} C_d a(z)\left(|U|^3 + |V|^3\right)$$

← TKE production

$$Q^* = (R_{L\downarrow} - R_{L\uparrow}) + (R_{S\downarrow} - R_{S\uparrow})$$

$$= (1 - f_{urb})\{(1-\alpha_G)R_{S\downarrow} + \Delta R_L\} + f_{cnyn} R_{N_{hc}} \exp[-k \cdot bai(0)]$$

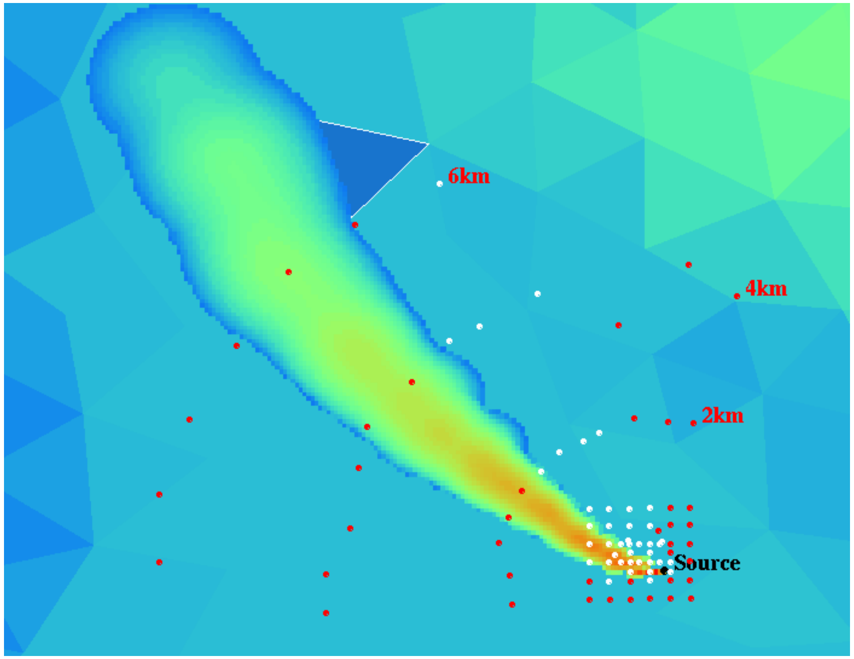
$$= Q_H + Q_E + Q_G$$

Surface energy budget modification

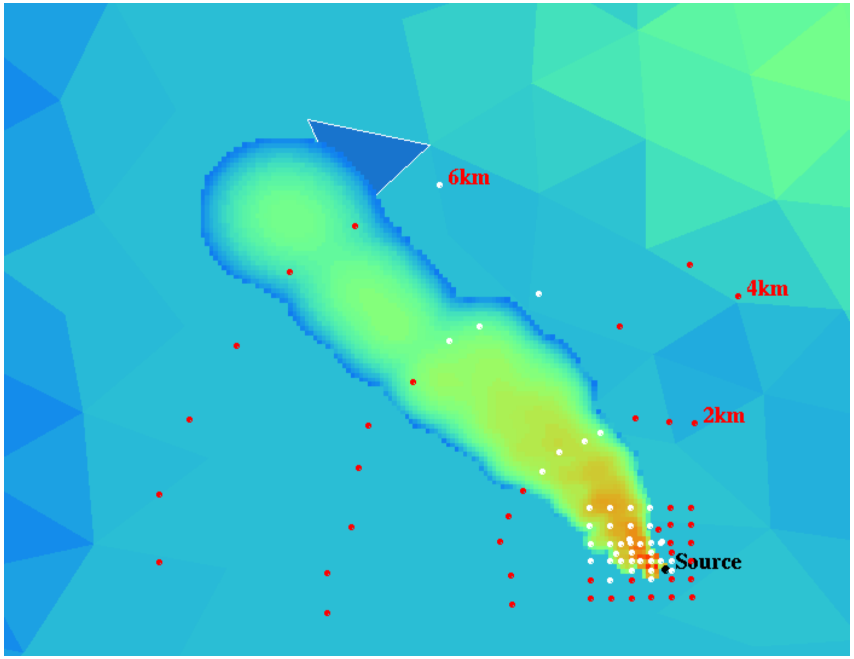
OMEGA Simulation of URBAN 2000

(Midnight 10/25 to 1:00 am 10/26)

Without Urban Parameterization



With Urban Parameterization



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A Hard Dose of Reality

- **Urban issues dominate the Offensive, Defensive, & Homeland Security scenarios**
- **Urban warfare is now the norm**
  - **Most of the recent Marine deployments involved urban areas**
  - **US Forces are ill-prepared to fight in an urban setting**
- **Terrorist activity is likely to focus on urban targets**
  - **The nature of terror is to put fear into a population**
  - **The population is based in the cities**
- **Weapons of Mass Destruction (WMD) are now readily available world-wide**

Our adversary generally has the home court advantage and while we may overcome the advantage with superior technology most of the technology is susceptible to the (local) weather. Unless we understand the details so that we can use that technology to its fullest we mitigate to a large extent the investment in technology.

The Fundamental Question:
Which Way Does the Wind Blow?

- **NOAA Washington DC Testbed**
  - **80 – 90º Difference between DCA & Downtown *Building Tops* (!)**
  - **Need winds *inside* the urban canyon**
- **Thermally driven often outnumber mechanically driven situations**
  - **Implies a need to understand the urban micro-climate**
    - » **Implies a need for more surface information**
- **Cannot measure everywhere – so we need to know how to analyze what we do measure properly**

Required: An Integrated Program

- Basic Observing Program
  - Atmospheric processes in an urban environment
  - Remote sensing of surface thermal properties
- Fundamental Algorithm / Process Modeling
  - Surface properties derived from remote sensing
  - Parameterized air-surface interaction
- Numerical modeling / Computational Science
  - Advanced algorithms for data assimilation & prognostic forecasting
  - Methods for real-time data mining & dissemination
- Real-time Information Transfer
  - Push / Pull binary, graphic, & text data

Technology Challenges - I

- **Remote Sensing**
  - **Surface properties**
    - » **Albedo, heat capacity, thermal conductivity, porosity**
    - » **Vegetation, anthropogenic activity**
  - **Atmospheric condition**
    - » **Temperature, moisture, wind profiles**
    - » **Precipitation, aerosols, trace gases**

Point weather forecasting depends on the details. A general understanding of the surface and atmosphere is insufficient.

Technology Challenges - II

- **Transition from observations to information**
  - **PSALM**
    - » **Property / Sensor / Analysis / Local verification / Model interface**
  - **Physical modeling**
    - » **Detailed surface fluxes in complex and urban terrain**
    - » **Cloud processes**
    - » **Radiative feedback of aerosols**
    - » **Multiscale interactions**

A model is the instantiation of our knowledge of a system. If we cannot formulate a model, then we must ask whether we truly understand the problem.

Technology Challenges III

- **High performance computing**
  - **Numerical methods on massively parallel platforms**
  - **Operational implementations of HPC**

    The U.S. government is falling behind other countries in large-scale weather prediction and climate modeling because it overemphasizes the need to achieve megaspeeds across multiple processors. . . The government's high-performance computing programs focus too much on achieving trillions of floating-point operations per second, thereby marginalizing Earth science computing.

    - Ricky Rood (Data Assimilation Office, NASA/GSFC)

    I personally don't think it's a matter of transporting existing codes, my suspicion is we're going to need new ways of solving the equations.

    - David Evans (NOAA / OAR)

- **Integration of sensors & data mining**
  - **Space-based reconnaissance**
  - **UAV & Internetted sensor platforms**
  - **Mining information from a sea of data**

Technology Challenges - IV

- **Data Transfer**
  - ***It is not what you know – it is what you think of in time!***
    Salada Tea
  - **Need to convert bits into information into knowledge**
  - **Need tools to provide binary, graphic, and text output**
- **Response Support**
  - **Need automated decision support tools to collapse the decision tree and shorten the response time**