High resolution urban air quality modeling with an immersed boundary method in WRF

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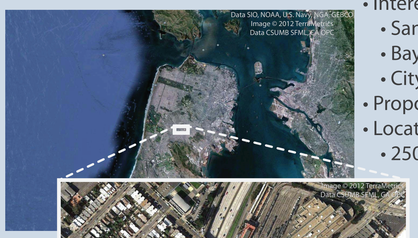
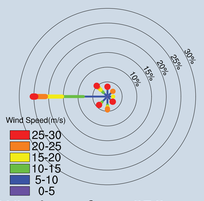
MOTIVATION



Proposed affordable housing location

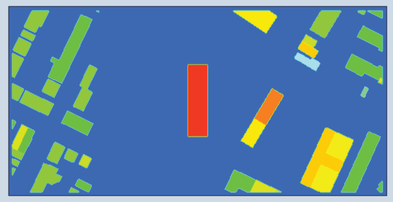
- Interest in modeling urban air quality
  - San Francisco Department of Public Health
  - Bay Area Air Quality Management District
  - City of San Francisco
- Proposed affordable housing development
- Located downwind from interstate 280
  - 250,000+ vehicles per day
- Modeling using IBM-WRF
  - Complex terrain
  - Building-resolving
  - Mesoscale to microscale nesting
  - Realistic meteorological input



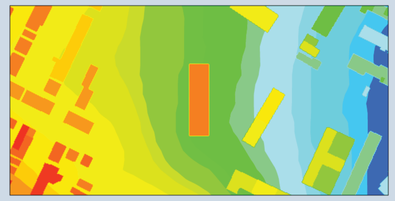
Windrose from SFO met tower
June 2011 - May 2012

- Proposed development location is within the San Bruno gap
  - An opening in the coastal mountains
  - Funnels the seabreeze from the Pacific Ocean
  - Creates consistent westerly winds

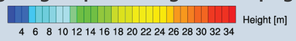
DOMAIN



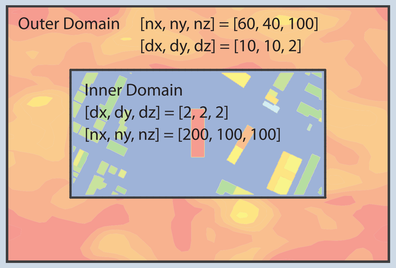
Average building heights AGL



Building heights plus background topography

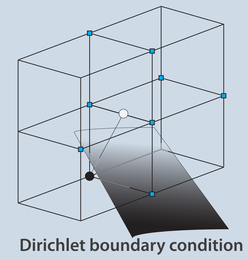


- Semi-idealized domain setup for preliminary testing
- Outer domain
  - Flat plate
  - Periodic boundary conditions
  - Run for 2 hours to develop turbulence
- Inner domain
  - Includes buildings from a San Francisco Department of Public Health dataset
  - 1-way nested configuration



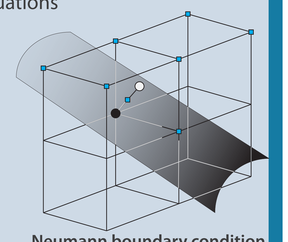
IBM-WRF

- Lundquist et al. 2010, 2012
- Weather Research and Forecasting model (WRF) modified to use an immersed boundary method (IBM)
  - Allows representation of urban geometries in WRF
- Cartesian rather than terrain following vertical coordinate
  - Terrain intersects grid, resulting in "cut cells"
  - Computational nodes in solid domain & adjacent to cut cells are "ghost-points" (black circle)
  - Ghost-point values establish appropriate boundary conditions through addition of body force term to conservation equations for momentum & scalars (equations #1a & #1b)



Dirichlet boundary condition

Equation #1 (a.): $\partial_t V + V \cdot \nabla V = -\alpha \nabla p + \nu \nabla^2 V + g + F_B$
(b.): $\partial_t \varphi + V \cdot \nabla \varphi = \nu_t \nabla^2 \varphi + F_\varphi + F_B$

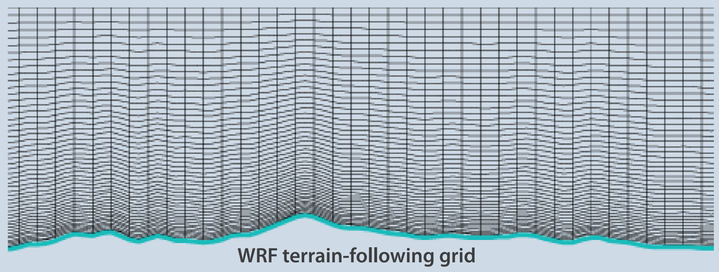


Neumann boundary condition

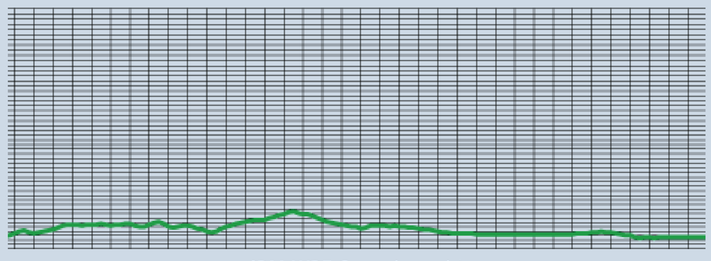
INTERPOLATION TECHNIQUE

- Ghost cell (black circle) is reflected across the boundary and labeled an image point (white circle)
- 8 nodes nearest the image point and within fluid domain (blue squares) are used in an inverse distance weighted interpolation scheme
- Ghost-point value is determined using image-point value & equation #2a or #2b.

Equation #2 (a.): $\varphi_G = 2\varphi_\Omega - \varphi_I$
(b.): $\varphi_G = \varphi_I - \overline{GI} \left. \frac{\partial \varphi}{\partial n} \right|_\Omega$

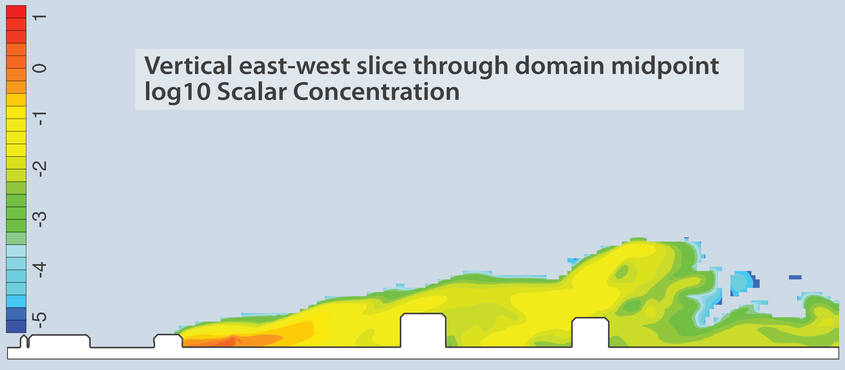


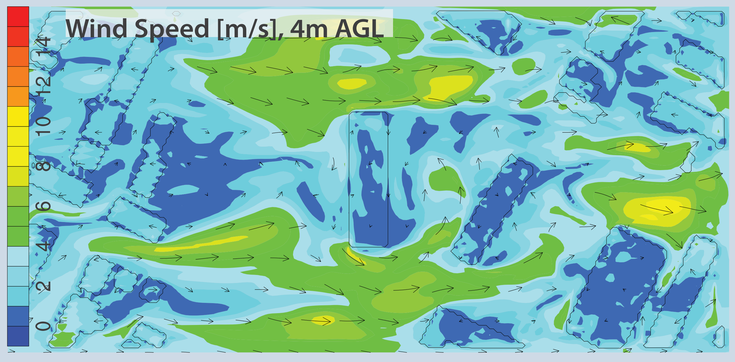
WRF terrain-following grid

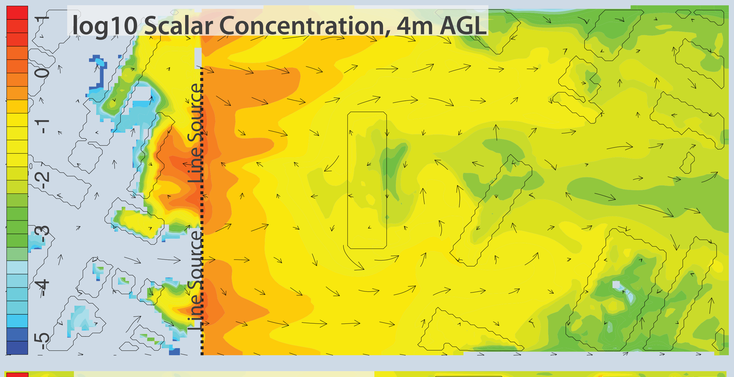


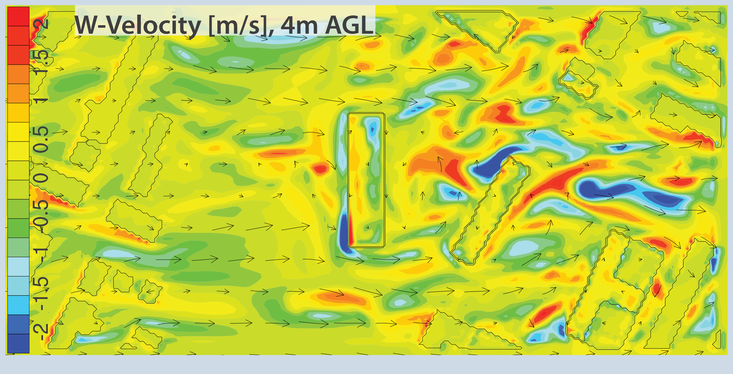
IBM-WRF Cartesian grid

RESULTS



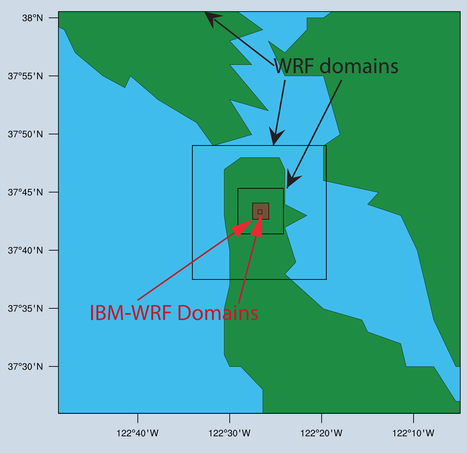


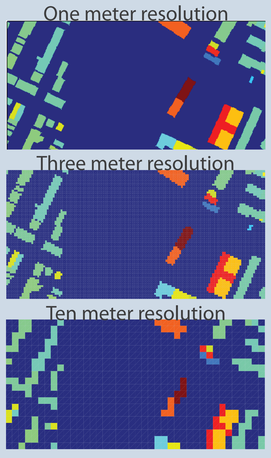




WRF TO IBM-WRF NESTING

- Concurrent one-way nesting from WRF domain to IBM-WRF domain
- Currently in development!
- Enables transfer of meteorological information from mesoscale to microscale
- Issue of illresolved terrain features on middle resolution nests
  - Virtual buildings / addition of drag to nodes within poorly resolved terrain features





CONCLUSIONS

If you have any questions please contact me at wiersema@berkeley.edu

- Preliminary testing shows that IBM-WRF performs well when simulating flow through complex urban terrain
- With continued modification, IBM-WRF will be well equipped for high resolution urban air quality modeling

REFERENCES

Lundquist, K.A., Chow, F.K., and J.K. Lundquist. 2010: An immersed boundary method for the Weather Research and Forecasting model. *Mon. Weather Rev.* **138 (3)**, 796-817.

Lundquist, K.A. 2010: Immersed boundary methods for high resolution simulation of atmospheric boundary-layer flow over complex terrain. Ph.D. thesis, University of California, Berkeley.

Lundquist, K.A., Chow, F.K., and J.K. Lundquist. 2012: An immersed boundary method enabling large-eddy simulations of complex terrain in the WRF model. *Monthly Weather Review*, in press.

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