Progress Towards An Improved High-Fidelity Forecasting Capability using Combined Mesoscale and Microscale Models

Presented by

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at the

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Hazard and Environmental Modeling Session

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Outline

- **Summary of the SBIR Phase I Findings**
- **Overview of coupling framework using MCEL**
- **CFD Model and Related Software Development Overview and Progress**
    - **Cartesian Adaptive Mesh Refinement-based Virtual Cell Embedding**
    - **Specialized Parallel RANS Solver**
    - **Wind library database and common file format**
- **Work plan**

Acknowledgements

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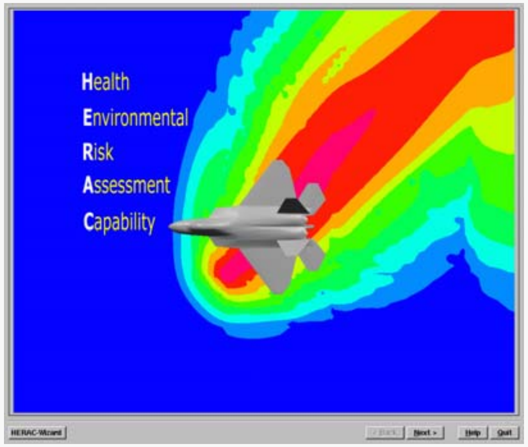
Defense Applications Branch

Mission

Support the DOD, DHS, DoE and Industrial Customers via Technology Transfer of First-Principles Based Scientific Computing Applications and Methodologies

AFFTC Edwards AFB

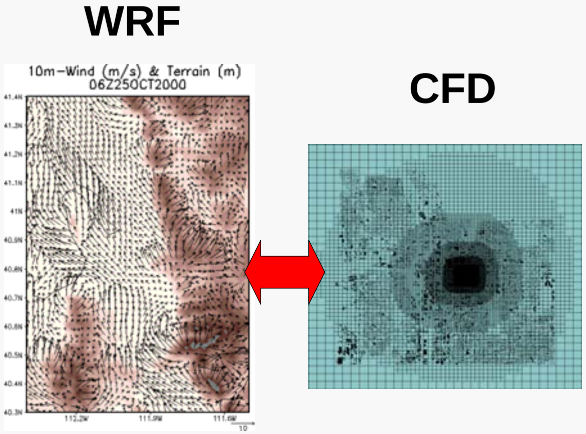
Health and Environmental Risk Assessment Capability: HERAC



CFD-based Risk Assessment for A/C Maintenance

DTRA

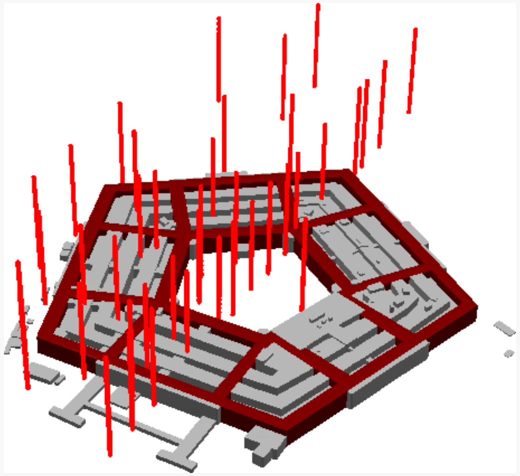
Coupled Micro- and Mesoscale Weather Models



Improved High-Fidelity Microscale T&D via Coupled NWP and CFD

PFPA/DARPA

Pentagon Shield CFD Model Component



Operational Force Protection System to Guard against CBRN/E

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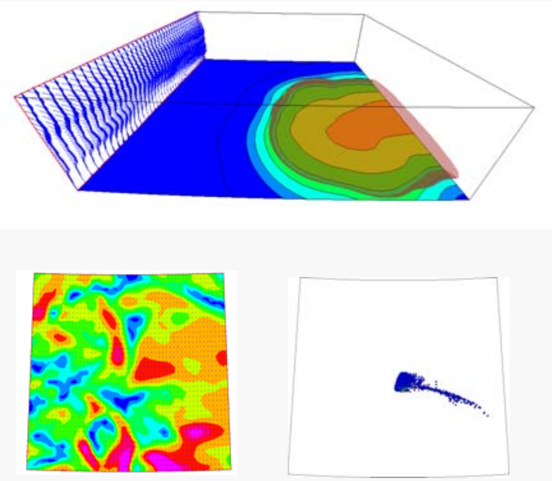
DTRA

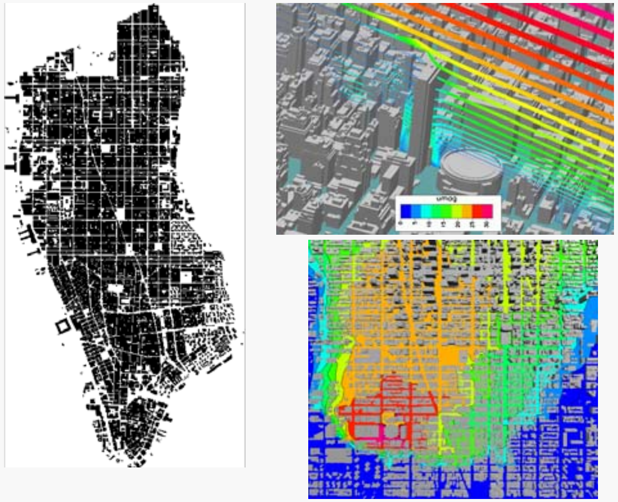
Real-Time 3D Visualization Capability



Client/Server Visualization Capability for Next Generation Consequence Assessment Models

DHS/DTRA

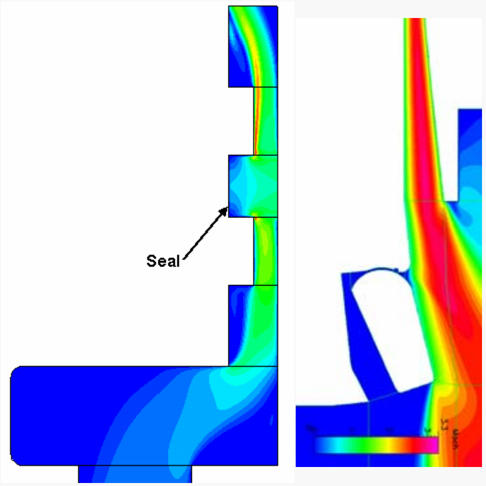
CFD Support for National Field Tests



Transport and Dispersion Studies Pre- and Post-Test, Urban Dispersion Program (UDP)

NASA

CEV Heat Shield Gap Analyses



Ablator Gap Seal Flow and Heat Transfer Analyses

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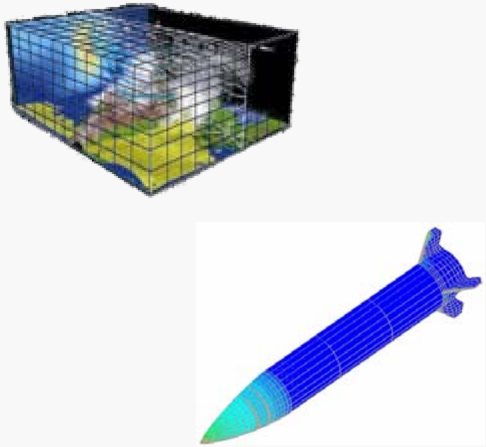
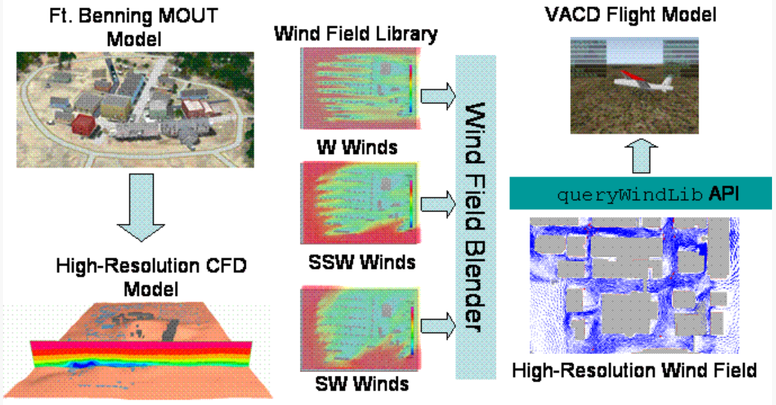
Army	AFRL/VACD	Private Firm
Missile Weather Encounter Modeling Software	**High Resolution Micro-UAV Wind Fields**	**Building Environmental Impact Study**





Couple GCAT output and ATAC Missile Model: Coatings, Ablation, Hydrometeor Impact…

CFD Wind Libraries for use by Micro-UAV Flight Vehicle Models

Determine effect of potential building in Manhattan

WRF + CFD-Urban: Investigate Improved T&D Capability

SBIR Phase I: "*Improved High-Fidelity Forecasting Capability using Combined Mesoscale and Microscale Models*"

  - **Tech. Monitor: CDR Stephanie Hamilton**

- **Investigate improvement in T&D accuracy via merging capability of Mesoscale and Microscale Models**
- **Focus upon community models:**
  - **Weather Research and Forecasting Model: WRF**
- **Evaluate Downscale Data Transfer upon CFD-Urban T&D Accuracy:**
  - **Use Urban 2000, IOP 10, Compute Statistical Measures**
    - **Raging Waters Met Station input (baseline)**
    - **WRF Forecast Mode: Noah and Noah/UCM Urban Parameterization Schemes**
- **Investigate Upscale Data Transfer: Compare WRF and CFD-Urban Fields**
- **Demonstrate Operational Concept:**
  - **Cyclical Met Data Ingest using Event-Driven CFD-Urban**

CFD-Urban: Urban Area T&D Model

Computational Fluid Dynamics Modeling for Wind, Turbulence, Transport and Dispersion in Urban Areas

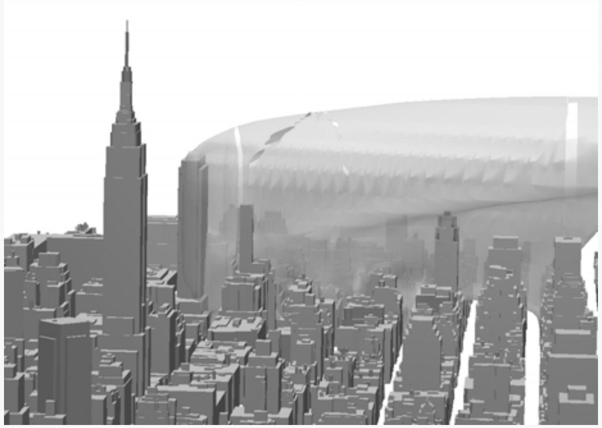
Specialized Model Generation, Setup, Processing

Building Models: GIS, Lidar/imagery, CAD

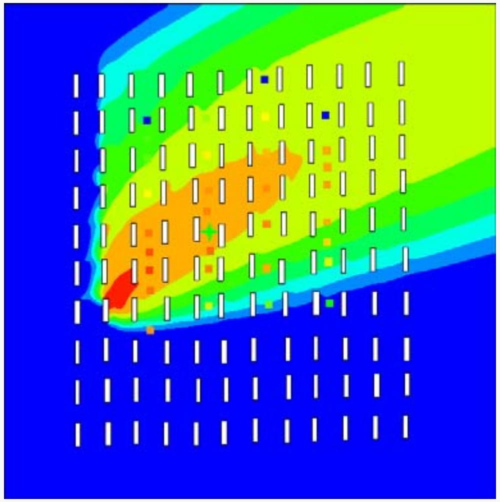
Flow and Turbulence: Steady/Unsteady, RANS, LES

Transport: Eulerian (gases), Lagrangian (particles)

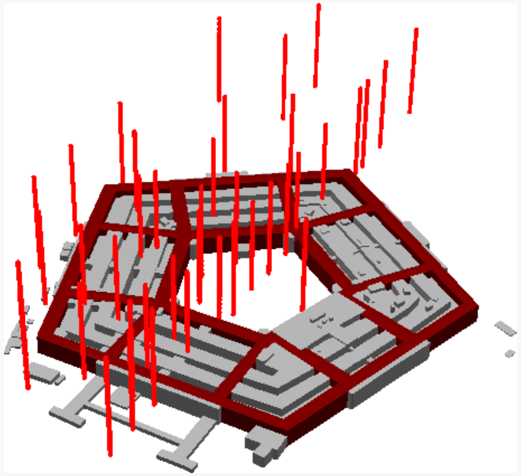
Vertical Mixing, Lateral Spreading, Turbulence Generation



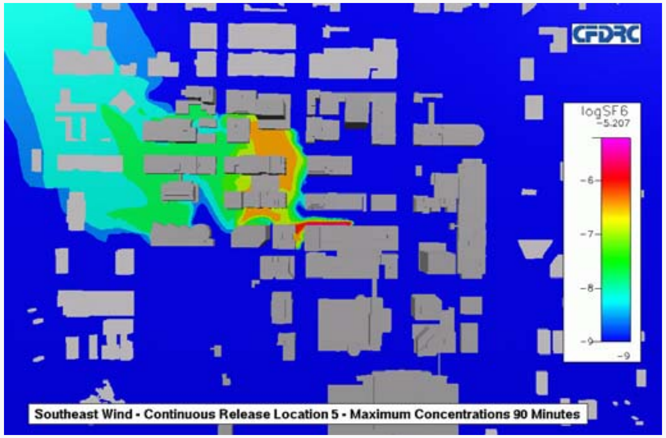
MSG05 and MID05 Support



MUST



Pentagon Shield Model



JU2003 Support

T&D Model Accuracy Characterization: IOP 10 Urban 2000

- **Urban 2000: Field Test conducted in Salt Lake City**
  - **SF6 released in Central Business District**
  - **Samplers located in CBD and on “arcs” located downstream**
  - **WRF Forecast Corresponding to IOP 10**

•Statistical Comparison of Predicted to Measured Concentration Data on arcs noted

$$\mathrm{FB}=\frac{\left(\overline{C_o}-\overline{C_p}\right)}{0.5\left(\overline{C_o}+\overline{C_p}\right)}$$

$$\mathrm{MG}=\exp\left(\overline{\ln C_o}-\overline{\ln C_p}\right)$$

$$\mathrm{NMSE}=\frac{\overline{\left(C_o-C_p\right)^2}}{\overline{C_o}\;\overline{C_p}}$$

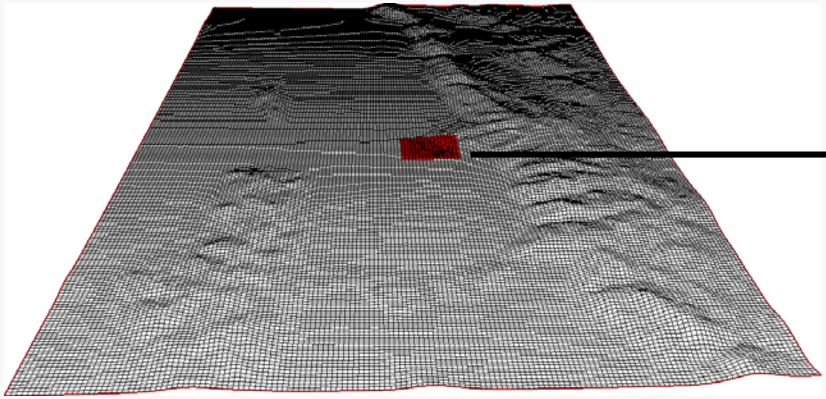
$$\mathrm{FAC2}=\text{fraction of data that satisfy }\; 0.5\le\frac{C_p}{C_o}\le 2.0$$

$$\mathrm{VG}=\exp\left[\overline{\left(\ln C_o-\ln C_p\right)^2}\right]$$

Acceptable values:

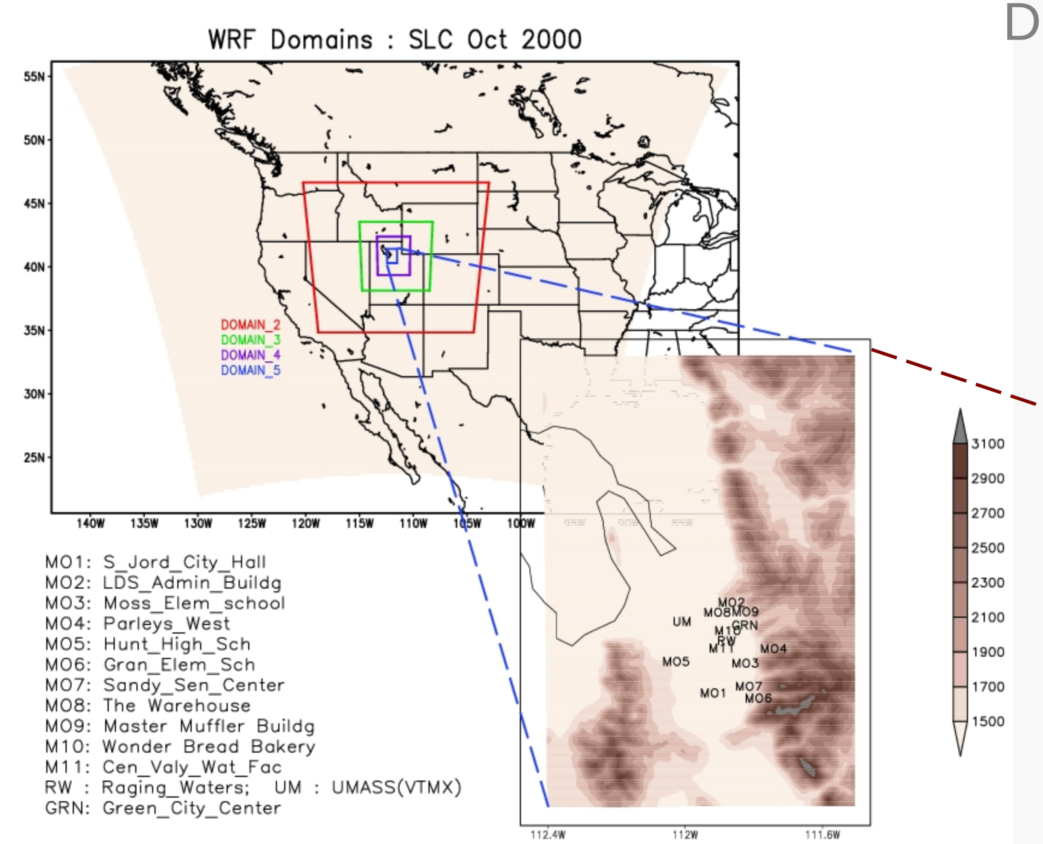
- **FAC2 > 0.5**
- **-0.3 < FB <0.3 (0.7 <MG < 1.3)**
- **NMSE < 4 (VG <1.6)**

WRF Lowest Grid Level



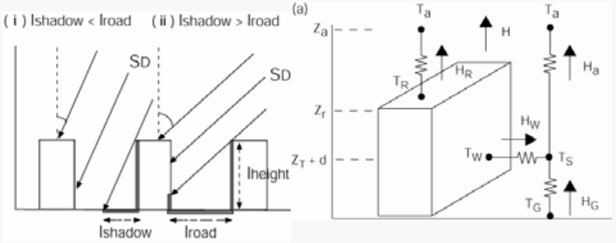
WRF Forecast Model Runs: Urban 2000 IOP 10 Period

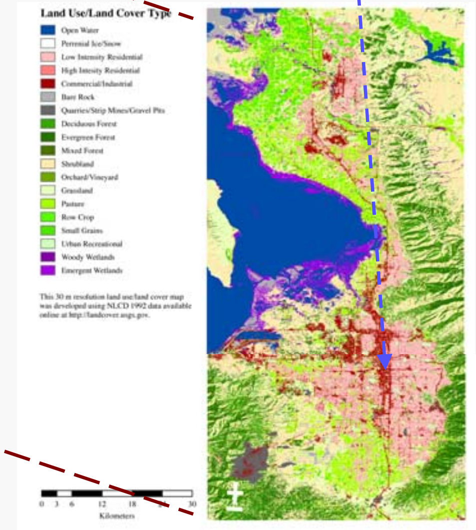
Domains: 40.5,13.5,4.5,1.5,0.5 Km



Complex terrain on WRF nested D-5 (0.5 km grid spacing) over the Salt Lake City area

Single layer Urban Canopy Model





Complex urban land use distribution over SLC

WRF to CFD-Urban: Downscale Transfer Procedures

- **Process WRF datasets (NetCDF format):**
  - **Interpolate data to CFD-Urban grid boundary faces**
  - **Continuous, linear interpolant**

$$f_L = \sum_{n=1}^{4} N_n f_n \qquad f_U = \sum_{n=5}^{8} N_n f_n \qquad f(x,y,z) = f_L + (f_U - f_L)\frac{(z - z_L)}{(z_U - z_L)}$$

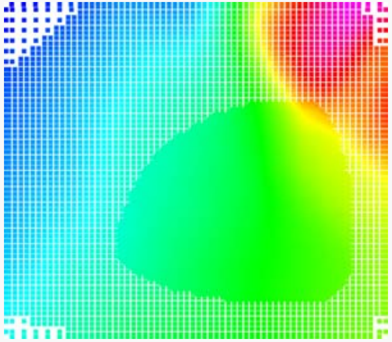
- **Pressure: Remove hydrostatic variation by subtracting ideal atmosphere and imposing base pressure on this "column"**
  - **Allows imposition of lateral pressure gradient from WRF**

$$\Delta P = P_{WRF,G} - P_h = P_{WRF.G} - P_b\left[1 - \frac{1}{\kappa}\frac{g}{RT_b}(z - z_b)\right]^{\kappa}$$

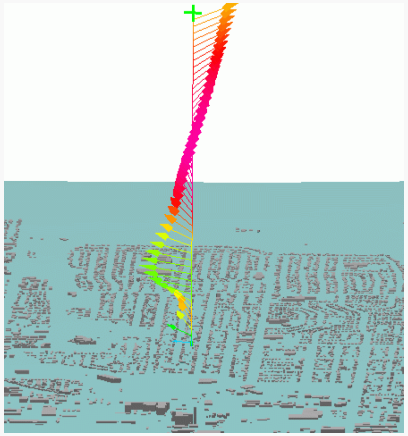
- **Turbulence Field:**
  - **Directly use TKE from the MYJ model ("TKE_MYJ")**
  - **Compute TKE dissipation rate using TKE and momentum diffusion coefficient ("AKM_M")**

$$\varepsilon = \rho C_\mu k^2 / \mu_t$$

Lateral, WRF Imposed Pressure Gradient



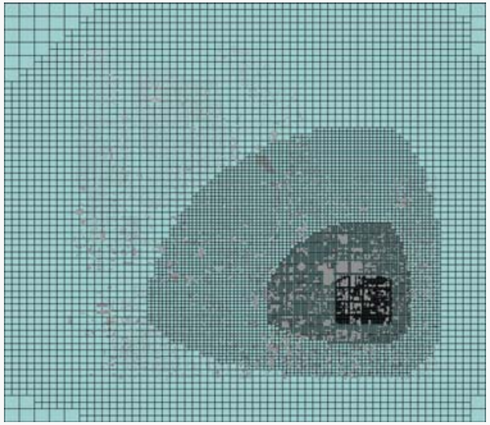
Flow Turning



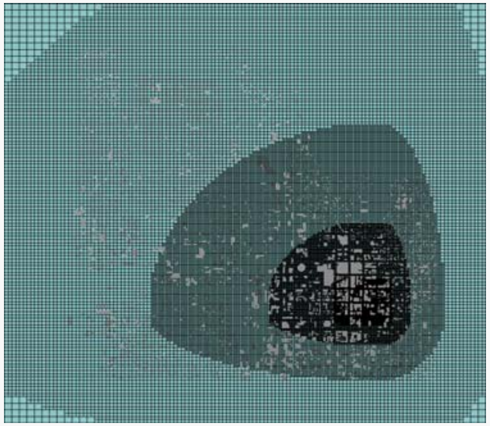
CFD-Urban Model Runs

- Unsteady Mode:
  - Solve Mass, Momentum, Turbulence Model Equations, and Transport Equation unsteady
- Quasi-Steady Mode:
  - Use libraries of equilibrium wind fields computed at different times: 15 minute intervals from WRF output
- Downscale Data Transfer (Boundary Conditions)
  - Isolated Met Station Input: Raging Waters (baseline)
  - WRF/Noah: 15 Minute Intervals
  - WRF/Noah/UCM: 15 Minute Intervals
- Cartesian Adaptive/Prismatic Grids
  - Quadtree in (x,y), Extruded in z
  - High resolution where needed with high grid quality
  - Coarse: 20 to 200 m
  - Fine: 10 to 100 m
  - 8.4 x 7.4 Km Domain

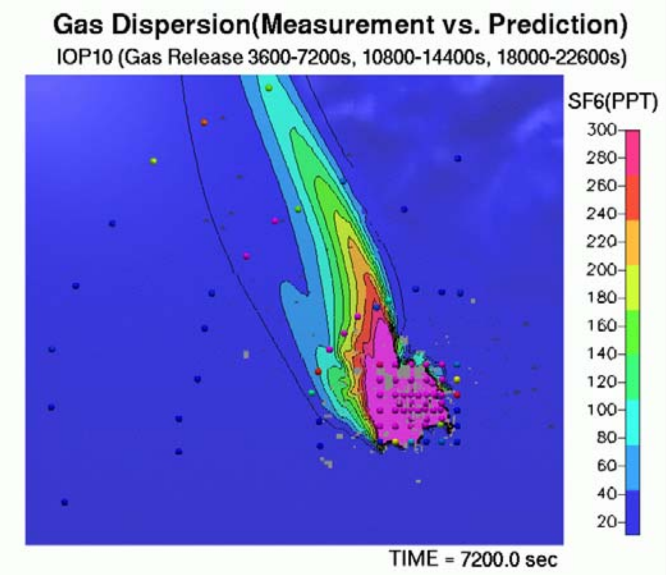
Coarse: 325,000 cells

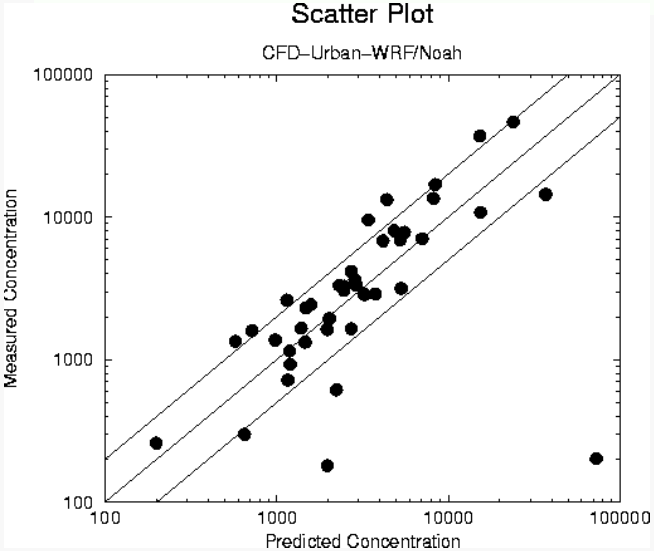


Fine: 1,300,000 cells



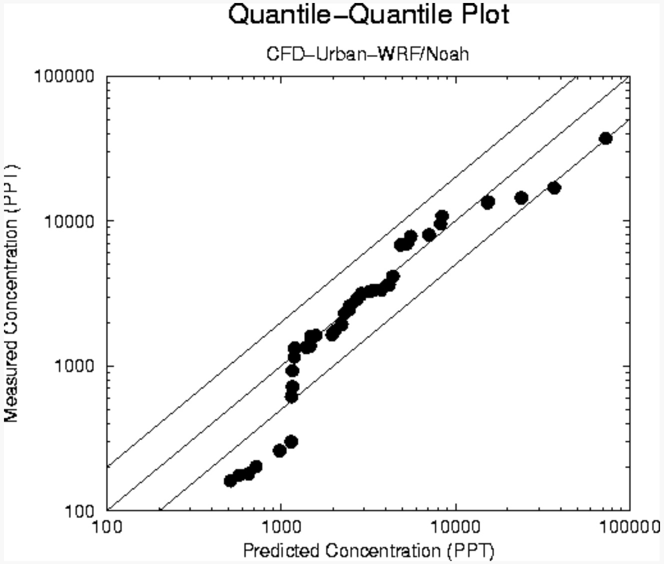
WRF/Noah Downscale: Quasi-Steady, Coarse





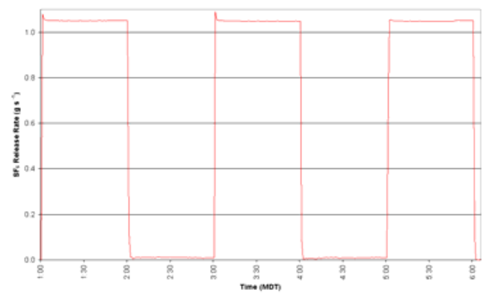
Above-to-Ground Level Shear and Plume Travel Direction Changes with Time

	Near Source	R2	R3	R4	All
FB	-0.77	0.4	0.8	0.8	-0.76
NMSE	34.36	1	2.3	1.8	53.7
MG	0.74	1.6	2	2.1	1.04
FAC2	0.57	0.4	0.4	0.5	0.51

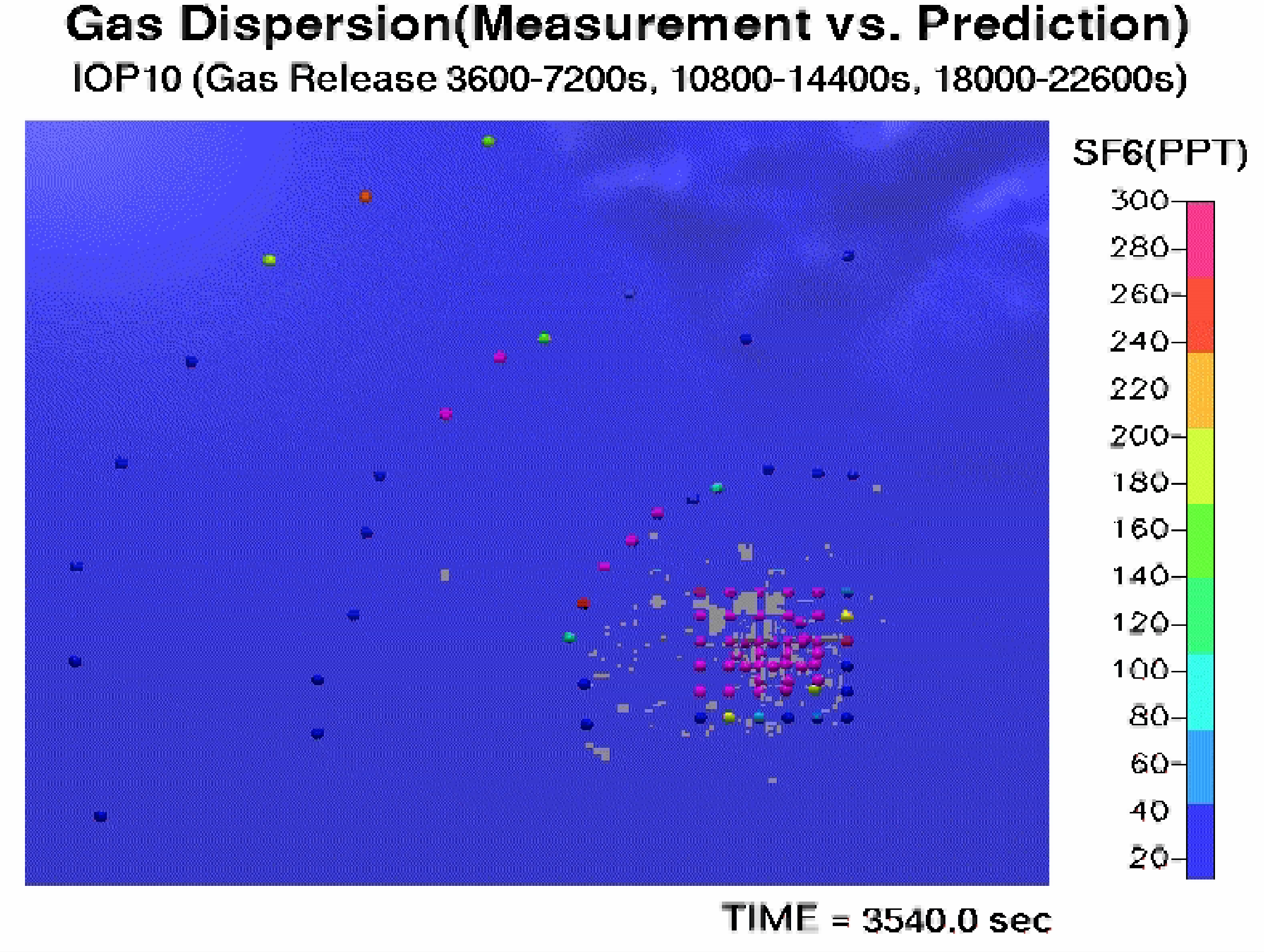


Sample of Results: IOP 10 Urban 2000

- **Entire IOP 10**
    - **3 Releases/Pauses**



- **WRF Data for BC**
- **Quasi-steady approach:**
    - **Wind/Turbulence fields at 15 minute intervals**
    - **Unsteady T&D using Unified Frozen Hydro Solver**



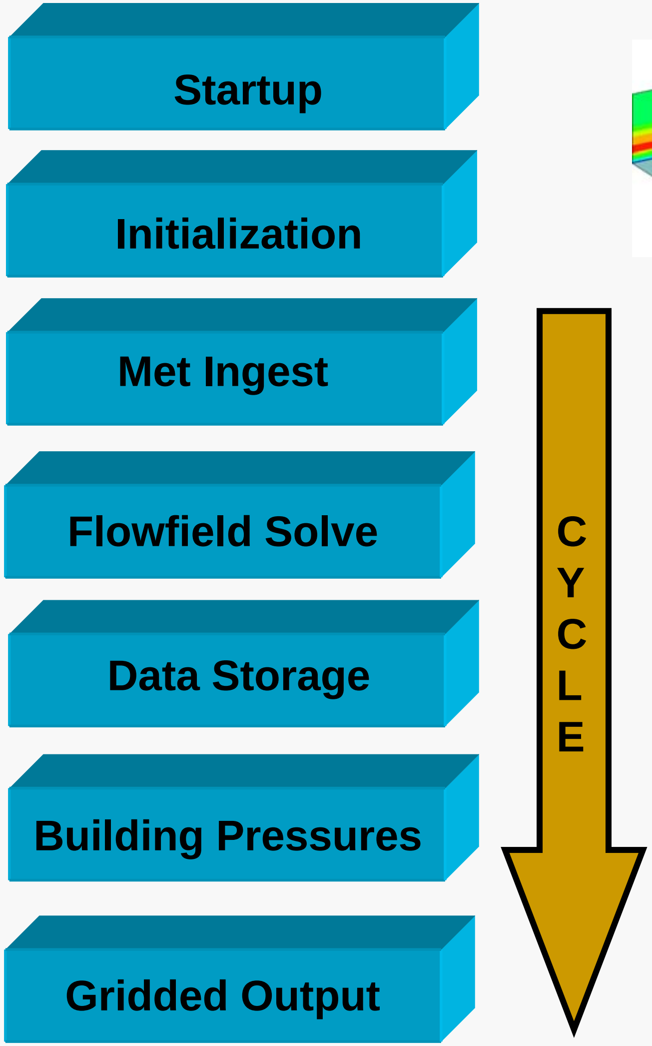
Summary of Results: IOP 10 Urban 2000

- Three sets of calculations:
    - Raging Waters Input: Use sounding data (single sounding) at all boundary faces
    - WRF Downscale Data Transfer: Unsteady Flow, Turbulence and Contaminant
    - WRF Downscale Data Transfer : Quasi-Steady Flow (“Wind Library”), Frozen Hydro Contaminant Transport

	Near Source	R2	R3	R4	All
FAC2: RW	0.12	0.17	0.36	0.38	0.18
FAC2: Unsteady	0.08	0.17	0.36	0.38	0.16
FAC2: Quasi-Unsteady	0.57	0.42	0.36	0.5	0.51
MG: RW	25.42	14.11	4.58	5.06	15.83
MG: Unsteady	15.89	11.64	4.77	5.679	11.69
MG: Quasi-Unsteady	0.74	1.59	1.96	2.05	1.04

- Quasi-Steady approach appears to be best mode of operation:
    - Steady-state wind/turbulence fields at set intervals in time using WRF data as boundary conditions: Library of Wind Fields
    - Use Unified Frozen Hydrodynamics Approach for T&D
- Unsteady flow/turbulence/transport: Time step restrictions
    - Too costly for accuracy or inaccurate because time step is too big

Pentagon Shield CFD Component: Operational Concept



Startup

Initialization

Met Ingest

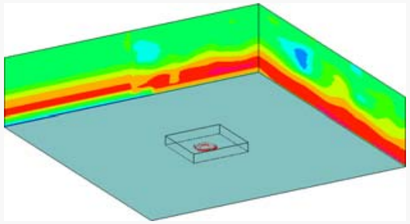
Flowfield Solve

Data Storage

Building Pressures

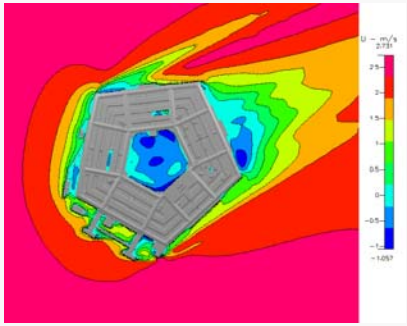
Gridded Output

CYCLE



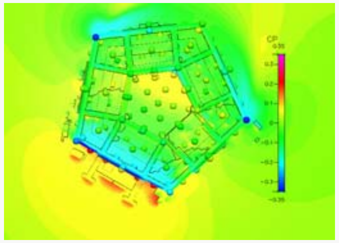
Ingest Gridded Met Data Set

Apply as Boundary Conditions



Flow+Turbulence

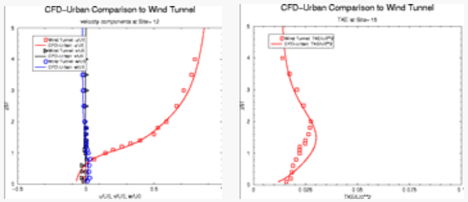
Solve



Building

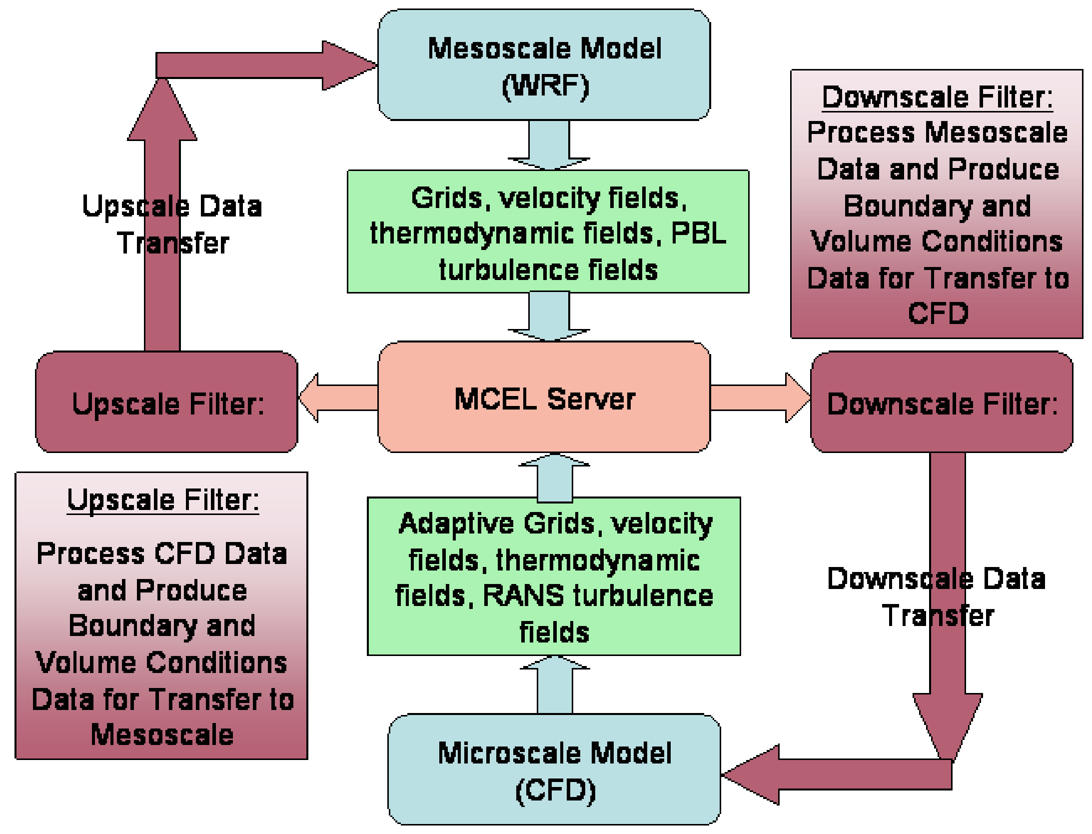
Pressures

Velocity and
Turbulence
Fields



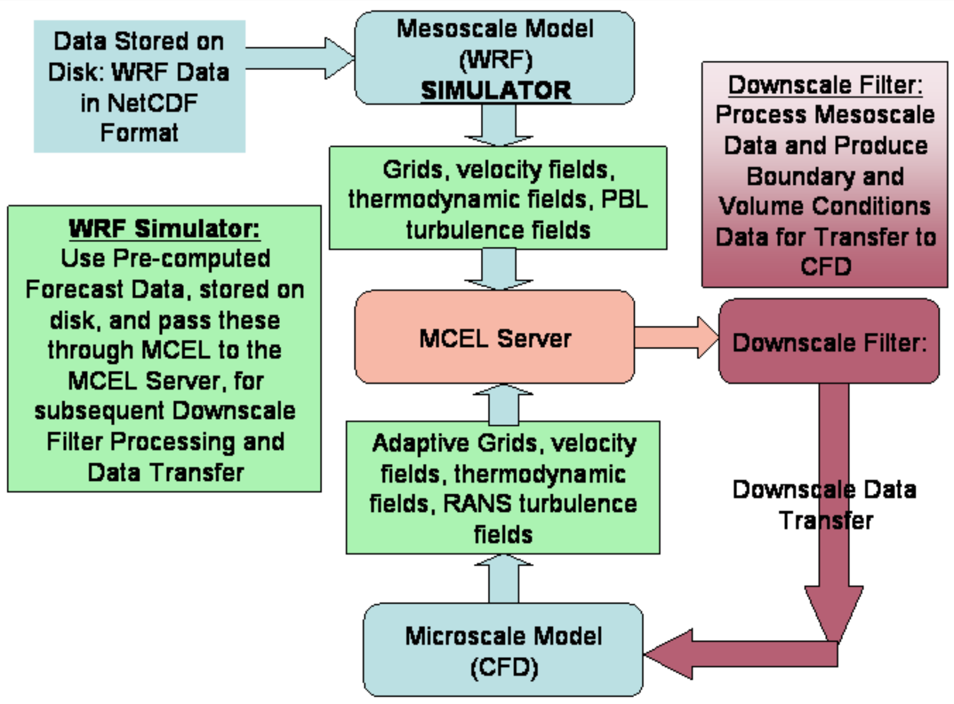
“Merged” CFD and Mesoscale Model Concept

- Model Coupling Environmental Library (MCEL) to couple:
  - Weather Research and Forecasting (WRF) Model
  - Specialized Urban CFD Model
- MCEL is a dataflow based model:
  - Models send data to the MCEL Server
  - Filters “Pull” data from servers and manipulate it
- MCEL is based upon using CORBA:
  - Client/Server design allows all components to operate relatively independently
  - Heterogeneous environments



"Merged" CFD and Mesoscale Model Concept

- **Downscale Filter:**
  - **Pulls "WRF" data from the MCEL server and "downscales" the data for use as applying boundary conditions to the CFD solver**
- **"WRF Simulator": Simulates WRF being in the loop and pushes data to the server using WRF native data formats (netCDF)**
  - **MCEL data caching capability being investigated for this purpose**


Data Stored on Disk: WRF Data in NetCDF Format

Mesoscale Model (WRF) **SIMULATOR**

Grids, velocity fields, thermodynamic fields, PBL turbulence fields

WRF Simulator: Use Pre-computed Forecast Data, stored on disk, and pass these through MCEL to the MCEL Server, for subsequent Downscale Filter Processing and Data Transfer

Downscale Filter: Process Mesoscale Data and Produce Boundary and Volume Conditions Data for Transfer to CFD

MCEL Server

Downscale Filter:

Adaptive Grids, velocity fields, thermodynamic fields, RANS turbulence fields

Downscale Data Transfer

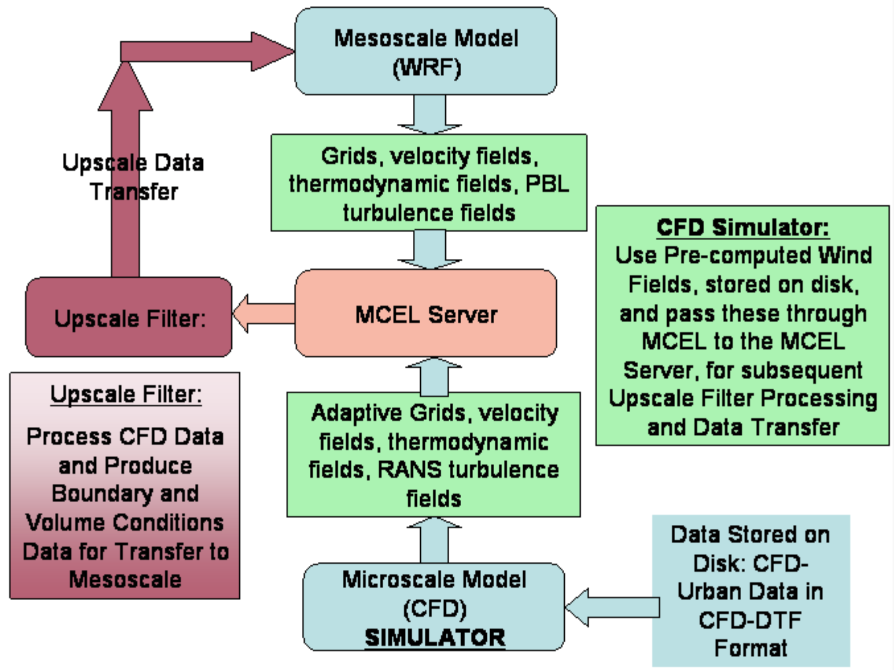
Microscale Model (CFD)

Downscaling:

- **Interpolate WRF velocity and turbulence fields onto CFD mesh**
- **Downscale "filter" pulls MCEL data from server, interpolates onto CFD mesh**
- **Uses "sub-cube" of finest nest**

“Merged” CFD and Mesoscale Model Concept

- **Upscale Filter:**
    - **Pulls “CFD” data from the MCEL server and “upscales” the data for use in WRF**
    - **Debating what to upscale, but consensus appears to be volumetric data**
- **“CFD Simulator”:Simulates CFD being in the loop and pushes data to the server using CFD native data formats (CFD-DTF)**
    - **MCEL data caching capability being investigated for this purpose**



Mesoscale Model (WRF)

Grids, velocity fields, thermodynamic fields, PBL turbulence fields

Upscale Data Transfer

MCEL Server

Upscale Filter:

CFD Simulator: Use Pre-computed Wind Fields, stored on disk, and pass these through MCEL to the MCEL Server, for subsequent Upscale Filter Processing and Data Transfer

Upscale Filter: Process CFD Data and Produce Boundary and Volume Conditions Data for Transfer to Mesoscale

Adaptive Grids, velocity fields, thermodynamic fields, RANS turbulence fields

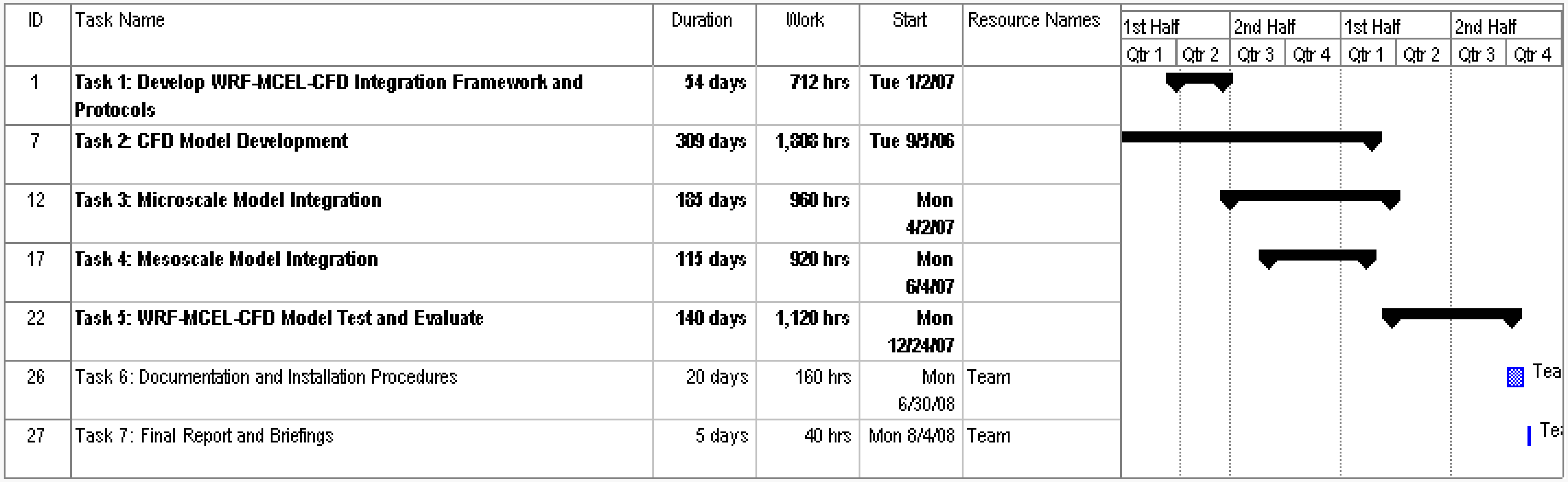
Microscale Model (CFD) **SIMULATOR**

Data Stored on Disk: CFD-Urban Data in CFD-DTF Format

Upscaling:

- **Compute momentum flux-integral for all cells contained within (coarser) WRF cells**
- **“Decimation” produces body force tendency, replaces drag terms from urban canopy model**
- **Uses “sub-cube” of finest nest**

Schedule and Work Plan



ID	Task Name	Duration	Work	Start	Resource Names
1	**Task 1: Develop WRF-MCEL-CFD Integration Framework and Protocols**	**54 days**	**712 hrs**	**Tue 1/2/07**	
7	**Task 2: CFD Model Development**	**309 days**	**1,808 hrs**	**Tue 9/5/06**	
12	**Task 3: Microscale Model Integration**	**185 days**	**960 hrs**	**Mon 4/2/07**	
17	**Task 4: Mesoscale Model Integration**	**115 days**	**920 hrs**	**Mon 6/4/07**	
22	**Task 5: WRF-MCEL-CFD Model Test and Evaluate**	**140 days**	**1,120 hrs**	**Mon 12/24/07**	
26	Task 6: Documentation and Installation Procedures	20 days	160 hrs	Mon 6/30/08	Team
27	Task 7: Final Report and Briefings	5 days	40 hrs	Mon 8/4/08	Team

Task 1: Upscale/Downscale Data and Protocols are being defined (delays getting all contracts/subcontracts in place)

Task 2: New, specialized solver and system under development

Task 3: Not yet begun

Task 4: Not yet begun

Task 5: Not yet begun

Task 6: Not yet begun

Specialized CFD Solver and Related Development

- **Upgrade mesh generation, numerics and parallel processing software to permit faster processing rates and higher fidelity physics:**
  - **Mesh Generation:**
    - **Cartesian Adaptive grids combined with Virtual Cell Embedding and cell-based Porosity for sub-cell resolution of features**
  - **Numerics:**
    - **Low-Mach Number Pre-Conditioned, Reynolds-Averaged Navier-Stokes Equations**
    - **Coupled mass+momentum+energy more suitable for atmospheric flows**
  - **Parallel Processing Software**
    - **Maximal use of the PETSc (Portable Extensible Toolkit for Scientific Computing) library**
    - **System of Non-Linear Equation Solvers (SNES) framework**
      - **Newton-Krylov-Schwarz parallel, implicit**

“Feed the PETSc engine”

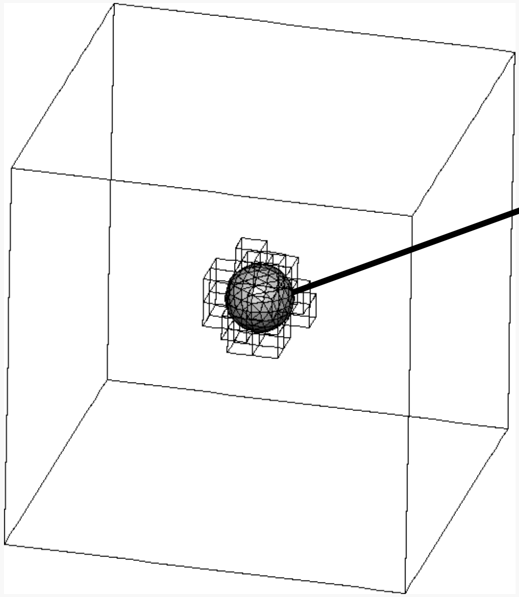
Technical Progress to date: AMR_VCE

- Adaptive Mesh Refinement Virtual Cell Embedding: AMR_VCE
- Solution adaptive Cartesian mesh using hierarchical (octree) system
    - Based upon HAMR classes and techniques
- Triangulated surface queries and tools using the GNU Triangulated Surface Library (GTS)
- Basic Algorithm:
    - Refine mesh where cells are “cut” by body (in/out) until a given level of refinement
    - Take each cell and “virtually” refine it near the boundary until a given level of (much finer) refinement
    - Use the geometric information of the adaptively refined “virtually embedded cell” to obtain approximations to the boundary to be represented in the larger “parent” cell
    - Insure Geometric Conservation Law consistency during construction of the cut cell centroids, integration points etc.
    - An “Adaptive Mesh Refinement” refinement of VCE [Landsbury, Boris]

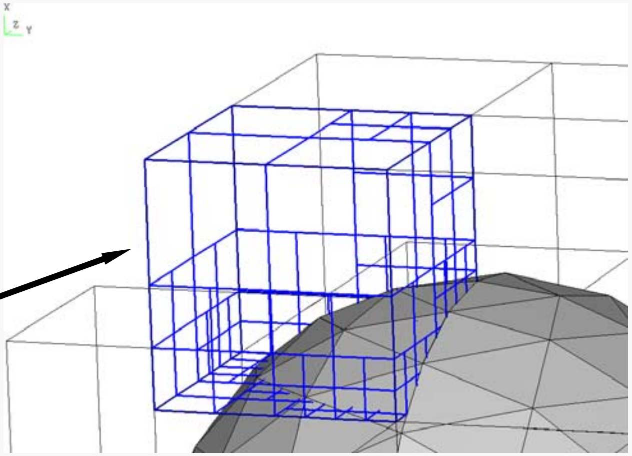
Technical Progress to date: AMR_VCE

- **Example: Sphere (represented via STL)**

VCE Cells Boundaries



Single AMR_VCE Cell (blue)

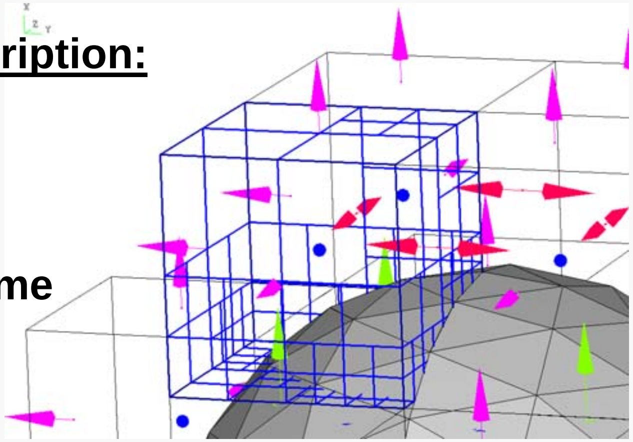


<u>“Cut” Cell Geometric Description:</u>

Cut Cartesian Faces (CCF)

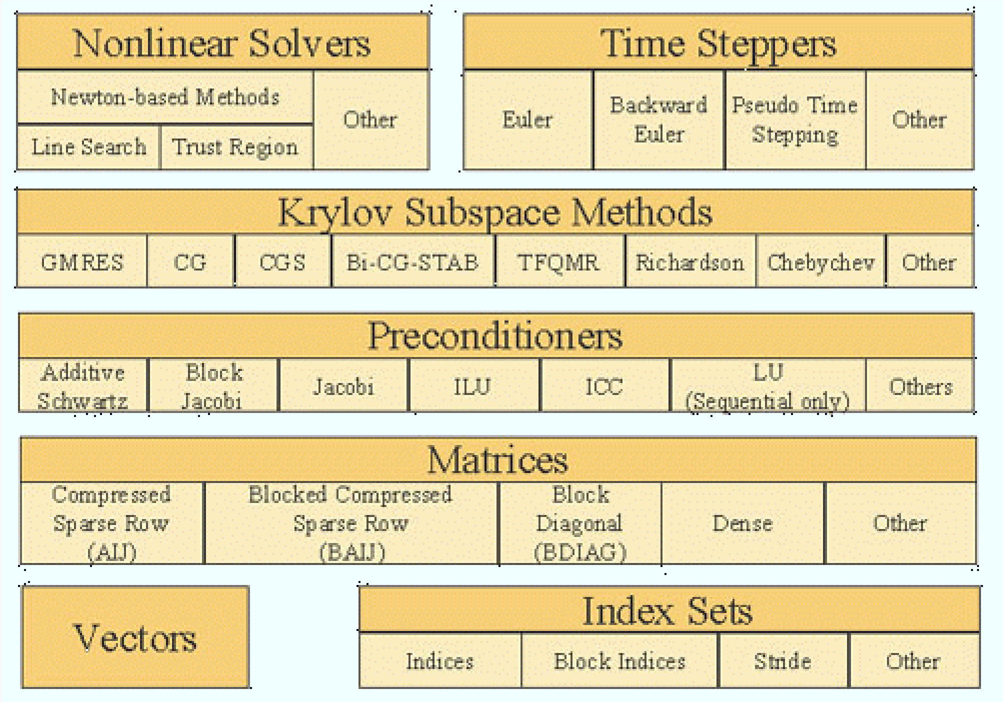
Cut Face

Cut Cell Centroid and Volume



Technical Progress to date: Flow Solver Technology

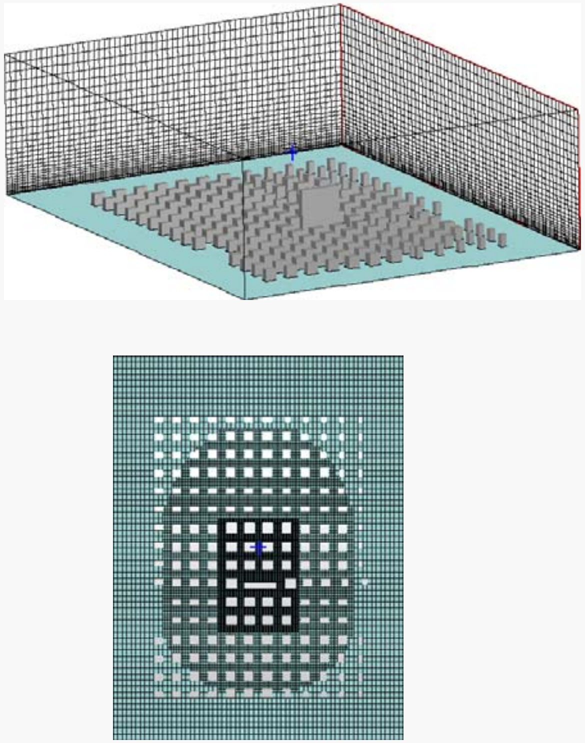
- **Evaluation and Testing of PETSc**
- **Parallel Extensible Toolkit for Scientific Computation (PETSc)**
  - **Developed by Argonne National Labs for parallel solution of sparse matrices encountered in scientific computing.**
  - **Becoming a very widely used application**

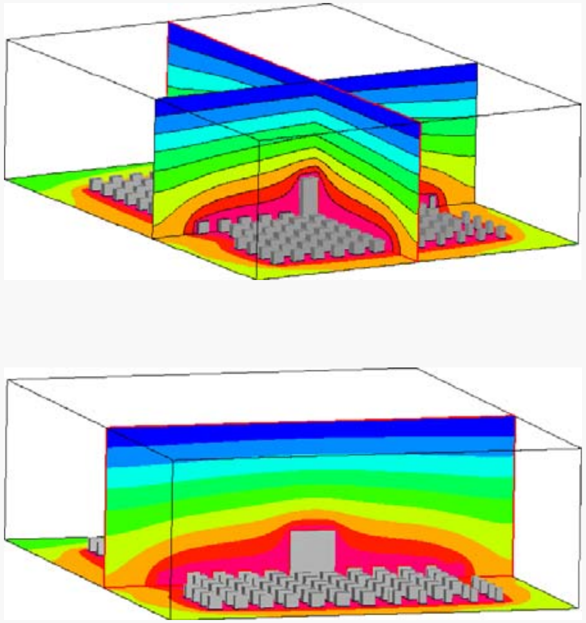


- **Parallel computing framework using basic “classes” supported in the PETSc library**
- **Provides large variety of Krylov-based solvers and matrix preconditioners, all in parallel.**
- **Proven to be very efficient and scalable.**
- **Choices of use:**
  - **Develop as usual, retrofit PETSc**
  - **Design from start to use PETSc**

Technical Progress to date: Flow Solver Technology

- “Iterative” Approach to developing the PETSc-specialized flow solver:
  - Laplace Equation solver: Serial, Parallel
  - Euler Equation Solver: Parallel, low-Mach Number Preconditioned
  - RANS Solver: Add viscous terms and 2-equation Turbulence Model ($k\varepsilon$ or MYJ)





Boundary Conditions:

- u=1 on Buildings
- u=0 on “Sky” boundary
- Zero gradient on all others
- 380,000 unknowns
- 2.4M matrix elements

Flow Solver Technology: Low Mach Preconditioning

- **Low-Mach Number Preconditioning Approach: [Weiss, et al., 1995, Merkle, et al., 1996]**
  - **Fully-coupled mass, momentum and energy equations, “Compressible” formulation**
  - **Preconditioning removes stiffness of equations as Mach number approach zero**

$$\frac{\partial}{\partial t}\iiint W dV + \iint [F - G] \bullet dA = 0$$

Conservation Law Form, Conserved Variables

$$\kappa(\lambda) \approx \frac{\lambda_{\max} - \lambda_{\min}}{\left(\lambda_{\max} + \lambda_{\min}\right)/2}$$

Condition number of hyperbolic system is directly related to the eigenvalues

$$\left(K\frac{\partial W}{\partial Q}\right)\frac{\partial}{\partial t}\iiint Q dV + K\iint [F - G] \bullet dA = 0$$

Primitive Variables, Pre-multiply by preconditioning matrix, K (not in conservative form now…)

$$K\frac{\partial W}{\partial Q} = \begin{pmatrix} \rho_P & 0 & 0 & 0 & \rho_T \\ 0 & \rho & 0 & 0 & 0 \\ 0 & 0 & \rho & 0 & 0 \\ 0 & 0 & 0 & \rho & 0 \\ -1 & 0 & 0 & 0 & \rho C_P \end{pmatrix}$$

Note that terms pre-multiplying density time derivate approach zero as the Mach number approaches zero, decoupling mass from the other equations.

$$\kappa(\lambda) \approx \frac{1}{M}$$

Flow Solver Technology: Low Mach Preconditioning

$$\Gamma \frac{\partial}{\partial t}\iiint Q dV + \iint \left[F - G\right] \bullet dA = 0$$

Conservation Law Form, Primitive Variables, pre-conditioned equations

$$\Gamma = \left(K^{-1}\Gamma_{nc}\right)$$

$$= \begin{pmatrix} \Theta & 0 & 0 & 0 & \rho_T \\ \Theta v_x & \rho & 0 & 0 & \rho_T v_x \\ \Theta v_y & 0 & \rho & 0 & \rho_T v_y \\ \Theta v_z & 0 & 0 & \rho & \rho_T v_z \\ \Theta H - 1 & \rho v_x & \rho v_y & \rho v_z & \rho_T H + \rho C_P \end{pmatrix}$$

Low-Mach Number Preconditioning replaces "true" EOS derivatives with modified forms that removes the stiffness of the equations:

$$\Theta = \left(\frac{1}{U_r^2} - \frac{\rho_T}{\rho C_P}\right) \qquad U_r = \begin{cases} \varepsilon c, & if \quad |v| < \varepsilon c \\ |v|, & if \quad \varepsilon c < |v| < c \\ c, & if \quad |v| > c \end{cases}$$

$$u = v.\hat{n} \quad u' = u(1-\alpha) \quad \alpha = \left(1 - \beta U_r^2\right)/2 \quad c' = \sqrt{\alpha^2 u^2 + U_r^2}$$

- **System of equations now remains well conditioned at all speeds and for all EOS**

$$\lambda\left(\Gamma^{-1}\frac{\partial F}{\partial Q}\right) = u, u, u, u' + c', u' - c'$$

$$\kappa(\lambda) \approx \frac{\sqrt{\alpha^2 + (U_r/u)^2}}{(1-\alpha)}$$

- **Compressible** $\kappa(\lambda) \approx \frac{1}{M}$
- **Compressible, Low Mach** $\kappa(\lambda) \approx 1$
- **Incompressible** $\kappa(\lambda) \approx 1$

Flow Solver Technology: Low Mach Preconditioning

$$\Gamma \frac{\partial \tilde{Q}}{\partial t}\Delta V + \sum_{faces}\left[\tilde{F} - \tilde{G}\right]A_{face} = 0$$

$$F = \frac{1}{2}\left(F_L + F_R\right) - \frac{1}{2}\left|A\right|\Delta W$$

$$\left|A\right|\Delta W \cong A\Delta W = \Gamma\left|A_\Gamma\right|\Delta Q$$

Discrete, Conservative Form, Primitive Variables, Pre-conditioned System

Upwind (Hyperbolic Systems) Form

Roe's FDS or Central differencing with 4-th order dissipation using preconditioned hyperbolic system Eigenvalues and Eigenvectors

("Speed" vs "Accuracy": Who will win?)

- **Use Newton-Krylov-Schwarz Approach to solve the discrete, preconditioned equations:**
  - **Proven scalability and high-performance using the PETSc suite**
  - **Similar techniques as PETSc-FUN3D, which won the 1999 Gordon Bell Award**

$$\left[\frac{\Gamma}{\Delta t} - \frac{\partial R}{\partial Q}\right]\Delta Q = R(Q)$$

$$CFL^N = CFL^{N-1}\left(\frac{\left\|f^{N-1}\right\|}{\left\|f^{N}\right\|}\right)^{\beta}$$

Technical Progress to date: Flow Solver Technology

- Developing flow solver from the ground up to be PETSc compliant
- Using lessons learned from many different unstructured flow solvers, parallel processing studies:
  - Interleaved data structures, ordering of unknowns and visitation order (coloring)
  - Reduction in cache misses, communication patterns, line-search strategies…
- Use the PETSc SNES to solve the parallel system of equations:
  - Provide 2 functions called by SNES solver:
    - Residual evaluation and Jacobian evaluation

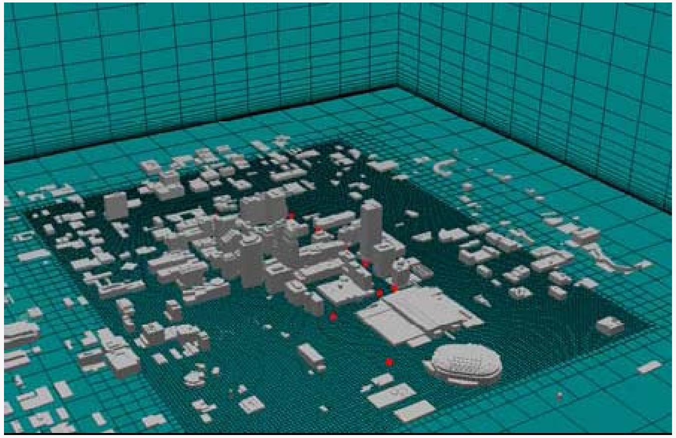
```
SNESCreate(MPI_COMM_WORLD,&snes);

SNESSetType(snes,"ls");

SNESSetFunction(snes,pData-
>rhs,formFunction,PETSC_NULL);

MatCreateMPIBAIJ(PETSC_COMM_WORLD,bs,m,n,M,
N,&d_nnz,d_nz,o_nnz,o_nz, &J)

SNESSetJacobian(snes,J,J,formJacobian,PETSC
_NULL);
```

```
SNESGetKSP(snes,&ksp);

KSPSetType(ksp,KSPBCGSL);

SNESSetTolerances(snes,1.0e-10,1.0e-
10,1.0e-40,10000,10000);

KSPSetTolerances(ksp,1.e-10,1.e-
10,1e+50,100);

SNESSolve(snes,PETSC_NULL,pData->sol);
```

FEED THE PETSc SNES SOLVER

Technical Progress to date: Flow Solver Technology

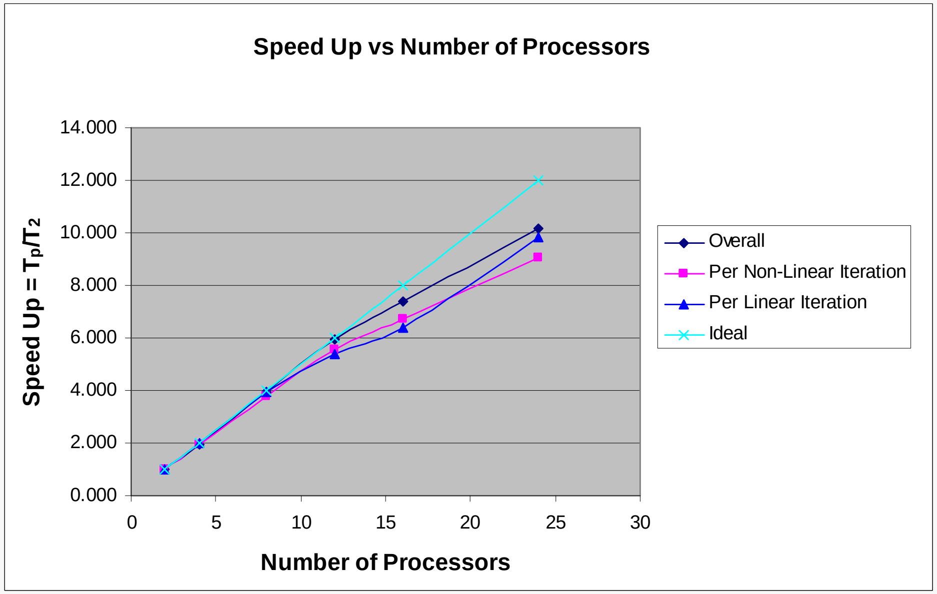
- **Scalability study: Euler equations, non-preconditioned**

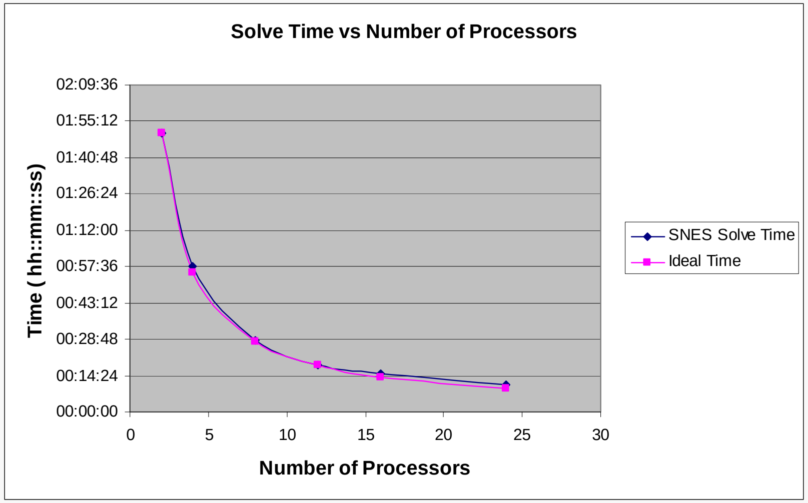


Case 1: Oklahoma City CBD Grid generated by CFD-Urban

- **175,000 cells**

•Linear Solver: BiCGSTAB*(l)*, Preconditioner: Block Jacobi, ILU on each block.





Tail-off after 12 processors due to using dual processors(!)

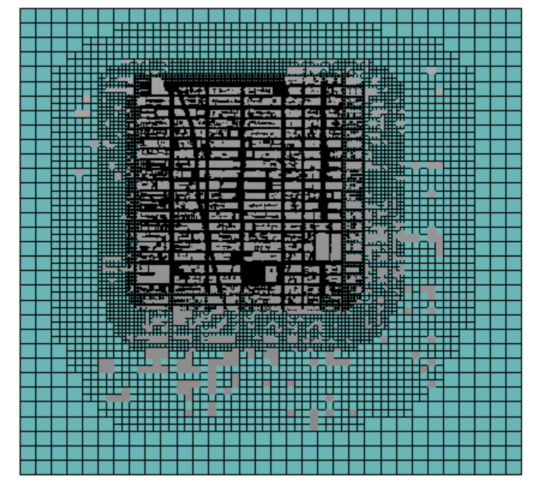
Technical Progress to date: Flow Solver Technology

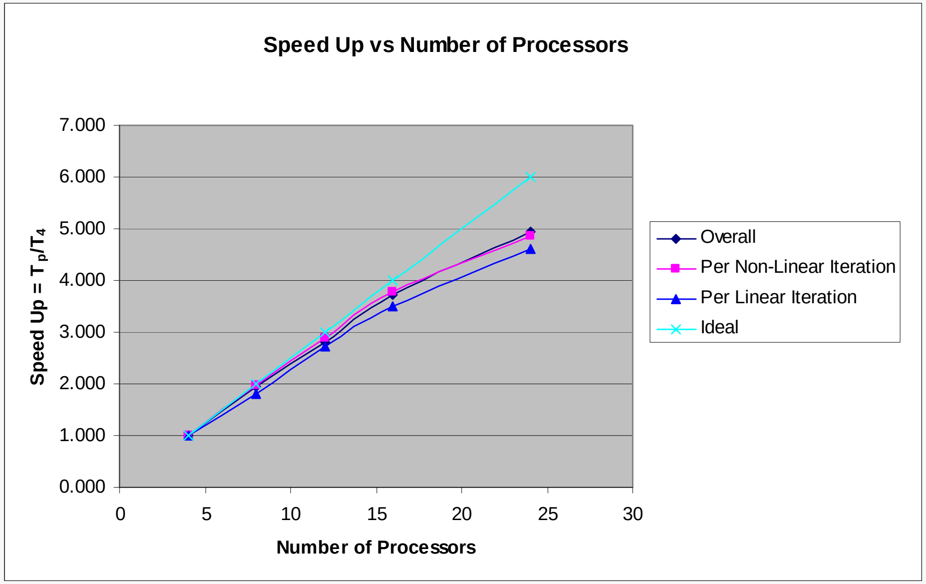
- **Scalability study: Euler equations, non-preconditioned**

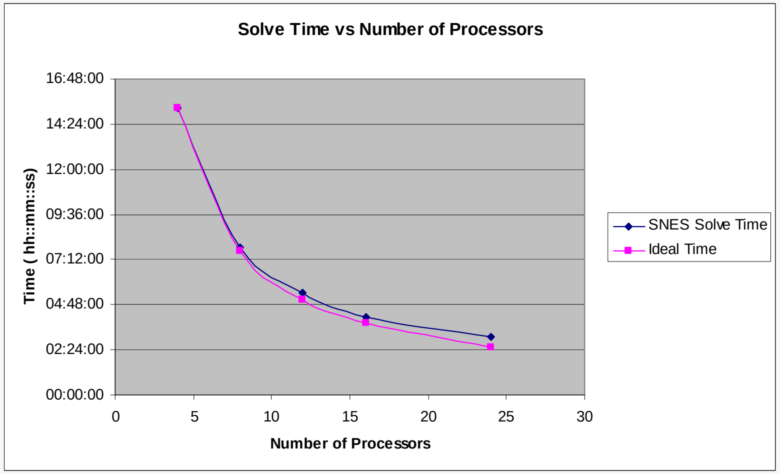
Case 2: Midtown Manhattan Grid generated by CFD-Urban

- **1,460,000 cells**

- **Linear Solver: BiCGSTAB*(l)*, Preconditioner: Block Jacobi, ILU on each block.**



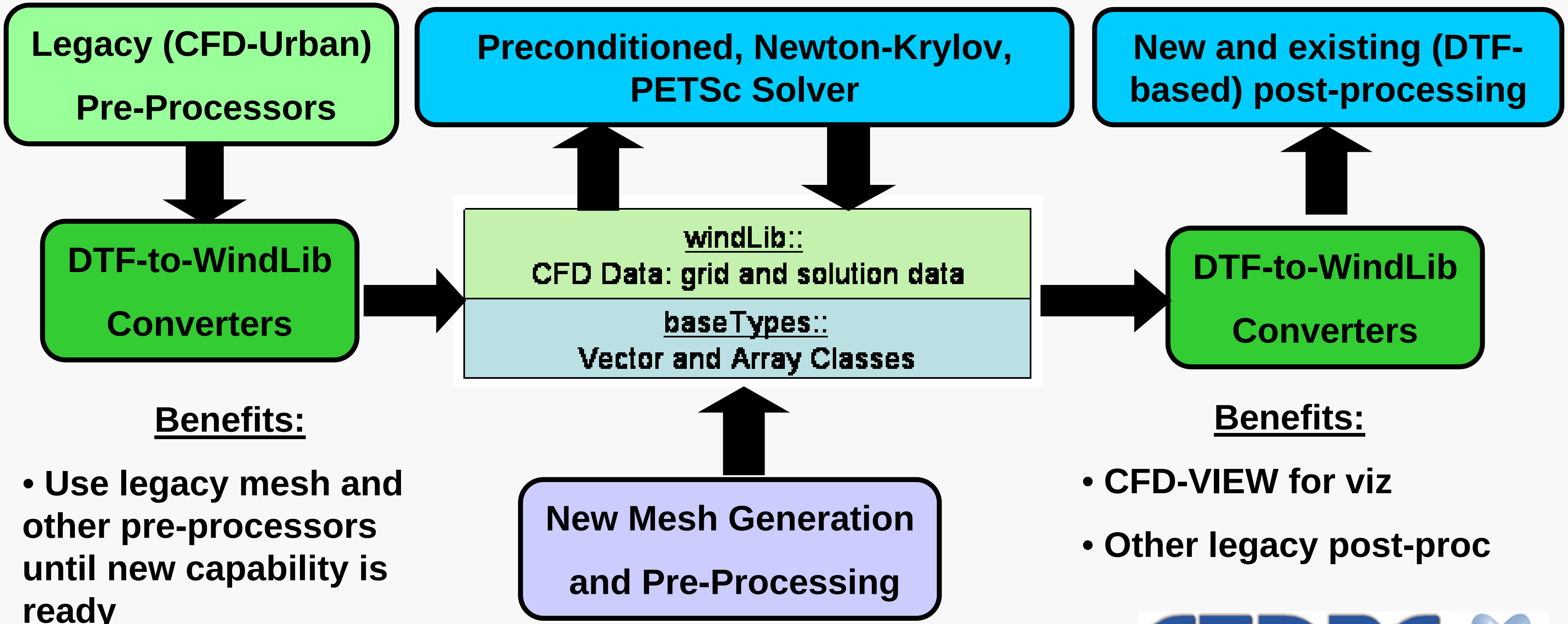




Tail-off after 12 processors due to using dual processors(!)

Wind Library Database API and Classes

- C++ classes/namespaces devoted to storage and access of grids and solution data
- Move away from ESI (ex-CFDRC) proprietary CFD-DTF and related libraries
- baseTypes:: derived from std namespace vector<T>
- windLib:: hierarchical data structures stored using simple strings and disk access



Legacy (CFD-Urban) Pre-Processors

DTF-to-WindLib Converters

Preconditioned, Newton-Krylov, PETSc Solver

windLib::
CFD Data: grid and solution data

baseTypes::
Vector and Array Classes

New Mesh Generation and Pre-Processing

New and existing (DTF-based) post-processing

DTF-to-WindLib Converters

Benefits:

- Use legacy mesh and other pre-processors until new capability is ready

Benefits:

- CFD-VIEW for viz
- Other legacy post-proc

Conclusions and Plans

- **Beginning to work with MCEL, downscale/upscale filters**
- **Flow solver development is proceeding according to plan**
- **If all goes according to plan: Will be coupled this time next year**