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Joint Effects Model Urban IPT

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JEM Urban IPT Purpose and Goals

- **Increment 2 (formerly Block 2) of the Joint Effects Model (JEM) has an urban transport and dispersion requirement**

- **Joint Science and Technology Office (JSTO) established the JEM Urban IPT to enable:**
  - A formal process for model selection, giving due consideration to the JEM Capability Production Document (formerly Operational Requirements Document)
  - Representation of the services in the selection process
  - Documentation of the process & results for eventual presentation to the Joint Requirements Office (JRO) and the JEM program office

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IDA's Role

- **JSTO has requested IDA to facilitate the JEM Urban IPT**
  - IDA has no stake in the outcome of the selection process
  - Objectivity and freedom from bias
- **IDA has been tasked by JSTO to:**
  - Identify potential models
  - Screen models with respect to the selection criteria
  - Evaluate performance & effectiveness of models and identify potential JEM integration issues
  - Document process, results, and recommendations

Urban Model Selection Criteria

- **Models must be in accord with the JEM Capability Production Document (formerly JEM ORD)**
- **Models must meet requirements laid out in the JEM Block II Request for Information (RFI), conducted in 2004**
- **Model source code must be releasable to the U.S. Government**
  - No insurmountable proprietary issues
  - No insurmountable intellectual property issues
- **Other model requirements**
  - Acceptable hardware requirements
  - Acceptable data requirements
  - Acceptable preprocessing requirements
  - Acceptable level of expertise required to run models
- **Verification & Validation (V&V) history**
  - Models must have documented internal V&V
  - Models must have independent V&V (IV&V) involving comparisons to tracer releases at urban field trials
    - » Urban 2000 (Salt Lake City)
    - » Joint Urban 2003 (Oklahoma City)

Analysis Methodology

- **Review historical V&V documentation for models**
- **Perform model runs**
  - Using well-defined and open protocols, compare model predictions to Joint Urban 2003 tracer sampler data
    - » Time permitting, compare (re-compare) models to Urban 2000 field trials
  - Evaluate performance using established comparison metrics
    - » “Standard” T&D statistics
    - » Measure of Effectiveness (MOE)
    - » Rigorous hypothesis testing

Urban Models Under Consideration (1 of 2)

- **Urban Dispersion Model (UDM), DSTL, UK**
  - Gaussian Puff model that incorporates interactions with obstacles; interactions are functions of building density, height, and plume size
  - Presently in HPAC
- **Urban Windfield Module (UWM), Titan Corp.**
  - 3D wind field model; uses averaged NS equations and thermal/energy equations with distributed drag parameterization
  - Presently in HPAC
- **Micro-Swift-Spray, SAIC**
  - Micro-Swift: Empirical 3D wind field model that defines displacement, cavity, and wake “zones” around buildings
  - Micro-Spray: Lagrangian particle model that accounts for reflections from building surfaces
  - Presently in HPAC (beta testing)

Urban Models Under Consideration (2 of 2)

- **MESO/RUSTIC, ITT**
  - RUSTIC: 3D wind field model; uses averages NS equations and TKE dissipation method for turbulence
  - MESO: Lagrangian particle model that accounts for reflections from building surfaces
- **QUIC-URB/QUIC-PLUME, Los Alamos**
  - QUIC-URB: Empirical 3D wind field model (Röckle, 1990) to account for buildings
  - QUIC-PLUME: Lagrangian particle model that accounts for reflections from building surfaces

JEM Runtime Requirement

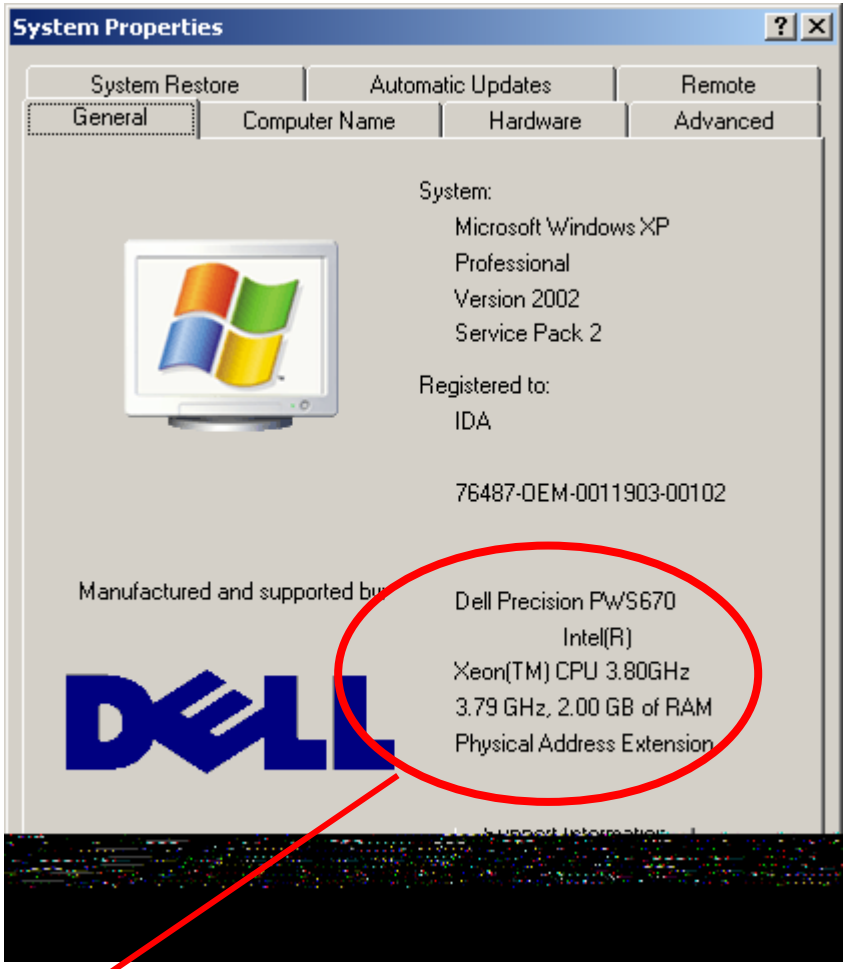
JEM Key Performance Parameter (KPP) 6a, *Joint Effects Model (JEM) Capability Production Document, Version 2.0, June 2006*

JEM, running without advanced features turned on, such as secondary evaporation, complex terrain, microscale meteorology, shall provide hazard prediction data and graphical display, for up to two known (location, agent, dissemination) source terms, within 10 minutes.

For the following analyses we will do single releases and compare runtimes against *5 minutes*

HPAC Urban Model Runtime Comparisons:
Computer Specs and General Info

Computer



Single processor used during runs

General

- **Runs done using HPAC 4.04 SP3**
  - Includes vendor provided MicroSWIFT/MicroSpray (MSS)
- **Predictions for continuous releases of Joint Urban 2003 (JU2003) Field Trials**
  - 29 releases
    - » 30 minute releases
    - » 2 hour project time
  - Two Met Options
    - » Post Office rooftop PWIDS (PO7)
    - » Surface and upper air met from nearby airports (BAS)
  - SWIFT run with HPAC to generate mass-consistent winds

HPAC Urban Model Runtime Comparisons:
Urban Modes, Domains, and Spatial Resolution

- **HPAC spatial domain: ~ 100 km x 100 km x 2.5 km**

- **Urban model configurations run within HPAC 4.04 SP3**
  - Urban Canopy parameterization = UC
  - Urban Dispersion Model (UDM) alone = DM
  - Urban Windfield Module (UWM) alone = WM
    - » UWM run in “high” and “low” horizontal spatial resolution
  - Urban Dispersion Model + Urban Windfield Module = DW
    - » UWM run in “high” and “low” horizontal spatial resolution
  - MicroSWIFT/MicroSPRAY = MSS
    - » MSS run in “high” and “low” horizontal spatial resolution

- **Horizontal domain, grid size, and number of particles for high and low resolution**

	"Low"			"High"		
	domain size	grid size	number of particles	domain size	grid size	number of particles
UWM	> 2500 m	> 50 m	NA	> 500 m	> 5m	NA
MSS	0.8 km x 0.8 km	5m	50000	1 km x 1 km	3m	100000

HPAC Urban Model Runtime Comparisons:
Oklahoma City, Baseline Weather

29 Oklahoma City Runs; Baseline Weather (BAS)				
Urban Mode/Resolution	Average Run Time (min)	Median Run Time (min)	Min Run Time (min)	Max Run Time (min)
Urban Canopy	2.1	2.1	1.9	2.5
UDM Alone	3.3	3.1	2.1	6.2
UWM Alone, low resolution	3.0	3.0	2.4	3.6
UWM Alone, high resolution	85.0	80.5	44.0	263.6
UWM + UDM, low resolution	3.8	3.7	2.7	5.2
UWM + UDM, high resolution	85.9	82.4	46.0	263.4
MSS, low resolution	28.7	26.5	21.3	55.1
MSS, high resolution	61.7	59.3	50.1	85.1

Satisfies JEM requirement

Does not satisfy JEM requirement, but is within 5 minutes

Does not satisfy JEM requirement

HPAC Urban Model Runtime Comparisons:
Oklahoma City, Post Office Weather

29 Oklahoma City Runs; Post Office Weather (PO7)				
Urban Mode/Resolution	Average Run Time (min)	Median Run Time (min)	Min Run Time (min)	Max Run Time (min)
Urban Canopy	1.9	1.9	1.7	2.0
UDM Alone	2.9	2.8	1.9	5.7
UWM Alone, low resolution	3.2	3.2	2.8	3.7
UWM Alone, high resolution	86.3	91.1	50.3	146.5
UWM + UDM, low resolution	3.8	3.8	2.8	5.1
UWM + UDM, high resolution	86.8	92.2	51.0	145.8
MSS, low resolution	28.4	26.9	23.5	50.4
MSS, high resolution	61.8	60.6	54.6	76.1

Satisfies JEM requirement

Does not satisfy JEM requirement, but is within 5 minutes

Does not satisfy JEM requirement

MESO RUSTIC Urban Model Runtime Comparisons: *Background*

- **Developer recommended MESO-RUSTIC configuration for *detailed scientific modeling*:**
  - RUSTIC grid resolution 3 - 5 meters in the urban center
  - 300,000 - 500,000 MESO particle tracers
- **MESO-RUSTIC configuration necessary to *run in several minutes (versus hours)*:**
  - 1.4 km x 1.4 km domain (Oklahoma City central business district only)
  - 25 to 50 m uniform horizontal grid resolution
  - Only two RUSTIC steady-state wind solutions per continuous release
  - 40,000 MESO particle tracers
  - 1 hour of simulated transport and dispersion
- **Timing runs were performed on a 3.40 GHz Pentium 4 with 1.0 GB RAM (single processor)**

MESO RUSTIC Urban Model Runtime Comparisons:

Timing results for 25 m and 50 m grid resolution; 40,000 particles

25 m RUSTIC grid resolution
40,000 MESO particles

IOP	Release	RUSTIC (min)	MESO (min)	Total (min)
2	3	10.13	1.50	11.63
4	2	9.07	1.07	10.13
4	3	7.33	0.83	8.17
7	1	13.12	2.05	15.17
9	3	8.23	3.00	11.23
Averages		9.58	1.69	11.27

50 m RUSTIC grid resolution
40,000 MESO particles

IOP	Release	RUSTIC (min)	MESO (min)	Total (min)
2	3	3.20	1.45	4.65
4	1	3.48	0.90	4.38
4	2	2.37	0.83	3.20
4	3	5.42	1.37	6.78
7	1	3.85	1.98	5.83
9	3	3.38	0.47	3.85
Averages		3.62	1.17	4.78

Satisfies JEM requirement

Does not satisfy JEM requirement, but is within 5 minutes

Does not satisfy JEM requirement

Times do not include the 1-3 minutes to generate the RUSTIC grid (could be pre-computed)

MESO RUSTIC Urban Model Runtime Comparisons:

Timing results for 25 m and 50 m grid resolution; 400,000 particles

25 m RUSTIC grid resolution
400,000 MESO particles

IOP	Release	RUSTIC (min)	MESO (min)	Total (min)
2	3	10.13	12.40	22.53
4	2	9.07	8.45	17.52
4	3	7.33	6.37	13.70
7	1	13.12	18.98	32.10
9	3	8.23	30.25	38.48
Averages		9.58	15.29	24.87

50 m RUSTIC grid resolution
400,000 MESO particles

IOP	Release	RUSTIC (min)	MESO (min)	Total (min)
2	3	3.20	14.07	17.27
4	1	3.48	8.53	12.02
4	2	2.37	9.27	11.63
4	3	5.42	12.97	18.38
7	1	3.85	20.73	24.58
9	3	3.38	4.08	7.47
Averages		3.62	11.61	15.23

Satisfies JEM requirement

Does not satisfy JEM requirement, but is within 5 minutes

Does not satisfy JEM requirement

RUSTIC only Urban Model Runtime Results:
Larger grid size & higher resolution grids

A) 8.0 km x 8.0 km grid – single steady-state wind solution

IOP	Release	RUSTIC Runtime (min)
2	3	174.35
4	1	372.63
4	2	240.82
4	3	159.67
7	1	150.90
9	3	372.63

B) 1.4 km x 1.4 km grid at higher resolutions – single steady-state wind solution (times in minutes)

		RUSTIC Runtimes (min)		
IOP	**Release**	**20 m resolution**	**14 m resolution**	**7 m resolution**
2	3	12.47	50.33	286.90
7	1	34.38	134.87	487.23
9	3	22.77	87.60	381.05

Does not satisfy JEM requirement

QUIC-URB QUIC-PLUME Initial Runtime Analyses: *Background*

- **Developer recommended QUIC-URB, QUIC-PLUME configuration for *detailed scientific modeling*:**
  - QUIC-URB horizontal grid resolution of ~ 5 meters
  - ~ 400,000 QUIC-PLUME particle tracers
- **QUIC-URB, QUIC-PLUME configuration necessary to *run in several minutes (versus ~ 1 hour)*:**
  - 1.4 km x 1.4 km domain (Oklahoma City central business district only)
  - 10 m horizontal grid resolution (6 m vertical resolution)
  - 8 steady-state wind solutions per continuous release (15 minute averaged winds)
  - < ~ 50,000 QUIC-PLUME particle tracers
  - 2 hours of simulated transport and dispersion
- **Computer**
  - 2.33 GHz MacBook Pro (running Windows XP) with 2.0 GB RAM

QUIC-URB QUIC-PLUME Initial Runtime Analyses:
Example timing results for "low" (10 m) resolution

Post Office PWIDS weather data
15 minute averages, 8 updates
2 hours of simulation time

IOP 1, Continuous release: 10 m QUIC-URB grid resolution

# of QUIC-PLUME Particles	QUIC URB (min)	QUIC PLUME (min)	Total (min)
10000	3.08	2.19	5.27
50000	3.08	9.19	12.27
100000	3.08	14.88	17.96
200000	3.08	33.73	36.81
400000	3.08	61.85	64.93

Satisfies JEM requirement
Does not satisfy JEM requirement, but is within 5 minutes
Does not satisfy JEM requirement

QUIC-URB QUIC-PLUME Initial Runtime Analyses:
Example timing results for "high" (5 m) resolution

Post Office PWIDS weather data
15 minute averages, 8 updates
2 hours of simulation time

IOP 1, Continuous release: 5 m QUIC-URB grid resolution

# of QUIC-PLUME Particles	QUIC URB (min)	QUIC PLUME (min)	Total (min)
10000	15.56	4.55	20.11
50000	15.56	7.79	23.35
100000	15.56	17.20	32.76
200000	15.56	23.75	39.31
400000	15.56	47.86	63.42

Does not satisfy JEM requirement

Beyond the 10 Minute Requirement

- **Many (non-operational, non-combat) release scenarios exist where time is *not critical***
- **For such scenarios it may make sense to have a model that can give "high fidelity" results in runtimes greater than 5 minutes, but less than say, one hour**
- ***JEM 10 minute requirement alone may not exclude models from eventual/potential JEM consideration***

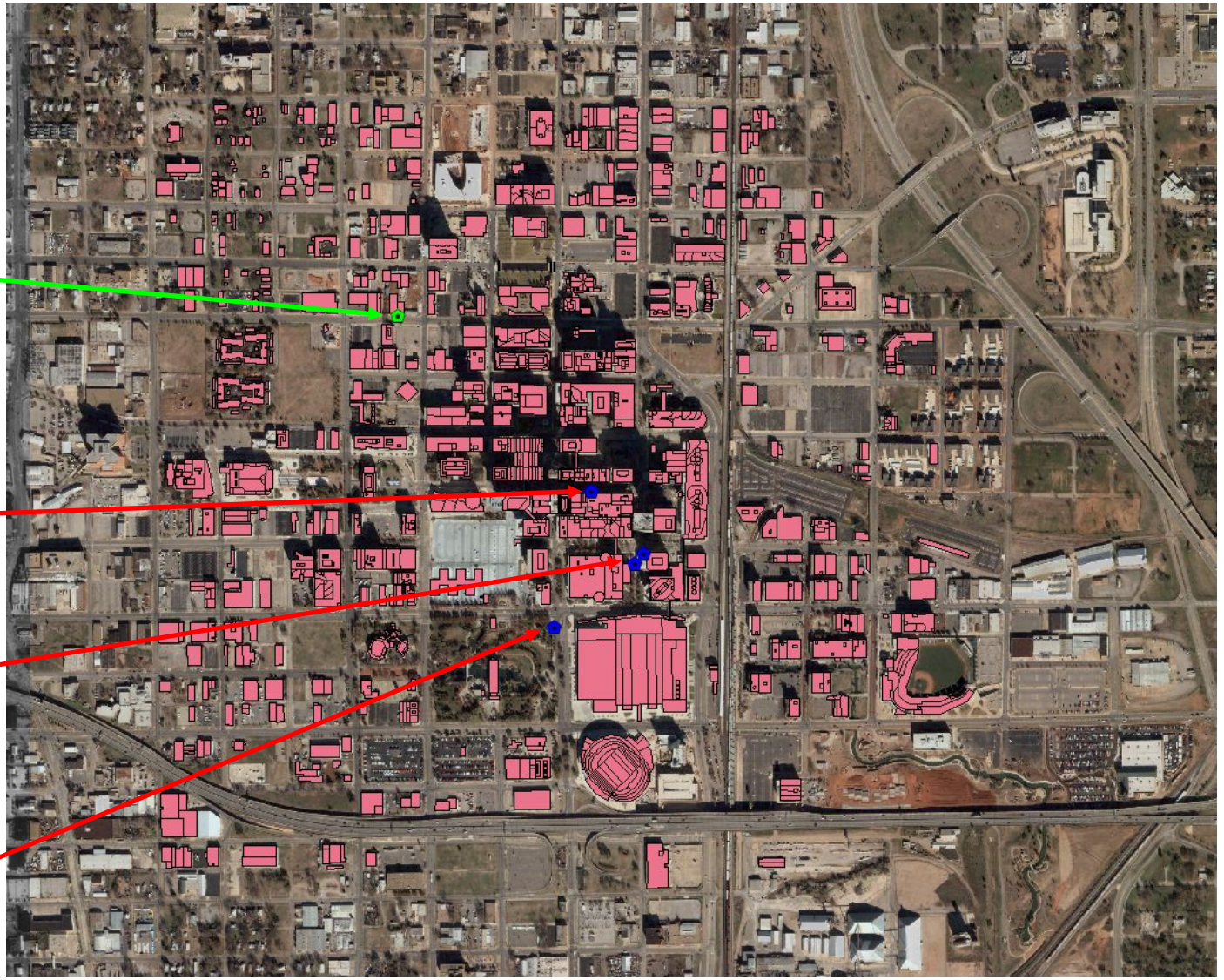
Summary / Way Ahead

- **Timing Results**
  - HPAC models
    - » UC, UDM, UWM (low resolution) and UDM/UWM (low resolution) satisfy the JEM 10 minute requirement
    - » MSS does not satisfy JEM 10 minute requirement even with low resolution
    - » UWM with high resolution (singly or with UDM) does not satisfy JEM 10 minute requirement
  - MESO/RUSTIC
    - » Can satisfy the JEM 10 minute requirement, but only with low resolution (10 times coarser than recommended) and small numbers of tracer particles (10 times fewer than recommended)
    - » Quality of low resolution/low particle number predictions is still under investigation
  - QUIC-URB/QUIC-PLUME
    - » Can satisfy the JEM 10 minute requirement, but only with low resolution (2 times coarser than recommended) and small numbers of tracer particles (8 times fewer than recommended)
    - » Quality of low resolution/low particle number predictions is still under investigation
- **To Do**
  - Near term: Full report to JEM Urban IPT (February '07)
  - Far term: Complete detailed intercomparison between all models (~ June '07, currently underway)

Go EAGLES!

BACKUPS

JU2003 Downtown - Releases



HPAC Urban Model Runtime Comparisons: *Summary*

- **Based on these Oklahoma City runs, the following models and configurations *satisfy the JEM runtime requirement***
  - Urban canopy model
  - UDM
  - UWM with low resolution
  - UDM together with low resolution UWM
- **Based on these Oklahoma City runs, the following models and configurations *do not satisfy the JEM runtime requirement***
  - UWM with high resolution
  - UDM together with high resolution UWM
  - MSS with both low and high resolutions

MESO RUSTIC Urban Model Runtime Comparisons: *Summary*

- **MESO/RUSTIC can satisfy the JEM 10 minute requirement consistently only when run with:**
  - Low grid resolution (50 m - ***a factor of 10 coarser than recommended***)
  - Particle numbers roughly ***a factor of 10 fewer than recommended***
  - Few steady-state wind updates
- **RUSTIC is the time bottleneck – can take *hours* for high resolution (<10 m) grids or larger (several km) domains**
- **MESO itself can run on the order of 10 minutes for 1 hour of simulated time using the recommended number of particle tracers on a coarse RUSTIC grid (> 25 m)**
  - Can run on the order of minutes using a reduced number of tracers
  - Grid resolution does not seem to be the limiting time factor for MESO
- **MESO-RUSTIC results have not yet been validated at low resolution**

QUIC-URB QUIC-PLUME Initial Runtime Analyses: *Summary*

- **QUIC-URB and QUIC-PLUME can satisfy the JEM runtime only when run with**
  - Low grid resolution (10 m - ***a factor of 2 coarser than recommended***)
  - Low number of tracer particles (< ~ 50, 000 - ***a factor of 8 fewer than recommended***)

- **For low grid resolution, the QUIC-PLUME (particle evolver) runtime dominates the total runtime**
  - QUIC-PLUME runtime goes roughly linearly with increasing particle number for small particle numbers (~ 10^4), then sub-linearly for high number of particles (~ 10^5)

- **For high resolution, the runtime for QUIC-URB alone does not satisfy the JEM 10 minute requirement**