Use of HPC to Leverage Operational Mesoscale Meteorological Support for ATEC Test Ranges

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Outline

• Review of ATEC 4D Weather (4DWX) models
• Goals of DPG HPC Applications
• DPG HPC System (hardware)
• R&D of advanced 4DWX Models on HPC
  – Ensemble Real Time Four Dimensional Data Assimilation and forecasting system (E-RTFDDA)
  – Range climatology using Climo-FDDA
  – Very high-resolution modeling of range weather
  – Global Meteorology on Demand (GMOD)
  – T&D applications coupling with E-RTFDDA
• Summary
ATEC Test Centers

- Cold Regions Test Center (CRTC) Alaska
- Dugway Proving Ground (DPG) Utah
- Aberdeen Test Center (ATC) Maryland
- White Sands Missile Range (WSMR) New Mexico
- Yuma Proving Ground (YPG) Arizona
- Electronic Proving Ground (EPG) Arizona
- Redstone Technical Test Center (RTTC) Alabama
Primary Type of Modeling Support at ATEC Ranges

Aberdeen Test Center – maritime conditions
  - Ballistic testing and sound propagation

Cold Regions Test Center – arctic weather
  - Missiles, wheeled and tracked vehicles, various ground forces

Dugway Proving Ground – desert atmospheric boundary layer
  - Chemical and biological dispersion and diffusion

Electronic Proving Ground (Ft. Huachuca) – RF propagation
  - Transmission and path loss, UAV flights

Redstone Technical Test Center – subtropical humid weather
  - Convective precipitation and lightning effects, visibility

White Sands Missile Range – upper air in desert environments
  - Missiles, ballistic wind effects, live fire testing, wind drift effects

Yuma Proving Ground – desert atmospheric effects
  - Parachute drops, medium to long-range artillery
Example: CRTC Model Domain Configuration

CRTC D1 (DX=30 km)  CRTC D2 (DX=10 km)
Example: CRTC Model Domain Configuration (Terrain in Domains 3 and 4)

CRTC D3 (DX=3.3km)

CRTC D4 (DX=1.1km)
Example: WSMR and YPG Model’s Fine-mesh (Terrain in Domain 3)

WSMR D3 (3.3km)  
YPG D3 (3.3km)

The model simulates detailed range local terrain forcing
Specify “Non-standard” Land Use and SST

DPG D4

Playa

MODIS Urban Areas

WSMR D3

Lava

Urban Canopy Modeling

White Sands

Crops

Forest

Urban Canopy Modeling

Great Salt Lake Temperature

First day: 20080521

AVHRR SST

MODIS SST + RTG

NCAR
DPG HPC – An Impetus to 4DWX

• ATEC/NCAR 4DWX Modeling System
  → To provide superior recent and current analyses, nowcasting and short-term forecasting of range weather, and climatology, to support tests at Army test ranges and off-site regions

• DPG HPC Platform
  → A springboard for leveraging 4DWX weather technologies and sciences that critically rely on HPC supercomputing capabilities
Dugway HPC

- 2 administrative nodes
- 2 interactive nodes
- 65 compute nodes
- 4 storage Agami raid

- 4X Infiniband interconnect
- Gigabit file system network
- 100Mbit management network
- Remote power control
- Environmental monitoring
- BIOS/system console interaction
- EM64T 3.73GHz Intel Dempsey chip set
- Split 2MB + 2MB L2 cache
- 260 processors
- 65 systems, dual core, dual processor
- 4 19” cabinets
- SuSE SLES 9 64-bit operating system
- Clusterworx cluster management system
DPG HPC – Application Goals

• R,D,T&E cutting-edge mesoscale numerical weather analyses and prediction technologies
  (RTFDDA, E-RTFDDA, EnKF, C-FDDA … )

• Provide advanced weather products for Army applications: real-time and/or historical

• Improve 4DWX DSS capabilities for ATEC range tests, e.g. SCIPUFF, NAPS, …

• Build a GMOD tool for applying the 4DWX models for ATEC emergent and/or special events

• To demonstrate and prepare an ATEC operation next-gen 4DWX capability for future implementation
1. Ensemble Prediction System

• Predict the observed distribution of events
• Predict uncertainty in the day’s prediction (variance)
• Predict the distribution of observed atmospheric states (covariance)
• Predict the extreme events that are possible on a particular day
• Provide a range of possible scenarios for a particular forecast
4DWX-RTFDDA: the Current Capabilities

RTFDDA System

RTFDDA Regional-scale model, based on WRF & MM5

New 12 - 48 h forecast every 1 - 12 hr cycles, using all obs up to "now"

obs-nudging
analysis-nudging
WRF-VAR

All WMO/GTS
GOES
Radars
Wind Prof
MESONETs
ACARS
Etc.
TAMDAR

Forecast
4DWX  E-RTFDDA: New capabilities

Ensemble-RTFDDA System

- Boundary UC
- Physics UC
- Obs UC
- Analysis UC
- External forcing UC

Ensemble Generator + Filter

RTFDDA Members

Probabilistic Forecasting products

*UC: uncertainties

29th HPC User Forum, 8-10 September 2008  Tucson, AZ
E-RTFDDA: Capability Design

Ensemble Real-Time Four-Dimensional Data Assimilation and Forecasting System.

– Built upon 4DWX RTFDDA (upon WRF and MM5) that are operated at the ATEC ranges

– Multiple models and multiple ensemble schemes
  WRF and MM5; Perturbations for B.C., I.C., Obs., Data assimilation weights, model physics, including static and evolving land surface properties; 3DVAR default error statistics; ETKF; time-lag breeding; EnKF ...

– Member (perturbations) selection based on weather regimes and special application needs

– Flexibility: research, operation and incorporation of new community achievements
Implementation Strategy: 3-Tiers

1. Ensemble Generator
   Construct an exhaustive ensemble member library

2. Member Selector
   Pick the most appropriate members of an affordable ensemble size for specific applications

3. Member Execution
   Integrate data analysis and forecast with a continuous cycling mechanism

Probabilistic analysis and forecast products
HPC E-RTFDDA Executions

Each member runs on 1 - 10 nodes dependent on the member model sizes, using MPP with Infiniband
E-RTFDDA Demo Op for DPG

D1: map \( \Delta X = 30 \text{ km} \)
D2: terrain \( \Delta X = 10 \text{ km} \)
D3: land use \( \Delta X = 3.33 \text{ km} \)
## 30 WRF and MM5 Members of DPG E-RTFDDA

<table>
<thead>
<tr>
<th>E#</th>
<th>LBC</th>
<th>WRF Members (15)</th>
<th>E#</th>
<th>LBC</th>
<th>MM5 Members (15)</th>
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<tr>
<td>1</td>
<td>NAM</td>
<td>Control: WRF baseline physics</td>
<td>16</td>
<td>NAM</td>
<td>Control: MM5 baseline physics</td>
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<tr>
<td>2</td>
<td>GFS</td>
<td>Control: WRF baseline physics</td>
<td>17</td>
<td>GFS</td>
<td>Control: MM5 baseline physics</td>
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<tr>
<td>3</td>
<td>NAM</td>
<td>SLAB land surface</td>
<td>18</td>
<td>NAM</td>
<td>Simple cloud-effect radiation</td>
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<tr>
<td>4</td>
<td>NAM</td>
<td>MYJ PBL</td>
<td>19</td>
<td>NAM</td>
<td>ETA TKE PBL</td>
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<tr>
<td>5</td>
<td>NAM</td>
<td>MYJ PBL + GD Cumulus</td>
<td>20</td>
<td>NAM</td>
<td>Kain-Fritsch cumulus</td>
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<td>6</td>
<td>NAM</td>
<td>WMS6 microphysics</td>
<td>21</td>
<td>NAM</td>
<td>Goddard microphysics</td>
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<tr>
<td>7</td>
<td>NAM</td>
<td>GD cumulus</td>
<td>22</td>
<td>GFS</td>
<td>Betts-Miller cumulus</td>
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<tr>
<td>8</td>
<td>GFS</td>
<td>Thomason microphysics</td>
<td>23</td>
<td>GFS</td>
<td>Reisner 3-ice microphysics</td>
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<td>9</td>
<td>GFS</td>
<td>MYJ PBL + WMS5 microphysics</td>
<td>24</td>
<td>GFS</td>
<td>CCM2 radiation</td>
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<td>10</td>
<td>GFS</td>
<td>MYJ PBL</td>
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<td>GFS</td>
<td>GFS LBC Phase-uncertainty 1</td>
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<td>MYJ PBL + GD Cumulus</td>
<td>26</td>
<td>GFS</td>
<td>Symmetric perturb to Member 25</td>
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<td>BMJ cumulus</td>
<td>27</td>
<td>GFS</td>
<td>GFS LBC Phase-uncertainty 2</td>
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<td>GFS</td>
<td>BMJ cumulus in 3.3 km grid</td>
<td>28</td>
<td>GFS</td>
<td>Symmetric perturb. to Member 27</td>
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<td>14</td>
<td>GFS</td>
<td>GD cumulus in 3.3 km grid</td>
<td>29</td>
<td>GFS</td>
<td>Correlated sounding perturbation</td>
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<td>15</td>
<td>GFS</td>
<td>KF cumulus in 3.3 km grid</td>
<td>30</td>
<td>GFS</td>
<td>Symmetric perturb. to Member 29</td>
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DPG E-RTFDDA Web-based Products

Probabilistic Products
- Ensemble Image Viewer
- Ensemble Meteogram at SAMS01
- Ensemble Meteogram at SAMS 07
- Ensemble Meteogram at SAMS 06
- Ensemble Meteogram at SAMS 12
- Ensemble Meteogram at Cedar Mt
- Ensemble Meteogram at Boulder

Ensemble Mean
- Ensemble Mean - RTFDDA Image Viewer

Control Members: NAM/MM5 and GFS/WRF
- MM5 baseline member - RTFDDA Image Viewer
- MM5 baseline member - status monitor
- WRF baseline member - RTFDDA Image Viewer
- WRF baseline member - status monitor
- Ensemble Node Status monitor

Dugway Proving Grounds Forecast Model
- DPG high resolution (1.1km) WRF RTFDDA
- DPG high resolution (1.1km) MM5 RTFDDA

System Description and References
Surface and X-sections
- Mean, Spread, Exceedance Probability, Spaghetti, …

Pin-point surface and profiles
- Mean, Spread, Exceedance Probability, Spaghetti, wind roses, histograms …
10-m Winds at SAMS08 Site

Cycle 2008031406 for DS08 (40.2 / -113.17)

SPD (m/s)

Forecast Time (2008031406 cycle)
Ensemble spread-skill (speed absolute error) correlation for winds at SAMS12, DPG

![Graph showing MAE and Spread](image)

**Graph Details:**
- **Axes:**
  - Y-axis: Mean Absolute Error/Std Dev (m/s)
  - X-axis: Forecast hours (for 06Z cycle only)

**Right Graph:**
- **X-axis:** Spread (Std Dev; m/s)
- **Y-axis:** Skill (Mean Absolute error (m/s))
- **Correlation:** corr: 0.602894
2. Evaluation of the impact of model resolution on a summer convection event at WSMR

Forecasting experiments
Subsequent grid refinements with 2-way nested-grids up to four grids:

EXP D1 $\rightarrow$ D1 only,  EXP D2 $\rightarrow$ D1 / D2,
EXP D3 $\rightarrow$ D1/D2/D3,  EXP D4 $\rightarrow$ D1/D2/D3/D4

D1: 160 x 121,  DX = 13.5 km
D2: 166 x 166,  DX = 4.5 km
D3: 316 x 322,  DX = 1.5 km
D4: 460 x 460,  DX = 0.5 km

Note:
The model result analysis

40 nodes (160 procs) with Infiniband
Terrain Height at Different Resolutions

D1
13.5km

D2
4.5km

D3
1.5km

D4
0.5km
Verification of the model 3-h rain ended at 21Z, 8 August 2005
3. CFDDA for Army Range
mesoscale climate reanalysis

- **4DWX CFDDA:** Climo Four-Dimensional data assimilation with WRF or MM5

  A dynamical climatology downscaling from the available coarse grid climate analysis (~200 km) and local underlying forcing and observations to the range scale (1 - 3 km) for 30 or more years
CFDDA: An Example

Frequency of occurrence of wind speed above 7.5 ms\(^{-1}\)

GMATC JJA 2006

00:00 UTC

06:00 UTC

12:00 UTC

18:00 UTC

frequency (%)

0  5  10  15  20  25
4. DPG-HPC GMOD Tool

- Run 4DWX models (RTFDDA, E-RTFDDA and C-FDDA) at any region over the globe with button-click
  (Using dedicated group HPC nodes as needed)

- Backup the real-time modeling and/or facilitate case studies at the Army ranges and off-sites of interest
  (With existing and/or enhance 4DWX modeling capabilities)

- Support R&D modeling effort and experimental operation of the 4DWX modeling systems on HPC
  (High-resolution modeling; E-RTFDDA model developments including reforecast for ensemble output calibration …)
HPC-GMOD System – A virtual tour
5. Couple T&D model with E-RTFDDA

- Hourly E-RTFDDA analyses and forecasts are converted to MEDOC for download
- Run SCIPUFF on the HPC and produce the mean and spread of plume dosages and concentrations

Web display:
Animation of dosage and concentration and thumbnail maps
Ensemble Statistics of Dosage of Hypothetical Release SF6
(0300 – 0645 UTC July 28, 2008)

Ensemble Mean
07/28/2008 03:25 GMT

Ensemble Spread
07/28/2008 03:25 GMT

Mountains

Surface Dosage Ens. Mean $10^3$ kg·sec·m$^{-3}$

Surface Dosage Ens. Std $10^3$ kg·sec·m$^{-3}$
Scenario Dosage of Hypothetical Release SF6
(0300 – 0645 UTC July 28, 2008)

30 members
3.3 km grids
Various perturb.
Plan for FY09 - 10

- Continue to the R&D of E-RTFDDA sciences and technologies
- Customize probabilistic weather products, tailoring for range decision needs
- Continue to enhance the GMOD tools and DSS applications
- Conduct extremely high-resolution weather simulation over the Army range using WRF-LES RTFDDA
- Produce range-scale climatology using C-FDDA
Summary

- ATEC 4DWX modeling systems provide operational multi-scale, rapid-updated weather analyses and forecasts for seven Army test ranges.

- DPG HPC enables R,D,T&E of the advanced weather modeling capabilities including ensemble analysis and prediction, range micro-climatology construction, extreme high-resolution weather modeling and DSS application simulations.

- An experimental 30-member E-RTFDDA has been operated for Dugway Proving Ground since August 2007 and highly used and recommended by end-users.

- The 4DWX modeling R&D work on the HPC is on-going, toward next-Gen ATEC 4DWX capabilities.
End.