An MM5 and WRF-based rapid-cycling multi-scale weather analysis and forecasting system for supporting the test and evaluation at the Army Cold Region Test Center

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Outline

➢ An introduction of the NCAR WRF-based multi-scale, rapid-cycling, (Ensemble-) RTFDDA system and range applications
➢ RTFDDA application at the Army Cold Region Test Center (CRTC), AK, and case studies
➢ Summary
Measurements are relatively sparse and irregular in space and time.

Data itself are not sufficient to describe the structures of local-scale circulations.

→ A full-physics model + full use of all data

How to?
R
t
T
F
D
D
A
 Modeling System

Real-Time Four Dimension Data Assimilation and forecasting system, developed by NCAR and ATEC (Army Test and Evaluation Command)

- Built upon MM5 and WRF-ARW,
- Real-time and Retrospective,
- Multi-scale: meso-γ → α (δx = 0.5 – 45 km),
- Rapid-Cycling: at flexible intervals of 1 – 12 hrs
- FDDA: 4-D continuous “obs-nudging”,
- Forecast (0 – 48 hours), and
- Climatology
RTFDDA: “Obs-nudging” 4DDA

WRF/ MM5

OBS

ETA/ AVN

Analysis & Forecast

WRF: “Dx/Dt = …” → “Dx/Dt = … + W (y_{obs} - x)”

\[ W = G \cdot W_{qf} \cdot W_{\text{horizontal}} \cdot W_{\text{vertical}} \cdot W_{\text{time}} \]

At each grid point, the weighted effects from all the nearby observations are summed.

The weights can vary with the distance between the grid points and the observation in horizontal space, vertical space, and time.

Distance between observation and grid point

Data point

Area affected by data point

\[ A_p = \frac{\sum w_i \cdot \text{value}_i}{\sum w_i} \]
NCAR/ATEC RTFDDA System

“Observation-Nudging”

New 12 - 48 h forecast every 1 - 12 hrs, using all obs up to “now”

RTFDDA
Regional-scale model, based on MM5/WRF

obs
Cold start
FDDA
Forecast

All WMO/GTS
MODIS/GOES
Radars
QuikScat
Mesonets
ACARS
TAMDAR
Etc.

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NCAR RTFDDA Applications

- 2002-SLC Olympics
- 2004-Athens Olympics
- 2006-Torino Olympics
- Joint Urban 2003, OKC
- Colorado wild fire
- Military operations
- Army test ranges
- Homeland security
- Pentagon “shield”
- FAA aviation weather
- Kauai island effect
- New York City
- 2005 Hurricanes
- TAMDAR appli.
- …

12 Regular Operational RTFDDA Systems
20+ Special Operation Sites
Ensemble-RTFDDA System

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

Ensemble Generator + Filter → RTFDDA Members → Probabilistic Forecasting products

*UC: uncertainties

RTFDDA → Ensemble-RTFDDA

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Extended from RTFDDA, E-RTFDDA possesses many features that are uniquely beneficial for mesoscale weather capabilities:

- continuous ensemble analysis and forecasting
- multi-scale, down to 1 - 3 km grid
- dynamic perturbation optimization
- globally-relocatable, and
- a next-gen NWP testbed for integration of “cutting-edge” data assimilation technologies.
DPG E-RTFDDA Operation (Debut on 10 Sep. 2007)

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4DWX

DPG Ensemble RT-FDDA (E-RTFDDA)

Probabilistic Products
- Ensemble Image Viewer
- Ensemble Meteogram at SAMS01
- Ensemble Meteogram at SAMS 07
- Ensemble Meteogram at SAMS 08
- Ensemble Meteogram at SAMS 12
- Ensemble Meteogram at Cedar Mtn
- Ensemble Meteogram at Boulder

Ensemble Mean
- Ensemble Mean - FDDA Image Viewer

Control Members: NAM/MM5 and GFS/WRF
- MMS baseline member - FDDA Image Viewer
- MMS baseline member - status monitor
- WRF baseline member - FDDA 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) MMS RTFDDA

System Description and References
RTFDDA applications at the Army Cold Region Test Center (CRTC), Alaska and simulation of a cold-air event with WRF-based RTFDDA
CRTC Model Domain Configuration

CRTC D1 (DX=30 km)  CRTC D2 (DX=10km)

Little Alaska Weather Symposium  12-13 May 2008  Fairbanks, AK

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CRTC Model Domains 3 and 4

CRTC D3 (DX=3.3km)

CRTC D4 (DX=1.1km)

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Winter vs Summer Test for CRTC (D3)

Surface winds and 1h rain (animated, 24 hours; 12Z – 12Z)

Winter (Jan 4 – 5, 2007)

Summer (Aug 13 – 14, 2007)
Winter vs Summer Test for CRTC (D3)
Surface temperature and winds (animated, 24 hours; 12Z – 12Z)

Winter (Jan 4 – 5, 2007)

Summer (Aug 13 – 14, 2007)
Comparison of objective verification

CTRC 10 - 12h forecast D2 (August 1 – 18, 2007)

- T RMSE (°C)
- Q RMSE (g kg⁻¹)
- SPD RMSE (m s⁻¹)
- DIR RMSE (°)

GMT HOUR

New WRF

MM5

GRID 2

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Case Study: Jan 21 – 27, 2007

T2m at selected CRTC stations

D4

T2 (°C)

TIME (DDHH)

S01
S09
S10
S11

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Surface:
Psl
T-2m
Winds-10m

00Z Jan. 22
-18Z Jan. 27
3 hourly
Surface:
T-2m
Winds-10m

23Z Jan. 23
00Z Jan. 27
Vertical X-section
T (C)
Wind barbs

00Z Jan. 24
-  
00Z Jan. 27

Cross-section for: 2007-01-24_00:00:00
Init: 2007-01-22_00:00:00

Temperature (C)
winds (kts)

Cross-Section: (12,9) to (65,66)

Distance (Km)
Height (km)

Temperature (C)

-36 -32 -28 -24 -20 -16 -12 -8 -4 0
Θ and RH time-height
Comparison of model and radiosonde observations

D4

Radiosonde

(63.89N, 145.87W) 17:30 UTC

Height (km)

Temperature (°C)

126WRF
125WRF
124WRF
126OBS
125OBS
124OBS

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Challenges!

T2m at selected CRTC stations

OBS

WRF

Time (DDHH)
18 h forecasts of surface winds and temperature, D3
Valid at 12Z Jan. 5, 2007

WCTRL  WCT2W  WPMYJ  WRGOD

WAF01  WAF02  WAF04  WAF08
1. NCAR/ATEC jointly developed and operate a RTFDDA system at CRTC, Alaska, where complex terrain exists.

2. Operational verification statistics of and case studies indicates valuable model skills, and challenges as well.

3. Ensemble-RTFDDA has been developed, which will significantly leverage the current modeling research and future operations at CRTC.

4. By integrating advanced DA approaches, including hybrid WRF-VAR and EnKF into E-RTFDDA, ability we hope to better address the model capability.

5. Meanwhile, we’ll work with AirDat on TAMDAR, and study land surface physics, along with the of Polar-WRF group(s)’s findings, to enhance the (E-)RTFDDA.
“Observation-nudging”

- A Newtonian Relaxation Process
  - Relax model toward observations
  - Hoke and Anthes (1976), Stauffer and Seaman (1994) …

- A Chaos Synchronization Process
  - Couple model and natural evolutions
  - Yang et al. (2005), Duane et al. (2006), …
What is “Observation-nudging”? 

\[
\frac{Dx}{Dt} = \ldots + GW \left( x_{\text{obs}} - x_{\text{model}} \right)
\]

where \( x = T, U, V, P1, P2 \ldots \)

W is nudging weight function

G is called nudging factor

\( G \rightarrow \text{Small enough not to destroy } \ldots, \text{ and big enough to } \ldots \)

W \( \rightarrow f (x, y, z, t, q_f) \)
Weighting functions should depend on grid sizes; local terrain; observation quality, location, time and platforms; and air stream properties.

\[ W = W_{\text{time}} W_{qf} W_{\text{horizontal}} W_{\text{vertical}} \]

The weights can vary with the distance between the grid points and the observation in horizontal space, vertical space, and time.

\[ A_i = \frac{\sum W_j \cdot \text{value}_j}{\sum W_j} \]

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