WRFDA 2009 Updates

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1. Overview

WRFDA - the Weather Research and Forecasting (WRF) Data Assimilation system is a component of the WRF modeling system developed at the National Center for Atmospheric Research. WRFDA is an advanced data assimilation system, contained with the WRF software that provides state-of-art 3D/4D variational (3D/4D-Var) and hybrid variational/ ensemble techniques (Barker et al. 2004; Huang et al. 2009a; Wang et al. 2008).

With the recent release, version 3.1, WRFDA can assimilate:

- In-Situ observations:
  - Surface (SYNOP, METAR, SHIP, BUOY).
  - Upper air (TEMP, PIBAL, AIREP, ACARS, TAMDAR).
- Remotely sensed observations:
  - Atmospheric Motion Vectors (geo/polar).
  - SATEM thickness.
  - Ground-based GPS Total Precipitable Water/Zenith Total Delay.
  - SSM/I oceanic surface wind speed and TPW.
  - Scatterometer oceanic surface winds.
  - Wind Profiler.
  - Radar radial velocities and reflectivities.
  - Satellite temperature/humidity/thickness profiles.
  - GPS refractivity (e.g. COSMIC).
- Radiances (using RTTOV or CRTM):
  - HIRS NOAA-16, NOAA-17, NOAA- 18, METOP-2
  - AMSU-A NOAA-15, NOAA-16, NOAA-18, EOS-Aqua, METOP-2
  - AMSU-B NOAA-15, NOAA-16, NOAA-17
  - MHS NOAA-18, METOP-2
  - AIRS EOS-Aqua
  - SSMIS DMSP-16
- Bogus data
  - TC bogus
  - Global bogus

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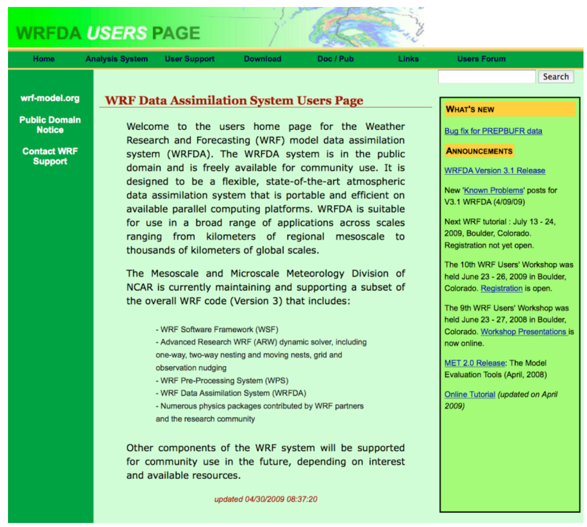
WRFDA is used in both applied and research settings. It is used as the analysis component of several international operational data assimilation systems. It is also used by those centers, as well as by university and research institutions, for data assimilation research.

WRFDA is a community data assimilation asset that is maintained and supported by NCAR. In 2009, NCAR developed the WRFDA website where one can browse,



or download WRFDA documentation, tutorials, test data, participate in user forums, and obtain the latest code. See http://www.mmm.ucar.edu/wrf/users/wrfda

WRFDA development and support is provided by a dedicated team of NCAR scientists. Those scientist works with the international data assimilation community to improve the scientific and software engineering aspects of WRFDA. The international community interacts with NCAR's WRFDA team through various channels: (i) NCAR's visiting scientist program, (ii) WRFDA user forums and workshops, (iii) bi-annual tutorials, (iv) an online support facility, called WRF-Help, (v) collaborative operational center research projects, and (vi) university/graduate student research projects. Generally, the WRFDA workshops and tutorials are held at the NCAR facilities in Boulder, Colorado, USA. Occasionally they are held overseas to accommodate user community needs. For the benefit of the community, NCAR posts all tutorial presentations at http://www.mmm.ucar.edu/wrf/users/wrfda/tutorial.html

2. WRFDA 3.1

WRFDA 3.1 was released in April 2009. It includes many new features and options that have been added since WRFDA 3.0 release in 2008. Details concerning the new updates, bug fixes, and code optimization can be found on WRFDA web page. Huang et al (2009b). contains a comprehensive review of the changes between WRFDA 3.0 and 3.1. Two important improvements, the 4D-Var component and the radiance data assimilation capability, were requested by the community at the 2008 WRF Workshop. Other new features include the following:

a) The 4D-Var component of WRFDA, including the WRF tangent linear model and WRF adjoint model.
b) Radiance assimilation capability, including interfaces to both CRTM and RTTOV radiative transfer packages, and bias correction schemes.
c) The Lanczos minimization algorithm. The adjoint of analysis and the code for forecast sensitivity to observations.
d) WRFDA interface to the WRF-NMM core (Rizvi and Pattanayak, 2009).
e) WRFDA interface to the global WRF.
f) Global background errors, including the extensions both in gen_be, the module to compute background errors, and in WRFDA.
g) Observation operator for TAMDAR (Wang, et al 2009).
h) Buddy check for upper air and surface observations.
i) Option to run 3/4D-Var on C-grid (the default is still on A-grid).
j) Further development of hybrid code, in particular the vertical localization and 3D alpha control variable.
k) Assimilation of observations in PREPBUFR format.
l) Assimilation of observations in MADIS format.

3. WRFDA 3.1.1

NCAR's WRFDA team is currently working on a minor revision release, WRFDA 3.1.1. The expected release date is 31 July 2009. The details of that release will be available on the WRFDA web page. The revisions are expected to include:

a) More user friendly features with latest bug fixes.
b) Some of the important libraries like BLAS, LAPACK and BUFR etc. will be included as a part of the source code.
c) Shared-memory parallelization (sm) and distributed-memory (dm) with shared-memory parallel (sm+dm).
d) 4D-Var capability with enhanced computational efficiency.
e) Update in gen_be to produce WRF-ARW background errors for NCEP GSI.
f) Updated grid verification tool.
g) Implementation of new analysis control variables. Some details about this work are described in the following section.

4. Ongoing work

4.1 4D-Var optimization

The WRFDA team is transforming the WRFDA 4D-Var system, which uses three concurrently running executables (Huang, et al. 2009a), into a single executable (Stark, et al. 2009). The transformation is using the Earth Modeling System Framework (ESMF) to streamline the WRFDA 4D-Var algorithm. The primary motivation is to improve computational performance and scaling by eliminating the reliance on disk-based I/O for inter-component communication. The single executable design will employ two very different communication strategies to balance generality and performance. First, the traditional top-down hub and spoke coupling will be used to link the nonlinear and the variational components, since they are easily separated into distinct tasks. Second, a put-get strategy, known as direct coupling, will be used to optimize data communication in the inner minimization loop of the CG solver. Tight communication links between the variational, tangent linear, and adjoint components make the more traditional hub and spoke strategy impractical and necessitate the direct coupling approach.

4.2 Lateral boundary control in 4D-Var

The control of lateral boundaries is important for the assimilation of observations near those boundaries. Such control may also be important for assimilating phenomena that propagate through the lateral boundaries during the early part of the assimilation window and are observed well inside the model domain during the later part of the assimilation window. To address these issues, an additional penalty term, J_{LBC}, is added in the 4D-Var cost function, closely following the JMA formulation (Kawabata et al. 2007) and the HIRLAM formulation (Nils Gustafsson, personal communication). This is an ongoing research effort and the results will be reported in the near future.

4.3 ACAPS

WRFDA is also being used to conduct research for the development of a three-dimensional (3-D) cloud analysis and prediction algorithm as part of the Air Force Weather Agency (AFWA) Coupled Assimilation and Prediction System (ACAPS). The primary objectives are to: (i) assist the AFWA system with fully exploiting the vast amount of satellite data that will be available from the National Polar-orbiting Operational Environmental Satellite System (NPOESS), and (ii) improve the AFWA operational system so it can analyze and predict 3-D clouds more accurately. ACAPS is being developed as a community-based unified system that will utilize the latest available science.

4.4 Hydrometeors

The WRFDA radiance data assimilation capability (Liu and Barker, 2006) has been extended to assimilate radiances over cloudy and/or precipitating areas (Liu et al. 2009). These extensions include: (i) extending CRTM interface to include the hydrometeor profiles (cloud liquid water, cloud ice, rain, snow, graupel, hail) as input, (ii) replacing the moisture control variable with a total water control variable $Q_t=Q_{wv}+Q_{clw}+Q_{rain}$, and (iii) using TL and AD of a warm-rain physical scheme for partitioning Q_t increment into individual Q_{wv}, Q_{clw} and Q_{rain} increments. Further research will be focusing on enhancements related to 4D-Var and the non-incremental formulation of WRFDA.

4.5 Multivariate analysis for humidity

Presently, WRFDA in 3D-Var mode is univariate for humidity (Barker, et al. 2004). Following Berre (2000), the WRFDA team is developing a new set of control variables to provide for a multivariate moisture analysis. With that approach, the background errors in humidity are correlated to background errors in temperature, pressure and winds so that humidity observations lead to analysis increments in temperature, pressure and winds, and vice versa (Krysta et al. 2009). This research is ongoing and results from the prototype multivariate moisture analysis will be reported.

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