



WRF Data Assimilation System

Xin Zhang Michael Duda Syed Rizvi Xiang-Yu Huang

NCAR Earth System Laboratory

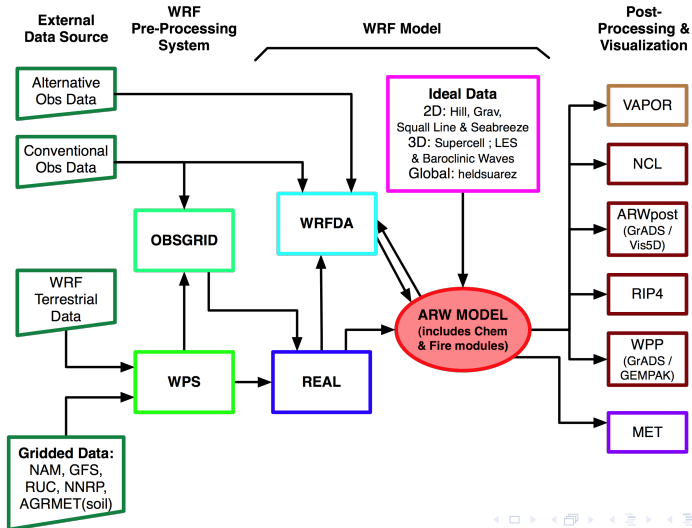
Presented on August 3, 2010
WRFDA Tutorial

NCAR is sponsored by the National Science Foundation

What is WRFDA ?

- WRFDA : A Data Assimilation system for WRF (ARW) model
 - Variational and Ensemble methods
 - Used for both research and operational data analysis
- It is a supported community model, i.e. a free and shared resource with distributed development and centralized support

WRF Modeling System Flow Chart



WRFDA Applications

Goal: Community WRF DA system for

- regional/[global](#)
- research/operations, and
- deterministic/probabilistic applications

Techniques:

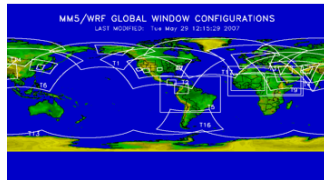
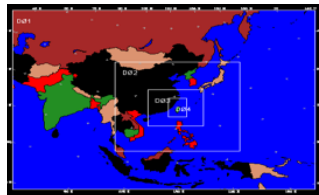
- 3D-Var
- 4D-Var (regional)
- [Ensemble DA](#)
- [Hybrid Variational/Ensemble DA](#)

Model: WRF (ARW, [NMM](#), [Global](#))

Support:

- NCAR/ESL/MMM/DAS
- NCAR/RAL/JNT/DATC

Observations: Conv. + Sat. + Radar



Prepare the BE

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x} - \mathbf{x}^b)^T \mathbf{B}^{-1}(\mathbf{x} - \mathbf{x}^b) + \frac{1}{2}(\mathbf{y} - H(\mathbf{x}))^T \mathbf{R}^{-1}(\mathbf{y} - H(\mathbf{x}))$$

- Nominally, $\mathbf{B}$ is the background error covariance

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 - be.dat file (CV option 5) from test case tar file can only be used with the domain from online tutorial

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 - be.dat file (CV option 5) from test case tar file can only be used with the domain from online tutorial
 - be.dat.cv3 (CV option 3) from source code tar file can be used for general test domains
- Ultimately, **B** should be specific to the particular model domain (and season)

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- In cycling mode: the output of the WRF model
 - WRF can output wrfinput-formatted files used for cycling

Prepare the Observations

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 - Prepbufr format data directly
- Observation error covariance also provided by OBSPROC (R is a diagonal matrix)
- Separate input file (ASCII) for radar, both reflectivity and radial velocity
- Separate input file for satellite radiances, BUFR format

Run WRFDA

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x} - \mathbf{x}^b)^T \mathbf{B}^{-1}(\mathbf{x} - \mathbf{x}^b) + \frac{1}{2}(\mathbf{y} - H(\mathbf{x}))^T \mathbf{R}^{-1}(\mathbf{y} - H(\mathbf{x}))$$

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- H is the observational operator, which calculate the counterpart of observations in model space
- Conjugate gradient method
- Try to find a $\mathbf{x}^a$, which make the J minimal



Update Boundary Condition

- After creating an analysis, $\mathbf{x}^a$, we have changed the initial conditions for the model

Update Boundary Condition

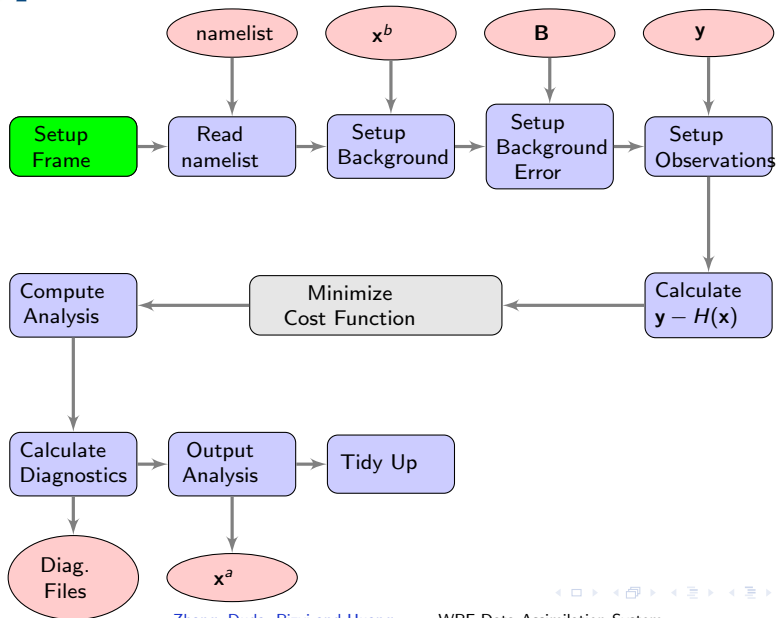
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- The update_bc program adjusts these tendencies based on the difference $\mathbf{x}^a - \mathbf{x}^b$

Update Boundary Condition

- After creating an analysis, $\mathbf{x}^a$, we have changed the initial conditions for the model
- However, tendencies in wrfbdy_d01 file are valid for background, $\mathbf{x}^b$
- The update_bc program adjusts these tendencies based on the difference $\mathbf{x}^a - \mathbf{x}^b$
- Of course, if $\mathbf{x}^a$ was produced for reasons other than running WRF, there is probably not a need to update boundary conditions

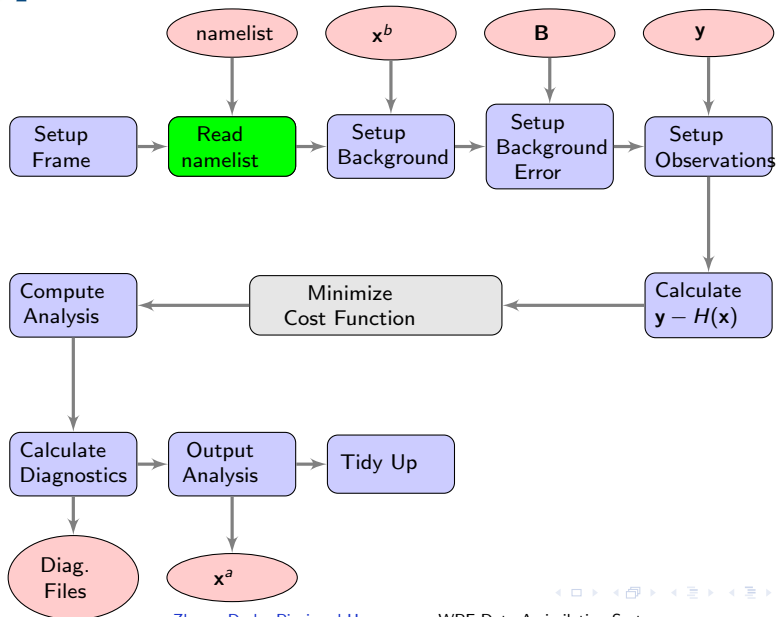


Setup Frame

- Reads grid dimensions from *namelist.input* file

Setup Frame

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- Use WRF framework distributed memory capability to initialize tile, memory, patch dimensions, etc.

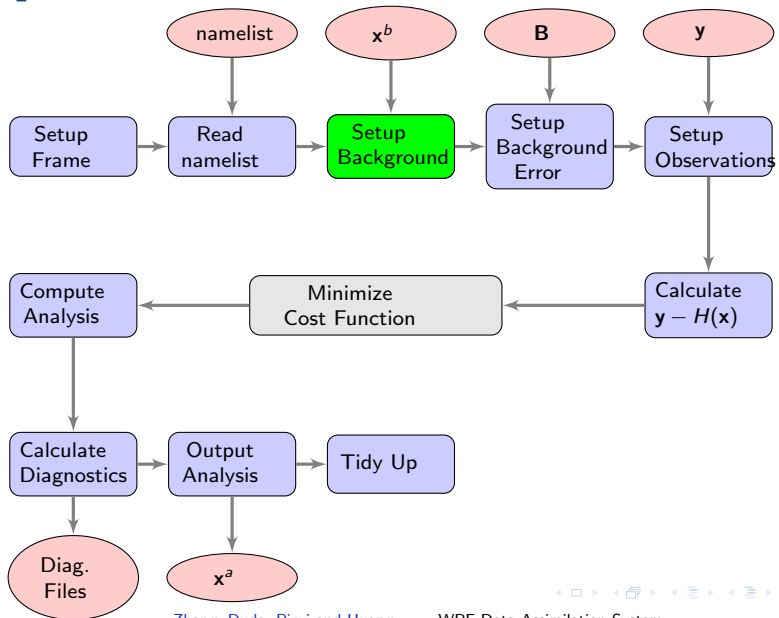


Read namelist

- Reads WRFDA data assimilation options from namelist.input file

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- Performs consistency checks between namelist options.



Setup Background

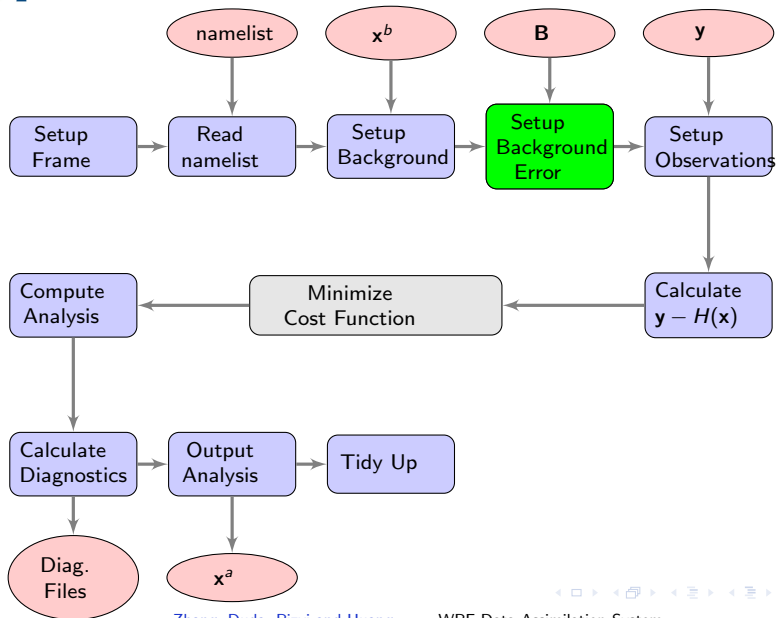
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Setup Background

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- Extracts fields used by WRFDA

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- Reads the first-guess file
- Extracts fields used by WRFDA
- Creates background FORTRAN 90 derived data type *xb* etc.
- Reference : **Online BE Documents**



Setup Background Error

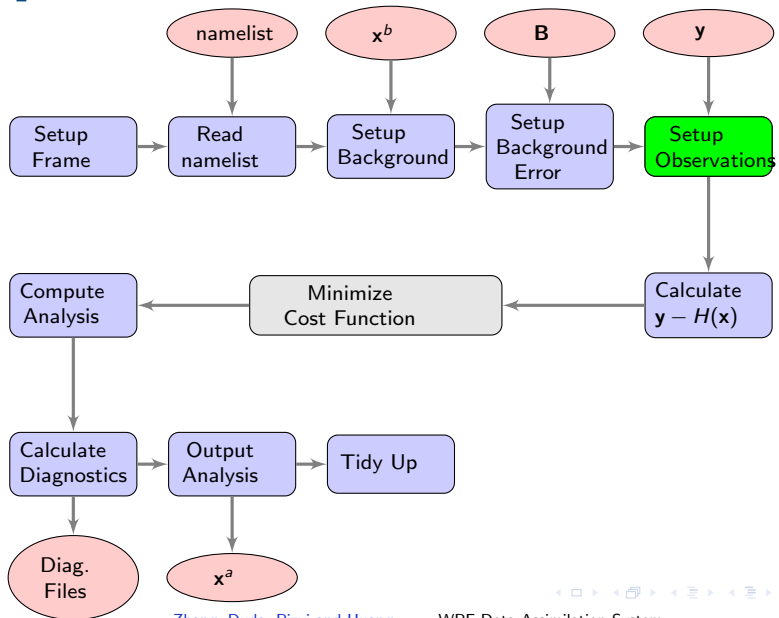
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- Creates background error FORTRAN 90 derived data type *be*



Setup Observations

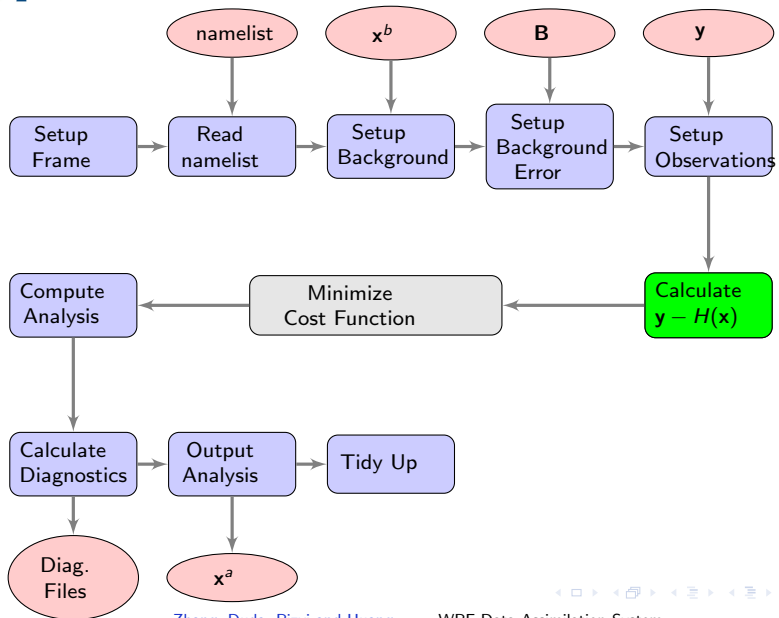
- Reads in observations

Setup Observations

- Reads in observations
- Creates observation FORTRAN 90 derived data type *ob*

Setup Observations

- Reads in observations
- Creates observation FORTRAN 90 derived data type *ob*
- Domain and time check



Calculate Innovation

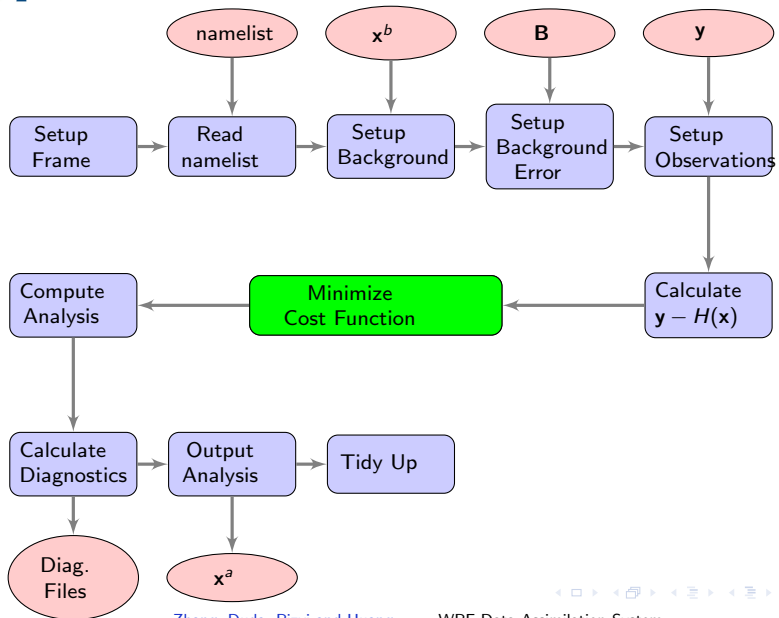
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Calculate Innovation

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- Computes observation minus first guess ($\mathbf{y} - H(\mathbf{x})$) value
- Creates innovation vector FORTRAN 90 derived data type *iv*





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- Computes cost function (if desired)

Minimization

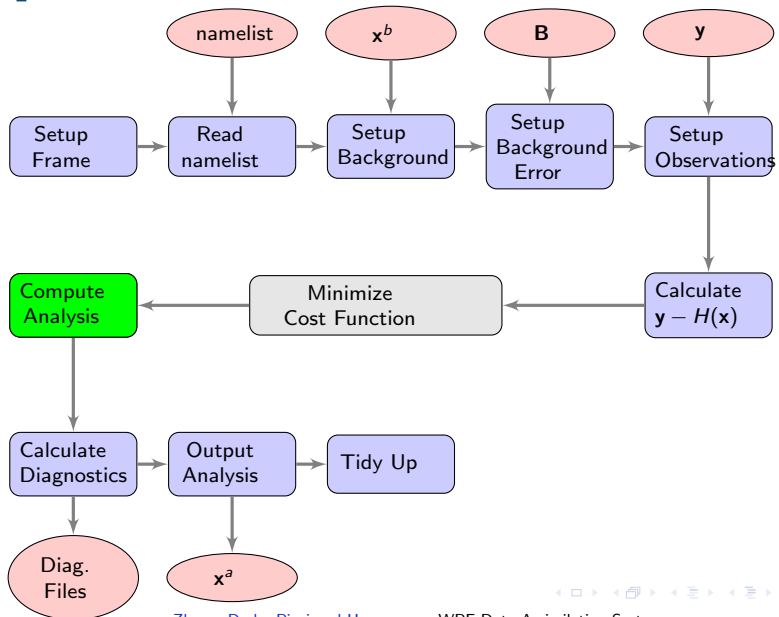
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Minimization

Use conjugate gradient method

- Initializes analysis increments to zero
- Computes cost function (if desired)
- Computes gradient of cost function
- Uses cost function and gradient to calculate new value of analysis control variable



Compute Analysis

- Once WRFDA has found a converged control variable, convert control variable to model space analysis increments

Compute Analysis

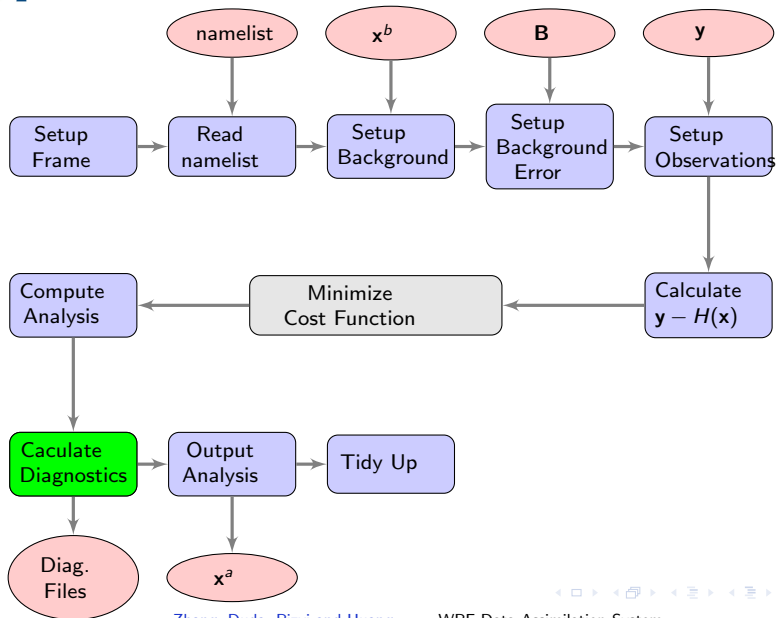
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$$\text{analysis} = \text{first-guess} + \text{analysis increment}$$
- Performs consistency checks, e.g., remove negative humidity etc.
- Optionally, do outer loop



Calculate Diagnostics

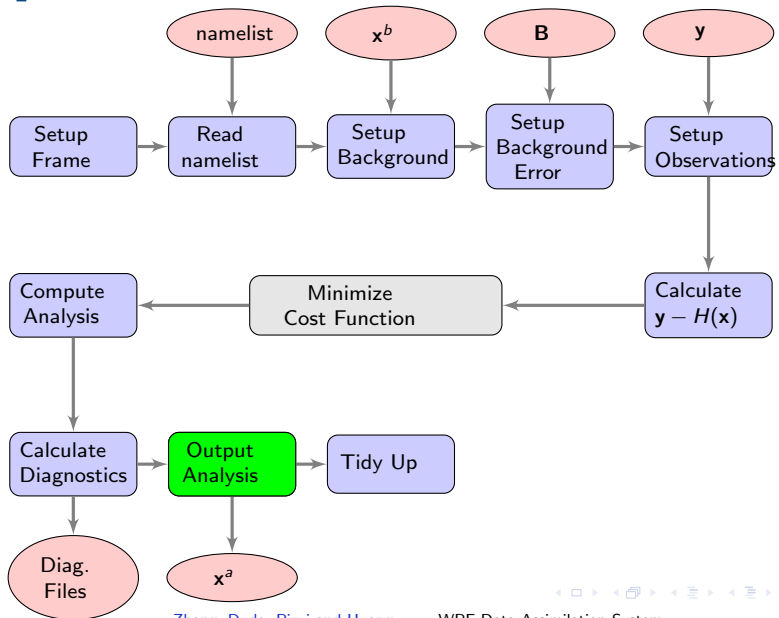
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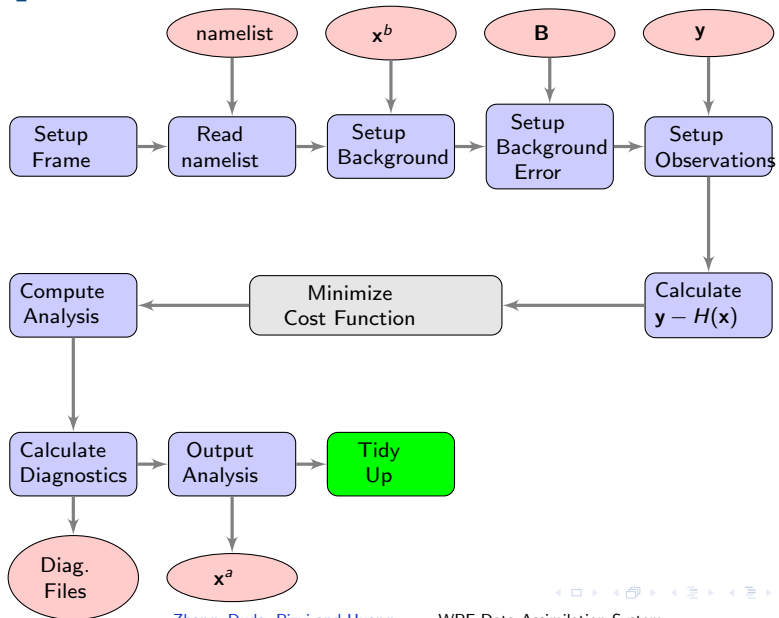
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- Statistics include minimum, maximum (and their locations), mean and standard deviation.



Output Analysis

- Outputs analysis in native model format.



Tidy Up

- Deallocate dynamically-allocated arrays, structures, etc.

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- Timing information

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- Clean end to WRFDA

Quick Start

- Supported parallel mechanisms
 - Serial
 - Distributed-memory(dm)
 - Shared-memory(sm) (use with cautions, thread safe compiler)
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- Supported platforms
 - IBM: XLF
 - Linux: PGI, IFORT, GFORTRAN (higher version needed)
 - Macintosh intel: PGI, G95
- Included libraries
 - CRTM 2.0.2 (well tested)
 - RTTOV 8.7 (upgrading to V9)
 - BUFR, BLAS and LAPACK

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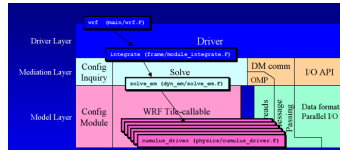
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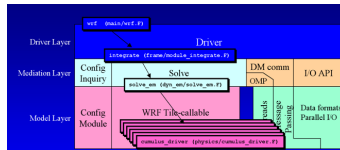
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- 40 executables should be generated under `var/build` directory

WRFDA Software Framework



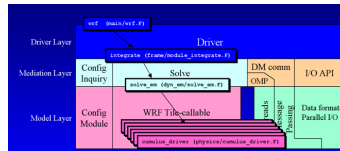
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WRFDA Software Framework



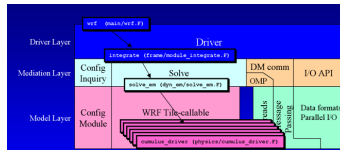
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 - Input/Output of first guess and analysis files
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WRFDA Software Framework



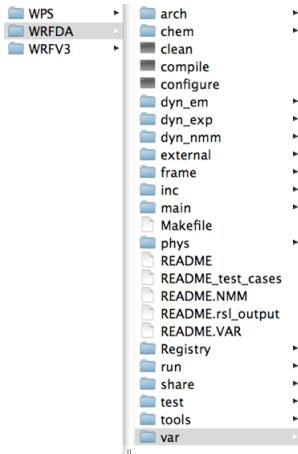
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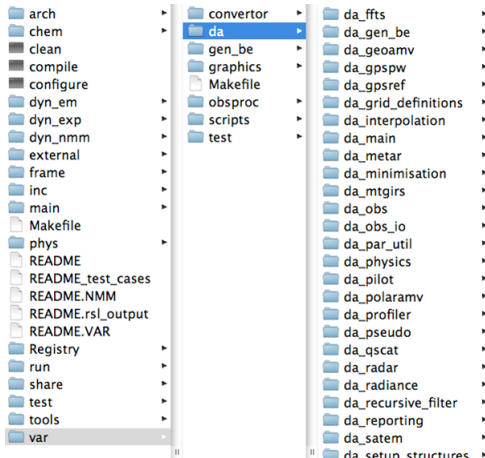
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 - The WRF Registry mechanism to handle definitions of fields, halos, type, package and transposes (**Registry.wrfvar**)
 - The WRF build system (clean, configure, compile)

WRFDA Code Organization



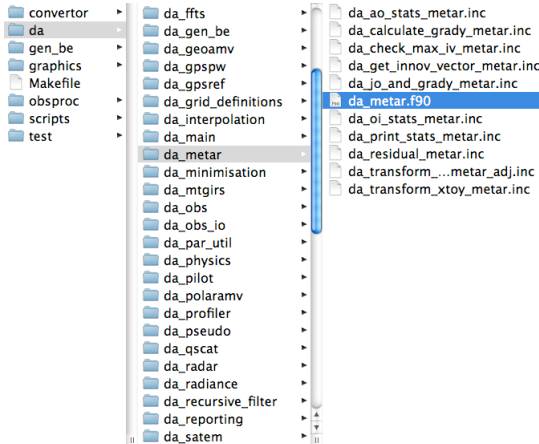
Besides the directories for WRF, the WRFDA tar file contains a *var* directory, which holds all of the WRFDA code

WRFDA Code Organization



Generally, each subdirectory of *da* contains a Fortran module with the same name

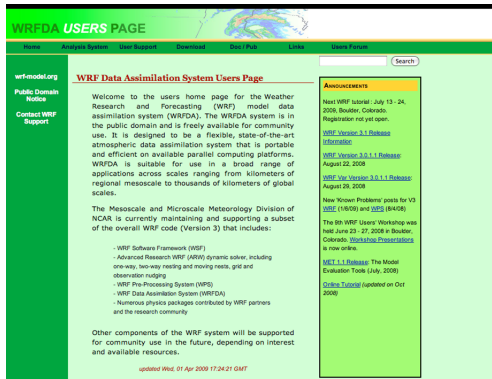
WRFDA Code Organization



- da_metar.f90 contains a Fortran module
- Each .inc file corresponds to a subroutine within the module

Online WRFDA Resources

WRFDA has a dedicated page, similar to the ARW Users page:
WRFDA User Page



The screenshot shows the "WRFDA USERS PAGE" with a navigation bar and a main content area. The navigation bar includes links for Home, Analysis System, User Support, Download, Data/Put, Links, and Users Forum. The main content area is divided into three columns. The left column contains links to wrf-model.org, Public Domain Notice, and Contact WRF Support. The middle column, titled "WRF Data Assimilation System Users Page", contains a welcome message, a list of supported components, and a note about future support. The right column, titled "ANNOUNCEMENTS", contains a list of recent updates and releases.

WRFDA USERS PAGE

Home Analysis System User Support Download Data/Put Links Users Forum

Search

wrf-model.org
Public Domain Notice
Contact WRF Support

WRF Data Assimilation System Users Page

Welcome to the users home page for the Weather Research and Forecasting (WRF) model data assimilation system (WRFDA). The WRFDA system is in the public domain and is freely available for community use. It is designed to be a flexible, state-of-the-art atmospheric data assimilation system that is portable and efficient on available parallel computing platforms. WRFDA is suitable for use in a broad range of applications across scales ranging from kilometers of regional mesoscale to thousands of kilometers of global scales.

The Mesoscale and Microscale Meteorology Division of NCAR is currently maintaining and supporting a subset of the overall WRF code (Version 3) that includes:

- WRF Software Framework (WRF)
- Advanced Research WRF (ARW) dynamic solver, including one-way, two-way nesting and moving nests, grid and observation nudging
- WRF Pre-Processing System (WPS)
- WRF Data Assimilation System (WRFDA)
- Numerous physics packages contributed by WRF partners and the research community

Other components of the WRF system will be supported for community use in the future, depending on interest and available resources.

updated Wed, 01 Apr 2009 17:24:21 GMT

ANNOUNCEMENTS

Next WRF tutorial: July 13 - 24, 2009, Boulder, Colorado. Registration not yet open.
[WRF Version 3.1 Release Information](#)
[WRF Version 3.0.1.1 Release](#)
August 22, 2008
[WRF Var Version 3.0.1.1 Release](#)
August 29, 2008

New 'Known Problems' posts for V3
[WRF](#) (1/6/08) and [WPS](#) (6/4/08)

The 6th WRF Users' Workshop was held June 23 - 27, 2008 in Boulder, Colorado. [Workshop Presentations](#) is now online.

[MET 1.1 Release](#): The Model Evaluation Tools (July, 2008)
[Online Tutorial](#) (updated on Oct 2008)

Online Resources

From the WRFDA page, one can access:

Analysis System	User Support	Download	Doc / Pub
Downloads Overview			
WRFDA			
TESTDATA			
WRFNL			
WRFPLUS			
TOOLS			
Input Data from NCAR			
NCEP ftp			

WRFDA Source Code

Before you download, please take a look at the [Domain Notice](#), and [Users' below](#). This registration form is to let you know who is using the code. It also **subscribes** you to the WRF news email list. We are using this list to broadcast any messages regarding the code.

Analysis System	User Support	Download	Doc / Pub
System Overview			
WRF-Var V3.1			
WRF-Var Online Tutorial			
WRF-Var Tools			
Data assimilation and their real-time state. Variational Differences between the analysis and observation difference between three-dimensional (3D) and four-dimensional (4D) data assimilation.			

Analysis System	User Support	Download	Doc / Pub
Features in WRF-Var V3.1			
Release Updates			
How to Compile			
How to Run			
Namelists			
Known Problems and Fixes			

Analysis System	User Support	Download	Doc / Pub	Links
Pubs & Docs Overview				
Tech Notes				
WRFDA User's Guide				

Documents & Publications

References:

Barker, D. M., W. Huang, Y.-R. Guo, and A. Bourgeois, 2003: A Three-Dimensional Variational (3DVAR) Data Assimilation System For Use With MM5. NCAR/TN-453+STR, 68 pp. (Available from UCAR Communications)



WRFDA Application
WRFDA Overview
WRFDA Implementation
WRFDA Software

Quick Start
WRFDA Software Framework
WRFDA Code Organization
Online WRFDA Resources



Thank You

The NESL Mission is:

To advance understanding of weather, climate, atmospheric composition and processes;
To provide facility support to the wider community; and,
To apply the results to benefit society.

NCAR is sponsored by the National Science Foundation