Mesoscale and
Microscale
Meteorology

WRF-Var System

WRF Tutorial

July 21st 2008

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WRF-Var in the WRF Modeling System

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WRF-Var

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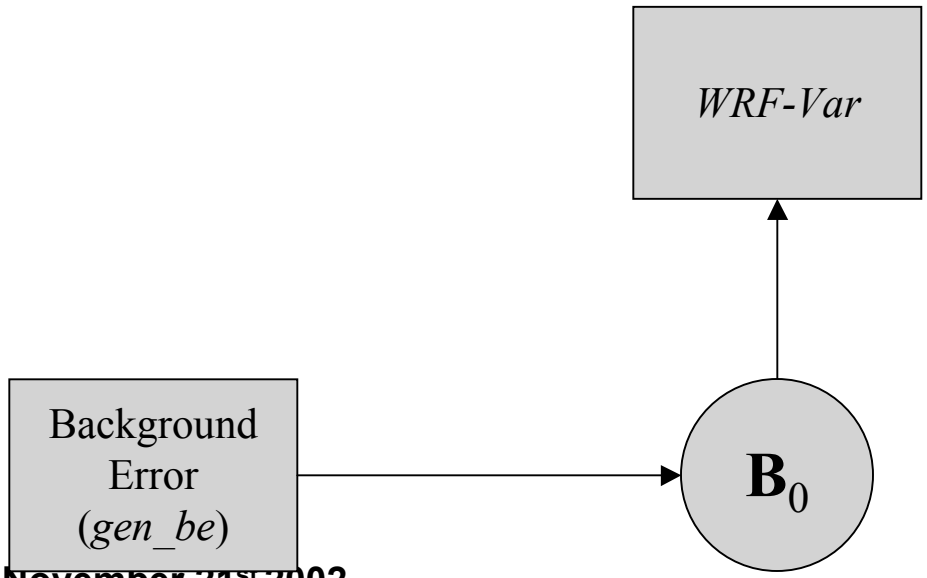
WRF-Var in the WRF Modeling System

1. Prepare BE data (initially use default statistics)



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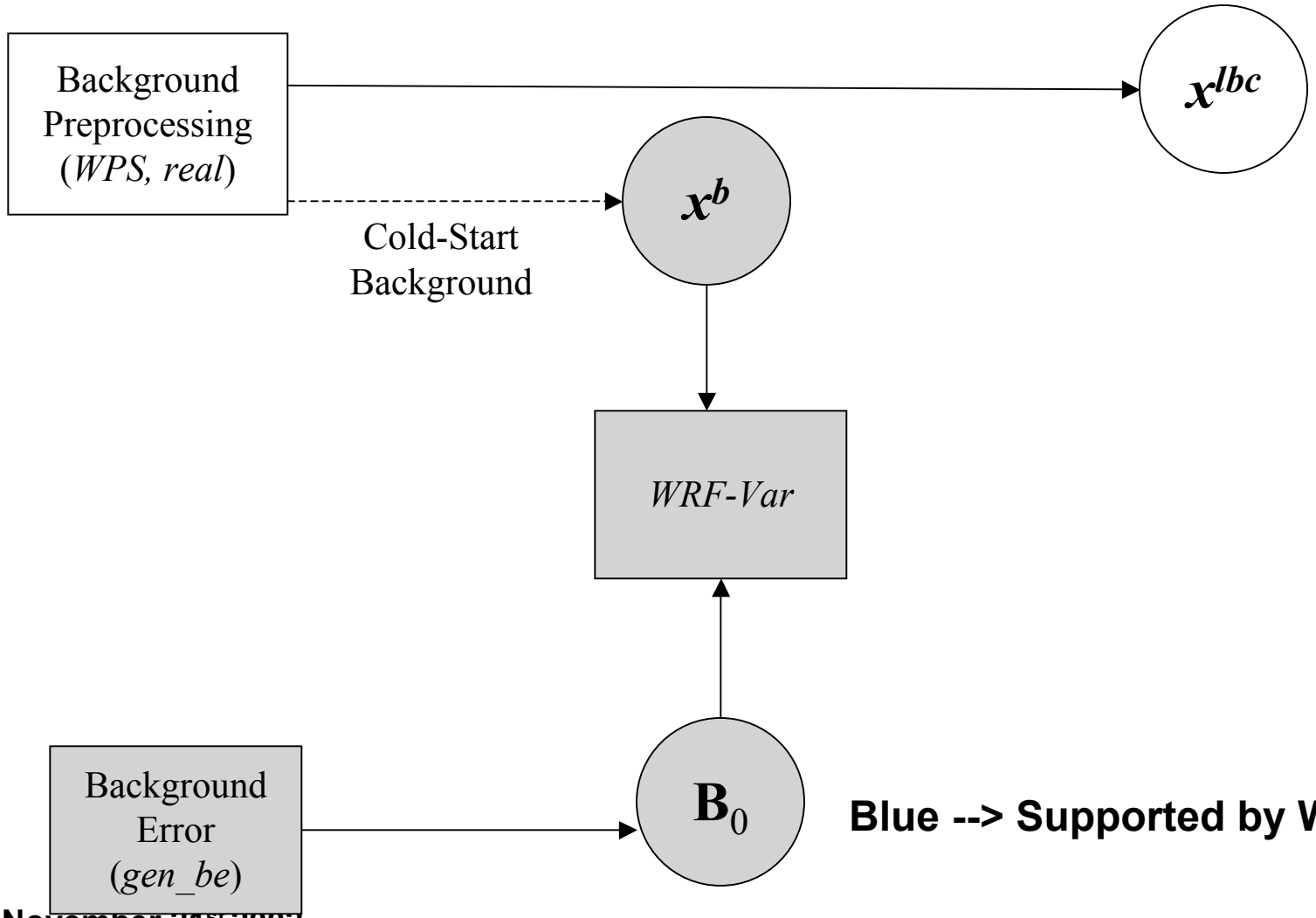
WRF-Var in the WRF Modeling System

2. Prepare background (WPS & real)



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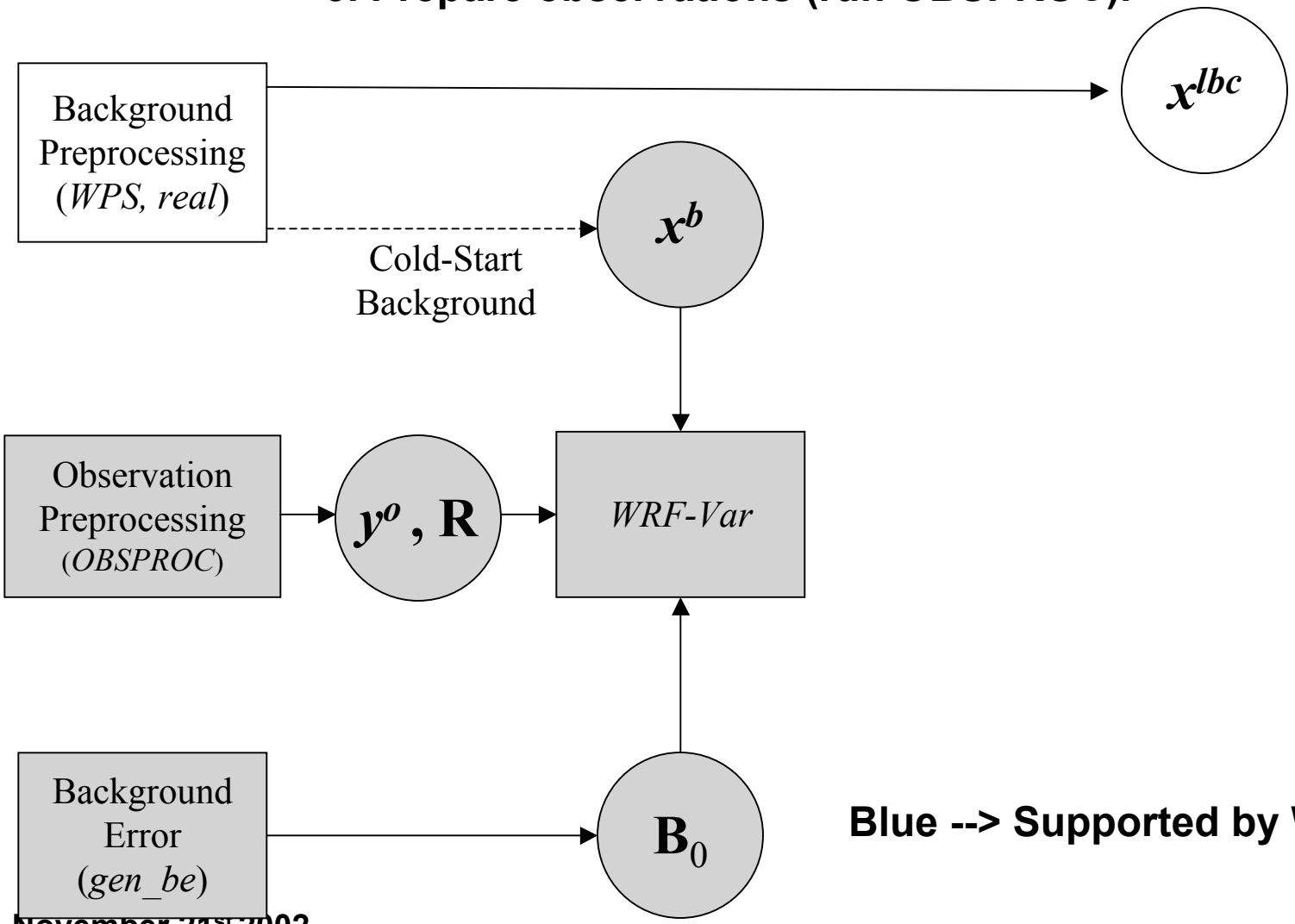
3. Prepare observations (run OBSPROC).



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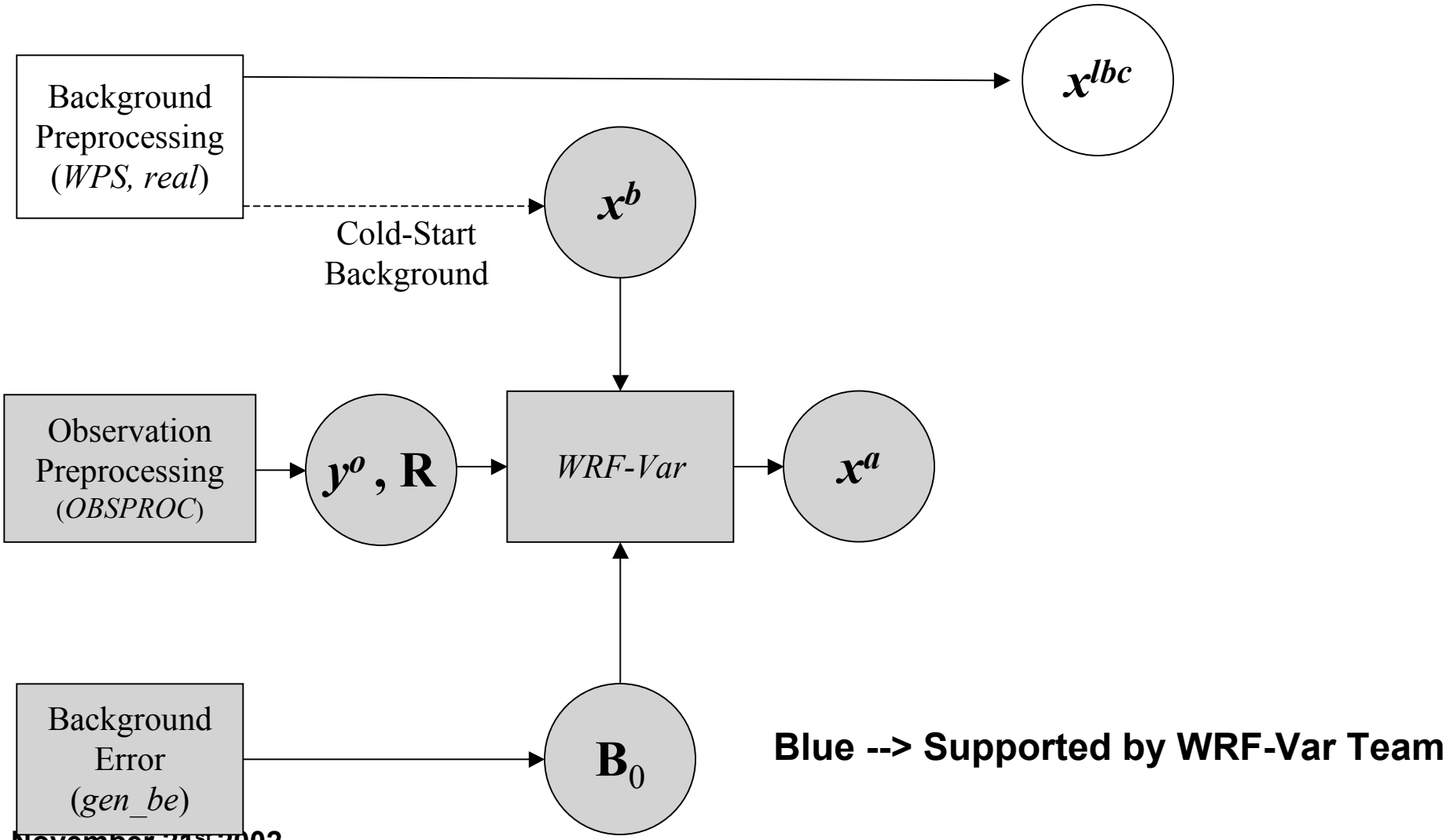
Observation Input (y^o)

- Observation input for WRF-Var is supplied through observation preprocessor (OBSPROC)
- WRF-Var accepts input both in ASCII & BUFR format
- Separate input file (ASCII) for Radar, both reflectivity and radial velocity.

WRF-Var in the WRF Modeling System

4. Run WRF-Var.



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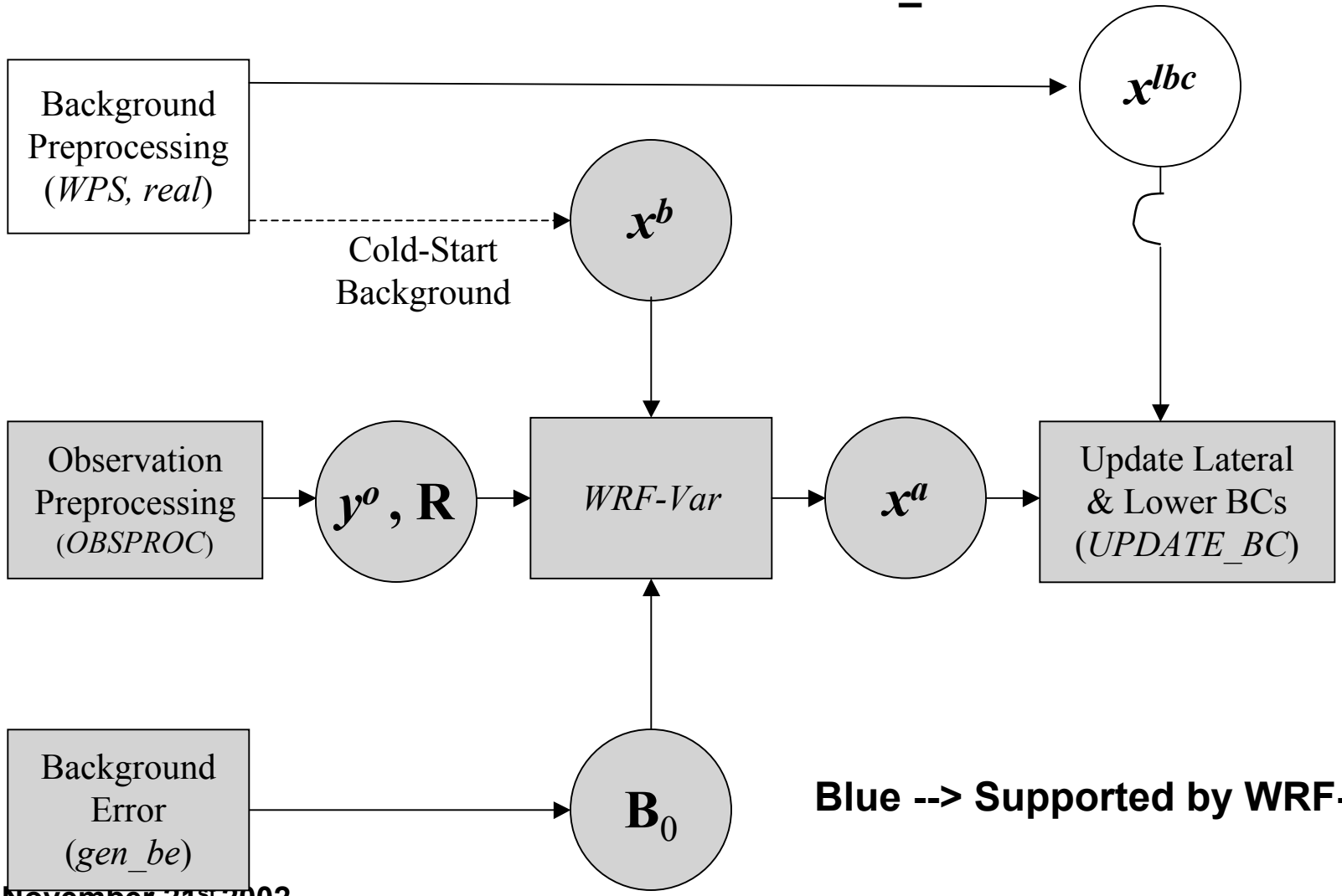
5. Run UPDATE_BC.



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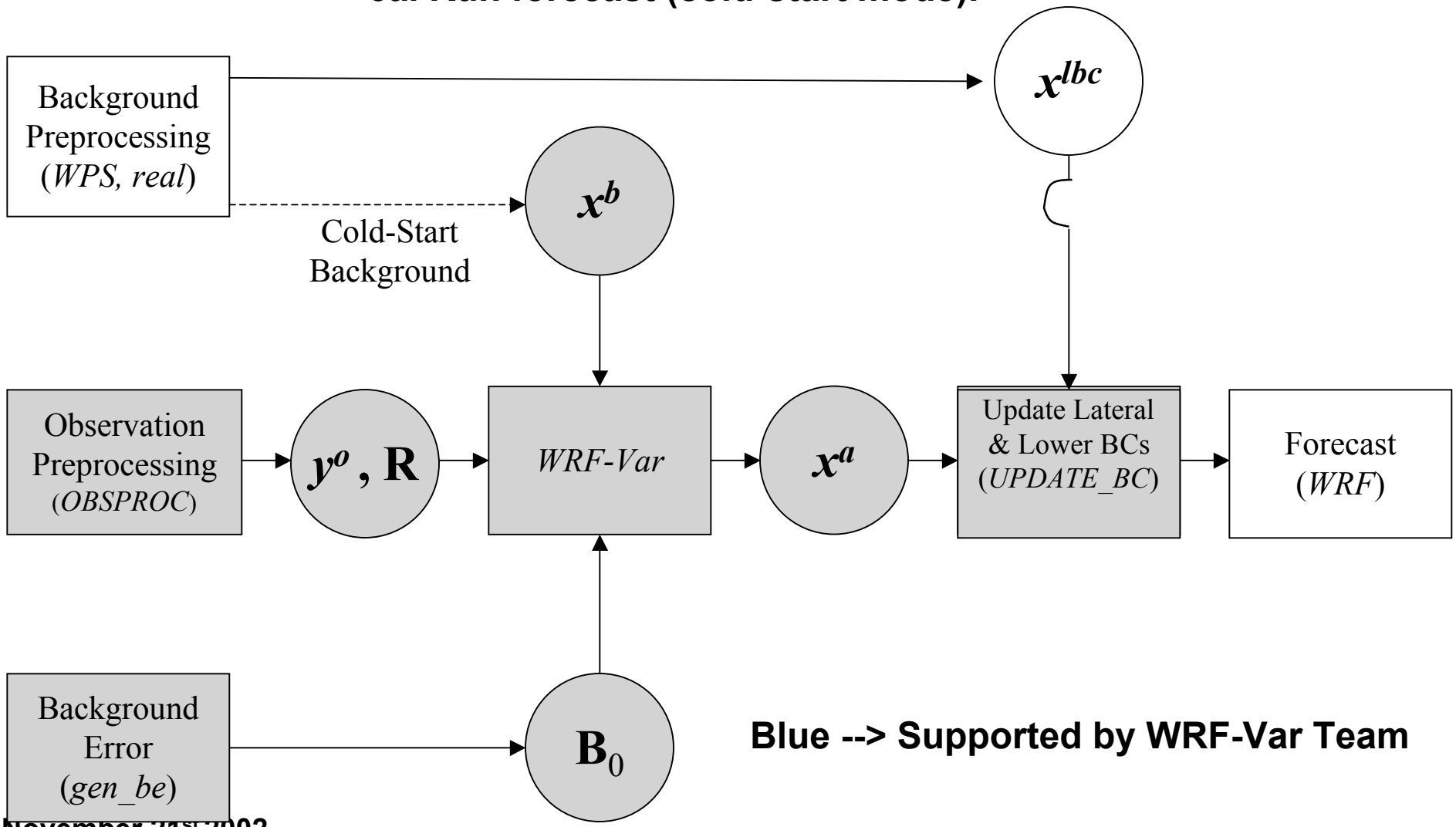
6a. Run forecast (cold-start mode).



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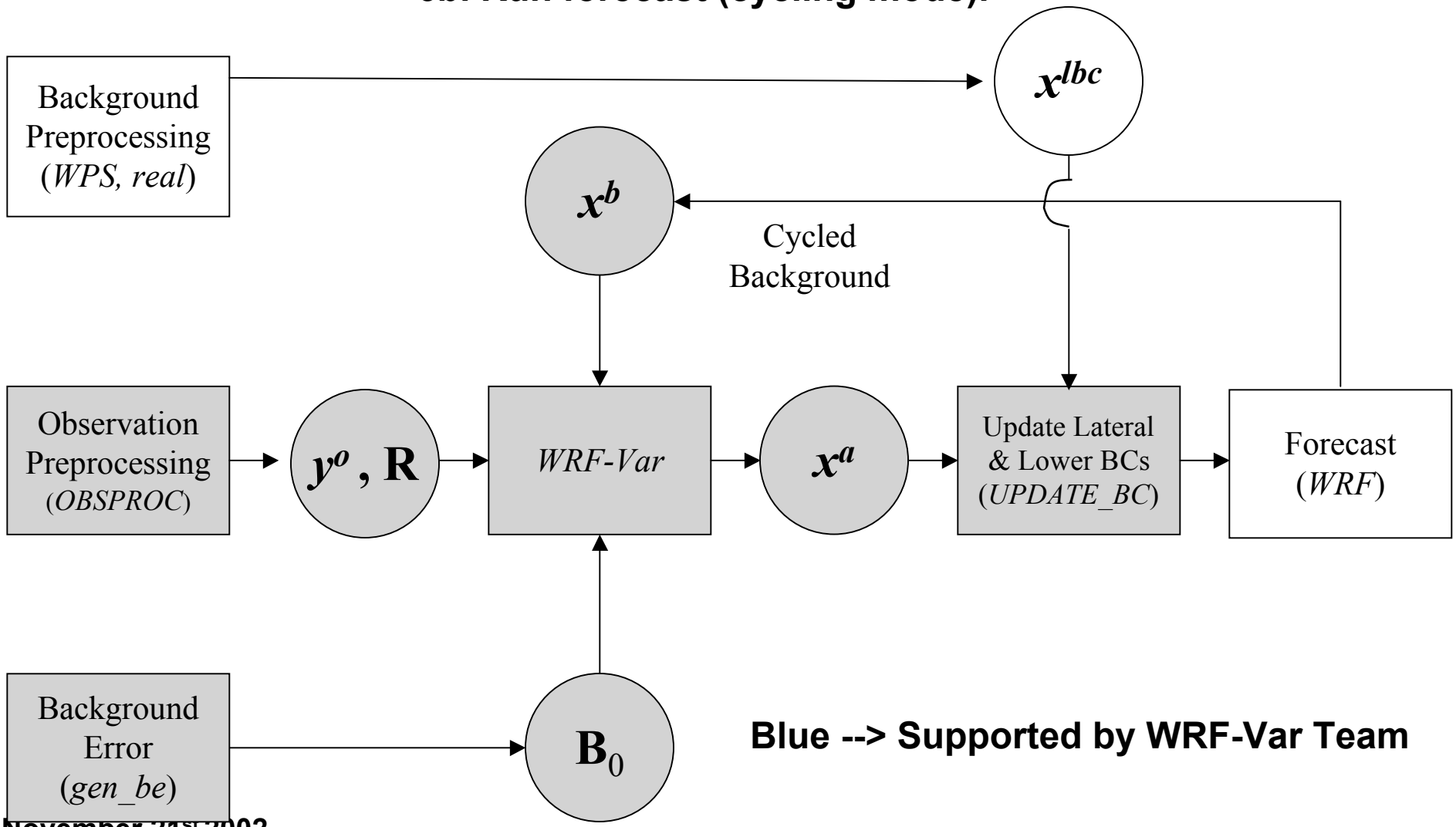
6b. Run forecast (cycling mode).



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Background Error (BE) for WRF-Var

- The number 1 question from WRF-Var users is

"What background error are best for my application?".

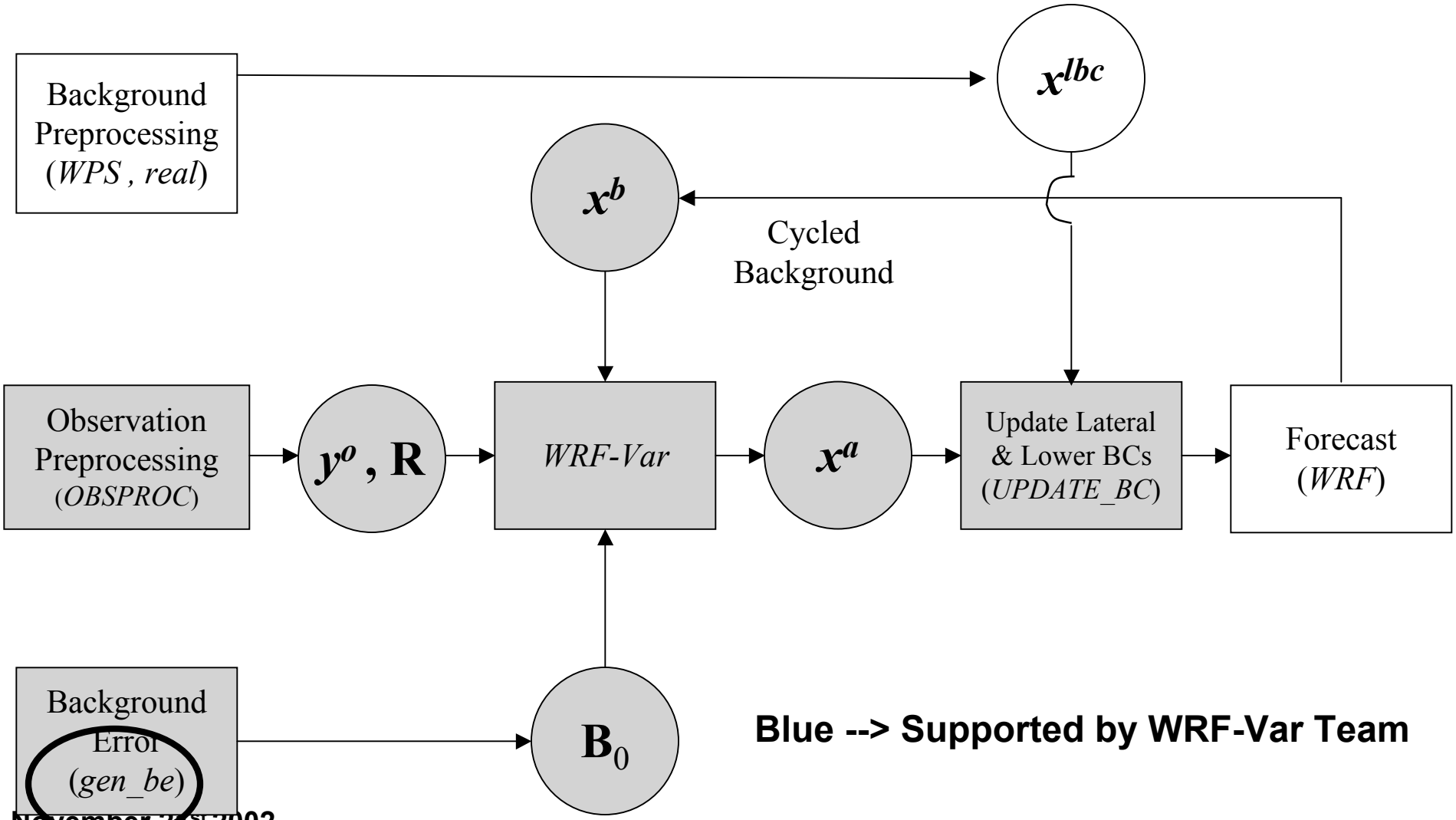
Answer:

- Create your own once you have run your system for ~a few weeks.
- Implement, tune, and iterate.

A new utility "*gen_be*" has been developed at NCAR to calculate BEs.

WRF-Var in the WRF Modeling System

7. WRF-Var/WRF Ultimate Configuration!



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WRF-Var Software

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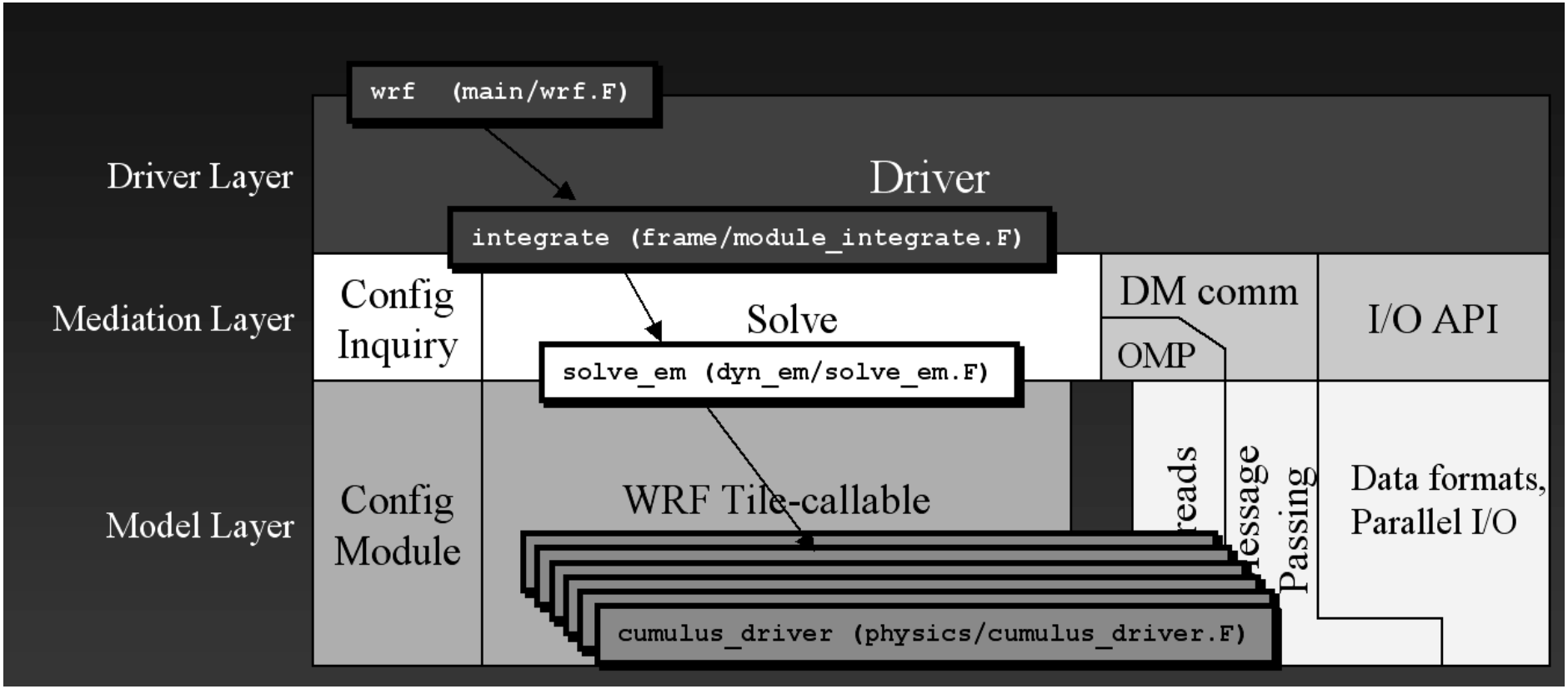
Supported Platforms and compilers:

- **IBM (AIX)----xlf**
- **PC (Linux)-----pgi**
- **SGI (IRIX)-----ifort (tested by 3rd party)**

- **Only serial and dmpar are supported**

Directory Structure



WRF ▼ ⟶ WRF-Var
Integrate ⟶ da_wrfvar_interface
Solve_em ⟶ da_solve
Cumulus_driver ⟶ obs. (da_ships) or da_minimisation etc.

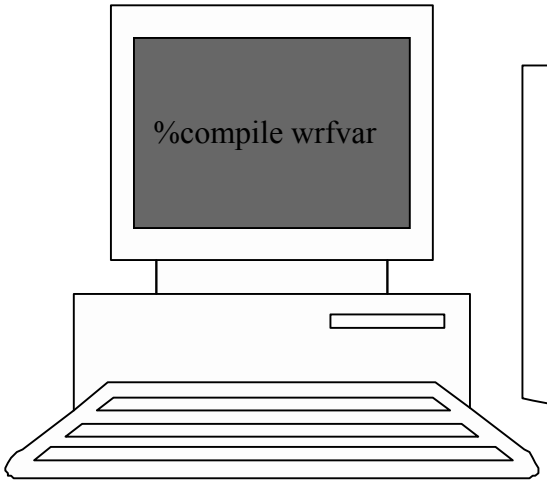
Grid Representation in Arrays

- **Increasing indices in WRF-Var arrays run**
  - **West to East (X, or I-dimension)**
  - **South to North (Y, or J-dimension)**
  - **Bottom to Top (Z, or K-dimension)**
- **Storage order in WRF-Var is IJK, but this is a WRF-Var convention, not a restriction of the WRF Software Framework**

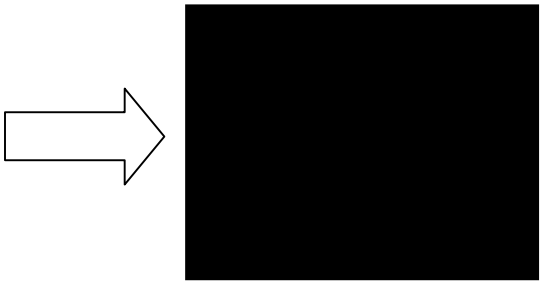
WRF-Var Registry

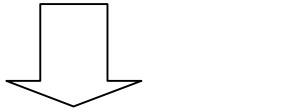
- "Active data-dictionary" for managing WRF-Var data structures
  - Database describing attributes of model state, intermediate, and configuration data
    - » Dimensionality, number of time levels, staggering
    - » Association with physics
    - » I/O classification (history, initial, restart, boundary)
    - » Communication points and patterns
    - » Configuration lists (e.g. namelists)
  - Program for auto-generating sections of WRF from database:
    - » Argument lists for driver layer/mediation layer interfaces
    - » Interprocessor communications: Halo and periodic boundary updates, transposes
    - » Code for defining and managing run-time configuration information
- Automates time consuming, repetitive, error-prone programming
- Insulates programmers and code from package dependencies
- Allow rapid development
- Documents the data

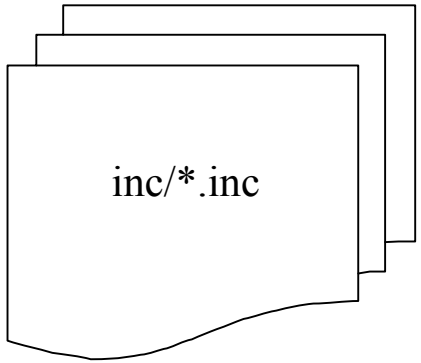
Registry Mechanics

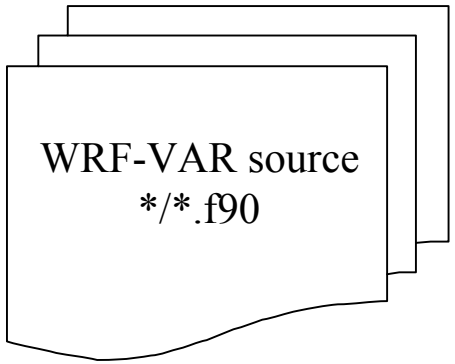



```
# Registry file
#
# table entries are of the form
#<Table> <Type> <Sym>         <Dims>   <Use>    <NumTLev> <Stagger> <IO>
#
state    real   ru             ikj     dyn-rk      2         X      irh
state    real   u              ikj     dyn-rk      2         X      irh
state    real   ru_m           ikj     dyn-rk      1         X
i1       real   ru_tend        ikj     dyn-rk      1         X
 . . .
## communications
halo      HALO_RK_A    24:u_2,v_2,w_2,t_2,tp_2,rw_2,rom_2;4:pp,pip
halo      HALO_RK_B    4:rtp_2
halo      HALO_RK_C    4:ru_2,rv_2,du,dv
 . . .
```

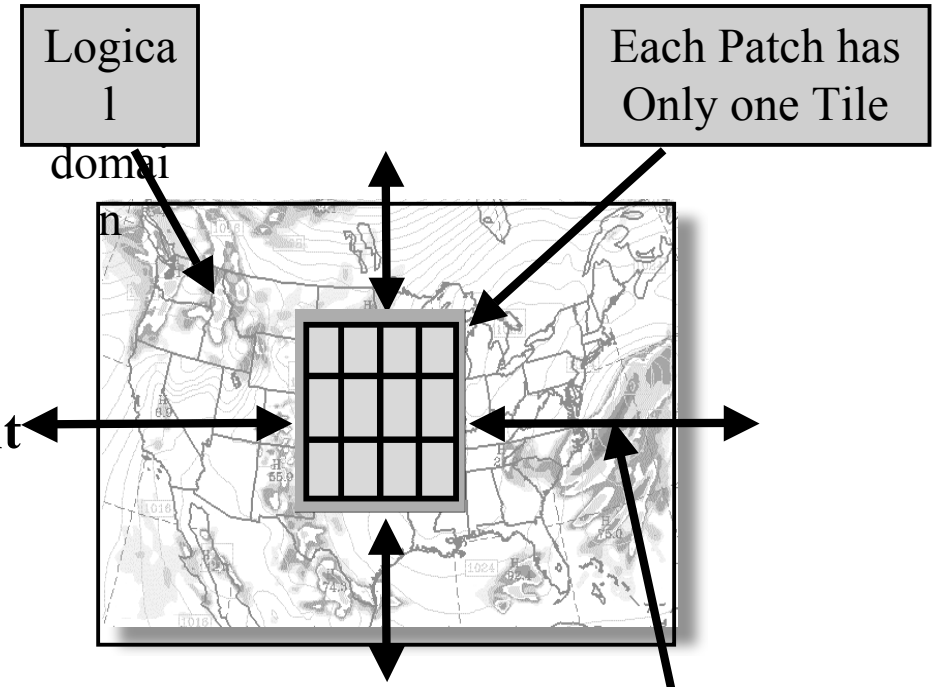








Parallelism in WRF-Var: MPI Decomposition



- **Single version of code for efficient execution on:**
  - **Distributed-memory**
  - **Vector and microprocessors**

Model domain is decomposed for parallelism

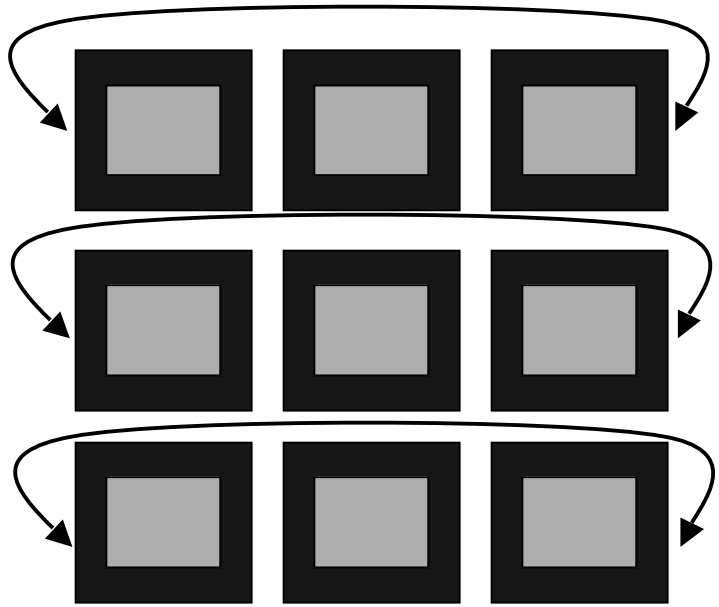
Patch: **section of model domain allocated to a distributed memory node**

Tile: **same as patch in WRF**

Distributed Memory Communications

- **Halo updates**
- **Periodic boundary updates**

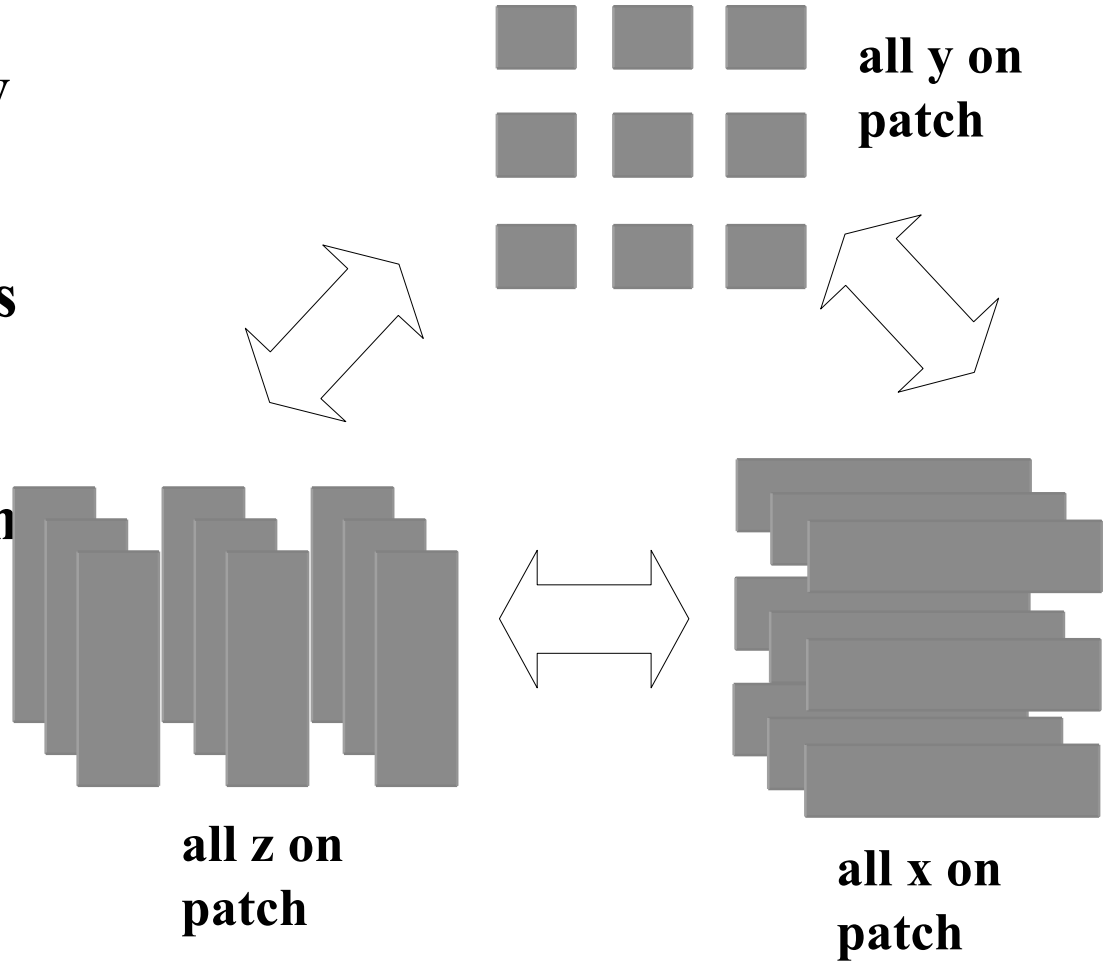
  (only needed for global 3dvar)



Distributed Memory Communications

- Halo updates
- Periodic boundary updates
- Parallel transposes
- "nproc_x = 1"

  (For global option



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WRF-Var Code Overview

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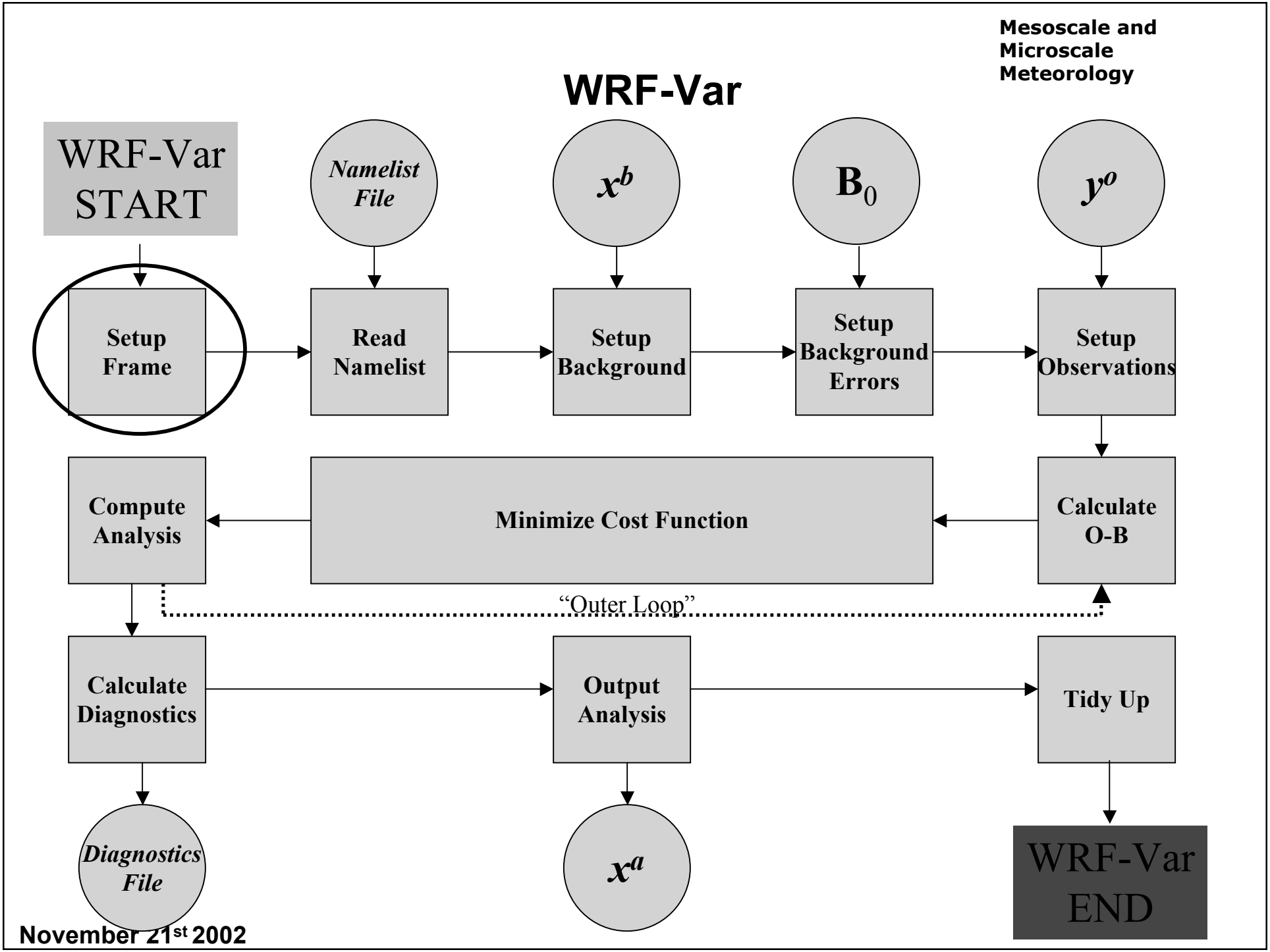
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WRF-Var
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x^b
B_0
y^o
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"Outer Loop"
Calculate Diagnostics
Output Analysis
Tidy Up
Diagnostics File
x^a
WRF-Var END
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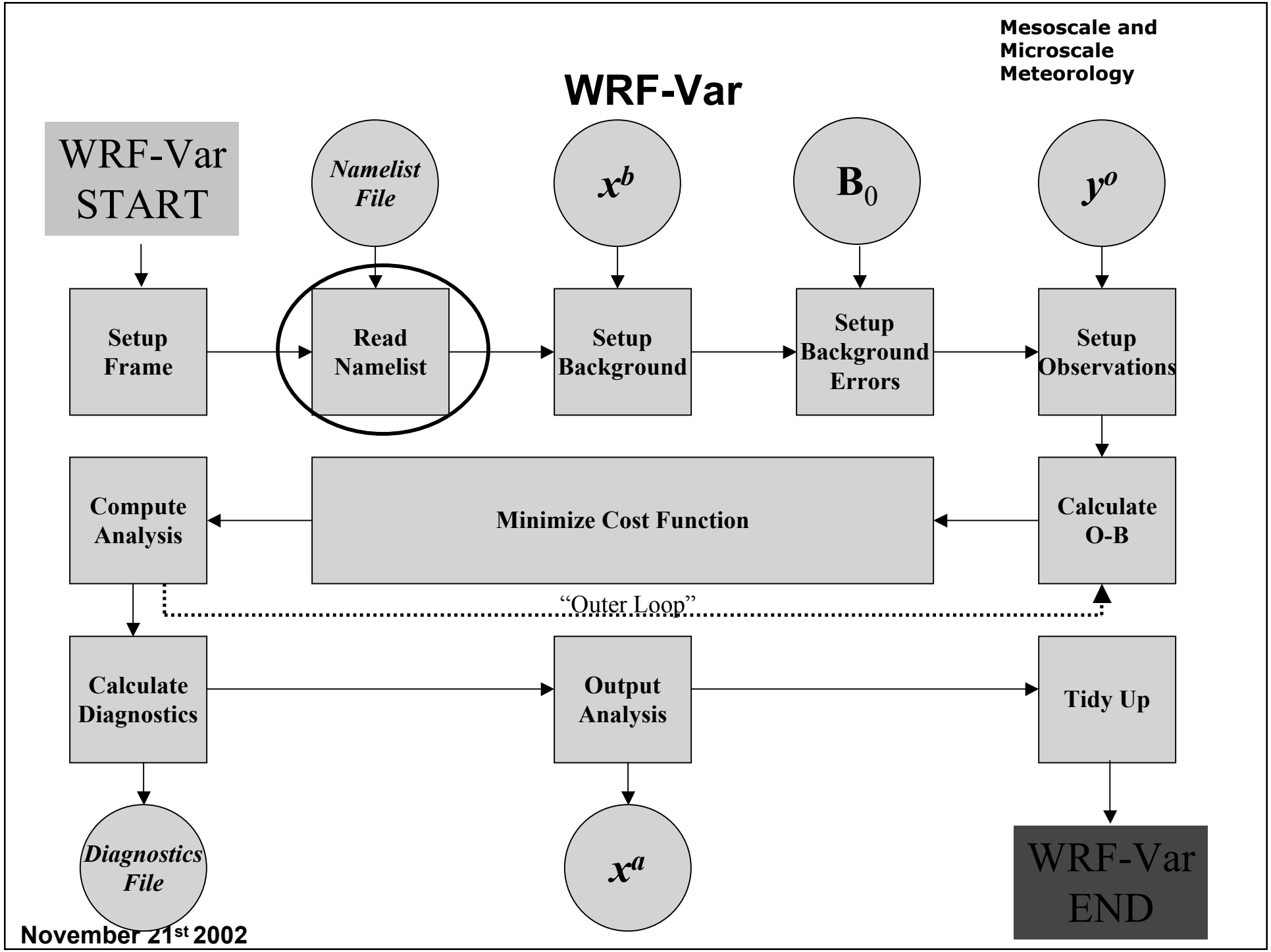
Setup Frame

- **Reads grid dimensions from "namelist.input" file.**
- **Use WRF framework's distributed memory capability to initialize tile, memory, patch dimensions, etc.**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x^a
WRF-Var END
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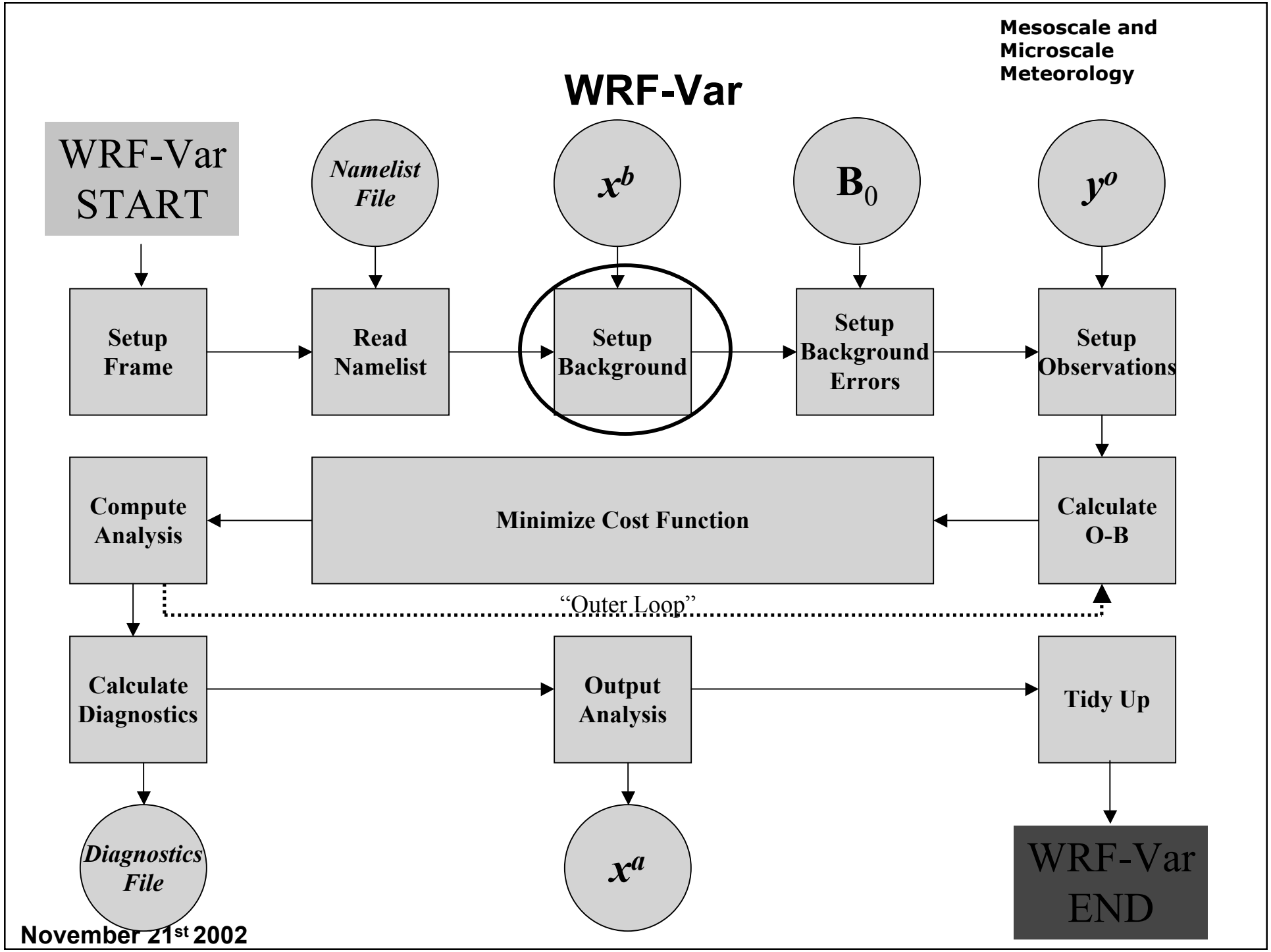
Read Namelist

- Reads WRF-Var data assimilation options from "namelist.input" file.

- Performs consistency checks between namelist options.

namelist.input

```
&wrfvar1
var4d=true,
multi_inc=0,
var4d_coupling=2,
global=false,
/
&wrfvar2
/
&wrfvar3
ob_format=2,
num_fgat_time=7,
/
&wrfvar4
use_synopobs=true,
use_shipsobs=true,
use_metarobs=true,
use_soundobs=true,
use_pilotobs=true,
use_airepobs=true,
use_geoamvobs=true,
use_polaramvobs=true,
use_bogusobs=true,
use_buoyobs=true,
use_profilerobs=true,
use_satemobs=true,
use_gpspwobs=true,
use_gpsrefobs=true,
use_qscatobs=true,
use_radarobs=false,
use_radar_rv=false,
use_radar_rf=false,
/
&wrfvar5
check_max_iv=true,
/
&wrfvar6
ntmax=100,
/
&wrfvar7
/
&wrfvar8
/
&wrfvar9
/
&wrfvar10
/
&wrfvar11
cv_options_hum=1,
check_rh=2,
seed_array1=2007081421,
seed_array2=2007081421,
/
&wrfvar12
/
&wrfvar13
/
&wrfvar14
/
&wrfvar15
/
&wrfvar16
/
&wrfvar17
analysis_type="3D-VAR",
/
&wrfvar18
analysis_date="2007-08-
14_21:00:00.0000",
/
&wrfvar19
/
&wrfvar20
/
&wrfvar21
time_window_min="2007-08-
14_21:00:00.0000",
/
&wrfvar22
time_window_max="2007-08-
15_03:00:00.0000",
/
&wrfvar23
jcdfi_use=false,
jcdfi_io=false,
jcdfi_tauc=21600,
jcdfi_gama=0.1,
jcdfi_error_wind=3.0,
jcdfi_error_t=1.0,
jcdfi_error_q=0.001,
jcdfi_error_mu=1000.,
/
&time_control
run_hours=27,
run_minutes=0,
run_seconds=0,
start_year=2007,
start_month=08,
start_day=14,
start_hour=21,
start_minute=00,
start_second=00,
end_year=2007,
end_month=08,
end_day=15,
end_hour=03,
end_minute=00,
end_second=00,
interval_seconds=21600,
input_from_file=true,
frames_per_outfile=1,
debug_level=0,
history_interval_s=10800,
inputout_interval_s=3600,
auxinput3_interval_s=3600,
inputout_begin_h=6,
inputout_begin_m=0,
inputout_begin_s=0,
inputout_end_h=6,
inputout_end_m=0,
inputout_end_s=0,
input_outname="wrfinput_d<domain
>_<date>",
write_input=true,
/
&fdda
/
&domains
time_step=240,
e_we=123,
e_sn=111,
e_vert=27,
num_metgrid_levels=27,
p_top_requested=5000,
interp_type=1,
t_extrap_type=1,
dx=45000,
dy=45000,
i_parent_start=0,
j_parent_start=0,
smooth_option=0,
nproc_x=0,
eta_levels= 1.000, 0.990, 0.978,
0.964, 0.946, 0.922, 0.894, 0.860,
0.817, 0.766, 0.707, 0.644, 0.576,
0.507, 0.444, 0.380, 0.324, 0.273,
0.228, 0.188, 0.152, 0.121, 0.093,
0.069, 0.048, 0.029, 0.014, 0.000,
/
&physics
mp_physics=3,
ra_lw_physics=1,
ra_sw_physics=1,
radt=45,
sf_sfclay_physics=1,
sf_surface_physics=1,
bl_pbl_physics=1,
cu_physics=1,
cudt=1,
num_soil_layers=5,
mp_zero_out=0,
co2tf=0,
/
&dynamics
w_damping=1,
diff_opt=1,
km_opt=1,
dampcoef=0.0,
time_step_sound=4,
base_temp=290.0,
/
&bdy_control
specified=true,
real_data_init_type=3,
/
&grib2
/
```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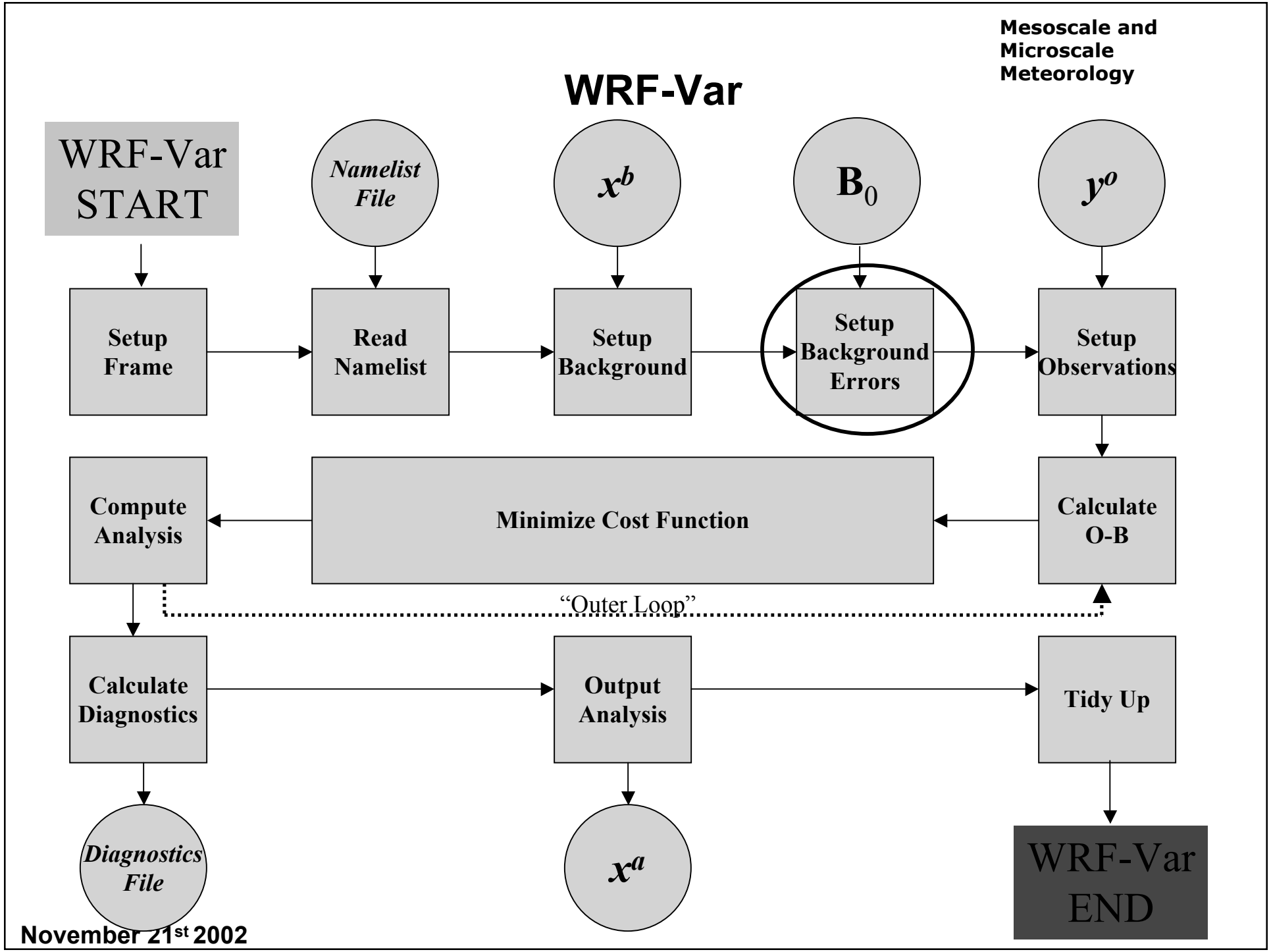
Setup Background (First-Guess)

- **Reads in the first-guess field.**
- **Format depends on namelist option :**
  "fg_format" ; 1= WRF, etc.
- **Extracts necessary fields.**
- **Creates background FORTRAN 90 derived data type "xb" e.g. xb % mix, xb % u(:,:,:), ….**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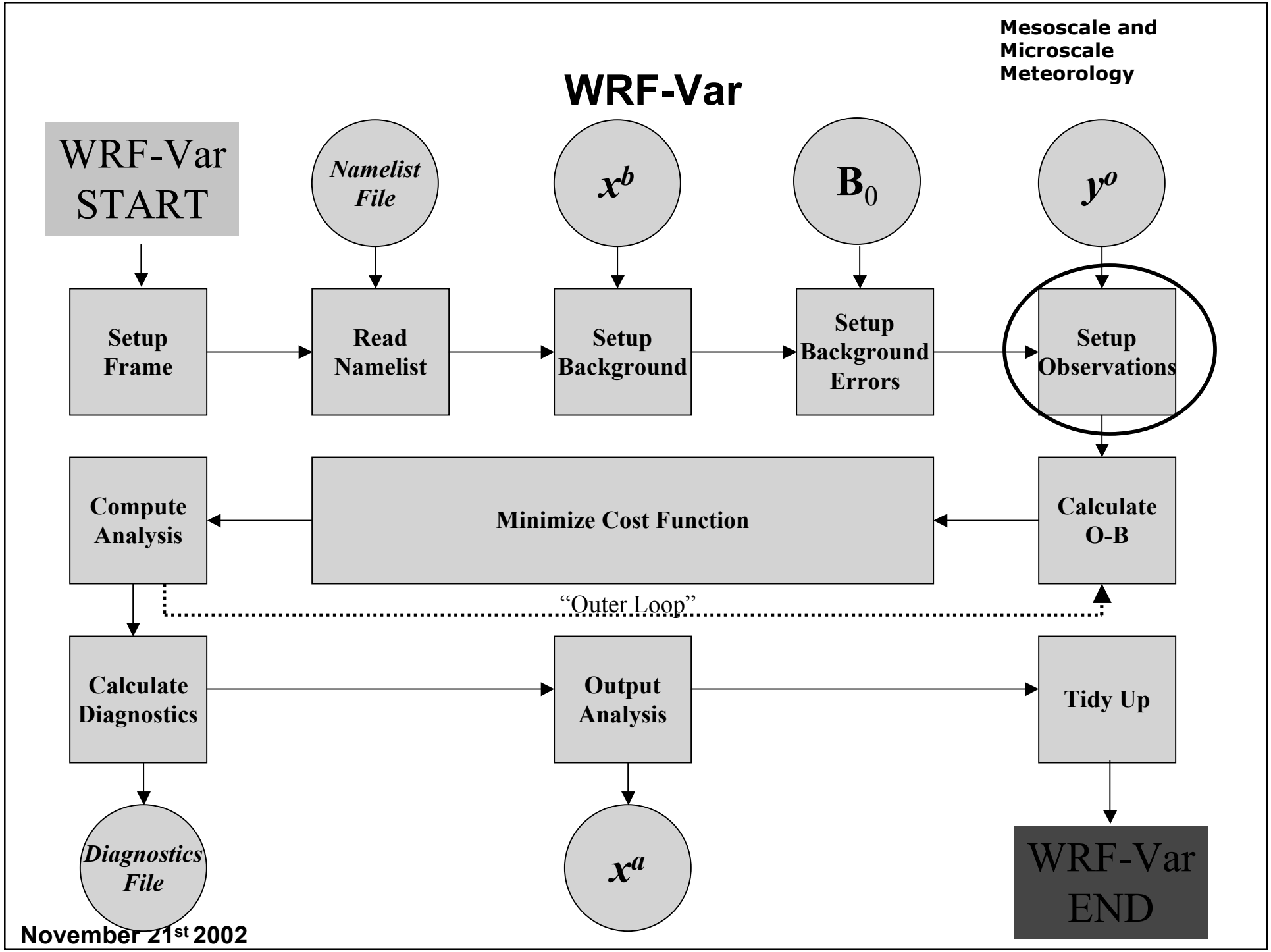
Setup Background Errors (BE)

- Reads in background error statistics.
- Extracts necessary quantities – eigenvectors, eigenvalues, lengthscales, regression coefficients, etc (see gen_be talk).
- Creates background error FORTRAN 90 derived data type "be" e.g. be % v1 % evec(:,:), be % v2 % eval(:), etc, ….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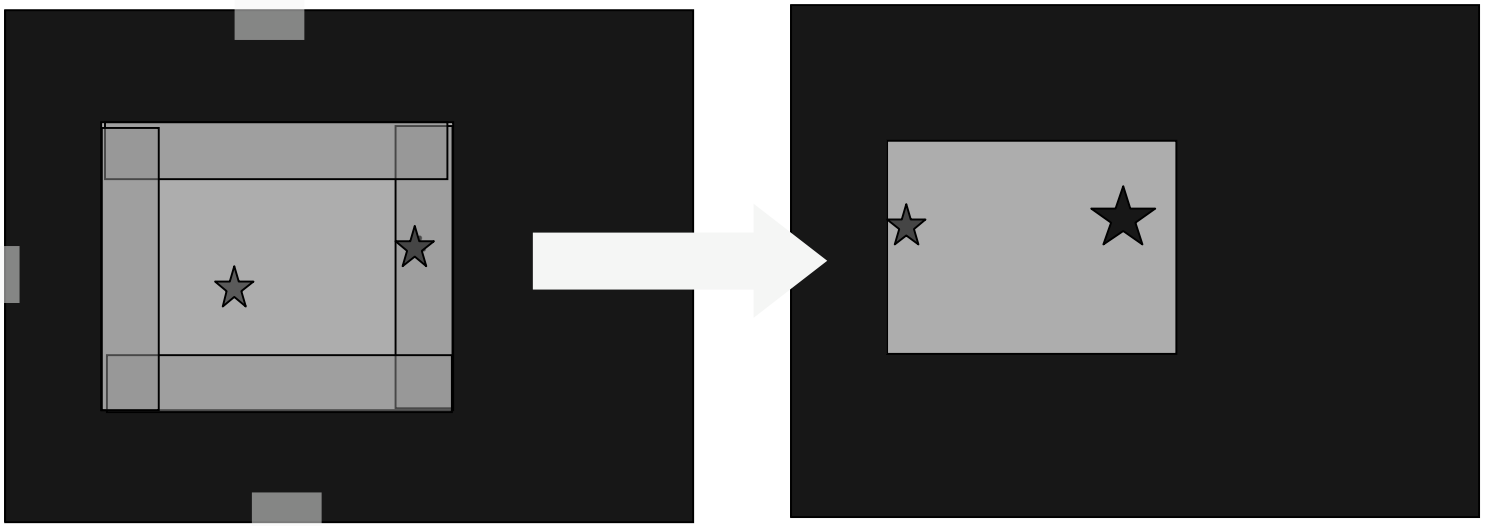
Setup Observations

- **Reads in observations.**
- **Format depends on namelist variable "ob_format"**
  1 = BUFR, 2 = ASCII "WRF-Var" format.
- **Creates observation FORTRAN 90 derived data type "ob" e.g. ob % metar(:), ob % sound(:) % u(:), etc, ….**
- **Identifies Obs outside/inside the domain**

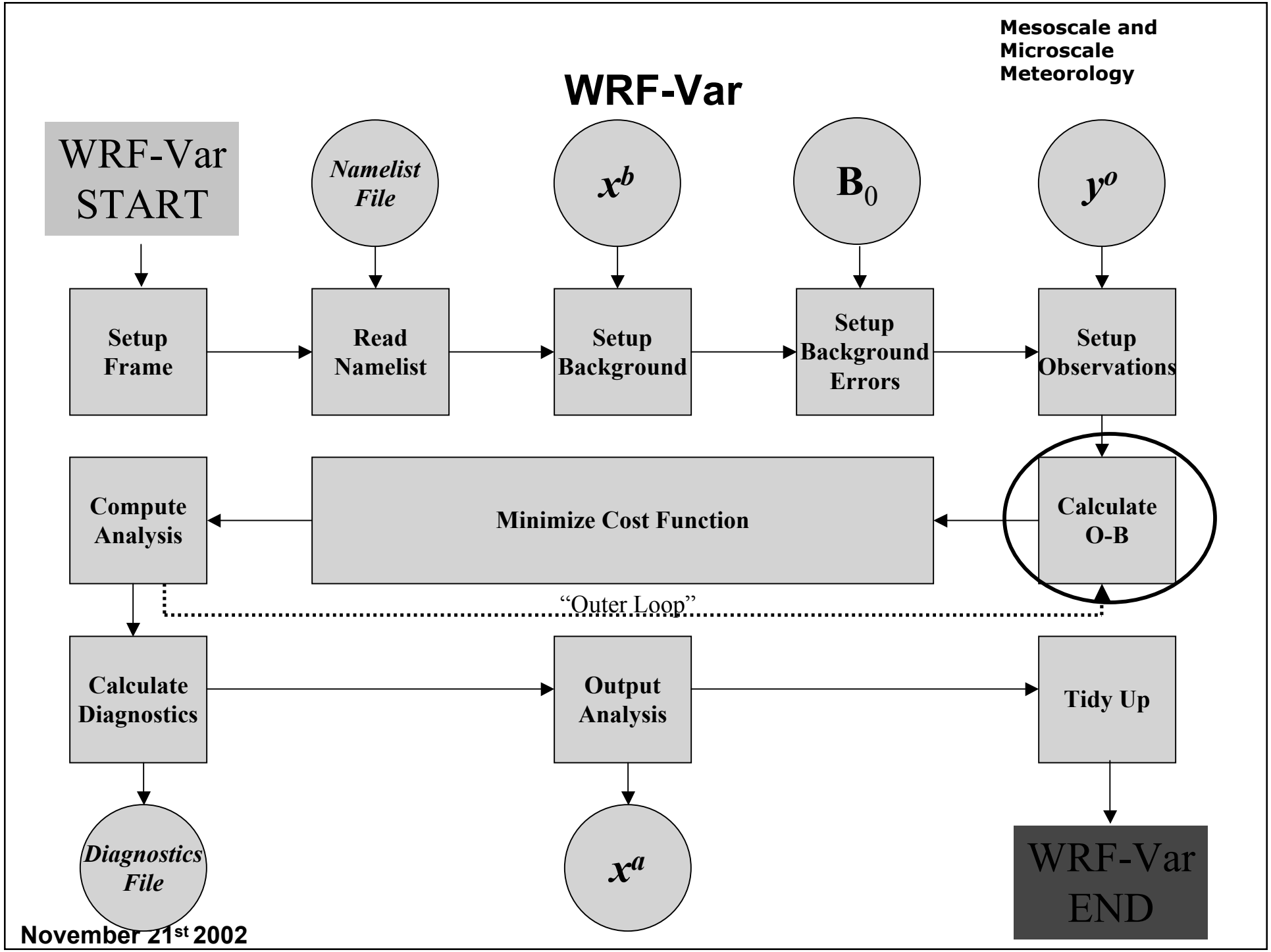
Observation in Distributed Memory

- Halo Region Observation
- For global option obs. on East & West boundaries are duplicated



Obs. on one processor's halo

Obs. on neighboring processor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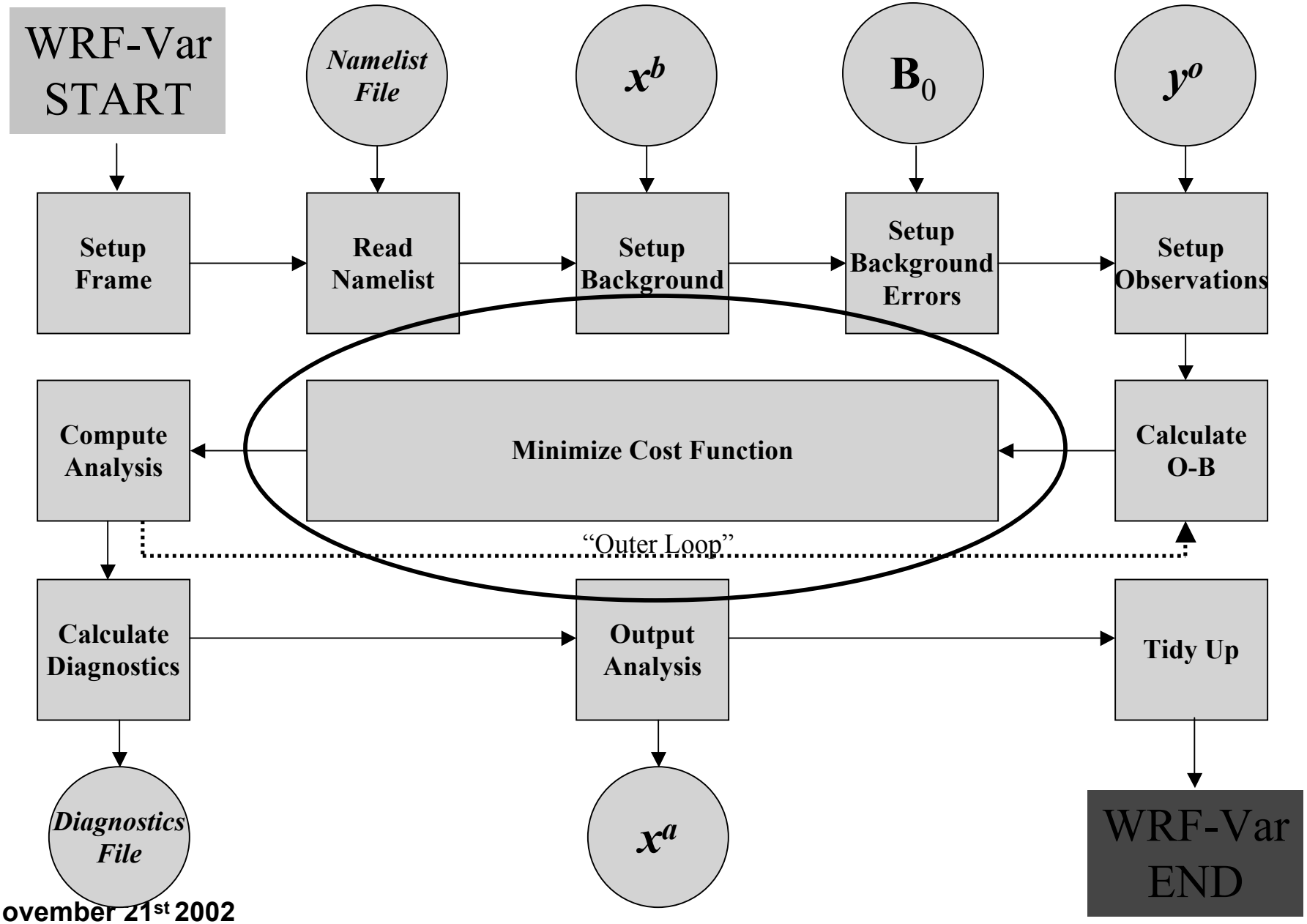
Calculate Innovation Vector (O-B)

- Calculates "model equivalent" B of observation O through interpolation and change of variable.
- Computes observation minus first guess (O-B) value.
- Creates innovation vector FORTRAN 90 derived data type "iv" e.g. iv % metar(:), iv % qscat(:) % u,
- iv % sound(:) % u(:), etc ….

WRF-Var

Mesoscale and Microscale Meteorology



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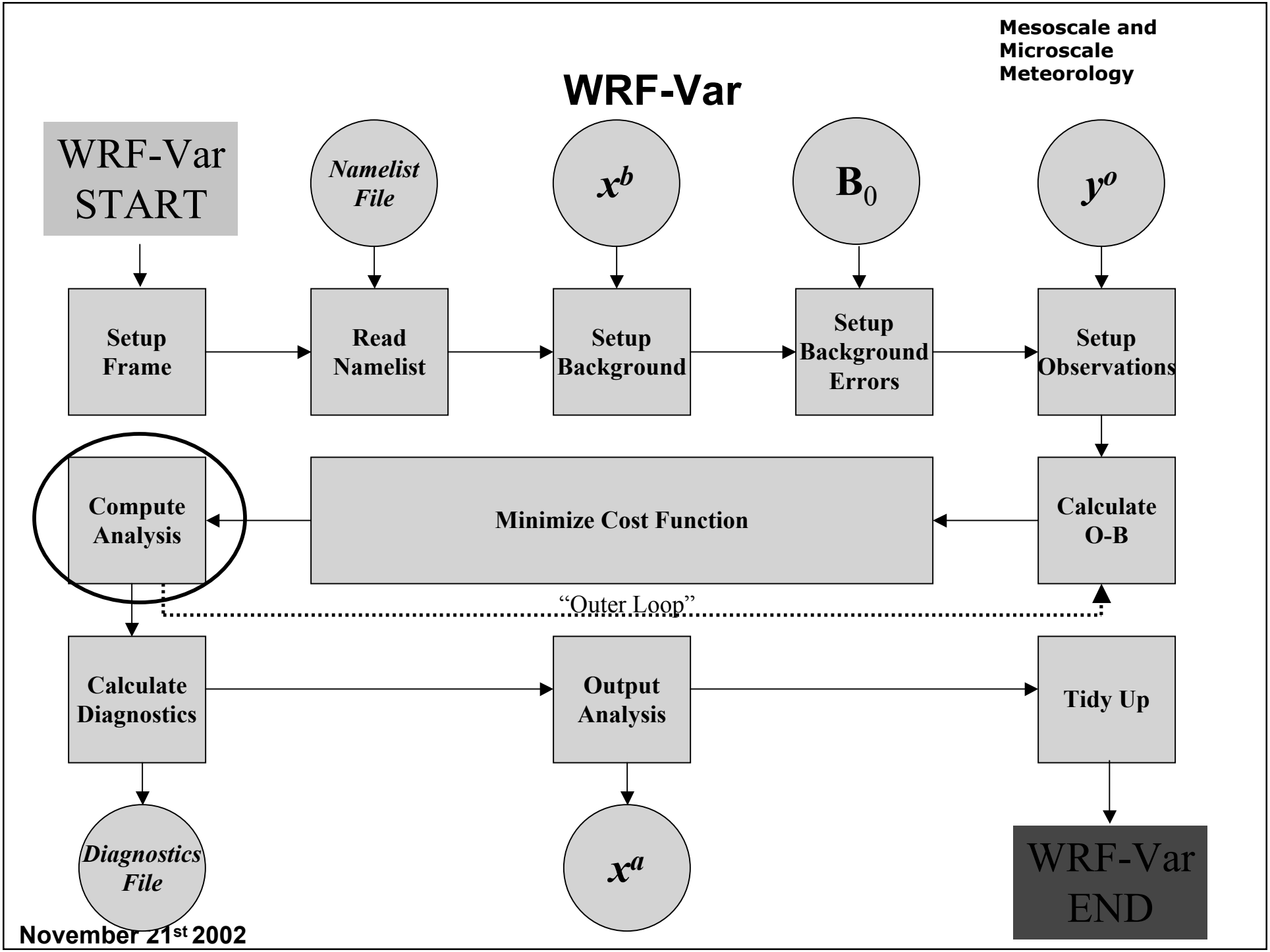
Minimize Cost Function

- **Conjugate Gradient**
- **(a) Initializes analysis increments to zero.**
- **(b) Computes cost function (if desired).**
- **(c) Computes gradient of cost function.**
- **(d) Uses cost function and gradient to calculate new value of analysis control variable (v)**
- **Iterate (b) to (d)**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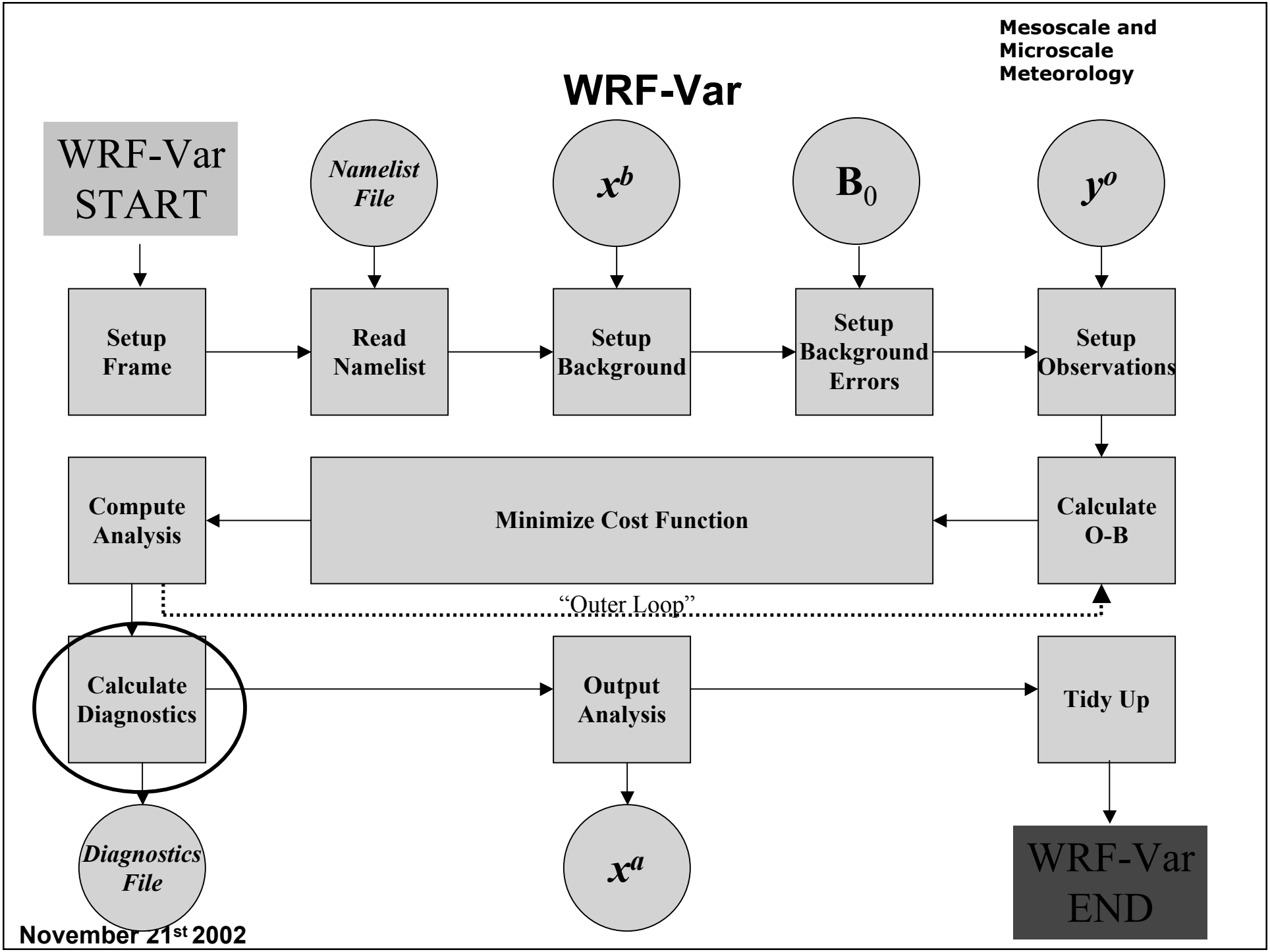
Compute Analysis

- **Once WRF-Var has found a converged control variable, convert control variable to model space analysis increments**

- **Calculate:**

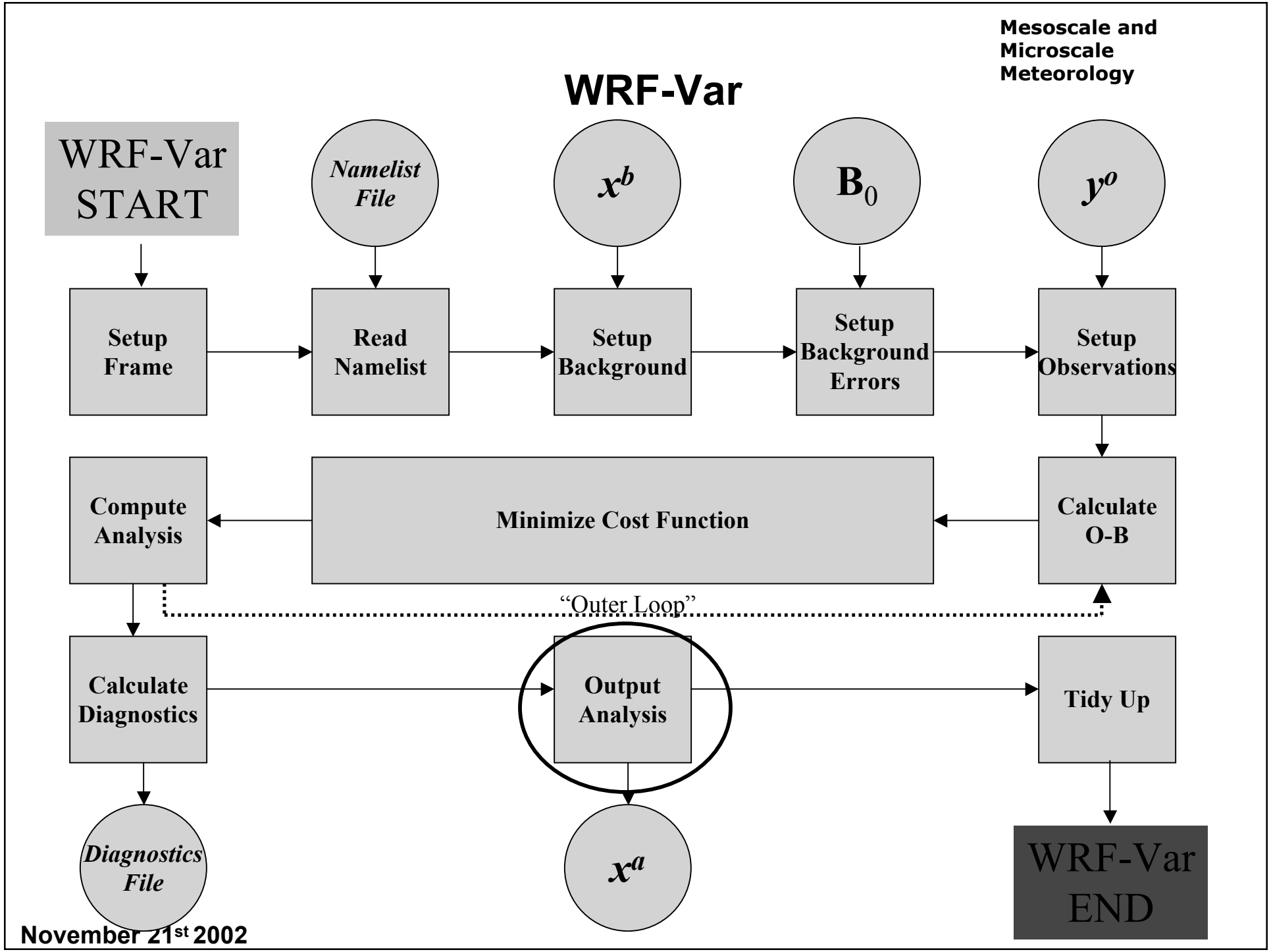
  analysis = first-guess + analysis increment

- **Performs consistency checks e.g. remove negative humidity etc.**


Mesoscale and Microscale Meteorology
WRF-Var
WRF-Var START
Namelist File
x^b
B_0
y^o
Setup Frame
Read Namelist
Setup Background
Setup Background Errors
Setup Observations
Compute Analysis
Minimize Cost Function
Calculate O-B
"Outer Loop"
Calculate Diagnostics
Output Analysis
Tidy Up
Diagnostics File
x^a
WRF-Var END
November 21st 2002

Compute Diagnostics

- **Compute O-B, O-A statistics for all observation types and variables.**
- **Compute A-B (analysis increment) statistics for all model variables and levels.**
- **Statistics include minimum, maximum (and their locations), mean and standard deviation.**
- **Compute "specialist diagnostics" for error tuning (fort.45, fort.46, fort.47, fort.50 etc.).**


Mesoscale and Microscale Meteorology
WRF-Var
WRF-Var START
Namelist File
x^b
B_0
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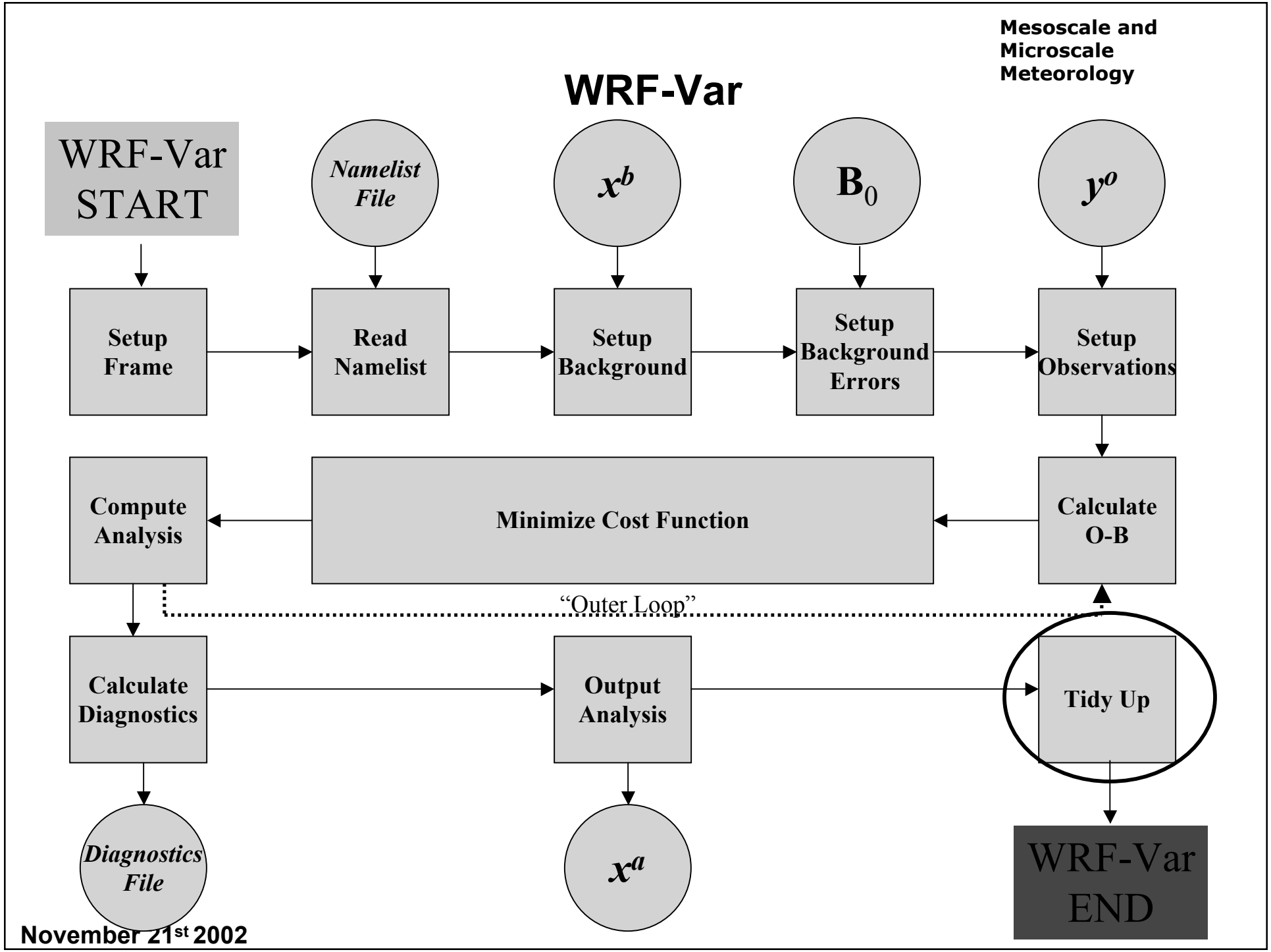
x^a
WRF-Var END
November 21st 2002

Output Analysis

- **Outputs analysis in native model format. Choice is made through namelist option "fg_format"**

  1 = WRF, etc.

- **Also output analysis increments (for diagnostic purposes) in native model format. Switch off by setting WRITE_INCREMENTS = .FALSE. in namelist.input.**


Mesoscale and Microscale Meteorology
WRF-Var
WRF-Var START
Namelist File
x^b
B_0
y^o
Setup Frame
Read Namelist
Setup Background
Setup Background Errors
Setup Observations
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"Outer Loop"
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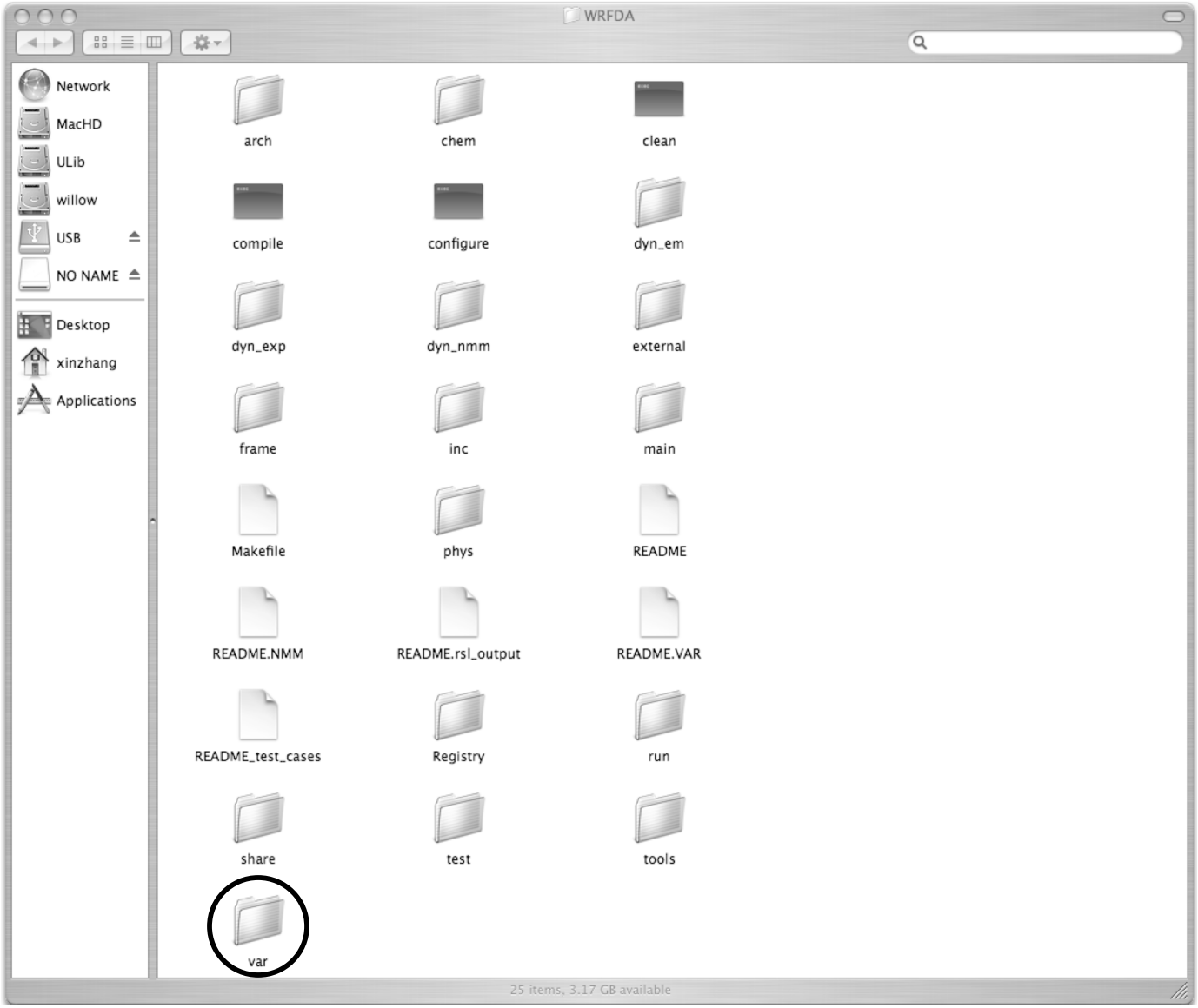
x^a
WRF-Var END
November 21st 2002

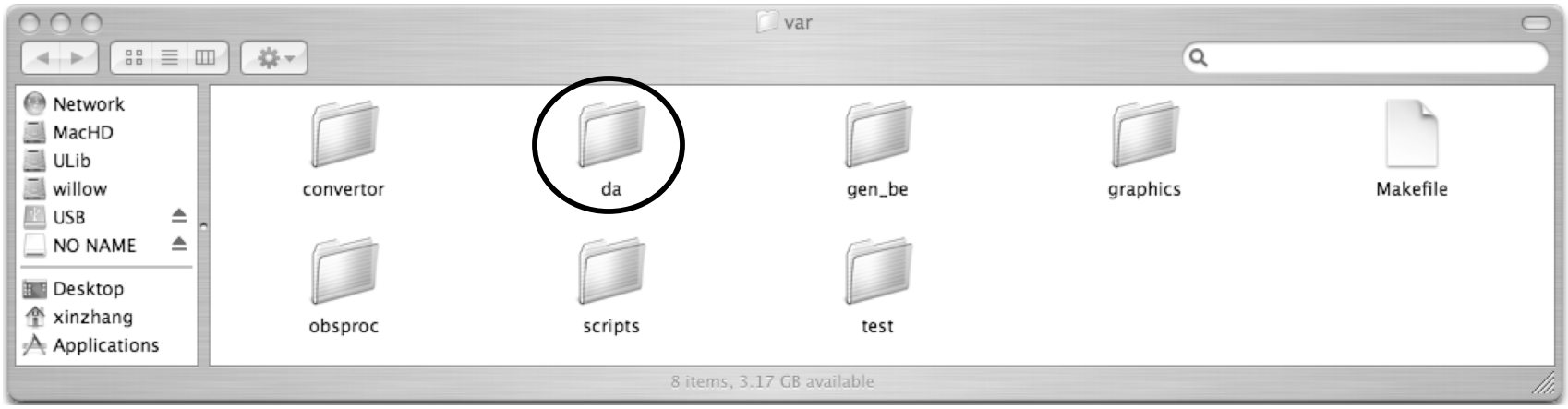
Tidy Up

- **Deallocate dynamically-allocated arrays, structures, etc.**
- **Timing information.**
- **Clean end to WRF-Var.**

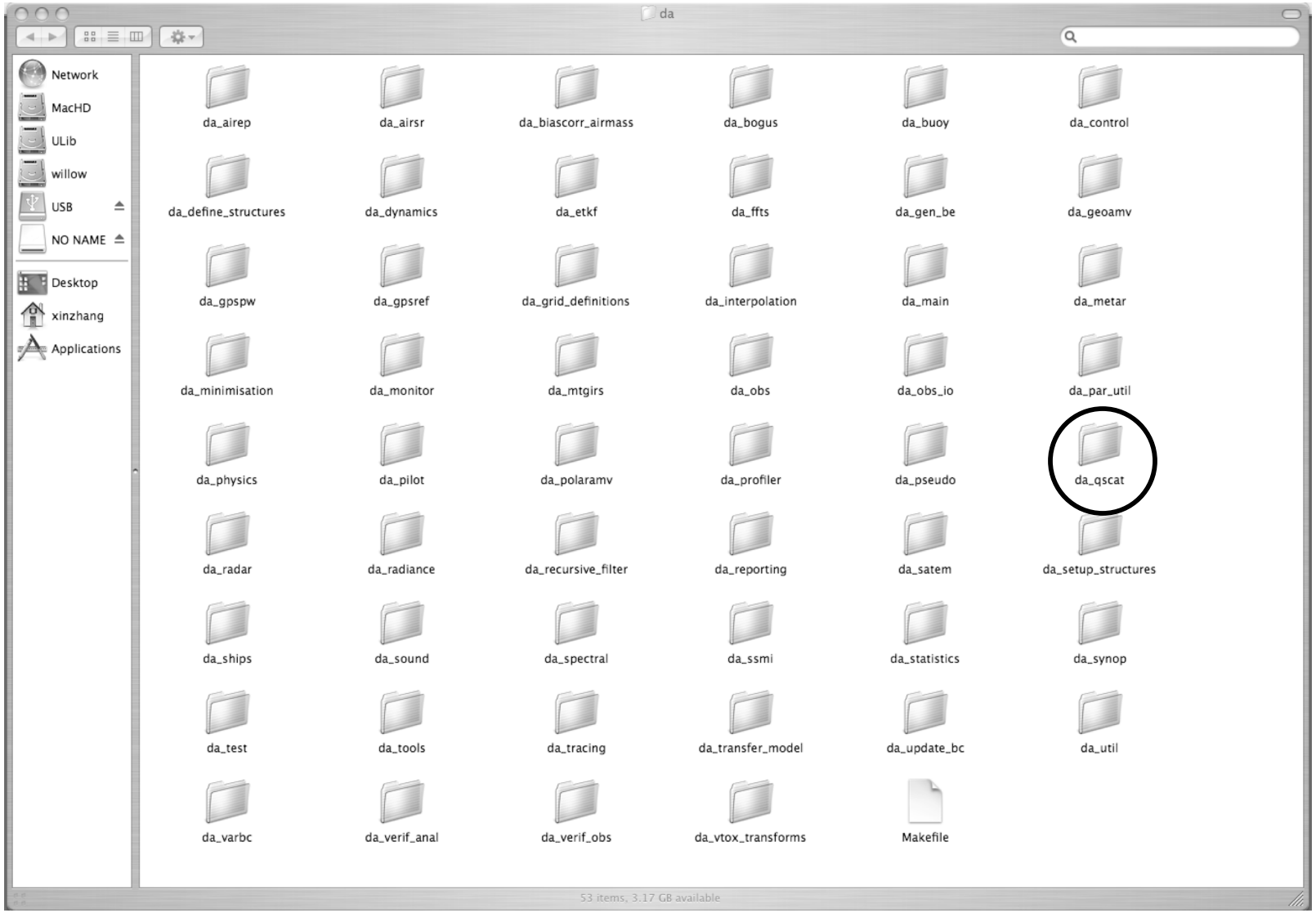
Source Code 1: *WRFDA/var*



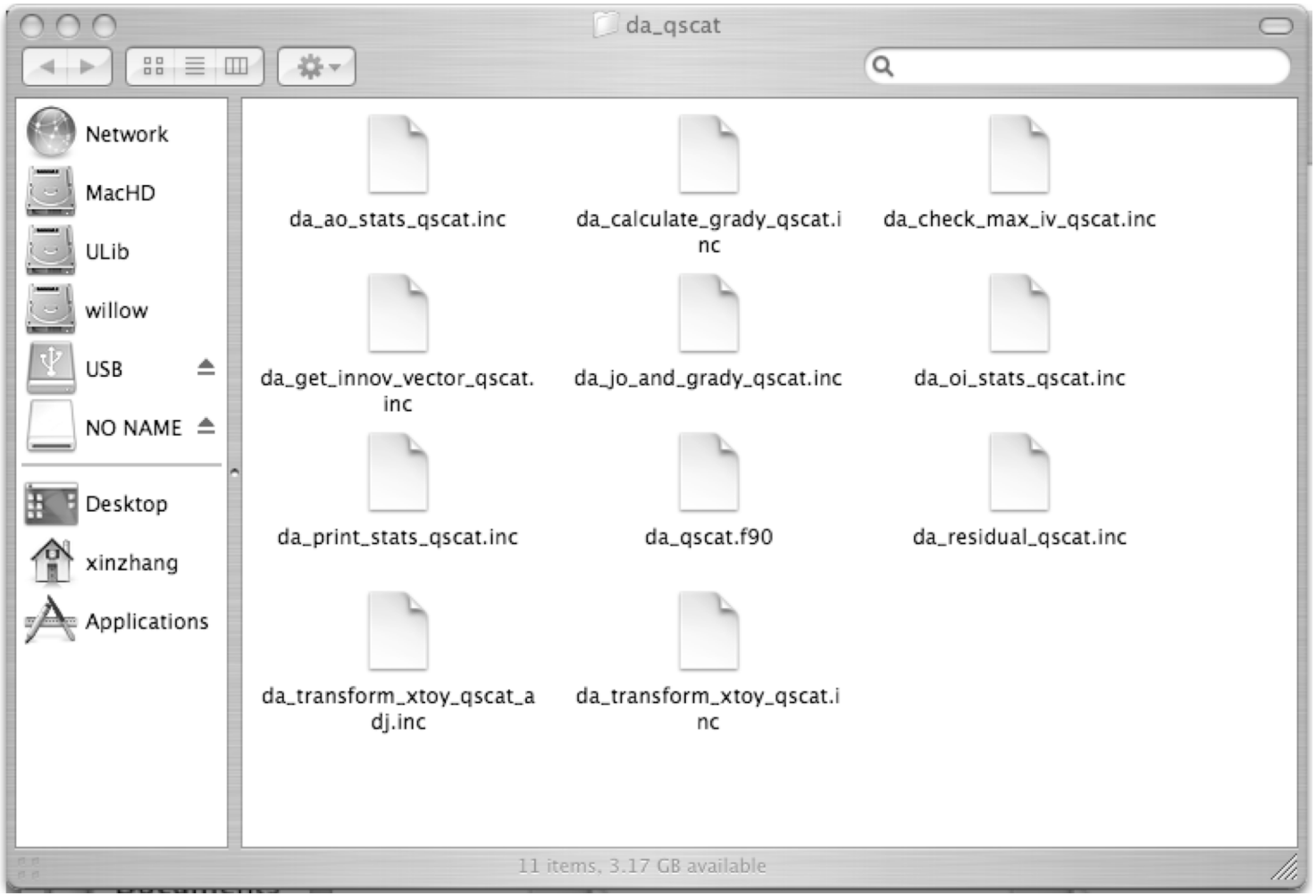
Source Code 2: *WRFDA/var/da*



Source Code 3: *WRFDA/var/da*



Source Code 4: *WRFDA/var/da/da_qscat*



Source Code 5: *WRFDA/var/da/da_qscat.f90*

da_qscat.f90

da_qscat.f90:1

```
module da_qscat

   use module_domain, only : domain

   use da_control, only : obs_qc_pointer,max_ob_levels,missing_r, &
      check_max_iv_print, check_max_iv_unit, v_interp_p, v_interp_h, &
      check_max_iv, missing, max_error_uv, max_error_t, rootproc, &
      qscat, max_error_p,max_error_q, trace_use_dull, &
      max_stheight_diff,missing_data,max_error_bq,max_error_slp, &
      max_error_bt, max_error_buv, anal_type_verify, kms,kme,kts,kte
   use da_define_structures, only : maxmin_type, iv_type, y_type, jo_type, &
      bad_data_type, x_type, number_type, bad_data_type
   use da_interpolation, only : da_to_zk, &
      da_interp_lin_3d,da_interp_lin_3d_adj
   use da_par_util, only : da_proc_stats_combine
   use da_par_util1, only : da_proc_sum_int
   use da_statistics, only : da_stats_calculate
   use da_tools, only : da_max_error_qc, da_residual, da_convert_zk
   use da_tracing, only : da_trace_entry, da_trace_exit

   ! The "stats_qscat_type" is ONLY used locally in da_qscat:

   type residual_qscat1_type
      real          :: u                        ! u-wind.
      real          :: v                        ! v-wind.
   end type residual_qscat1_type

   type maxmin_qscat_stats_type
      type (maxmin_type)        :: u, v
   end type maxmin_qscat_stats_type

   type stats_qscat_type
      type (maxmin_qscat_stats_type)  :: maximum, minimum
      type (residual_qscat1_type)     :: average, rms_err
   end type stats_qscat_type

contains

#include "da_jo_and_grady_qscat.inc"
#include "da_residual_qscat.inc"
#include "da_check_max_iv_qscat.inc"
#include "da_get_innov_vector_qscat.inc"
#include "da_ao_stats_qscat.inc"
#include "da_oi_stats_qscat.inc"
#include "da_print_stats_qscat.inc"
#include "da_transform_xtoy_qscat.inc"
#include "da_transform_xtoy_qscat_adj.inc"
#include "da_calculate_grady_qscat.inc"

end module da_qscat
```

Procedure for adding new Observations

- **Edit** da_define_structures.f90 **to add new data type.**
- **Make new observation sub-directory under** "var/da"**.**
- **Develop desired programs like getting innovation vector, forward observation operator, tangent linear & its adjoint, gradient & cost function etc. in this new sub-directory.**
- **Input observation (update** da_obs**).**
- **Sometimes it might be needed to add certain grid arrays in** Registry.wrfvar**.**
- **Link into minimization package (**da_minimisation.f90**)**

Learning To Use WRF-Var

- **Run through the Online WRF-Var Tutorial available at:**

  http://www.mmm.ucar.edu/wrf/users/docs/user_guide_V3/users_guide_chap6.htm

- **If still confused, ask questions via:**

  wrfhelp@ucar.edu