

# **A guide to the WRF numerical weather prediction model**

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# 1 Introduction

This report aims at providing some instructions and advice on the procedure to install and run one of the latest versions of the WRF numerical model<sup>1</sup> (Weather Research and Forecasting, version 2.1.1 updated on November 8, 2005). This tutorial was inspired by some explorations in the field of high-resolution numerical modelling of the atmosphere, carried out at OSMER during the FORALPS project. Besides being useful in the forecasting activity when initialized with synoptic-scale analyses, numerical weather prediction models also offer the opportunity of understanding the physics of meteorological processes, by means of idealized simulations or case studies. This report, born out of the conviction that numerical models can provide added value to the skills of any meteorological service, is meant as an instrument to share knowledge about the technicalities of one of the many models freely available today.

All you need to run the WRF model are a personal computer or workstation, and some free software. Like the greatest majority of atmospheric simulation software, WRF has been designed in order to be run on UNIX or Linux machines. A porting to machines with MSWindows operating systems is only possible by using the Cygwin Linux emulator for Windows (<http://www.cygwin.com/>): this approach is not recommended, being the effort required to have Cygwin up-and-running much larger than the one needed to learn Linux from scratch.

If you are concerned with the choice of a particular Linux distribution, you should consider installing a Debian-based one (either Debian itself, <http://www.debian.org/>, or the more user-friendly Ubuntu, <http://www.ubuntu.com/>, or Kubuntu, <http://www.kubuntu.org/>). Compared to other Linux kinds, these distributions allow a very simple installation of new software packages (e.g. libraries or shell interpreters), provided the apt-get package and an Internet connection are available. For instance, the Synaptic application in Ubuntu allows to check if a particular software is available on repository sites on the Internet, and to install it with a few mouse clicks.

## 2 Pre-requisites

First of all you will need to get the WRF and WRFSI (WRF Standard Initialization) source codes (WRFV2.1.1.TAR.gz and wrfsi\_v2.1.1.tar.gz) from the download area of the WRF web-site (<http://www.mmm.ucar.edu/wrf/users/downloads.html>). You will also need the WRF Standard Initialization input data, which can also be retrieved from [ftp://aftp.fsl.noaa.gov/divisions/frd-laps/WRFSI/Geog\\_Data](ftp://aftp.fsl.noaa.gov/divisions/frd-laps/WRFSI/Geog_Data). A 3DVAR data assimilation system is also available there.

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<sup>1</sup> WRF 2.1.1 was the latest available version of the modelling system available at the time of writing this report (April 2006). That model release had been superseded by version 2.2.1 by the time of printing (March 2008). The installation files of version 2.1.1 can still be downloaded from:

<http://www.mmm.ucar.edu/wrf/src/WRFV2.1.1.TAR.gz>

[http://www.mmm.ucar.edu/wrf/src/wrfsi\\_v2.1.1.tar.gz](http://www.mmm.ucar.edu/wrf/src/wrfsi_v2.1.1.tar.gz)

An updated online tutorial referring to WRF 2.2.1 has been published online, and is available at:

<http://www.mmm.ucar.edu/wrf/OnLineTutorial/index.htm>

## 2.1 *Compilers and Scripting Language*

These compilers and shell interpreters are needed to install and run WRF properly:

- A Fortran compiler, capable of compiling both Fortran 90 and 77 style code. The compiler `g77` will not work. Appropriate choices are the Intel `ifort` compiler (free for study and research uses), or the Portland `pgf` compiler (commercial).
- a C compiler (`gcc` is recommended).
- `perl 5.04` or better.
- `perl-TK` (for the Graphical interface). To test if it is installed on your machine you can type: `perl -e "use Tk"`. If you are returned to the prompt without errors or messages, then the software correctly installed. If not, you should install it (view the section below).
- the C and Bourne shells (`cs`h and `ba`sh).
- the `make` utility, either Unix or GNU, version 3.75 or higher.
- UNIX text/file processing utilities: `m4`, `sed` and `awk`.

It is very important to check if all these facilities are installed on your machine at the very beginning of the procedure, even before decompressing and de-tarring the code.

## 2.2 *Software libraries*

The `netCDF` library, version 3.3.1 or higher (including the I/O API packages) is the only external package required by WRF. It can be retrieved at the Unidata homepage:

```
http://www.unidata.ucar.edu/packages/netCDF/
```

## 2.3 *Post-Processing Utilities*

Several utilities can be used to represent graphically the outputs of the WRF numerical model. These include the `NCL`, `Vis5D` and `RIP` software packages. Another good choice is to use the `GrADS` package; in this case the program `WRF2GrADS` is available, and provides the capability to convert the WRF output into an input format for `GrADS`.

## 2.4 *Installing the netCDF library*

First of all, it is important to notice that the WRF code and the Fortran libraries that it needs to link have to be built using the same compiler. So, for instance, you want to compile WRF codes on a Linux system using the PGI compiler (developed by the Portland Group and available at <http://www.pgroup.com/products/workpghpf.htm>), make sure that the `netCDF` library is also installed using the PGI compiler.

These are the steps needed to install:

- de-tar your source file where you want to install the libraries:  

```
tar xvf netCDF-3.6.0.tar
```
- move to the directory created  

```
cd netCDF-3.6.0
```

- Set the environment variable CPPFLAGS:  

```
export CPPFLAGS='-DpgiFortran'
```
- Type the following instructions:  

```
./configure - -prefix=/opt/netCDF-3.6.0
make
make test
make install
```
- Set the NETCDF environment variable  

```
export NETCDF=/opt/netCDF-3.6.0
```

This last command should also be added in the `.profile` or `.bash_profile` file of all users; this step is needed to avoid setting the NETCDF variable at any new login to the machine.

## 2.5 *Installing Perl/Tk*

Unpack the Tk-source code and cd to the resulting directory. Then install by typing:

```
perl Makefile.PL X11=/usr/X11 X11LIB=/usr/X11/lib64
make
```

## 2.6 *Installing the NCAR Graphics package*

Download the source code from <http://ngwww.ucar.edu/ng/download.html> and untar the file:

```
tar -xvf ncarg-4.4.1.src.tar
```

This step will create a directory named "ncarg-4.4.1". Set the environment variable NCARG to this directory. For instance:

```
export NCARG=/home/wrf/ncarg-4.4.1
```

Note that in the csh shell you must use the `setenv` command instead of `export`.

Make sure you have the software libraries required. As a minimum you should have the following libraries with associated include files: X11 Xaw Xext Xm Xmu Xt. These should be installed in directories like `/usr/X11R6/lib64` and `/usr/X11R6/include`.

Unix users should note that the default configuration file for Linux machines assumes you have a 32-bit architecture and are using GNU compilers. If this is not the case, i.e. if use are on a UNIX platform, then you have to copy the appropriate `$NCARG/config/LINUX.xxx` file to `$NCARG/config/LINUX`. For example:

```
cp $NCARG/config/LINUX.64.PGI $NCARG/config/LINUX
```

After choosing the appropriate configuration files, cd to the `$NCARG` directory and type:

```
./Configure -v
```

If Configure recognizes your system correctly, the script will ask you some questions regarding the directories where you want the software to be installed, the compilers you wish to use, the directories where libraries are installed, etc..

Once the compilation has been carried out, you can check if the options selected are correct by typing:

```
make Info
```

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If everything looks ok you can start the installation procedure. If not, view the `INSTALL_README` file in the `$NCARG` directory at the section “Modify configuration files to recognize your system”.

To compile and install, type: `make Everything >& make-output&`

To follow the installation process, which may take several minutes:

```
tail -f make-output
```

Now you have to set some environment variables: if libraries, binaries and includes are all installed in the same parent directory (for instance `/home/wrf/ncarg-4.1.1`), then you only need to set the `$NCARG_ROOT` variable.

Once the environment variables are set, you should check if `$NCARG_ROOT/bin` is in your search path and if `$NCARG_ROOT/man` is in your man path. You can do this permanently by modifying the `./profile` file in your home, by adding the following lines:

```
export NCARG_ROOT=/home/wrf/ncarg-4.1.1
PATH=$PATH:$NCARG_ROOT/bin
MANPATH=$MANPATH:$NCARG_ROOT/man
```

Finally, you should test the installation by typing:

```
ncargex cpex08
$NCARG_ROOT/bin/ctrans -d X11 cpex08.ncgm
```

## 2.7 NCL Graphics

Download the source code from:

```
https://www.earthsystemgrid.org/
```

Registration is required to download the data. Request an account and then, when registered, jump to latest NCL release from the shortcuts menu. Note that the registration request has to be accepted, and that this could require one or two working days.

After downloading the software package, just un-tar it in the `$NCARG_ROOT` directory.

# 3 Building The WRF Code

## 3.1 Installing the ARW-WRF solver code

Once you get the WRF zipped tar file, and after checking that all the software required are available (in particular check for netCDF libraries), first of all you have to unzip and un-tar the file, using the `p` option to preserve paths:

```
tar xzpf WRFV2.1.TAR.gz
```

Then move to the `WRFV2/` directory that has been created

```
cd WRFV2/
```

and type:

```
configure
```

If your netCDF path is not set, then you will be asked to set it; answer yes to the first request. At the second request write first the path for the include/ directory, and then the path for the lib/ one. You should know in advance where these directories are positioned in your computer, e.g.:

```
/opt/netCDF-3.5.0/include
/opt/ netCDF-3.5.0/lib
```

After setting the netCDF path, you will be given a list of supported platforms: select your platform type by entering the correspondent number.

The procedure will finally result in the creation of a configure.wrf file.

### 3.1.1 *Testing the model*

After the installation, the code needs to be compiled before running; the model should also be evaluated on some test cases provided with the code itself. Some of the tests are idealized cases (i.e. they represent atmospheric processes in simulation domains with realistic but not real boundary conditions and topography), while others (those with the `_real` extension) are real ones.

Type:

```
compile
```

Typing this without any argument should provide you all the available choices:

```
compile em_b_wave
compile em_grav2d_x
compile em_hill2d_x
compile em_quarter_ss
compile em_squall2d_x
compile em_squall2d_y
compile exp_real
compile nmm_real
compile em_real
```

If you have successfully compiled an idealized case you should have two executable files in your main/ directory, named ideal.exe and wrf.exe; These files will also be linked in the test/name\_case/ and run/ directories.

Move to the ideal case directory test/name\_case/ or to the run/directory

Example:

```
cd test/em_hill2d_x/
```

or:

```
cd run/
```

Prepare the starting conditions for the ideal case by typing ideal.exe. If you see a file called run\_me\_first.csh in the test case directory, run this one first by typing run\_me\_first.csh; this program will provide links to some data files needed to run the model.

The ideal.exe program will generate the wrfinput\_d01 file in the same directory. Then you can run the model by typing wrf.exe.

After completion you should see one or more output files (netCDF files) named like wrfout\_d01\_0001-01-01\*, and some restarting files named wrfst\*. The number of the output files depends on the namelist options used.

You should compile and run all the ideal case for testing the model.

For real data cases, you need input files from the standard initialization.

### 3.2 *Installing WRFSI and WRFSI GUI*

First of all you have to decide where you want to install the code.

After the installation you will have 4 top-level directories, one containing the source code (\$SOURCE\_ROOT, the directory created when you un-tar the source code), one for the executable system (\$INSTALLROOT), one for the data specific to a particular domain (\$DATAROOT) and one for external data and the intermediate pre-processed GRIB data (\$EXT\_ DATAROOT). In a typical installation \$SOURCE\_ROOT and \$INSTALLROOT are the same directory.

If not specified differently, wrfsi will use the following default directories:

```
SOURCE_ROOT=/path_to_where_you_untarred_the_code/wrfsi
INSTALLROOT=SOURCEROOT
DATAROOT=SOURCE_ROOT/domains
EXT_DATAROOT=SOURCE_ROOT/extdata
```

It is recommended that the INSTALLROOT be an immediate subdirectory of your WRF model top level directory. Therefore you should de-tar the wrfsi code in the WRFV2/ directory created installing the WRF code.

In addition to the tar file containing the SI package, you must also obtain and extract the tiled surface data sets (global topography, land use, albedo, etc.). These files are available at the ftp site:

```
ftp://aftp.fsl.noaa.gov/divisions/frd-laps/WRFSI/Geog_Data
```

You should download at least the following files:

```
greenfrac.tar.tgz
soiltemp_1deg.tar.tgz
topo_10m.tar.tgz
albedo_ncep.tar.tgz
```

They are huge, and might require a very long time for downloading; therefore, you should pay attention that the files aren't corrupted when you unzip and untar them to SOURCE\_ROOT/ext\_data/GEOG or to a directory of your choice.

For a typical installation, cd to the WRFV2 directory, unzip and de-tar the wrfsi source code, and move to the wrfsi/ directory created. This will be your \$SOURCE\_ROOT directory.

Ensure perl is installed and in your default path.

Check where you have installed the "global" data sets. If you have put those data in some place different from the wrfsi default (wrfsi/ext\_data/GEOG), then set an environment variable called GEOG\_DATAROOT pointing to that directory. Otherwise, use on the next command line the option -geog\_dataroot=path-to-globaldata. You should also specify your machine-type with the option -machine="your machine type".

Move into the wrfsi/ directory and execute the installation running the perl program install\_wrfsi with the indicated arguments, which are in general:

```
perl install_wrfsi.pl - -geog_dataroot=path-to-globaldata -
-machine='...'
```

or, in a specific example:

```
perl install_wrfsi.pl - -geog_dataroot=/opt/geo-data/wrf_database
-
-machine='pc'
```

This should build the code with a standard installation. To install the WRFSI GUI software, reply 'Yes' when prompted during the installation of WRFSI. If you do so the GUI will be installed directly and you will not need to make the installation by yourself. If you don't, you can anyway build the code yourself by going into the gui/ directory and typing: perl install\_gui.pl.

For details about the ingestion of ECMWF data as initial and boundary conditions, please refer to Section 5 of this report.

Note that the previous release of the wrfsi code (wrfsi2.0.5) had a bug now fixed. If you are installing that version you should go into the wrfsi/gui/src directory and modify the 'Makefile' changing the following line:

```
$(CC) -o $(EXE1) $(MAIN1) -I$(SRCROOT)/src/include $(LIB)
$(LAPSLIBS) /usr/lib/libm.a;
```

with:

```
$(CC) -lm -o $(EXE1) $(MAIN1) -I$(SRCROOT)/src/include $(LIB)
$(LAPSLIBS);
```

i.e. adding the -lm option and deleting the path to /usr/lib/libm.a.

### 3.3 *Installing the 3d-Var Data Assimilation System*

The WRF-Var package is a variational data assimilation system. Its purpose is to produce an accurate image of the state of the atmosphere (named analysis) combining observations with a modeled state (background forecast or first guess). In particular, the 3D-Var algorithm performs the analysis of three-dimensional meteorological fields, by minimizing a cost-function with variational methods. Further details about the general features of data assimilation can be found in the FORALPS Report "Spatial interpolation of surface weather observations in Alpine meteorological services" by A. Lanciani and M. Salvati, while further information on the WRF 3D-Var algorithm is available at:

<http://www.wrf-model.org/development/group/WG4>

Installing and running WRF-Var requires a Fortran 90 compiler. The following platforms are currently supported: IBM, DEC, SGI, PC/LINUX (with Portland group compiler), Cray-X11 and Apple G4/G5.

#### 3.3.1 *The 3D-Var Observation Preprocessor (3DVAR\_OBSPROC)*

This software creates an observation file for subsequent use in WRF-Var, and plots a map of the distribution of observations. Download the 3DVAR\_OBSPREC code from:

[http://www.mmm.ucar.edu/individual/barker/wrfvar/3DVAR\\_OBSPROC.tar.gz](http://www.mmm.ucar.edu/individual/barker/wrfvar/3DVAR_OBSPROC.tar.gz)

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Then go to your working directory and un-tar it typing:

```
tar zxvf 3DVAR_OBSPROC.tar.gz
```

cd to the resulting directory and type

```
make
```

to compile. This should take a minute or less depending on the machine. At the end of the process check for the presence of the executable 3dvar\_obs.exe in the src/ directory.

### 3.3.2 *The WRF-Var code*

Download the WRF-Var code from:

```
http://www.mmm.ucar.edu/individual/barker/wrfvar/wrfvar.tar.gz
```

go to your working directory and un-tar and unzip it typing:

```
tar -zxvf wrfvar.tar.gz
```

cd to the resulting directory and type:

```
configure
```

You will be queried to choose an option between var and be; the first one creates the compiler options for WRF-Var, while the second one sets up the calculation of background error statistics. If you wish to compile WRF-var, type configure var.

At this point you should see a list of compilation options, as obtained for the WRF-ARW code, depending on what platform you are using and on the running options you want (single or multiple processor, different compilers). Check if the configure file (configure.defaults\_wrfvar) has been created.

If so, you can compile typing:

```
compile var
```

This should create the wrfvar.exe executable in the main/ directory.

### 3.3.3 *The WRF\_BC code*

To update WRF lateral boundary conditions, download the WRF\_BC code from:

```
http://www.mmm.ucar.edu/individual/barker/wrfvar/WRF\_BC.tar.gz
```

go to your working directory, un-tar and unzip the file by typing:

```
tar -zxvf WRF_BC.tar.gz
```

Then cd to the WRF\_BC directory created. It is useful to check the netCDF libraries setting in the Makefile, and to correct any wrong link.

To compile, type:

```
make
```

You will see an executable named update\_wrf\_bc.exe

## 3.4 *Installing the WRF to GrADS Converter*

You have various options to obtain a graphical depiction of the netCDF output files; one of these is using the GrADS software. In this case, you need to convert the WRF output to the input format needed by GrADS, using the wrf2grads converter. No graphics are generated by this tool. Once the

data is in the correct format, you will have to learn some basic GrADS usage to generate the necessary plots (<http://grads/iges.org/grads>).

First of all you have to obtain the wrf2grads TAR file from the WRF download page, and untar it:

```
tar xvf wrf2grads.tar
```

Move to the WRF2GRADS directory so created and edit the Makefile to select the compiler flags for your machine. You can do that just de-commenting the flags you're interested in and commenting the others. You should also correct the paths for the netCDF libraries depending on their location on your machine.

E.g. If you work on a Linux machine, your Makefile should be modified as:

```
# compaq flags
#LIBNETCDF = -L/usr/local/netCDF/lib -lnetCDF -lm
#INCLUDE = -I/usr/local/netCDF/include -I./
#FC = f90
#FCFLAGS = -g -C -free
#CPP = /usr/bin/cpp
#CPPFLAGS = -I. -C -P -Dsbe
# linux flags
LIBNETCDF = -L/opt/netCDF-3.5.0/lib -lnetCDF -lm
INCLUDE = -I/opt/netCDF-3.5.0/include -I./
FC = pgf90
FCFLAGS = -g -C -Mfree
#FCFLAGS = -fast -Mfree
CPP = /usr/bin/cpp
CPPFLAGS = -I. -C -traditional -Ddirect
# Sun flags
#LIBNETCDF = -L/usr/local/netCDF/lib -lnetCDF -lm
#INCLUDE = -I/usr/local/netCDF/include -I./
#FC = f90
#FCFLAGS = -g -C -free
#CPP = /usr/ccs/lib/cpp
#CPPFLAGS = -I. -C -P -Ddirect -Dbytesw
```

Note that some systems (e.g. AMD64) do not need the `-Dbytesw` option in the `CPPFLAGS`; you should delete it in this case.

Run:

```
make
```

to create the `wrf_to_grads` executable. You can link the `wrf_to_grads` converter in your binaries directory by running the following command:

```
ln -s WRF2GRADS_dir_path/wrf_to_grads
your_bin_dir_path/wrf_to_grads
```

### 3.5 *Installing the WRF NCL*

Some NCL scripts are provided by the WRF developers, to create graphical representations (NCAR Graphics metafiles) of real and ideal datasets, as well as of ARW static/input and output files, and of WRF-Var output data. In order to run these scripts, you must have installed the NCL binaries, as explained before.

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Obtain the WRF\_NCL TAR file from the WRF download page:

```
http://www.mmm.ucar.edu/wrf/users/download/get\_source.html
```

Untar the archive and copy the file DOThluresfile to /hluresfile. This is the file that controls the color, background, fonts and size of your plot. This must have the name indicated and must be located in your home directory.

Build the external function emphwrf\_user\_fortran\_util\_0.so, running one of the make\_ncl\_fortran scripts available in the WF\_NCL directory; choose the script that matches your machine type and architecture:

```
make_ncl_fortran.linux wrf_user_fortran_util_0
```

This will create the files:

```
so_locations  
wrf_user_fortran_util_0.o  
wrf_user_util_0.so
```

Remember to set correctly in the make\_ncl\_fortran script (a csh script) the path to the NCAR Graphics and to other libraries. It could also be useful to read some information about the wrapit77 function (part of the NCAR Graphics routine); see for example:

```
http://www.ncl.ucar.edu/Document/Manuals/Ref\_Manual/NclExtend.shtml  
1
```

If you experience problems in compiling, try replacing lines 39 to 45 in make\_ncl\_fortran.linux, i.e.:

```
pgf77 -g -c $argv[1].f -L/standalone/local/ncarg/lib \  
-L/usr/X11R6/lib -L/usr/local/lib \  
-I/standalone/local/ncarg/include \  
-I/usr/X11R6/include -lhlu -lncarg -lncarg_gks \  
-lncarg_c -lX11 -Wl,-Bstatic \  
-L/usr/lib/gcc-lib/i386-redhat-linux/egcs-2.91.66 \  
-lg2c -Wl,-Bdynamic -lm
```

with:

```
nhlf77 -c $argv[1].f
```

This is likely to result in a successful compilation.

### 3.6 *Installing the read\_wrf\_nc utility*

This utility was created to allow a user to look at a WRF netCDF file at a glance. It has a large number of options to allow examining at a specific part of the netCDF file, and is written in Fortran 90, which will allow users to add their own options. The utility can be used for input / output and static files. Of course, you must have the netCDF libraries installed in order to use it.

Download the code from:

```
http://www.mmm.ucar.edu/wrf/users/download/get\_source.html
```

Move the downloaded file to a directory of your choice. To compile the code, use the compile flags at the top of the utility. For example on a Linux machine you need to type:

```
pgf90 read_wrf_nc.f -L/usr/local/netCDF/lib -lnetCDF -lm  
-I/usr/local/netCDF/include & -Mfree -o read_wrf_nc
```

Note that you have to set the correct path to your installation of netCDF libraries. Compilation will result in creating the executable `read_wrf_nc`, which you might want to link in your `/home/bin` directory.

## 4 Running The Model

### 4.1 *Running the WRFSI Graphical User Interface*

Note that the web-site and user's guide for the WRFSI GUI are available at:

```
http://wrf-si.noaa.gov/gui/
http://wrf-si.noaa.gov/gui/users_guide/V3/users_guide.pdf
```

You are likely to find there all of the information you need in order to run the WRF Standard Initialization procedure.

To run WRFSI,

```
cd /home/wrf/WRFV2/wrf-si/
```

and launch the executable

```
wrf_tools
```

Enter the domain panel selecting the “Domain selection” button, and create your domain by choosing “Create new domain” from the “Choose what you want to do” pull-down menu. You can create or copy or delete domains. Choose a name for the domain, and edit other box fields (change path, give the user name and a brief simulation description) if desired.

Press the “Next” button to enter the horizontal grid panel. This panel allows the user to define the domain by drawing a bounding box (selecting the “Domain bounding box” option) and/or by explicitly editing (selecting the “Grid values” option) some variables as map projection, centre point longitude and latitude, number of points in the x and y dimensions, distance between gridpoints. Press “Update map” to view your domain on the map on the left and commit your changes.

Press “Next” to enter the vertical grid panel. Edit vertical levels choosing one of the options in the pull-down menu or editing the levels via the text editing window.

Press “Next” to enter the localization parameter panel. Edit the path to your geographical data.

Press “Next” to enter the “Localize Domain” panel. Press “Localize” to run the domain localization process. This can take some time, depending on the domain size. You can view the results of this process with the “Domain Graphics” panel if you have installed NCAR Graphics and NCL.

Now you can go to the Initial Data interface (button on the left). The “Source” panel allow the user to add available model data (in .GRIB format). Once edited, press the “Save” button. Go to the “Script” panel, where you can edit the command line arguments for the `grib_prep.pl` script and launch it. First of all choose a data source from the pull-down menu, then edit the command line following the instructions in the command line window. Finally, press “Run”.

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Once the program stops running, go to the “Interpolate Data” interface. This operation provides initial and boundary conditions running the wrfprep.pl program. In the “Control” panel you can edit the parameters needed for the interpolation. Go to the “Script” panel to edit the command line arguments, following the help in the command line options window. Press “Run”.

At the end of the run, upon success you will have some files in the directory wrfsi/domains/your\_domain/siprd/, named as:

```
wrf_real_input_d01_yyyy_mm_dd_hh:00:00
```

Copy or link these files in the directory where you will run the wrf model:

```
cp wrf_real_input_d01* /home/WRFV2/test/em_real/
```

### 4.2 *Running the WRF model*

To run the WRF model, go to the WRFV2/ directory:

```
cd /home/WRFV2
```

Compile em\_real and move to the appropriate directory, i.e. the one where you have wrf\_real\_input\_files and the two executable real.exe and wrf.exe cd test/em\_real. Edit the namelist.input file with the same domain parameters you have selected by means of the WRFSI. You can find them listed in the wrfsi.nl namelist file, in the directory wrfsi/domains/your\_domain/static/. Remember setting the forecast time, the number of grid points and vertical levels, the spatial resolution, the integration time step (as a rule of thumb, this should be about 6 times the spatial resolution in km, due to a combination of numerical stability criteria). The namelist.input file is also used to modify the settings of physical parameterizations. You can find all the relevant information in the README.namelist.

Run the real.exe program:

```
real.exe
```

When real.exe is successfully terminated run the model:

```
wrf.exe
```

or

```
wrf.exe >& wrf.log &
```

Once your run is finished you will have one or more output files named as wrf\_output\_date.

### 4.3 *Running the WRF 3d-Var system*

#### 4.3.1 *The 3D-Var observation preprocessor*

Edit the namelist.3dvar\_obs in the 3DVAR\_OBSPROC directory. You should read the README.namelist for details, and keep in mind that some default namelists can be used as an example. For instance, the namelist.3dvar\_obs.wrfvar-tut can be used for the test data provided with the program:

```
cp namelist.3dvar_obs.wrfvar-tut namelist.3dvar_obs
```

Then you should edit the full path to observation file (ob.little\_r), the grid dimensions (test data nestix=nestjx=45) and the grid resolution (dis=200km).

Now you can run the program typing:

```
3dvar_obs.exe >& 3dvar_obs.out
```

If the program ends normally you should have an observation data file `obs_gts.3dvar` which can be used as input to WRF-Var. A dedicated routine allows to have a look at the data distribution for each type of observation. Type:

```
cd MAP_plot
```

then modify the shell script `Map.csh` to set the time window and the full path of input observation file just created. Then type:

```
Map.csh
```

and once the job is completed you will have a `gmeta.{analysis_time}` file. View it by typing:

```
idt gmeta.yyyymmddhh
```

Copy the output file created in your `$DAT_DIR` directory (the directory where you stored your observational data):

```
mv obs_gts.3dvar $DAT_DIR/obs_gts.3dvar.yyyymmddhh
```

and clean up by typing

```
make clean
```

#### 4.3.2 *The WRF-Var code*

Move to the `wrfvar/run/` directory, edit the `namelist.3dvar` file and the `DA_Run_WRF-Var.csh` script. Type:

```
A_Run_WRF-Var.csh script
```

This will create the `wrf_3dvar_output` file.

#### 4.3.3 *The WRF\_BC code*

Move to the `WRF_BC` directory, edit the `new_bc_csh` script with correct paths to the `wrf_3dvar_output` file, the `wrfbody*` and `wrfinput*` files (output from WRFSI). Run the script, which should modify the `wrfbody_d01` file. Finally, rename the 3dvar output file as `wrfinput`:

```
mv wrf_3dvar_output wrfinput_d01
```

### 4.4 *Running the wrf2grads converter*

Once you have obtained your model outputs you can see look at them directly with NCL graphics, or convert them for use with other graphical packages with one of the programs available. For example, this section provides the instructions to use the WRF to GrADS converter.

Edit the `control_file` indicating the timesteps and variables to process (although the list contains all variables, those indented with a blank space will be ignored), and selecting the input files (absolute or relative paths are both accepted). Even in this case, indentation with a blank space discards the file from the list. You should also set if the case is real/ideal or static, indicating which vertical levels to interpolate. For more information, you can read the `README` file relative to the `control_file`.

Now you can run the program by typing:

```
wrf_to_grads control_file MyOutput [-options]
```

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This will create a MyOutput.ctl and a MyOutput.dat file that can be read by GrADS. You can select one of the different debugging levels available using options. If you set no option, only basic information will be written to the screen. The -v and -V flags will instead print out some (or a lot of) debug information.

Now you should be able to use GrADS opening the ctl file or running some of the scripts available in the WRF2GRADS directory. Pay attention to the fact that the grads scripts presume you named your ctl files by specified names. If you have not done so, you can simply modify the GrADS script at the 'open name file' command line.

Note that when converting WRF output to GrADS format using the map background option, the location of forecast gridded data is shifted with respect to the geographical background. In particular, everything seems to be shifted to the south. You can notice this for example plotting the land-mask field with GrADS. This problem arises because wrf2grads uses constant increments in the y direction (latitude direction), while latitudes in the WRF netCDF output are not equidistant (since the grid space is defined in kilometers and not in degrees).

Therefore you should modify the code eliminating the constant increment and using the latitudes specified in the netCDF file, as already made for the vertical levels. So:

```
cd WRF2GRADS/
```

There, you should edit the module\_wrf\_t0\_grads\_util.F file, by finding the following lines:

```
write(13,('"ydef ",i4," linear ",f9.4," ",f8.4)') &  
ny,xlat(1,1),(abs(xlat(1,1)-xlat(nx,ny))/(ny-1))
```

and replacing them with:

```
write(13,('"ydef ",i4," levels ")') ny  
do jtest=1, ny  
    write(13,('" ",f10.5)') xlat(1,jtest)  
enddo
```

### 4.5 *Running the read\_wrf\_nc utility*

To run the utility, type:

```
read_wrf_nc wrf_data_file_name [-options]
```

Note that you can use only one option at time. Launching the program with the -h option will give you a complete description of all the available options and of their usage.

A special option, the “-EditData VAR”, will allow you to change a specific field and write it back in the WRF netCDF file. This option will change your current WRF netCDF file, so take care when using it. Two important things you should have in mind using this option:

- you can change only one file at time. So if you need to have more than one field changed, you will need to run the program several times, each with a different “VAR”.
- if you have multiple times in your WRF netCDF file then all the available times for the variable selected will be changed. To prevent it from happening, use the -t option, i.e. to change only the first three times of the T2 variable: [-EditData T2 -t 1 3].

To use this option, first of all make a copy of your netCDF file. Then move it to where you installed read\_wrf\_nc and edit the read\_wrf\_nc.f file. Search the file for the subroutine user\_code. At this point you will have to make your changes. Add an elseif-statement for the variable you

want to change. You have to use either the “data\_real” or the “data\_int” array, where the first is meant for real data and the second for integer data. Here you can find some examples:

- If you want to change all (all time periods too) values of U to a constant 10.0 m/s, you would add the following IF\_statement:

```
elseif ( var == 'U') then
  data_real = 10.0
```

- If you want to change some of the LANDMASK data from LAND to SEA points:

```
elseif ( var == 'LANDMASK') then
  data_real(10:15,20:25,1) = 0
```

- If you want to change all ISLTYP (this is an INTEGER field representing soil category) category 3 into category 7:

```
elseif ( var == 'ISLTYP') then
  where (data_int == 3 )
    data_int = 7
  endwhere
```

After finishing the compilation, re-compile and run the program with the -EditData VAR option. You will be prompted if this is really what you want to do. Only answering yes will allow the changes to take effect.

## 5 Ingesting ECMWF data

### 5.1 *Creating the Vtable*

To extract and decode the appropriate data from GRIB files for the model initialization, the WRFSI program use some ASCII tables, the so called Vtables, where the variables of interest and their proper GRIB code are listed. Since different GRIB files may have different codes for the same variable, you will need different Vtables to use GRIB files from different data providers.

At the moment, WRF only provides Vtables for NAM/Eta 104, 212 grid, NAM/Eta data in AWIP format, GFS (or AVN), NCEP/NCAR reanalyses, RUC and AFWA’s AGRMET land surface model output. If you wish to add a source, simply copy one of the Vtables into another one called Vtable.NAME, where NAME is of your choice, and edit it changing codes and variables according to your needs. You will need to add an entry to grib\_prep.nl that matches this name. You can find the Vtables and the gri\_prep.nl file in the directory \$EXT\_DATAROOT/static (where \$EXT\_DATAROOT = /wrfsi/extdata/).

In the following, you can find the Vtable created to ingest ECMWF data (both analyses and forecasts) and the changes made in the namelist file

```
cd $EXT_DATAROOT/static/
```

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open with an editor the `grib_prep.nl` file and add your new entry in the following lines:

```
&gpinput_defs
SRCNAME = 'ETA', 'GFS', 'AVN', 'RUCH', 'NNRP', 'NNRPSFC', 'SST', 'ECMWF'
SRCVTAB =
'ETA', 'GFS', 'AVN', 'RUCH', 'NNRPSFC', 'NNRPSFC', 'SST', 'ECMWF'
SRCPATH = '/path/to/eta/GRIB',
'/path/to/avn/GRIB',
'/path/to/avn/GRIB',
'/path/to/ruch.GRIB',
'/path/to/nnrp/GRIB',
'/path/to/nnrp/sfc/GRIB',
'/path/to/ncep/sst/GRIB',
'/path/to/ecmwf/GRIB',
SRCCYCLE = 6,6,6,6,12,12,24,12
SRCDELAY = 3,4,4,3, 0, 0,36, 0
```

Note that `SRCNAME` and `SRCVTAB` could differ because more different models (or different configurations of the same model) may use the same GRIB table. In any case, by default the GRIB files that you wish to ingest should be renamed as:

```
SRCNAME:yyyy-mm-dd_hh
```

where

```
yyyy=year
mm=month
dd=day
hh=hour
```

The `SRCNAME` will also define the prefix of the final output files in `$EXT_DATAROOT/extprd`.

In the code lines above, `SRCCYCLE` is the number of hours between new model runs of the `SRCNAME` model, while `SRCDELAY` defines the number of hours after the `SRCNAME`'s initial valid time after which you expect the entire run to be available.

Finally, edit `Vtable.ECMWF` according to the example below:

GRIB1	Level	From	To	REGRID	REGRID	REGRID	
Param	Type	Level1	Level2	Name	Units	Description	
130	100	*		T	K	Temperature	
131	100	*		U	m s-1	U	
132	100	*		V	m s-1	V	
157	100	*		RH	%	Relative Humidity	
129	100	*		GEOPT	m{2}s{-2}		
				HGT	m	Height	
167	1	0		T	K	Temperature at 2 m	
168	1	0		DEWPT	K	Dew Point Temperature at 2 m	
165	1	0		U	m s-1	U at 10 m	
166	1	0		V	m s-1	V at 10 m	
134	1	0		PSFC	Pa	Surface Pressure	
151	1	0		PMSL	Pa	Sea-level Pressure	
39	112	0	7	SM000010	fraction	Soil Moisture of 0-10 cm sub_soil layer	
40	112	7	28	SM010040	fraction	Soil Moisture of 10-40 cm sub_soil layer	
41	112	28	100	SM040100	fraction	Soil Moisture of 40-100 cm sub_soil layer	
42	112	100	255	SM100200	fraction	Soil Moisture of 100-200 cm sub_soil lyr	



### 5.3 *Possible problems*

#### 5.3.1 *TSK unreasonable*

You may experience problems while running the WRF preprocessing program `real.exe`, when ingesting both Skin Temperature (TSK) and Sea Surface Temperature (SST) from ECMWF data. A possible error report might look like the following:

```
error in the TSK
i,j=      3          1
landmask=  0.000000
tsk, sst, tmn=  0.000000      0.000000      0.000000
----- FATAL CALLED -----
FATAL CALLED FROM FILE: module_initialize_real.b  LINE: 420
TSK unreasonable
```

This problem arises because ECMWF GRIB files contain SST equal to 0 on land gridpoints. When reading these data, WRFSI might encounter a gridpoint expected to be on the sea based on USGS data, but being on the land according to the ECMWF model. In this case, a temperature  $TSK=SST=0$  is assigned to that gridpoint. This value is obviously unreasonable, and causes the program to stop. To solve the problem, do not ingest ECMWF SST, but TSK only.

#### 5.3.2 *Sub-soil levels*

There is a difference between ECMWF sub-soil layers and those used by the WRF Land Surface Model (LSM). The former uses the 0-7 cm, 7-28 cm, 28-100 cm, 100-255 cm layers, whereas the latter uses 0-10 cm, 20-40 cm, 40-100 cm and 100-200 cm. It is possible to trick the model software by naming the soil levels in the ECMWF data with their NOAA-LSM name; this is done when defining the `Vtable`. Anyway, the proper way to handle this problem would be to interpolate ECMWF soil data to NOAA-LSM levels; or, even better, to get soil temperature and humidity data from a source different from ECMWF, such as GFS. In this case you should create a second `Vtable` for the LSM (Land Surface Model) fields, named e.g. `Vtable.SRCLSM` (where SRC should be an acronym of the source used for soil data, e.g. GSM), and run the `grib_prep.pl` program twice: once for the soil fields with the new `Vtable`, and once for the remaining with the old `Vtable` (with soil field lines removed). After that, set the following in the `wrfsl.nl` file:

```
INIT_ROOT='SRCNAME'
LBC_ROOT='SRCNAME'
LSM_ROOT='LSMSRC'
```

See the ARW Modeling System User's guide at the chapter "Using multiple data sources".

#### 5.3.3 *GRIB data format*

Your initial GRIB data should span all the time window you plan to forecast or simulate, with surface and upper level data. Data should be stored in the GRIB stream ordered by date or forecast range. This because the `grib_prep.pl` program would go trough the GRIB file until finding the selected `END_TIME`, and quitting. This might cause the loss of some important data. For instance, if surface data at all times are stored at the beginning of your GRIB, while all upper air data follow, then the `grib_prep` program will missing of the latter.

If your data aren't stored correctly, sort them using the `wgrib` program. E.g., to sort by forecast range type the following:

```
wgrib grib_file | sort -t: -k13,13 -n | wgrib -i grib_file -grib -
o new_grib_file
```

Moreover, surface and upper level data should be defined in the same domain, with the same grid spacing and geographical dimensions. If not so you can reduce the larger domain using the `ggrib` program (currently a beta version). For instance, to reduce the domain size type:

```
ggrib grib_file_old grib_file_new westlon southlat eastlon
northlat
```

If you fail obtaining surface and upper level data in the same domain, then you have to split them in two separate files, and proceed as explained at the end of the previous section: create two separate Vtables (e.g. `Vtable.ECMWFSFC` and `Vtable.ECMWFUPL`), and run the `grib_prep.pl` program twice, once for the surface and once for the upper levels. You will have to set the surface `SRCNAME` (e.g. `ECMWFSFC`) as `LSM_ROOT` as explained in the ARW Modeling System User's guide chapter "Using multiple data sources".

## 6 References

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**NOTES**