Analyzing and Visualizing WRF-ARW data using NCL

18th Annual WRF User’s Workshop

Mary Haley • CISL / TDD / VAST

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The National Center for Atmospheric Research is sponsored by the National Science Foundation
Goals for this 90-minute tutorial

• Brief introduction to NCL and WRF-NCL

• Demo three ways for plotting WRF-ARW data

• Provide TIPS along the way

• Give you time to try sample scripts
http://www.ncl.ucar.edu/Training/Tutorials/WRF_Users_Workshop/
A scripting language developed at NCAR and tailored for the analysis and visualization of geoscientific data

http://www.ncl.ucar.edu/
NCL Overview

- A scripting language similar to Matlab, Python, IDL
- Tailored to climate and weather
- Has variable types, if-then-end if, do loops, arithmetic operators, functions, procedures
- Built around the NetCDF variable model
- F90-like array arithmetic
- Can call your own Fortran or C routines
Why use NCL?

- Developed in NCAR/CISL in close collaboration with NCAR scientific staff
- Mature package (20+ years)
- Open source, free
- Extensive website, hundreds of examples
- Well-supported
- Intensive training workshops
1. File input and output

• Data model based on netCDF model (metadata describes data)

• **One function** reads all supported data formats:
  – NetCDF3, GRIB 1 and 2, HDF4, HDF5, HDF-EOS2, HDF-EOS5, shapefiles, NetCDF4
  – Writes NetCDF3, NetCDF4, and HDF4

• OPeNDAP-enabled client available

• ASCII, Fortran/C binary (read and write)

• “Never fear a data format”
2. Data analysis

• Array-based math
• Hundreds of functions
  - WRF-ARW specific functions
  - Climatologies
  - Spherical harmonics
  - Interpolation and regridding
  - Crop / Heat stress
  - EOFs
• Most automatically handle missing data
3. Visualization

- Publication quality and customizable 2D visualizations
- Contours, XY, vectors, wind barbs, streamlines
- Maps with common map projections
- Handles data on rectilinear, curvilinear, and unstructured grids (MPAS, triangular meshes)
- Specialized scripts for meteograms, skew-T, wind roses, histograms, cross section, panels
- Over 1,400 visualization “options”
WRF-NCL

NCL suite of analysis and visualization functions tailored for WRF-ARW model data
• Included with NCL since 2006
• Developed by staff in NCAR/MMM
• Maintained by MMM and CISL
• Functions for calculating basic diagnostics (\texttt{wrf_user_getvar})
• Functions for customized visualizations
• Website with lots of analysis and visualization examples
# Full list of WRF-NCL functions

http://www.ncl.ucar.edu/Document/Functions/wrf.shtml

## NCL functions to be called by user
- `wrf_user_getvar`
- `wrf_user_ij_to_ll`
- `wrf_user_intrp2d`
- `wrf_user_intrp3d`
- `wrf_user_list_times`
- `wrf_user_ll_to_ij`
- `wrf_user_unstagger`
- `wrf_user_vert_interp`

## Graphics
- `wrf_contour`
- `wrf_vector`
- `wrf_overlays`
- `wrf_map`
- `wrf_map_overlays`
- `wrf_map_resources`
- `wrf_map_zoom`

## WPS intermediate files
- `wrf_wps_open_int`
- `wrf_wps_rddata_int`
- `wrf_wps_rdhead_int`
- `wrf_wps_read_int`
- `wrf_wps_write_int`
- `wrf_wps_close_int`

## Computational routines not generally called directly by user
- `wrf_avo`
- `wrf_cape_2d`
- `wrf_cape_3d`
- `wrf_dbz`
- `wrf_eth`
- `wrf_omega`
- `wrf_pvo`
- `wrf_rh`
- `wrf_slp`
- `wrf_uvmet`
- `wrf_td`
- `wrf_tk`
- `wrf_smooth_2d`
- `wrf_helicity`
- `wrf_updraft_helicity`
- `wrf_virtual_temp`
- `wrf_wetbulb`
- `wrf_interp_1d`
- `wrf_interp_2d_xy`
- `wrf_interp_3d_z`
- `wrf_ij_to_ll`
- `wrf_ll_to_ij`
Main WRF-NCL function: `wrf_user_getvar`

`wrf_user_getvar` - Get fields from input file and/or calculate diagnostics

```plaintext
a = addfile("wrfout_d01_2005-08-28_00:00:00.nc","r")

cttmp = wrf_user_getvar(a,"ctt",0) ; 0 \rightarrow first time step

slp = wrf_user_getvar(a,"slp",1) ; 1 \rightarrow second time step

tc = wrf_user_getvar(a,"tc",-1) ; -1 \rightarrow all time steps

hgt = wrf_user_getvar(a,"ter",0) ; terrain, 1st time step
```
### Main WRF-NCL function: `wrf_user_getvar`

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>avo</td>
<td>absolute vorticity [10^-5 s^-1]</td>
</tr>
<tr>
<td>eth</td>
<td>Equivalent Potential Temperature [K]</td>
</tr>
<tr>
<td>cape_2d</td>
<td>Returns 2D fields mcape/mcin/lcl/lfc</td>
</tr>
<tr>
<td>cape_3d</td>
<td>Returns 3D fields cape and cin</td>
</tr>
<tr>
<td>ctt</td>
<td>Cloud Top Temperature [degC]</td>
</tr>
<tr>
<td>dbz</td>
<td>Reflectivity [dBZ]</td>
</tr>
<tr>
<td>mdbz</td>
<td>Maximum reflectivity [dBZ]</td>
</tr>
<tr>
<td>geopt</td>
<td>Full model geopotential [m2 s^-2]</td>
</tr>
<tr>
<td>helicity</td>
<td>Storm Relative Helicity [m^-2/s^-2]</td>
</tr>
<tr>
<td>omg</td>
<td>Omega [C]</td>
</tr>
<tr>
<td>p</td>
<td>Full model pressure [Pa]</td>
</tr>
<tr>
<td>pressure</td>
<td>Full model pressure [hPa]</td>
</tr>
<tr>
<td>pvo</td>
<td>potential vorticity [PVU]</td>
</tr>
<tr>
<td>pw</td>
<td>Precipitable Water</td>
</tr>
<tr>
<td>rh2</td>
<td>2m Relative Humidity [%]</td>
</tr>
<tr>
<td>rh</td>
<td>Relative Humidity [%]</td>
</tr>
<tr>
<td>slp</td>
<td>Sea level pressure [hPa]</td>
</tr>
<tr>
<td>ter</td>
<td>Model terrain height [m]</td>
</tr>
<tr>
<td>td2</td>
<td>2m dew point temperature [C]</td>
</tr>
<tr>
<td>td</td>
<td>Dew point temperature [C]</td>
</tr>
<tr>
<td>tc</td>
<td>Temperature [C]</td>
</tr>
<tr>
<td>theta</td>
<td>Potential temperature [K]</td>
</tr>
<tr>
<td>tk</td>
<td>Temperature [K]</td>
</tr>
<tr>
<td>tv</td>
<td>Virtual temperature [K]</td>
</tr>
<tr>
<td>twb</td>
<td>Wet bulb temperature [K]</td>
</tr>
<tr>
<td>updraft_helicity</td>
<td>Updraft helicity [m^-2/s^-2]</td>
</tr>
<tr>
<td>ua</td>
<td>U component of wind on mass points</td>
</tr>
<tr>
<td>va</td>
<td>V component of wind on mass points</td>
</tr>
<tr>
<td>wa</td>
<td>W component of wind on mass points</td>
</tr>
<tr>
<td>uvmet10</td>
<td>10m U and V components of wind rotated to earth coordinates</td>
</tr>
<tr>
<td>uvmet</td>
<td>U and V components of wind rotated to earth coordinates</td>
</tr>
<tr>
<td>z / height</td>
<td>Full model height [m]</td>
</tr>
</tbody>
</table>
Demo: wrf_user_getvar

Using `wrf_user_getvar` to read data and / or calculate diagnostics

- `wrf_demo_getvar_simple.ncl`
- `wrf_demo_getvar_all.ncl`
- `wrf_demo_getvar_clo.ncl`
Run NCL script with "-n" option to turn off "(0)" output.

**TIP**
```ncl
ncl -n wrf-demo-getvar-simple.ncl
```

Use "-Q" to turn off version and copyright

**TIP**
```ncl
ncl -n -Q wrf-demo-getvar-all.ncl
```
Can set NCL variables when you run a script:

```
ncl 'd="slp"' wrf_demo_getvar_clo.ncl
```

```python
f = addfile("wrfout_d01_2008-09-29_16:30:00","r")

var = wrf_user_getvar(f,d,0)

printVarSummary(var)
printMinMax(var,0)
```
```ncl
; --- Open WRF output file
f = addfile("wrfout_d01_2008-09-29_16:30:00","r")

; --- Read HGT variable
hgt = wrf_user_getvar(f,"HGT",0) ; read first time step

printVarSummary(hgt) ; summary of variable, no values!
printMinMax(hgt,0) ; min/max of variable
print(hgt) ; prints EVERYTHING, can be too much

; --- Calculate sea level pressure at all time steps
slp = wrf_user_getvar(f,"slp",-1) ; [Time | 1] x [south_north | 197] x [west_east | 206]
printVarSummary(slp)
printMinMax(slp,0)

; --- Calculate u and v on mass points; put on same grid
u = wrf_user_getvar(f,"ua",0)
v = wrf_user_getvar(f,"va",0)

printVarSummary(u) ; [bottom_top | 32] x [south_north | 197] x [west_east | 206]
printVarSummary(v) ; the same size as "u"
```
Three ways to plot WRF-ARW data

• WRF-specific functions
  – wrf_contour
  – wrf_vector
  – wrf_map_overlays / wrf_overlays

• gsn_csm functions (native and non-native map)
  – gsn_csm_contour_map
  – gsn_csm_vector_map
Demo: plotting “HGT” variable

Using WRF-NCL functions to create plots

wrf_demo_plot_hgt.ncl

wrf_demo_plot_hgt_custom.ncl
wrf_demo_plot_hgt.ncl

; This load no longer needed in NCL V6.4.0
; load "${NCARG_ROOT}/lib/ncarg/nclscripts/wrf/WRFUserARW.ncl"

;--- Open file and read a variable
f = addfile("wrfout_d01_2005-08-28_00:00:00","r")
hgt = wrf_user_getvar(f,"HGT",0)

printVarSummary(hgt) ; LOOK AT YOUR DATA!
printMinMax(hgt,0)

;--- Where to send the graphics
wks = gsn_open_wks("x11","wrf_demo_plot_hgt") ;"png","pdf","svg"

;--- Set one plotting resource
res = True
res@cnFillOn = True ; Turn on color fill

;--- Create a contour plot
contour = wrf_contour(f,wks,hgt,res)

;--- Draw the contours over a map
plot = wrf_map_overlays(f,wks,contour,False,False)
OUTPUT FROM WRF V3.7 MODEL
WE = 51 ; SN = 74 ; Levels = 30 ; Dis = 30km ; Phys Opt = 3 ; PBL Opt = 1 ; Cu Opt = 1
Open file and read a variable

```ncl
f = addfile("wrfout_d01_2005-08-28_00:00:00","r")
hgt = wrf_user_getvar(f,"HGT",0)
```

Where to send the graphics

```ncl
wks = gsn_open_wks("x11","wrf_demo_plot_hgt")
```

Set one plotting resource

```ncl
res = True
res@cnFillOn = True       ; Turn on color fill
contour = wrf_contour(f,wks,hgt,res)
```

Draw the contours over a map

```ncl
mpres = True
mpres@mpGeophysicalLineThicknessF = 2.0        ; WRF–NCL uses 0.5
mpres@mpGeophysicalLineColor = "black" ; and "gray"
```

```ncl
plot = wrf_map_overlays(f,wks,contour,False,mpres)
```
Demo: overlaying multiple plots

Creating multiple overlays

wrf_demo_plot_overlays.ncl
wrf_demo_plot_overlays.ncl

```ncl
f = addfile("wrfout_d01_2005-08-28_00:00:00","r")

;--- Open a file and get several diagnostics
slp = wrf_user_getvar(f, "slp", 0)
t2  = wrf_user_getvar(f, "T2", 0)
u10 = wrf_user_getvar(f, "U10", 0)
v10 = wrf_user_getvar(f, "V10", 0)

wks = gsn_open_wks("x11","wrf_demo_plot_overlays")

;--- Line contours
os   = True
os@cnLineColor   = "NavyBlue"
os@cnLineThicknessF = 2.0
plt_slp = wrf_contour(f,wks,slp,os)

;--- Filled contours
ot   = True
ot@cnFillOn   = True
plt_tc = wrf_contour(f,wks,t2,ot)

;--- Vectors
ov   = True
ov@NumVectors = 47
plt_vec = wrf_vector(f,wks,u10,v10,ov)

;--- Overlay vectors, line contours, and filled contours on a map
plot = wrf_map_overlays(f,wks,(/plt_tc,plt_slp,plt_vec/),False,False)
```
TEMP at 2 M (K)
Sea Level Pressure (hPa)
U at 10 M (m s⁻¹)

Sea Level Pressure Contours: 984 to 1014 by 2

TEMP at 2 M (K)

290 292 294 296 298 300 302 304 306 308 310

OUTPUT FROM WRF V3.7 MODEL
WE = 91 ; SN = 74 ; Levels = 30 ; Dis = 30km ; Phys Opt = 3 ; PBL Opt = 1 ; Cu Opt = 1
Where to find WRF-NCL scripts

NCL Examples Page:
http://www.ncl.ucar.edu/Applications/

WRF-NCL Examples Page:
http://www.ncl.ucar.edu/Applications/wrf.shtml

Scripts and full-sized images available.

Google “WRF ARW NCL”

**Basic Plots**
- Basic Plot Setup (This series of examples takes users through some basic steps in generating plotting scripts.)
  - Get and plot a single field
  - Multiple input files

**Basic Surface Plots**
- Surface 1
- Surface 2
- Surface 3

**Plots on Model Levels**
- Clouds
  - Levels from wrfout files
  - Levels from metgrid files

**Plots on Interpolated Levels**
- Height Levels
- Pressure Levels

**Plotting Precipitation**
- Precipitation

**Diagnostics**
- CAPE
- dBZ
- Vorticity
  - (More diagnostics are available, shown are only some newer/special diagnostics)

**Cross-section Plots**
- Height - Through a Pivot Point
- Height - Point A to Point B
- Pressure
- Limited Vertical Extent
  - For 3D fields

**Speciality Plots**
- Overlay
- Zoom
- Overlay & Zoom
  - Panel 1
  - Panel 2
- Meteograms
- WRF Time Series data
  - All fields in a file

**Preview Domain**
- This functionality, although available in NCL version 5.0.1, is still experimental.
  - Preview

**Global WRF**
- qWRF_merc

**Idealized cases**
- wrf_Cray2x
- wrf_HL82d
- wrf_Squall_2d_x
- wrf_Squall_2d_y
- wrf_Shearstress2x
- wrf_RWave
- wrf_QSS
Visualizing WRF with gsn_csm_xxx scripts

Why?

• More control for customizing plots
• Don't want all those titles
• Plot WRF data on different map projection than what's on WRF file
• Can plot subset of data easier
• Need to compare with plots of non WRF data
To plot data in *NATIVE* WRF map projection defined on file:

1. Call “wrf_map_resources” to set up map resources
2. Set `tfDoNDCOverlay` resource to True
3. Set `gsnAddCyclic` resource to False
4. Call one of the `gsn_csm_xxx_map` functions:
   - `gsn_csm_contour_map`
   - `gsn_csm_vector_map`
   - `gsn_csm_streamline_map`
Demo: plotting WRF using gsn_csm functions

GSN scripts with different levels of customization

wrf_demo_plot_tc_gsn.ncl
wrf_demo_plot_tc_gsn_minor_custom.ncl
wrf_demo_plot_tc_gsn_major_custom.ncl

Original WRF-NCL script (for comparison)

wrf_demo_plot_tc.ncl
gsn_csm_script – native projection

```python
a = addfile("wrfout_d01_2005-08-28_00:00:00","r")
tc = wrf_user_getvar(a,"tc",0)

wks = gsn_open_wks("x11","wrf_demo_plot_tc_gsn")

;---Required to properly set up WRF map projection
res = wrf_map_resources(a,True)
res@tfDoNDCOOverlay = True
res@gsnAddCyclic = False
res@cnFillOn = True
res@cnLinesOn = False

plot = gsn_csm_contour_map(wks,tc(0,:,:,:),res)
```
a = addfile("wrfout_d01_2005-08-28_00:00:00","r")
tc = wrf_user_getvar(a,"tc",0) ; Temperature (C)

wks = gsn_open_wks("x11","wrf_demo_plot_tc")

res = True
res@cnFillOn = True

contour = wrf_contour(a,wks,tc(0,:,:,:),res)
plot = wrf_map_overlays(a,wks,contour,False,False)
WRF-NCL script

Init: 2005-08-28 00:00:00

OUTPUT FROM WRF V3.7 MODEL
WE = 91 ; SN = 74 ; Levels = 30 ; Dif = 30km ; Phys Opt = 3 ; PBL Opt = 1 ; Cu Opt = 1
Visualizing WRF with gsn_csm_xxx scripts

To plot data in \textit{NON-NATIVE} map projection:

1. Set special "\texttt{lat2d}" / "\texttt{lon2d}" attributes
2. Set options for the map projection you want
3. Set \texttt{gsnAddCyclic} resource to False
4. Call one of the \texttt{gsn_csm_xxx_map} functions:
   
   – \texttt{gsn_csm_contour_map}
   
   – \texttt{gsn_csm_vector_map}
   
   – \texttt{gsn_csm_streamline_map}
gsn_csm script – non-native projection

```python
a = addfile("wrfout_d01_2005-08-28_00:00:00","r")
tc = wrf_user_getvar(a,"tc",0)

;---Required for using different map projection
tc@lat2d = wrf_user_getvar(a,"lat",0)
tc@lon2d = wrf_user_getvar(a,"lon",0)

wks = gsn_open_wks("x11","wrf_demo_plot_tc_gsn_nn")

res@mpMinLatF = min(tc@lat2d)-5 ; Select area of
res@mpMaxLatF = max(tc@lat2d)+5 ; map to view.
res@mpMinLonF = min(tc@lon2d)-5
res@mpMaxLonF = max(tc@lon2d)+5
res@mpOutlineBoundarySets = "National"

res@gsnAddCyclic = False
res@cnFillOn = True
res@cnLinesOn = False

plot = gsn_csm_contour_map(wks,tc(0,:,:,:),res)
```
Major customization – Satellite map projection

wrfout_d01_2005-08-28_00:00:00

Temperature degC

Color scale:
- 37
- 36
- 35
- 34
- 33
- 32
- 31
- 30
- 29
- 28
- 27
- 26
- 25
- 24
- 23
- 22
- 21
- 20
- 19
- 18
- 17
- 16
- 15
- 14
NCL has support for shapefiles, allowing you to use the numerous free shapefiles for adding your own map outlines.
Global Administrative Areas database ([http://www.gadm.org](http://www.gadm.org)) offers consistent administrative boundaries at many levels. The level 0 database (nations) is good to use for global or mesoscale results, level 1 is the first level of sub-national administration (typically states/provinces and territories) while level 2 offers the second level of administration and is potentially useful for high-resolution plots.
China shapefiles from gadm.org/country

CHN_adm0.shp

CHN_adm1.shp

CHN_adm2.shp

CHN_adm3.shp
Demo: adding shapefile outlines

Shapefiles downloaded from

http://www.gadm.org/country/

wrf_demo_plot_tc_shapefiles.ncl
wrf_demo_plot_tc_gsn_shapefiles.ncl
```ncl
f = addfile("wrfout_d01_2008-09-29_16:30:00","r")
tc = wrf_user_getvar(f,"tc",0)

wks = gsn_open_wks("x11","wrf_demo_plot_tc_shapefiles")

res = True
res@cnFillOn = True ; Turn on color fill
contour = wrf_contour(f,wks,tc(0,:,,:),res)

;--- Create contours over a map (nothing is drawn because PanelPlot is True)
pltres = True
pltres@PanelPlot = True ; Tells wrf_map_overlays to not draw plot
pltres@NoTitles = True ; Turn off titles
plot = wrf_map_overlays(f,wks,contour,pltres,False)

;--- Add shapefile outlines
lnres = True
lnres@gsLineColor = "Gray25"
lnres@gsLineThicknessF = 3. ; default is a little thin
usa_id = gsn_add_shapefile_polylines (wks,plot,"USA_adm/USA_adm0.shp",lnres)
mex_id = gsn_add_shapefile_polylines (wks,plot,"MEX_adm/MEX_adm1.shp",lnres)
cub_id = gsn_add_shapefile_polylines (wks,plot,"CUB_adm_shp/CUB_adm2.shp",lnres)

draw(plot) ; Now draw the plot
frame(wks) ; and advance the frame
```
USA, Mexico, Cuba shapefile outlines added

wrfout_d01_2005-08-28_00:00:00
Init: 2005-08-28_00:00:00

Temperature (°C)

Temperature

OUTPUT FROM WRF V3.7 MODEL
WE = 91 ; SN = 74 ; Levels = 30 ; Dist = 30 km ; Phys Opt = 3 ; PBL Opt = 1 ; Cu Opt = 1
Demo: masking against shapefile outlines

load "./shapefile_utils.ncl"
tc = wrf_user_getvar(f,"tc",0)
tc@lat2d = wrf_user_getvar(f,"lat",0) ; Needed for masking
tc@lon2d = wrf_user_getvar(f,"lon",0)

;--- Mask one level of tc against country outline of Cuba
nl = 3 ; level index
tc_mask = shapefile_mask_data(tc(nl,:,:),"CUB_adm0.shp", True)
NCL debugging tips

- Start with an existing script, if possible
- Use editor enhancements for coloring of syntax, functions, etc
- Use indentation (even though not needed)
- Use `printVarSummary`, `printMinMax`, `print` to examine variables
- Carefully read documentation for functions
- Read errors and warnings carefully 😊
Tips for graphics

• Make sure spelling the resource name correctly

• For nice-looking graphics:
  – Increase line thicknesses
  – Use color wisely
  – Use "SVG" format for web
  – For presentations: increase resolution of PNG images (use "convert -trim " to trim the images)

```plaintext
wtype = "png"
wtype@wkWidth = 2500
wtype@wkHeight = 2500
wks = gsn_open_wks(wtype,"myplot")
```
Tips for new and advanced users

• Read the NCL User Guide

• Visit the NCL Examples page

• Join the ncl-talk email list

• Install a UNIX editor enhancement for NCL
Thank you!

http://www.ncl.ucar.edu/Training/Tutorials/WRF_Users_Workshop/