# Documentation on Initializing WRF-NMM with WRF- Var

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**Introduction:**

The Weather Research and Forecasting (WRF) Variational (WRF-Var) Data Assimilation System developed at NCAR is mainly devoted for providing initial condition to NCAR's WRF-ARW version of WRF. The latest WRF-Var Version3.0 release has the capability to assimilate all the conventional, radar (refractivity & radial velocity), GPS (refractivity & Total Zenith delay) data. For details about WRF-Var, please refer to http://www.wrf-model.org/development/group/WG4 . Parallel with WRF-Var, the Grid Statistical Interpolation (GSI) scheme developed at National Center for Environmental Prediction (NCEP) serves the need of providing initial condition to Non-hydrostatic Mesoscale Model (NMM) version of WRF (WRF-NMM). For details about GSI, please refer to http://www.emc.ncep.noaa.gov/gmb/treadon/gsi . Both the analysis schemes, WRF-Var and GSI have its own advantages and disadvantages.

It was decided to develop a utility, to integrate WRF-Var with WRF-NMM in the sense that WRF-Var should be able to accept WRF-NMM forecast as its first guess (FG) and after analysis the updated FG is acceptable to WRF-NMM. This document describes, basic strategy followed to achieve this target. It also helps any new user to use this utility. This utility was successfully tested on "Indian Domain". The geographical location and configuration about this domain is given in Figure --- and Table. --- respectively. Some results about this domain are also documented with this manuscript.

Currently WRF-Var does analysis on non-staggered Arakawa-A grid (shown in Fig.---). Main input from WRF-ARW model to WRF-Var, are, the wind (U & V) components, perturbations of potential temperature, surface pressure, height, mixing ratio on staggered Arakawa-C grid (shown in Fig. ) at sigma levels. The perturbation variables here are defined as deviations from a time invariant hydrostatically balanced reference state in the usual sense of WRF-ARW. The vertical co-ordinates are defined in terms of terrain following hydrostatic pressure vertical co-ordinate ($\eta$) as follows:

$$\eta = (p_h - p_{ht}) / \mu \quad \text{where} \quad \mu = p_{hs} - p_{ht}$$

Where, $p_h$ is the hydrostatic component of the pressure, and $p_{hs}$ and $p_{ht}$ refer to the values along the surface and top boundaries, respectively.

Analysis control variables for WRF-Var are stream function ($\psi$ ), unbalanced (in statistical sense) part of velocity potential ($\chi$), temperature (T), surface pressure (Psfc) and the moisture (pseudo relative humidity).

In order to build up the strategy to input WRF-NMM field in WRF-Var, it is very essential to survey what type, and at what gird the WRF-NMM fields are available. WRF-NMM has been build up with Arakawa E-grid staggering with rotated lat-lon projection. In rotated lat-lon projection, the rotation of the natural, geodesic latitude longitude has been done in such a way that, the intersection of the equator and prime meridian intersects at the center of the computational domain. This rotated framework provides more uniform horizontal grid spacing and reduces the convergence of the meridians over the domain. The transformation equations can be described as follows:

$$
\begin{aligned}
\Lambda &= arctg \frac{\cos\varphi \sin(\lambda - \lambda_0)}{\cos\varphi_0 \cos\varphi \cos(\lambda - \lambda_0) + \sin\varphi_0 \sin\varphi} \\
\Phi &= \arcsin(\cos\varphi_0 \sin\varphi - \sin\varphi_0 \cos\varphi \cos(\lambda - \lambda_0))
\end{aligned}
$$

where,

$$
\begin{aligned}
\varphi &= \arcsin(\sin\varphi_0 \cos\Phi \cos\Lambda + \cos\varphi_0 \sin\Phi) \\
\lambda &= \lambda_0 + \arcsin(\frac{\sin\Lambda \cos\Phi}{\cos\varphi_0})
\end{aligned}
$$

As described above, currently WRF-Var does the analysis on staggered Arakawa A-grid with a minimum requirement of above stated fields. But, WRF-NMM is designed in staggered Arakawa E-grid in which, there is some deviations like sensible temperature (T), specific humidity (Q), geopotential height (FIS) found in the output variable list. Again, there is no map factor concept available in WRF-NMM, as it does not require for rotated lat-lon projection. As WRF-NMM deals with the pressure-sigma hybrid vertical co-ordinate, so there is a concept of sigma value in pressure domain (ETA1, $0<eta_1<1$, $eta_2=0$) and sigma value in sigma domain (ETA2, $0<eta_2<1$, $eta_1=1$) (shown in fig ---) is available. So, in order to provide appropriate variables to WRF-Var with suitable grid structure, a utility has been written to convert certain fields in desired format.

TBD-------
Explain WRF-NMM vertiocal co-ordinates

**Development Strategy:**

After carefully examining basic WRF-Var framework and WRF-NMM output fields, this work was visualized to be achieved in four stages.

a) Preparing desired WRF-NMM fields as initial FG input to WRF-Var
b) Updating WRF-Var
c) Updating desired WRF-NMM field with WRF-Var analysis increments
d) Generation of background error for WRF-NMM suited to WRF-Var

Here it may be noted that item (d) is domain specific and so needs to be repeated every time a new domain is tried. Details about these stages are discussed below.

**a) Preparing desired WRF-NMM fields as initial FG input to WRF-Var:**

Keeping in view that basic WRF-Var framework is mainly devoted to WRF-ARW, it was decided to perform this job outside WRF-Var. Accordingly, a utility named, “E2C” is written which mainly does the grid conversion (from Arakawa-E to Arakawa-C grid) of the desired WRF-NMM fields. It was essential because currently WRF-ARW & WRF-Var share common registry and so without changing registry it was not possible to read WRF-NMM output file. With this procedure, all the WRF API/O, especially the MPI features may be utilized as such without changing WRF “Registry”. All WRF-NMM variables sharing same name (with similar meaning) as in WRF-ARW, like wind component (U & V) etc. are packed by “E2C” converter as such. For WRF-NMM specific variables like, mass of the pressure regime (PDTOP), sigma values for sigma regime (ETT1), sigma values for pressure regime (ETA2 ) etc., a parallel suitable array (which currently WRF-Var do not use) is identified in WRF-ARW list of variables to pack these variables. A complete list of WRF-NMM variables packed by “E2C” converter with details against which WRF-ARW name it is packed, units etc. is described in Appendix…..

**b) Updating WRF-Var:**

Since the beginning of WRF-Var development, it has been a policy to maintain a single version (unified) of WRF-Var code. Keeping this in view, following new variables (along with its assigned values) have been added in WRF-Var for branching the code logic if it is aimed to run with WRF-NMM FG input.

```
FG_FORMAT_WRF_ARW_REGIOANL  = 1
FG_FORMAT_WRF_NMM_REGIOANL = 2
FG_FORMAT_WRF_ARW_GLOBAL     = 3
FG_FORMAT_KMA_GLOBAL              = 4
```

These names are self explanatory. WRF-Var code reads it against “FG_FORMAT”, which is one of its “namelist” variables. Thus, depending upon the value of “FG_FORMAT”, WRF-Var does branching for operations like locating observation co-ordinate, forward & adjoint operations etc. WRF-NMM specific “rotated lat-lon” projection has been included in WRF-Var as a separate routine. For maintaining consistency with the original WRF-Var code, following new subroutines have also been introduced.

*da_setup_firstguess_wrf_nmm_regional*
*da_transfer_wrf_nmm_regional_to_xb*
*da_transfer_xatowrf_nmm_regional*
*da_write_increments_for_wrf_nmm_regional*
*da_llxy_rotated_latlon*

Main function of these subroutines are described in Appendix-B

Updated WRF-Var has passed all the transform tests collectively and individually including the “adjoint”. It has also been tested to ensure that it gives same results (compared to the original code) when it is run with WRF-ARW FG input. It is also verified that serial, single and multiple CPU runs should produce same results.

**c) Updating desired WRF-NMM field with WRF-Var analysis increments:**

Currently when WRF-Var is run with WRF-ARW (regional or global) FG, updated FG is directly written in “analysis” file. We have to deviate from this practice when FG input is from WRF-NMM. This is because in this case the FG is not the original WRF-NMM output but an intermediate file created in step a) as mentioned above. It holds only the desired input fields for WRF-Var only and not all the WRF-NMM fields. To overcome this problem it was decided to write (currently in binary format) the analysis increments in a separate file. A separate utility, named “A2E” , is written to read WRF-Var analysis increments and update the original WRF-NMM fields. This utility needs to be run outside WRF-Var. This is a very simple procedure and it reduces the interpolation error (from Arakawa-A to Arakawa-E grid) as this operation is done only on increments and not on the full WRF-NMM fields.

Here it may be noted that this procedure is consistent with the existing WRF-Var logic when it is run with FG from Korean Meteorological Administration (KMA) global model, which is currently different than WRF-ARW.

**e) Generation of background error for WRF-NMM suited to WRF-Var:**

To achieve this, “gen_be” utility of WRF-Var has been updated to accept WRF-NMM output. Currently there are basically five stages to run “gen_be”. For more details about “gen_be” please refer to WRF-Var online documentation (web reference for my talk --------). To accommodate WRF-NMM input to “gen_be”, it is only the “gen_be_stage0” needs updating. Accordingly, the main source code dealing with “gen_be_stage0” namely, “gen_be_stage0_wrf.f90” have been modified. To run this utility with “WRF-NMM” case, one needs to run “E2C” converter on WRF-NMM forecasts and this goes as input to “gen_be_stage0” program. To keep track whether it is WRF-ARW or WRF-NMM, a new ASCII variable named “WRF_OPTION” has been introduced which currently, can accept any of the following three values.

WRF_OPTION = “ARW_GLOABL” or,
= “ARW_REGIONAL” or,
= “NMM_REGIONAL”

Thus depending on user’s “WRF_OPTION” choice, which is self explanatory, the “gen_be_stage0” runs accordingly. The “WRF_OPTION” needs to be specified at run time (via “gen_be” wrapper script). After update, “gen_be_stage0” has been tested independently and also collectively with all other stages.

The updated code was run (with “NMC_Method” option for “Indian domain” with WRF-NMM one month (----, 2007) forecasts input (both 00 & 12 UT) to produce the desired WRF-NMM background error statistics for updated WRF-Var. Fig. ----- (first five leading eigen vectors), Fig. ---- (Eigen values), Fig. ----- (scalelength) show. Regression coefficients (-----).

**An end-to-end testing of the code:**

## *Appendix-A:*

List of WRF-NMM variables packed by “E2C” converter utility to be used by WRF-Var & its “gen_be” utility.

| WRF-NMM | WRF-Var Variable (desired) | Dimension | staggering | Units | Description | Remarks |
|---|---|---|---|---|---|---|
| U | U | 3D | X | $ms^{-1}$ | X-wind component | |
| V | V | 3D | Y | $ms^{-1}$ | Y-wind component | |
| W | W | 3D | Z | $ms^{-1}$ | Vertical velocity | TBD |
| U10 | U10 | 2D | - | $ms^{-1}$ | 10m X-wind component | TBD |
| V10 | V10 | 2D | - | $ms^{-1}$ | 10m Y-wind component | TBD |
| T2 | T2 | 2D | - | K | 2m Temperature | TBD |
| QS | Q2 | 2D | - | Kg/Kg | 2m Specific Humidity | TBD |
| T(Sensible) | T | 3D | - | K | Dry temperature | |
| Q | QVAPOR | 3D | - | Kg/Kg | Specific humidity | |
| - | QCLOUD | 3D | - | - | Cloud Water mixing ratio | TBD |
| - | QRAIN | 3D | - | - | Rain water mixing ratio | TBD |
| - | QICE | 3D | | - | Ice mixing ratio | TBD |
| - | QSNOW | 3D | - | - | Snow mixing ratio | NAP |
| - | QGRAUP | 3D | - | - | Graupel mixing ratio | NAP |
| PD | PSFC | 2D | - | Pa | Mass in sigma domain | |
| PDTOP | MU | 2D | - | Pa | Mass in pressure domain | In NMM, PDTOP is a single value, but we pack as 2D array |
| ETA1 | ZNW | 1D | Z | - | Sigma in pressure domain (Higher) | |
| ETA2 | ZNU | 1D | Z | - | Sigma in sigma domain (Lower) | |
| PT | P_TOP | Single value | - | Pa | Model top pressure | |
| - | MAPFAC_MX | 2D | - | - | Map scale factor on mass grid in X-direction | Calculated in converter program |
| DX_NMM | MU0 | 2D | - | m | East-West Distance | |

| | | | | | | |
|---|---|---|---|---|---|---|
| DX | DX | Single value | - | m | East-West Distance | Changed in the global attribute |
| DY | DY | Single value | - | m | North-South Distance | "do" |
| DX | CF1 | Single value | - | degree | East-West Distance | |
| DY | CF2 | Single value | - | degree | North-South Distance | |
| - | HGT | 2D | - | m | Terrain height at mass | Calculated from surface geopotential |
| Times | Times | Character variable | - | - | Forecast valid time | |
| TSK | TSK | 2D | - | K | Skin temperature | TBD |
| SST | SST | | - | K | Sea surface temperature | TBD |
| F | F | 2D | - | $m^{-1}$ | Coriolis sine term | TBD |
| SOILTB | TMN | 2D | - | K | Soil temperature | TBD |
| GLAT | XLAT | 2D | - | Degree North | Latitude at mass points | -90 to +90 |
| GLON | XLONG | 2D | - | Degree East | Longitude at mass points | -180 to +180 |
| ACSNOW | SNOWC | 2D | - | | Flag indicating snow coverage | 1 for snow cover (TBD) |
| LU_INDEX | LU_INDEX | 2D | - | - | Land use category | (TBD) |
| LANDMASK | LANDMASK | 2D | | | Land mask | 1 for Land<br>0 for Water (TBD) |
| - | XLAND | 2D | - | - | Land mask | 1 for land<br>2 for Water (TBD) |
| SMC | SMOIS | 3D | Z | $m^3m^{-3}$ | Soil moisture | Levels below ground (TBD) |
| STC | TSLB | 3D | Z | K | Soil Temperature | Levels below ground (TBD) |
| SEAICE | SEAICE | 2D | - | - | Sea Ice Flag | (TBD) |
| IVGTYP | IVGTYP | 2D | - | - | Vegetation Category | (TBD) |
| ISLTYP | ISLTYP | 2D | - | - | Dominant Soil Category | (TBD) |
| VEGFRA | VEGFRA | 2D | - | - | Vegetation Fraction | (TBD) |
| SNOWH | SNOWH | 2D | - | m | Snow Depth | (TBD) |
| | | | | | | |

## *Appendix-B:*

**da_setup_firstguess_wrf_nmm_regional:**
It sets up analysis first guess (FG) for WRF-Var with WRF-NMM forecasts.

**da_transfer_wrf_nmm_regional_to_xb:**

It transfers relevant WRF-NMM fields, packed by “E2C” converter utility in Xb-array.

**da_transfer_xatowrf_nmm_regional:**

Converts analysis increments to WRF-NMM increments to be written.

**da_write_increments_for_wrf_nmm_regional:**

It writes analysis increments (in binary format) for the desired WRF-NMM variables which needs to be updated.

**da_llxy_rotated_latlon:**

It incorporates rotated lat/lon map projection in WRF-Var.