# Merging GFDL and GFS analyses for MM5 Initialization of Hurricanes

Robert E. Hart
Florida State University Department of Meteorology, Tallahassee, Florida, rhart@fsu.edu

## 1. INTRODUCTION

As the sophistication of global models has increased, their role in hurricane track forecasting has received increasing prominence. The vast majority of these global models use data assimilation techniques that do not result in a sufficiently realistic intensity or structure of hurricanes at analysis time, even when reasonably high resolution grids are used. Since it has been established that hurricane motion and intensity/structure are intimately related (e.g. Velden and Leslie 1991), this begs the question of how much "potential skill" is not yet being exploited by numerical models given the weak initializations. Until variational techniques can routinely provide fully balanced, realistic, three-dimensional analysis hurricanes (e.g. Xiao et al. 2000) in real-time, some techniques have focused on "vortex specification", such as GFDL (Kurihara et al. 1993). While similar approaches exist for MM5 (Low-Nam and Davis 2001; Wang and Frank 2000), the stability of the specified synthetic vortex in certain environments is questionable based upon experience. To alleviate this problem, one can make use of the success of the GFDL initialization output through merger of its vortex with the environment specified by a global model (e.g. GFS). During 2007 (and continuing into 2008), this process was used to examine the impact such a merger has on MM5 TC track and intensity forecasts.

## 2. METHODOLOGY

The GFDL grid is small compared to the coarse MM5 grid (Figure 1). As a result, MM5 cannot simply be initialized with the GFDL initial conditions since it would lead to holes where there was not coverage by the GFDL domain. Thus, these gaps have to be filled in with another model analysis. However, it is naturally of paramount importance that the merger process does not lead to spatial discontinuities in the MM5 initialization. Fortunately, the GFDL initialization scheme uses the GFS analysis as the environment into which the synthetic vortex is placed. This enables us to use the GFS analysis to fill in those gaps without creating discontinuities. While this solves one of the major technical issues, there does remain the major question of what to do in the event of multiple storms – given the GFDL analysis performs the highest resolution synthetic vortex insertion for only one TC per run.

A simple and effective solution to this problem is to simply use, for each gridpoint, the column of data that has the lowest MSLP from all available grids. This ensures that for each vortex, the most robust representation is included. The result is a continuous global dataset which includes the most robust representation of each TC for which the GFDL was run. The merger is performed using shell-scripting and GrADS, with the final merged global dataset converted to GRIB1 format using the LATS interface -- for ingest into MM5 PREGRID. The shell script is shown on the left, with the GrADS merger script on the right, attached below the poster. The timeline of execution in real-time using 42cpus for an example run (0000UTC) is shown next:

0300UTC: Process 3hr to 120hr boundary condition files from 1800UTC GFS run
0330UTC: Process 0000UTC GFS analysis and complete MM5 preprocessing
0400UTC: Start 33km basin-scale MM5 with GFS-only initial conditions
0500UTC: 0000UTC GFDL output arrives
0600UTC: Perform merger of all available GFDL analyses with 00UTC GFS analysis
0615UTC: 33km basin-scale GFS-initialized MM5 forecast to 120hr completed
0630UTC: Start 33km basin-scale MM5 with GFDL/GFS merger initial conditions
0830UTC: 33km basin-scale GFDL/GFS initialized MM5 forecast to 120hr completed
0830UTC: Start11km western Atlantic GFDL/GFS-initialized MM5 forecast
1430UTC: 11km western Atlantic GFDL/GFS-initialized MM5 72hr forecast completed

Note that if no GFDL output arrives by 06UTC, the 11km domain will be initialized with the GFS only.

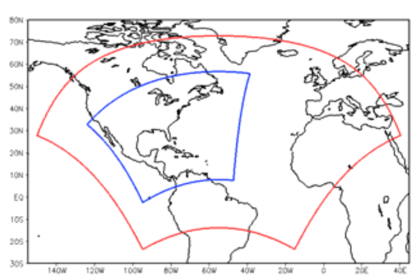


Figure 1: 33km and 11km domains used in the 2008 real-time setup. The 33km is 325x450 gridpoints, and the 11km is 505x604 gridpoints. The 33km produces a forecast for 120hr while the 11km produces a forecast for 72hr. The source of initial conditions for the atmosphere is a merger of all available GFDL analyses at 1/6° resolution with the 1/2° GFS global analysis. SST is fixed and is provided by the 1/12° NCEP RTGSST one-day old global field. Model physics include Kain-Fritsch convection, mix-phase explicit moisture, and Blackadar PBL. Note that the 2007 setup had a 45km and 15km domain (Figures 2-6), while the 2008 setup has the 33km and 11km domains shown above.

## 3. EXAMPLE MERGING

Hurricane Felix (2007) was chosen as an example to demonstrate the success of the merger given the striking underrepresentation in the 1/2° GFS analyses and the stable merger and integration that results when MM5 is initialized with the merged grids. The quality of the representation is a function of the resolution of the MM5 grid, given the source GFDL analyes are of 1/6° resolution. As a result, there is a necessary degree of slight shedding of the vortex structure on the coarse resolution domain. However, for a majority of the runs on the fine resolution domain (15km in 2007 and 11km in 2008), the vast majority of the vortex intensity was retained during the first few hours of integration, as shown below.

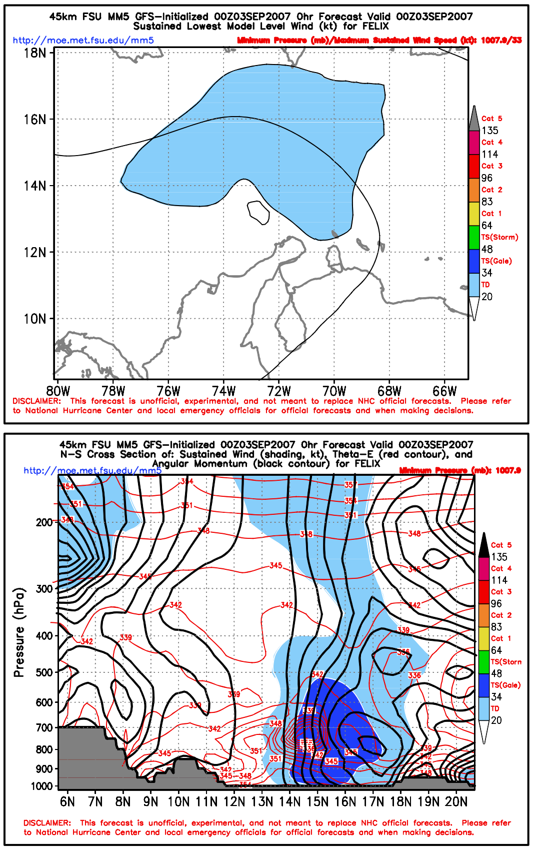



Figure 2: Felix representation in the MM5 coarse domain: 1/2° GFS initialization. Left figure is the surface representation, including MSLP (black contour) and sustained lowest model level wind (shading). The right figure is a meridional cross section through the storm, showing wind speed (shading), $\theta_E$ (red contour) and angular momentum (black contour). Grey shading is terrain.

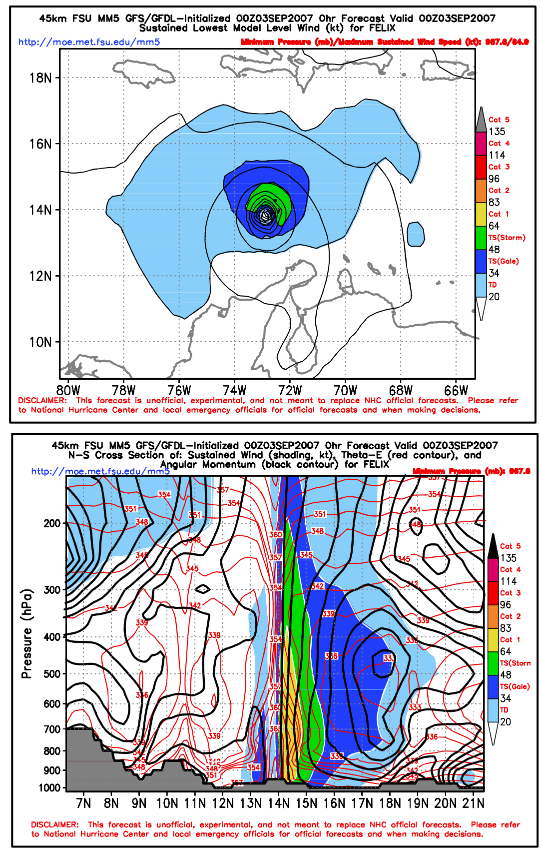



Figure 3: Felix representation in the MM5 coarse domain: 1/6° GFDL/GFS initialization. As in Figure 2, except for the merger of all available GFDL domains with the GFS analysis.

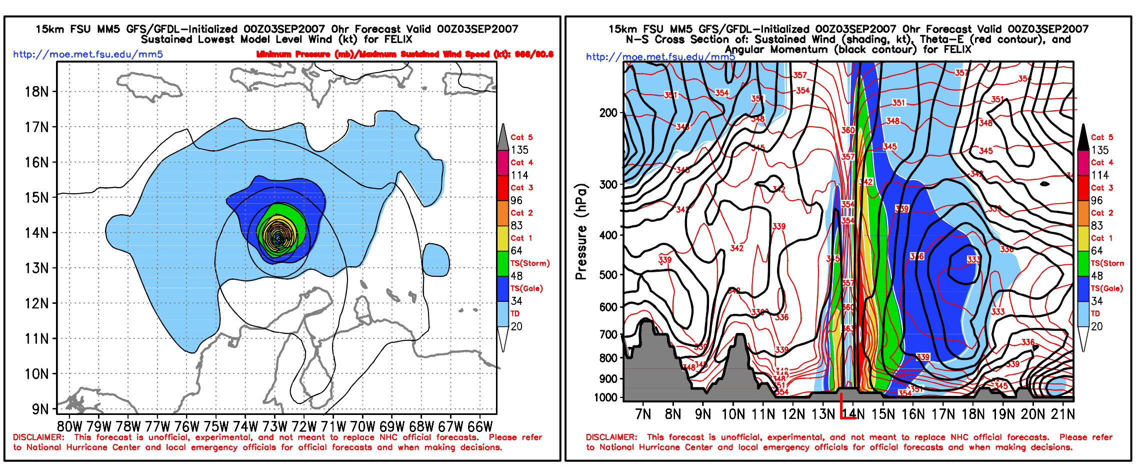



Figure 4: Felix representation in the MM5 fine domain: 1/6° GFDL/GFS initialization. As in Fig. 3, except for the higher resolution domain. Note the increased intensity compared to Fig. 3 despite using the same merged grids for initial.

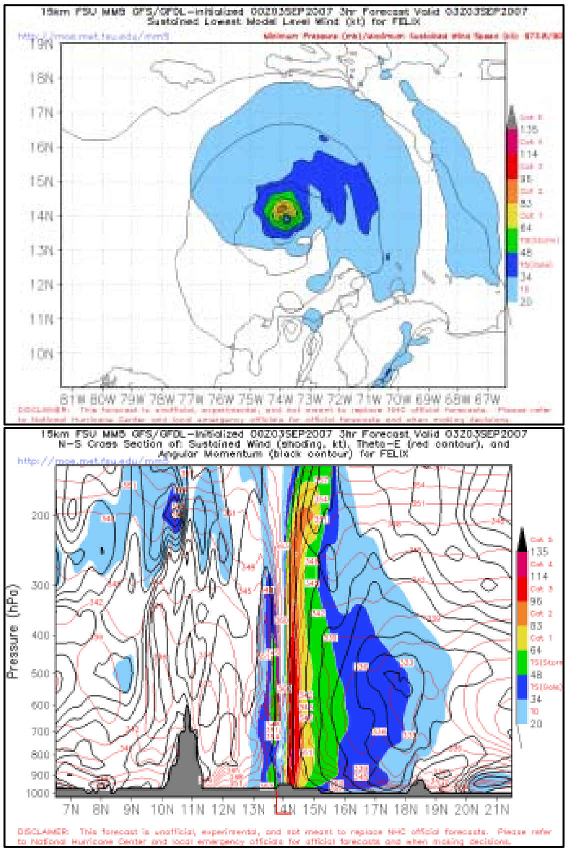
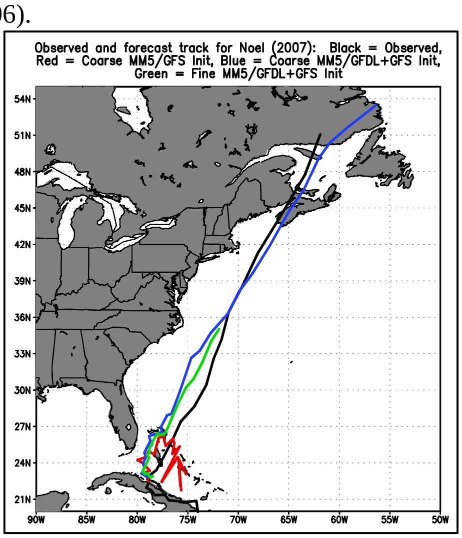



Figure 5: Three hour forecast in MM5 using the initial conditions shown in Fig. 4. Despite the merging, regridding and change in resolution, the initial vortex is surprisingly stable.

## 4. FORECAST IMPACT

The merger process wasn't fully debugged and implemented in real-time until mid-way through the 2007 hurricane season (approximately late August). As a result, there is not yet a full season that can be evaluated for track and intensity forecast impact when using the merged grids to initialize. However, one case is shown here (Noel, 2007) since it represented a case of trough interaction and extratropical transition (ET), and thus the initial conditions are likely to have played a more critical role in the sensitivity of the forecast (Hart et al. 2006).



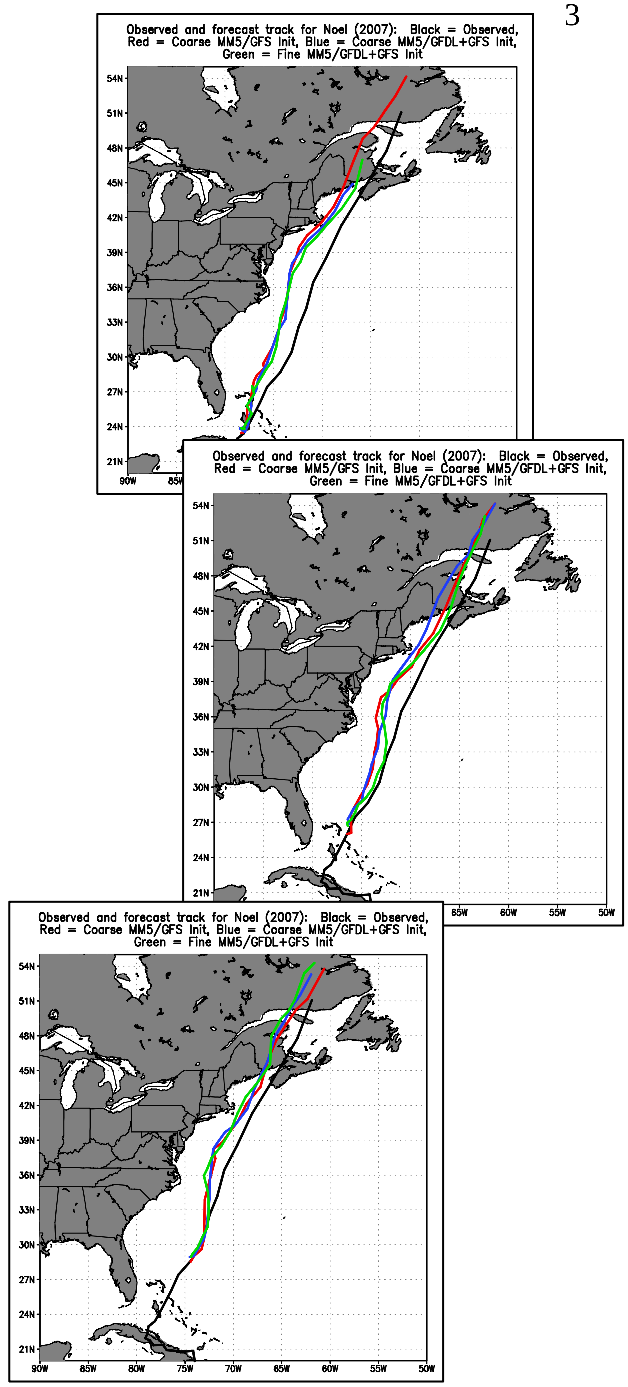




Figure 6: Track forecast comparison for four consecutive MM5 runs for Hurricane Noel (2007). Left: 2007110100 initialization; Top: 2007110112; Middle: 2007110200; Bottom 2007110212. Black line is observed; red line is coarse MM5 initialized with GFS; Blue line is coarse MM5 initialized with GFDL/GFS merger; Green line is fine MM5 initialized with GFDL/GFS merger. Note in the first run that the initialization change can easily determine decay or intensification of the TC (red vs. remainder). Note also that in general the GFDL+GFS merger initialization leads to a decrease in the left bias of the short-term forecast and an overall improved 3-5 day forecast. However, also note that in the last forecast run, when extratropical transition has begun (see Poster P1G.5 in this Conference), there is little benefit from the merged representation. Although many more cases need to be examined, this preliminary result suggests that the GFDL/GFS merger may lose benefit for track & intensity forecast once a baroclinic environment has interacted with the TC.

## 5. SUMMARY

A simple technique was developed to quickly merge GFDL and GFS analyses to provide a global analysis for real-time mesoscale model initialization, with the benefits of high-resolution hurricane structure representation provided by the GFDL. This merger occurs through choosing the atmospheric column in each gridpoint of the various source grids that has the associated lowest MSLP. The merger has been tested for a half season of 2007, with as many as three simultaneous GFDL analyses (one per storm), and the resulting merger with the GFS analysis is nearly devoid of discontinuity given the GFDL itself uses the GFS as the first guess. The resulting integration of MM5 using these merged grids for initialization shows a stable, balanced vortex that sheds little structure. Indeed, at 11km or 15km resolution, the initial vortex often intensifies in the first 3hr. An example of Noel (2007) shows that there is benefit to forecast track (and intensity, not shown) using the merged grids, including reduced short-term left track bias presumably from erroneous beta-gyre structure. Preliminary results suggest that using the highly idealized GFDL-type vortex structure close to ET may impede forecast improvement. This approach will be utilized for a full TC season for the first time in 2008. The overall skill, as compared to GFDL and GFS-initialized MM5, will be presented in a future manuscript.

## 6. ACKNOWLEDGMENTS

The author is indebted to the GrADS authors, including COLA/IGES, Brian Doty, Jennifer Adams, Mike Fiorino, the authors of LATS at NASA GSFC GMAO including Arlindo da Silva and Mike Fiorino, and many others, including Wesley Ebisuzaki, for providing the numerous tools that made this task possible within a few hundred lines of code rather than tens of thousands. This approach benefitted from discussions with Henry Winterbottom, Clark Evans, and Ryan Maue of Florida State University. Please see http://moe.met.fsu.edu/mm5 for the real-time TC forecasts resulting from this approach.

## 7. REFERENCES

Hart, R., J. L. Evans, and C. Evans, 2006: Synoptic composites of the ET lifecycle of North Atlantic TCs: Factors Determining Post-Transition Evolution. *Monthly Weather Review*, 134, 553-578.

Kurihara, Y., M.A. Bender, and R.J. Ross, 1993: An initialization scheme of hurricane models by vortex specification. *Mon .Wea. Rev.,* 121, 2030-2045.

Low-Nam, S. and C. Davis, 2001: Development of a TC bogussing scheme for the MM5 system. Preprint for the 11th PSU/NCAR MM5 User's Workshop, Boulder, CO, 130-134.

Velden, C.S. and L.M. Leslie, 1991: The Basic Relationship between TC Intensity and the Depth of the Environmental Steering Layer in the Australian Region. *Weather and Forecasting*., 6, 244-253.

Wang, H. and W.M. Frank, 2000: An initialization scheme for a hurricane prediction system. Preprint for the 24th Conference on Hurricanes and Tropical Meteorology. American Meteorological Society.

Xiao, Q., X. Zou, B. Wang, 2000: Initialization and Simulation of a Landfalling Hurricane Using a Variational Bogus Data Assimilation Scheme. *Monthly Weather Review*, 128, 2252-2269.

## 8. APPENDICES

### a. DoMerge.csh c-shell script

```
#!/bin/csh

# Script to merge all available gfdl 1/6deg GRIB files with the corresponding
# 1/2 degree global GFS GRIB file
# Bob Hart
# Last modified 26 August 2007

cd /otto/r0/rhart/mm5/MERGE

set mm5dir = "/otto/r0/rhart/mm5/"

set run = `cat ${mm5dir}/realtime/run`
set yymmdd = `echo $run | cut -c3-8`
set hr = `echo $run | cut -c9-10`

set gfdlfiles = `ls /moe/GRIB/${yymmdd}/*${run}*grib6th*f00`
if ($#gfdlfiles > 0) then
  set gfdlnames = ""
  foreach gfdlfile ($gfdlfiles)
    set name = `echo $gfdlfile | cut -d"/" -f5 | cut -d"." -f1`
    grib2ctl.pl $gfdlfile ${name}.idx > ${name}.ctl
    set nx = `grep xdef ${name}.ctl | cut -d" " -f2`
    set dx = `grep xdef ${name}.ctl | cut -d" " -f5`
    set xinit = `grep xdef ${name}.ctl | cut -d" " -f4`
    set chk = `echo $xinit | cut -d"." -f1`
    if ($chk < 0) then
       set xinit2 = `echo "$xinit + 360" | bc -l`
    else
       set xinit2 = $xinit
    endif
    egrep -v xdef ${name}.ctl > temp.ctl
    echo "xdef $nx linear $xinit2 $dx"  >> temp.ctl
    mv temp.ctl ${name}.ctl
    gribmap -i ${name}.ctl
    set gfdlnames = "${gfdlnames} ${name}"
  end

  set hr = `echo $run | cut -c9-10`

  grib2ctl.pl /itchy/r0/GRIB2/${yymmdd}/gfs.t${hr}z.pgrb2f00.grib1 gfs.idx > gfs.ctl
  egrep -v "(zdef|^1000)" gfs.ctl > temp.ctl
  set name = `echo $gfdlfiles[1] | cut -d"/" -f5 | cut -d"." -f1`
  egrep "(zdef|^1000)" ${name}.ctl >> temp.ctl
  mv temp.ctl gfs.ctl
  gribmap -i gfs.ctl

  echo "$#gfdlfiles ${gfdlnames}" | grads -clb "run merge.gfdl.gs"
 grads -clb "run lats4d.gs -q -format grads_grib -table merge.table -i merge.ctl -o
       ${run}.gfsgfdlmerge.grb"
  rm -f merge.ctl merge.grid udf*
endif
```

## b. GrADS merge.gfdl.gs script

```
pull data
numfiles=subwrd(data,1)

"open gfs.ctl"
ff=1
while (ff <= numfiles)
   name=subwrd(data,ff+1)
   "open "name".ctl"
   ff=ff+1
endwhile


plevs="1000 950 900 850 800 750 700 650 600 550 500 450 400 350 300 250 200 150
       100 50 10"
pp=1
while (pp<=21)
    plev.pp=subwrd(plevs,pp)
    pp=pp+1
endwhile

* 3d variable names in gfs and gfdl files
pvars="tmpprs hgtprs ugrdprs vgrdprs rhprs"
* 2d variable names in gfs and gfdl files
svars="prmslmsl pressfc"
* 2d variable names with mixed names
mvars="ugrd10m vgrd10m"
* 2d variable names with gfs only [but still needed by mm5]
gvars="tmp2m rh2m weasdsfc icecsfc tmpsoilt soilwsoilt"

"set display color white"
"q dims"
rec=sublin(result,5)
t0=subwrd(rec,6)
"clear"
lat1=-20
lat2=85
lon1=180
lon2=430
glat1=-10
glat2=60
glon1=225
glon2=290
ds=0.2
nx=(lon2-lon1)/ds+1
ny=(lat2-lat1)/ds+1
"!echo 'dset ^merge.grid' > merge.ctl"
"!echo 'undef 9.999E+20' >> merge.ctl"
"!echo 'title merged data' >> merge.ctl"
"!echo 'options yrev' >> merge.ctl"
"!echo 'title merged data' >> merge.ctl"
"!echo 'ydef "ny" linear "lat1" "ds"' >> merge.ctl"
"!echo 'xdef "nx" linear "lon1" "ds"' >> merge.ctl"
"!echo 'tdef 1 linear "t0" 1mo' >> merge.ctl"
"!echo 'zdef 21 levels' >> merge.ctl"
"!echo '"plevs"' >> merge.ctl"
"!echo 'vars 15' >> merge.ctl"
vv=1
while (subwrd(pvars,vv) != "")
  var=subwrd(pvars,vv)
  "!echo '"var" 21 99 "var"' >> merge.ctl"
  vv=vv+1
endwhile
vv=1
while (subwrd(svars,vv) != "")
  var=subwrd(svars,vv)
  "!echo '"var" 0 99 "var"' >> merge.ctl"
  vv=vv+1
endwhile
vv=1
while (subwrd(mvars,vv) != "")
  var=subwrd(mvars,vv)
  "!echo '"var" 0 99 "var"' >> merge.ctl"
  vv=vv+1
endwhile
vv=1
while (subwrd(gvars,vv) != "")
  var=subwrd(gvars,vv)
  "!echo '"var" 0 99 "var"' >> merge.ctl"
  vv=vv+1
endwhile
"!echo 'ENDVARS' >> merge.ctl"
"set gxout fwrite"
"set fwrite merge.grid"

* Now do the merger of 3d variables
vv=1
while (subwrd(pvars,vv) != "")
  var=subwrd(pvars,vv)
  zz=1
  while (zz <= 21)
     "set lat "lat1-5" "lat2+5
     "set lon "lon1-5" "lon2+5
     rc=mergeit(numfiles,var,var,plev.zz)
     "set lat "lat1" " lat2
     "set lon "lon1" " lon2
     "set gxout fwrite"
     "d varmerge"
     zz=zz+1
  endwhile
  vv=vv+1
endwhile

* Now do the merger of surface variables

vv=1
while (subwrd(svars,vv) != "")
  var=subwrd(svars,vv)
    "set lat "lat1-5" "lat2+5
  "set lon "lon1-5" "lon2+5
  rc=mergeit(numfiles,var,var,1000)
  "set lat "lat1" " lat2
  "set lon "lon1" " lon2
  "d varmerge"
   vv=vv+1
endwhile

* Now do those with mixed variable names

"set lat "lat1-5" "lat2+5
"set lon "lon1-5" "lon2+5
rc=mergeit(numfiles,ugrd10m,ugrdhag,1000)
"set lat "lat1" " lat2
"set lon "lon1" " lon2
"d varmerge"

"set lat "lat1-5" "lat2+5
"set lon "lon1-5" "lon2+5
rc=mergeit(numfiles,vgrd10m,vgrdhag,1000)
"set lat "lat1" " lat2
"set lon "lon1" " lon2
"d varmerge"

* Now do the gfs-only vars

vv=1
while (subwrd(gvars,vv) != "")
  var=subwrd(gvars,vv)
  "set lat "lat1-5" "lat2+5
  "set lon "lon1-5" "lon2+5
  "define varmerge=regrid2("var".1,"ds","ds",bl)"
  "set lat "lat1" " lat2
  "set lon "lon1" " lon2
  "d varmerge"
  vv=vv+1
endwhile

"disable fwrite"
"quit"

function mergeit(maxfile,gfsvar,gfdlvar,level)

* Merge all gfdl runs into gfs.   For each gridpoint, use the domain having
* the lowest MSLP of all domains

"set lev "level
"define slpglobe=regrid2(prmslmsl.1,0.2,0.2,bl)"
"define varmerge=regrid2("gfsvar".1,0.2,0.2,bl)"

ff=2
while (ff <= maxfile+1)
   "define gfdlslp=regrid2(prmslmsl."ff",0.2,0.2,bl)"
   "define gfdlfield=regrid2("gfdlvar"."ff",0.2,0.2,bl)"
   "define gfdlfield=maskout(gfdlfield,slpglobe-gfdlslp)"
   "define tempgrid=maskout(varmerge,const(0*gfdlfield-1,0,-u))"
   "define varmerge=const(tempgrid,0,-u)+const(gfdlfield,0,-u)"
  ff=ff+1
endwhile

return(1)
```