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Service Change Notice 21-20 Updated
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From: Mike Farrar, Director
National Centers for Environmental Prediction

Subject: Updated: Upgrade NCEP Global Forecast Systems (GFS) to v16: Effective March 22, 2021

Updated to reflect delay in implementation date to Monday, March 22 due to Critical Weather Day.

Effective on or about March 22, 2021, beginning with the 1200 Coordinated Universal Time (UTC) run, the National Centers for Environmental Prediction (NCEP) will upgrade the GFS and Global Data Assimilation System (GDAS) from version 15.3 to 16.0. NCEP also will roll in the operational standalone global deterministic WAVEWATCH III wave model Multi_1. In the event of a Critical Weather Day (CWD) declaration, the implementation may be delayed.

GFS version 16.0 is the first major upgrade to the Finite Volume Cubed Sphere (FV3) dynamical core-based GFS, which replaced the spectral dynamical core in June 2019. In this upgrade, NCEP is increasing the number of model vertical layers from 64 to 127 and extending the model top from the upper stratosphere (~55 km height) to the mesopause (~80 km height).

The model physics upgrades include:

- Employing a new scheme to parameterize both stationary and non-stationary gravity waves that are not explicitly resolved by the model.
- Using a new scale-aware turbulent kinetic energy based moist eddy-diffusivity mass-flux vertical turbulence mixing scheme to better represent the planetary boundary layer processes.
- Updating the RRTMG radiation package to improve solar radiation absorption by water clouds and the cloud overlapping algorithm.

In addition, NCEP is making major changes to the following parts of the data assimilation system:

- Spinning up an offline land model with observed precipitation in the Global Land Data Assimilation System to provide improved land initial conditions.
- Replacing the Ensemble Square Root Filter with the Local Ensemble Kalman

Filter (LETKF) that offers a model space localization and linearized observation operator.
- Employing the 4-Dimensional Incremental Analysis Update (4D-IAU) technique.
- Adopting a stochastic kinetic energy backscattering (SKEB) perturbation technique in the ensemble forecast component used to prescribe background error covariances.
- Updating variational quality control.
- Applying the Hilbert curve to aircraft data.
- Correcting the inter-channel correlated observation error for Cross-track Infrared Sounder (CrIS) over sea surfaces and Infrared Atmospheric Sounding Interferometer (IASI) over sea and land.
- Assimilating new satellite observations.

With this upgrade, for the first time, NCEP is merging the operational standalone global deterministic WAVEWATCH III based wave model Multi_1 (wave_multi_1.v3.3) into the GFS system. The WAVEWATCH III model is updated and coupled to the GFS using a one-way coupling scheme in which the atmospheric model provides forcing to the wave model using the NOAA Environmental Modeling System (NEMS).

NCEP has also made major changes in other components of the forecast system including system infrastructure, post-processing and product generation.

The Environmental Modeling Center (EMC) has conducted a set of retrospective and real-time experiments, covering part of the 2018 hurricane season and the period from May 10, 2019, to the present, for a comprehensive evaluation of the model upgrades. GFSv16 showed improved forecast skills in the following areas:

- Improved 500-hPa height anomaly correlation scores and synoptic patterns in the medium-range, including better position of relevant frontal boundaries.
- Mitigation of the low-level cold bias seen in GFS.v15 during the cool season.
- Increased identification of tropical cyclone threats with higher success ratio and longer lead times.
- Improved QPF Equitable Threat Scores (ETS) and bias in the medium-range.
- Improved snowfall location and amounts with longer lead times.
- Improved ability to capture the temperature profile in shallow, cold air masses.
- Improved forecasts of stratospheric temperature, circulation, ozone and water vapor.

Improvement in wave model science and products includes:

- Simplifying the wave model's multi-grid design from a 9-grid mosaic to a 3-grid mosaic comprising a 10 arcmin global core, a 15 arcmin grid in the Southern ocean and a 9km polar stereographic grid in the Arctic.
- Extending the wave forecast range from 180 to 384 hours.
- Optimizing the wave physics parameters (atmosphere-wave interaction physics, numerical diffusion correction (Garden Sprinkler Effect - GSE), and dissipation sink terms) to increase wave height model skill and

surface ocean currents from the RTOFS model and are including the parameters as forcing to the wave model.
In addition to the parameters already being produced in operations, GFS Wave gridded binary version two (grib2) files will contain the Inverse Mean Wave Frequency, the Mean Period and Direction of Combined Wind Waves and Swell, a third swell partition and the ocean currents and ice cover used by the model.

Evaluation of both the real-time and retrospective parallels can be found at:

https://www.emc.ncep.noaa.gov/users/meg/gfsv16/

which includes relevant links to various evaluation and verification websites.

A real-time feed of the GFSv16 output is available on para NOAA Operational Model Archive and Distribution System (NOMADS) for both NCEP Web services and NOAAPort output here:

https://para.nomads.ncep.noaa.gov

and on the Model Analysis and Guidance (MAG) website here:

https://magpara.ncep.noaa.gov

Due to ongoing maintenance, the availability of both websites may be sporadic.

Details of major changes to the GFSv16.0 are spelled out in separate sections as follows:

A. Changes to forecast model components and physics
B. Changes to the wave model
C. Changes to data assimilation components and techniques
D. Changes to product output on web services:
1. Changes to directory structures on the NCEP web services.
2. Changes to the output file formats and names on the NCEP Web services.
3. Changes to variables on the NCEP web services.
4. Additions to product and file on NCEP web Services.
5. Removal of products from NCEP web Services.
6. Changes in product volume and delivery time.
7. Removal of products from NOAAPort/Satellite Broadcast Network (SBN).

A. Changes to forecast model components and physics

- Updated Planetary Boundary Layer (PBL) scheme, namely a scale-aware Turbulent Kinetic Energy Based Moist Eddy-Diffusivity Mass-Flux (sa-TKE-EDMF) parameterization for vertical turbulent mixing.
- New parameterization of sub-grid scale gravity-wave physics.
- Updated radiation package to improve solar radiation absorption by water clouds and a revised cloud overlap assumption for radiation calculation.
- Revised ground heat flux calculation over snowpack.
- Improved cloud microphysics for computing ice cloud effective radius.

B. Changes to the wave model

The current operational stand-alone global deterministic wave model Multi_1 (wave_multi_1.v3.3) will become a component in the GFS, coupled using a one-way scheme in which the atmospheric model provides winds to the WAVEWATCH III model. New features include a grid redesign, wave-current interaction and improved physics optimized to more frequent atmospheric forcing.

C. Changes to data assimilation components and techniques

- Use observational precipitation to drive and spin up the uncoupled Global Land Data Assimilation System (GLDAS) in the GDAS cycle to provide more realistic land initial conditions.
- Use a Local Ensemble Kalman Filter (LETKF) with model space localization and linearized observation operator to replace the Ensemble Square Root Filter (EnSRF).
- Apply a new 4-Dimensional Incremental Analysis Update (4D-IAU) technique.
- Turn on Stochastic Kinetic Energy Backscatter (SKEB) scheme in GDAS ensemble forecasts.
- Update variational Quality Control (QC).
- Apply Hilbert curve to aircraft data
- Update aircraft bias correction with safeguards.
- Assimilate additional COSMIC-2 GNSS-RO data (COSMIC-2 E1 and E2).
- Apply correlated observation error for CrIS over sea surfaces and IASI over sea and land.
- Assimilate AMSU-A channel 14 and ATMS channel 15 without bias correction.
- Assimilate CSR data from ABI_G16, AHI_Himawari8, and SEVIRI_M08.
- Assimilate AVHRR from NOAA-19 and Metop-B for near sea-surface temperature (NSST).
- Assimilate high-density flight-level wind, temperature and moisture observations in tropical storm environment.
- Upgrade to Community Radiative Transfer Model (CRTM) v2.3.0.

D. Changes to product output on web services

With this upgrade, the following changes occur on either the NCEP web services:
https://nomads.ncep.noaa.gov/pub/data/nccf/com/
ftp://ftpprd.ncep.noaa.gov/pub/data/nccf/com/

or on the NWS Web services:
https://tgftp.nws.noaa.gov/SL.us008001/ST.opnl/
ftp://tgftp.nws.noaa.gov/SL.us008001/ST.opnl/

1. Changes to directory structures on the NCEP web services

WAVEWATCH III multi_1 products found on NOMADS/ftpprd in:
pub/data/nccf/com/wave/prod/
will be replaced by GFS.v16 Wave products and moved to the GFS directory structure for NOMADS/ftpprd:
pub/data/nccf/com/gfs/prod/

The directory structure for all GFS products on NOMADS/ftpprd will be changed to differentiate products from the atmospheric and wave components, respectively:

Atmospheric output:
pub/data/nccf/com/gfs/prod/gfs.YYYYMMDD/CC/atmos
pub/data/nccf/com/gfs/prod/gdas.YYYYMMDD/CC/atmos
pub/data/nccf/com/gfs/prod/enkfgdas.YYYYMMDD/CC/atmos

Wave output:
pub/data/nccf/com/gfs/prod/gfs.YYYYMMDD/CC/wave
pub/data/nccf/com/gfs/prod/gdas.YYYYMMDD/CC/wave

2. Changes to the output file formats and names on the NCEP Web services

- GFS native grid files: The format of GFS analysis and forecast history files is changed from nemsio (binary) to netcdf, including a change of file extension. For example:

gfs.tCCz.atmanl.nemsio --> gfs.tCCz.atmanl.nc
gfs.tCCz.sfcanl.nemsio --> gfs.tCCz.sfcanl.nc
gfs.tCCz.atmfHHH.nemsio --> gfs.tCCz.atmfHHH.nc
gfs.tCCz.sfcfHHH.nemsio --> gfs.tCCz.sfcfHHH.nc

Where CC is 00, 06, 12, 18 and HHH is 000-012.

- GDAS native grid files: The format of GDAS analysis and forecast history files is changed from nemsio (binary) to netcdf, including a change of file extension. For example:

gdas.tCCz.atmanl.nemsio --> gdas.tCCz.atmanl.nc
gdas.tCCz.sfcanl.nemsio --> gdas.CCz.sfcanl.nc
gdas.tCCz.atmfHHH.nemsio --> gdas.tCCz.atmfHHH.nc
gdas.tCCz.sfcfHHH.nemsio --> gdas.tCCz.sfcfHHH.nc

Where CC is 00, 06, 12, 18 and HHH is 000-012.

- ENKFGDAS native grid files: The format of EnKF forecast history files is changed from nemsio (binary) to netcdf, including a change of file extension. For example:

gdas.tCCz.sfcfHHH.nemsio --> gdas.tCCz.sfcfHHH.nc

- WAVE grib2 files: The output grib2 file names change to align with the rest of the GFS.
* Prefix changes from multi_1 to gfswave or gdaswave
* Grid resolution naming convention changes and some products replaced by new output:

glo_30mext --> global.0p25
glo_30m --> global.0p16, gsouth.0p25
at_10m --> atlocn.0p16
wc_10m --> wcoast.0p16
ak_10m --> arctic.9km

ep_10m --> epacif.0p16

Example:
multi_1.glo_30mext.t00z.f000.grib2 -> gfswave.t00z.global.0p25.f000.grib2

- GFSWAVE bulletin and spectra tar files: The station output names will change with the prefix going from multi_1 to gfswave for the wave bulletin and spectra tar files, and the spectra tar file will be split into two tar files.

Example:
multi_1.t12z.spec_tar.gz->
gfswave.t12z.spec_tar.gz - buoy points through FH384
gfswave.t12z.ibp_tar.gz - boundary points through FH180

- GTG turbulence: The file that contained the GTG turbulence will be replaced by a file with both GTG turbulence and icing severity:

gfs.tCCz.gtg.0p25.fFFF.grib2 -> gfs.tCCz.wafs_0p25.fFFF.grib2

3. Changes to variables on the NCEP web services

- The following changes will be made to GFS station Binary Universal Form for the Representation of meteorological data (BUFR) soundings:

* Remove station elevation adjustment from grid terrain to station terrain. When model grid terrain height is different from station elevation, temperature, humidity and pressure were adjusted to the station surface in GFS V15. This adjustment is removed in GFS V16 based on feedback from field offices.
* Correct unit and values for surface evaporation. The values and units of the net surface evaporation in GFS V15 is actually the surface latent heat net flux with unit of (W m-2). The values have been changed to net surface evaporation with units of kg/m**2.
* Replace nearest neighbor grid point for BUFR station HILO Hawaii with a better-represented grid point with similar terrain height and profile to the station. This update was made after extensive investigation. The original grid point is located to the west of the station (lat/lon: 19.73967/204.8438); the new grid point is to the south (lat/lon: 19.62252/204.9609).
* Add BUFR station character IDs to the sounding files in the header section.

- Update atmospheric pressure GRIB (pgrb2) files as follows:

* Unify all 3-D fields to have the same 41 standard isobaric layers for all forecast hours, including analysis time.
* Add seven more pressure levels (at 0.01, 0.02, 0.04, 0.07, 0.1, 0.2, 0.7 hPas) for all isobaric fields in the upper stratosphere and the mesosphere.
* Add several new variables including cloud ceiling height (HGT), instantaneous total column cloud fraction (TCDC), instantaneous cloud fraction (LCDC/MCDC/HCDC) at low/middle/high cloud, 1 and 4 km radar reflectivity (REFD), radar reflectivity (REFD) at model layer 1 and 2,

mixed layer convective available potential (CAPE) and convective inhibition (CIN), plant canopy surface water (CWAT), soil moisture (SOILL) at 0-0.1, 0.1-0.4, 0.4-1,1-2 m below ground level, sea ice thickness (ICETK), surface roughness (SFCR), sea ice skin temperature (ICETMP), soil type (SOTYP), vegetation type (VEG) and frictional velocity (FRICV).
* Remove the legacy field 5-wave height (5WAVE), one of the two land-sea masks LANDN, and the icing severity. The icing severity will be moved to the new file: gfs.tHHz.wafs_0p25.fFFF.grib2.
* Replace the land-sea mask (LAND) obtained via nearest neighbor interpolation with the one interpolated via bi-linear interpolation.
* Replace filtered Shuell Sea Level Pressure with unfiltered one using the same ID (PRMSL). The heavily filtered Shuell Sea Level has caused confusion to users due to its inconsistency with the 10m wind field.
* Change labeling of time averaged cloud fraction at low/middle/high clouds from TCDC to LCDC, MCDC, HCDC.
* Increase GRIB precision for several variables. A complete list can be found here:

https://www.nco.ncep.noaa.gov/pmb/changes/GFSv16_sflux_precision.pdf

- Remove all isobaric specific humidity fields (SPFH) from atmospheric pressure GRIB backup (pgrb2b) files. A subset of these isobaric specific humidity fields have been moved to pgrb2 files; SPFH at the following pressure levels have been removed: 125 hPa to 975 hPa every 50 hPa.
- Replace legacy synthetic nadir GOES 12/13 with synthetic nadir ABI GOES-R in the following files: gfs.tCCz.goessimpgrb2fFFF.grd221.
- Remove lifted index (LFTX)from the surface flux (sfluxgrb) files; users may get this field from pressure GRIB (pgrb2) files.
- Change the Grib2 master table version number from 2 to 6 for all variables in gfs.tCCz.wafs_grb45fFF.grib2.
- Replace Clear Air Turbulence (CATEDR) and Mountain Wave Turbulence (MWTURB) with Maximum EDR (MaxEDR). The Maximum EDR is the maximum of Clear Air Turbulence and Mountain Wave Turbulence and thus contains information from the two individual turbulence components already.

4. Additions to Products and Files on NCEP Web Services

- New parameters are included in the gfswave grib2 output files:

* Significant wave height of third swell partition (SWELL:3).
* Mean wave period of third swell partition (SWPER:3).
* Mean wave direction of third swell partition (SWDIR:3).

- Add gdas.tCCz.crisf4.tm00.bufr_d files containing level 1B radiance data from the S-NPP/N20 CrIS instrument. The previously available CrIS data was discontinued by the upstream provider in early 2020.

- Add the new file gfs.tHHz.wafs_0p25_unblended.fFF.grib2 to be used by UK Met Office to produce blended WAFS products. The file contains icing severity and GTG turbulence on limited ICAO standard levels of exact numbers, as well as CB field.

- Add the station time series BUFR station lists.  The new stations are:

048327 18.77N  98.96E VTCC Chiang Mai, Thailand
048381 16.47N 102.78E VTUK Khon Kaen, Thailand
048400 15.77N 100.14E VTPN Nakhon Sawan, Thailand
048407 15.25N 104.87E VTUU UBON Ratchathani, Thailand
048453 13.67N 100.61E BKK Bangkok, Thailand
048568  7.19N 100.61E VTSH 10 Songkhla, Thailand

- Add new consolidated aviation file: gfs.tHHz.wafs_0p25.fFFF.grib2 containing GTG turbulence and icing severity.
- Change the grib2 parameter of icing severity changed from 234 to 37 and the mnemonic from ICSEV to ICESEV.

- Interpolate Icing Severity and Turbulence products onto ICAO standard levels of reference numbers instead of standard pressure levels.

5.  Removal/Replacement of products from NCEP web services

- Replace legacy synthetic nadir GOES 12/13 on global 1 degree grid with synthetic nadir ABI GOES-R products on global .25 degree grid.  Remove gfs.tCCz.goessimpgrb2.1p00.fFFF and replace with gfs.tCCz.goessimpgrb2.0p25.fFFF.

- Remove WAFS blended product at 1.25 degrees: WAFS_blended_YYYYMMDDHHfFF.grib2

- Remove Wave Products with replacements where noted:
* All products from legacy grids: akw, enp, wna, nww3
* All 4-arcmin grib2 data files: ak_4m, at_4m, wc_4m
* Binary forcing files (icean_5m, gfs_30m, aoc_15m)
* CSV bulletins (csbull)
* multi_1.glo_30m.tCCz.fFFF.grib2 removed, replaced by:
gdaswave.tCCz.global.0p16.fFFF.grib2,
gfswave.tCCz.global.0p16.fFFF.grib2,
gdaswave.tCCz.gsouth.0p25.fFFF.grib2, and
gfswave.tCCz.gsouth.0p25.fFFF.grib2
* multi_1.at_10m.tCCz.f???.grib2 removed, replaced by
gdaswave.tCCz.atlocn.0p16.fFFF.grib2 and
gfswave.tCCz.atlocn.0p16.fFFF.grib2
* multi_1.wc_10m.tCCz.f???.grib2 removed, replaced by
gdaswave.tCCz.wcoast.0p16.fFFF.grib2 and
gfswave.tCCz.wcoast.0p16.fFFF.grib2
* multi_1.ep_10m.tCCz.f???.grib2 removed, replaced by
gdaswave.tCCz.epacif.0p16.fFFF.grib2 and
gfswave.tCCz.epacif.0p16.fFFF.grib2
* multi_1.ak_10m.tCCz.fFFF.grib2 removed, replaced by
gdaswave.tCCz.arctic.9km.fFFF.grib2 and gfswave.tCCz.arctic.9km.fFFF.grib2
* multi_1.glo_30mext.tCCz.fFFF.grib2 removed, replaced by
gdaswave.tCCz.global.0p25.fFFF.grib2 and
gfswave.tCCz.global.0p25.fFFF.grib2

6. Changes in product volume and delivery times

- Increase in data volume of the pgrb2 files by approximately 55% per file.
- Increase in data volume of sflux files by approximately 29%.
- Increase in data volume of pgrbfull files by approximately 32%.
- Decrease data volume of pgrb2b files by approximately 5%.
- Increase data volume of each bufr station from 100kb to 190kb; Increase AWIPS collective files size by about 90%.

- Delay in the delivery of the GFS atmos pgrb2 output for all resolutions, starting at 8 minutes for forecast hour 000 and growing to 11 minutes for forecast hour 384.
- Delay in the delivery of GDAS atmos pgrb2 output by up to 26 minutes.
- Delay in the delivery of GDAS ensemble (ENKF) atmos output 19 to 23 minutes.
- Delay in the delivery of Synthetic GOES products gfs.tHHz.goessimpgrb2.0p25.fFFF files by up to 14 minutes.
- Delay in the delivery of WAFS product gfs.tHHz.wafs_grb45fFF.grib2 by 21 minutes.
- Delay in the delivery of gfs.tCCz.wafs_0p25.fFFF.grib2 by up to 21 minutes, which replace the GTG turbulence product gfs.tCCz.gtg.0p25.fFFF.grib2
- Delay in the delivery of WAFS wafsgfs_L_tCCz_intdskFF.grib2 and wafsgfs_P_tCCz_intdskFF.grib2
- Delay in the delivery of bufrsnd products by up to 8 minutes.
- Delay in the delivery of the wave spectra and bulletin files (gfswave.tHHz.spec_tar.gz, gfswave.tHHz.bull_tar, gfswave.tHHz.cbull_tar) by up to 85 minutes due to the increase in wave forecast from 180 to 384 hours.

7. Removal of products from NOAAPort/SBN

- 5-wave height (5WAVH) legacy variable from AWIPS products: 20km grids (CONUS, Alaska, Puerto Rico, Pacific region) and LAT/LON 1.0 degree grid.
- U and V winds and temperature in wintemv legacy bulletin format for select levels: 850mb, 700mb, 500mb, 400mb, 300mb,250mb, 200mb, 150mb, 100mb.
- Ship information in navybull legacy bulletin.
- U and V winds, temperature, height, relative humidity in gridbuls legacy bulletin.
- Gridded wind-waves from AWIPS products including Alaska 10-arcmin, Alaska 4-arcmin, Atlantic 4-arcmin and West Coast 4-arcmin. The Alaska grids will be replaced by the Arctic 9km grid.
- Gridded wave steepness (wstp) AWIPS products for all domains.
- Legacy NWW3 grids in grib1 format.

All WMO headers proposed for removal are listed here:

https://www.nco.ncep.noaa.gov/pmb/changes/gfsv16_removal_grids.php

NCEP urges all users to ensure their decoders can handle changes in content order, changes in the scaling factor component within the product definition section (PDS) of the GRIB files, and volume changes. These

elements may change with future NCEP model implementations. NCEP will make every attempt to alert users to these changes before implementation.

NCEP will evaluate all comments to determine whether to proceed with this upgrade.

For questions regarding these model changes, please contact:

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For questions regarding the data flow aspects of these data sets, please contact:

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National Service Change Notices are online at:

https://www.weather.gov/notification/

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