HRRR/HRRR-E Guidance
2017-8 WPC Winter Weather Experiment

Web: https://rapidrefresh.noaa.gov/hrrr/HRRRE/

GRIB-2 output grids also available via FTP

ESRL/GSD

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HRRR Ensemble (HRRRE)

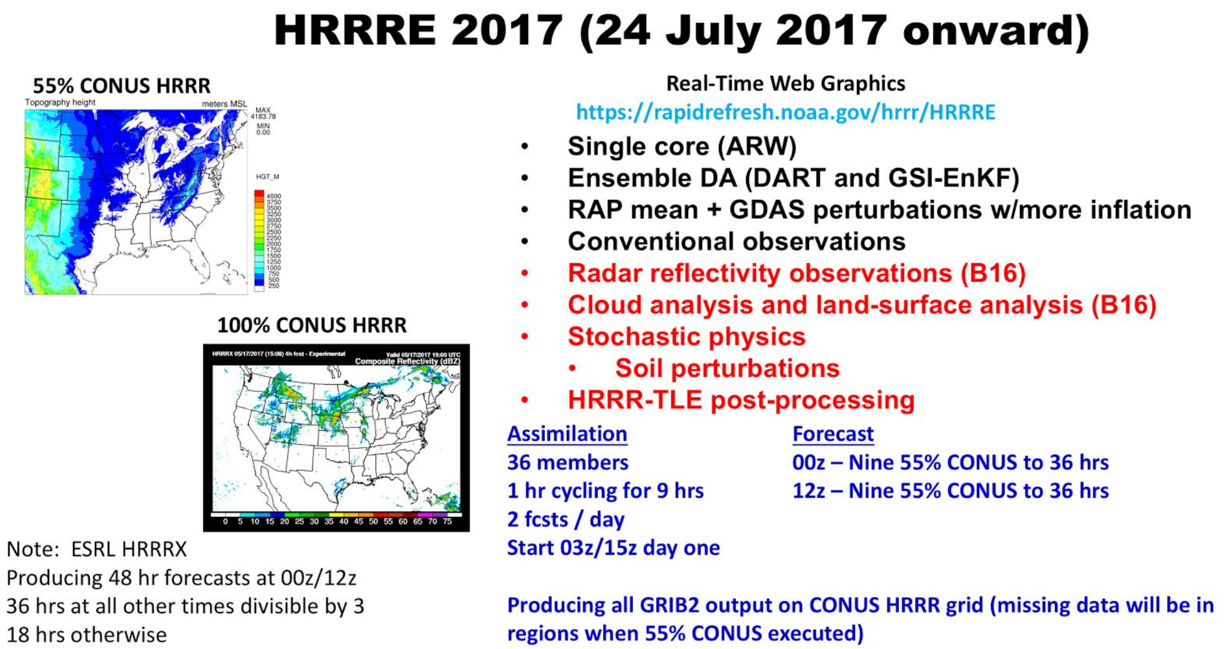
Goals and General Description

The HRRRE is an experimental convective-allowing ensemble analysis and forecasting system run at NOAA/ESRL/GSD. It is being developed and tested for three main reasons: (1) improving 0-12 h high-resolution forecasts through ensemble-based, multi-scale data assimilation, (2) testing ensemble-design concepts for 0-36 h forecasts produced with a single model, and (3) providing a foundation for experimental, on-demand, very-high-resolution applications such as Warn-on-Forecast. HRRRE has been run experimentally with initial versions in spring 2016 and spring 2017. This document describes the HRRRE version starting July 2017 including for the 2017-18 WPC Winter Weather Experiment.

The deterministic HRRR currently assimilates observations with a hybrid ensemble-variational (EnVAR) method, and the background ensemble for this assimilation is the 80-member GDAS (GFS) ensemble. One idea being tested in the HRRRE is using a higher-resolution, convective-allowing ensemble instead for assimilation. (As indicated in the specific information below, the HRRRE and GFS are still coupled because the HRRRE's parent RAP model is initialized from the GFS, and initial HRRRE perturbations come from the GDAS ensemble.) A background ensemble with explicit convection enables direct assimilation of high-resolution observations such as radar reflectivity in convective storms. This high-resolution, ensemble-based assimilation could lead to improved forecasts, particularly in the 0-12 h range.

Longer forecasts require more attention to model error. Soil-moisture perturbations and stochastic parameter perturbations to the MYNN PBL scheme have both been tested as ways to introduce realistic growth of ensemble spread during the 0-36 h forecast. Stochastic parameter perturbations to other parameterization schemes will also be tested in the coming year.

During selected demonstration periods, the HRRRE analyses and forecasts provide initial and boundary conditions for a prototype Warn-on-Forecast system run at the National Severe Storms Laboratory. The Warn-on-Forecast project is developing on-demand, high-resolution, ensemble-based, 0-3 h numerical weather prediction capabilities to support warnings of severe convective storms and flash flooding.



Specific Information

Model

- WRF-ARW version 3.8+, combining elements of versions 3.8 and 3.9 plus other GSD-specific features
- Configuration identical to experimental HRRR (https://rapidrefresh.noaa.gov/hrrr/), except that the domain covers the central and eastern US only (55% of HRRR domain*), and a standard vertical coordinate is used instead of a hybrid coordinate.
- Physics is as described in Benjamin et al. 2016, MWR http://journals.ametsoc.org/doi/abs/10.1175/MWR-D-15-0242.1 except that a deep convection parameterization is not used.

Data-Assimilation Ensemble

- 36 members
    - 3-km horizontal grid spacing
    - Initial ensemble-mean atmospheric state from RAP analysis
    - Atmospheric spatial perturbations from members 1-36 of GDAS ensemble
    - Initial ensemble mean of land-surface state from HRRR
    - Random soil-moisture perturbations added to each member at initial time
    - Random perturbations to MU, U, V, T, and QVAPOR added to boundary conditions of each member
- Initialization at 0300 and 1500 UTC, followed by hourly cycling for 9 h to 1200* and 0000 UTC, respectively

Hourly Data Assimilation

- Observations
    - NCEP bufr conventional observations, as in HRRR (http://www.emc.ncep.noaa.gov/mmb/data_processing/data_processing/)
    - MRMS gridded radar reflectivity observations, thinned in horizontal and vertical directions
- Gridpoint Statistical Interpolation (GSI) for observation preprocessing and calculation of ensemble priors
- DART ensemble adjustment Kalman filter (EAKF) for assimilation
    - Analysis variables: U, V, T, QVAPOR, PH, MU, QCLOUD, QRAIN, QICE, QSNOW, QGRAUP
    - Gaspari-Cohn compact pseudo-gaussian for localization
    - Horizontal localization radius (full radius, where weight reaches zero) 300 km and 18 km for conventional and radar observations, respectively
    - Vertical localization radius (full radius, where weight reaches zero) 8 km and 6 km for conventional and radar observations, respectively
    - GSI adjustments applied to each member individually after EAKF
        - Soil adjustment, as in HRRR
        - Cloud clearing based on satellite observations, as in HRRR
- Relaxation to prior spread (inflation factor 1.2) after assimilation each hour

Ensemble Forecasts

- 9-member, 36-h forecast* initialized from first 9 members of data-assimilation ensemble at 1200 and 0000 UTC
- 3-km horizontal grid spacing
- Random perturbations to MU, U, V, T, and QVAPOR added to boundary conditions of each member
- Post processing: An ensemble post-processing system is applied to the nine HRRRE forecast members to produce all-season weather hazard probabilities including heavy rainfall as is done with the time-lagged HRRR. For the 2017-18 Winter Weather Experiment, HRRR-E probabilities are the fraction of members that exceed a given threshold, or predict a given precipitation type, at a point. The final probability field (100*(n/total)) is smoothed using a Gaussian filter of width 25 km.

High Performance Computing

- The HRRRE runs on xjet: Intel Haswell CPU, 24 cores/node, and 64 GB memory/node. Hourly cycling requires 144 nodes (3456 processors). Resources for the free ensemble forecasts vary according to the requirements of specific real-time demonstrations.

* In the near future, we will implement the following changes for the Winter Weather Experiment: hourly cycling from 0300 to 0900 UTC (instead of 1200 UTC), followed by a 51-h forecast initialized at 0900 UTC. We also plan to nest the 3-km HRRRE grid within a 15-km grid, to improve forecasts and facilitate collaboration with NCAR. In fall 2018, we are hoping to expand the HRRRE 3-km domain to match the full-CONUS HRRR domain.

Future Plans

We are working towards merging HRRR, HRRRE, and HRRR-TLE activities. We are exploring the possibility of the HRRR being a control member of the HRRRE, with the HRRR initialized with GSI hybrid data assimilation using the HRRRE as the background ensemble. We also plan to apply the post processing in the HRRR-TLE to the combined system.

Teams at GSD and NCAR are working together to develop convective-allowing ensemble analysis and prediction. During the upcoming two years, we will run parallel systems during demonstration periods. The HRRRE running at GSD and a new version of the NCAR ensemble will use shared codes and configurations. Running similar systems with verification will allow us to test new ideas for data assimilation and forecasting.

The ultimate goal of this work is to inform the design of a future operational, single-model, hourly-updated, convective-allowing ensemble analysis and forecasting system developed jointly with EMC. We are also involved in the development and testing of FV3, to support the unification of NWP applications from global to local scales. Some of this development involves transitioning capabilities in the existing WRF-ARW version of the RAP-HRRR system to FV3. We are testing an enhanced version of the operational GSI-EnKF code that includes directly reflectivity data assimilation and will use it for real-time runs with verification. HREF, the current operational convective-allowing ensemble prediction system, is a multi-model system. Through verification of HREF and HRRRE forecasts, we will compare and contrast the forecast spread produced by the multi-model and single-model approaches.

Contributors

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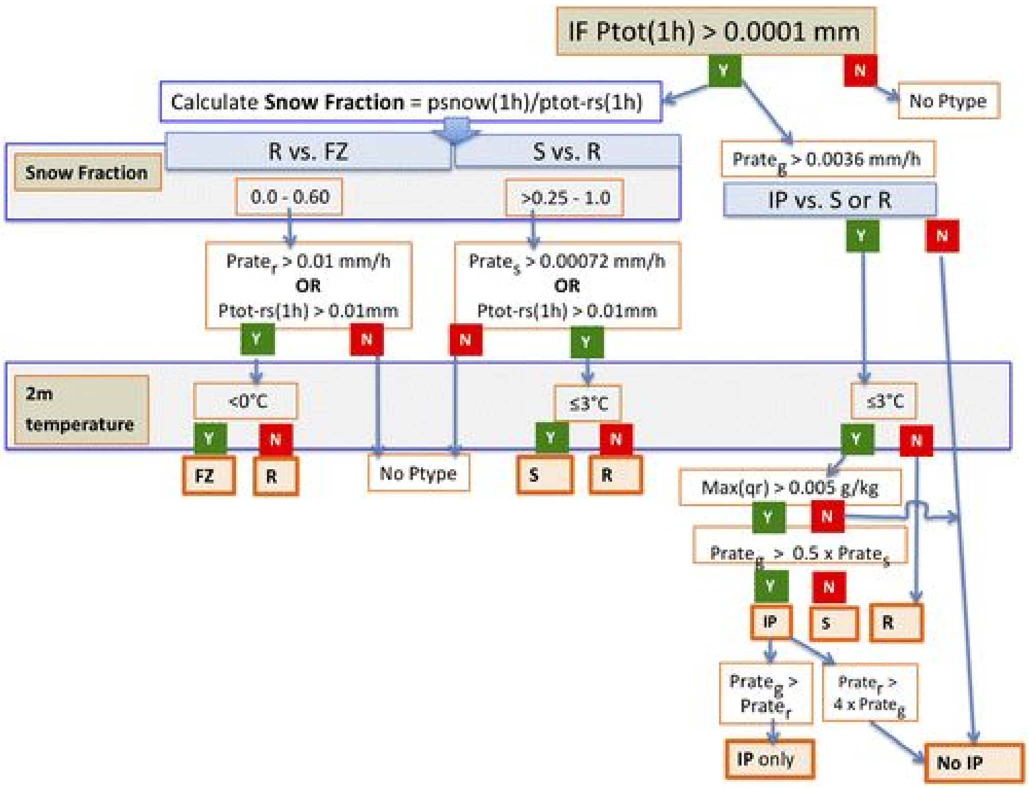
HRRR/HRRR-E Precipitation Type Algorithm

HRRR and HRRR-E both use a microphysics-based algorithm to predict instantaneous precipitation type (snow, sleet, rain and/or freezing rain). Output is in the form of categorical (0

or 1) grids for each precipitation type, stored in GRIB-2 fields CSNOW, CICEP, CRAIN, and CFRZR. Multiple precipitation types may be forecast simultaneously, up to 3, with the only exception being that the algorithm will predict either rain OR freezing rain. The algorithm uses 2-m temperature, 3-D hydrometeor mixing ratios and fall rates to provide a first guess of precipitation type reaching the ground. A flow-chart of the algorithm is shown below, with further details available in the following Weather and Forecasting article:
Benjamin, S., J. M. Brown, and T. G. Smirnova, 2016b: Explicit precipitation-type diagnosis from a model using a mixed-phase bulk cloud-precipitation microphysics parameterizations. *Wea. Forecasting,* **31**, 609–619. http://journals.ametsoc.org/doi/abs/10.1175/WAF-D-15-0136.1



HRRR/HRRR-E Variable-Density Snowfall Algorithm

HRRR and HRRR-E both use a variable-density snowfall accumulation algorithm. The output of this algorithm, contained in the "ASNOW" GRIB-2 field, is the total depth of new snowfall and graupel/sleet accumulation. Note: in the Thompson microphysics scheme and this algorithm, falling sleet is considered graupel.

At *every model time step*, the algorithm first determines snow-water-equivalent and graupel-water-equivalent precipitation rates using the mixing ratios and fall rates of these hydrometeors at the lowest model level. Next, some melted water equivalent is subtracted from these totals if the land surface temperature is above 0C. Snow and graupel density functions are then applied to determine the rate of increase of total snow+graupel depth. The product of this accumulation rate (m/s) and the model time step (20 s) yields a snowfall+graupel depth accumulation that is added to a running total depth. At every hour, HRRR and HRRR-E output this running total as ASNOW.

Snow-to-liquid and graupel-to-liquid ratios are linear functions of the temperature at the lowest model level (typically ~8 m), given by:

*snow density (kg/m^3) = min(250,1000/max(4.179,(13.*tanh((274.15-(x+273.15))/3))))*

*graupel density (kg/m^3) = min(50.,1000/max(2,(3.5*tanh((274.15-(x+273.15))/3))))*

The minimum and maximum densities possible from the snow equation are 76 and 250 kg/m^3, respectively, equal to snow-to-liquid ratios of 13:1 and 4:1.

HRRR Deterministic Winter Precipitation Fields

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Water Equivalent of Accumulated Snow Depth (kg/m^2 or mm)

Discipline 0, Category 1, Parameter 13, "WEASD"

- Snow-only water-equivalent accumulation at surface from microphysics
- Ignores contributions from graupel, rain or ice
- Reported as "accumulation" and starts with zero value
- Provided in both one-hour and run-total forecast buckets
- Can multiply by a climatological or fixed 10:1 ratio to estimate accumulated snow depth

Accumulated Snow Depth (m)

Discipline 0, Category 1, Parameter 29, "ASNOW"

- Variable-density accumulation of all frozen precipitation types from the microphysics, minus snow melt, computed inside the land surface model (RUC)
- Includes contributions from snow, graupel and ice with temperature-dependent density
- Reported as "accumulation" and starts with zero value
- Provided only as run-total forecast

- Can be evaluated against the traditional SWE*10 estimate
- Used as the input to the HRRR-E 6-h snowfall probabilities

Accumulated Graupel Depth (kg/m^2 or mm)

Discipline 0, Category 1, Parameter 227, "FROZR"

- Graupel-only (i.e. sleet) accumulation at surface from microphysics
- Ignores contributions from snow or rain
- Reported as "accumulation" and starts with zero value
- Provided in both one-hour and run-total forecast buckets

Accumulated Freezing Rain Depth (kg/m^2 or mm)

Discipline 0, Category 1, Parameter 225, "FRZR"

- Freezing rain accumulation at surface from rain precipitation type in microphysics, minus melting, computed inside the land surface model (RUC) using same diagnosis as instantaneous categorical freezing rain
- Ignores contributions from snow or graupel
- Reported as "accumulation" and starts with zero value
- Provided in both one-hour and run-total forecast buckets

Water Equivalent Snow Depth (kg/m^2 or mm)

Discipline 0, Category 1, Parameter 13, "WEASD"

- Water equivalent of "snow pack" as reported by the land-surface model
- All frozen precipitation included (snow, graupel, ice)
- Cycled from previous forecasts and can have non-zero starting value
- Includes effects of new frozen precipitation, melting and sublimation
- Provided as an instantaneous surface value at the top of each hour

Snow Depth (m)

Discipline 0, Category 1, Parameter 11, "SNOD"

- Depth of "snow pack" as reported by the land-surface model
- All frozen precipitation included (snow, graupel, ice)
- Cycled from previous forecasts and can have non-zero starting value
- Includes effects of new frozen precipitation, melting and sublimation
- Provided as an instantaneous surface value at the top of each hour

Percent of Frozen Precipitation (%)

Discipline 0, Category 1, Parameter 39, "CPOFP"

- Ratio of frozen precipitation (snow + graupel + ice) to total precipitation (snow + graupel + ice + rain)
- Provided as an instantaneous surface value at the top of each hour

Categorical Snow Precipitation Type (0 = no or 1 = yes)

Discipline 0, Category 1, Parameter 36, “CSNOW”

- Identification of snow precipitation type at surface based on explicit microphysics, precipitation intensity and surface temperature
- Identification of precipitation for very small rates < 0.01”/hr
- Can exist with one or more other precipitation types
- Provided as an instantaneous surface value every 15 min into forecast

Categorical Graupel Precipitation Type (0 or 1)

Discipline 0, Category 1, Parameter 35, “CICEP”

- Identification of graupel (sleet or ice-pellets) precipitation type at surface based on explicit microphysics, precipitation intensity and surface temperature
- Identification of precipitation for very small rates < 0.01”/hr
- Can exist with one or more other precipitation types
- Provided as an instantaneous surface value every 15 min into forecast

Categorical Freezing Rain Precipitation Type (0 or 1)

Discipline 0, Category 1, Parameter 34, “CFRZR”

- Identification of freezing rain precipitation type at surface based on explicit microphysics, precipitation intensity and surface temperature
- Identification of precipitation for very small rates < 0.01”/hr...i.e. freezing drizzle
- Can exist with one or more other precipitation types
- Provided as an instantaneous surface value every 15 min into forecast

Categorical Rain Precipitation Type (0 or 1)

Discipline 0, Category 1, Parameter 33, “CRAIN”

- Identification of rain precipitation type at surface based on explicit microphysics, precipitation intensity and surface temperature
- Identification of precipitation for very small rates < 0.01”/hr
- Can exist with one or more other precipitation types
- Provided as an instantaneous surface value every 15 min into forecast