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Rapidly Updating Analysis
DRAFT White Paper

I. Introduction

Real-time situational awareness for National Weather Service forecasters and other users is a critical capability. Forecasters require accurate, rapidly updated analyses of the physical environment to guide warnings and short-term forecasts for public safety and efficient, weather-sensitive commerce. Products generated from real-time analyses benefit many users including aviation, energy emergency managers and the general public. Although a Rapidly Updating Analysis (RUA) will first be focused on the atmosphere, there are increasing requirements for extensions to other parts of the physical environment such as land, surface water, the cryosphere, ocean and coastal waters, and hazardous chemical releases. Further into the future, it is envisioned that the RUA and Warn-on-Forecast NWP will merge into a tightly coupled operational forecast and warning system for severe weather. A global RUA extension, highly dependent on satellite data, is also envisioned.

"Consistency" is a current major concern with NWS products and takes three major forms as described below.

1. Spatial and temporal consistency in analyzed products across NWS service boundaries has been identified as an overall NWS weakness. Across NWS region and Weather Forecast Office (WFO) boundaries, real-time analysis products should be seamless across these boundaries and represent a coherent evolution of the environmental state over time. A national-scale analysis at the highest feasible resolution (currently 2.5 km) ensures consistency throughout the domain.
2. Temporal consistency between real-time analyses and short-term (1-6 hour) numerical weather prediction grids is important for forecast continuity and enhances the operational forecaster's ability to put out watches and warnings. While it has been challenging to achieve this sort of temporal consistency, the increased horizontal resolution of hourly updated fields at 3 km provided by the High-Resolution Rapid Refresh (HRRR) has narrowed the gap between real-time analyses and hourly numerical guidance and enabled some short-term predictive skill for deep convection. This skill improvement is critical for aviation and short-term severe weather applications.
3. Finally, physical consistency across the analyzed product set is critical for understanding the real-time situation. For example, precipitation distribution and history should be related to, and consistent with, soil moisture, runoff and stream flow. Separate analyses of these quantities and real-time products from multiple platforms will not necessarily be consistent.

II. Rapidly Updating Analysis Development

A real-time local analysis ("nowcasting") capability has been available on AWIPS using the Local Analysis and Prediction System (LAPS) software. Consistent with its local emphasis, observations from local sources contribute to hourly updates as well as those transmitted by the AWIPS SBN. As of 2010, almost 75% of Eastern and Central Region forecasters used LAPS,

particularly for event-driven needs for severe weather and convective potential. Now, however, transmission of local observations to the Weather and Climate Operational Supercomputer System (WCOSS) is highly efficient so that most local observations are available for central processing with low latency. In addition, consistency for fast-moving weather across local analysis boundaries is an issue. Development of a high-resolution, national-scale analysis is now feasible and can be a foundational part of the NWS product improvement. When this analysis is used operationally to initiate skillful short-term forecasts, temporal continuity will be achieved and effective forecaster use will follow.

Two major development projects are now paving the way for the envisioned national RUA. These are the recently implemented Multiple-Radar-Multiple-Sensor (MRMS) system on the IDP servers in the NCEP "Compute Farm." MRMS output features highly utilized radar-derived products assembled from WSR-88D, DoD Weather Surveillance, Canadian Weather, and FAA Terminal Doppler Weather Radars. Three-dimensional reflectivity mosaics and Quantitative Precipitation Estimates (QPEs) over CONUS and adjacent areas of Mexico and Canada are produced at ~1-km horizontal grid mesh and 2-min refresh cycle. In addition, gridded products derived from radar reflectivity merged with very-short-range High-Resolution Rapid Refresh (HRRR) model forecasts, e.g. 3-d hydrometeor fields, are under development, and a full 3-dimensional RUA is the next step. The MRMS extended products and the RUA will both utilize the operational Gridpoint Statistical Interpolation (GSI) data assimilation system, which is currently used to initialize the HRRR as well as all other operational NCEP atmospheric modeling systems.

The second project is the maturing Real-Time Mesoscale Analysis (RTMA). The RTMA generates hourly surface sensible weather analyses (also tested at 15-min frequency by GSD) and is undergoing intensive upgrades to fix known issues, primarily for analyses over steep topography, as well as adding new analysis variables needed by the field, such as sky cover and significant wave height. The underlying RTMA software is a two dimensional version of the GSI and, as such, it can process all types of observations. A second application of the same RTMA/GSI software is the Un-Restricted Mesoscale Analysis (URMA), which uses additional, late-arriving observations that did not make the RTMA data-cutoff in real time. URMA is executed by running the same RTMA system, but 6 hours later in time, to pick up the late-arriving observations. URMA is slated to become the "Analysis of Record" for the NWS, against which operational forecasts will be verified. The RTMA system will form the backbone of extension to three dimensions. This can be accomplished by leveraging the well-documented ability of the GSI data assimilation system to use a wide and diverse set of observations, which includes but is not limited to in situ sounding information from rawinsondes, aircraft data, radar data, and satellite data. The GSI, therefore, is capable of producing a meteorologically and geographically consistent snapshot of the atmosphere with high update frequency and low latency.

III. Proposed Way Ahead

A. Project Goals

The project goals are:

a. Develop a three-dimensional atmospheric analysis, updated at sub-hourly intervals with aircraft, radar, satellite and other high-frequency data;

b. Link, as a physically continuous sequence of grids, the atmospheric analysis with forecasts at one hour and beyond from NCEP's operational models;

c. Build additional analysis capability, physically and temporally consistent with the atmospheric analysis, to serve the marine and hydrological communities. Additional variables will include soil moisture, runoff fraction, soil temperature, marine surface winds, wave height, and beach state (e.g. riptide potential).

d. Develop capability to analyze emergency applications such as hazardous spills into the RUA.

B. Multiple Line Office Collaboration Using Community-based Software

The most important factor in RUA development is to have a collaborative and mutually supporting relationship between OAR Labs, NESDIS, and NWS. In this way, experts in each Line Office can contribute in a complementary manner. Although details need to be worked out, OAR, NESDIS and NWS have all agreed, in principle, to collaborate on a RUA development, with the GSI code as the primary analysis engine. One major advantage of the GSI is its current ability to use remotely-sensed (satellite and radar) observations in great detail and from the broadest set of instruments available. A second major advantage is that the GSI is a true community-based system, serving multiple operational data assimilation systems and models. Contributions to GSI development from multiple investigators within NOAA, NASA, NCAR, and academia are currently being made as a result of the code management structure. New GSI users can take advantage of community tutorials and excellent system documentation to come up to speed.

For RUA development, the project will depend heavily on experience in rapid updating for the Rapid Refresh and HRRR models from the ESRL/GSD Earth Modeling Branch as well as expertise in analysis techniques and products from LAPS developers. EMC will also provide experience with the NAM Rapid Refresh development. NSSL will provide strong experience with radar products, radar data quality control and the expertise in extending MRMS system with GSI-based analysis products. NESDIS STAR and the JCSDA will be able to bring expertise on real-time satellite radiances, derived products and a strong record of collaborating on satellite data assimilation. Finally, EMC will also provide the GSI code management and development, expertise in data assimilation, as well as testing and integration with the NCEP operational system. Collaboration among all parties is important for the eventual realization of a successful RUA system.

C. Proposed Development Path

a. The first development emphasis will be to improve the RTMA, which is ongoing and supported by Sandy Supplemental funds. Accurate analysis of the most important surface sensible weather variables (temperature, dew point and wind), in heterogeneous terrain with sparse observations is a critical first step. Current work focuses on improving the background field and access to all of the available observations, improving RTMA fit to observations, and expanding RTMA products to cover the National Digital Forecast Database (NDFD) set. Several experimental (non-real time) versions of the RTMA background are

now being tested, including the HRRR and a combined HRRR (3 km) and 4 km hourly NAM Rapid Refresh (NAMRR), with no static data reject lists. Even more importantly, these higher resolution inputs reduce the burden on downscaling codes that generate the 2.5 km interpolated background.

b. Use of radar data in 3-d high-resolution data assimilation will continue to be developed. Radar-derived heating rates are used in the HRRR data assimilation and provide very effective information for initialization of convective and cloud-free areas. This initialization is extremely challenging due to the need for adjusting broad fields of divergent wind, moisture and temperature to generate the observed precipitation, even outside the initially cloudy areas. Since radar data provides line-of-sight (one wind component) information away from (and toward) the radar sites (both wind components can be derived at the radar site via the VAD technique but are sufficiently accurate in low wind gradient situations), analysis constraints must be derived to help generate an improved analysis. Precipitation type information directly from the radar reflectivity and dual-polarization data is also very important information. MRMS products will begin to use background information through the GSI to generate more consistent fields.

c. Use of satellite sounding radiance data over land is increasing as improvements to the Community Radiative Transfer Model (CRTM) and to land-surface state estimates continue to be made. Further improvements to the GSI cloud/hydrometeor assimilation capability, already used in the HRRR and RAP and NAMRR to generate total sky-cover and 3-d cloud fields, will be a key component for RUA products. The GOES-R sounder data will provide high time and space resolution information to be combined with increased in-situ observations from aircraft and surface networks.

d. Lightning data from ground-based detection networks and in the future, from GOES-R, can be used as proxy reflectivity through flash density to further improve cloud/hydrometeor fields and corresponding divergent wind fields.

d. The increase in aircraft soundings of temperature, wind and moisture will be foundational input for increasing local RUA accuracy throughout CONUS, Alaska, Hawaii and Guam. Improved coverage of mesonet data should also increase quality of the surface analysis.

e. While the RTMA currently has a 2-d sky-cover analysis, the RUA will include a 3-d hydrometeor analysis with diagnosed cloud cover and precipitation analysis, refreshed at sub-hourly intervals, and derived from satellite, radar and surface observations and ensemble-based background errors.

D. Timeline

The RUA is a very complex project, dependent on application of new scientific data assimilation techniques and increased operational High Performance Computing (HPC). RTMA development activities are well under way and scientific development is beginning, especially for assimilation of cloud-impacted radiances, which is an essential first step. However, combining detailed input from both satellites and radar will take considerable testing and will likely proceed with steps of increasing complexity. Operational products might appear in the 2018-19 time period.

The RUA will become a sufficiently detailed and accurate representation of the environmental state and will be combined with an ensemble-based high-resolution forecast system built from the HRRR with planned augmentation from the NAMRR. This combined system should unfold in the 2025 time period. A fully operational Warn-on-Forecast capability, using extension of this system at 1-km horizontal resolution or better, is estimated to occur around 2025.

Once the RUA becomes a sufficiently mature operational product, it should be incorporated into a Reanalysis Project to serve as the "Analysis of Record" for the NWS.