Cloud Diagnostic and Analysis Studies with the Rapid Refresh Forecast System (RRFS) and the Real-Time Mesoscale Analysis (RTMA)

Craig Hartsough[1], Terra Ladwig[2], Ming Hu[2], Guoqing Ge[1],
Steve Weygandt[2], Eric James[1], Stan Benjamin[2], Curtis Alexander[2]

[1] National Oceanic and Atmospheric Administration, Global Systems Laboratory (GSL)
[2] Cooperative Institute for Research in Environmental Sciences (CIRES)

RRFS Cloud Analysis

The hydrometeor analysis is a key data assimilation component for initializing and forecasting clouds and precipitation. Successful C&V forecasts in the HRRR can be partly attributed to the hydrometeor analysis and it is now ready for testing and evaluation in the Rapid Refresh Forecast System (RRFS).

Research on the use of partial cloud information in RRFS would not be possible without this critical testing. A huge positive outcome of the current hydrometeor analysis work is that this testing will enable the hydrometeor analysis to be installed into the real-time runs of RRFS.

Experiment Design

The RRFS hydrometeor analysis experiments are based on a recent set of software components for RRFS that we are referring to as “Base A”. The Base A tag represents a snapshot of the model, physics, data assimilation, and utilities from late February 2022. Additional experiments will be completed with future RRFS versions.

The RRFS experiments were run for a retrospective experiment from 12-15 May 2021. A RRFS experiment with the hydrometeor analysis on (“On”) is compared to an otherwise identical experiment with the hydrometeor analysis off (“Off”).

At the first data assimilation cycle, differences between On and Off were examined. Specific humidity (left) and cloud water (right) differences at low levels show areas in which the analysis added/removed moisture and (Figure 1). The cloud building based on METAR ceilometer observations creates the characteristic “tuna can” shape in the differences like those in Mississippi in Figure 1. Cloud building from satellite observations can also be detected in this example over the Pacific. There are also regions that indicate cloud clearing is also taking place like parts of Texas. This example is consistent with the single analysis case study results and indicates that the hydrometeor analysis is making the expected modifications to the model background.

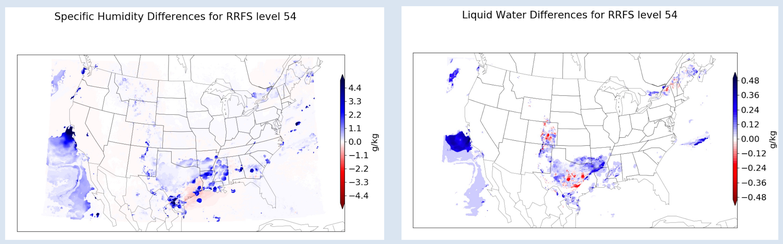

Figure 1. Difference fields for specific humidity (left) and cloud water (right) showing change that occurs to the analysis when the hydrometeor analysis is turned on relative to being turned off.

Contact

Craig Hartsough
CIRES at NOAA/GSL
Craig.Hartsough@noaa.gov

Terra Ladwig
NOAA/GSL, Federal
Terra.Ladwig@noaa.gov

Visual Comparisons

Figure 2 shows the analysis ceiling and 2-hour forecast ceiling for the experiment without the hydrometeor analysis (a,b) and with the hydrometeor analysis On (c,d) for the 00 UTC cycle on 13 May 2021. The hydrometeor analysis clears the coverage of high clouds in the Intermountain West and Northern Great Plains, as well as clearing spurious mid-level clouds across Kansas, Western Oklahoma, and in the Ohio Valley. Since early RRFS verification indicates a high bias in relative humidity, clouds and precipitation, along with a cold bias, the hydrometeor cloud clearing is of critical importance. It is encouraging to see the large cloud clearing taking place. The hydrometeor analysis also correctly adds clouds, for example, over the Pacific west of Washington/Oregon. The hydrometeor analysis changes persist in the 2-hour forecast and generally look more accurate for ceiling.

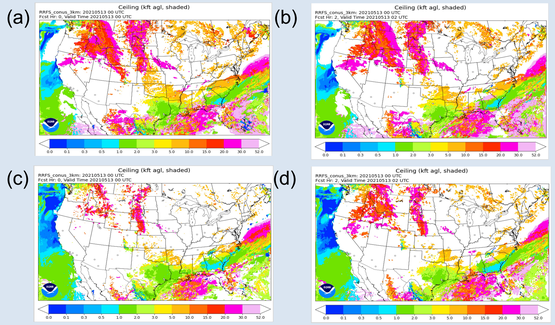

Figure 2. Ceiling forecasts with no cloud analysis at (a) 00h and (b) 02h forecast time, and with the cloud analysis at (c) 00h and (d) 02h forecast time.

The hydrometeor analysis is also able to modify precipitating hydrometeors (rain, snow, graupel). The clearing of spurious precipitation is also very critical due to the current RRFS biases. For example the reduction of reflectivity in the Northern Rockies and Plains in the analysis at 0 UTC on 13 May creates a more accurate analysis and 2-hour forecast compared to observations (Figure 3 and 4).

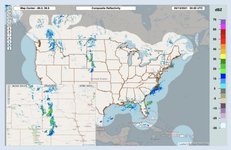

Figure 3. MRMS composite reflectivity image for 00Z on 13 May 2021. Inset: enlarged view of composite reflectivity over the northern Rockies and Plains.

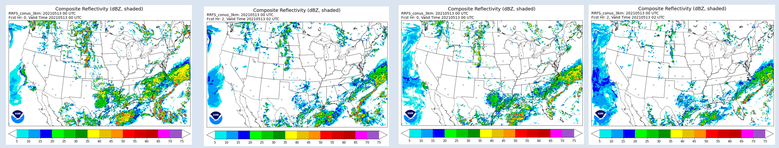

Figure 4. Composite reflectivity forecasts with no hydrometeor analysis at (a) 00h and (b) 02h forecast time, and with the hydrometeor analysis at (c) 00h and (d) 02h forecast time.

Verification

Overall the hydrometeor analysis verification indicates improvement over the control. The skill of the analysis as measured by the Critical Success Index (CSI) is higher for the experiment with the hydrometeor analysis for ceiling at each of the aviation critical thresholds (500, 1,000, and 3,000 ft). The 6-hour forecasts also have more skill, but as expected the differences are smaller in the forecasts. Figure 5 shows the CSI results for the 1,000 ft ceiling threshold.

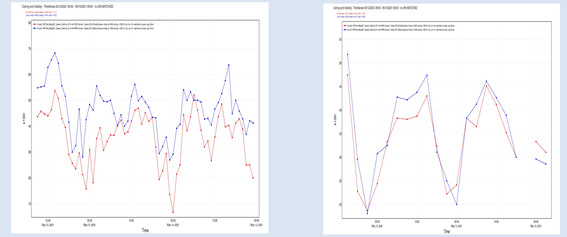

Figure 5. Critical Success Index (CSI) scores for RRFS forecasts of ceiling below 1000 feet AGL. Left: 00h analysis. Right: 06h forecasts. Blue: hydrometeor analysis on. Red: hydrometeor analysis off.

The hydrometeor analysis increases the high bias for low ceilings in RRFS analyses (Figure 6). In general we know that the hydrometeor analysis adds more clouds than it removes and tends to increase the bias. However the addition of clouds is often beneficial because it captures the aviation-critical low cloud events. The bias in the 6-hour forecasts shows only slightly higher values for the hydrometeor analysis experiment.

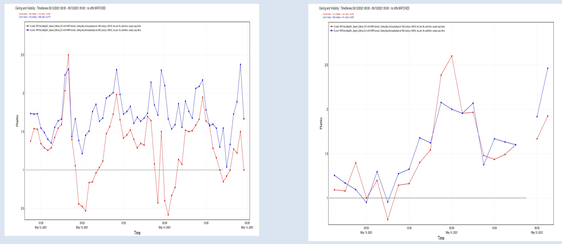

Figure 6. Bias statistics for RRFS forecasts of ceiling below 1000 feet AGL. Left: 00h analysis. Right: 06h forecasts. Blue: cloud analysis on. Red: cloud analysis off.

Performance diagrams for ceiling at thresholds of 500’ and 1000’ show that having the cloud analysis turned on (blue) provides better overall results than with the analysis off (red) under both criteria.

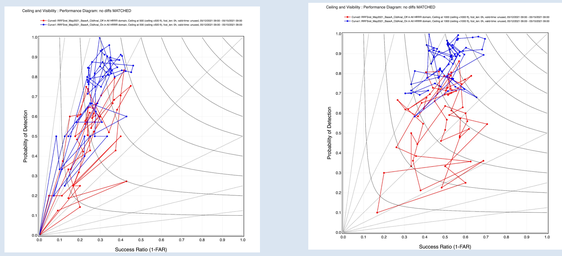

Figure 7. Performance diagrams for ceiling at thresholds of 500’ (left) and 1000’ (right). Blue: cloud analysis on. Red: cloud analysis off.