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FIM PERFORMANCE FOR SOME OF THE MAJOR EVENTS OF THE 2010-11 WINTER SEASON

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1. INTRODUCTION

At the last Weather and Forecasting/Numerical Weather Prediction Conference in Omaha in 2009 we showed some examples of forecasts from a new global model known as the FIM, for Flow-following finite-volume Icosahedral Model, that was developed at the Global Systems Division (GSD) of ESRL (Szoke et al. 2009). In addition to the icosahedral horizontal grid, other differences between the FIM and current operational global models such as the Global Forecast System (GFS) and the European Centre for Medium-Range Weather Forecast model (ECMWF) include an adaptive isentropic-sigma hybrid vertical coordinate that is used in the FIM. At the earlier conference we demonstrated that FIM forecasts compared favorably to those from the GFS and ECMWF for some challenging “dropout” cases, and suggested that the performance was consistent with a potential future role as part of the North American Ensemble Forecast System (NAEFS).

Since the last conference there have been a number of improvements to the FIM (these are detailed in an accompanying talk at this conference by Benjamin et al. 2011). Additionally, there are a number of versions of the FIM (discussed in the next section) that were not available in 2009. With this in mind the goal of a paper for this conference was to give some examples of forecasts from the various versions of the FIM, and compare these forecasts to operational models such as the GFS and the ECMWF.

Over the last couple of years we have examined a wide variety of weather events in both summer and winter, and including tropical systems, in terms of FIM performance relative to other operational models. Generally we have found that the FIM forecasts, which are initialized from the identical conditions as the operational GFS, can be similar to the GFS or ECMWF, but by 120 hours into the forecasts do not systematically resemble a particular model. In some instances the FIM forecast will be different from either model, but well within the scope of reasonable solutions (say, as seen in an ensemble of forecasts). Both are characteristics of the FIM that appear to make it a potential useful addition to a global forecast ensemble.

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When we submitted the abstract to this conference, we intended on using the onslaught of Nor’Easters that hit the East Coast in the winter of 2009-10 as our primary examples, since these events had such significant impact. However, this winter has also seen a number of high impact events, both on the East and West Coast and in between, which were challenging forecasts for the operational models. Since the FIM and its various versions continue to undergo development, it is more appropriate to use more recent examples in our comparisons. Therefore, after a couple of examples of typical FIM model behavior relative to the other operational models, we will concentrate on a number of recent events from the current (2010-11) winter.

2. CHARACTERISTICS OF THE FIM

As noted, the acronym FIM indicates that the model uses a flow-following (i.e. quasi-Lagrangian) vertical coordinate, finite-volume numerics, and an icosahedral global grid. An update and more detailed description of the FIM can be found in the talk by Benjamin et al. (2011, this conference), and on the FIM website at http://fim.noaa.gov/. The spacing of this icosahedral grid is unique in that it is basically the same at any point on the globe, rather than varying from pole to equator in a typical grid point model. Figure 1 shows the FIM icosahedral grid with an overlaid image of temperature at the surface.

The basic FIM is run twice per day at ESRL/GSD, at 1200 and 0000 UTC, out to 240 h. The horizontal resolution for this version of the FIM, as determined by the distance between the cell centers of the rhombi, is 30.2 km, and is referred to as G8 (“FIM8”). The FIM uses an isentropic-sigma hybrid coordinate, similar to the Rapid Update Cycle (RUC) model. The first FIM real-time runs began in February 2008, using GFS initial conditions, GFS physical parameterizations, and physics from the Weather Research and Forecasting (WRF) model. In November 2008 the vertical resolution of the FIM was increased from 50 levels with a top at 200 mb to 64 levels with a top at 10 mb. A variety of other changes have occurred since late 2008, with several versions of the FIM being run in real-time to test various configurations.

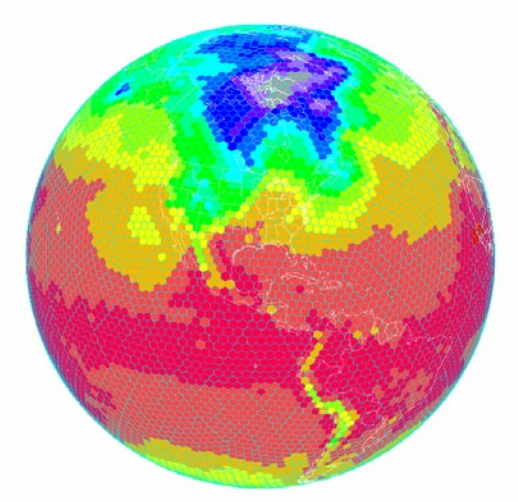


Figure 1. The icosahedral grid of the global FIM.

The various FIM configurations that are shown in this paper are summarized below (number in parentheses is the horizontal grid resolution in km):

- FIM = FIM8 - GFS GSI (30)
- FIMZ15 = FIM9 – EnKF (15)
- FIMY – EnKF (30)
- FIMX ~ FIMChem = FIM7 – GFS GSI (60)

Here GSI stands for Gridpoint Statistical Interpolation and EnKF Ensemble Kalman Filter as methods of initializing the FIM.

One of the major changes during the past year was the implementation of the GFS physics into all the versions of the FIM. In order to continue our evaluation of FIM performance relative to GFS, we obtained the physics package for the operational GFS upgrade in late February 2010 (the actual upgrade into NCEP operations occurred 1200 UTC 28 July 2010). The main components of this upgrade were

- Updating radiation for
- increased CO^2 concentration;
- ability to use cycled O^3 concentrations from the Global Data Assimilation System instead of relying on a climatological O^3 distribution.
- Introduction of monthly climatology of aerosol distribution for use in both the long and short-wave radiation routines.
- Updating shallow convection from a simple enhanced mixing above the planetary boundary layer to the Simplified Arakawa Schubert (SAS, Hong and Pan 1998) mass-flux scheme appropriately adapted for shallow (top ~ 3km AGL) convection.
- Minor change to the PBL scheme to introduce more vertical mixing above the planetary boundary layer.
- Updating the deep convection (SAS) scheme by replacing the former randomized cloud-top to a specified entrainment rate for the updraft and downdraft, and allowing detrainment from the updraft to occur at all levels, not just at the updraft equilibrium level.
- Extensive code cleanup having appreciable effect on calculations.

Aside from the GFS physics comparisons, old and new, we continued to compare real-time FIM results between the operational GFS initial conditions based on the operational GSI 3dVAR (see Hamill et al. 2011). In general, we tried to keep at least one pair of real-time runs at G8 (30km horizontal grid spacing) running with an identical model and physics configuration, differing only in the use of one or another of this pair of initial conditions. For the most part, FIMY, FIMZ and FIM9 used these EnKF initial conditions during the second half of 2010.

The introduction of the new physics package into the real-time FIM runs was not complete at the time some of the real-time forecasts presented in this paper were made. In particular, the long-wave radiative effect of CO^2 was recently discovered to have been inadvertently turned off. This error was fixed beginning with all runs on 17 Jan 2011, and therefore was present for all but the last two cases discussed in the next section. We believe the impacts of this error on specific forecasts presented here is small, since the radiative time scale of relevance is arguably an order of magnitude larger than the synoptic. Moreover, the impacts are the same in all FIM runs, so comparisons between different FIM runs are still considered worthy of examination. We also note that differences between FIM forecasts and those with GFS or the ECMWF noted here are qualitatively similar to differences between these models we have observed with FIM runs using the old GFS physics when that was also part of the GFS operational configuration.

3. CASES

We will begin with an overview case that demonstrates some of the typical behavior we have seen when comparing the FIM model to other operational models. When the abstract for the conference was submitted we intended to show cases from the winter of 2009-10, which featured several impressive East Coast winter storms. However, given the evolving nature of the FIM as noted above, and the occurrence of another round of very impressive and challenging recent storms, our cases will be from the 2010-11 winter season, through early February 2011. We will also show examples of model performance for a couple of other less dramatic examples.

3.1 *Case 1: Mid-January 2011 potential western trough*

The first case is simply a comparison between 7-day (168-hour) forecasts of 500-mb height for a case of a shortwave trough coming down the backside of an upper-level ridge positioned along the West Coast in mid-January 2011. Forecasts from the FIM (unless otherwise noted, FIM will denote the FIM-30 km run),

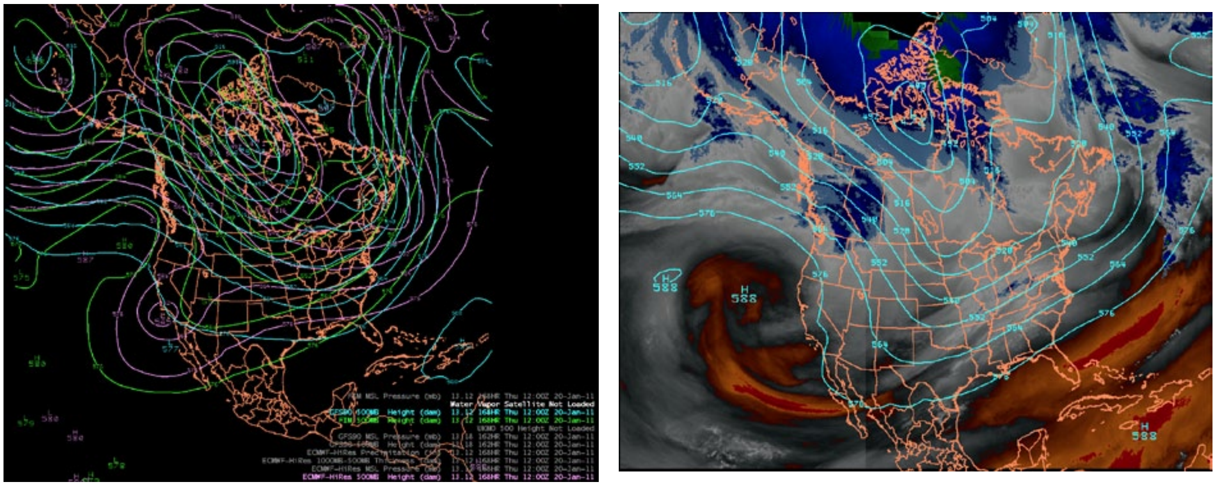


Figure 2. Comparison of the FIM (green), GFS (cyan), and ECMWF (magenta) 168-h forecasts of 500-mb height (contours every 12 dm) from the 1200 UTC on 14 January 2011 runs (left side). The verifying analysis is shown on the right for 1200 UTC 20 January 2011.

GFS, and ECMWF are shown in Figure 2, along with the corresponding analysis.

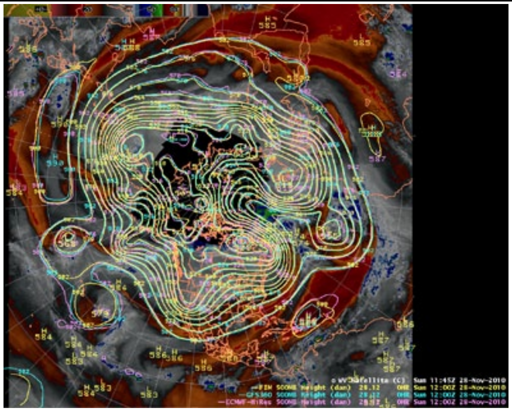
A comparison of the GFS and ECMWF forecasts shows a difference that is quite typical between these two models with situations such as this; the ECMWF will often dig the shortwave trough far more than the GFS, which is typically more progressive. For this particular initialization, the FIM forecast was between the two predictions, not as deep as the ECMWF but digging the trough more than the GFS. Over the last couple of years we have often seen this behavior; that is, a solution between the GFS and ECMWF when those models differ. At other times, however, the FIM solution can be more similar to one of the models, although this can change from run to run, favoring the GFS for one run and the ECMWF for another. Indeed, for this case, a run initialized 36-h later and valid at the same time as the forecasts in Figure 2 (not shown) was similar to the ECMWF, which continued to be deeper than the GFS. As it turned out, the wave dug somewhat into the Central Rockies, deeper than the GFS forecast shown in Figure 2 but not nearly as much as the ECMWF. This turned out to be a significant shortwave as it tracked eastward, with the associated storm system leaving a swath of snow from the Rockies across the CONUS all the way into New England.

3.2 *Case 2: Late November to mid-December 2010 – High latitude Atlantic block*

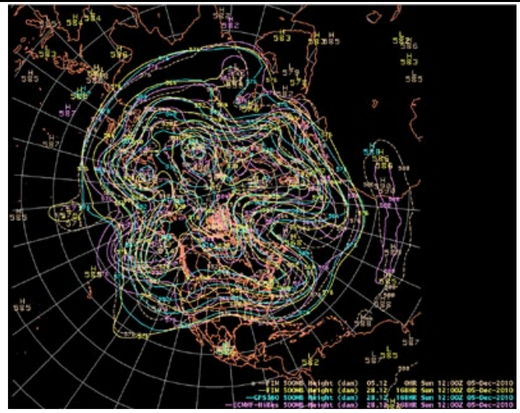
A very pronounced upper-level ridge built northward to very high latitudes from late November into December 2010, with a deep trough upstream over eastern North America and a deep trough downstream that brought a spell of harsh winter weather to Europe in the weeks before Christmas. Meanwhile record warm temperatures extended northward into the Arctic. The strong omega block persisted for two to three weeks, and while it persisted the longer forecasts showed less variation than would typically be the case for December, as well as greater accuracy. The point of showing this case is to demonstrate that the FIM model 500-mb forecasts were very consistent with the forecasts from the ECMWF and GFS across the Northern Hemisphere, even out to 10 days or more days.

The first set of forecasts in Figure 3 is for runs initialized at 1200 UTC on 28 Nov 2010. As seen in the analysis, the block is already in place in the Atlantic, with a high-amplitude 500-mb ridge extending northward across Greenland. The 168-h forecasts from this run are in extremely good agreement for the block, which persists with little change in the forecast, and in good agreement for the main features around the Northern Hemisphere. The verifying analysis is overlaid (dashed line) on the 168-h forecast. For the 240-h forecast time the predictions remain in remarkably good agreement for the upper-level ridge in the Atlantic, and the troughs over the Northeast and Europe. For this forecast the verifying analysis is shown in the figure in the lower right panel, and comparison of the forecast with the analysis indicates that if anything the blocking pattern was even more amplified than in the forecasts.

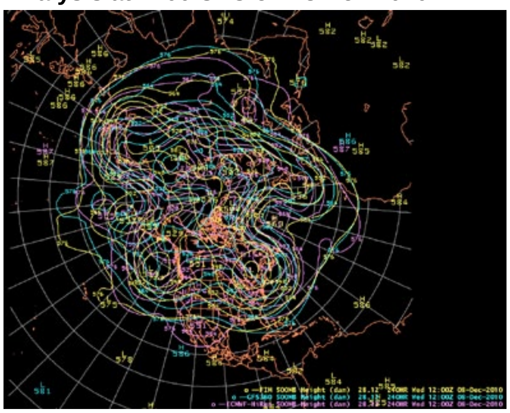
By 240-h into the forecast there are some areas around the Northern Hemisphere where the model forecasts do disagree. The most prominent is over the Southwestern CONUS, where the ECMWF forecast a large closed low that is not in the GFS and FIM forecasts. The verification indicates there was no such closed low, although there is a sharp shortwave trough over Arkansas that is not in any of the forecasts.



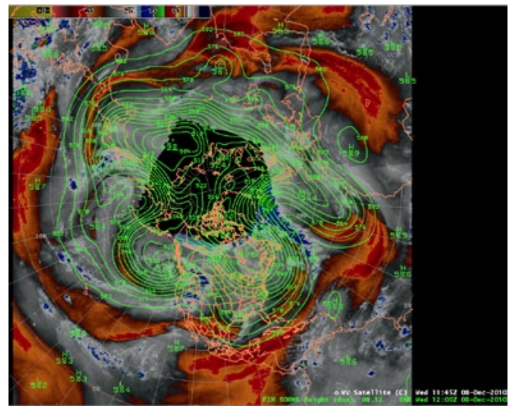
Analysis at 1200 UTC on 28 Nov 2010



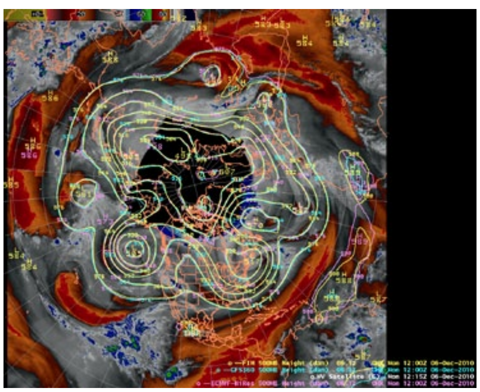
168-h forecast valid 1200 UTC 3 Dec 2010



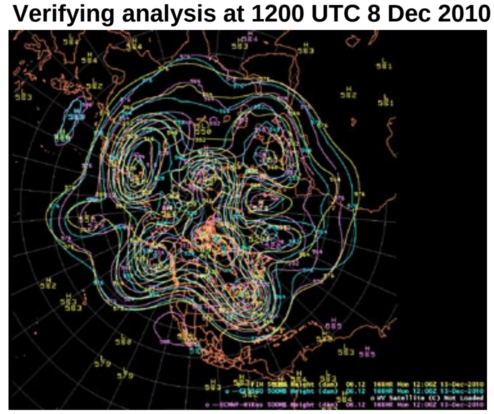
240-h forecast valid 1200 UTC 8 Dec 2010



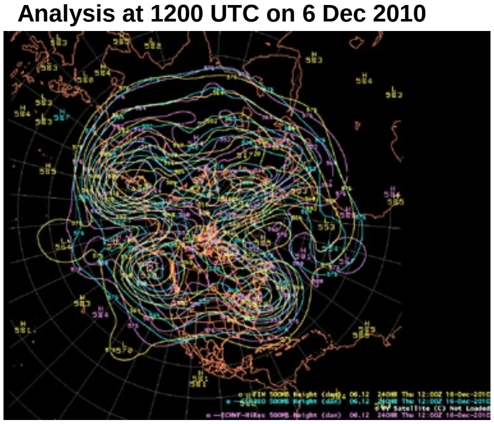
Verifying analysis at 1200 UTC 8 Dec 2010



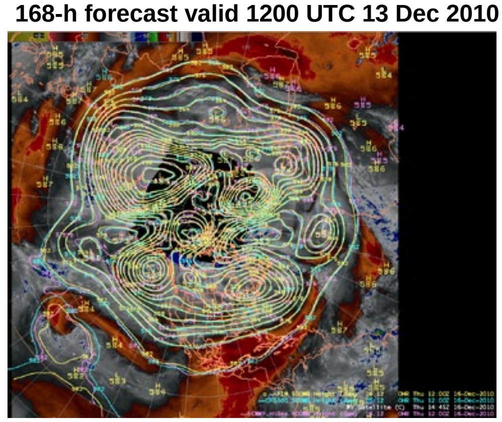
Analysis at 1200 UTC on 6 Dec 2010



168-h forecast valid 1200 UTC 13 Dec 2010



240-h forecast valid 1200 UTC 13 Dec 2010



Verifying analysis at 1200 UTC 13 Dec 2010

Figure 3. Comparison of the FIM, ECMWF, and GFS for two sets of forecasts for Northern Hemisphere 500-mb heights. Colors as in Figure 2 for this and subsequent figures with comparisons.

The other set of forecasts is from over a week later, initialized on 1200 UTC on 6 Dec 2010. The analysis shows that the Atlantic block was not quite as amplified on 6 Dec as it was two days later (as noted above). The forecasts continued to show a persistent block, although energy begins to undercut it with a system moving beneath the upper-level ridge and across the Atlantic after about a week into the forecast. With this occurring model agreement by 240-h was certainly not as good overall as for the forecast from a week earlier, but generally still good for a 10-day forecast.

The energy undercutting the Atlantic block allowed for a shift in the mean ridge position that had been along the West Coast to an inland position more over the CONUS. This opened up the West Coast to a long fetch of very moist flow off the Pacific, and indeed mid-December began the start of an extremely wet system that focused on California for several days. The next case takes a brief look at this period and some of the model precipitation forecasts.

3.3 *Case 3: Mid-December 2010 – Heavy West Coast precipitation event*

As noted at the end of the previous case, the breakdown of the Atlantic block shifted the West Coast ridge inland and set up that area for a major precipitation event. Over a several day period from 17-20 Dec 2010 Northern and Central California was blasted with an incredible storm. Precipitation totals in the higher terrain areas ranged from 10 to 15 inches, with snowfall of 5 to 10 feet and more. Mammoth Ski Area in Central California peaked out at 162 inches of snow at the higher portion of the area, with a peak wind gust of 164 mph. The 7-day precipitation totals for the CONUS ending at this time are seen in Figure 4.

As seen in the last section, the change in the pattern that led to the big storm was well forecast by the models, as were the heavy precipitation amounts for Central and Northern California. Not quite as well forecast far in advance was the amount of precipitation

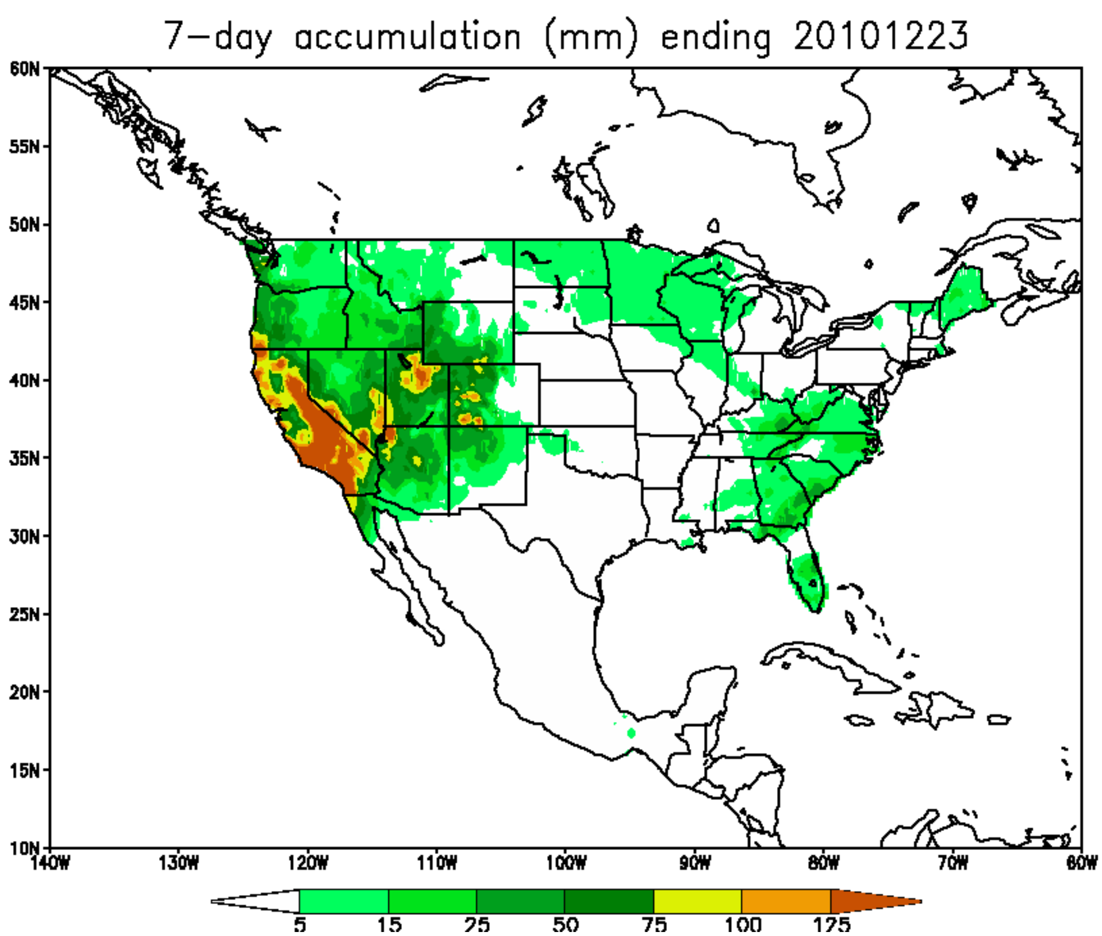


Figure 4. Seven-day precipitation totals ending on 1200 UTC 23 Dec 2010. These totals can be roughly compared to the forecasts shown in Figure 5. Maximum amounts were in the 10-15 in (~300-~450 mm) within the area in red in the figure.

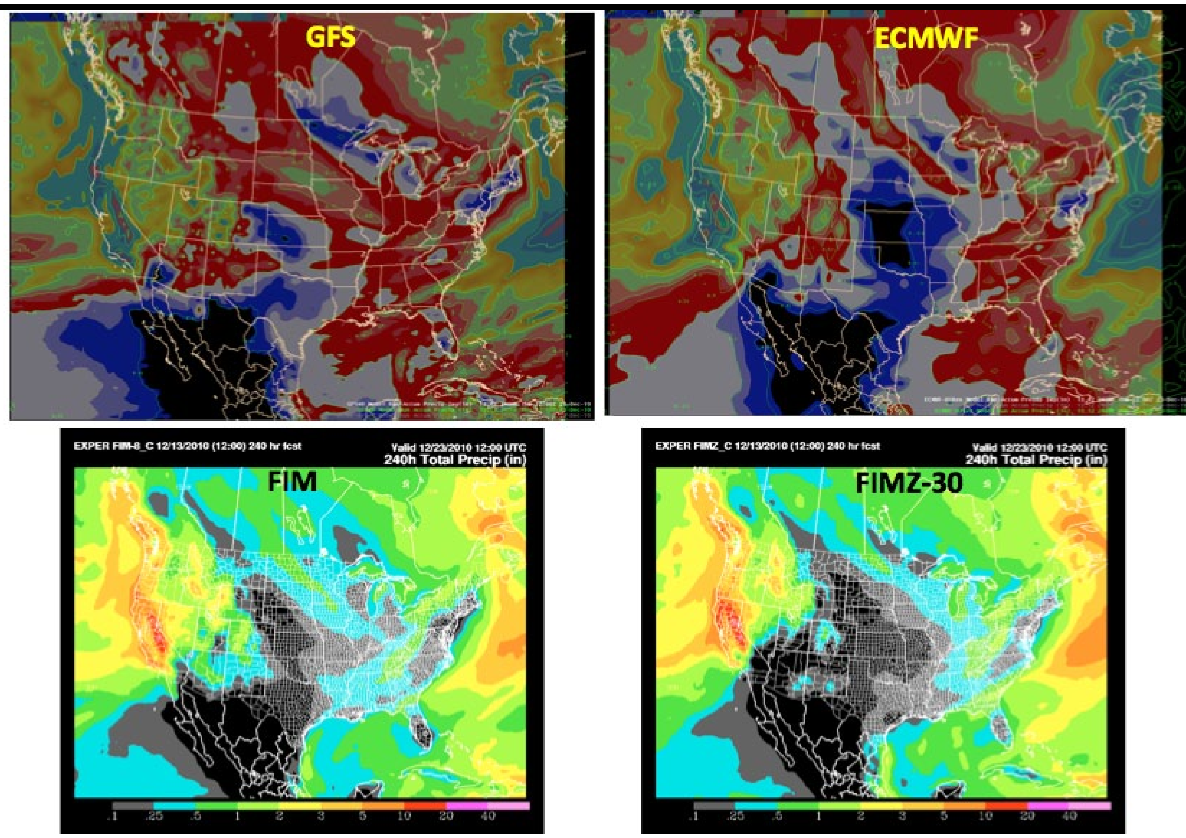


Figure 5. Forecasts from runs initialized at 1200 UTC on 13 Dec 2010 for run accumulated precipitation ending at 1200 UTC on 23 Dec 2010.

that ended up dousing Southern California and areas of the Southwest, as the atmospheric river dipped southward after 19 Dec. But for this case we will concentrate on a comparison of 10-day precipitation forecasts ending at 1200 UTC on 23 Dec 2010.

Most of the precipitation, at least in the West, fell during this part of the 10-day forecast period, so the distribution shown in Figure 4 can be compared to the forecasts shown in Figure 5. In Figure 5 the color tables match for the top two figures (from AWIPS) and the bottom two (from the FIM web page). The two FIM forecasts are similar in amounts across Central California (greater than 10 in) but the FIM has extends the precipitation better into Southern California. The ECMWF and GFS also have a similar distribution to each other and to the FIM. All forecasts show the "atmospheric river" as a band of heavier precipitation extending to the west-southwest off the California coast and into the eastern Pacific.

3.4 *Case 4: Pre-Christmas 2010 Close call/false alarm Nor'Easter*

The relatively quiet late fall and early winter along the East Coast looked to be about to change as longer range forecasts showed a potential East Coast snowstorm. What is interesting about this case is the fluctuation between subsequent runs, with seemingly a different model taking a turn with a threatening forecast. A sampling of this variation for three different initialization times is shown in Figures 6 to 8. All the model forecasts verify at the same time, 1200 UTC on 20 Dec 2010, with the GFS analysis for this time displayed in Figure 6. As seen in the verification, the storm ended up going out to sea and barely brushing the coastline (although, it did end up stalling in the Gulf of Maine with considerable wrap-around moisture after 20 Dec that did produce accumulating snows in parts of New England).

It is interesting to speculate on the fallout of this model inconsistency for a storm that proved to miss the large populations centers along the East Coast, in terms of how forecasters viewed the model predictions for the next storm that was soon on the horizon, the big post-Christmas blizzard that blasted New Jersey and New York City, as well as New England, after leaving a swath of snow across many southern states on Christmas Day. The NWS forecasts as that event got closer were actually quite good, with the issue here being how much trust the forecasters would have had in the longer to medium range predictions after just going through a false alarm situation.

Examination of the figures for this case shows the model differences were quite significant. For the first prediction shown (Figure 6) for the 180-h forecasts from 1200 UTC on 13 Dec, the GFS is seen to be the most threatening, with the FIM much farther out to sea, as was the ECMWF (in addition to being faster to move the storm northward). For the forecasts initialized 48-h later (Figure 7) the GFS is still quite close to the coast, with a considerable amount of precipitation (which would be

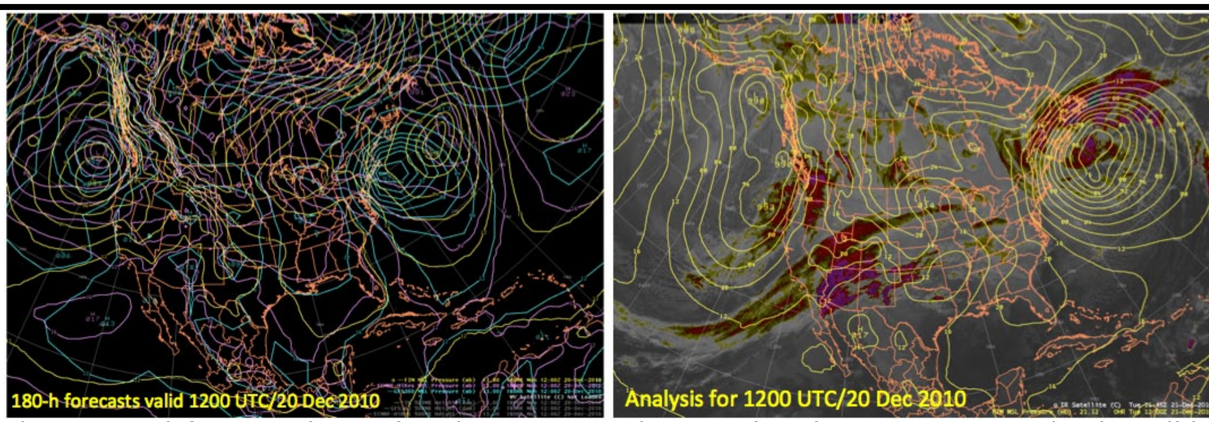


Figure 6. 180-h forecasts of MSLP from the FIM, GFS and ECMWF from the 1200 UT compared to the verifying analysis on the right for 1200 UTC 20 Dec 2010.

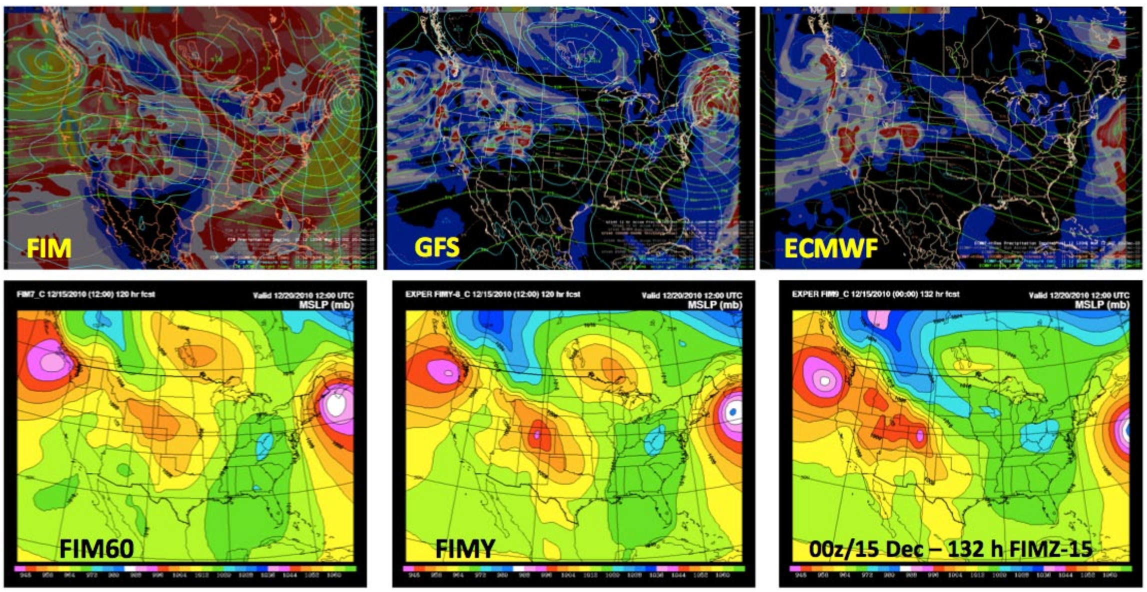


Figure 7. Comparison of 120-h forecasts (except for FIMZ-15) of mslp from the GFS, ECMWF and various versions of the FIM, from the 1200 UTC 15 Dec 2010 runs, valid at 1200 UTC 20 Dec 2010. Also shown in the top row is 500 mb height and 12-h precipitation (run total accumulated precipitation for the FIM).

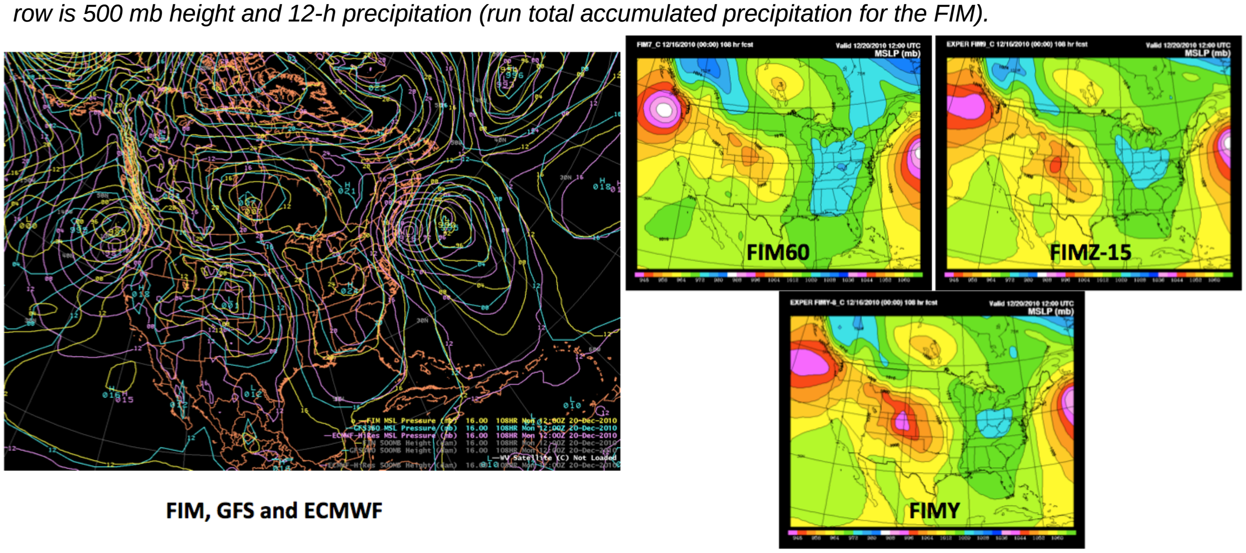


Figure 8. Similar to Figure 7, but for 108-h forecasts from the 0000 UTC 16 Dec 2010 valid 1200 UTC 20 Dec.

largely snow) wrapping back into New England. The FIM, which is initialized in the same way as the GFS, is a little farther to the east with the storm, just enough so to keep most of the snow out to sea. The ECMWF has the storm well off the coast, as does the FIMY and FIMZ-15 (these both use ENKF initialization, with the FIMY at 30 km and the FIMZ-15 at 15 km horizontal grid resolution; the FIMZ is run only at 0000 UTC so that run is shown here). The lower resolution FIM60, which is otherwise identical the FIM, is quite similar in position to the FIM forecast with the strong low just far enough offshore. What is quite interesting (and probably was perplexing for forecasters) is that in the next set of runs 12-h later (Figure 8) the ECMWF swapped places with the GFS, with its forecast now producing a big storm. The FIM runs remained off shore for this forecast cycle. Given this was less than 5 days to the potential event, there was a lot of forecast uncertainty still occurring in the operational models.

3.5 *Case 5: Post-Christmas 2010 big Nor'Easter*

This was the big one, a raging blizzard that moved up the East Coast after tracking eastward across the nation and dropping a swath of snow on Christmas Day across parts of the deep South. The storm originated from the last big system to hit the West Coast before Christmas, which dropped flooding rains across Southern California. The associated upper-level shortwave tracked eastward and then joined with a southward moving system in the northern jet stream to form a deepening trough over the eastern CONUS. With plenty of cold air in place, having been drawn southward behind the storm discussed in the last section, the stage was set for a major snowstorm for many of the big cities along the East Coast for 26-27 Dec 2010. An overview of the East Coast snowfall for the event is shown in Figure 9, along with one of the many classic blizzard scenes from New York City with the storm. The combination of very cold temperatures and strong winds along with very heavy accumulations over a relatively short period (generally less than 24 h) made this a very significant and high impact storm.

As noted earlier, forecasts within a couple of days the event were quite good, with numerous watches and then warnings issued by the various NWS WFOs in advance of the storm. Here we will focus on the medium to longer range forecasts for the storm, where there was considerable variation among the models and issues of whether the storm would head out to sea, as the previous one had, or move up the coast and produce a big event. The goal is to examine how the FIM fit into the model spread seen in the operational models (particularly the GFS and ECMWF), and to compare the different versions of the FIM to discern what effect, if any, different model initialization techniques (GSI vs. ENKF) and resolution had on the forecasts. A number of consecutive initialization times with complete sets of runs were saved, and here we only show a relatively small sample that will attempt to represent some of the forecast issues faced in interpreting the model.

We begin with a longer range, 240-h (10-day) forecast comparison, shown in Figure 10, which also includes a verifying analysis for 1200 UTC on 27 Dec, when the deepening surface low was over Cape Cod. There is a wide variation in the three deterministic model forecasts shown, which should not be surprising considering they are 10-day forecasts. The ECMWF low has quickly moved northward and was well off the coast, and the GFS has a surface low well out to sea. For this forecast time the FIM did a remarkably good job, with a deepening surface low moving up the East Coast in good agreement with what occurred.

Figure 9. Snowfall totals for selected locations along the East Coast, courtesy of The Weather Channel. Photo is from 27 Dec 2010 showing the deep snow and blowing snow after the storm has passed through New York City, from the New York Times.

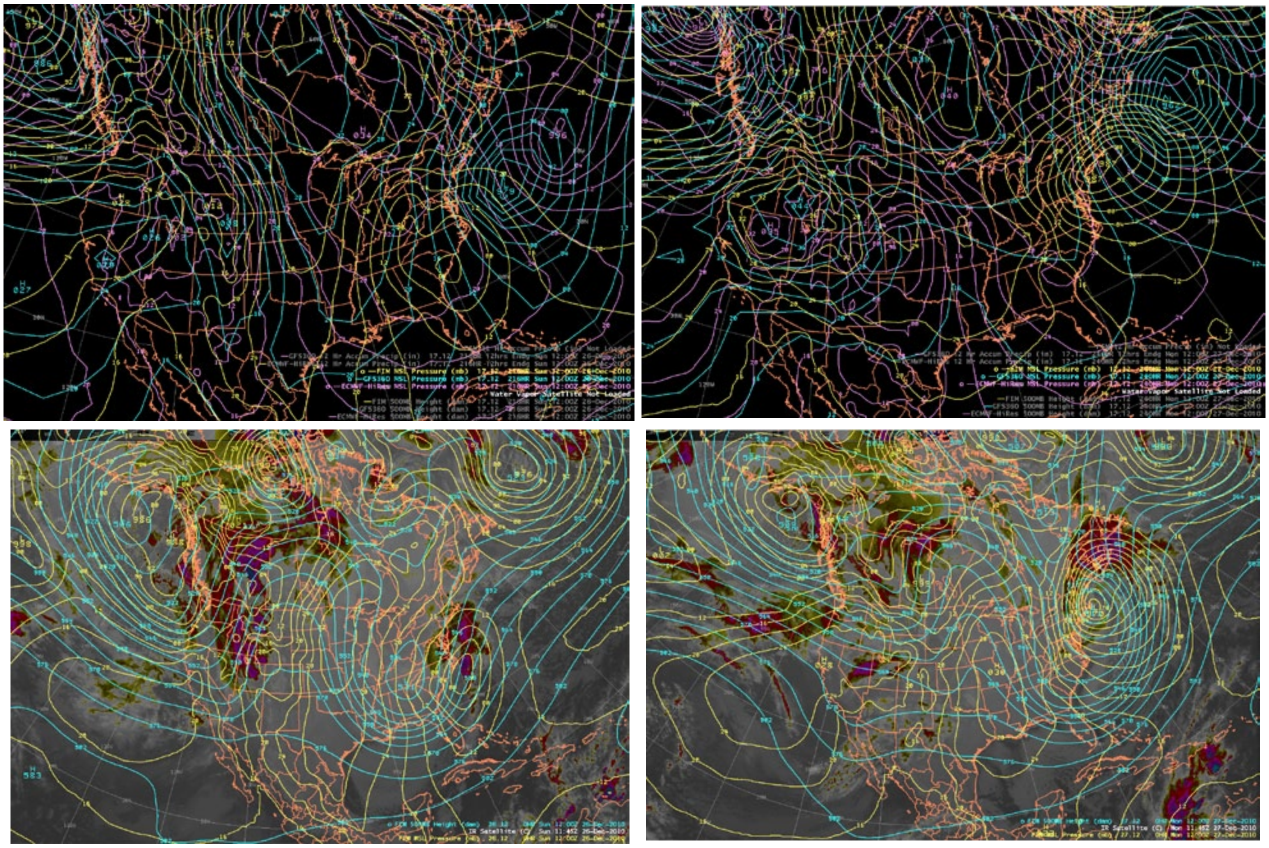


Figure 10. Forecasts of MSLP from the 1200 UTC 17 Dec 2010 FIM, GFS and ECMWF runs. Top left - 216-h forecast valid 1200 UTC 26 Dec; top right – 240-h forecast valid 1200 UTC 27 Dec 2010. Bottom row shows the corresponding FIM analyses of MSLP and 500-mb height for 1200 UTC 26 Dec (left) and 1200 UTC 27 Dec (right).

The subsequent forecasts over the next several days were not nearly as good from the FIM, with a much weaker storm that remained out to sea. This is seen in Figure 11, which shows MSLP comparisons for subsequent runs (12-h runs initialized at 0000 and 1200 UTC only are shown, no off-hour 1800 or 0600 UTC runs). Through the runs initialized on 0000 UTC 19 Dec all three (FIM, ECMWF and GFS) models were too fast in moving the storm up the coast. The intensity and position of the surface low varies considerably between FIM runs, while the GFS tended to be closest to the coast but quickest to move the storm northward. The ECMWF surface low remained rather far out to sea until the run initialized on 0000 UTC 19 Dec, then really slowed the storm down and moved it closer to the coast by the next run (on 1200 UTC 19 Dec).

In subsequent runs the ECMWF remained quite consistent in keeping the storm closest to the coast and in having a significant East Coast snowstorm. The GFS and FIM, meanwhile, generally remained too far off the coast with their forecasts. The FIM especially tended to delay any deepening until the storm had gone north of Cape Cod, generally following the pattern of the storm discussed in the previous section that did indeed stay out to sea before intensifying east of New England just before Christmas.

The next set of forecasts shown were initialized on 0000 UTC 20 Dec and are shown in Figure 12. This time we include a comparison of the various versions of the FIM as well. The typical behavior of some of the previous runs is illustrated in the comparison of the FIM and the ECMWF and GFS forecasts, with the ECMWF remaining the most threatening prediction. Comparing the various FIM versions, we can see that they all were still keeping the low too far off the coast in this set of runs.

Interestingly, the FIM60 (or FIM7), with the coarsest horizontal grid resolution equivalent to ~60 km, has the low closest to the coast of all the FIM runs (though still too far off the coast for significant precipitation on land). It also tended to be the slowest in moving the storm northward up the coast. Resolution does not improve the storm position forecast, at least for this initialization time.

An even larger set of forecast comparisons is shown in Figure 13, where we have added forecasts from the UKMET and NOGAPS models. The verifying time for the forecasts is either 0000 or 1200 UTC on 27 Dec, with the time chosen when the surface low was predicted to be closest to the coast. An MSLP analysis from the FIM for 0000 UTC 27 Dec is shown for

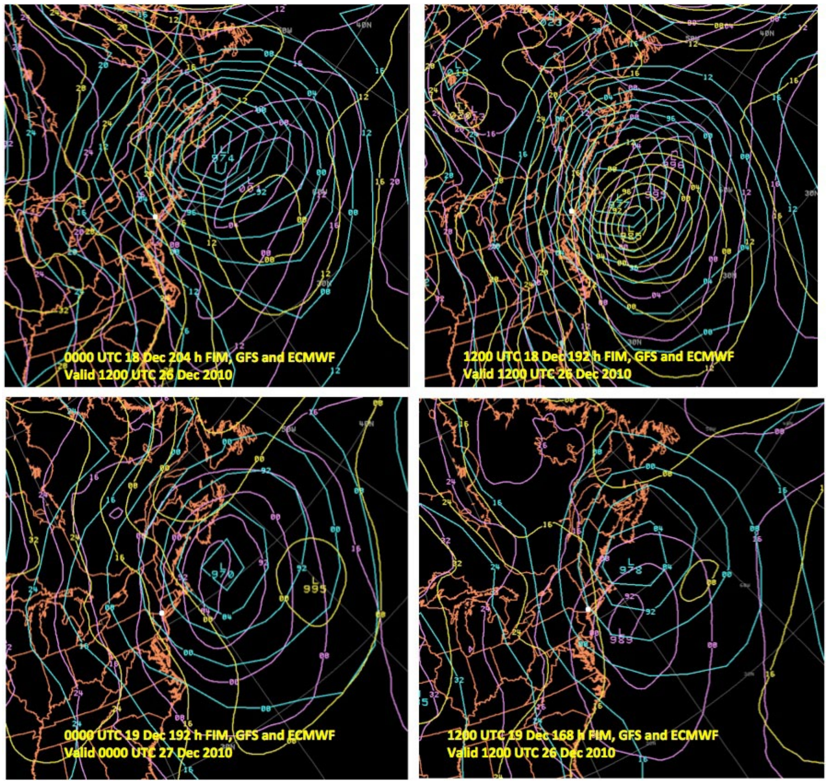


Figure 11. Series of forecasts of MSLP from the FIM, GFS and ECMWF runs initialized at 0000 UTC 18 Dec through 1200 UTC 19 Dec 2010, valid at the time indicated. Note that the pressure interval varies from 4 mb for the top row to 8 mb in the bottom row. White dot marks location of New York City.

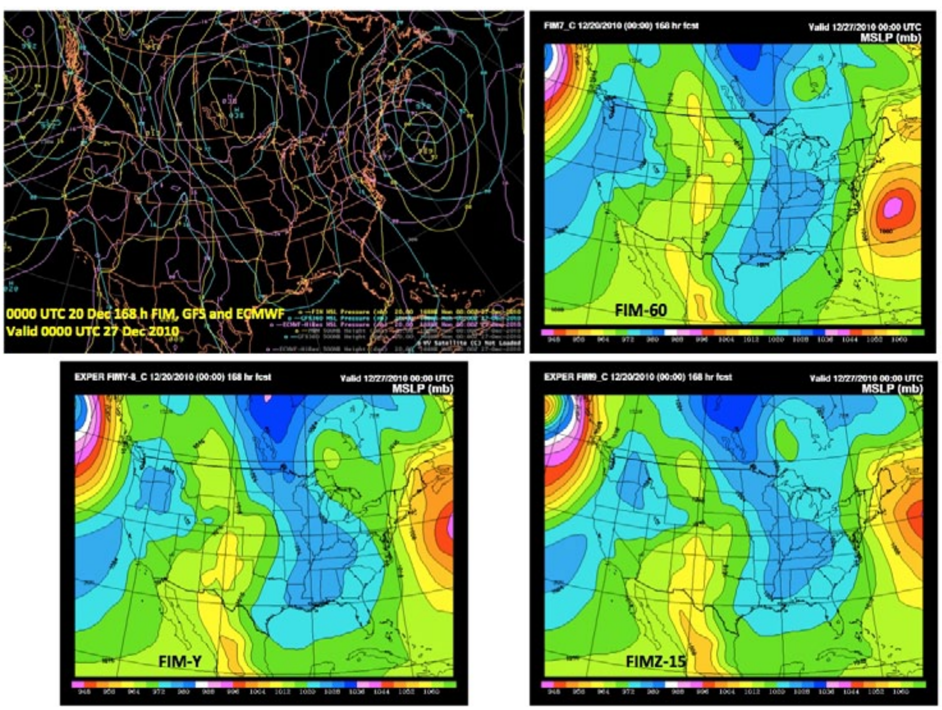


Figure 12. Forecasts of MSLP for runs initialized at 0000 UTC 20 Dec 2010, for 168-h forecasts valid at 0000 UTC 27 Dec. Note that the pressure interval is at 8 mb in the panel with the FIM, GFS and ECMWF.

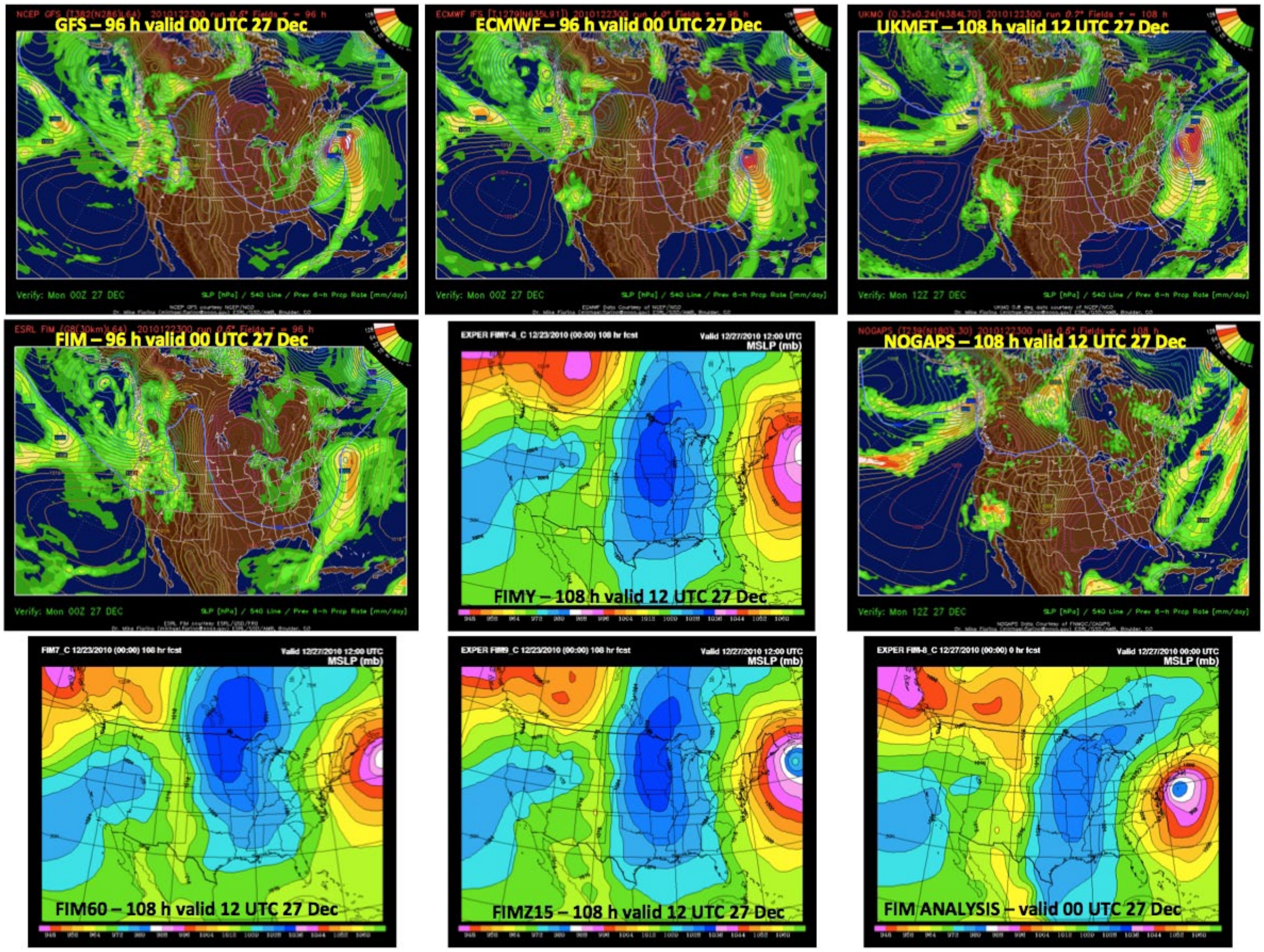


Figure 13. Forecasts of MSLP (and for some panels 6-h precipitation rate and 540 dm 1000-500 mb thickness line) for runs initialized at 0000 UTC 23 Dec 2010. The forecasts are for either 96 or 108-h, valid at the time indicated on each panel.

reference. There is considerable variation in the forecasts, although the GFS is now closer to the ECMWF, which remains closest to what verified. The FIM remains too far out to sea, as do the various FIM versions. The highest resolution FIM run (FIM9, labeled FIMZ15 in the figures) is now notably stronger with the central pressure of the storm.

The final initialization time shown is one of the more perplexing, and surely must have been cause for some concern amongst operational forecasters leading up to this event. In Figure 14 we present a similar comparison as in Figure 13, except that the FIMZ15 run was not available for this time (in its place is a forecast of 500-mb heights from the FIM, GFS and ECMWF, with little notable difference seen in that forecast).

All forecasts shown in Figure 14 are 60-hour predictions from 1200 UTC 24 Dec, valid at 0000 UTC on 27 Dec 2010. This is now quite close to the event, and yet there is still considerable variation in the forecasts. Perhaps the most interesting is that the ECMWF forecast is now taking the storm too far out to sea to produce any major snow accumulation in the big coastal cities along the East Coast. This is a dramatic change from what had been several days worth of very consistent runs. A very similar prediction is seen in the UKMET forecast, which had also been closer to the coast in some earlier runs. In contrast, the GFS is now an excellent forecast, with an intense storm positioned quite close to where it verifies, just east of New York City. The FIM made a very dramatic westward shift to its track in this run, after being consistently too far out to sea, and its forecast is just a little east of the GFS. The FIM60 is similar to the FIM, but remains slightly slower and is a bit further south at the forecast time. These two FIM runs use the same GSI initialization used in the GFS. The FIMY uses EnKF initialization, and its forecast looks similar to the ECMWF, with a more elongated low that remains a bit too far off the coast to produce a big storm.

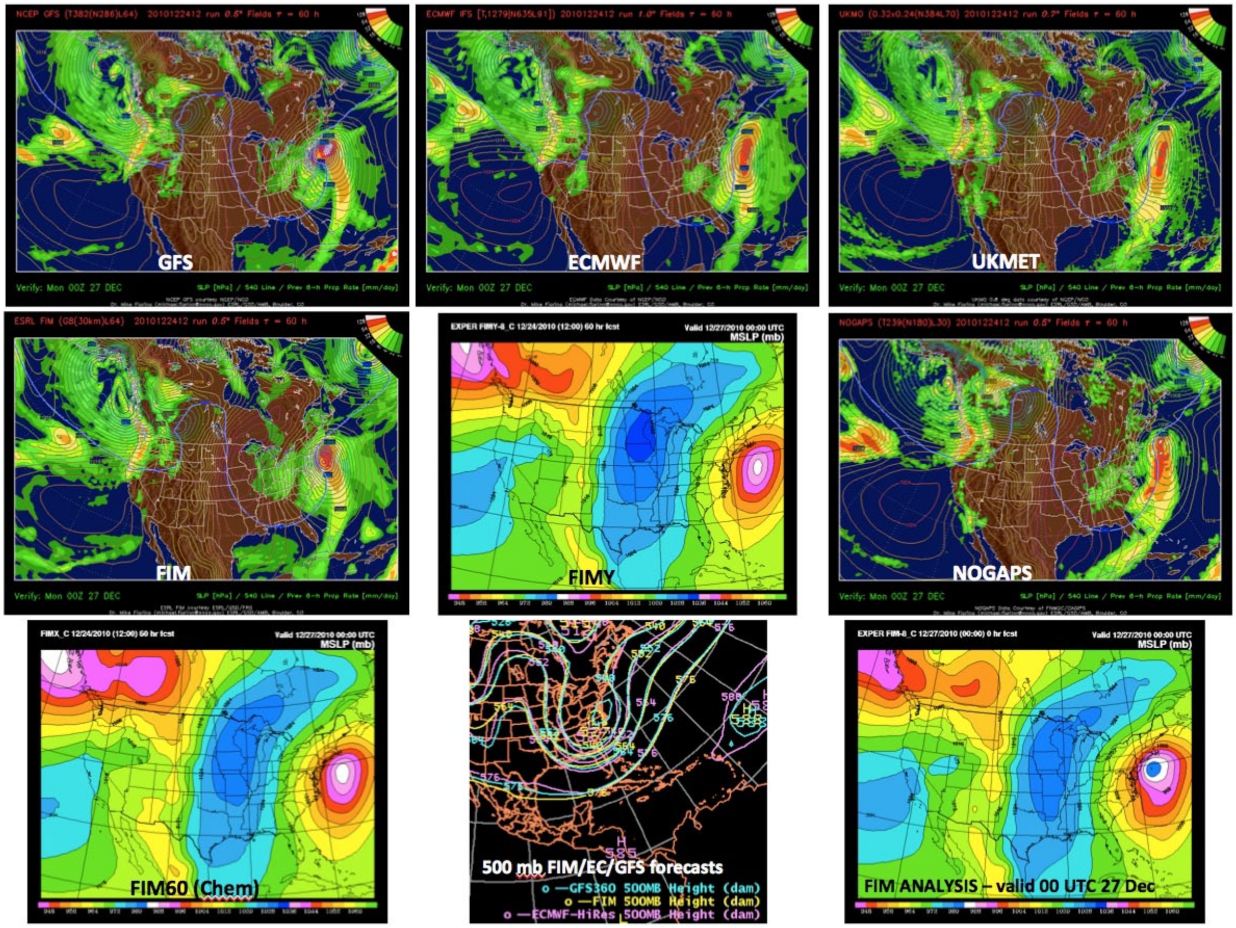


Figure 14. 60-h forecasts of MSLP (and for some panels 6-h precipitation rate and 540 dm 1000-500 mb thickness line) for runs initialized at 0000 UTC 23 Dec valid at 0000 UTC on 27 Dec 2010 (analysis shown in the lower right). Also included is a 60-h forecast of 500-mb height (at 12 dm intervals) from the GFS, FIM and ECMWF in the middle of the bottom row.

3.6 ***Case 6: Late January 2011 Nor'Easter***

The very active pattern for the East Coast continued through January, and in late January (actually during the AMS Annual Meeting) a storm intensified near the Mid-Atlantic and moved up the coast, leaving a swath of heavy snow from Washington D.C. to Boston (Figure 15). This is an interesting case to examine in that this Nor'Easter was another in a string of difficult storms to predict, with a range of model forecasts only a few days ahead of the event.

The first set of forecasts are shown in Figure 16 and illustrate that in the longer range timeframe the various models all were predicting a fairly weak storm that, to varying degrees, was predicted to head out to sea with little precipitation along the coast. Of these early forecasts, the FIM models tended to be farthest offshore, while the GFS was closer. The next sets of forecasts (shown in Figure 17) are from consecutive runs initialized two days later.

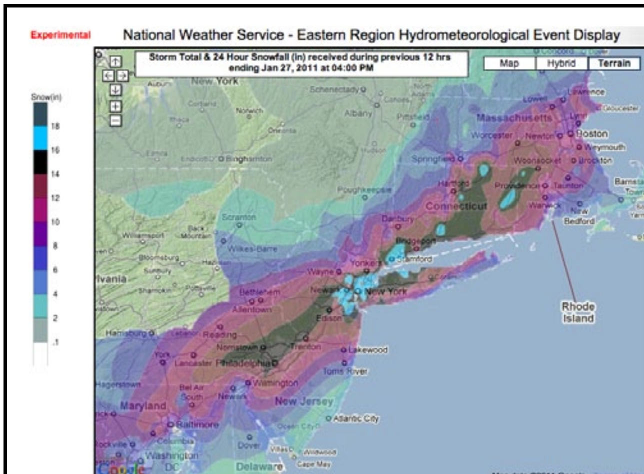


Figure 15. Snowfall totals (inches) for 26-27 Jan 2011.

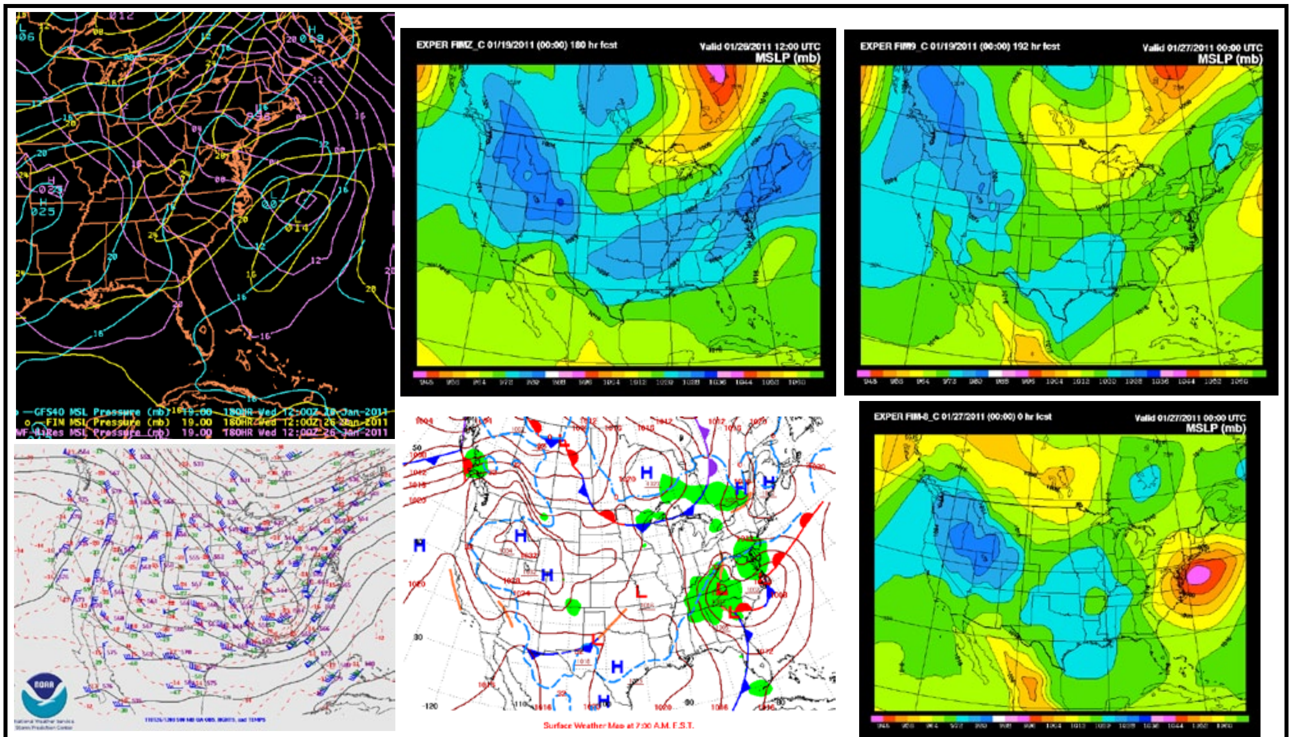


Figure 16. Top row: longer range (180-192 h) forecasts of MSLP for runs initialized at 0000 UTC 19 Jan 2011 valid at 1200 UTC on 26 Jan or 0000 UTC on 27 Jan 2011. Lower row shows analyses at 1200 UTC 26 Jan for 500-mb (lower left) and surface (middle), and of MSLP from the FIM for 0000 UTC on 27 Jan (lower right).

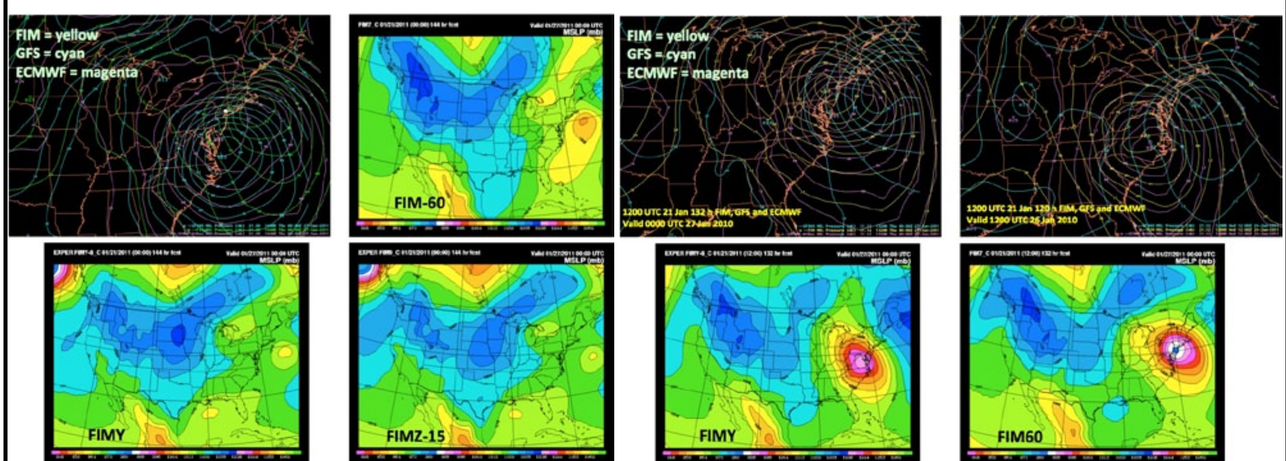


Figure 17. Two sets of 4-panels of MSLP forecasts from the various models. Left side: 144-h forecasts from 0000 UTC 21 Jan 2011, valid 0000 UTC 27 Jan. Right side: forecasts from 12-h later (1200 UTC 21 Jan), but for two valid times for the GFS/ECMWF/FIM MSLP comparisons.

The forecasts in Figure 17 illustrate the variability that was present in the model predictions, and the considerable change from the forecasts shown in Figure 16. In particular, for the runs initialized on 0000 UTC 21 Jan the operational GFS and ECMWF both predicted a major storm that would be positioned just off the coast to the south of New York City 6-days later, on 0000 UTC 27 Jan. The standard version of the FIM was quicker to move the storm up the coast, but also had a significant system. The central pressure of ~990 mb in the FIM forecast was not as deep as that predicted by the ECMWF (988 mb) and GFS (985 mb), however, both the FIM and the GFS deepened the storm significantly 12-h later (GFS down to 979 mb and FIM to 974 mb as the storm moved farther to the northeast). The other FIM versions were weaker with the storm, with the highest resolution FIMZ-15 still farthest out to sea. Interestingly, the lower resolution FIM-60 was stronger than the higher resolution FIMZ-15 and FIMY. Recall that the later two versions of the FIM use the EnKF initialization, whereas the FIM-60 uses GSI. The standard FIM also uses GSI, and the FIM-60 forecast was actually quite similar to that from the FIM, except the surface low was not as deep, which is consistent with the FIM having twice the horizontal grid resolution.

For the next set of forecasts from 1200 UTC on 21 January (right side of Figure 17) big changes occurred in the FIMY, which came into agreement with the other models in predicting a big storm (FIMZ-15 is not available for this time since it is only run at 0000 UTC). One significant change in all the FIM runs was in the storm track, which was shifted considerably farther to the west than just 12 h previous. In fact, the new storm track in the FIM took the predicted deepening low well inland, which would have produced a change to rain for all the major cities. In contrast, the GFS had the most threatening snow forecast, with a strong storm stalling southeast of Long Island.

A full comparison of various model runs is available for the next initialization time, 0000 UTC on 22 January, and these are shown in Figure 18. The forecast time displayed for each model was chosen as the time when the storm was the most threatening to the East Coast, which was generally the 120-h forecast valid at 0000 UTC on 27 January. All the model forecasts in Figure 18 have a strong storm, but there are notable position differences in some of the forecasts. For example, the GFS storm is predicted to be considerably farther offshore than in earlier forecasts, while the ECMWF, NOGAPS and UKMET all have a strong low quite close to the coast. The standard FIM model has a forecast that is farther out to sea than these three models, but not as far to the east as the GFS. Similar to the comparison discussed for the forecasts in Figure 17, the FIM60 has a similar position forecast to the FIM, but a storm that is not as strong, again consistent with its lower horizontal resolution.

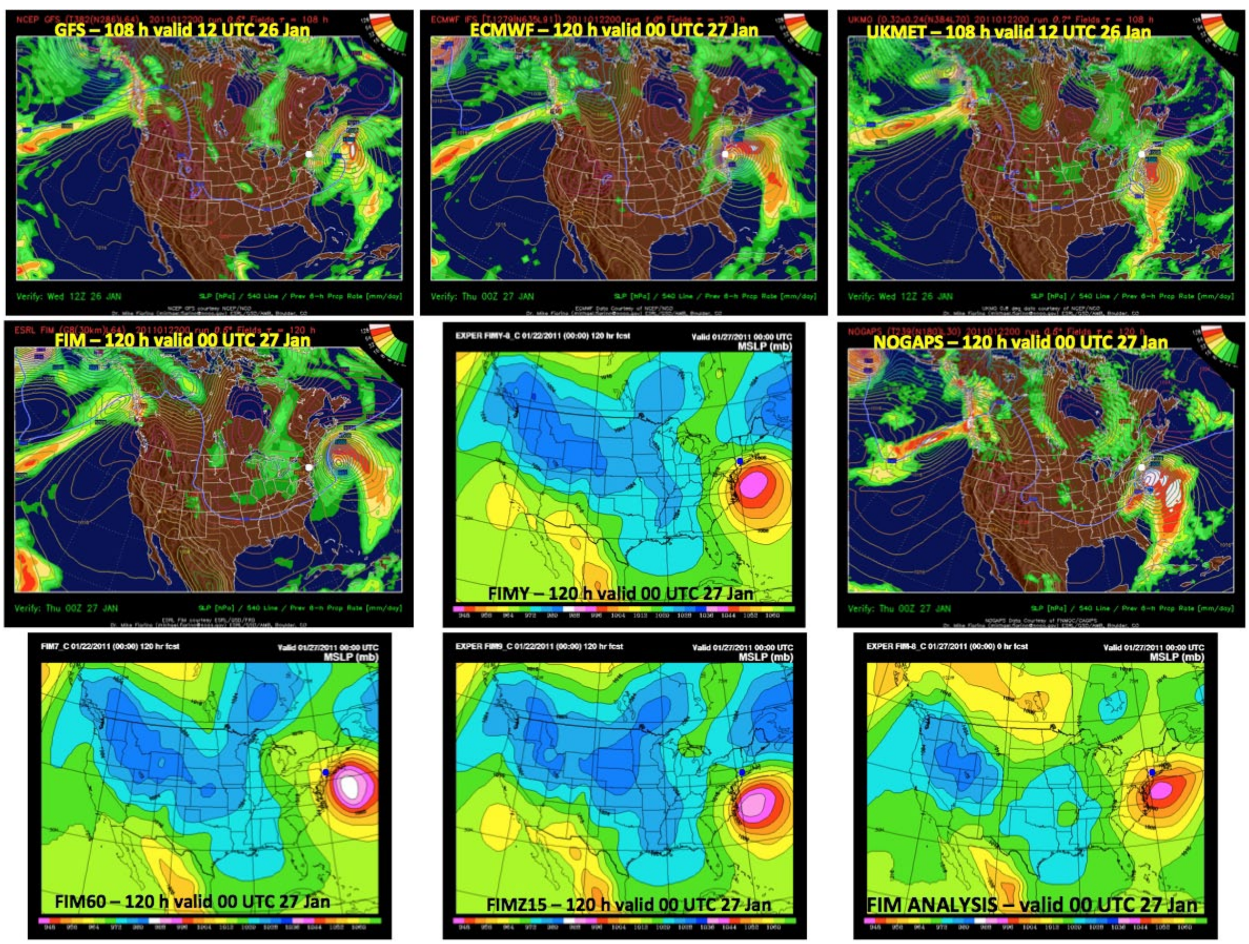


Figure 18. Comparison of forecasts for various model runs initialized at 0000 UTC 22 Jan 2011. The forecasts are valid for the time when the surface low was deemed most threatening, generally 120-h valid at 0000 UTC 27 Jan (the time of the analysis in the lower right. Some of the forecasts show only MSLP (4 mb interval), while other panels also display the 12-h precipitation rate (mm/day) and 1000-500 mb 540 dm thickness line, as well as MSLP at a 2 mb interval. Finally, a dot (white or blue) marks the approximate location of New York City, for reference.

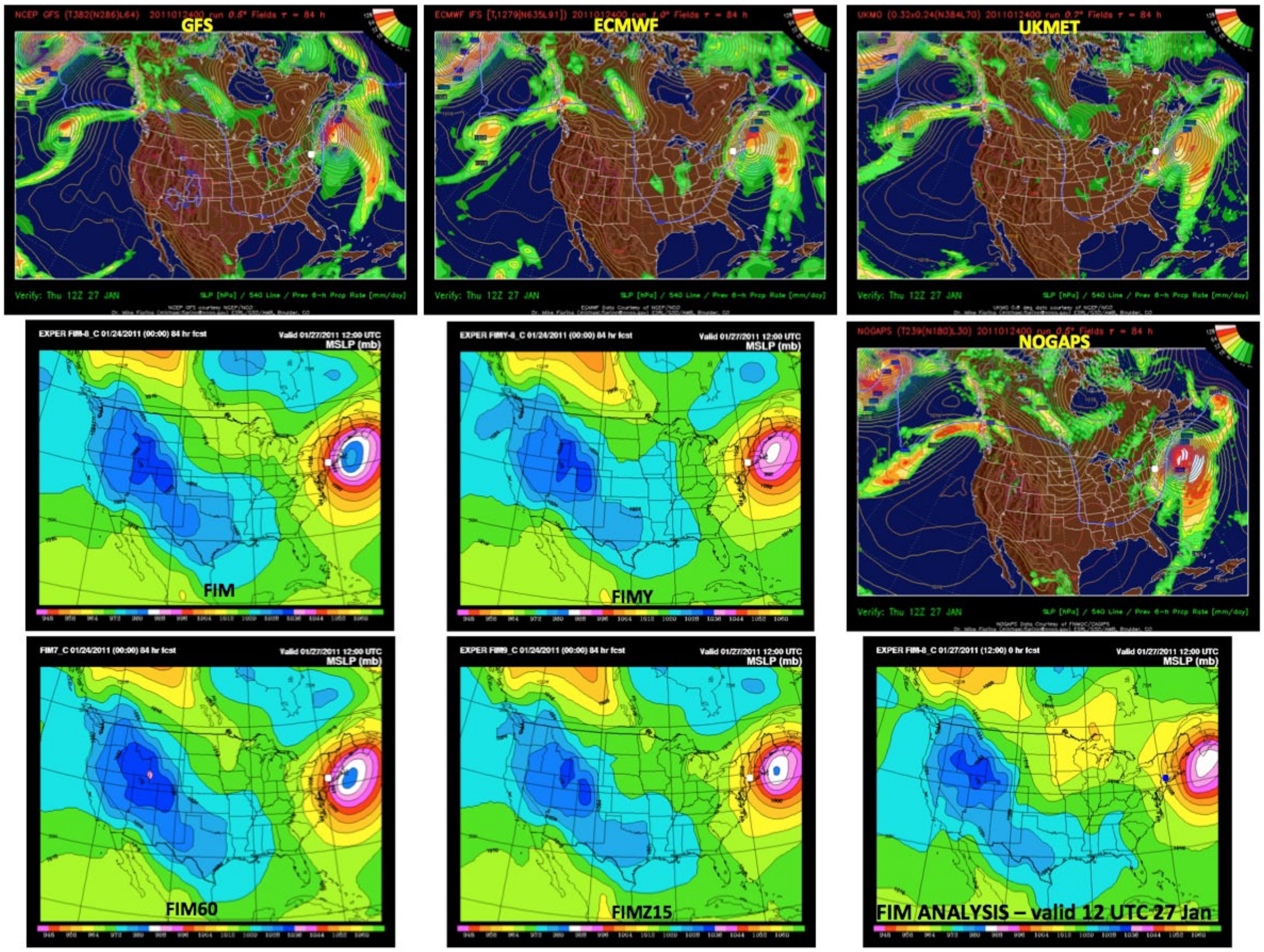


Figure 19. As in Figure 18, but for runs initialized on 0000 UTC/24 Jan. All are 84-h forecasts valid for the analysis time shown in the lower right, 1200 UTC on 27 Jan.

Examining the other two FIM runs (FIMY and FIMZ-15), both using the EnKF initialization, we see that the forecasts are quite similar, with the main difference a deeper surface low in the higher resolution FIMZ-15. The final set of forecasts are shown in Figure 19 for a shorter-range prediction, 84-h verifying on 1200 UTC on 27 Jan, initialized at 0000 UTC 24 Jan. These shorter-range forecasts are overall similar, with more subtle variations in position. Comparing to the analysis, the GFS has the better forecast position, with a storm that moves northward more quickly than in the other models, although the central pressure (976 mb) is stronger than what was observed (984 mb). This tendency for a stronger than observed storm is also seen in the two FIM runs that use the GSI initialization also employed by the GFS, with the FIM storm comparable in strength to the one forecast by the GFS, and the FIM60 storm similar in position but about 4 mb weaker. Note that even the FIM60 storm is stronger than either of the storms predicted by the EnKF versions of the FIM (FIMY and FIMZ-15). Of the FIM runs, the FIMZ-15 appears to have the best position and strength forecast.

3.7 *Case 7: The great "Groundhog Day" blizzard*

The last case examined was a huge storm in the middle of the nation on 1-2 Feb 2011 that produced blizzard conditions from Oklahoma to Wisconsin, along with an eastward-extending swath of snow and ice all the way to New England. This was an enormous storm affecting a large area of the country. In Figure 20 we show a montage that includes a couple of storm photos (from downtown Kansas City and the result of the storm on Lake Shore Drive in Chicago) along with a map of the snow totals, and the NWS Watches and Warnings that had been issued as of 2226 UTC on 31 Jan 2011.

As can be seen in Figure 20 by the huge area with a Blizzard Warning in place before the snow began, in some places for more than 24 h, the NWS did an excellent job of forecasting this event. Here we will examine more the medium to long-range forecast timeframe, when the exact track and magnitude of the storm still had considerable uncertainty. One way to illustrate this uncertainty is shown in Figure 21 through a series of "EPSgrams" for Chicago.

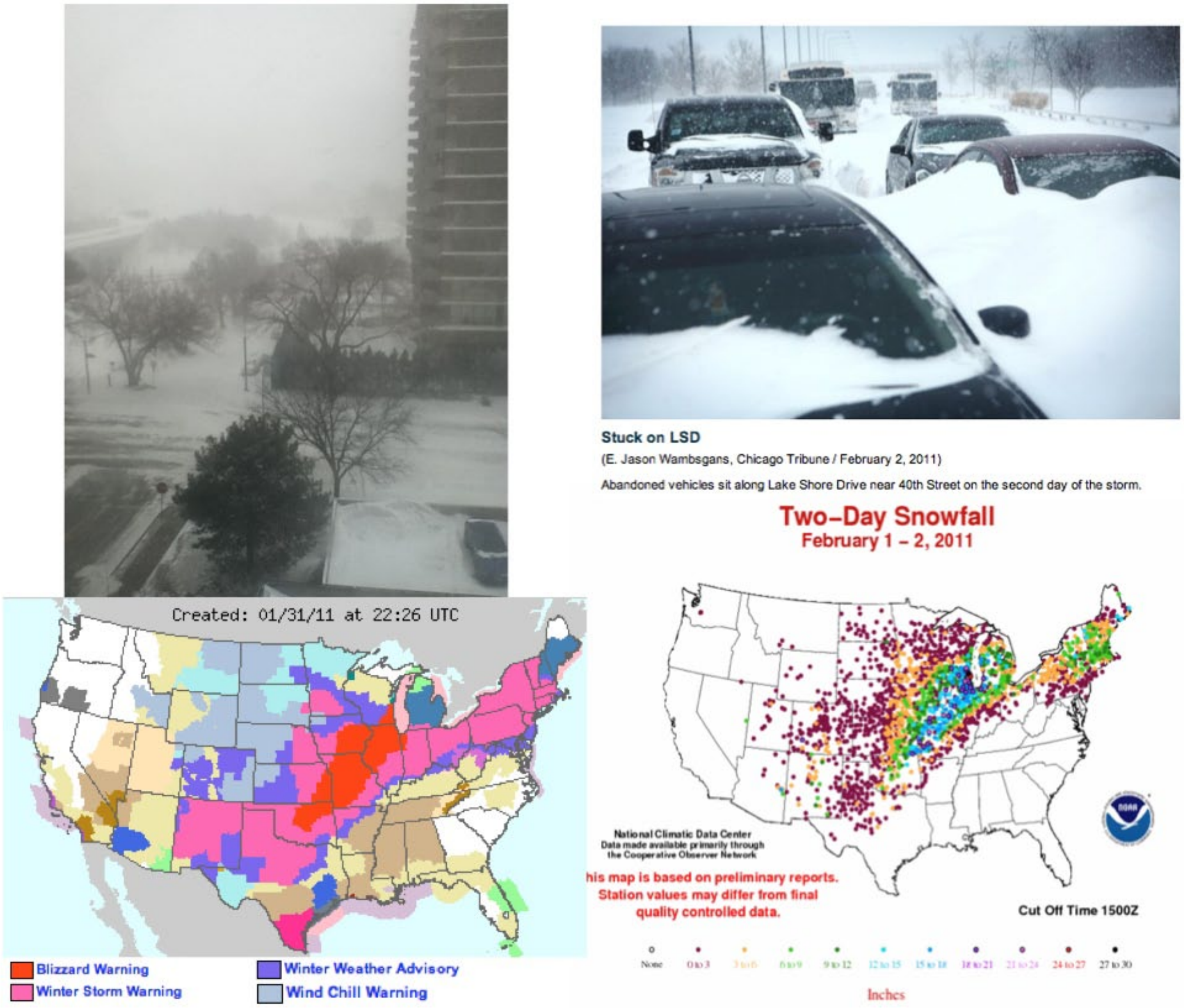


Figure 20. A montage of information for the 1-2 Feb 2011 blizzard. Top left – blizzard in progress near downtown Kansas City (Missouri) in the late afternoon on 1 Feb (courtesy of Carrie Szoke); top right – scene the next day (2 Feb) of stranded cars along Lakeshore Drive in Chicago, Illinois (from the Chicago Tribune). Lower right – total snowfall from the storm, and in the lower left, the large area of the nation covered by various NWS Warnings and Advisories, as of 31 Jan at 2226 UTC.

The EPSgram is a way of displaying the variations of the ensemble member forecasts in a graphical form. At first glance, it looks like the event may have been predicted in the two earliest forecasts shown (top row of Figure 21), but it turns out upon examination of the actual forecasts that the precipitation shown in the graphs is from a more northern wave that was being forecast to track eastward through the Midwest and which did in fact occur, but this system preceded the main storm, which was not forecast. In fact, examination of the various plots indicates that the storm was not very well predicted until the forecasts initialized on 27-28 Jan (bottom rows).

This is an interesting case of the models basically making a relatively good forecast of the larger scale quite far in advance, but not being able to capture important smaller-scale complexities involving the interactions of a northern and southern stream wave. These two troughs are seen in the 500 mb analyses shown in Figure 22, which also displays surface analyses for the same times (0000 and 1200 UTC on 2 Feb). The surface low that produced the big storm is actually associated with the shortwave trough seen lifting northeastward through the lower Midwest in the two analyses displayed in Figure 22. The actual storm was not terribly deep, with a minimum MSLP of about 997 mb reached at 0600 UTC on 2 Feb. However, an extremely impressive pressure gradient of over 50 mb was present between the surface low and the strong Arctic high that moved southward into the High Plains, resulting in the blizzard conditions over a huge area along with bitter cold temperatures behind the storm.

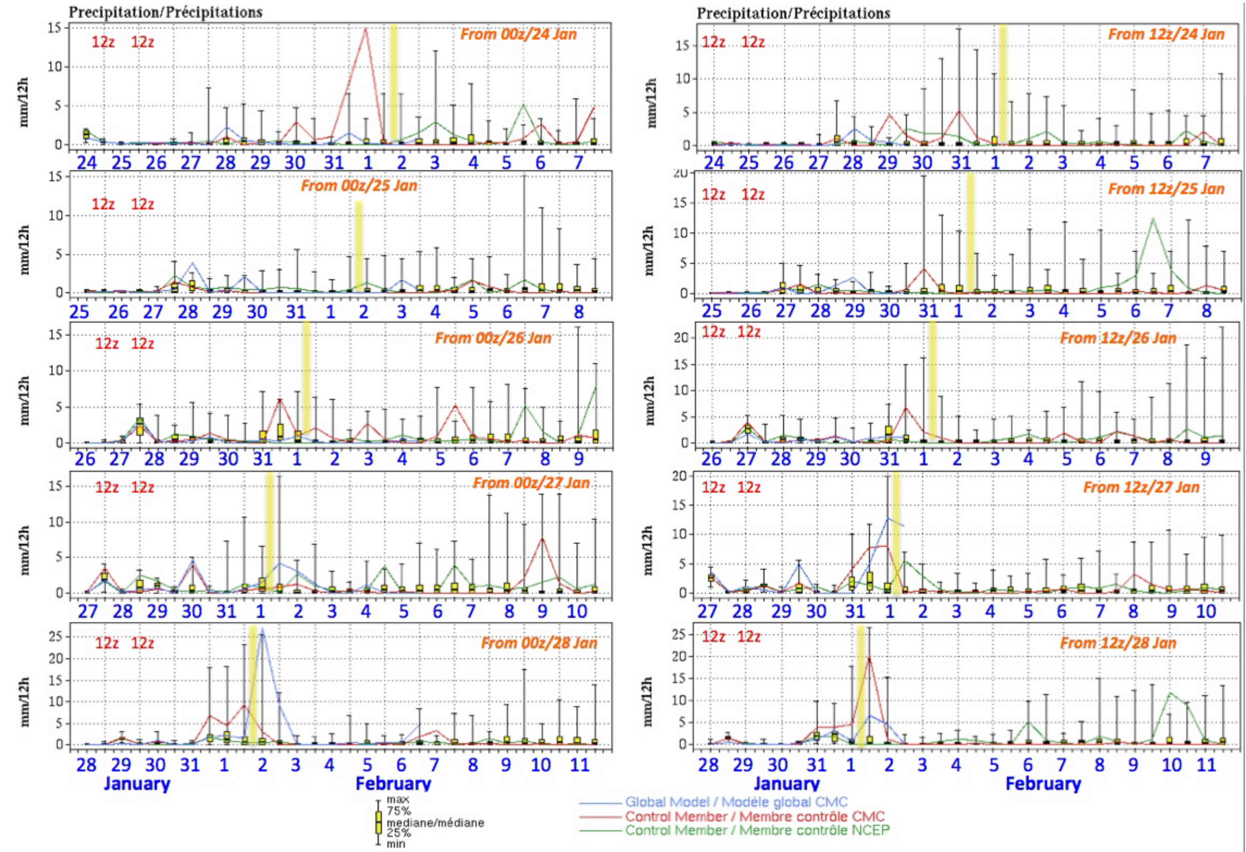


Figure 21. NAEFS EPSgrams of 12-h precipitation amount (in mm) for Chicago, Illinois, for consecutive initialization times from 0000 UTC/24 Jan through 1200 UTC/28 Jan. The period of interest (when maximum snow occurred in Chicago) is highlighted by the yellow bar.

The source of the shortwave trough associated with the storm was a progressive smaller-scale system that broke underneath the high-amplitude upper-level ridge that had been in place for some time along the West Coast. The system brought an end to a several week dry period for parts of California when it moved across Northern California at the end of January. It then dropped into the Southwest and weakened by 31 January. This wave then ejected northeastward on 1-2 Feb, kicked out by a separate shortwave that moved southward into the Rockies, diving down the east side of the still present high-amplitude West Coast upper-level ridge. The two waves remained separate, with the northern one ending up closing off over the Southwest.

A model error that was prominent in many of the medium to longer-range forecasts involved a quite different evolution of the two waves. Generally, the northern wave was far too progressive, only modestly digging south before sliding eastward, while the southern wave that came off the Pacific and across north-central California ended up as the one left behind over the Southwest. An example of the longer range forecasts is shown in Figure 23. As noted, the forecast for the overall trough position across the CONUS is not far off from what is observed (as shown in Figure 22), but a detailed look at the model evolution leading to the forecast shows it was quite different from the actual evolution of the northern and southern waves. Examining the MSLP forecasts in Figure 23, the result of the different evolution in the models was a lack of any storm at all through the middle of the nation. Instead, there is a cold front pushing off the East Coast and then stalling near the Gulf Coast, with at best a weak surface low forming along the front.

The various FIM versions and the GFS had similar forecasts for the next several runs, with the northern wave remaining too progressive, no storm in the middle of the nation, and a weak low along the East Coast. The ECMWF did a much better job of handling the two waves by the next forecasts from 0000 UTC/25 Jan, although the ejecting southern wave was relatively weak, so the storm moving through the middle of the nation was fairly modest. However, even the ECMWF continued to have trouble with the two troughs. For example, in the ECMWF run from 1200 UTC/25 Jan the two waves were predicted to phase into a single trough, with the result a much quicker storm moving into the mid-CONUS. By the next run (from 0000 UTC/26 Jan), shown in Figure 24, the ECMWF returned to a much better forecast, but variability remained, as seen by a poorer forecasts in the run 24-h later (Figure 25).

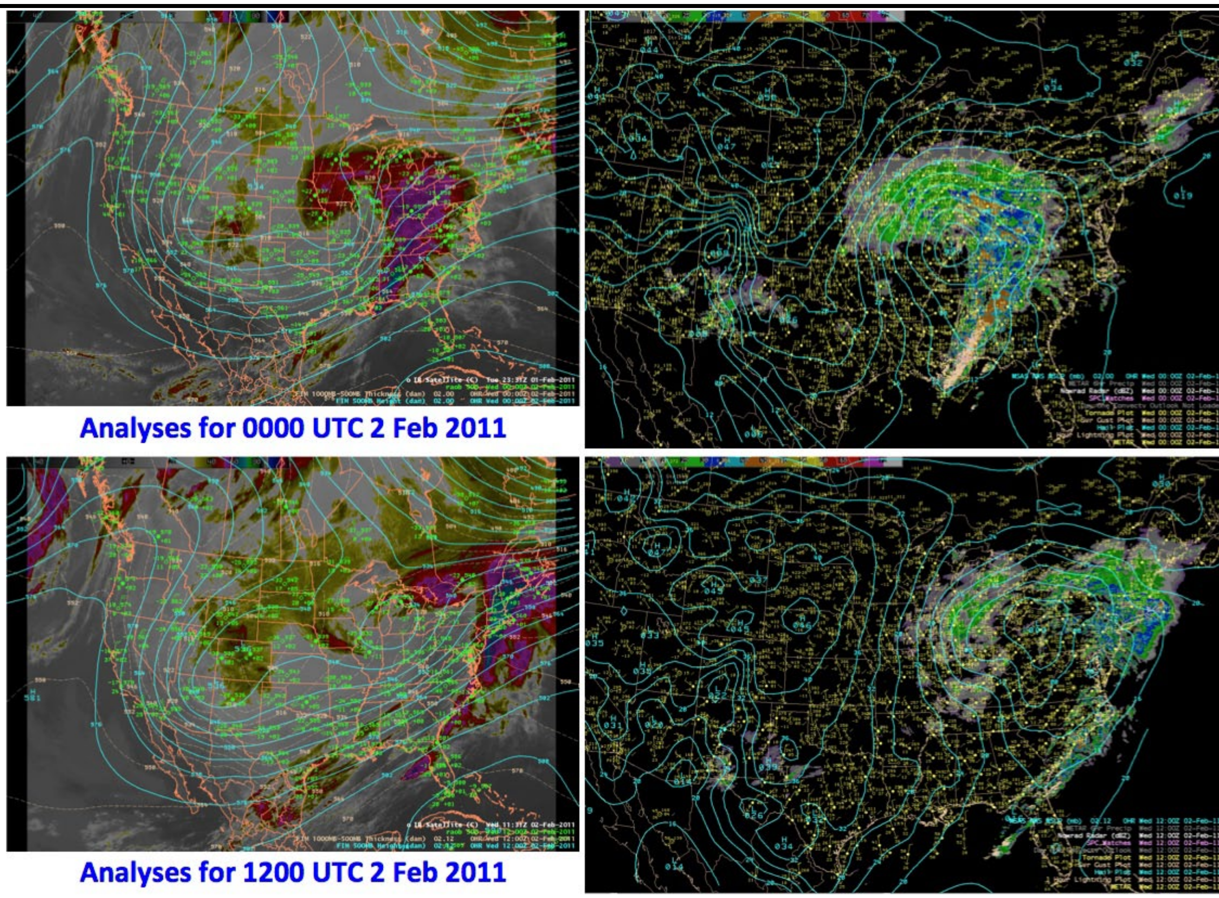


Figure 22. Analyses for 500 mb height (6 dm intervals) with data (left side) and for surface MSLP (4 mb intervals) with surface plot (right side) for 0000 UTC/2 Feb (top row) and 1200 UTC/2 Feb.

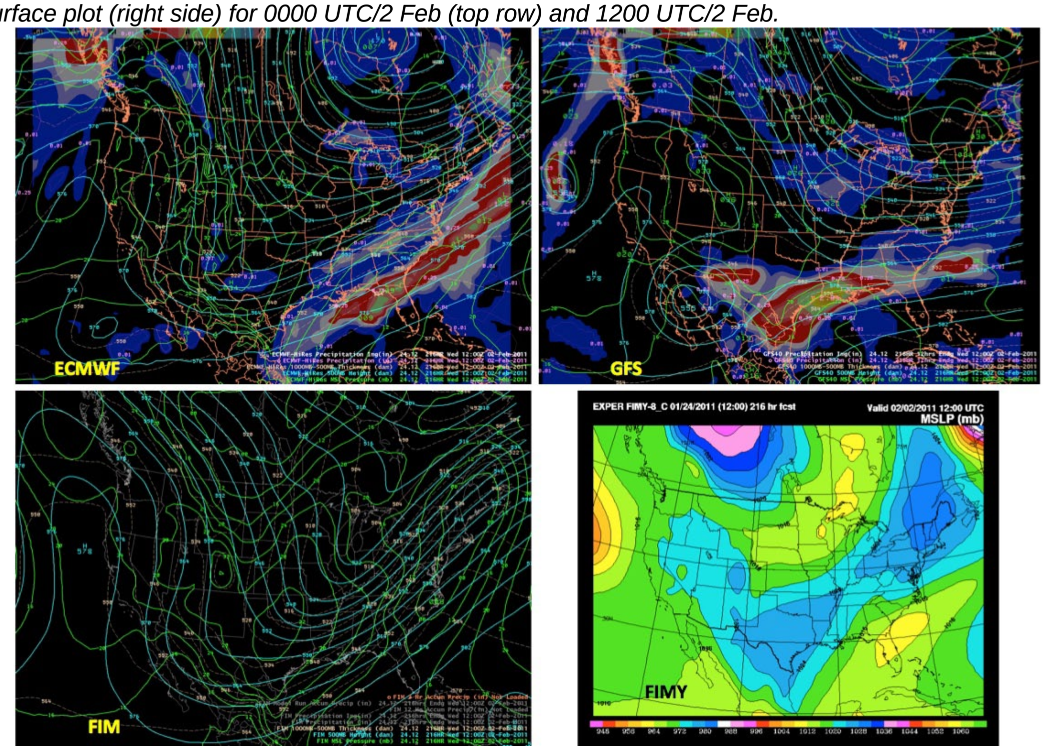


Figure 23. Longer range (216-h) forecasts valid 1200 UTC/2 Feb from the 1200 UTC/24 Jan runs. Fields shown are MSLP (4 mb intervals), and for all but FIMY 500 mb height (12 dm intervals) and 12-h precipitation (inches, for the ECMWF and GFS only).

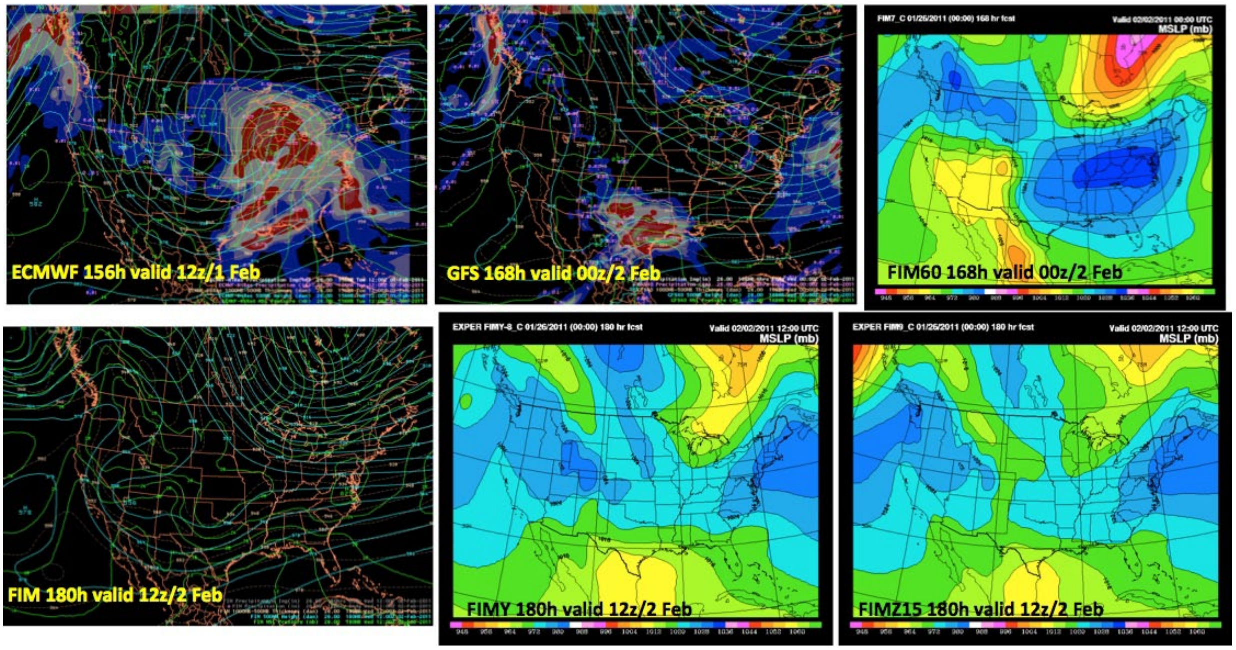


Figure 24. As in Figure 23, but for runs initialized on 0000 UTC/26 January.

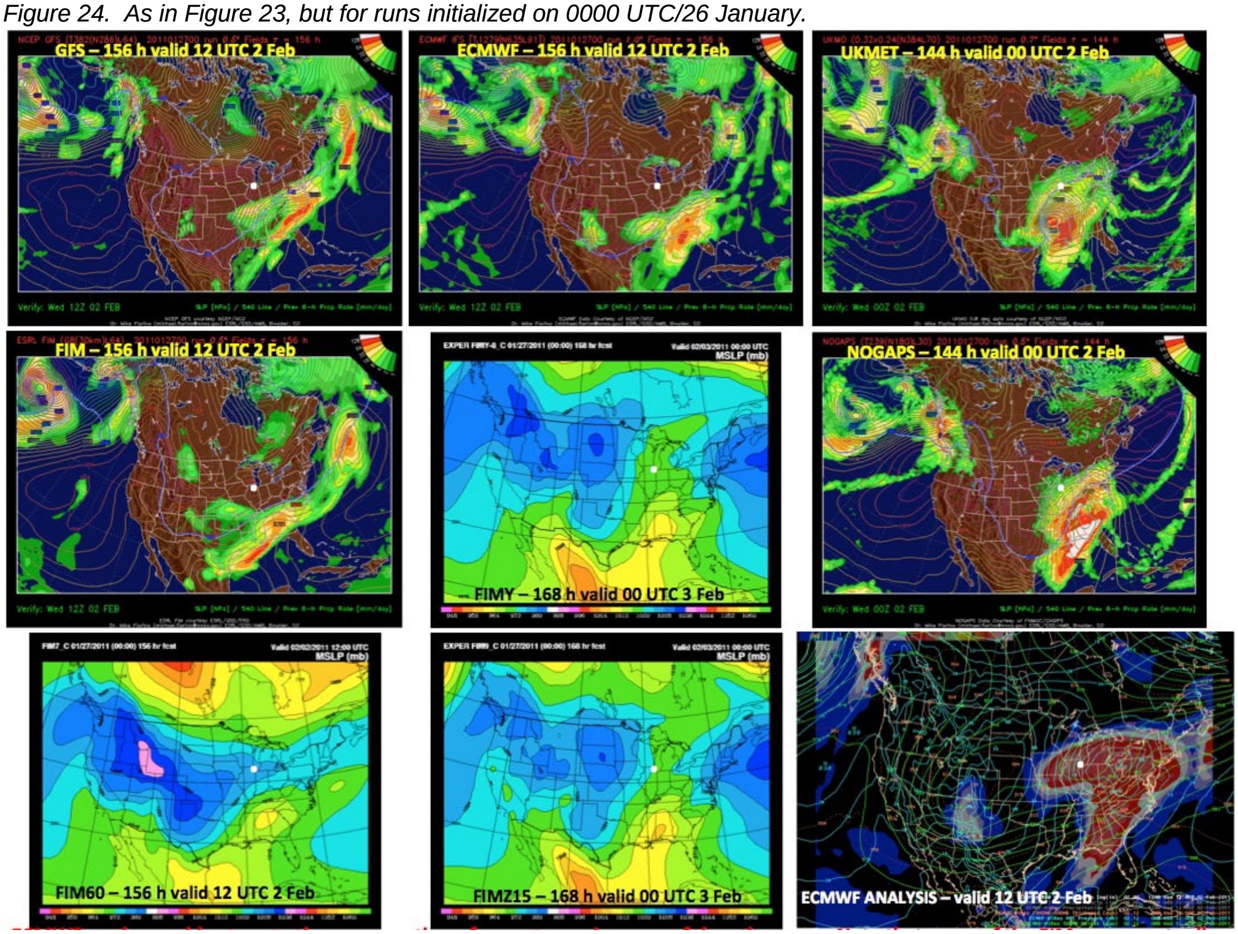


Figure 25. As in Figure 18, but for runs initialized on 0000 UTC/27 Jan, valid at the times indicated. The precipitation field shown as an image in the ECMWF analysis is actually a 12-h forecast from the previous run.

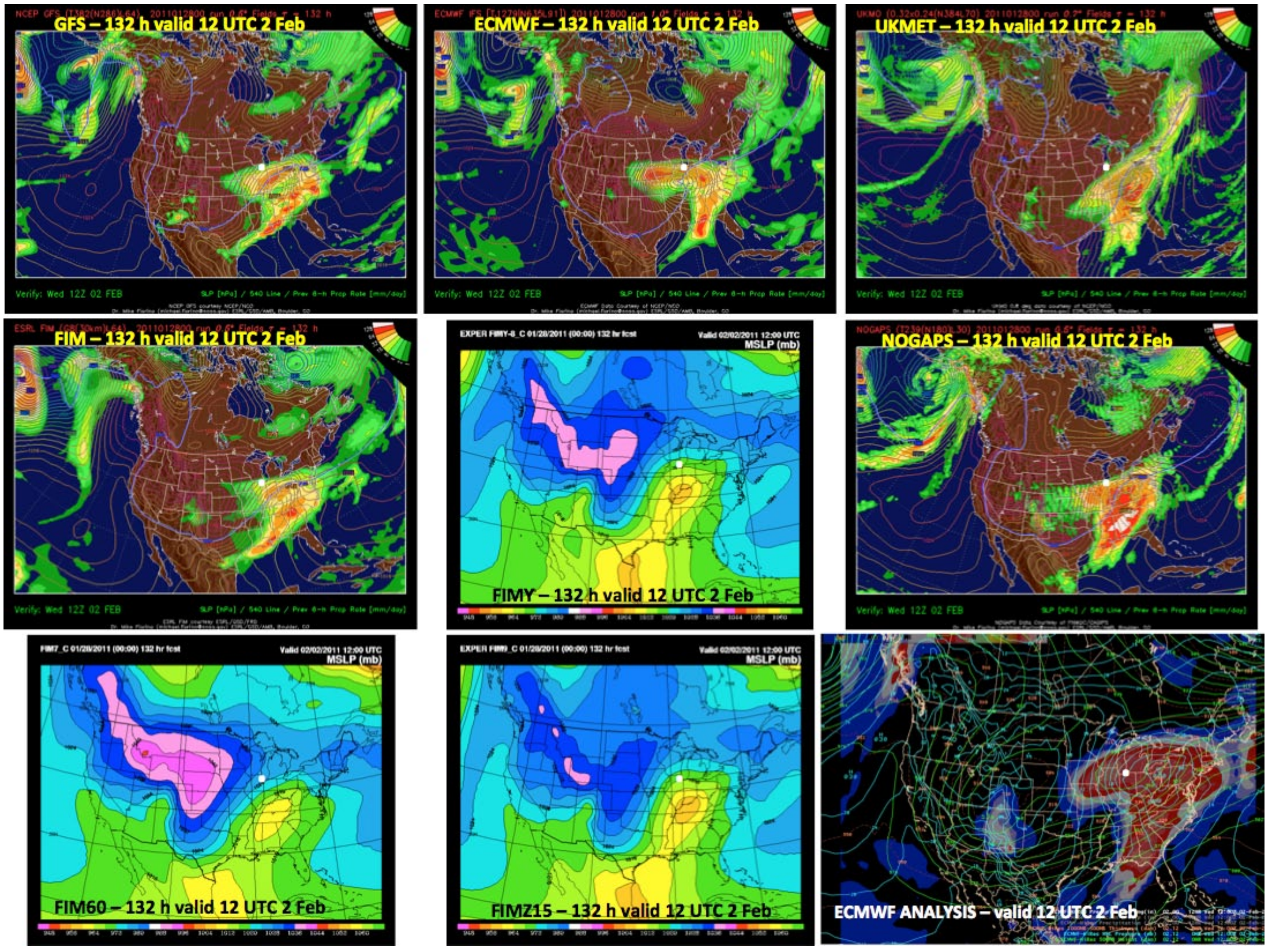


Figure 26. As in Figure 25, but for runs initialized on 0000 UTC/28 Jan. All are 132-h forecasts valid for the time of the analysis shown in the lower right, 1200 UTC on 2 Feb.

Taking a closer look at the 500 mb forecasts from the ECMWF, GFS and FIM shown in Figure 24, the fundamental difference between the ECMWF, which produces a storm in the Midwest, and the other two models, is in the handling of the northern wave. The ECMWF in this run has captured the greater digging of the northern wave into the Rockies, which results in the ejection of the southern wave, albeit somewhat faster and weaker than observed, but quite good for a 6-7 day forecast. The FIM and GFS remained too progressive with the northern wave, with the trough lingering over the Southwest the system that had come in across California. The other FIM runs behaved similarly, and because of this the GFS and none of the FIM versions produced any Midwestern storm.

Other model runs (UKMET and NOGAPS) have been added to the comparison shown in Figure 25 for the 0000 UTC/27 Jan cycle. One intriguing point about this comparison, noted earlier, was the change in the forecast for the ECMWF to one that did not produce a Midwestern storm, after several earlier runs that did. In fact, the ECMWF forecast now closely resembles the GFS and the other FIM model predictions. Of these runs, the GFS has the most northern extent to the precipitation, though is still way too far south. The best forecast of this group belonged to the UKMET. A look at the 500 mb forecasts (not shown) reveals that there were still a lot of variations in how the northern and southern waves were handled. The GFS was different from previous runs in correctly digging the northern wave into the Rockies causing the southern wave to eject eastwards. The southern wave still tracked too far to the south, but the correct configuration of the two troughs led to the more northern extent to the precipitation seen in the GFS.

After 27 Jan the forecasts all became much improved, as seen in the last figure that shows a comparison of forecasts from the models initialized on 0000 UTC/28 Jan. The dot in the figures marks the approximate location of Chicago, where the final total of 21.2 in of snow ranked the storm as the third highest in history dating back to 1886. Most of the forecasts in Figure 26 that have precipitation show the northern edge right near Chicago, with the ECMWF farther north. Comparing just the various versions of the FIM in Figure 26, the position and strength of the storm are close in all the FIM versions. Close examination of the forecasts though indicates that the FIMY and FIMZ-15, with the EnKF initialization, have nearly identical positions and strength, while the FIM and FIM60, which both use GSI (like the GFS), also have the same position (and similar to the GFS), but the low is shifted more to the east. Because of this slight shift, the FIMY and FIMZ-15 have heavier precipitation extending farther to the north of Chicago than the FIM, and are similar to the better ECMWF forecast. The FIM60 has the most southern edge to the precipitation shield, probably a reflection of a somewhat weaker storm. Subsequent forecasts after 0000 UTC/28 Jan generally continued to improve, with a trend towards more precipitation farther to the north that included Chicago.

4. SUMMARY AND CONCLUSIONS

We have given an overview of FIM model performance for a variety of recent events, including a a significant high-impact blizzard for the Northeast and another for the middle of the nation. We concentrated on more recent events because of a number of changes that have taken place over the last year, including the change to the GFS physics package.

In general, the FIM will typically have a forecast that is often close to the operational GFS and ECMWF, not showing any particular tendency to necessarily favor one model over the other when the two disagree. We demonstrated this with our first case, while the second case showed that under conditions of increased predictability (a stable Atlantic block), the FIM forecasts were in good agreement out to the 10-day time frame with the operational models.

Comparison of the various versions of the FIM model for some of the recent cases showed some systematic differences. The forecasts from the two FIM versions that used the EnKF initialization (FIMY and FIMZ-15 (FIM9)) generally compared well to each other, and the same was true for the two versions that used GSI (the “standard” FIM (FIM8) and the FIM60 (FIM7). The effects of resolution were often, though not always, noticeable in terms of a stronger surface low, for example. Changes to the forecasts often occurred at different times for the GSI vs. EnKF initialized runs, with some tendency for the EnKF to lag the GSI. These changes were not always towards a better forecast, however. Also, the sample size is quite small at this point.

We do have a long record of FIM behavior compared to other operational models in terms of statistical scores such as RMS error at 500 mb, and these have shown the FIM to be comparable with the GFS through forecasts out to 7 days. The record is not so long for the different versions of the FIM after recent changes, so these will be monitored in the future. Overall, however, it appears that the FIM forecasts are of good quality and could be a potential member to an expanded version of the NAEFS in the future.

5. ACKNOWLEDGEMENTS

We thank Tracy Smith of GSD for an internal scientific review and Annie Reiser of GSD for a technical review.

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