

Page	Explanation (self-explanatory pages omitted)
4	<p>Frame 1: DGEX is the same as the Eta model, except over a smaller domain. It starts with the Eta forecast valid at 78 hours, rather than picking up at 84 hours when the usual Eta run ends, to help adjust for the shock caused by moving the boundaries in. The GFS from the previous model cycle is used for boundary conditions, so essentially it is that 6-hour-old GFS which is being downscaled.</p> <p>Frame 2: Note how much smaller the DGEX domains are than the Eta 0-84 hour domains. The combination of smaller domain and long forecast time allows the boundary conditions to strongly drive the forecast.</p>
5	<p>Frame 1: The motivation for DGEX is to provide dynamically and physically self-consistent higher-resolution fields more compatible with the NDFD topography and resolution than possible with the GFS model. The intent is that this should represent a downscaled version of the GFS solution. These fields could be used as input to the GFE in the extended range periods the same as Eta grids can be for the first three days, though of course any model data will need to be edited for some changes. However, this editing would be far less time consuming than building in topographic and other detail absent in GFS grids, leaving the forecaster more time to focus on other parts of the forecast.</p>
7	<p>The first step in using the DGEX is to evaluate whether the GFS run it is trying to downscale is a good forecast. I don't show that step here, but this was a simple case with not much precip or other complicating factors and there was good agreement among the ensemble members. The next step is to check if the DGEX actually is producing the same large-scale forecast as the GFS. It usually does but not always! The model run shown here will be used several times in this teletraining session. The purpose of this loop and the one which follows is to show that, in this case, the DGEX does indeed have the same large-scale solution as the GFS. Only 4 images, every 12 hours, around day 5 and 6 are shown.</p> <p>Note that the comparison is against the GFS from the <i>previous</i> (6-hours-earlier) model cycle, because that is the run which is supplying the boundary conditions. There is not necessarily any relationship between the DGEX and the GFS with the same initial time.</p>
9	<p>Color scale on all frames is identical, with interval of 200 meters. The deep brownish-red color is below sea level. Region shown is extreme southern CA, southwest AZ, southern tip of NV, and adjacent coastal waters and portions of Mexico.</p> <p>Frame 1: The best available digital topography data, the Digital Elevation Model 30-arcsecond data from the U.S. Geological Survey. Even this is a smoothed version of the ravines and jagged peaks that contribute to the weather conditions experienced by the public.</p> <p>Frame 2: Averaging over 3x3 blocks of 30-arcsecond data gives topography on the scale of just under 3 km, comparable to the NDFD terrain used in western WFOs.</p> <p>Frame 3: GFS running at T254 now has some output on a 1/2-degree grid, which is finer than any GFS grids in AWIPS. However, the topography still only captures terrain variations on scales of hundreds of kilometers.</p> <p>Frame 4: Eta (same for DGEX) on 12-km grid. Field is contoured for plotting. However...</p> <p>Frame 5: the model actually sees steps on grid squares. (exact step values are not shown but</p>

	<p>are within the color ranges indicated)</p> <p>Frame 6: Identical to previous frame but in gray scale, monotonically ranging from light to dark as elevation increases. Maps of model fields will be overlayed on this background map.</p>
10	<p>Loop of forecast and observed 2-meter temperatures over 2 diurnal cycles for forecasts of days 4-6. Click boxes in control panel to view plots, which may be viewed individually or in any combination. Underlying map is DGEX topography. The color scale appears when METAR temperatures are selected. Colors are the same for both models and observations, with contours every 5 deg F in the middle of color ranges. For example, the light green contour is for 70 degrees. Thus, when contours and METAR plotted numbers are the same color, the forecast is good, while contrasting colors reveal large error.</p> <p>GFS 2-meter temperature forecast hardly reflects the real topography, instead reflecting its model topography.</p> <p>DGEX 2-meter temperature forecast shows the effects of elevation on a much finer scale, but not down to the 5 km or 2.5 km scale of NDFD. It also has a larger diurnal range and faster rise in the late morning even over the relatively flat lowlands where the two models have nearly the same terrain height. These differences are consistent over all three diurnal cycles.</p> <p>METAR observations reveal an outstanding match with the DGEX forecast, good even out to 6 days shown here and even out to 8 days! The match is not perfect. The DGEX is consistently too cold at night in some places, but at Flagstaff (northeastern most METAR) it was not cold enough at night. The DGEX terrain only differs by 60 meters from the station elevation at Flagstaff but it chops off the peaks nearby, perhaps therefore missing some nocturnal cold air drainage. Overall, it is no contest -- the DGEX temperatures are far superior to the GFS, and the DGEX has successfully downscaled the GFS large-scale conditions.</p> <p>This is an excellent example of when the DGEX works as intended. This example shows the value, as well as the scale limitations - DGEX doesn't downscale all the way down to NDFD scale - and some imperfections. Obviously you'd rather start with DGEX grids than GFS grids in this case.</p>
11	<p>Now let's look at 10-meter winds. Same format, same times, DGEX in blue, GFS in yellow, METARs in red. Model winds are at every output grid point (12 km for DGEX).</p> <p>The GFS clearly misses the strong easterlies around Phoenix the first day and widespread southerlies the third day. The DGEX picks up the latter but not the former. Overall the mesoscale detail and topographic channeling of flow in the DGEX which are absent in the GFS match the observations reasonably well, but there are a few large direction errors.</p> <p>This is a best case scenario, and again we can see value in using the DGEX compared to the GFS but also some imperfections.</p>
12	<p>Here's an example where it didn't do so well. Area of focus is ND and MT at day 7.</p> <p>Frame 1 shows that the 500 heights and pattern are very similar, not going to cause any major differences over the area of interest (ND/MT).</p> <p>Frame 2 shows large ensemble spread, with the GFS run being an outlier. This suggests poor forecast confidence and especially that the run being downscaled in the DGEX is unlikely to</p>

	<p>verify.</p> <p>Frame 3 shows the forecast temperatures in the DGEX and GFS. The gradients toward the western end of the region shown are terrain effects, but most of the picture is over the flat sloping high plains. The DGEX is colder in the cold air mass, warmer in the warm air mass, and has a somewhat different position of the front due to different influences of snowcover to the north and the usually better capability of the Eta in predicting southward-moving cold surges over the high plains. The question is, is this useful, does it help in generating your NDFD grids?</p> <p>Frame 4 shows the verification. The large scale was wrong - there was no major cold plunge. In situations when the GFS scenario is unlikely to verify, the downscaled information is not helpful.</p>
13	<p>This flow chart represents one possible approach to using the DGEX. Most cases will track either straight down the chart, such as in the example just shown, or straight across the chart, but sometimes there will be notable large-scale differences between the models, in which case the DGEX can be considered one of the various solutions to evaluate.</p> <p>For evaluating any model forecast out to a week, the importance of checking model analyses against the strength and position of major weather features - jets, cyclones, ridges, etc. far upstream, such as over the central and even west Pacific, as well as downstream for blocks, etc. cannot be stressed enough. Having the DGEX available does nothing to change that.</p>
14	<p>Frame 1: In addition to those shown here, other levels or parameters may be available where supplied by regional offices that are pulling data off the NCEP ftp server.</p> <p>Frames 2-4: Examples of fields that are smoothed. The smoothing is applied on views of all scales, not just national scale. The 500 hPa heights example shows ripples from flow over the Rockies. The 850 hPa temperature case is fairly typical of hot mixed layers advecting northeast over the plains. The sea level pressure example has a high over the Gulf coast and a trough over the Ohio Valley, with no precipitation or strong jet streak or any other apparent cause of the ripples in the unsmoothed field.</p> <p>Frame 5: Winds are not smoothed. Thus, derived parameters using gradients of the wind will have large values. In this case, small wind perturbations marking the model's response to convection have yielded absolute vorticity patches in excess of <math>30 \times 10^{-5} \text{ s}^{-1}</math> and negative absolute vorticity patches below <math>-5 \times 10^{-5} \text{ s}^{-1}</math>.</p> <p>Frame 6: The min and max temperatures are ICWF grids, which means they are not accumulated during the model run itself. Instead, they sample model output at output times. Thus, the min and max temperature are not the min and max at any time step during the night or day period but only use temperatures at output times. In addition to the 6-hour output times you receive, NCEP outputs temperatures at 3-hour intervals solely for the purpose of improving sampling for the max and min temperature grids. Any spike that occurs between those times is missed, and any maxes or mins that occur outside the 12-hour windows are not considered. Temperatures valid at 00 UTC and 12 UTC are considered for both the min and the max.</p> <p>Frame 7: The fields generated by smart inits for the GFE are not the same as the fields seen in the D2D. As with other models, smart inits typically alter some model fields such as temperatures to account for the NDFD topography, utilizing the model 30 hPa-thick boundary layer grids. The DGEX model grids input into the smart init are not smoothed for any fields and are all on a 12-km grid. The sky grids in Tim Barker's DGEX smart init are derived internally and do not use the model grids of the same fields. The smart init version 2.1 has been updated to make use of the 3-hour max/min temperature sampling in the DGEX grid by starting with the</p>

	smart init temperatures on the NDFD grid and adding in a difference field of the DGEX max/min compared to the 6-hourly temperature data.
15	One of the main lessons from error statistics is that the current run of the GFS (same initial time as DGEX) has better fits to observations than DGEX surface and aloft for all parameters except RH, but DGEX makes a small improvement over the run it downscales, the one from six hours before. The other main lesson is that results vary geographically, with the far west where topography plays a dominant role benefiting the most while the eastern states see no statistical improvement.
16	Time series of error statistics showing day-to-day variability in fits to observations. Despite the large swings from one day to another, the DGEX at 144 hours and GFS at 150 hours, which is the run supplying boundary conditions to DGEX, track together. The GFS at 144 hours, the run with the same initial time as the DGEX, also tends to track similarly, showing that run-to-run fluctuations in skill over a region are smaller than differences in regime-related changes in skill. The different plots are shown to illustrate that these results hold for heights, temperatures, and winds at the surface and aloft on scales ranging from CONUS to smaller sections of the country.
17	These plots show model fits to raobs at mandatory levels at and above 850 hPa. The most pronounced result is the large improvement the DGEX makes over the GFS in RH in the mid- to upper troposphere. Otherwise, the latest GFS, previous GFS, and DGEX all have very similar error magnitudes when averaged over all of Alaska or all of CONUS, with the latest GFS run generally edging out the others.
18	<p>We would hope that the DGEX would have an edge in surface variables due to fitting topographic features missed by the GFS, as we saw in the example from Arizona and southern California. These plots show the forecast and observed temperatures and wind speeds averaged over several weeks and all stations in the regions indicated. The random component of error is averaged out, so it only reveals the systematic error, the bias. The shape and amplitude of the diurnal cycle is far better in DGEX than in the GFS, though each model has its biases in different regions. The temperature biases in Eta, and thus also what we expect for DGEX, vary seasonally, so you won't expect to see these same biases throughout the year, but overall the smaller systematic error in DGEX compared to GFS is encouraging. Unfortunately, despite the improvement in bias, typical RMS errors (not shown) are actually nearly the same as, and in some cases worse for the DGEX than the previous GFS run. Thus, in terms of accuracy in fitting METAR data, the DGEX does not appear to improve upon the GFS except in certain regions, particularly the west.</p> <p>Statistics for the last two weeks updated daily for each of the regions shown in frame 4 can be found at the web site listed, which you can view now by clicking on "Show URL" on the VISITview control panel.</p>
19	The IFPS SOO Science Team (ISST) conducted a survey of offices participating in the DGEX evaluation. The survey showed that by far the most popular DGEX parameter used for populating the GFE was wind direction. Also, it showed that nearly 60% of evaluators found the DGEX to be a useful additional forecast tool while less than one in six thought it provided no value. The comments highlight the dramatically better resolution of physical processes in the DGEX than in the GFS while expressing concern about uncertainty in the overall forecast in which those details are embedded.
20	The leading cause of GFS-DGEX differences is the downscaling itself, as we already saw. These differences are local in character, affecting small-scale sensible weather and not affecting the large-scale fields. However, remember that a model can only accurately predict features at least around 7 grid spaces in wavelength, around 84 km for the Eta. Smaller phenomena forced by

	<p>model coast lines and terrain gradients will appear but will be too weak and too broad.</p> <p>The second major cause of GFS-DGEX differences is the interaction between resolution and physics, as shown in the next two examples. This is no different than you already see in the 0-84 hour Eta forecasts. The characteristics of the 0-84 hour Eta carry over into the DGEX to 192 hours.</p>
21	<p>Loop of the low-level jet. Colors are wind speeds and purple barbs are raobs. This is for the same case we already examined, where the large scale scenario was the same for both models and had higher certainty than usual. Note the much stronger and somewhat narrower jet in the DGEX. However, the placement of the jet at 12 UTC on March 23 is too far south in DGEX, so although the magnitude of the jet is much better in the DGEX than in the GFS, the fit to observations at any particular point is not better. The nocturnal low-level jet is a byproduct of diurnal thermally-induced upslope over sloping terrain, and the better handling of its amplitude is related to the DGEX also better handling the high plains mixed layer and diurnal cycle.</p>
22	<p>Next is a snowcover situation, again for the same model runs. We start by checking whether the GFS and DGEX agree on 850 hPa temperatures for the times and region of interest. They are mostly within around 1 °C of each other in this case.</p>
23	<p>The observed snow cover in this case extends north of a line roughly from Grand Forks to south of Eau Claire to near Green Bay. Northern Wisconsin appears dark on the visible images due to forest blocking view of the ground.</p>
24	<p>The background field indicates thin and deeper snow cover in the GFS forecast. The format for temperatures is the same as in the first example.</p> <p>Due to its resolution, the GFS doesn't show sharp detail in its temperatures, but it is consistent with its snow cover pattern and it does sometimes pack a tight gradient, such as in the excellent forecast valid 12 UTC March 22.</p> <p>Despite nearly the same 850 hPa forecast, the 2-meter temperatures in the DGEX are much different, with much tighter gradient. Often it is too cold over snow, especially at night. At day 7, it made a remarkably good forecast. As warm air surged northward, the DGEX was far superior with its gradient and surface temperature pattern over the Wisconsin region on each side of the snow line, though the GFS was better with the broader pattern further west over Minnesota and the Dakotas.</p>
26	<p>The hydrological cycle in the GFS cycles much faster than in the Eta model, with more evaporation over land, more precipitation, and higher atmospheric water content which is reflected in mean RH, precipitable water, and 2-meter dewpoints. The same is also true as the Eta runs out to later forecast times in the DGEX, as shown here in the precipitable water field for the same runs we have been looking at. Typically the DGEX is too dry and the GFS is too moist. The location of the moisture plume is similar in both model forecasts, and neither is correct, as they have too much over the plains and not enough over south and southwest Texas.</p> <p>The final Eta model upgrade package is expected to be implemented early in 2005, and those changes will be in the DGEX at the same time. The changes in the land surface model projected for that bundle produce far higher evaporation rates, yielding a climate much more like the GFS than the current Eta. Further development work could alter that result, and if testing shows harmful impact, the changes will not go in. Check the "what's new" section at the top of the COMET Operational Model Matrix (<a href="http://meted.ucar.edu/nwp/pcu2/index.htm">http://meted.ucar.edu/nwp/pcu2/index.htm</a>) around the time of the model implementation for information about the impact of the upcoming model changes.</p>

27	The next example of model physics profoundly altering the forecast is for a summer convective blow-up in the GFS. The precipitation loop presented here shows the event originating over the Black Hills by 6 UTC July 22 and tracking coherently for more than 48 hours, ending up in southwest Kentucky and even reaching into Tennessee. This is an example of grid-scale convection, where the coarse-resolution model creates an enormous grid-resolved cumulonimbus, with most of the precipitation from the grid-scale microphysics rather than the convective parameterization. Observe that the DGEX does not have a corresponding spurious feature, though it does start to produce a smaller one of its own at 162 hours over the southwest corner of MN.
28	This grid-scale convection impacted all aspects of the GFS forecast over the entire midwest. The 850 hPa plots for selected times shows the GFS creating a strong low center which reaches southwest MO by 06 UTC July 23, with strong northeast winds on its back side, dragging cool air hundreds of miles further southwest into Kansas than the DGEX is predicting and broad model disagreement still 36 hours later.
29	Note how different the surface winds, temperatures, and dewpoints are over the entire area from Nebraska to Georgia.
30	The percentage of sky covered by cloud at any level also is completely different, nearly inverse patterns, in that same region. Also, as is typical for each model, the DGEX shows nearly overcast or nearly clear conditions almost everywhere while the GFS shows more partly cloudy areas and hardly any areas with under 10% cloud cover.
31	<p>Is the DGEX really like another ensemble member? Remember, it starts with the Eta 78-hour forecast, so it does use different initial conditions than the GFS run which it downscales. In cases of high sensitivity to initial conditions, does the DGEX produce different large-scale conditions than the GFS it is downscaling?</p> <p>The answer is generally the GFS boundary conditions drive the DGEX so strongly that even in cases of large ensemble spread, the large-scale patterns match. This is especially true for the Alaska domain, which is smaller than the CONUS domain.</p>
32	Alaska example showing ensemble forecasts. Notice the divergence of solutions and that the operational GFS run is an outlier even among all the ensemble members in its handling of the block and undercutting system.
33	Evolution of DGEX and corresponding 6-hour-previous GFS run are nearly identical in 500 hPa height, 250 hPa winds, and sea level pressure.
34	The scenario when dynamics does sometimes produce differences between the GFS and DGEX is in split flow situations. In this case, the GFS had more ridging between the northern stream flow and the wave which dropped into the western trough, eventually allowing the wave to pinch off, while the DGEX retained a positively tilted wave which sheared out.
36	What do you expect the most important factor is affecting the accuracy of the DGEX forecast?
37	<p>This case focuses on downscaled surface temperatures and winds over the Pacific Northwest.</p> <p>Frame 1: The 850 hPa height gradient driving conditions for downscaling is very similar in both models.</p>



	<p>Frame 2: Actual terrain with 30-arcsecond resolution</p> <p>Frame 3: Same but averaged over around 3 km x 3 km blocks, similar to NDFD scale</p> <p>Frame 4: DGEX terrain (same as Eta), using same color scale. Model steps are within the ranges indicated; exact step values not shown</p> <p>Frame 5: Same but with 120 h forecast of 10-meter winds superimposed. Note direction of flow channeled through passes and Puget Sound, and stronger winds over the Olympic mountains and over the ocean.</p> <p>Frame 6-7: GFS terrain and with wind superimposed, valid at the same time as DGEX in previous frame. Note the absence of wind channeling or other effects. The winds clearly represent only the large-scale flow.</p> <p>Frame 8: DGEX temperatures (color shading) valid at the same time, with terrain contoured in white instead of showing grid box steps. Note the close correspondence between model terrain and temperature, though the patterns show some asymmetric offset possibly due to upslope effects and clouds.</p> <p>Frame 9: Same for GFS, with same color scale and GFS topography in white contours. Note the absence of any of the features seen in the DGEX.</p>
38	<p>How good was the DGEX downscaling?</p> <p>Frame 1: Observed and forecast temperatures at the same time as just shown and in same format as with previous cases. While the DGEX is clearly better, note that it was much too cool, errors in excess of 10 °F with some in excess of 20 °F in the north and along a north-south axis east of the coastal range from Puget Sound south into Oregon.</p> <p>Frame 2: 10-meter wind comparison. Overall a very nice forecast by DGEX. But what do you notice around the southeast edge of Puget Sound and how might it have contributed to the temperature errors? (obs shows east winds = downslope)</p> <p>Frame 3: 850 hPa wind comparison, raobs in lavender. Is this a decent large-scale forecast? Are these errors typical of a 5-day forecast? What do you notice about the wind errors that contributed to the surface temperature forecast errors?</p> <p>The moral of the story is that large-scale conditions govern the downscaling. Modest errors in the large-scale forecast often result in large errors in the downscaled sensible weather conditions, but even those errors may be less than not performing any downscaling to the GFS forecast.</p>
39	<p>Here is the GFS version of the diurnal evolution of the Florida sea breeze on a summer day. Temperatures are in color shades, precipitation in red contours, and wind barbs for 10-meter winds. There is no apparent signature of any sea breeze.</p>
40	<p>Same for the DGEX valid at the same time for the run forced by the GFS run just shown, and all colors and color scales are the same. This is a day 6 forecast. The DGEX has a mid-day confluence zone along the east coast with mean southwest flow over the northern part of the peninsula and extensive area coverage of precipitation across the central peninsula, while it has hot conditions across northern FL and southern GA. During the evening it develops easterly to southeasterly mean flow over the southern and eastern parts of the region, pushing the</p>

	convergence zone inland over northern FL and toward the western coast in southern FL.
41	How did the DGEX sea breeze verify? At 18 UTC, some of the early precip over central FL verified, but the mean southwest flow and coastal confluence zone over the northern part of the peninsula did not. At 00 UTC, the entire scenario did not. The wind direction forecast had errors of 90 degrees or more almost everywhere. The moral of the story is that just because the DGEX shows a physically consistent feature that will definitely be present in reality and is completely absent in the GFS does not ensure that the feature is properly forecast in the DGEX. In fact, using the DGEX without modification would not have reduced error compared to using the GFS which had no sea breeze at all. Again, the downscaling problem was in the large-scale flow, in this case the surface flow which determines the structure and placement of the sea breeze.
43	How can the DGEX be used in cases of high uncertainty? Start by assessing the situation. Focusing on the trough in the central and eastern US, what are the ensembles showing? How does the operational GFS run compare to the other ensemble members?
44	This loop compares the same operational GFS run to the DGEX run which uses it for boundary conditions. It shows that despite lack of agreement among the GFS ensemble members, the DGEX is handling the deep trough nearly the same as the driving GFS run. The high vorticity spokes in the DGEX are also a typical example of its downscaling a synoptic system. However, given the uncertainties in the large-scale aspects of the trough, is this downscaling useful?
45	The precipitation pattern likewise is overall similar but with much sharper structure in the DGEX. Again, is this detail useful? It is physically and dynamically consistent, but what are the chances it would verify? If the trough cuts off, it may indeed end up with a pattern like the DGEX is showing but the timing and placement may be off. Does the structure it presents have information that could be useful to users of your forecast, and how could that be represented in your forecast?
46	<p>However, even in cases of high uncertainty, the terrain effects on temperature in the DGEX can still improve upon the GFS, and adjusting the DGEX toward ensemble guidance large-scale conditions can cut down on big errors.</p> <p>Frame 1: The DGEX forecast and the LAPS analysis valid at the same time. (LAPS has mistakes over the ocean; focus on land areas)</p> <p>Frame 2: Compare the DGEX forecast to the effect of adjusting it toward <i>ensemble</i> MOS using the "MatchGuidance" tool. Ensemble MOS is the average value of the MOS forecasts for each of the ensemble members, not MOS for the ensemble mean.</p> <p>Frame 3: Differences from LAPS reveal that synoptic error is cut in half by adjusting toward the ensemble mean, though errors are still large.</p>
49	<p>An example of an unseasonable pattern, showing anomalies of more than 3 standard deviations.</p> <p>Frame 1: Eta 500 hPa and 700 hPa geopotential height analysis and anomalies in standard deviations from normal</p> <p>Frame 2: GFS and DGEX heights show an extremely anomalous deep trough in about the right place but not quite as deep/anomalous as observed, with DGEX showing just slightly less amplitude than GFS</p>



Frame 3: Ensembles are showing good agreement for an unseasonably deep trough

Frame 4: The NEXRAD precipitation estimate accumulated over several days exceeded 8 to 12 inches over a broad area off the North Carolina coast associated with this anomalous event. The DGEX and GFS both produce impressive heavy precipitation swaths, flagging the possibility of such an event, though the DGEX swath was too far offshore and both models didn't have quite as much as observed.

Both the GFS and the DGEX have shown they can predict unusual and extreme large-scale events, though the event may verify with an even larger anomaly.