Talking points for "Utilizing Synthetic Imagery from the NSSL 4-km WRF-ARW model in forecasting Severe Thunderstorms".

1. This training session is part of a series that focuses on applications of synthetic imagery from the NSSL 4-km WRF-ARW model. In this training session we'll consider applications of the synthetic imagery towards severe weather events. The primary motivation for looking at synthetic imagery is that you can see many processes in an integrated way compared with looking at numerous model fields and integrating them mentally.
2. Synthetic imagery is model output that is displayed as though it is satellite imagery. Analyzing synthetic imagery has an advantage over model output fields in that the feature of interest appears similar to the way it would appear in satellite imagery. There are multiple sources of synthetic imagery available on the web, for example the CRAS model at the university of Wisconsin has been available in AWIPS via the LDM for some time. The primary focus of this training session is synthetic imagery generated from the NSSL 4-km WRF-ARW model. The model is run once a day (at 0000 UTC), it uses WSM6 microphysics. This is a 1-moment package, meaning the model predicts only the mass, and not the number concentration, of each hydrometeor species. Hydrometeors include cloud water, cloud ice, snow, graupel, and rain. Certain model output fields, including the hydrometeors in addition to temperature, pressure, heights, water vapor, and canopy temperature are sent to CIRA and CIMSS.
3. Those fields are used as inputs into a model that generates simulated satellite brightness temperatures. Gaseous absorption (by water vapor, primarily) is calculated for cloud-free grid columns, and Modified Anomalous Diffraction Theory is used to obtain scattering and absorption by the cloud particles. Cloud water and cloud ice are the only hydrometeors having a non-negligible effect on the resulting brightness temperatures.
4. Given the 1-moment microphysics, particle number concentration must be guessed at. Since particle size is proportional to the ratio of the mass to the number concentration, the uncertainty in the number concentration leads to uncertainty in the particle size, which in turn leads to errors in the cloud optical depths. This is most often manifested by thin cirrus having brightness temperatures that are too cold. For more information on the details of synthetic imagery generation, refer to the references on the student guide webpage.
5. Hourly output is generated for the 9 to 36 hour forecast, valid 09Z of Day 1 to 12Z of Day 2. The synthetic imagery is ready to view by about 10:00 UTC. The model outputs brightness temperatures for a number of satellite bands. The bands are those that will appear on GOES-R since the project is based on demonstrating products that will be available on the GOES-R satellite, scheduled for launch in 2016. The bands are very close to those found on the current GOES satellites, so that the principles discussed in this training session readily apply to operational GOES satellites of the present. In this training session, we're only going to focus on the 10.35 um IR band and 2 of the 3 available water vapor bands. We will be discussing the water vapor channel you are used to looking at, 6.5 um, and we'll also be looking at the 7.4 um water vapor channel which is available on the GOES sounder. Next, we'll look at the differences between these two water vapor channels.
6. The weighting function profile gives us a clear indication of what level in the vertical the channel is seeing. Here are the weighting function profiles based on a sounding at North Platte, NE for the 6.9 um and 7.3 um wavelengths. The maximum values for the 6.9 um channel are around 400 to 500 mb. Think of this as the net temperature of the layer of moisture the channel sees peaks around 400 to 500 mb, with decreasing values above and below that layer. Let's

contrast that with the 7.3 um curve shown in purple which sees the moisture at lower-levels and over a broader depth. Note that the layer the channel sees is variable, and depends on the thermodynamic profile. The advantage of looking at the 7.4 um channel is detecting vertical motions through a deeper layer as well as detection of mid-level jet streaks.

7. We now begin looking at cases. We'll start each case by looking at the SPC storm reports. For this case from June 21, 2010 note the numerous severe weather reports across Wisconsin, Illinois and Iowa, while further west, we see numerous reports in Montana and Colorado.

8. Here is the WRF-ARW synthetic imagery for the 6.95 μm water vapor channel. This is from the 00 UTC 21 June 2010 model run, so we're looking at the 12 to 30 hour forecast during this loop as the imagery is labeled 12 UTC to 06 UTC. Note the region of convection during the morning hours in Illinois moving towards Indiana. MCS's appear much smaller in the synthetic imagery compared to observations for reasons we'll discuss later. Note the darker region of warmer brightness temperatures that appears to be associated with a shortwave. Convection develops in response to this shortwave in the Iowa, Wisconsin, Illinois region from the afternoon hours and moves eastward through the evening. Further west, we see a cutoff low over western Montana. We see a jet streak that moves from Arizona into Colorado as depicted by a region of relatively fast moving area of cooler brightness temperatures. This visual comparison of a jet streak with how it would show up in the water vapor imagery makes comparison between model output and GOES imagery even easier. We see convection develop in response to the cutoff low over Montana and futher south across Colorado to the northern Texas panhandle in response to the jet streak. Visually, we can readily see the mid to upper level features in the synthetic imagery that can lead to convection which makes for an easy comparison with water vapor imagery.

9. Here is the GOES water vapor imagery for the same period as the synthetic imagery. First, note the morning MCS across Illinois moving into Indiana. It does appear much larger in GOES compared to the synthetic imagery because the synthetic imagery typically underdoes the areal extent of the anvil cirrus. MCS's will almost always appear too small in the synthetic imagery for this reason. Note in the GOES imagery that the MCS persists longer than the synthetic imagery showed. This is another common thing to look for in the synthetic imagery, in that it is typically too quick to dissipate the convection. The model did a pretty good job with the convection associated with the shortwave as it moved across Iowa, Wisconsin and Illinois. In the west we can readily identify the cutoff low in Montana and the convection associated with it. The model did a very good job with the jet streak as it moved from Arizona into Colorado. Brightness temperatures in the synthetic imagery will typically be warmer than observed in GOES imagery, which is why we see the jet streak streak show up in the GOES imagery as a larger region of colder brightness temperatures. The storms associated with this jet streak have a much larger anvil cirrus than the synthetic imagery showed. This is a known bias so you will just need to keep this in mind when identifying thunderstorms in the synthetic imagery. In review, we see some areas where the forecast convection timing and location looked good, other areas, not as good. Remember we are looking at model output, and not even considering low-level features such as visible imagery and surface observations. The main utility of the synthetic water vapor imagery is identifying shortwave and jet streaks that may play a role in the initiation, maintenance and intensity of convection.

10. Here is the WRF-ARW synthetic IR imagery for the same time period. During the SPC spring experiment, the sector was over this region so we will be looking at the central US for this

reason. The advantage to this channel is that low-level features will show up. This is useful when analyzing cloud cover, to see if clouds will dissipate and allow for sufficient insolation to warm up the surface. Note the morning clouds in eastern Colorado that are forecast to dissipate by late morning. Outflow boundaries from the forecast thunderstorms are seen as lighter (colder brightness temperatures), there is an example in northern Missouri. These kind of details are usually beyond the ability of the model to accurately represent, however it's important to note their presence and what effect that might have in the near future in the model.

11. Here is the GOES IR imagery for the same time period. The most obvious difference between the synthetic imagery and the GOES imagery is that the storms in the synthetic imagery appear smaller, that is the cloud tops are not as cold as they should be and, more apparently, the areal coverage of the colder cloud tops is underdone. Remember that the model will perform best regarding convection in situations with relatively strong synoptic forcing, such as shortwaves and jet streaks that become juxtaposed with low-level convergence boundaries. Note the model does relatively well with the convection in Illinois, Iowa and Wisconsin since it's associated with a shortwave. Note the region of cirrus associated with the jet streak mentioned before as its moving from Arizona into Colorado. The timing of that cirrus as it becomes juxtaposed with a low-level convergence boundary near Denver seems to correspond quite well to convective initation. Note the early cloud cover in eastern Colorado does dissipate as was forecast by the model, this is one utility of the synthetic IR imagery that you would not use the synthetic water vapor imagery for.

12. SPC storm reports for May 12, 2010

13. Here is the WRF-ARW synthetic water vapor imagery. Note the representation of the MCS early on in Missouri, Iowa, Illinois and Indiana. This is typical for the model in that there are many holes in the clouds compared to an MCS appearance in GOES imagery with a uniform canopy of cold cloud tops. The model shows a trough in the west, so that there is strong southwest flow across the plains. The model develops afternoon convection in Iowa at the leading edge of a dark region, and further south in Kansas although it is difficult to see in the imagery since they are small. Notice the extensive region of higher clouds that are forecast to develop in the southern plains, this can play a key role in where the model predicted thunderstorms will develop. This is typical of the model, so at times it may be difficult to pick out on the imagery storms that are developing, let's look at the zoomed in IR imagery to help us out.

14. Here is the WRF-ARW synthetic IR imagery for May 12, 2010. Cloud coverage would definitely be a key forecast question here, not only the high clouds that are forecast to develop over the southern plains, but also the low-level clouds. The model has quite a bit of low clouds from central Kansas northward, and high clouds south of there into Oklahoma. The model has thunderstorms developing in between those two regions along a boundary in central Kansas, again, note how small they appear, don't expect large storms with extensive cirrus canopies in the model. Note the long streaks associated with the high clouds in Texas and Oklahoma, they don't appear natural. The long streaks of high clouds are optically thicker in the model than observed, expect to see this fairly often when analyzing what appear to be high level cirrus in the model. The best approach is to compare the GOES imagery with the forecast images during the morning to early afternoon hours, note if the model appears to be doing well or not and this will gauge how much confidence you should have in the synthetic imagery for the late afternoon and evening hours.

15. Here is a comparison of the synthetic IR imagery versus the GOES IR imagery through 1800 UTC. Note the imagery around 12 UTC depicting the MCS across Missouri, Iowa, Illinois and Indiana. In the same location as was forecast, but with a different appearance. Remember, the model output MCS's will appear small and sometimes be full of holes in the canopy cirrus. The model does pick up on the high cloud cover development across Texas and Oklahoma by this time. The model has a good handle on the low cloud cover over Kansas. Let's look at the higher resolution visible imagery next.

16. Here is the corresponding GOES visible imagery through 1732 UTC. There is clearing in the warm sector region south of the cold front in Kansas, so confidence in thunderstorms developing in that region should increase. Further south in Oklahoma, the cirrus can be seen developing in Texas and advecting towards Oklahoma, however there is a region in western Oklahoma along a dryline that appears it will not be impacted by the cirrus.

17. Here is the corresponding GOES visible imagery after 1732 UTC. The model did pretty well with the area of clearing that developed in central Kansas, where thunderstorms initiated along a cold front, and north of the cirrus shield. Recall, the model did not have convection further south in Oklahoma, but by monitoring trends in the IR and visible imagery we can gain confidence in convective initiation near the dryline in Oklahoma as insolation occurred there.

18. SPC storm reports for August 4, 2010.

19. Here's the WRF-ARW synthetic water vapor imagery for August 4 2010. Note the convection that develops across Ohio around 20-21 UTC. It appears to originate just north of a dark zone along a line of higher clouds, this could be from an earlier MCS across Illinois that the model dissipated too quickly. The model forecast convection in Ohio moves southeast, experiences upscale growth and merges with convection along a line in Kentucky into West Virginia. The convection continues to move southeast towards Virginia and is then forecast to dissipate.

20. Here's the corresponding GOES water vapor imagery. We look back further to 04 UTC through the overnight hours to see that there was an MCS over Illinois around 11 UTC that moved east where new convection developed along the MCS boundary in Indiana. Afterwards, it was a fairly similar depiction to what was forecast in the model with upscale growth and movement to the southeast, this is when there were numerous severe wind reports.

21. SPC storm reports for May 19, 2010. Note the numerous reports in Oklahoma.

22. The WRF-ARW synthetic imagery for May 19 shows an elongated trough centered around Colorado and Wyoming. Note the dark region that appears to be a shortwave rotating around the trough from New Mexico, moving towards the Texas panhandle followed by western Oklahoma. The model develops convection in response to this shortwave in Oklahoma.

23. Here's the corresponding GOES water vapor imagery which shows a good agreement with that model in initiating storms along the leading edge of the shortwave.

24. WRF-ARW 7.34 μm synthetic imagery for May 19. This band has a weighting function that peaks lower in the atmosphere than the 6.95 μm band we just looked at, usually around 600 mb. This band can give us indications of mid-level jets, and since we're looking lower into the atmosphere, may provide details about the characteristics of the environment associated with the dark zone. There is a well defined dark zone at the southern end of the trough that moves eastward and expands during the day. Convective initiation occurs at the leading edge of this dark zone during the afternoon in Oklahoma.

25. Corresponding GOES sounder 7.4 μm imagery. The resolution is greater than 10 km, but you can detect the dark region we discussed in the previous slide. Remember that in general, the

synthetic imagery has warmer brightness temperatures than observed on GOES. This actually makes it easier to identify the dark zones in the synthetic imagery, then we can go to the GOES imagery and identify it there. In this example, convection develops along the leading edge of the dark zone in Oklahoma, very similar to the depiction in the synthetic imagery. It's important to understand what you're looking at in the imagery when you see a dark zone, next we'll look at this in more detail.

26. Here's the visible imagery with the surface observations shortly before convective initiation. The key boundaries are an outflow boundary and an approaching cold front. The afternoon convection develops along these boundaries and where the leading edge of the dark zone on the 7.4 µm imagery exists.

27. Here is the sounding from Amarillo, Texas before and after the passage of the GOES 7.4 µm dark zone. After the dark zone passage, lapse rates steepen due to temperatures aloft getting colder. These are key ingredients for destabilization which likely explain the dark zone's role in assisting in convection initiation and maintainence.

28. SPC storm reports for June 25, 2010. We'll focus on Minnesota for this case.

29. Here is the WRF-ARW synthetic water vapor imagery for June 25, 2010. A ridge is located over the southeast to south central US with a trough to the west so the strongest flow is north of the ridge which is situated across the northern Plains and Minnesota. There are indications of an early MCS in Minnesota, remember, it will appear much less obvious in the synthetic imagery compared to the GOES imagery. The model develops what appears to be intense convection later in the afternoon in the wake of the MCS. We say "intense" because we see relatively large area of cold clouds tops and anvil cirrus, along with a dark zone signature in the forecast imagery, which you see at times in the vicinity of intense storms as you get strong subsidence around a strong updraft.

30. Here is the corresponding GOES water vapor imagery. We see a relatively good forecast in that there was a morning MCS, convection developed in the wake of the MCS and appeared quite intense in the GOES water vapor imagery as well with a noticeable dark zone signature induced by the storm caused by compensating subsidence in the vicinity of a strong updraft.

31. Here is the WRF-ARW synthetic IR imagery for the same time period. The morning MCS in southern Minnesota leaves behind a boundary of low-level clouds (cooler brightness temperatures) that is east-west oriented and appears to be an outflow boundary. This can be compared with visible imagery during the late morning to early afternoon hours to see if this is evolving similar to the way the model forecast. Thunderstorms are forecast to develop along the MCS outflow boundary by 21 UTC in southern Minnesota. Interestingly enough, the next image at 22 UTC shows what appear to be intense storms, with an enhanced-v signature on the dominant storm. The thunderstorm activity continues through the evening hours as they move southeast towards Iowa.

32. Here is the corresponding GOES IR imagery. This would be considered a successful forecast of an early MCS in Minnesota, with later convective development along the MCS outflow boundary. Convective initiation occurred between 20 and 21 UTC, as the model predicted. The storms did appear quite intense, recall there were a number of tornado reports. We also observed an enhanced-v signature in the GOES imagery, as was also depicted in the synthetic imagery. Cases such as this show the potential of utilizing synthetic imagery in forecasting, just keep in mind that not every case will be forecast this well as we are looking at model output with its familiar limitations.

33. SPC storm reports for June 20, 2010. For this case, we'll focus on the region from Montana to Colorado.

34. The WRF-ARW synthetic water vapor imagery shows an upper low over Oregon with a strong jet to its southeast from Utah to Wyoming to Montana. The model has quite a bit of convection, from Montana southward into the Plains. The earliest convection occurs in Montana where strong forcing near the upper low exists. Storms in Wyoming and northeast Colorado seem to be associated with the upper level jet moving through the region.

35. Here is the WRF-ARW synthetic IR imagery. Note the low-level clouds at 14 UTC in Nebraska nosing into portions of northeast Colorado. There are also low-level clouds across Wyoming. Both areas of low clouds are forecast to dissipate leading to afternoon insolation then followed by convection. Across Iowa, an early MCS moves east, there is clearing behind the MCS and later convective initiation near Omaha.

36. Here is the corresponding GOES IR imagery. Note that the majority of the low-level clouds in Wyoming dissipate, leading to clearing and isolated afternoon severe storms. In northeast Colorado, the low-level clouds look much more widespread than forecast, pushing all the way to the Front Range, thus the lack of insolation appears to be responsible for the lack of thunderstorms in this region. Further east in Iowa, we see considerable cloud cover and additional convection during the day, and thunderstorms do not initiate in this area as the model forecasted.

37. Here is the corresponding GOES visible imagery. The visible imagery can be monitored to check to see if cloud coverage trends forecast by the model are taking place. For example, in this case the low-level clouds across northeast Colorado are covering a larger area than forecast and are not dissipating during the day, this played a key role in limiting the insolation and thus thunderstorm development probabilities.

38. Synthetic imagery from model output is becoming more popular, so that we're seeing a greater number of models producing synthetic imagery. The operational 4-km NAM-Nest synthetic imagery is also available for viewing. There are some differences between the NAM-Nest and the NSSL WRF-ARW that we've been discussing. The NAM-Nest synthetic imagery is currently available from the 0000 UTC run, with output available from 0000 UTC through the 60 hour forecast. The output is hourly through 36 hours and 3 hourly thereafter out to 60 hours. The synthetic imagery early in the forecast period will appear more smooth since it is a reflection of the model spin up period. The band being simulated in the NAM-Nest is 6.5 um rather than 6.95 um, this corresponds to the water vapor band on the current GOES satellite. Remember 6.5 um is sensing slightly further up in the atmosphere, so that brightness temperatures will be slightly cooler than that from 6.95 um. One of the key differences between the 2 models is the different microphysics package, the NAM-Nest makes use of the Ferrier scheme whereas the NSSL WRF-ARW makes use of the WSM6 scheme. Because of this, the biases we discussed earlier regarding thunderstorms appearing too small and anvil cirrus coverage appearing too small and sometimes full of holes, will not apply. We've found that the areal coverage of cloud cover associated with thunderstorms tends to be either closer to reality or slightly overdone in the NAM-Nest compared to GOES imagery. As you gain experience in looking at synthetic imagery between different models, you will notice these differences (primarily a consequence of different microphysics packages being used) and may develop preferences. The synthetic imagery from both of these models is available at the URL below, and also via AWIPS. Next, we will compare the synthetic imagery from these 2 models for a particular event.

39. In this case from 29 March 2013, the IR synthetic imagery from the NSSL WRF-ARW is on the left, while the NAM-Nest is on the right. Excluding the differences due to being two different model forecasts, note the cloud cover associated with the thunderstorms are generally greater in the NAM-Nest compared with the NSSL WRF-ARW. Keep these differences in mind and of course remember to view simulated radar reflectivity to assess forecast convection.

40. Here is the same time period as the previous slide, except here the NAM-Nest forecast is on the left with the corresponding GOES imagery on the right. The NAM-Nest does not underestimate the anvil cirrus on thunderstorms like the NSSL WRF-ARW does, due to the different microphysics package being used. Keep in mind, this doesn't necessarily mean one model forecast is better than the other.

41. Where can you view the synthetic imagery? The WRF-ARW imagery we've been showing is part of the GOES-R proving ground products that are available in AWIPS via the LDM. Let us know if you're interested in obtaining synthetic imagery in your AWIPS, our contact information is provided on the last slide of this training session. The imagery is available on the web at CIRA at this URL, select the synthetic imagery from the suite of other GOES-R proving ground products. CIMSS also makes the imagery available at the URL shown. Finally, if you're interested in model output fields from the WRF-ARW model, it's available at the URL shown here.

42. Conclusions (1).

43. Conclusions (2).