Training Script for GOES-R Fog/Low Stratus Products

1. GOES-R Fog/Low Stratus detection and thickness products have been developed by Mike Pavolonis (NOAA/NESDIS) and Corey Calvert (UW-CIMSS). These products tell you where low ceilings and reduced visibilities are most likely to occur.
2. The first two GOES-R Series satellites, GOES-R (now GOES-16 in the GOES-East Position) and GOES-S (now GOES-17 in the GOES-West position) were launched in Nov 2016 and March 2018, respectively, and became operational in December 2017 and February 2019, respectively. This slide shows the 16 visible, near-infrared and infrared channels, and the resolution at nadir. Both satellites scan the Contiguous US and offshore Pacific Waters (including Hawaii) at 5-minute intervals. GOES-17 does have a faulty Loop Heat Pipe mechanism. The Loop Heat Pipe is designed to remove excess heat from the satellite; because GOES-17's is not functioning to spec, there are times of the year when night-time data are lost, typically in the months running up to and out of Equinox.
3. Fog and Low Stratus has a great impact on aviation. It is therefore appropriate to gear the FLS algorithm to the aviation community. The GOES-R FLS detection product identifies the probability that a given satellite pixel contains IFR (Instrument Flight Rule), or lower, conditions defined as having a cloud ceiling below 1000 feet above ground level or surface visibility less than 3 statute miles. There are also Probability of MVFR and Low IFR products.
4. Why do you want to use these products? A couple uses are listed here. Any forecaster could probably add to this list.
5. Traditional Fog/Low Stratus products have several limitations. GOES-R products are designed to mitigate these limitations.
6. The traditional brightness temperature difference between the near infrared (3.9 micrometers) and the window channel (near 11 micrometers) exploits the emissivity differences in water clouds that exist at those two wavelengths. One of the main limitations in the traditional BTD products arises when multiple cloud layers exist – if the satellite cannot view the low clouds because a higher cloud blocks the view, detection is impossible. Solar reflection during the day also changes the brightness temperature difference signal, and that complicates the interpretation of the field. Another important limitation is that the traditional brightness temperature difference does not differentiate between elevated stratus clouds (that are not hazardous) and low stratus clouds (that are hazardous). This makes it difficult to obtain an accurate depiction of hazardous areas from an aviation standpoint. As an example, we will consider two regions with similar enhancements – that is, where the difference between the 3.9 and 11 micrometer brightness temperatures is similar. Frame 2 on this page highlights the signal – very similar – at Pittsburgh and at Corpus Christi. The observation at Corpus Christi TX shows a surface visibility of 3 miles and a cloud ceiling of 600 feet. These observations are consistent with IFR rules. The radiosonde from Corpus Christi, TX (Frame 3) shows near-surface saturation that is consistent with the observations. This indicates that the cloud is located within

the isothermal or inversion layer close to the surface. Western Pennsylvania has a brightness temperature difference signal that is similar to that over Texas. However, the surface station at Pittsburgh, PA reported a visibility of 10 miles and a cloud ceiling height of 4700 feet. Thus, two similar brightness temperature difference signals are associated with very different aviation weather conditions. The sounding from Pittsburgh, PA (Frame 4) shows an elevated saturated layer, again consistent with the observation from the surface station of a cloud ceiling of ~4700 ft. This elevated cloud in Pittsburgh has roughly the same brightness temperature difference signal as the low cloud from Corpus Christi, thus making it difficult to differentiate the hazardous fog/low stratus clouds from the non-hazardous stratus clouds using the 11-3.9 micrometer brightness temperature difference alone. Vertical profiles such as this help to differentiate between the two, but they are very limited in time and in space.

7. Multiple cloud layers also cause problems for fog detection, as highlighted in this slide (the same time as used for Pittsburgh/Corpus Christi) . Central North Dakota and upstate New York both shows stations with IFR conditions – but the Brightness Temperature Difference field does not show a strong signal because mid-level clouds and cirrus are present. It's only with obvious low clouds – made up entirely of cloud droplets (as at Pittsburgh and Corpus Christi) that the emissivity-drive differences rue the signal. Frame 2 shows the IFR Probability field for the time. Three Good Things are happening. (1) Regions of elevated stratus – such as in/around Pittsburgh – are screened out (2) Regions with dense fog – Corpus Christi – are highlighted and (3) regions with mixed layer clouds (North Dakota) also have a signal.
8. The theoretical basis for the Fog/Low Stratus product is described next. The GOES-R FLS products (Frame 2) use data from several of the Imager channels – including the visible during the day. For geostationary products only, data from the previous time are used as well to maintain temporal continuity. Unlike the traditional brightness temperature difference, which uses only the difference between two satellite channels, the GOES-R Fog/Low Stratus products are data fusion products. Satellite data are fused with other ancillary data using a Naïve Bayesian Model. The ancillary data includes a digital elevation map, surface type and surface emissivity (these are static datasets), daily sea surface temperature and snow/ice cover maps, and modeled surface temperature and relative humidity data (as well as profiles) from the Rapid Refresh (over most of CONUS/Canada/Alaska) or the GFS (globally elsewhere). Surface observations are not directly used – but those observations do influence results because they have a large impact on the model fields. The combination of all these data yield the GOES-R Fog/Low Stratus products that are available in AWIPS. The total time it takes to produce the GOES-R FLS products once the satellite data is downloaded is only about 2-3 minutes. Frame 3 lists which GOES-R Channels are used – and for what purpose.
9. The brightness temperature difference is mostly a yes/no field. In contrast, the GOES-R Fog/Low Stratus product is a quantitative estimate; it is presented as a probability that suggests how likely IFR conditions are to be present. In the image shown, the redder regions are where IFR conditions are most likely to be present. High likelihood of IFR (Frame 2) – that is, probabilities exceeding 75% – usually correspond well with surface observations. In these regions there is a strong likelihood of low clouds based on the satellite data, and also a strong likelihood of low clouds based on the model RH fields – meaning saturation is occurring less than 1000 feet off

the surface in the forecast model. Surface observations will usually be consistent with IFR conditions. IFR probabilities between 45% and 75% (Frame 3) can occur with a combination of satellite and model predictors of IFR. Strong satellite indicators of fog/low stratus combined with weak model indicators of fog/low stratus, OR moderate indicators of fog/low stratus from both predictors (satellite and model) OR strong indicators from the model predictors and weak indicators from the satellite predictor. In this probability range there is a relatively high confidence that IFR conditions are present. Surface observations will likely be consistent with IFR conditions. These values are most frequent when satellite data cannot detect low clouds – because high clouds are present. Only the strong signal of the model saturation is driving the Probability value in that case. IFR probabilities between 20% and 45% (Frame 4) represent low confidence that IFR conditions are present. These probabilities arise when moderate and weak predictions of fog/low stratus occur. That is, when satellite predictions of IFR give moderate indicators of fog/low stratus and model predictors of IFR give weak indicators of fog/low stratus OR when satellite predictors are weak and model predictors are moderate. When the GOES-R IFR probabilities fall into this range a user should further monitor these areas with additional information (if present) to rule out or gain confidence on the presence of fog/low stratus. IFR probabilities of less than 20% (Frame 5) represent a very low confidence that IFR conditions are present. Surface observations rarely will verify IFR conditions. Both satellite and model predictors of fog/low stratus are weak in this case. Fog and low stratus are unlikely in these regions. Consider carefully that cirrus clouds (Frame 6) can change the IFR probabilities, as shown in this example. Both predictors – satellite and model – must give a strong indication of fog/low stratus for the highest probabilities, and that cannot happen if cirrus clouds are present, as in this case off the coast of Oregon. With time (Frame 7), you should be able to distinguish between regions where satellite-only data are being used (as in the River Valleys here in central Pennsylvania) and regions where model data are used only (southwest New York) and where both are used (northwest Pennsylvania). The other GOES-R FLS product included in this training module is the cloud thickness (Frame 8). This is calculated empirically and estimates the thickness, in feet, of the highest liquid cloud layer *that is not overlain by higher clouds.* That last caveat is important. Cloud thickness will only be available for single layer water clouds. Even when FLS is present, FLS cloud thicknesses will not be computed in areas such as under cirrus shields or convective thunderstorms. This product can be used to infer shallow fog layers and differentiate between thicker/thinner parts of clouds. The GOES-R cloud thicknesses can also be used to estimate the dissipation time of radiation fog after sunrise, which will be described in more detail later in this training.

10. These GOES-R Fog/Low Stratus products were validated using surface observations of ceiling and of visibility over CONUS. Validation used 12 days of data – one day from each month during a year – and included about 1100 GOES-East scenes. The critical success index (CSI) was calculated as a function of the GOES-R IFR probability and traditional BTD threshold. Bottom line is that the GOES-R product was determined to be about twice as skillful as the brightness temperature difference product at detecting hazardous IFR conditions – the maximum CSI for the GOES-R product was about twice the maximum CSI for the brightness temperature difference. In Frame 2, the same figure is shown for Alaska. What drives the superior

performance of the IFR Probability fields? Regions of mid-level stratus are screened out via IFR Probability, and regions of dense fog underneath cirrus canopies (or multiple cloud layers) are included.

11. There are a few artifacts that may be noticed when using the GOES-R FLS products. One of them arises due to model boundaries. Model fields are used in this data fusion product. The higher resolution rapid refresh is used over North America and over adjacent waters, and different model resolutions are available. GFS data are used elsewhere globally. Not surprisingly, there is often a seam visible at the outer edge of the Rapid Refresh domain where the model fields do not exactly mesh. For WFOs this should not be an issue but it may be for marine forecasts.
12. Another issue comes from a stray light correction that occurs at certain times of the year that causes the GOES-R IFR probabilities to be inflated artificially. However, it should be noted that this effect is more noticeable in the brightness temperature product (the 'traditional' Fog Product) than the GOES-R FLS products.
13. The GOES-R Fog/Low Stratus products change as day turns to night, and as night turns to day. The changes arise from different predictors (or different weights for the same predictors) being used to compute the product. Probabilities are a bit larger in daytime, usually, because the cloud mask is more confident that clouds are or are not present (because the visible imagery can be used as part of the cloud mask) The GOES-R Cloud Thickness product is unavailable during twilight conditions, but is available all night and during most of the day for single layer water clouds. *Note that these features are apparent in the animation.*
14. Five+ examples will be shown that use GOES-R series data. A partial list is here.
15. This Night Fog image shows where stratus clouds are present over Illinois behind a departing low pressure system – the thick clouds with the front stretch from Ontario, Ohio and Pennsylvania southward. The satellite is seeing the top of this stratus deck, but it doesn't tell you much about the cloud base – does the cloud extend down to the surface? Frame 2 shows the Night Time Microphysics RGB at the same time – you will see the characteristic signal of stratus clouds over IL, but it's very tough to use either product to identify regions of IFR conditions. Frame 3 shows ceilings/visibilities – and the only region with IFR conditions is downwind of Lake Michigan – check out the observation at South Bend for example. Frame 4 shows the radiosonde from Lincoln IL – its location is circled – and the saturation with the mid-level stratus is apparent. Frame 5 shows the IFR Probability field for this time, and probabilities are very low over Illinois. In this region, the Rapid Refresh is not showing low-level saturation, so IFR Probabilities are very low. Rapid Refresh does suggest low-level saturation downwind of Lake Michigan, and IFR Probabilities are larger there.
16. This is an example of a front moving through the northeast US. IFR probabilities accompany it. Are there ways to tell where IFR conditions are most likely in this cloudy region? It's difficult to tell solely from the visible imagery where the IFR conditions are present. IFR Probability fields show a region of higher probabilities stretching from Pennsylvania northeastward to Maine. You can use features in AWIPS to overlay the visible imagery on top of the IFR Probability fields, and have the IFR Probability peek through. In this case, Rapid Refresh data are highlighting the region of low-level saturation.

17. IFR Probability fields over Idaho and Montana are shown in this series of images. Topographic features are important in the depiction of IFR Probability fields. Visible imagery (Frame 2) over Idaho and Montana shows cloudiness over the region – but there is little in the cloud field that suggests where IFR conditions might be present (You can see one or two observations of IFR conditions). The Day Fog Brightness Temperature Difference field also shows the widespread cloudiness (but there is little in the field to suggest there's a relationship between the brightness temperature difference field and the surface observations). IFR Probability fields show highest probabilities over higher terrain in Idaho and Montana. You can see a similar relationship in the high terrain, typically, that surrounds the Central Valley of California when clouds are present. The terrain rises up into the mountains and IFR conditions result.
18. A big challenge in detecting low ceilings/reduced visibilities occurs underneath extensive cirrus shields, as might occur with landfalling cyclones in the Pacific Northwest, or by nor-easters along the northeast coast. This animation shows an hour of cirrus shielding. There are low clouds apparent to the south over southern Oregon, and you might see occasional glimpse of low clouds through the high clouds when gaps appear. But it's pretty hard to see where the low clouds are when high clouds are present!
19. GOES-R IFR Probabilities show a different distribution than the cirrus clouds. These fields are mostly being driven by numerical model output – because of the extensive cloud shields. When the fields are smooth, the IFR Probability field will be smooth as well – as over the Pacific Ocean. You can see regions where cloud data are being used over the ocean – larger IFR Probability values that occur where satellite data information can augment the model-driven IFR Probability value.
20. Here's another example that shows how IFR probability fields screen out regions of elevated stratus. The extensive cirrus shield over Texas masks regions of low clouds. It's difficult to relate the Night Fog brightness temperature difference field, or the Night Time Microphysics field (which relies heavily on the Night Fog Brightness Temperature Difference field for its 'green' component), to reported IFR conditions. The IFR probability field (frame 3) shows a complex distribution of IFR conditions. Regions under cirrus show smaller values – because satellite information cannot be used to detect low clouds. Regions without high clouds – such as the western edge of the Texas panhandle – show higher values because both model data and satellite data are being used in the computation (and the field there looks more pixelated).
21. Over the western United States, both GOES-16 and GOES-17 could be used. GOES-16 has an advantage over GOES-17: It has a better-functioning Loop Heat Pipe, and GOES-17 does not. GOES-17 will suffer from data drop-outs during some nights of the year. GOES-17, however, has smaller pixels sizes on the west coast, and smaller parallax shifts. This slide shows values over the San Francisco Nay area; note how the cloud location shifts between GOES-16 (over land) and GOES-17 (over the Pacific ocean). Which do you think is more realistic? Note also that the GOES-17 pixel size is smaller.
22. This shows a similar GOES-16 v. GOES-17 comparison, but over the state of Washington.
23. In this (repeat) slide you should be able to distinguish between regions where satellite-only data are being used (as in the River Valleys here in central Pennsylvania) and regions where model data are used only (southwest New York) and where both are used (northwest Pennsylvania).

Only satellite data can be used where thin river valleys are present – because they might not be resolved in the 13-km resolution Rapid Refresh model. The region over the southern Tier of NY is mostly being determined by model data – the model is suggesting that fog has developed there before the satellite has observed it, so the probabilities are a bit lower than they are over NW Pennsylvania where both model and satellite suggest IFR conditions might be occurring.

24. This figure shows the relationship between the last-before-sunrise cloud thickness estimated by the GOES-R algorithms and the number of hours required for the Fog to dissipate. The data are for radiation fog only – other types of fogs may advect large distances over time, or they may be sustained by factors other than radiational processes that vary in a predictable way as the sun rises.
25. The following slides show radiation fog dissipating with time. The initial image is at 1102 UTC. GOES-R IFR probabilities are in the upper left, GOES-R Cloud thickness in the upper right, traditional brightness temperature difference product in the lower left, and visible imagery in the lower right. The 1102 UTC image (Frame 2), the last one before twilight conditions invalidate the GOES-R cloud thicknesses, shows maximum thicknesses around 1000 feet in north central Florida/southeastern Georgia. That 1000 feet correlates to a dissipation time of slightly more than 3 hours. Once the sun rises (Frame 3), the radiation fog starts to burn off. (This is the 1245 UTC image) At 1345 UTC (Frame 4), GOES-R cloud thickness suggests that the southern part of the red circled area is thicker – expect it burn off after the northern half. By 1415 UTC (Frame 5), the fog is fractured and continues to erode from the outsides in. By 1445 UTC (Frame 6), the fog has dissipated, just under 4 hours after the last night time cloud thickness calculation at 1102 UTC. So this example is consistent with the scatterplot that relates cloud thickness to dissipation time.
26. The 5-minute time step with GOES-R allows the field to be used to predict when a moving fog field might move over a region, as in this case with fog moving over Tampa Bay. Note in this animation how the IFR Probability field changes slightly every hour. At the top of every hour, new Rapid Refresh data are used – because a different more recent model becomes available. Usually, this change is pretty subtle because run-to-run differences in the Rapid Refresh model are small, but even the subtle changes are noticeable, as in this animation.
27. Some benefits.
28. This case compares IFR Probability to other fog-detection products in a region with Dense Fog Advisories over much of the southeastern United States. Frame 2 shows the IFR probability field, an extensive region of high values during a time with the Dense Fog advisories. Frames 3 and 4 show the Night Fog Brightness Temperature Difference and the Night time Microphysics field. Note the high clouds over Alabama that prevent satellite-based detection of the low clouds. This case is also interesting because the IFR conditions over coastal South Carolina and the IFR probability there are very much model driven – the Night Fog Brightness Temperature Difference and the Night Time Microphysics RGB do not have particularly strong signals of fog there. Also, check out the low IFR Probabilities over Tennessee, a region where stratus clouds are indicated. This mid-level stratus signal is being screened out of the IFR Probability field by Rapid Refresh data – that is, by a lack of low-level saturation in the Rapid Refresh model there.

29. The strength of IFR Probability is that it fuses satellite data that identifies low clouds with model data that identifies low-level saturation. Thus, regions of mid-level stratus can be screened out, and regions of fog underneath multiple cloud layers (or single cirrus layers) can be identified. In addition, regions of low clouds in otherwise clear regions can be identified. There are multiple ways to detect fog/low stratus. Make sure you understand the strengths and weaknesses of the product you choose to use!
30. Augmentation work is ongoing. Much of the focus after GOES-17's launch was in understanding the affect of the Loop Heat Pipe issue, and on getting both products to flow through the SBN to AWIPS (before SBN distribution – scheduled for 2020 – distribution was via an LDM pull)
31. There is additional training material on this product. In particular, frame 2 shows the 'Fog Blog' which is an ongoing effort to document regionally-specific descriptions of Fog events and how IFR Probability fields were useful for those events. You can go to the site and search for events in different categories or in different locations.
32. FAQs. IFR Probability will not detect IFR conditions caused by smoke *unless that smoke seeds a dense fog.* Smoke and fog have different properties as far as satellite detection goes, and Rapid Refresh model data does not predict smoke. Thus, IFR Probability does not identify smoke-caused IFR conditions. Ice Fog detection is also a challenge for this product.
33. Comments or questions can be directed to the people on this slide.