P9.16 AN EFFORT TO IMPROVE MARINE STRATUS FORECASTS USING SATELLITE CLOUD CLIMATOLOGIES FOR THE EUREKA, CA REGION

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1. INTRODUCTION

A major forecast challenge for the National Weather Service (NWS) Eureka forecast office is the marine stratus and fog that forms along the northwest California coast. Marine stratus develops on the eastern periphery of the Pacific anticyclone during the warm season in a zone of upper level subsidence. The cool ocean temperatures in this region combined with the subsidence aloft create a strong inversion within the marine layer. The marine stratus that forms in this layer can persist for many days at a time. The low ceilings and visibility that often accompany these clouds are a major hazard to aviation at the Crescent City (CEC) and Eureka/Arcata (ACV) airports, in addition to travelers on highway 101 along the Redwood coast. This study will investigate the potential utility of using satellite cloud composites when forecasting the duration and burn off rate of the marine stratus deck along the NW California coast.

Past studies have shown how satellite derived composites can be useful in forecast decisions. Combs et al. (2004) found cloud composites useful in forecasting fog formation and dissipation over the San Francisco bay area when compared with changes in sea level pressure and wind regimes. Connell et. al (2001) showed that hourly cloud composites compared to wind regimes were useful in forecasting sea breeze convection in Florida. Combs et al. (2001) showed that using cloud composites per wind regime highlighted persistent cloud features that preceded convective development in the mid Atlantic region.

This project takes a similar approach by using cloud composites to calculate an average burn off rate of the summertime stratus deck along the northern California coast according to the cloud top height, which is used as an estimate of the marine layer depth (hereafter, MLD). Cloud composites have been produced every hour for different marine layer depths. The end goal is to provide forecasters with a climatology tool to more accurately determine where and at what time the low stratus deck will scatter out along the coast.

2. DATA AND METHODOLOGY

For this project, images for channels 1 (Visible), 2 (3.6 μm) and 4 (10.7 μm) from the Geostationary Operational Environmental Satellite (GOES) were obtained from an archive collected at CIRA. The GOES West images were collected every other hour for May through September, 1999-2009, cover the western U.S., and are sampled to 4-km resolution. Each image was quality checked, then sectorized to cover the County Warning Area (CWA) for the Eureka, CA office and the surrounding region (Figure 1). After discussion with the local office, the data was further divided into four monthly periods starting in mid-May (May 15 - June 15, June 16 - July 15, July 16 - August 15, August 16 - September 15). Then the data were grouped by hour for further processing.

The data was further reduced to days with minimal disruption to the marine layer. This included only days when there were no synoptic or strong mesoscale disturbances affecting the region. This stipulation was based on local knowledge of the mechanisms that disrupt the marine boundary layer and distort the depth of the stratus. In instances of synoptic forcing, the low stratus may not form, or the burn-off rate will either slow down or in some cases reverse direction causing clearing at the coast while marine stratus remains inland. Neither event is considered typical stratus behavior so was removed from this study that seeks to describe the typical stratus dissipation.

For this project, we are most interested in fog and marine stratus throughout a twenty-four hour period. To detect these low clouds, we are using a method similar to one described by Jedlovec and Laws (2003).

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Basically, the 10.7 μm and 3.6 μm images are matched according to time and are divided into sets for a given month and hour of the day (for instance, all 1200 UTC images for June 2003). For each image pair, a difference value is calculated by subtracting the 3.6 μm brightness temperature value from the 10.7 μm brightness temperature value for each pixel. Then for each pixel location, the largest negative difference and the smallest positive difference is determined for the entire month and hour to form two composite images. In addition, the warmest 10.7 μm temperature value for each pixel location in the set is also determined.

Figure 1: Topography map for Eureka, CA NWS office's County Warning Area

Once these three composites are produced, two tests are performed. The first is the minimum difference test. If the 10.7 μm - 3.6 μm temperature difference calculated earlier for a given pixel in an image pair is negative, and the absolute value of the difference minus the negative composite value is greater than a threshold value (5.1K over land, 4.1K over ocean), it is tagged as cloud. Otherwise, it is considered clear. If the difference is positive, it is tagged cloud if the difference minus the positive composite value is greater than the threshold value (2.0K). After this test is done for all of the pixels in the image pair, a final test is performed on all the 'clear' pixels. If the 10.7 μm temperature for the pixel is 18.5K colder than the warmest 10.7 μm temperature composite value, it is retagged cloud. The same procedure is performed on the rest of the image pairs. During daylight hours, a final check on clear pixels is performed using the method described in Reinke et al (1992). A monthly, hourly background of the visible channel consisting of the darkest value minus cloud shadows was determined for each pixel location. Then each visible pixel in each image of the set was compared to this background. If the value was greater than the background plus a threshold value, the pixel was retagged as cloudy.

Table 1: MLD regimes and heights

Regimes	Marine Layer Depth
1	< 100 feet
2	101-750 feet
3	751-1250 feet
4	1251- 1750 feet
5	1751-2250 feet
6	2251-2750 feet
7	> 2751 feet
8	> 1751 (regimes 5,6&7)

The next step is to classify the data into 8 'regimes' according to the marine stratus layer's depth (MLD) at 1200 UTC. Locally, this is just before dawn during the summer when the MLD is normally at its deepest. Table 1 shows the regimes and corresponding depths. While regime 1 is listed in the table, it was rarely used since days with clouds under 100 feet were not normally marine stratus cases.

The MLD was estimated according to where the clouds pool against the terrain. The Coastal Range is a north-south oriented mountain range situated immediate to the coast. The elevation changes drastically from the Pacific Ocean (0ft MSL) to the highest peaks (9000ft MSL) in approximately 50 miles. An estimate of cloud top height can be gathered by doing a comparison of where the edge of the cloud deck meets the terrain. Cloud/no cloud images were produced at CIRA for each day at 1200 UTC, then sent to Eureka and entered into their GIS system. MLD was determined by where the cloud deck settled against the terrain at several points. The terrain height was determined through GIS methods at these points and those values were averaged to estimate MLD. The assumptions are that the top of the marine layer stratus is coincident with the top of the marine layer. This height is also coincident with the base of the marine inversion at the time of maximum stability in the marine inversion layer, just before dawn.

3. ANALYSIS OF CLIMATOLOGIES

3.1 *General climatologies*

As a first step, hourly cloud climatologies using all data from 1999-2005 were produced for each calendar month (May-September). These provide a general climatology of the area that can be used as a baseline for comparisons with the regime climatologies. Figures 2-4 show examples of these general climatologies for July at 1200, 1800, and 0000 UTC, representing pre-dawn, late morning, and early evening. Note that these images cover more than the Eureka CWA, which is in the northwest quadrant. The San Francisco Bay area and Lake Tahoe are included for geographical reference.

The general climatologies point out the main features of the region's weather during the summer months. There is a noticeable difference between the ocean and land.

The ocean tends to have cloud amounts above 60% and often greater than 80%, which is comprised of mostly marine stratus. Inland, the skies tend to be much clearer with cloud amounts less than 25%. Usually, these clouds are comprised of either high cloud or cumulous development over the inland mountain ranges. The boundary between these two contrasting areas is the coastal region. Marine stratus penetrates inland into low areas along the coast and into the Eel river valley overnight, and then retreats back to the ocean during the day. This is the location of the Eureka CWA and the area we are most interested in.

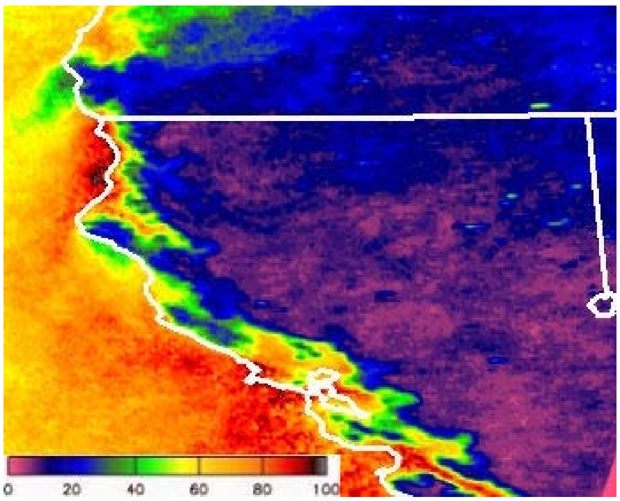

Figure 2: Cloud % for Eureka, CA region during July 1999-2005 for 1200 UTC (5 am PDT).

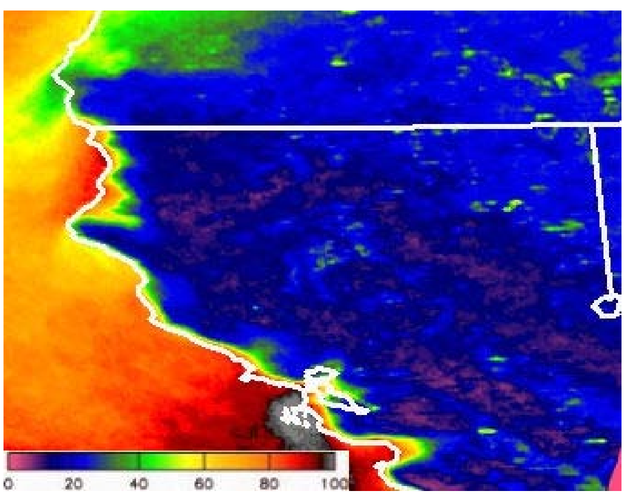

Figure 3: Cloud % for Eureka, CA region during July 1999-2005 for 1800 UTC (11 am PDT)

3.2 *Marine Layer Depth regimes*

One useful tool for analyzing the success of a given regime set is to look at the number of cases (images) that fall within each regime for a given period. The graph in Figure 5 shows the average number of cases for each regime in each time period. It is obvious that for all periods, Regime 3 (MLD of 751-1250 ft) has the most cases, while Regime 4 (1251-1750 ft) also

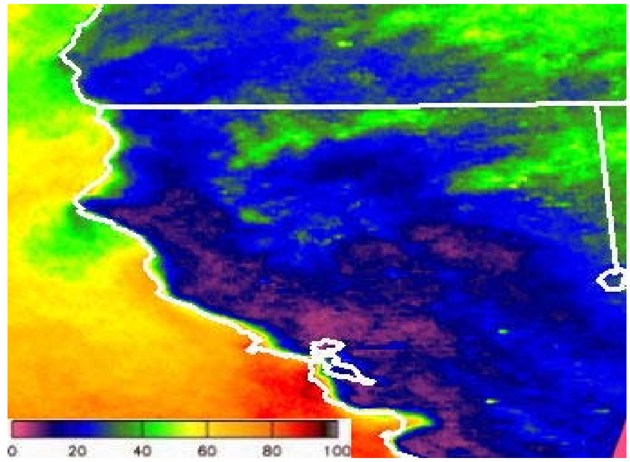

Figure 4: Cloud % for Eureka, CA region during July 1999-2005 for 0000 UTC (5 pm PDT)

provides a decent number of cases for each period. However, the number of cases in many of the other regimes are quite low. For useful results, satellite composites require at least ten cases. Regime 2 (101-750 ft) has enough cases for all but the May-June period. However, Regime 5 (1751-2250 ft) only has enough cases in the July-August period, and the two higher MLD Regimes (6 and 7) do not have enough cases in any period. This is unfortunate, since the Regime 5 period with enough data show that these regimes could be quite interesting and helpful to the office during these events. The best way to increase these numbers would be to add more years of data. Since that option is not available for this project, Regime 8 was created by combining Regimes 5, 6 and 7. While this is not ideal, it did boost the number of cases to provide useful climatologies for all periods except the August-September.

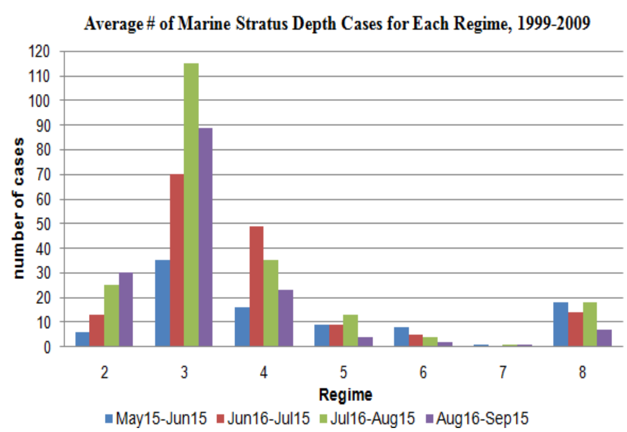

Figure 5: Average number of cases for each MLD regime for each time period

3.3 *Comparison between MLD regime climatologies*

To see how the MLD regime climatologies compare with the general climatologies and each other, we will start with the regime with the most data. Figures 6-8 are Regime 3 climatologies during July 16–August 15,

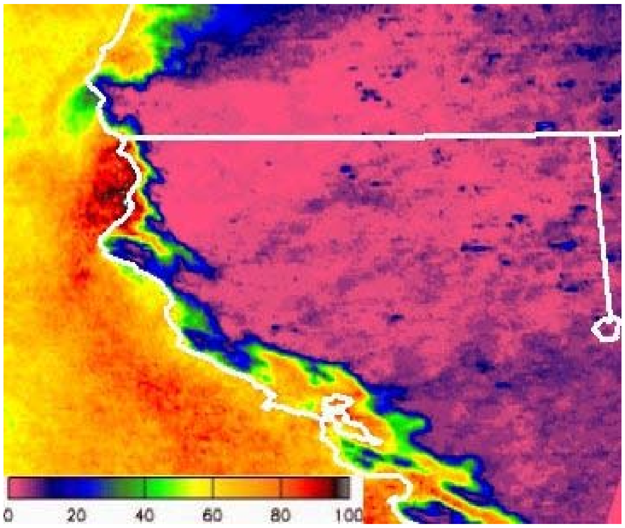

Figure 6: Cloud % for Regime 3 during July 16-Aug15 1999-2009 for 1200 UTC (5 am PDT)

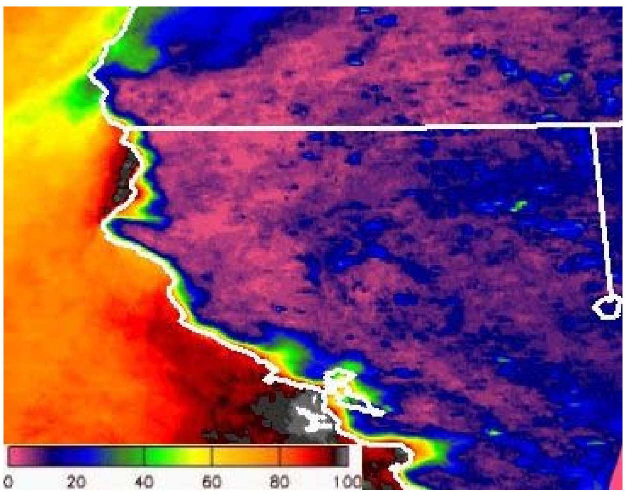

Figure 7: Cloud % for Regime 3 during July 16-Aug15 1999-2009 for 1800 UTC (11 am PDT)

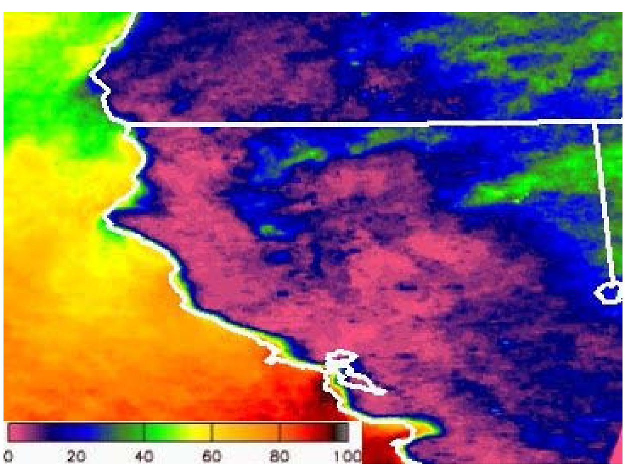

Figure 8: Cloud % for Regime 3 during July 16-Aug15 1999-2009 for 0000 UTC (5 pm PDT)

1999-2009 at 1200, 1800, and 0000 UTC. While these are not an exact match to the July 1999-2005 climatologies, they are still quite similar. This is not unexpected, since Regime 3 would have contributed a lot of data used in the general climatologies. However, there are subtle differences. For instance, large land areas at all three times have lower cloud percents (< 3%) in Regime 3 climatologies than in their general counterparts. This suggests there is an even stronger contrast between areas covered by marine stratus and nearby locations on days when this occurs. Also, while the locations of inland marine stratus penetration is very similar in all three time periods, the cloud percents tend to be higher in Regime 3. Again, this is reasonable, since the general climatology would include clear days.

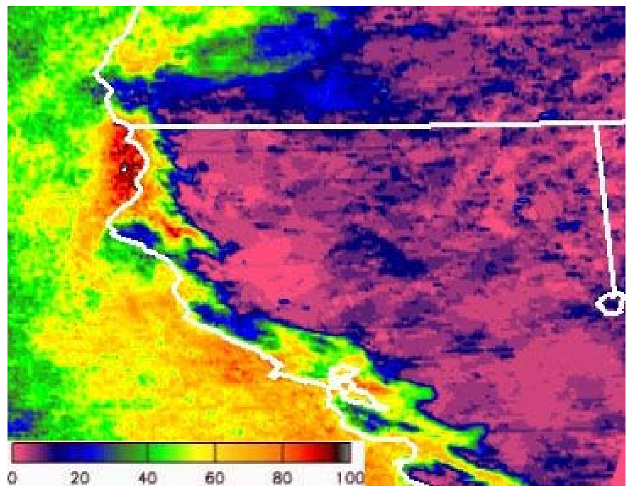

Figure 9: Cloud % for Regime 4 during July 16-Aug15 1999-2009 for 1200 UTC (5 am PDT)

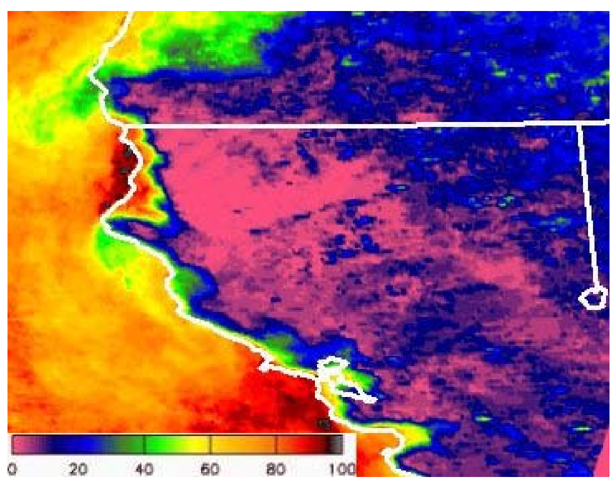

Figure 10: Cloud % for Regime 4 during July 16-Aug15 1999-2009 for 1800 UTC (11 am PDT)

Next, we will look at Regime 4 for the same period and times (Figures 9-11). There are subtle differences between Regime 3 and Regime 4. The main difference is that the extent of cloud percents greater than 50% covers more area in all three time periods in Regime 4 than Regime 3. This indicates not only that the marine stratus has reached farther inland for Regime 4 at predawn (Figure 9), but also that it takes longer for it to burn off back to the ocean. While in Regime 3 the stratus has mostly cleared off to below 25% along the coast by 5 pm (Figure 8), there is still significant cloud percent in Regime 4 over Eureka, Arcata and Crescent City at the same time of day (Figure 11).

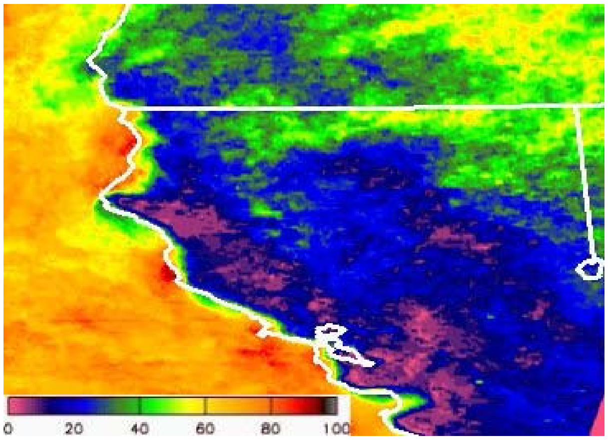

Figure 11: Cloud % for Regime 4 during July 16-Aug15 1999-2009 for 0000 UTC (5 pm PDT)

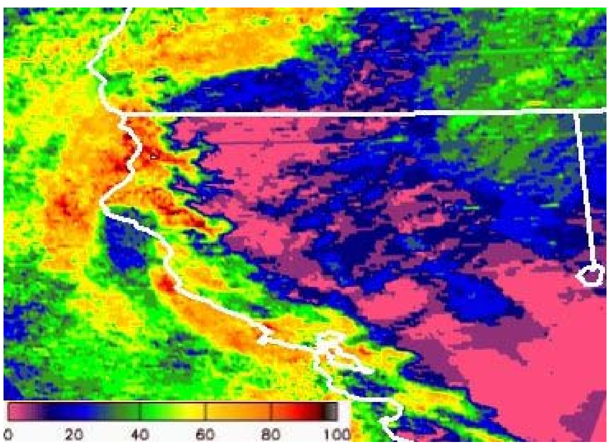

Figure 12: Cloud % for Regime 5 during July 16-Aug15 1999-2009 for 1200 UTC (5 am PDT)

Finally, we will look at Regime 5 for the same period and times (Figures 12-14). This regime doesn't have as many cases as Regimes 3 and 4, which is why Regime 5 climatologies don't look as smooth. However, the difference between Regime 5 and the other two is striking, especially for 1200 UTC (Figure 12). Not only has the marine stratus penetrated farther inland for Regime 5 as compared to Regime 4, but a second tongue of high cloud percent values has entered the Klamath river valley north of Arcata. The Eureka office has suspected from surface observations that there is a tipping point around 2000 feet before marine stratus enters the valley, which the climatologies seem to confirm. For the 1800 and 0000 UTC, the marine stratus has retracted from the river valleys, but still has very high cloud percent values for a large area along the coast.

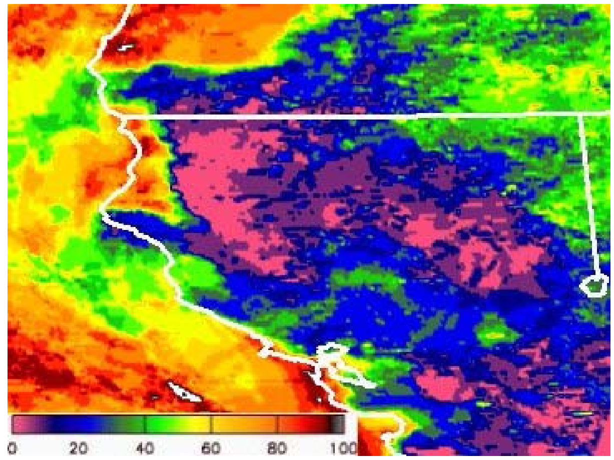

Figure 13: Cloud % for Regime 5 during July 16-Aug15 1999-2009 for 1800 UTC (11 am PDT)

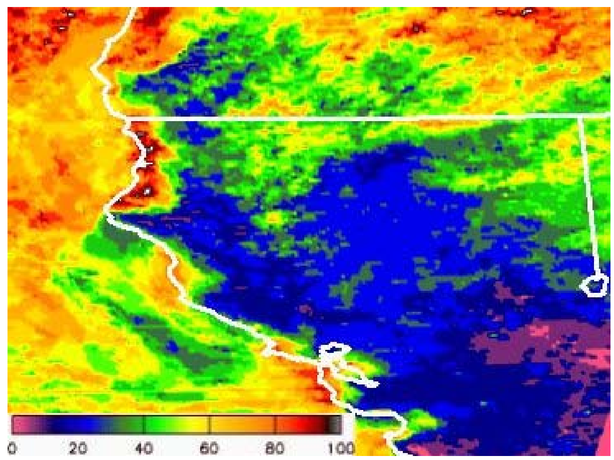

Figure 14: Cloud % for Regime 5 during July 16-Aug15 1999-2009 for 0000 UTC (5 pm PDT)

4. PRELIMINARY VALIDATION

CIRA provided the MLD regime climatologies to the Eureka office for use in their AWIPS D2D system during April 2010. During the summer of 2010, the office began work in validating these products for use in their forecasts. One way was to compare ground observations to the climatologies. This was conducted by determining the time of burn-off at two METAR sites located at the KACV and KCEC air terminals using surface observations for the 2008 summer season. The average value of the nine pixels from the satellite climatology surrounding the air terminals was determined for each hour after sunrise. An average of 50% cloud cover or less indicated the end of the burn-off hour with 30 minutes earlier estimated to be the burn-off time. These times were then compared to the METAR observations. Preliminary results show the burn-off time from satellite data lags behind the observational data by about 4 hours. Research is ongoing to explain this lag. Possible explanations include the 4 km resolution of the satellite data, partially cloud-filled pixels, the 50% threshold, and the centering of the nine pixel grid. Comparisons of a one pixel approach representing the observation site versus a 9 pixel approach surrounding the site were conducted, but no appreciable difference was found.

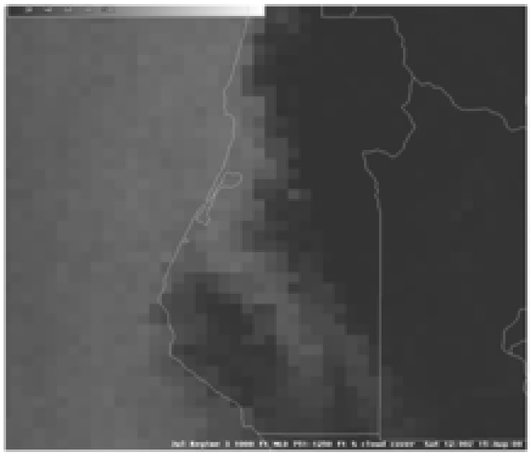

Figure 15: Cloud % for Regime 3 during July 16-Aug15 1999-2009 for 1200 UTC (5 pm PDT) for the Eureka CWA

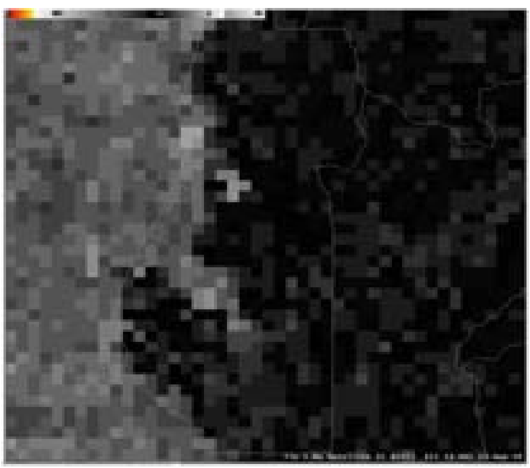

Figure 16: Fog product image from GOES data for the Eureka CWA at 1200 UTC on August 13, 2010.

A more successful validation done by the Eureka office was to compare recent satellite observations to the climatologies. One such comparison was done on August 13, 2010. Note that this day was not included in the data used to produce the cloud climatologies. Independent sources, such as PIREPs (pilot reports) and visual spotter reports, estimated the marine layer depth to be 1000 feet or Regime 3. Figure 15 shows a black and white version of the cloud climatology for 1200 UTC over the Eureka CWA (extract from Figure 6). Figure 16 is the fog product at 1200 UTC on August 13. The locations and shape of high cloud percent values in the climatology is a fairly good estimation of the cloud in the image. The same is true for Figures 17 and 18, which shows the climatology and a visible image from the same day at 1800 UTC, respectively.

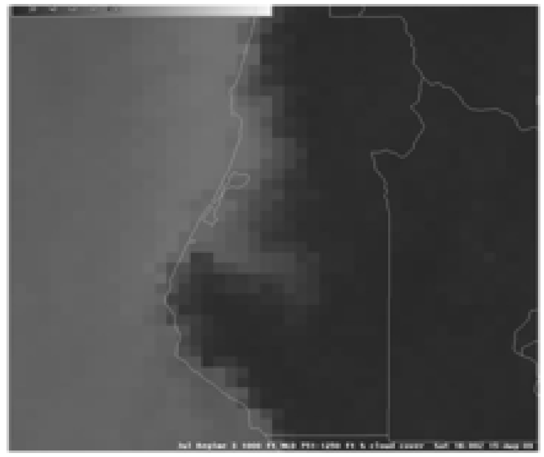

Figure 17: Cloud % for Regime 3 during July 16-Aug15 1999-2009 for 1800 UTC (5 pm PDT) for the Eureka CWA

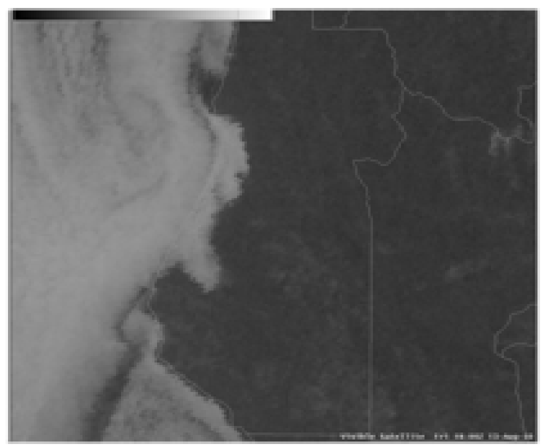

Figure 18: Visible image from GOES for the Eureka CWA at 1800 UTC on August 13, 2010.

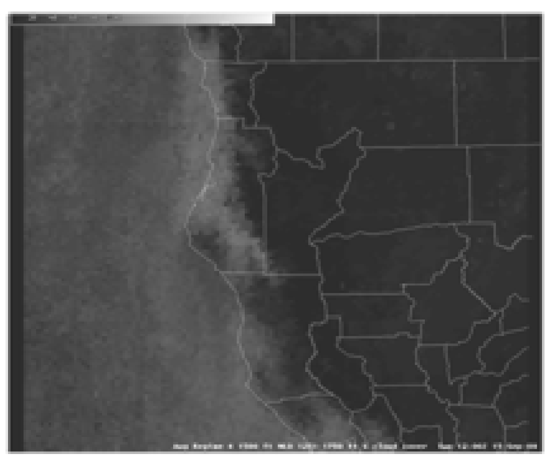

Figure 19: Cloud % for Regime 4 during Aug16-Sep15 1999-2009 for 1200 UTC (5 pm PDT) for the Eureka CWA

A similar comparison was done for August 19, which independent sources estimated the MLD to be 1500 feet or Regime 4. Figures 19 and 20 show the climatology and the fog product image for 1200 UTC, Figures 21 and 22 show the climatology and visible image for 1400 UTC, while Figures 23 and 24 show the climatology and visible image at 1800 UTC. The 1200 and 1400 UTC climatologies compare well with the images, though the 1800 UTC is not as good a match.

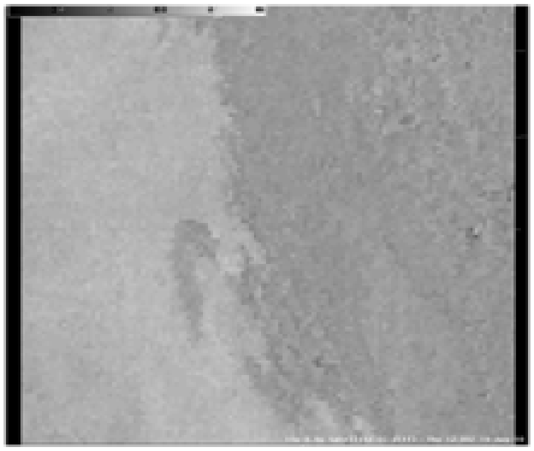

Figure 20: Fog product image from GOES data for the Eureka CWA at 1200 UTC on August 19, 2010.

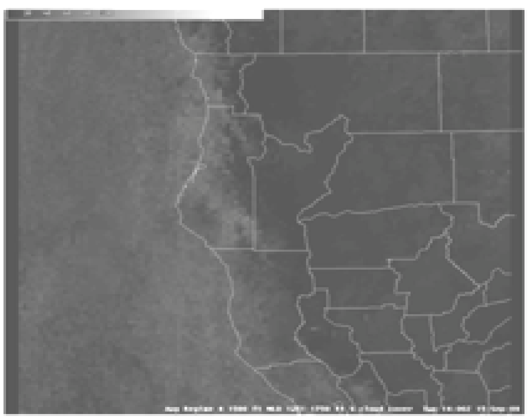

Figure 21: Cloud % for Regime 4 during Aug16-Sep15 1999-2009 for 1400 UTC (5 pm PDT) for the Eureka CWA

5. CONCLUSIONS AND FUTURE WORK

Cloud climatologies are a useful tool for examining local and regional meteorological events. By dividing the data into MLD regimes, more information about the coverage of marine stratus clouds under given conditions can be obtained. The results seem especially promising for the higher level MLD regimes, which may not occur as often as the lower regimes but show a different picture in cloud coverage inland.

These products have been provided to NWS forecasters in Eureka, CA to aid with marine stratus forecasts.
Future plans include utilizing the climatology images to

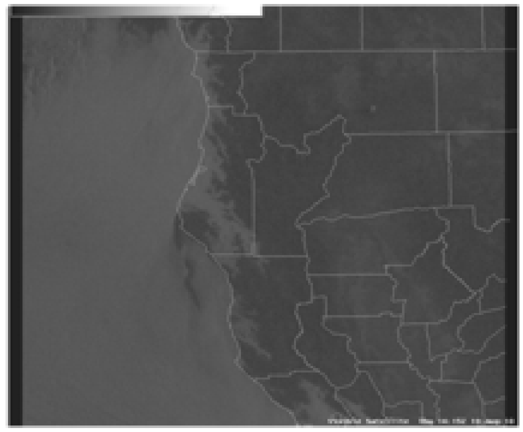

Figure 22: GOES Visible image for the Eureka CWA at 1400 UTC on August 19, 2010.

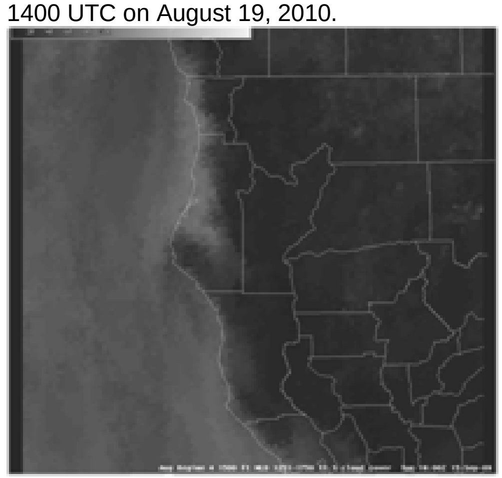

Figure 21: Cloud % for Regime 4 during Aug16-Sep15 1999-2009 for 1800 UTC (5 pm PDT) for the Eureka CWA

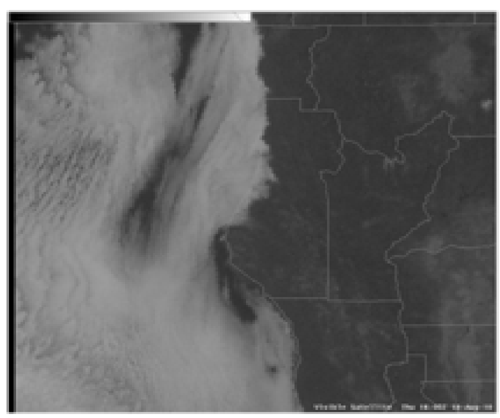

Figure 22: GOES Visible image for the Eureka CWA at 1800 UTC on August 19, 2010.

develop templates for the AWIPS Graphical Forecast Editor (GFE) to provide low level cloud grids. These can be used as a first guess for cloud cover forecasts. In addition, the early GIS analysis of satellite images will be used as a base for the development of a burn-off forecasting tool for WFO Eureka aviation forecasters.

To learn more about the product and regional satellite climatologies, visit the websites at http://rammb.cira.colostate.edu/research/goes-r/proving_ground/cira_product_list/eureka_marine_stratus_cloud_climatologies.asp

http://rammb.cira.colostate.edu/research/satellite_climatologies/

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