ANTARCTIC FOG DEPICTION VIA SATELLITE ANALYSIS

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1. INTRODUCTION

McMurdo Station, Antarctica suffers from one to as much as four days of fog per month on average. The nearby airfields suffer from as much as four times that number. Even though there is a decreasing trend in fog occurrence at the station, forecasting fog is critical for aviation safety and logistics operations. Despite the recent installation of web cameras, satellites will offer the best regional view of the primarily advective fogs as they approach McMurdo and the near by airfields. The Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on the Terra and Aqua satellites is the platform used in this satellite analysis.

2. RGB PCI FOG DEPICTION: A PRINCIPAL COMPONENT ANALYSIS METHOD

There are various modern methods to depict fog via satellite imagery, with recent advances requiring ancillary information. For a depiction to be of use at an Antarctic station with limited communication links, having little to no ancillary data is ideal. With such a limit, and with a desire to have the satellite observations themselves aid in determining fog, a principal component analysis (PCA) provides a means for depicting features. (Hilllger 2002a, 2002b, and 2003; Lazzara 2008). PCA is often performed on a dataset to reduce the redundancy in it – as can be the case with the MODIS multi-spectral observations. It is also used to bring out features in the dataset, which is the objective here.

The approach takes multiple spectral channels of a sample satellite observation, and determines the principal component "images" (PCI) for a given number of input channels. It was originally applied toward imager and especially the multi-channel sounder on the GOES satellite series. The first PCI depicts the features from the original observation that explain the most variance of the data and the features that are most common in the input channels. Similarly, the second PCI depicts the features from the observation that explain the second most variance of the data, and typically the differences between the input channels (Hillger 1996). Higher order PCs usually depict noise and other differences between the input channels. In its application here, the PCA provides information on variance spatially and spectrally, and does not offer the additional temporal variance that most Empirical Orthogonal Function (EOF) analyses accomplish.

In applying this procedure to fog depiction, a selection of specific spectral channels from the MODIS satellite observations were used rather than attempting to employ all 36 channels. Some of the 36 channels are not able to contribute to fog depiction such as the ocean color channels, and carbon dioxide channels for upper troposphere applications. This initial reduction in channels chosen is based on ability of the channel to show fog or contribute in some way to low-level moisture and low cloud determination. The final selection of channels is listed in Table 1.

The final use of the PCI is a combined red green blue (RGB) combination of the first two principal components, with twice the weighting (via both red and green) on the second component image. The PCI analysis and RGB compositing are done in the McIDAS interactive processing system (Lazzara et al. 1999) The results reveal that this method provides an alternative means for enhancing features including fog, as the fog and low cloud features in the image are subtly

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distinguished from other features in the field of view (See Figure 1). However, investigation of the higher order PC images not shown here revealed that much less meteorological information and more noise was present.

Table 1. Selected MODIS channels for principal component analysis to depict fog.

MODIS Channel	Wavelength (μm)	Detection Properties
1	0.64	Visible channel reflectance
6	1.62	Near infrared - low reflectance of snow
7	2.11	Near infrared absorption of liquid water
22	3.97	Shortwave infrared emission and solar reflection
31	11.0	Infrared emission of clouds

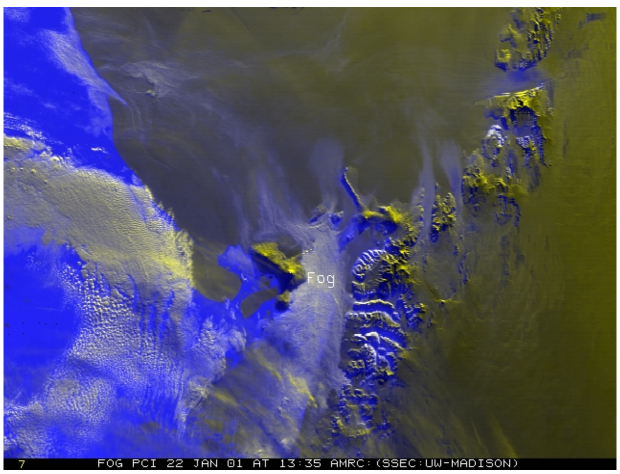

Figure 1. An RGB PCI fog depiction image for 13:35 UTC on 22 January 2001 from the Terra satellite.

3. VALIDATION AND LIMITATIONS

An abbreviated exercise was conducted to determine the validity of the RGB PCI fog depiction. Ten fog cases were used to test how well spatially the product compared to relative humidity observations from the Automatic Weather Station (AWS) network. Although it is difficult, using the AWS network, to discern high relative humidity causes, as precipitation, blowing snow and fog (King and Turner 1997, Knuth 2007) are all plausible, it is the only spatially available independent observation network available for this informal validation. Figure 2 shows an example of how well the RGB PCI fog depiction compares to AWS relative humidity observations for approximately the same time.

The ten validation cases consisted of 105 satellite scenes centered on Ross Island and McMurdo. The region covered an area roughly 450 km (north/south) by 600 km (east/west). Scenes were selected in the 12 to 48 hours before the densest fog for each case. A breakpoint of 90% relative humidity from the AWS observations was used for the validation criteria. It is important to note that the relative humidity measurement has an accuracy of only +/- 5%, and can drift after installation. Hence, this selection of 90% may be too conservative in some situations.

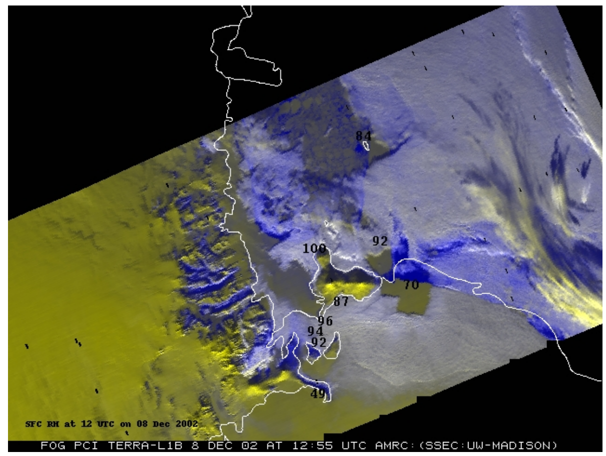

Figure 2. A sample RGB PCI fog depiction image with relative humidity observations from the AWS network plotted. Notice the high relative humidity reports occurring at AWS stations within the enhanced/highlighted white fog/low cloud regions, while there is lower relative humidity at Laurie II AWS, reporting 70%, in a clear region without fog.

The procedure involved dividing the satellite data into regions that indicate fog and those that do not indicate fog. Next, the AWS observations were used for each of those types to determine if the observation matched or "hit" the satellite observation or did not match or "missed" the satellite observation. Hence, for regions that the satellite indicated fog/low cloud, a "hit" would be a match of the collocated AWS observations greater than or equal to 90% relative humidity. Conversely, a "miss" would be a relative humidity observation below 90% collocated with the satellite indicating fog. For regions the satellite does not indicate fog/low cloud, a "hit" denotes an AWS observation that matched with a value less than 90% while a "miss" indicates an AWS observation that did not match with an unexpected relative humidity greater than or equal to 90%. Approximately 903 AWS observations were used in the 105 scenes over the ten cases.

The results of the analysis are summarized in Table 2. From the perspective of the satellite indicated clear or "dry" regions, the method validated fairly well, with 287 AWS observations agreeing with the satellite observations with only 53 misses. Of those misses, some may be due to slight lags between the AWS observation time and the satellite observation time. Hence there are “near” misses, with some observations being very close to being proper observations of fog/low clouds. From the point of view of the satellite indicated fog/low cloud, the results of the validation on the surface has the satellite no better than a 50-50 chance of a correct depiction. However, this validation requires the consideration of comparison. The satellite is a topside view and cannot distinguish between fog and low cloud, for example. If there is a case of low cloud, the 3 meter tall AWS can very likely be correctly recording drier conditions in the layer of air below a low cloud deck. Of the 226 fog misses, some could be an indication of low clouds. Although this method may or may not be effective in distinguishing between the two, a low cloud deck can still violate landing criteria for classes of aircraft that utilize the airfields in the McMurdo area (e.g. C-17) Additionally, the accuracy of the relative humidity data and the possible issues with drift add to the uncertainty in this validation.

Table 2. Validation results of AWS relative humidity observations as compared to RGB PCI satellite observations.

Fog Hit	Fog Miss	Clear Hit	Clear Miss	Uncertain
223	226	287	53	114

The satellite depiction, as noted, does have limitations. An additional limit is the dependency on solar zenith angle. The performance of RGB PCI fog depictions during October is clearly impacted by the very low solar zenith angle. This impact affects visual interpretation. This skews the peak months of usage toward the core austral summer months of November, December, January and February. There is some value to the depiction in the low light months of October and March; however, its interpretation will be different than the other months of the operational field season.

4. FUTURE DIRECTIONS

While single and two-channel methods will continue to have their place in monitoring fog, the multi-spectral tests introduced here present a step forward in the detection and depiction of fog and low clouds. The RGB PCI fog depiction provides a new and alterative approach to other modern methods. However, multi-spectral tests need more scrutiny to determine their value in an operational setting. The RGB PCI depiction method as outlined here does not perform the same in low solar zenith angle periods of the year, and not all in the polar night. It will also have difficulty discerning between fog and other low clouds, but does have some skill to identify low cloud/fog features that can impede aviation operations. This method does not require ancillary data. This is a clear advantage operationally in the United States Antarctic Program (USAP) as there is limited bandwidth to off-continent resources, such as not being able to acquire complete numerical model output that might be required by other determination methods. In any case, RGB PCI depiction does offer a means of accenting the features. Effort next season will be to install this capability at McMurdo Station and make this available to weather forecasters for their evaluation.

5. ACKNOWLEDGEMENTS

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