P1.28 **STUDY OF FOG PROPERTIES USING LANDSAT DATA**

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1. INTRODUCTION

*Recently, advances have been made in the analysis of fog and low clouds using satellite imagery. For example, NOAA/NESDIS has developed several experimental products derived from GOES infrared channels that describe low clouds and fog, giving the bases of low clouds as well as the thickness of the low cloud and fog layers (Ellrod, 1995; Lee, 1997).

In our research, LANDSAT imagery and, to a lesser extent, AVHRR imagery is used. LANDSAT Thematic Mapper (TM) images over the cities of Seattle and Chicago are analyzed to provide information on typical fog spatial structure and scale, and homogeneity and variability of liquid water content over the region of fog. Fog optical depths and visibility are mapped in the urban areas and then correlated with concurrent measurements taken in the nearby airports- Boeing Field International (BFI) near Seattle and Meigs Field near Chicago.

Radiative transfer calculations using MODTRAN have been developed to estimate top of atmosphere spectral reflectances as a function of total liquid water in a vertical path, and mean droplet radii. Using these calculations, the reflectances in the visible and near infrared channels of the LANDSAT images are used to derive liquid water content and radii. The liquid water content can be correlated with visibilities observed in the airports to formulate a relationship between the two parameters. Since we know one of the important variables in defining fog is the liquid water content, its relationship to visibility is a useful one to understand. We hope to apply the techniques to interpret the readily available daily GOES images to give us an ongoing database of visibility in middle and high cloud free areas.

2. BACKGROUND

Visibility in fog is known to be non-uniform, as fog is seen to take on a cellular structure similar to that of stratocumulus (Gerber, 1980; Welch, 1986). The distribution of this variability is important to the free space optics industry, as routine weather observations (even one minute ASOS observations) are inadequate to capture fog's spatial and temporal variability. Additionally, the relation of visibility to the liquid water content of fog could be a useful tool in determining expected fog visibilities.

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3. DATA SOURCES

This study uses two types of satellite images of very different spatial resolutions and temporal sampling: Landsat and AVHRR. The Landsat imagery used was Bands 2 (λ=0.56μm) and 5 (λ=1.65μm) collected at 30 m spatial resolution. The AVHRR imagery used was Band 1 collected at 1 km resolution. Surface meteorological observations are used from Boeing Field (BFI) and Seattle-Tacoma Airport (SEA) to correlate reported visibilities with reflectances from the Seattle images. Surface meteorological observations from Meigs Field (CGX), O'Hare International Airport (ORD), and Midway Airport (MDW) are used to correlate reported visibilities with reflectances from the Chicago images.

4. ANALYSIS

Fog events at two major cities – Seattle and Chicago - were selected for case studies.

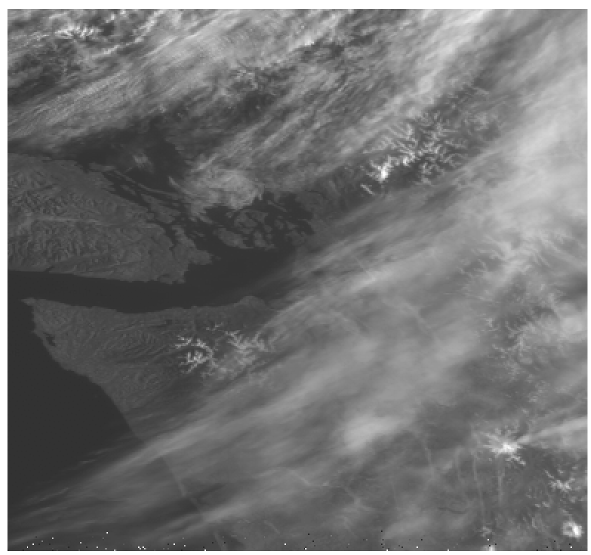

Figure 1. AVHRR Band 1 (λ=0.63μm) Image collected March 19, 1992 showing Puget Sound.

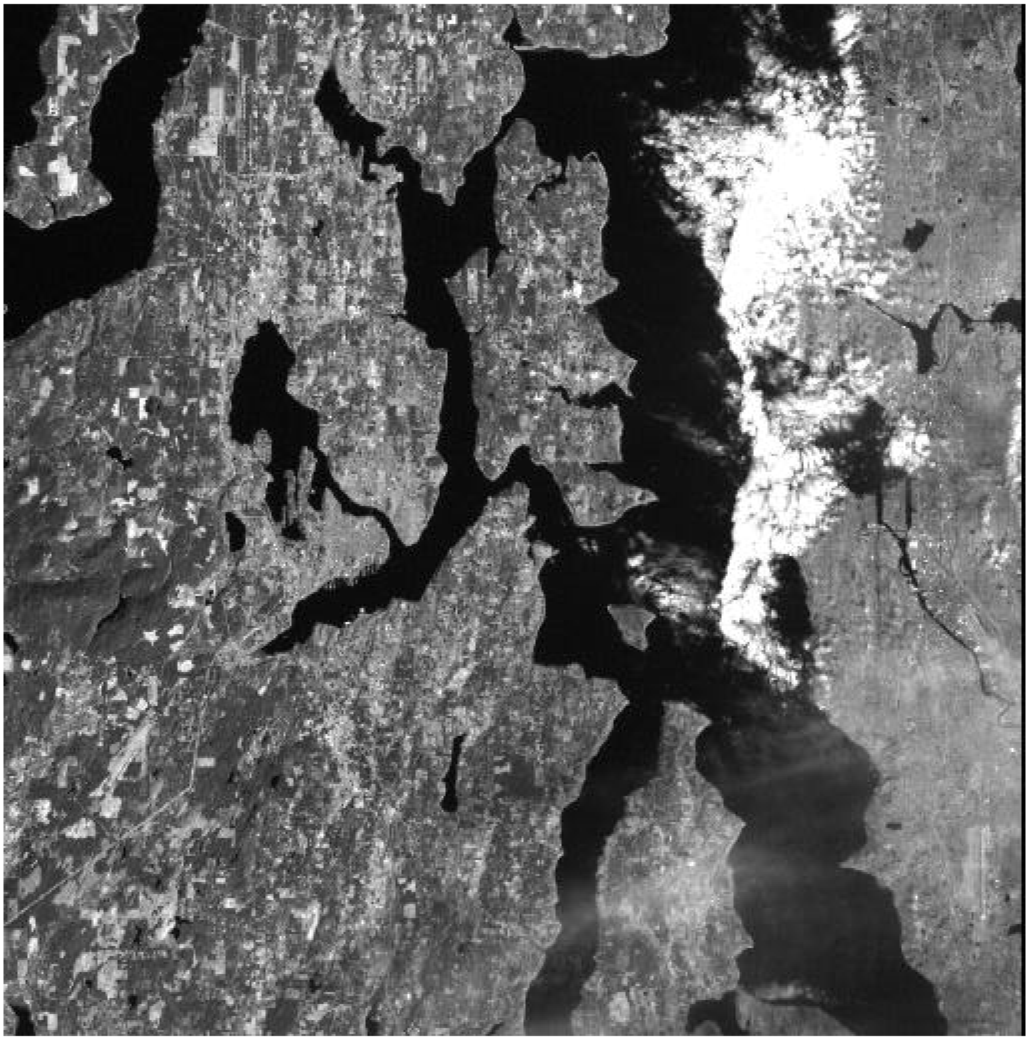

Figure 2. Landsat Band 5 (λ=1.65μm) image collected 3/19/92 showing fog and low clouds around downtown of Seattle area.

4.1 Seattle Case Study

On March 19, 1992, fog and low clouds were observed around the Seattle area during the morning hours. The AVHRR image collected at 1600 UTC (Figure 1) shows cirrus clouds over the southerly portion of Puget Sound. Dendritic patterns can be seen on the Olympic Peninsula (left center) and in the Cascade Range (right). Major bright feature in lower right corner is Mt. Rainier. The AVHHR 1 km resolution, however, is too coarse to adequately resolve the fog structures around downtown Seattle.

A Landsat image collected at 1730 UTC (Figure 2) shows cells of fog clustered around downtown Seattle area. Visibility observed at BFI showed visibility as low as 200 m during the hours immediately prior to the collection of this image. Observations at SeaTac (12 miles south of downtown Seattle) showed visibilities of 6000 m or better.

The fog cells ranged in size from 150 m up to 800 m. A key point in terms of the interest of mapping fog for FSO telecommunications, a fog event of this type might impact operations of optical telecommunications in downtown Seattle but the event would not be observed in AVHRR imagery or by other local airports such as SeaTac.

Several pixels from the image where fog was present were selected for analysis. MODTRAN was used calculate liquid water path based on the reflectivity for Landsat Bands 2 and 5 (Kuji, 2000). Results (Table 1) show a large variability in liquid water in the three sample pixels. The variability in liquid water is considerably larger than the standard error in the prediction relation (47 gm/m^2). This indicates that the variability is real and raises the possibility that there could be systematic regional differences in liquid water and visibility in the image.

Table 1. Calculated liquid water path from selected fog pixels from Landsat image in Figure 2.

Broadband Albedo	Band 2 Vis Reflectance (λ=0.56μm)	Band 5 IR Reflectance (λ=1.65μm)	Liquid water (g/m^2)
0.175	0.23	0.18	221
	0.17	0.14	129
	0.16	0.14	414

4.2 Chicago Case Study

During the morning of March 1, 1994, rolls of fog were observed over Chicago. Figure 3 shows a Landsat Band 2 image of Chicago and rolls of fog oriented WSW-ENE. The rolls of fog are Langmuir cells similar to stratocumulus clouds (Welch, 1986; Welch et al., 1988; Wielicki, 1986). The rolls are very regularly spaced at 1.4 km.

The northeast corner of the image shows higher brightness due to the underlying pack ice on Lake Michigan. As with the Seattle case study, the downtown Chicago area is under a blanket of fog while areas just south show clear skies.

Observations at Meigs Field just east of downtown right on Lake Michigan showed visibilities as low as 400 m at the surface. Midway and O'Hare Airports, both further from Lake Michigan, reported no ground fog, but both reported very low cloud ceilings. Midway (14 km from the lake) showed ceiling at 150 m while O'Hare (20 km from lake) showed ceiling at 270 m.

5. DISCUSSION

LANDSAT provides a superb nominal spatial resolution of 30 meters. However, the limited availability of the data and its expense make it difficult to complete extensive studies. In the past few years, new sensors on GOES 8-10, have allowed a spatial resolution of two kilometers. AVHRR can also be used at a slightly finer resolution (1 km) to detect fog. Although, this is still too large to detect the smallest cellular structure of fog, it is adequate to help determine some of the structure. After learning what we have from LANDSAT, exploring AVHRR and GOES data, with its reliable frequency may help to extend this study.

6. REFERENCES

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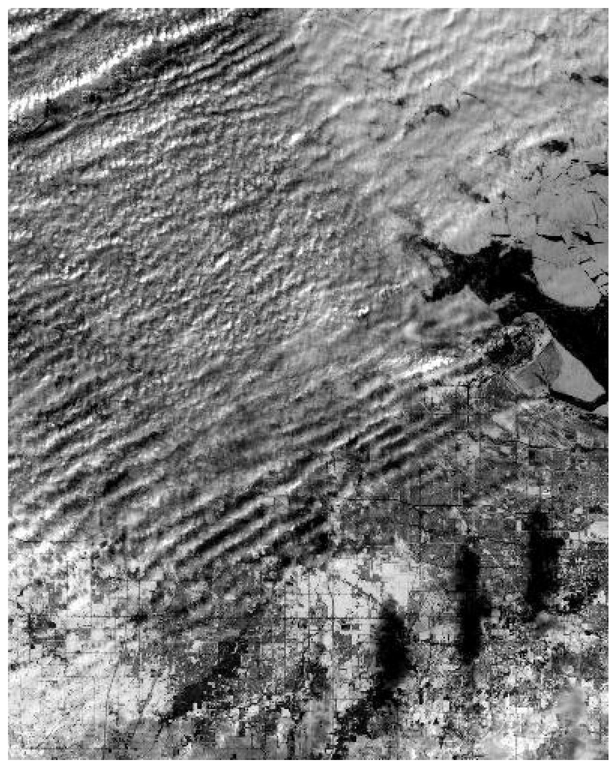

Figure 3. Landsat Band 2 (λ=0.56μm) image collected 3/1/94 showing rolls of fog over Chicago.