POLAR ORBITER: STEREO HEIGHTS AND CLOUD MOTIONS

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ABSTRACT

As a demonstration, a combination of POLDER and AVHRR images were used to calculate geometric cloud heights and motions. Reproducibility of the height is 1km with the 6 km resolution pixels of Polder. This is supported by simulation studies and example real world clouds near Point Barrow in Alaska. A similar demonstration mixing POLDER and GOES is discussed. Also a comparison is made to the Oxygen A band cloud height estimates.

1. Introduction

The analysis of cloud motions in polar regions is difficult due to the lack of geosynchronous satellite observations used for this purpose in tropical and mid latitude regions. Using pairs of polar orbiters satellites will allow some estimate of motion, but additional parallax adjustments are required, so one needs to know the cloud height from a separate source. Here we discuss the use of POLDER data with the addition of one other view point to estimate cloud motion and geometric height.

The POLDER instrument concept allows the observation of the surface below up to 14 times at different view angles within 4 minutes (Deschamps et al 1994). It was originally designed for bi-directional reflectance measurements, but we are testing its use for stereo height estimates. The sequence of POLDER views were mapped into a common projection assuming the reflecting object came from the surface of the earth. Any displacement from one view to an other is due to the fact that the cloud is above the surface (parallax) or has moved (wind) between the measurement times. There is actually an ambiguity between along track motion and height above the ground so at least one additional image from a different view point is required to resolve the motion. For these tests, we use either GOES or AVHRR observations more than 10 minutes away from the mean POLDER observations.

2. Alaska case study

Figure 1 shows an image from POLDER of clouds over Alaska near Point Barrow (71^{o}N, -156^{o}W). The imaged area is roughly 1000x1000 km^2; the continent being in the lower-right corner as indicated by the coastline. The analysis proceeds by selecting a circular patch of pixels at the center time of the sequence, then correlating with the other images in the sequence. This matching was also performed with the remapped AVHRR image. The POLDER data has 6 km resolution visible pixels which would seem too large to provide stereo information, but in fact the correlation matching is able to measure the displacements to better than $\pm$ one pixel. Aligning with the edge of an extended object provides enough information to estimate positions to about $\pm$ 2 km (Campbell 1998). These apparent locations, viewpoints, and times were analyzed with the Asynchronous Stereo scheme (Campbell, 1998). This performs a least squares fit to estimate the height and motion of the object.
Shown in figure 1 are the cloud motion vectors and an estimate of the height. For instance the cloud over the land south of Point Barrow in the image is moving north at about 4km altitude. In the circle

are the corresponding winds at different heights from the Point Barrow radiosonde. That is not coincident in time, so a precise match should not be expected.

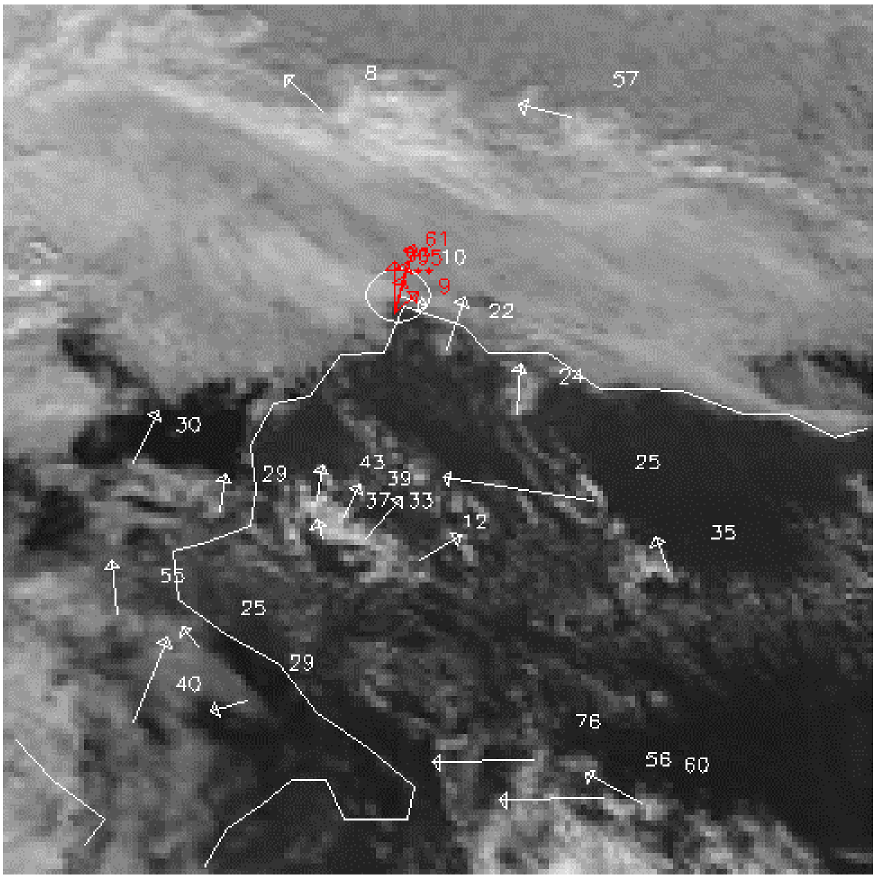

Figure 1. Image of Polder visible radiances over Alaska on June 19, 1997 at 22:30Z. Super imposed are estimate of the cloud motions and heights (hectometers). The red or black wind rose in the circle shows the Point Barrow radiosonde at 0Z, June 20.

To get some estimate of the accuracy of the measurements, some test clouds were tracked repeatedly, starting at locations offset $\pm$ one pixel east-west and north-south. Table 1 shows a list of the heights, motions and standard deviations from this boot strap reproducibility study. This is really a test of the tracking procedure and small errors in matching the clouds from the different scenes.

Table 1. Sample reproducibility test. Av = average of 5 heights, sd = standard deviation of the 5.

Averages (5 trials)			Standard Deviations (5 trials)		
Height	U (m/sec)	V (m/sec)	Height	U (m/sec)	V (m/sec)
0.73	-2.72	1.60	0.26	0.69	0.30
-0.39	0.85	3.80	0.13	0.38	0.33
3.39	0.51	7.02	0.04	0.28	0.14
4.66	3.82	5.77	0.45	0.70	1.17
2.67	-4.66	0.09	0.19	0.76	0.20
2.30	3.97	7.63	0.34	1.36	1.07
1.17	0.69	-0.87	0.24	1.87	1.13
0.45	0.70	1.17	0.49	1.30	1.26

3. Baja California case study

A second example was analyzed merging GOES and Polder viewing clouds over Baja, Mexico, figure 2. Here we were able to make a comparison with the asynchronous stereo analysis of GOES 8 plus GOES 9. This comparison of two geometric techniques is a better measure of the accuracy of the analysis. Figure 3 shows the GOES analysis, which actually appears more consistent in the cloud motions and heights than the Polder result (fig 2). The GOES data was actually mapped into the Polder projection at 6 km resolution before the analysis.

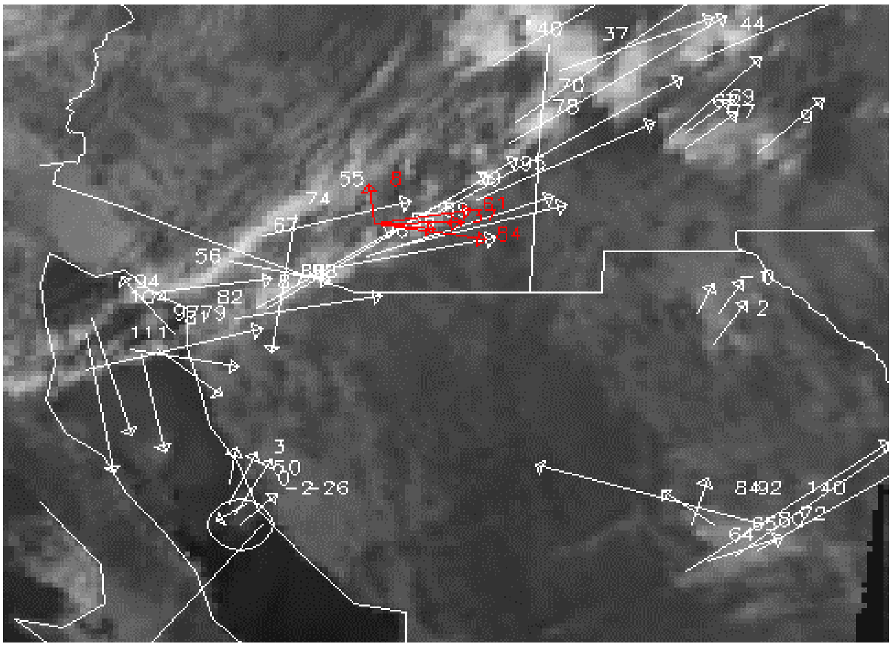

Figure 2. Polder visible radiances over Baja on April 29, 1997, 18:47Z. The heights are shown in hectometers. Notice that there is some residual motion of the islands in the Gulf of California. The Tucson sounding winds are shown in red.

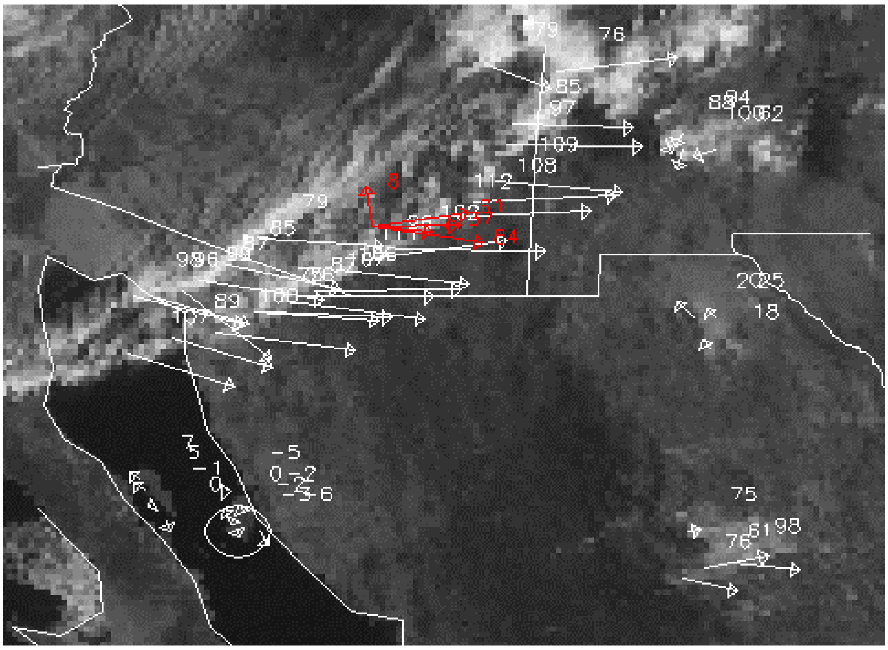

Figure 3. Image of GOES 9 visible radiances over Baja on April 29, 1997, remapped to the Polder projection. Notice that the islands in the Gulf of California do not move.

Figure 4 is the scatter diagram of the heights of the two geometric analyses over Baja. From the scatter of the heights and the variation in cloud motion vectors in figure 2, the results based on POLDER observations are not very accurate. An improvement is possible to these results by forcing the motion of the islands to zero. This is a typical problem with the geometric techniques, the accuracy of heights and motions is sensitive to small navigation errors. In many cases with pairs of GOES satellites, adjustments need to me made to force alignment in the navigation. Finding reliable landmarks to adjust the navigation in polar regions is especially difficult. Certainly, where available the GOES results would be more useful than the Polder estimates. But the primary interest in using polar orbiter data is in areas with out two geosynchronous views.

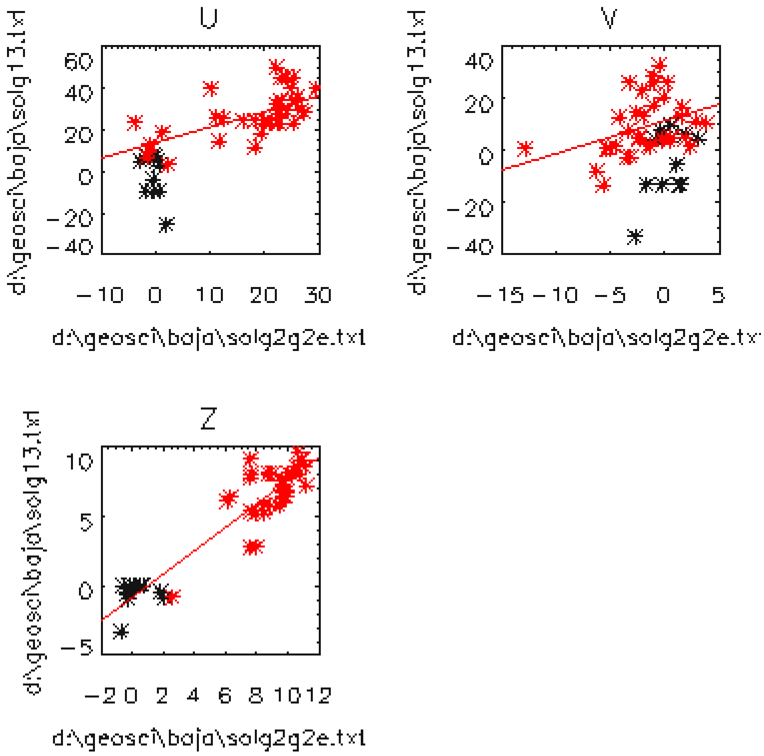

Figure 4. Scatter between GOES 8 and 9 results and Polder plus GOES 9 results. U and V are the components of the cloud motion and Z is the height (km).

4. Oxygen Heights

In addition to the bi-directional imaging capabilities of POLDER, there are two channels which measure the reflected radiance in the Oxygen A absorption band at 765 nm. The ratio of he two observed radiances provide a measure of the oxygen absorption between the satellite and the reflection surface, assumed to be a spectrally white reflector., Because the oxygen is well mixed in the atmosphere, this absorption is related to the height of the cloud (Parol et al. 1999). Figure 5 shows an image of the cloud top pressure estimate based on this differential absorption technique.

This shows some artifacts. The cirrus clouds over the Gulf of California are higher that those adjacent over the land. There is considerable variability from one view point to the next for the same cloud. It turns out that the cloud is not a simple reflecting surface. Some of the visible radiation is scattered within the cloud top and some of the radiation from ground penetrates the cloud (Parol et al. 1999). These contaminate the Oxygen absorption signals. Figure 5 is actually a composite of the minimum cloud height over the 14 views of the cloud masking some of the variability of the estimates.

Using the Tucson sounding, the pressures were converted to geometric height for comparison to the Asynchronous heights. Finally figure 6 shows a scatter plot of the geometric heights and the Oxygen heights. The Oxygen heights show considerable variability in space and from the many view points so these are the lowest heights in the region from the multiple view points.

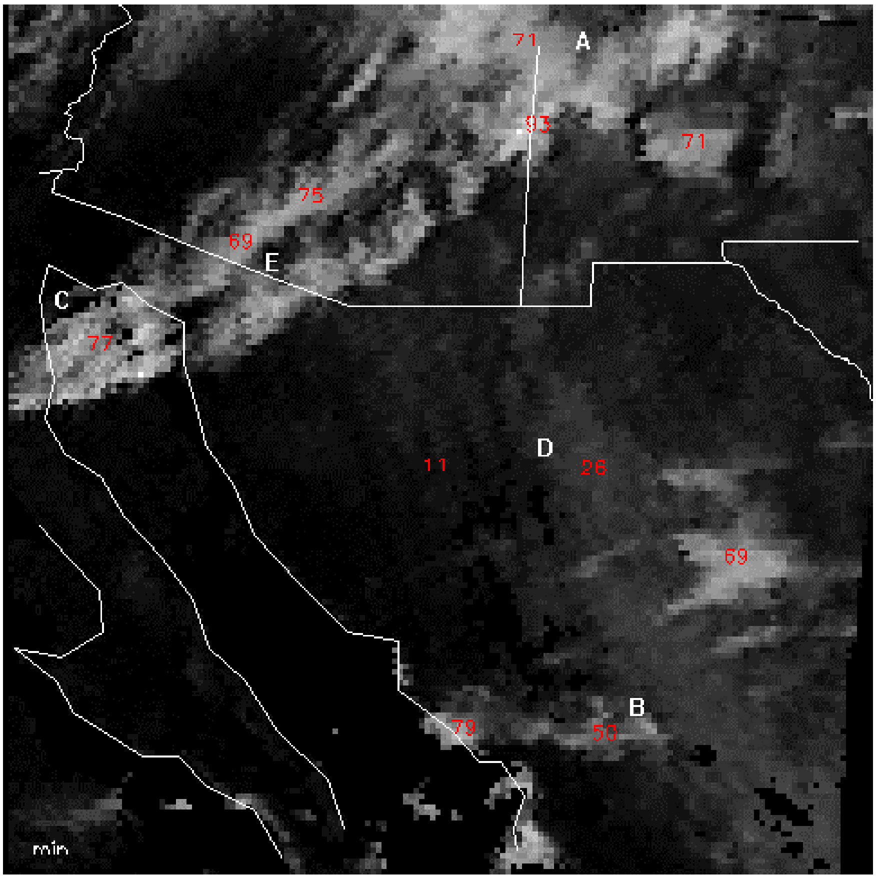

Figure 5. Image of Oxygen A band heights. The numbers are heights in hectometers derived from the Tuscon sounding. The minimum height from the 14 views of each location.

5. Discussion

The geometric cloud heights and motion have some quantitative information but high precision is not possible. Application to special case studies is possible to understand special meteorological events. There are several limits to their regular use: The pixel resolution is just barely able to detect cloud location changes. Organizing the data and verifying the navigation alignment between different satellites is not easily automated.

The standard way to estimate cloud top height is to use the cloud top temperature and a temperature profile estimate. For comparison the cloud heights in table 2 were estimated by interpolation from the Tucson sounding.

Table 2. Selected points from figure 5 analyzed several ways. Heights in km and temperature in Kelvin.

Table 2	Oxygen Z (km)	Geometric Z	GOES Temperature	Temperature > Z
A	5.6	4.7	234	9.3
B Cirrus ocean	8.6	8.6	242	8.2
C	8.0	6.8	243	8.1
D	8.5	6.9	228	10.
E	3.7	7.3	233	10.
F	7.4	5.1	242	8.2
G	7.0	6.8	243	8.1

The Oxygen A band heights show some skill but there are some artifacts with different backgrounds and cloud types. Using the geometric cloud height estimates could be used as a verification tool to better understand the variability of the Oxygen method and filter out the unphysical height estimates. These anomalous heights are an indication of other physical processes are occurring in the reflections from the cloud like multiple scattering in the cloud or transmission of light from the underlying surface.

Application of the technique to the MISR data from the TERRA satellite with its much better resolution should provide accurate geometric cloud heights.

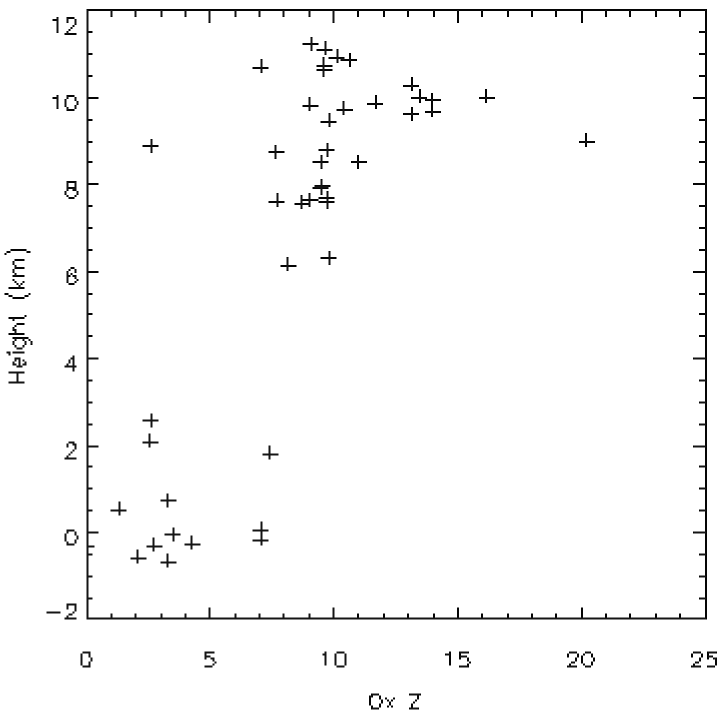

Figure 6. Comparison of geometric heights with Oxygen heights, Baja case. Asynchronous stereo height on the vertical axis and Oxygen A band cloud top pressures converted to height with a nearby sounding.

6. Conclusion

This study has shown that geometric techniques can be used with polar orbiter observations. The accuracy of the POLDER results is limited by the imager resolution and has limited information content. With smaller pixel resolution of MISR on the TERRA better results should be expected. The Oxygen results show considerable variability which demonstrates that the cloud transmission (surface contribution) and its spatial variability must be accounted for in a quantitative use of the oxygen cloud height product.

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