Proceedings for the 13th International Winds Workshop
27 June - 1 July 2016, Monterey, California, USA

POLAR WINDS FROM SHORTWAVE INFRARED CLOUD TRACKING

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Abstract

In the polar regions there is often very little temperature contrast between clouds and the underlying snow or ice surface, and they are nearly equally bright in the visible portion of the electromagnetic spectrum. This creates a situation of very low contrast between the two, which impacts cloud tracking and the derivation of wind information because there are fewer good features to track. In the shortwave infrared (SWIR), however, the optical properties of liquid-phase clouds and snow/ice are significantly different, and therefore the contrast between low clouds and the surface is large. This is particularly true at wavelengths of 1.6, 2.1, and 3.7 μm. In theory, shortwave infrared data will provide additional features for cloud tracking and atmospheric motion vector derivation in the polar regions during the day, especially for low clouds. Here we use a SWIR band of the Moderate Resolution Imaging Spectroradiometer (MODIS) for the derivation of atmospheric motion vectors over the Arctic and Antarctic. Accuracy statistics for six months of data indicate that the SWIR wind statistics are as good as the traditional infrared window cloud-track winds.

INTRODUCTION

Wind information over the polar regions has been generated with data from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on NASA's Terra and Aqua satellites and the Advanced Very High Resolution Radiometer (AVHRR) on NOAA satellites since 2001. The MODIS polar wind products have been used operationally in various numerical weather prediction (NWP) centers worldwide since 2003; AVHRR winds have been used operationally since 2007. A similar wind product from the Visible Infrared Imager Radiometer Suite (VIIRS) instrument on the Suomi National Polar-orbiting Partnership (S-NPP) satellite became operational at NOAA in 2014 and is used by some NWP centers.

The properties of winds – speed, direction, and altitude – are derived by tracking clouds in MODIS, AVHRR, and VIIRS data, and by tracking water vapor with MODIS. However, polar clouds are notoriously difficult to detect and characterize with satellite imagers because of the similarities between their temperature and reflectance properties and those of the underlying snow and ice surface. Ubiquitous lower-tropospheric temperature inversions in winter and nearly isothermal temperature profiles in summer result in a very small temperature contrast between low, stratiform clouds – the most common cloud type over much of the Arctic Ocean – and the surface. In the visible, clouds and snow/ice are similarly bright, again resulting in very low contrast. This lack of contrast means that there are fewer good features to track, yielding fewer and/or lower quality wind vectors.

In the shortwave infrared (SWIR) the scattering properties of liquid-phase clouds and snow/ice are significantly different. Clouds are much brighter than the underlying snow or ice surface and the contrast between low clouds and the surface is large in SWIR bands around 1.6, 2.2, and 3.7 μm (Figure 1), a fact that has been exploited in polar cloud detection at least since the early 1990s. AVHRR, MODIS, and VIIRS all have bands at 1.6 and 3.7 μm; MODIS and VIIRS also have bands at 2.1-2.2 μm. In theory, SWIR data will provide more good features for cloud tracking and atmospheric motion vector (AMV) derivation in the presence of sunlight ("daytime"), especially for liquid clouds.

Here we exploit the additional contrast between liquid clouds and snow or ice at SWIR wavelengths in deriving AMVs over the polar regions. Winds are derived from the Terra and Aqua MODIS 2.1 μm band for March through August 2016 over both polar regions. The algorithm that has been applied to AVHRR and MODIS for over a decade is employed. The derived winds are validated with radiosonde data.

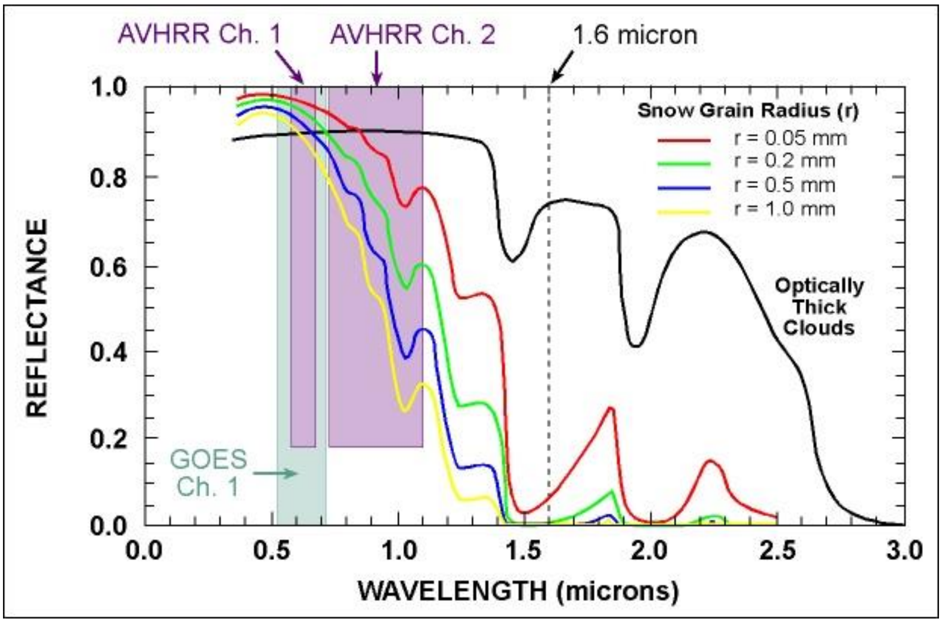

Figure 1: **Spectral signatures of snow and optically thick liquid clouds throughout the visible, near-infrared, and shortwave infrared portions of the electromagnetic spectrum. The GOES channel 1 and AVHRR channels 1 and 2 bands are shown.**

METHODOLOGY

Cloud and water vapor tracking with MODIS and AVHRR data is based on the procedure that has been used for Geostationary Operational Environmental Satellite (GOES) wind retrievals since the 1990s, and more recently with MODIS and AVHRR (Nieman et al., 1997 and Velden et al., 1997, 1998, 2005). For MODIS, cloud features are traditionally tracked in the infrared (IR) window band at 11 μm, and water vapor (WV) features are tracked in the 6.7 μm band. AVHRR and VIIRS do not have a water vapor band so only IR cloud-drift winds are derived. After remapping the orbital data to a polar stereographic projection, potential tracking features are identified. Additional details are provided in Key et al. (2003).

Here we employ a SWIR band in the same way as the IR and WV bands. Height assignment is done using the 11 μm IR channel. It should be noted that there is not a universally accepted wavelength range for the term “shortwave infrared”. In the ISO 20473 scheme, the range 0.79 - 3 μm is termed “near-infrared”. Byrnes (2009) defines the SWIR range as 1.0 - 2.5 μm; NASA describes it as 1.1 - 3 μm. For this study, the 2.1 μm on Aqua MODIS is used. In theory, a 1.6 μm band would produce similar results. Liquid clouds and snow/ice exhibit similar reflectance characteristics in the far end of the SWIR range at 3.7 - 3.9 μm, sometimes called the “solar infrared”, though the use of such bands is complicated by the thermal emission component of the observed radiance.

The different appearance of cloud and surface features in the visible, shortwave infrared, and thermal infrared are illustrated in Figure 2 for the Arctic and Figure 3 for the Antarctic. Note the large SWIR contrast between clouds and the snow/ice surface over the Arctic Ocean (Figure 2) and the Antarctic continent (Figure 3).

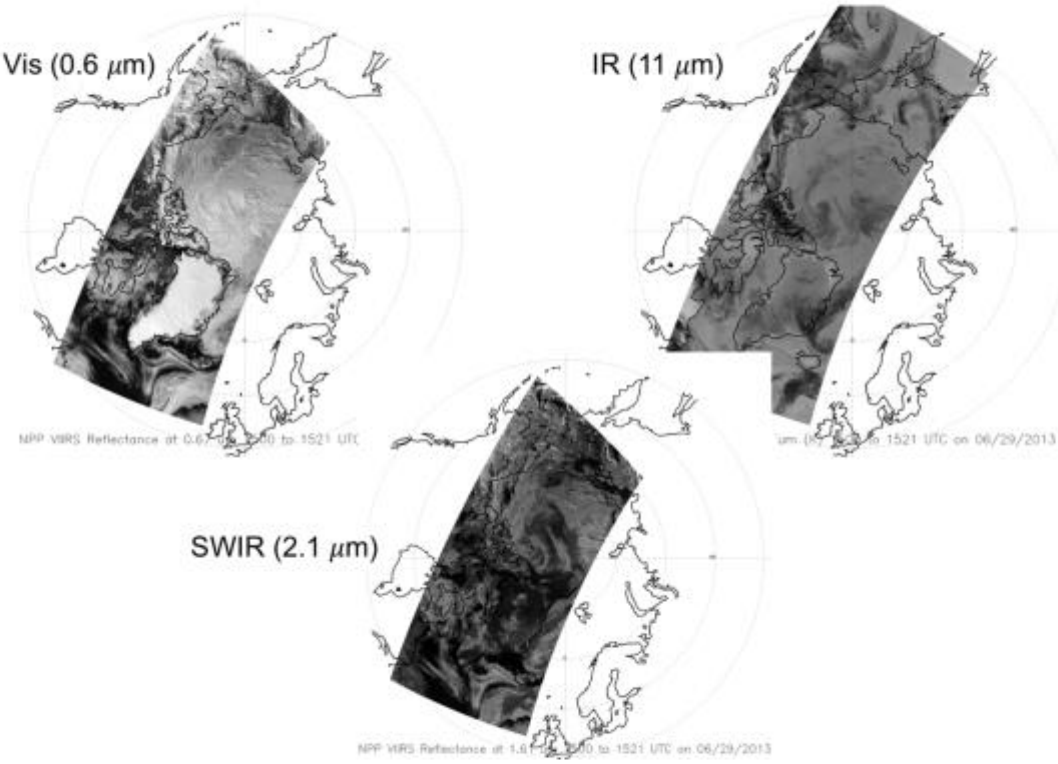

Figure 2: **VIIRS visible (0.6 μm), shortwave infrared (2.2 μm), and thermal infrared (11 μm) over the Arctic on 29 June 2013. Sea ice and snow appear bright in the visible and dark in the shortwave infrared**.

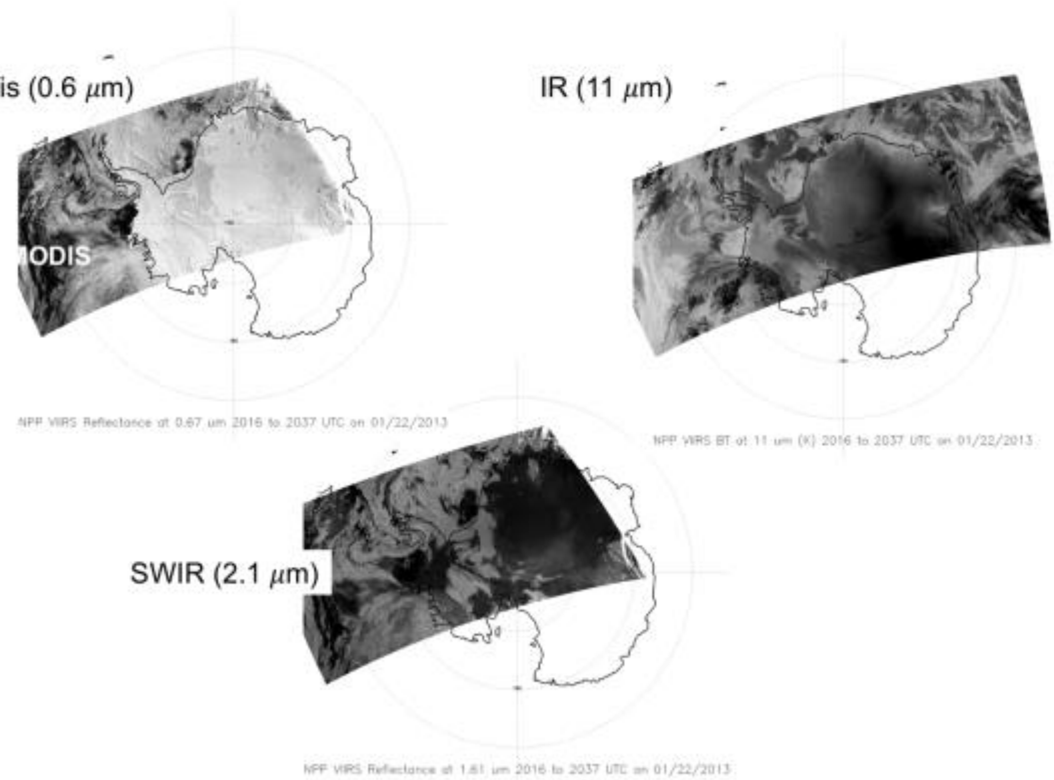

Figure 3: **VIIRS visible (0.6 μm), shortwave infrared (2.2 μm), and thermal infrared (11 μm) over the Antarctic on 29 June 2013. The snow/ice surface over Antarctica appears bright in the visible and dark in the shortwave infrared**.

RESULTS

Two examples of the MODIS SWIR wind retrievals are shown in Figures 4 and 5. Also shown are the combined infrared and water vapor retrievals. Wind vector heights are grouped into low (yellow), middle (cyan), and high (magenta) categories for illustration only. Overall, the SWIR winds are qualitatively similar to the infrared and water vapor winds in speed, direction, and height/pressure. As expected, additional low-level features can be seen, as indicated by the circled areas. This is likely a result of the larger spectral contrast between the liquid clouds and surface.

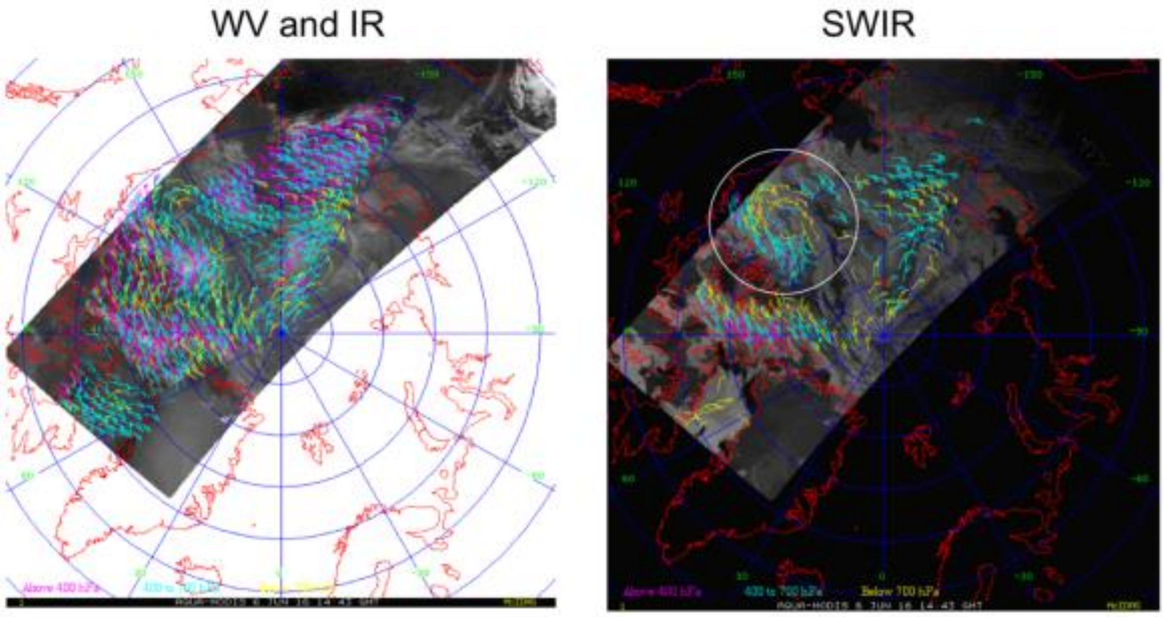

Figure 4: **Winds over the Arctic derived from MODIS infrared and water vapor channels (left) and from the SWIR band (right) on 6 June 2016 at 14:43 GMT.**

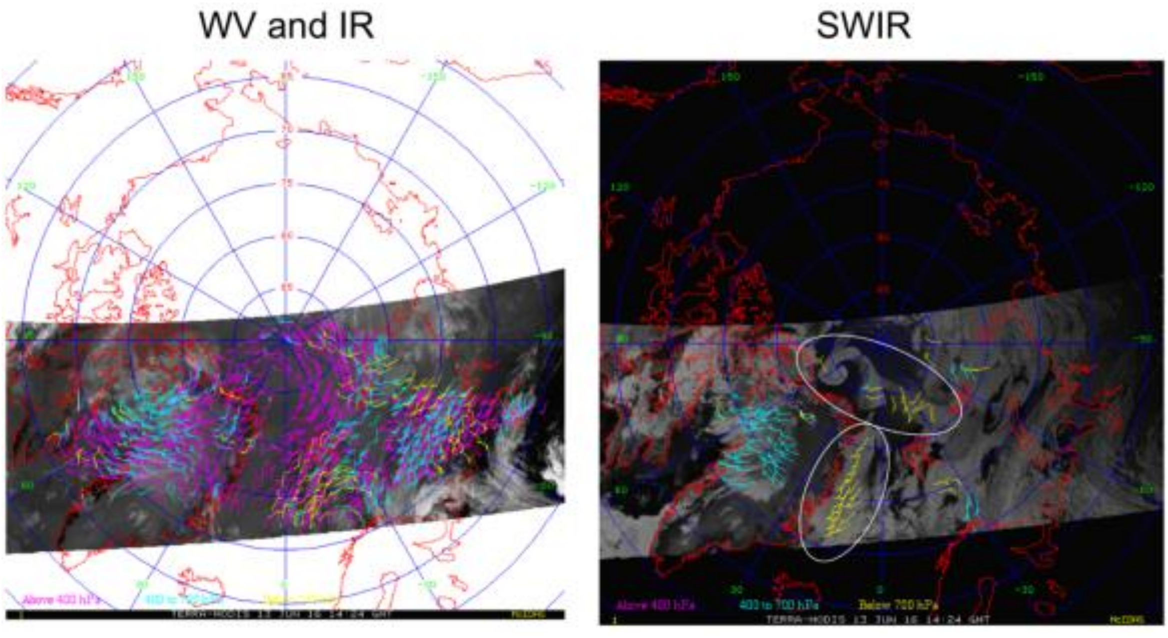

Figure 5: **Winds over the Arctic derived from MODIS infrared and water vapor channels (left) and from the SWIR band (right) on 13 June 2016 at 14:24 GMT.**

Somewhat surprisingly, however, the vertical distributions of the SWIR and IR winds are similar (Figure 6). Wind vector heights in the range of 700-800 hPa are most common for both bands. It is possible that the differences in the vertical distributions for SWIR and IR winds would become more obvious if only high-quality vectors were counted, i.e., vectors with Quality Indicator (QI) values greater than some threshold.

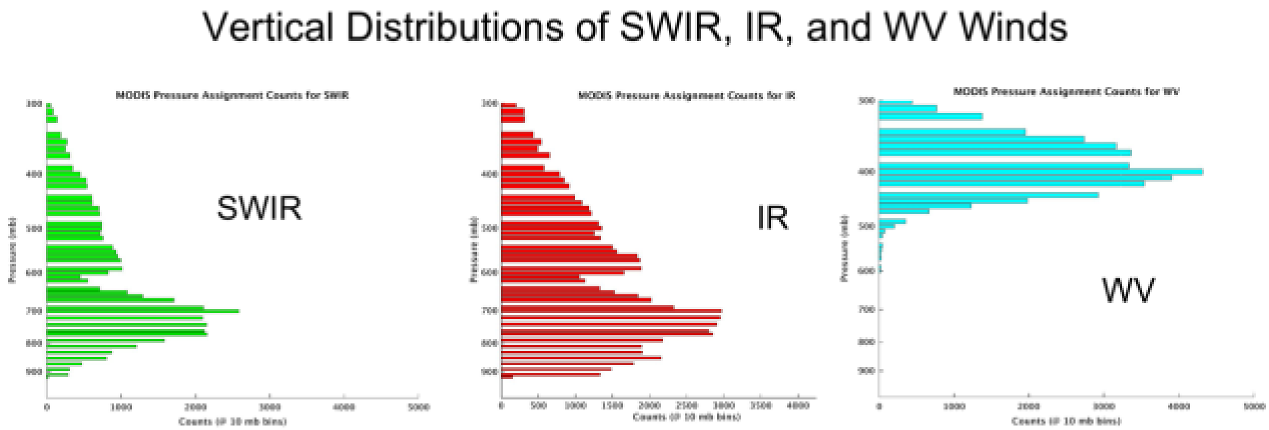

Figure 6: **The vertical distribution of MODIS SWIR, IR, and WV winds over the Arctic and Antarctic for March-June 2016.**

Validation statistics for the SWIR and IR winds are given in Table 1. They are based on March – August 2016, daytime only matchups with radiosonde data, so the sample sizes are small. Overall, the accuracies for both bands are similar.

	COUNT	Vector RMSE		Normalized Vector RMSE		Speed Bias		Average Wind Speed	
		IR	SWIR	IR	SWIR	IR	SWIR	IR	SWIR
HIGH	107	5.55	5.80	0.24	0.25	-0.63	-0.22	22.73	23.04
MID	281	5.35	5.22	0.31	0.30	-0.83	-1.26	16.36	15.92
LOW	38	4.82	4.67	0.48	0.46	-0.91	-1.01	9.21	9.17
TOTAL	426	5.37	5.33	0.29	0.29	-0.78	-0.98	17.56	17.11

Table 1: **Statistics for a comparison of Aqua and Terra MODIS IR window and SWIR winds to radiosonde winds.**

CONCLUSIONS

The optical properties of liquid clouds and snow/ice are such that the contrast between them is very high in the shortwave infrared (SWIR) portion of the electromagnetic spectrum. Therefore, tracking clouds in a SWIR band (e.g., 1.6 or 2.1 µm) should provide additional tracking targets, particularly for low- to mid-level clouds.

Accuracy statistics for six months of data indicate that the SWIR wind statistics are as good as the infrared window cloud-track winds. There are fewer SWIR wind vectors than IR cloud-track winds, primarily because for the case study period there is little daylight in the Arctic, and low, liquid clouds over the Antarctic continent are not common. Nevertheless, it is expected that the near-infrared cloud track winds will be a valuable complement to current polar winds products.

Polar winds from the Terra and Aqua MODIS 2.1 μm band are now routinely produced for the Arctic and Antarctic as a research product. Graphics are available at http://stratus.ssec.wisc.edu/products/rtpolarwinds/.

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