USING THE GOES 3.9 µm SHORTWAVE INFRARED CHANNEL TO TRACK LOW-LEVEL CLOUD-DRIFT WINDS

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ABSTRACT

Low-level (600-950 hPa) cloud-drift winds produced from the 3.9 µm shortwave infrared (SWIR) channel on GOES-8/10 are being developed to compliment the IR and visible winds currently being produced operationally at NOAA/NESDIS. This near-infrared channel provides a cleaner atmospheric window (compared to the operational 10.7 µm longwave IR channel -- LWIR) for superior low-level cloud detection at night. By enhancing the brightness temperatures in the SWIR images prior to their input into the UW-CIMSS wind algorithms, the relatively flat gradients that are characteristic of this channel can be sharpened. This procedure typically produces a ~40% overall improvement in low-level cloud-track winds detection over identical non-enhanced operational LWIR winds. The SWIR channel's susceptibility to reflected sunlight from cirrus and especially low-level cumulus clouds limits its usefulness to nighttime applications. The SWIR low-level cloud-drift winds are currently being transitioned to NOAA/NESDIS operations and should greatly enhance the volume of low-level wind information currently available from geostationary satellites at night.

1. Introduction

Current techniques for tracking low-level (600-950 hPa) cloud-drift winds at night utilize the 10.7 µm longwave infrared (LWIR) window channel on the GOES Imager. This channel compliments the visible winds that are generated during the day, but doesn't provide as complete coverage of low-level wind information as the higher resolution visible channel. The 3.9 µm shortwave infrared (SWIR) channel available on GOES is a slightly cleaner window channel than the LWIR channel, making it more sensitive to warmer (lower-tropospheric) temperatures. The SWIR channel is also not as sensitive as the LWIR channel to cirrus clouds that may obscure low-level cloud tracers. These 2 characteristics of the SWIR channel make it a potentially superior channel for producing low-level cloud-drift winds at night. Techniques were developed to enhance the SWIR imagery as well as improve the UW-CIMSS tracking algorithm's ability to detect cloud tracers in these enhanced images. As is demonstrated in this paper, the SWIR winds provide significantly increased low-level wind information at night over that which is currently available with the routine operational LWIR techniques.

2. Methodology

a. Motivation for Improving Low-Level Cloud Detection

Traditionally, geostationary satellite wind coverage has been diurnally consistent in the mid to upper-levels (100-600 hPa) through the use of the 6.7 µm water vapor and 10.7 µm LWIR channels. However, in the low-levels (600-950 hPa), cloud drift wind data has been provided by a combination of the visible and LWIR channels, depending on the time of day. The visible channel provides far superior low-level tracer detection than the LWIR channel. This is due to its finer spatial resolution and decreased susceptibility to attenuation by low-level moisture. Unfortunately, nighttime low-level satellite wind coverage typically decreases sharply when the visible channel is no longer available. This creates a situation of overall reduced wind information for the user as well as a diurnally dependent jump in coverage for models that are attempting to ingest and assimilate these low-level satellite winds in a time-consistent manner.

Using the 3.9 µm channel on the GOES-8/10 satellites, SWIR cloud-drift winds have been developed to provide improved nighttime low-level satellite wind coverage (Velden and Dunion 2001). The SWIR channel is slightly more sensitive to warmer temperatures and less sensitive to thin cirrus than the 10.7 µm longwave infrared (LWIR) channel traditionally used to track low-level clouds at night. This allows for a higher detectability rate of low-level (600-950 hPa) cloud tracers in the SWIR channel. Improved low-level nighttime wind coverage can provide forecasters with more wind data as well as reduce the diurnal inconsistencies that may be a challenge to data assimilation into models.

b. Solar Contamination in the SWIR Channel

The SWIR channel is susceptible to solar contamination during daylight hours due to the proximity of this wavelength to the visible spectrum. Cirrus clouds are somewhat reflective of solar radiation and cumulus clouds are highly reflective in the SWIR channel. Since low-level cumulus clouds are the main source of targets for low-level cloud-drift winds, this reflectance causes tracking problems due to saturation effects. The reflected solar energy received at the GOES sensor from the cumulus clouds can make them appear to be warmer than even the underlying ocean surface at times. This makes tracer detection extremely difficult and potentially erroneous. Therefore, we found the usefulness of this channel for winds derivation to be limited to nighttime applications because of its sensitivity to solar contamination. However, this is acceptable since cloud-tracking using the visible channel is already very effective in daylight hours.

An algorithm for tracking the position of the solar terminator has been added to the UW-CIMSS tracking software to flag out any cloud tracers that are detected in quasi-sunlit conditions. Any cloud tracers that are within a specified temporal distance from the calculated solar terminator are flagged. As a default, UW-CIMSS flags any tracers that are less than twice the image time spacing used to generate the cloud-drift winds. For example, SWIR winds generated using 15 min. satellite imagery will be flagged if they are within 30 min. of the position (either side) of the solar terminator.

c. SWIR Image Enhancements and Algorithm Adjustments

The SWIR channel is characterized by relatively small gradients in brightness temperatures in the warmer low levels. This limits the ability of the UW-CIMSS tracking algorithm to detect viable cloud targets and resultant tracers over time. A technique was developed to enhance the SWIR imagery by stretching the brightness temperature contrast in the warmer end of the spectrum (low levels). Specifically, the brightness temperature range from 50-160 is stretched to 0 255. This enhancement greatly improves the gradients in the low-levels at the cost of confining the mid to upper-level gradients in the image. Therefore, tracer detection is strictly limited to cloud tracers ≥600 hPa (based on brightness temperature determined heights). The image enhancement technique is performed on the triplet of SWIR images used to track the cloud features. An LWIR image coincident with the SWIR target image is used to height assign the SWIR-tracked cloud-drift winds. Finally, in order to take advantage of the improved gradients in the enhanced SWIR images, the maximum gradient settings/thresholds routinely used to track clouds in the IR were relaxed.

3. Improvements in Nighttime Low-Level Cloud-Drift Wind Detection

Recent tests have shown that the new SWIR technique (compared to the operational LWIR technique) results in a ~40% increase in the number of nighttime low-level cloud-drift winds tracked in both the Atlantic and Eastern Pacific. Figure 1a shows visible low-level cloud-drift wind coverage provided by GOES-8 for 3 October 2001 1645 UTC. Features such as the well-defined ridge in the north central Atlantic and a possible tropical wave axis in the western Caribbean are suggested by the visible cloud-drift winds. However, these features are more difficult to discern looking at the LWIR nighttime cloud-drift winds, just hours later (Fig. 1b). The corresponding SWIR nighttime cloud-drift winds in Fig. 1c depict these features much more effectively. The SWIR winds provide low-level wind coverage that is much more comparable to that of the visible winds. This smoother transition from daytime to nighttime wind coverage is a desirable feature for model data assimilation.

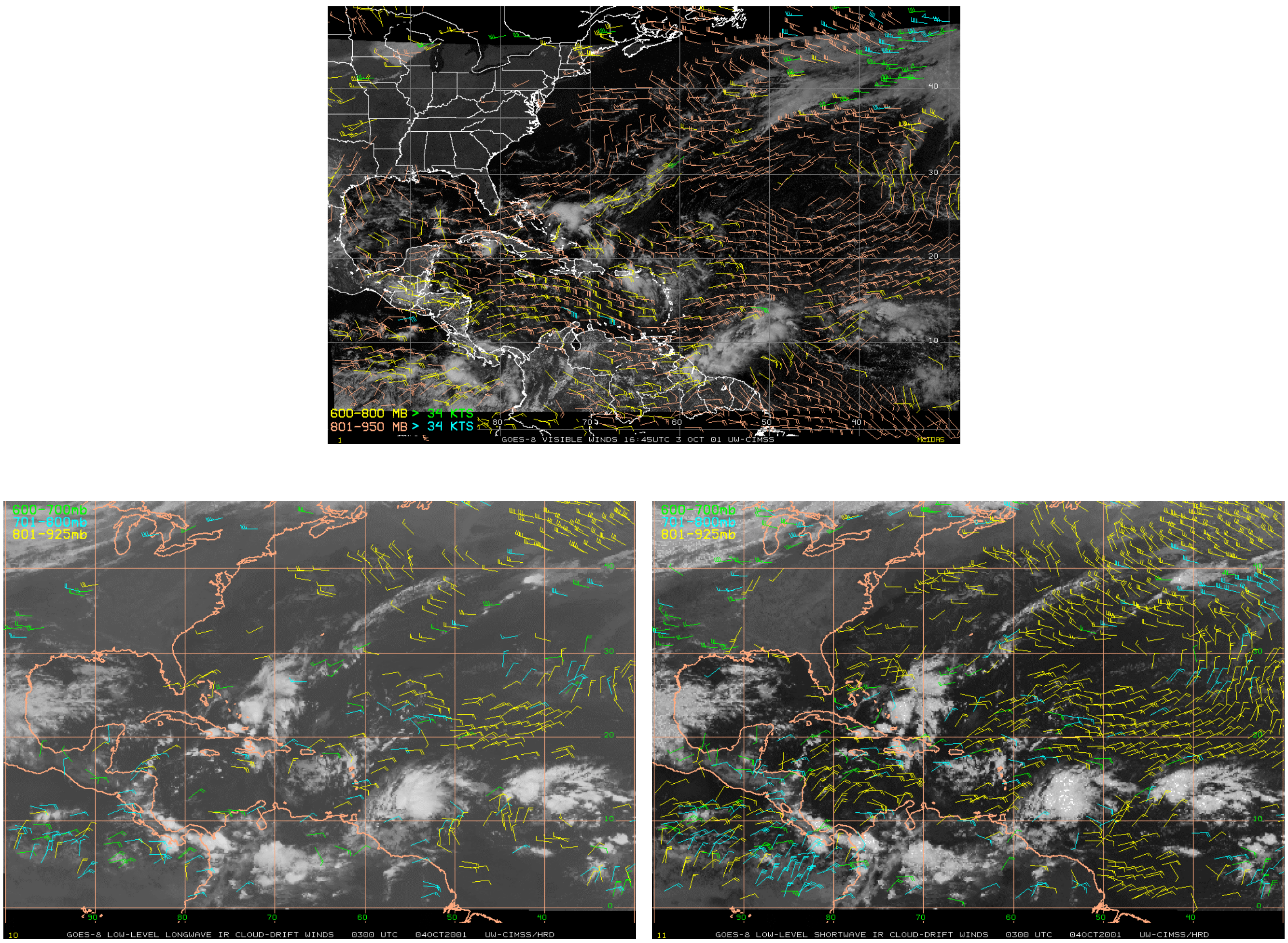

Figure 1 (a,b,c): Comparison of GOES-8 visible (top), LWIR bottom, left), and SWIR (bottom, right) cloud drift wind coverage in the western Atlantic Basin on 3 October 2001.

Figure 2a shows low-level visible cloud-drift winds in the environment of Tropical Storm Florence on 13 September 2000 1845 UTC. Since this storm did not have a well-developed central dense overcast at the time, cloud tracers were easily detected in its inner core region. The NOAA Hurricane Research Division uses methods described by Dunion and Velden (2002) to reduce these winds to the surface (10 m) for use in its operational tropical cyclone surface wind analyses. These surface-reduced cloud-drift winds are useful for determining a tropical cyclone's outer wind radii, particular the radius of tropical storm force (17 ms^{-1}) winds (Dunion et al. 2002). Figure 2b shows the coverage provided by operational LWIR winds just 8 hours later. Though some low-level wind information is available with the LWIR winds, the coverage is inferior to the visible winds. Figure 2c shows the corresponding SWIR low-level cloud-drift winds and indicates coverage that is similar to that provided by the visible winds. The ability of the nighttime SWIR winds to compliment the visible winds helps provide continuous wind information around tropical cyclones for use in real-time operations.

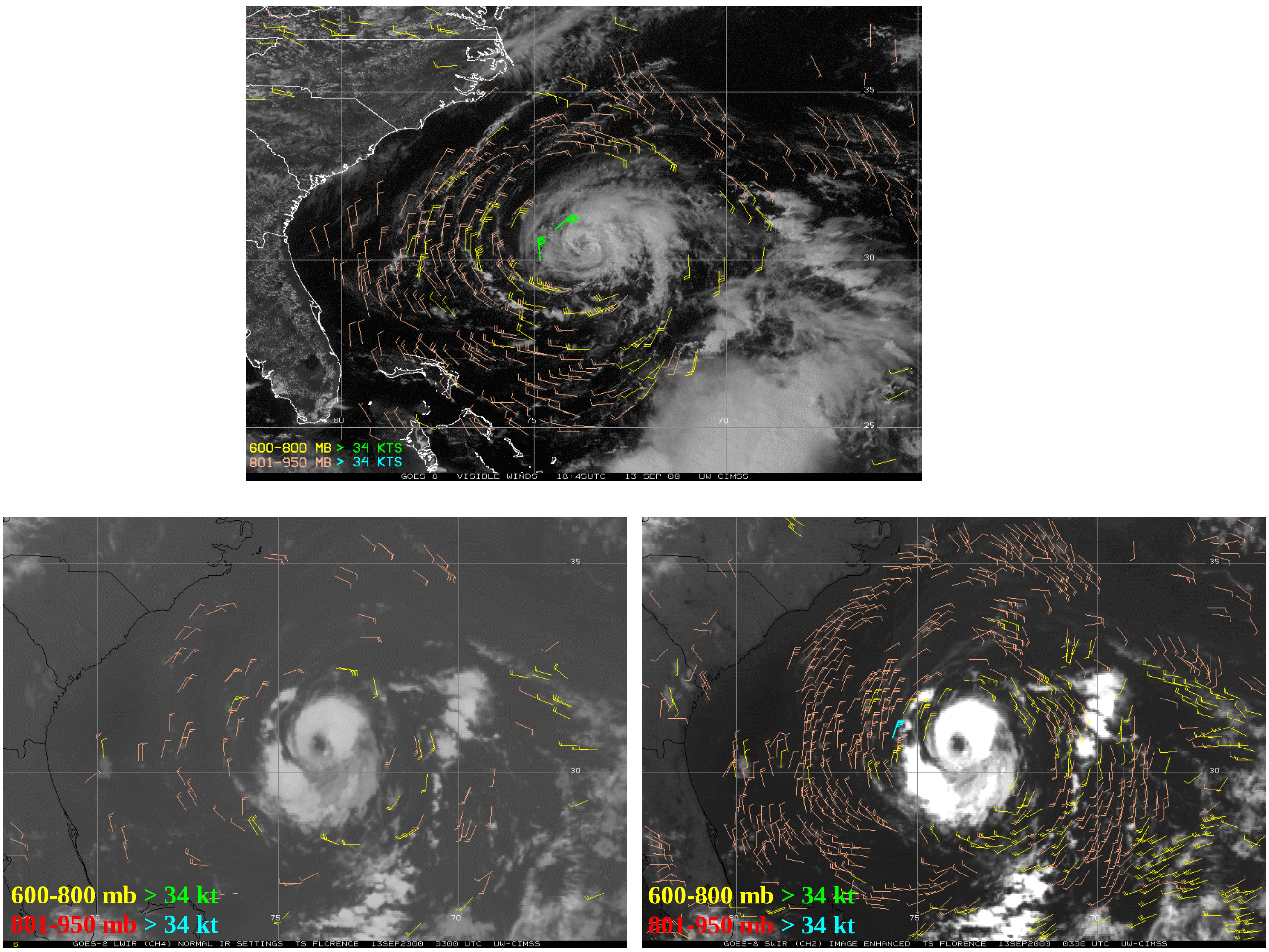

Figure 2 (a,b,c): Comparison of GOES-8 visible (top), LWIR (bottom, left), and SWIR (bottom, right) cloud drift wind coverage in the environment of Tropical Storm Florence on 13 September 2000.

4. Conclusions and Recommendations

The 3.9 µm SWIR channel onboard GOES is superior to the 10.7 µm LWIR channel for providing nighttime low-level (600-950 hPa) cloud-drift wind coverage in both the large scale and storm scale environments. The following are conclusions and recommendations drawn from this study:

- The 3.9 µm SWIR channel is a slightly cleaner window channel than the 10.7 µm LWIR channel, making it more sensitive to warmer low-level temperatures. The SWIR channel is also not as sensitive to cirrus clouds that may obscure low-level cloud tracers. These 2 characteristics of the SWIR channel make it a superior channel for producing low-level cloud-drift winds at night.

- The SWIR channel is susceptible to solar contamination during daylight hours. An algorithm for tracking the position of the solar terminator has been added to the UW-CIMSS software to flag out any cloud tracers that are detected in quasi-sunlit conditions.

- The SWIR channel is characterized by relatively small gradients in brightness temperatures in the low-levels. This limits the ability of the tracking algorithm to detect viable cloud tracers over time. A technique was developed to enhance the SWIR satellite images by stretching the brightness temperature contrast in the warmer low levels. This technique significantly improves low-level cloud tracer detection at night.

- In order to take advantage of the improved gradients in the enhanced SWIR images, the gradient settings in the targeting module were relaxed to further improve cloud tracer detection.

- Recent tests have shown that the new SWIR technique results in a ~40% increase (compared to operational LWIR methods) in the number of nighttime low-level cloud-drift winds tracked in both the Atlantic and Eastern Pacific. No measurable degradation in the quality of the winds relative to the LWIR product was found.

- The SWIR coverage enhancement reduces the daytime versus nighttime disparity in low-level cloud-drift wind data coverage that currently exists using only the LWIR, and will likely improve the ability of models to assimilate this satellite data.

- The NOAA Hurricane Research Division has methods for reducing visible and SWIR winds to the surface (10 m) for use in its operational tropical cyclone surface wind analyses (Dunion and Velden 2002). These surface-reduced cloud-drift winds are useful for determining a tropical cyclone's outer wind radii, particular the radius of tropical storm force (17 ms^{-1}) winds (Dunion et al. 2002).

- The GOES 3.9 µm SWIR winds are currently being transitioned from UW-CIMSS development to NESDIS (see Daniels et al., this volume) and are projected to be running operationally by the end of 2002.

- The new European geostationary satellite (MSG) as well as the next Japanese geostationary satellite (MTSAT) will have the 3.9 m channel and the ability to process low-level SWIR winds operationally. This study demonstrates the utility of this channel to enhance nighttime low-level wind coverage in advance of global production in the near future.

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