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CLOUD DETECTION AND PROPERTY RETRIEVAL ACROSS THE DAY/NIGHT TERMINATOR

Gary B. Gustafson[1] and Robert P. d'Entremont

Atmospheric and Environmental Research, Inc.
Lexington, MA

1. INTRODUCTION

The problem of retrieving useful cloud information from satellites in the vicinity of the day/night terminator has been largely ignored. However, in the face of operational requirements that drive, for example, the NPOESS-C3 (0530 ascending node) orbit there is growing recognition that algorithms must be designed to operate in this difficult domain. Recent work in support of Air Force mission planning activities has resulted in development of cloud detection and cloud spatial/microphysical property retrieval algorithms specifically intended to operate across the terminator. To date these have been validated using data from the GOES and Meteosat Second Generation (MSG) geostationary platforms, though they should be generally applicable to multispectral sensor data from polar-orbiting systems as well.

Detection algorithm characteristics include use of reflectance-channel data into the nighttime side of the terminator to help detect vertically developed clouds that may be directly illuminated on one side, empirical normalization functions to adjust reflectance values for solar zenith angle dependence in the 80-105° region, and midwave IR algorithms that automatically adapt to the transition from emitted plus reflected during daytime to emitted only at night. Cloud property retrieval algorithms rely on multispectral IR channel pairs at some combination of 6.7, 8.5, 10.5, and 12.0 μm, and as such are insensitive to solar illumination. Time-series plots of cloud masks show high consistency across the terminator for all cloud types including marine stratus. Comparisons of cloud top/base retrievals to ground-based lidar/radar estimates indicate good agreement, particularly for transmissive cirrus.

[1] *Corresponding author address:* Gary Gustafson, Atmospheric and Environmental Research, Inc., 131 Hartwell Ave, Lexington, MA 02421-3126; email: ggustafs@aer.com.

2. CLOUD DETECTION

Detection is accomplished using a hybrid temporal/multispectral analysis technique developed by d'Entremont and Gustafson (2003). The approach uses a decision tree algorithm similar to that popularized by Saunders and Kriebel (1988) wherein each branch consists of an independent algorithmic test designed to discriminate clouds from the background based on a specific temporal and/or spectral signature – refer to Table 1 for a summary of the individual tests. An overall cloud/no-cloud decision is obtained by evaluating results of all tests simultaneously.

From the table it can be seen that several tests use sensor channel data sensitive to reflected solar that complicates their use across the terminator. Traditionally these tests have been applied over daytime conditions only. Modifications were added to extend their applicable range to include terminator regions. Terminator regions are defined by tunable solar zenith angle (θ_{sol} – Fig. 1) thresholds selected to identify conditions where a scene can exhibit both daytime and nighttime signatures. Current values are 80° (θ_{day}) and 105° (θ_{night}).

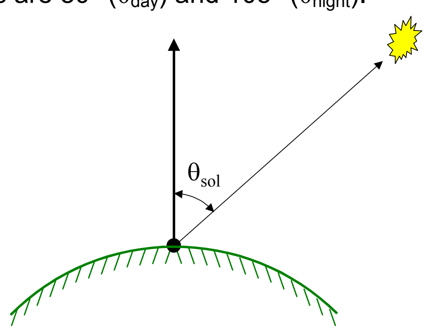


Fig. 1 Solar zenith angle

Reflectance contrast: This cloud test compares visible/near-IR channel data to an estimate of the corresponding clear-scene value. If the observation exceeds the estimate by more than a defined threshold amount then the pixel is classified as cloud filled. Different clear-scene

Test Name	Description	Sensor Channels[2]	Day	Night	Term
Temporal difference	Compare time rate of change in thermal IR and reflectance channels to predicted background change	VIS, NIR, TIR	X	X	X
Dynamic threshold	Use temporal difference results to classify nearby pixels with similar spectral signatures	VIS, NIR, TIR	X	X	X
IR contrast	Compare IR window to external surface temperature estimate	TIR	X	X	X
Split IR	Evaluate split thermal IR temperature difference for ice and small water droplet clouds	TIR	X	X	X
VIS-NIR contrast	Evaluate relative reflectance from visible to near IR to identify vegetated land and water backgrounds	VIS, NIR	X		
Geometric sun glint	Evaluate reflectance angle for possibility of glint	N/A	X		X
Static desert	Use external geography database to identify desert	N/A	X		X
External snow/ice	Use external snow/ice database	N/A	X		
Spectral sun glint	Evaluate multispectral signature to discriminate glint background from reflective clouds	VIS, NIR, MWIR, TIR	X		X
Spectral desert	Evaluate multispectral signature to discriminate reflective land background from reflective clouds	VIS, NIR, TIR, SWIR, MWIR,	X		X
Spectral snow/ice	Evaluate multispectral signature to discriminate snow/ice background from reflective clouds	VIS, NIR, TIR, SWIR, MWIR	X		
Reflectance contrast	Compare measured reflectance to expected clear-scene reflectance based on background tests	VIS, NIR	X		X
Mid-thermal IR contrast	Evaluate relative reflection/ transmission across midwave to thermal IR	MWIR, TIR	X	X	X
Low cloud/fog	Evaluate relative emissivity across midwave to thermal IR to identify water droplet clouds	MWIR, TIR		X	X

[2] VIS ~ 0.65 µm, NIR ~ 0.85 µm, SWIR ~ 1.6 µm, MWIR ~ 3.9 µm, TIR ~ 10.7 and/or 12.0 µm

Table 1 Summary of cloud and background tests

estimates, sensor channels and threshold levels are used depending on background type. Over land backgrounds the reference value is obtained from a dynamic database constructed from previous observations for points that have been classified as cloud free. The database is designed to gradually update as new data are added. Over water a default value is used.

To account for variations in solar illumination, reflectance-channel data are typically normalized by an inverse cosine function on solar zenith. However, this tends to introduce too large an adjustment for angles greater than ~60°. To extend the test into the terminator region an empirical relationship was established for larger angles. GOES data were collected for a large number of terminator cases covering different seasons and geographic conditions. The data were cloud-cleared and stratified by solar zenith angle. Fig. 2 shows a example of how the intensity varies across the terminator for one case.

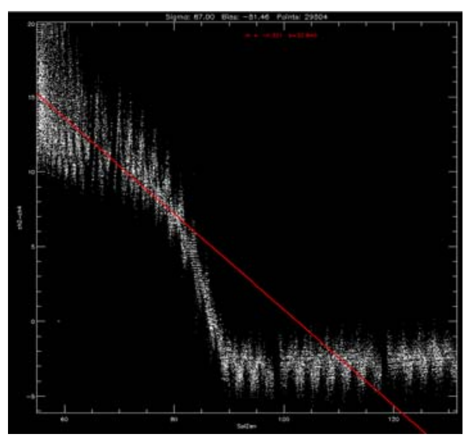


Fig. 2 Sample visible channel observations across the day-night terminator

The mean-condition for the entire data set is plotted as the red curve in Fig. 3. This was fitted in a least-squares sense to a cosine function (black curve) that is used by the cloud-detection algorithm to predict the solar-zenith dependence of the measured visible-channel reflectance. Reflectance-channel data are used out to a solar zenith angle of 99°.

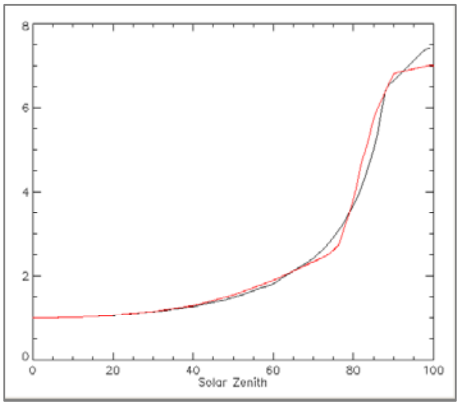


Fig. 3 Derived empirical solar enhancement function (red) and fitted curve (black)

Midwave-thermal IR contrast. A large positive brightness temperature difference between the mid and long wave IR during daytime, indicates a liquid water cloud that is preferentially reflective in the MWIR. Smaller positive temperature differences during both day and night are representative of a transmissive cirrus cloud. The magnitude of the daytime MWIR – TIR temperature difference is strongly dependent on the amount of solar illumination (increasing with increased illumination) so the test uses a solar zenith angle dependence to establish appropriate positive threshold levels for different times of day. Terminator thresholds are a linear interpolation on θ_{sol} between default daytime and nighttime values (Th_{day} and Th_{night}).

Default values are established based on the background conditions

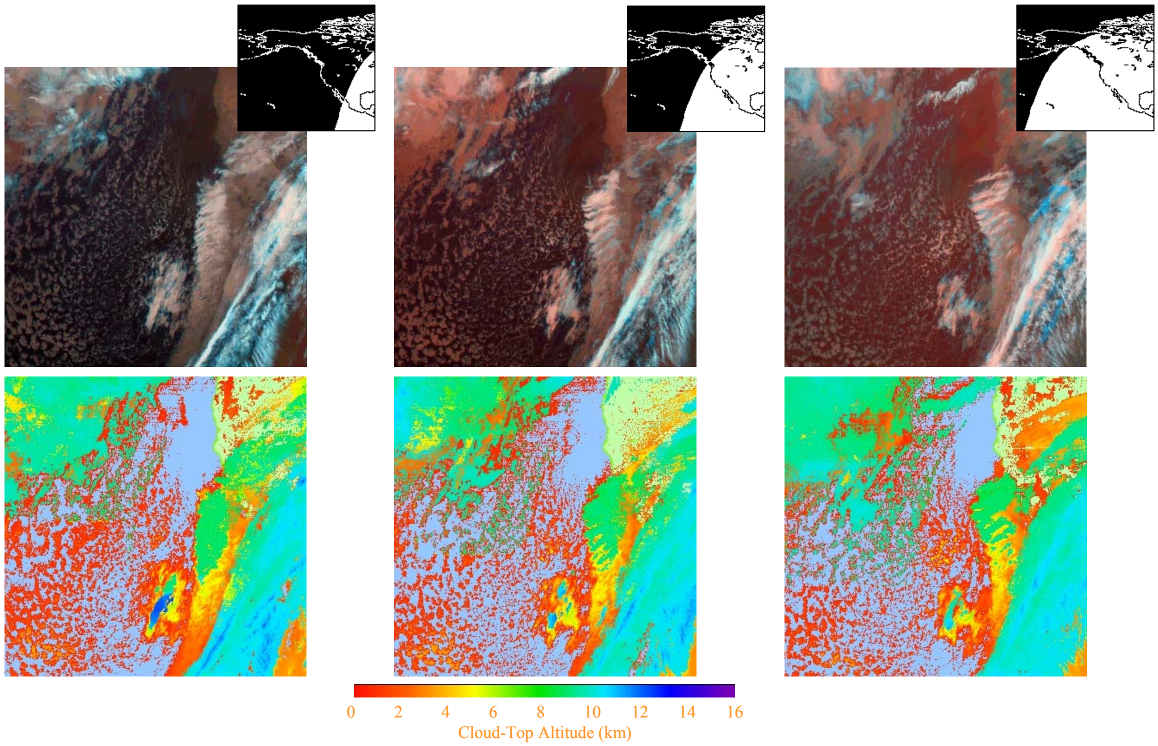
$$T_{MWIR}-T_{TIR} > \begin{cases} \theta_{sol} \le \theta_{day} : Th_{day} \\ \quad : Th_{day} + \Delta Th_{day\text{-}night}\left(\dfrac{\theta_{sol}-\theta_{day}}{\Delta\theta_{day\text{-}night}}\right) \\ \theta_{sol} \ge \theta_{night} : Th_{night} \end{cases}$$

Background Tests: Reflectance thresholds are also dependent on background. For example sun glint, desert, and snow/ice backgrounds can all exhibit strong signatures similar to clouds. To avoid misclassification a set of external databases and dynamic multispectral background tests are used to identify these regions and, where possible, classify individual pixels within the regions as either bright background or cloud. The sun glint and desert tests have also been extended to operate across the terminator using the same type of correction/ interpolation algorithms discussed above for the cloud tests. In addition, the MWIR channel data used in the IR contrast tests are extremely sensitive to reflective backgrounds, so additional safeguards were added such that a reflectance-angle-dependence is built into the cloud threshold over water surfaces and over deserts an empirical offset is added.

3. Results

Examination of cloud algorithm performance over the terminator revealed that sensitivity to thin cirrus and low cloud are often reduced during the hours immediately surrounding local sunrise or sunset. This is manifest as low clouds that appear, disappear, and then reappear in cloud mask time series.

Conditions off the U.S. west coast frequently stress the ability of automated algorithms to detect the persistent marine stratus decks and frequent cirrus incursions. Consequently testing of the terminator algorithms has focused on that area. GOES-10 data are routinely processed through the cloud detection algorithms and results posted on the web (www.aer.com/cloud). Typically data updates are received from the satellite over the region of interest every 15 minutes – more frequently during rapid scan events. Fig. 4 shows a four-hour time series captured during local sunrise. The figure contains fairly representative results illustrating the consistency that has been achieved across the terminator. The black/white images at the top right show the local terminator line (θ_{sol} = 90°). The 3.9-10.7-12.0 μm (red-green-blue) color composite images at the top show how the MWIR cloud signature changes as the sun rises above the horizon – transitioning from a negative MWIR-TIR difference (red) to a positive one (blue). The corresponding cloud top altitude retrievals shown in the bottom row of panels shows that both the low (red) clouds over the ocean, and the higher cirrus (green-blue) are consistently detected and correctly classified throughout the sequence, independent of the solar illumination.



(a) **(b)** **(c)**

Fig. 4 GOES-10 3.9-10.7-12.0 μm composite imagery (top) at 1330 (a), 1530 (b), and 1730 (c) and corresponding cloud to altitude retrieval (bottom).

4. REFERENCES

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Saunders, R.W. and K.T. Kriebel, 1988: An improved method for detecting clear sky and cloudy radiances from AVRR data. *Int. J. Remote Sensing,* **9**, 123-150.