TWO SIMPLE GOES IMAGER PRODUCTS FOR IMPROVED WEATHER ANALYSIS AND FORECASTING

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Abstract

Two new products, constructed from GOES Imager data, are presented: the shortwave albedo product and the day/night albedo product. These products are based on physical quantities needed by forecasters in real-time to support their operational activities. Real-time loops of the products may be viewed on the RAMSDIS Online Experimental Web Site (http://www.cira.colostate.edu/RAMM/Rmsdsol/ROLEX.html). *The products are being inserted into AWIPS at CIRA and in the NWS Western Region.*

1. Introduction

The Geostationary Operational Environmental Satellite (GOES) I-M-series satellites (*GOES-8, 9, 10,* and *11* to date) are significantly improved over the previous generation of geostationary weather satellites (Menzel and Purdom 1994). Among the improvements are: better spatial resolution, more channels, improved detectors, and greater precision. Some of these advances have been exploited in the imagery and products available to operational forecasters, but the information available from the enhanced satellites' capabilities is far from exhausted. This paper introduces two new or improved, but yet simple, products that provide enhanced information, which can be applied directly to weather analysis and forecasting.

The new products presented in this paper were conceived in large part during the COMET (Cooperative Program for Operational Meteorology, Education and Training) Satellite Meteorology courses (http://www.comet.ucar.edu/class/satmet). Students at the two-week courses are forecasters, primarily with the National Weather Service (NWS), but also from the U.S. Department of Defense, the Meteorological Service of Canada, and other agencies. During the presentations and ensuing discussions in the class, a recurring theme brought up by the forecasters is their need to have access to digital image products that bring out the features that are important to their warning and forecast duties. In response to these repeated requests, two new products were developed.

The philosophy behind the approach used to develop these new products follows. First, operational forecasters rarely have the time to conduct a detailed analysis of a satellite image or product as can be done in a laboratory. The new GOES image products must be readily and reliably available. The products were developed so that they can be implemented in a local forecast office, which for the NWS means getting the products into the Advanced Weather Interactive Processing System (AWIPS). Each of these products was tested at the Cooperative Institute for Research in the Atmosphere (CIRA) on Regional and Mesoscale Meteorology (RAMM) Advanced Meteorological Satellite Demonstration and Interpretation System (RAMSDIS) units (Molenar et al. 2000). Satellite images from both *GOES-8* and *GOES-10* (the current eastern and western satellites) were used. Also, both operational 8-bit images from NOAA servers and 10-bit images from the CIRA ground station were used.

Second, the derived product images need to provide an accurate analysis of the meteorologically important features. However, the algorithm does not need to work on the unimportant features of the image. Experienced operational forecasters are skilled at focusing on the important features and ignoring the rest. For example, an algorithm designed to monitor a low-level feature such as fog/stratus clouds does not need to be precise for high cold clouds. Another important point is that the critical features in the products can be highlighted by using a specific enhancement curve tailored for each product.

Third, the derived image products should represent the physical quantities that are needed by operational forecasters rather than the radiometric quantities measured by the satellite instruments. For example, images derived from most longwave infrared channels are converted to temperatures for display.

The two products presented in this paper are derived using the visible and two infrared channels from the GOES imager. The products are called the shortwave albedo and the day/night albedo. Real-time loops of the products may be viewed on the RAMSDIS Online Experimental Web Site (http://www.cira.colostate.edu/RAMM/Rmsdsol/ROLEX.html).

2. The Shortwave Albedo Product

The so-called "fog product" has revolutionized fog and liquid water cloud detection at night. As described by Ellrod (1995), liquid water clouds have a lower emittance (emissivity) at 3.9 μm (GOES channel 2) than at 10.7 μm (channel 4). Whereas the emittance of a "thick" liquid water cloud at 10.7 μm is near 1.0, the emittance at 3.9 μm is near 0.7. The result is that at night, the brightness temperature at 3.9 μm ($T_{3.9}$) is less than that at 10.7 μm ($T_{10.7}$). This difference has been exploited to produce the fog product (or fog-stratus product):

$$\textit{fog product} \equiv T_{10.7} - T_{3.9}\,. \tag{1}$$

Basically, the difference in brightness temperature is plotted as an image, with light gray-to-white representing positive $T_{10.7}$ - $T_{3.9}$ values and dark gray-to-black representing negative values. On the RAMSDIS units, a linear enhancement is used so that clear areas, whether land or ocean, appear gray; fog or stratus appears white; and thin cirrus appears black.[1]

During the day, the fog product becomes less useful. Solar radiation at 3.9 μm is not negligible, as it is at 10.7 μm. After sunrise, liquid water clouds (albedo ~0.3) reflect solar radiation to the satellite, and it appears that the clouds warm. $T_{3.9}$ becomes larger than $T_{10.7}$. In the fog product, liquid water clouds turn black due to the reflected solar radiation. To handle this problem, the "reflectance product" has been developed (Dills et al. 1996). Let $L_{3.9}$ be the measured radiance at 3.9 μm. $L_{3.9}$ is linearly related to the counts returned by the GOES Imager and can be calculated using the equations of Weinreb et al. (1997, 1998) or Hillger (1999). Assume further that $T_{10.7}$ represents the physical temperature of the cloud. Then the Planck function $B_{3.9}(T_{10.7})$ represents the 3.9 μm radiance that the satellite would measure if there were no solar reflection. The difference, when converted into appropriate 8-bit display counts, is the reflectivity product:

$$\textit{reflectivity product} \equiv L_{3.9} - B_{3.9}(T_{10.7}). \tag{2}$$

It is an estimate of the solar radiance reflected from the surface being observed. In this product, liquid water clouds appear white, land and ocean appear dark (near zero reflection), and cirrus appears black to gray. Unfortunately, the reflectivity product becomes less useful at night.

One can take advantage of the day/night limitations present in the fog-stratus and reflectivity products that result from the 3.9 μm channel. Because the reflection of solar radiation in the daytime and the lowered brightness temperatures at night over liquid water clouds are caused by the same phenomenon (increased albedo / decreased emittance), it is possible to develop a simple, unified product which is applicable both day and night. The radiance measured by the GOES Imager at 3.9 μm is composed of reflected and emitted parts. The emitted part can be approximated as

$$\textit{emitted radiation} = \varepsilon_{3.9}\, B_{3.9}(T_{10.7}) = (1 - A_{3.9})\, B_{3.9}(T_{10.7}), \tag{3}$$

where $\epsilon_{3.9}$ is the 3.9 μm emittance, and $A_{3.9}$ is the 3.9 μm albedo. The reflected radiation starts with the 3.9 μm solar irradiance of the scene, which can be approximated as

$$\textit{solar irradiance} = B_{3.9}(T_{sun})\, \Omega_{sun} \cos\zeta, \tag{4}$$

where Ω_{sun} is the solid angle of the sun subtended at the earth (6.8 x 10^{-5} sr), ζ is the solar zenith angle, and T_{sun} = 5888 K at 3.9 μm (Thekaekara 1972). The radiance reflected to the satellite from a particular point or location is the product of the bidirectional reflectance and the solar irradiance. Assuming that the point is an isotropic surface (which scatters radiation uniformly in all directions), the bidirectional reflectance is simply $\pi^{-1}A_{3.9}$ (see Kidder and Vonder Haar 1995, pp. 79-81, for details). Thus, the reflected radiation is

$$\textit{reflected radiation} = \frac{1}{\pi} A_{3.9} B_{3.9}(T_{sun})\Omega_{sun} \cos\zeta = A_{3.9} L^*_{3.9} \cos\zeta\,, \tag{5}$$

where $L^*_{3.9}$ is the radiance reflected from a 100% albedo isotropic surface when the sun is directly overhead:

$$L^*_{3.9} \equiv \frac{1}{\pi} B_{3.9}(T_{sun})\Omega_{sun}. \tag{6}$$

Therefore, the radiance measured by the satellite can be written as the sum of the emitted and reflected radiation:

$$L_{3.9} = (1 - A_{3.9}) B_{3.9}(T_{10.7}) + A_{3.9} L^*_{3.9} \cos\zeta\,, \tag{7}$$

or, solving for $A_{3.9}$,

$$\textit{shortwave albedo} \equiv A_{3.9} = \frac{L_{3.9} - B_{3.9}(T_{10.7})}{L^*_{3.9} \cos\zeta - B_{3.9}(T_{10.7})}. \tag{8}$$

At night (ζ> 90°) the same equation applies if we simply set $L^*_{3.9}$ = 0.

To construct the shortwave albedo product, 3.9 μm and 10.7 μm GOES Imager data are processed using eq. (8). Then 3.9 μm albedos from -30% to +30% are displayed as a gray scale from black to white. Negative albedos result for thin cirrus at night due to transmission of warmer radi-

[1]Unfortunately, this enhancement curve did not get into the AWIPS system as the default, so that on AWIPS, fog-stratus areas appear dark. There is a correction to change the default enhancement for the fog-stratus product that can be found on the Western Region AWIPS Page (http://awips.wrh.noaa.gov). Go to AWIPS technical note 4.2-21 "Modifying How the Fog Product is Generated".

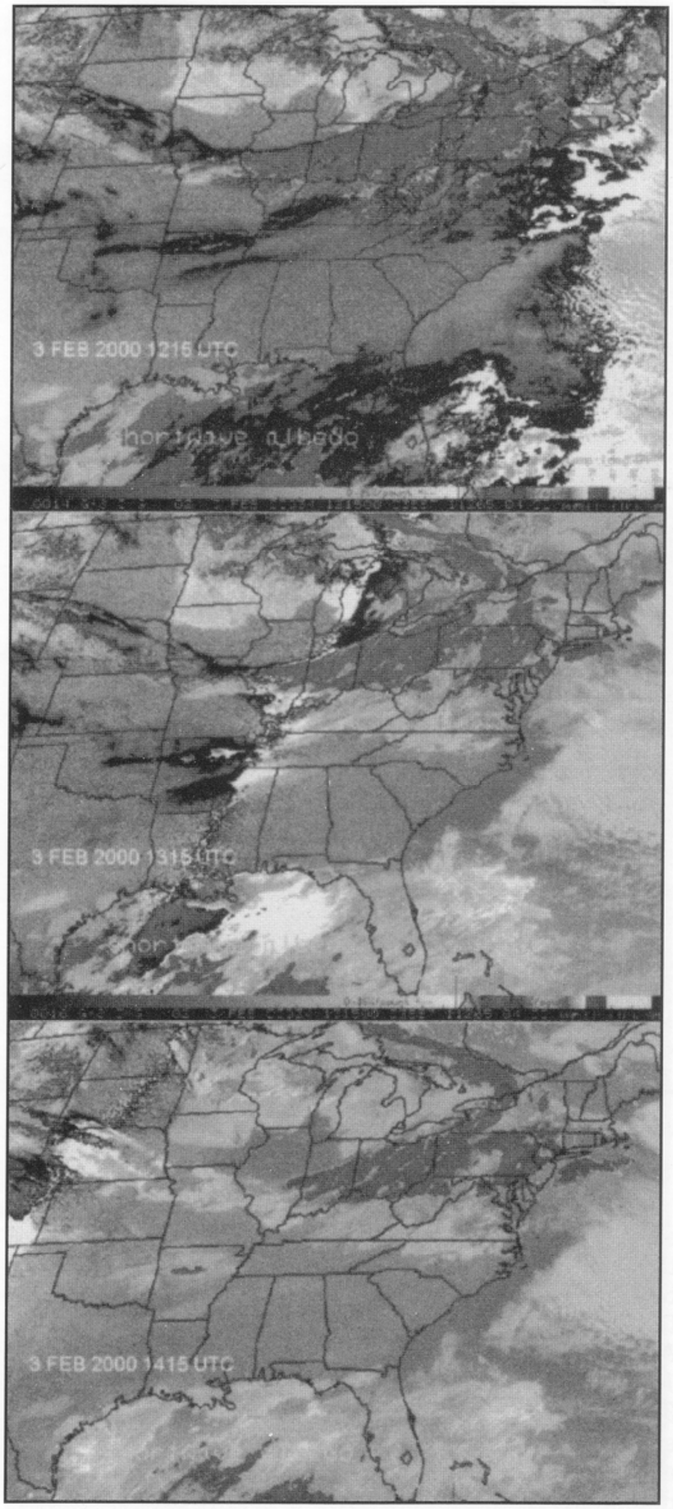

Fig. 1. A series of shortwave albedo product images separated by 1 h. Cold clouds are colored, white indicates liquid water clouds, black indicates thin cirrus, and gray indicates land, ocean, or snow cover.

ances from below the cloud. Since the GOES 3.9 μm channel was designed to measure warm temperatures, noise is a problem at low temperatures. Whenever $T_{10.7}$ is less than -30°C, we replace the 3.9 μm albedo with the color-coded $T_{10.7}$ as in the standard infrared (10.7 μm) image.

Figure 1 shows a series of three shortwave albedo product images that span sunrise. Liquid water clouds appear white; land, ocean and snow cover (see next section) appear gray; thin cirrus appears black at night (left of the terminator); and cold clouds are colored. It is easy to detect liquid water clouds day or night. Because the sun is bright at 3.9 μm ($L^*_{3.9}$ is on the order of 10 to 100 times $B_{3.9}(T_{10.7})$) the denominator of eq. (8) changes from negative at night to positive during the day, thus causing a dramatic change from black to white in a narrow band near the terminator. For thin cirrus clouds, reflected solar radiation overcomes the transmitted radiation, and thin cirrus clouds turn gray during the day.

Basically, the shortwave albedo product is simply a normalized reflectivity product. This normalization means that a constant color (enhancement) table can be used at all times of the day, and that artificial "stretching" of the data is not needed.

For the weather forecaster, the chief use of the shortwave albedo product is to detect and track liquid water clouds including fog. Because liquid water clouds appear bright white both day and night, they are easy to find in the image, which speeds the analysis and forecast process. This unambiguous signal is especially useful in areas of mixed cloud and in areas of cloud over snow cover. For comparison, Fig. 2 shows the weather at 1200 UTC 3 February 2000.

3. The Day/Night Albedo Product

Visible channel imagery is probably the most easily interpreted type of satellite product. Basically, the visible channel shows what the human eye would see from 36,000 km above the surface of the earth. However, raw visible imagery suffers from the fact that it is a combination of two effects: the albedo of the underlying scene (in which the forecaster is interested) and the solar elevation angle (in which he or she is not interested). The albedo in the visible channel is obtained as follows.

GOES Imager channel 1 (0.65 μm) data can be converted to reflectance, R, by the calibration equations of Weinreb et al. (1997, 1998). This reflectance would be the albedo *if the sun were overhead at every point*. There is a straightforward calculation to correct for the variation in solar angle. We do two things to the reflectance: (1) multiply by the secant of the solar zenith angle and (2) multiply by the square of the ratio of the earth-sun distance to the mean earth-sun distance. The latter correction is small (within 1 ± .034) but it is easily accomplished because it is a byproduct of the zenith angle calculation. In equation form,

$$\textit{isotropic albedo} = R\left(\frac{d}{\bar{d}}\right)^2 \sec\zeta \qquad (9)$$

where ζ is the solar zenith angle, d is the earth-sun distance, and $\bar{d}$ is the annual-average earthsun distance. The resulting product is called the *isotropic albedo* because it is what the albedo would be if the scene were an isotropic reflector, i.e., one that reflects uniformly in all directions and does not have bidirectional effects. This isotropic albedo is not a new cal-

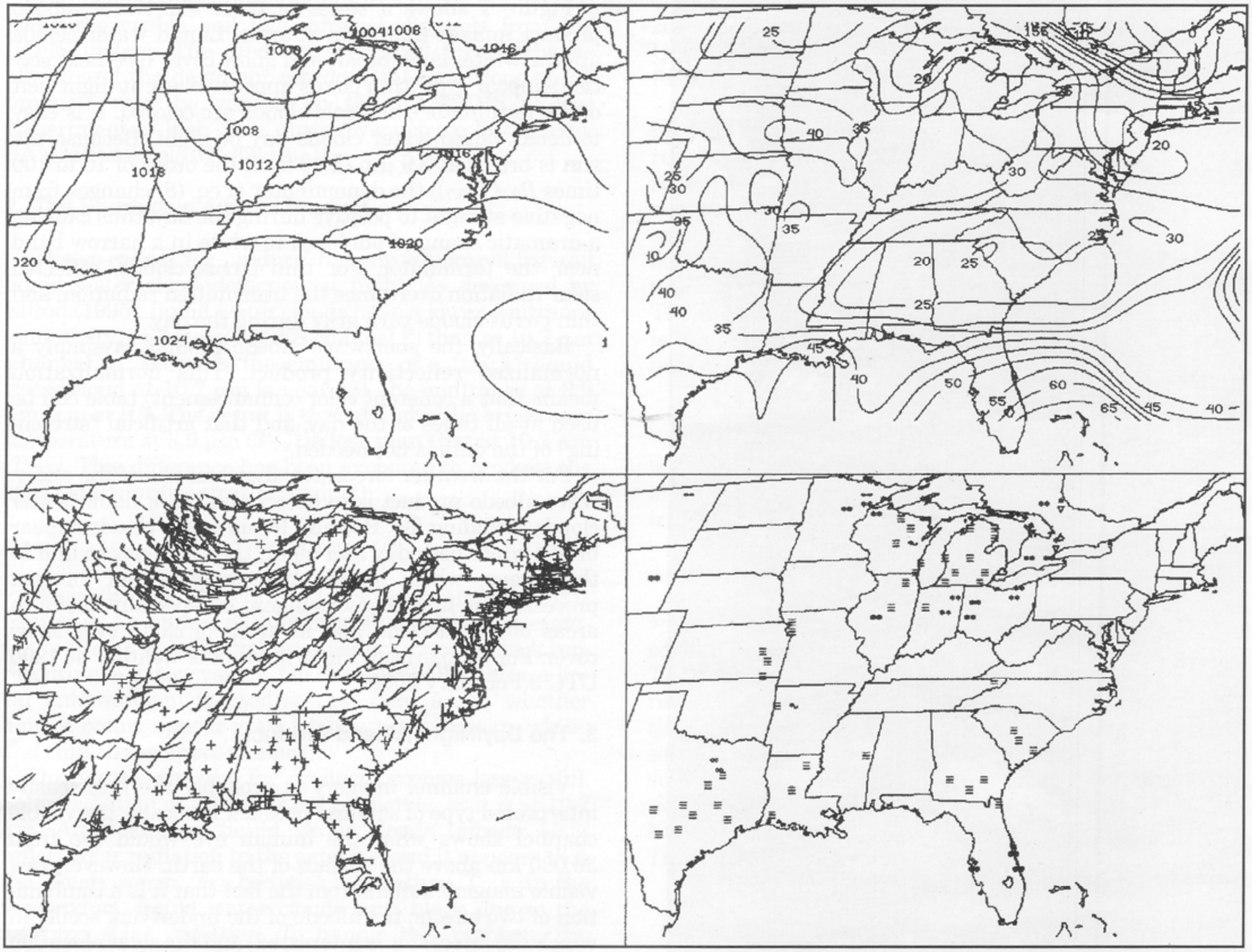

Fig. 2. Observations at 1200 UTC 3 February 2000. (a) Sea-level pressure (mb), (b) surface temperature (°F), (c) wind (kt), and (d) significant weather.

culation. It has been done for many years by people who study the radiation budget of earth and others (see chapter 10 of Kidder and Vonder Haar 1995 for an explanation and bibliography). However, the isotropic albedo is new to operational weather forecasters.

The sun is up only during the day, of course. To make the product more interesting and more continuous from day to night, we insert the 3.9 μm albedo when the sun is down (but without the colored infrared cold clouds—cold clouds are simply black). This product is referred to as the *day/night albedo* because the 0.65 μm albedo (isotropic) is used during the day and the 3.9 μm albedo is used at night.

Figure 3 shows the day/night albedo product for the same three times shown in Fig. 1. Note that in the daytime portion (right) the clouds all have nearly the same brightness, independent of sun angle. In the normal visible image, the portion near the terminator would be quite dark and would drastically limit ability to see any clouds (unless a special low light enhancement is used). The isotropic albedo can be thought of as a physically based enhancement, which brings out the clouds (the meteorologically important features in the image) uniformly across the image. Also note that by comparing the bottom image in Figs. 1 and 3, or by looking at the sequence of images in Fig. 3, one can discover that northern Illinois is snow-covered. Snow cover has nearly the same (low) 3.9 albedo as clear ground or water; thus snow cover is not detectable in 3.9 albedo images and it cannot be confused with more reflective clouds as it can in visible imagery.

The chief operational forecasting application of the day/night albedo product is in analyzing clouds, especially near sunrise and sunset. This product could be useful in constructing cloud climatologies (Reinke et al. 1992; Gould and Fuelberg 1996) because the threshold for distinguishing clouds is much less strongly related to sun angle than in the uncorrected visible image. Another cloud climatology could be constructed at night using the 3.9 μm albedo product.

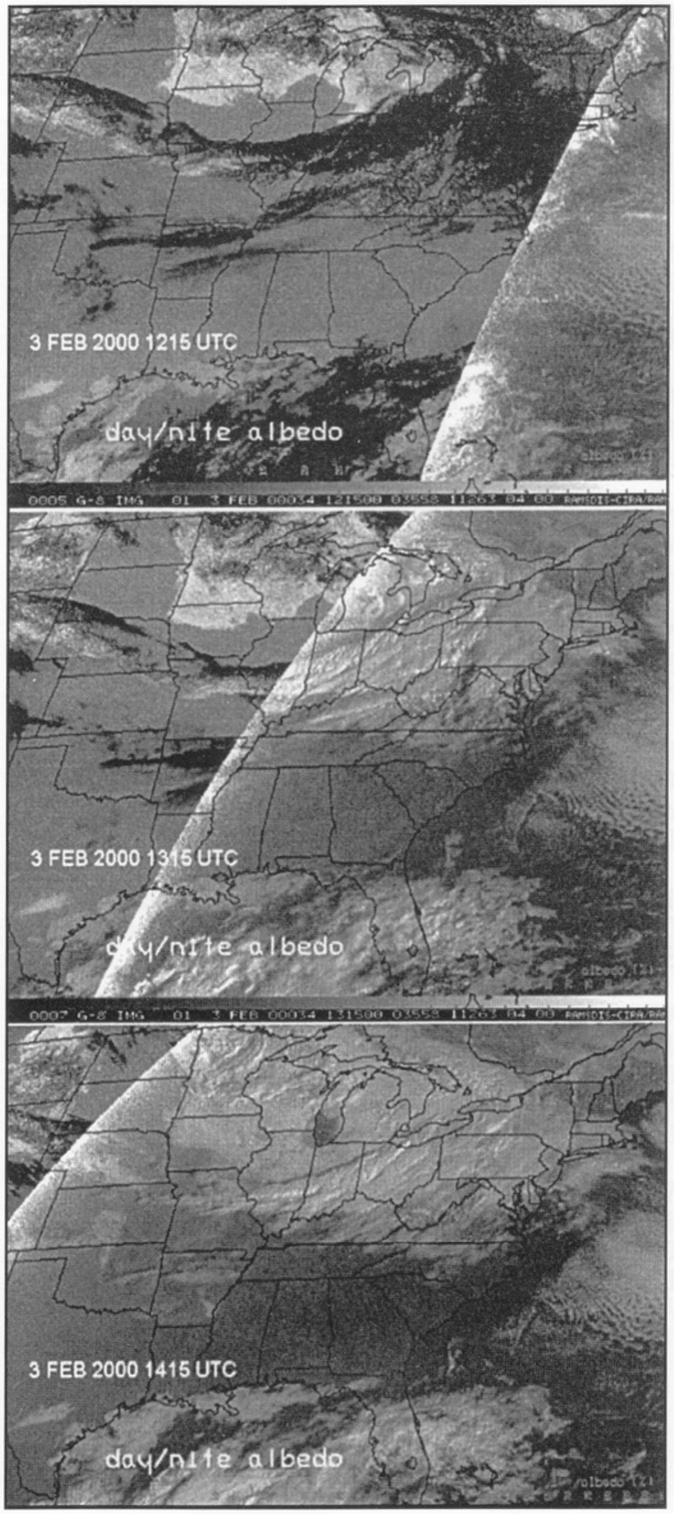

Fig. 3. A series of day/night albedo product images separated by 1 h. On the left (sun down) is the 3.9 μm albedo. On the right (sun up) is the isotropic albedo. These images are at the same times as those in Fig. 1.

4. Concluding Remarks

Two new products, constructed from GOES Imager data, are presented. They are the shortwave albedo product and the day/night albedo product. These are the type of products that forecasters need (based on the requests of students at the Satellite Meteorology classes). They are simple, easily produced, reliable, and physically based. Each of these products has been tested using both *GOES-8* and *GOES-10* imagery. They are available in real-time on the RAMSDIS Online Experimental Web Site (http://www.cira.colostate.edu/RAMM/Rmsdsol/ROLEX.html).

If these products are to be useful to National Weather Service forecasters, they must be available on AWIPS. The images are produced in the laboratory at CIRA on RAMSDIS. We are currently working on converting them to netCDF format and loading them into our experimental AWIPS through LDAD (Local Data Acquisition and Dissemination). There are no major technical difficulties in doing this, and it should be accomplished by the time this paper is published. A version of the shortwave albedo product is already being provided on AWIPS through LDAD at all 24 NWS Western Region forecast offices.

Finally, we note that although we have presented these products as GOES products, nearly the same spectral channels are present on the Advanced Very High Resolution Radiometer (AVHRR) instrument on the polar-orbiting NOAA satellites at a higher resolution (1 km). (To convert AVHRR counts to radiances, see the *NOAA Polar Orbiter Data User's Guide* (1998) for the TIROS N and NOAA 6 through 14 satellites, or see the *NOAA KLM User's Guide* (1999) for NOAA 15 and higher.) Because the channels are different, slightly different parameters are necessary: at 3.7 μm, $T_{sun} \approx 5827$ K (Thekaekara 1972).

Acknowledgments

The authors would especially like to thank their students in the COMET Satellite Meteorology class, discussions with whom directed the thinking toward constructing these products. Work on this project was supported by NOAA grants NA67RJO152 and NA67WD0097 and by the Department of Defense Center for Geosciences/Atmospheric Research Agreement #DAAL01-98-2-0078.

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