To be presented at the AMS Sixth Conference on Satellite Meteorology and Oceanography, January 5-10, 1992, Atlanta, GA.

PHOTOMETRIC CORRECTION OF GOES VISIBLE SATELLITE IMAGES

Steven C. Albers*

NOAA Forecast Systems Laboratory
Boulder, Colorado

1. INTRODUCTION

At NOAA's Forecast Systems Laboratory, images at visible wavelengths from the GOES-W satellite are being processed to correct for variations across the field in image brightness, prior to display on meteorological workstations. The purpose is to alleviate the distracting effects of changing image brightness over space and time, allowing meteorologists viewing satellite animation to better focus on cloud features within the images.

The principal correction is a function of solar elevation angle, and additional corrections are applied for phase and emission angles. The phase angle is the angle subtended between the sun and the satellite as seen from a particular earth location within the satellite image. The emission angle is the zenith angle of the satellite as seen from the earth. A spatially dependent, linear contrast stretch is applied individually to each pixel in the image as a function of these parameters. The stretch also varies with time.

2. CALCULATION OF CONTRAST STRETCH PARAMETERS

The contrast stretch correction is semi-empirical. We first assume the earth's surface brightness to be proportional to the sine of the solar elevation angle. The above premise is insufficient because the pixel values of the raw satellite images appear to have neither a linear nor a logarithmic response with respect to the incident solar radiation. As a result, the following method was devised to define the stretch parameters.

The contrast stretch parameters vary according to a function that is approximately proportional to the logarithm of the sine of the solar elevation angle. The function was arrived at iteratively by animating satellite images over varying illumination conditions. Viewing a single large-scale image near the terminator was also helpful. The stretch parameters have no effect when the solar elevation is 58°, but are set to increase both brightness and contrast for lower elevation angles. The converse applies for higher elevation angles. At an angle of 58°, the unmodified satellite data produce an acceptable range of grey shades when displayed on our workstations; this provides a good reference point.

When the calculated solar elevation is less than 8°, a slightly increased corrected value is used to reduce the contrast stretch near the terminator. A 3.8° floor is placed on the corrected elevations (−0.4° for the true elevations) to avoid enhancing noise on the dark side of the terminator with excessive stretching. Other small empirical changes to the stretch parameters versus the solar elevation angle are applied as fine tuning.

Figure 1 illustrates the variation in the four stretch parameters with solar elevation angle. The contrast stretch is a linear function mapping the input brightnesses r_1 and r_2 onto the output brightnesses r_3 and r_4, respectively. The stretch parameters are given by:

$$r_1 = 68 + w\log\left(\frac{\sin(\theta)}{\sin(58^o)}\right) + p \tag{1}$$

$$r_2 = 220 + 60\log\left(\frac{\sin(\theta)}{\sin(58^o)}\right) + p \tag{2}$$

$$r_3 = 68 \tag{3}$$

$$r_4 = 220 \tag{4}$$

where θ is the solar elevation angle and p is a phase angle correction described below. Coefficient w is explained below in association with Fig. 3.

The phase and emission angles in this example are assumed to be zero. Constants r_3 and r_4 correspond to typical brightness values (on a scale from 0-255) of cloud-free and cloudy areas, respectively, with the sun at the 58° reference altitude. The fact that the two pairs of curves each intersect at a solar altitude of 58° confirms that no correction is applied at that altitude. The r_1

*Jointly affiliated with the Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, CO.

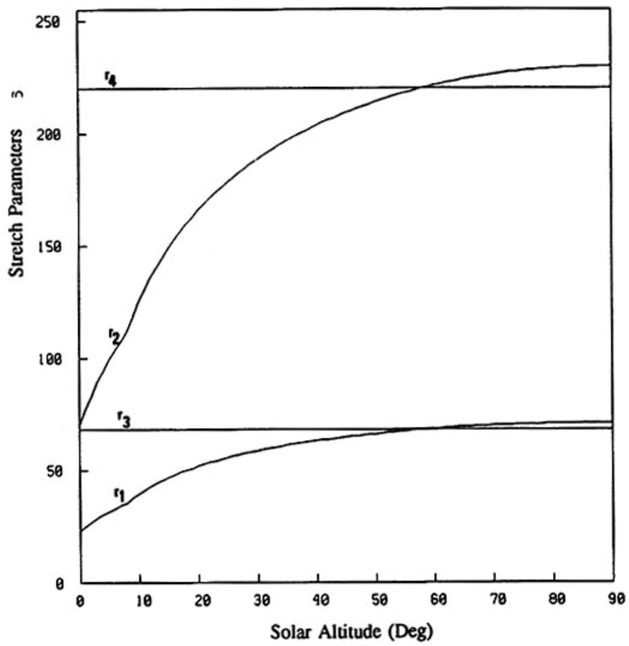


Fig. 1. The four parameters used in the contrast stretch are plotted as a function of solar elevation angle.

value primarily controls the rendition of clear land or sea areas, whereas r_2 mainly affects cloud-covered portions of an image.

The phase and emission angles play a secondary role as mentioned earlier. At large phase angles, the image is dimmed to correct for backscattering. Backscattering appears more pronounced at low latitudes and is one reason that the phase correction is significant only for small emission and solar zenith angles. The phase effect is not significant at large emission angles (i.e., near the earth's limb), probably because atmospheric scattering prevents direct rays from traversing the atmosphere when both the sun and the satellite are at low angular altitudes as seen from the earth.

Figure 2 shows the phase correction p added to both r_1 and r_2 as a function of phase angle.

$$p = 20\cos(\phi^6)\cos(e)\sin(\theta) \qquad (5)$$

In Equation 5, p is the phase correction, ϕ is the phase angle, e is the emission angle, and θ is the solar elevation angle. The emission and solar zenith angles are both set to zero in Fig. 2, corresponding to a point on the earth's equator beneath the satellite at local noon. This situation presents the greatest possibility of enhanced backscattering at low phase angle. The phase effect is most evident near local noon during March and October for mid-northern latitudes.

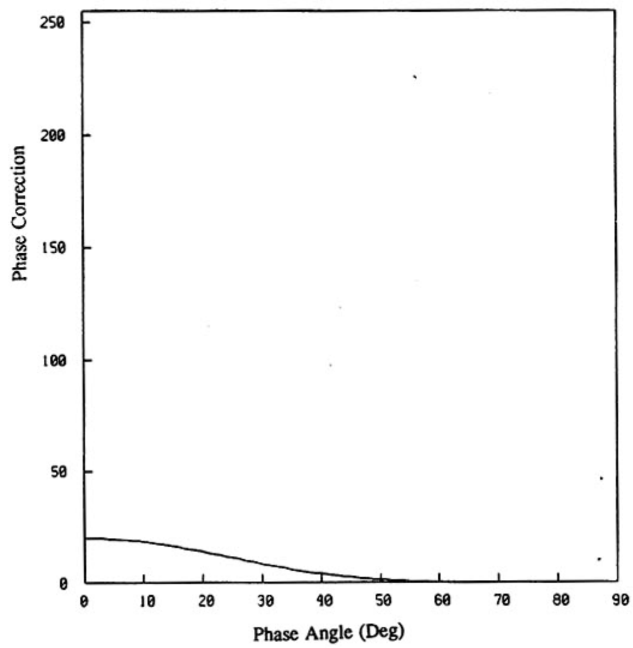


Fig. 2. Corrections subtracted from the stretch parameters r_1 and r_2 are plotted as a function of phase angle (degrees). The solar elevation here is assumed to be 90° with an emission angle of 0°.

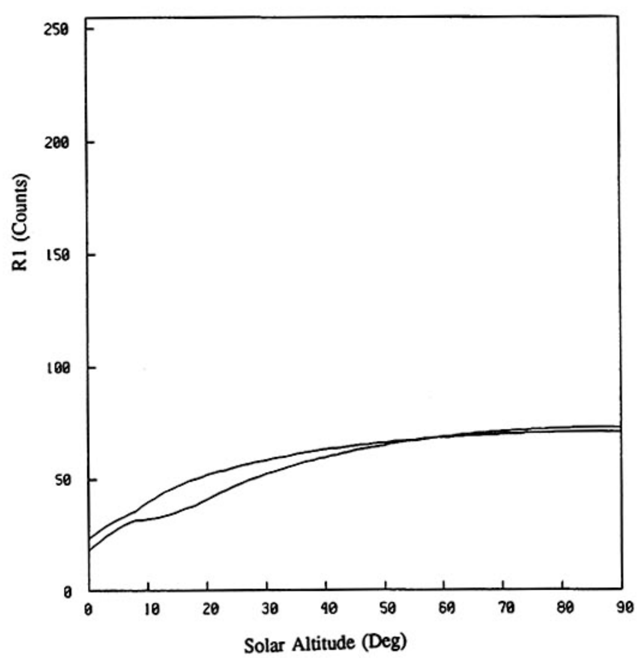
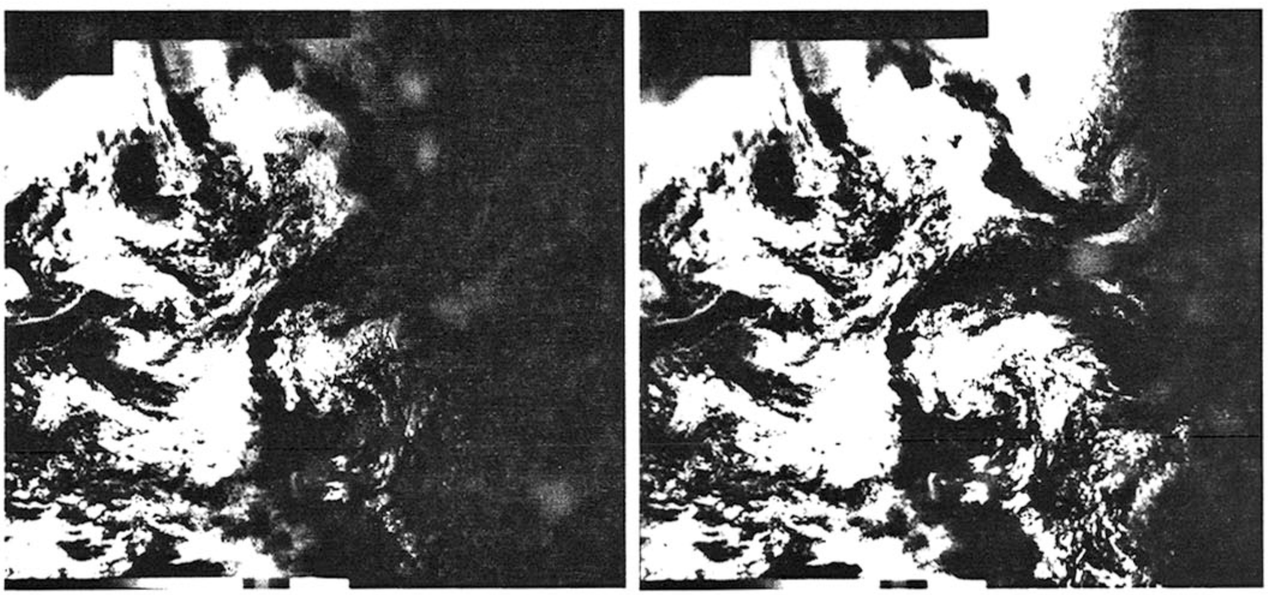


Fig. 3. Two different plots of contrast stretch parameter r_1 vs. solar elevation angle. The lower one (at low solar elevation) is used to properly compensate for land surface brightness changes in local-scale satellite images. The other works better on large-scale images where both land and ocean are present.

Figure 3 shows two different curves of the constrast stretch parameter, r_1, versus solar elevation angle. The lower curve properly compensates for land surface brightness changes in local-scale satellite images predominantly showing land. In generating this curve, weight w in equation (1) varies from 30 at high solar elevation to 20 at low elevation. The upper curve (where $w = 18$) performs better on large-scale images that include both land and ocean. Oceanic areas tend to darken less rapidly with lower sun angles, hence less stretching is needed and r_1 becomes numerically greater.

The algorithm is efficient as evidenced by a 2 second run time for a 512 by 512 satellite image on a VAX 6400 computer.



(a) (b)

Fig. 4 Examples of a GOES-W visible satellite image, (a) before, and (b) after normalization. The area covered is the United States, much of Canada, and adjoining portions of the Atlantic and Pacific oceans. The image was acquired on 6 September 1991 0000 UTC.

3. EXAMPLE

Figures 4a and b illustrate a visible satellite image acquired from GOES-W before and after photometric correction. The 0000 UTC 6 September 1991 image shows the United States, much of Canada, and adjoining portions of the Atlantic and Pacific oceans. The terminator lies roughly north-south across the eastern quarter of the image. In Fig. 4a, much of the image in the central United States appears dark because of the low sun angle. In Fig. 4b, most of this area has been restored to full brightness. A cyclonic storm is now visible in northeastern Canada (upper right part of image). Cloud details are visible right up to the terminator. The normalization is especially pleasing to observe when the images are animated in time; one can track a cloud feature in the visible imagery throughout all the daylight hours without noticeable changes in brightness.

4. CONCLUSION

The photometric correction given to visible images of the United States has been tested on meteorological workstations at FSL and at the Weather Forecast Office in Denver, Colorado, for approximately one year. The results subjectively appear much improved over uncorrected images. Cloud details become easy to see right up to the terminator. The images have an overall pleasing appearance when animated, as the distraction of brightness variations as the loop progresses is virtually eliminated. One minor drawback is that vertically developed cloud edges such as cumulonimbus may look too bright near the terminator; however, this is a very localized situation.