Remote Sensing Brief

L. Wald
J. M. Monget
Centre de Télédétection et d'Analyse des Milieux Naturels
Ecole Nationale Supérieure des Mines de Paris
Sophia Antipolis, 06565 Valbonne, France

Reflectance Contrast Observed by Landsat between a Calm and a Rough Sea

A model is used to predict changes in reflection coefficient as a function of wind speed.

It is well known that changes in sea-state induce changes in sea reflection coefficient. It has been demonstrated that such changes can be measured on Landsat imagery (Maul and Gordon, 1975; Wald and Monget, 1982). The scope of this note is to quantify these changes and especially to estimate to what extent the contrast in reflectance between a calm and a rough sea can be observed on Landsat imagery.

The changes in sea reflection coefficient versus wind speeds are well described by the model of Cox and Munk (1954). For a given wind speed, this model predicts the frequency distribution of the occurrence of the wave slopes, which are responsible for the direct sunlight reflection.

This model was used by Plass *et al.* (1975) in a more complex atmosphere-ocean system. In particular, they studied the influence of sea-surface waves on the upward radiance measured at the top of the atmosphere and just above the ocean surface as well as the downward radiance just below the ocean surface and deeper down into the ocean. Their computations were made at wavelengths of 460 and 700 nm. They pointed out that the difference in the radiance curves computed for wind speeds of 5 and 10 m/s is greater in the red wavelength rather than in the blue. This result suggests that it may be possible to measure changes in the sea-state from satellite at wavelengths greater than 700 nm. In addition, the upwelled radiance at lower wavelengths is very sensitive to the suspended materials within the upper layer of the sea. A change in the observed reflectance in the blue wave-lengths can be induced either by a change in sea-state or by a change in sea-water content. The near infra-red spectral band is certainly a simpler tool for sea-state studies.

Wald and Monget (1982) do not take into account atmosphere, but they consider the appearance of foam for high wind speeds in their calculations of the glitter reflectance. The contribution of diffuse skylight in total glitter reflectance is neglected, because it only amounts to 1 percent of the sun glitter reflectance. Their model is a function of the zenithal and azimuthal angles of both

Table 1. Estimates of the Period of Contrast Observations by Landsat, for Various Latitudes. Atmospheric Absorption is Assumed to be 30 Percent

LATITUDE	25° N	35° N	45° N	55° N
Mean local time	9 h 57 m	10 h 06 m	10 h 20 m	10 h 33 m
Range of solar zenith angles throughout the year	57°–27.9°	64.7°–27.9°	72.0°–29.7°	80.5°–35.5°
Range of solar azimuth angles	147°–90°	152°–106°	158°–127°	162°–143°
Period of contrast observation (atmospheric absorption of 30%)	end January–mid December	mid February–November	March–October	April–mid September
Number of days in this period	325	265	220	165

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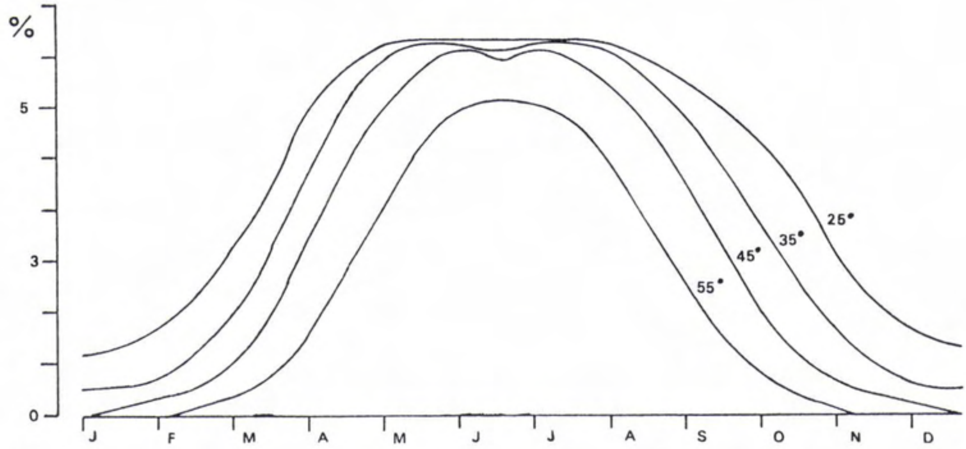

FIG. 1. Reflectance contrast observed on Landsat imagery for a non-absorbing atmosphere throughout the year for various latitudes: 25° N, 35° N, 45° N, and 55° N. See text for explanation.

sun and satellite, and the authors compute the glitter reflectance for the Landsat MSS band 7 channel (800-1100 nm) year round. They point out that the signal induced by sea-state variations and observed from a near-polar orbiting satellite depends on the period of the year. This signal is minimum during late autumn and winter and maximum during June.

Because the signal reflected by the sea surface is very weak, whatever the sea state is, one can ask if Landsat is able to discriminate between a rough sea and a calm one. Thus the question is: what are the conditions required by Landsat to detect a contrast between a rough sea and a calm sea?

This question is of interest for oil spill detection because oil reduces sea-state and the reflection coefficient of thin films in the near infrared can be compared to the sea water reflectance. This is of course a rather crude approximation and the authors are fully aware of the complexities of oil spill signatures in general.

We have used the tabulations of Wald and Monget (1982) in order to estimate the contrast in reflectance between a rough sea (wind speed of 14 m/s) and a calm sea (wind speed of 5 m/s). This has been done for the various observational geometries experienced by Landsat throughout the year, and for the latitudes 25° N, 35° N, 45° N, and 55° N. All these conditions are summarized in Table 1 and the resulting graphs are shown in Figure 1.

One may point out that the difference in reflectance between a rough and a calm sea is always positive in these cases of observation. Thus, a rough sea will always appear brighter in Landsat MSS band 7 imagery than will a calm sea.

At satellite altitude, glitter reflectance values are to be decreased typically by 30 percent, due to atmospheric absorption. Knowing that the reflectance resolution of the MSS band 7 is about 1 percent, one can now estimate the periods in the year when the contrast can be detected by Landsat. From Figure 1, one sees that Landsat imagery can discriminate between rough and calm sea-states from the end of January to mid-December for the latitude 25° N, from mid-February to November for 35° N, from March to October for 45° N, and from April to mid-September for 55° N. It is only within this framework that Landsat can be usefully considered for oil pollution monitoring.

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