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SATELLITE-DERIVED GREEN VEGETATION FRACTION FOR THE USE IN NUMERICAL WEATHER PREDICTION MODELS

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ABSTRACT

A simple procedure to derive areal fraction of green vegetation, f_g, from normalized difference vegetation index (*NDVI*) data was used to produce global monthly f_g $(0.15°)^2$-resolution maps, which are now being incorporated in the National Centers for Environmental Prediction (NCEP) regional and global models. Assuming that the vegetated part of the pixel is covered by dense vegetation (i.e., its leaf area index is high), we calculate $f_g=(NDVI-NDVI_o)/(NDVI_\infty-NDVI_o)$, where $NDVI_o$ and $NDVI_\infty$ are specified as the lower and upper 5% of the global *NDVI* distribution for the whole year and in this study are assumed independent of vegetation/soil type. Preliminary tests indicate that the incorporation of the NDVI-derived green vegetation fraction, instead of the previously prescribed values, leads to improvement in modeling surface fluxes.

INTRODUCTION

Modern land surface parameterizations (LSP) in numerical weather prediction and general circulation models require specification of vegetation characteristics, depending on two basic parameters -- vegetation type and amount (see e.g. reviews by Avissar and Verstraete, 1990; Koster and Suarez, 1992; Wood et al., 1992). Vegetation type is usually prescribed from the available global vegetation maps (based on ground observations), whereas vegetation amount is parameterized using the leaf area index and the fractional area of the vegetation occupying each model grid point. The *green* vegetation, represented by its fraction, f_g, within the grid and by the number of vegetation layers, that is the *green* leaf area index, L_g, control the evapotranspiration processes at the surface-air interface*. Thus, the evapotranspiration schemes used in weather and climate models account for the vegetation amount through f_g and L_g.

Since global/seasonal distributions of f_g and L_g are unknown, rather arbitrary tabulated values have been often used based on ground observations over different vegetation types. If at all possible, the only way to specify these parameters globally is from space. Much effort has been invested, particularly, in developing methods to retrieve f_g and L_g from satellite observed vegetation indices based on reflectance measurements from different sensors including the Advanced Very High Resolution Radiometer (AVHRR) onboard NOAA polar orbiting satellites. For AVHRR, analysis has been performed mostly on vegetation indices, including the normalized difference vegetation index $NDVI=(\rho_2-\rho_1)/(\rho_2+\rho_1)$, where ρ_1 and ρ_2 are the visible and near-IR reflectances, respectively, derived from its channels 1 (0.63 μm) and 2 (0.85 μm) (e.g., Kerr, 1992; Price, 1992; Gillies and Carlson, 1995; Wittich and Hansing, 1995; Sellers et al., 1996).

Improved LSPs, which account for vegetation using f_g and L_g, are being tested in the NCEP's operational regional (Eta) and global medium range forecast (MRF) models (Chen et al., 1995; Pan, personal communication). These new LSPs have shown sensitivity of the predicted fluxes to the above vegetation parameters, hence the need of more realistic specification of their spatio-temporal variability over the globe.

* Stems and dead vegetation contribute to the *total* vegetation cover, f, and *total* leaf area index, L, that are responsible for radiative, heat and momentum transfers from the vegetation to the atmosphere as well as the evaporation of the intercepted water. Photosynthesis is controlled by f_g and L_g. This study concentrates on the evapotranspiration and does not explore other questions.

MODELING AT-SENSOR SIGNAL

In cloud-free conditions over land, at-sensor satellite signal is a net result of the reflection, scattering, emission and absorption at the surface and in the atmosphere. The surface signal, in turn, is an average of the signals from green vegetation, soil, dead vegetation, and shadows within the radiometer field-of-view (FOV). Thus, in addition to the atmospheric effects, the NDVI measurement is an unresolved combination of: 1) the green vegetation relative areal extent, represented by f_g; 2) green vegetation vertical density, characterized by L_g, which is equivalent to the number of the green leaf layers; 3) geometric structure, depending mostly upon vegetation type (and to some extent upon its state), characterized by leaf angle distribution; 4) plant "greenness", characterized by its pigment chemistry (chlorophyll concentration) and its physiology (mesophyll); and 5) the properties of the non-green portion, i.e. soil, stems and dead vegetation. Let us assume that there is no spatial variability in soil moisture and that all green vegetation within a map cell has the same radiative properties and the same "greenness". Also, assume that dead vegetation and soil are indistinguishable, and shadows and atmospheric effects are negligible. Then, based on previous studies (e.g., Baret and Guyot, 1991), the observed *NDVI* can be approximated as

$$NDVI = f_g \cdot [NDVI_0 + (NDVI_\infty - NDVI_0) \cdot exp(-k \cdot L_g)] + (1-f_g) \cdot NDVI_0 \quad (1)$$

The term in the brackets describes the signal $NDVI_g$ from pixel's vegetated part, covering the fractional area f_g of that pixel uniformly with L_g layers of vegetation; the parameters $NDVI_0$ and $NDVI_\infty$ describe the signals from bare soil ($L_g \to 0$) and dense green vegetation ($L_g \to \infty$), respectively, and for this study are assumed independent of soil/vegetation type. The above equation represents a special case of a more general situation with a nonuniform vegetated part, when f_g and L_g can be presented as an integral over mosaic "tiles" (Avissar 1992) shown in Figure 1 (top).

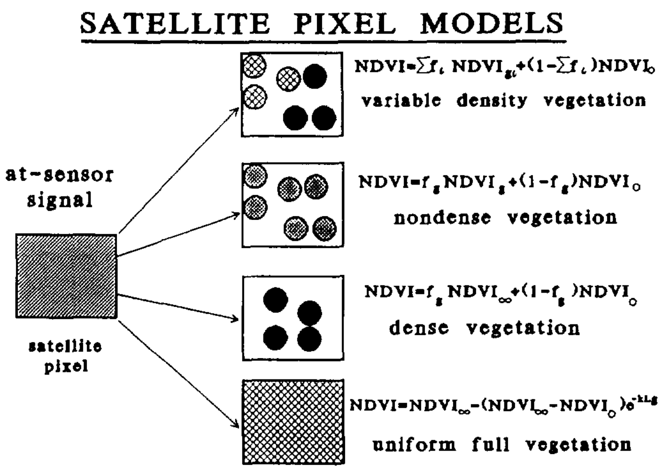

Fig. 1. Different models of forming an at-satellite NDVI signal.

Figure 1 illustrates the fact that the same at-sensor signal from a single satellite pixel can be produced by a uniformly distributed vegetation of a certain density, L_g (bottom panel), or by a patchy structure, with different combinations of density, L_g, and areal fraction, f_g (first three). The general case (top) is simplified when L_g is spatially invariant within the vegetated part of the patchy pixel (L_g=const) (second panel from the top), and is further reduced to a simpler case when the vegetation is highly dense, i.e. $L_g \to \infty$ (third panel). The respective models are also shown. We stress that all four situations may produce the *same* at-sensor signal.

The above considerations show that one *NDVI* measurement does not allow simultaneous retrieval of the green leaf area index, L_g, and the fractional vegetation area, f_g. For those working in atmospheric science, this situation can be compared to remote sensing of clouds when one faces a similar ambiguity of a combined effect of cloud optical thickness (analogue of kL_g, where k is the extinction coefficient), and its fractional cover (analogue of f_g). Thus, the same observed signal (in both vegetation and cloud remote sensing) can result from different combinations of the optical density and fractional coverage. This complexity is discussed by Price (1992).

RESULTS

Despite the aforementioned problems, satellite-derived vegetation indices have been used in several model studies. Most of them have been restricted to mesoscale modeling, Gillies and Carlson (1995) being among the latest one. Recently, the available global satellite datasets made it possible to derive seasonal distribution of vegetation cover over the global land surface. To our knowledge, there have been only two such initiatives (Sellers et al., 1996; Chase et al., 1996), and both were directed at deriving L_g. Yet, no global data on f_g have been produced so far, but is needed by those LSPs that use a mosaic-grid approach, i.e. evapotranspiration is calculated as a weighted average between soil evaporation and evapotranspiration from vegetation, f_g being the weighting factor.

In this study, f_g was derived using a mosaic-pixel approach assuming dense vegetation for the vegetated part of the pixel ($L_g=\infty$, third panel from top in Figure 1) (cf. with Kerr et al., 1992; Gillies and Carlson, 1995; Wittich and Hansing, 1995):

$$f_g=(NDVI-NDVI_0)/(NDVI_\infty-NDVI_0) \qquad (2)$$

Monthly maps of f_g were produced from the 5-year *NDVI* climatology (Gutman et al., 1995) with $(0.15°)^2$ resolution. Presently, they are being incorporated in NCEP models and preliminary results are encouraging (Chen et al. 1995). Practically, the approximation of "dense vegetation" means that the value of L_g should be high enough to allow neglecting the exponent term in (1) ($exp(-kL_g)\approx 0$). The saturation threshold depends not only on L_g, but on the vegetation type, characterized by the extinction coefficient, k. Figure 2 shows that the error in f_g resulting from the "dense vegetation" assumption is multiplicative: it is negligible when $f_g<<1$, and is well within $\delta f_g\approx 0.1$ when $L_g>2$ for $f_g\sim 1$ (cf. with Carlson et al. (1990) who show that for ground observations the threshold for L_g ranges between 2 and 6).

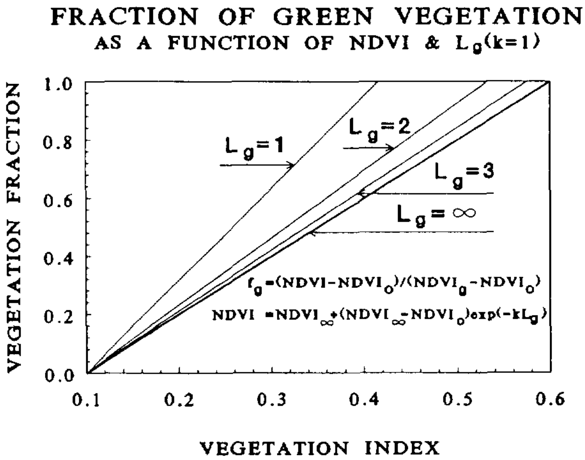

Fig.2. Sensitivity of derived fractional vegetation cover to the variability in L_g.

Thus, most of the uncertainty in the derivation of f_g is due to the unknown L_g and the uncertainties in the *NDVI* values, including asymptotic parameters $NDVI_0$ and $NDVI_\infty$, with errors due to residual cloud contamination and uncorrected atmospheric/angular effects. Several directions towards improvement of f_g are: 1) specification of L_g using independent measurements; 2) development of the "uniformity" maps, which would identify whether the uniform- or mosaic-pixel approach is more appropriate, using high resolution data; 3) development of better quality NDVI datasets with atmospheric/angular corrections applied. Some of the above issues are in progress, therefore we can anticipate that the input fields of f_g and L_g for numerical models will gradually become more accurate. At this stage, it is important to explore the needed accuracy of these variables to make it consistent with the accuracy of the models that use them. Thus, more sensitivity studies are needed which would investigate the impact of the above uncertainties on the model simulated fluxes.

Note that only two vegetation variables are discussed in this article. However, the minimum stomatal resistance, surface roughness and albedo are also of great importance in characterizing surface fluxes. These parameters depend mainly upon surface type, whereas the latter two vary also with the surface state seasonally and interannually. Among these variables, surface albedo has the most potential to be derived from AVHRR globally as a function of time. Surface roughness is sometimes parameterized through NDVI or, perhaps, can be derived from other sensors. On the other hand, vegetation classifications and vegetation type maps are rapidly improving using multispectral/multitemporal approaches.

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