ATMET Technical Note

Number 1

Modifications for the Transition From LEAF-2 to LEAF-3

Prepared by:

ATMET, LLC
PO Box 19195
Boulder, Colorado 80308-2195

Robert L. Walko
Craig J. Tremback

October 2005

Table of Contents

1 Modification of LEAF to Use NDVI

The Land Ecosystem-Atmosphere Feedback model (LEAF) is a submodel of RAMS that evaluates energy and water budgets at the Earth's surface and their interactions with the atmosphere. LEAF is a representation of surface features including vegetation, soil, lakes and oceans, and snow cover and their influence on each other and on the atmosphere. LEAF includes prognostic equations for soil temperature and moisture for multiple layers, vegetation temperature and surface water including dew and intercepted rainfall, snow cover mass and thermal energy for multiple layers, and temperature and water vapor mixing ratio of canopy air. Exchange terms in these prognostic equations include turbulent exchange, heat conduction and water diffusion and percolation in the snow cover and soil, longwave and shortwave radiative transfer, transpiration, and precipitation.

A special feature of LEAF is its ability to represent subgrid scale variations in surface characteristics, such as vegetation type, terrain slope, soil type and moisture, or bodies of water, which often vary considerably over short horizontal distances. This is done by subdividing each surface grid cell into multiple subgrid patches, where each patch consists of its own multiple snow cover and soil layers, vegetation, and canopy air (except for water surface patches), and prognostic variables are evaluated for all these components by patch. In this statistical dynamical approach, all patches interact with the same overlying column of air, each according to its fractional area of coverage.

LEAF has evolved along with RAMS, and the current standard version, LEAF-2, has been in use for a few years (Walko, et.al., 2000). The practice in LEAF-2 for obtaining the essential vegetation characteristics of leaf area index (LAI), fractional coverage, albedo, and roughness height, has been to specify them according to vegetation class. This was further modified with an additional seasonal dependence for LAI and fractional coverage whose amplitude is likewise a function of vegetation class and latitude. Recent improvements in the representation of these vegetation parameters, which have been implemented in the SiB2 biophysics model (Sellers, et. al., 1996), were recently adopted in LEAF as well, and comprise the first stage of developing a newer version called LEAF-3. These improvements are based on independent satellite observations of vegetation greenness, represented by NDVI. The NDVI value provides valuable information on the spatial and temporal variability of greenness, which is absent from the simple model used in LEAF-2.

Technical Aspects

Two remotely sensed vegetation indices are derived from visible and near-infrared (NIR) channel reflectances (0.58 to 0.68 um and 0.73 to 1.10 um):

normalized difference vegetation index (NDVI):

$$NDVI = \frac{a_n - a_v}{a_n + a_v}$$

simple ratio (SR):

$$SR = \frac{1 + NDVI}{1 - NDVI}$$

where a_v and a_n are hemispheric reflectances for visible and NIR wavelength intervals. Figure 1-1 shows the relationship between NDVI and Simple Ratio (SR).

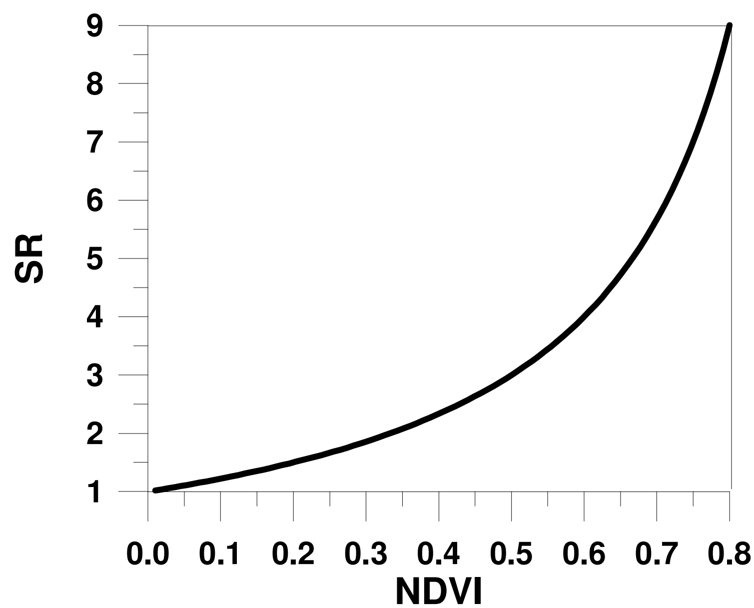

Figure 1-1. Relationship between normalized difference vegetation index, NDVI, and simple ratio, SR.

Calculation of FPAR from NDVI Data

The relation between FPAR and SR is nearly linear (Sellers et al., 1992), so we need to determine two known points. We assumed that the value of the 98th percentile of NDVI distribution represents vegetation at full cover and maximum activity, with FPAR values close to unity. We also assumed that the fifth percentile value represents no vegetation activity and an FPAR value of 0.001. The relation between FPAR and SR is then given by:

$$FPAR = FPAR_{\min} + (SR - SR_{i,\min}) \frac{(FPAR_{\max} - FPAR_{\min})}{SR_{i,\max} - SR_{i,\min}}$$

where the maximum ($FPAR_{max}$ = 0.950) and minimum ($FPAR_{min}$ = 0.001) values of FPAR are independent of vegetation type; $SR_{i,max}$ and $SR_{i,min}$ are the SR value corresponding to 98th and 5th percentile of the NDVI data population for a given vegetation type.

Calculation of Vegetation Parameters

Green leaf area index, L_G, is estimated directly from FPAR. The relationship between FPAR and L_G, is dependent on F_{cl}, the vegetation clumping factor.

$$L_G = L_{G,\max}\left[F_{cl}\frac{FPAR}{FPAR_{\max}} + \left(1 - F_{cl}\right)\frac{\log(1 - FPAR)}{\log(1 - FPAR_{\max})}\right]$$

Vegetation fractional area coverage is computed by

$$F_V = F_{V_{MAX}}\left(1 - e^{-E_V L_T}\right)$$

The albedo of the vegetation components and the vegetation roughness length are computed by

$$\alpha_V = \alpha_G F_G + \alpha_B\left(1 - F_G\right)$$

$$z_0 = H_V\left(1 - b_z e^{-h_z L_T}\right)$$

The following parameters are defined as a function of vegetation class only

- $L_{V_{MAX}}$ - maximum green leaf area index
- F_{cl} - vegetation clumping factor
- $F_{V_{MAX}}$ - maximum fractional coverage
- α_G - green vegetation albedo
- α_B - brown vegetation albedo
- $FPAR_{\max}$ - maximum FPAR value
- H_V - vegetation height
- L_D - dead matter area index
- L_S - stem matter area index

and b_z, h_z ,, and E_V are constant for all vegetation classes.

The quantities total leaf area index, L_T, and green fraction, F_G, depend in part on the observed NDVI value, and are given by

$$L_T = L_G + L_D + L_S$$

$$F_G = {L_G}/{L_T}$$

where L_D is a dead matter area index corresponding to dead matter and L_S corresponds to stems and other non-green supportive tissues.

The NDVI dataset has been obtained and prepared for RAMS with monthly values defined over the globe at 1/120 degree spacing of latitude and longitude. NDVI values in the equation for SR above are interpolated in time and space from the NDVI dataset. In order to implement these equations into LEAF-3, it was necessary to modify the set of vegetation classes represented in LEAF, as well as some of the biophysical parameters standard to each class.

This process is described in the following section, which describes the main changes between LEAF-2 and LEAF-3.

2 Landuse Class and Parameter Changes

This section describes steps that were taken to develop LEAF-3 landuse classes and their associated land surface parameters (LSPs).

We began with the LEAF-2 classes, which were comprised of BATS and LDAS classes. Table 2-1and Table 2-2 are the LSP tables from LEAF-2 as it was in version 5.0 of RAMS:

Table 2-1. BATS LSPs.

albedo	emiss	lai	d lai	v frac	dv frac	z0	zdisp	root dep	LEAF-2 CLASS # AND DESCRIPTION
.14	.99	0.0	0.0	.00	.00	.00	0.1	.0	0 Ocean
.14	.99	0.0	0.0	.00	.00	.00	0.1	.0	1 Lakes rivers streams (inland water)
.40	.82	0.0	0.0	.00	.00	.01	0.1	.0	2 Ice cap/glacier
.10	.97	6.0	1.0	.80	.10	1.00	15.0	1.5	3 Evergreen needleleaf tree
.10	.95	6.0	5.0	.80	.30	1.00	20.0	1.5	4 Deciduous needleleaf tree
.20	.95	6.0	5.0	.80	.30	.80	15.0	2.0	5 Deciduous broadleaf tree
.15	.95	6.0	1.0	.90	.50	2.00	20.0	1.5	6 Evergreen broadleaf tree
.26	.96	2.0	1.5	.80	.10	.02	.2	1.0	7 Short grass
.16	.96	6.0	5.5	.80	.30	.10	1.0	1.0	8 Tall grass
.30	.86	0.0	0.0	.00	.00	.05	.1	1.0	9 Desert
.25	.96	6.0	5.5	.10	.10	.10	.5	1.0	10 Semi-desert
.20	.95	6.0	5.5	.60	.20	.04	.1	1.0	11 Tundra
.10	.97	6.0	1.0	.80	.20	.10	1.0	1.0	12 Evergreen shrub
.20	.97	6.0	5.0	.80	.30	.10	1.0	1.0	13 Deciduous shrub
.15	.96	6.0	3.0	.80	.20	.80	20.0	2.0	14 Mixed woodland
.20	.95	6.0	5.5	.85	.60	.06	.7	1.0	15 Crop/mixed farming
.18	.95	6.0	5.5	.80	.60	.06	.7	1.0	16 Irrigated crop
.12	.98	6.0	5.5	.80	.40	.03	1.0	1.0	17 Bog or marsh

Table 2-2. LDAS LSPs, but emissivity based on above

albedo	emiss	lai	d lai	v frac	dv frac	z0	z disp	root dep	LEAF-2 CLASS # AND DESCRIPTION
.06	.97	6.0	1.0	.80	.10	.98	10.2	1.0	18 Evergreen needleleaf forest
.08	.95	6.0	1.0	.90	.50	2.21	20.7	1.2	19 Evergreen broadleaf forest
.06	.95	6.0	5.0	.80	.30	.92	9.2	1.0	20 Deciduous needleleaf forest
.09	.95	6.0	5.0	.80	.30	.91	7.2	1.2	21 Deciduous broadleaf forest
.07	.96	6.0	3.1	.80	.21	.87	6.5	1.1	22 Mixed cover
.08	.96	5.7	2.3	.80	.17	.83	7.4	1.0	23 Woodland
.18	.96	5.0	4.0	.80	.20	.51	3.6	1.0	24 Wooded grassland
.10	.97	5.1	3.7	.63	.19	.14	1.4	.7	25 Closed shrubland
.12	.97	6.0	5.4	.22	.12	.08	.2	.6	26 Open shrubland
.11	.96	2.6	2.0	.73	.11	.04	.2	.7	27 Grassland
.10	.95	6.0	5.2	.84	.55	.11	.2	.7	28 Cropland
.16	.86	0.7	0.6	.07	.03	.05	.2	.5	29 Bare ground
.15	.90	4.8	3.6	.74	.31	.80	1.1	.8	30 Urban and built up
.09	.97	4.6	2.6	.80	.19	.51	3.6	.9	24y Wooded grassland
.10	.90	4.8	3.6	.74	.31	.23	1.1	.8	30y Urban and built up

Classes “24y” and “30y” were the originals and were replaced by 24 and 30 with larger albedos because RAMS currently uses broadband solar radiative fluxes and does not separate visible and near IR as does SiB2. Except for classes 24 and 30, class numbers above 17 were not actually used in LEAF-2. LDAS albedo values listed above apply to the visible part of the spectrum only.

The first change to numerical algorithms in developing LEAF-3 from LEAF-2 was to input NDVI and use it, as in SiB2, to compute SR, FPAR, green leaf and total area indices (GLAI and TAI), and roughness height Z0. In addition, the dependence of vegetation albedo and transmissivity on GLAI and TAI, as used described in SiB2, is combined with the LEAF-2 formulation to obtain expressions for albedo and vegetation fractional cover as a function of GLAI, TAI, and LEAF-3 class.

These changes eliminate the need for dlai, dvfrac, and zdisp from Table 2-1 and Table 2-2, and at the same time add the need for dead-vegetation albedo, maximum simple ratio, stem/branch area index SAI, dead leaf area index, fractional clumping, and vegetation height. In order to construct a table of vegetation classes and LSP values for LEAF-3, we carried out a series of development steps beginning with Table 2-1 and Table 2-2. We first expanded Table 2-1 and Table 2-2 by adding the 9 SiB2 categories and selected LSP values and in addition added and modified LSP values of the BATS classes. The vegetation cover fraction V in the SiB2 classes is identified with the vegetation fractional coverage vfrac of the BATS and LDAS classes. LEAF-2 displacement heights were converted to full canopy heights by dividing by 0.63, the assumed ratio in LEAF-2. SAI values listed for standard BATS classes, which were not used in LEAF-2, were added to the provisional table. LEAF-2 albedos from BATS were updated to be 50-50 averages of visible and near IR values, which caused an increase in most of the values. LDAS and SiB2 albedos were entered in the table as weighted averages between visible and near IR, with a 2/3 weight given to the visible values and a 1/3 weight given to the near IR values. This weighting gives lower values than a 50-50 weighting and was done partly because the SiB2 and LDAS albedos are generally higher than the BATS values. Also, I believe that near IR is attenuated more than visible by the atmosphere, so there is more visible at the surface (visible is 45% and near IR is 46% at the top of the atmosphere), but I need to check on this. In spite of what any model may indicate for LAI and SAI values over water, icecap, or desert, they are all set to 0 here because LEAF-3 will assume no vegetation in these areas. The full provisional Table 2-3, Table 2-4, and Table 2-5 at this stage were as follows, with strings of letters added as place holders where values are not specifically defined for a given BATS, SiB2, or LDAS class (note that for BATS and LDAS classes, the glai_max value is given whereas for SiB2 classes, the tai_max value is given):

Table 2-3. BATS LSPs (glai_max).

albv_ live	albv_ dead	emisv	sr_m ax	tai_ max	sai	frac_cl ump	vfrac	rootd ep	hveg	LEAF-2 CLASS # AND DESCRIPTION
.00	alvd	.99	srmx	0.0	0.0	fcl	.00	0.0	.0	0 Ocean
.00	alvd	.99	srmx	0.0	0.0	fcl	.00	0.0	.0	1 Lakes, rivers, streams
.00	alvd	.82	srmx	0.0	0.0	fcl	.00	0.0	.0	2 Ice cap/glacier
.14	alvd	.97	srmx	6.0	2.0	fcl	.80	24.0	1.5	3 Evergreen needleleaf tree
.14	alvd	.95	srmx	6.0	2.0	fcl	.80	32.0	1.5	4 Deciduous needleleaf tree
.18	alvd	.95	srmx	6.0	2.0	fcl	.80	24.0	2.0	5 Deciduous broadleaf tree
.12	alvd	.95	srmx	6.0	2.0	fcl	.90	32.0	1.5	6 Evergreen broadleaf tree
.20	alvd	.96	srmx	2.0	4.0	fcl	.80	.3	1.0	7 Short grass
.19	alvd	.96	srmx	6.0	2.0	fcl	.80	1.6	1.0	8 Tall grass
.30	alvd	.86	srmx	0.0	0.5	fcl	.00	.2	1.0	9 Desert
.26	alvd	.96	srmx	6.0	2.0	fcl	.10	.8	1.0	10 Semi-desert
.20	alvd	.95	srmx	6.0	0.5	fcl	.60	.2	1.0	11 Tundra
.14	alvd	.97	srmx	6.0	2.0	fcl	.80	1.6	1.0	12 Evergreen shrub
.18	alvd	.97	srmx	6.0	2.0	fcl	.80	1.6	1.0	13 Deciduous shrub
.15	alvd	.96	srmx	6.0	2.0	fcl	.80	32.0	2.0	14 Mixed woodland
.20	alvd	.95	srmx	6.0	0.5	fcl	.85	1.1	1.0	15 Crop/mixed farming
.18	alvd	.95	srmx	6.0	2.0	fcl	.80	1.1	1.0	16 Irrigated crop
.12	alvd	.98	srmx	6.0	2.0	fcl	.80	1.6	1.0	17 Bog or marsh

Table 2-4. LDAS LSPs, BATS emis (glai_max).

albv_ live	albv_ dead	emisv	sr_ max	tai_ max	sai	frac_ clump	vfrac	root dep	hveg	LEAF-2 CLASS # AND DESCRIPTION
.14	.24	.97	rmx	6.0	sai	fcl	.80	17.0	1.0	18 Evergreen needleleaf forest
.17	.24	.95	srmx	6.0	sai	fcl	.90	35.0	1.2	19 Evergreen broadleaf forest

.14	.24	.95	srmx	6.0	sai	fcl	.80	15.5	1.0	20 Deciduous needleleaf forest
.19	.24	.95	srmx	6.0	sai	fcl	.80	20.0	1.2	21 Deciduous broadleaf forest
.16	.24	.96	srmx	6.0	sai	fcl	.80	19.2	1.1	22 Mixed cover
.17	.27	.96	srmx	5.7	sai	fcl	.80	14.3	1.0	23 Woodland (decid and evg bl?)
.20	.36	.96	srmx	5.0	sai	fcl	.80	7.0	1.0	24 Wooded grassland
.20	.29	.97	srmx	5.1	sai	fcl	.63	.6	.7	25 Closed shrubland
.22	.27	.97	srmx	6.0	sai	fcl	.22	.5	.6	26 Open shrubland
.23	.43	.96	srmx	2.6	sai	fcl	.73	.6	.7	27 Grassland
.20	.40	.95	srmx	6.0	sai	fcl	.84	.6	.7	28 Cropland
.21	.12	.86	srmx	0.7	sai	fcl	.07	.2	.5	29 Bare ground
.20	.36	.90	srmx	3.6	sai	fcl	.74	6.0	.8	30 Urban and built up

Table 2-5. SiB2 LSP's (tai_max).

albv_ live	albv_ dead	emisv	sr_m ax	tai_ max	sai	frac_ clump	vfrac	root dep	hveg	LEAF-2 CLASS # AND DESCRIPTION
.22	.24	emv	4.141	7.0	.08	.0	1.0	35.0	1.5	31 Broadleaf evergreen trees
.22	.24	emv	6.168	7.0	.08	.0	1.0	20.0	1.5	32 Broadleaf deciduous trees
.18	.24	emv	6.168	7.5	.08	.5	1.0	20.0	1.5	33 Broadleaf and needleleaf trees
.16	.24	emv	5.431	8.0	.08	1.0	1.0	17.0	1.5	34 Needleleaf evergreen trees
.16	.24	emv	5.431	8.0	.08	1.0	1.0	17.0	1.5	35 Needleleaf deciduous trees
.26	.43	emv	5.135	5.0	.05	.0	1.0	1.0	1.0	36 C4 grassland + [Sv- tv-b soil]
.22	.24	emv	5.135	5.0	.05	1.0	.1	.5	1.0	37 Broadleaf shrubs with bare soil
.26	.43	emv	5.135	5.0	.05	.0	1.0	.6	1.0	38 Dwarf trees and shrubs
.26	.43	emv	5.135	5.0	.05	.0	1.0	1.0	1.0	39 Agriculture or C3 grassland

The set of 40 classes in Table 2-3, Table 2-4, and Table 2-5 was reduced down to 21 classes by combining obvious or apparent repeated classes or similar classes with similar LSP values. The Global Ecosystems Framework documents (Olson, 1993) with their cross referencing tables between Olson, BATS, and SiB2 were used as a guide for combining landuse classes between BATS, LDAS, and SiB2 classification schemes. These documents were also used for deciding which classes to NOT combine between BATS, LDAS, and SiB2 classifications. For example, certain Olson classes fit very well into a BATS class but not into a SiB2 class, or very well into a SiB2 class but not into a BATS class, even though the SiB2 and BATS classes are also cross-referenced to each other. In these cases, it seemed best to keep the SiB2 and BATS classes separate with distinct LSP values. LSP values, where duplicated, were taken to lie somewhere inside the full range indicated above. In cases where an LSP value was never defined for a particular class (for example, albedo of dead vegetation and maximum simple ratio are not defined for Tundra), an estimate was made based on LSP values for other classes.

Special consideration was needed in order to rectify values for glai_max and sai from BATS classes with values for tai_max and sai from SiB2 classes. The expectation should be that tai_max = glai_max + sai based on how SiB2 defines these quantities, and the fact that tai_max values in SiB2, at least for the main tree categories, are 1 or 2 greater than the glai_max values specified for these classes in BATS and LDAS is consistent with this equation. In addition, BATS defines sai values of 2 for these classes, which is also in approximate agreement, and in typical forests of these categories, a stem and branch area index of order 1 seems physically realistic. On the other hand, SiB2 gives much lower sai values of .08 for these classes. Because the SiB2 sai values are inconsistent with all other numbers and in addition seem to be too low based on physical grounds, these values will be averaged with the larger BATS values (which sometimes exceed the quantity (tai_max - glai_max) with tai_max defined in SiB2 and glai_max defined in BATS).

Another consideration regarding tai values is that in LEAF-3, they will be used to define vegetation fractional coverage, veg_frac, which represents the fraction of downward radiation that is intercepted by vegetation. In LEAF-2, veg_frac was specified independently of tai. If tai is allowed to become as low as SiB2 sai values, as in the case for deciduous trees in winter, interception would become essentially zero, which again seems unrealistic for most deciduous forests. Thus, sai values of order 1 will be used for most landuse classes with vegetation.

SiB2 values of tai_max are considerably lower for grasses, shrubs, dwarf trees, and agriculture than for trees, which seems more correct than the equality of glai_max values for these classes in BATS, so the SiB2 model is followed here. By the same reasoning, tlai_max of semi-desert and tundra, classes that are not explicitly represented in SiB2, are significantly reduced in the LEAF-3 data. The BATS sai value for short grass (4.0) is very large. This would seem to represent not ‘stem’ matter but instead dead grass, i.e., grass that was once green and therefore was represented by glai. Because LEAF-3, as SiB2, will treat stem/branch matter and dead (once green) matter separately, the sai values for short and tall grass are reduced from the BATS values. We also add two LSP quantities. The first called ‘dead fraction’, or dead_frac. This will denote the maximum amount of the maximum green lai that can be present as dead matter. This value is set relatively large for grass and much smaller for trees and shrubs. The second new LSP quantity is minimum stomatal resistance, or rcmin. It is just transferred from the dsmax data statement from subroutine canopy and inverted from maximum conductance to minimum resistance.

The following steps were taken in combining BATS, LDAS, and SiB2 classes in Table 2-3, Table 2-4, and Table 2-5:

1. Classes 18 and 34 were merged in with class 3
2. Classes 20 and 35 were merged in with class 4
3. Classes 21 and 32 were merged in with class 5

4. Classes 19 and 31 were merged in with class 6
5. Class 27 was merged in with class 7
6. Class 36 was merged in with class 8
7. Class 29 was merged in with class 9 and defined as having no vegetation
8. Class 37 was merged in with class 10.
9. Classes 25 and 26 were merged in with classes 12 and 13.
10. Classes 22 and 33 were merged in with class 14.
11. Classes 28 and 39 were merged in with class 15.
12. Class 23 was deleted because it is not particularly different from other classes and because LDAS classes are not directly referenced to Olson classes.
13. Class 38 was deleted because classes 11-13 seem to cover it.

To fill in the gaps, class 24 was renumbered to class 18 and class 30 was renumbered to class 19. Class 20 was added with the same vegetation characteristics as class 6 in order to cover Olson class 72: mangrove. This class is mapped to evergreen broadleaf trees in SiB and SiB2, but is also a persistent wetland. LEAF classes 17 and 20 will both be treated as wetlands as pertains to soil and surface water.

With the above mergers and deletions, Table 2-6 was constructed:

Table 2-6. LEAF-3 Classes

albv_green	albv_brown	emisv	sr_max	tai_max	sai	veg_clump	veg_frac	veg_ht	root dep	dead_frac	rcmin	LEAF-3 CLASS # AND DESCRIPTION
.00	.00	.00	.0	0.0	.0	.0	.00	.0	.0	.0	0.	0 Ocean
.00	.00	.00	.0	0.0	.0	.0	.00	.0	.0	.0	0.	1 Lakes, rivers, streams
.00	.00	.00	.0	0.0	.0	.0	.00	.0	.0	.0	0.	2 Icecap/glacier
.00	.00	.00	.0	0.0	.0	.0	.00	.0	.0	.0	0.	3 Desert, bare soil
.14	.24	.97	5.4	8.0	1.0	1.0	.80	20.0	1.5	.0	500.	4 Evergreen needle leaf tree
.14	.24	.95	5.4	8.0	1.0	1.0	.80	22.0	1.5	.0	500.	5 Deciduous needle leaf tree
.20	.24	.95	6.2	7.0	1.0	.0	.80	22.0	1.5	.0	500.	6 Deciduous broadleaf tree
.17	.24	.95	4.1	7.0	1.0	.0	.90	32.0	1.5	.0	500.	7 Evergreen broadleaf tree
.21	.43	.96	5.1	4.0	1.0	.0	.75	.3	.7	.7	100.	8 Short grass
.24	.43	.96	5.1	5.0	1.0	.0	.80	1.2	1.0	.7	100.	9 Tall rass
.24	.24	.96	5.1	1.0	.2	1.0	.20	.7	1.0	.0	500.	10 Semi, desert
.20	.24	.95	5.1	4.5	.5	1.0	.60	.2	1.0	.0	50.	11 Tundra
.14	.24	.97	5.1	5.5	1.0	1.0	.70	1.0	1.0	.0	500.	12 Evergreen shrub
.20	.28	.97	5.1	5.5	1.0	1.0	.70	1.0	1.0	.0	500.	13 Deciduous

												shrub
.16	.24	.96	6.2	7.0	1.0	.5	.80	22.0	1.5	.0	500.	14 Mixed woodland
.22	.40	.95	5.1	5.0	.5	.0	.85	1.0	1.0	.0	100.	15 Crop/mixed farming, C3grassland
.18	.40	.95	5.1	5.0	.5	.0	.80	1.1	1.0	.0	500.	16 Irrigated crop
.12	.43	.98	5.1	7.0	1.0	.0	.80	1.6	1.0	.0	500.	17 Bog or marsh
.20	.36	.96	5.1	6.0	1.0	.0	.80	7.0	1.0	.0	100.	18 Wooded grassland
.20	.36	.90	5.1	3.6	1.0	.0	.74	6.0	.8	.0	500.	19 Urban and builtup
.17	.24	.95	4.1	7.0	1.0	.0	.90	32.0	1.5	.0	500.	20 Wetland evergreen broadleaf tree

The cross referencing table from Olson classes to the above 21 LEAF-3 classes was developed, Table 2-7, for subroutine datp_datq. Note that subroutine datq_lsp is no longer used.

Table 2-7. Relationship of LEAF-3 classes to Olson classes

Olson	**LEAF-3**	**Olson**	**LEAF-3**	**Olson**	**LEAF-3**	**Olson**	**LEAF-3**
1	19	27	13	53	18	79	3
2	8	28	14	54	17	80	2
3	4	29	18	55	17	81	3
4	5	30	4	56	12	82	20
5	6	31	4	57	12	83	0
6	7	32	4	58	7	84	17
7	9	33	14	59	10	85	17
8	3	34	14	60	3	86	17
9	11	35	6	61	10	87	4
10	16	36	6	62	10	88	14
11	10	37	4	63	11	89	7
12	2	38	7	64	14	90	3
13	17	39	7	65	18	91	3
14	1	40	15	66	18	92	3
15	0	41	15	67	18	93	3
16	12	42	6	68	18	94	3
17	13	43	7	69	13	95	3
18	14	44	7	70	6	96	3
19	18	45	15	71	5	97	8
20	4	46	16	72	4	98	12
21	10	47	16	73	11	99	7
22	2	48	16	74	12	100	6
23	17	49	16	75	0	101	18

24	0		50	8		76	0		102	15
25	0		51	8		77	0		103	15
26	12		52	8		78	0		104	15

3 References

Sellers, P.J., 1992: Canopy reflectance, photosynthesis and transpiration. Part III: A reanalysis using enzyme kinetics-electron transport models of leaf physiology. Remote Sens. Environ., 42, 187-216.

Sellers, P.J., D.A. Randall, G.J. Collatz, J.A. Berry, C.B. Field, D.A. Dazlich, C. Zhang, G.D. Collelo, and L. Bounoua, 1996: A revised land surface parameterization (SiB2) for atmospheric GCMs. Part I: Model formulation. J. Climate, 9, 676-705.

Walko, R.L., L.E. Band, J. Baron, T.G.F. Kittel, R. Lammers, T.J. Lee, D. Ojima, R.A. Pielke, C. Taylor, C. Tague, C.J. Tremback, and P.L. Vidale, 2000: Coupled atmosphere-biophysics-hydrology models for environmental modeling. J. Appl. Meteor., 39, 931-944.