植被及多角度遥感

植被遥感模型分类

在RAMI中的几种典型场景

Homogeneous discrete

植被遥感意义及内容

意义：

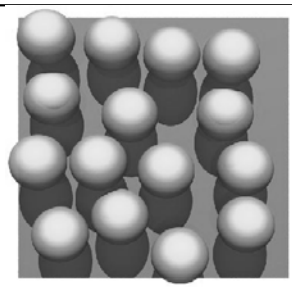
- 人类生存及发展
- 地—气能量及物质交换
- 环境保护（防止土壤侵蚀，吸收CO_2）

内容：

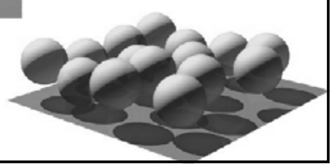
- 植被覆盖区域，划分植被类型
- 反演植被参数
- 估算与光合作用有关物理量

} 模型

植被遥感模型分类



Heterogeneous turbid



植被遥感模型分类

- **统计/经验模型**

  将反射率特征与冠层参数建立统计关系（植被指数）

  简单，适用性强，随着地面先验知识积累和观测波段、角度增多，优势减弱。

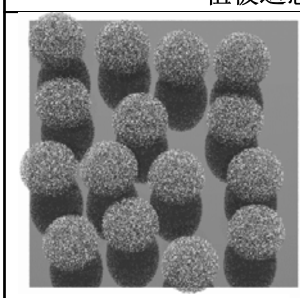
- **物理模型**

  基于辐射传输或几何光学原理

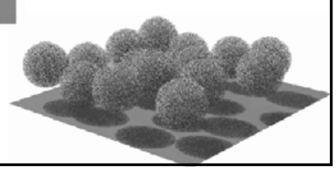
  - Homogeneous turbid （均匀、绿色气体）
  - Heterogeneous solid（不均匀实体组合，经典的GO模型）
  - Homogeneous discrete （均匀、叶片）
  - Heterogeneous turbid （不均匀、绿色气体）
  - Heterogeneous discrete （不均匀、叶片）

  RAMI(Radiation transfer Model Intercomparison)

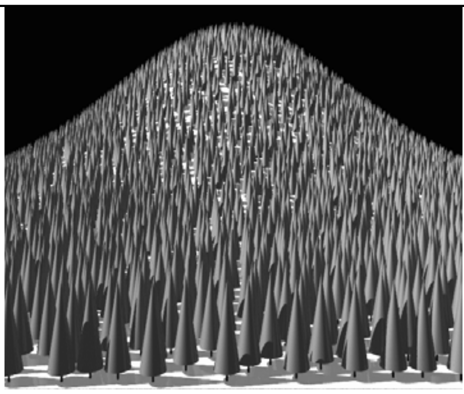
植被遥感模型分类



Heterogeneous discrete

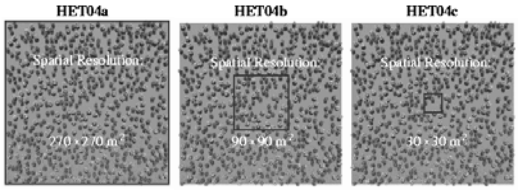


植被遥感模型分类



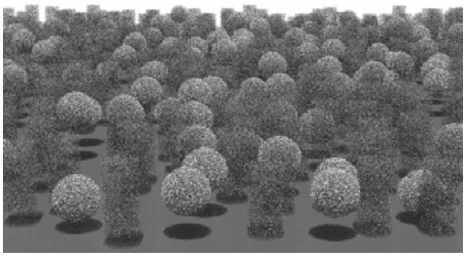
考虑地形，圆锥实体（树冠）+圆柱（树干）

植被遥感模型分类



尺度问题

植被遥感模型分类



球形+圆柱形 ➔ 模拟混合林

植被遥感模型参数

结构参数：

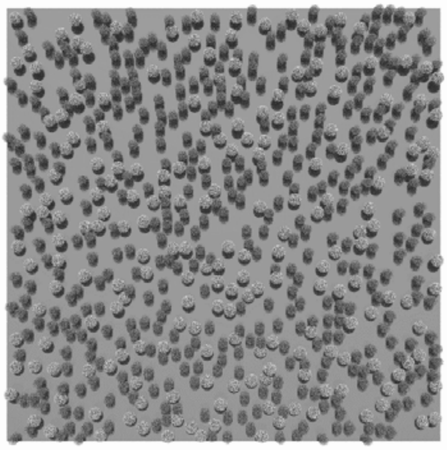
- 总的长、宽、高
- LAI(leaf area index)

  地表单位面积上方所有叶子单面面积或总面积的一半之总和。无量纲。

  LAI影响反射、透射的强度，与太阳辐射作用及遥感信号强弱相关。也决定了碳吸收和与大气间的能量交换。与农业、林业、全球变化等应用直接挂钩。
- FAVD(Foliage area volume density)

  某一高度上单位体积内叶面积的总和，单位1/m。
- LAD(Leaf Angle Distribution)

  叶面的法线方向的概率分布，通常只考虑倾角。



植被遥感模型参数

光学参数：

- 叶子反射率、透过率
- 土壤表面反射率

植被遥感原理 — 模型

建模基本步骤：

- 建立概念模型（ *Specification* ）
- 将概念模型转换为数学模型(*formulation*)
- 生成计算机代码，在计算机中运行 (*Implementation*)
- 通过数据显示、敏感性分析、误差分析等对模型进行评价(*Evaluation*)

The model is gradually extended so that its output conforms more closely to empirical observations of real vegetation canopies.

It is also follows the principal of simplicity sometimes referred to as ‘Occam’s Razor’ or, less formally, as Keep It Simple Stupid (KISS)!

植被遥感原理 — 模型

模型建立

- Assumptions of the conceptual model:
  - 不同的表面(比如植被，土壤，水，雪，冰) 反射不同的太阳辐射(反射率是地表类型的函数)。
  - 地表覆盖为不同物质的混合体。
  - 被反射的太阳辐射是研究区域不同地表类型相对面积比的函数。
- Note that all the assumptions are testable
- For the moment, however, we will simply accept them

植被遥感原理 — 模型

植被建模基础概念

- 太阳发射电磁辐射
- 忽略大气效应，到达地表的太阳辐射可能被吸收或反射回空中。
- 反射及吸收的平衡是一个控制地球气候的重要因子
- 吸收部分被作为热辐射再次发射，使地球大气的底层变暖。

植被遥感原理 — 模型

Why state the assumptions?

Stating the assumptions explicitly achieves a number of things, including:

1 We clarify in our own minds the fundamental conceptual basis of our model(让自己清楚)

2 We provide sufficient information for potential users of the model to（让别人清楚）

i) understand its scope and limitations,

ii) challenge its underlying assumptions, and perhaps

iii) derive an improved model in the future

植被遥感原理 — 模型

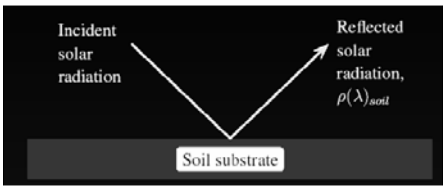
植被建模基础概念

- 地球表面由不同的物质覆盖 (比如植被，土壤，水，雪，冰), 每种物质反射不同的太阳辐射。
- 一个给定的表面所反射的太阳辐射(*reflectivity* or *reflectance*)与其物理、化学及生物特性紧密联系。
- 地球气候系统部分地决定于地球表面物质的分布，而反过来又控制着这些分布。
- 如果将来气候变冷，地球大部份被冰雪覆盖，大量的入射辐射将被反射回太空，导致地表进一步变冷，大气层降低 (positive feedback)。
- 实际上，大部份地表是不同物质的混合。
- 因此，被反射或吸收的太阳辐射是这些地表覆盖的相对面积比的函数。

植被遥感原理 — 模型

Formulating the model

- Imagine an area entirely covered by bare soil

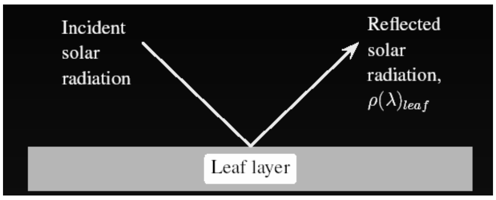


- The fraction of incident solar radiation that is reflected from this area is dependent only on the reflectance of the soil ($0 \leqslant \rho(\lambda)_{soil} \leqslant 1$)
- $\rho(\lambda)_{soil}$ has the meaning `the reflectance (ρ) of soil varies as a function of wavelength (λ)'

植被遥感原理 — 模型

Formulating the model

- Imagine another area entirely covered by vegetation (leaves) through which none of the soil substrate is visible

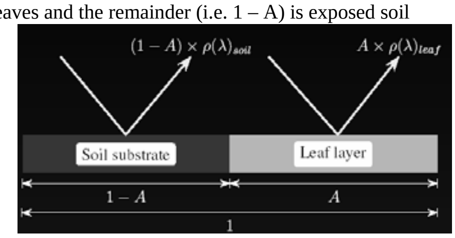


- The fraction of incident solar radiation that is reflected from this area is dependent only on the reflectance of the leaves ($0 \leqslant \rho(\lambda)_{leaf} \leqslant 1$)

植被遥感原理 — 模型

Formulating the model

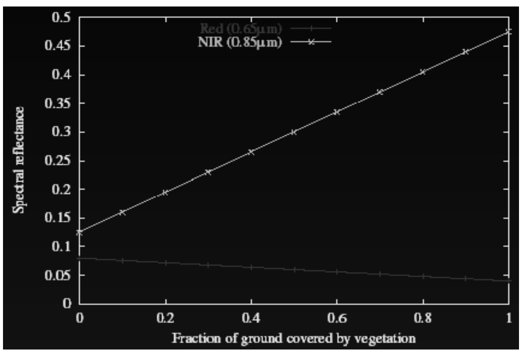
- Now imagine the case where we have a mixture of vegetation (leaves) and soil
- Assume some fraction ($0 \leqslant A \leqslant 1$) of the total area is covered by leaves and the remainder (i.e. 1 – A) is exposed soil



- If incoming solar radiation is distributed equally across the area, the total spectral reflectance is given by: $\rho(\lambda)_{total} = A\rho(\lambda)_{leaf} + (1 - A)\rho(\lambda)_{soil}$

植被遥感原理 — 模型

Plotting the results

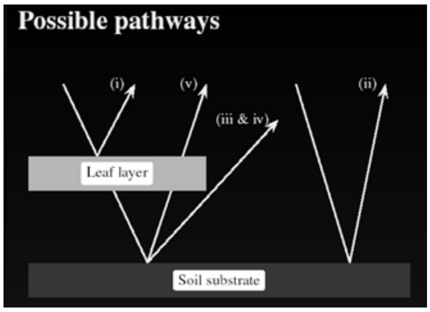


植被遥感原理 — 模型

Enhancing the model

- Simple model portrays the surface as a single layer (slab) in which the vegetation and soil lie side-by-side
- Unrealistic representation of most vegetation canopies
- Leaves are usually located above the soil substrate
- Implies that we really need a *two-layer* model
- Assumptions, scope and limitations of our model are otherwise as before

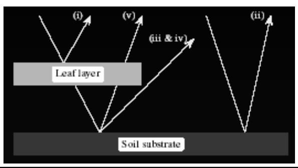
植被遥感原理 — 模型



植被遥感原理 — 模型

Possible pathways

(i) reflect directly from leaf layer
(ii) pass down through gap in leaf layer, reflect from soil substrate and escape up through gap in leaf layer
(iii) pass down through leaf layer, reflect from soil substrate and escape up through gap in leaf layer
(iv) pass down through gap in leaf layer, reflect from soil substrate and pass up through leaf layer
(v) pass down through leaf layer, reflect from soil substrate and pass back up through leaf layer



植被遥感原理 — 模型

Transmittance and absorptance

- Introduced two new phenomena into conceptual model of Earth surface reflectance — one explicitly (*transmission* or *transmittance*) and one implicitly (*absorption* or *absorptance*):
  - *transmission* is the process by which radiation passes through an object, such as a leaf
  - *transmittance* is the fraction of solar radiation incident upon an object that is transmitted through it
  - *absorption* is the process by which radiation is absorbed by an object (i.e. radiation that is neither reflected nor transmitted)
  - *absorptance* is the proportion of incident radiation that is absorbed by the object.

植被遥感原理 — 模型

Components of 2-layer model

- Components of the two-layer model:
  - (i) $A\ \rho(\lambda)_{leaf}$
  - (ii) $(1-A)\ \rho(\lambda)_{soil}(1-A)$
  - (iii) $A\tau(\lambda)_{leaf}\ \rho(\lambda)_{soil}(1-A)$
  - (iv) $(1-A)\ \rho(\lambda)_{soil}\ A\tau(\lambda)_{leaf}$
  - (v) $A\tau(\lambda)_{leaf}\ \rho(\lambda)_{soil}\ A\tau(\lambda)_{leaf}$
- Even if we ignore the 3rd, 4th and 5th terms, above, our 2-layer model differs from the 1-layer case:

$A\ \rho(\lambda)_{leaf} + (1-A)\ \rho(\lambda)_{soil}$ (1-layer model)
$A\ \rho(\lambda)_{leaf} + (1-A)\ \rho(\lambda)_{soil}(1-A)$ (2-layer model)(植被不透明)

植被遥感原理 — 模型

Formulating the model

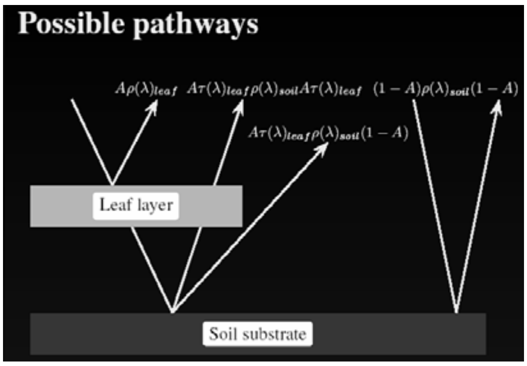
- Use the symbols A, $\rho(\lambda)_{leaf}$ and $\rho(\lambda)_{soil}$ as before
- Define
  - $\tau(\lambda)_{leaf}$ — spectral transmittance of the leaves,
  - $\alpha(\lambda)_{leaf}$ — spectral absorptance of the leaves and
  - $\alpha(\lambda)_{soil}$ — spectral absorptance of the soil
- Noting that
  $1 = \rho(\lambda)_{leaf} + \tau(\lambda)_{leaf} + \alpha(\lambda)_{leaf}$
  and
  $1 = \rho(\lambda)_{soil} + \alpha(\lambda)_{soil}$
  assuming that the soil is completely opaque

植被遥感原理 — 模型

Total canopy reflectance

- Total canopy reflectance sum of the five component terms:
  $\rho(\lambda)_{total} = A\ \rho(\lambda)_{leaf} + (1-A)\ \rho(\lambda)_{soil}(1-A)$
  $+ A\tau(\lambda)_{leaf}\ \rho(\lambda)_{soil}(1-A)$
  $+ (1-A)\ \rho(\lambda)_{soil}\ A\tau(\lambda)_{leaf}$
  $+ At(l)_{leaf}\ \rho(\lambda)_{soil}\ A\tau(\lambda)_{leaf}$
- Looks daunting, so let's substitute
  CR for $\rho(\lambda)_{total}$ (total canopy reflectance),
  LR for $A\ \rho(\lambda)_{leaf}$ (radiation reflected from leaf layer),
  LT for $A\tau(\lambda)_{leaf}$ (radiation transmitted through leaf layer),
  SR for $\rho(\lambda)_{soil}$ (radiation reflected from soil substrate), and
  gap for (1– A) (radiation passing through a gap in leaf layer)

植被遥感原理 — 模型



植被遥感原理 — 模型

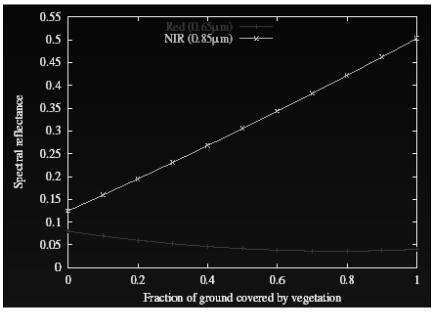
Total canopy reflectance

- Two-layer model now reads:
  CR = LR + (gap × SR × gap) + (LT × SR × gap)
  +(gap × SR × LT) + (LT × SR × LT)
- Note 3rd and 4th terms above are equivalent (i.e. LT × SR × gap = gap× SR × LT), so we can simplify as follows:

  CR = LR + (gap × SR × gap) + 2 × (LT × SR × gap)
  + (LT × SR × LT)

植被遥感原理 — 模型

Evaluating the output



植被遥感原理 — 模型

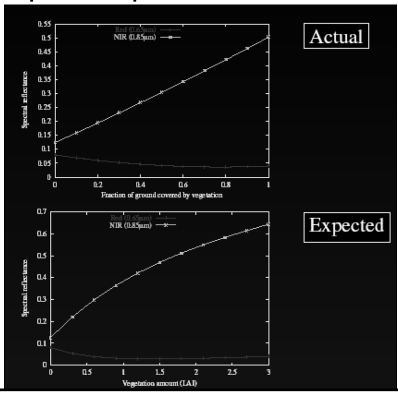
Multiple Scattering

- Current version of the two-layer model is:
  CR = LR + (gap × SR × gap)
  + 2 × (LT × SR × gap) + (LT × SR × LT)

- Instructive to note that 1st and 2nd terms, above, describe radiation that has interacted *once* with the vegetation canopy — either the leaf layer (LR) or the soil substrate (gap × SR × gap), but not both
- The 3rd term (LT × SR × gap) describes radiation that has interacted *twice* with the canopy (in this case, the leaf layer and the soil substrate)
- The 4th term (LT × SR × LT) describes radiation that has interacted *three times* with the canopy (the leaf layer, the soil substrate and the leaf layer again)

植被遥感原理 — 模型

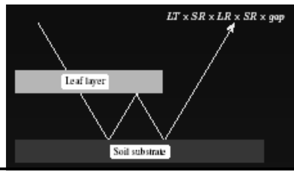
Actual vs. expected output



植被遥感原理 — 模型

Multiple Scattering

- Radiation that interacts more than once with the vegetation canopy is said to be *multiply scattered* (c.f. *singly scattered*)
- Common to refer to the scattering *order*:
  - 2nd-order scattering — radiation scattered (i.e. reflected or transmitted) twice within the canopy,
  - 3rd-order scattering — radiation scattered three times, etc.
- Improve the 2-layer model by incorporating higher-order (4th, 5th, . . .) interaction effects?
- 4th-order scattering: LT × SR × LR × SR × gap



植被遥感原理 — 模型

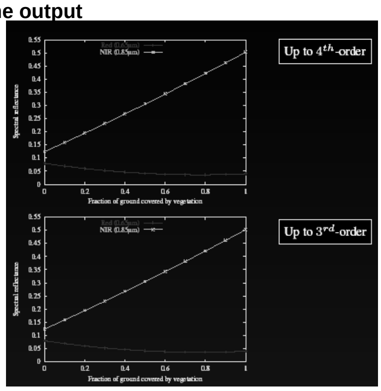
Actual vs. expected output

- Expect spectral reflectance to have non-linear relationship with respect to fractional vegetation cover in both the red and the near-infrared parts of the spectrum
  - Red wavelengths — relationship is *indirect* (negative)
  - Near-infrared (NIR) — relationship is *direct* (positive)
  - Both red and NIR exhibit an *asymptotic* trend, with the red appearing to reach its asymptote sooner than the NIR

- Discrepancy suggests that the 2-layer model is still too simplistic
- Go back once more and improve the conceptual model, updating the associated mathematical and computational models accordingly

植被遥感原理 — 模型

Evaluating the output



植被遥感原理 — 模型

Diminishing multiple scattering

- Taking 4th-order scattering events into account has had very little impact on the output from the two-layer model.
- Reason? — 4th-order scattering component is the product of five fractional values (i.e. LT × SR × LR × SR × gap)
- So, if A = 0.5, $\rho(\lambda)_{leaf} = 0.475$, $\tau(\lambda)_{leaf} = 0.475$ and $\rho(\lambda)_{soil} = 0.125$
- Such that LR = 0.2375, LT = 0.2375, SR = 0.125 and gap = 0.5
- 4th-order = 0.2375×0.125×0.2375×0.125×0.5≈0.00044
- Contribution due to single scattering from the leaf layer is LR = 0.475×0.5 = 0.2375 (~ 550 times greater than that due to fourth-order scattering)

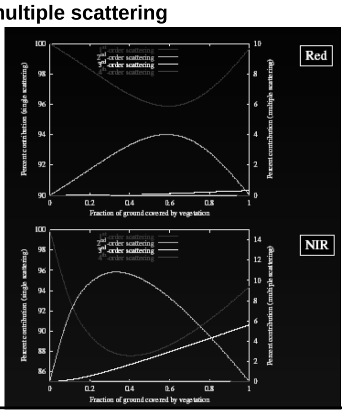
植被遥感原理 — 模型

Leaf Area Index（叶面积指数）

- 多层模型中叶面积指数的应用:
  - Leaves in each leaf-layer completely covers the ground below, LAI = n × 1, where n is the number of leaf layers (e.g. 2 × 1 = 2)
  - Leaves in each layer cover half of the ground below, LAI = n × 0.5 (e.g. 2 × 0.5 = 1)

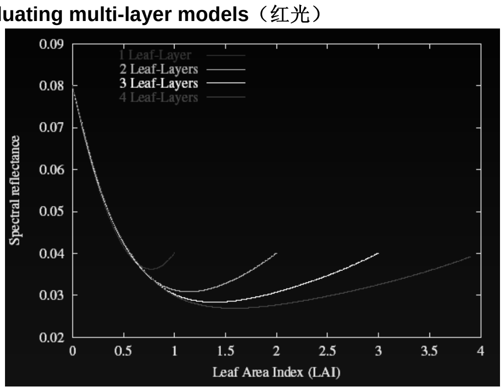
植被遥感原理 — 模型

Evaluating multiple scattering



植被遥感原理 — 模型

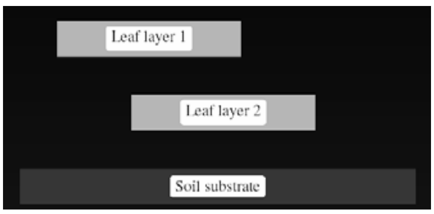
Evaluating multi-layer models（红光）



植被遥感原理 — 模型

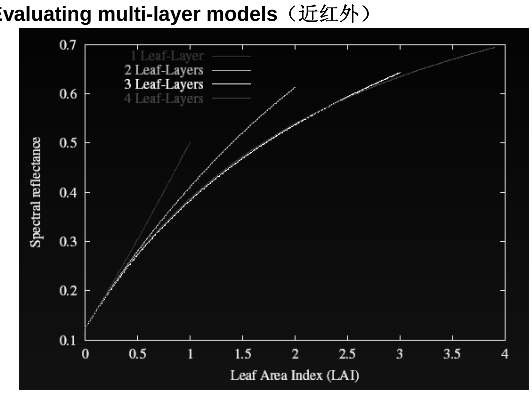
Multiple leaf-layer models

- Alternative is to *increase the number of leaf layers*
- Improved representation of 3D structure of real vegetation canopies



植被遥感原理 — 模型

Evaluating multi-layer models（近红外）



植被遥感原理 — 模型

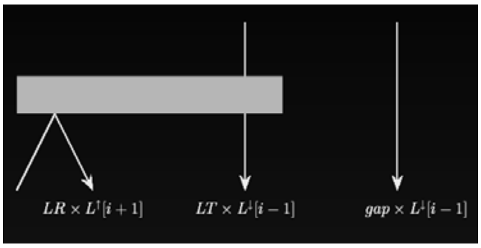
模型的迭代解

- Developed a number of multiple-layer models of reflection from a vegetation canopy
- Sophistication of the models increased by including
  - More leaf layers
  - Higher-orders of multiple scattering
- Corollary — code became longer and more complex

植被遥感原理 — 模型

Two-Stream Approximation

- Downward travelling flux:



植被遥感原理 — 模型

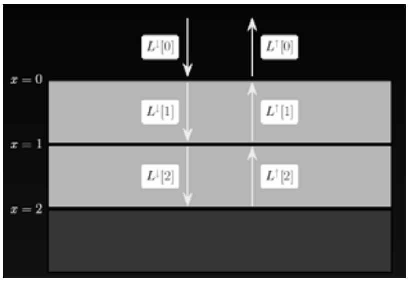
Rethinking the problem

- Problem of determining all possible pathways through the canopy gets harder as more leaf-layers and higher-orders of multiple scattering are incorporated into the model
  - Over 100 different pathways that solar radiation can trace through the model canopy given three leaf-layers and considering upto 7th-order multiple scattering!
- Chances of us omitting or `double counting' certain pathways is quite high under such circumstances
- Clearly, need to rethink the mathematical and computational solution to the problem

植被遥感原理 — 模型

Iterative Approach

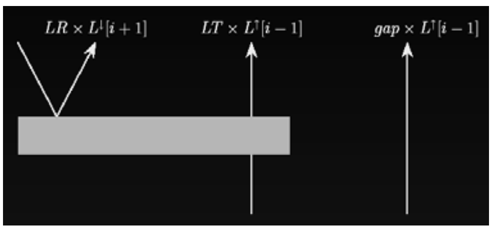
- Two-stream model of radiation transport through a multiple leaf-layer vegetation canopy



植被遥感原理 — 模型

Two-Stream Approximation

- Two `streams' of radiation, travelling in opposite directions, passing through the canopy
- Upward travelling flux:



植被遥感原理 — 模型

Two-Stream Approximation

- Code preamble and set-up boundary conditions

```
BEGIN {
  # Total incident solar radiation
  LDown[0]=1;

  # Boundary condition – soil substrate
  R[layers+1]=rhoSoil;
  T[layers+1]=0;
```

植被遥感原理 — 模型

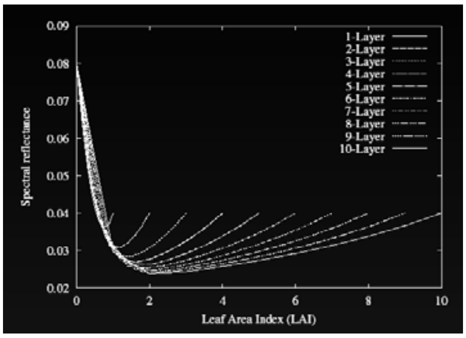
Two-Stream Approximation

- Main for loop varies fractional ground cover of leaves per layer (N.B. same for all leaf layers)
- Next loop calculates the gap fraction and likelihood of reflection or transmission from each leaf layer

```
for (coverFraction=0;coverFraction<=1.0;coverFraction+=0.1){
  # Set up leaf layers
  for(i=1;i<=layers;i++){
    gap[i]=1−coverFraction;
    R[i]=rhoLeaf*coverFraction;
    T[i]=tauLeaf*coverFraction;
  }
```

植被遥感原理 — 模型

Plotting the results (Red)



植被遥感原理 — 模型

Two-Stream Approximation

- Next iterate to a solution for each leaf layer

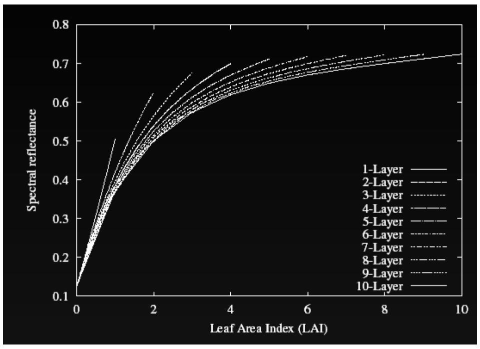
```
for ( iteration=1; iteration<=20;iteration++){
  # Deal with each of the leaf layers in turn
  for (i=1; i<=layers; i++){
    LUp[i]=(LDown[i−1]*R[i]) + \
      (LUp[i+1]*gap[i]) + \
      (LUp[i+1]*T[i]);
    LDown[i]=(LUp[i+1]*R[i]) + \
      (LDown[i−1]*gap[i]) + \
      (LDown[i−1]*T[i]);
  }

  LUp[layers+1]=LDown[layers]*R[layers+1];
  }

  printf( "%5f %10.8f\n", coverFraction*layers, LUp[1]);
 }
}
```

植被遥感原理 — 模型

Plotting the results (Nir)



植被遥感原理 — 模型

Kubelka-Munk Equations

- Equations that underpin the previous code commonly known as the Kubelka-Munk equations

$$dI\uparrow = -(S + K)I\uparrow dx + I\downarrow Sdx \quad (1)$$

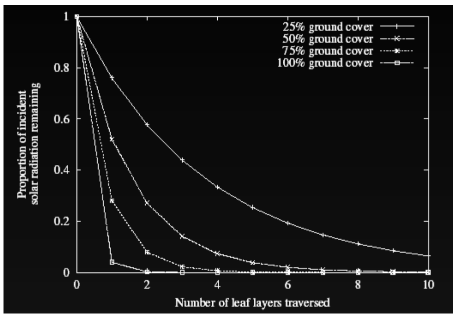
$$dI\downarrow = -(S + K)I\downarrow dx + I\uparrow Sdx \quad (2)$$

- where x is distance into the turbid medium, K is an absorption coefficient, S is a scattering coefficient, $I\uparrow$ is the upward travelling flux and $I\downarrow$ is the downward travelling flux.

植被遥感原理 — 模型

Taking things further

- Can use the model to determine how much light penetrates to different depths into the canopy



植被遥感原理 — 模型

辐射传输模型

辐射传输理论(Radiative transfer theory)

辐射传输理论最初是从研究光辐射在大气（包括行星大气）中传输的规律和粒子（包括电子，质子，中子等基本粒子）在介质中的输出规律时总结出来的规律性知识。

基本表现：“碗边”效应，随着观测角增大，反射亮度增大

可以解释为视线穿过的路径变长，
包含了较多的散射

植被遥感原理 — 模型

KM方程

$$\frac{dE^-}{d(-\tau)} = -(\alpha+\gamma)E^- + \gamma E^+ + S_1F^- + S_2F^+ \quad (1)$$

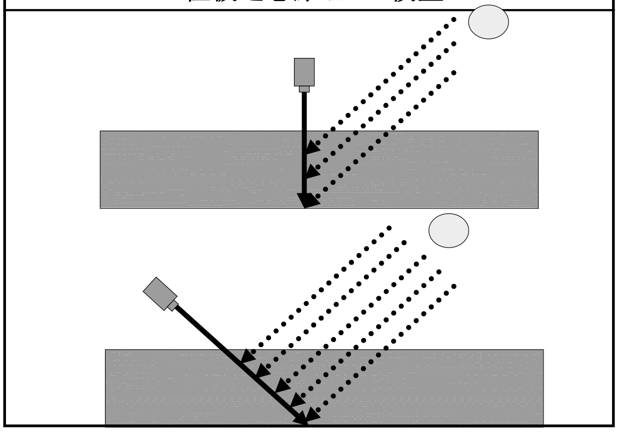
$$\frac{dE^+}{d\tau} = -(\alpha+\gamma)E^+ + \gamma E^- + S_1F^+ + S_2F^- \quad (2)$$

$$\frac{dF^-}{d(-\tau)} = -(K+S_1+S_2)F^- \quad (3)$$

$$\frac{dF^+}{d\tau} = -(K+S_1+S_2)F^+ \quad (4)$$

α 为吸收系数，γ 为散射系数，S_1与S_2分别为平行辐射的散射系数，即由直射辐射向漫辐射的转换系数，脚标“1”与“2”分别表示前向与后向，K为平行辐射的吸收系数。

植被遥感原理 — 模型



植被遥感原理 — 模型

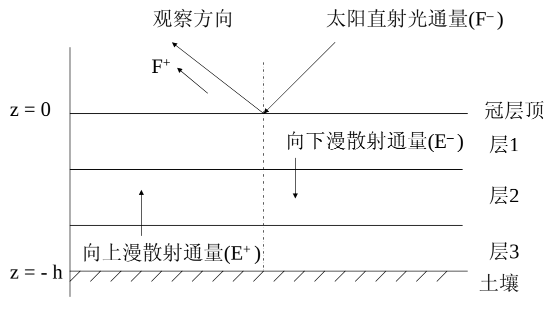
$$d\tau = FAVD(z)dz$$

$$E^+ = \int_0^{2\pi} d\phi \int_0^{\frac{\pi}{2}} L(\tau;+\mu,\phi)\mu\sin\theta d\theta$$

$$E^- = \int_0^{2\pi} d\phi \int_0^{\frac{\pi}{2}} L(\tau;-\mu,\phi)\mu\sin\theta d\theta$$

植被遥感原理 — 模型

植被辐射传输模型的理论基础是辐射传输方程，但是辐射传输方程是一个微分——积分方程，只有数值解，目前通用的解法→KM理论（四通量近似或二流近似）



植被遥感原理 — 模型

K—M方程各项的物理意义：
以方程（1）为例， E^-的减少由下列因素决定：

① 通过dτ时因吸收和散射而减少的量；
② 由E^+的后向散射而增加的量；
③ 由直射辐射向散射辐射的转化而增加的量（包括前向与后向）；
④ 方程（3）（4）表明准直辐射自身在传输过程中永远是“减少项”，即直射向漫射的转变是不可逆的。

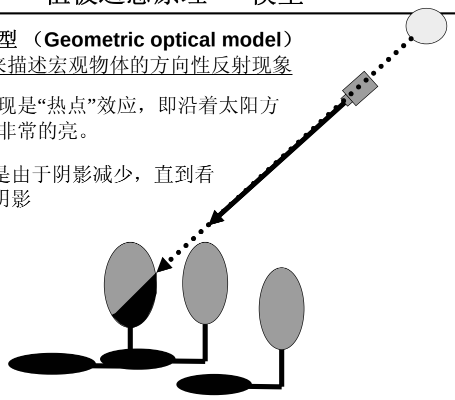
植被遥感原理 — 模型

几何光学模型 （**Geometric optical model**）

<u>主要用来描述宏观物体的方向性反射现象</u>

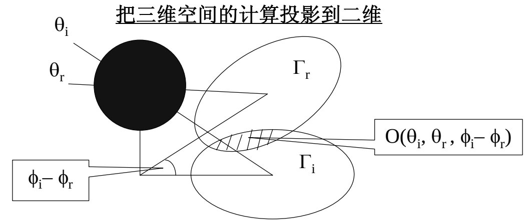
基本表现是“热点”效应，即沿着太阳方向看去非常的亮。

主要是由于阴影减少，直到看不到阴影



植被遥感原理 — 模型

<u>**把三维空间的计算投影到二维**</u>



$\Gamma_i = \pi R^2 / \cos\theta_i = \pi R^2 \sec\theta_i$

$\Gamma_r = \pi R^2 / \cos\theta_r = \pi R^2 \sec\theta_r$

在r方向看到的树冠承照面部分 $\Gamma_c = \frac{1}{2}\left(1 + < \vec{i}, \vec{r} >\right)\Gamma_r$

植被遥感原理 — 模型

基本思想是景合成模型，即光照面与阴影面的加权和。可以解释热点现象。

$$L_s = K_g L_g + K_c L_c + K_t L_t + K_z L_z$$

关键：光照面与阴影面的所占比例的计算

光照面与阴影面的亮度？

代表：Li-Strahler 几何光学模型

最早用圆锥来表示针叶林，后吸取了Jupp等的改进，用椭球来模拟。

植被遥感原理 — 模型

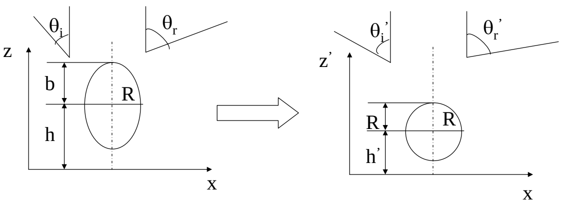
<u>**引入概率几何学中的基本原理– Boolean 原理**</u>

假设在区域A内随机投掷N个炸弹，每个炸弹的平均破坏面积为a，则没有遭到炸弹破坏的面积A′：

$$A' = Ae^{-N(a/A)} = Ae^{-\lambda a}$$

$$K' = A'/A = e^{-\lambda a}$$ 单位面积有λ个

植被遥感原理 — 模型



椭球在垂直方向拉伸变换为球

$Z' = (R/b)Z$ $h' = (R/b)h$

$\theta_i' = \tan^{-1}(b/R)\tan\theta_i$ $\theta_r' = \tan^{-1}(b/R)\tan\theta_r$

植被遥感原理 — 模型

Li – Strahler 几何光学模型中四分量的面积比

对于稀疏林地、灌丛

可见光照地面 $K_g = e^{-\lambda[\Gamma_i + \Gamma_r - O(\theta_i, \theta_r, \phi_i - \phi_r)]}$

可见光照树冠 $K_c = 1 - e^{-\lambda\Gamma_c}$

阴影树冠 $K_t = e^{-\lambda\Gamma_c} - e^{-\lambda\Gamma_r}$

阴影地面 $K_z = 1 - K_g - K_c - K_t$

当森林茂密，观测方向远离天顶时，需考虑树冠间的相互遮蔽→GOMS模型

植被遥感原理 — 模型

GO-RT模型：几何光学向辐射传输的逼近
联系两者的关键是间隙率模型

间隙率：

① 概率间隙率，当光线穿越树冠距离为S时，而不被拦载的概率。

② 几何间隙率，设树冠的投影面积为A，而其中光斑的总面积为S，则 S / A被称为几何间隙率。

③ 物理间隙率，设在树冠的阴影面内有一点（x,y），其辐照度为E（x,y），如果投射到树冠上的辐照度为E_0，则$E(x,y)/E_0$，便称之为物理间隙率。

植被遥感原理 — 模型

树冠的间隙率为不同位置间隙率的积分：

$$P_{gap}(\theta) = \frac{1}{A}\iint_A e^{-\tau s(x,y,\theta)}dxdy$$

将二维问题变为一维：

$$P_{gap} = \int_0^\infty p(s)e^{-\tau s}ds$$

对于规则的形体，可以计算路径长度及其分布

植被遥感原理 — 模型

* 几何孔隙率 $g_{gap} = \begin{cases} 1 & (x,y\text{为光照点}) \\ 0 & \text{否则} \end{cases}$

$$G_{gap} = \frac{1}{A}\iint_{(x,y)\in A} g_{gap}(x,y)dxdy$$

* 物理空隙率 $e_{gap}(x,y) = E(x,y)/Eo.$

$$E_{gap} = \frac{1}{A}\iint_{(x,y)\in A} e_{gap}(x,y)dxdy$$

* 概率空隙率 $P_{gap} = \frac{1}{A}\iint_{(x,y)\in A} p(x,y)dxdy$

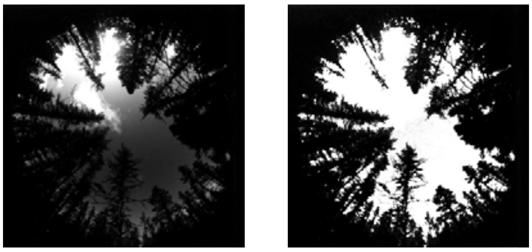
注意不同的（x,y）对应着不同的S值，显然P(x,y)是与S值相联系的，而前两种定义并不关心S的取值大小。

植被遥感原理 — 模型

<u>利用冠层间隙率可以推算**LAI**</u>

In Situ Measurements of LAI

Hemispherical Photographs



植被遥感原理 — 模型

对于均匀连续的植被冠层，Monsi和Sakei首先建议采用下面的负指数衰减的表示式：

$$P_{gap} = e^{-kL/\cos\theta}$$

其中L为叶面积指数，k是叶面积在θ方向的投影比例。

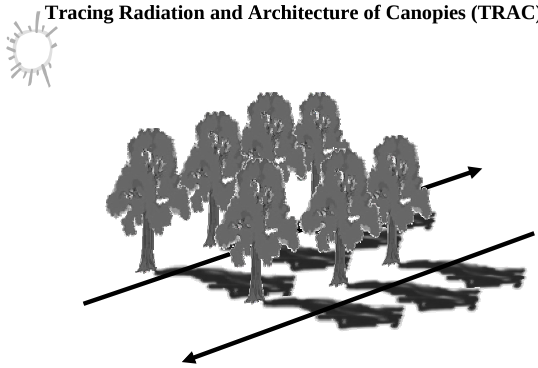
对于不连续的植被，李小文和Strahler定义间隙率为路径长度s的函数：

$$P_{gap}(s) = e^{-\tau s}$$

其中，τ 表示每单位长度的衰减指数，与叶面积指数、叶倾角分布及叶片的透过率有关。

植被遥感原理 — 模型

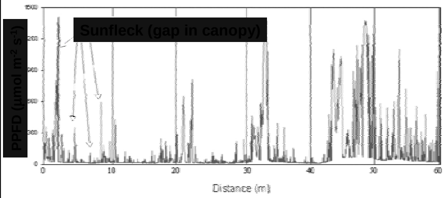
Tracing Radiation and Architecture of Canopies (TRAC)



植被遥感原理 — 模型

In Situ Measurements of LAI

Tracing Radiation and Architecture of Canopies (TRAC)



http://www.ccrs.nrcan.gc.ca/ccrs/rd/apps/landcov/beps/trac_e.html

植被遥感原理 — 模型

计算机模拟模型

- 蒙特卡洛方法

  用随机数描述入射光的位置、方向、植被组分位置、方向、种类及是否发生碰撞，如果碰撞，可能被吸收和散射。直到光子被吸收或达到传感器。大量的循环。

- 结构真实模型

  利用计算机图形学产生植被真实结构，以加快计算速度。

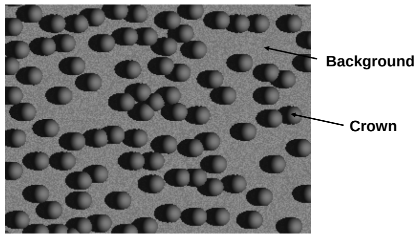
植被遥感原理 — 模型

LAI-2000

植被遥感原理 — 模型

Reflection from Canopy

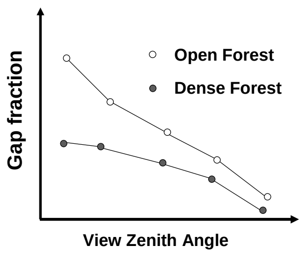
Nadir view



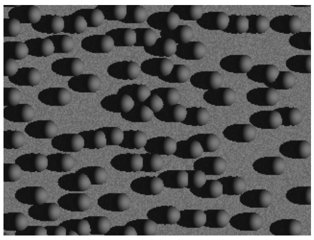
Shaded and non-shaded areas

sza = 33.7 deg

植被遥感原理 — 模型

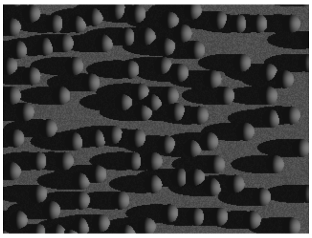


植被遥感原理 — 模型



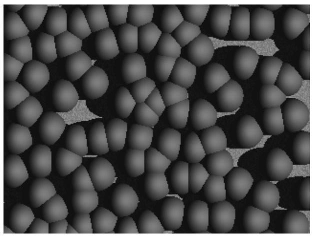
sza =45 deg

植被遥感原理 — 模型



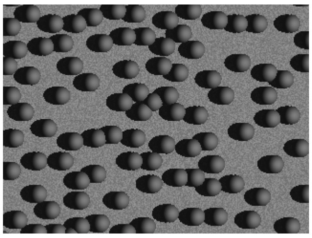
sza = 63.4 deg.

植被遥感原理 — 模型



植被遥感原理 — 模型

Reflection from Canopy



植被遥感原理 — 模型

物理模型面临的问题：

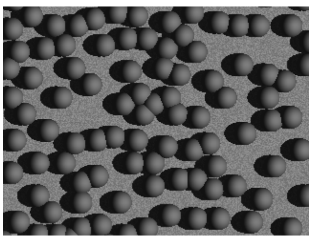
- 复杂，造成反演困难
- 实际的植被反射既包含了热点效应，又有碗边效应

解决办法：**线性核驱动模型**

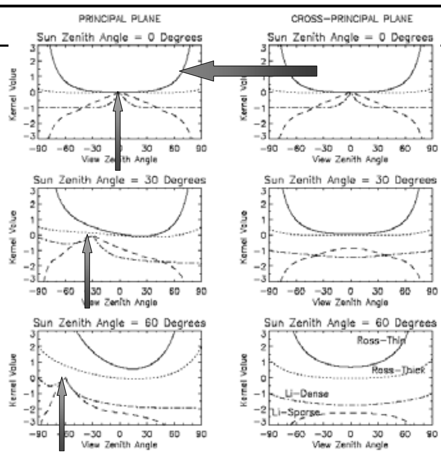
$$R(\theta_i,\theta_v,\varphi) = f_{iso} + f_{geo}k_{geo}(\theta_i,\theta_v,\varphi) + f_{vol}k_{vol}(\theta_i,\theta_v,\varphi)$$

- 各向同性核
- 体散射核
  RossThin（罗斯薄层）、RossThick（罗斯厚层）
- 几何光学核
  LiSparse（李氏稀疏）、LiDense（李氏致密）
  最新发展为LiTransit核

植被遥感原理 — 模型



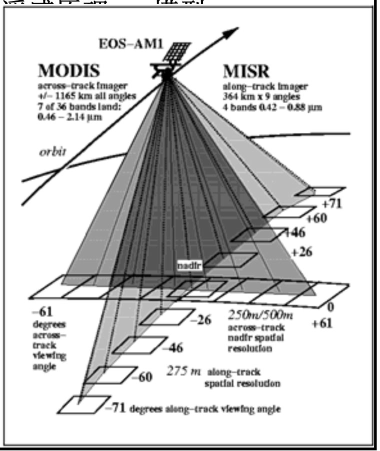
体散射核与几何光学核的基本形状



植被

多角度数据的获取：

- 大FOV，不同时刻的图像重叠(MODIS, POLDER)
- 多传感器或同一传感器不同角度成像(MISR, ATSR, SPOT, ASTER)

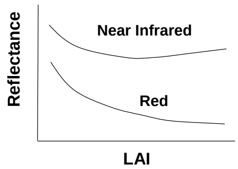


植被遥感原理 — 植被指数

Forests

More trees-foliage means more shadows when the density is low

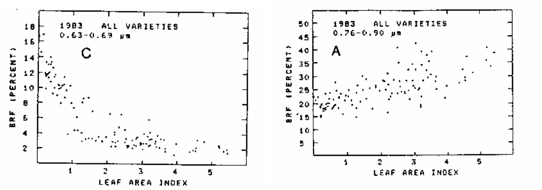
Because transmittance in near-infrared is high infrared shadows appear less shaded than shadows in visible



植被遥感原理 — 植被指数

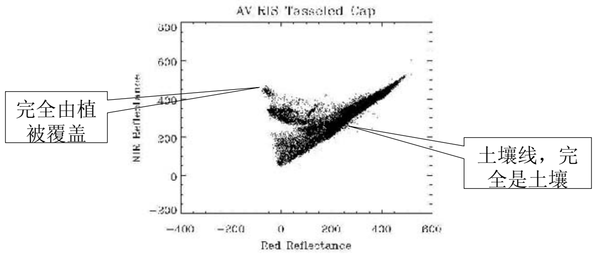
基本思想：通过不同波段的组合变换，得到一个值来衡量植被的多少(abundance)及活力(vigour)

Response of Red and NIR to LAI changes in crops



Martin and Heiman, 1986,
Photogrammetric Engineering and Remote Sensing

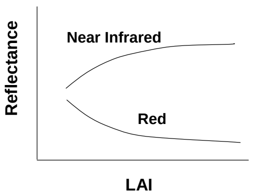
植被遥感原理 — 植被指数



穗帽

植被遥感原理 — 植被指数

croplands, grasslands

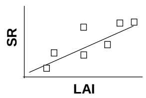


植被遥感原理 — 植被指数

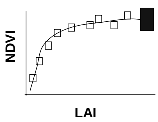
- 两类植被指数:
  1. 比值型

  优点是可以抑制噪声

Simple Ratio (SR) $SR = \frac{R_{ir}}{R_r}$



Normalized Difference Vegetation Index (NDVI)



$$NDVI = \frac{R_{ir} - R_r}{R_{ir} + R_r}$$

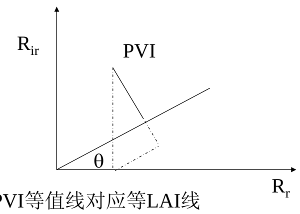
Saturation problems

植被遥感原理 — 植被指数

2.垂直距离型

优点是可以削弱土壤影响。如果忽略土壤线与R_{ir}轴的截距，垂直距离植被指数就是某一点（R_r, R_{ir}）到土壤线间的垂直距离。

$$PVI = R_{ir}\cos\theta - R_r\sin\theta$$



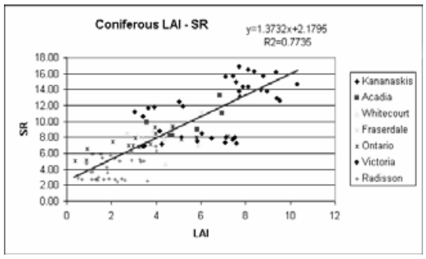
希望PVI等值线对应等LAI线

植被遥感原理 — 植被指数

Satellite-based LAI algorithm development

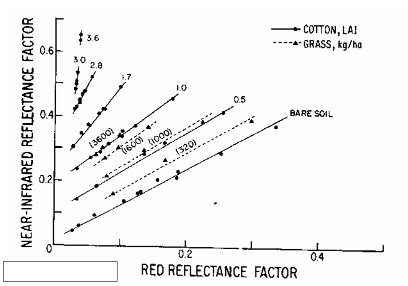
Canada-wide LAI map validation involving all five forest research centres and several universities

(satellite: Landsat; ground data: TRAC)



Chen et al. 2001, *Remote Sensing of Environment*

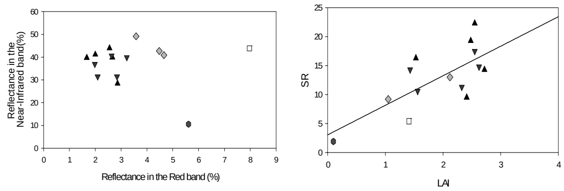
植被遥感原理 — 植被指数



Huete, 1988, *Remote Sensing of Environment*

植被遥感原理 — 植被指数

LAI - Agriculture



植被遥感原理 — 植被指数

为了进一步减弱土壤的影响， Huete (1988)提出了土壤调节植被指数 Soil Adjusted VI（SAVI）

$$SAVI = \frac{(R_{ir} - R_r)}{(R_{ir} + R_r + L)}(1 + L)$$

极高植被覆盖，L = 0；极低植被覆盖，L=1；一般 L=0.5

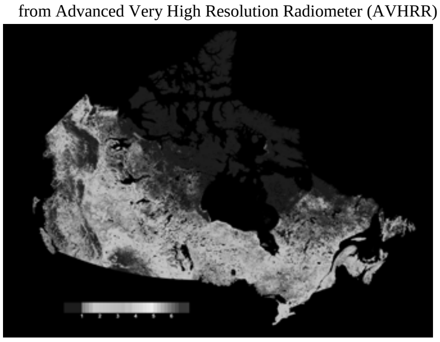
Qi et al. (1994)进一步提出了modified SAVI (MSAVI)，通过遥感数据本身得到L，形成了一个新的植被指数：

$$MSAVI = \rho_n + 0.5 - \sqrt{(\rho_n + 0.5)^2 - 2(\rho_n - \rho_r)}$$

植被遥感原理 — 植被指数

Example LAI map

from Advanced Very High Resolution Radiometer (AVHRR)



Chen et al. 2001, Remote Sensing of Environment

植被遥感应用

• 植被在可见光~近红外的波段范围内重要的反射特征使得植被可以与无机物质明显区别开。

• 不同植被的反射特征不同
• 不同植被分布及土壤类型，反射也不同

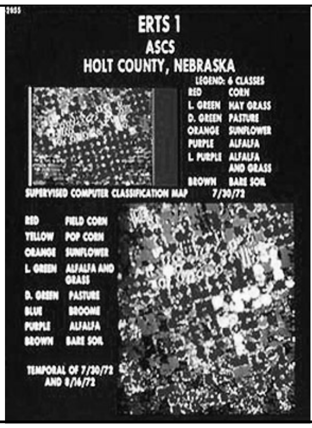
• 落叶林通常比常绿针叶林反射更高

• 多光谱遥感图像的成功应用范例是检测农作物产量，方法主要是识别主要的作物类型：小麦、大麦、黍、燕麦、玉米、大豆、水稻等

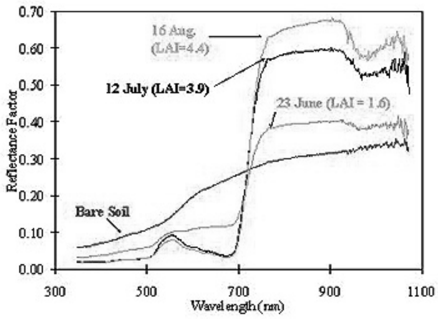
植被遥感应用

植被遥感应用

ERTS1发射不久得到的作物分类图



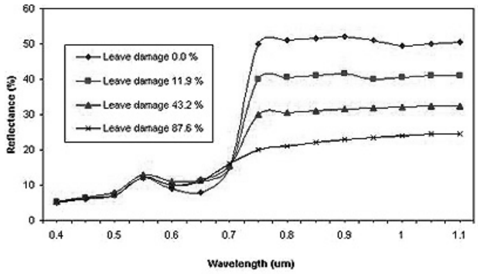
植被遥感应用



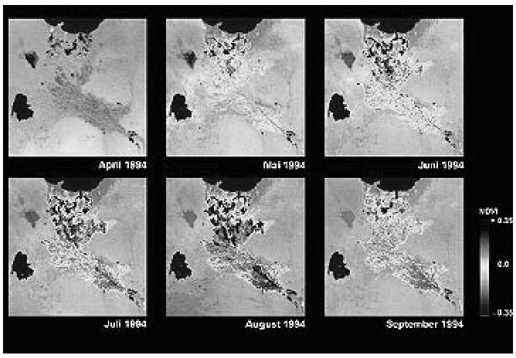
LAI随时间变化

植被遥感应用

探测作物胁迫（水分缺或虫害时），主要表现为作物的近红外反射持续降低

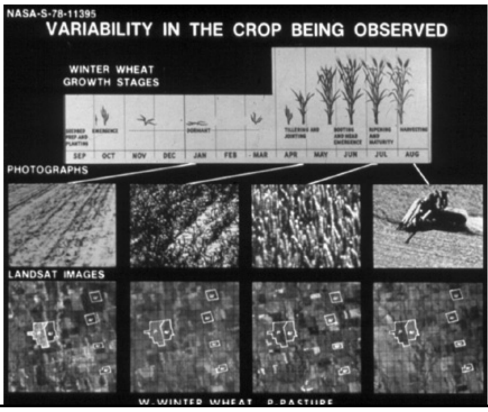


植被遥感应用



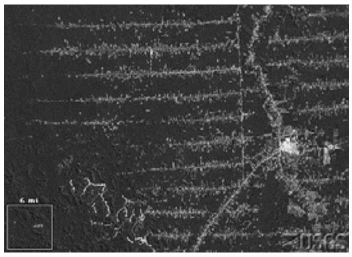
NDVI反映植被的变化

植被遥感应用



植被遥感应用

亚马孙河流域的森林砍伐



1 August 1986, Landsat 5 MSS bands 4 2 1

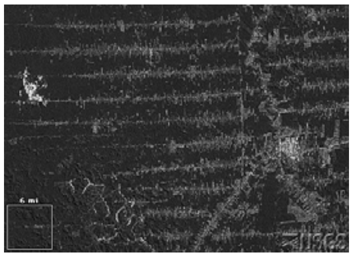
植被遥感应用

在巴西，覆盖着世界上最大的热带雨林、有“地球之肺”和“绿色心脏”之称的亚马孙森林，流淌着世界上流量最大的河流亚马孙河，散布着世界上最大的湿地潘塔纳尔沼泽地，生存着世界上最大的动植物群落。

Commercial map, bipolar oblique conical projection

植被遥感应用

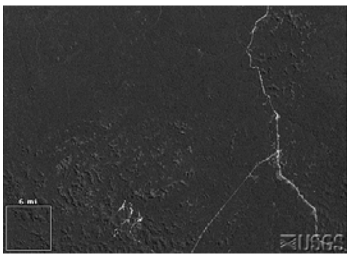
亚马孙河流域的森林砍伐



22 June 1992, Landsat 4 TM bands 4 3 2

植被遥感应用

亚马孙河流域的森林砍伐



19 June 1975, Landsat 2 MSS bands 4 2 1