Monitoring vegetation: theoretical basis

Tiit Nilson

Tartu Observatory, Estonia

JOINT NASA LCLUC SCIENCE TEAM MEETING AND GOFC-GOLD/NERIN, NEESPI WORKSHOP: Monitoring land cover and land use in boreal and temperate Europe. August 25-28, 2010, Tartu Observatory, Tartu, Estonia

Theoretical basis of quantitative remote sensing in the shortwave part of the solar spectrum

- Transmission of solar radiation through the atmosphere – atmospheric radiative transfer
- Reflection of direct solar radiation and diffuse skylight by the ground surface (vegetation) – radiative transfer in vegetation

Courtesy of © Sovzond © SSC Satellitbild 1996

http://www.kidsgeo.com/images/earths-atmosphere.jpg

Radiative transfer in vegetation: Theoretical options

- Geometric-optical models
- Turbid medium (radiative transfer) approach
- Computer simulation like Monte-Carlo
- Radiosity method

  - Combined methods
  - Importance of analytical methods

Juhan Ross
14.08.1925 -
21.06.2002

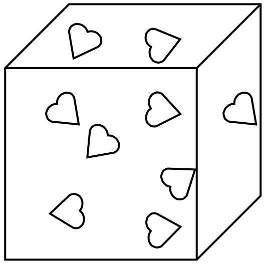
History of the turbid medium approach

Juhan Ross and his Tartu team (starts from 1960-s)

- Formulated the radiative transfer (RT) equation for vegetation canopies. Started as a fundamental research with an idea by Nichiporovich to create new plants with an optimum structure to absorb radiation and produce the highest photosynthesis.
- RT equation forms the main theoretical basis for remote sensing of vegetation. Turbid medium concept.

Juhan Ross & Tartu team

- Introduced the necessary quantitative structural and optical characteristics of vegetation (foliage area volume density, leaf angle and orientation distribution and the respective projection function (G-function), leaf scattering phase function, (area) scattering phase function for the elementary volume or leaf layer, etc.)



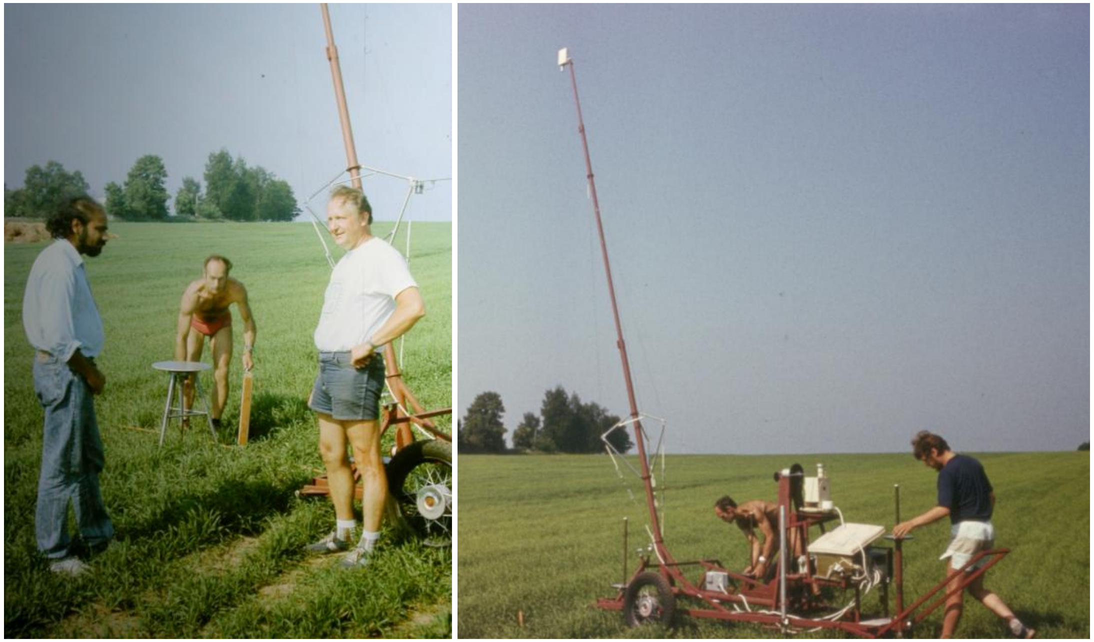
u(x,y,z) – leaf area volume density, leaf area index (LAI)
leaf normal's zenith angle θ_L and azimuth φ_L distribution $g(\theta_L,\varphi_L)$
projection of unit leaf area onto a plane perpendicular to a view direction $G(\theta)$
scattering phase function for a leaf $\gamma_\lambda(\theta,\varphi,\theta',\varphi',\theta_L,\varphi_L)$ and for a leaf layer $\Gamma_\lambda(\theta,\varphi,\theta',\varphi')$ defined on leaf area basis

Tartu team

- Approximate analytic solutions of the radiative transfer equation for different regions of the spectrum: first order scattering for the visible and PAR region, two stream approximation for the near infrared. Several versions of canopy reflectance models created
- Exact solution of the RT equation for vegetation with horizontal and Lambertian leaves and isotropic soil
- Formulated the concept of foliage clumping (clustering) and its effect on canopy gap fraction and radiation transmission

Tartu team

- Several remote sensing instruments designed and made, numerous field measurements to test the models

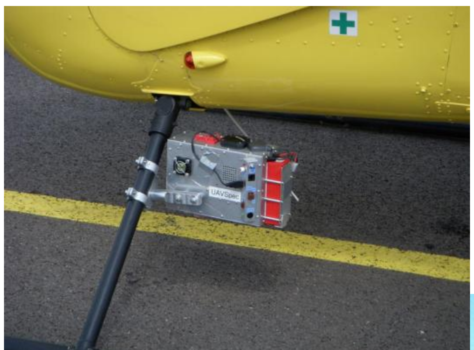


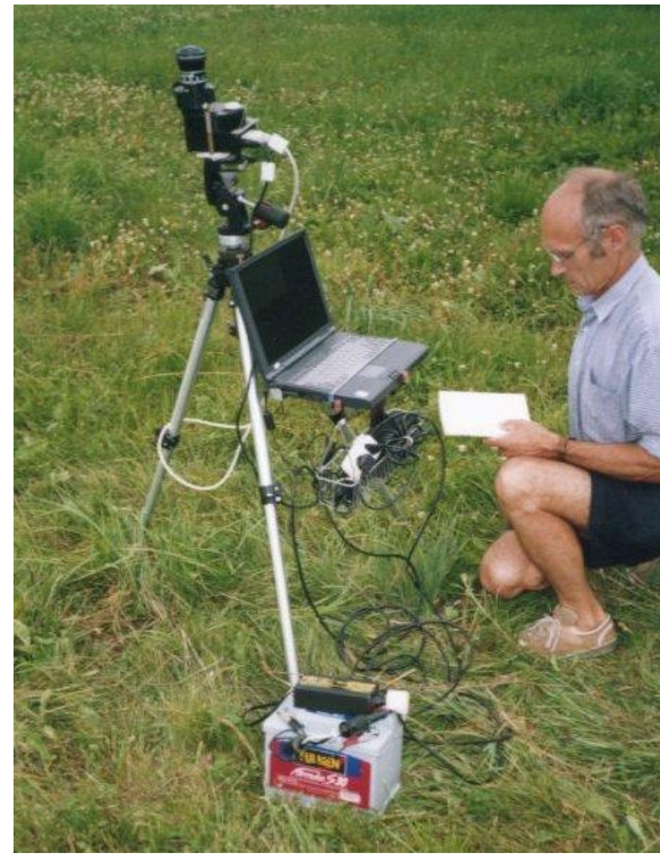
Kuusk's field goniometer (1988)

Point quadrat instrument (1969)

Aho – Sulev field radiometer (1980)

- Imaging hemispheric-view CCD radiometer (1999)
- detailed dataset (2006-2009) for a few forests, partly included into RAMI IV





J. Ross & Tartu team

Some milestones

- Ross & Nilson radiative transfer and vegetation structure model (1968)
- Ross' book (Russian version in 1975, English version in 1981
- Myneni & Ross edited Springer book (1991)
- Nilson's 1971 Agricultural Meteorology clumping paper
- Nilson 1977 statistical gap fraction model (LAI from gap fraction suggestion, hot spot for forests)
- Kuusk & Nilson approximate analytical reflectance model for homogeneous canopies (1985, 1989, 1995)
- Kuusk's hot spot model (1991)
- Nilson and Kuusk & Nilson forest reflectance model (FRT) (1990, 1991, 1994, 2000)

Problems with the turbid medium approach

- Still not quite clear how to define the elementary volume, for which the energy balance condition is written, esp in 3D case
- Two (somewhat) contradictory assumptions
  - Large enough, so that foliage volume density and leaf orientation functions are applicable
  - Small enough, so that mutual shadowing within it is excluded
  - Inability to describe the hot spot
- Validity demonstrated by comparisons with the Monte-Carlo simulations
- Spatial variability of leaf area and orientation

Stand structure models

- Canopy structure description, a rather impractical task
- 3D structure
  - Foliage area volume density
  - Leaf angle and orientation distribution
- 1D structure
- Computer-simulated plants
- 3D tomography

Stand structure and gap fraction, a key question

- Important optically, related to the photon’s free path
- Simulation of gap fraction
- Point quadrat experiment and gap fraction theoretical formula: How well is the probability of zero contacts related to the mean and variance of contact number? Mean contact number is determined by the leaf area and its orientation, variance by the pattern of spatial dispersion
- Modern techniques, such as laser scanning
- Is the exponential gap fraction formula (Beer-Lambert or Poisson formula) good enough in real plant canopies? Reference to computer simulations (e.g. work by Nadia Rochdi)

Stand structure and gap fraction

- Description of clumping
- Jing Chen's interpretation of clumping scales in forests

$$P(\theta) = \exp\left[-\frac{G(\theta) L \Omega_E}{\gamma_E \cos\theta} \right]$$

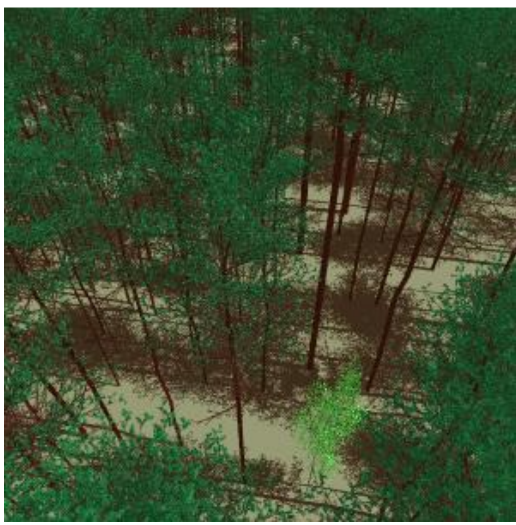
Beyond-shoot level Ω_E and shoot level γ_E of clumping separated. Beyond-shoot (crown) level cannot be described by just a multiplicative factor in the exponent! Thanks to Jing Chen, I get hundreds of references, however, I am not very happy with such interpretation

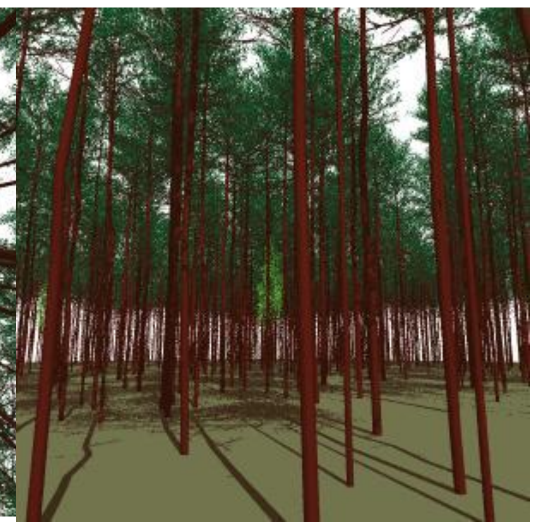
Role of basic research and analytical methods

- Like studies on eigenvalues and eigenvectors of the radiative transfer equation initiated by Y. Knyazikhin and his colleagues – basic properties of radition field in different regions of the spectrum, the theory of spectral invariants. Dr. Matti Mõttus (once supervised by J. Ross) currently involved in this activity
- Resulted in approximate algorithms for the canopy reflectance
- Help in understanding of basic RT properties

Importance of the RAMI initiative

- RAMI RAdiation transfer Model Intercomparsion initiative, currently RAMI IV, includes some actual canopies
- http://rami-benchmark.jrc.ec.europa.eu/HTML/RAMI-IV/RAMI-IV.php





To conclude

- The vegetation radiative transfer problem forms a basis for vegetation remote sensing. It deserves much more attention
- The problem has long history. We here in Tartu are happy to have given a contribution to the history
- There are lots of things still to be done

- Thanks for the attention!