Canopy radiation simulation in the EALCO model

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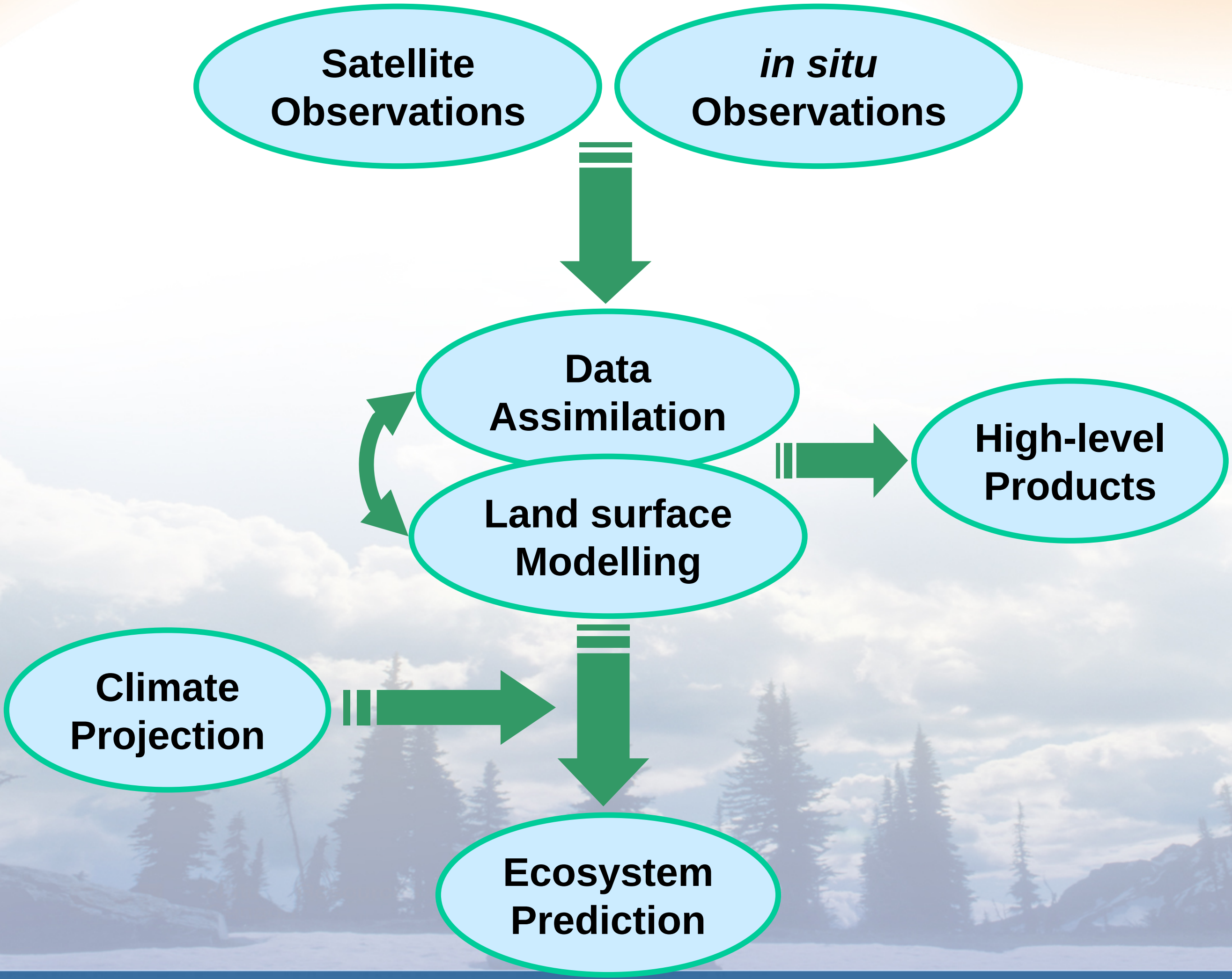
Outline

- Ecosystem modelling and satellite data assimilation
- Radiation module in the EALCO model
  - Canopy radiation (and surface albedo) calculations
- Results
- Issues

Ecosystem Modelling & Data Assimilation

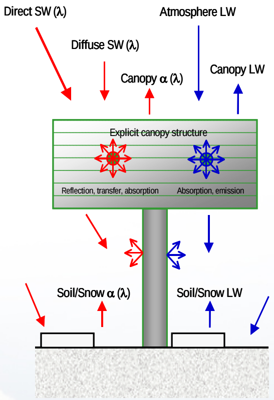


- *Data acquisition*
- *Built on the EALCO model and remote sensing products at CCRS*
- *Multi-source data integration & assimilation*
- *High-level products generation*
- *Ecosystem scenarios & assessment*

The EALCO Model

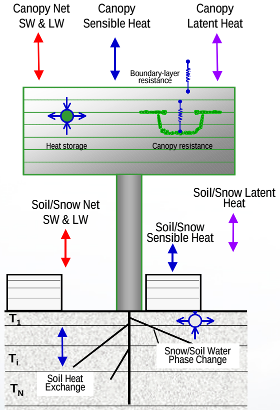
(Ecological Assimilation of Land and Climate Observations)

Radiation



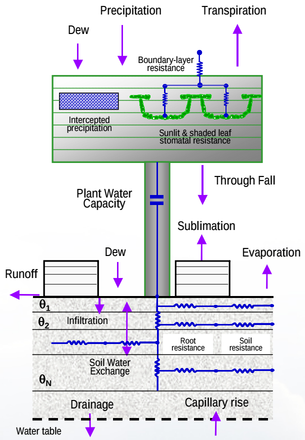
Gap probability-based successive orders of scattering approach that includes heterogeneity of stands and crown elements and the multiple scattering of radiation. Multi-canopy layers and multi-wavelength for solar radiation calculations. Separation of direct and diffuse radiation components. Outputs include surface (spectral) albedo, canopy (layer) and soil/snow surface solar radiation absorption, and longwave radiation balance. References: Wang et al. (2002a); Wang (2005); Wang et al. (2007).

Energy



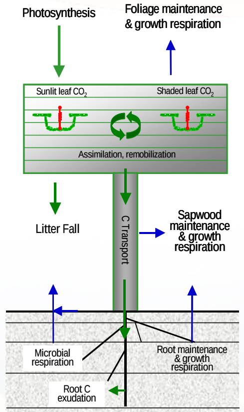
Numerical solution of energy balance equations for canopy and for underlying soil/snow. Canopy energy balance coupled with plant water and CO_2 dynamics. Multiple (user-defined) soil layers and self-prognostic (dynamic) snow-layering scheme for heat transfer using finite difference method. Outputs include canopy, soil and snow sensible and latent heat exchanges and their physical variables such as temperature, heat flux, soil freeze and thaw, and snow depth and snow coverage fraction. References: Wang et al. (2002b), Wang (2007).

Water



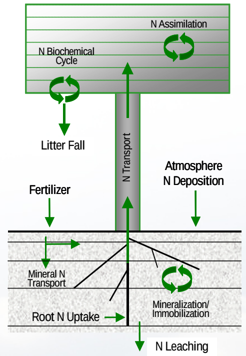
Numerical solution of dynamic water balance equation of soil-root-canopy-atmosphere system. Multi-layer hydraulic resistances for soil and roots (radial and axial). Atmospheric and physiological control on evapotranspiration through solving the plant energy-water-intercellular CO_2 dynamics. Groundwater exchanges with upper soils. Outputs include evaporation/sublimation, transpiration, runoff, groundwater recharge, dew and frost, and soil water content. References: Wang et al., (2002b), Wang (2007), Zhang et al. (2007).

Carbon



Identification of five plant tissues and seven soil C pools. Identification of sunlit vs. shaded leaves. Photosynthesis using Farquhar model. Respiration includes plant maintenance & growth (autotrophic) respirations and soil microbial (heterotrophic) respiration in each soil layer. Model determined plant phenology, tissue growth and development, and stand chronosequence. Outputs include gross primary production, net primary production, net ecosystem production, and plant and soil C conditions. References: Wang et al. (2001, 2002c).

Nitrogen

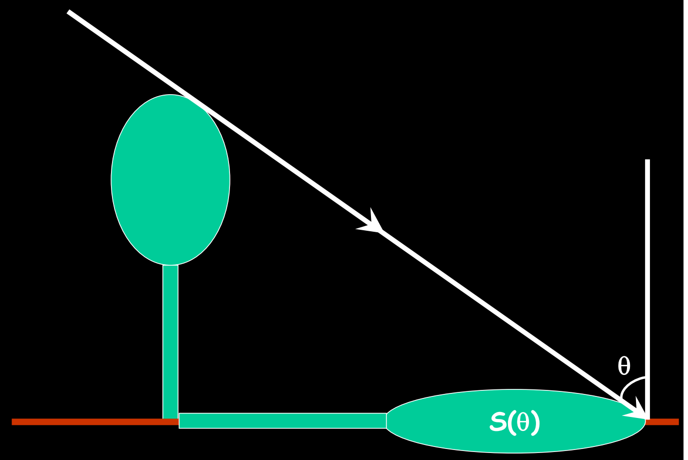


Nitrogen (N) balance among atmospheric deposition, ecosystem leaching, management (e.g., fertilizer), and plant and soil N contents. Plant and soil N balanced by root N uptake and litterfall. Root N uptake including both active and passive N transfers in the soil-root system. Identification of 5 plant and 7 soil N pools corresponding to the carbon pools. Outputs include plant root N uptake, soil N mineralization and immobilization, and the N biogeochemical cycles. References: Wang et al. (2001, 2002c).

Recent References of EALCO:

- Wang, S., *et al.*, 2009, Modelling the response of canopy stomatal conductance to humidity. *Journal of Hydrometeorology* (in press).
- Wang S., 2008, Simulation of evapotranspiration and its response to plant water and CO2 transfer dynamics. *Journal of Hydrometeorology*, 9:426-443.
- Yinsuo Z., *et al.*, 2008, Impact of snow cover on soil temperature and its simulation in a boreal aspen forest. *Cold Regions Science and Technology*, 52:355-370.
- Wang S., *et al.*, 2007, Simulation of canopy radiation transfer and surface albedo in the EALCO model. *Climate Dynamics*, 29:615-632.
- Wang S., 2005, Dynamics of surface albedo of a boreal forest and its simulation. *Ecological Modelling*, 183, 477-494.

Canopy radiation modelling - gap probability



- Single stand

$$a_1(\theta) = e^{\frac{-G(\theta)(\kappa LAI + \gamma WAI)}{NS(\theta)\cos(\theta)}}$$

- Canopy

$$a(\theta) = P_0(S)a_1^0(\theta) + P_1(S)a_1^1(\theta) + P_2(S)a_1^2(\theta) + \ldots\ldots = \sum_0^\infty P_n(S)a_1^n(\theta)$$

- Assuming Poisson distribution of stands in the horizontal dimension

$$a(\theta) = e^{-NS(\theta)\left[1 - a_1(\theta)\right]}$$

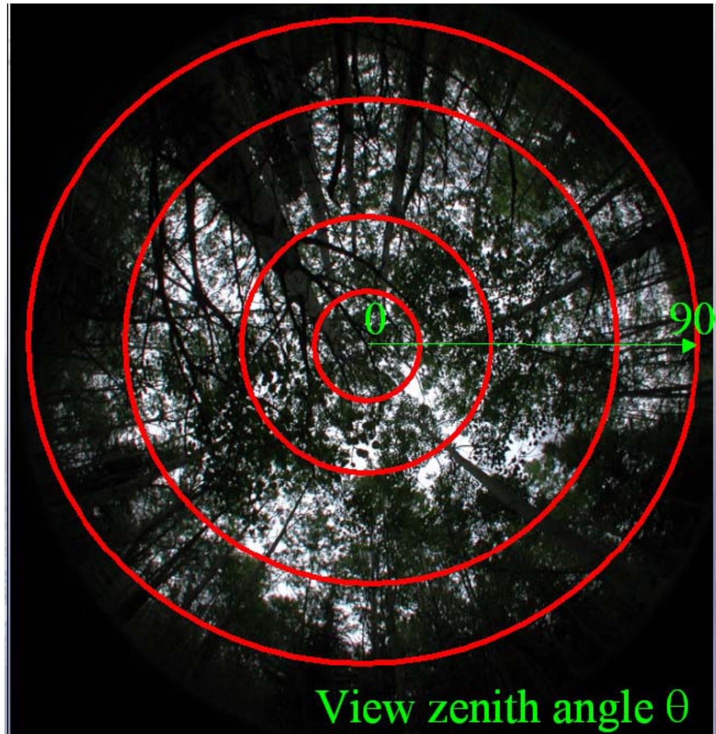
Canopy radiation modelling

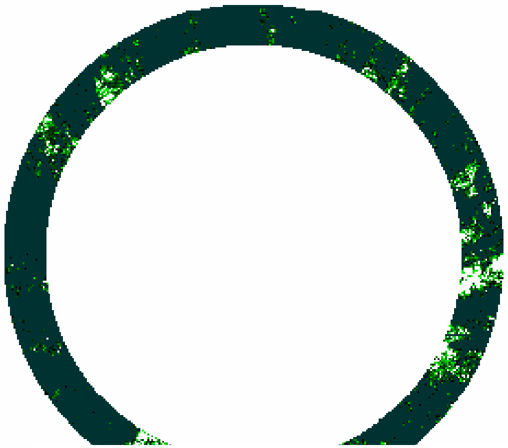
In EALCO, canopy is further divided into multi-layers in order to obtain the radiation profile within canopy

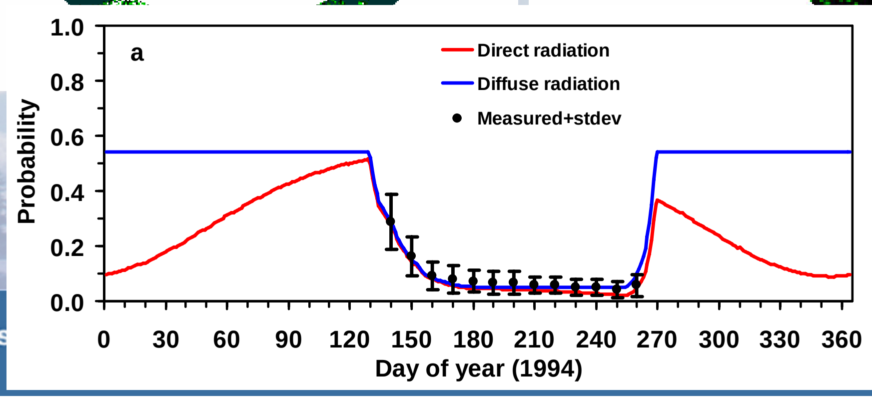
- **Vertical:** $a_{0,l}(0), \quad 0 < l \le L+1$ Used for precipitation penetration/interception
- **Direct:** $a_{0,l}(SZA), \quad 0 < l \le L+1$
- **Diffuse:** $a_{0,l} = \int_0^{2\pi}\int_0^{\frac{\pi}{2}} a_{0,l}(\theta)\sin(\theta)d\theta d\phi / 2\pi, \quad 0 < l \le L+1$
- **Scatter:** $a_{l,m} = \int_0^{2\pi}\int_0^{\frac{\pi}{2}} a_{l,m}(\theta)\sin(\theta)d\theta d\phi / 2\pi, \quad 0 \le l \le L+1, \quad 0 \le m \le L+1$

- Based on the gap probability and optical parameters of ecosystem elements (leaf, wood, soil, snow), a 1-D multi-wavelength ray tracing algorithm was developed in EALCO.
- Output: canopy radiation absorption, ground surface radiation absorption, top-of-canopy albedo, sunlit vs. shaded LAI.

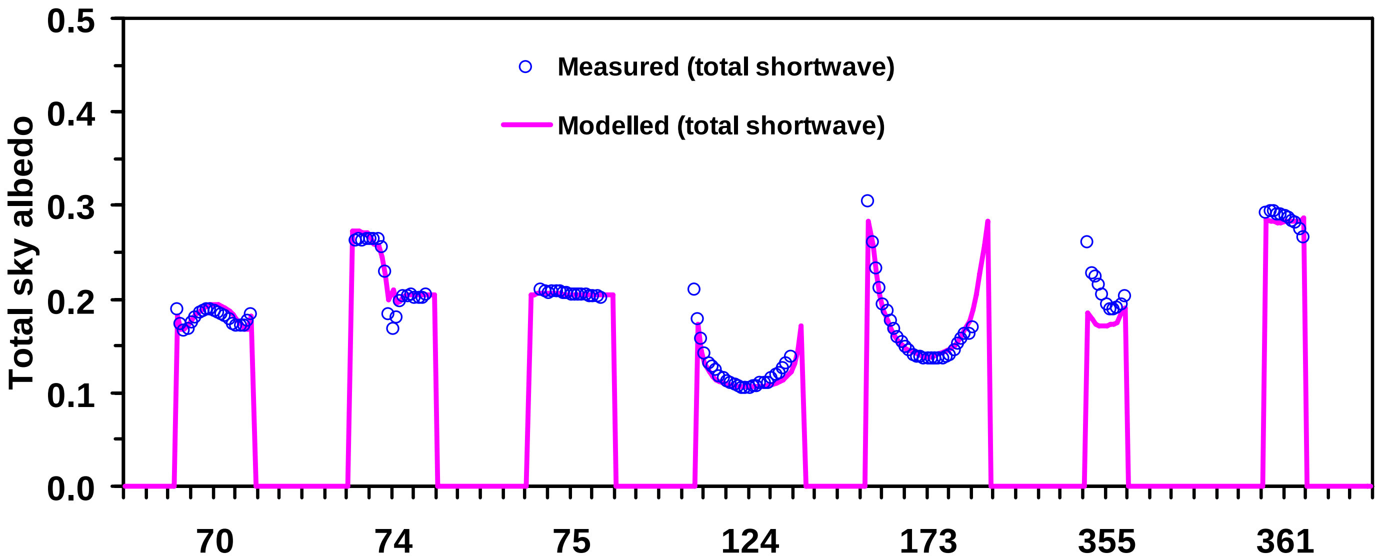
Estimating gap probability







Model validation – closed canopy



Ground S. + clear

Canopy S. + cloudy

Ground S. + overcast

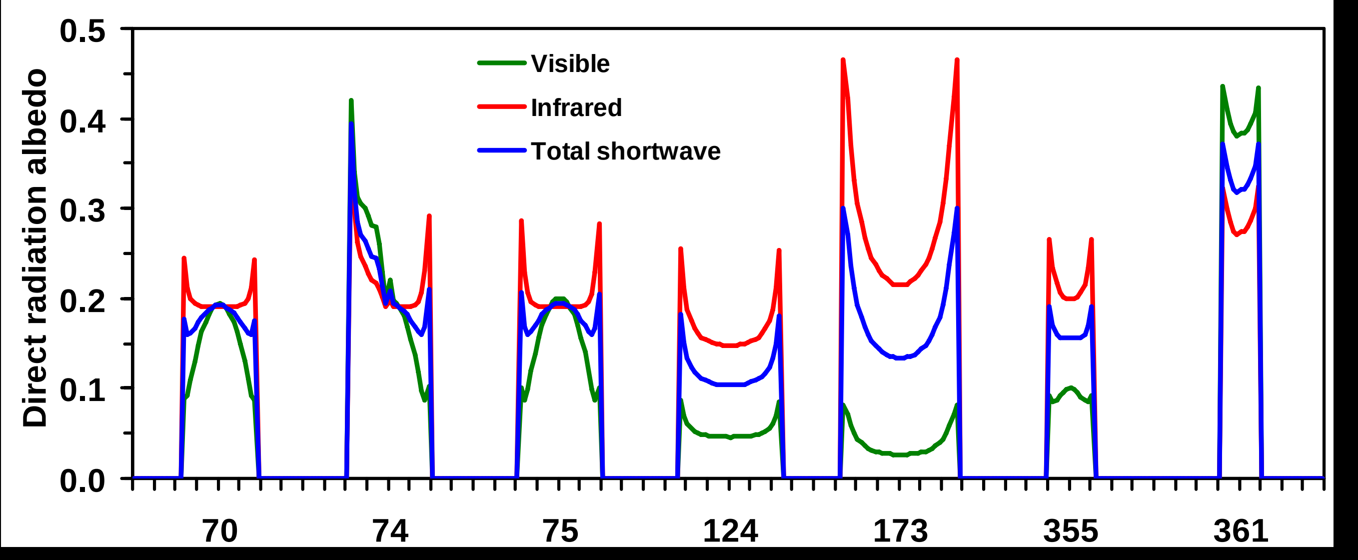
No snow + no leaf

Leaf + clear sky

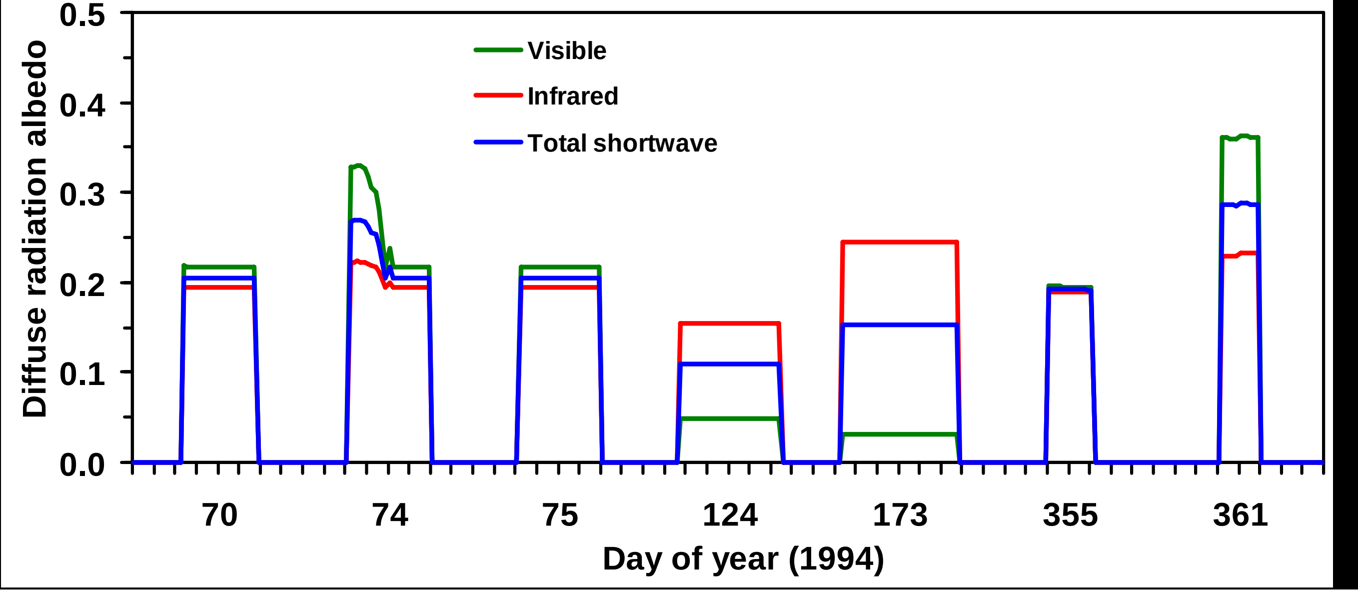
Ground S. + clear

Canopy S. + overcast

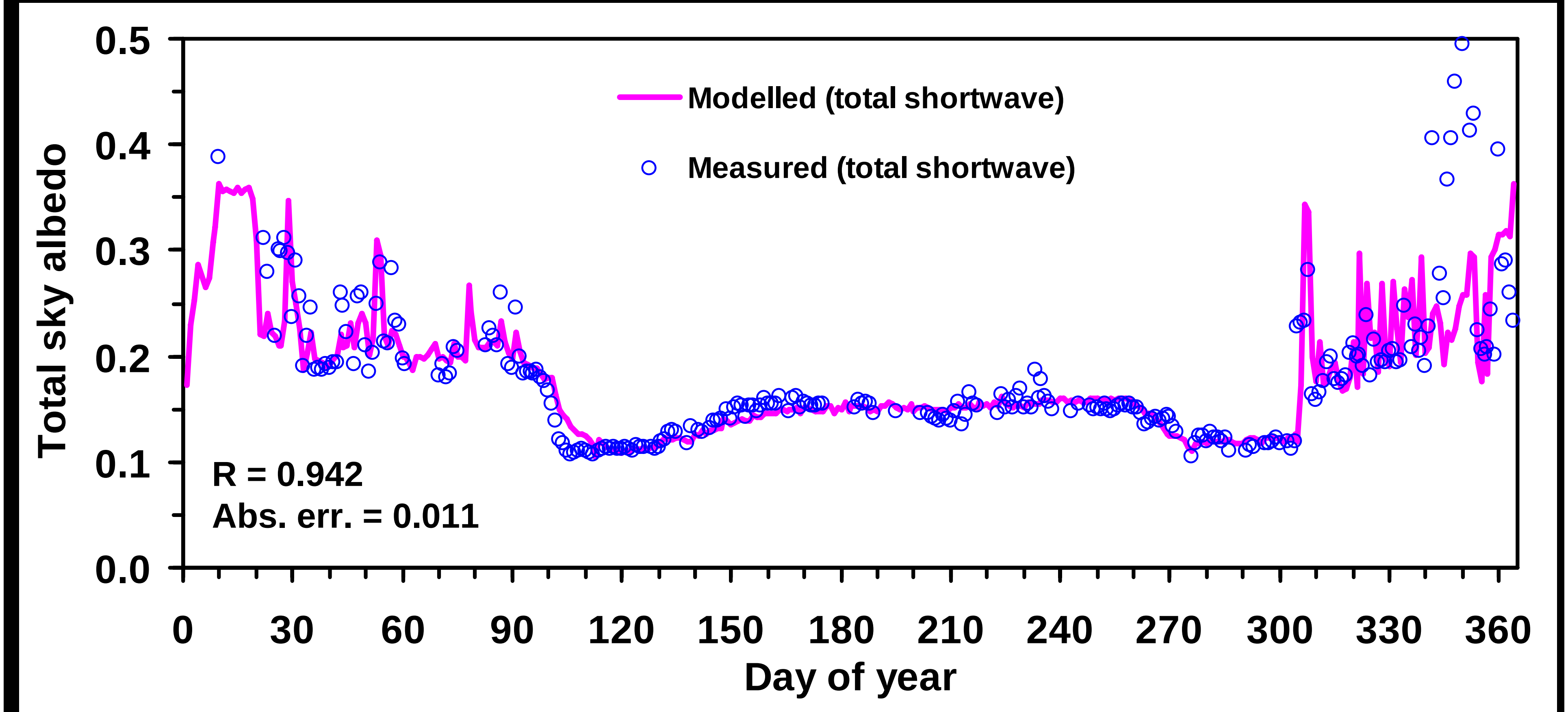
Model validation - closed canopy



Large seasonal variations in the spectral properties of surface albedo

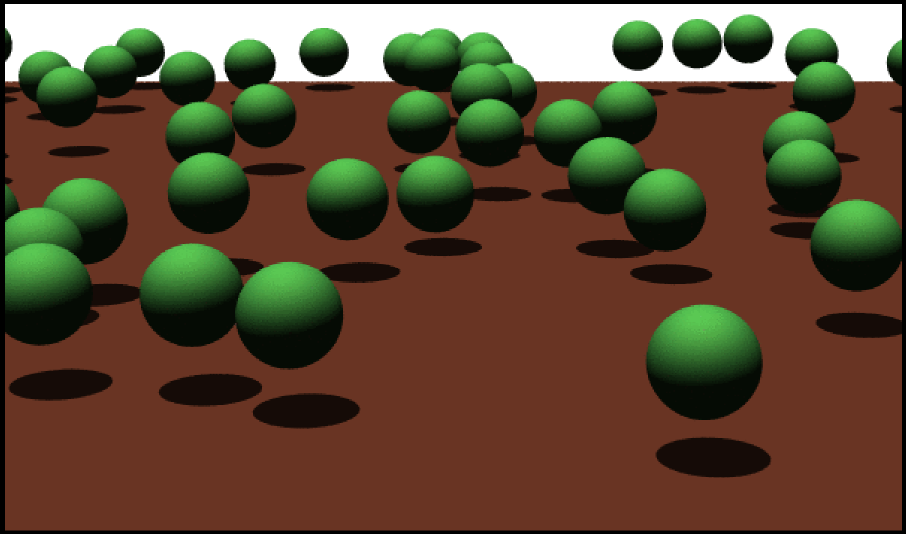


Model validation - closed canopy



Snow contribution to surface albedo <0.1, although canopy is leafless

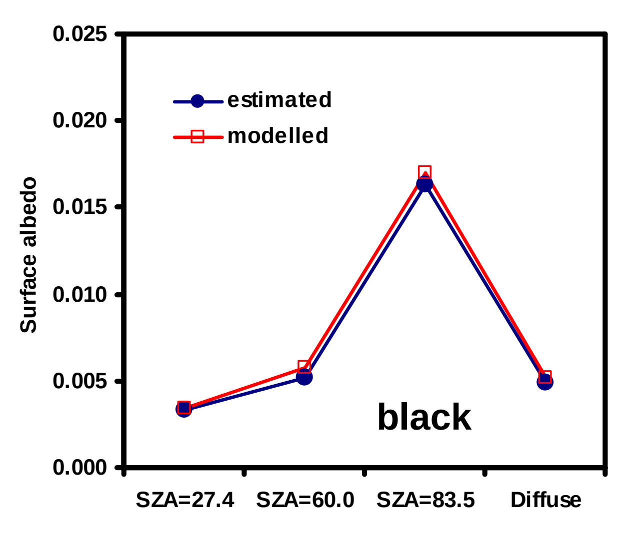
Model validation – open canopy

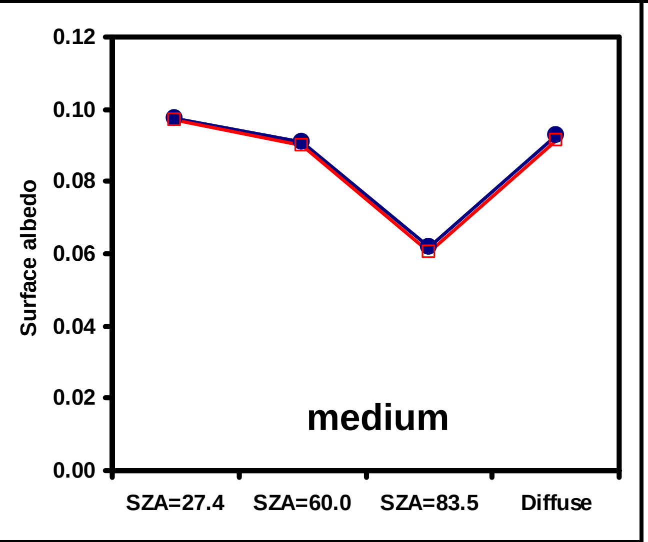


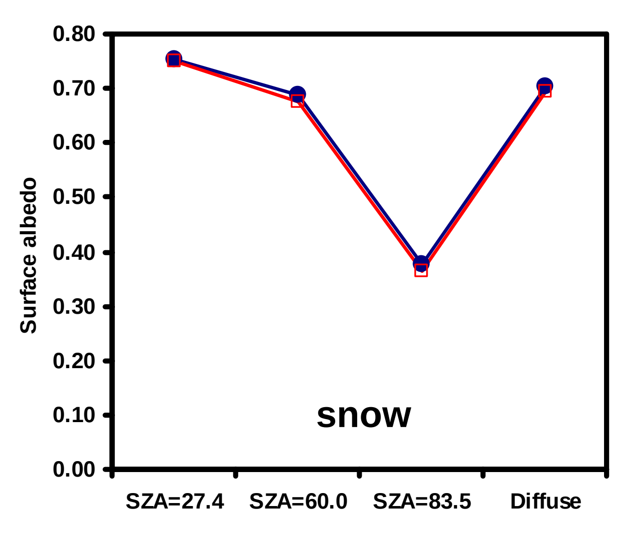
RAMI4PILPS (http://rami-benchmark.jrc.it/HTML/Home.php)

Open forest:

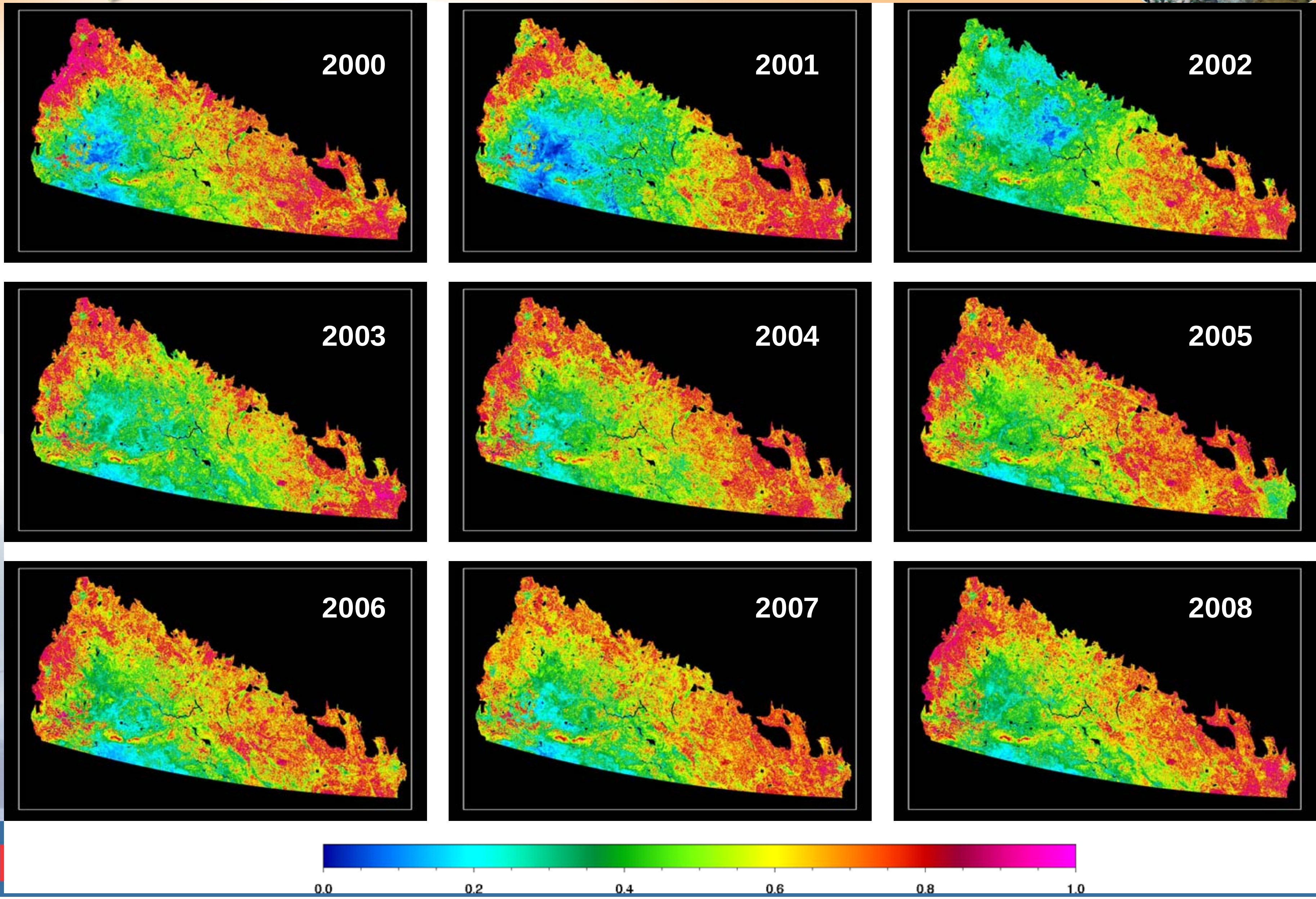
- LAI = 0.50 $m^2 m^{-2}$
- Stand density = 12.8/hectare
- Ground surface brightness:
  - Black
  - Medium
  - snow





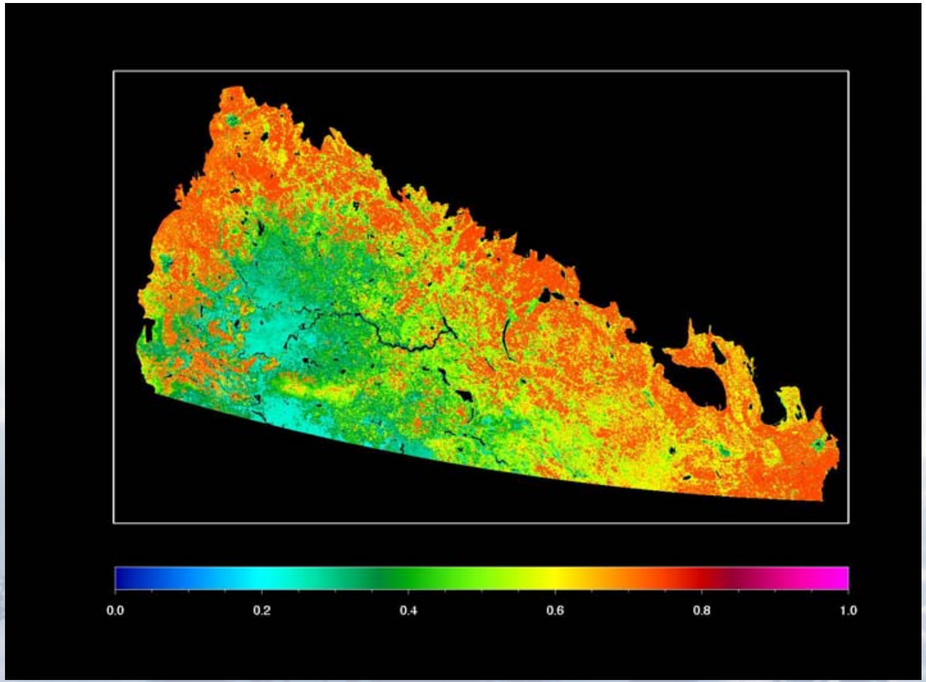


fAPAR in Canadian prairie

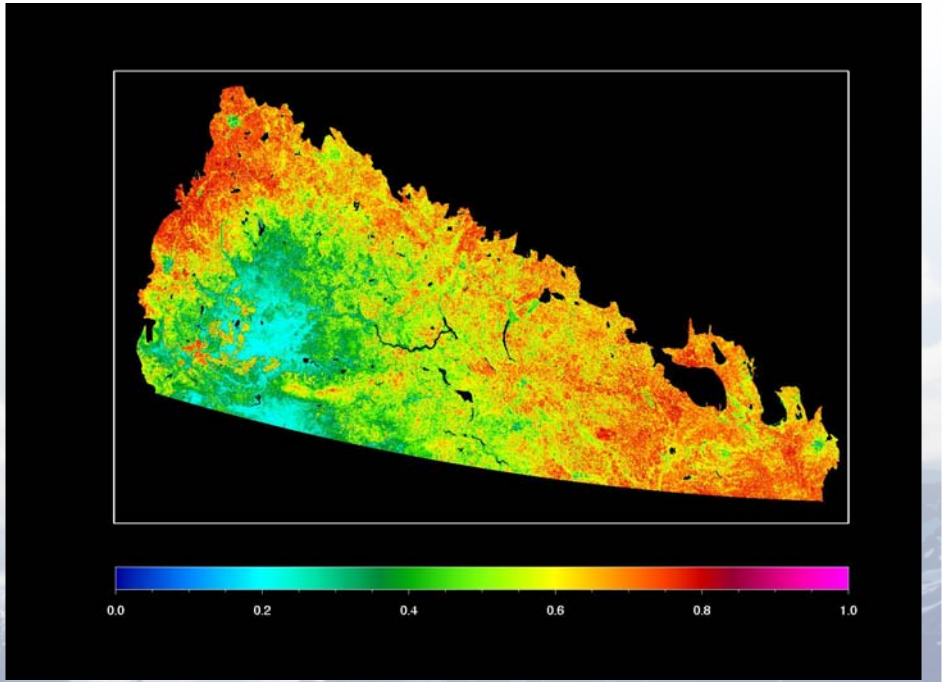


Modelled vs. satellite NDVI (July 11,2000)

EALCO

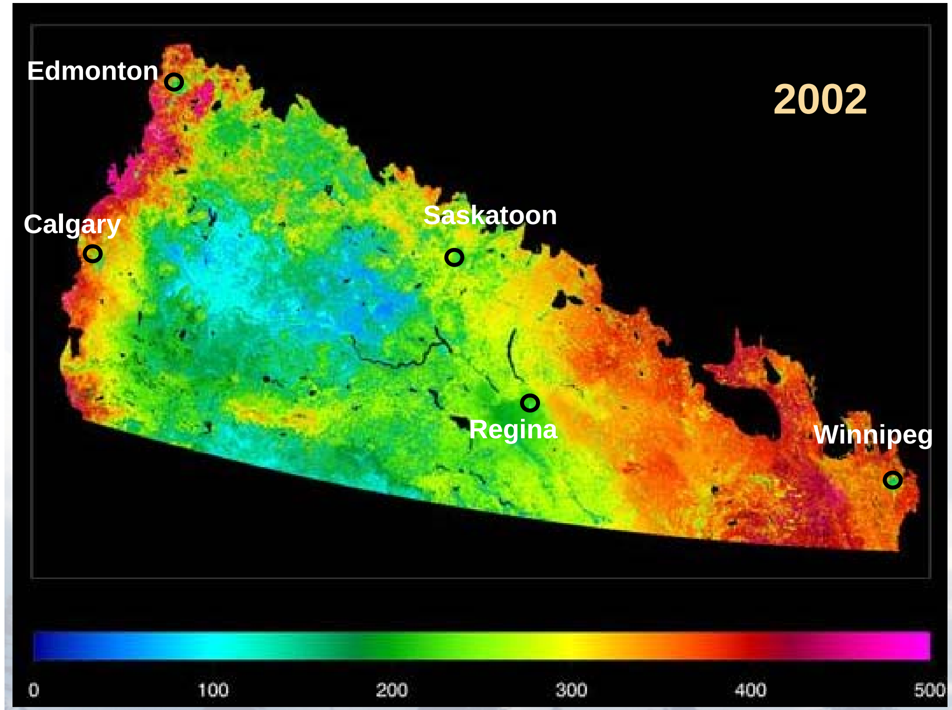


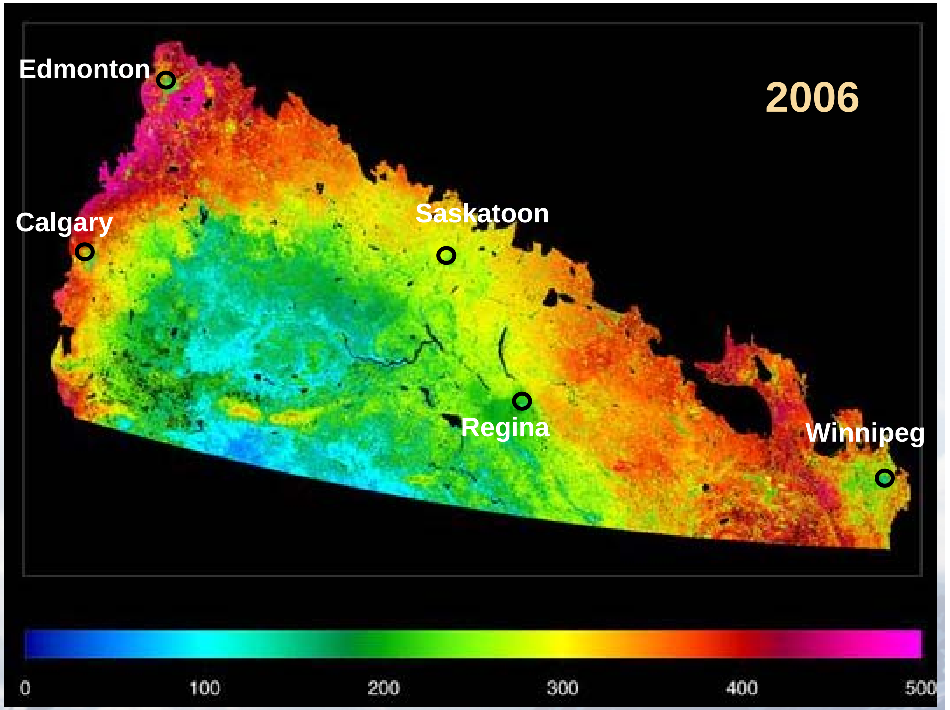
MODIS



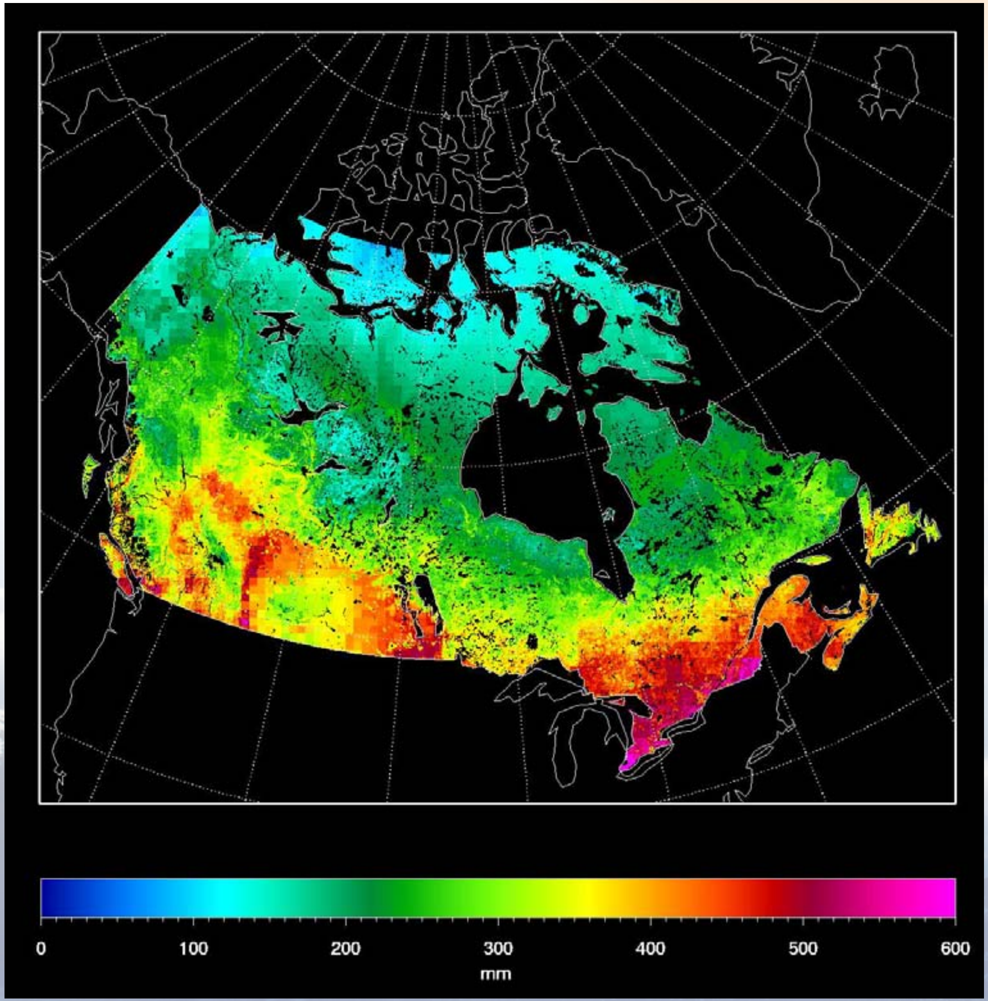
Plant Productivity

Plant productivity at 250m spatial resolution by EALCO





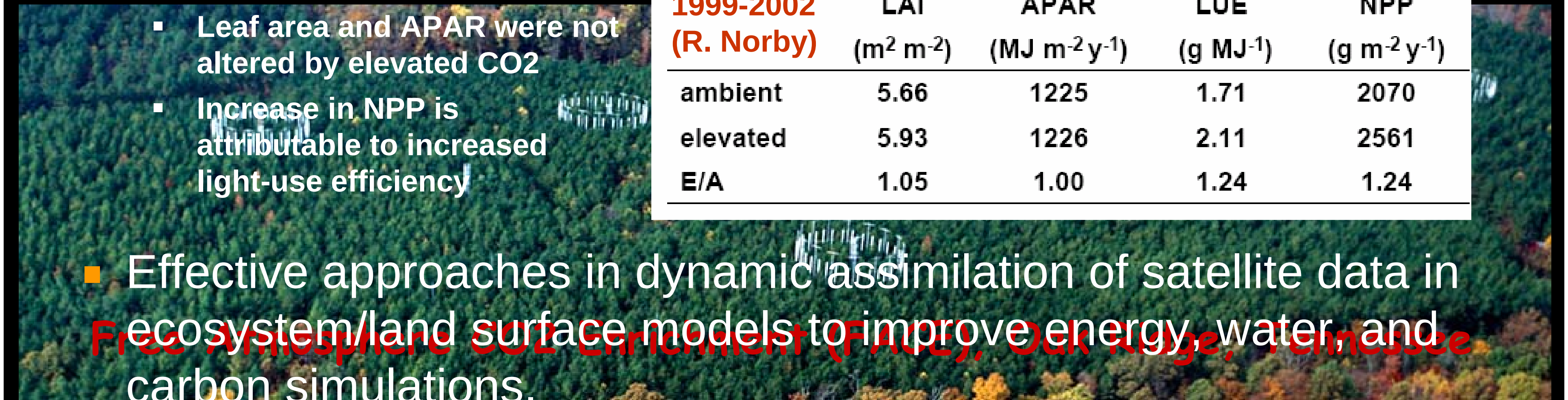
Evapotranspiration



Issues

- Sub-pixel LC variations and vegetation complexity.
- Dynamics of optical parameters under changing ecosystem conditions
  - e.g., Leaf reflectance change with leaf water potential (e.g., drought)
- Uncertainties in ecological interpretation of radiation absorption
  - e.g.,
    - **Leaf area and APAR were not altered by elevated CO2**
    - **Increase in NPP is attributable to increased light-use efficiency**

1999-2002 (R. Norby)	LAI ($m^2\ m^{-2}$)	APAR ($MJ\ m^{-2}\ y^{-1}$)	LUE ($g\ MJ^{-1}$)	NPP ($g\ m^{-2}\ y^{-1}$)
ambient	5.66	1225	1.71	2070
elevated	5.93	1226	2.11	2561
E/A	1.05	1.00	1.24	1.24



- Effective approaches in dynamic assimilation of satellite data in ecosystem/land surface models to improve energy, water, and carbon simulations.
- …