Evaluating vegetation albedo for a clumped, multi-level canopy radiative transfer scheme and impacts on simulated primary productivity and GISS GCM climate

Carlo Montes[1] (Carlo.Montes@nasa.gov), Nancy Y. Kiang[1], Wenze Yang[2], Wenge Ni-Meister[3], Crystal Schaaf[4], Igor Aleinov[5], Jeffrey A. Jonas[5], Feng Zhao[2], Tian Yao[4], Zhuosen Wang[4] and Qingsong Sun[4]
[1]NASA Goddard Institute for Space Studies, NY | [2]University of Maryland, College Park, MD | [3]Hunter College, City University of New York, NY
[4]University of Massachusetts - Boston, MA | [5]Center for Climate Systems Research, Columbia University, New York, NY

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

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Abstract A new Analytical Clumped Two-Stream (ACTS) canopy radiative transfer scheme was developed for the Ent Terrestrial Biosphere Model, the Dynamic Global Vegetation Model coupled to the NASA Goddard Institute for Space Studies (GISS) General Circulation Model (GCM) and its Land Surface Model. By accounting for foliage clumping and vegetation heterogeneities, ACTS allows a better representation of canopy radiative transfer with a minimal computational cost, and allows for prognostic calculation of canopy light transmittance and albedo for changing canopy structures. A very good performance was found in previous site-scale assessments, but the on-line evaluation at the global scale is pending. For this, coupled GISS GCM-Ent/ACTS simulations will be carried out and evaluated in terms of simulated vegetation albedo, primary productivity and climate sensitivity to the new canopy radiative transfer. Satellite-based observations of global vegetation canopy structure and different model configurations will be used to assessing model performance and improvements provided by ACTS.

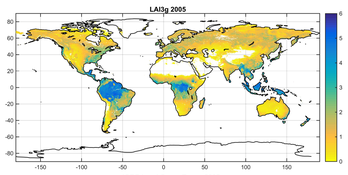
Motivation and objectives

Dynamic Global Vegetation Models (DGVMs) are now a common component of General Circulation Models (GCMs), and their coupling allows representing feedbacks between the atmosphere and the terrestrial biosphere. However, much of the uncertainties in capturing biosphere-atmosphere feedbacks arise from gaps in simulating ecosystem C fluxes by DGVMs due to homogeneous canopies representation in current DGVMs or non-linear relationship between vegetation features (leaf area index, height) and biomass. The biophysical processes determining C fluxes are closely related to the radiation environment, suggesting that a proper canopy radiative transfer physics along with structural features such as vertical stratification and vegetation clumping in DGVMs is crucial in order to accurately capture C fluxes. In the same direction, obtaining vegetation structure parameters such as plant densities and vertical foliage profiles (VFP) to be used as input to DGVMs is a relevant issue so as to optimize/constrain vegetation physical parameterizations which currently contribute to the large uncertainty in prediction of the C cycle.

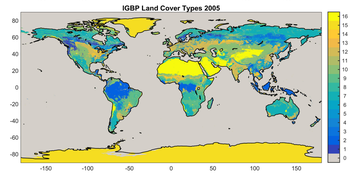
Under the working hypothesis of that a better canopy physics and structure representation can improve model performance in terms of radiative balance and carbon/energy fluxes, this work aims at evaluating the efficacy of a new canopy radiative transfer model, the Analytical Clumped Two-Stream (ACTS) model in the Ent Terrestrial Biosphere Model (Ent TBM). Impacts on climate will be examined in terms of land surface albedo, vegetation-atmosphere exchanges and climate feedbacks. For boundary conditions for ACTS, new satellite-derived datasets of global vegetation vertical canopy structure will be used.

Global Vegetation Structure Dataset (GVSD)

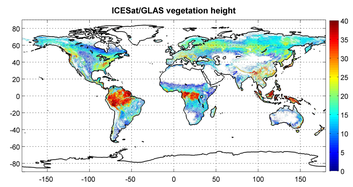
New vegetation parameters will be derived by using recently available satellite-based databases: plant densities, vertical foliage profile



GIMMS/MODIS LAI3g
Leaf Area Index (Zhu et al., 2013)



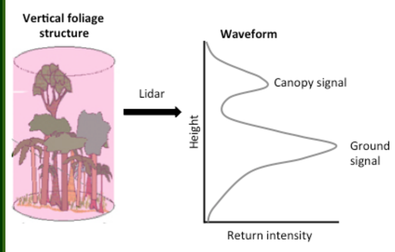
MODIS land cover classification (IGBP)
MODIS Plant Functional Types (PFTs)



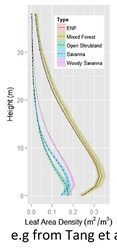
ICESat/GLAS Vegetation height
(Simard et al., 2011)

Observations from the Geoscience Laser Altimeter System (GLAS) on board ICESat (Ice, Cloud, and land Elevation Satellite) will be used to derive vertical foliage profiles:

- 1064 nm laser pulses
- Footprint diameter 65 m
- GLA01 product: waveform
- GLA14 product: gaussian fits to GLA01



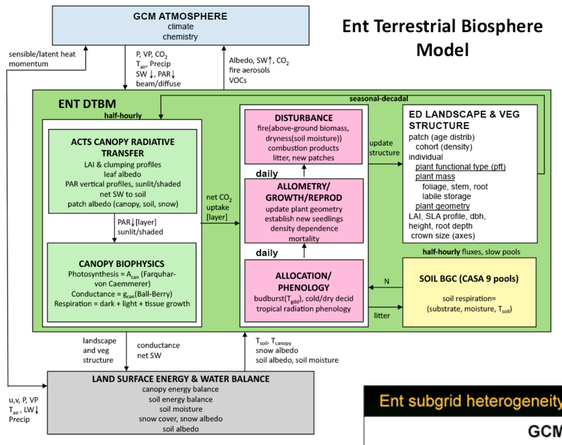
- Vegetation height
- Foliage profile



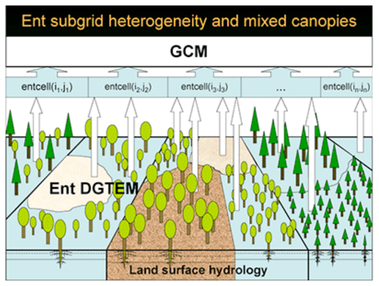
e.g from Tang et al., 2014

The Ent Terrestrial Biosphere Model (Ent TBM)

The Ent TBM is a next generation DGVM designed to be coupled with GCMs and LSMs. By accounting for vegetation height of mixed and dynamically changing canopies for a set of 17 PFT. Ent TBM introduces canopy heterogeneities in order to advance in both carbon fluxes (light use and respiration) and carbon stocks representation in DGVMS, along with the use of Lidar satellite data to constrain vegetation structure.



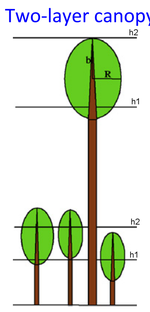
At the subgrid level, PFTs are represented by stratified cohorts organized in homogeneous patches.



The analytical clumped two-stream (ACTS) model

The ACTS model (Ni-Meister et al., 2010) is a canopy radiative transfer model combining an analytical expression derived from the Geometric Optical Radiative Transfer (GORT) scheme to account for foliage clumping and a two-stream scheme to solve the radiation absorbed, reflected, and transmitted within plant canopies for vertically-layered canopies with non-overlapped ellipsoidal crowns:

Two-layer canopy



Clumping factor

$$P_{gap}(\theta) = \exp\left(-\left(\frac{GL\gamma}{\cos\theta}\right) + \lambda S_{trk}\right)$$

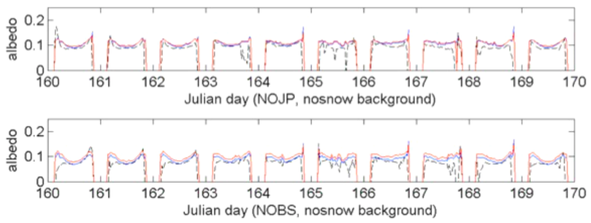
Trunk shading effect

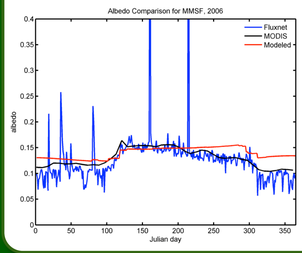
P_{gap} = canopy gap fraction
L = Leaf area index
θ = solar zenith angle
G = leaf orientation factor

Light profiles and albedo

- Vertical and horizontal heterogeneity of plant canopies
- Minimal computational cost

Comparison of FLUXNET measured (dotted line), ACTS (red) and full GORT (blue) half-hourly surface albedo during summer (1995) over pine (NOJP) and spruce (NOBS) forest.

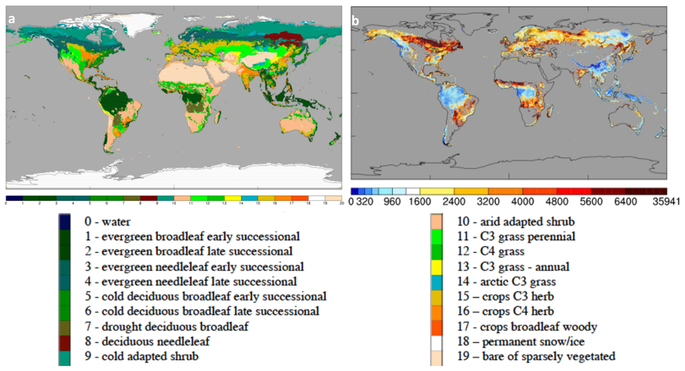




Comparison of MODIS (black), FLUXNET measured (blue) and ACTS modeled (red) noon surface albedo in 2006 over the Morgan-Monroe State Forest (IN, USA).

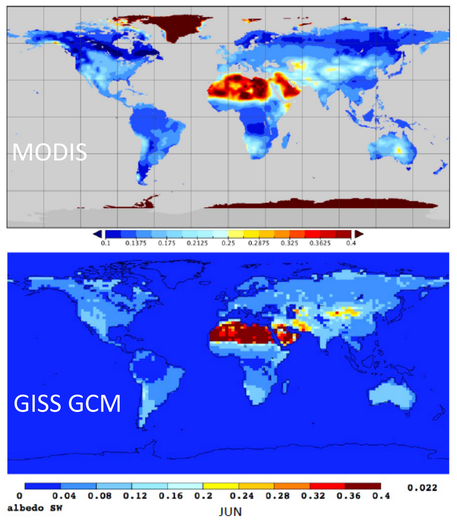
Preliminary results

1) Ent GVSD: a first version of the Ent GVSD was obtained by using datasets as the previously described in order to obtain estimates of dominant PFT cover (a) and plant densities by using allometric relationships (b).



2) ACTS: global off-line simulations

GISS GCM shortwave snow-free albedo from the preliminary Ent GVSD and bare soil albedoes from Rosenzweig and Abramopoulos (1997) and Matthews (1984). While the general pattern is similar, some discrepancies exist, likely associated with:



- Ent TBM v/s MODIS endmember spectral properties
- Inaccuracy in Ent TBM prescribed values of bare soil albedo

Current and future work

GVSD products:
- Stratified versions of the Ent GVSD
- Vertical foliage profiles derived from ICESat/GLAS

ACTS: on-line GISS GCM evaluation in terms of
- Impacts on surface albedo
- Gross primary productivity
- Simulated climate

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