The Ent Dynamic Global Terrestrial Ecosystem Model (Ent DGTEM):
What does it do, how does it do it,
and what can it do for you

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Harvard: Paul Moorcroft, Yeonjoo Kim
NASA-GSFC: Randy Koster

NASA-GISS, Lunch Seminar, October 8, 2008
COMMUNITY GOALS

SCIENTIFIC COMMUNITY:
ENT will be a standalone set of modules that can be used by the climate modeling community to couple with land hydrology models and atmospheric GCMs

NASA:
• Span the goals of Goddard, GISS, and NAI
• Use with:
  • GMAO modeling system to allow assimilation of satellite data
  • GISS GCM for long-term climate studies
  • Virtual Planetary Laboratory extrasolar planet models
Outputs: * Fast time scale fluxes of water, carbon, nitrogen and energy between the land surface and the atmosphere
* Diurnal surface fluxes
* Seasonal and inter-annual vegetation growth and soil biogeochemistry
* Decadal to century scale change in vegetation structure and soil C and N.

Approach: * Radiative transfer, biophysics, biogeochemistry, and ecological dynamics integrated in a consistent, prognostic, process-based manner
* Unique features: mixed vegetation canopies, coupled C and N cycles, leaf albedo function of photosynthetic N,
* Computationally efficient but biologically realistic
* Suitable for two-way coupling and parallel computing in GCMs

Research questions:
* seasonal weather evolution
* vegetation phenology
* the carbon budget
* climate variability
* paleoclimate
* global change scenarios
* vegetation-climate feedbacks
* astronomical biosignatures
Ent subgrid heterogeneity and mixed canopies

<table>
<thead>
<tr>
<th>entcell(i₁,j₁)</th>
<th>entcell(i₂,j₂)</th>
<th>entcell(i₃,j₃)</th>
<th>...</th>
<th>entcell(iₙ,jₙ)</th>
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GCM

Land surface hydrology

Ent DGTEM
Individual tree: C & N pools

Ellipsoid crowns for canopy radiative transfer

- foliage C & N
- stem = live + dead C&N
- root = fine + coarse C&N
- labile storage C & N

active tissue
dead tissue
Structured ecosystem model:
- discretization of size and age -structured partial differential equations
Ent Special Features

• Canopy radiative transfer:
  * Foliage clumping derived from Geometric-Optical Radiative Transfer model (GORT, Ni, et.al., 1999)

• Canopy biophysics: Two schemes

• Growth/allocation/allometry:
  * Daily updates
  * Consistent with ellipsoid crowns of radiative transfer scheme
  * Phenology (seasonality) includes tropical radiation seasonality, boreal cold hardening of photosynthetic capacity

• Ecological dynamics:
  * Disturbed patch-age and vegetation size-structured ensemble scheme of Moorcroft, et.al. (2001)
  * Fire (coming Spring 2009)
Ent “Core” Plant Functional Types (PFTs):

1-2: evergreen broadleaf, early and late successional*
3-4: evergreen needleleaf, early and late successional*
5-6: cold deciduous broadleaf, early and late successional
7: drought deciduous broadleaf
8: deciduous needleleaf
9: cold adapted shrub
10: arid adapted shrub
11: C3 grass - perennial
12: C4 grass
13: C3 grass - annual
14: arctic C3 grass
15: C4 crops - herbaceous
16: crops - woody broadleaf

*Based on Reich, et.al. (1999) data on specific leaf area/nitrogen/leaf longevity relations.
Diagnostics/outputs from Ent

LAI
Canopy conductance
CO₂ flux components
C stocks
Albedo
Vegetation cover types

Eventually:
VOCs
N fluxes and stocks
Fire emissions
Roughness length
Canopy heat capacity
## Progress to date

<table>
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<tr>
<th>Level 0:</th>
<th>Process</th>
<th>Summary</th>
<th>Site tests</th>
<th>Global offline</th>
<th>Coupled GISS GCM (prescr. CO2)</th>
<th>Coupled GMAO GCM (prescr. CO2)</th>
<th>Coupled GISS GCM (interactive CO2)</th>
<th>Future Work</th>
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<tbody>
<tr>
<td>Canopy radiative transfer</td>
<td>· Vertical light profiles with clumped foliage · Albedo</td>
<td>· Vertical light profiles many sites · Albedo · November: coupling to biophysics</td>
<td>MODIS - January GISS GHY - January</td>
<td>Jan 2009</td>
<td>Jan 2009</td>
<td>Jan 2009</td>
<td>Testing of EGVS-LIDAR</td>
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<tr>
<th>Level 1:</th>
<th>Process</th>
<th>Summary</th>
<th>Site tests</th>
<th>Global offline</th>
<th>Coupled GISS GCM (prescr. CO2)</th>
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<th>Coupled GISS GCM (interactive CO2)</th>
<th>Future Work</th>
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<tr>
<td>Biophysics</td>
<td>· Photosynthesis · Autotrophic respiration · Conductance of water vapor</td>
<td>· Boreal pine, temperate broadleaf deciduous, C3 annual grass, oak savanna · tropical rainforest, C4 grass (in progress)</td>
<td>GSWP2 1985- In progress 1996 testing</td>
<td>In progress</td>
<td>In progress</td>
<td>· In progress</td>
<td>· AR5 runs start: Jan 2009</td>
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<tr>
<th>Level 2:</th>
<th>Process</th>
<th>Summary</th>
<th>Site tests</th>
<th>Global offline</th>
<th>Coupled GISS GCM (prescr. CO2)</th>
<th>Coupled GMAO GCM (prescr. CO2)</th>
<th>Coupled GISS GCM (interactive CO2)</th>
<th>Future Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenology/allocation</td>
<td>· Timing of leafout and senescence · Allocation of carbon to foliage, stems, roots, reproduction</td>
<td>· Same sites as biophysics</td>
<td>Nov 2008</td>
<td>Jan 2009</td>
<td>TBA</td>
<td>March 2009</td>
<td>· AR5 runs? (unlikely)</td>
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<th>Coupled GMAO GCM (prescr. CO2)</th>
<th>Coupled GISS GCM (interactive CO2)</th>
<th>Future Work</th>
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<th>Veg data</th>
<th>Process</th>
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<th>Coupled GMAO GCM (prescr. CO2)</th>
<th>Coupled GISS GCM (interactive CO2)</th>
<th>Future Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land cover/use</td>
<td>· Construct Ent global vegetation structure (EGVS) dataset</td>
<td>Ent 16 PFT cover from MODIS cover + Matthews height in progress</td>
<td>Nov 2008</td>
<td></td>
<td></td>
<td></td>
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<td>Update with LIDAR data</td>
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</table>
Canopy radiative transfer for changing vegetation structure

GORT (Ni, et.al., 1999) ellipsoid crowns and gap probabilities

Clumped Beer’s law $f(\text{ellipticity, foliage density})$

- Vertical light profiles tested on boreal needleleaf forest, broadleaf deciduous, eucalyptus and being coupled to Ent biophysics
- Albedo tested on above, to be tested against MODIS albedoes

Canopy albedo
Canopy radiative transfer - field tests

LVIS Lidar foliage profiles - broadleaf

PAR transmittance
broadleaf forest

Albedo - boreal spruce

black--field value, blue--Full GORT, red—ana GORT
Ent global off-line preliminary runs
GSWP2 1986-1995 forcings

$$\text{NPP} = \text{GPP} - \text{Rauto}$$

$$\text{NEE} = \text{NPP} - \text{Rsoil}$$
Ent soil carbon spin-ups at Fluxnet sites

Comparison of Ent model to previous models

<table>
<thead>
<tr>
<th>PFT</th>
<th>kg-C/m²</th>
<th>no explicit depth structure (implicitly 0–30 cm)</th>
<th>with explicit depth structure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>fixed Q10</td>
<td>arctan</td>
</tr>
<tr>
<td>C3 grassland</td>
<td></td>
<td>2.8</td>
<td>1.5</td>
</tr>
<tr>
<td>Deciduous forest</td>
<td></td>
<td>8.6</td>
<td>2.1</td>
</tr>
<tr>
<td>Savanna</td>
<td></td>
<td>2.8</td>
<td>1.4</td>
</tr>
<tr>
<td>Evergreen needleleaf forest</td>
<td></td>
<td>58</td>
<td>18</td>
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</table>

Kharecha et al., in prep
Losses of Soil carbon (top 30 cm) during GSWP2 run from initial ISRIC-WISE:

- temperature & moisture responses
- litterfall?

Ent/GSWP2 soil carbon change 1983-1995
GISS GCM coupled runs

Land Carbon Fluxes: Net sink 41.6 Gt-C/yr (Pg-C/yr)

GPP = Gross primary productivity

R_auto = Plant respiration

R_soil = Soil respiration

NEE = GPP - R_auto - R_soil

Interactive CO₂: Land currently a net sink at pre-industrial climate
Fix: phenology, new land cover specs., allocation/litter scheme, etc.
Phenology - Site Evaluation

- Temperate – Harvard Forest, Morgan Monroe State Forest
- Mediterranean – Vaira Grassland, Tonzi Savanna
- Boreal - Hyytiala pine forest, Finland
- Tropical – Tapajos National Forest (in progress)
- Tundra - Barrow (in progress)

November:
Tundra then
Global off-line tests

LAI

Cold-deciduous broadleaf
IN

Cold-deciduous broadleaf
MA

Cold/drought-deciduous bl.
CA

C3 annual grass
Tonzi, CA

C3 annual grass
Vaira. CA

air temperature

air temperature

air temperature

plant available water

plant available water

Tropical rainforest
Amazon

Boreal pine forest
frost hardening, Finland

Red - measurements
Black - Ent

CO₂ flux
Ent HOW-TO Demo: cvs checkout GISSClim

[entkian@gis5cclim/GISSClim] nkian% ls

CVS  workspace  ent
CVS  makefile  r_ent_fbb.mk
CVS  include  mod  scripts  src

WorkSpace:
CVS  Makefile  README_Entstandalone  r_ent_fbb.mk  r_ent_fbb_SGI.mk  r_1mm_ent_fbb.mk  r_1mm_ent_fbb_quark.mk
arch:
CVS  Rules.make  base.mk
decks:
CVS  lam_standalone.R
include:
CVS  rundeck_opts.h
mod:
CVS  REALME  mpi_defs.h
scripts:
CVS  comp_mkdep.pl  ent_copy_forcings  ent_gondoc.pl  pproc_dep.pl  srmakedepend
src:
CVS  Ent_standalone  drivers  gisS_LSM
Ent  Makefile  gisS_LSM_standalone  main_ent.f
foo  gisS_LSM_standalone  main_lsm.f

Ent:
CVS  entries  Repository  Root

#canopyradiation.f #canopyspritters.f
CVS  Makefile  REALME  disturbance.f  ent_pfts_ENT.f  phenoLOGY.f
CVS  Workspace  ent.f  ent_prescribed_drv.f  reproduction.f
FIBspts.f, -1.12,-  canopyspritters.f  ent_1mm_drv.f  ent_prescribed_updates.f  soilg.t.f
FIBspts.ENT.f  canopyspritters.f  ent_1mm_drv.f  ent_types.f  util.f
FIBspts_ENT.f, -1.21,-  canopyspritters.f  ent_mod.f  ent_type.f  utility.f
FIBphotosynthesis.f  coherents.f  ent_pfts.f  patches.f

Ent_standalone:
CVS  HOW-TO  Makefile  ent_forcings.f  ent_prog.f  entrc.example

drivers:
CVS  lam_standalone.f

gisS_LSM:
CVS  CHY_COM.f  CHY_ENT.f  Makefile  SNOW_DRV.f  VEG_COM.f  rundeck_opts.h
CHY.f  CHY_drv.f  CHY_ENT_drv.f  snow.f  vegetation.f  veg_drv.f

gisS_LSM_standalone:
CVS  Makefile  domain_decomp.f  drv_export_forc.f  lam_standalone.f  mmao_utils.c  sys_utils.c

shared:
CVS  CONFG f  Makefile  PARAM.f  PARSER.f  SYSTEM.f  TRIGIAG.f  UTILBLL.f
Warning: GCM/GHY biases

Temperature, soil moisture, Cloudiness/radiation

TOTAL Evapotranspiration

Too much canopy interception:
How GCM uses canopy conductance.
- Also adversely affects GPP.

Canopy interception fraction

Transpiration fraction

Off-line GSWP2 runs with GISS ground hydrology

Soil evaporation fraction
Acknowledgments

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References


