Advancing Representation of Terrestrial Physics to Support Water-Carbon Coupling in GFDL’s Earth-System Models

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Water and Carbon Coupling at Regional Scales: Key Issues and a New Approach
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Once upon a time, anthropogenic climate change was very simple. CO$_2$ emissions raised atmospheric CO$_2$ concentrations, which affected radiative transfer, which warmed and moistened the lower atmosphere, affecting precipitation, soil moisture, and runoff. Some details remained to be worked out.
Questions:

• How does land (soil, vegetation, topography) contribute to the determination of global climate and water cycle?
• How does climate change affect the water cycle and water availability?

• How does (did, will…) vegetation disturbance (natural and anthropogenic) and recovery affect the global carbon cycle? What is the role of water?
• How does vegetation disturbance and recovery directly affect climate and global water and energy cycles?
• How do ecosystems respond to changes in the global carbon cycle? What is the role of water?
• How does climate change affect the carbon cycle through terrestrial and aquatic ecosystems?
• How does climate respond to development of water resources?
• How does sea level respond to development of water resources?
• What role does land play in generating long-term persistence in the climate system?
• How can new observational technologies be exploited to improve land models?
canopy interception, throughfall, etc.

photosynthesis
respiration
carbon fluxes
dynamic vegetation

multi-layer
snow pack

multi-layer soil
sat/unsat
frozen/unfrozen

plant phenology
fire
land clearance, wood harvesting
\[ \frac{\partial (\theta_l + \theta_s)}{\partial t} = \frac{\partial}{\partial z} \left[ K \left( \frac{\partial \psi}{\partial z} - 1 \right) \right] - r - g \]

\[ \frac{\partial [C(\theta_l, \theta_s)T]}{\partial t} - L_f \frac{\partial s}{\partial t} = \frac{\partial}{\partial z} \left[ \lambda \frac{\partial T}{\partial z} - q_l c_1 T \right] - h_r - h_g \]

\[ K = \left[ \alpha(z) \right]^2 K_{ref} \left( \theta_l \right) \]

\[ \psi = \psi_{ref} \left( \theta_l, \theta_s \right) / \alpha(z) \]

\[ \alpha(z) = \alpha_\infty + (\alpha_0 - \alpha_\infty) \exp \left( -\frac{z}{z_s} \right) \]
landscape-based groundwater divergence and saturated areas
\[ w(x)T(D) \frac{d}{dx} [z(x) - D] = q \int_{x}^{l} w(x') dx' \quad D > 0 \]

\[ T(D) = K_b b + K_s z_s \exp\left(-\frac{D}{z_s}\right) \]
sub-grid partitioning of grid area

~20-layer lake, with ice cover, snow pack

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Normalized-Difference Vegetation Index, Annual Mean

Observed data from MOD43C2 V004 MODIS BRDF/Albedo Parameters 16-day L3 Global 0.05-Degree Climate Modeling Grid (CMG) Binary Data Sets
Annual Range of Vertically Integrated Water-Mass Storage (kg m$^{-2}$)

Observed data from the GRACE mission as processed by the Center for Space Research, Univ. of Texas.
Lake-Level Variations (m)

Observed data from USDA/FAS/OGA and NASA Global Agricultural Monitoring Project. Lake surface height variations from the USDA’s Global Reservoir and Lake web site. Altimetric lake-level time-series variations from the Topex/Poseidon and Jason-1 missions.
Basin Runoff Ratios

Good news, bad news.
Depth to Water Table or Permafrost (m)
Permafrost Extent

Yellow: permafrost present; MAAT below freezing
Red: permafrost absent; MAAT below freezing
Blue: permafrost present; MAAT above freezing
Summary Comments

• Extended scope/”granularity,” qualitatively realistic
  – Soil water profile (vs. “bucket”)
  – Permafrost and seasonal freezing
  – Landscape-driven heterogeneity
  – Rivers
  – Lakes
  – Groundwater
  – Framework for water use
• Improvement/degradation of water-balance partitioning
• Work in progress
  – Input data sets -> parameters
  – Hillslope tiling
  – Water use and irrigation
• Applications: Return to the questions