The Integrated Biosphere Simulator (IBIS) Version 2-- Overview and Philosophy
Life before IBIS

3 different classes of models:

- *Land surface models* (SVATs): BATS, SiB, LSX, LSM, etc.

- *Biogeography models*: BIOME, MAPPS, etc.

- *Terrestrial biogeochemistry models*: TEM, CENTURY, CASA, BGC, DEMETER, etc.
Past Model Characteristics

• *Land surface models* -- fixed vegetation, limited biogeochemistry

• *Biogeography models* -- limited energy & water balance, limited biogeochemistry

• *Biogeochemistry models* -- fixed vegetation, limited energy & water balance

*Can we build one model that integrates all these different processes and more?*
IBIS global terrestrial ecosystem model
Links Processes Across Different Time Scales

“Fast” responses
• Land surface processes: fluxes of energy, water, momentum
• Canopy physiology: photosynthesis, respiration

“Medium” processes
• Vegetation phenology: leafout, senescence, dormancy

“Slow” processes
• Vegetation growth (transient vegetation dynamics)
• Above & below-ground carbon & nitrogen cycling
Integrated Biosphere Simulator (IBIS)-2

**ATMOSPHERE**
- Nitrogen cycling
- Nitrogen mineralization
- Nitrification
- Denitrification

**VEGETATION DYNAMICS MODULE**
- Gross primary production
- Total respiration
- Net primary production
- Allocation and turnover
- Growth of leaves, stems & roots
- Mortality & disturbance

**LAND SURFACE MODULE**
- Canopy physics
  - Energy balance
  - Water balance
  - Aerodynamics
- Soil physics
  - Energy balance
  - Water balance
- Plant physiology
  - Photosynthesis & leaf respiration
  - Stomatal conductance

**VEGETATION PHENOLOGY MODULE**
- Canopy nitrogen allocation
- Budburst
- Senescence
- Dormancy

**BELOWGROUND CARBON & NITROGEN CYCLING MODULE**
- Carbon cycling
  - Decomposition of litter & soil organic matter
- Nitrogen cycling
  - Nitrogen mineralization
  - Nitrification
  - Denitrification

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physiologically based formulations of canopy photosynthesis and conductance

physically-based model of snow temperature, extension and depth

physically-based model of soil temperature, soil moisture and soil ice with depth
IBIS Formulations

• *Canopy physics:*
  – Solar & Infrared radiative transfer
  – Two-stream approximation
  – Diffusive & turbulent fluxes of heat and water vapor through canopy and soils (including soil ice)
  – Wind speeds through the canopy

• *Soil physics*
  – Water, ice (Richard’s equation)
  – Darcy’s Law for vertical water flux
IBIS Formulations

- **Canopy physiology:**
  - Mechanistic photosynthesis (Farquhar et al. 1980)
    - Light and water limitations
  - Semi-mechanistic stomatal conductance (Ball & Berry)
  - Coupled photosynthesis-stomatal conductance model (Collatz et al. 1991)
    - => coupled flow of carbon & water
  - Canopy scaling (APAR within canopy for net assimilation)
IBIS Formulations

- **Canopy phenology:**
  - Budburst and litterfall of winter-deciduous plants based on climatic limits, constraints, accumulated GDD
  - Drought deciduous plants respond to net canopy carbon budget
IBIS Formulations

- Vegetation Dynamics:
  - 12 Plant Functional Types (PFTs)
    - 8 in upper canopy (trees)
    - 4 in lower canopy (shrubs and cool/warm grasses)
  - Compete for light & water
    - LAI - Shading - radiation; root profiles
  - Competition is a consequence of the annual carbon balance
  - Geographic distribution
    - Cold tolerance limits, growing degree-day requirements, and minimum chilling requirements
Table 1.

**Description of IBIS-2 Plant Functional Types (PFTs)**

Foley et al., 1996; Kucharik et al., 2000 Global Biogeochemical Cycles
IBIS Formulations

- *Soil biogeochemistry*:
  - CENTURY-like model
  - Active microbial pool
  - Daily timestep
IBIS Soil Biogeochemistry Submodel

C:N (roots 60, leaves 40, wood 200)

Litter Pools (above and belowground)
  Turnover ~ days to weeks (k value)
  DPM - decomposable plant material (C/N ~ 6)
  SPM - Structural plant material (C/N ~ 100)
  RPM - Resistant (lignin) plant material (C/N ~ 150)

Microbial Biomass (labile)
  Turnover ~ weeks - months (k value)
  C/N ~ 8-10

Slow C Pools (POM/NOM)
  Turnover ~ 10-20 years (k value)
  C/N ~ 10-12

Passive C Pools (stabilized/recalcitrant)
  Turnover ~ 100s-1000s of years (k value)
  C/N ~ 10-12

C Mineralized/CO$_2$ Released
N Immobilized/Mineralized

Litterfall for natural vegetation
  Spread evenly (daily) across entire year

Adapted from Kucharik et al., 2000 - Global Biogeochemical Cycles
A few other notes about the biogeochemistry model…

• Numerical acceleration is needed to establish equilibrium of C and N pools

• K values (decomposition constants) are modified by soil temperature (Lloyd & Taylor, 1994) and moisture (Linn and Doran, 1984); which influence microbial activity
  – Aboveground litter pool - surface layer
  – All other soil C pools by weighted average soil temperature and moisture (by root profile)

• We do not explicitly simulate soil C & N as a function of soil layer

• Current leaching values of DOC are more of a “fudge” so that C does not build up exponentially in soils

• Classes of microbes are not simulated; they are assumed to all behave similarly to soil T and moisture regardless of biome type
IBIS Implementation

- Offline and coupled modes (GCM)
  - Requires temperature, wind speed, radiation, humidity, precip
- Hourly time step (normally)
- Climate data – daily or monthly mean, gridded values
  - Climatology (30-yr average climate : 1981-2010)
  - Inter-annual variability (CRU: 1901-2007)
    - 0.5 degree resolution local to global scale
  - 8km x 8km resolution with ZedX daily climate dataset (1948-2007)
  - Weather generator used to get daily/sub-daily values

- Soil data (texture) as function of depth (IGBP - Global STATSGO - US) - lookup table for properties

- Mode: cold-start, dynamic vegetation, fixed vegetation
- Coupling to THMB (terrestrial hydrology model with biogeochemistry)
Examples of IBIS-2 Model Output

• From Kucharik et al., 2000 published in *Global Biogeochemical Cycles*
Plate 4c. Simulated Vegetation Types

From Kucharik et al., 2000 *Global Biogeochemical Cycles*
Plate 1a. Simulated Runoff

Plate 1b. Observed Runoff

From Kucharik et al., 2000 Global Biogeochemical Cycles
Cogley
Simulated yrs 176-200

From Kucharik et al., 2000 *Global Biogeochemical Cycles*
Figure 4

From Kucharik et al., 2000 Global Biogeochemical Cycles
From Kucharik et al., 2000 Global Biogeochemical Cycles

Plate 6a. Simulated Total Soil Carbon Density
Plate 6b. Observed Soil Carbon Density
Plate 6d. Simulated Total Litter Carbon (Aboveground and Fine Root)
Plate 6d. Simulated Mean Carbon Residence Time in Litter and Soil Carbon
From Kucharik et al., 2000 *Global Biogeochemical Cycles*
From Kucharik et al., 2000 Global Biogeochemical Cycles

**Plate 7a. Simulated Microbial Biomass Carbon**

**Plate 7b. Simulated Total Soil Carbon Respiration (Fine Root and Microbial)**
### IBIS-2 Annual Average Global Quantities for Contemporary Biosphere 1965-1994

**Table 4.**

<table>
<thead>
<tr>
<th>Biome</th>
<th>Area $^1$ ($10^6$ km$^2$)</th>
<th>GPP $^1$ (Gt C yr$^{-1}$)</th>
<th>NPP $^1$ (Gt C yr$^{-1}$)</th>
<th>LAI m$^2$ m$^{-2}$</th>
<th>Biomass $^1$ (Gt C m$^{-2}$)</th>
<th>FRB, $^1$ (Gt C m$^{-2}$)</th>
<th>$\tau$ <em>veg</em> years</th>
<th>Litter $^1$ (Gt C m$^{-2}$)</th>
<th>SOM $^1$ (Gt C m$^{-2}$)</th>
<th>$\tau$ <em>som</em> years</th>
<th>MB $^1$ (Gt C m$^{-2}$)</th>
<th>Soil CO$_2$ $^1$ (Gt C yr$^{-1}$)</th>
<th>NEE $^1$ (Gt C yr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical evergreen forest</td>
<td>19.30</td>
<td>1.89</td>
<td>0.90</td>
<td>6.8</td>
<td>9.1</td>
<td>0.18</td>
<td>10.0</td>
<td>0.60</td>
<td>9.5</td>
<td>11.2</td>
<td>0.20</td>
<td>1.15</td>
<td>0.037</td>
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<tr>
<td>Tropical deciduous forest</td>
<td>7.70</td>
<td>1.23</td>
<td>0.57</td>
<td>4.2</td>
<td>5.4</td>
<td>0.11</td>
<td>9.4</td>
<td>0.42</td>
<td>7.9</td>
<td>11.4</td>
<td>0.12</td>
<td>0.70</td>
<td>0.053</td>
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<td>Temperate broadleaf evergreen forest</td>
<td>7.20</td>
<td>1.57</td>
<td>0.83</td>
<td>6.2</td>
<td>8.2</td>
<td>0.16</td>
<td>9.8</td>
<td>0.88</td>
<td>13.8</td>
<td>16.5</td>
<td>0.24</td>
<td>0.96</td>
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<td>Temperate needleleaf evergreen forest</td>
<td>3.29</td>
<td>1.14</td>
<td>0.57</td>
<td>4.3</td>
<td>5.9</td>
<td>0.20</td>
<td>10.5</td>
<td>0.59</td>
<td>11.0</td>
<td>24.3</td>
<td>0.20</td>
<td>0.71</td>
<td>0.037</td>
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<tr>
<td>Temperate deciduous forest</td>
<td>9.67</td>
<td>1.14</td>
<td>0.62</td>
<td>4.6</td>
<td>8.3</td>
<td>0.16</td>
<td>13.5</td>
<td>0.81</td>
<td>13.7</td>
<td>23.1</td>
<td>0.21</td>
<td>0.66</td>
<td>0.049</td>
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<tr>
<td>Boreal evergreen forest</td>
<td>14.50</td>
<td>0.66</td>
<td>0.37</td>
<td>3.3</td>
<td>5.5</td>
<td>0.13</td>
<td>15.1</td>
<td>0.81</td>
<td>19.4</td>
<td>54.0</td>
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<tr>
<td>Boreal deciduous forest</td>
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<td>0.55</td>
<td>0.33</td>
<td>2.7</td>
<td>6.2</td>
<td>0.08</td>
<td>18.5</td>
<td>1.33</td>
<td>24.4</td>
<td>80.5</td>
<td>0.12</td>
<td>0.29</td>
<td>0.026</td>
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<td>Evergreen/deciduous mixed forest</td>
<td>4.23</td>
<td>0.91</td>
<td>0.48</td>
<td>3.8</td>
<td>7.6</td>
<td>0.14</td>
<td>15.8</td>
<td>0.89</td>
<td>13.4</td>
<td>35.8</td>
<td>0.17</td>
<td>0.50</td>
<td>0.039</td>
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<td>Savanna</td>
<td>5.34</td>
<td>0.93</td>
<td>0.35</td>
<td>3.3</td>
<td>2.4</td>
<td>0.13</td>
<td>6.7</td>
<td>0.29</td>
<td>6.5</td>
<td>20.3</td>
<td>0.12</td>
<td>0.61</td>
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<td>Grassland/steppe</td>
<td>21.20</td>
<td>0.76</td>
<td>0.24</td>
<td>2.8</td>
<td>0.4</td>
<td>0.13</td>
<td>1.8</td>
<td>0.08</td>
<td>7.6</td>
<td>32.3</td>
<td>0.10</td>
<td>0.53</td>
<td>-0.005</td>
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<td>Dense shrubland</td>
<td>1.50</td>
<td>0.44</td>
<td>0.22</td>
<td>2.2</td>
<td>0.9</td>
<td>0.13</td>
<td>4.2</td>
<td>0.41</td>
<td>7.2</td>
<td>37.8</td>
<td>0.09</td>
<td>0.27</td>
<td>0.025</td>
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<td>Open shrubland</td>
<td>6.02</td>
<td>0.17</td>
<td>0.05</td>
<td>0.7</td>
<td>0.3</td>
<td>0.03</td>
<td>7.3</td>
<td>0.08</td>
<td>1.8</td>
<td>57.1</td>
<td>0.03</td>
<td>0.15</td>
<td>-0.040</td>
</tr>
<tr>
<td>Tundra</td>
<td>6.24</td>
<td>0.39</td>
<td>0.21</td>
<td>2.3</td>
<td>0.3</td>
<td>0.10</td>
<td>1.5</td>
<td>0.75</td>
<td>30.1</td>
<td>138.6</td>
<td>0.10</td>
<td>0.24</td>
<td>0.018</td>
</tr>
<tr>
<td>Desert</td>
<td>18.80</td>
<td>0.02</td>
<td>0.001</td>
<td>0.1</td>
<td>0.04</td>
<td>0.004</td>
<td>38.4</td>
<td>0.01</td>
<td>0.4</td>
<td>398.2</td>
<td>0.006</td>
<td>0.022</td>
<td>-0.013</td>
</tr>
<tr>
<td>Polar Desert/Rock/ice</td>
<td>0.83</td>
<td>0.02</td>
<td>0.02</td>
<td>0.2</td>
<td>0.03</td>
<td>0.007</td>
<td>1.7</td>
<td>0.11</td>
<td>5.5</td>
<td>143.1</td>
<td>0.007</td>
<td>0.017</td>
<td>0.002</td>
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<tr>
<td>Global Average</td>
<td>0.87</td>
<td>0.41</td>
<td>3.4</td>
<td>4.2</td>
<td>4.2</td>
<td>0.15</td>
<td>13.4</td>
<td>0.49</td>
<td>10.6</td>
<td>89.6</td>
<td>0.13</td>
<td>0.33</td>
<td>0.0174</td>
</tr>
</tbody>
</table>

$^1$We note that Greenland, part of the Canadian Archipelago and Antarctica are not included in IBIS simulations.

From Kucharik et al., 2000 *Global Biogeochemical Cycles*
What has IBIS-2 given us?

- An ecosystem modeling tool
  - Dynamic Global Ecosystem Model (DGEM)
- Capability to simulate vegetation competition - structure - function
- Global Water Balance
- Global Carbon Balance