Regional Model-Data Comparison: An NACP Interim Synthesis Project

Coordinators: Andy Jacobson, Mac Post, Debbie Huntzinger, Bob Cook

Participants: Dozens of modeling teams and data providers, Canada, USA, Mexico, Europe
Regional MDC Questions with Focus on North America

• Interannual Variation
  – What is the spatial pattern and magnitude of interannual variation in carbon fluxes during 2000-2005?
  – What are the components of carbon fluxes and pools that contribute to this variation?

• 2002 Drought
  – Do model results and observations show consistent spatial patterns in response to the 2002 drought?
  – From measurements and ecosystem models, can we infer what processes were affected by the 2002 drought?

• Identification of Sources/Sinks
  – What are the magnitudes and spatial distribution of carbon sources and sinks, and their uncertainties during 2000-2005?
CarbonTracker Estimated C Source/Sink

CarbonTracker Inversion Model, Net Terrestrial Summer Flux (gC/m²/yr)

www.esrl.noaa.gov/gmd/ccgg/carbontracker/
Figure 8. NEP maps for the coterminous United States from 2000 to 2004. Units are in Pg C per year, with red shading as annual C sinks and blue shading as annual C sources.
Use of Multiple Data Sources

- CO$_2$ Flux
- Flux tower sites
- Forward Models
- MODIS
- Survey Data

Data Sources:
- GPP, LAI, NPP
- Soil C, Crop NPP, Forest Biomass

Locations:
- continent
- region
- site
Regional MDC Objectives

- Development of benchmark data sets and approaches for model-data evaluation.
- Evaluation of strengths and weaknesses of various model formulations, both inverse models and ecosystem models resulting from the comparison to data.
- Formal comparison of inverse and forward ecosystem model results for enhancing identification and diagnosis of temporal and spatial patterns of carbon fluxes.
- Understanding of mechanistic processes which lead to model differences
Synthesis of Interim NACP Results

Ecosystem Models

• Contribute in hand regional, continental results (including ones cut from global analyses)
• A range of temporal and spatial resolutions
• *No standardization of model runs!*

Inversion Models

• Contribute North America results in hand from TRANSCOM or from other relevant activities
• Spatial scales
  – TRANSCOM regions, and
  – 1° grids centered on half-degrees
• Temporal scale - monthly
## Ecosystem (Forward) Models

<table>
<thead>
<tr>
<th>Forward Models</th>
<th>Time Period</th>
<th>Time Granularity</th>
<th>Spatial Granularity</th>
<th>Data Format</th>
<th>Data Content</th>
<th>Info</th>
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<tbody>
<tr>
<td>CLM-CASA</td>
<td>2000-2004</td>
<td>Monthly</td>
<td>Global</td>
<td>netCDF</td>
<td>GPP, NPP, NEE, NEF, TIAI, landfrac, LEAFC, LITTER, SOILC, WOODC, CWDC, FROOTC</td>
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<td>netCDF</td>
<td>NEE</td>
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<tr>
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<td>N. America</td>
<td>netCDF</td>
<td>NEE</td>
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<td>CASA GFed2</td>
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<td>Monthly</td>
<td>N. America</td>
<td>netCDF</td>
<td>NEE, GPP, R (Ra+Rh)</td>
<td>Info</td>
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<td>TEM6</td>
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<td>N. America &gt;45°N</td>
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<td>ISO-LSM</td>
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<td>Daily</td>
<td>ARM-CART</td>
<td>netCDF</td>
<td>FC02 (NEE)</td>
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<td>Oregon</td>
<td>netCDF</td>
<td>GPP, NPP, NAP, auto_resp, hetero_resp, wman</td>
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<td>DLEM</td>
<td>2000-2005</td>
<td>Monthly</td>
<td>N. America</td>
<td>netCDF</td>
<td>GPP, NEE, NPP, Ra, Rh, TotLivBiom, TotSoilCarb</td>
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<td>MOD17</td>
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<td>netCDF</td>
<td>GPP, Reco</td>
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<td>N. America</td>
<td>netCDF</td>
<td>NPP, resp (Rh), NEE</td>
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</table>

Inversion Models

• **Results by Transcom Regions**
  – Transcom3 IAV inversion (D Baker), 13 models
  – Rödenbeck Jena, 3 different networks
  – CarbonTracker
  – FRCGC Japan (Patra)
  – U Michigan geostat, 2 models
  – LSCE France (Peylin)
  – LSCE France (Chevallier)
  – LSCE France (Rayner)
  – Penn State (Butler), 2 models

• **Results by 1 degree**
  – U of Toronto
  – CarbonTracker
  – LSCE
  – Jena
  – U of Michigan
  – MLEF-PCTM – Colorado State University
Observations and Measurements

• Satellite based
  – In Hand:
    • MODIS GPP
    • MODIS NPP (annual)
    • MODIS LAI, FPAR, NDVI, EVI (gap filled, smoothed – from MODIS for NACP)

• Survey
  – In Hand:
    • NASS crop yield based annual NPP
    • Soil C (WISE-FC version 3.0), 30cm, 100cm
    • FIA based biomass
  – In Development:
    • Fast-track change in forest/agriculture C stocks for Canada, USA, Mexico

• Site based
  – Eddy flux NEE, estimated GPP, NPP

All of these are not strictly direct measurements and involve some level of model intervention
Conversion to Common Grid - both Data and Model

• Spatial Resolution: 1°x1°, centered at (x.5, y.5 for each grid cell)
• Domain: 50° to 170° W longitude, 10° to 84° N latitude
• Temporal Resolution: monthly (or annual)
• netCDF files, CF-1 convention
  • ftp://nacp.ornl.gov/synthesis/2008/firenze/continental
Fast-Track Inventory-based data for evaluation of Forward Ecosystem Models

- Organization of Inventory-Based Information
- By 48/49 states in the U.S. (Alaska not available)
- By 18 reporting units in Canada
- By states in Mexico
- Aggregated estimates for 2000-2005

### Agriculture Data by County

<table>
<thead>
<tr>
<th>Sub-region</th>
<th>Cropland area</th>
<th>Soil C</th>
<th>Delta Soil C</th>
<th>NPP</th>
<th>RH</th>
<th>NEE</th>
<th>Harvest Removals</th>
<th>Fire Emissions</th>
<th>Area Burned</th>
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<td>U.S.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X (252 Tg)</td>
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<td>?</td>
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<tr>
<td>Mexico</td>
<td>X</td>
<td>X</td>
<td></td>
<td>?</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
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</table>

### Forest Data by State

<table>
<thead>
<tr>
<th>Sub-region</th>
<th>Forest area</th>
<th>Veg C</th>
<th>Delta Veg C</th>
<th>NPP</th>
<th>RH</th>
<th>NEE = (NPP – RH – Fire Emissions)</th>
<th>Harvest Removals</th>
<th>Fire Emissions</th>
<th>Area Burned</th>
</tr>
</thead>
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<tr>
<td>Canada</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X (45 Tg)</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>U.S.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X (140 Tg)</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Mexico</td>
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<td></td>
<td></td>
<td>X</td>
<td>?</td>
<td>?</td>
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</table>
Inverse Models

- Produce model predictions of atmospheric CO$_2$ mole fractions
- Compare with the observed atmospheric CO$_2$ mole fraction
- Difference between them is attributed to differences in estimated (first guess) and the actual sources and sinks
- Numerical techniques, reduce these differences and solve for a set of sources and sinks that most closely matches the observed CO$_2$ mole fraction
Inverse models: Seasonal NEE cycle for North American Temperate

PgC/yr

Mar May Jul Sep Nov

-10 -5 0 5

t3iav.CSU.gurney t3iav.MATCH.bruhwiler t3iav.PCTM.zhu roedenbeck.jena.s99 chevallier.lsce

t3iav.GCTM.baker t3iav.MATCH.chen t3iav.TM2.lsce carbontracker butler.ps.u.s

t3iav.GISS.fung t3iav.MATCH.law t3iav.TM3.heimann patra.frcgc butler.ps.u.c

t3iav.GISS.prather t3iav.NIES.maksutov roedenbeck.jena.s93 mich.glbgs

t3iav.JMA.CDTM.maki t3iav.NIRE.taguchi roedenbeck.jena.s96 peylin.lsce
Inverse models: Seasonal NEE cycle for North American Temperate
Use of Multiple Data Sources

- **Atmospheric Inversions**
- **Forward Models**
- **MODIS**
  - GPP, LAI, NPP
- **Survey Data**
- **Flux tower sites**
- **CO$_2$ Flux**

- continent
- region
- site
- flux footprint size
- Soil C, Crop NPP, Forest Biomass
North America: C Flux

Convention:
(-) sink
(+) source

C Flux Average 2000-2005

Net Carbon Exchange, (Pg C/month)

Jan  | Mar  | May  | Jul  | Sep  | Nov
-1.0 | -0.5 | 0.0  | 0.5  | 1.0  |
Spatial Aggregation – TransCom Regions

North America boreal NEE

North America temperate NEE

Net Ecosystem Exchange, NEE (Pg C/month)

Jan Mar May Jul Sep Nov

CASA GFEDv2
CASA
NASA-CASA
CLM-CASA
CLM-CN
DLEM
MC 1
ORCHIDEE
SiB 3.0
TEM6
IAV of Carbon Exchange from Forward Models

Forward models: IAV of NEE for North American Boreal

Forward models: IAV of NEE for North American Temperate
### Summary of NEE (boreal and temperate) comparison between Inverse and Forward Models

<table>
<thead>
<tr>
<th></th>
<th>Inversions</th>
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<th>Forward models</th>
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<td></td>
<td>25\text{th} percentile</td>
<td>Central</td>
<td>75\text{th} percentile</td>
<td>25\text{th} percentile</td>
<td>Central</td>
<td>75\text{th} percentile</td>
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<td>Uptake</td>
<td>0.7</td>
<td>1.0</td>
<td>1.4</td>
<td>0.0</td>
<td>0.3-0.5</td>
<td>0.4</td>
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<tr>
<td>IAV peak-peak</td>
<td>0.8</td>
<td>1.2</td>
<td>1.6</td>
<td>0.2</td>
<td>0.5</td>
<td>0.8</td>
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<tr>
<td>IAV (sd)</td>
<td>0.26</td>
<td>0.34</td>
<td>0.44</td>
<td>0.06</td>
<td>0.18</td>
<td>0.29</td>
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2002 Inter-Model Annual Carbon Flux

Mean Carbon Flux

Standard Deviation Carbon Flux

Inverse Models
N=6

Forward Models
N=12
2004 Inter-Model Annual Carbon Flux

Mean Carbon Flux

Standard Deviation Carbon Flux

Inverse Models
N=6

Forward Models
N=12
Forward Model Mean July C Flux
Forward or Ecosystem Models

• Large diversity of model types constructed for different reasons
  – Statistical relationships with environmental factors
  – Biologically based process representations based on experimental analyses
  – Incorporate a subset of processes that contribute to total CO\textsubscript{2} flux – often disturbances that, for a single location, are episodic are left out (NEE vs. NECB).

• More ecosystem components are modeled and therefore allows comparison with wider range of observations

• Long-term carbon pools, steady-state issues, dependence on initial conditions introduce difficulties
Use of Multiple Data Sources

- Atmospheric Inversions
- MODIS
- GPP, LAI, NPP
- Survey Data
- Flux tower sites
- Soil C, Crop NPP, Forest Biomass
- CO₂ Flux
- continent
- region
- site
- flux footprint size
Spatial Aggregation Forward Models for TransCom Regions

Boreal North America, monthly GPP

Temperate North America, monthly GPP

Prepared by Andy Jacobson, NOAA
Boreal North America, IAV of GPP

Temperate North America, IAV of GPP
Inter-Model Variation in NEE Components – JJA (summer) 2002

Models included:
- CLM-CASA
- CLM-CN
- ORCHIDEE
- VEGAS1
- EC-LUE
- MC1
- TEM6
- CASA-GFed2
- NASA-CASA
- DLEM

Mean

1 Standard Deviation

GPP

Ra

Rh
Inter-Model Variation in NEE Components – JJA (summer) 2004

Models included:
- CLM-CASA
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Use of Multiple Data Sources

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- **Forward Models**
- **MODIS**
- **Survey Data**
- **Flux tower sites**
- **CO₂ Flux**
- **Soil C, Crop NPP, Forest Biomass**

**Data Sources**:
- GPP, LAI, NPP
- Soil C, Crop NPP, Forest Biomass
Agricultural NPP

- Select 1 degree cells that are 50% managed agriculture
- Compare model NPP in same 1 degree cells
Agricultural NPP

Net Primary Productivity, Pg C/year

- NASS Cropland NPP
- CASA GFEDv2
- CLM-CASA
- CLM-CN
- DLEM
- MC1
- NASA-CASA
- ORCHIDEE
- VEGAS
Forward Model Summary and Observations

• Forward models are very different and do not agree on timing or spatial distribution of C sources/sinks

• Examination of NEE components shows GPP is largest component of discrepancies

• Need additional analyses
  – Site data and information about model performance with site NEE
  – Examine managed forest NPP, esp. Southeast US
  – Need to clarify additional components of NECB in addition to components of NEE
Proceeding from Here

Need Additional Model Variables:

- GPP, NPP, NEE, Ra, Rh, LAI (FPAR, NDVI, EVI), Soil C, Biomass at monthly or annual times

Need Additional Model Experiments:

- Especially various disturbance effects – fire, biomass harvest, insect outbreaks
- CO$_2$ forcing, N deposition, management

Need ideas:

- Additional regional/continental observation based datasets
- Creative methods for model-data comparison
Reporting of Current Findings

Tasks

• Gather additional forward model metadata
  – What components of NECB are included
  – How processes are represented
  – Details on boundary and forcing conditions

• Develop Manuscripts
  1. Fast-track Forest and Agriculture inventory – Model comparison
  2. Temporal Analysis – mostly completed, need to complement with and “expert” update of the SOCCR estimates on an annual time step (Jacobson, McGuire, Post, others). This could involve interaction with Site Synthesis results for non-managed ecosystems (Tundra, wetlands, grasslands, etc.)
  3. Spatial Analysis (Huntzinger, Post)
  4. Extreme event analysis (Zeng)
After the Interim Synthesis: The Well Planned Regional Synthesis

- Conduct a formal regional scale data-model comparison
- Development of benchmarks for model evaluation ala C-LAMP
- Development of inventory change estimates and uncertainties in those estimates that are spatially and temporally resolved – Soil C, Forest, Agriculture
- Evaluation of inversion sensitivity to terrestrial biosphere model priors and other inversion uncertainties
- Evaluation of sensitivity of flask station CO$_2$ concentration estimates to terrestrial biosphere model and fossil fuel fluxes
- Model-data synthesis activities should NOT be delayed until after all data collection. They should begin now!