Development of a region-specific fire scheme under the CAM5-CLM4.5 coupling framework

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Motivation

- What is the relationship between climate variability and fire activities?
- Are the hypothetical two-way interactions significant?
- How will the regional climate be likely to change under the interactive fire forcing?

- Net global mean temperature change by source sectors

A schematic diagram of climate-fire interactions

(IPCC AR5, Chapter 8, 2013)
Methodology—Development roadmap

Stage 1: Fire Scheme Improvement

Finished:
(1) DATM-CLM offline parameterization;
(2) Validation with satellite/in situ observations;

Stage 2: Interaction evaluation

Ongoing:
(1) CAM-CLM online coupling with dynamic fire;
(2) Implementation of multiple constraint/feedback mechanisms;

Stage 3: Decadal prediction

To be started:
(1) Prediction with decoupled fire;
(2) Prediction with coupled fire feedback;

Objectives:
1) Identify key climate factors modulating fire activities;
2) Understand fire feedbacks to regional climate variability;
3) Investigate fully coupled fire-climate interactions;
4) Predict decadal regional climate variability with improved fire forcing;
Methodology—Model vs. Observation

Remote-sensing analysis
- Retrieval validation
- Assumption refinement

Regional Context

Satellite
- MODIS
- CALIPSO
- MISR
Global fire spots;
Aerosol loading;
Aerosol type;
Plume height;

Aerosol-type prediction

Airborne/field campaign
- HIPPO
- ARCTAS
- ARCPAC
- SOAS
- BBOP
- AERONET
Chemical/microphysical
details in fire plumes and
downwind atmosphere;

Model validation
- Parameterization
- Climate sensitivity
- Underlying mechanism

Model
- CLM
- CAM
Space-time interpolation;
Diagnosis and prediction;
Preliminary results—global fire activities

- **Peak Month of Fire Seasons**
- **Monthly burned area**

- 5 PFT Groups
- 14 GFED Regions
Preliminary results—multiple climate factors

💡 Climate factors

<table>
<thead>
<tr>
<th>Factors</th>
<th>Ignition ($f_m$)</th>
<th>Spread ($C_m$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{max}}$</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>RH</td>
<td>+/-</td>
<td>-</td>
</tr>
<tr>
<td>Precipitation</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Soil water</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

\[
f_m(i,j) = \frac{NFIRE_{\text{obs}}}{NFIRE_{\text{potential}}} = f(T_{\text{max}}, RH, Prec_10d, wf)
\]

\[
C_m(i,j) = \frac{BA_{\text{obs}}}{BA_{\text{potential}}} = f(RH, Prec_30d)
\]

- $f_m$: fuel combusitivity on fire occurrence;
- $C_m$: fuel combusitivity on fire spread;
- $NFIRE_{\text{potential}}$: fire counts without constraints;
- $BA_{\text{potential}}$: burned area with constraints on fire counts only;
- $T_{\text{max}}$: maximum air temperature at 2 m;
- $RH$: relative humidity;
- $Prec_{10d}$: 10-day running mean total precipitation;
- $Prec_{30d}$: 30-day running mean total precipita;
- $wf$: soil water for top 0.05 m soil layers;
- $i$: region id; $j$: PFT id;

💡 Region-specific natural constraints

[Graphs showing region-specific natural constraints for different regions including scatter plots and trend lines, indicating global and region-specific constraints.]
Preliminary results—human impacts

\[ N_f = N_if_a f_m (1 - f_s) \]

- **Anthropogenic constraints**

(1) Suppression effects:

\[ BA = N_f a \]
\[ a = f(u_{max}, WS, \tau, C_m) \]

- \( N_f \): fire counts;
- \( N_i \): fire counts w/o constraints;
- \( f_a \): fuel availability;
- \( f_s \): fire suppression;
- \( BA \): burned area;
- \( a \): averaged fire spread area;
- \( u_{max} \): maximum fire spread rate;
- \( WS \): wind speed;
- \( \tau \): average fire duration;

(\text{Li et al., 2012})
Preliminary results—global burned area

- Annual Burned Area

- CAM5CLM4.5_Upd

- GFED4, CRUCLM4.5_Org, CRUCLM4.5_Upd, CAM5CLM4.5_Org, CAM5CLM4.5_Upd

- Burned Area (km²/yr) × 10^4

- Burned Area (M km²)

- Burned Area (km²/yr) × 10^4

- Burned Area (M km²)

- CAM5CLM4.5_Upd FAREA_BURNED (%/yr) 2000-2000

- CAM5CLM4.5_Org, CRUCLM4.5_Upd, GFED4, CAM5CLM4.5_Upd
Preliminary results—global fire emissions

- Carbon emissions

\[ E_{\text{mis}} = EFs \times (BA \times Biomass \times CC) \]

- Sensible Heat Flux
- Moisture Flux

(M. Z. Jacobson, 2014)
Preliminary results—fire plumes

- Evaluation of plume heights

- 1-D plume rise model (Freitas, et al., 2006) results;

- A fraction (20-30%) of fire plumes inject directly into the free troposphere during daytime;

- Incompatible scales between the 1-D model and the 3-D global model;

- Requires simplified plume rise parameterization for 3-D modeling implementation;
Preliminary results—fire plumes

- **MISR satellite observations**
  - MISR 2002-2010

- **Plume heights fitting**

  The key parameters: (1) virtual injection velocity; (2) boundary layer height;

  \[
  w_0 = \frac{5}{6\alpha} \left( \frac{0.9\alpha F}{z_v} \right)^{1/3}
  \]
  (Viegas, 1998)

- **PLUMEH vs. FRP**
- **PLUMEH vs. \( w_0 \)**

  - Better correlation between virtual injection velocity and plume heights;
  - The fitting results can capture the major pattern of MISR plume heights: lower in tropics and higher in high latitudes.
Summary

- **Implications**
  1. Both climate and human activities play important roles in modulating fire activities;
  2. The updated fire scheme has good performance in both off-line and on-line simulations;
  3. Fully coupled fire-climate simulations are feasible although fire feedbacks to the climate system dependent on the mechanisms considered.

- **Working plan**
  1. Finish online coupled fire parameterization with more feedback mechanisms (BrC radiative effects, land cover change, etc.);
  2. Evaluation of interactive processes in the fire-climate system;
  3. Decadal predictions with fully coupled fire-climate forcing;
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