Vegetation-climate feedbacks modulate rainfall patterns in Africa under future radiative forcing

- THE ROLE OF BIOPHYSICAL FEEDBACK ON REGIONAL CLIMATE

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Outline

- Introduction
  - Vegetation feedback
  - Object of this study
  - CORDEX-Africa as a case study
- Methods
  - RCA-GUESS: a Coupled Vegetation-Climate regional ESM
- Results
  - Influences on land surface properties
  - Influences on atmospheric dynamics
- Conclusions
Vegetation feedback

- Influence climate via land-atmosphere interaction (Bonan et al. 2008)
  - Biophysical feedback: albedo feedback, hydrological feedback (ET)
  - Biogeochemical feedback: carbon cycle
Emerging vegetation changes in the past few decades

- Global land surface in the recent decades has changed significantly
- Changes in vegetation: net primary productivity, vegetation structure

(Jamali et al., 2014)
(Zhou et al., 2014)
(Jong et al., 2013)
Importance of vegetation feedback in the past few decades

- Circulation changes over Africa:
  - SSTs, land-ocean contrast: (Giannini et al., 2003):
    disable land-atmosphere interaction reduce internal variability of rainfall over land.

Precipitation variability is reproduced

Zeng et al., 1999
What is the role of vegetation feedback in future climate projection?

- How does the climate change in future?
- How does the vegetation change in future?
- What are the interactions between them, and how?
A Regional ESM - RCA-GUESS : Coupled Vegetation-Climate

- Regional climate model: RCA4 (Kjellström et al., 2005; Samuelsson et al., 2011):
  - Atmospheric processes
  - Low boundary conditions (e.g. Surface temp.)
- DVM: LPJ-GUESS (Smith et al., 2001) as a vegetation dynamics component:
  - PFTs
  - Carbon assimilation, respiration, allometric growth, tree height etc.
  - Resources competition
  - Stochastic bioclimatic disturbance (by patches), etc.
- Land surface scheme (LSS, Samuelsson et al., 2006, Smith et al., 2011):
  - Vegetated area (forest, crop), bare soil lake, river, etc.
  - Tile approach: high vegetated tile and low vegetated tile
Experimental design

- RCA-GUESS over the CORDEX-Africa:
  - Big enough to capture possible remote effect

- 0.44° resolution:
  - Small enough to consider land surface heterogeneity

- Boundary conditions: CanESM2:
  - Reproduce African climatology well
  - Well-validated SSTs

- Future climate scenario: RCP8.5

- Vegetation cover and population structure from 8 plant functional types (PFTs) in LPJ-GUESS were grouped in to evergreen and deciduous forest and herb then feedback to RCA.
Experimental design

<table>
<thead>
<tr>
<th>Runs</th>
<th>Vegetation Feedbacks</th>
<th>Radiative forcing(^a)</th>
<th>CO(_2) forcing(^b) for vegetation sub-model</th>
<th>Simulated period</th>
<th>Boundary condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>RP</td>
<td>Dynamic</td>
<td>Historical</td>
<td>Historical</td>
<td>1979-2011</td>
<td>ERA-Interim</td>
</tr>
<tr>
<td>FB</td>
<td>Dynamic</td>
<td>Transient under RCP8.5</td>
<td>Transient under RCP8.5</td>
<td>1961-2100</td>
<td>CanESM2</td>
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<tr>
<td>NFB</td>
<td>Prescribed vegetation simulated from 1961 to 1990</td>
<td>Transient under RCP8.5</td>
<td>Transient under RCP8.5</td>
<td>1991-2100</td>
<td>CanESM2</td>
</tr>
<tr>
<td>FB_CC</td>
<td>Dynamic</td>
<td>Transient under RCP8.5</td>
<td>Historical until 2005 and constant afterward</td>
<td>1991-2100</td>
<td>CanESM2</td>
</tr>
</tbody>
</table>

Notes: \(^a\) using equivalent atmospheric CO\(_2\) concentration; \(^b\) using actual atmospheric CO\(_2\) concentration.
Present-day climate

able to capture the main climatological features: spatial pattern, seasonality.
Future climate changes

- Temperature
  - +2-6°C in general
  - Warming of Land is larger than ocean

- Precip.:
  - Main changes happen in Monsoon area
  - Change over land following ITCZ
Vegetation feedback
Results: vegetation feedback effects

- Forest extension: driven by “CO$_2$ fertilization”, mainly happen in semi-arid area.

**Identified local effects:**
- Transpiration(+) -> shift in surface energy balance (EF+) -> cooling effect
- Warming effect, mainly for winter, arid area <- albedo (-) & radiation absorption (+)
Results: remote effects – land-ocean contrast

Vegetation feedback is not constrained in the local, remote effect is found!

Influences on the tropical convergence and parts of monsoon area
Results: remote effects – land-ocean contrast

Land-ocean temp. contrast and pressure contrast are highly correlated
Results: remote effects – circulation

Changes in westerlies wind speed
Results: remote effects – moisture flux

Given the changes in circulation, and according to Law of conservation of mass: the lost water must have some place to go.

Where have they been to?

Water over Land (-)

Water over Ocean (+)
Results: remote effects – rainbelt

Strengthened circulation
- Land ocean contrast
- boundary layer lapse rate
- surface energy balance
- etc.

Extension of rainbelt
- Shrinkage of rainbelt, via decrease in rainfall intensity, but ITF retains
- Longer rainy season for some regions (local effects)

Weakened inflow, e.g. Walker cell
To summarize

1. CO₂ concentration (+)
2. Savanna forest area (+)
3. Evaporation (+)
4. Surf. Temp. (-)
5. Land-ocean Temp. contrast (-)
6. Land-ocean pressure contrast (-)
7. Low-level westerlies & moisture inflow (-)
8. Central African Precipitation (-)

Tropical easterly jet (200mb)
African easterly jet (600mb)
Main messages:

• This is the first study of vegetation feedback on climate over CORDEX-Africa domain.
• Vegetation feedback can play an important role in future climate projection
• Because vegetation changes is an important feature for future land surface.
• Biophysical feedback is not merely constrained to be local, remote effects are also possible, its importance depends on regions.
• Size of simulation domain should be appropriate to capture the remote effects.
• The importance of land-ocean contrast to moisture inflow to land, and to its hydrological cycle
• Alternative understanding: changes in land-ocean contrast is not necessary driven by ocean (e.g. SSTs), but also can be from changes over land.
Thanks for listening!