Representing the Impact of Residential Energy Choice and Land Use Change on the Climate and Air Quality of Sub-Saharan Africa

Timothy Glotfelty, Diana Ramirez-Meija, Jared Bowden, Adrian Ghilardi, Yang Ou, Ashley Bittner, Andrew Grieshop, Robert Bailis, Pamela Jagger, and J. Jason West

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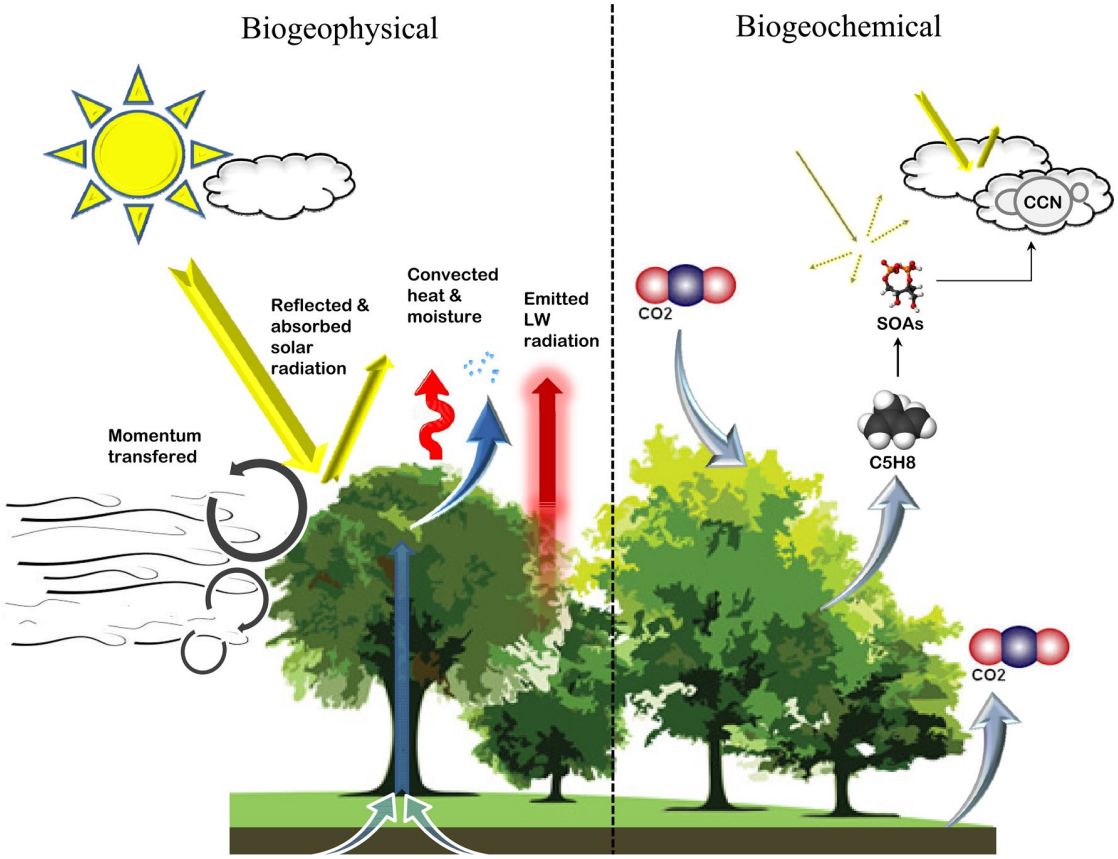
Land Use and Land Cover Impacts on Climate

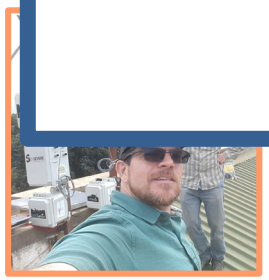


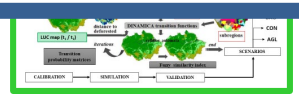
Bright et al., 2015

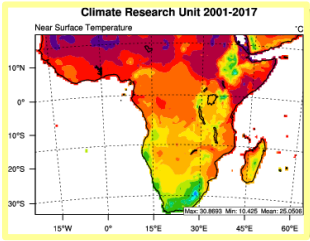
Africa Coupled Natural Human Systems Project

Social Science

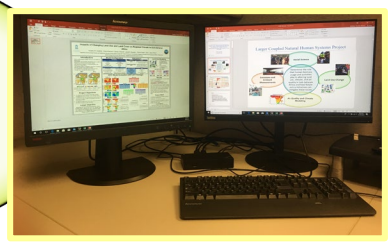
Understand the current and future impacts of land use and residential energy choice on the climate and air quality of Sub-Saharan Africa





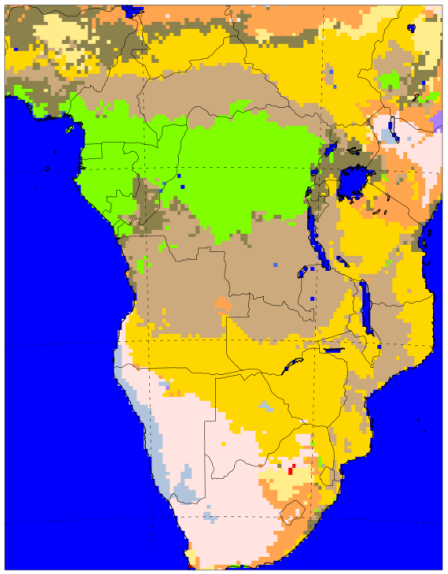


Air Quality and Climate Modeling



WRF-Chem Configurations

- WRF-Chem Domain Configuration
  - Area: Limited Sub-Saharan Africa
  - Horizontal Grid Spacing: 36 km
  - Vertical: 30 layers from the surface to 50mb
  - IC/BC: ERA-Interim (Met.) and CAM-Chem (Chem.)
- Physics Options
  - Cumulus: Grell 3D
  - Microphysics: Morrison Double-Moment
  - **Land Surface Model: CLM-AF**
  - Surface and Boundary Layer: MYNN
  - Radiation: RRTMG
  - Active Lake Simulation



- Chemistry Options
  - Gas-Phase: MOZART-VBS
  - Aerosol: MOSAIC-4 Bin
  - Photolysis: TUV
  - Dust Emission: GOCART-AFWA
  - Sea-Salt Emission: MOSAIC
  - Biogenic Emission: MEGAN
  - Active Plume rise Biomass Burning

Simulations

- Current Conditions (2001-2017)
- Simulations
  - Baseline: Emissions and land use change from year to year
  - LU01: Land use and land cover are held constant at the year 2001 values
  - EM01: Emissions are held constant at the year 2001 vales

- Future Conditions (2035-2044)
- Simulations
  - Business as Usual (BAU)
    - Current trends continue
    - Shared Socioeconomic Pathway: SSP3
  - Cleaner residential energy scenarios
    - Electricity
    - Liquefied Petroleum Gas (LPG)

Necessary Steps to Achieve WRF-Chem Modeling Objectives

- 1) Simulate logical changes in climate from land use and land cover change (100% Complete)
- 2) Harmonize changes in land use and land cover to natural biogenic VOC and dust emissions (50% Complete)
- 3) Develop an emissions inventory to adequately account for residential energy choices in Africa (80% Complete)
- 4) Project future emissions based on African residential energy scenarios (50 % Complete)

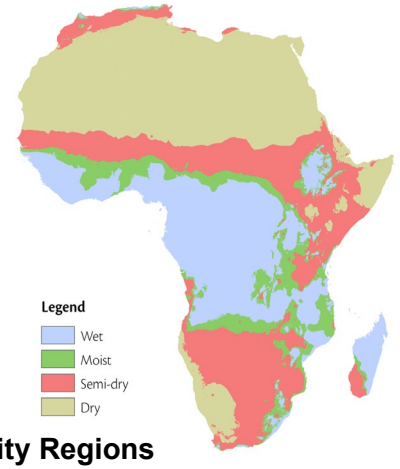
Step 1: Land Use Modeling Regions

18 regions based on:

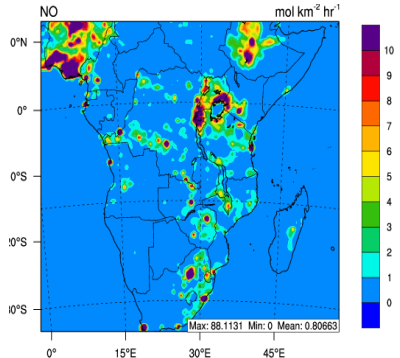
- CLIMATE ZONES
- SOCIO-ECONOMIC & ANTHROPOGENIC FACTORS

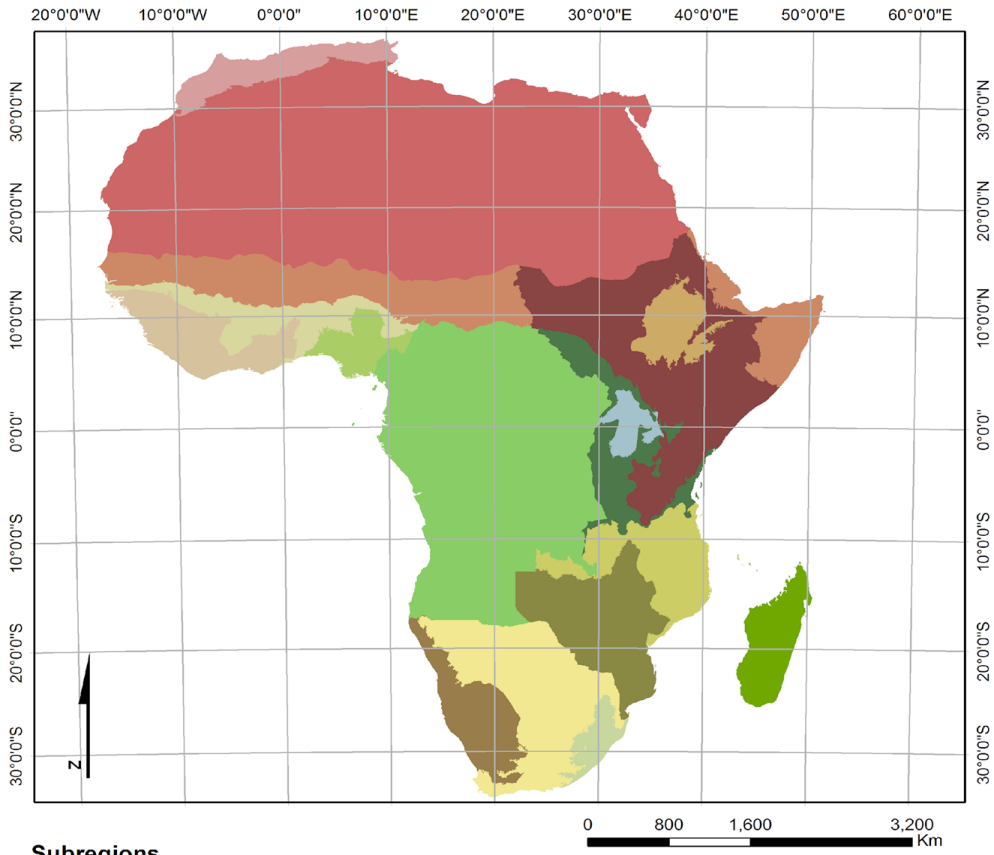
UN Geographic Region

Bio-climate Regions



Anthropogenic Activity Regions

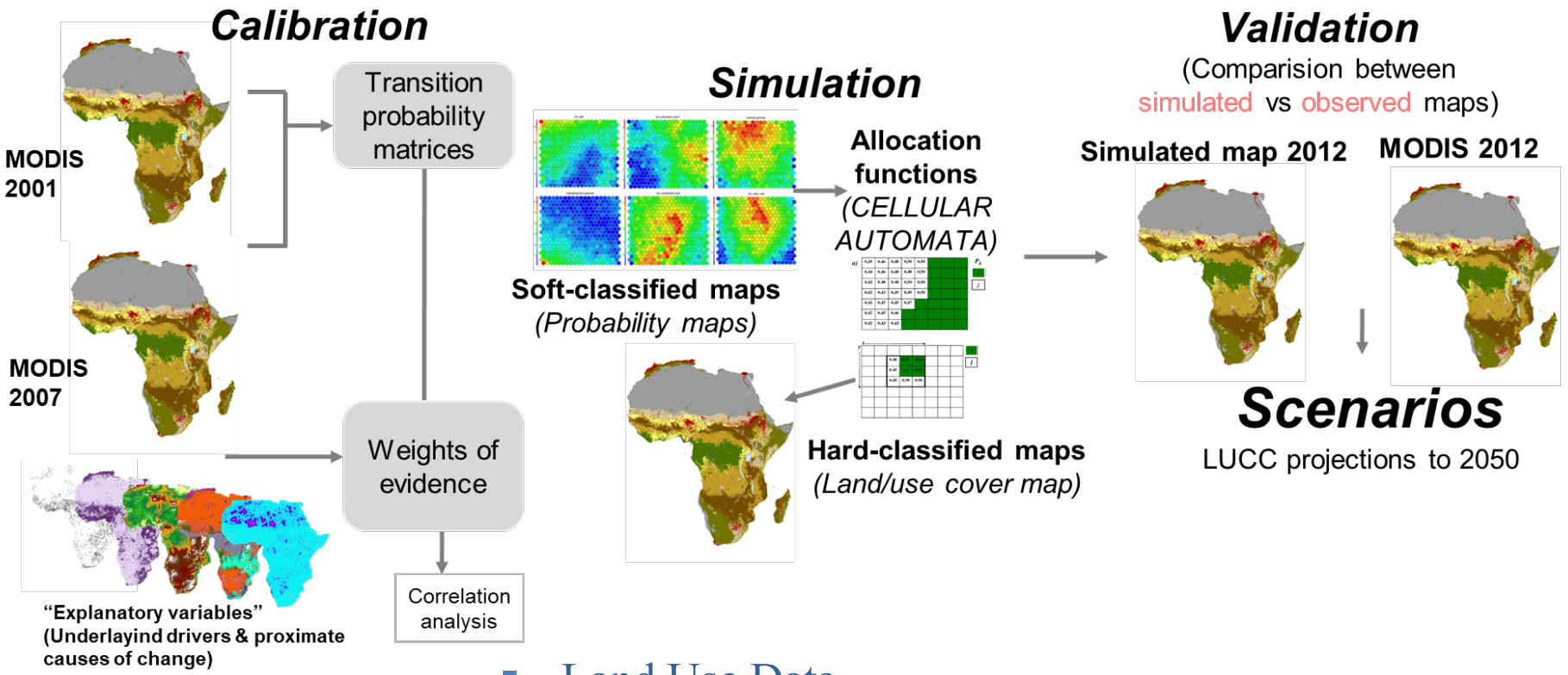




Subregions

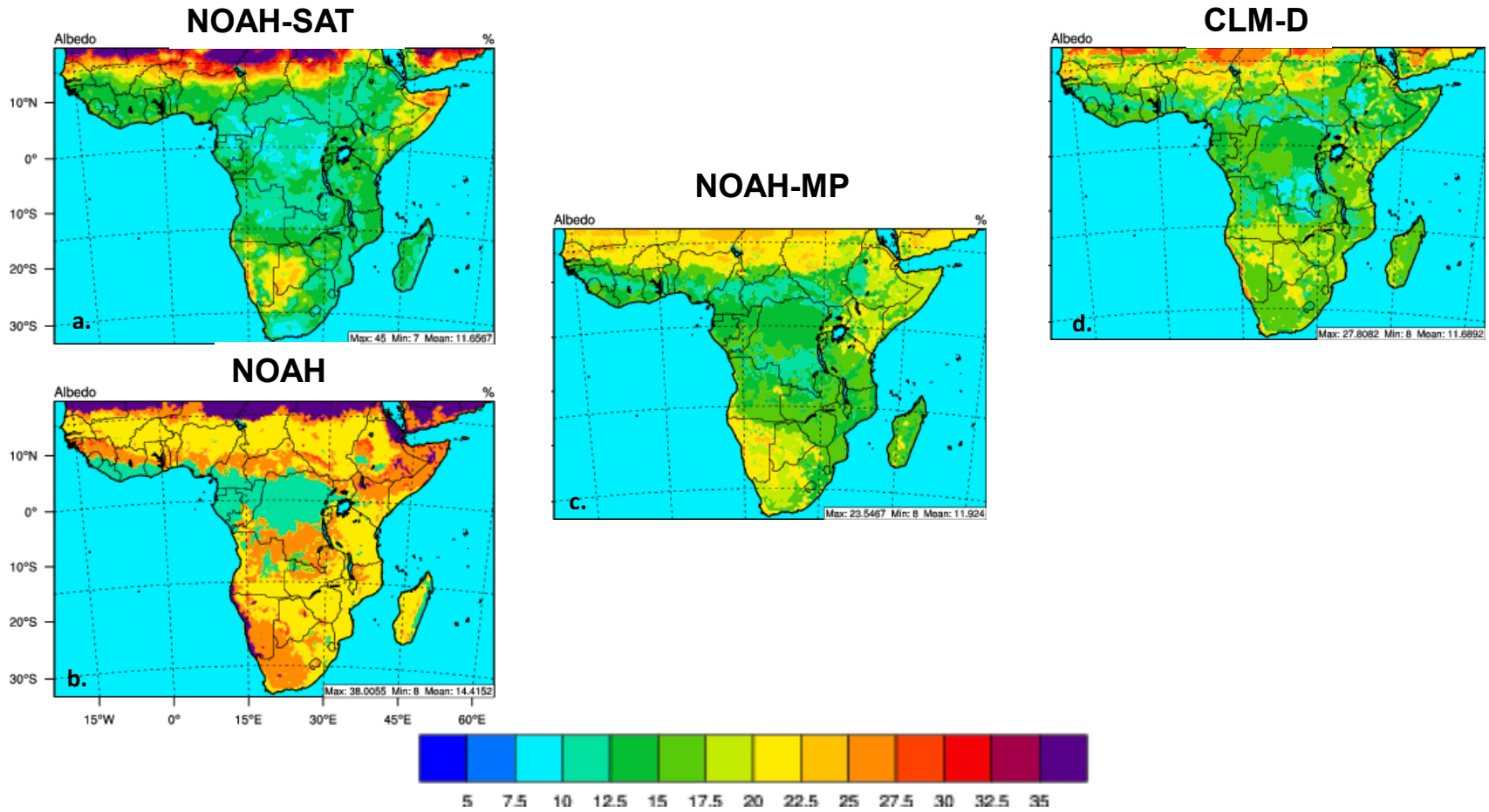
1. North Semi-Dry
2. North Dry
3. East Dry
4. East Semi-Dry
5. West Semi-Dry
6. East Wet / Ethiopian Highlands
7. West Moist
8. West Wet
9. Central Wet
10. West Wet / Nigeria
11. Central Moist
12. Central Wet / Lake Victoria
13. East Moist
14. Southeast Semi-Dry
15. East Wet / Madagascar
16. South Dry
17. South Semi-Dry
18. South Moist / Wet

Step 1: Land Use Modeling (Dinamica EGO)



- Land Use Data
  - MODIS MCD12Q1 Product
  - Training Period: 2001-2007
- Why Dinamica EGO?
  - Used to avoid noise from uncertainty in satellite products
  - MODIS products only available to 2013

Step 1: Deficiencies in WRF land Surface Models (Albedo)

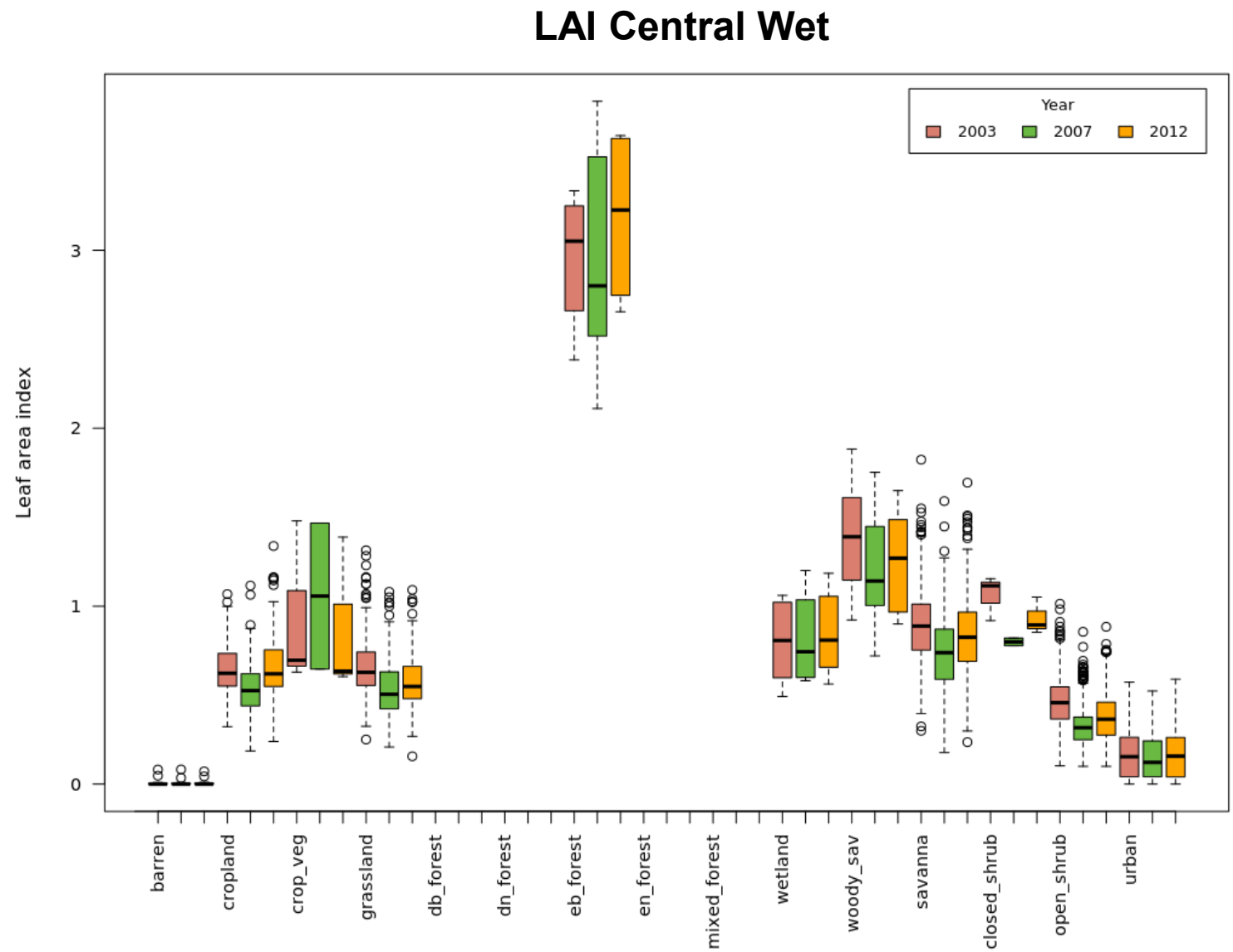


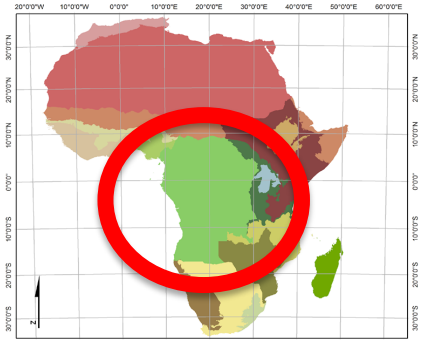
Glotfelty, T., Ramírez-Mejía, D., Bowden, J., Ghilardi, A., and West, J. J.: Limitations of WRF land surface models for simulating land use and land cover change in Sub-Saharan Africa and development of an improved model (CLM-AF v. 1.0), Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2020-193, in review, 2020.

Step 2: LULC Dependent Natural Emissions Input Datasets

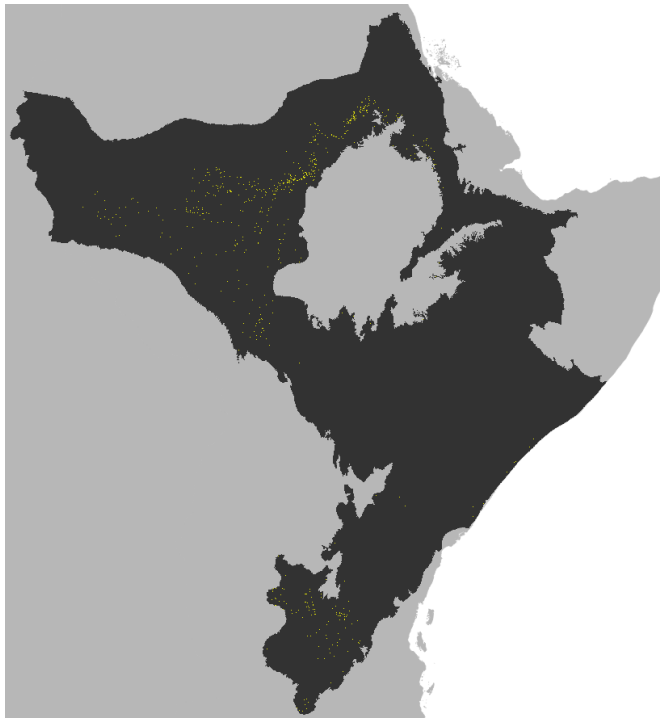
- GOCART-AFWA
  - Soil Erodability
- MEGAN
  - Leaf Area Index
  - Plant Functional Types
    - Needle Leaf Trees
    - Broad Leaf Trees
    - Shrubs
    - Herbaceous Cover
  - Isoprene Emission Factors

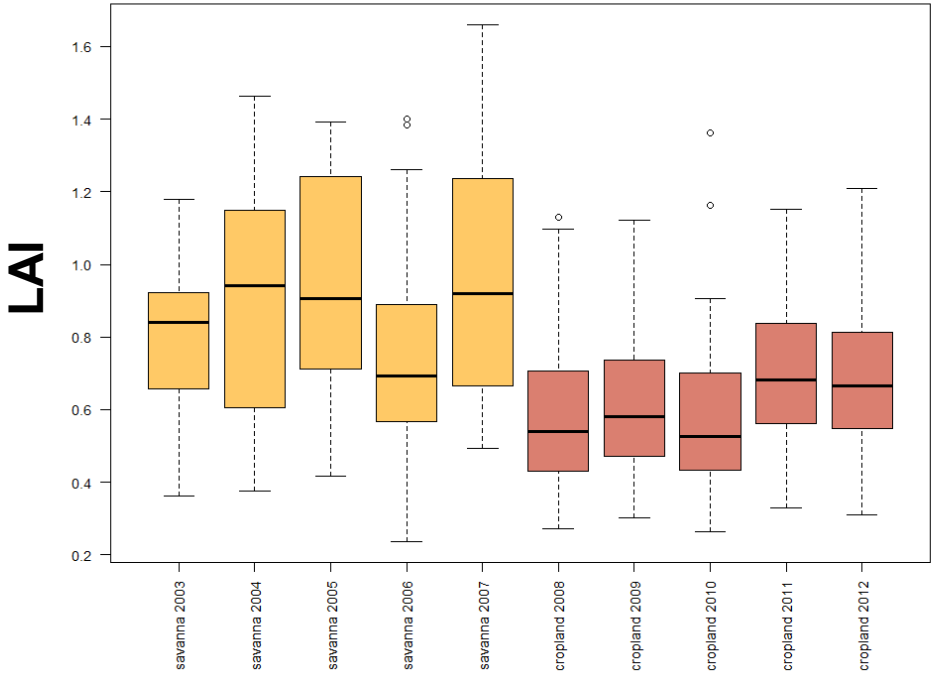
Step 2: LAI and LULC Relationship





Step 2: LAI and LULC Relationship

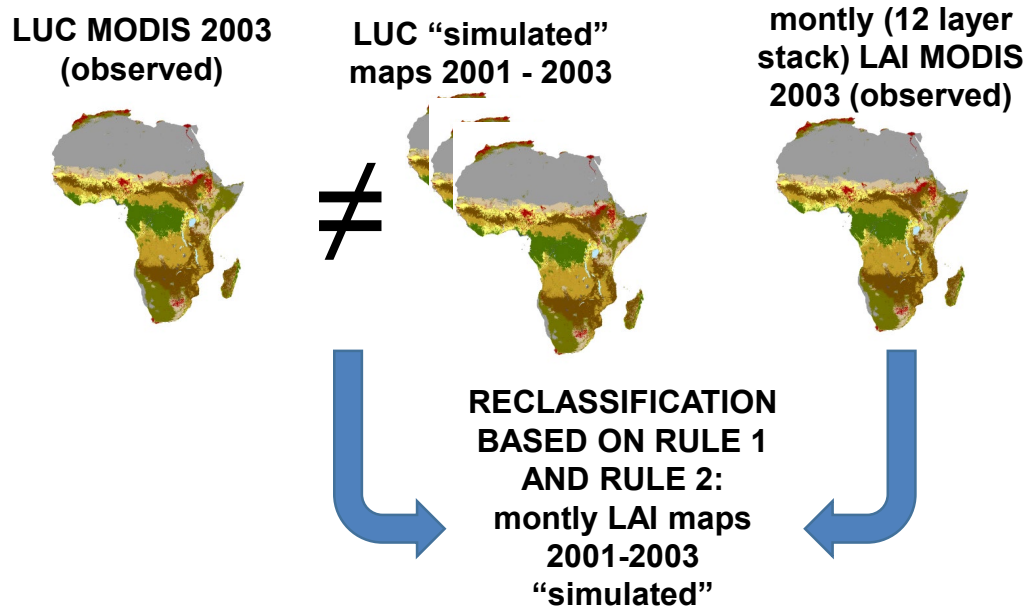




Yellow cells depict areas that underwent change from savanna to cropland in 2008

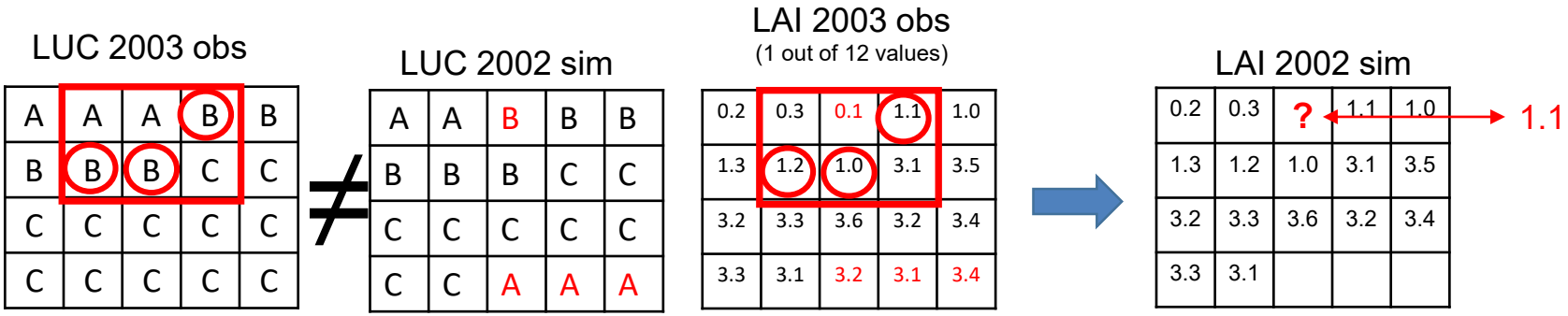
Step 2: Reclassification Methodology

STEP
1 **LUC maps pairs** are compared to identify cells that change



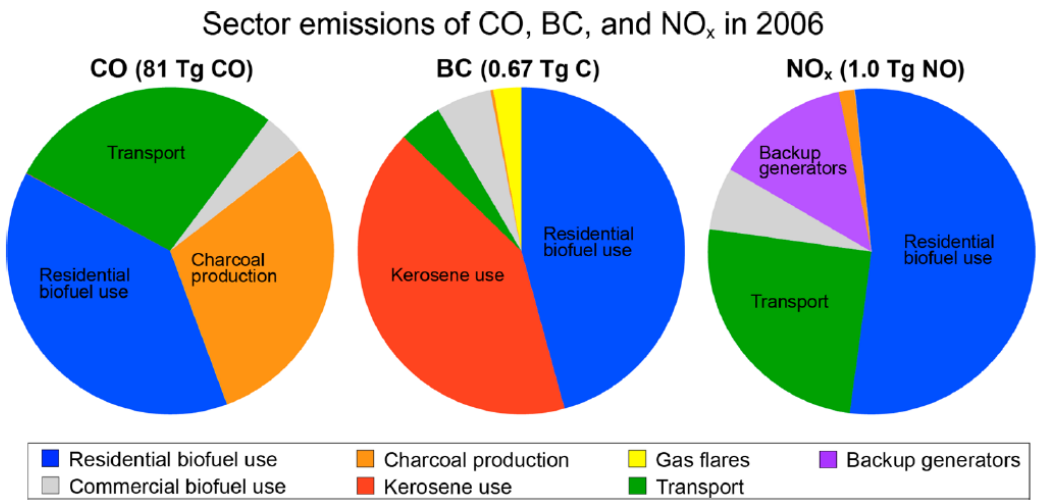
Rule 1: for cells that **do not change**, montly LAI values from 2003 (observed) are assigned (i.e. reclasification)

Rule 2: for cells that **do change**, the average montly LAI values of neighbour cells for each corresponding LUC class are assigned (in a moving window of 9x9 cells)
Result: Montly LAI maps 2001-2003 "simulated"



Step 3: DICE-Africa Emissions

- DICE-Africa (Marais and Wiedinmyer, 2016)
  - African inventory for Diffuse and Inefficient Combustion Emissions (DICE)
  - Years: 2006 and 2013
  - Derived from UN Estimates of Fuel Consumption (http://data.un.org/Explorer.aspx?d=EDATA)
  - Country Level Emissions
  - Residential Sources
    - Fuelwood, Charcoal, Charcoal Production, Household Generators, Crop Residue, and Kerosene
  - Transportation Sources
    - Cars and Motorcycles
  - Other Sources
    - Gas Flares and Oil Refining



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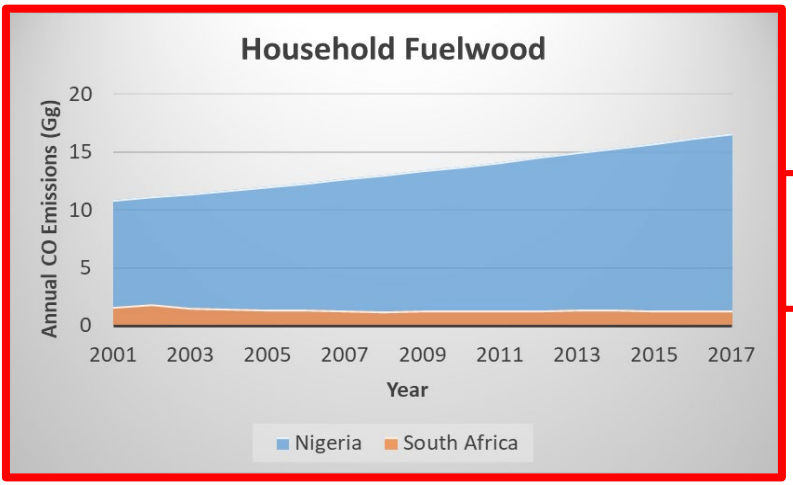
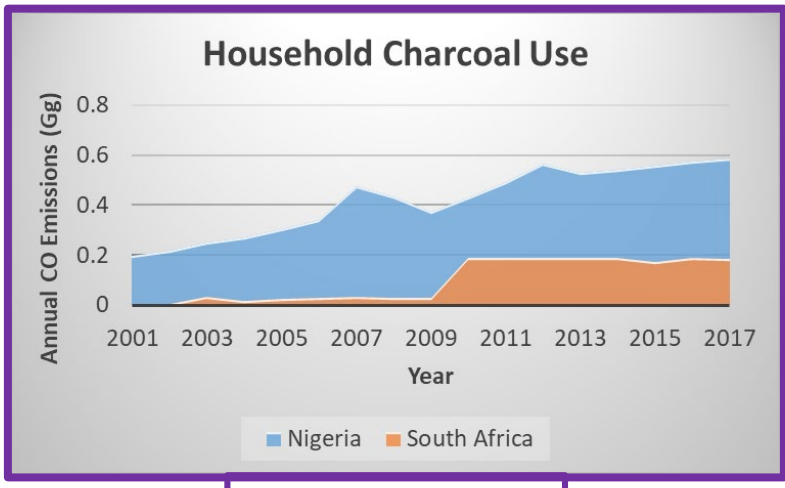
Step 3: DICE-Africa Methodology to Generate 2001-2017 Inventory

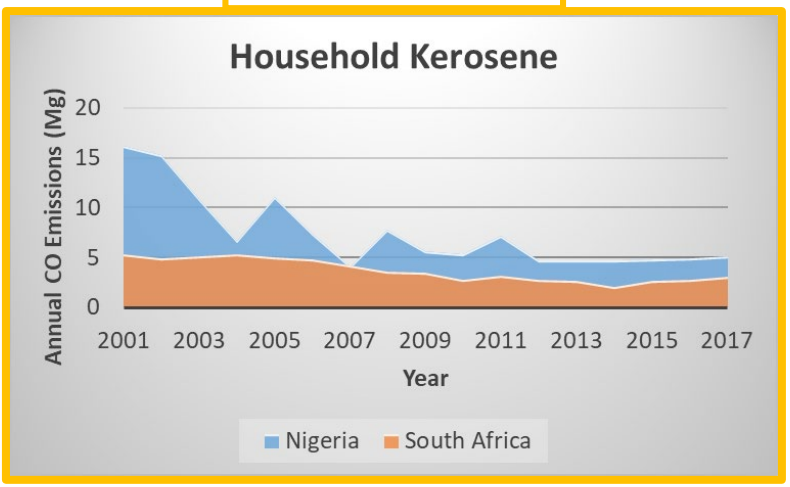


Fuelwood Change
Nigeria: 53%
South Africa: -20%

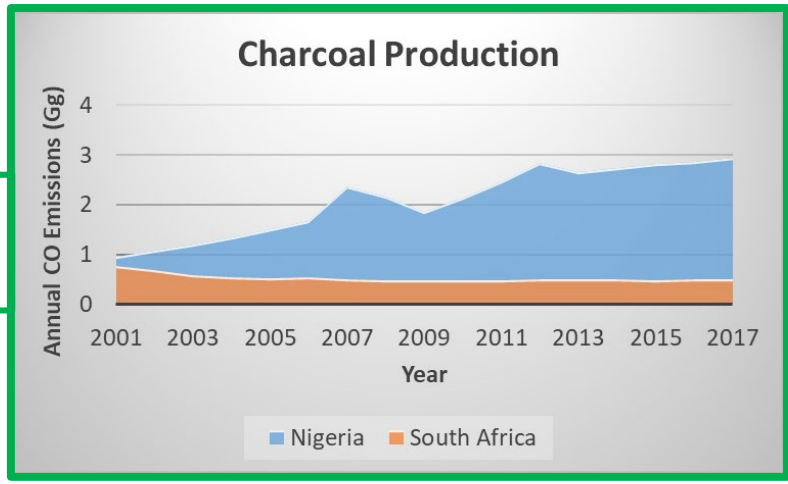


Charcoal Change
Nigeria: 199%
South Africa: 8983%

Kerosene Change
Nigeria: -69%
South Africa: -42%



Production Change
Nigeria: 204%
South Africa: -55%



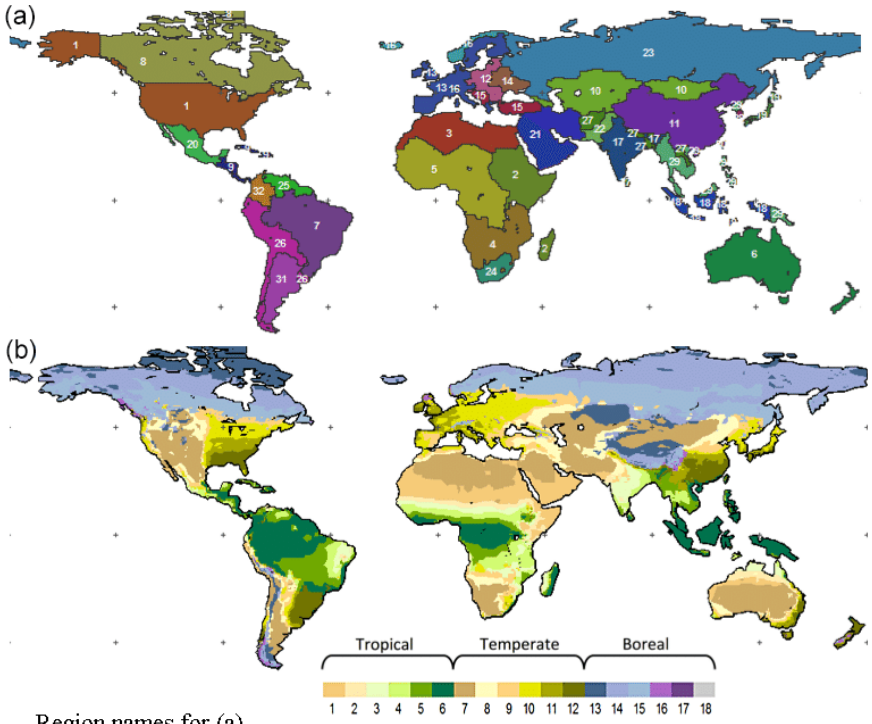
Step 4: Future Scenarios Residential Energy Projections (2040)

- Business As Usual (BAU)
  - Extrapolating current UN trends into the future
  - Fuelwood, charcoal, and crop residues remain the major residential fuel sources
- LPG
  - Biomass fuel sources are phased out by 2040 and primarily replaced with LPG
- Electricity
  - Biomass fuel sources are phased out by 2040 and primarily replaced with electricity

- We are projecting the DICE-Africa inventory
  - Works well for the residential sector

- What about the other emissions sectors?
  - SSP Historical Emissions for the current period

Step 4: Global Change Analysis Model (GCAM)



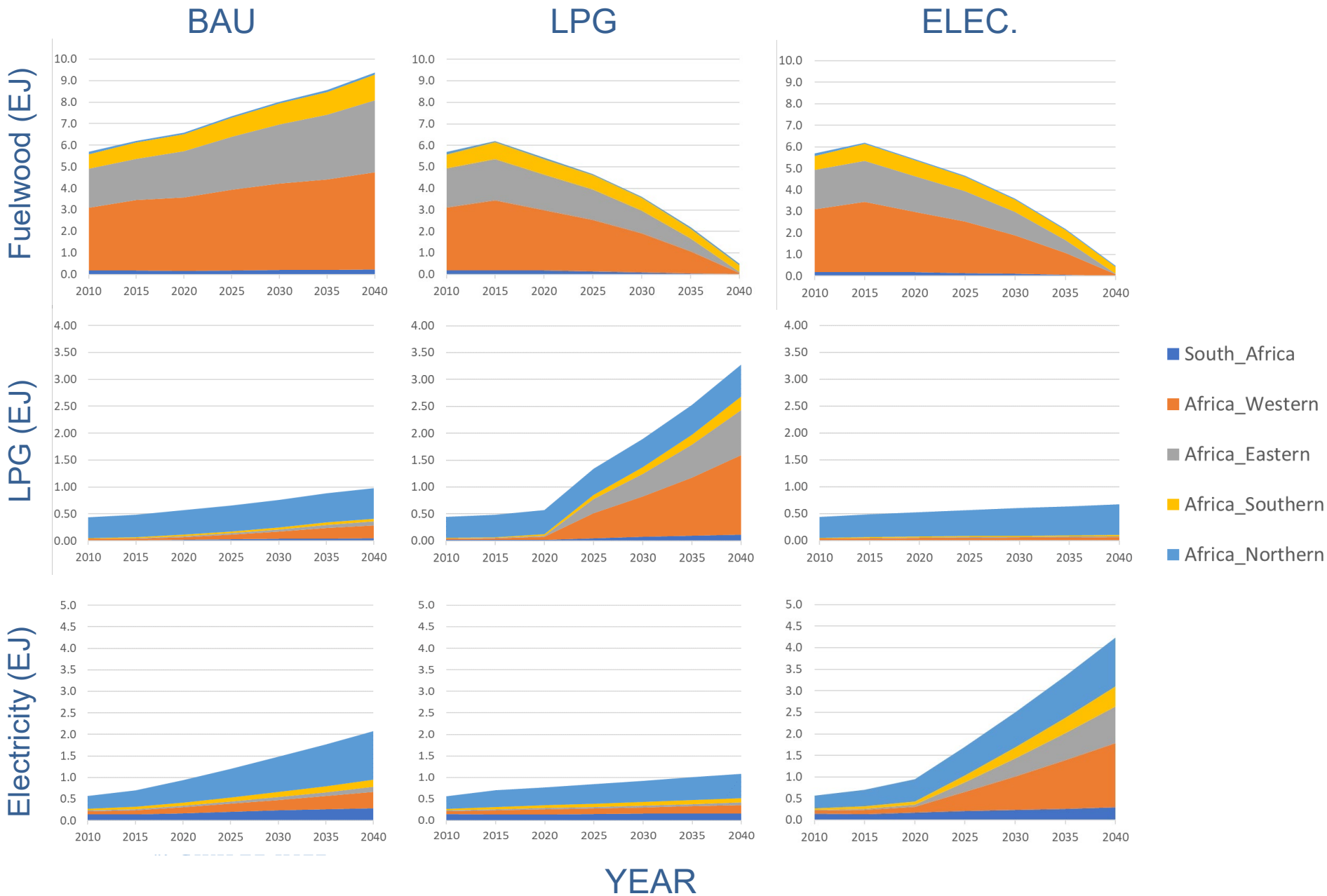
Region names for (a)

1- USA	9- Central America and Caribbean	17- India	25- South America Northern
2- Africa Eastern	10- Central Asia	18- Indonesia	26- South America Southern
3- Africa Northern	11- China	19- Japan	27- South Asia
4- Africa Southern	12- EU-12	20- Mexico	28- South Korea
5- Africa Western	13- EU-15	21- Middle East	29- Southeast Asia
6- Australia NZ	14- Europe Eastern	22- Pakistan	30- Taiwan
7- Brazil	15- Europe Non EU	23- Russia	31- Argentina
8- Canada	16- European Free Trade Association	24- South Africa	32- Colombia

Le Page et al., 2016

- GCAM
  - Integrated assessment/ economic model
  - Simulates Africa in 5 regions
    - Northern, Southern, Western, Eastern, and South Africa
  - We utilize the GCAM's Shared Socio Economic Pathway SSP3 scenario
    - Storyline is the closest to our BAU scenario
  - Use demand/pricing constraints to mirror our residential energy projections
  - Generate emission sectors consistent with our residential energy projections
    - power generation, industry, transportation, agriculture, etc…

Step 4: Future Scenarios Residential Energy Projections (2040)



Conclusions

- Fully representing the impact of land use and land cover on both climate and air quality in Sub-Saharan Africa is challenging with the current status of most publically available modeling tools
  - We have created CLM-AF to better simulate land use change in Africa
- More detailed country level emission inventories are needed to better understand the impacts of changing emissions in Sub-Saharan Africa
- The methodology discussed here provides a pathway forward for simulating these impacts in both Africa but also other developing regions of the world
- More work is needed in the future to truly harmonize these processes in regional climate models

Future Work

- Finish the reclassification for all datasets needed by WRF-Chem
- Finalize the DICE-Africa style gridded emissions
- Finalize the details of the future scenarios and conduct GCAM simulations to mirror these scenarios
- Conduct WRF-Chem simulations to elucidate the impacts of land use change and residential energy choice on the climate and air quality of Sub-Saharan Africa

Thank you

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- Eloise Marais and Christine Wiedinmyer

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