Integrating Remote Sensing Observations with NASA's GEOS-5 Modeling Framework in Support of Retrospective Analyses and Seasonal Prediction of Biosphere-Atmosphere CO_2 Flux

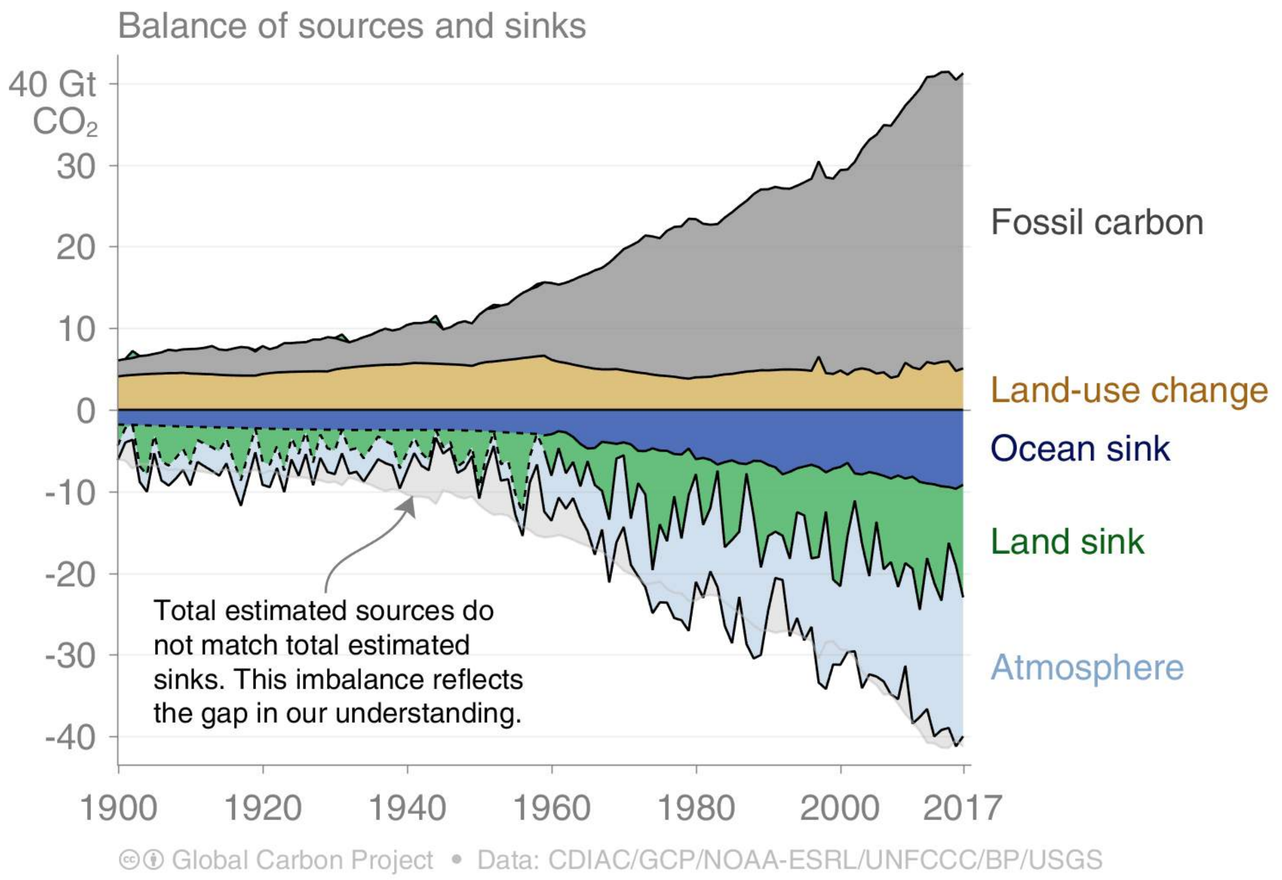
Lesley Ott[1], E. Lee[1,2], F. Zeng[1,3], C. Rousseaux[1,2], G. Hurtt[4], J. Randerson[5], A. Chatterjee[1,2], Y. Chen[5], L. Chini[4], S. Davis[5], L. Ma[4], B. Poulter[1], L. Sun[4], D. Woodard[5]

[1]NASA Goddard Space Flight Center
[2]USRA
[3]SSAI
[4]University of Maryland
[5]University of California, Irvine

Motivation (1)

1. Better understand the drivers of past carbon flux

- Developing modeling tools that make use of multiple satellite data constraints (see L. Ma poster)
- Improved understanding of the role of climate variability using atmospheric reanalyses
- Monthly varying land use transition data
- Characterization of the relative roles of the biological and physical ocean pumps (see G. Hurtt poster)
- Estimating the role of circulation changes on atmospheric carbon concentrations



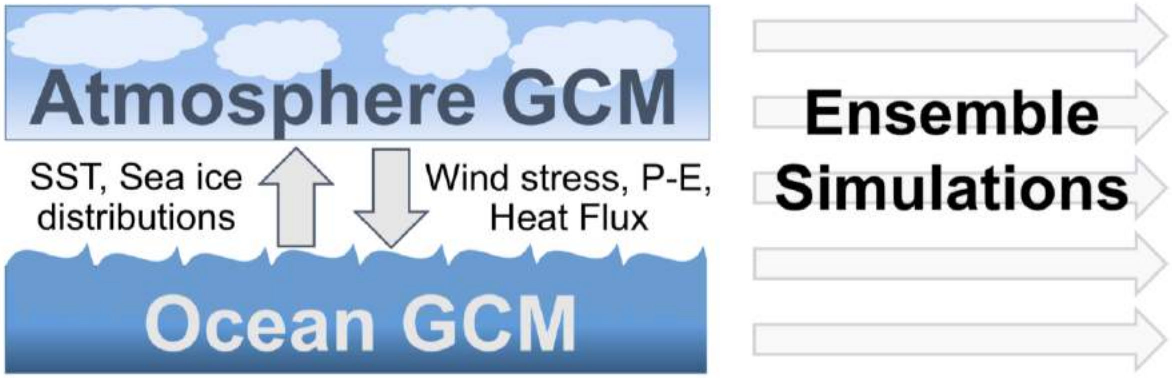
Le Quéré et al., 2018

Motivation (2)

2. Evaluate the extent to which carbon flux changes are predictable on seasonal timescales

- Seasonal forecasts show skill in predicting climate anomalies several months in advance, particularly in the tropics
- If extended to include carbon fluxes, such forecasts have the potential to support
  - NASA's ability to observe changes in the carbon cycle by providing a longer lead time
  - Quicker analysis of satellite observations in support of carbon monitoring

Seasonal Forecasting System



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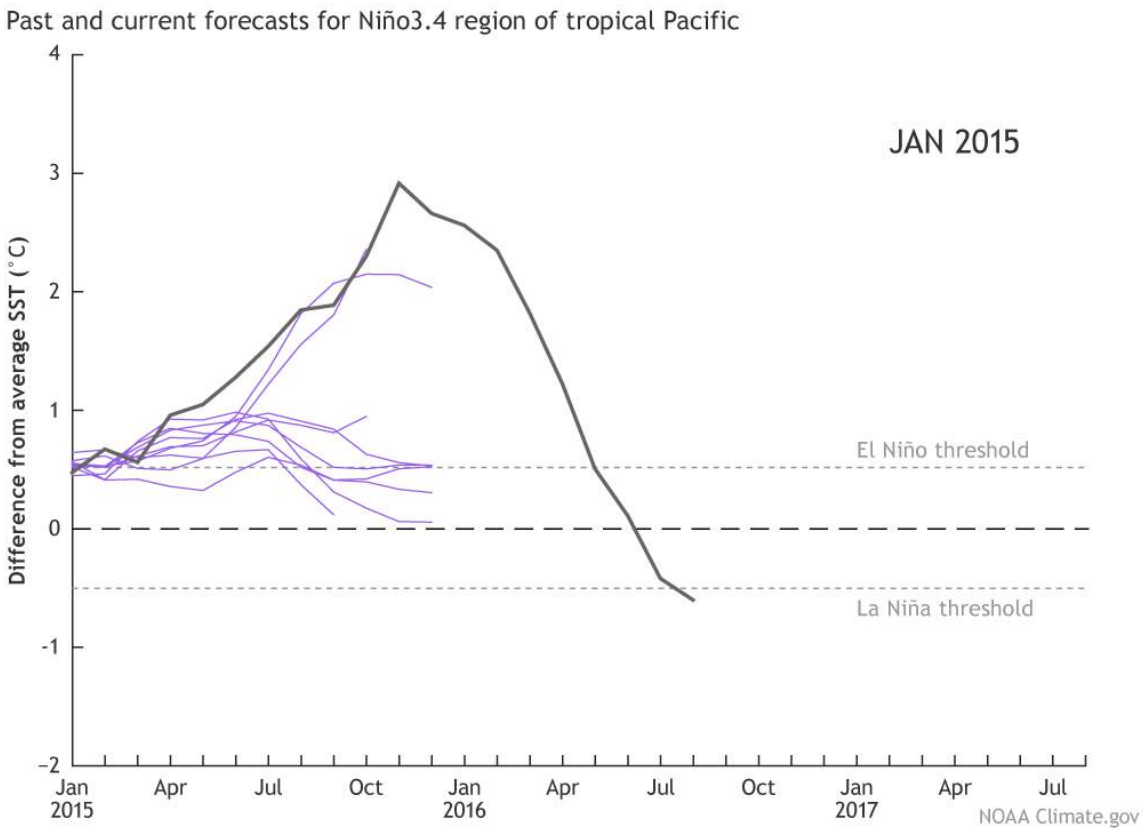
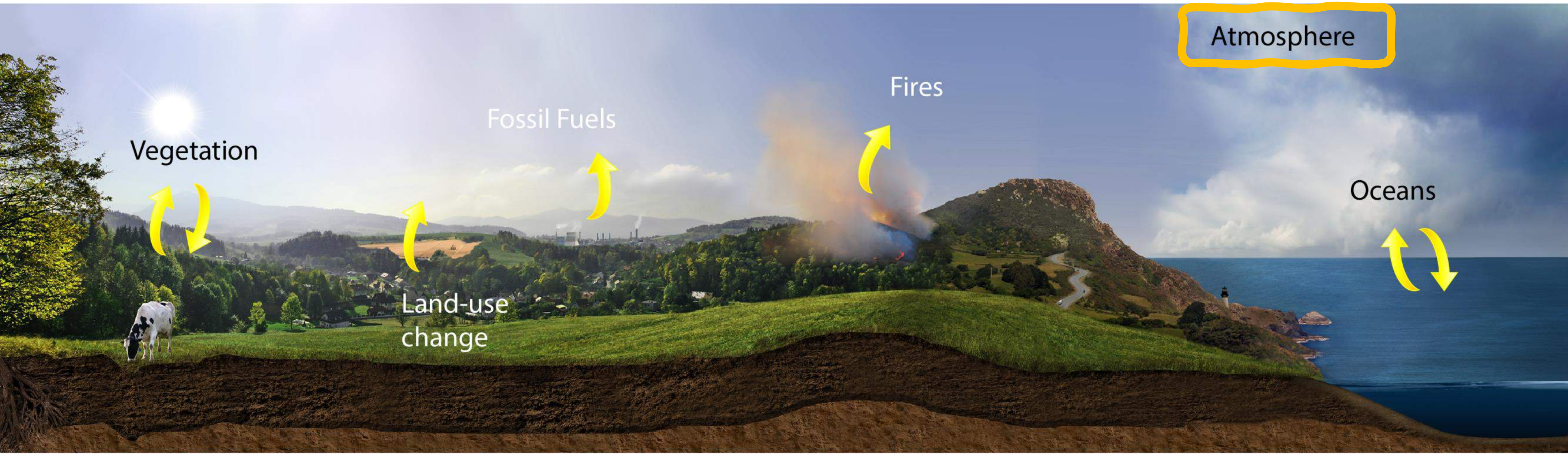
Forecasts of the 2015-16 El Niño



NOAA Climate.gov, 2016

How well can we forecast each of these components, and at what lead times?



Credit: NASA/Jenny Mottar and Abhishek Chatterjee

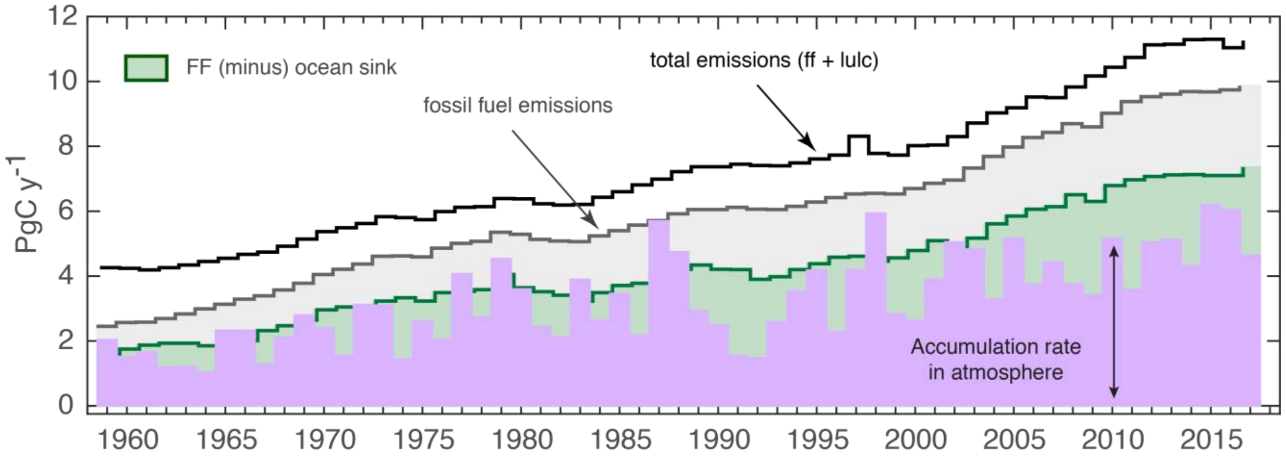
Forecasting Atmospheric CO_2 Growth Rate

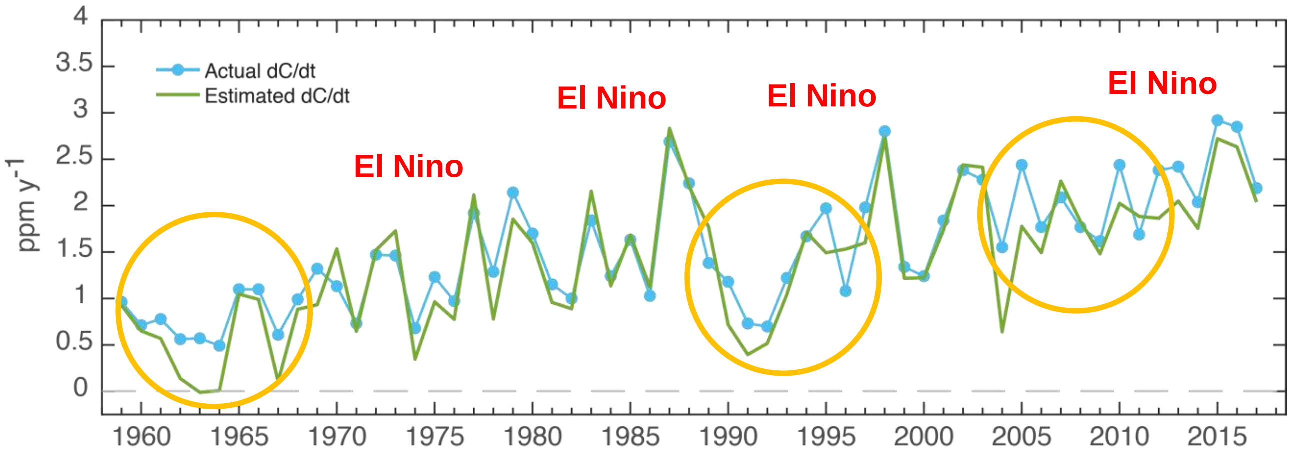
- Airborne Fraction (AF) = fraction of anthropogenic carbon emissions which remain in the atmosphere after natural processes have absorbed some of them

$$AF_{FF+LU} \equiv \frac{\frac{dC}{dt}(t)}{FF(t) + LU(t)}$$

- AF is a fundamental property of the carbon cycle (long-term avg. = 0.45)

- as part of this work, estimating **dC/dt** using MLR and information about anthropogenic emissions, modes of climate variability (ENSO, NAO, etc.) and other natural forcings (Chatterjee et al., *in prep.*) → initial results are extremely encouraging, stay tuned





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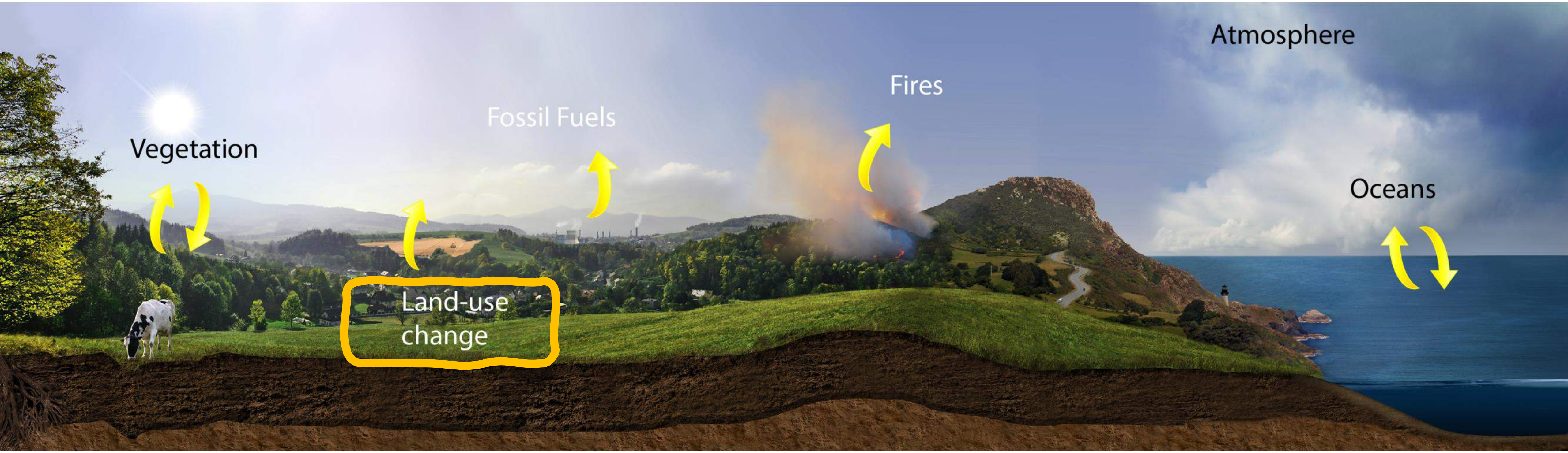
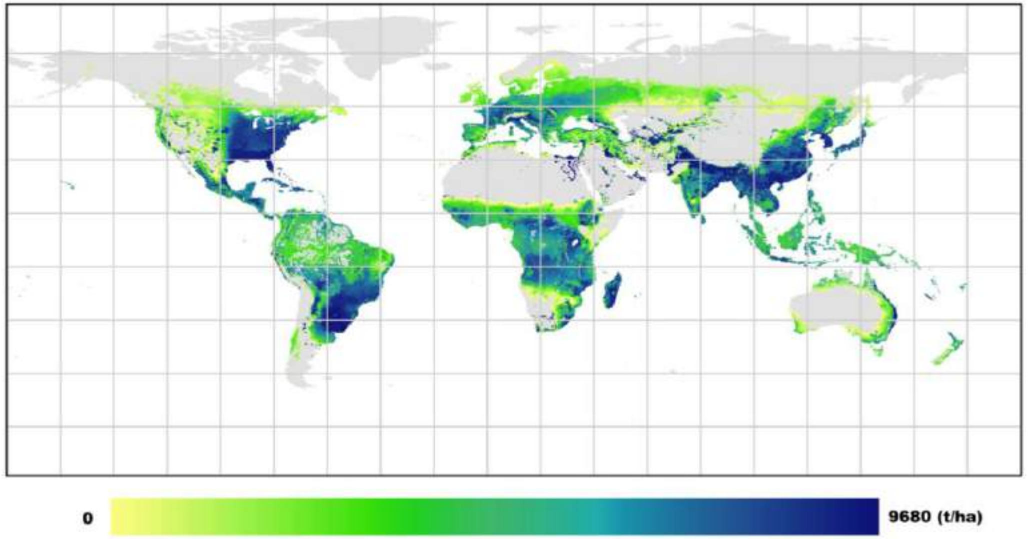


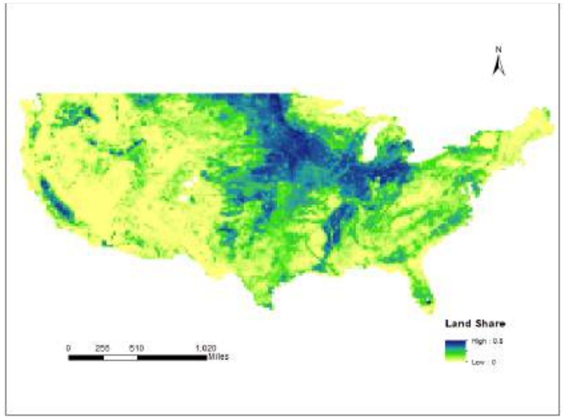
Credit: NASA/Jenny Mottar and Abhishek Chatterjee

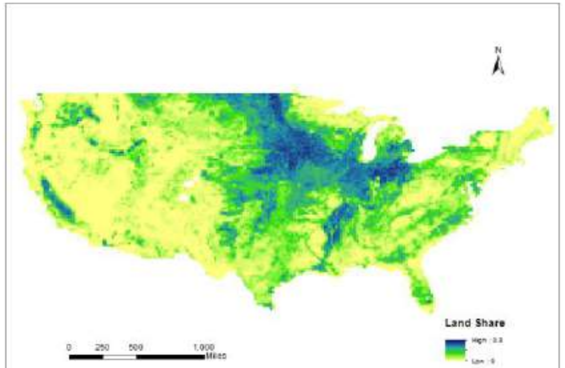
Land use predictions using economic models

Global cropland economic return (2000)



Cropland LUH 2011	Cropland prediction 2011





Absolute error RMSE: 0.033

- Simulation of major crop production using Agro-Ecological Zones model and cropland economic return calculation
- Development of Logistic Share Model of Land Use for Land Use prediction studies
- Applications in countries with reasonably good and accessible agricultural statistics (e.g. United States and Brazil)
- Because year-to-year changes are relatively small, greatest applications are on 2-5 year time horizon

L. Sun and G. Hurtt

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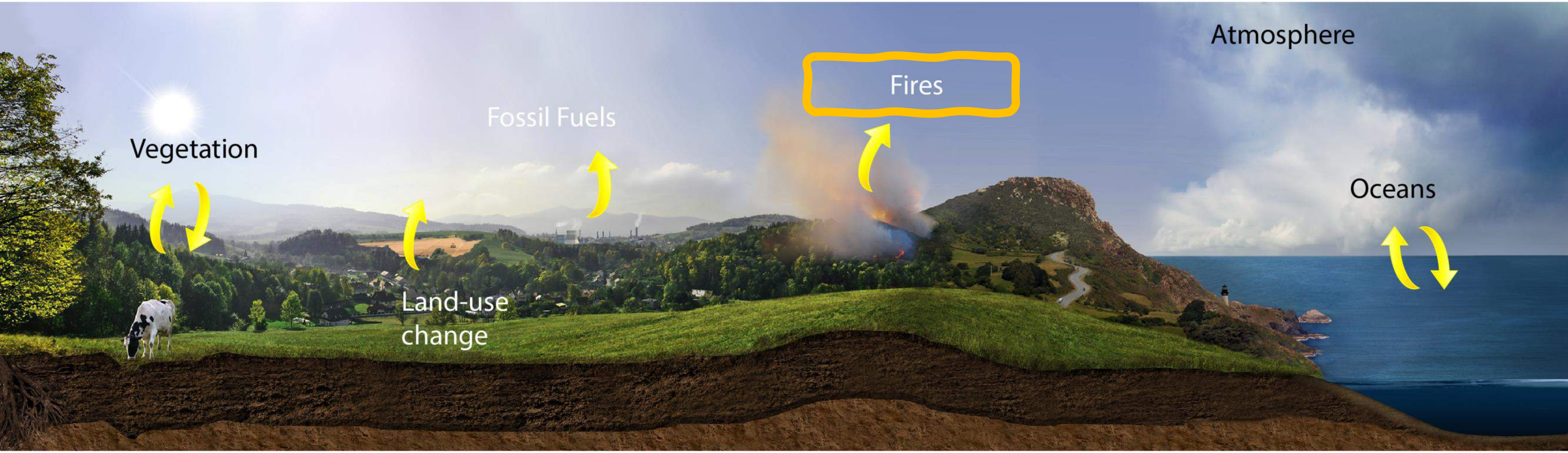
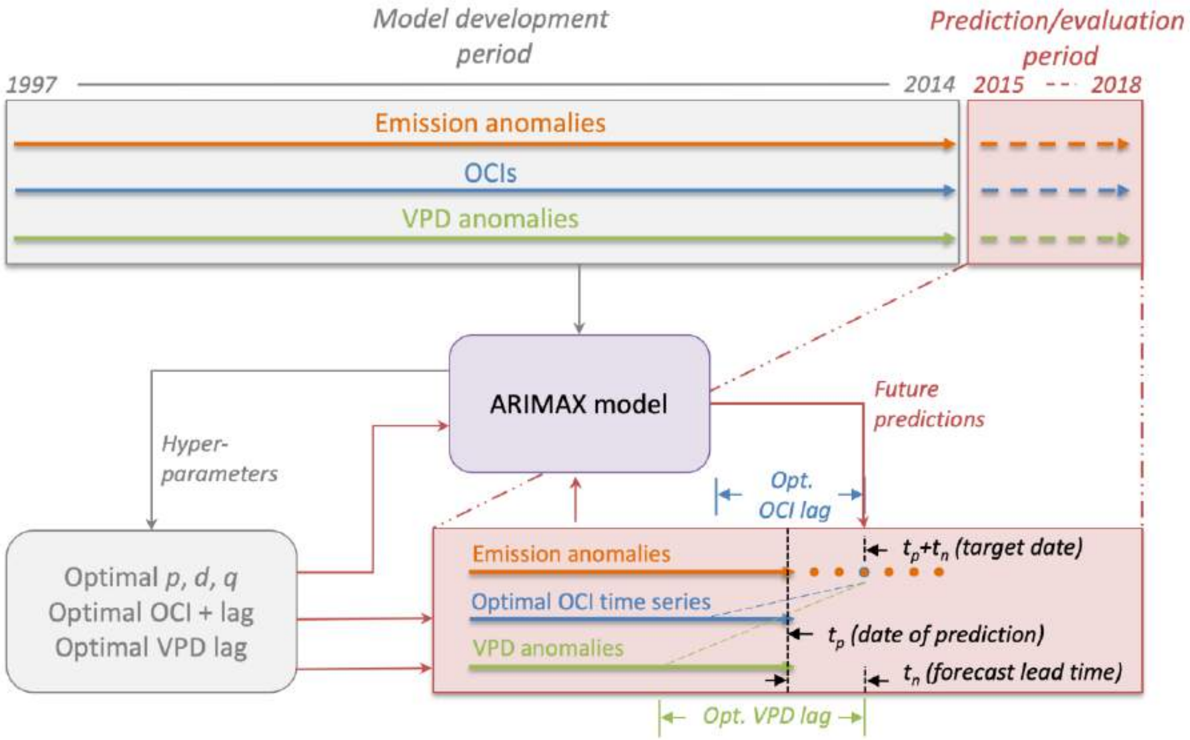


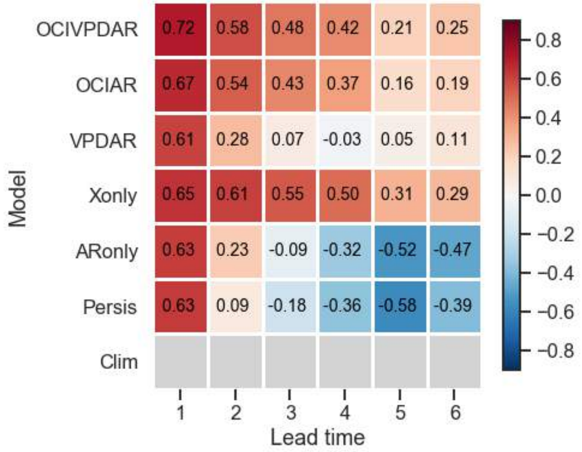
Credit: NASA/Jenny Mottar and Abhishek Chatterjee

Statistical fire forecasts using ocean climate indices (OCIs) and vapor pressure deficit (VPD)

ARIMAX: autoregressive (AR) integrated (I) moving average (MA) with exogenous variables (X)

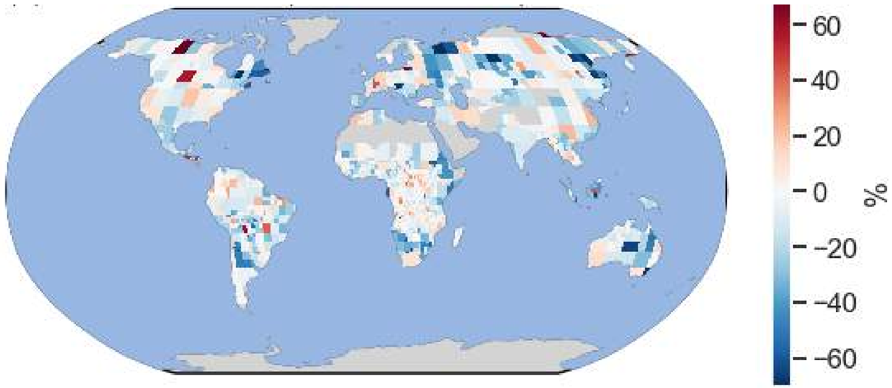
$$y'_t = c + \sum_{i=1}^{p}\alpha_i y'_{t-i} + \sum_{j=1}^{q}\beta_j \varepsilon_{t-j} + \sum_{k=1}^{n}\gamma_k x_k + \varepsilon_t$$





Anomaly correlation with observed burned area

RMSE changes from *Clim* to *OCIVPDAR* model



Y. Chen and J. Randerson

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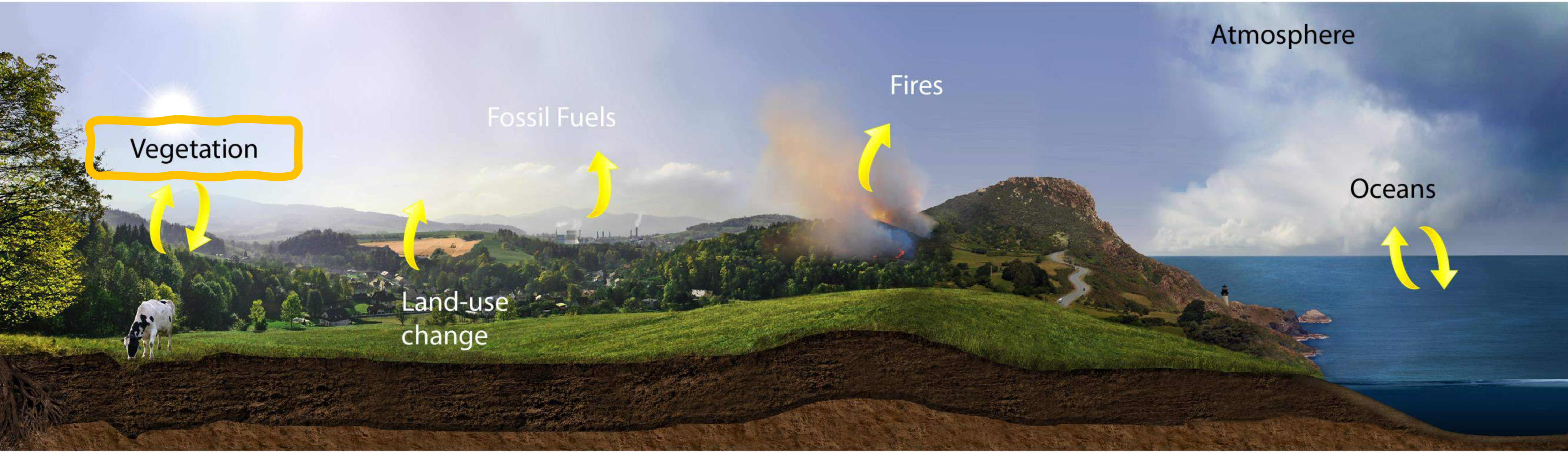
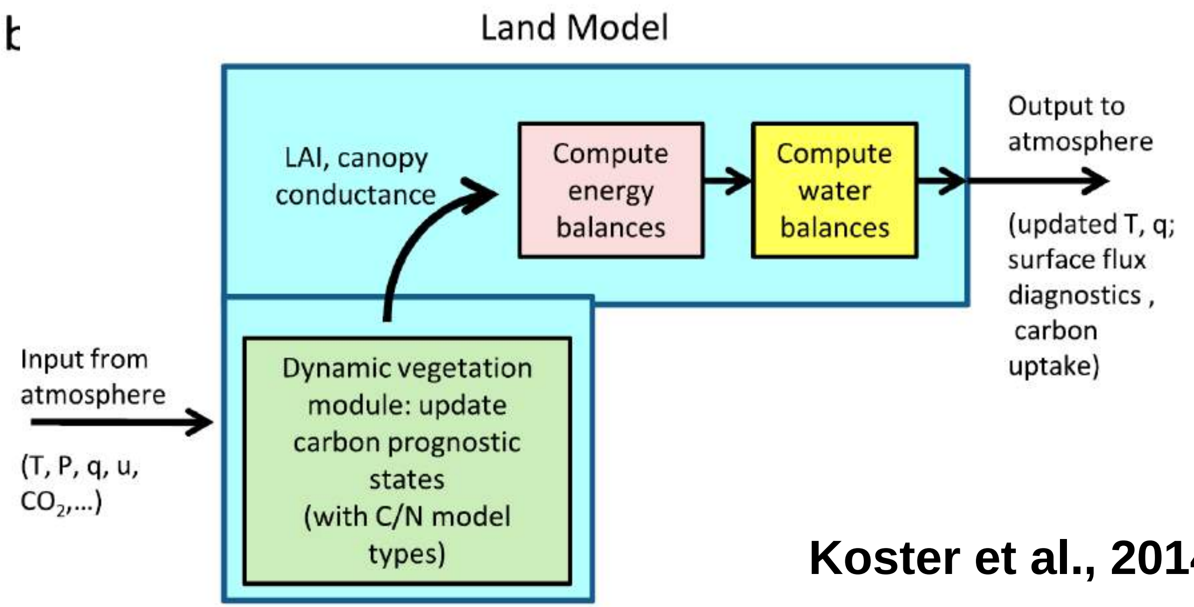


Credit: NASA/Jenny Mottar and Abhishek Chatterjee

Forecasts of NEE using two terrestrial biosphere models

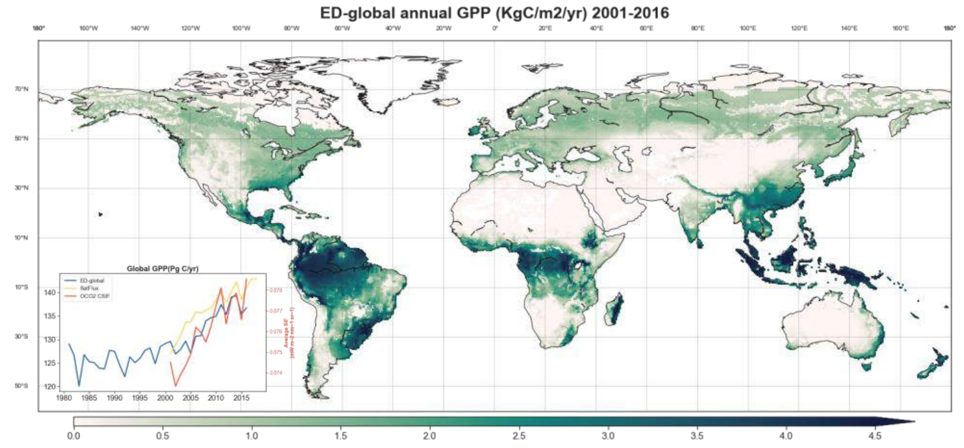
Catchment-CN

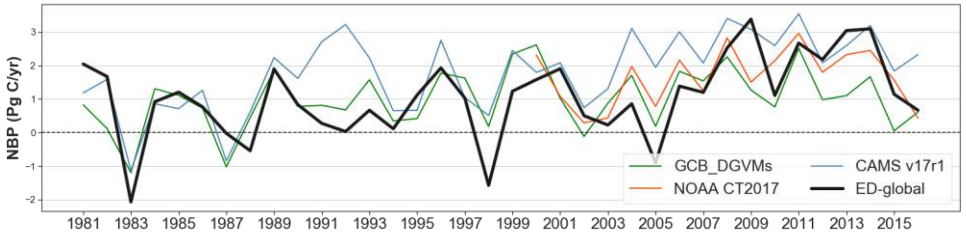


Koster et al., 2014

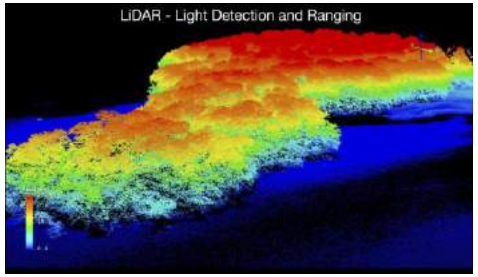
- Can be run offline or within GEOS modeling system – strong connection to met data assimilation and SMAP
- Merger of CLM C-N dynamics and GEOS water, energy balances

Global ED (UMD)





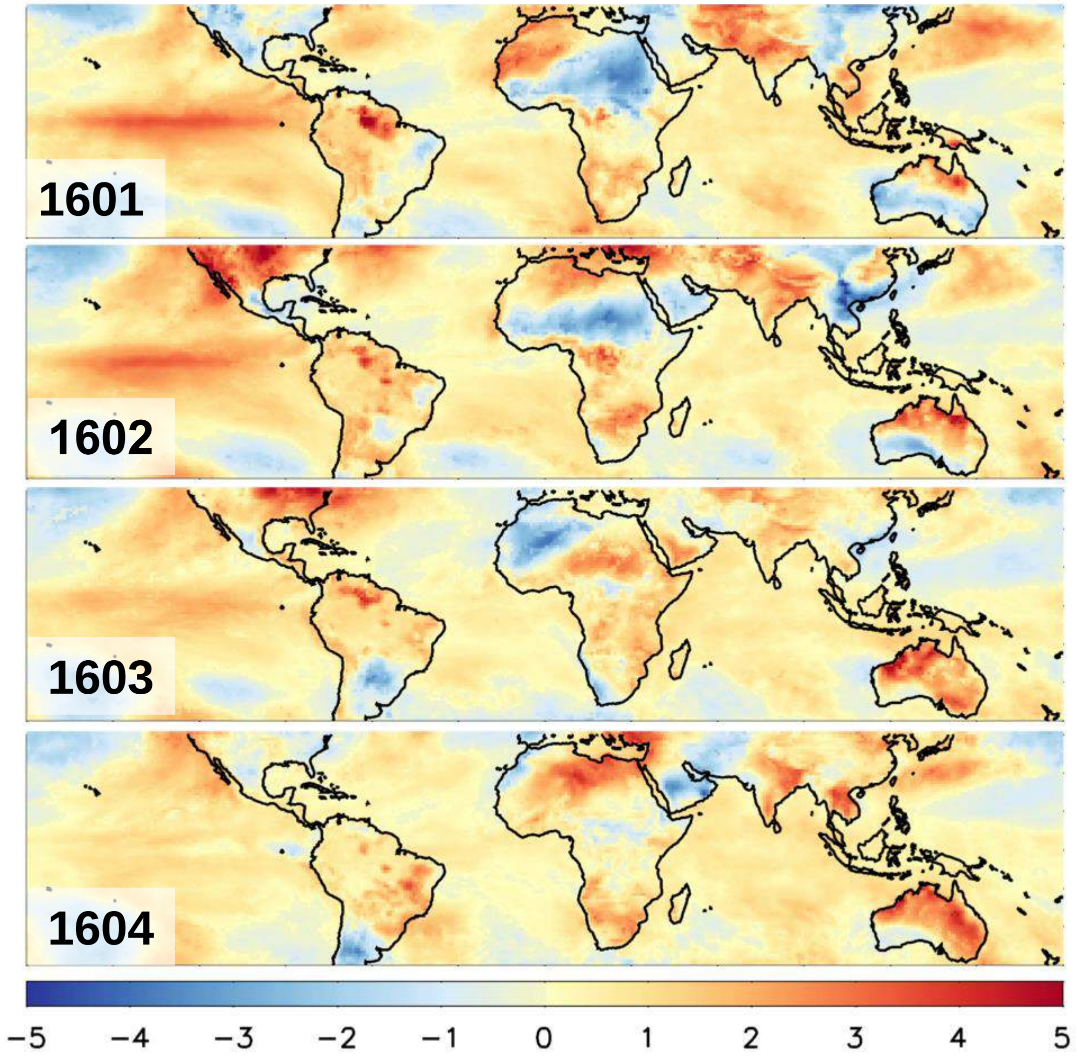
- Development of global Ecosystem Demography model (ED)
- Model-Data integration with remote sensing (LiDAR, Landsat)
- Applications in CMS, GEDI, IDS



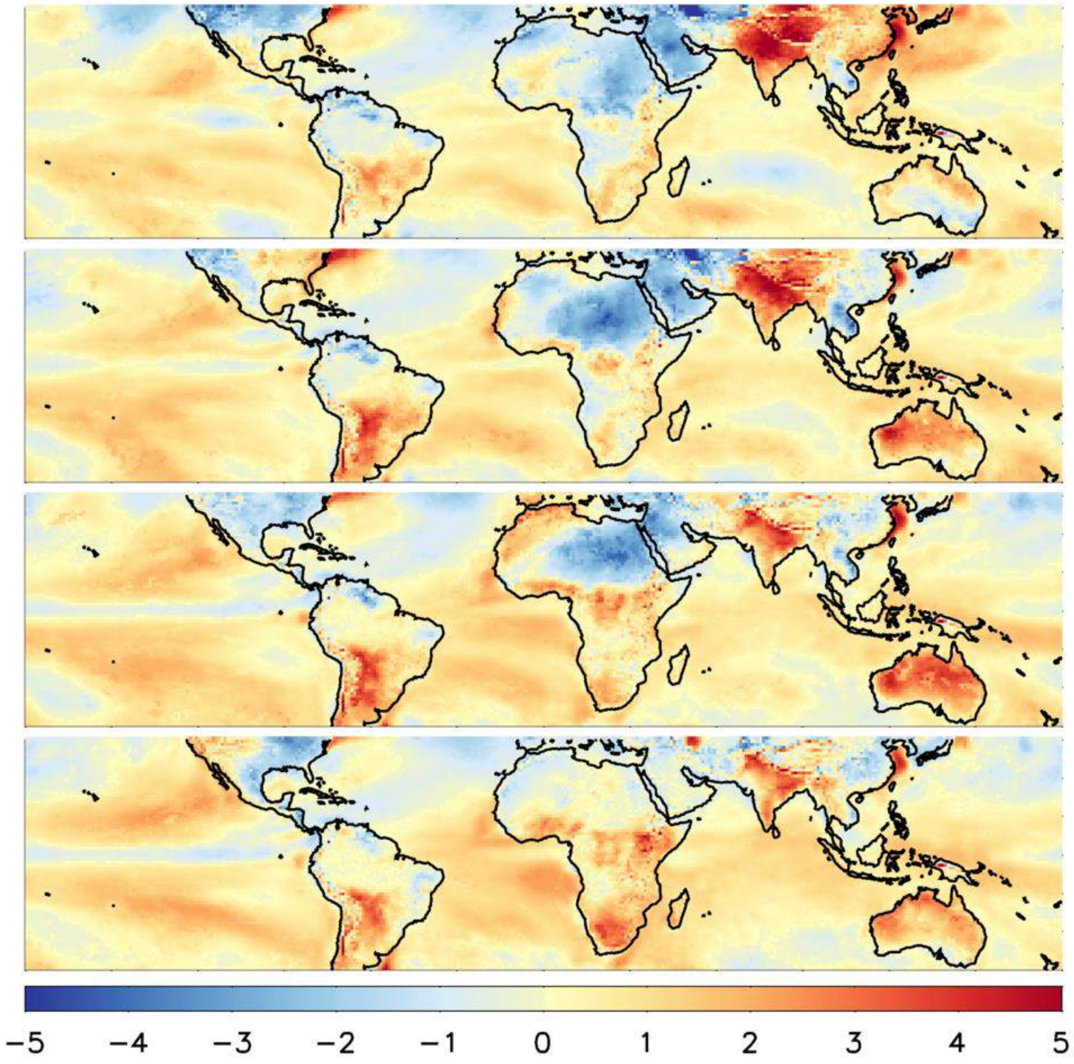
E. Lee, F. Zeng, G. Hurtt, and L. Ma

Case study: End of the 2015-16 El Niño

Observation-driven T Anomaly (K)



Raw Seasonal Forecast T Anomaly



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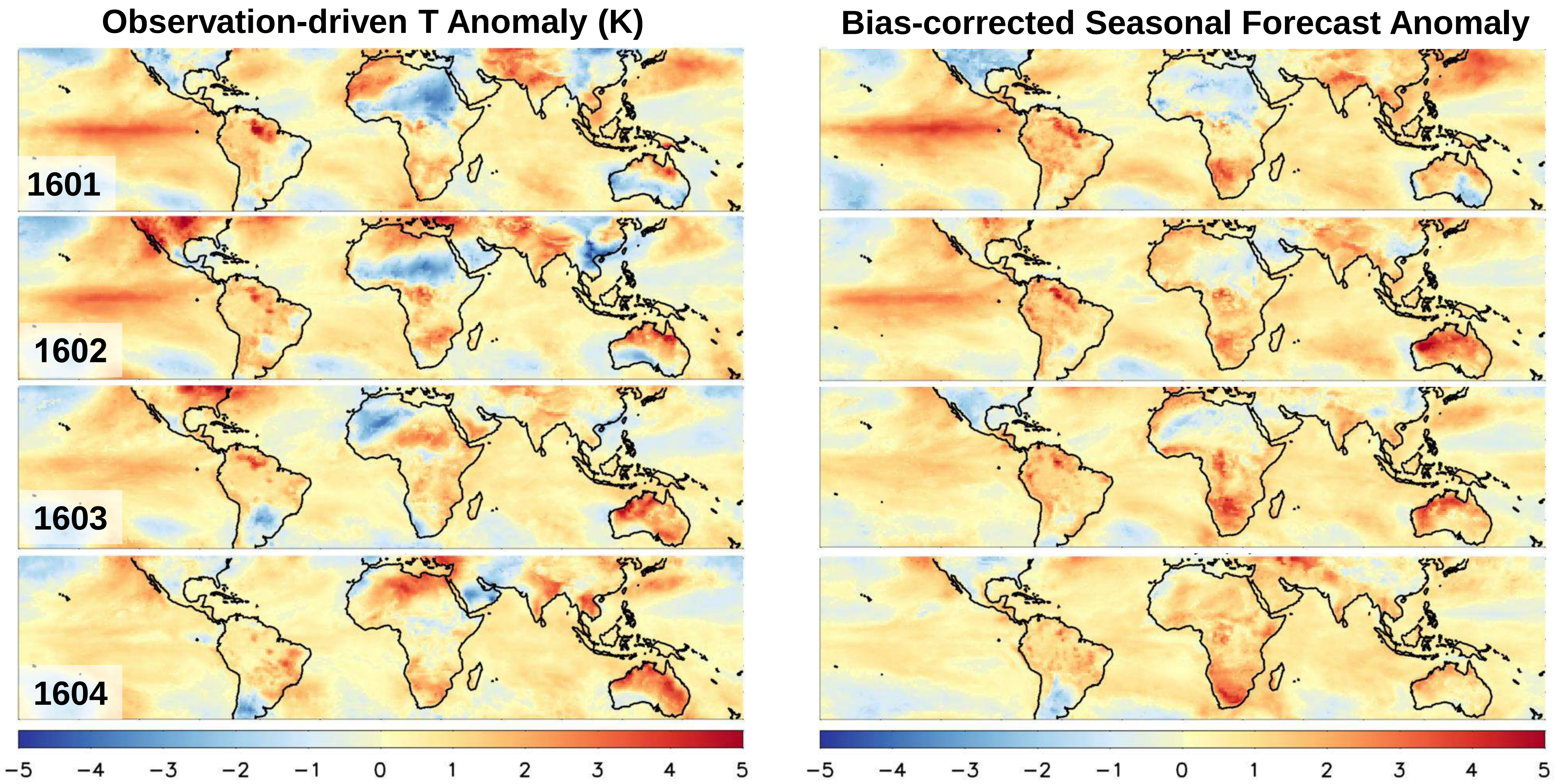

Bias correction courtesy of F. Zeng, K. Arsenault, A. Hazra, and S. Shukla

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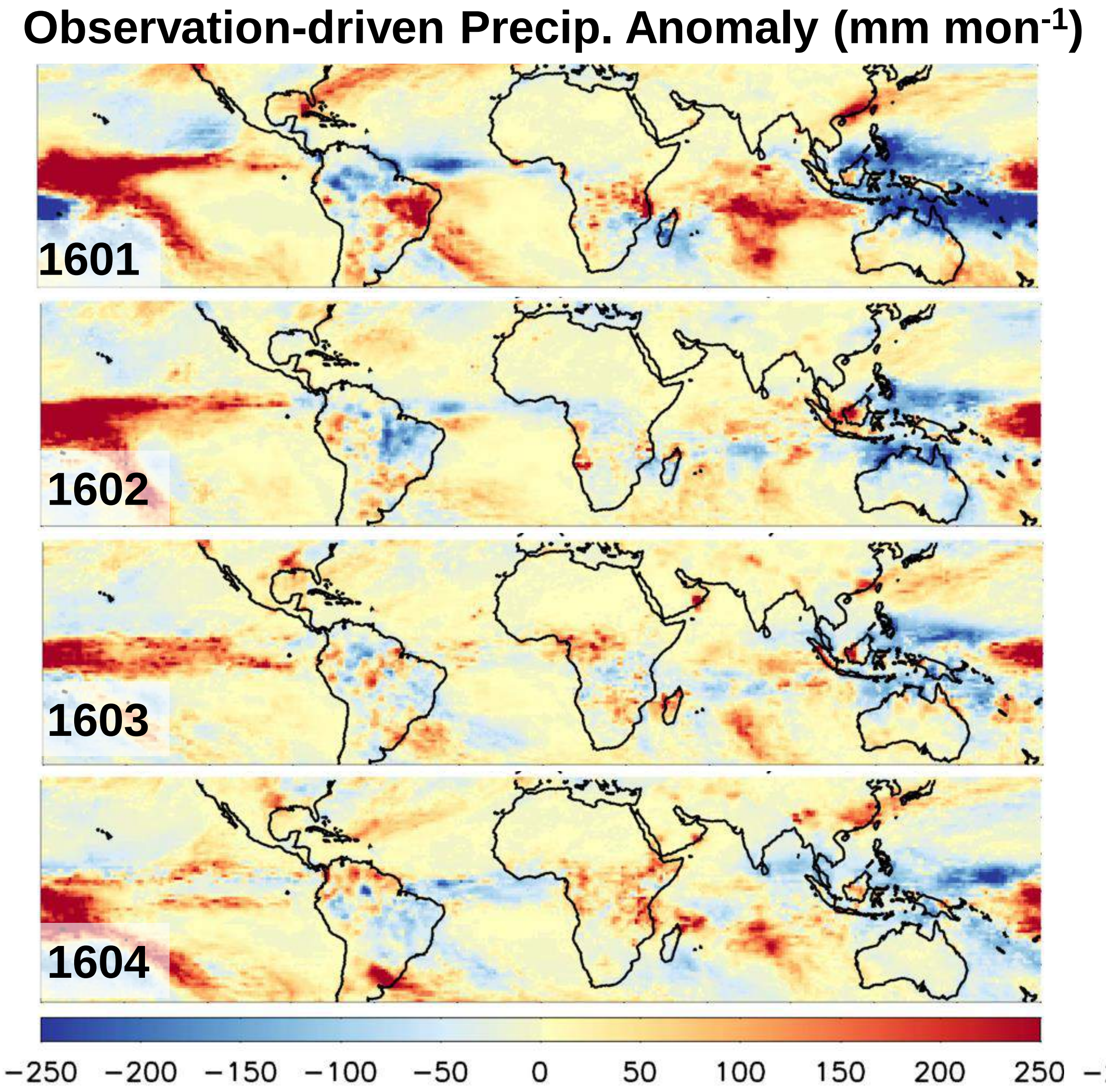

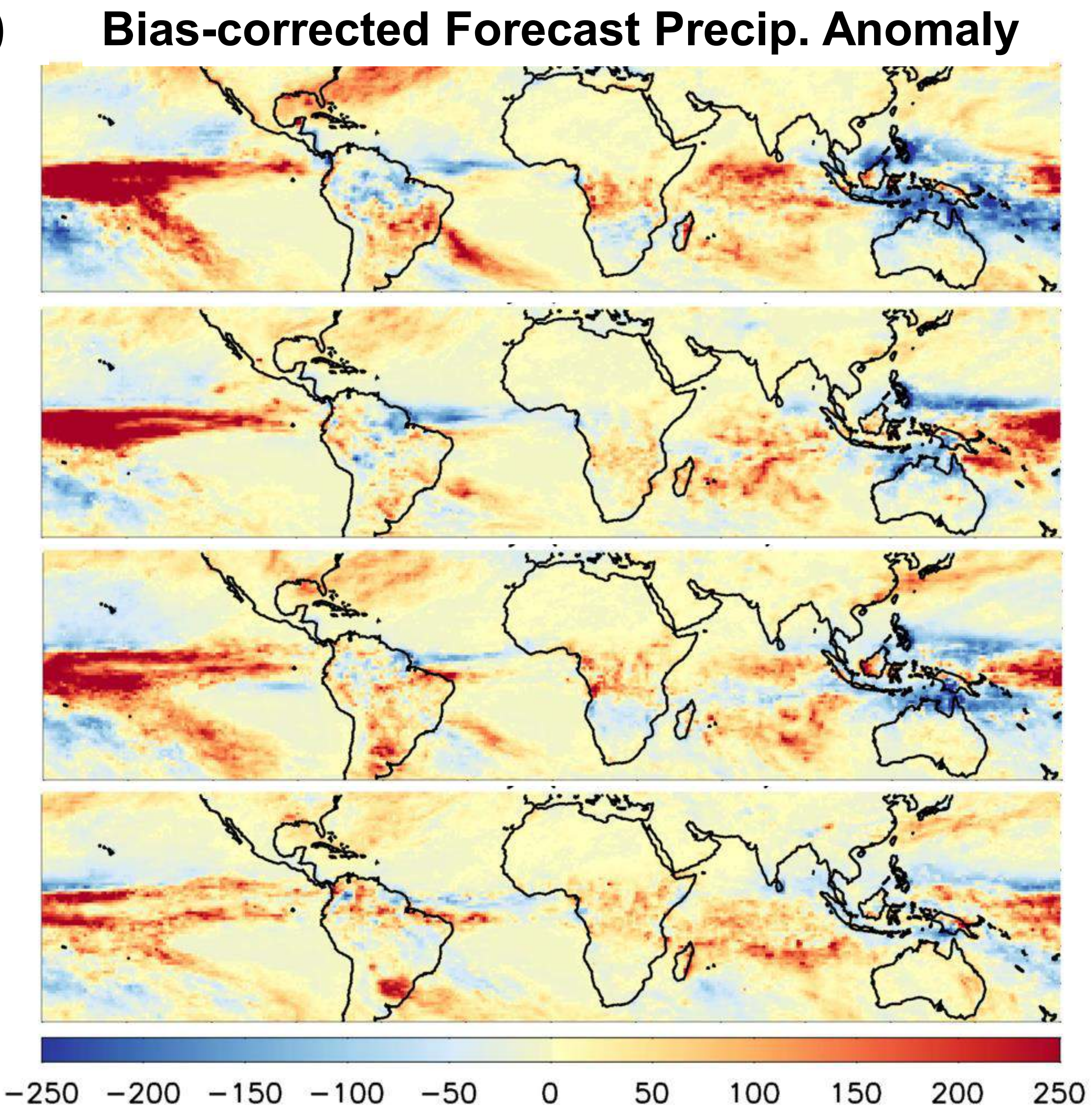

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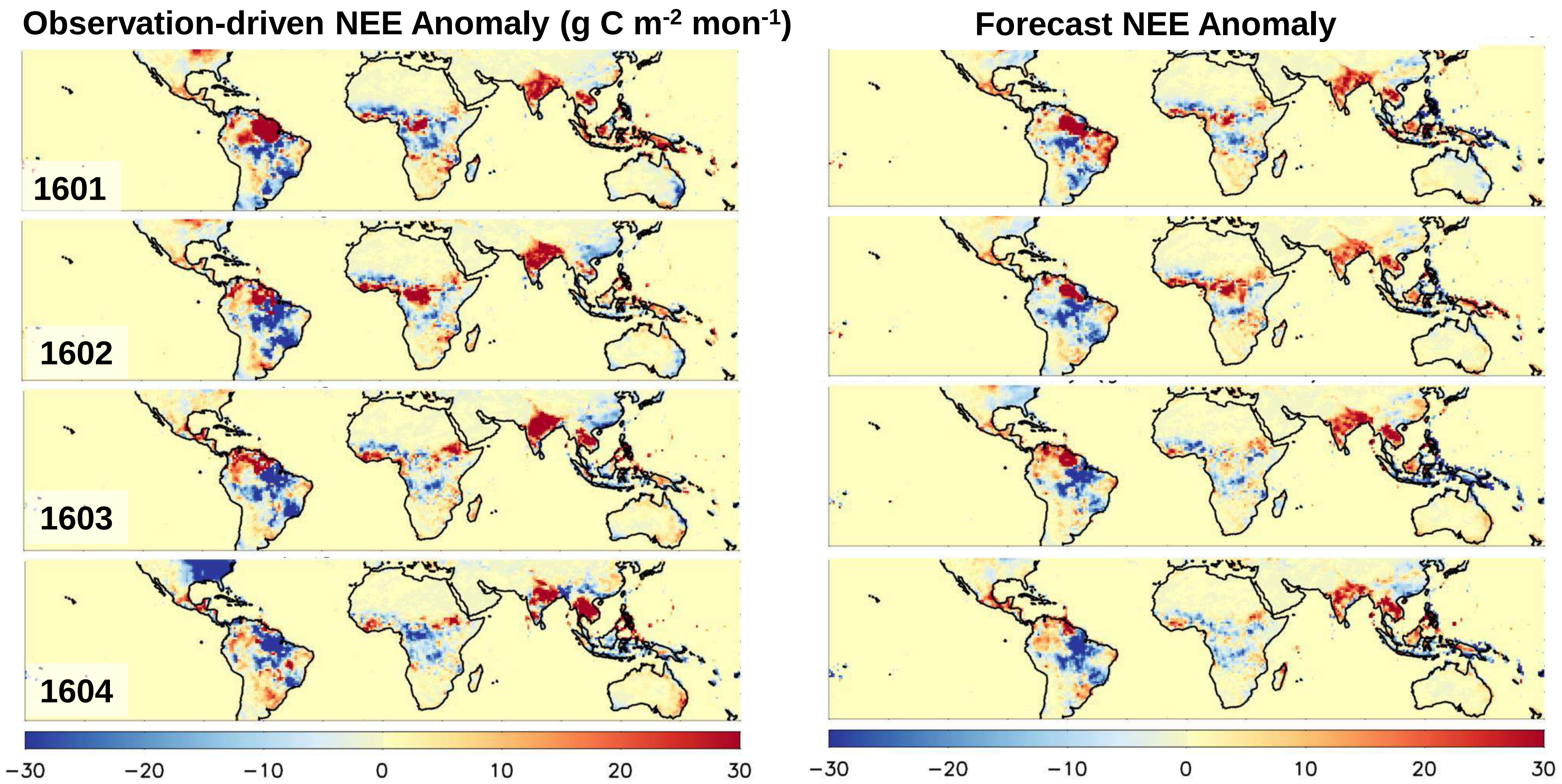
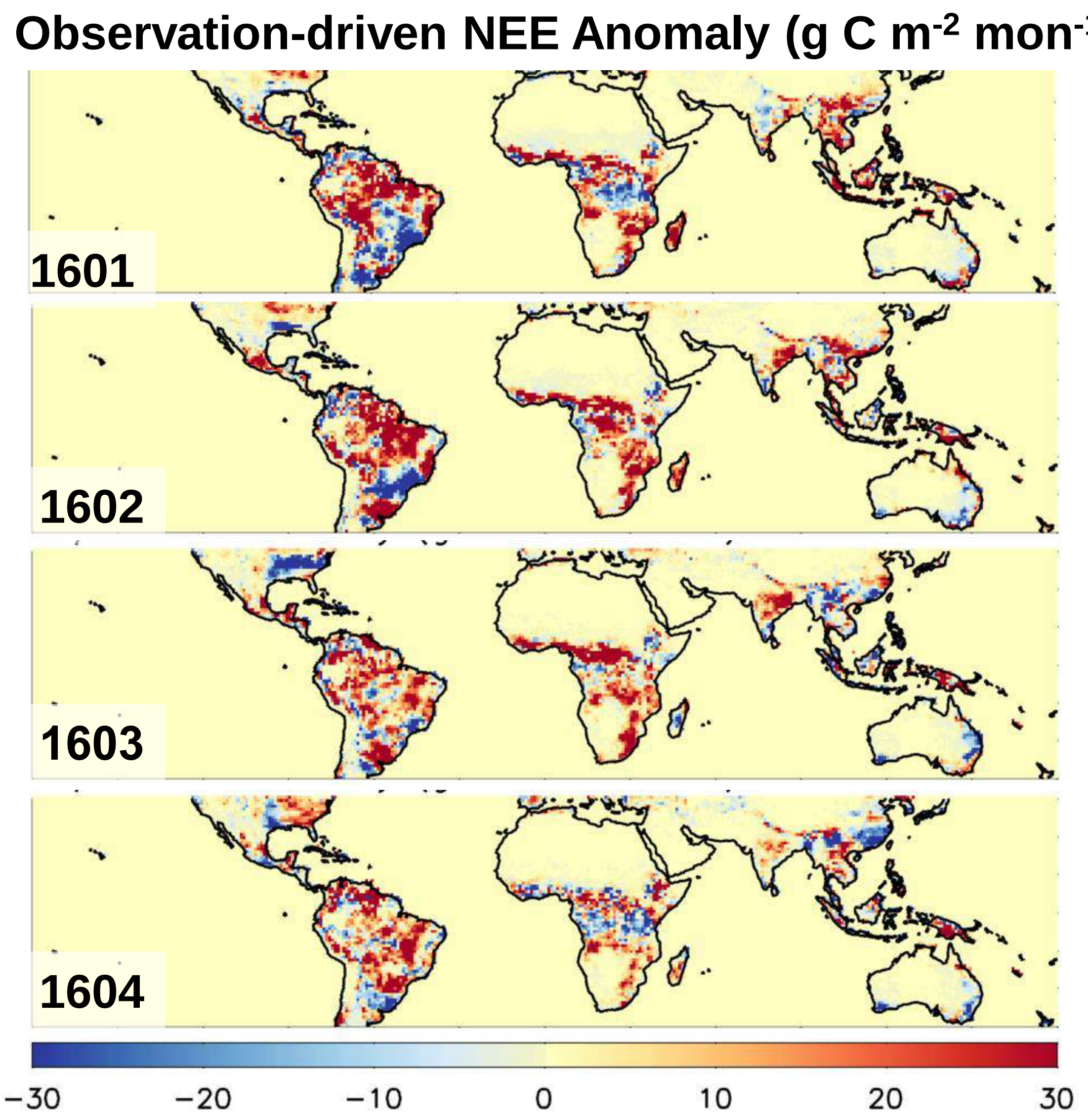
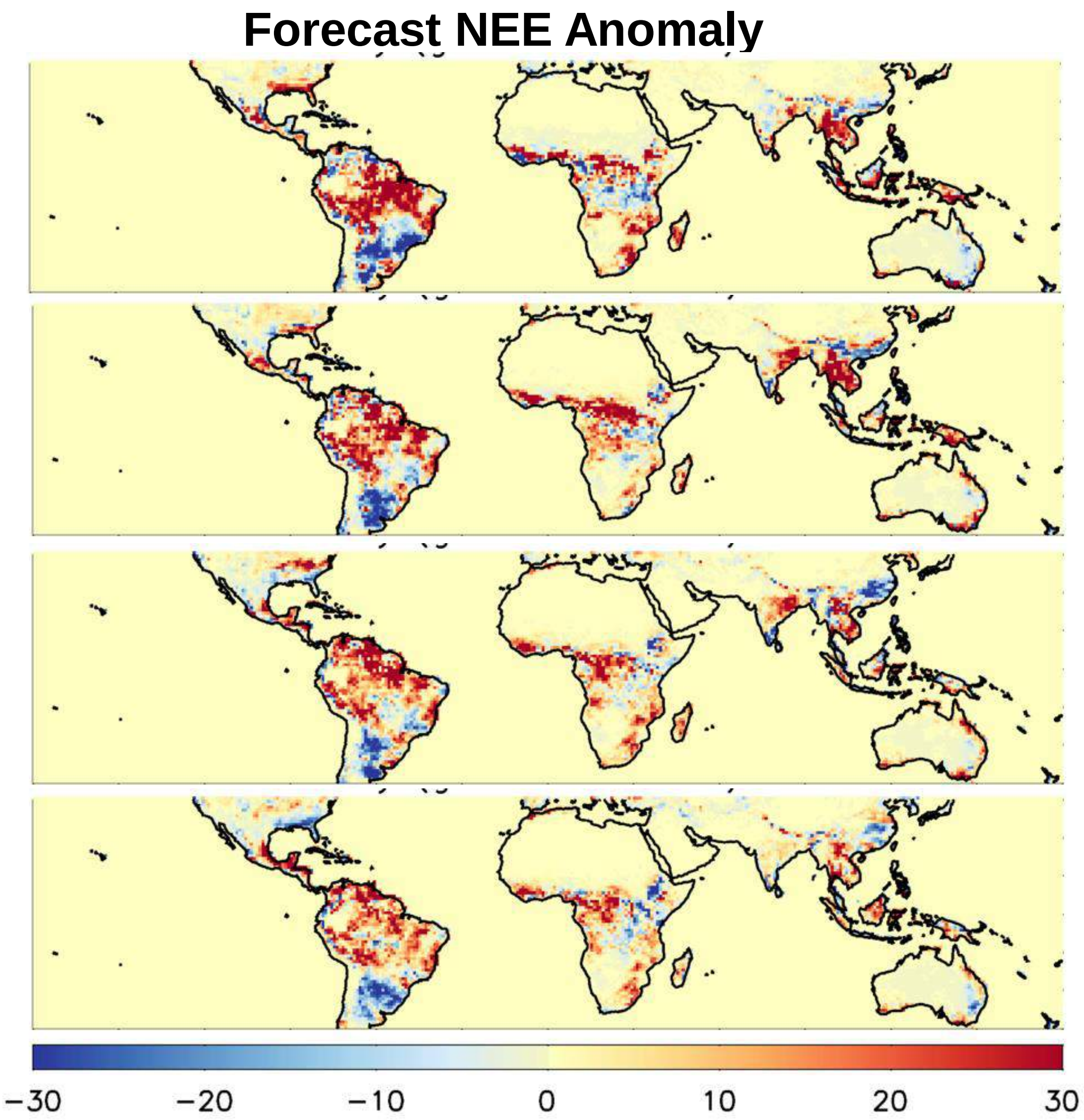
Predicted NEE Anomalies – Catchment-CN



F. Zeng and E. Lee

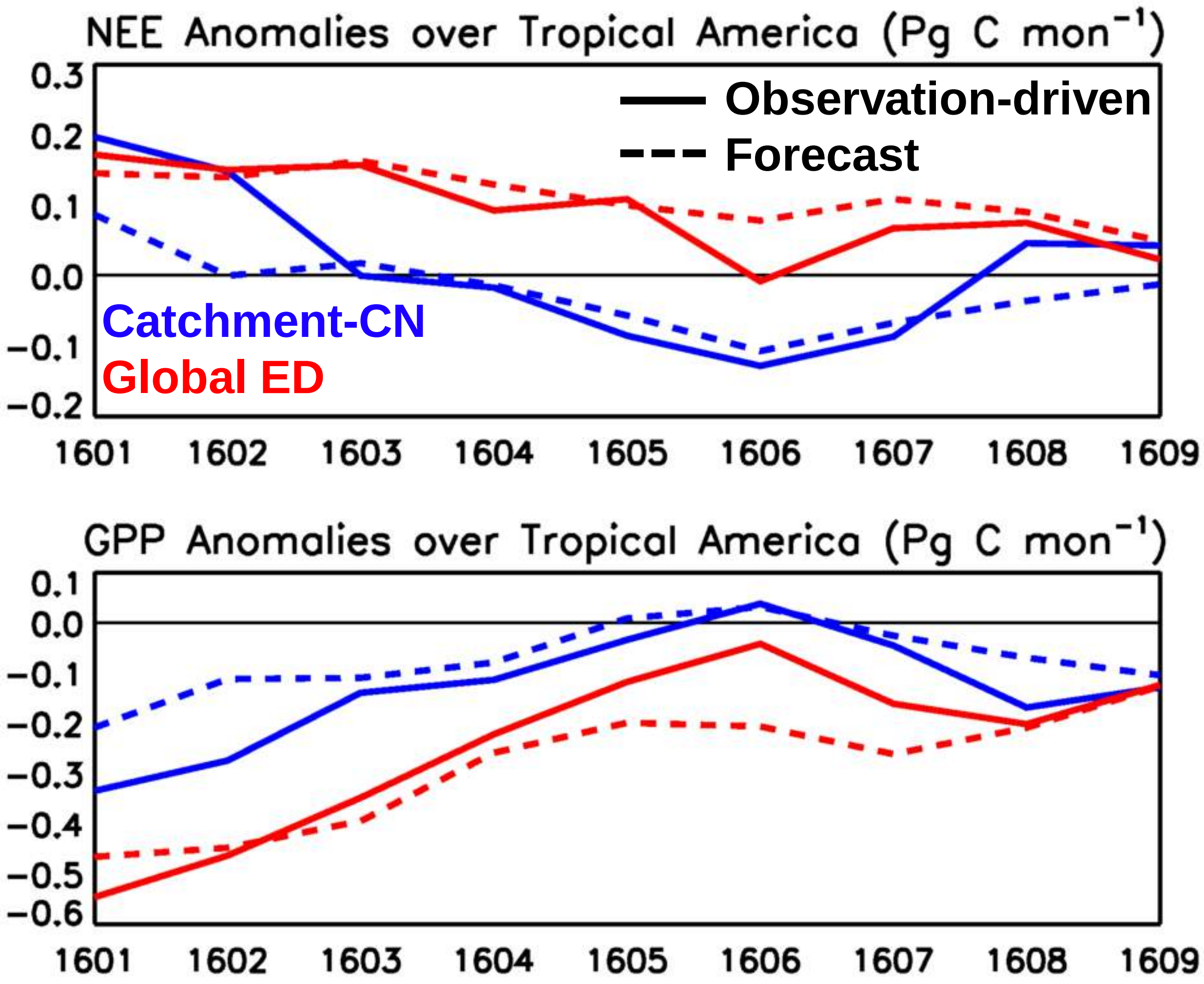
Predicted NEE Anomalies – Global ED





L. Ma and G. Hurtt

Comparing Tropical American Flux Anomalies



- Both TBMs driven by seasonal forecast meteorology predict consist flux anomalies out to ~4 months
- Both models predict positive NEE anomalies associated with reduced GPP
- Results are qualitatively consistent with inverse model results using OCO-2 data, though more careful analysis is needed to confirm this

Conclusions

- Through IDS, NASA is supporting the world's first seasonal carbon flux forecasts (thanks!)
- All components of the carbon cycle demonstrate some level of predictability, though establishing how, where, and how good is a work in progress (FF and ocean forecasts also ongoing but not shown here)
- Current generation seasonal climate forecasts require careful bias correction, but they contain information on temperature and moisture anomalies that can support skillful seasonal forecasts of NEE in some regions
- It's a work in progress, but seasonal carbon forecasts show the potential to support a variety of research applications including
  - Targeted remote sensing
  - Aircraft and field campaign deployments
  - Contributing to carbon budget analyses
  - Bridging a gap to provide more informed prior fluxes to atmospheric modelers