EVALUATING AMAZONIAN FOREST RESPONSE TO INCREASED DISTURBANCE: LESSONS FROM A GAP MODEL FOR FUTURE MODEL IMPROVEMENT

ACCELERATED CLIMATE MODELING FOR ENERGY (ACME)

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SCIENCE DRIVER

Motivation - Uncertainties in future terrestrial sources of atmospheric carbon dioxide from changes to forest disturbance and tree mortality rates, specifically in tropical forests.

(1) There has been evidence that climate change and forest disturbance are linked, such that a changing climate can influence the timing, duration, and intensity of disturbance regimes (Dale et al. 2001) (Fig. 1)

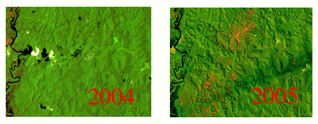
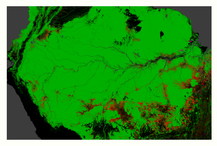


Fig. 1. Remotely sensed disturbance using Landsat. 100 km² Amazon landscape pre-disturbance and post-disturbance (red channel) (Chambers et al. 2013)



Amazon Deforestation 2000-2012 (Hansen et al. 2013)

- **Model Uncertainty – can global Earth System Models (ESMs) reproduce subtle, continual, and periodic disturbance and recovery behavior?**
- **Model Uncertainty – will the carbon cycle response due to disturbance effect mitigation strategies and the energy market sector in Integrated Assessment Models (IAMs)?**

(2) Currently there are large gradients between the Central Amazon and Western Amazon regions (Fig. 2). Such that the Western Amazon has "faster" dynamics; i.e. turnover, growth rates, and lower wood density. Evaluating the role that variations in disturbance rates play on influencing the variation between the two Amazon regions is warranted.

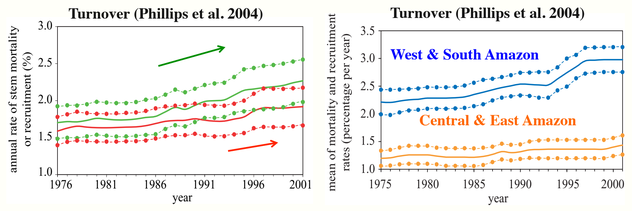


Fig. 2 "Faster" dynamics in Western Amazon vs. Central Amazon.

(Quesada et al. 2010)

(Q1) How do shifts in disturbance regimes and background mortality rates affect ecosystem processes and carbon cycling dynamics for tropical forests?

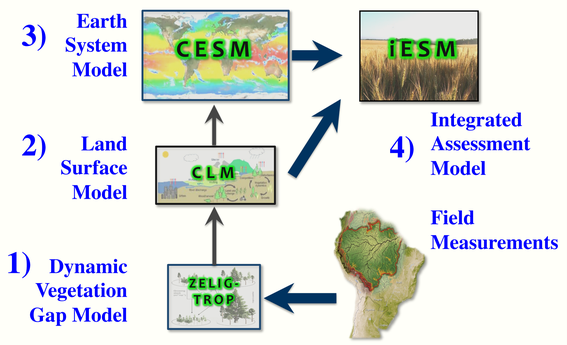
(Q2) Can the variability in forest dynamics and carbon stocks between the Western and Southern Amazon and the Central Amazon forests be explained by the variability in the natural disturbance regime (i.e. higher mortality rates)?

DESIGN OF METHODS

- **This project aims to evaluate the mortality and disturbance processes in two land surface models of varying scales, detail, and functionality (Community Land Model: CLM, and ZELIG-TROP).**
- **This task will benefit the Integrated Earth System Model (iESM) project, which combines CLM/CESM with a fully integrated human system component, and assist in developing mitigation strategies in response to energy market shifts due to natural disturbances.**

Design –

- **Individual-based, dynamic vegetation, forest gap model ZELIG-TROP (Holm et al. 2012) calibrated and verified for a complex Central Amazon forest; used as a "benchmark" model.**
- **Community Land Model (CLM) 4.5 CN, a global land surface model that is part of the Community Earth System Model (CESM).**
- **Two elevated disturbance treatments:**
  - **"High disturbance" = continual, annual 100% increase in mortality (~1% to 2%)**
  - **"Periodic disturbance" = 20% removal of stems, every 50 years**
- **Validation dataset for elevated disturbance = Western and Southern Amazon**
  - **RAINFOR inventory network**
  - **When accounting for wood density there is a lower aboveground biomass in W&S Amazon compared to C&E Amazon (Baker et al. 2004)**



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ACKNOWLEDGEMENTS

This research was supported by the Director, Office of Science, Office of Biological and Environmental Research of the U.S. Department of Energy under contract No. DE-AC02-05CH11231 as part of the Earth System Modeling Program (KP170302). This research used resources of the National Energy Research Scientific Computing Center, which is supported by the Office of Science of the U.S. Department of Energy under contract DE-AC02-05CH11231.

DEMONSTRATION OF METHODS

- **High Disturbance = led to 42% and 50% AGB decrease in ZELIG-TROP and CLM (Fig. 3b).**
- **Periodic Disturbance = led to 18% and 19% AGB decrease in ZELIG-TROP and CLM (Fig. 4c).**
- **CLM matched the gap model, and capturing disturbance-recovery processes.**
- **CLM does not capture intra-annual variation in coarse litter production; losses exceeded the gains.**
- **CLM4.5 still over predicts tropical forest biomass.**
- **Different processes caused reduced AGB between the models and empirical datasets. Driver of AGB reduction in empirical datasets: wood density; ZELIG-TROP: stand basal area; CLM 4.5: leaf area index (LAI).**

ZELIG-TROP (black) CLM (blue) Field data (green)

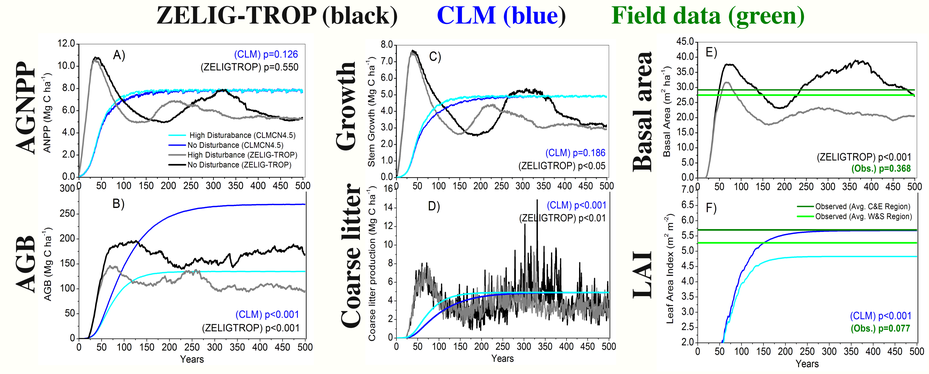


Fig. 3. High disturbance treatment (100% increase in background mortality) compared to No disturbance

(a) No significant effect on ANPP, (b) 42% and 50% decrease in AGB in ZELIG-TROP and CLM, (c) no significant effect on growth rates in CLM, (d) a slightly significant decrease in coarse litter production in ZELIG, and increase in CLM, (e) significant decrease in basal area in ZELIG-TROP, but not observed in field data, and (f) significant decrease in LAI in CLM, but not observed in field data.

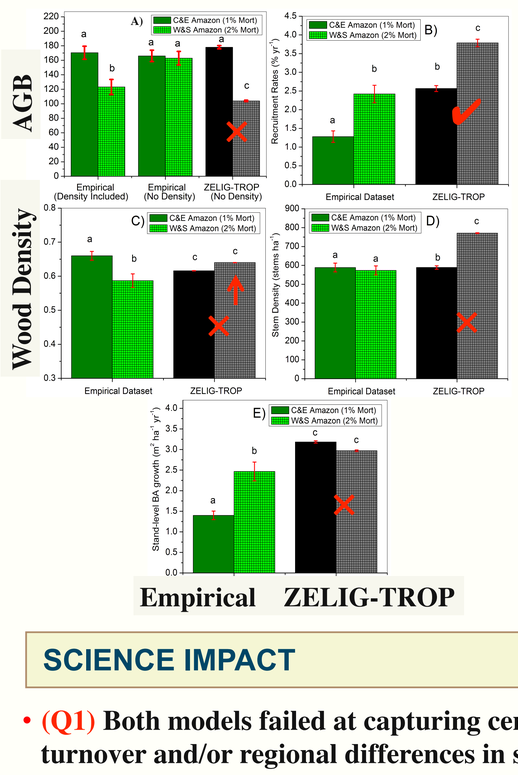


Fig. 4. The variability between Amazonian regions cannot be entirely explained by the variability in disturbance regime, but rather potentially sensitive to intrinsic environmental factors. (a) "False positive" in reduction in AGB with higher disturbance, because wood density not included in model calculation, (c) Wood density differed between the two regions. Under a high disturbance scenario wood density increased in the model.

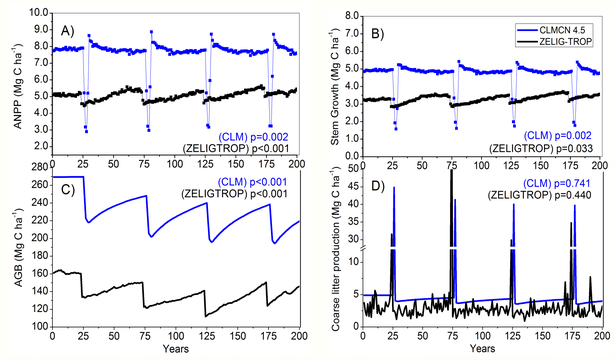


Fig. 5. CLM-CN model evaluation and comparisons to ZELIG-TROP for a periodic disturbance treatment: (a) ANPP, (b) stem growth, (c) aboveground biomass (AGB), and (d) coarse litter production rates, all measured in Mg C ha^{-1}.

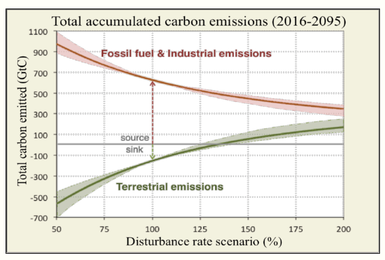
SCIENCE IMPACT

- **(Q1) Both models failed at capturing certain tropical forest processes associated with higher turnover and/or regional differences in species traits and processes has strong influence.**
  - **Getting the right answer (loss in biomass) for the wrong reason (Fig. 4).**
  - **Empirical data found decrease in wood density is the driver of AGB loss.**
  - **Accounting for wood density (proxy for functional traits) needs to be included in models.**

- **(Q2) This suggests that 1) the models are not accurately simulating all forest characteristics in response to increased disturbances, and 2) the variability between regions cannot be entirely explained by the disturbance regime, but rather potentially sensitive to intrinsic environmental factors and/or community composition.**

Improving Disturbance in ESMs –

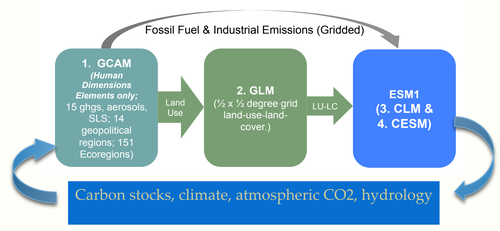
- **Need for demographic vegetation model in CLM (CLM-ED)**
- **Absolute value of AGB still high in CLM-CN 4.5 (for Central Amazon).**
- **Representation of regional variation in the Amazon Basin**
- **Need to link new updates to disturbance processes in fully coupled iESM framework**
- **Critical for future NGEE-Tropics observational and modeling work**



Study using GCAM, an economic/energy IAM, found that mitigation strategies are highly sensitive to future natural disturbance rates. In order to reach a 3.7 W m^{-2} level the mitigation strategies will be up to 2.5 times more costly.

(Le Page et al. 2013)) Sensitivities of climate mitigation strategies to natural disturbances. ERL

iESM Framework (3 models: GCAM, GLM, CLM/CESM)



DOE BER Climate Modeling PI Meeting, Potomac, Maryland, May 12-14, 2014
Funding for this study was provided by the US Department of Energy, BER Program. Contract # DE-AC02-05CH11231