Modeling increased disturbances in a Central Amazonian forest: lessons from a gap model for CLM improvement

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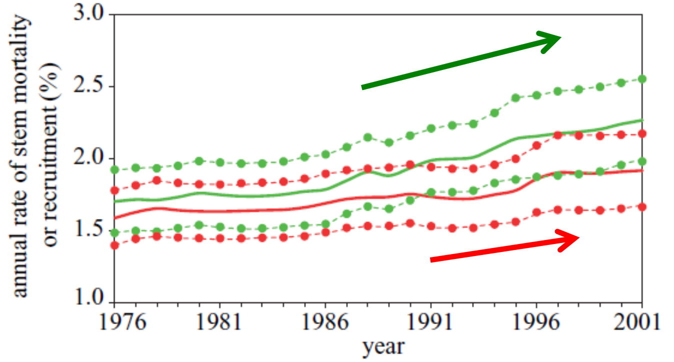
Increasing turnover rates in tropical forests

Turnover = average of mortality and recruitment rates

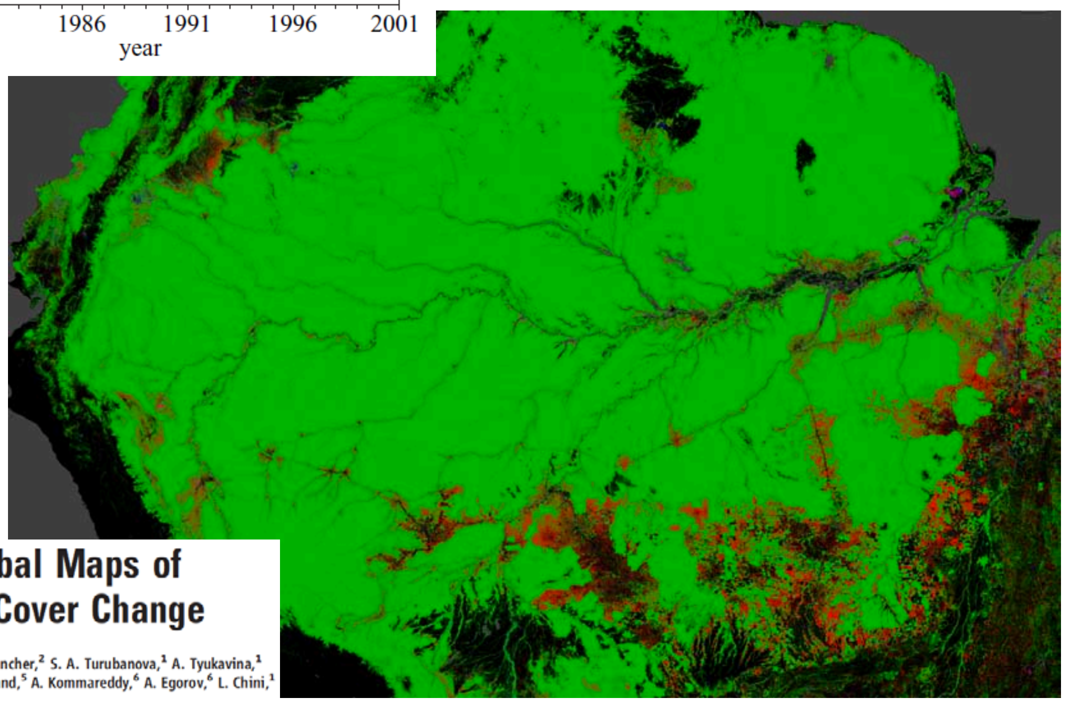
Motivation: Increased disturbance rates associated with climate change remains a major global change issue for Amazon forests.

Turnover (Phillips et al. 2004)



Amazonian forest dieback under climate-carbon cycle projections for the 21st century

P. M. Cox[1], R. A. Betts[1], M. Collins[2], P. P. Harris[3], C. Huntingford[3], and C. D. Jones[1]



Amazon Deforestation 2000-2012

High-Resolution Global Maps of 21st-Century Forest Cover Change

M. C. Hansen,[1]* P. V. Potapov,[1] R. Moore,[2] M. Hancher,[2] S. A. Turubanova,[1] A. Tyukavina,[1] D. Thau,[2] S. V. Stehman,[3] S. J. Goetz,[4] T. R. Loveland,[5] A. Kommareddy,[6] A. Egorov,[6] L. Chini,[1] C. O. Justice,[1] J. R. G. Townshend[1]

Approach

- To address this issue, we parameterized and calibrated ZELIG-TROP, a dynamic vegetation gap model, to simulate a complex Central Amazon forest toward evaluating disturbance-recovery processes under scenarios of increased disturbance rates

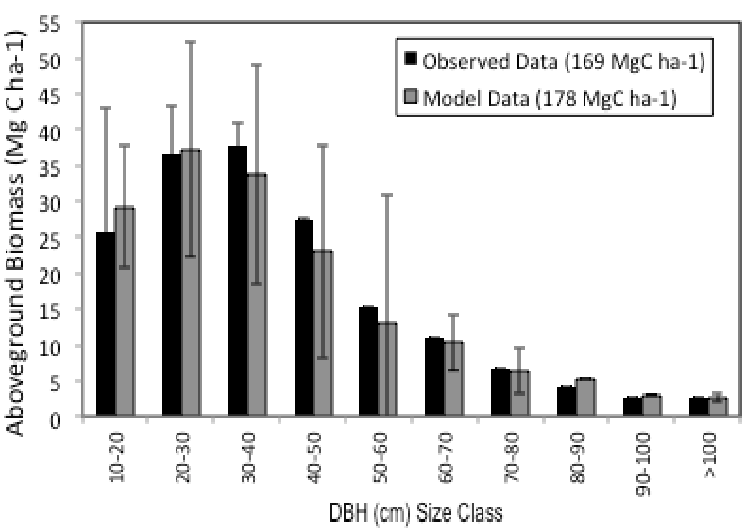
What are the differences after increasing disturbance rates in ZELIG-TROP vs. CLM-CN 4.5 for the Central Amazon?

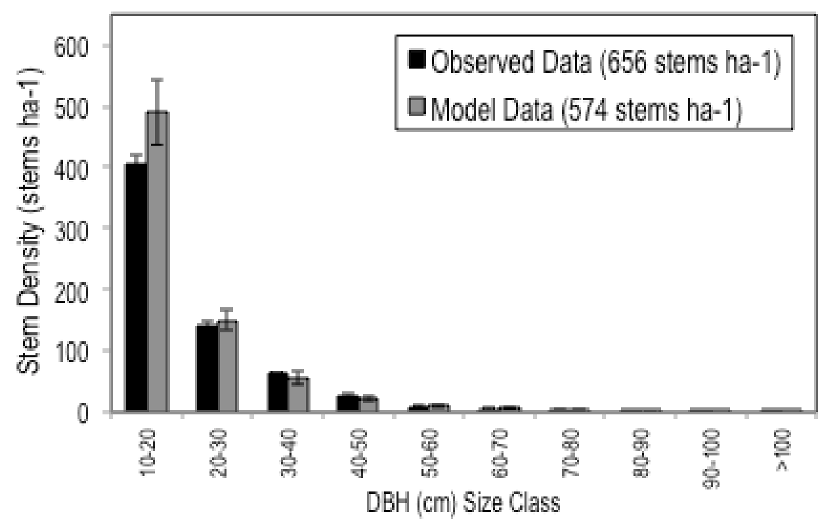
- ZELIG-TROP: Species specific parameterization (90 tropical tree species, Laurance et al. 2004)
- ZELIG-TROP: stochastic and mechanistic mortality algorithm
- CLM-CN 4.5: constant annual mortality of 2% yr^{-1}

Model Verification Results

	Avg. Basal Area (m2 ha^{-1})	Avg. Biomass (Mg C ha^{-1})	Avg. Stem Density (ha^{-1})	Avg. LAI	Avg. ANPP (Mg C ha^{-1} yr^{-1})
Empirical Data	30.06 (6.61)	169.84 (27.60)	656 (22)	5.7 (0.50)	6.5
ZELIG-TROP	32.96 (1.22)	178.38 (10.53)	574 (70)	5.8 (0.24)	5.4 (0.22)
Percent Diff. (%)	9.66	5.03	-12.49	1.75	-17.08
ZELIG-TROP min./max.	31.14/35.97	167.97/189.26	472/688	5.26/6.48	5.08/5.92

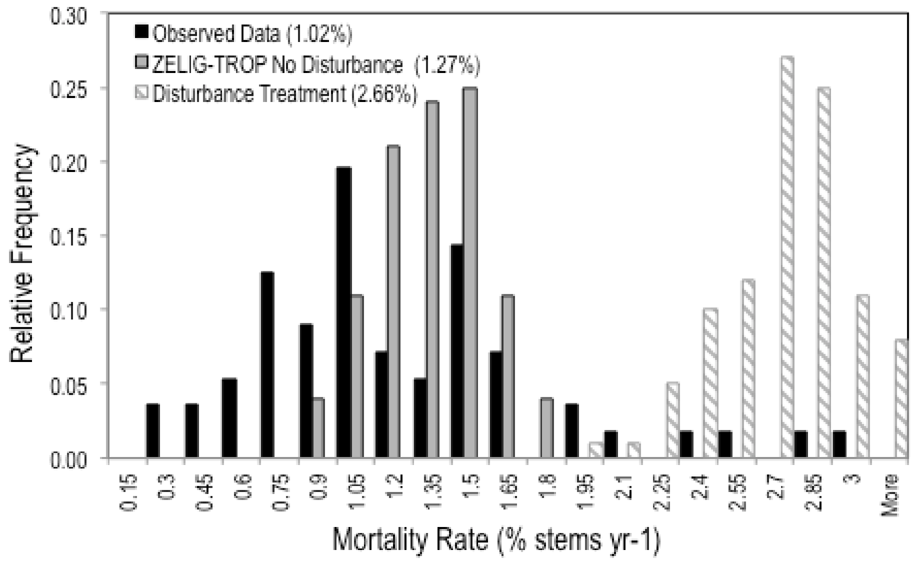
Compared ZELIG-TROP results to empirical data from long-term transect inventory plots located in the Central Amazon.





Modeled disturbance treatments

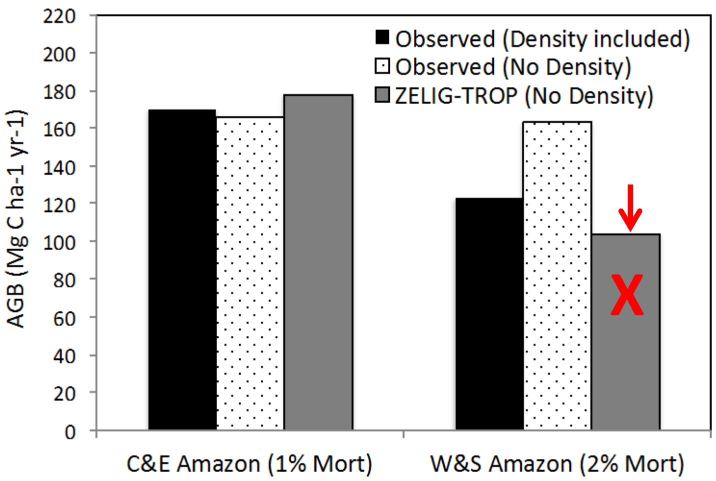
- <u>No Disturbance:</u> background mortality only (~1% yr^{-1}), using stochastic and mechanistic mortality algorithm
- <u>High/Continual Disturbance</u>: doubled background tree mortality rates in Central Amazon (~1% yr^{-1}) to ~2% yr^{-1} (100% increase in annual mortality)
- <u>Periodic disturbance</u>: removed 20% of stems every 50 years for 200 years
- Both treatments in ZELIG-TROP and CLM-CN 4.5
- Ran for 500 years, steady-state reached at last 100 years

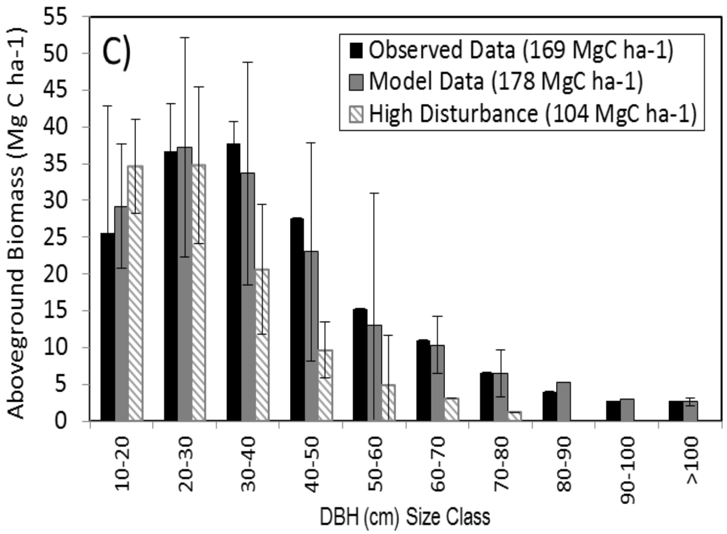


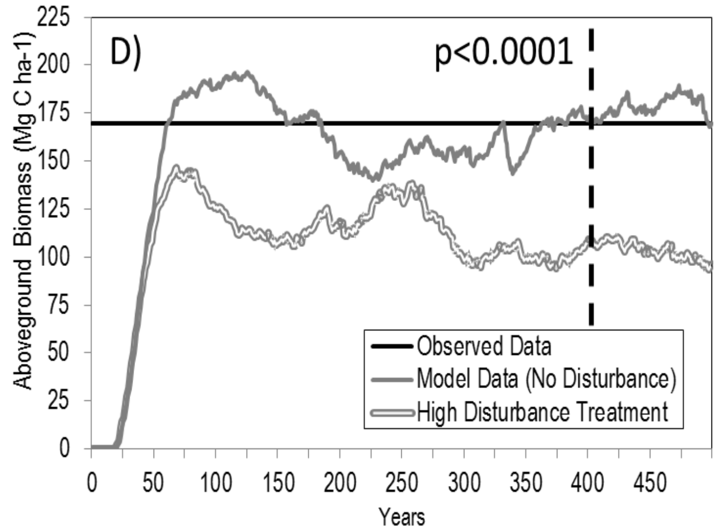
Field data: Chambers et al. 2004. Response of tree biomass and wood litter to disturbance in a Central amazon forest. Oecologia

Impacts of High Disturbance

- **42% decrease** in AGB (at steady-state)
- Net carbon loss of 74 Mg C ha^{-1}
- Treatment: Increasing disturbance in C&E Amazon to match turnover rates of W&S
- Drop in observed AGB only when including weighting for wood density in biomass equation
- **Model in-accurately predicted the loss in AGB due to increased mortality**
- Models and allometric equations should factor in wood density



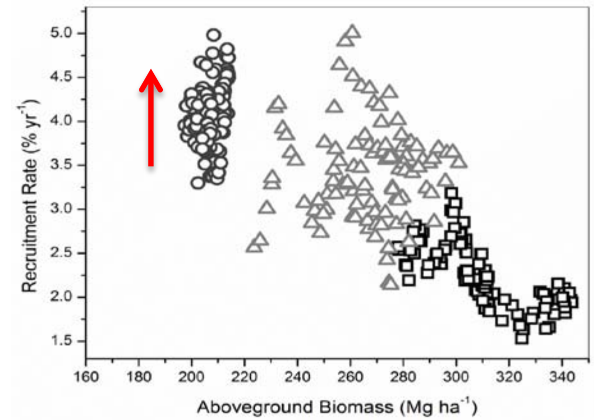




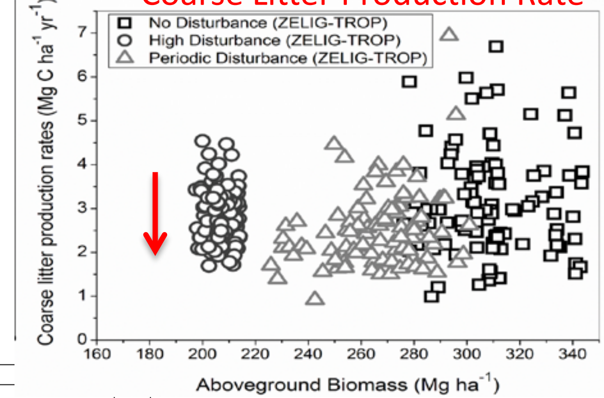
Impacts of High Disturbance

- **69% increase** in recruitment rates
- Mortality and recruitment tightly linked
- **8% decrease** in coarse litter production rates
- 34% **increase** in stem density
  - decrease in observed data w/ higher turnover
  - Opposite response to validation data
- 17% **decrease** in growth rates
  - increase in observed data w/ higher turnover
  - Opposite response to validation data (?)

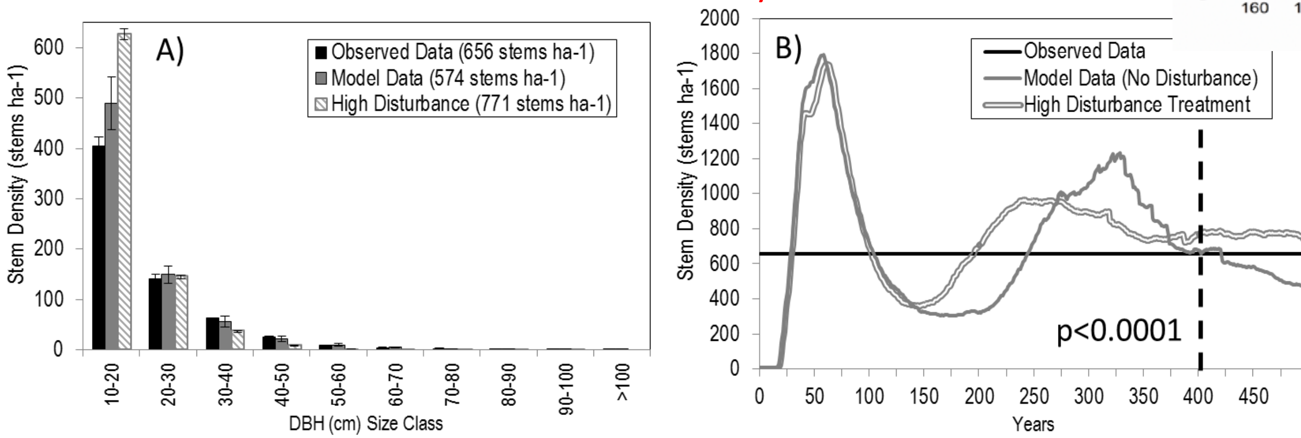
Recruitment Rate



Coarse Litter Production Rate



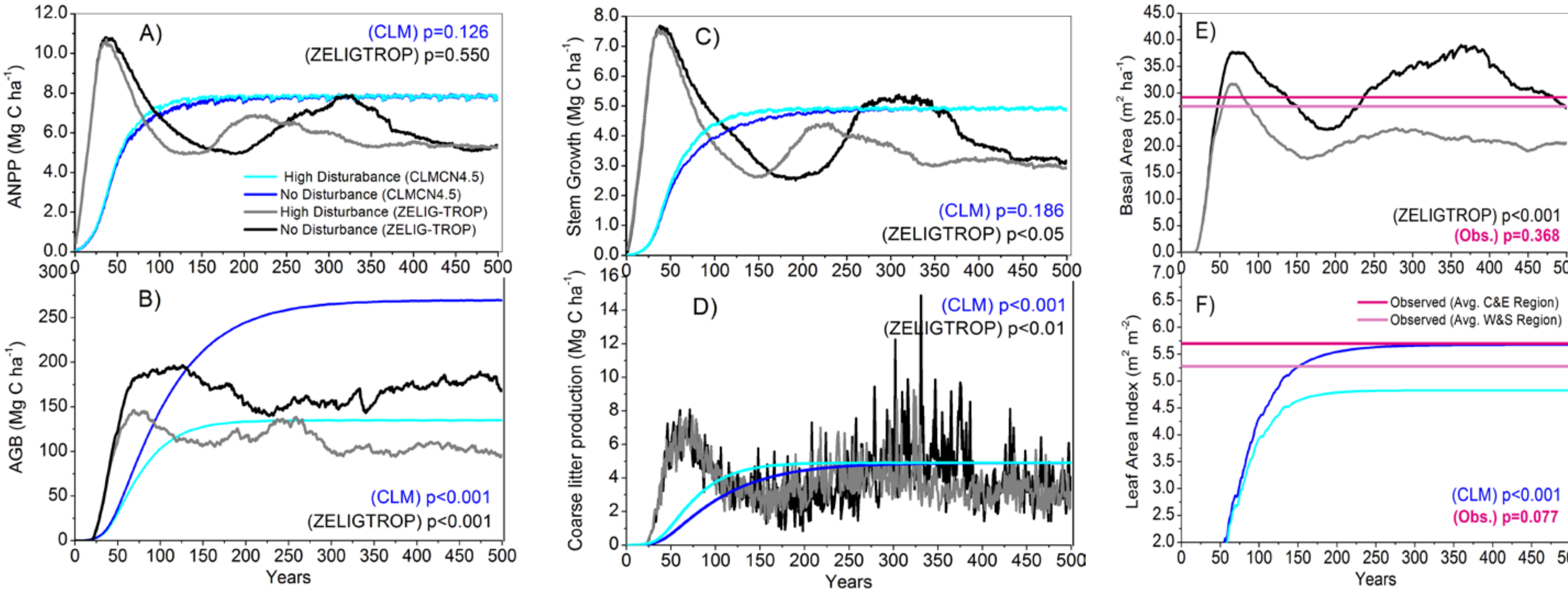
Stem Density



ZELIG-TROP vs. CLM-CN 4.5

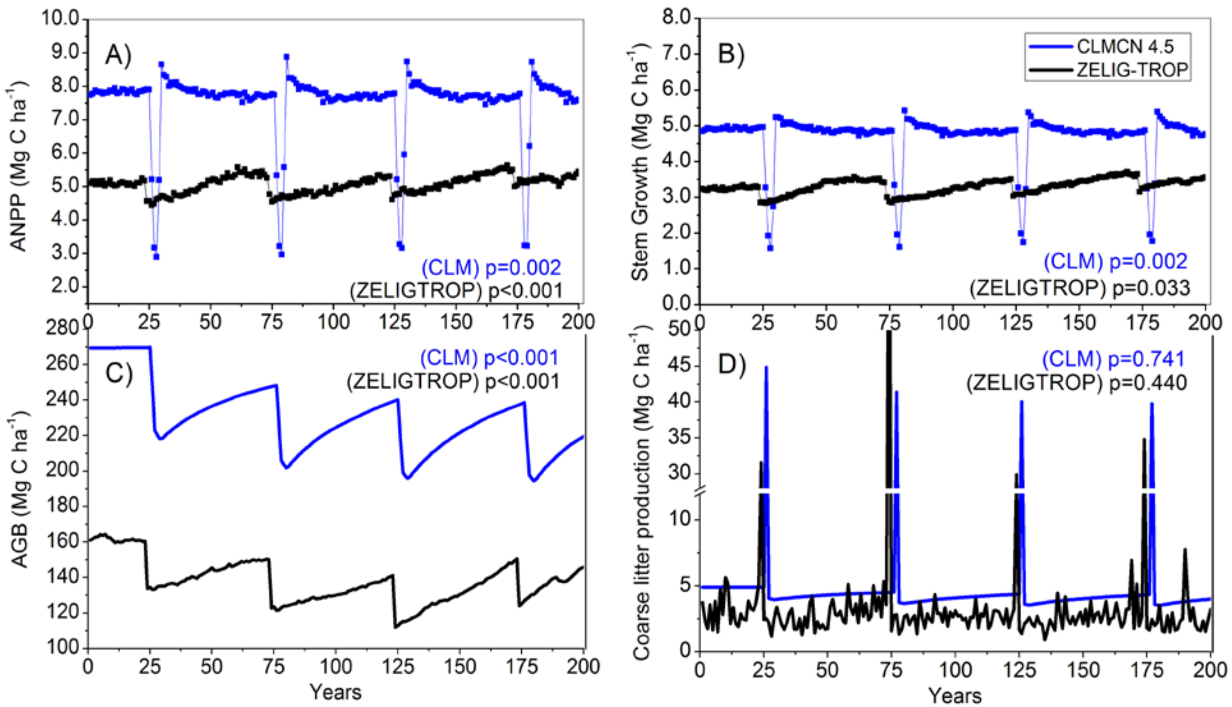
- Important for improving Earth System Modeling
- CLM 4.5 was very similar to “benchmark” gap model in terms of net biomass loss (AGB), and disturbance-recovery processes (42% vs. 50% decrease)
  - But, inaccurately getting the correct AGB response (false positive)
- Basal area drives loss of AGB in ZELIG-TROP, LAI drives loss of AGB in CLM, wood density drives loss of AGB in empirical data

Pink = empirical data



Periodic Disturbance Results

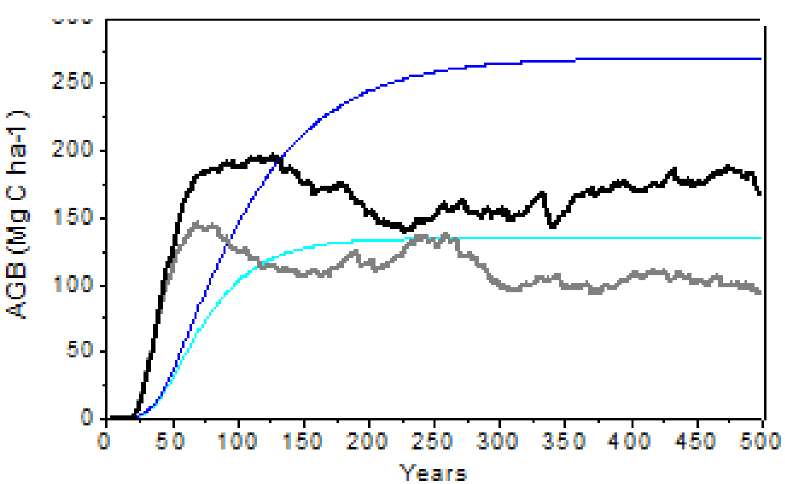
- CLM 4.5 was very similar to "benchmark" gap model in terms of net biomass loss (AGB), and disturbance-recovery processes
  - 18% vs. 19% decrease after each large-scale disturbance
  - 17% vs. 15% biomass recovery over the 50 year period
  - Negative total ΔAGB: -0.15 and -0.46 Mg C ha^{-1} yr^{-1} for ZELIG-TROP and CLM
- Some ANPP discrepancies with periodic disturbance. Significantly greater immediate decrease in ANPP in CLM and fast recover (vs. gradual recovery process)



ZELIG-TROP vs. CLM

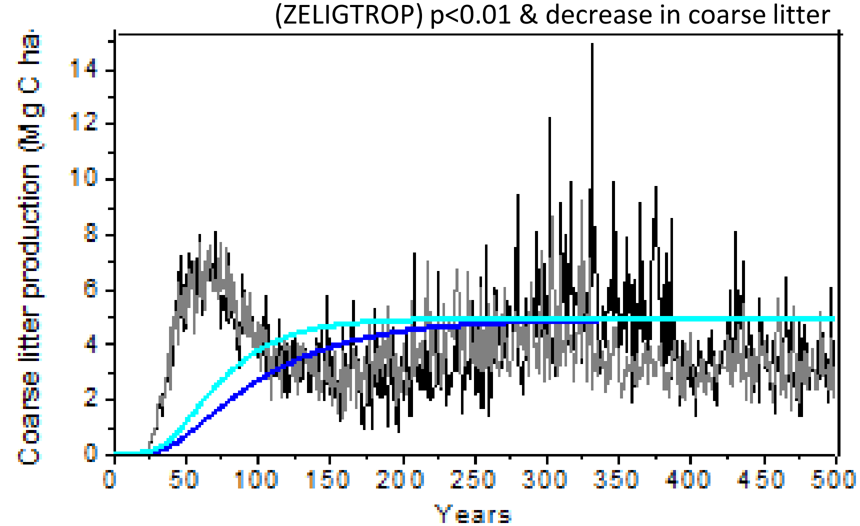
Discrepancies –

1) ZELIG-TROP = **74 Mg C ha^{-1}** average AGB net carbon loss; CLM = **134 Mg C ha^{-1}** as a result of doubling background mortality
2) The temporal variability in carbon stock and fluxes was not replicated in CLM
   - Large fluctuation in coarse litter production rate representative of a heterogeneous landscape, gap dynamics, and differences in plant demography
3) ZELIG-TROP = Gains that exceed the losses; CLM = losses that exceed the gains (but very minimal, probably not biologically significant)



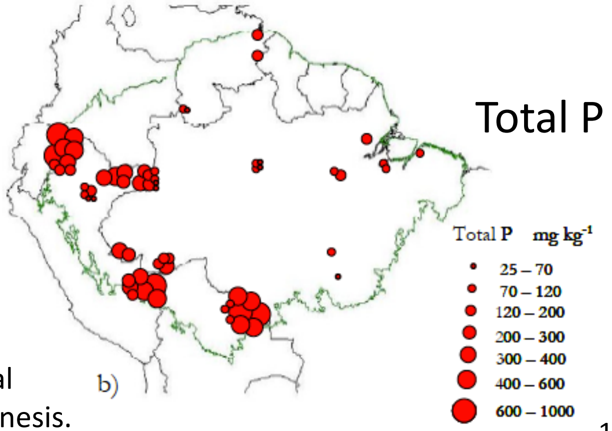
(CLM) $p<0.001$ & increase in coarse litter

(ZELIGTROP) $p<0.01$ & decrease in coarse litter



Summary

- Both models predicted a reduction in steady-state carbon stocks with increased disturbance and tree mortality.
  - BUT, inaccurate response. Wood density NOT included in the models, therefore the reduction in steady-state carbon stocks should not have taken place.
  - AGB – pseudo "false positive"
- Wood density, stem density, and growth rates – do not follow expected pattern between the regions, but instead show opposite response.
- This suggests that 1) the models are not accurately simulating all forest characteristics in response to increased disturbances, or 2) the variability between regions cannot be entirely explained by the variability in disturbance regime, but rather potentially sensitive to intrinsic environmental factors.
  - Soil genesis
  - Oxisols and spodosols (poorer soils) vs.
  - Ultisols, inceptisols, entisols (richer soils)



Quesada et al. 2010. Variations in chemical and physical properties of Amazon forest soils in relation to their genesis.

Summary – improving disturbance in ESMs

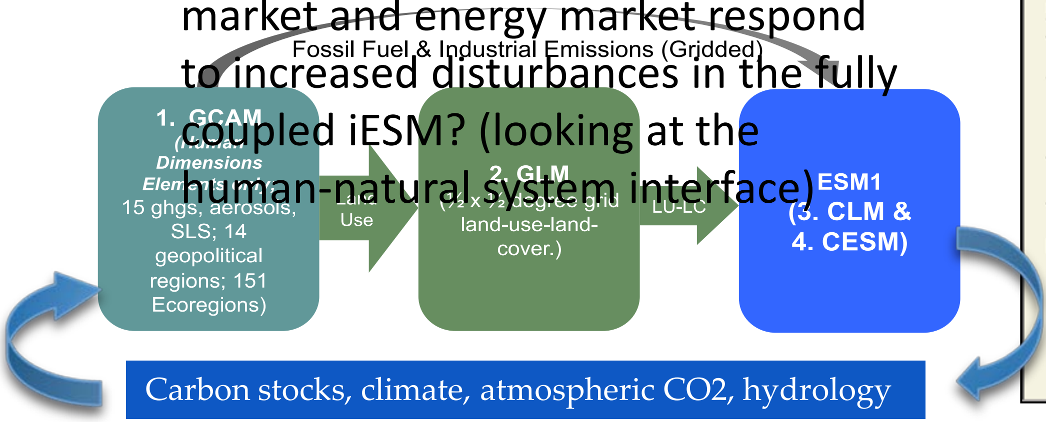
- The relative net biomass loss due to disturbances, as well as biomass recovery, was consistent between CLM and ZELIG-TROP, and for both disturbance types (continual and periodic).
- The relative net carbon loss was 42% vs. 50% for the high disturbance treatment, and 18% and 19% for the periodic disturbance treatment, in ZELIG-TROP and CLM respectively.
- Major differences between the two models were that the inter-annual variability in AGB and coarse litter production was not representative in CLM.
  - Need for demographic vegetation model in CLM (ED-CLM)
  - Absolute value of AGB still high in CLM-CN 4.5 (for Central Amazon).
- Second major difference was that the gains exceeded the losses in ZELIG-TROP, and the losses exceeded the gains in CLM, but probably not biologically significant (because the models do not have CO^2 fertilization, and the models are in an equilibrium steady-state).

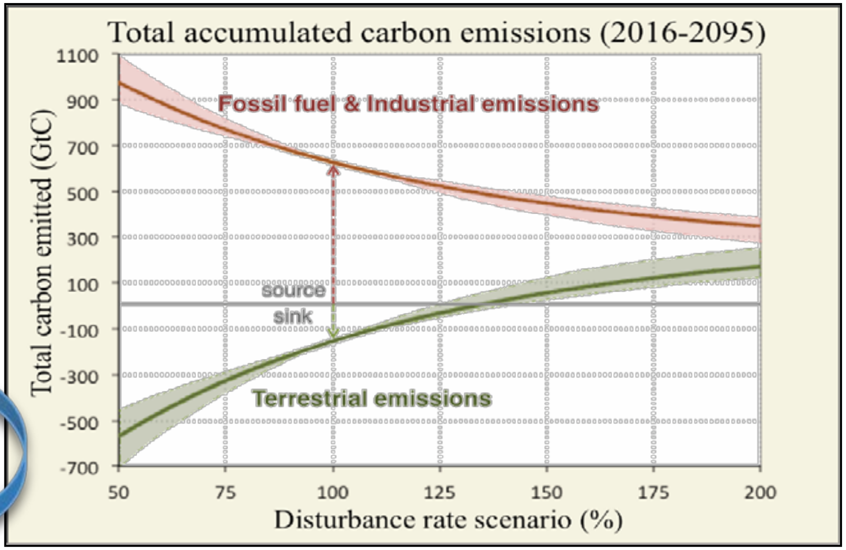
iESM Impact & Collaboration

- Integrated Earth System Model (iESM) – combining an Integrated Assessment Model (IAM) with an Earth System Model (ESM).
  - GCAM & GLM & CLM/CESM
  - Improve knowledge of coupled physical, ecological, and human system.

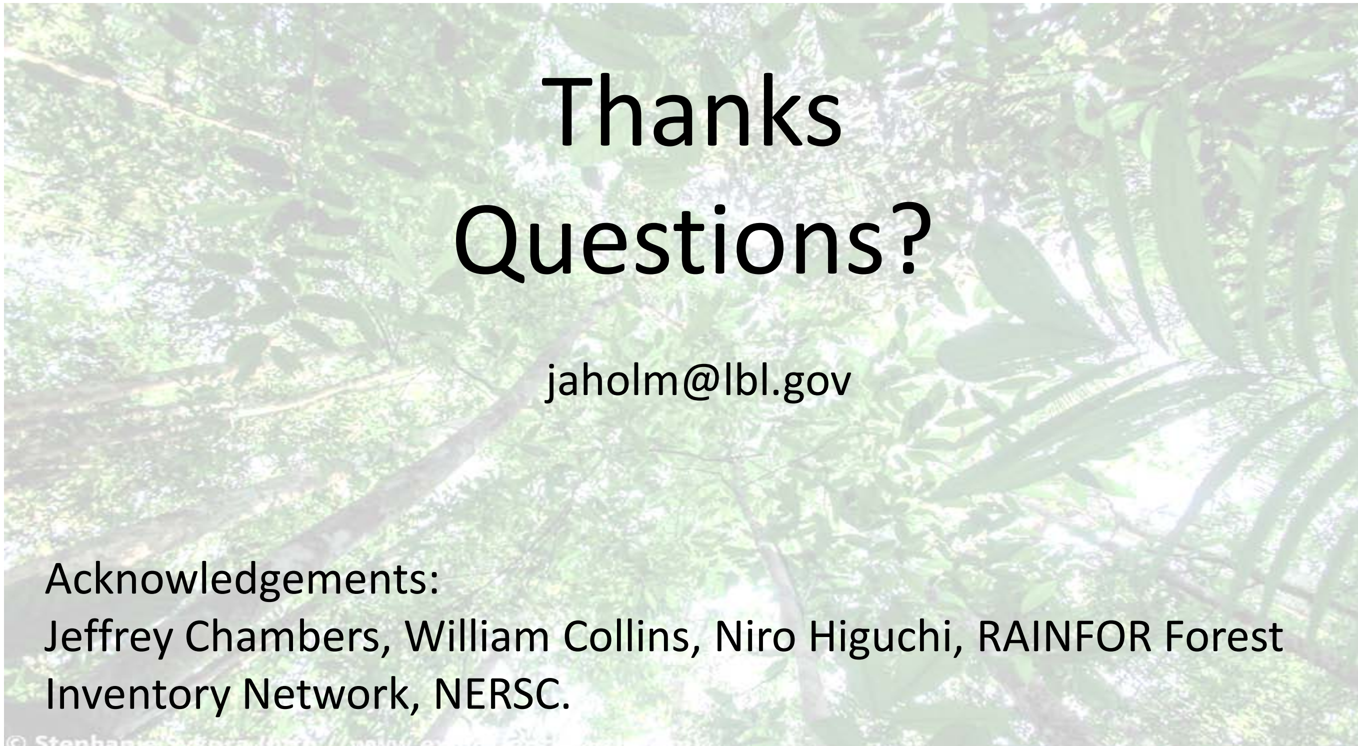
- Le Page et al. 2013
  - Analysis in GCAM only – Global Change Assessment Model
  - Dynamic economy, energy, and land use model
  - How to reach a stringent mitigation target (3.7 W m^{-2}) with natural disturbances increasing

Eventually, how does the carbon market and energy market respond to increased disturbances in the fully coupled iESM? (looking at the human-natural system interface)





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



Thanks
Questions?

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