Global terrestrial ecosystem resilience: a high-resolution multivariate analysis of patterns and drivers

1. Background: Detection of ecosystem resilience losses

Ecosystems around the world are under increasing pressure from multiple climatic and anthropogenic drivers. These can cause systems to shift from one state to another, often irreversible states through regime shifts. Regime shifts can occur gradually or abruptly, through incremental linear changes, or stochastic fluctuations in drivers but also via increased sensitivity to external shocks. They are often predicted by frequently uncorrelated resilience losses.[1]

To improve detection of resilience losses and understanding of drivers, it is therefore crucial to account for the multivariate, non-linear nature observed in the observed ecosystems. Most traditional early warning signals (EWS) of resilience losses, however, are based on assumptions made for univariate systems.

Our aim is to get comprehensive, multivariate understanding of resilience losses in global terrestrial ecosystems and their drivers, using vegetation indices and remote sensing data with a range of different EWS based on different mechanistic assumptions and machine learning models. We aim to answer two main questions:

1. What are the spatial patterns of resilience loss in terrestrial ecosystems as assessed with different EWS?
2. What are the relevant climatic and anthropogenic drivers of these resilience losses on global and local levels?

2. Methods: The analysis pipeline

- Critical slowing down (CSD) and Critical Speeding Up (CSU)
- Flickering
- Long-term system memory
- Assessing resilience losses
- Multivariate driver analysis
- Variable importance
- Partial dependence
- Local interpretable model-agnostic explanation (LIME)
- Kernel Normalized Difference Vegetation Index (KNDVI)
- Time series preprocessing
- Static location variables
- Climate change
- Anthropogenic drivers
- Generalized linear model Random forest Neural network
- Analysis report
- Theoretical concepts
- Methods
- Data

3. Preliminary results: Patterns and drivers of resilience losses

4. Discussion: What do we find?

How do geographic patterns of resilience loss compare between EWS indicators?[2]

- Resilience loss patterns are generally patchy, but show spatial clustering in specific regions, such as across Russia and central Asia, the western US, Northeastern Brazil, the western Amazon, and western Australia.
- In large tropical forests, resilience loss patterns show small scale, mixed variations, which is in agreement with previous work using different approaches.[2,3]
- Different EWS pick up signals in different patterns. The fractal dimension shows similar warning signals as the CSD-CSU patterns, with deviations mostly in the high latitudes. Flickering, on the other hand, seems to be associated with the boundaries between biomes, which might indicate shifting climatic conditions in regions of strong environmental gradients.

What role do different drivers play in determining signs of resilience loss?

For all EWS, static environmental variables are the strongest predictors in the driver models showing that sensitivity of different ecosystems to pressures is strongly determined by their biogeographic zone, which agrees with previous work.[2,7]

Both negative and positive changes in temperature and precipitation (mean and variance) lead to resilience losses. However, for moderate temperature increases (up to −0.2−0.2°C decade), the likelihood of resilience losses decreases. This might be associated with a CO2 fertilization effect that is cancelled out at higher increases.[4]

How do drivers compare with respect to CSD, CSU, flickering and long term memory?

- CSD occurrence is most strongly determined by change of mean monthly precipitation, with dry ecosystems showing highest resilience losses. This agrees with patterns found in local and global studies previously.[5]

- CSU patterns, contrarily, are determined more by mean temperature and temperature variability.

- Flickering and increasing long term memory occur more frequently in colder, high latitude ecosystems with high temperature variability. This is also where AC1 variance and AC1 and variance both show conflicting signals and can be a sign that there are still complex resilience losses ongoing.

Next questions...

- How are resilience losses in the water cycle connected to these patterns in terrestrial ecosystems?
- What can spatial EWS tell us about terrestrial resilience losses?
- What is the role of fast and slow dynamics of climate change drivers for the different EWS (e.g. intra-annual vs inter-annual variability)?

References

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5. Lotz et al., 2023, Philos. Trans. R. Soc. B. Biol. Sci. 378, 20220131

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