Early warning signals of simulated Amazon rainforest dieback

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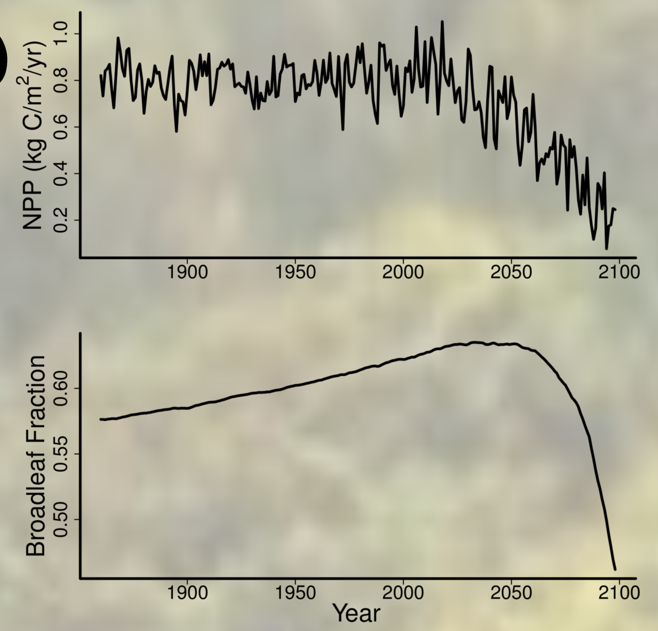
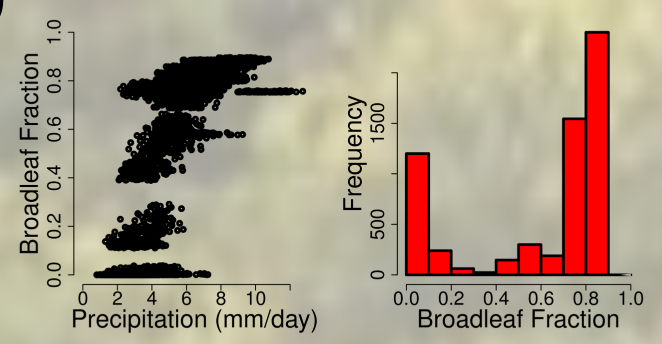
Introduction

- Dieback of the Amazon rainforest has been hypothesised as a tipping point in the climate system.
- Here output from 57 realisations of the general circulation model (GCM) HadCM3 are used to test proposed generic early warning signals (EWS).
- These signals have rarely been tested in complex GCMs or under realistic (and thus non-linear) emissions scenarios forcing a system.
- Output from one realisation of HadCM3 shows typical tipping behaviour in two variables related to forest productivity and size (Fig. 1).
- There is also evidence of multimodality of the forest (Fig. 2).

(1)



(2)

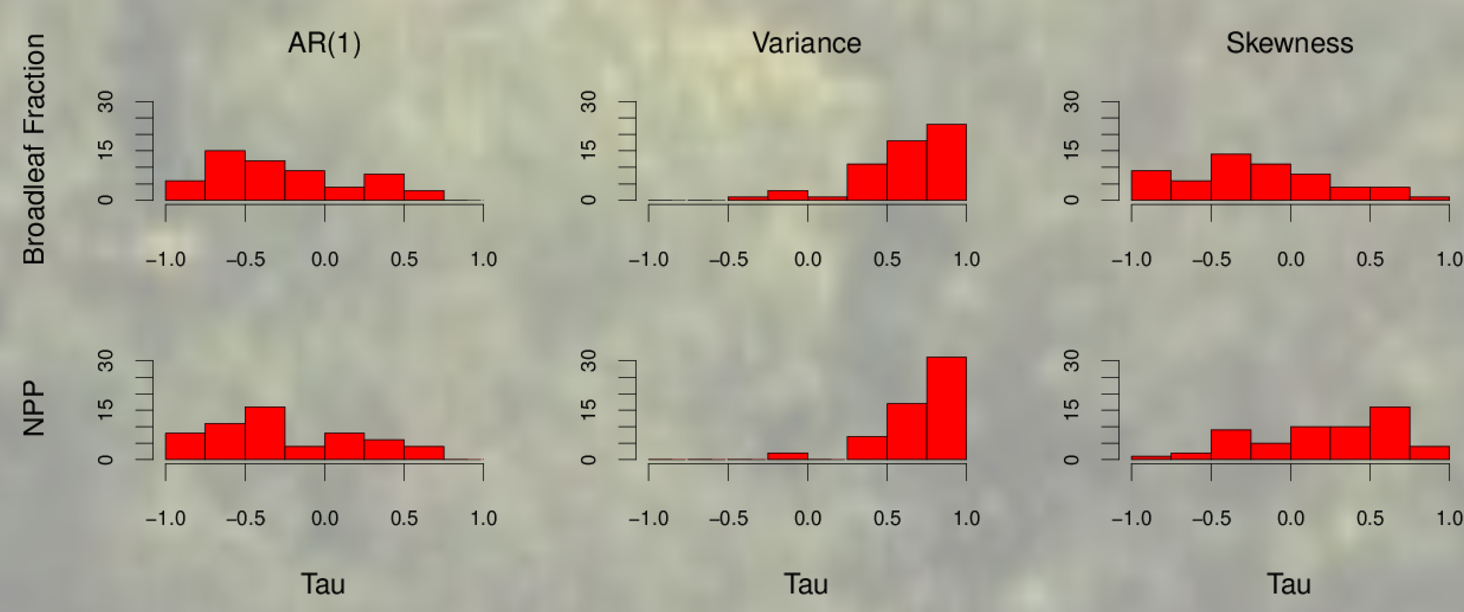


Methods

- Analysed data is obtained from a 57 member physics-perturbed ensemble of HadCM3 each subject to the same emissions scenario (A1B).
- Amazon region (40-70°W, 15°S-5°N) annual mean broadleaf fraction and NPP are extracted as time series.
- Each time series is cut-off just before the broadleaf fraction starts to decline dramatically (i.e. the start of dieback).
- Whole time series are used if no dieback is observed in that run.
- Each time series is detrended with a Kernal smoothing function with a 10 year bandwidth which subtracts a 10 year moving average.
- Then using a sliding window length equal to half the time series, the AR(1) coefficient, variance and skewness are estimated.
- AR(1) coefficient and variance are expected to increase towards a tipping point and skewness to tend toward the future state.
- Trends in each indicator are calculated using Kendall's tau correlation coefficient, which ranges between -1 (indicator is always decreasing) to 1 (always increasing).

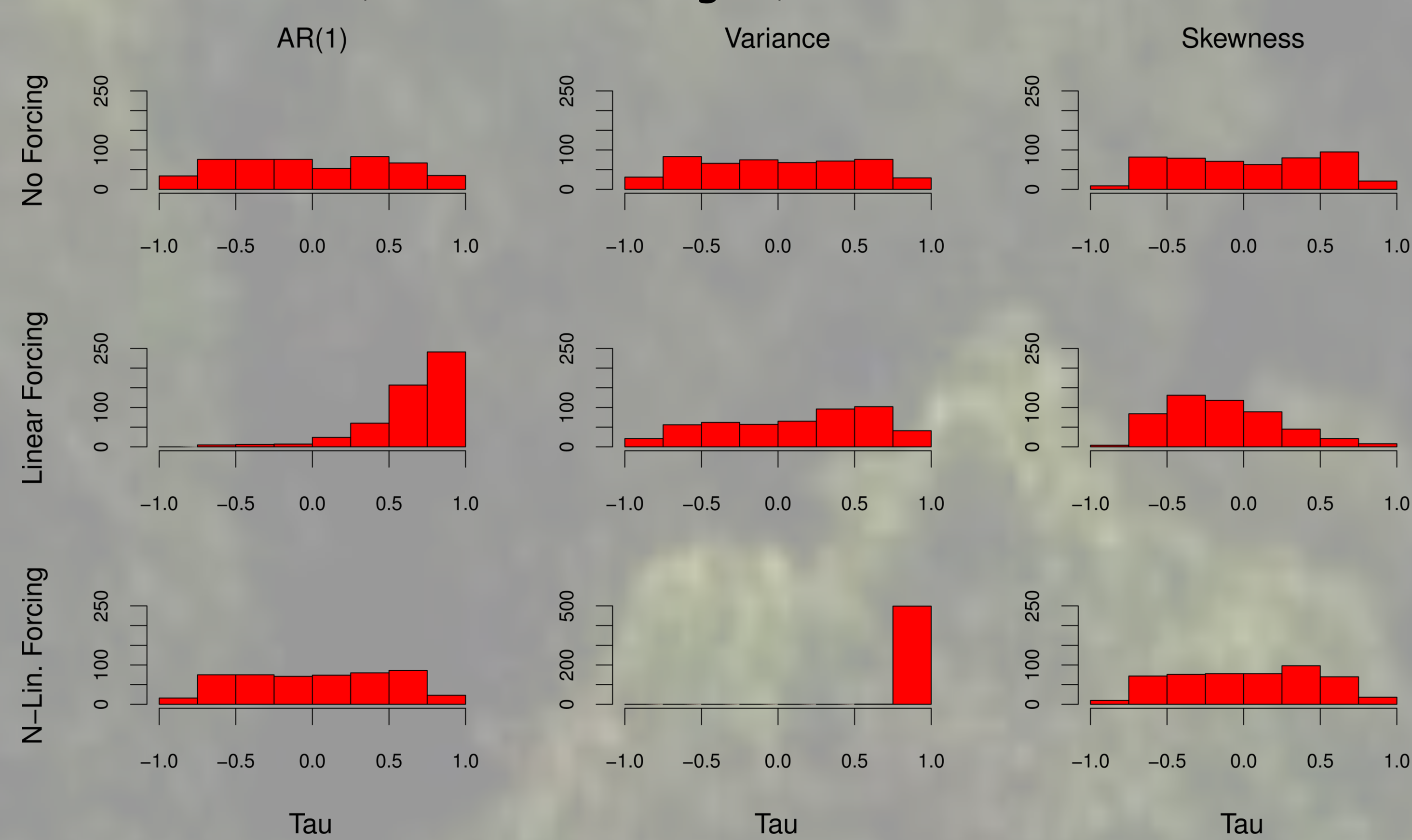
Results

(3)



- AR(1) coefficient estimation decreases across the ensemble and skewness is not very robust (Fig. 3). Variance appears to be the strongest signal.
- However increasing variance in temperature and precipitation can explain the increasing variance signal. This is caused by more frequent and intense El Nino events over the 21st century in the ensemble.
- The lack of a convincing signal can be partially explained by a simplified version of the TRIFFID equations used to determine the vegetation in the model (see below).
- As productivity P (NPP) decreases the equilibrium V* approaches the tipping point in a non-linear way (causing dieback). However from Fig. 1 it can be seen that NPP does not decrease until a few years before dieback.
- When simulating different forcings, signals are not observed when there is no forcing but are when linear forcing is applied (Fig. 4).
- Signals similar to those seen in Fig. 3 are observed when non-linear forcing with increasing noise perturbations is used (Fig. 4 bottom row).
- Decreases in AR(1) in Fig. 3 could be due to NPP increasing before it starts to decrease (not tested in Fig. 4).

(4)



$$\frac{dV}{dt} = PV(1-V) - GV$$

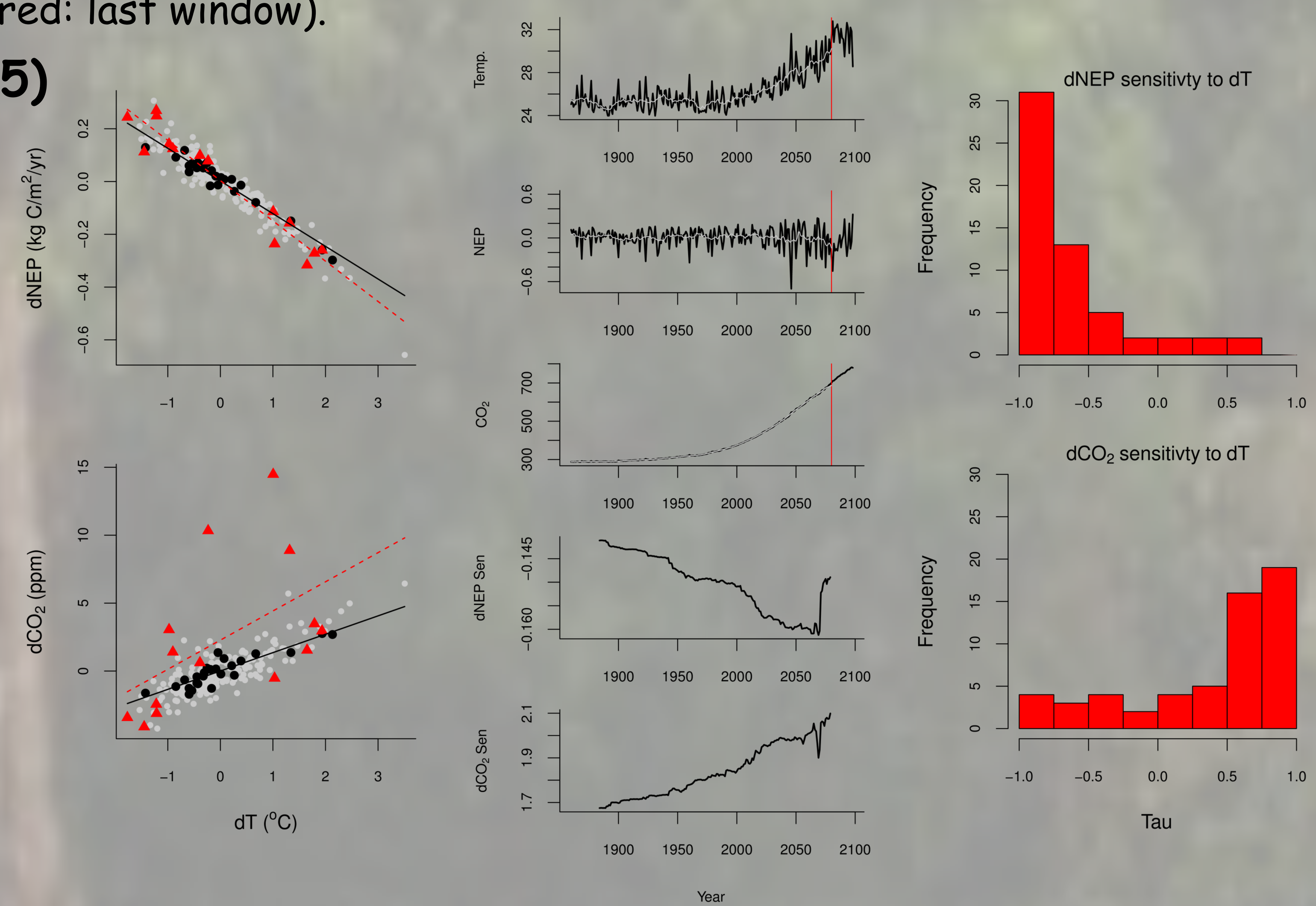
$$V^* = 1 - \frac{G}{P}$$

V - Vegetation
P - Productivity
G - Disturbance Parameter

Observable Indicators

- Due to a lack of convincing result from generic EWS, two process based indicators have also been tested. These 'system specific' indicators are not as easily transferable to other systems.
- NEP, CO_2 and temperature time series are detrended with a 10 year moving average (as in Methods, Fig. 5 middle column, top three plots).
- The sensitivities of NEP and CO_2 to temperature are then measured on a moving window of length 25 years. A linear regression is fitted through dNEP and dT, and dCO_2 and dT (the residuals from detrending), within this window.
- An example of this is shown in Fig. 5 (left column, black: first window, red: last window).

(5)



- The change in the regression coefficient is used as the EWS. Both are plotted in Fig. 5 (middle column, bottom two plots).
- As for the generic EWS, the tendency of these indicators is measured with Kendall's tau (Fig. 5 right column).
- These system specific indicators appear much more convincing (note that dNEP sensitivity should become more negative over time resulting in a negative tau).
- At the moment, there appears to be no threshold value which indicates dieback.
- There is however promise in these system specific indicators when generic EWS fail, especially as they use readily available variables (i.e. temperature and atmospheric CO_2).

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