

Tipping points

How can Earth Observation help?

Jan Verbesselt^{1,2} and Sebastian Bathiany³

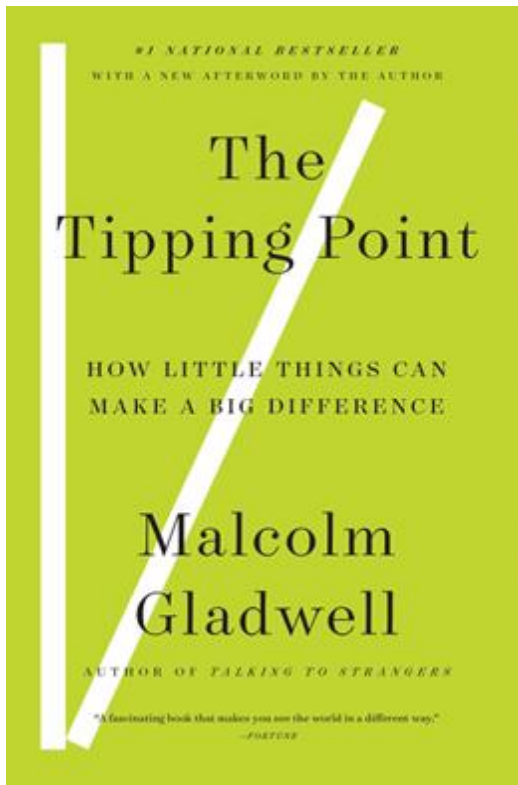
¹Belgian Science Policy Office, Earth Observation, Belgium

²Wageningen University, The Netherlands

³Technical University Munich



Abrupt shifts are all around us



Abrupt shifts happen in the Earth System

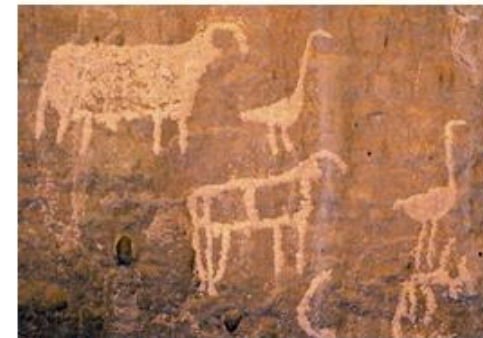
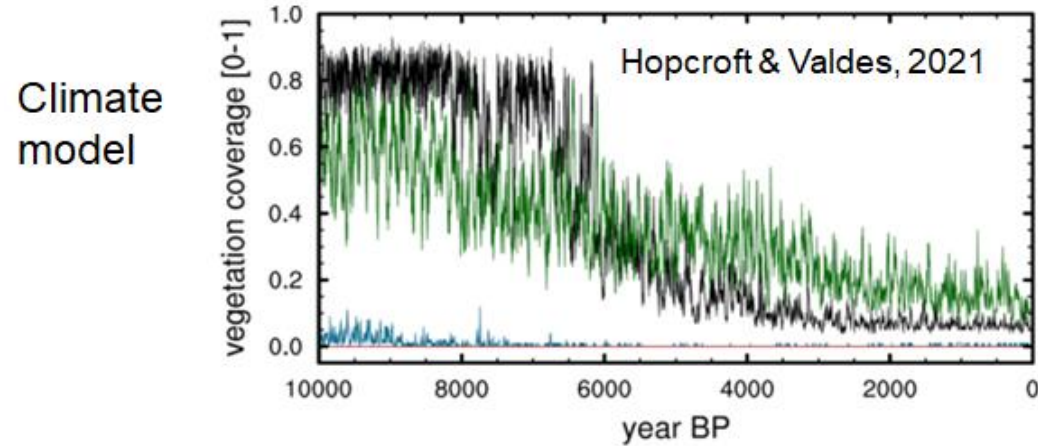
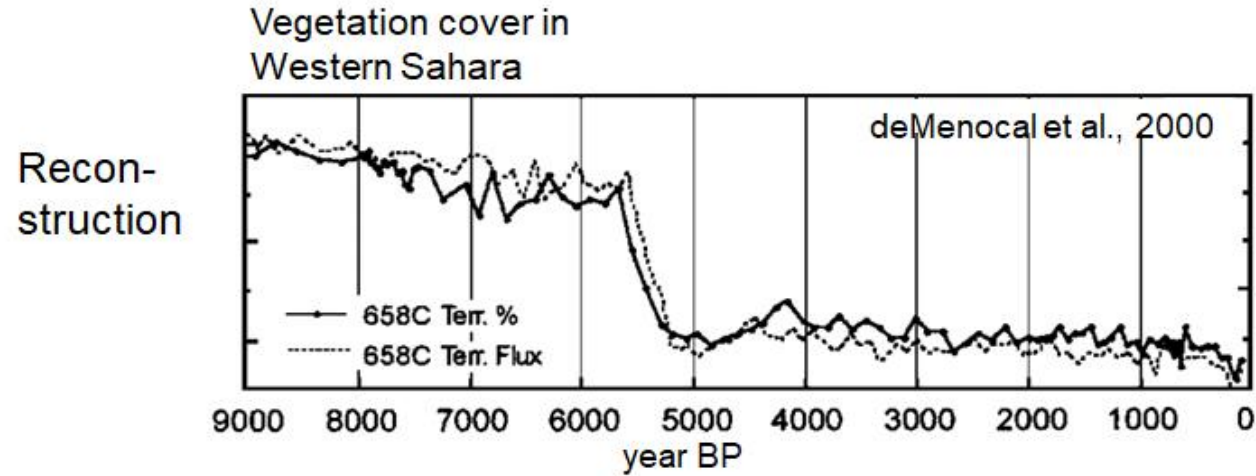
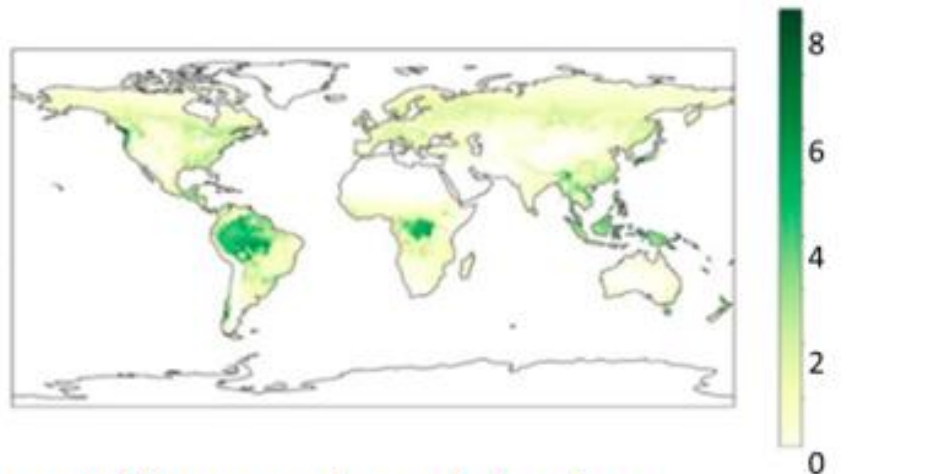


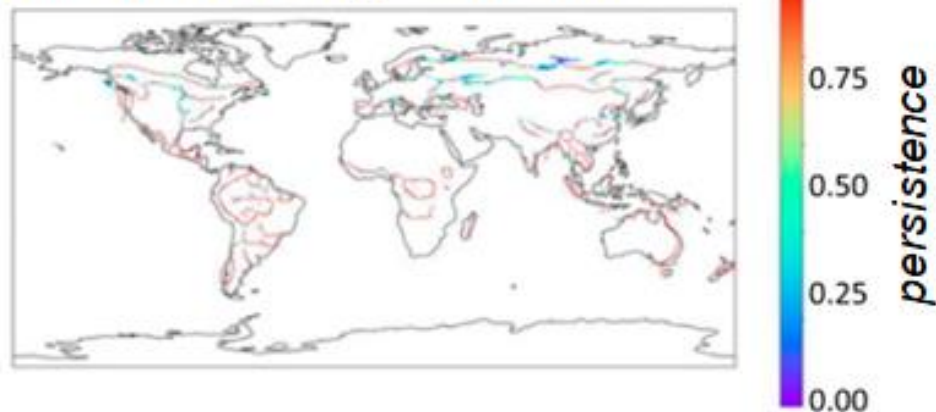
Photo: Philipp Hoelzmann

Edges in space can lead to abrupt shifts

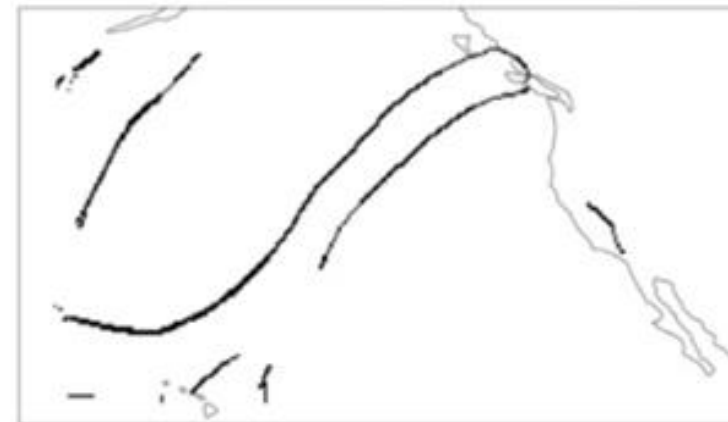
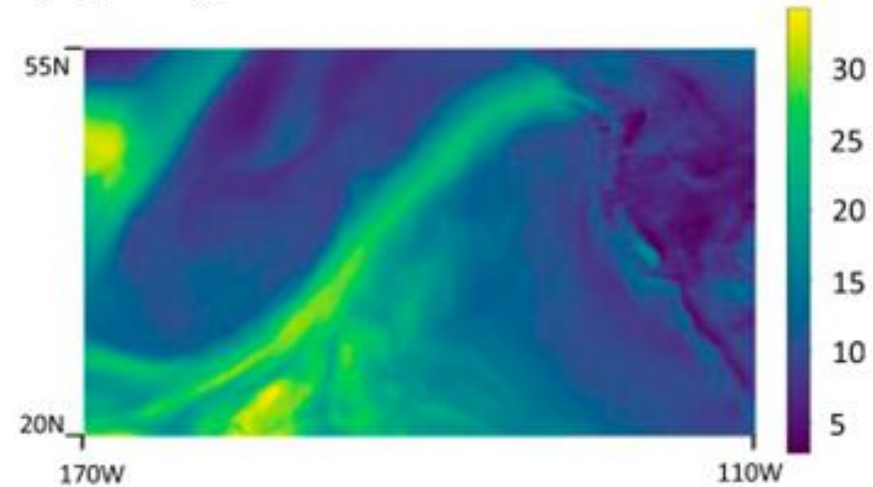
Leaf-area index,
AVHRR / MODIS



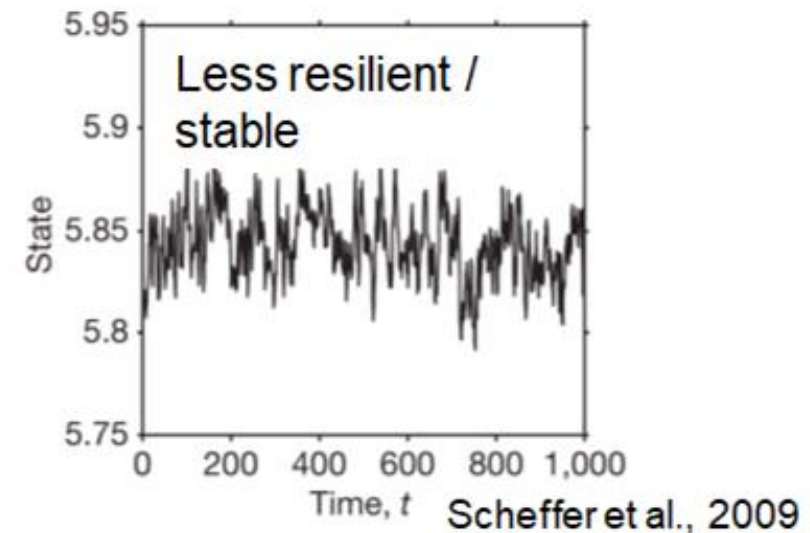
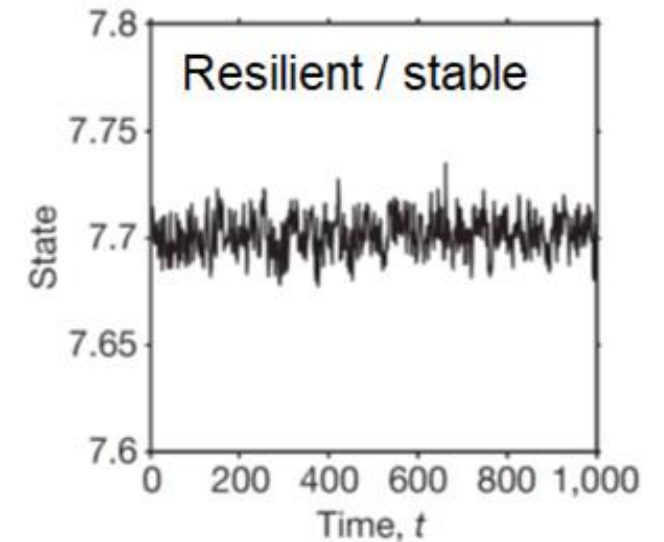
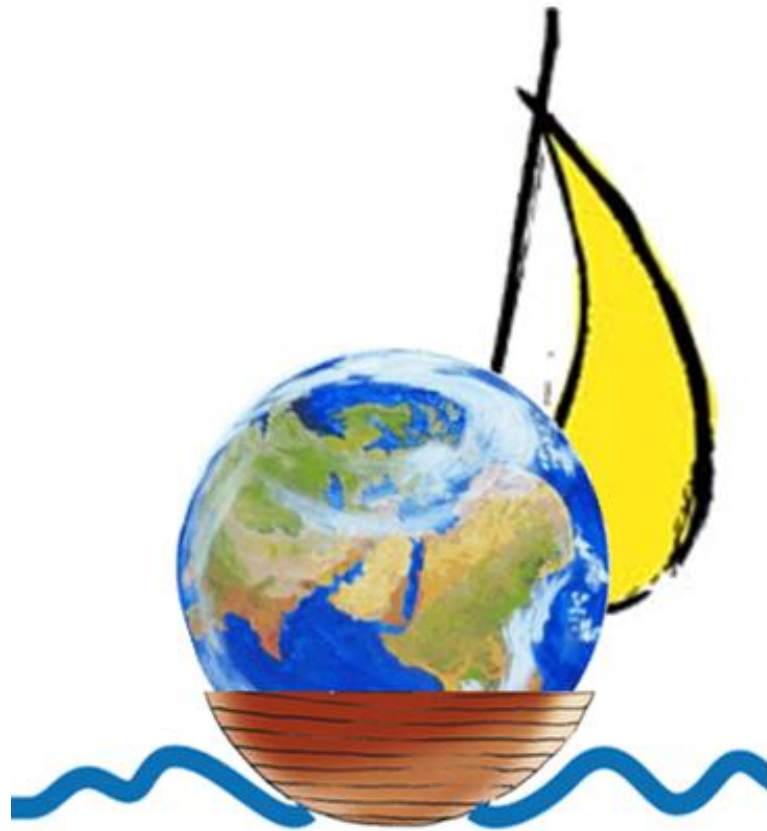
...seen with an edge detector



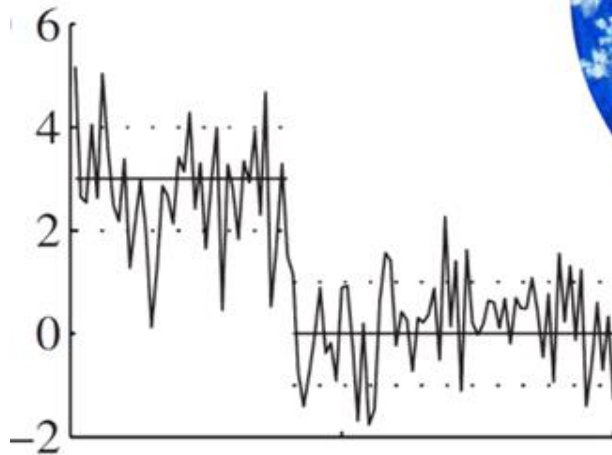
Vertically integrated water vapour
(kg/m²), *ERA5*



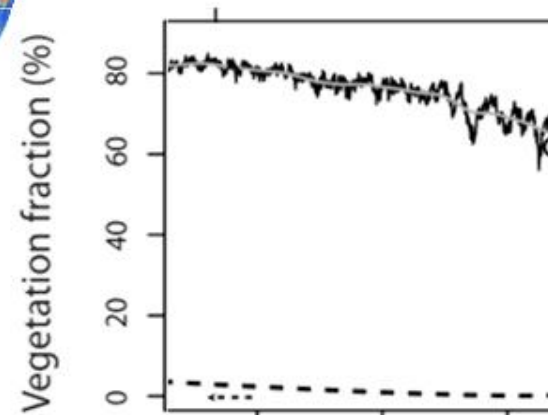
Loss of resilience can lead to abrupt shifts ("tipping points")



Probing EO for abrupt shifts and resilience indicators



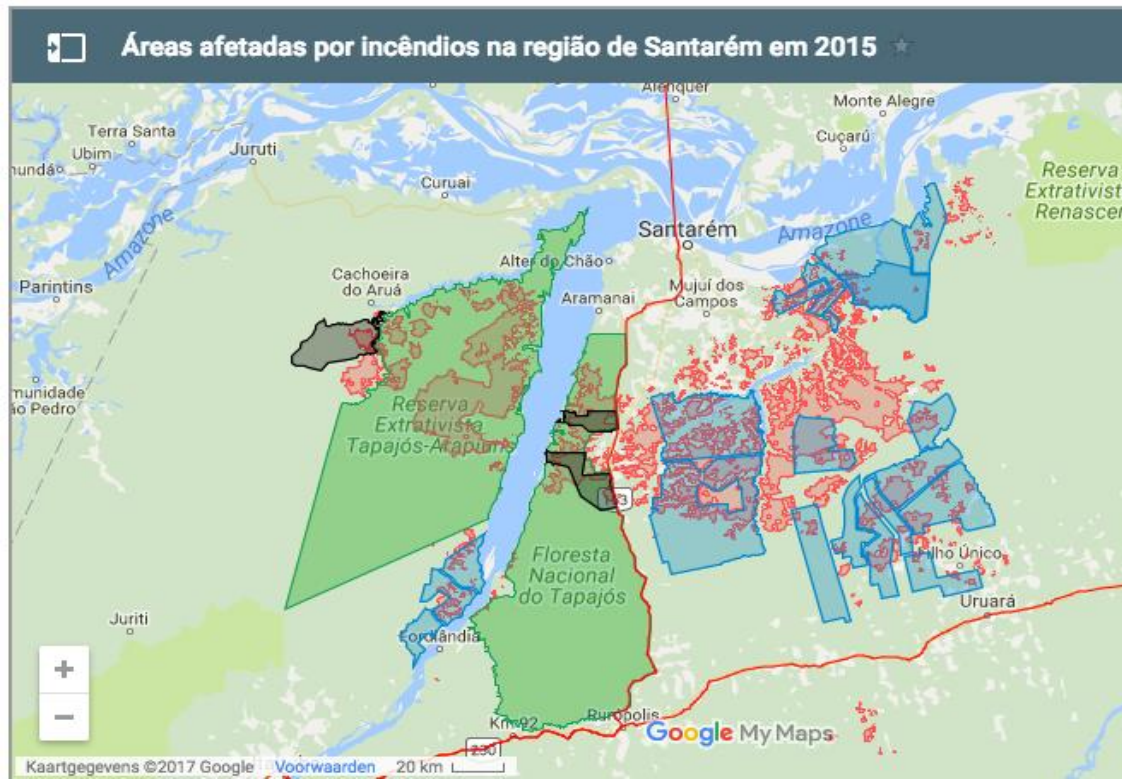
Beaulieu et al., 2012



Dakos et al., 2008

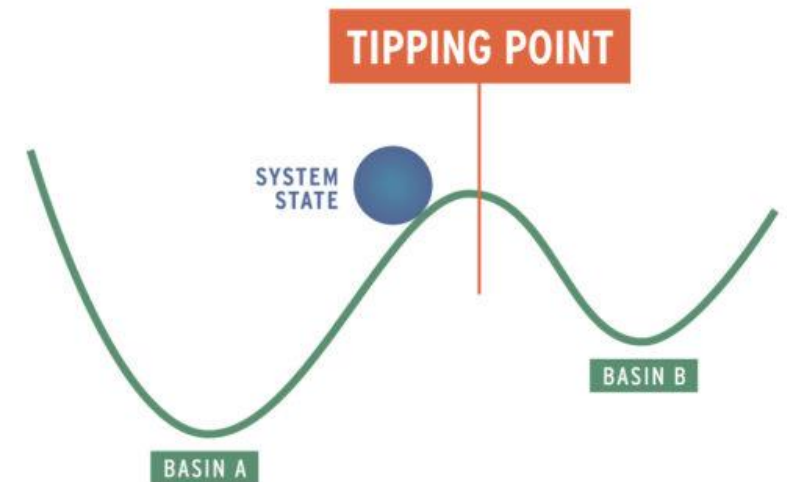
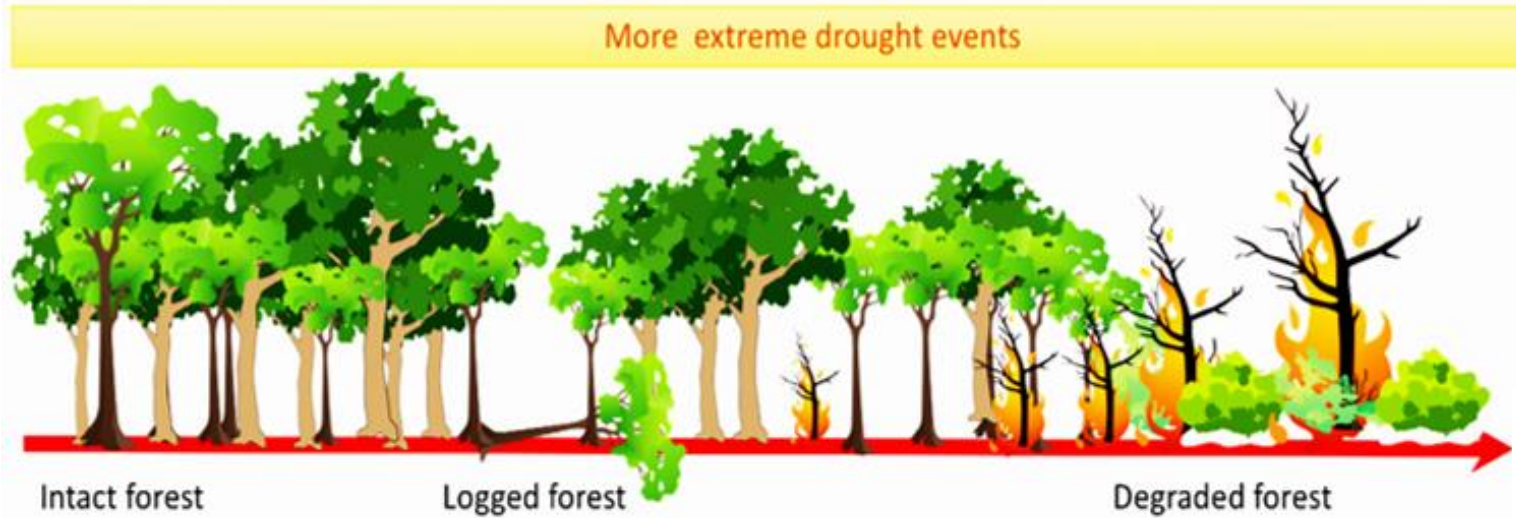
Extreme events – tipping points?

- Record breaking high temperatures and severe drought during e.g. El Niño



Tipping point

- Negative feedback loop

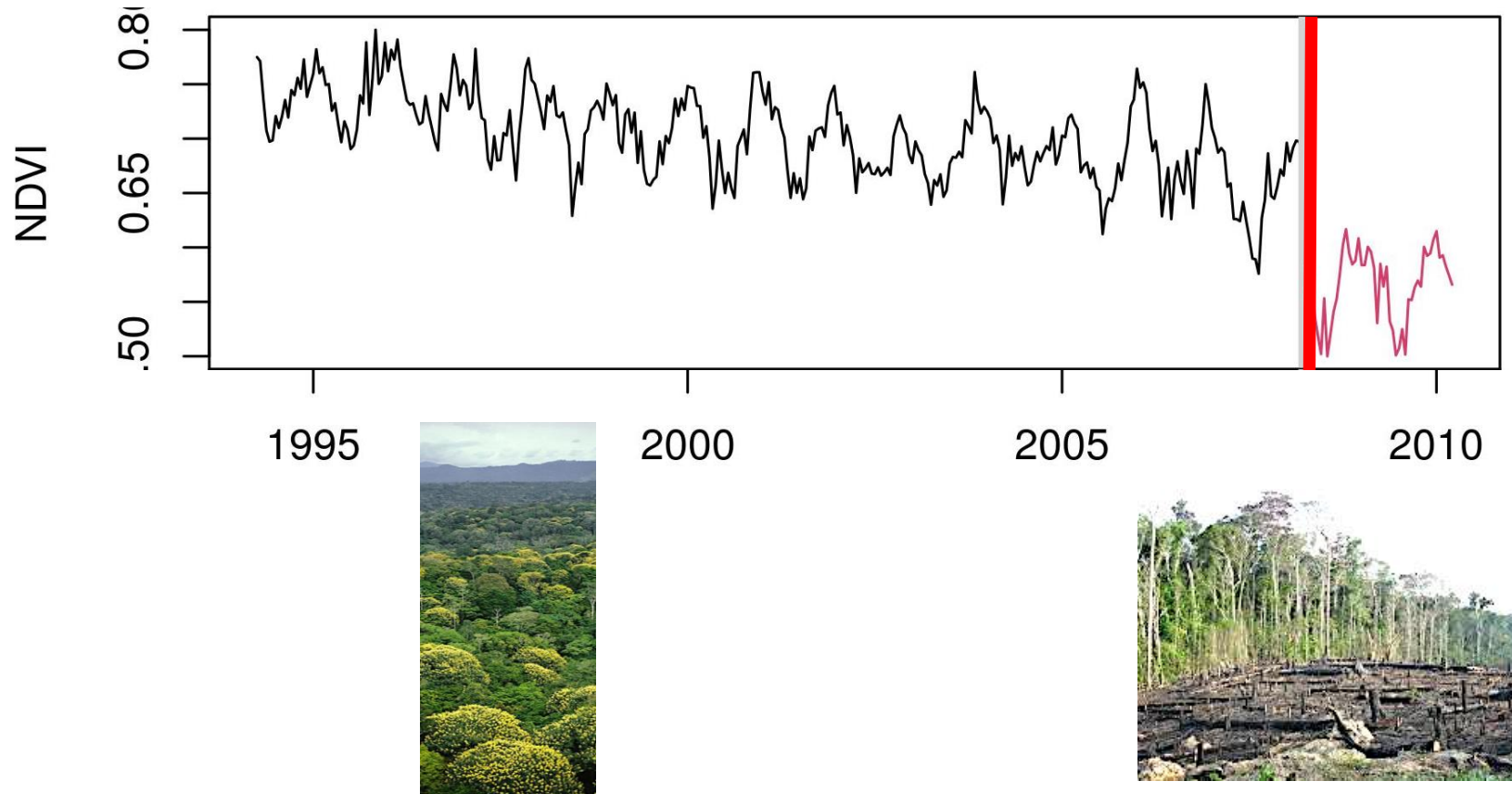


Measure resilience of tropical forests?



Long satellite image time series

- VOD: Passive microwave satellite retrievals from e.g. AMSR-E (Liu et al. 2011)
- NDVI: Optical satellite-based retrievals from MODIS, AVHRR (Pinzon et al. 2013)



Resilience

- Recovery rate from 'small' perturbations (e.g., droughts)



van Belzen, J. *et al.* (2017).

Remotely sensed resilience of tropical forests

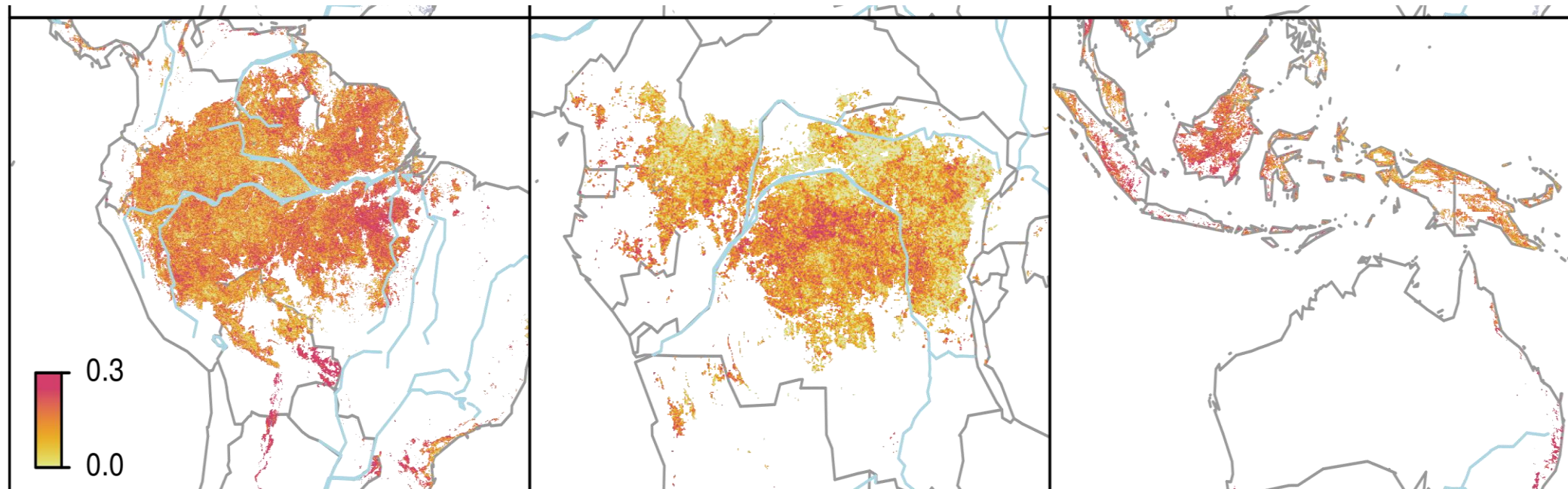
Jan Verbesselt^{1*}, Nikolaus Umlauf², Marina Hirota^{3,4,5}, Milena Holmgren⁶, Egbert H. Van Nes³, Martin Herold¹, Achim Zeileis² and Marten Scheffer^{3*}

- **The capacity to recover from disturbances**

South America

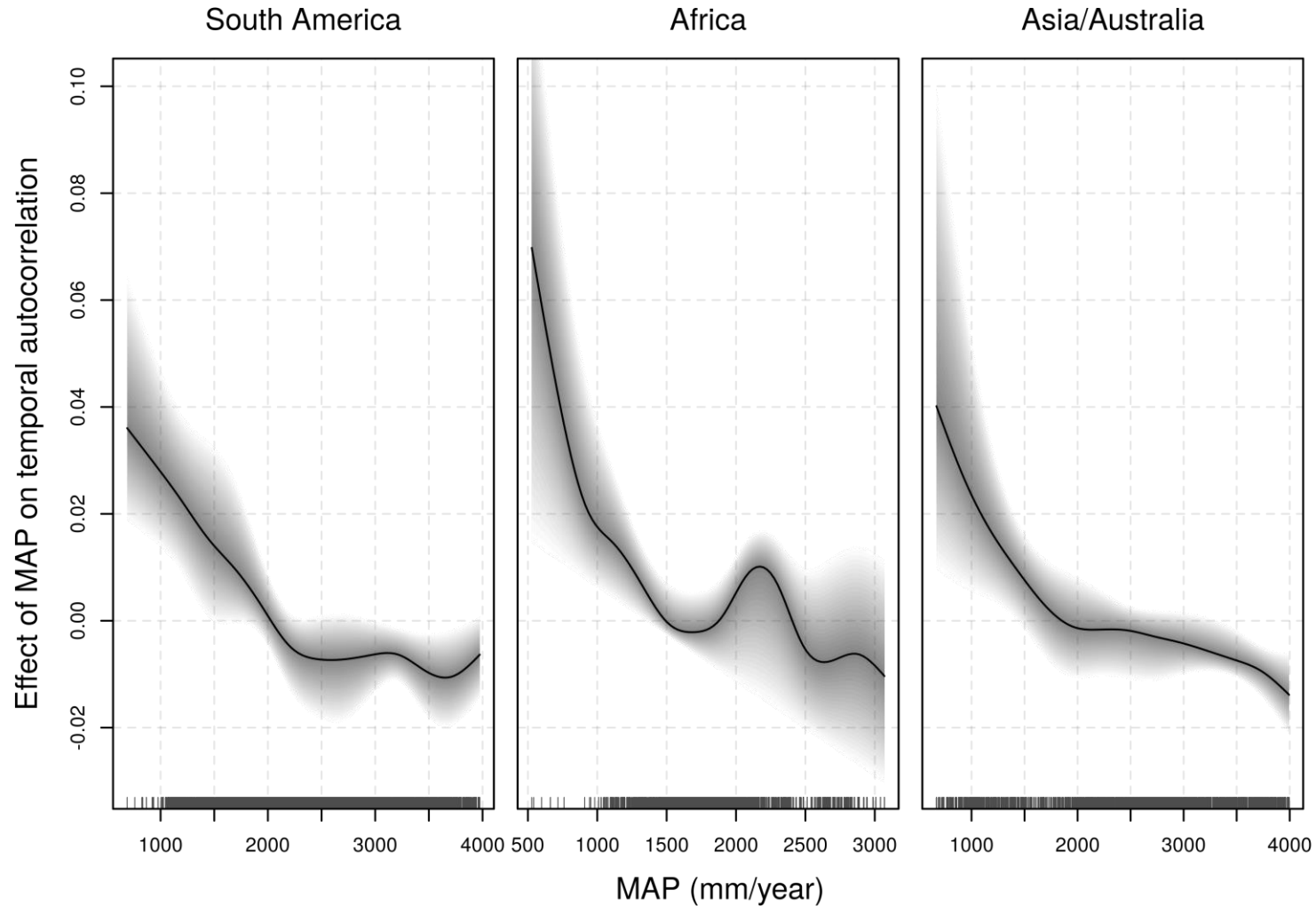
Africa

Asia & Australia



Temporal
Auto-correlation

Slowing down upon low rainfall amounts



Verbesselt, J. *et al.* Remotely sensed resilience of tropical forests. *Nat. Clim. Chang.* (2016).

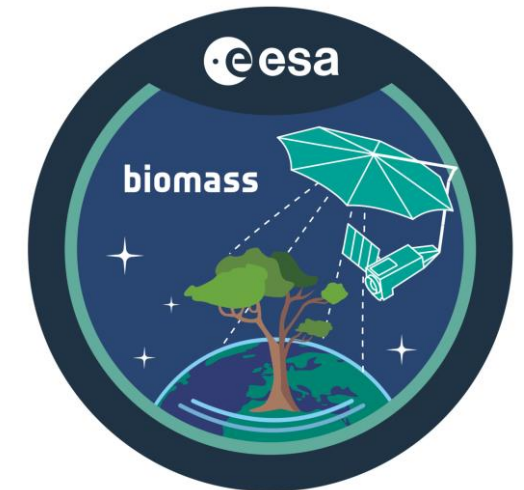
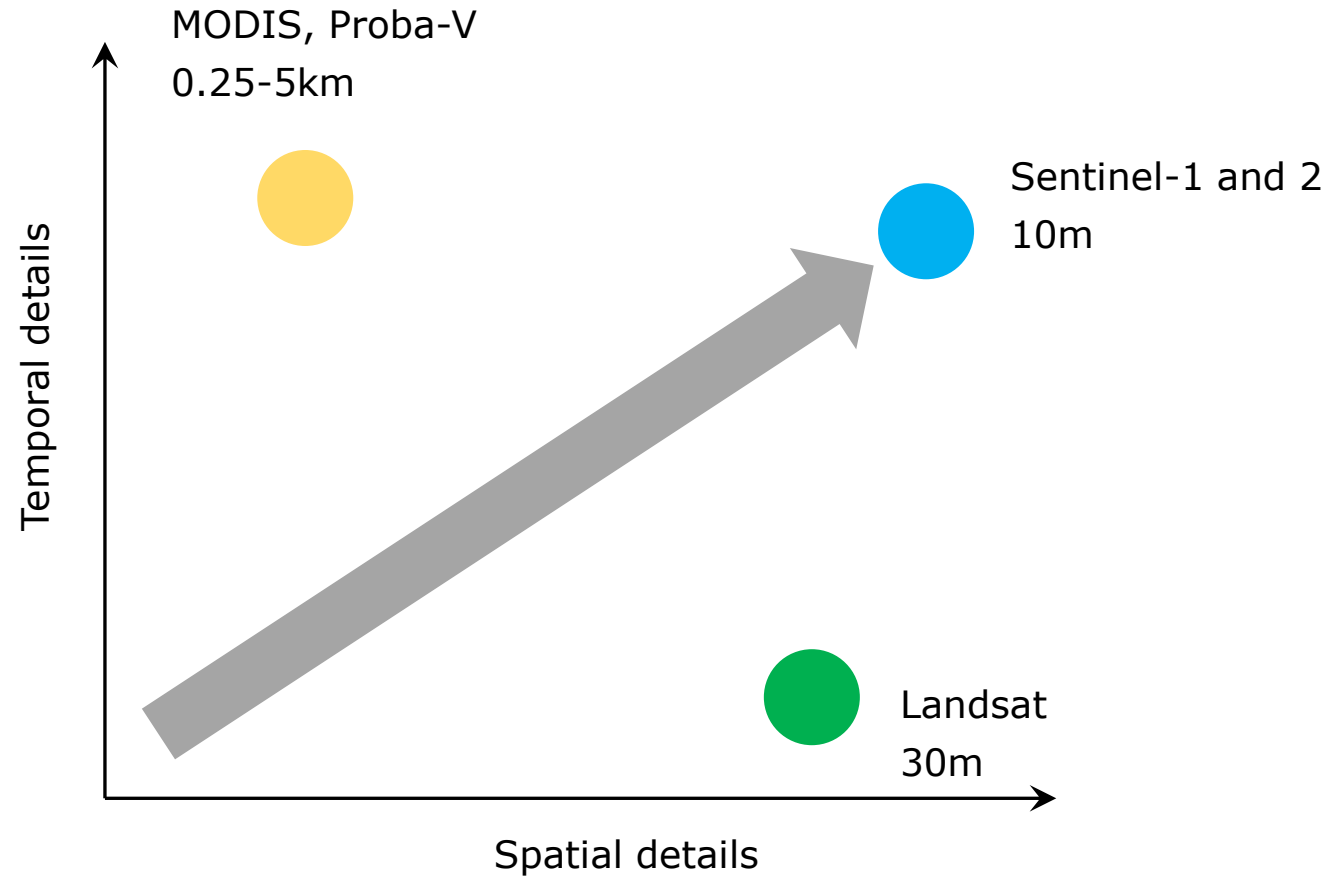
Effect of small-scale disturbances?

- Deforestation, shifting cultivation, fires, etc.



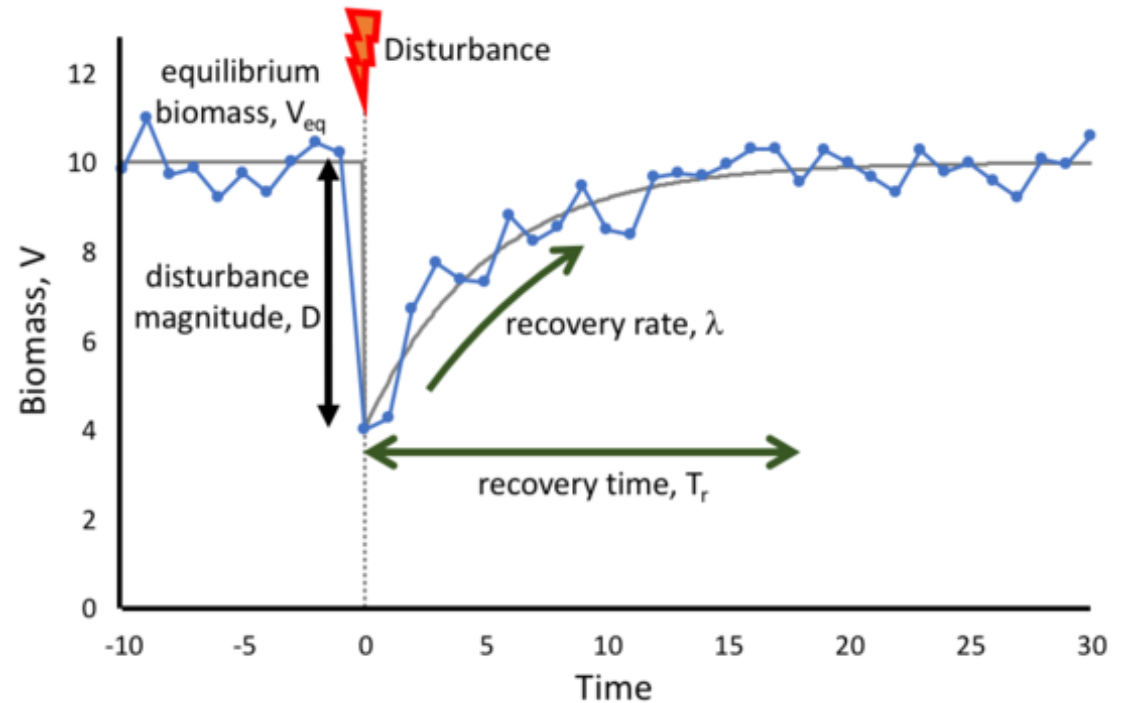
- Difficult to study with e.g., AVHRR, MODIS, AMSR-E
 - Coarse spatial resolution

New satellite sensors



ESA Biomass mission for 2023
P-band RADAR

Measure forest resilience



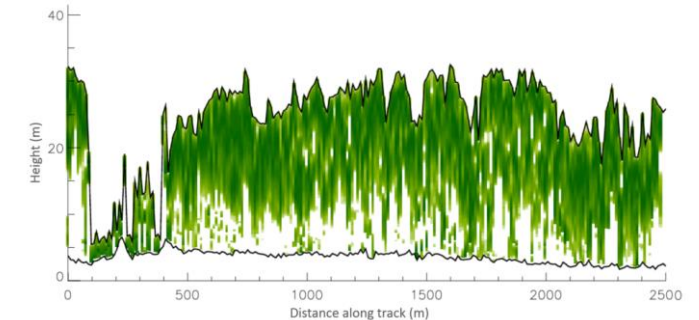
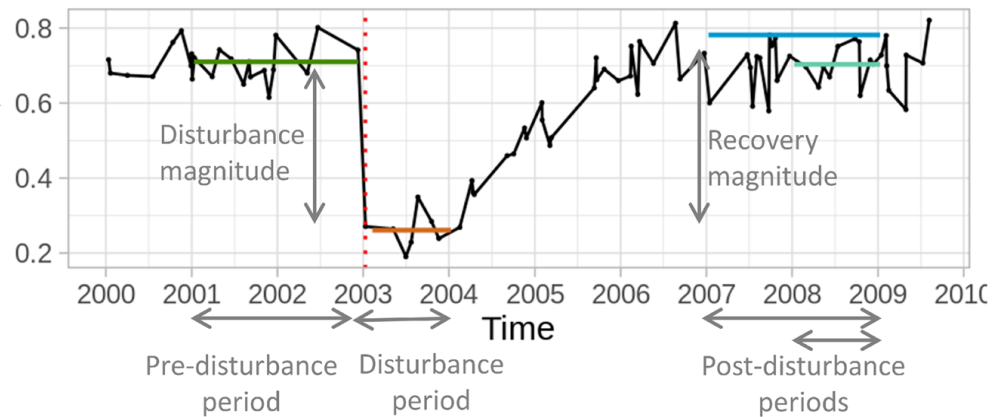
Evolution of the open-source BFAST functions for characterizing land change using satellite image time series (Sentinel, and Landsat) [Speaker](#)

Monitoring tropical forest recovery capacity using:

- De Keersmaecker, W. et al. **Evaluating recovery metrics derived from optical time series over tropical forest ecosystems.** RSE (2022)

- Milenković, M. et al. **Assessing Amazon rainforest regrowth with GEDI and ICESat-2 data.** Science of RS (2022)

EO index



Recovery indicator	Equation	Explanation
Relative Recovery Index	$RRI = \frac{ \max(f(t_{post})) - \bar{f}(t_{dist}) }{ \bar{f}(t_{pre}) - \bar{f}(t_{dist}) }$	Recovery magnitude relative to disturbance magnitude
Ratio of Eighty Percent	$R80p = \frac{\max(f(t_{post}))}{0.8 \bar{f}(t_{pre})}$	Post-disturbance state relative to 80% of pre-disturbance state
Year on Year Average	$YrYr = \frac{\bar{f}(t_{\Delta}) - \bar{f}(t_{dist})}{t_{\Delta} - t_{dist}}$	Related to post-disturbance slope

GEDI & ICESAT-2
Airborne LiDAR

Towards early warning using EO data

Can detailed recovery measures be a proxy for tipping points?



Smith, T., et al. Empirical evidence for recent global shifts in vegetation resilience. *NCC* (2022)