Path Dependence of Regional Climate Change

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Introduction

Recent research suggests that long-term global mean temperature and precipitation changes are proportional to cumulative CO_2 emissions, and independent of emissions pathway (Zickfeld et al 2012). Little research, however, has been done on path dependence of regional climate change, especially with regard to regions that may be affected by climate tipping points.

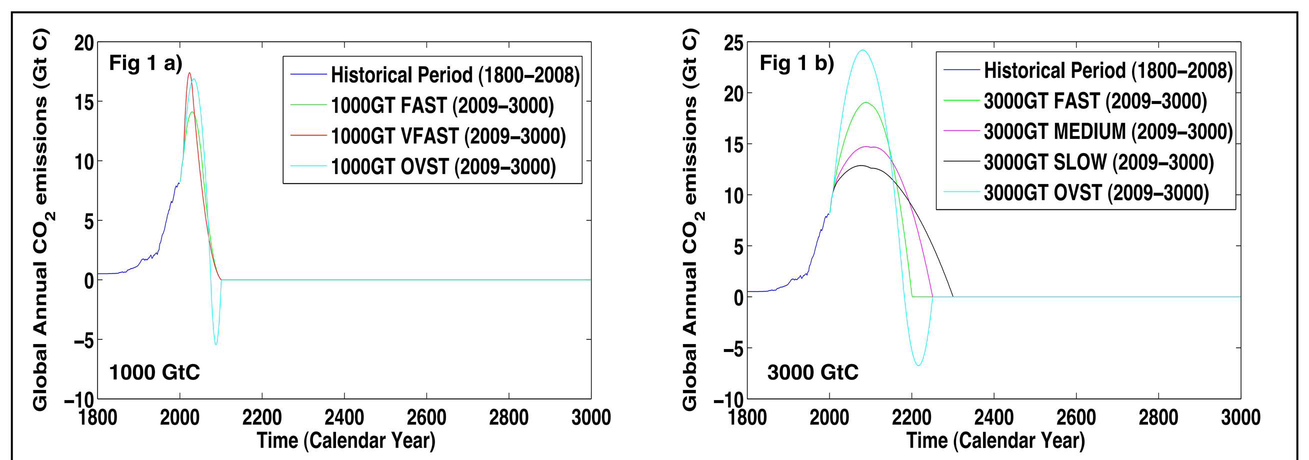
Tipping points are climate subcomponents (such as an ice sheet, or rainforest) which may exhibit a non-linear response to increased radiative forcing, once a critical threshold (such as temperature) is crossed (Lenton et al 2008). Some tipping points, such as the Greenland Ice Sheet, are thought to be subject to hysteresis, or path dependent behaviour (Robinson et al 2012).

Here we investigate whether or not long-term regional climate change is path dependent, focusing on regions potentially affected by the following tipping points: disappearance of summer Arctic Sea Ice; disappearance of the Greenland Ice Sheet; shutdown of the Atlantic Thermohaline Circulation; and dieback of the Amazonian Rainforest.

Methods

The research employs the University of Victoria's Earth System Climate Model version 2.9, an Earth System Model of Intermediate Complexity. It consists of a 3-dimensional ocean general circulation model, coupled with a dynamic-thermodynamic sea ice model, and a thermodynamic energy-moisture balance model of the atmosphere (Weaver et al 2001). This is then coupled with a terrestrial carbon cycle model (Meissner et al 2003), and an ocean carbon-cycle model containing an inorganic carbon and marine ecosystem component (Schmittner et al 2005). The most recent version of the model also includes a dynamic ice sheet model (Fyke et al 2011). Model coverage is global with a zonal resolution of 3.6° and meridional resolution of 1.8° (Weaver et al 2001).

The model was run to simulate the climatic response to 24 CO_2 emission scenarios from five main cumulative emission groups (1300 GtC, 2300 GtC, 3300 GtC, 4300 GtC, and 5300 GtC) (Figure 1). Emission scenarios include both fossil fuel emissions (of 1000-5000 GtC) and a cumulative 300 GtC of emissions from land use changes, and represent a variety of peak and decline scenarios with varying emission rates, as well as overshoot and instantaneous pulse emissions.



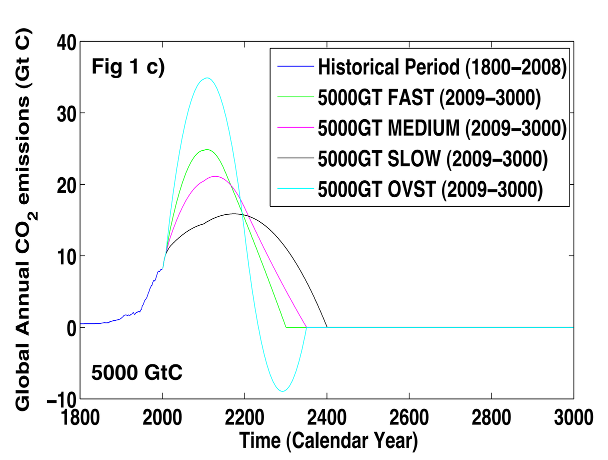


Figure 1: A) 1000 GtC, **B)** 3000 GtC, and **C)** 5000 GtC Cumulative Emission Group Scenarios. Note that VFAST, FAST, MEDIUM, SLOW and OVST refer to fossil-fuel emissions and do not include Land Use Emissions (these are separate).

Results

Temperature:

- Year 3000 global mean warming on the order of 2.3°C to 8.8°C (with respect to 1810) (Figure 2 a, b)
- Convergence of global mean temperatures after emission cessation
- Strong agreement, within cumulative emission groups, on spatial variation of temperature response

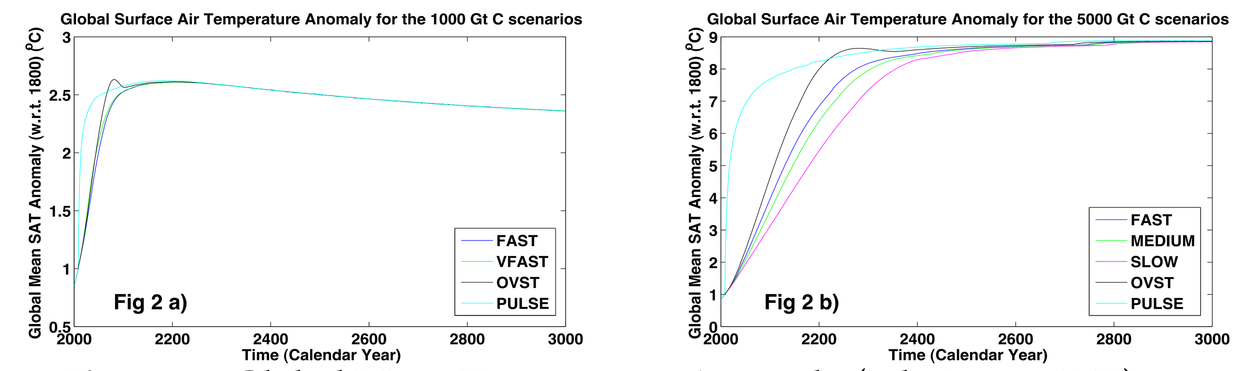


Figure 2: Global Mean Temperature Anomaly (relative to 1810) for the a) 1000 GtC scenarios and b) 5000 GtC scenarios

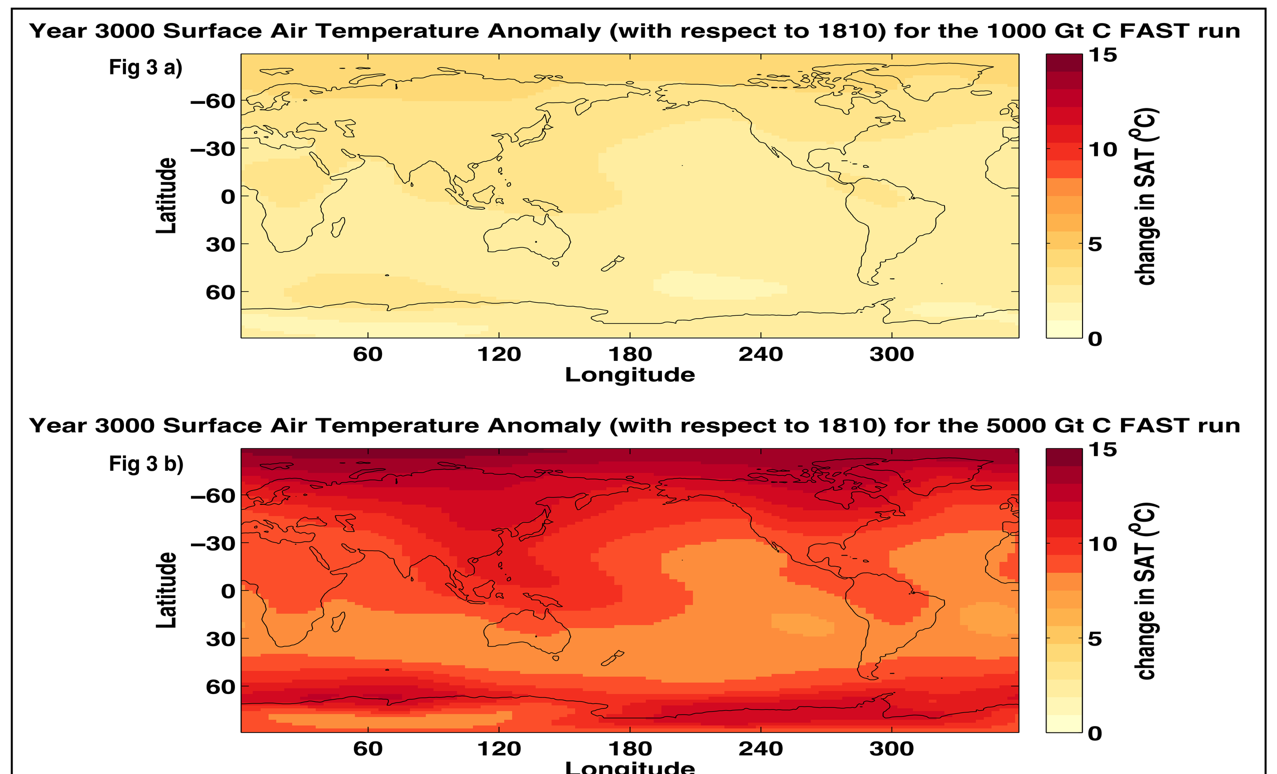


Figure 3: Regional Temperature Anomalies (relative to 1810) for the a) 1000 GtC FAST scenarios and b) 5000 GtC FAST scenarios

Summer Arctic Sea Ice Cover:

- Summer Arctic sea ice disappears between 2020 and 2260, for 3000 GtC – 5000 GtC cumulative emission groups (Figure 4)
- Transient rate of sea ice decline is pathway dependent; faster rates of decline for pathways with a higher peak emission rate
- Long term sea ice response is independent of emission pathway

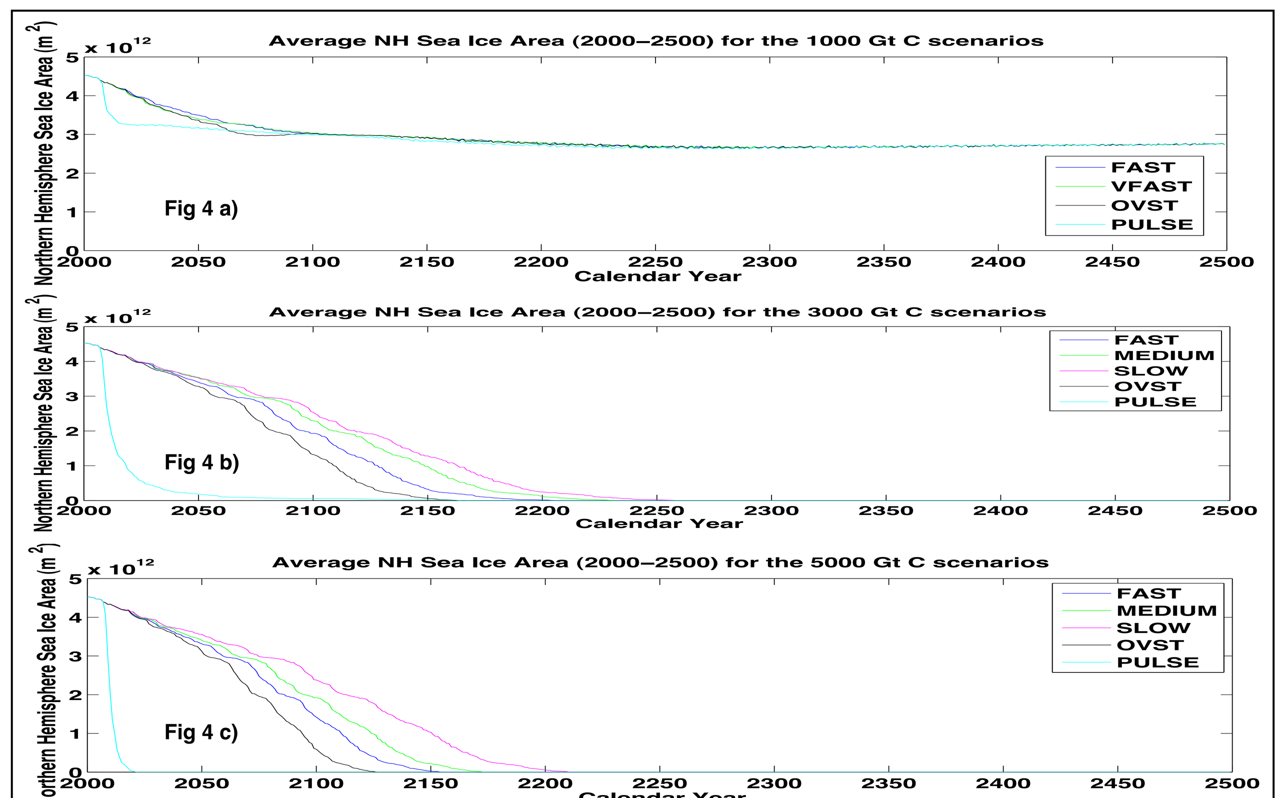


Figure 4: Annual September Average Sea Ice Area for the a) 1000 GtC, b) 3000 GtC, and c) 5000 GtC cumulative emission groups

Atlanic Thermohaline Circulation:

- MOC reaches minimum by 2200, with values ranging between 18-13 Sv (Figure 2 a, b)
- Peak MOC behaviour sensitive to emission rate (esp for 3000 – 5000 GtC scenarios; higher emission rates yield lower minimum MOC
- Long term response is path independent

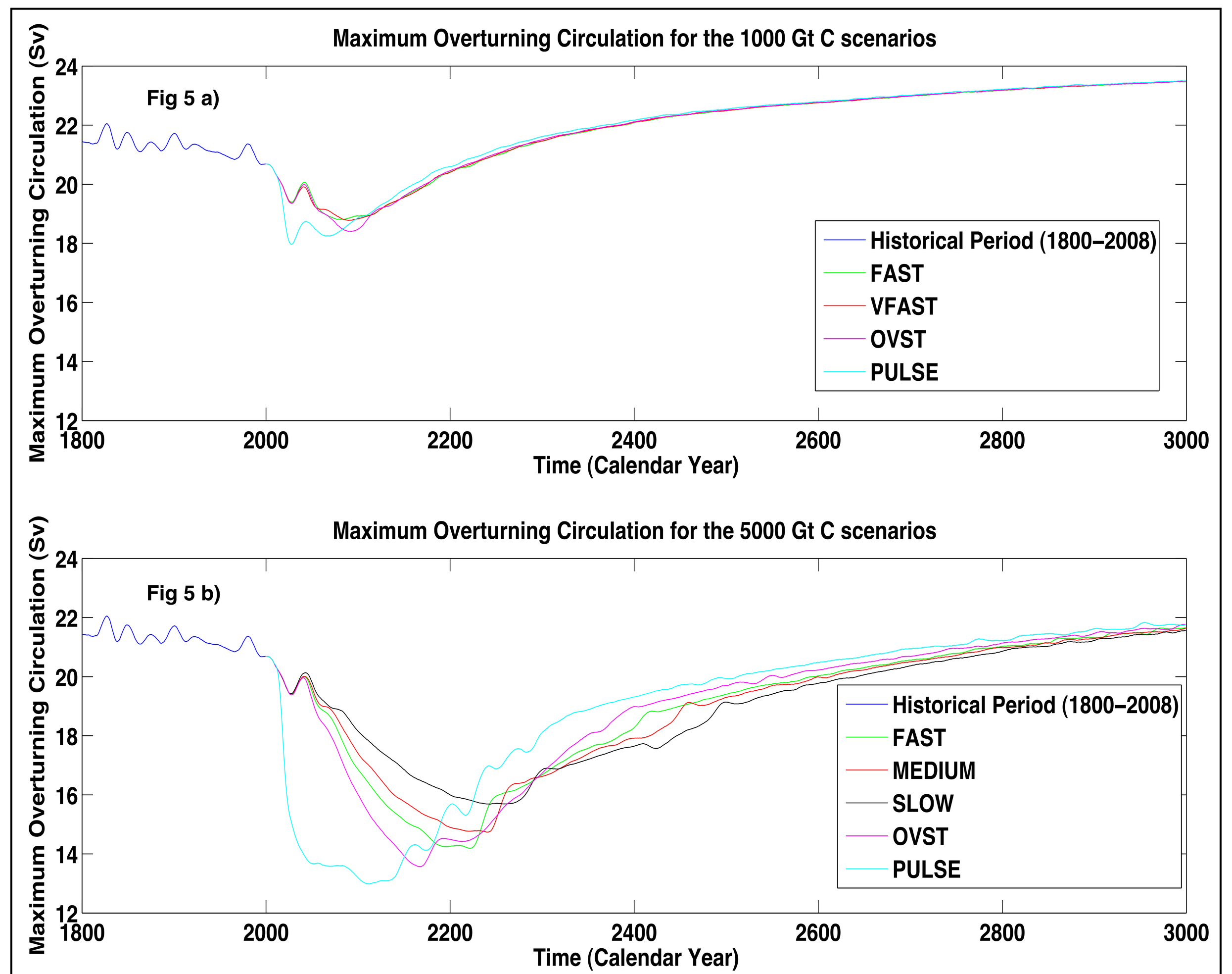


Figure 5: Maximum Overturning Circulation for the a) 1000 GtC and b) 5000 GtC cumulative emission groups

Amazon Rainforest:

- Broadleaf forest cover reduced by 10-20% over much of Amazon region for 5000 GtC scenarios (Figure 6a)
- Losses of broadleaf forest cover in the Amazon relatively small for 1000-4000 GtC scenarios (Figure 6b)
- C4 grass (Figure 6c) and shrub (Figure 6e) replace broadleaf forest in regions of loss
- Long term response of vegetation is not sensitive to emission rate; only to the overall total cumulative emissions.

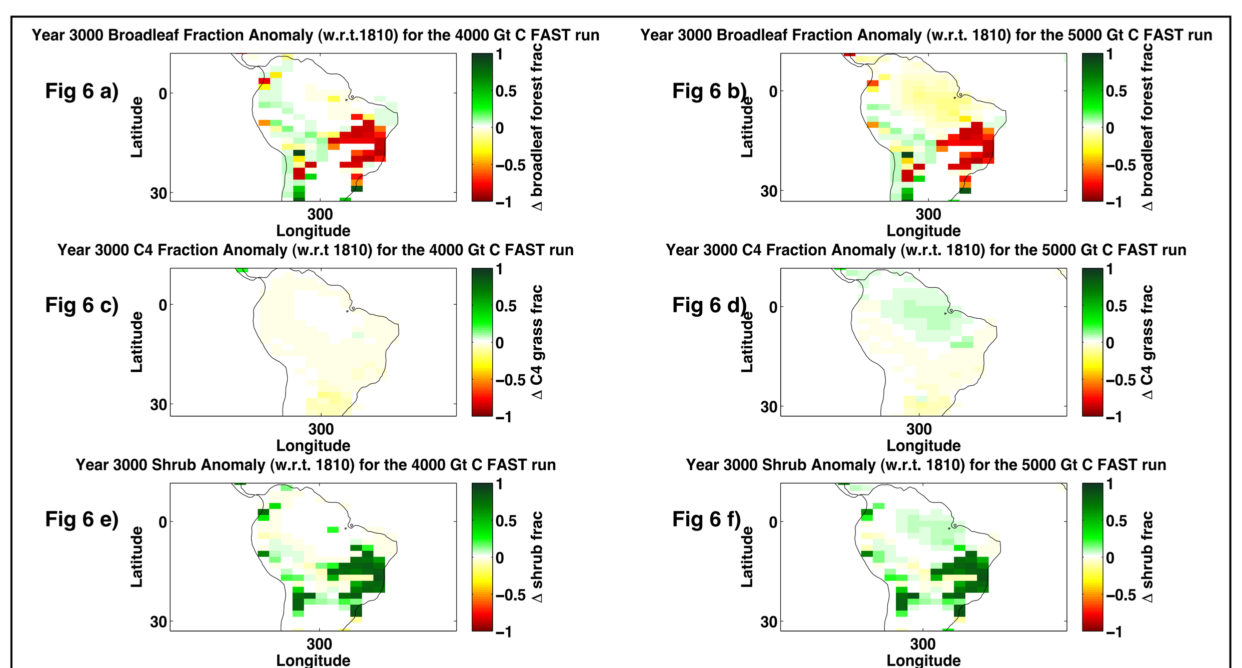


Figure 6: Change in a)/b) broadleaf forest cover c)/d) C4 grass cover and e)/f) shrub cover for the 4000 GtC (left)/5000 GtC (right) FAST scenarios

Amazon Precipitation

- Decreases on order of 400-500 mm/yr (Figure 7a) for 5000 GtC scenarios
- Decreases of ~ 300-400 mm/yr (Figure 7b) for 4000 GtC scenarios
- Regional variation in the long term precipitation response appears to be path independent.

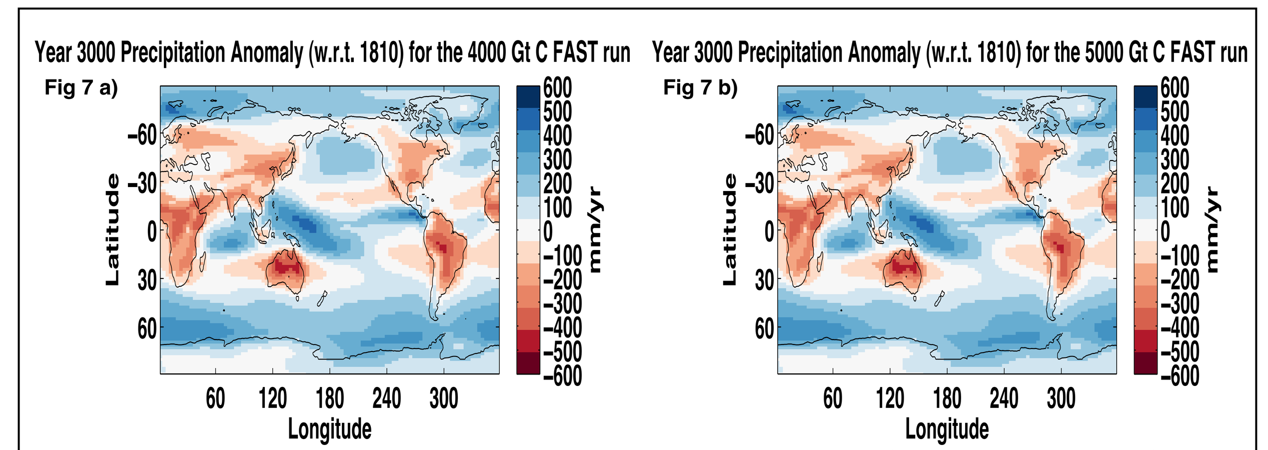


Figure 7: Mean Annual Precipitation Anomaly (relative to 1810) for the a) 4000 GtC FAST scenario and b) 5000 GtC FAST

Discussion

- Short-term response (before emission cessation) of all climate variables examined path dependent; vary with emission pathway
- Peak response of THC appears to show path dependence
- Amazon broadleaf forest cover showed very little change in broadleaf forest cover between 1000 and 4000 GtC, but non-negligible change occurs at 5000 GtC

What is next?

The 24 idealized emission pathways will be run again with a version of the UVic model coupled to an ice sheet model, in order to explore whether the Greenland Ice Sheet exhibits path dependent behaviour.

We will also perform further analysis on the simulations of summer Arctic sea ice cover, MOC, and Amazonian broadeaf forest to test whether or not they exhibit tipping point behaviour

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