Tipping points in the climate system and the economics of climate change

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Disclaimer: This research does not necessarily represent the views of the European Commission. All views are our own.

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Motivation and aims

Tipping points in the climate system are one of the principal reasons for concern about climate change (e.g. IPCC AR5)

In spite of this, leading economic estimates of the cost of climate change EITHER ignore these tipping points OR represent them in a highly simplified way that is impossible to calibrate

But all is not lost: an emerging literature incorporates individual tipping points in IAMs (e.g. Nordhaus on the GIS in PNAS, 2019)

Our aim is to bring this literature closer to incorporation in leading economic estimates of climate costs, by

- Reviewing and synthesising this literature
- Building a meta-model capable of incorporating all the tipping points studied so far and estimating the overall contribution to the social cost of carbon

Preview of main results

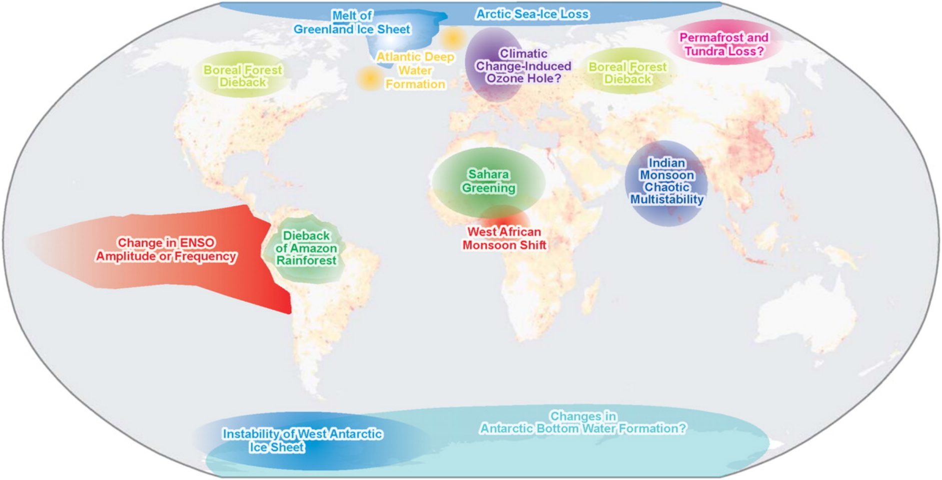
TPs covered in this study collectively increase the social cost of carbon (SC-CO_2) by 28% in our main specification

A so-far incomplete sensitivity analysis indicates the corresponding range is 2-71%

Main contributors are the methane feedbacks, i.e. permafrost melting (+10.6%) and dissociation of ocean methane hydrates (+9.4%)

- Papers agree on magnitude of Permafrost Carbon Feedback and put reasonably narrow bounds on it
- Conversely there is large uncertainty about ocean methane

What do you mean by tipping points in the climate system?



Source: Lenton et al. 2008 PNAS.

Literature overview

Broad search yielded 53 articles that:

1. Study a geophysical tipping point in relation to climate change
2. Undertake an economic valuation (i.e. do not just study geophysical impact)

Narrower search for realism in geophysical module yielded 22 articles that:

3. Couple a geophysical model of the tipping point with an IAM (e.g. DICE)
4. Examples of exclusions
   - Physically unrealistic tipping dynamics (instantaneous large jump in equilibrium climate sensitivity)
   - *Ad hoc* changes to the damage function

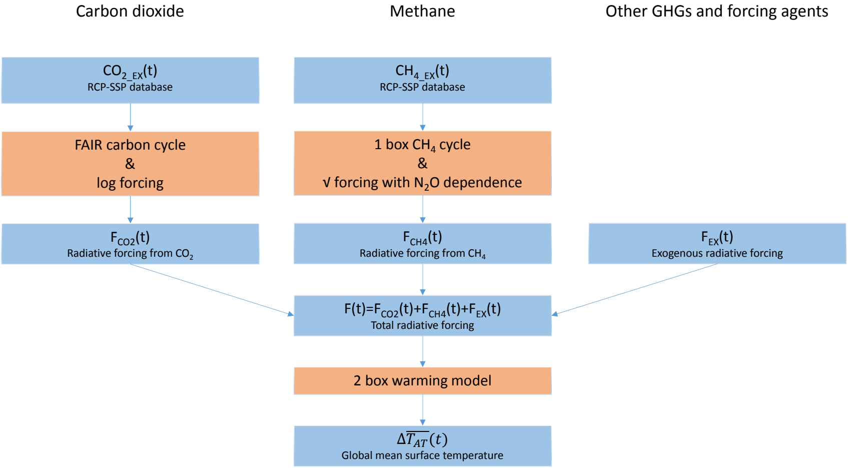
Models synthesised in this study

Tipping point	Papers	IAM	Model of TP	Uncertainty
PCF	Kessler (2017, *Clim. Chge. Econ.*)	DICE	Process-based	Deterministic & MC
	Hope & Schaefer (2016, *Nat. Clim. Chge.*)	PAGE09	Process-based	MC
	Yumashev et al. (2019, *Nat. Comms.*)	PAGE-ICE	Process-based	MC
OMH	Ceronsky et al. (2011, unpublished)	FUND	Tipping event	Deterministic & MC
	Whiteman et al. (2013, *Nature*)	PAGE09	Tipping event	MC
Amazon dieback	Cai et al. (2016, *Nat. Clim. Chge.*)	DSICE	Tipping event	Survival analysis
GIS disintegration	Nordhaus (2019, *PNAS*)	DICE	Process-based	Deterministic
WAIS disintegration	Diaz and Keller (2016, *AER P&P*)	DICE	Tipping event	Survival analysis
AMOC slowdown	Anthoff et al. (2016, *AER P&P*)	FUND	Tipping event	Deterministic
ISM variability	Belaia (2017, unpublished)	RICE	Process-based	Stochastic

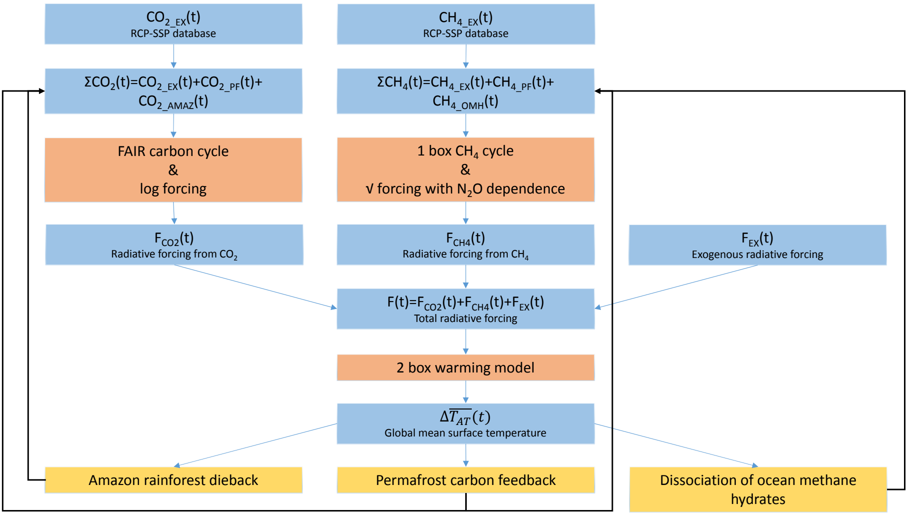
On the need for a "structural synthesis"

Papers use different boundary conditions (e.g. emissions), model structures, make divergent choices on common parameters (e.g. discount rate) and even report different welfare metrics (this last one is avoidable!)

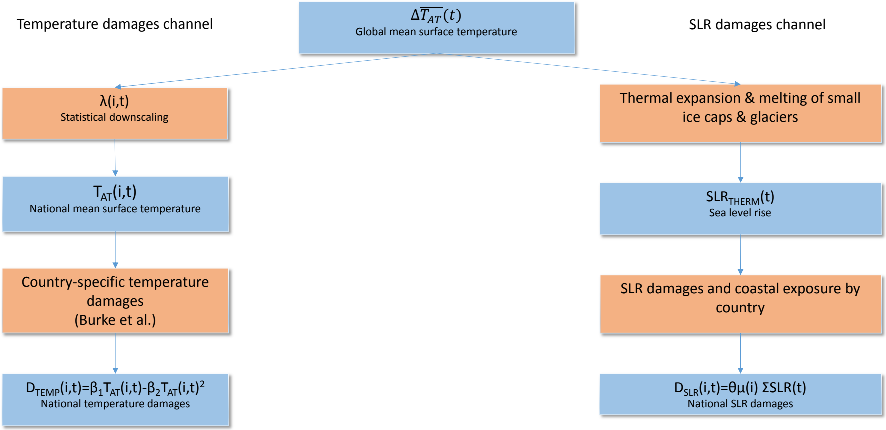
Climate model



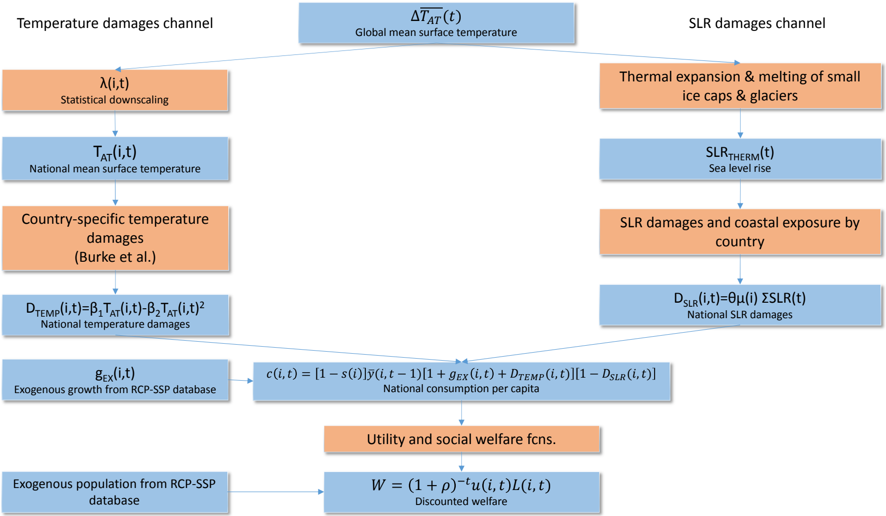
Climate model including carbon-cycle and albedo feedbacks



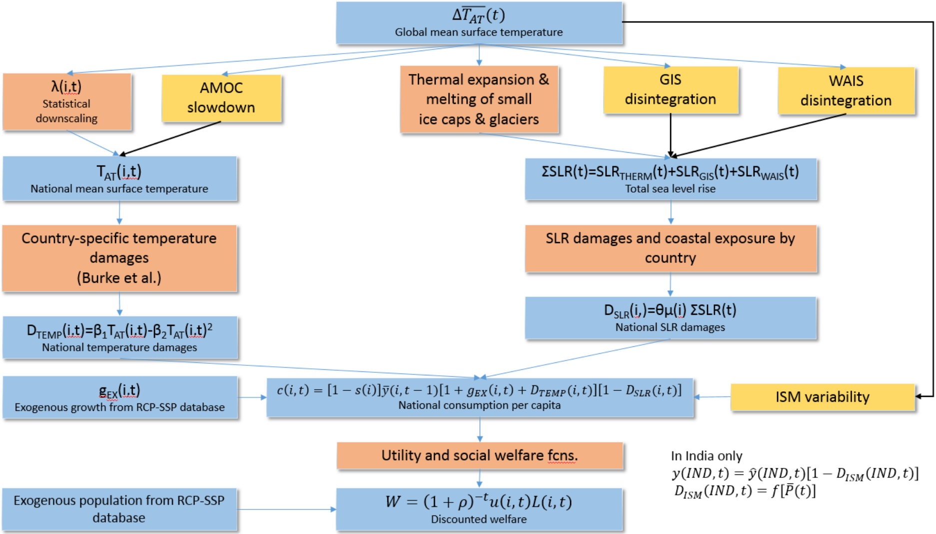
Temperature and SLR damages



Temperature and SLR damages, income and welfare



Plus ice-sheet disintegration and changes in large-scale circulation



In India only
$y(IND,t) = \hat{y}(IND,t)[1 - D_{ISM}(IND,t)]$
$D_{ISM}(IND,t) = f[\bar{P}(t)]$

Results: main specification

TP	SC-CO_2 (USD/tCO_2)	% increase due to TP
None	49.07	-
PCF	54.28	10.6
OMH	53.68	9.4
Amazon	49.47	0.8
GIS	49.69	1.3
WAIS	49.32	0.5
AMOC	48.33	-1.5
ISM	49.89	1.7
All	62.98	28.3
$\sum$ 'main effects'	-	22.7

Note: RCP4.5/SSP2; Kessler main PCF; Whiteman et al. main OMH; IPSL AMOC hosing

Different PCF scenarios

PCF scenario	W/o PCF	With PCF	% increase
None	49.07	-	-
Kessler (main)	-	54.28	10.6
Hope and Schaefer	-	52.63	7.2
Yumashev et al.	-	51.71	5.4
Average	-	52.87	7.8
Kessler 2.5%	-	53.18	8.4
Kessler 97.5%	-	56.95	16.1

Note: RCP4.5/SSP2

Different OMH scenarios

OMH scenario	W/o OMH	With OMH	% increase
None	49.07	-	-
Whiteman et al.	-	53.68	9.4
Ceronsky et al. 0.2Gt/yr	-	50.14	2.2
Ceronsky et al. 1.8Gt/yr	-	56.54	15.2
Ceronsky et al. 7.8Gt/yr	-	74.53	51.9

Note: RCP4.5/SSP2

Different AMOC scenarios

AMOC scenario	W/o PCF	With PCF	% increase
None	49.07	-	-
HADCM 7%	-	48.51	-0.6
BCM 24%	-	48.77	-0.6
IPSL 27%	-	48.33	-1.5
Hadley 67%	-	46.14	-6.0

Note: RCP4.5/SSP2

Sensitivity to emissions/socio-economic scenario

RCP-SSP	W/o TPs	With all TPs	% increase
RCP3-PD/2.6, SSP1	33.06	42.78	29.4
RCP4.5, SSP2	49.07	62.98	28.3
RCP6, SSP4	70.33	86.36	22.8
RCP8.5, SSP5	31.08	37.09	19.3

Note: Kessler main PCF; Whiteman et al. main OMH; IPSL AMOC hosing

Some further sensitivity analysis

Sensitivity test	W/o TPs	With all TPs	% increase
"Stern discounting"	83.08	109.23	31.5
"Nordhaus discounting"	38.95	49.55	27.2
Least sensitive climate ACC2/GISS-E2-R	12.58	17.01	35.3
Most sensitive climate MESMO/HadGEM2-ES	224.00	227.71	1.7
Pure levels damages	25.13	32.41	28.9
Pure growth damages $\approx$ Ricke et al. (2018)	2059.81	3513.08	70.6

Note: RCP4.5/SSP2; Kessler main PCF; Whiteman et al. main OMH; IPSL AMOC hosing

Conclusions

We built a 'meta' model to integrate different economic models of climate TPs, in order to estimate the overall effect on the SC-CO_2

Our central estimate so far is a 28% increase in the SC-CO_2, within a range of 2-71% (this is an incomplete estimate of the uncertainty)

- The largest contributions to the SC-CO_2 come from the PCF and OMH dissociation; the former seems much better constrained than the latter
- GIS and WAIS have small positive effect on SC-CO_2
- AMOC slowdown reduces the SC-CO_2
- ISM effect is large enough to register in global SC-CO_2

Our to-do list

Short to medium run

- Add Arctic sea-ice loss (surface albedo feedback)
- Maximally comprehensive sensitivity analysis
- Stochastic optimization of emissions

Longer run

- Improve TP modules for e.g. OMH
- Integrate new TPs, e.g. Boreal Forest Dieback, ENSO, West African Monsoon

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Comments, suggestions, critiques:

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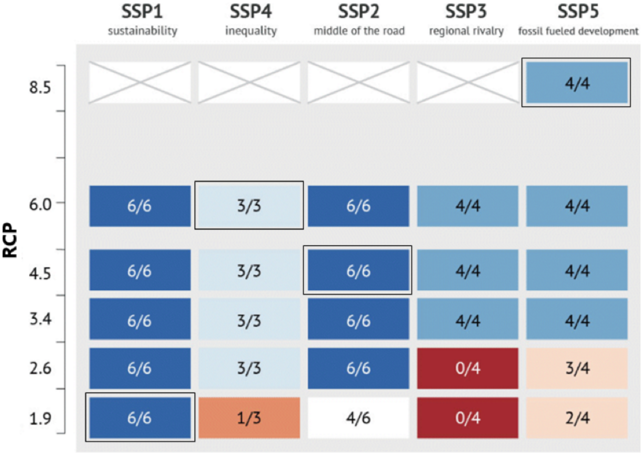
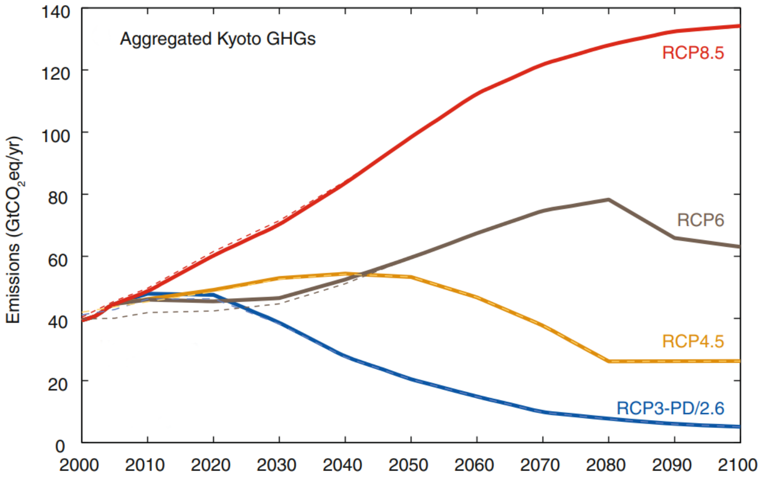
Where do emissions and growth rates come from?



Source: Carbon Brief.

Where do emissions and growth rates come from?



Source: Meinshausen et al. 2011 Climatic Change.

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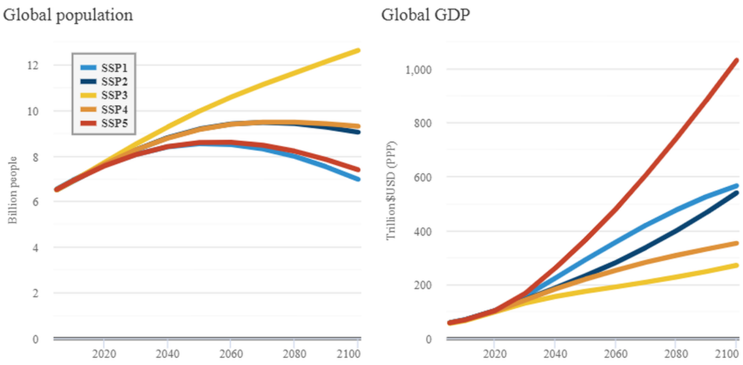

Source: Carbon Brief.

Income growth: levels versus growth damages

$$y(i,t) = \bar{y}(i,t-1)\left[1 + g_{\mathrm{EX}}(i,t) + D_{\mathrm{TEMP}}(i,t)\right]\left[1 - D_{\mathrm{SLR}}(i,t)\right],$$

where

$$\bar{y}(i,t-1) = \left[\varphi y_{\mathrm{EX}}(i,t-1) + (1-\varphi)\, y(i,t-1)\right]$$

Two different interpretations of the empirical evidence on temperature damages.

1. ($\varphi = 1$) Temperatures impact the level of income in each year. The production possibilities frontier is assumed to evolve exogenously.
2. ($\varphi = 0$) Temperatures impact the growth rate of income by directly impacting the accumulation of factors of production and/or by impacting productivity growth.