ASCENT
AVIATION SUSTAINABILITY CENTER

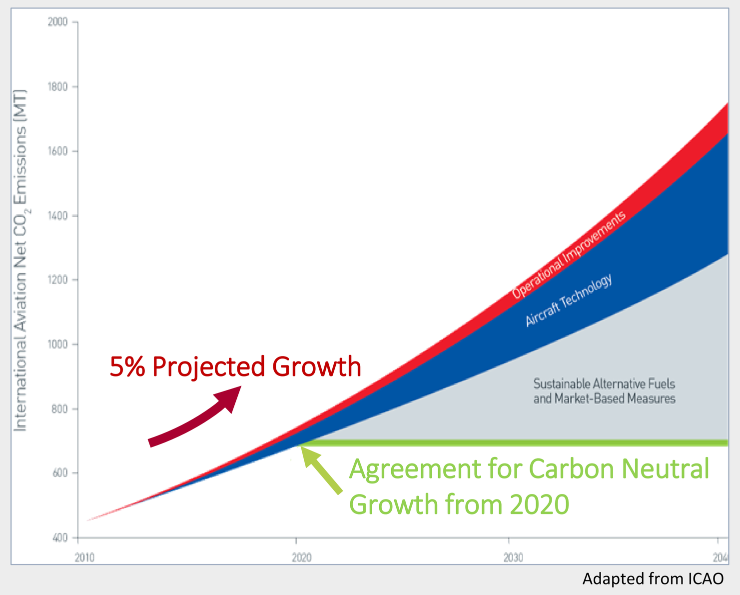
Project 021
Improving Climate Policy Analysis Tools

MIT LABORATORY FOR AVIATION AND THE ENVIRONMENT

Massachusetts Institute of Technology

Motivation and Objectives

- Aviation is estimated to cause
  - 2% of the global anthropogenic CO2 emissions
  - 5% of the global anthropogenic radiative forcing
- Impact is expected to increase



- Tools to **quantify current and future climate impacts** of aviation required
- **APMT-Impacts Climate** is a reduced order climate modeling tool, which has been developed for this purpose. Most recently:
  - Additional pathways for CH_4 and N_2O added
  - Damage function to capture US based climate damages implemented

Tool: APMT-IC

Aviation Operation Scenarios

Full flight emissions

CO_2
- Mass → Atmospheric Concentration *(Impulse Response Function)*
- Atmospheric Concentration → global RF *(IPCC)*

Short Lived Effects
RF's for short-lived effects *(Brasseur et al, 2016)*

RF values for each Species

Temperature Model
Global RF → Global ΔT *(2-Box Ocean Model)*

Global Average ΔT

Socioeconomic Impacts
- Global ΔT → % GDP *(DICE Model)*
- Discounting

Climate Cost

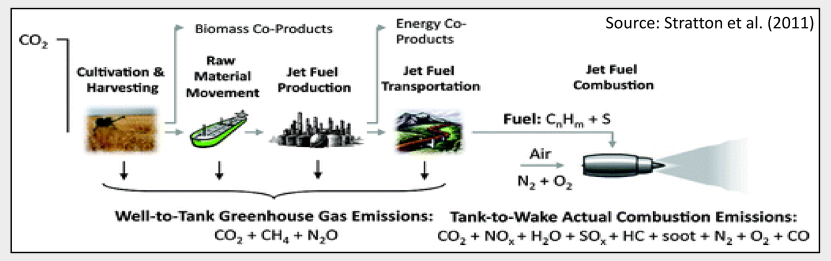
Policy Assessment

Current Work

Life Cycle: CH_4 and N_2O

Motivation

- Methane (CH_4) and nitrous oxide (N_2O) are powerful greenhouse gases.
- Biofuel production results in emission of both CH_4 and N_2O.
- Their climate impact significantly alter biofuel life cycle analysis. (Stratton et al. 2011)



Chemistry Background

N_2O Impact Pathway
→ (A) Direct Warming Impact Timescale ≈120 years

CH_4 Impact Pathway
→ (A) Direct Warming Impact Timescale ≈12 years
→ Indirect Warming: CH_4 Products
$CH_4 + OH \rightarrow H_2O + CH_3$
→ (B) Eventually forms CO_2
→ (C) Stratospheric water vapor
→ (D) If reaction occurs in the presence of NO_x, O_3 is produced

Approach

Concentration is modeled using first-order atmospheric lifetimes and a convolution approach.
N_2O: τ_perturb= 121 yr (+/- 15.3) (IPCC, AR5) including 3 year delay for N_2O to reach its stratospheric sink (Meinshausen et al., 2011).
CH_4: τ_perturb= 12.4 yr (+/- 2.3) (IPCC, AR5)
Background concentrations from RCP data.

(A) **Direct Radiative Forcing** (Etminan et al. 2016)

$$RF_{N_2O} = \left[a_2\,\bar{C} + b_2\bar{N} + c_2\bar{M} + 0.117\right] \times \left(\sqrt{N} - \sqrt{N_0}\right)^*$$
$$RF_{CH_4} = [a_3\,\bar{M} + b_3\bar{N} + 0.043] \times \left(\sqrt{M} - \sqrt{M_0}\right)^*$$
$$RF_{CO_2} = [a_1(C - C_0) + b_1|C - C_0| + c_1\bar{N} + 5.36] \times \ln(C/C_0)$$

where C, M, and N denote concentration of CO_2, CH_4, and N_2O respectively. C_0, M_0, and N_0 denote initial concentrations and bar indicates average between initial and present ($\bar{X} = 0.5(X + X_0)$).

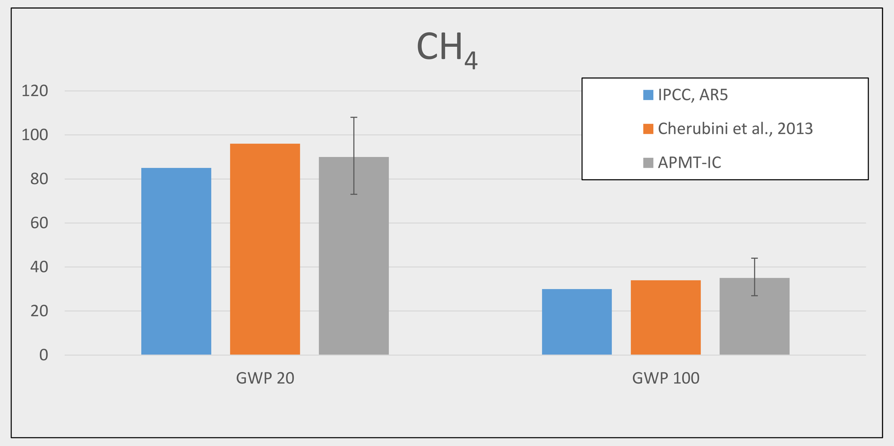
Indirect Methane Radiative Forcing

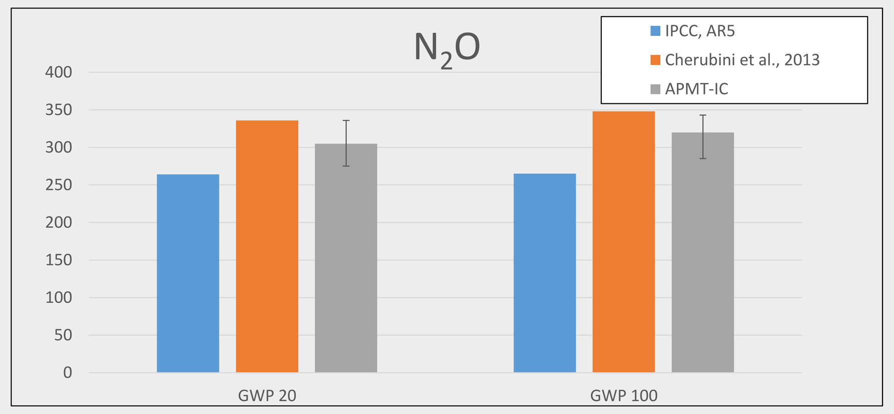
(C) **Stratospheric H_2O**
$RF^1 = \beta\alpha(C_{CH_4} + C^0_{CH_4})$
- $\beta = 0.15$
- $\alpha = 0.036$
- $C^0_{CH_4} = 722 +/- 25$ ppb
- 71% uncertainty

(D) **Tropospheric Ozone**
$RF = \alpha\, S_{CH_4} \Delta \ln(C_{CH_4})$
- $\alpha = 0.0335$
- $S_{CH_4} = 5$
- $C^0_{CH_4} = 722 +/- 25$ ppb
- 55% uncertainty

(B) **CO_2 Effect**
- Conserve of C atoms
- $CH_4 \rightarrow CO_2$.
- Only apply when CH_4 is from fossil fuel sources
- 50% uncertainty

Results and Comparison to Literature



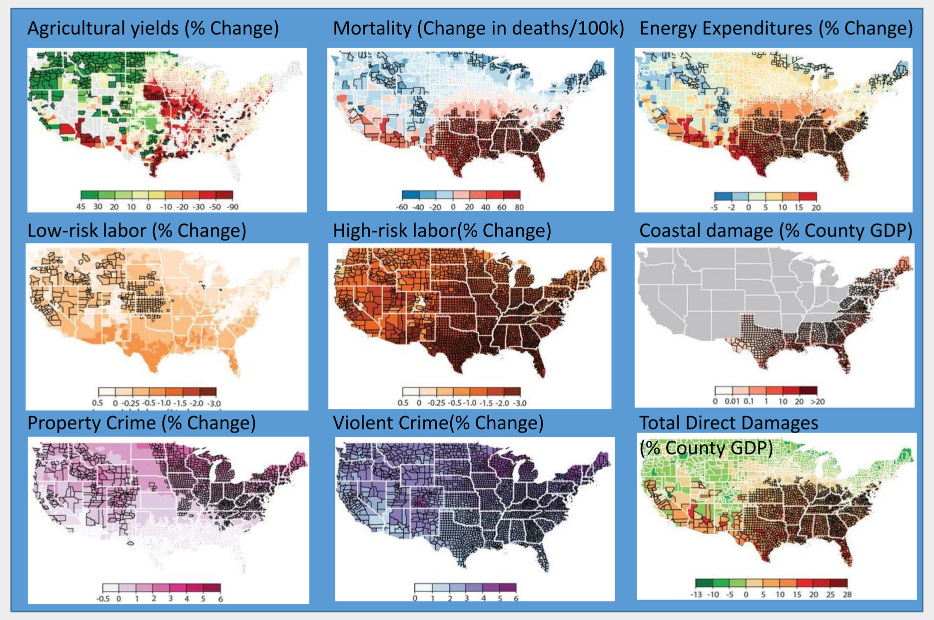


USA Specific Damages

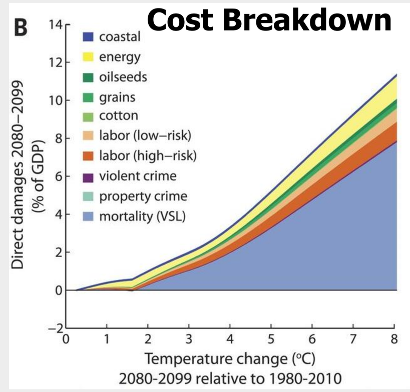
Motivation and Approach

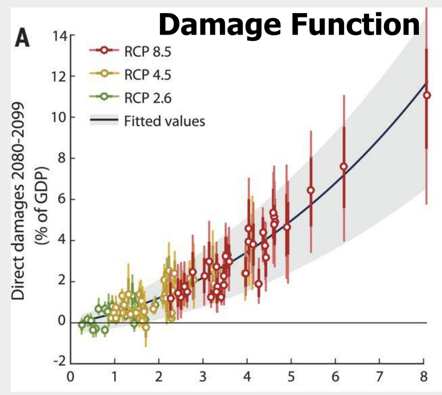
- Regionally differences in rainfall, temperature, and income are expected to lead to spatially heterogeneous climate damages.
- Inadequate agreement of top-down regionalized distribution of global damages. (Nordhaus, 2017)
- Bottom-up damage function for damages in the US only developed by Hsiang et al. (2017)

US Damage Function



US Damage Function

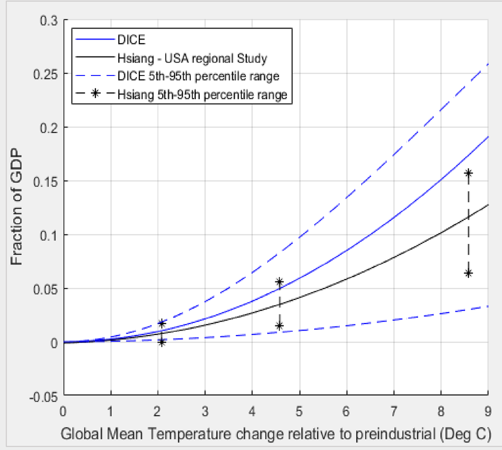




Damage function:
$D = 0.283\Delta T + 0.146\Delta T^2$ (%GDP)
- Where ΔT represents Global Mean Surface Temperature change.
- ΔT is w.r.t. 1980-2010

Uncertainty:
5th to 95th percentile as percentage of GDP
- At 1.5°C: −0.1 to 1.7%
- At 4°C: 1.5 to 5.6%
- At 8°C: 6.4 to 15.7%

DICE 2017 and Hsiang et al. (2017) Comparison



Implementation Notes

- SSP include US GDP scenarios. We verified whether low, mid, and high damage scenarios remain the same for global and US GDP.
- Hsiang et al. (2017) only includes uncertainty at discreet temperatures. Curve fit was applied to find uncertainty at all temperatures.
- APMT-IC computes temperature change relative to preindustrial. Using MAGICC6, temperature difference between preindustrial and 1980-2010 was calculated as 0.58 °C.

Calculated Social Cost of Carbon

Social Cost of Carbon for Emissions in 2015 on RCP4.5 Mid ($/1tonne CO_2 in 2007 USD)

	2% DR	2.5 % DR	3% DR	5% DR	7% DR	3% 95th PCTL
APMT-IC **v24b-Beta** (Global, DICE 2017)	$84	$55	$40	$15	$8.3	$103
APMT-IC **v24b-Beta** (US Only, Hsiang et al. 2017)	$6.6	$4.4	$3.0	$1.3	$0.76	$7.2

- It should be noted, **unified assumptions cannot be guaranteed** between the global damages and the US-only damages **("top-down" vs "bottom-up" approach**). As such **APMT-IC should not be used to conclude US based damages is a certain percentage of global damages**.
- In addition, it should be noted, that the US based damages implemented **do not include** economic **spill over effects** from damages outside of the US.

Future Work

- Working towards publication of **reduced order cost metrics** to evaluate **trade-off** of **climate** and **air quality** damages
- Investigate appropriateness of enhancing **spatial resolution of physical impacts** in APMT-IC.
- Re-asses **model sensitivity** to uncertainty distributions as well as **convergence characteristics** after last set of model updates.

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