Lecture 9
3 Feb 2025

Lecture 10
6 Feb 2025

CM 615

Climate change Impacts & Adaptation

Emission scenarios for future climate change

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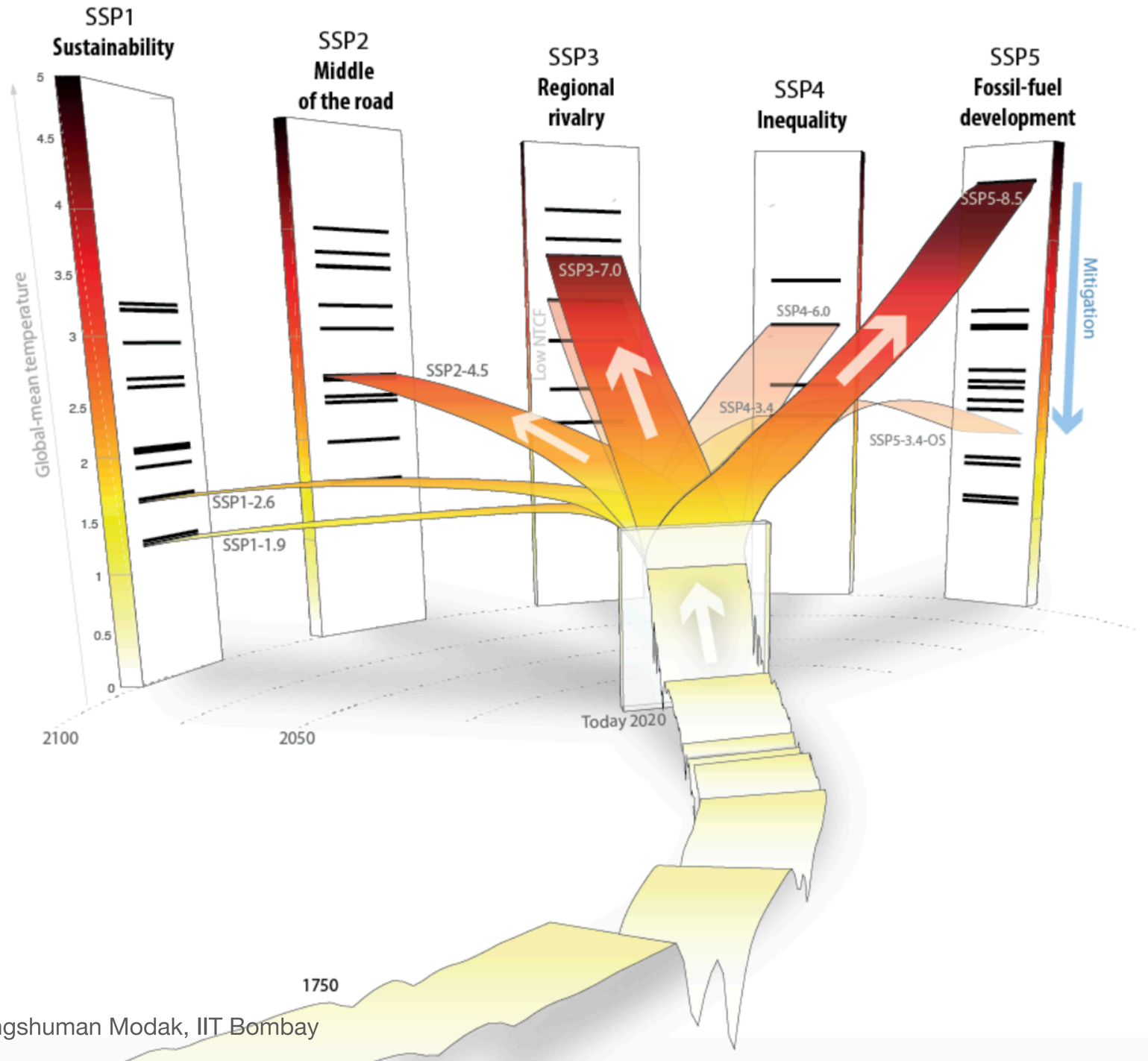
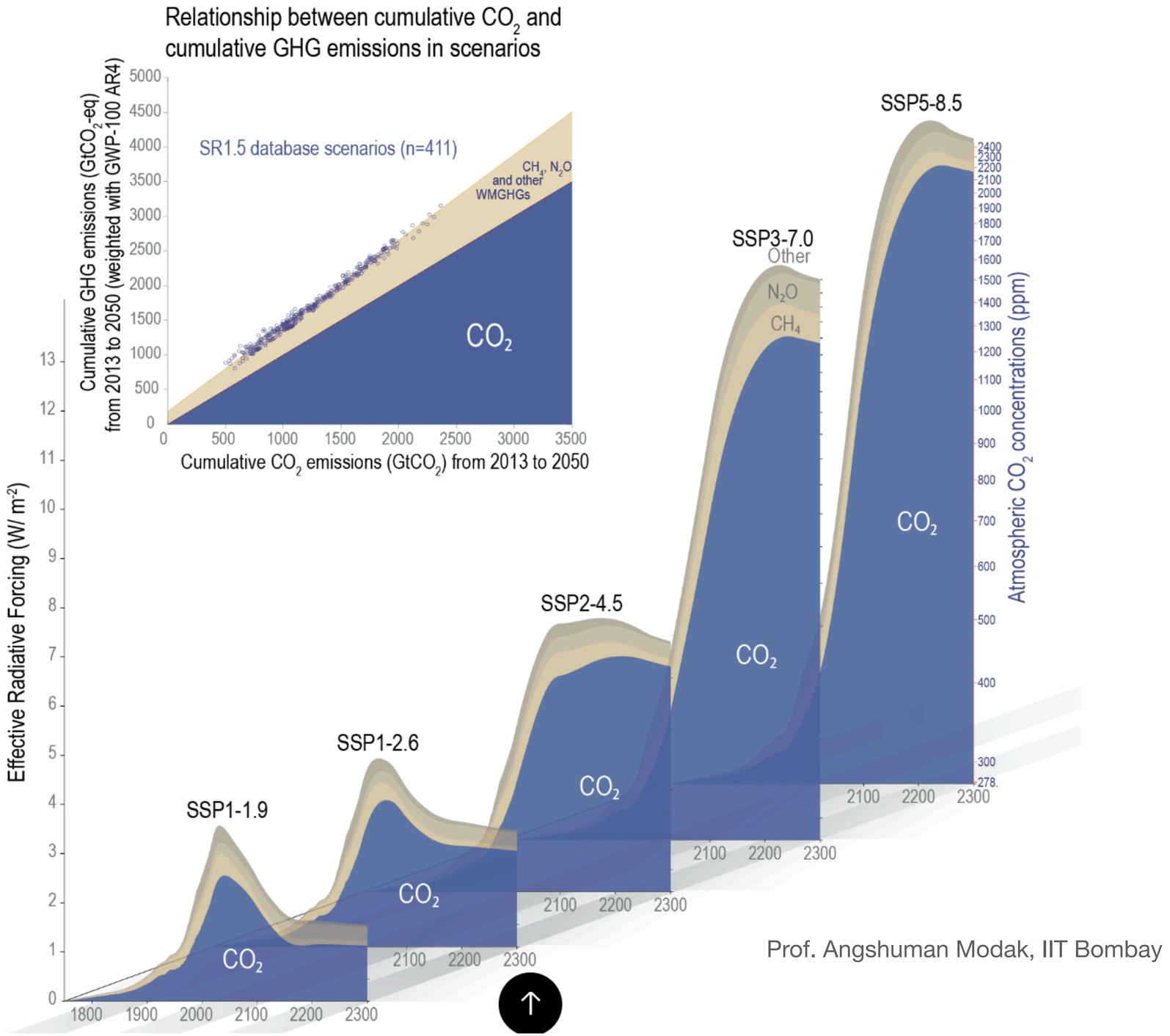


Meinshausen et al. (2020). The SSP scenarios and their five socio-economic SSP families. Shown are illustrative temperature levels relative to pre-industrial levels with historical temperatures (front light yellow band), current (2020) temperatures (white block in the middle), and branching of the respective scenarios over the 21st century along the different socio-economic SSP families.

https://climatedata.ca/

SSP	Description	Radiative Forcing (2100)	Example Policy Assumptions
SSP1 (Sustainability – "Green Road")	Rapid shift to clean energy, global cooperation, and environmental sustainability.	1.9 W/m²	Net-zero CO_2 by ~2050 (1.5°C target).
SSP2 (Middle of the Road)	Business-as-usual development with moderate progress on sustainability.	2.6 W/m²	Strong mitigation, likely below 2°C.
SSP3 (Regional Rivalry – "Rocky Road")	Nationalist policies, slow economic growth, and high fossil fuel dependence.	4.5 W/m²	Intermediate emissions (business-as-usual).
SSP4 (Inequality – "A Road of Divides")	High inequality, rapid technological progress for elites, and slow global mitigation efforts.	7.0 W/m²	High emissions, regional conflicts.
SSP5 (Fossil-Fueled Development – "Taking the Highway")	Strong economic growth, high fossil fuel use, and delayed climate policies.	8.5 W/m²	Extreme fossil fuel use, no mitigation.



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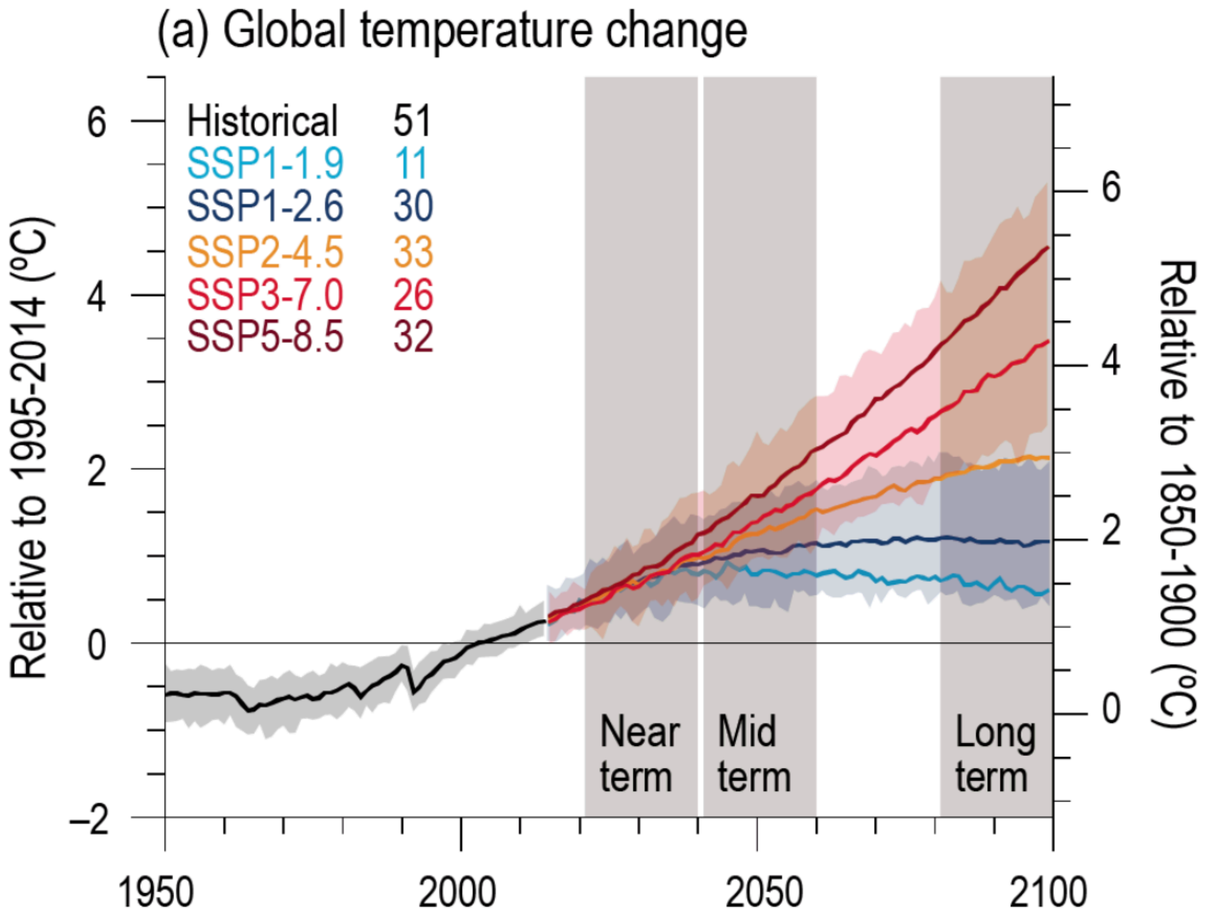
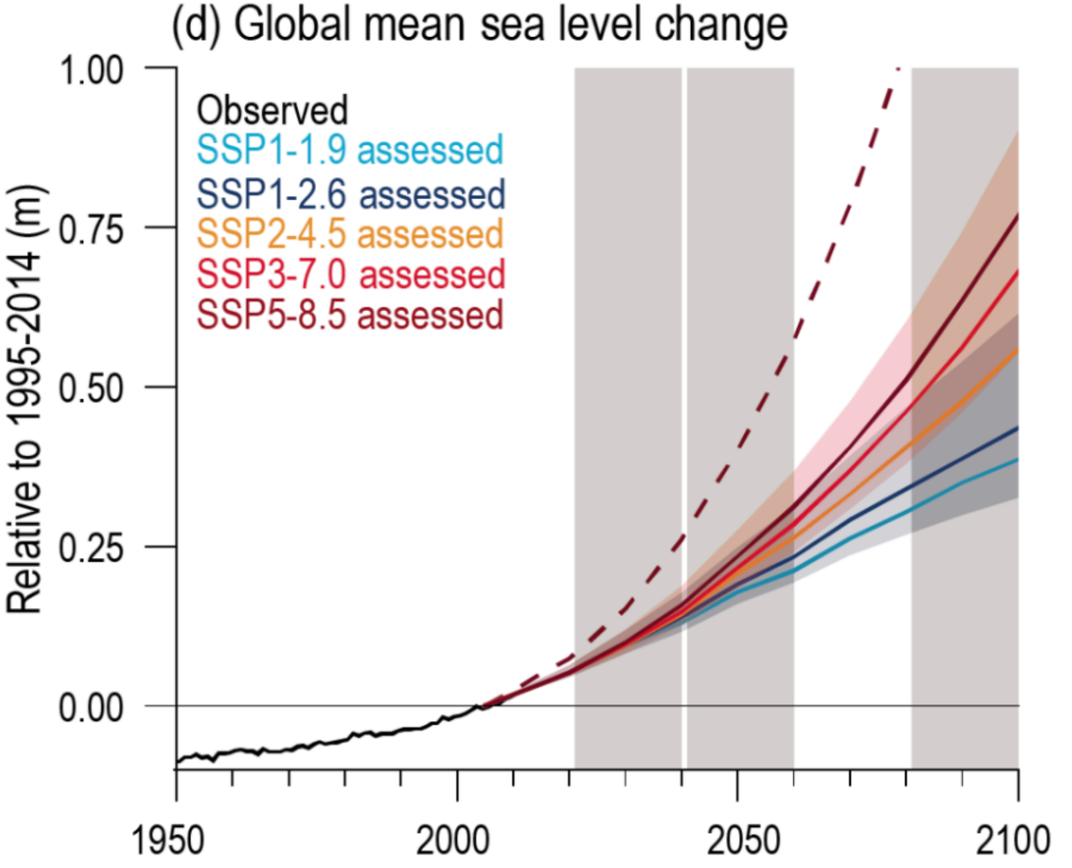
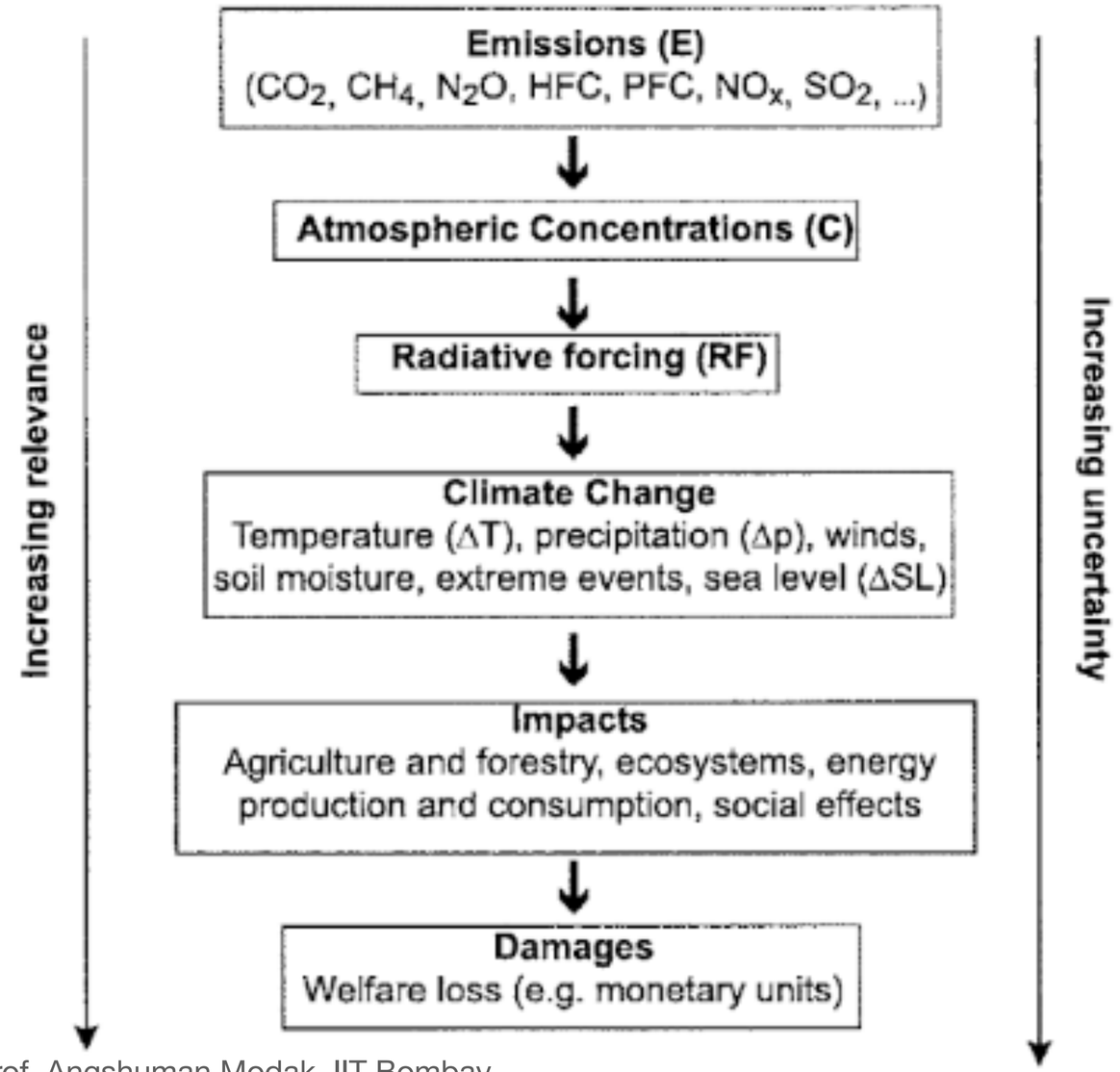

(a) Global temperature change
Historical 51
SSP1-1.9 11
SSP1-2.6 30
SSP2-4.5 33
SSP3-7.0 26
SSP5-8.5 32
Near term
Mid term
Long term
Relative to 1995-2014 (°C)
Relative to 1850-1900 (°C)
6
4
2
0
−2
1950
2000
2050
2100


(d) Global mean sea level change
Observed
SSP1-1.9 assessed
SSP1-2.6 assessed
SSP2-4.5 assessed
SSP3-7.0 assessed
SSP5-8.5 assessed
Relative to 1995-2014 (m)
1.00
0.75
0.50
0.25
0.00
1950
2000
2050
2100

Concept of emission metrics

The cause-effect chain



Emission metric is a simplified expression that describes the relationship between the emissions (cause) and any of its consequent effect.

It is desirable to link emissions to effects that occur later in the chain as they become more relevant. However, the calculations become more complex and incorporate higher uncertainties.

Class Quiz

- What is radiative forcing?
- Name an emission metric.
- Define GWP.

Global Warming Potential (GWP)

An emission metric representing climate impact by linking emissions to the radiative forcing for a particular pollutant. It is a relative metric that quantifies the climate impact of a pollutant with respect to CO_2.

Definition:

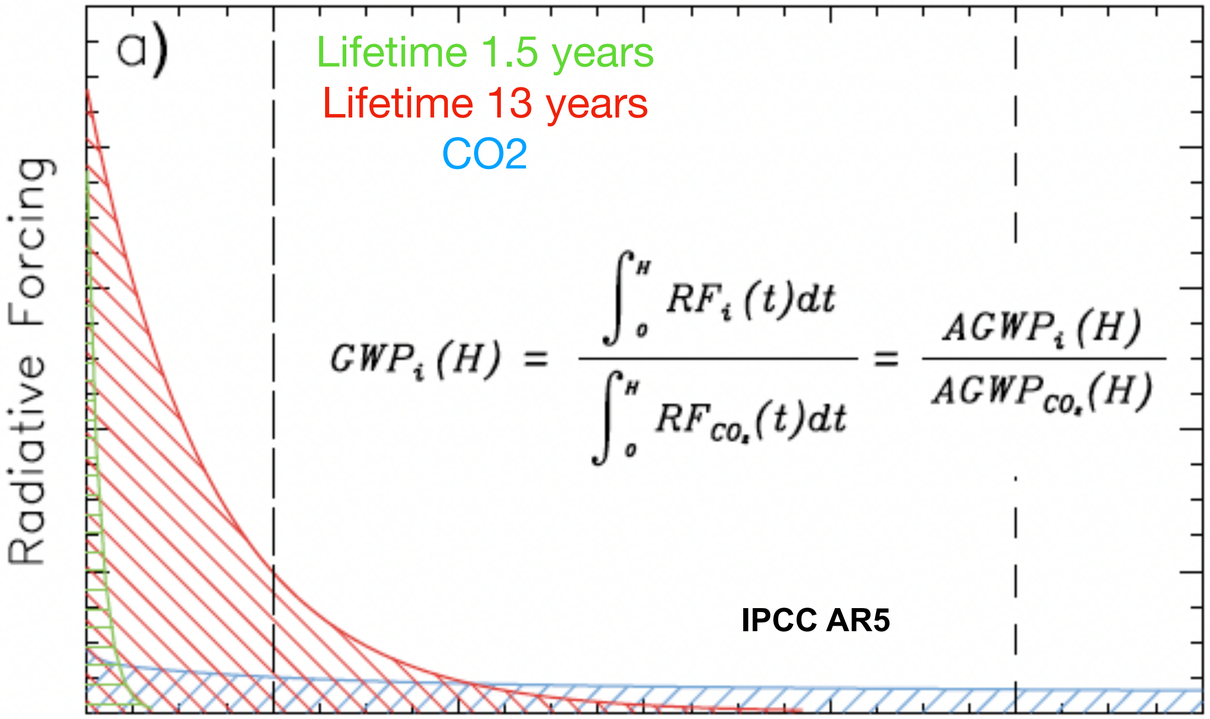
It is defined as the time-integrated radiative forcing over a specific time horizon of an emission pulse of a forcer, divided by the time-integrated radiative forcing over the same time horizon of an emission pulse of CO_2 of equal size (by weight).

Expression:

$$GWP(T)_i = \frac{\int_0^T RF_i(t)dt}{\int_0^T RF_{CO_2}(t)dt} = \frac{\int_0^T a_i c_i(t)dt}{\int_0^T a_{CO_2} c_{CO_2}(t)dt} = \frac{AGWP_i}{AGWP_{CO_2}}$$

T = time horizon (years) ;
i = pollutant;
a = radiative forcing per unit increase in concentration of the pollutant (Wm^{-2} $ppmv^{-1}$) ,
c = time decaying abundance of pulses of the pollutant (ppmv).
RF = radiative forcing ($W\ m^{-2}$)
AGWP = Absolute Global Warming Potential ($Joules\ m^{-2}$)

Global Warming Potential (GWP)

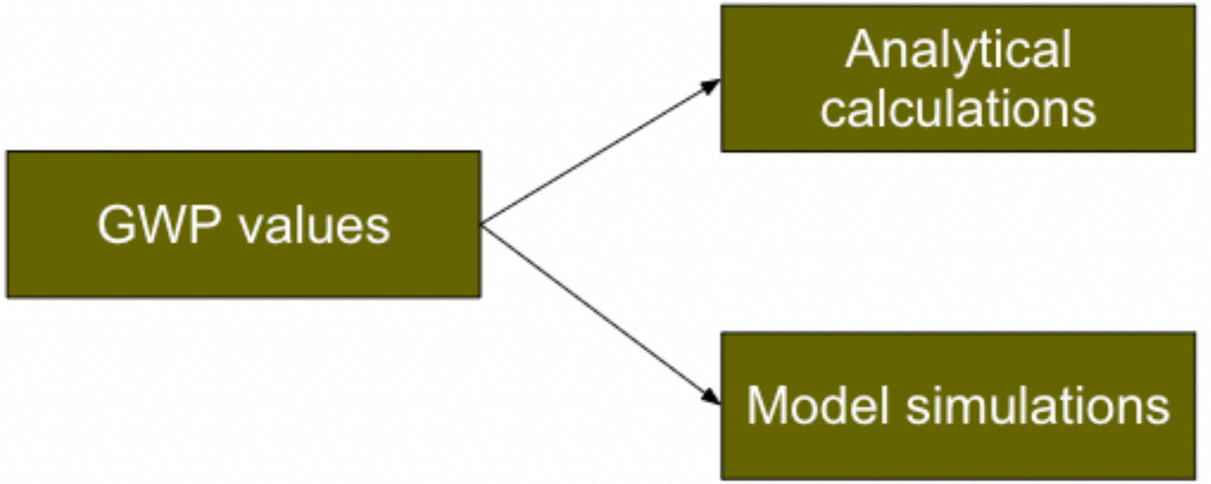


- A direct interpretation is that the GWP is an index of the total energy added to the climate system by a component in question relative to that added by CO2. However, the GWP does not lead to equivalence with temperature or other climate variables

- GWP may be somewhat misleading, and 'relative cumulative forcing index' would be more appropriate. It

- For pollutants with shorter lifetimes the numerator decreases at a faster rate as compared to that for long-lived species.
- Thus, at longer time horizons, the metric tends to reduces the emphasis of short-lived climate forcers

Estimates of GWP



By using the mathematical expressions time decaying abundances of pollutants and radiative forcing

By running earth system models with pulse emissions of pollutants

IPCC AR-5

	GWP 20	GWP 100
BC	2421.1	658.6
OC	-244.1	-66.4
SO2	-141.1	-38.4
CO	5.9	1.9
CH4	83.9	28.5
NOx	16.7	-10.8

- A choice of time horizon depend on the type of undesirable changes that are of greatest concern built on knowledge about impacts, thresholds and vulnerability and how this depends on level and rate of change.
- To simply put, GWP-100 for BC = 658.6 means it unit emission of BC will cause 658.6 times the radiative forcing as that of CO_2 over 100 years.

Application of GWP

Besides quantifying climate impacts, a primary application is to convert the emissions of all pollutants into a single unit -> **CO_2 – equivalent** (CO_2-e) for direct comparisons of different technologies, sources or scenarios of emissions.

Sector	BC Emissions (Gg/yr)	OC Emissions (Gg/yr)	SO_2 Emissions (Gg/yr)	CO Emissions (Gg/yr)	CH_4 Emissions (Gg/yr)	NO_x Emissions (Gg/yr)
Thermal Power Plants	6	20	3643	754	1671	2271
Residential	577	1168	206	38124	2790	801

$$CO_{2-eq} = \sum E_i \times GWP_i$$

Therefore, using GWP-100 values for each of the pollutant

Fuel Type	CO_2 - eq (MT/yr)
Thermal Power Plants	-113
Residential	438

Thus, thermal power plants have a net negative CO_2-eq due to high emissions of SO_2 and NOx.
It means they have a net cooling effect as compared to residential sector offsetting the energy added by other sectors.

Global Temperature change Potential (GTP)

An emission metric representing climate impact by linking emissions to the temperature change for a particular pollutant.

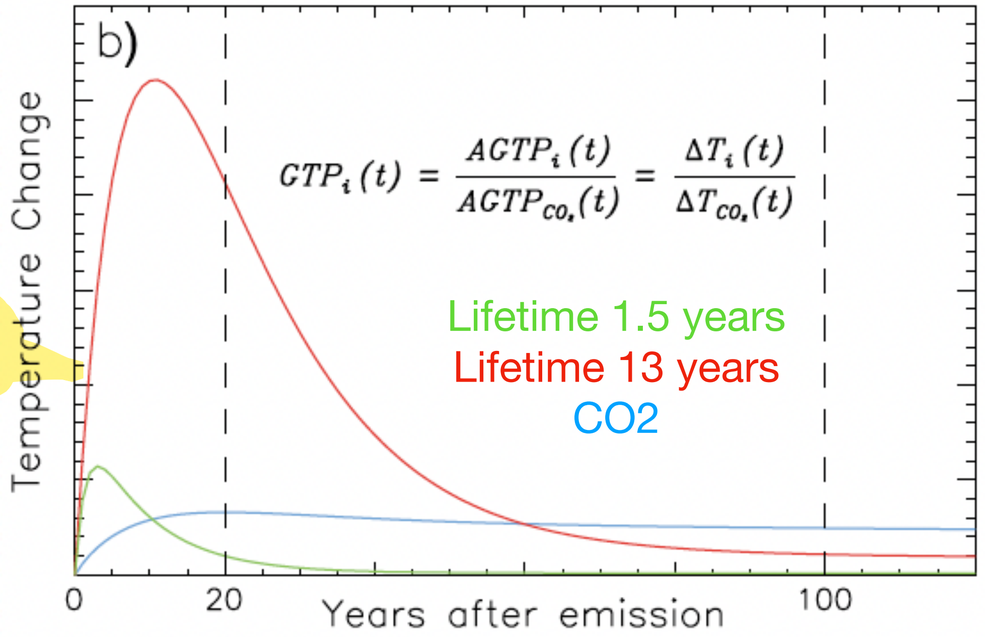
Definition:

It is defined as the temperature response after a certain time horizon of an emission pulse of a forcer, divided by the corresponding temperature response of an emission pulse of CO2 of equal weight.

Expression:

$$GTP(t)_i = \frac{AGTP_i(t)}{AGTP_{CO_2}(t)}$$

$$AGTP(t)_i = \frac{A_i}{C(\tau^{-1} - \alpha_i^{-1})}\left[\exp\left(-\frac{t}{\alpha_i}\right) - \exp\left(-\frac{t}{\tau}\right)\right]$$

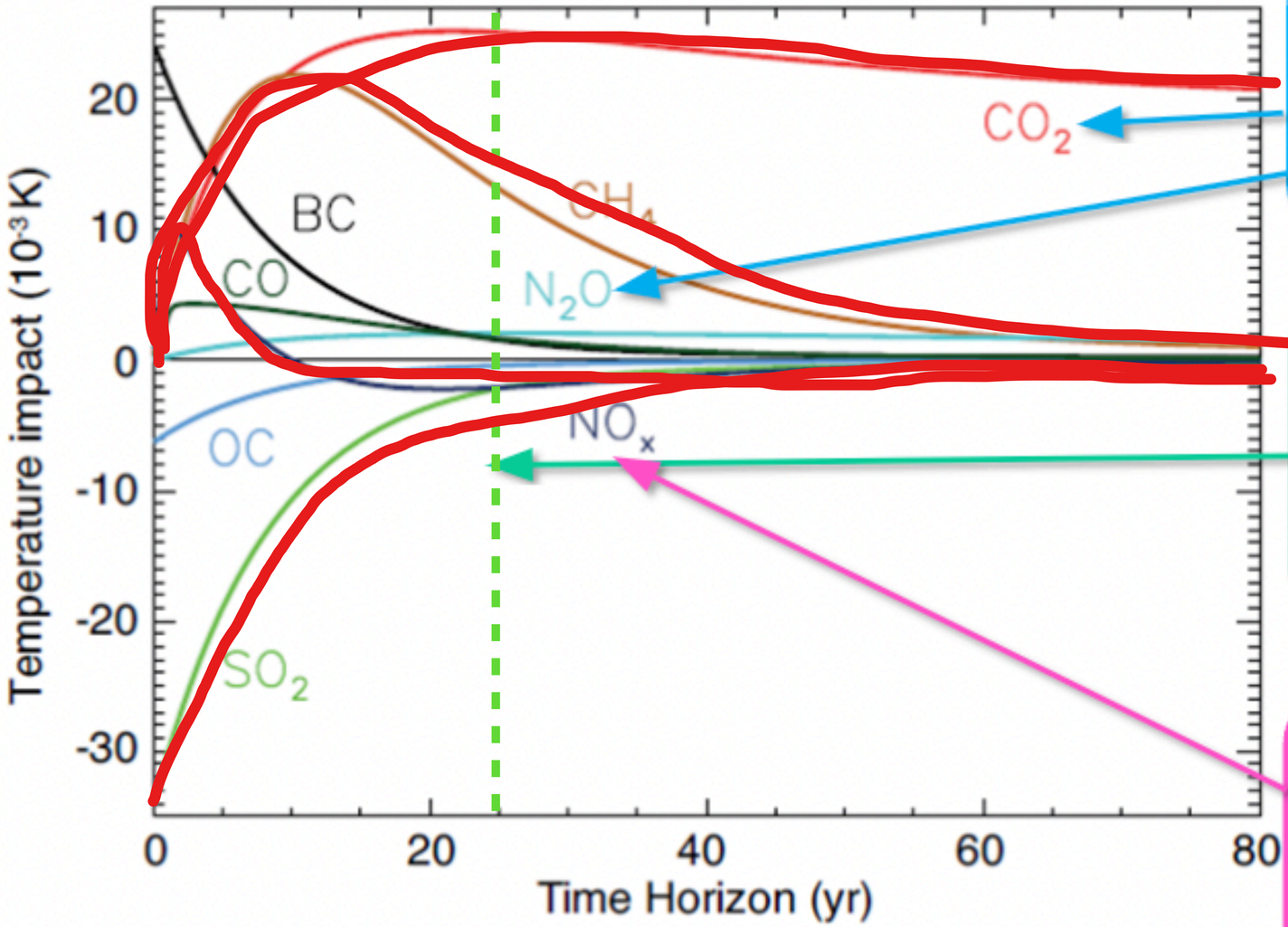


IPCC AR5

t = time (years); i = pollutant;
C = heat capacity (J K^{-1} m^{-2});
α = lifetime of pollutant (years);
τ = time constant = C × λ; (where, λ = climate sensitivity, (K (W m^{-2})$^{-1}$)
A = radiative forcing per unit increase in concentration of the pollutant (W m^{-2} $ppmv^{-1}$)
AGTP = Absolute Global Temperature change Potential (K $ppmv^{-1}$)

Evolution of impacts by species

Temperature response by pollutants after 1 year of emissions.



For long-lived GHGs the impact is weaker for 10-20 years, but persists for a century.

Short-lived forcers may exert even higher impacts than GHGs, but only within ~ 20 y after emission.

NO_x exerts both warming (in very short-term) and cooling (in near to long term).

IPCC, AR5, Ch8

Table 8.7 | GWP and GTP with and without inclusion of climate–carbon feedbacks (cc fb) in response to emissions of the indicated non-CO_2 gases (climate-carbon feedbacks in response to the reference gas CO_2 are always included).

	Lifetime (years)		GWP_{20}	GWP_{100}	GTP_{20}	GTP_{100}
CH_4[b]	12.4[a]	No cc fb	84	28	67	4
		With cc fb	86	34	70	11
HFC-134a	13.4	No cc fb	3710	1300	3050	201
		With cc fb	3790	1550	3170	530
CFC-11	45.0	No cc fb	6900	4660	6890	2340
		With cc fb	7020	5350	7080	3490
N_2O	121.0[a]	No cc fb	264	265	277	234
		With cc fb	268	298	284	297
CF_4	50,000.0	No cc fb	4880	6630	5270	8040
		With cc fb	4950	7350	5400	9560

IPCC AR5