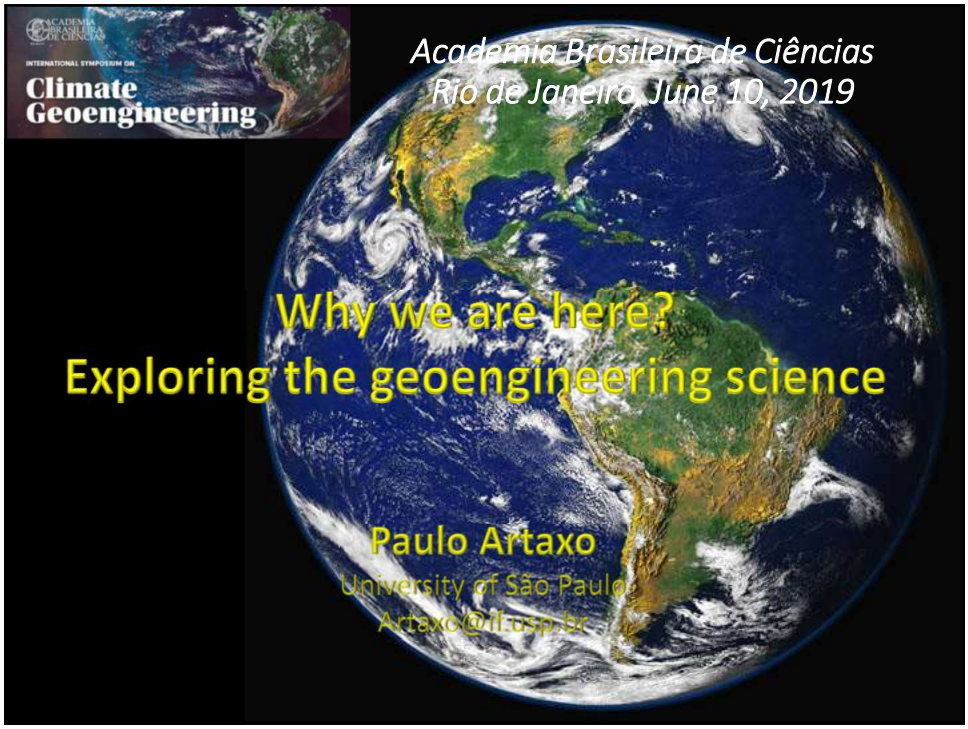
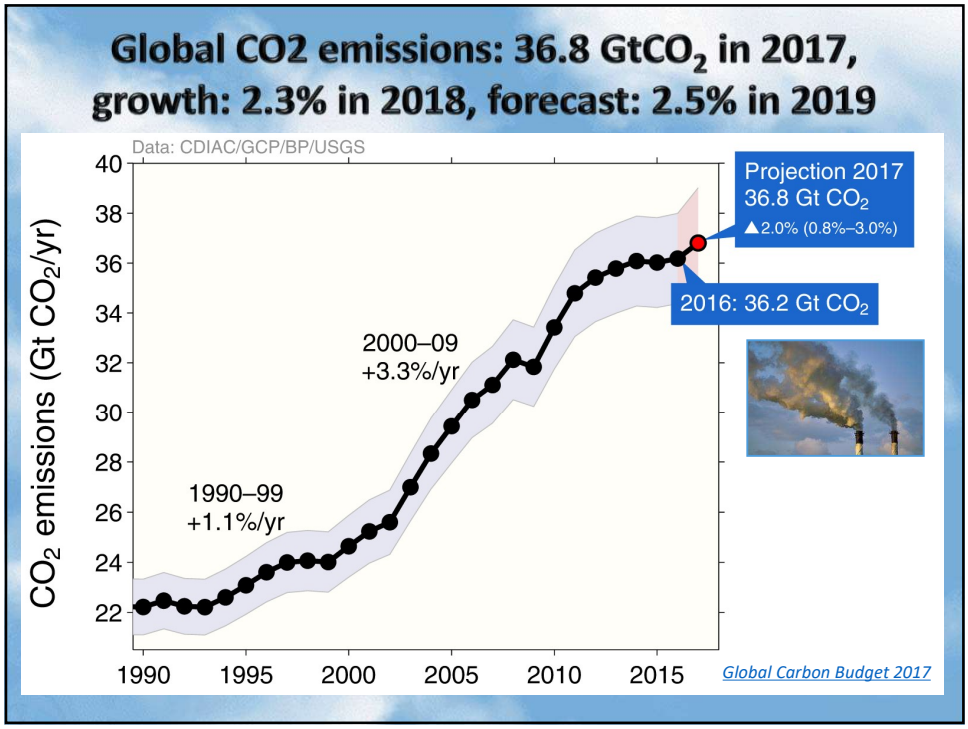

INTERNATIONAL SYMPOSIUM ON
Climate Geoengineering
Academia Brasileira de Ciências
Rio de Janeiro, June 10, 2019
Why we are here?
Exploring the geoengineering science
Paulo Artaxo
University of São Paulo
Artaxo@if.usp.br

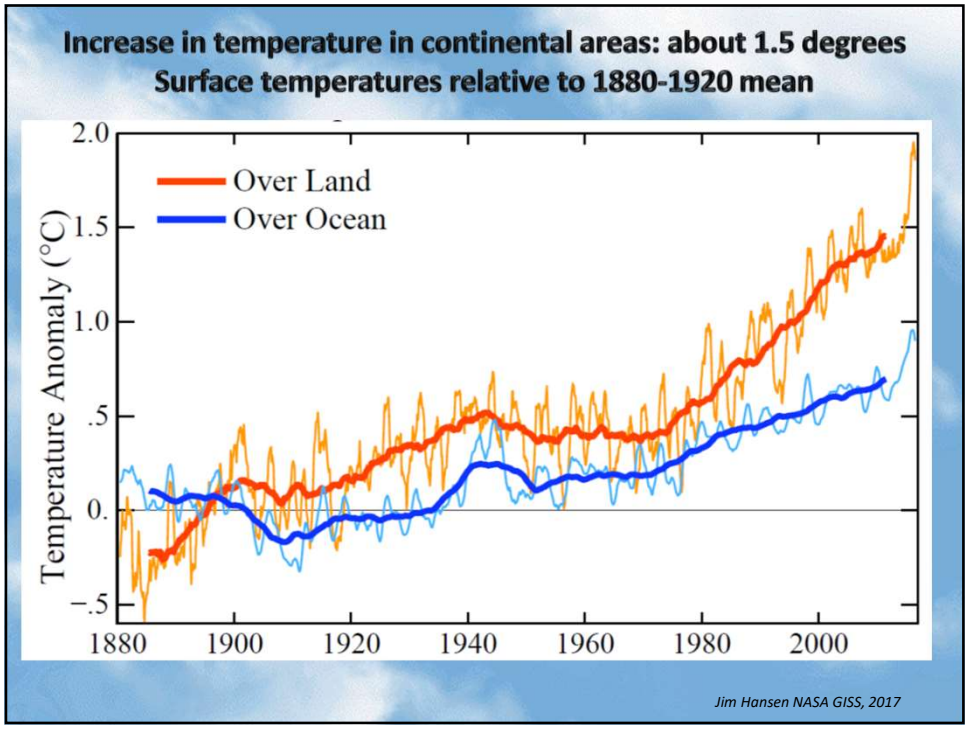
1


Climate Change Science is very solid, with hundreds of comprehensive reports
GEO6
HEALTHY PLANET HEALTHY PEOPLE
UN environment
CAMBRIDGE
STATE OF THE CLIMATE IN 2015
SPARC/IOC/GAW Report on Long-term Ozone Trends and Uncertainties in the Stratosphere
LOTUS
WCRP
ipbes
The assessment report on
LAND DEGRADATION AND RESTORATION
SUMMARY FOR POLICYMAKERS
ipbes
ipcc
CLIMATE CHANGE 2013
The Physical Science Basis
IPCC Fifth Assessment Report
Synthesis Report
ipcc
ipcc
Global Warming of 1.5°C
Summary for Policymakers
GLOBAL ENVIRONMENT OUTLOOK
GEO-6
REGIONAL ASSESSMENT FOR
LATIN AMERICA AND THE CARIBBEAN
UNEP

2

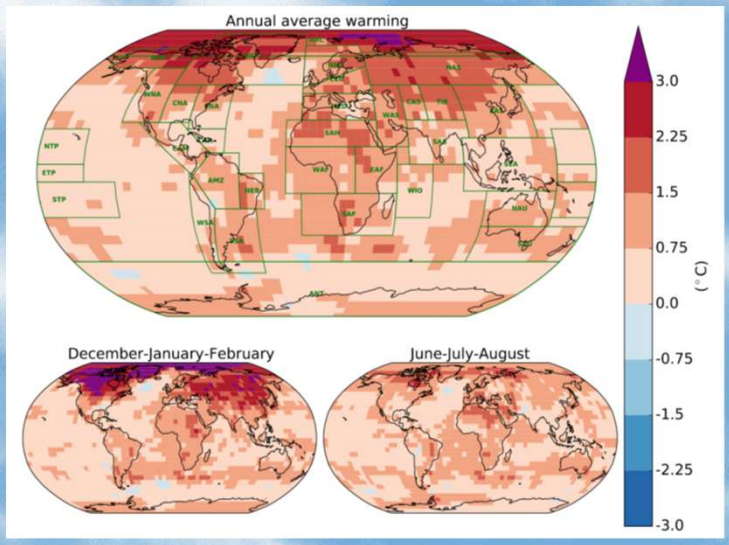

Global CO2 emissions: 36.8 GtCO2 in 2017, growth: 2.3% in 2018, forecast: 2.5% in 2019
Data: CDIAC/GCP/BP/USGS
CO2 emissions (Gt CO2/yr)
40
38
36
34
32
30
28
26
24
22
1990
1995
2000
2005
2010
2015
1990–99
+1.1%/yr
2000–09
+3.3%/yr
Projection 2017
36.8 Gt CO2
▲2.0% (0.8%–3.0%)
2016: 36.2 Gt CO2
Global Carbon Budget 2017

3


Increase in temperature in continental areas: about 1.5 degrees
Surface temperatures relative to 1880-1920 mean
Temperature Anomaly (°C)
2.0
1.5
1.0
.5
0.
−.5
Over Land
Over Ocean
1880
1900
1920
1940
1960
1980
2000
Jim Hansen NASA GISS, 2017

4

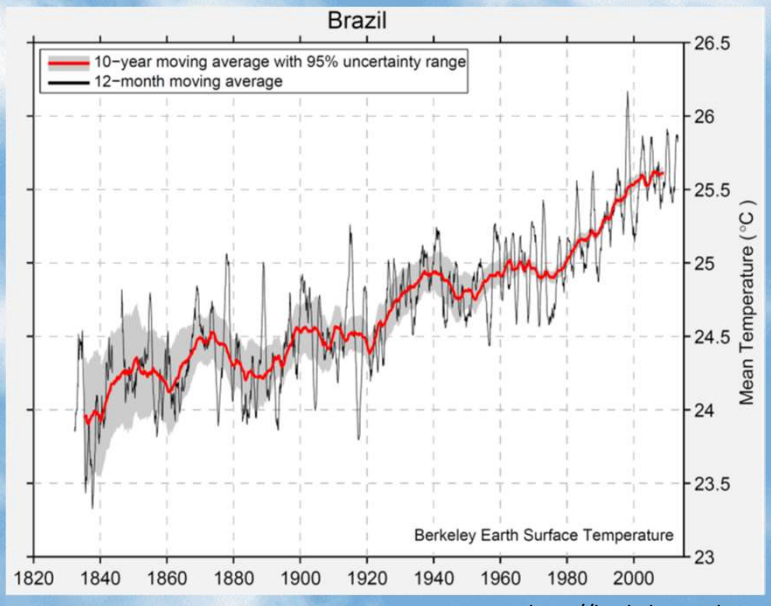
Observed increase in Temperature 1901 to 2012
Spatial distribution not homogeneous



Source: IPCC 2018 Special Report on Global Warming of 1.5°C

5

Average Temperature in Brazil

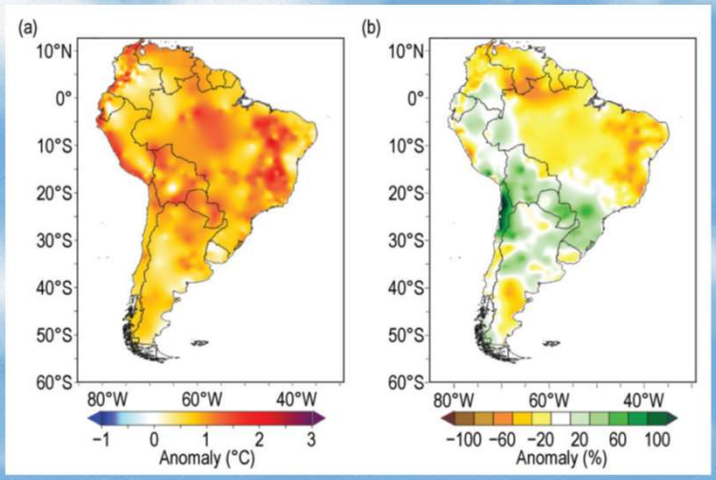


1.6 C

http://berkeleyearth.org/

6

South American (a) temperature anomalies (°C) and (b) precipitation anomalies



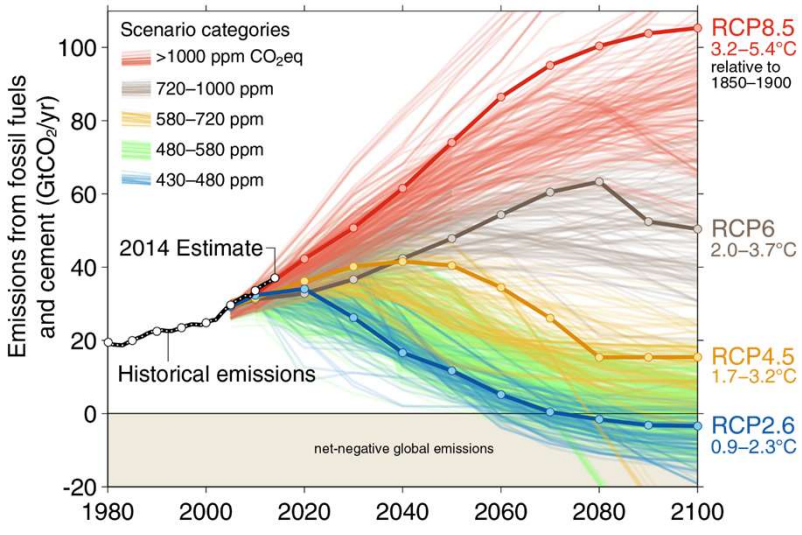
base period: 1981–2010.
Source 2016: State of the Climate in 2015, Bull. Amer. Meteor. Soc., 97 (8), 2016.

7

Emissões observadas e cenários futuros

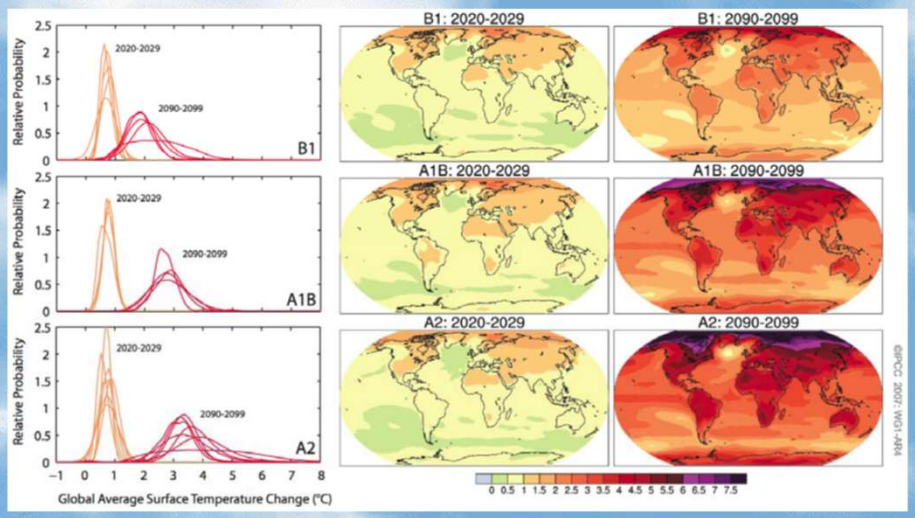
As emissões estão a caminho de um aumento de 3.2–5.4ºC acima de valores pré-industriais
Forte e contínua mitigação são necessários para a meta de 2ºC

Source: Fuss et al 2014



8

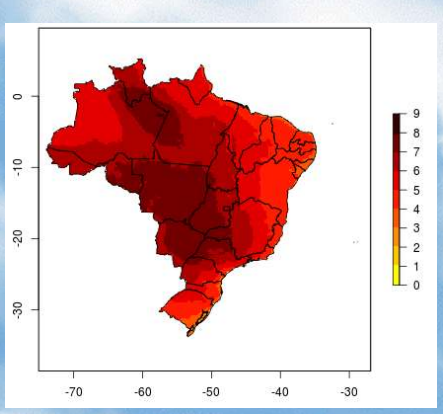
Estimates of temperature increase according to 3 emission pathways



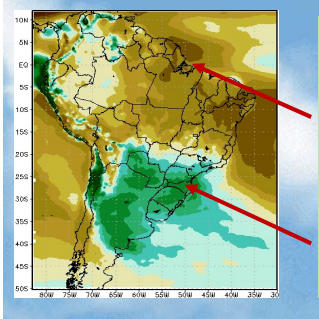
(IPCC 2013)

9

Expected increase in temperatures - Brazil 2071-2099



Changes in Precipitation expected for 2071-2100



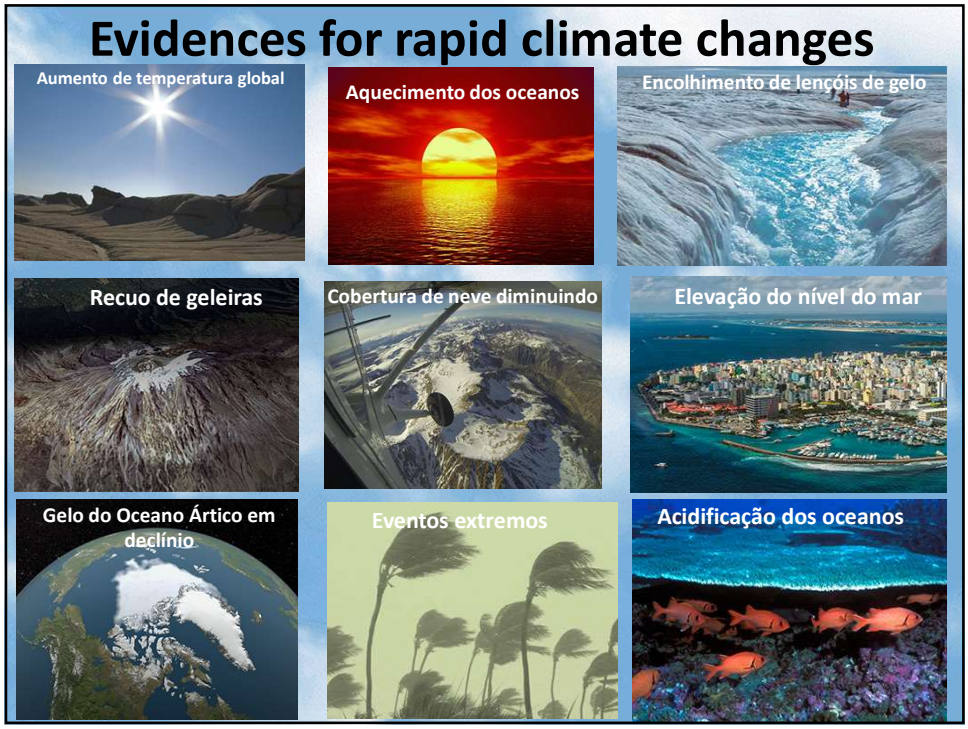
Mudanças na chuva (%) em 2071-2100 relativo a 1961-90.

Amazonia e Nordeste do Brasil → deficiência de chuvas

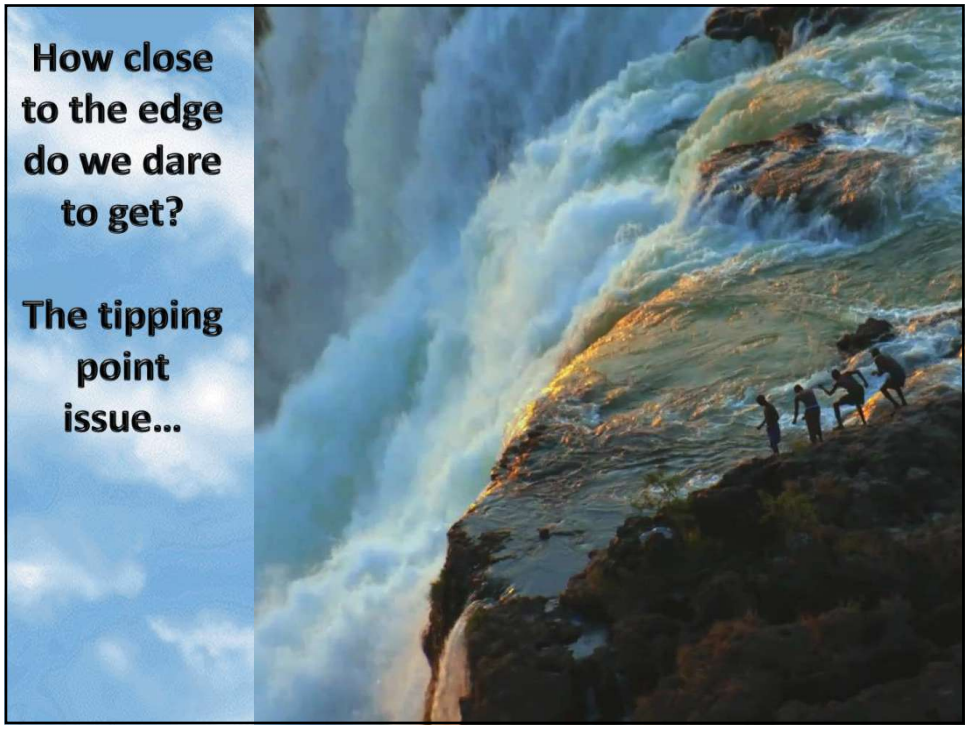
Sudeste da America do Sul → aumento nas chuvas

INPE, (RCP 8.5)

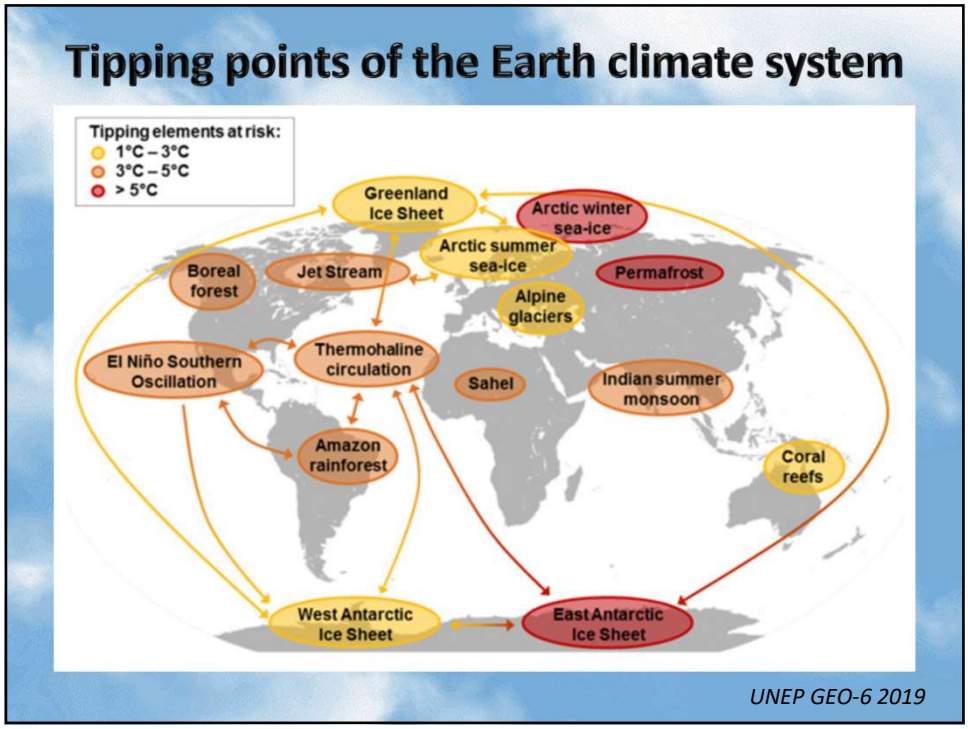
10


Evidences for rapid climate changes
Aumento de temperatura global
Aquecimento dos oceanos
Encolhimento de lençóis de gelo
Recuo de geleiras
Cobertura de neve diminuindo
Elevação do nível do mar
Gelo do Oceano Ártico em declínio
Eventos extremos
Acidificação dos oceanos

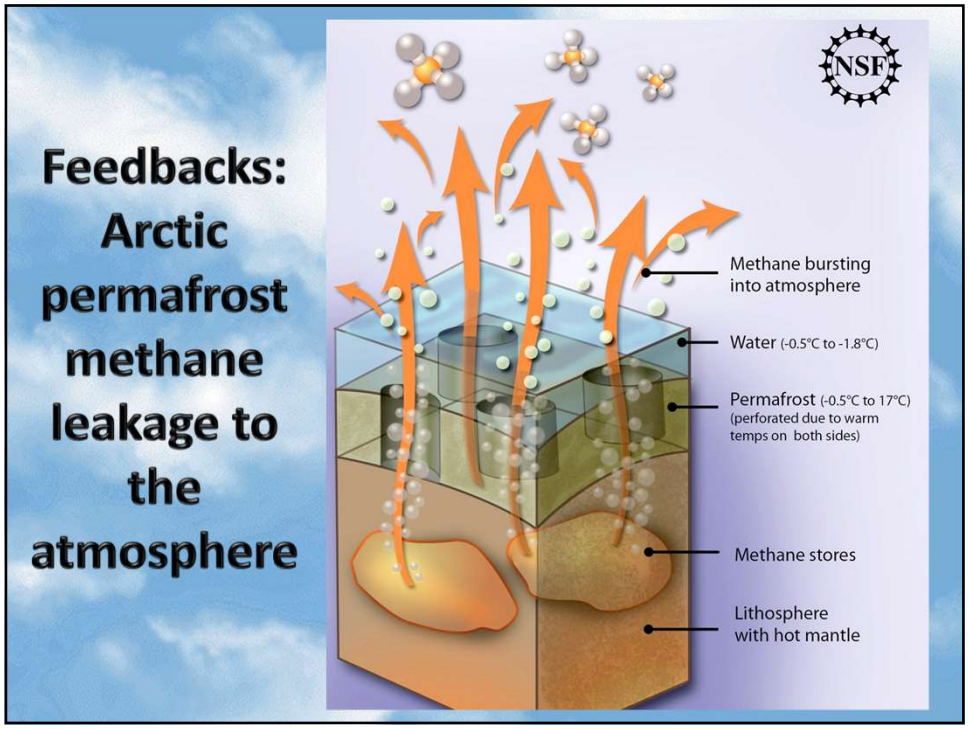
11


How close to the edge do we dare to get?
The tipping point issue...

12

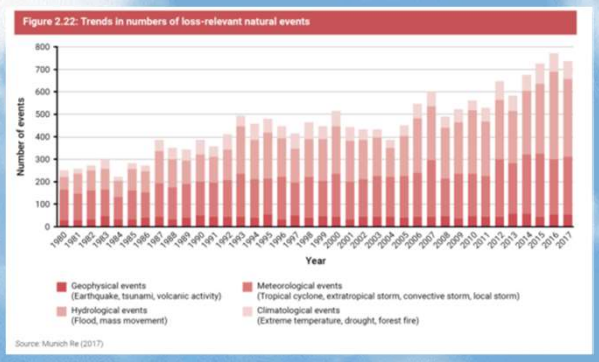

Tipping points of the Earth climate system
Tipping elements at risk:
1°C – 3°C
3°C – 5°C
> 5°C
Greenland Ice Sheet
Arctic winter sea-ice
Arctic summer sea-ice
Boreal forest
Jet Stream
Permafrost
Alpine glaciers
El Niño Southern Oscillation
Thermohaline circulation
Sahel
Indian summer monsoon
Amazon rainforest
Coral reefs
West Antarctic Ice Sheet
East Antarctic Ice Sheet
UNEP GEO-6 2019

13


Feedbacks: Arctic permafrost methane leakage to the atmosphere
NSF
Methane bursting into atmosphere
Water (-0.5°C to -1.8°C)
Permafrost (-0.5°C to 17°C)
(perforated due to warm temps on both sides)
Methane stores
Lithosphere with hot mantle

14

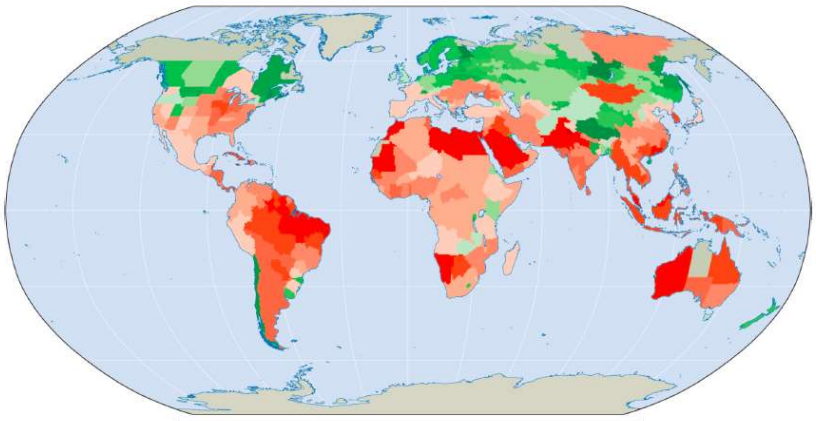
Riscos: Aumento na intensidade e frequencia de eventos climáticos extremos



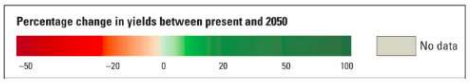
Já está ocorrendo desde a década de 80

15

Impacts on food production in a 3°C hoter world



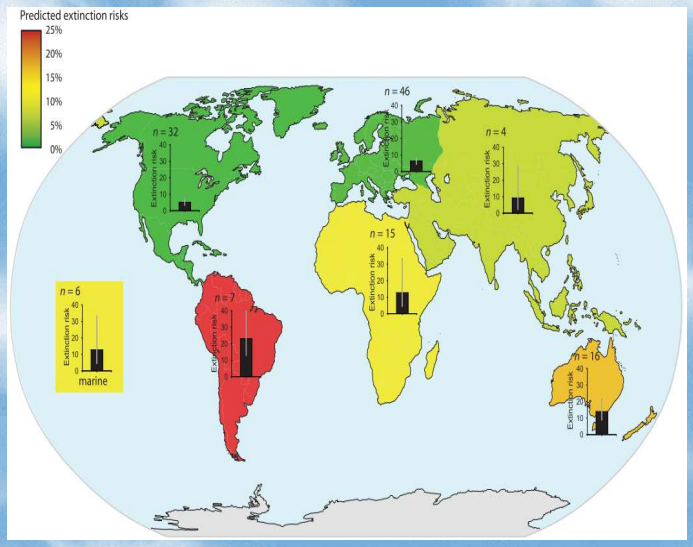
A mudança climática tem maior risco para a produtividade agrícola dos **países tropicais**



World Economic Forum: Global Risks 2016

16

Risco de perdas de espécies biológicas

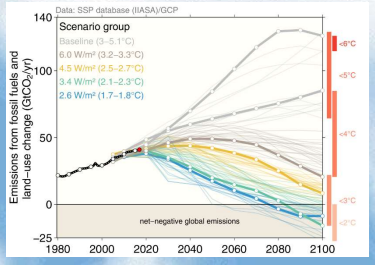


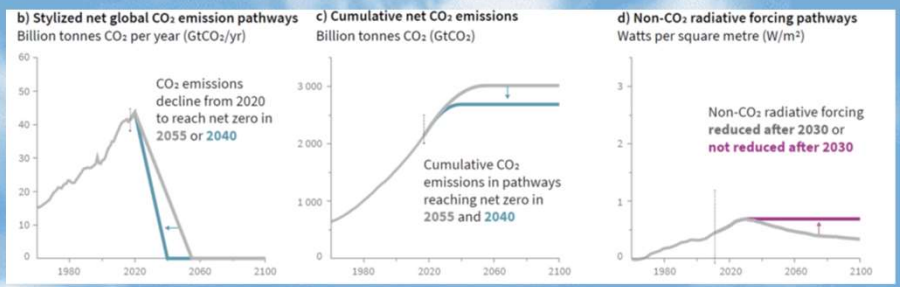
Os maiores riscos: América do Sul, Austrália (14 a 23%)

Fonte: Urban M.C-Nature, 2015

17

IPCC: Emissions reductions necessary to limit warming to 1.5 degrees





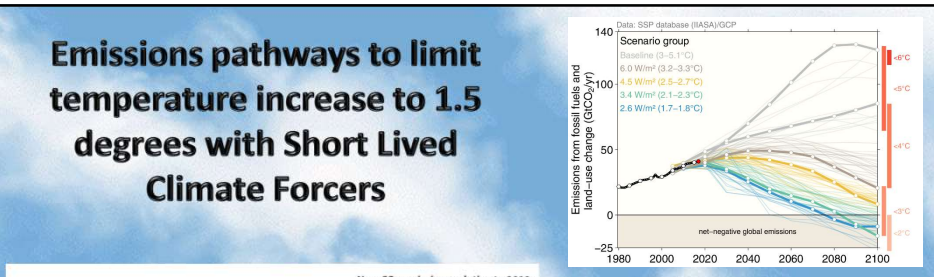
Faster immediate CO2 emission reductions limit cumulative CO2 emissions shown in panel **(c)**.

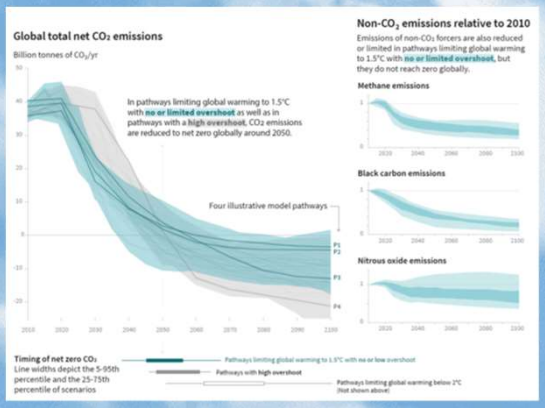
Maximum temperature rise is determined by cumulative net CO2 emissions and net non-CO2 radiative forcing due to methane, nitrous oxide, aerosols and other anthropogenic forcing agents.

Source: IPCC Special Report on Global Warming of 1.5°C

18

Emissions pathways to limit temperature increase to 1.5 degrees with Short Lived Climate Forcers





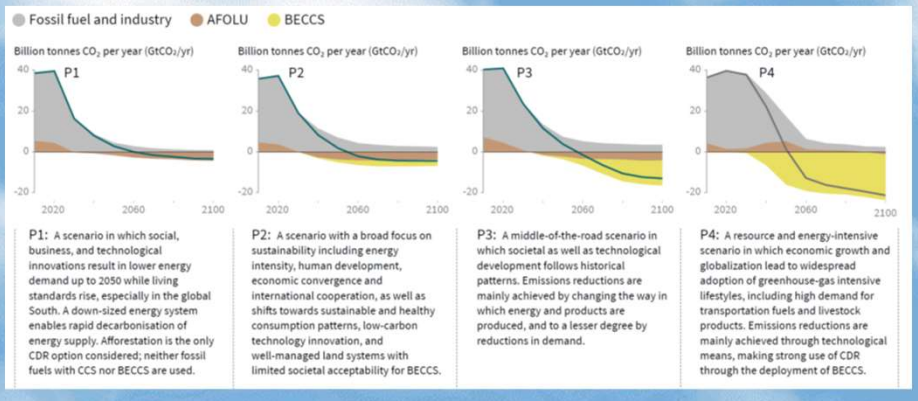
Faster immediate CO2 emission reductions (-5% per year, at 2020)

Maximum temperature rise is determined by cumulative net CO2 emissions and net non-CO2 radiative forcing due to methane, nitrous oxide, aerosols and other anthropogenic forcing agents.

Source: IPCC Special Report on Global Warming of 1.5°C

19

Net emissions for 4 possible scenarios



P1: A scenario in which social, business, and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A down-sized energy system enables rapid decarbonisation of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

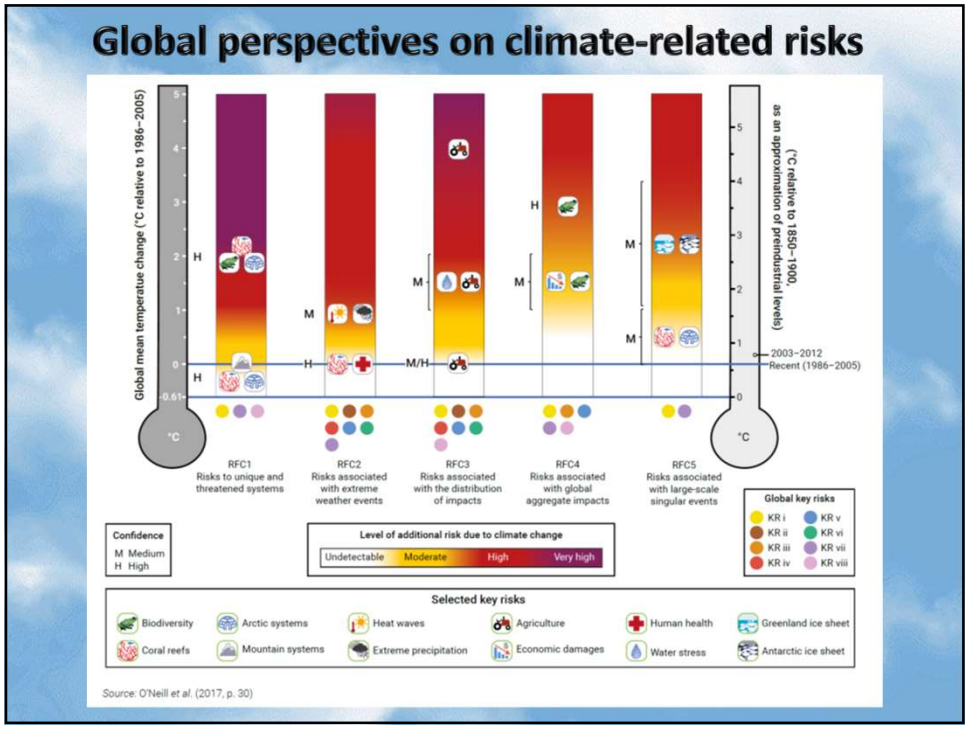
Source: IPCC Special Report on Global Warming of 1.5°C

AFOLU - Agriculture, Forestry and Other Land Use

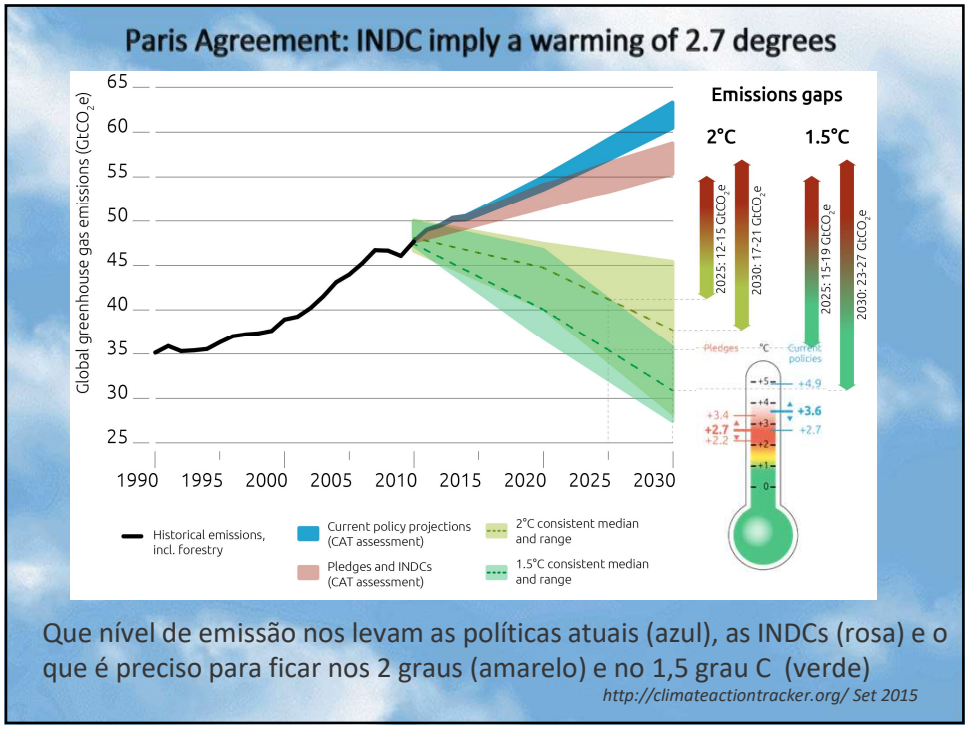
CDR - Carbon Dioxide Removal

BECCS - Bioenergy with Carbon Capture and Storage

20



21



Que nível de emissão nos levam as políticas atuais (azul), as INDCs (rosa) e o que é preciso para ficar nos 2 graus (amarelo) e no 1,5 grau C (verde)

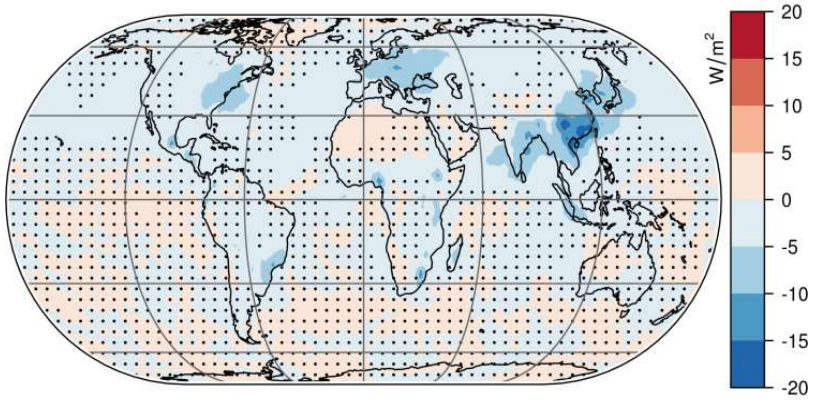
http://climateactiontracker.org/ Set 2015

22

Climate forcing from particulate air pollution

(aerosols have masked climate warming)

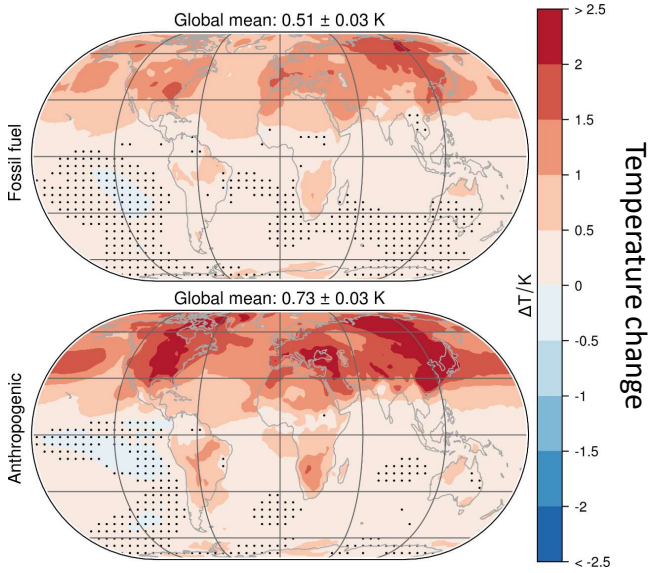
Direct + indirect aerosol radiative forcing is **–1.2 W m^{-2}**
(*net* effect of warming and cooling aerosols)



Radiative forcing of long-lived greenhouse gases is **+3.0 W m^{-2}**

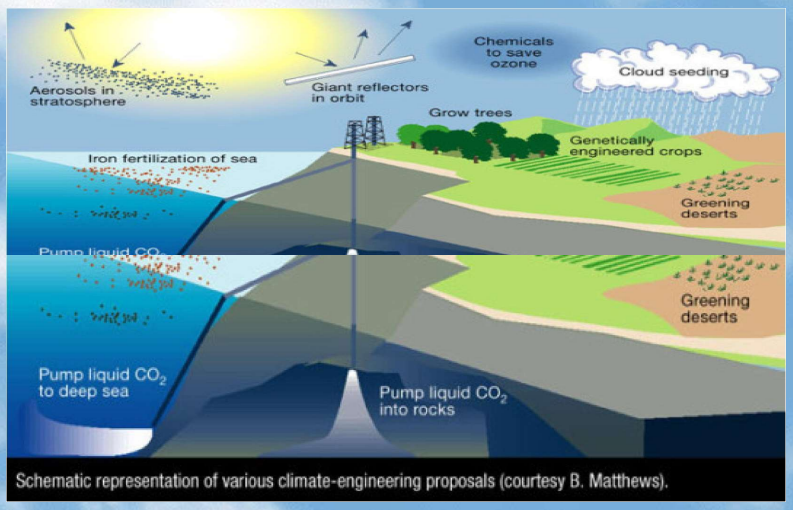
23

Temperature increase from *phase-out* of fossil fuel related and all particulate air pollution



24

Geoengineering is defined as
"deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change."



Schematic representation of various climate-engineering proposals (courtesy B. Matthews).

Shepherd, J. G. S. et al., 2009: *Geoengineering the climate: Science, governance and uncertainty*, RS Policy Document 10/09, (London: The Royal Society).

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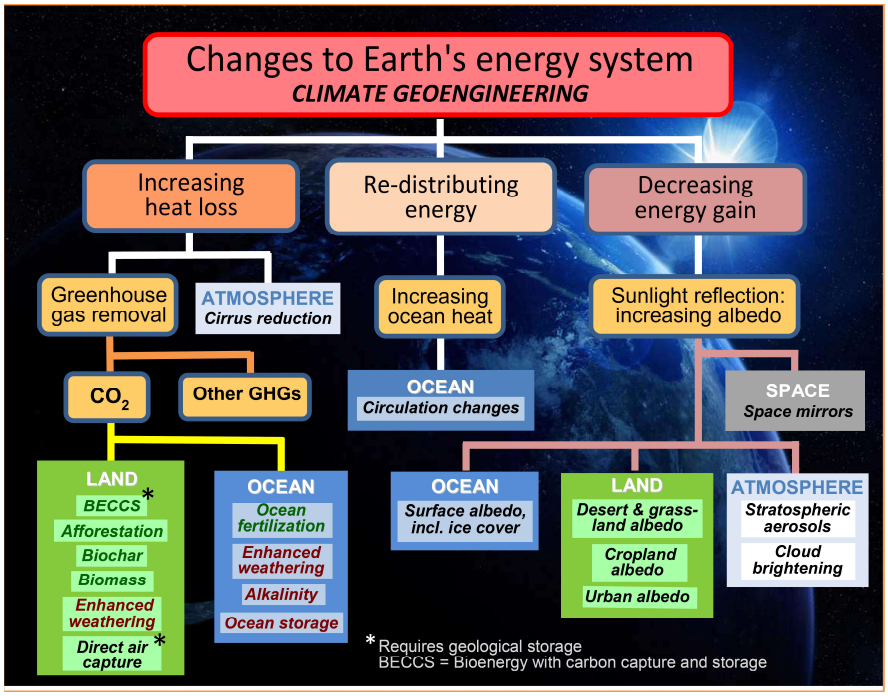
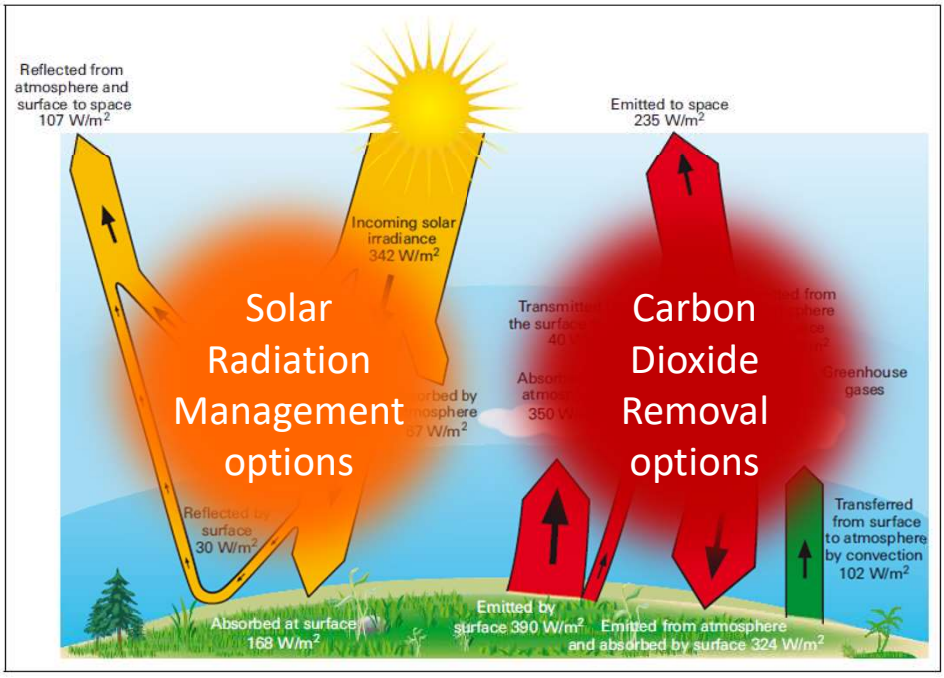


26



27

Very extensive literature…

IGBP Ambio task force

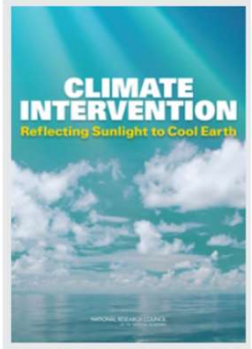
AMBIO 2012, 41:350–369
DOI 10.1007/s13280-012-0258-5

REVIEW PAPER

Ecosystem Impacts of Geoengineering: A Review for Developing a Science Plan

Lynn M. Russell, Philip J. Rasch, Georgina M. Mace, Robert B. Jackson, John Shepherd, Peter Liss, Margaret Leinen, David Schimel, Naomi E. Vaughan, Anthony C. Janetos, Philip W. Boyd, Richard J. Norby, Ken Caldeira, Joonas Merikanto, Paulo Artaxo, Jerry Melillo, M. Granger Morgan

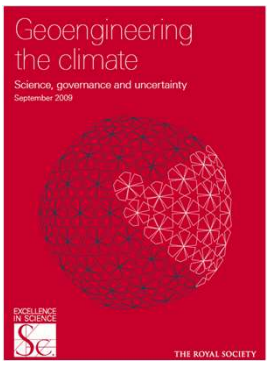
US National Academy of Sciences



Developing countries must lead on solar geoengineering research

The nations that are most vulnerable to climate change must drive discussions of modelling, ethics and governance, argue A. Atiq Rahman and colleagues.

UK Royal Society



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Governance is a critical issue

Stephen Hawking "Our planet and the human race face multiple challenges. These challenges are global and serious – climate change, food production, overpopulation, the decimation of other species, epidemic disease, acidification of the oceans. Such pressing issues will require us to collaborate, all of us, with a shared vision and cooperative endeavor to ensure that humanity can survive."

We have not yet managed to adopt a model of production capable of preserving resources for present and future generations, while limiting as much as possible the use of non-renewable resources, moderating their consumption, maximizing their efficient use, reusing and recycling them.

Governance is key:
How the necessary measure will be implemented?
Who drives and controls the implementation?

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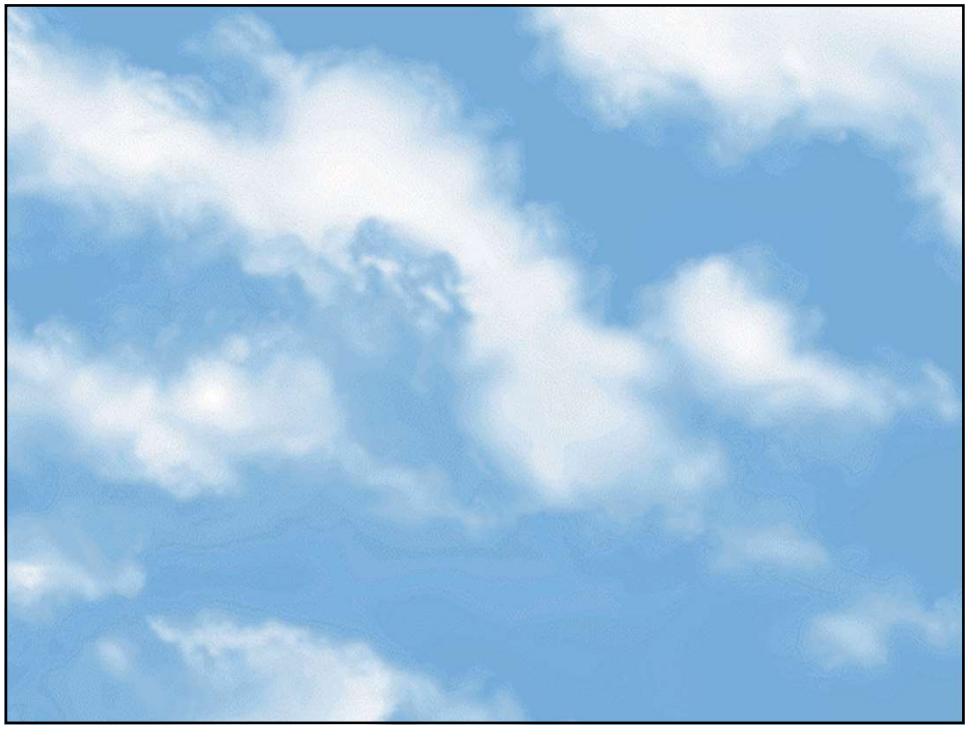

31

Geoengineering is defined as

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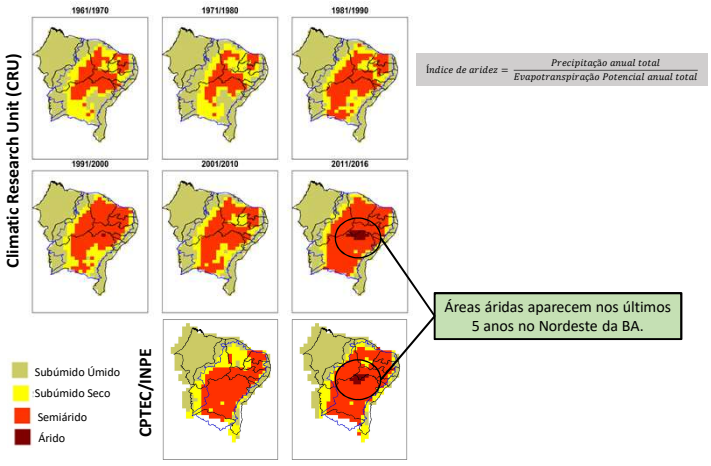
Shepherd, J. G. S. et al., 2009: *Geoengineering the climate: Science, governance and uncertainty*, RS Policy Document 10/09, (London: The Royal Society).

32

Índice de Aridez da UNEP para NEB com diferentes conjuntos de dados de chuva

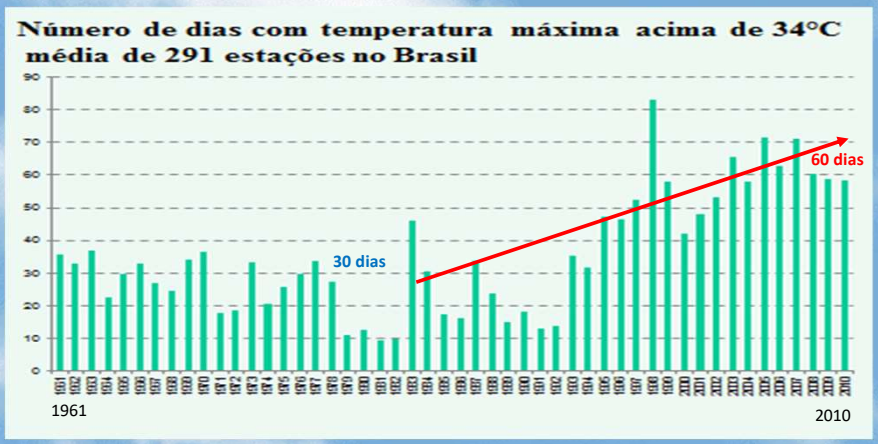


$$\text{Índice de aridez} = \frac{\text{Precipitação anual total}}{\text{Evapotranspiração Potencial anual total}}$$

Fonte: Marengo et al., 2019

33

Aumento da frequência de dias quentes com Tmax > 34 C no Brasil (1961-2010) para 291 estações meteorológicas do INMET



Fonte: EMBRAPA Informática na Agropecuária, Campinas, e CEPAGRI/UNICAMP

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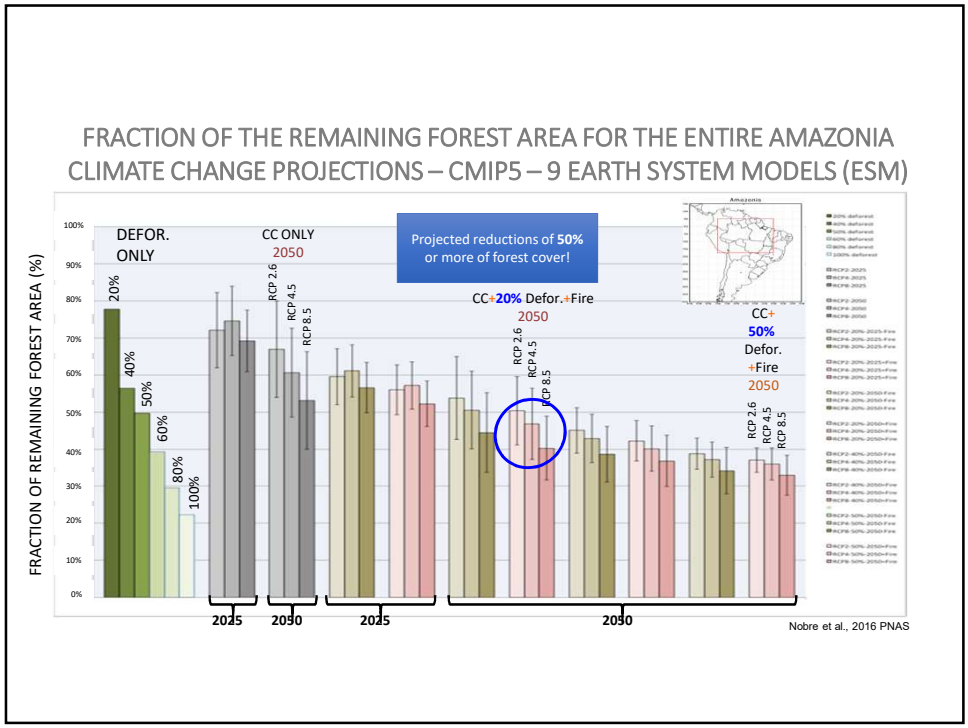
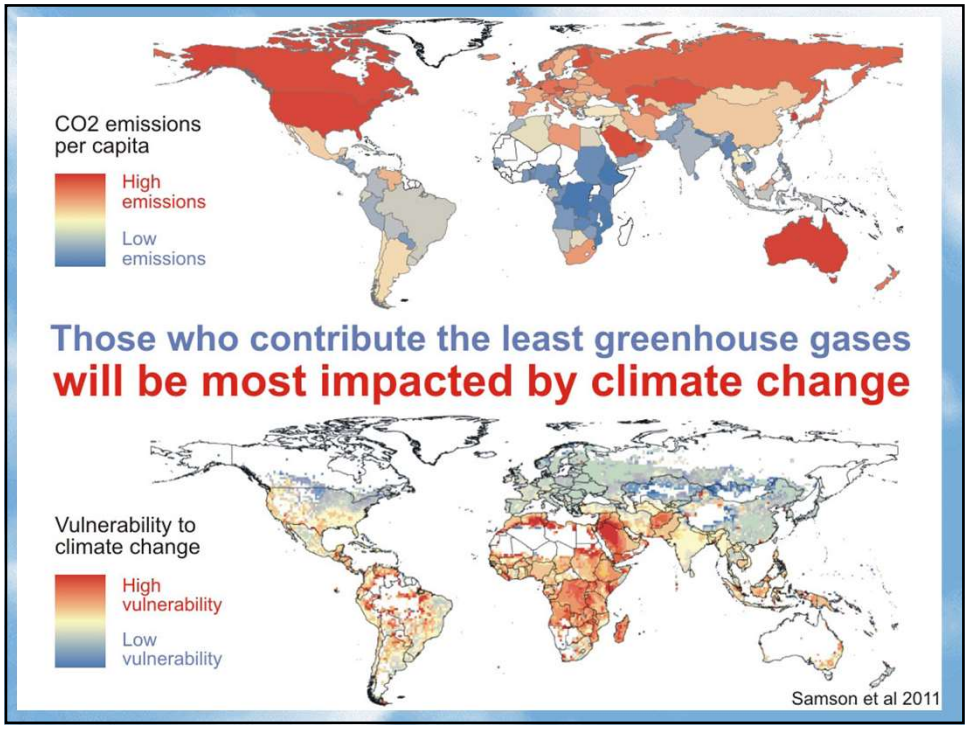
Evidências da rápida mudança climática
Aumento de temperatura global
Aquecimento dos oceanos
Encolhimento de lençóis de gelo
Recuo de geleiras
Cobertura de neve diminuindo
Elevação do nível do mar
Gelo do Oceano Ártico em declínio
Eventos extremos
Acidificação dos oceanos

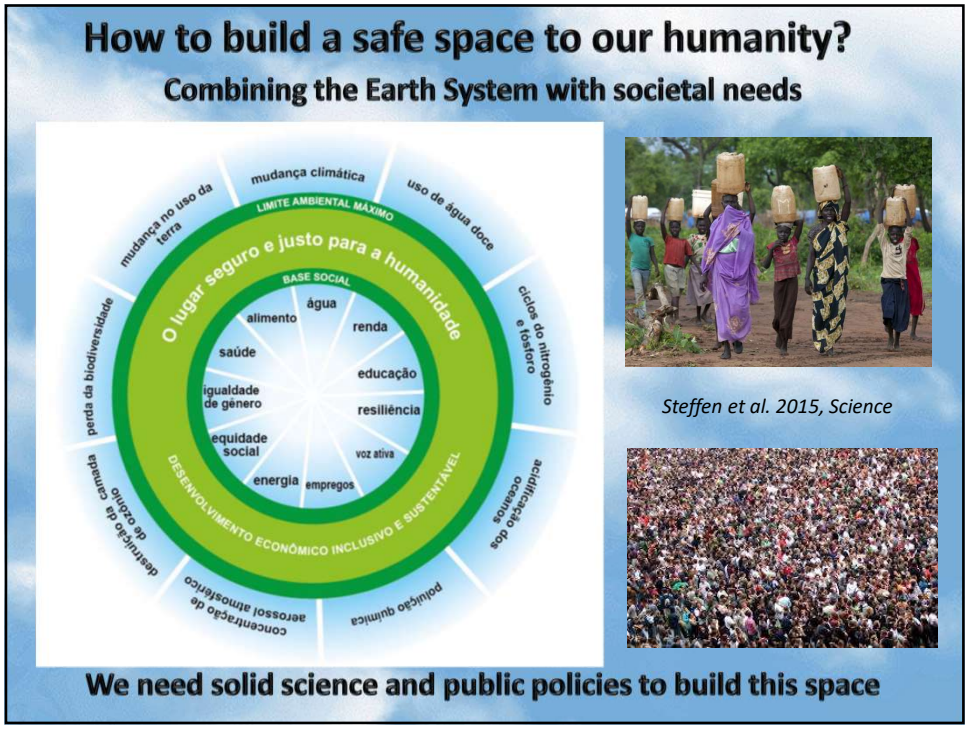
35


FRACTION OF THE REMAINING FOREST AREA FOR THE ENTIRE AMAZONIA
CLIMATE CHANGE PROJECTIONS – CMIP5 – 9 EARTH SYSTEM MODELS (ESM)
FRACTION OF REMAINING FOREST AREA (%)
DEFOR. ONLY
20%
40%
50%
60%
80%
100%
CC ONLY 2050
RCP 2.6
RCP 4.5
RCP 8.5
Projected reductions of 50% or more of forest cover!
CC+20% Defor.+Fire 2050
CC+ 50% Defor. +Fire 2050
2025
2050
2025
2050
Nobre et al., 2016 PNAS

36


CO2 emissions
per capita
High
emissions
Low
emissions
Those who contribute the least greenhouse gases
will be most impacted by climate change
Vulnerability to
climate change
High
vulnerability
Low
vulnerability
Samson et al 2011

37


How to build a safe space to our humanity?
Combining the Earth System with societal needs
mudança climática
uso de água doce
ciclos do nitrogênio e fosforo
acidificação dos oceanos
poluição química
concentração de aerossol atmosférico
destruição da camada de ozônio
perda da biodiversidade
mudança no uso da terra
LIMITE AMBIENTAL MÁXIMO
O lugar seguro e justo para a humanidade
BASE SOCIAL
água
renda
educação
resiliência
voz ativa
empregos
energia
equidade social
igualdade de gênero
saúde
alimento
DESENVOLVIMENTO ECONÔMICO INCLUSIVO E SUSTENTÁVEL
Steffen et al. 2015, Science
We need solid science and public policies to build this space

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