HONR 229L: Climate Change: Science, Economics, and Governance

Discussion #9: Climate Models: Perspective of a Physical Scientist

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Class Web Site: http://www.atmos.umd.edu/~rjs/class/honr229L

ELMS Page: https://myelms.umd.edu/courses/1269254

1 October 2019

HONR 229L: Climate Change: Science, Economics, and Governance

AT 8, Q1: The reading states "Climate is the average of weather" and includes a sentence that likely seems preposterous to many:

> Projecting changes in climate due to changes in greenhouse gases 50 years from now is a very different and much more easily solved problem than forecasting weather patterns just weeks from now.

The field of actuarial science can be viewed as being analogous to the field of climate prediction: an actuary studies the life expectancy of large groups of people, allowing insurance companies to thrive financially even though they will likely pay out a benefit of some sort upon the passing of everyone they insure.

Some contend that "actuarial science is to trying to predict when a specific person will pass away" as "climate science is to trying to predict the weather next month at a specific location such as College Park".

State whether you agree or disagree with this contention, and support your answer with a few sentences.

I believe that trying to predict climate 50 years from now will have a lot of error, as does predicting weather patterns weeks from now. Climate scientists can do their best to model temperature changes and make predictions of what vegetative cover would look like, but this is a *hard task because massive shifts in climate/ ecology will be made based on the [changes in precipitation that are very hard to accurately forecast].*

A climate model tries to show different alternatives based on different routes that we could globally take, but there is *no way to accurately predict human behavior* and *how environmentally friendly big corporations could become.*

The same goes for weather patterns, since we are living in an era of climate change, weather starts becoming more intense and unpredictable. For example, Maryland could have and has had it be sunny, rainy, hail, and snow all in the same day.

HONR 229L: Climate Change: Science, Economics, and Governance

AT 8, Q2: State: a) the most important and abundant GHG in the atmosphere
b) the most important anthropogenic GHG
c) the second most important anthropogenic GHG
d) the third most important anthropogenic GHG

Answers to b) – d) should be based on the magnitude of increase in the RF of climate, between 1750 and 2005

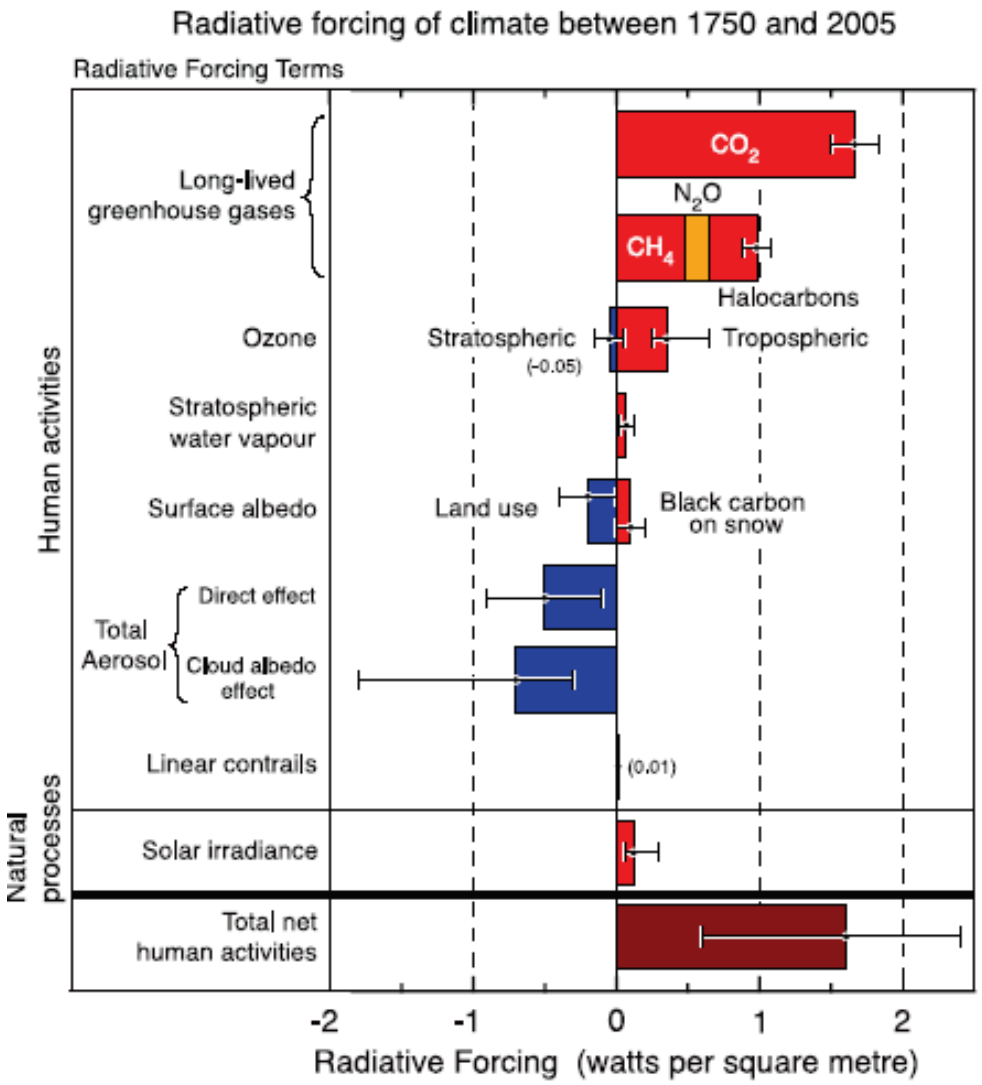
For one anthropogenic GHGs, explain how it is known that the increase in the abundance of this gas, since the start of the industrial revolution, is caused by human activity.

a) H_2O (water vapor) ⇦ **responds to human influence, but only indirectly in that a warmer atmosphere holds more water vapor**

b) CO_2 (carbon dioxide)

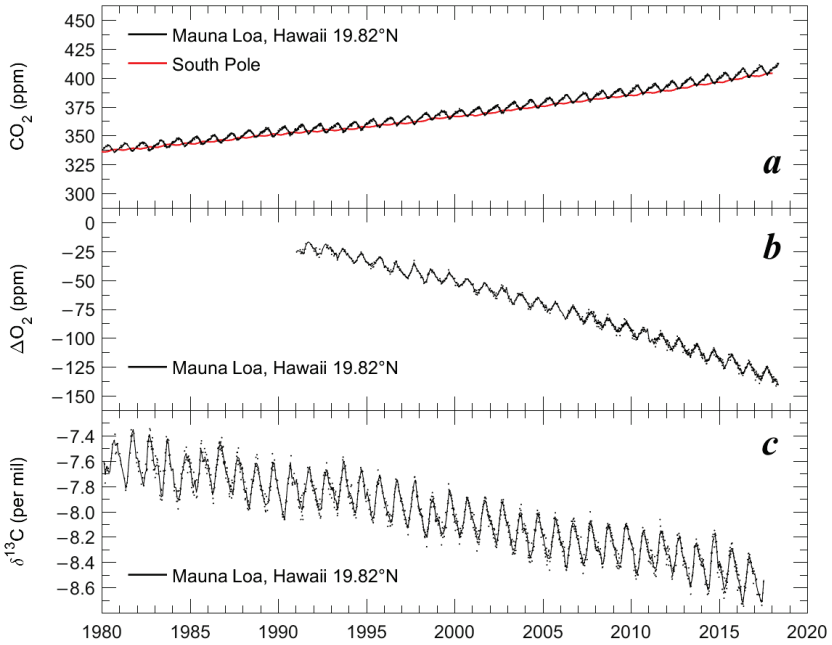
c) CH_4 (methane)

d) Hmmm … could be either N_2O (nitrous oxide), O_3 (ozone), or CFCs (halocarbons)



FAQ 2.1, Figure 2. *Summary of the principal components of the radiative forcing of climate change.*

Human fingerprint on rising CO_2



Update to Fig 1.7, Salawitch *et al.*, Paris Climate Agreement: Beacon of Hope, 2017

Combustion reactions:

$$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O + \text{heat}$$

$$2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O + \text{heat}$$

We know that CO_2 is anthropogenic for a variety of reasons. The first is that the *isotopic ratio of carbon atoms* in the atmosphere is *becoming lighter*. This is a signature of carbon that arises from biological processes because biological chemical reactions occur slightly faster when using lighter isotopes. This means that fossil fuels, which are derived from long dead organisms, when burned, disproportionately add lighter carbon isotopes to the atmosphere when compared to geological CO_2 contributors. Furthermore, the *concentration of oxygen in the atmosphere is decreasing very slightly at a rate that is roughly consistent with the addition of CO_2 to the atmosphere*. This indicates that the CO_2 being added to the atmosphere is coming from combustion reactions, thereby consuming some atmospheric oxygen in the process.

Carbon Tech On The Hill




- Erin Burns, Carbon180 https://carbon180.org
- Dr. Marcius Extavour, NRG COSIA Carbon XPRIZE https://carbon.xprize.org/prizes/carbon
- Roxanne Brown, United Steelworkers https://m.usw.org/union/leaders/international-executive-board/roxanne-brown
- John Litynski, Advanced Fossil Technology Systems, Department of Energy https://www.netl.doe.gov/coal/carbon-capture

Carbon 180

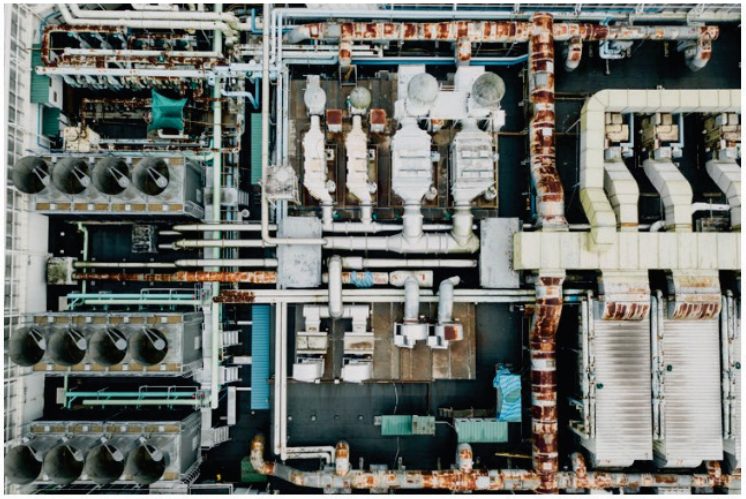
To champion carbon removal solutions through science and innovation.

We are a new breed of climate-focused NGO on a mission to fundamentally rethink carbon. We partner with policymakers, scientists and businesses around the globe to develop policy, promote research, and advance solutions that transform carbon from a liability to an asset. Our vision is to build a prosperous, carbon-conscious economy that removes more carbon from the atmosphere than we emit.

Growing the knowledge base

Increased focus (and funding) for R&D allows for testing and deploying technologies on a greater scale.

THE CONSORTIUM



Fostering real world use cases

By changing their operations to sequester carbon, smart businesses can activate a new source of productivity and value.

THE FELLOWSHIP **CARBON FARMING**

https://carbon180.org

Carbon XPRIZE

OPERATING COSTS

Teams will be responsible for funding their own technology development costs.

During Round 3 of the competition, XPRIZE will provide finalists with access to a testing bay connected to a power plant, located at one of two Carbon XPRIZE test facilities. At each test facility:

- Teams will have access to a testing bay, office space, and flue gas from the power plant (as described in the competition guidelines) at no cost.
- Teams will have access to electricity, water, and other inputs (as described in the competition guidelines) at a cost determined by the test facility.
- Teams will be responsible for all permitting costs, if applicable.
- Teams will be responsible for all waste disposal costs, if applicable.

JUDGING CRITERIA

During Round 1, teams will be evaluated on technical and business information provided in the Round 1 paper submission.

During Round 2 and Round 3, teams will be evaluated exclusively based on the scoring criteria (CO2 Converted and Net Value of Products) and performance thresholds for land and water, as described in the competition guidelines. Standard technical specifications and economic values that will be used in scoring the Net Value of Products will be available before the end of the regular registration period.

https://carbon.xprize.org/prizes/carbon

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https://carbon.xprize.org/prizes/carbon

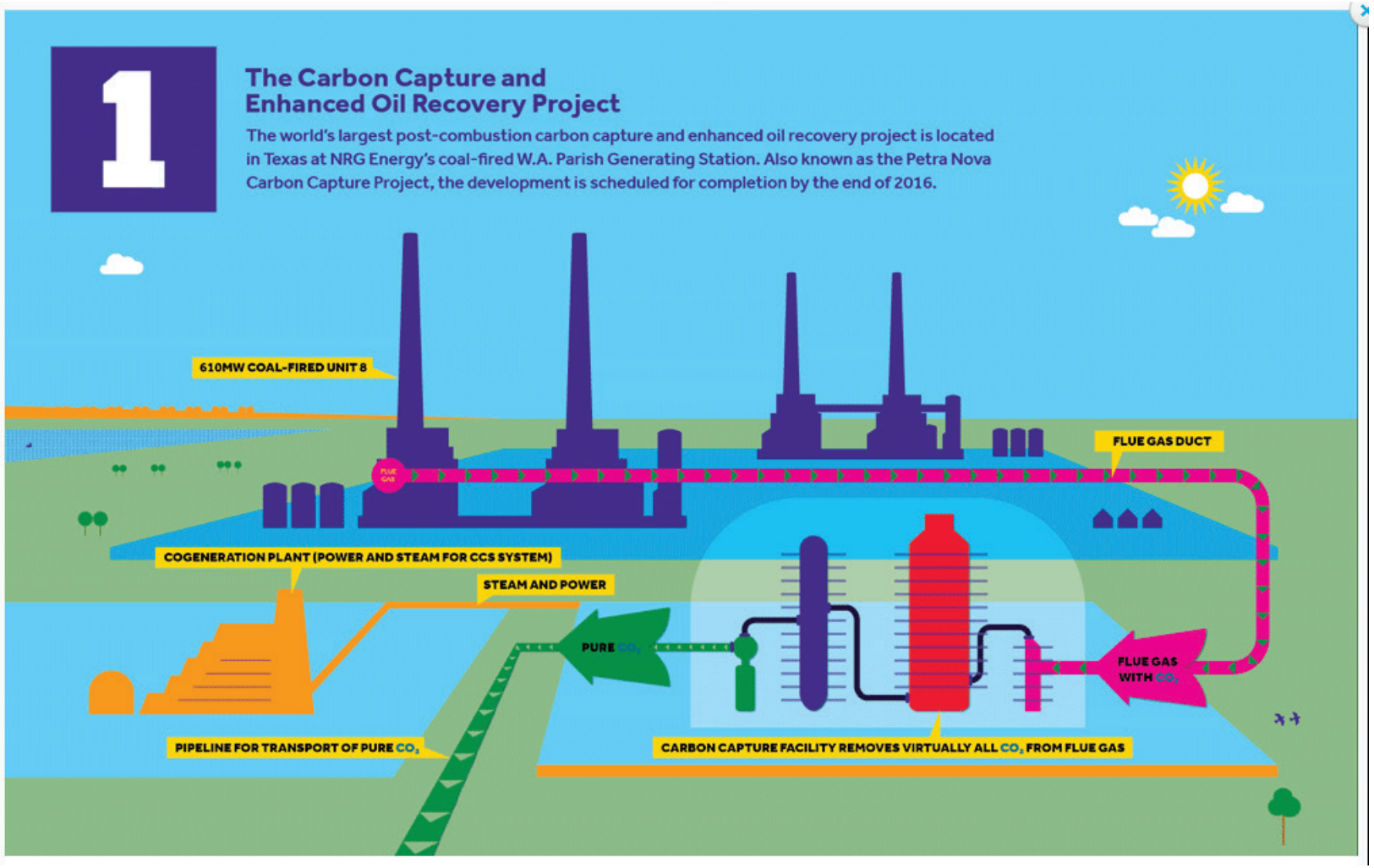
Petra Nova

Petra Nova Project near Houston Texas, jointly developed by Mitsubishi Heavy Industries, Ltd. (MHI), the Kansai Electric Power Co., and NRG Energy, Inc uses a solvent for CO_2 capture coupled to a 240 MW coal power plant

Cost : $ 1 billion ; DOE support: $190 million
https://www.eenews.net/stories/1060053094

http://www.nrg.com/generation/projects/petra-nova

Petra Nova



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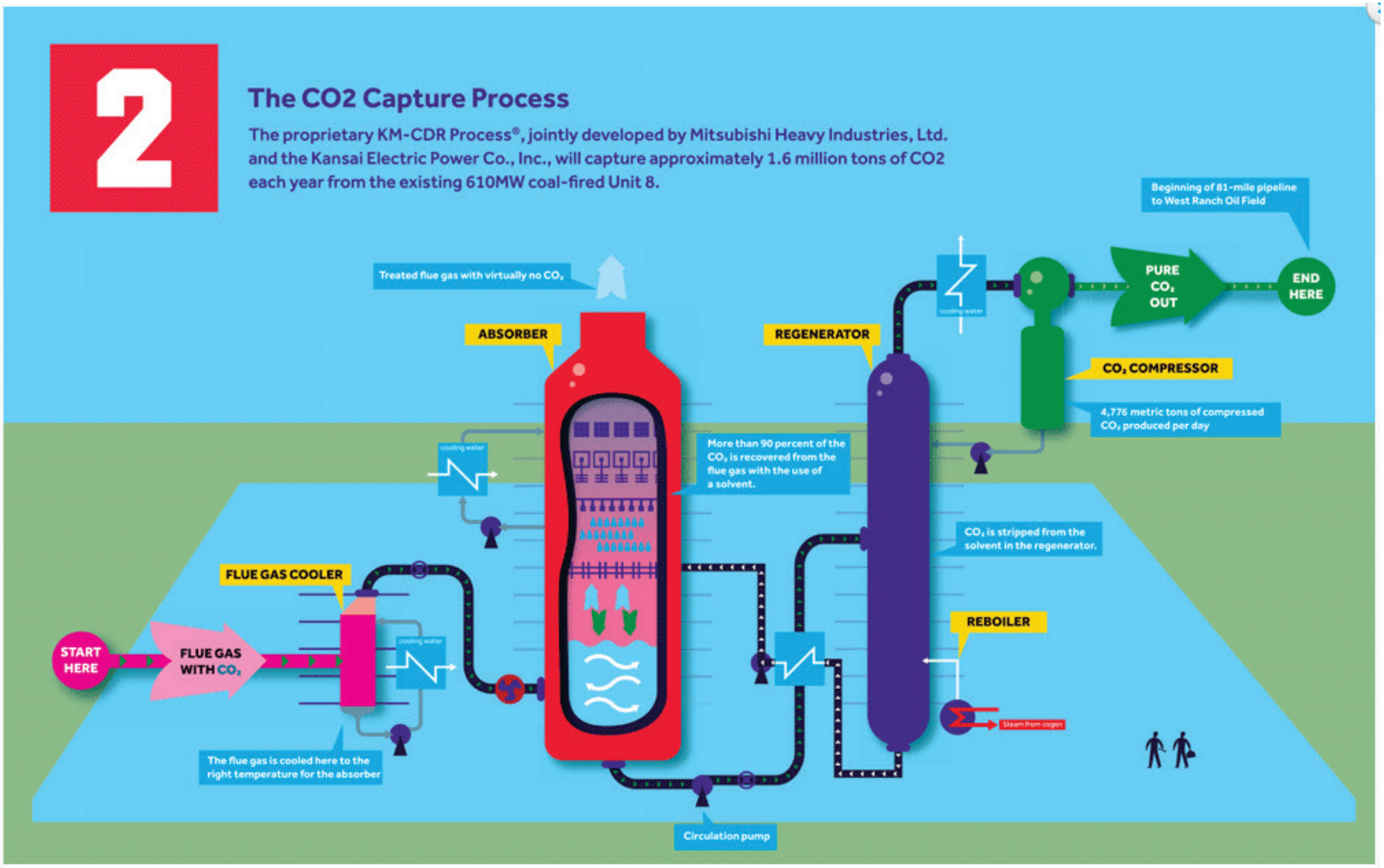
Petra Nova



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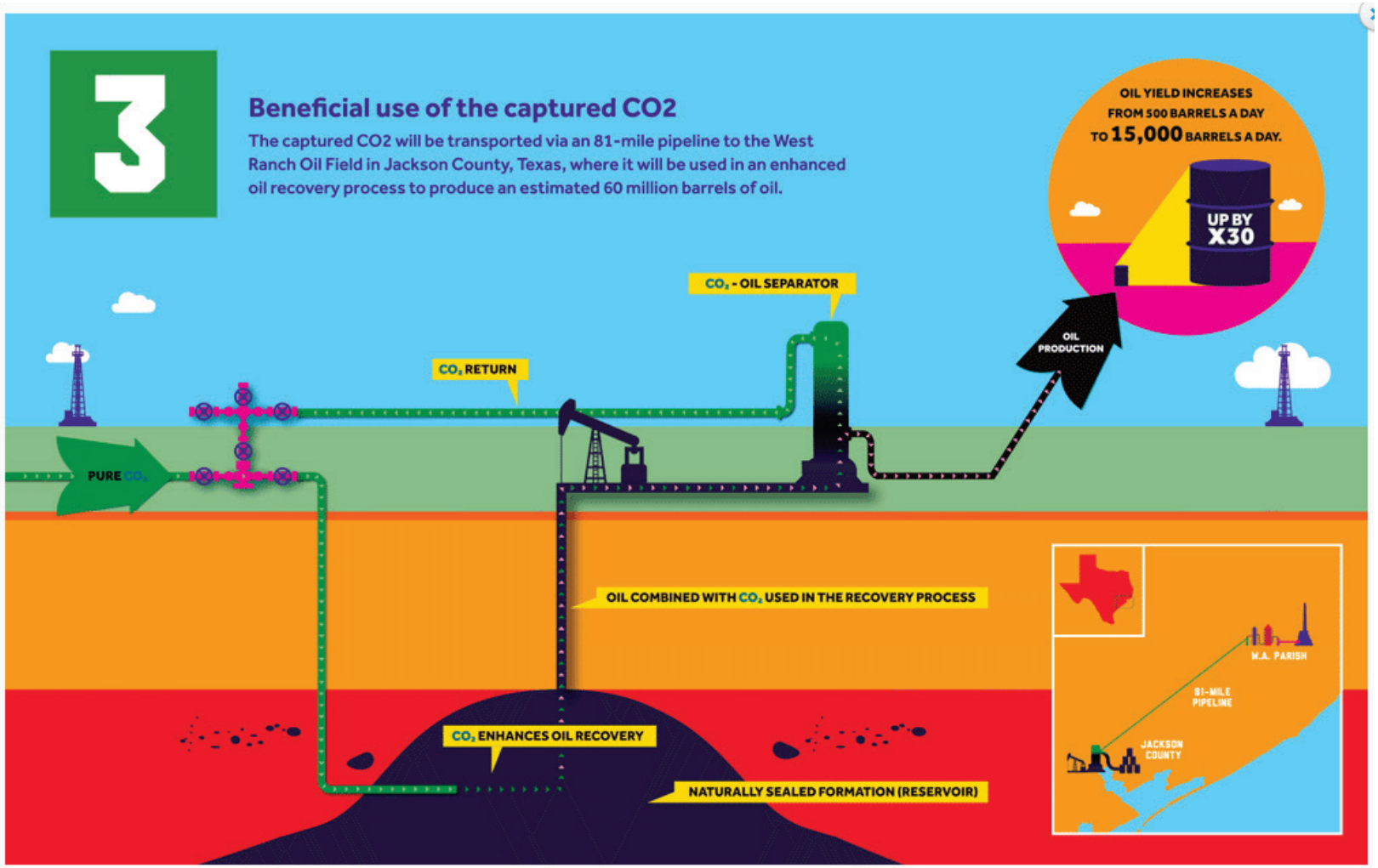
Petra Nova



http://www.nrg.com/generation/projects/petra-nova

45Q

45Q Tax Credit

The Bipartisan Budget Act of 2018 included in its entirety the FUTURE Act introduced in the U.S. Senate in 2017 to extend and reform the 45Q tax credit. Key provisions include:

- Increases the credit value incrementally over ten years from $10 to $35 per metric ton of CO_2 stored geologically through enhanced oil recovery and from $20 to $50 per ton for saline and other forms of geologic storage.
- Provides $35 per ton for CO_2 captured and put to beneficial uses beyond EOR that reduce lifecycle emissions.
- Authorizes the program for carbon capture projects that commence construction within 7 years from enactment, and projects meeting that timeframe can claim the credit for 12 years after being placed in service.
- Reduces the minimum eligibility threshold for qualified facilities from 500,000 metric tons of CO_2 captured annually to 100,000 tons for industrial facilities and 25,000 tons for CO_2 captured and put to beneficial uses other than EOR. Retains the 500,000-ton eligibility threshold for electric generating units.
- Awards the credit to the owner of the carbon capture equipment and allows transfer of the credit to other entities responsible for managing the CO_2 to provide greater flexibility for companies with different business models to utilize the tax credit effectively, including cooperatives and municipal utilities.
- Allows projects that involve carbon monoxide capture and direct air capture to qualify for the credit as well.

https://carboncapturecoalition.org/45q-legislation/

Congressman David Schweikert (R-Arizona) (since 2011)

https://schweikert.house.gov

Congressman David Schweikert (R-Arizona) (since 2011)

Republicans Look to American Innovation to Combat Global Climate Change

MAY 15, 2019 — BLOG

Rep. Schweikert, went through a number of examples of how the private sector is innovating in ways to reduce carbon emissions and increase clean energy production.

"We need to understand this technology and promote it," said **Rep. Schweikert**.

"The U.S. is leading the world is decreasing greenhouse gases – you can't deny that," said **Rep. Brady**. "Renewable energy is up and continues to grow . . . CO2 emissions have fallen to their lowest level in a generation . . . and emissions of the six most common pollutants that are tracked by the EPA have fallen 73 percent over the past three decades – you can't deny that."

"We are making progress," said **Rep. Brady**. "Is it enough? Absolutely not. But we can learn from what has brought us that progress to solve the challenges ahead of us."

https://gop-waysandmeans.house.gov/republicans-look-to-american-innovation-to-combat-global-climate-change/

CONGRESSMAN SCHWEIKERT URGES TREASURY DEPARTMENT TO PROVIDE GUIDANCE ON CARBON CAPTURE TAX CREDIT

April 11, 2019 | Press Release

Contact: Grace White (202) 225-2190

WASHINGTON, DC – Today, Congressman David Schweikert (AZ-06) sent a letter to Secretary of the U.S. Department of the Treasury Steven Mnuchin and Internal Revenue Service (IRS) Commissioner Charles P. Retting, urging updated guidance for stakeholders who qualify for the 45Q tax credits.

Since the Bipartisan Budget Act of 2018 was signed into law, stakeholders eligible to take advantage of the 45Q tax credit have been severely delayed as the Treasury Department has not released updated clarification or revised guidance to those looking to utilize 45Q.To ensure those eligible for the credit are receiving proper guidance so carbon capture investment projects can be carried out, the letter requests a shortened comment period and expeditious final implementation of the revised guidance, to ensure there is not additional time wasted for those who can take advantage of this tax credit.

The 45Q tax credit is a federal carbon capture utilization and storage tax credit that provides credit to power plants and industrial facilities who help decrease carbon emissions by implementing carbon capture and storage technologies at their facilities.

https://schweikert.house.gov/media-center/press-releases/congressman-schweikert-urges-treasury-department-provide-guidance-carbon

HONR 229L: Climate Change: Science, Economics, and Governance

Climate Models: Perspective of a Physical Scientist

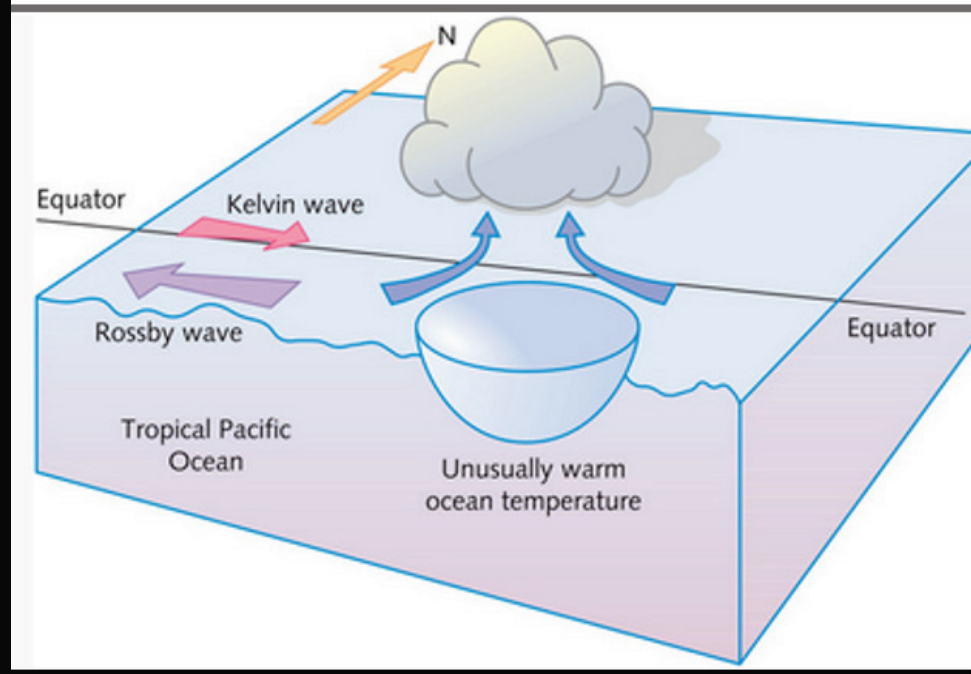
Cristy Ho

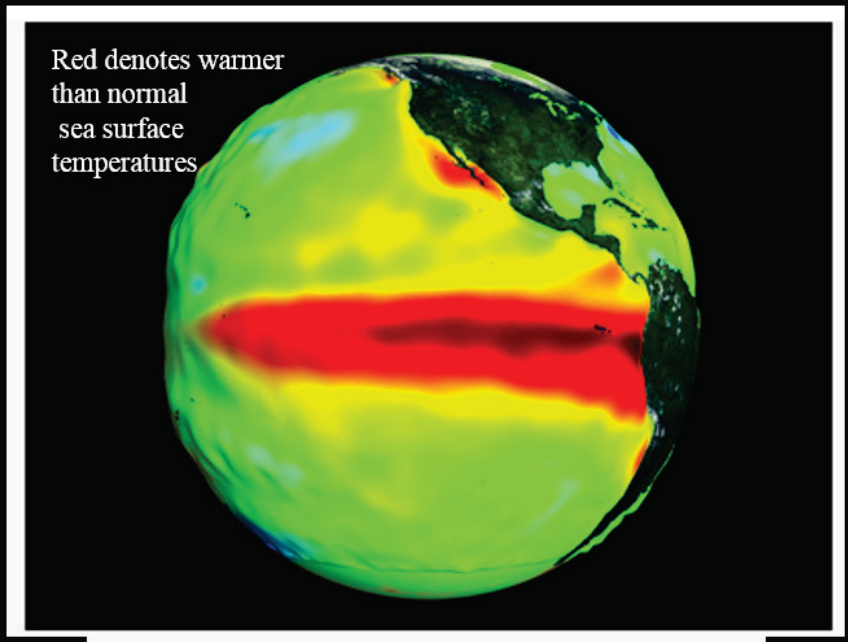
1 October 2019

El Niño

What happens to the ocean?
Where in the ocean?

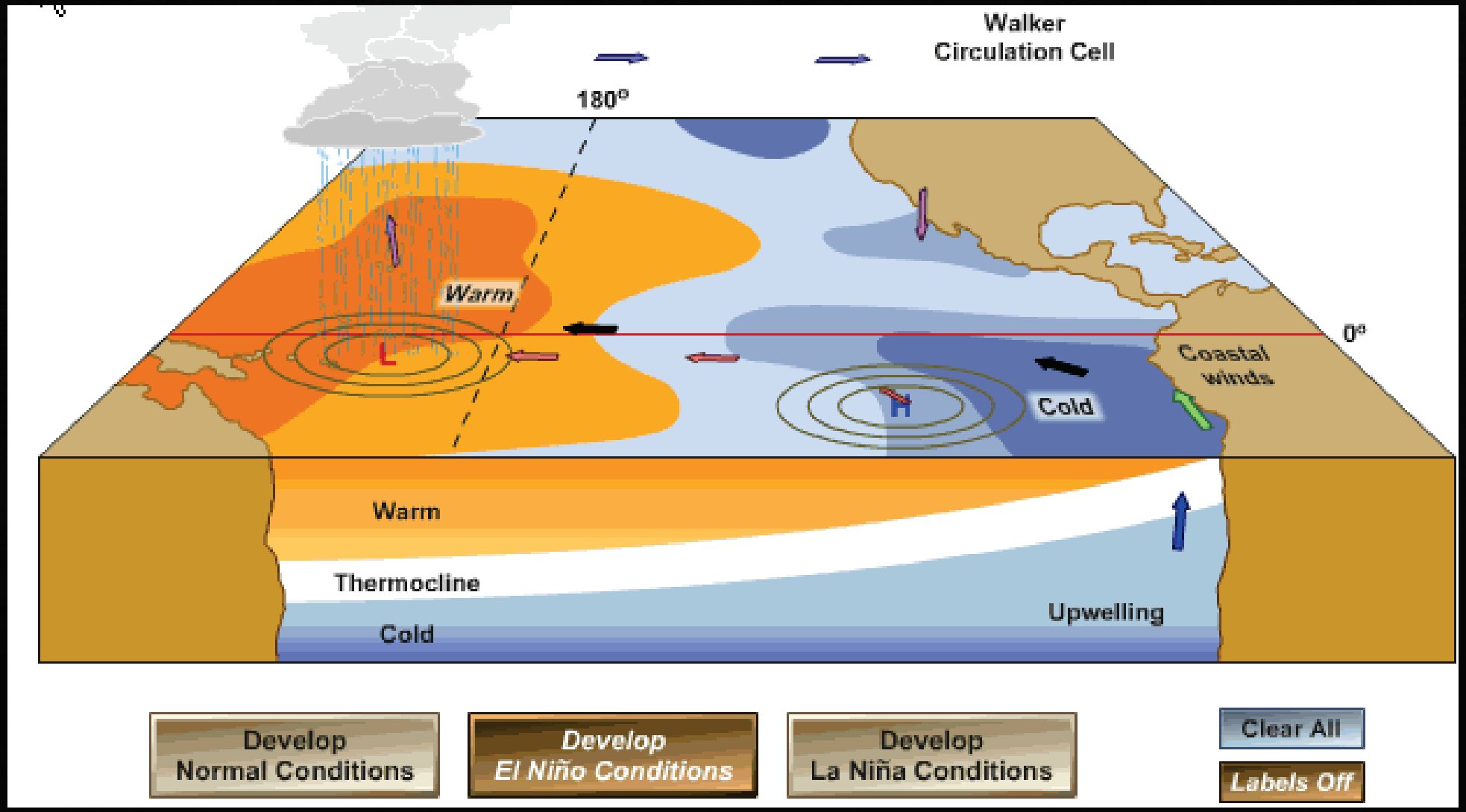
- Water warms up in the Pacific Ocean, off the east coast of South America
- Occurs every 3-5 years





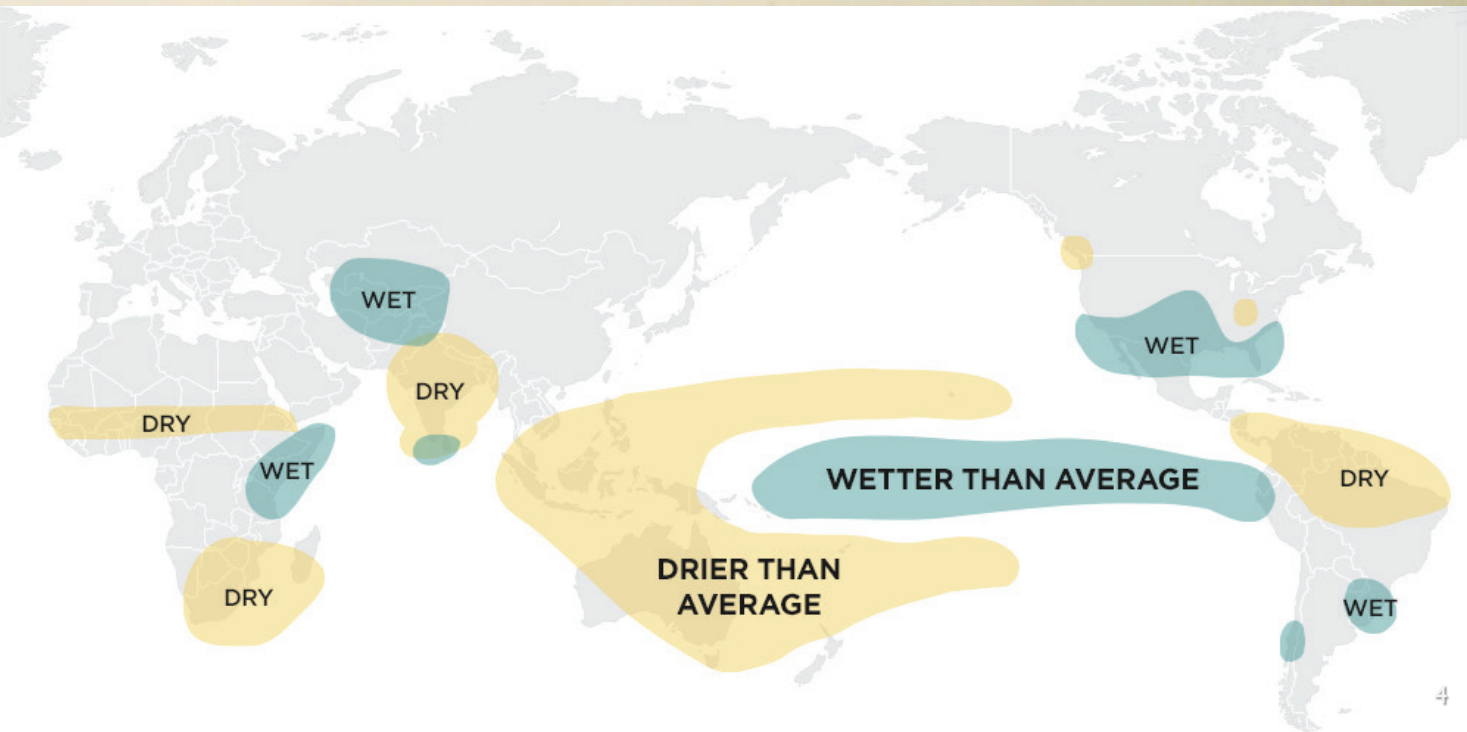
The El Niño event of 1997–8 is the most intense on record.

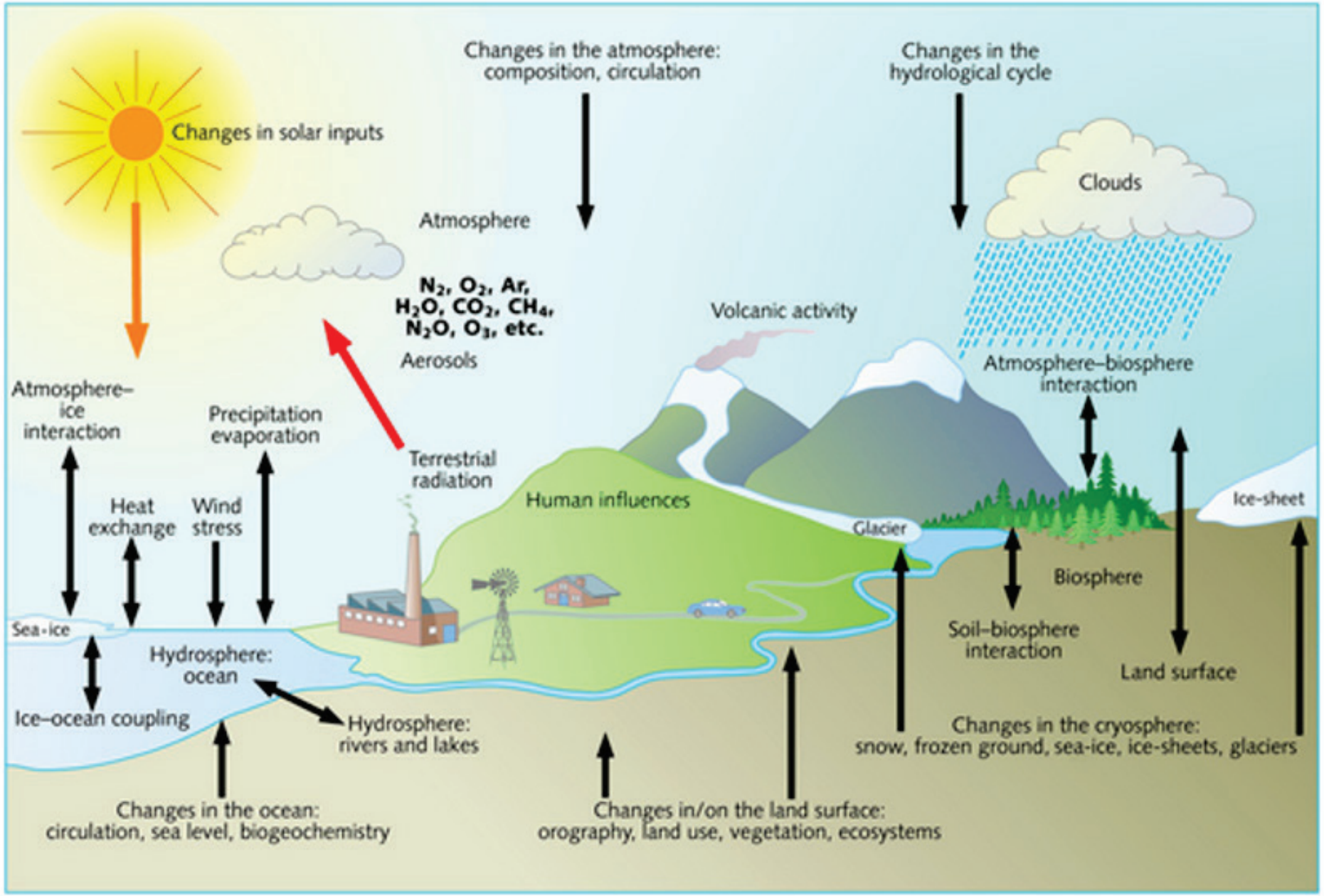
El Niño | In-Depth



Consequences of El Niño

- Droughts
- Floods
- Less nutrients rises near the ocean's surface




Changes in the atmosphere: composition, circulation
Changes in the hydrological cycle
Changes in solar inputs
Clouds
Atmosphere
N_2, O_2, Ar,
H_2O, CO_2, CH_4,
N_2O, O_3, etc.
Aerosols
Volcanic activity
Atmosphere–biosphere interaction
Atmosphere–ice interaction
Precipitation evaporation
Terrestrial radiation
Heat exchange
Wind stress
Human influences
Glacier
Ice-sheet
Biosphere
Sea-ice
Hydrosphere: ocean
Soil–biosphere interaction
Land surface
Ice–ocean coupling
Hydrosphere: rivers and lakes
Changes in the cryosphere: snow, frozen ground, sea-ice, ice-sheets, glaciers
Changes in the ocean: circulation, sea level, biogeochemistry
Changes in/on the land surface: orography, land use, vegetation, ecosystems

Improving Climate Models

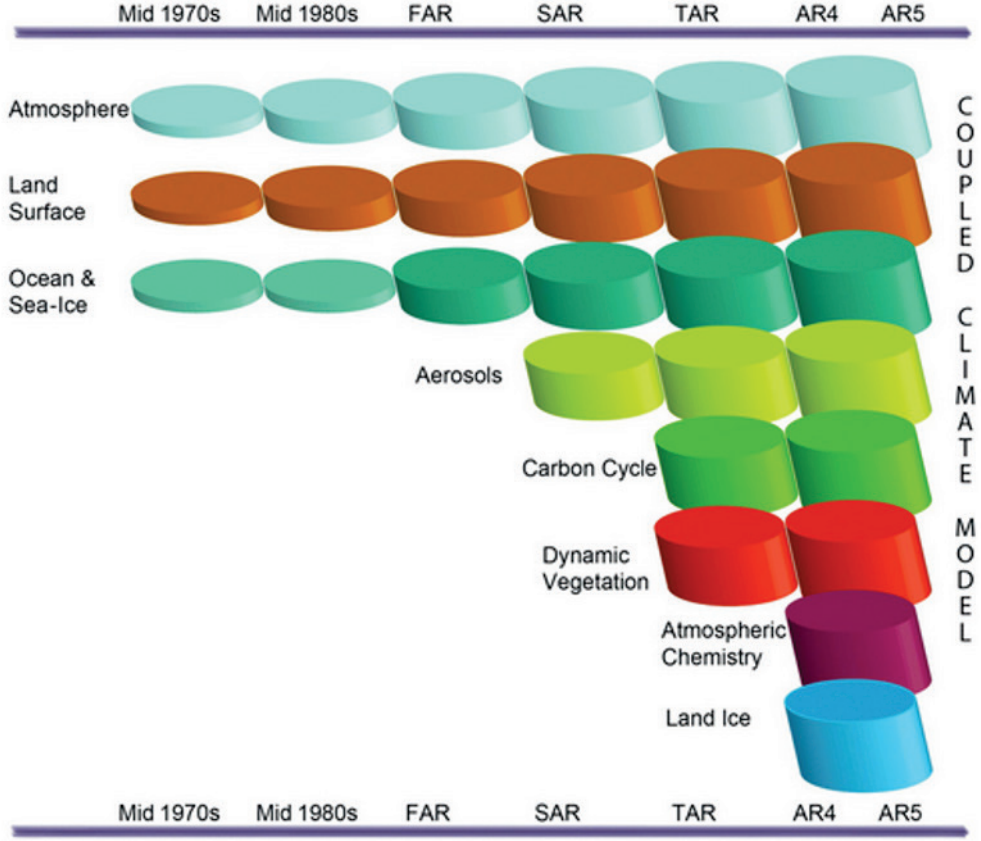


Figure 5.4 The range of parameters included in models has increased significantly since early models in the 1970s: models from mid 1970s; mid 1980s; IPCC First Assessment Report, FAR, 1990; IPCC Second Assessment Report, SAR, 1996; IPCC Third Assessment Report, TAR, 2001; IPCC Fourth Assessment Report, AR4, 2007; IPCC Fifth Assessment Report, AR5, 2013.

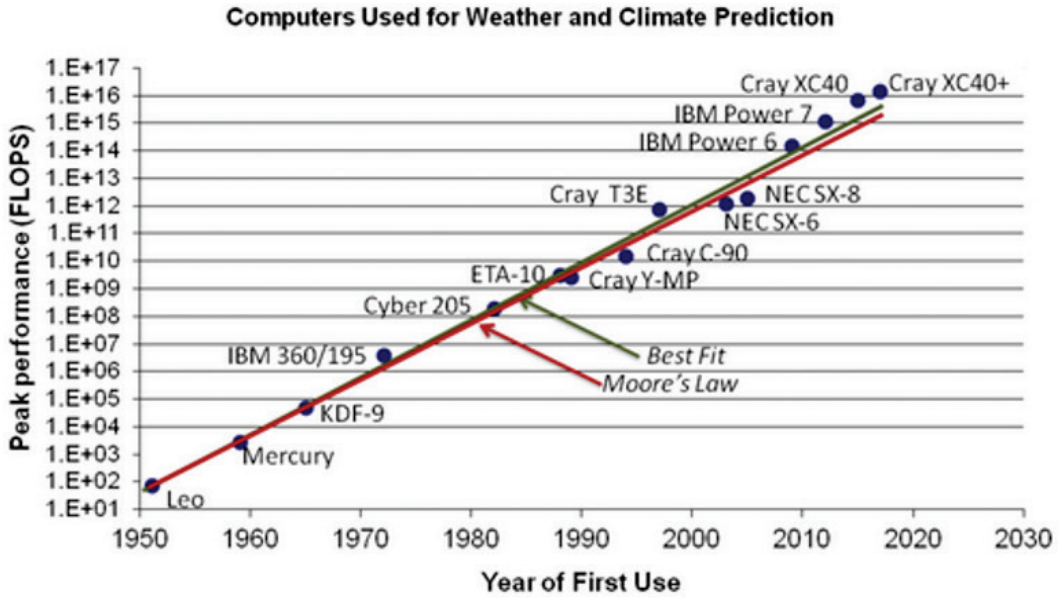
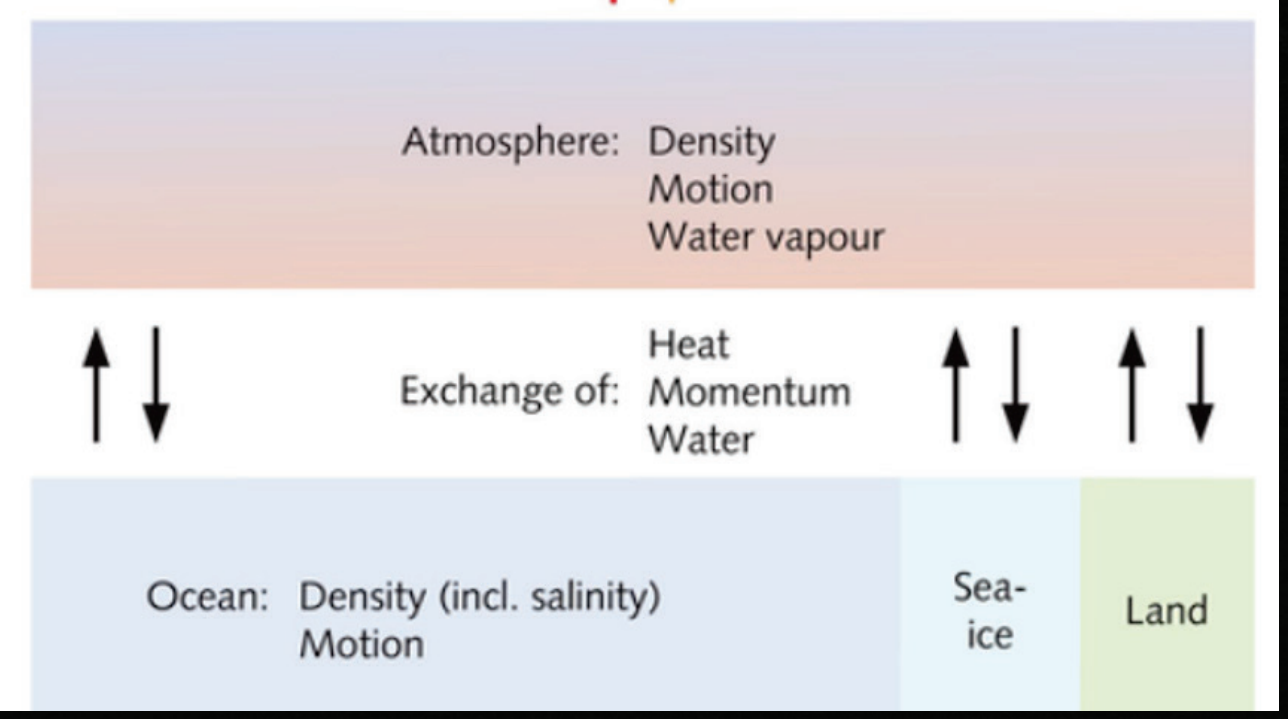


Figure 5.1 The growth of computer power available at major forecasting centres. The computers are those used by the UK Met Office for numerical weather prediction research, from 1965 to present for operational weather forecasting and most recently for research into climate prediction. They are also used for research and development. Richardson's dream computer of a large 'human' computer mentioned at the beginning of the chapter would possess a performance of perhaps 500 FLOPS (floating point operations per second). A good number of the fastest computers in the world spread over many countries are used at least partially for weather and climate modelling. The straight line illustrates a rate of increase in performance of a factor of 10 every five years.

Role of the Ocean in the Climate System



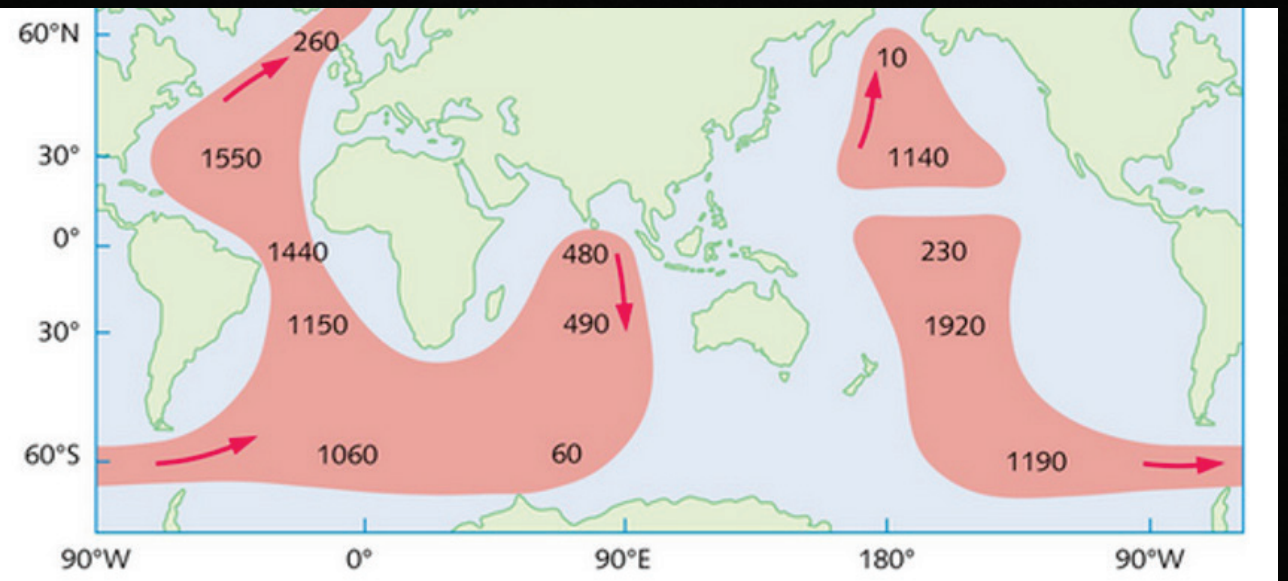
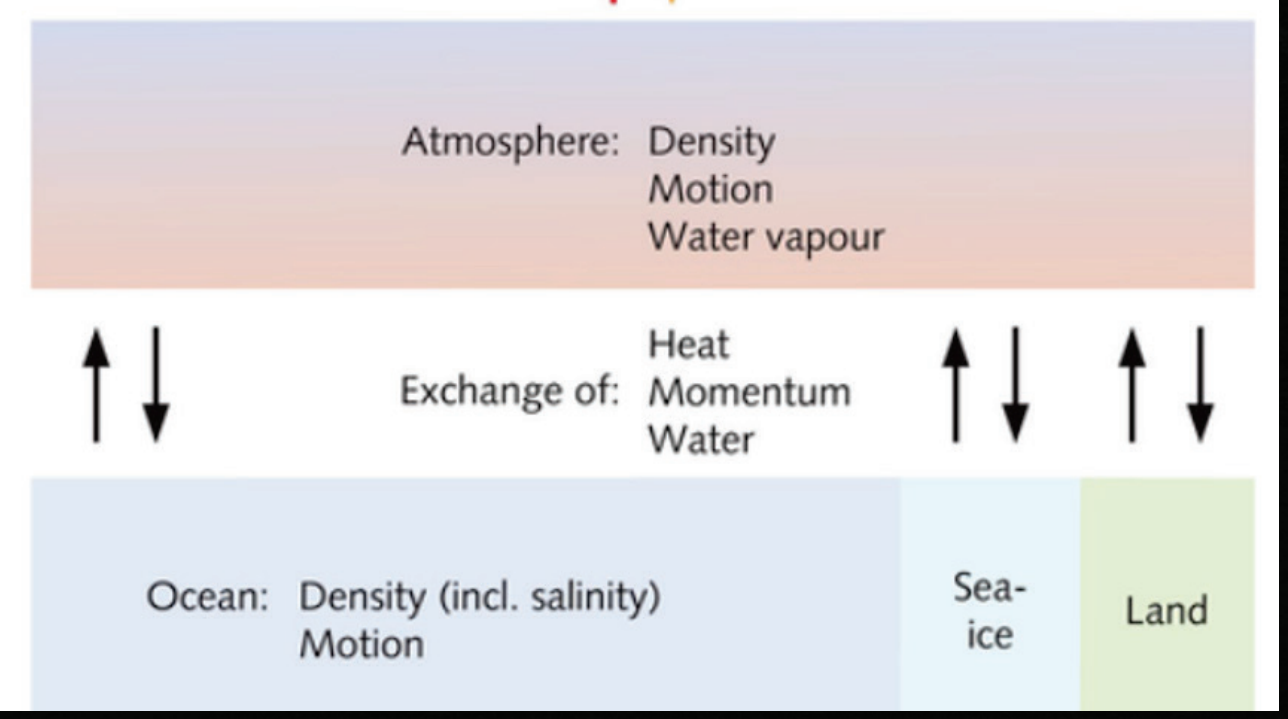
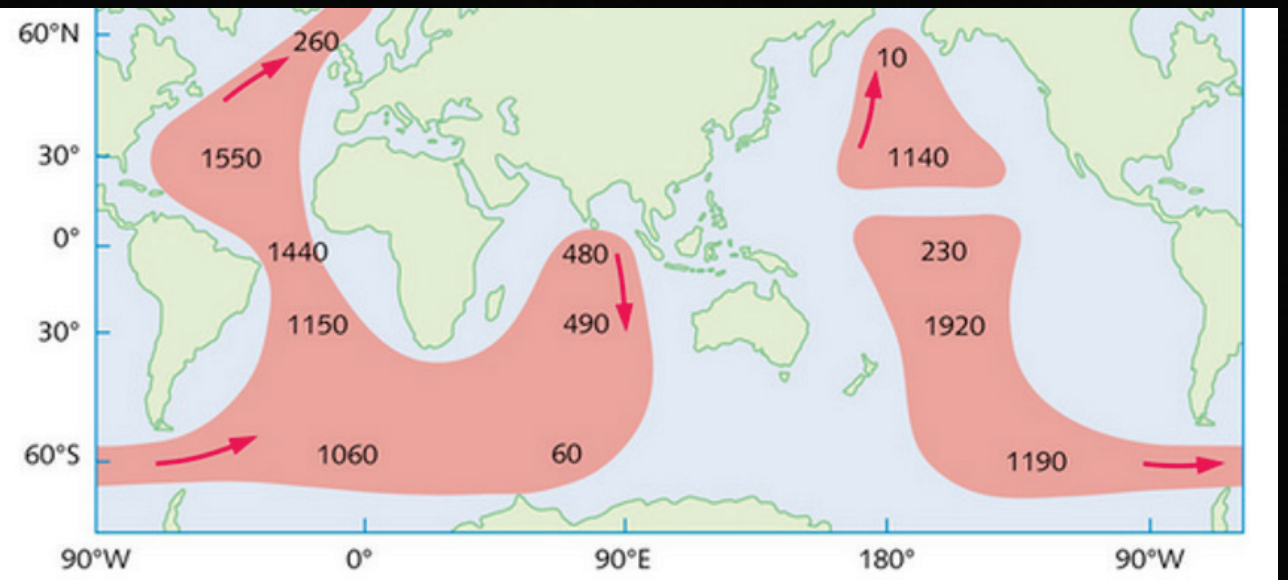


Figure 5.17 Estimates of transport of heat by the oceans. Units are terawatts (10^{12} W or 1 million million watts). Note the linkages between the oceans and that some of the heat transported by the North Atlantic originates in the Pacific.

Role of the Ocean in the Climate System

- Evaporated ocean water is the main source of atmospheric water vapor





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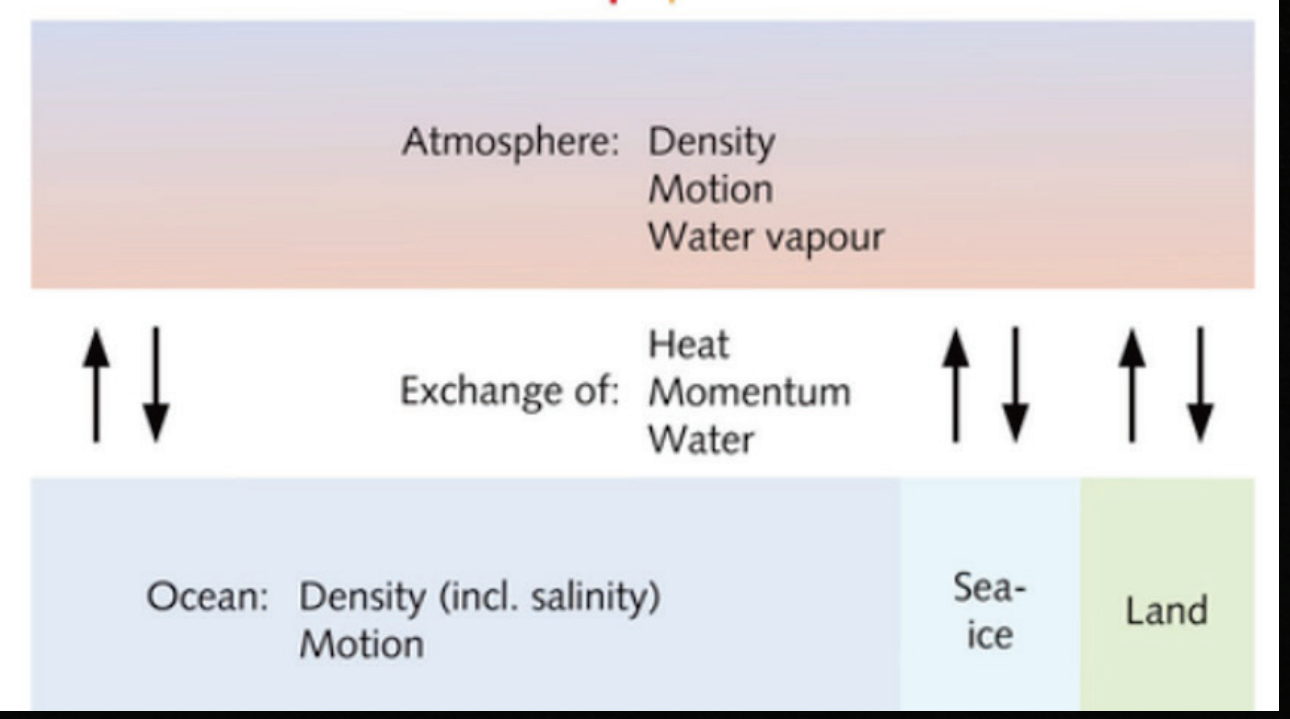

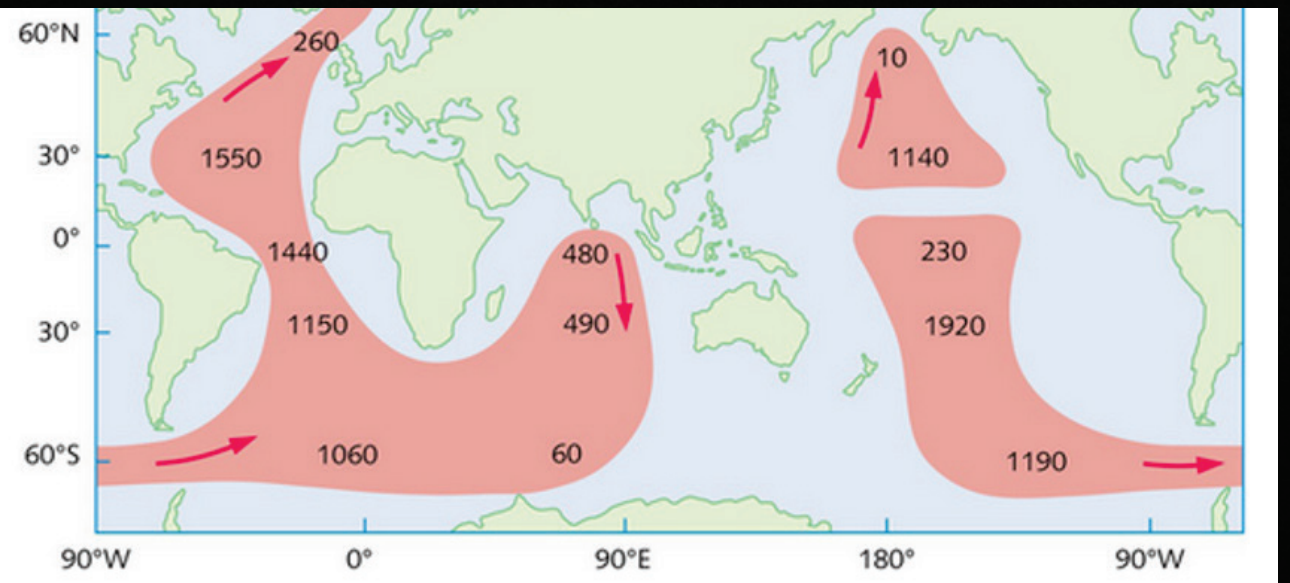

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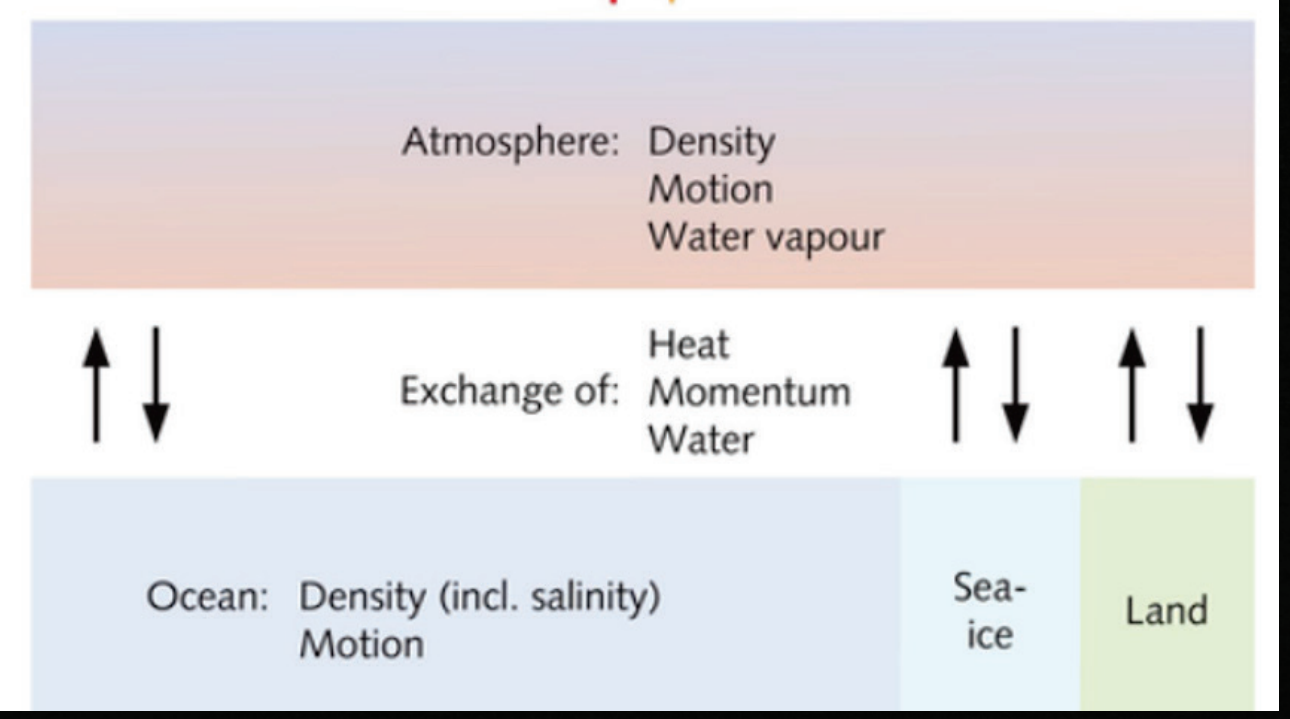
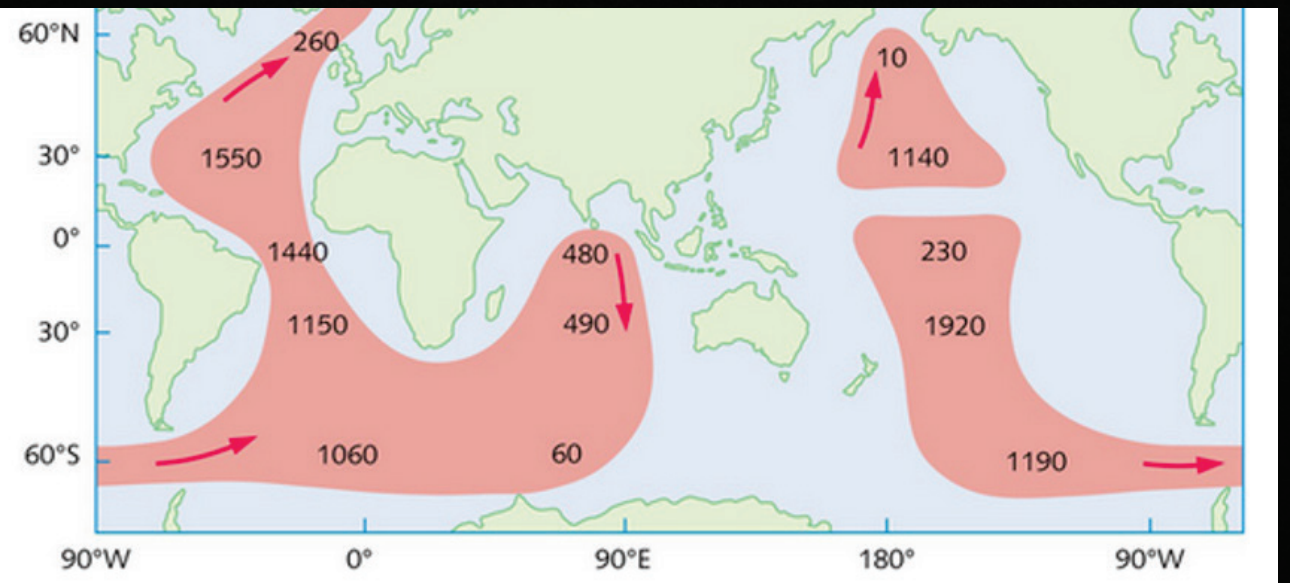
- Evaporated ocean water is the main source of atmospheric water vapor
- The ocean's large heat capacity dampens the extremes of atmospheric temperature





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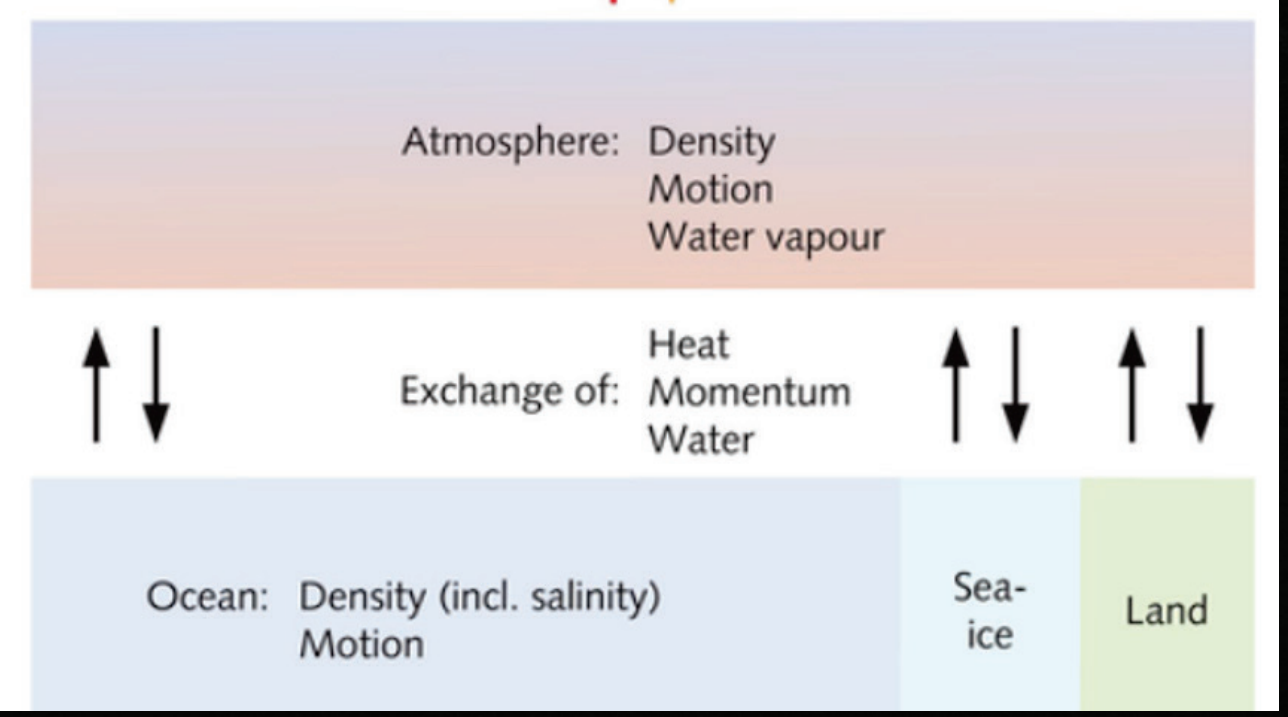
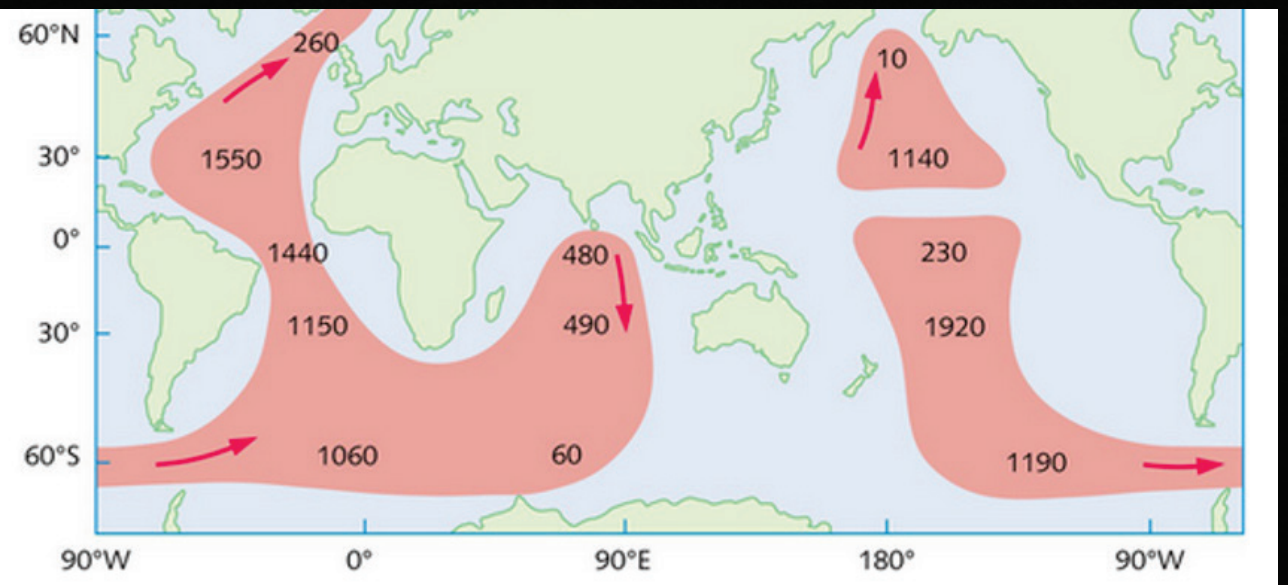
- The ocean redistributes heat from the equator to the polar regions





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Role of the Ocean in the Climate System

- Evaporated ocean water is the main source of atmospheric water vapor
- The ocean's large heat capacity dampens the extremes of atmospheric temperature
- The ocean redistributes heat from the equator to the polar regions
- Changes in the ocean's circulation causes feedbacks that affect climate

Feedbacks: Cloud Radiation

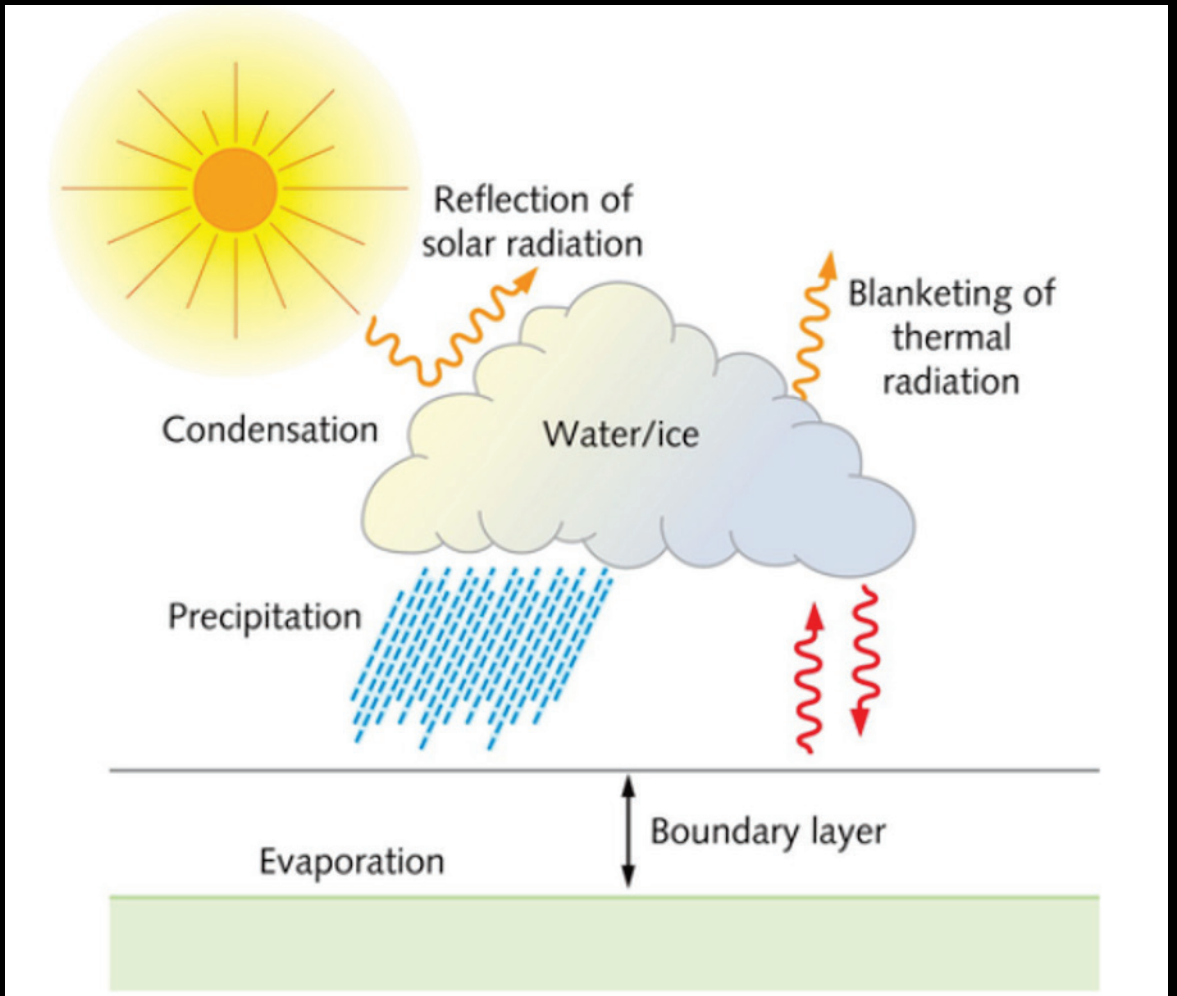


Figure 5.15 Schematic of the physical processes associated with clouds.

- Reduces heat by reflecting solar radiation back into space
- Traps heat by absorbing thermal radiation emitted by the Earth's surface
- Net Feedback depends on cloud temperature, height, content, etc.

How would global surface temperature respond if…

a) CO_2 x 2 with no feedbacks?

b) CO_2 x 2 with feedbacks?

Table 5.1 Estimates of global average temperature changes under different assumptions about changes in greenhouse gases and clouds

Greenhouse gases	Clouds	Change (in °C) from current average global surface temperature of 15°C
As now	As now	0
None	As now	−32
None	None	−21
As now	None	4
As now	As now but +3% high cloud	0.3
As now	As now but +3% low cloud	−1.0
Doubled CO_2 concentration otherwise as now	As now (no additional cloud feedback)	1.2
Doubled CO_2 concentration + best estimate of feedbacks	Cloud feedback included	3

Importance of understanding feedbacks?

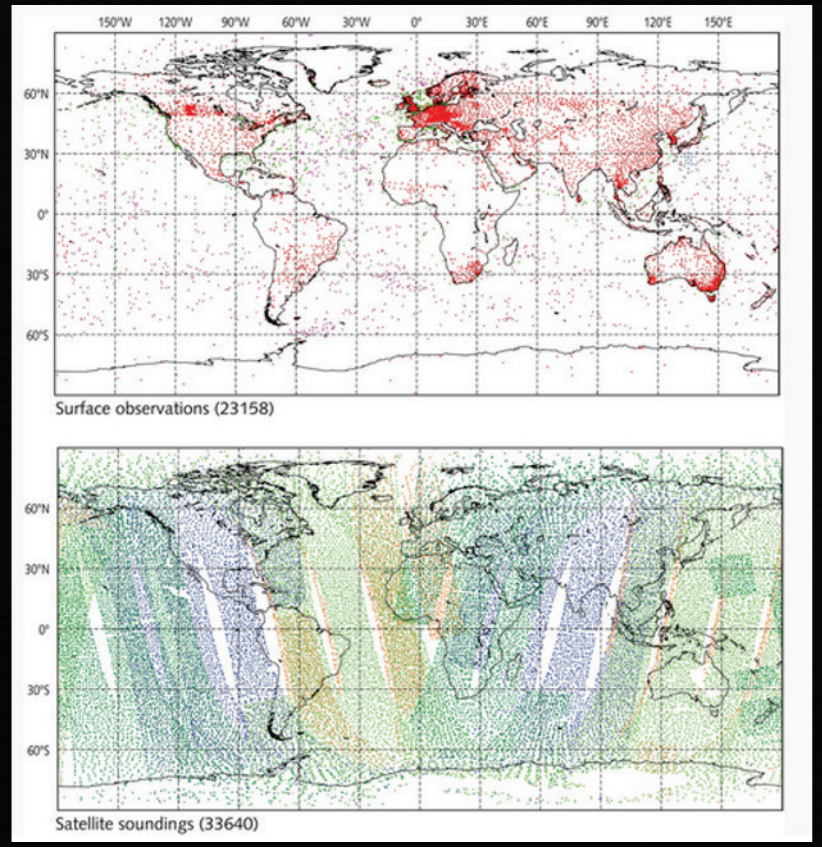
On a scale of "not important", "moderately important", or "very important“? Explain

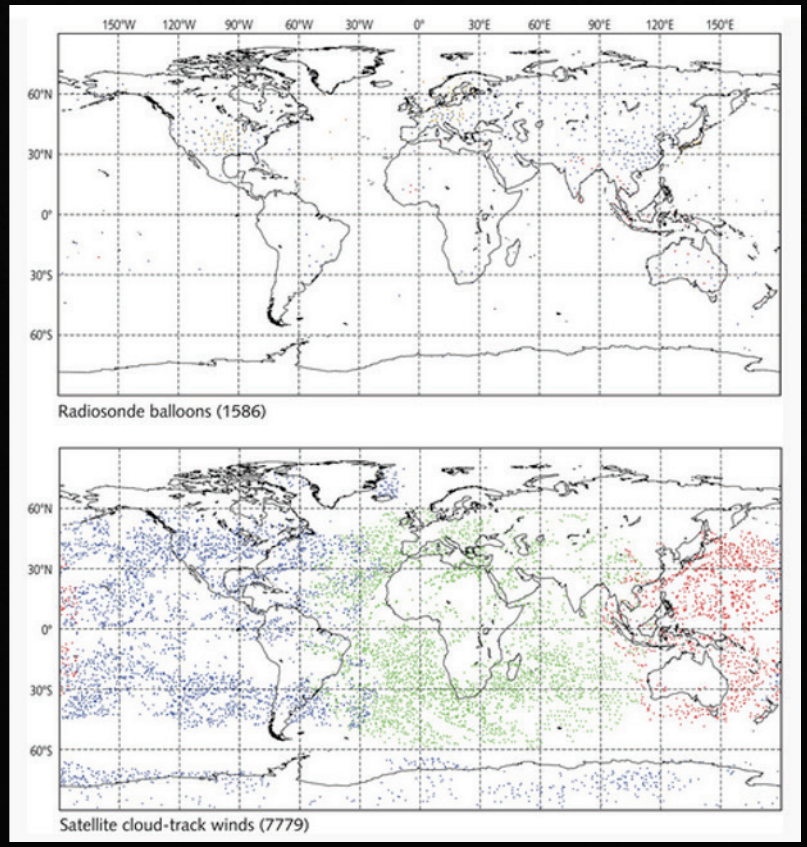
My Thoughts:

- Very important to achieving accurate projections of climate change
- Adding feedback can drastically change temperature predictions
  - Cloud feedback more than doubles the rise in global surface temperature
- The climate system is complex, so complex models that account for feedbacks are needed

How are climate models validated?

- Predictions are compared to observations of the climate
- Predictions are compared to concentration of chemical tracers
- Valid when predictions are consistent with observations





Are you convinced climate models are validated?

My thoughts:

Yes because climate models make what I consider to be successful predictions

Comparing Models to Observations

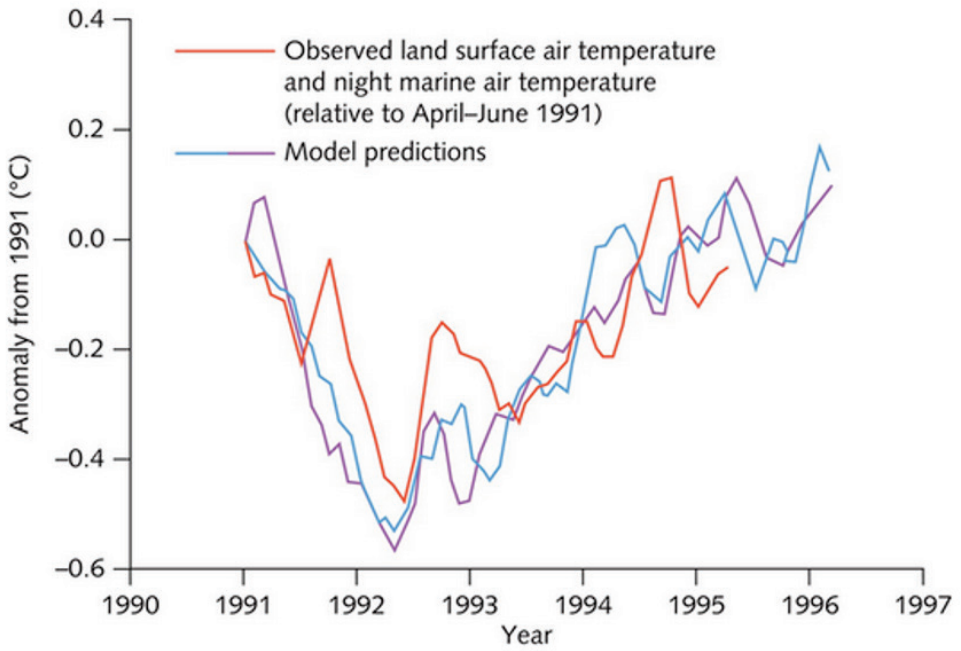
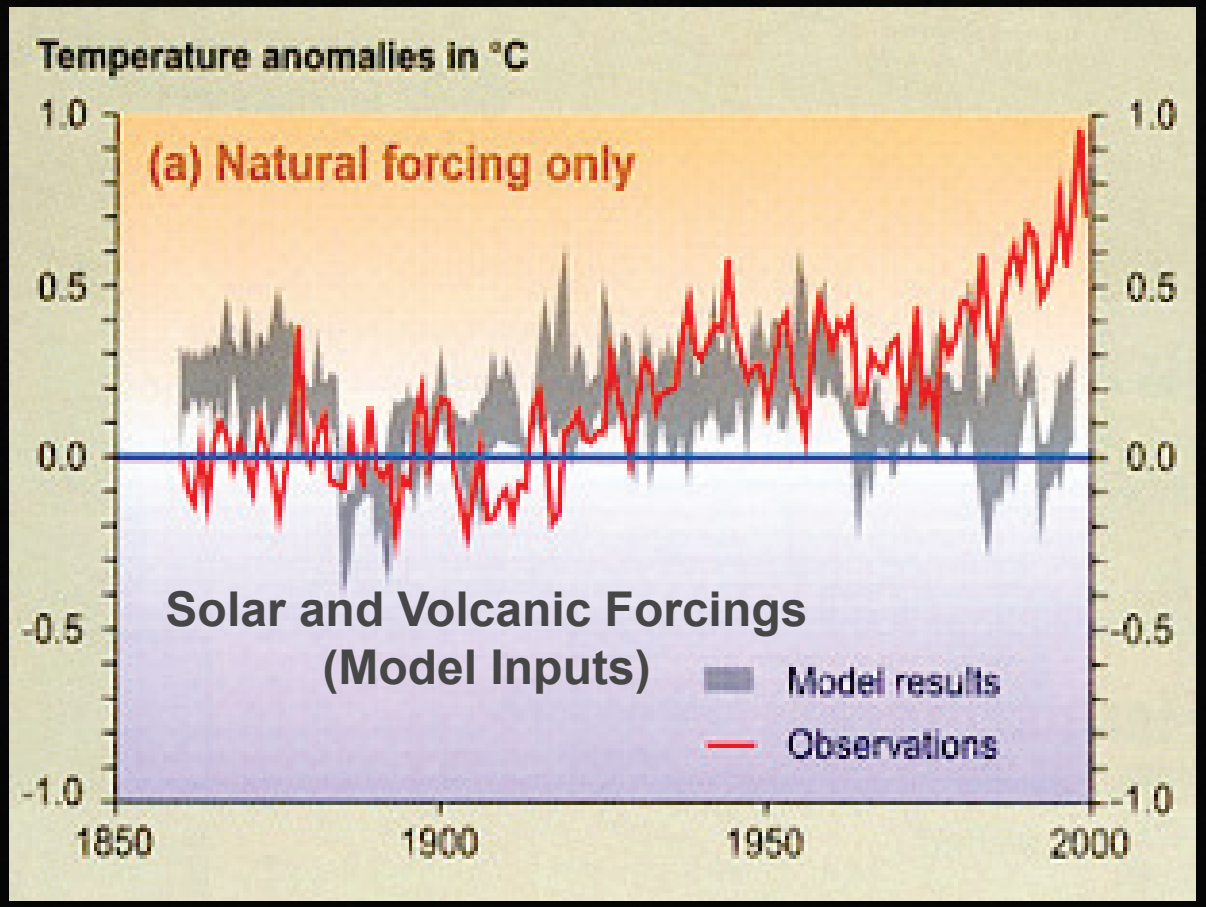
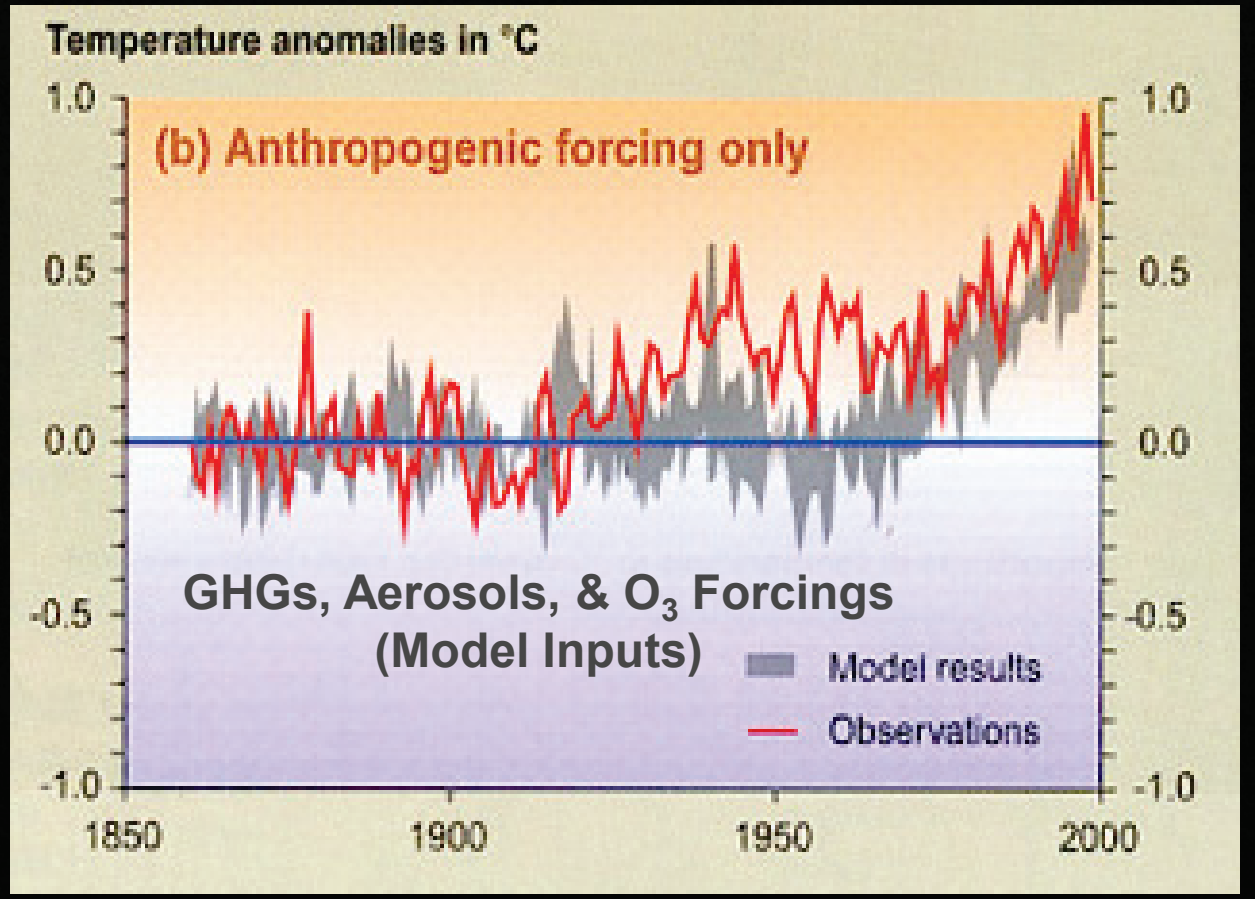


Figure 5.21 The predicted and observed changes in global land and ocean surface air temperature after the eruption of Mount Pinatubo, in terms of three-month running averages from April to June 1991 to March to May 1995.

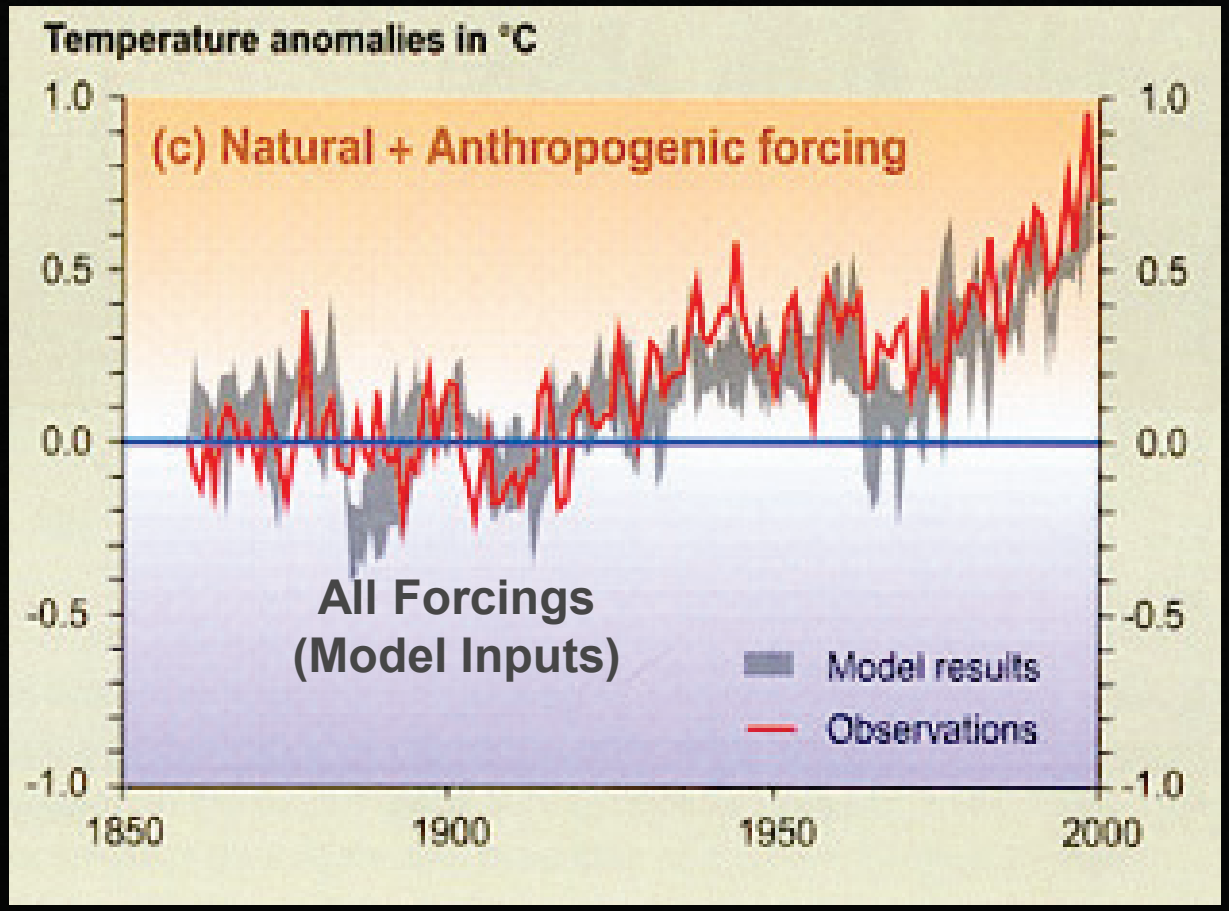
Comparison between modeled and observations of temperature rise since the year 1860



Comparison between modeled and observations of temperature rise since the year 1860



Comparison between modeled and observations of temperature rise since the year 1860



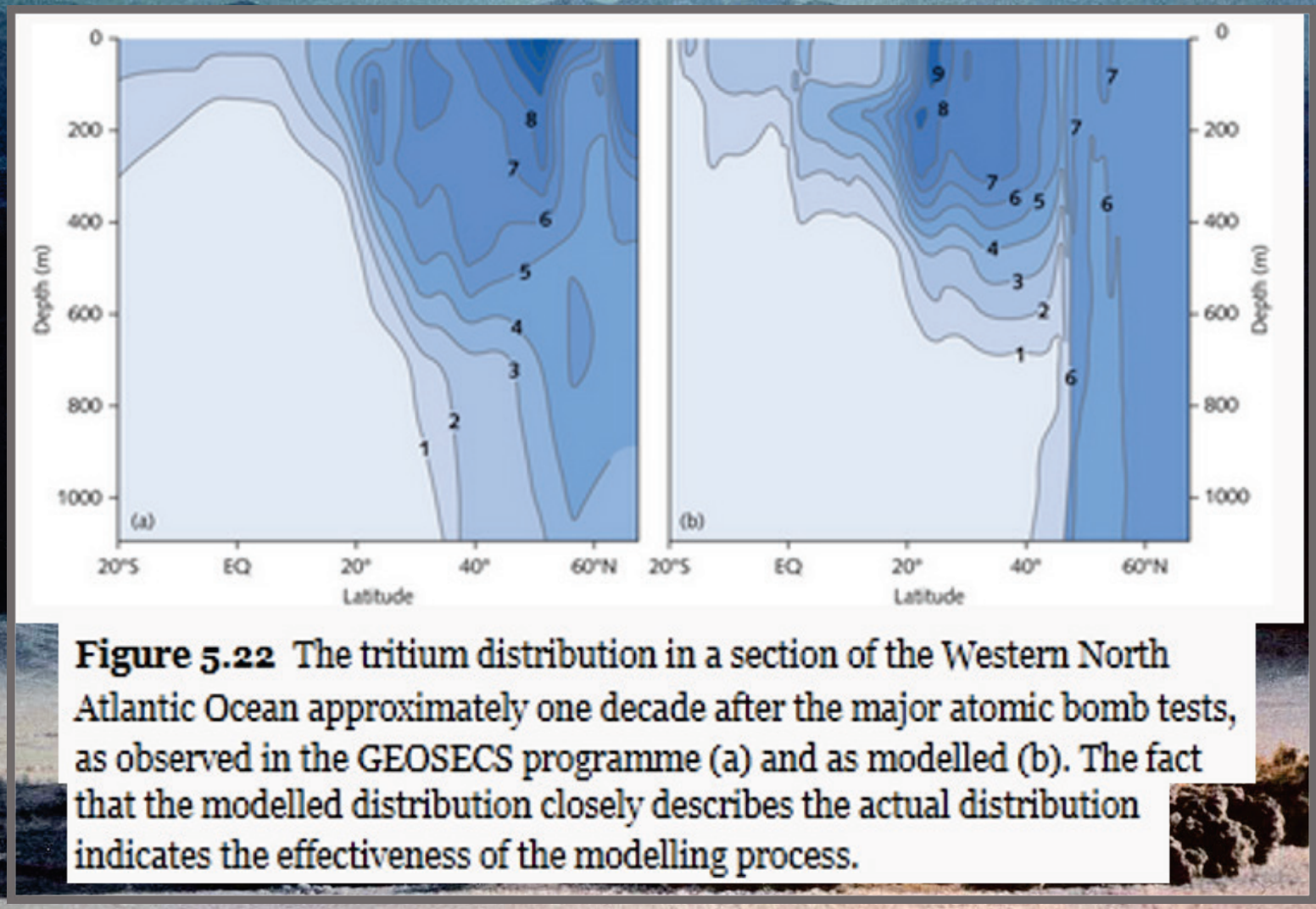


Figure 5.22 The tritium distribution in a section of the Western North Atlantic Ocean approximately one decade after the major atomic bomb tests, as observed in the GEOSECS programme (a) and as modelled (b). The fact that the modelled distribution closely describes the actual distribution indicates the effectiveness of the modelling process.

Final Thoughts

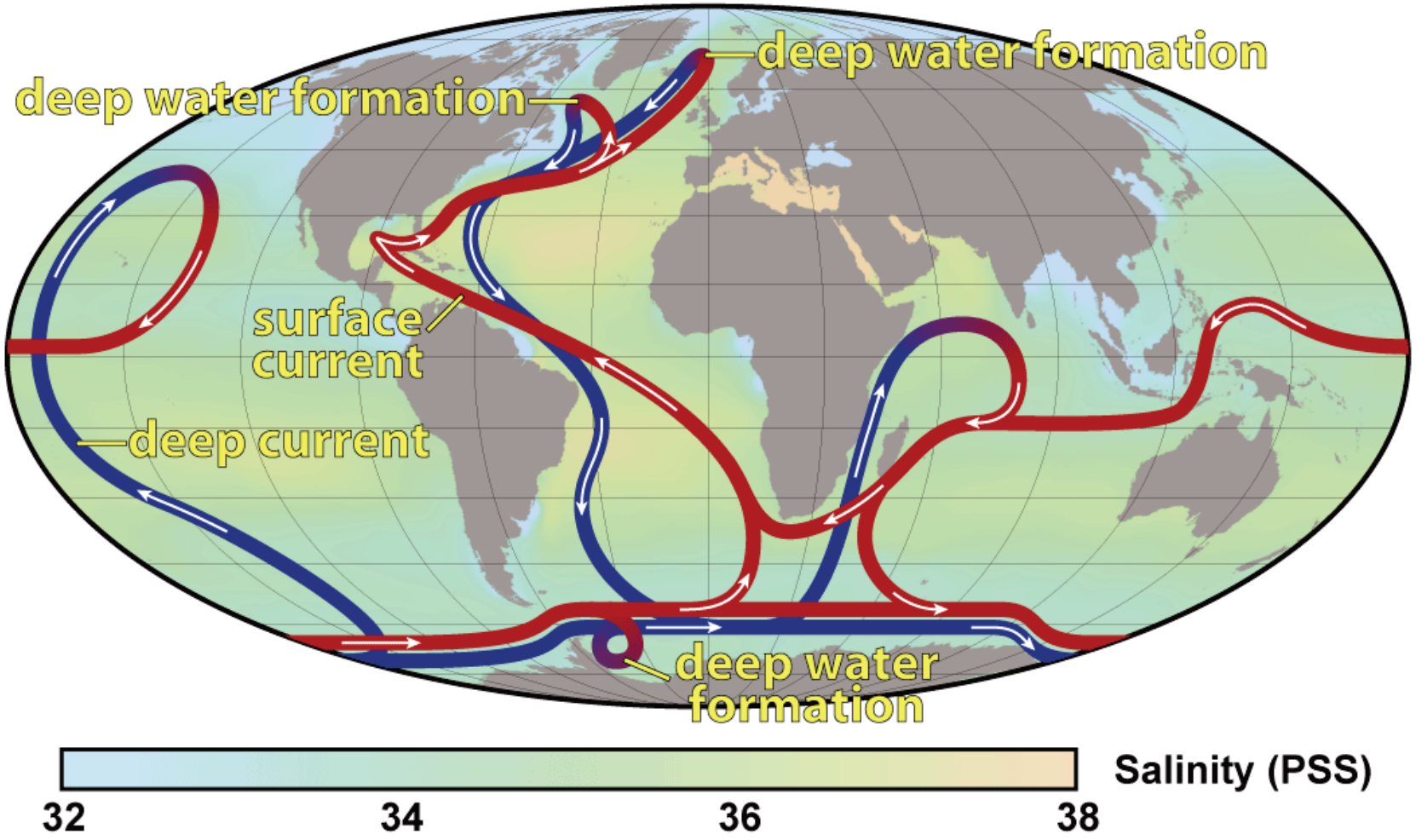
- Models cannot fully replicate the climate system
  - The climate system is an open system with many parameters
- Model predictions can be accurate enough to rely on
  - Can be improved by comparing predictions to past observations
  - Can be used to influence public policy

Climate Models: Perspective of a Physical Scientist

Last Word: Ross Salawitch

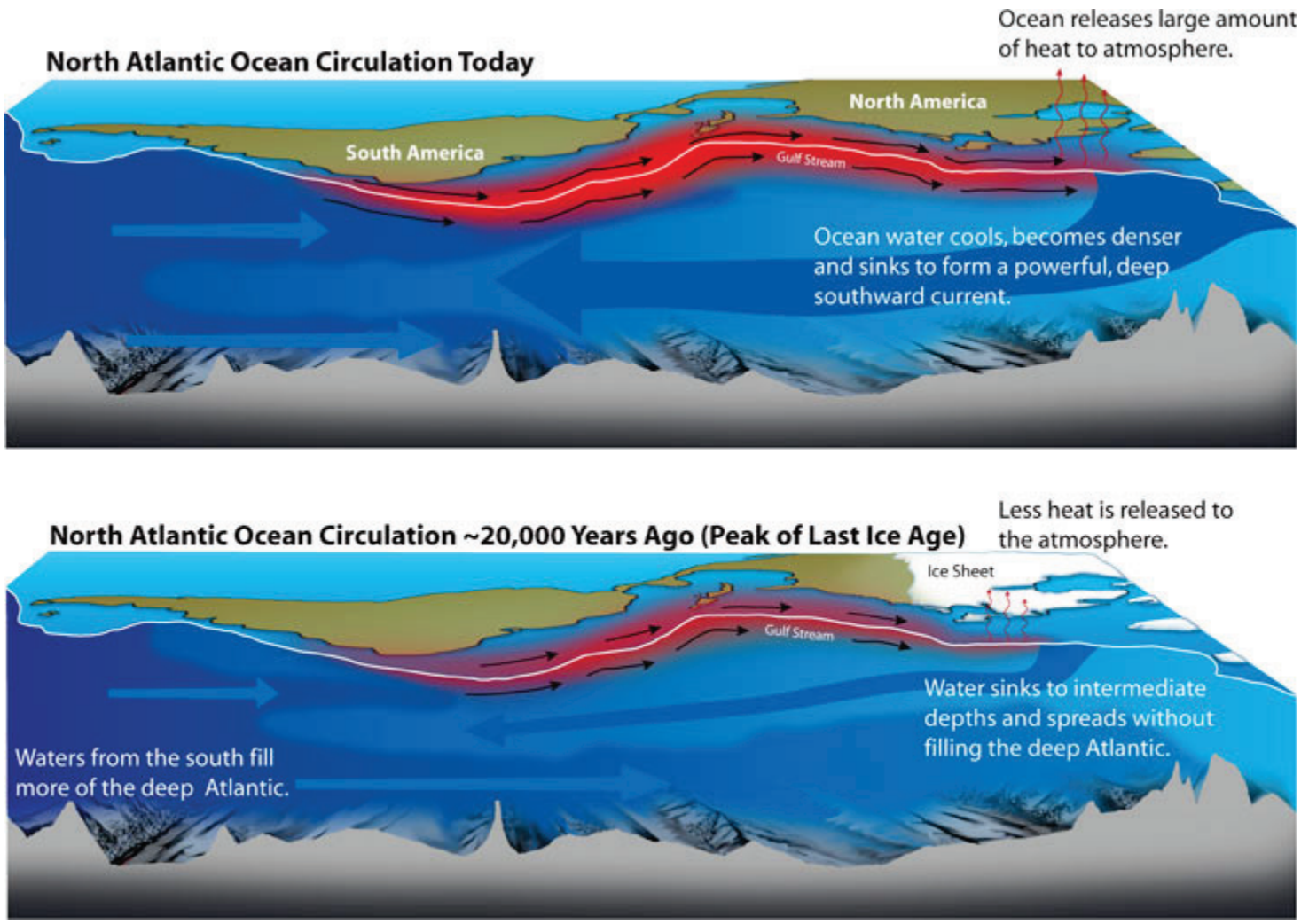
1 October 2019

Thermohaline Circulation



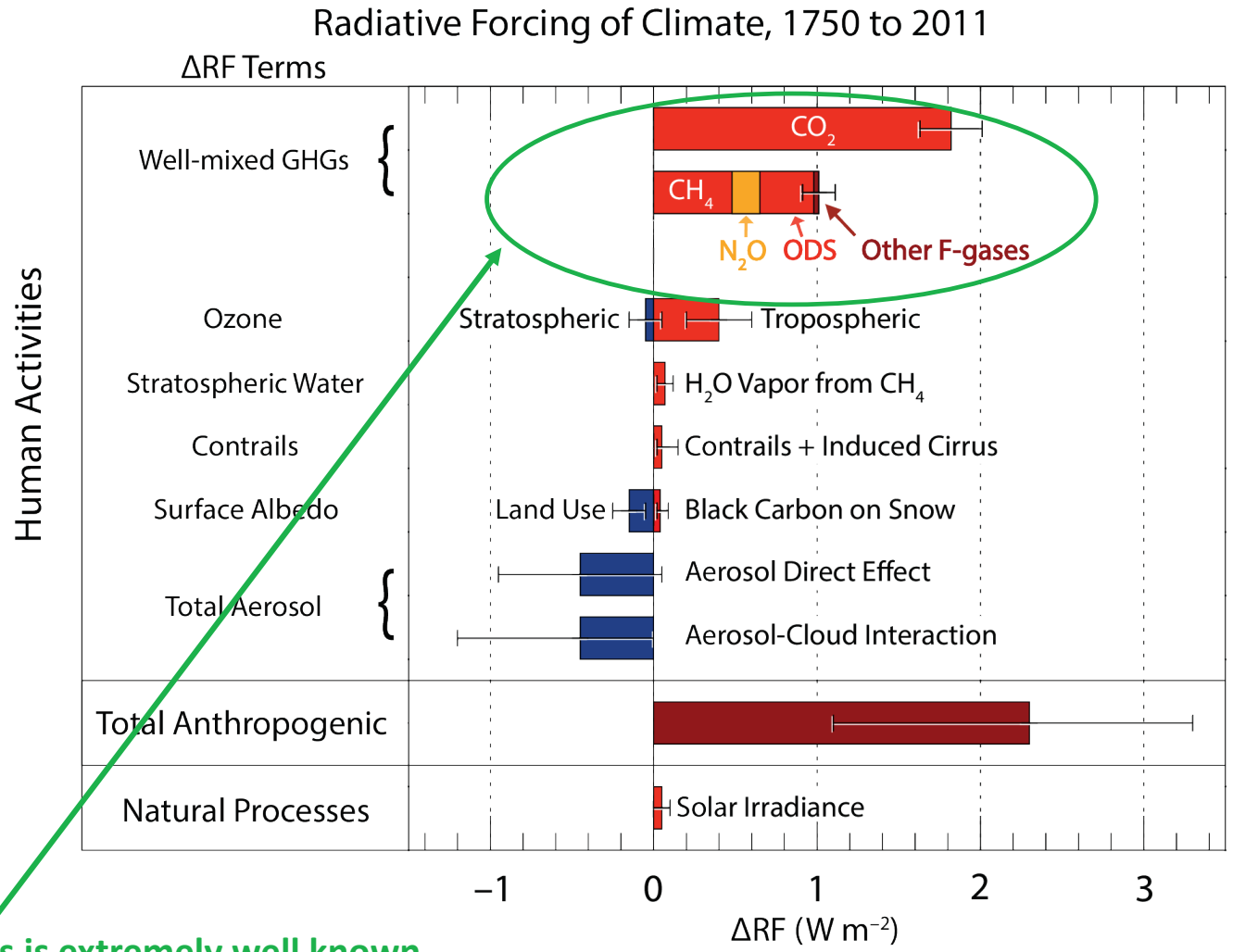
https://upload.wikimedia.org/wikipedia/commons/4/4c/Thermohaline_Circulation_2.png

Thermohaline Circulation



http://www.whoi.edu/cms/images/oceanus/2006/11/nao-en_33957.jpg

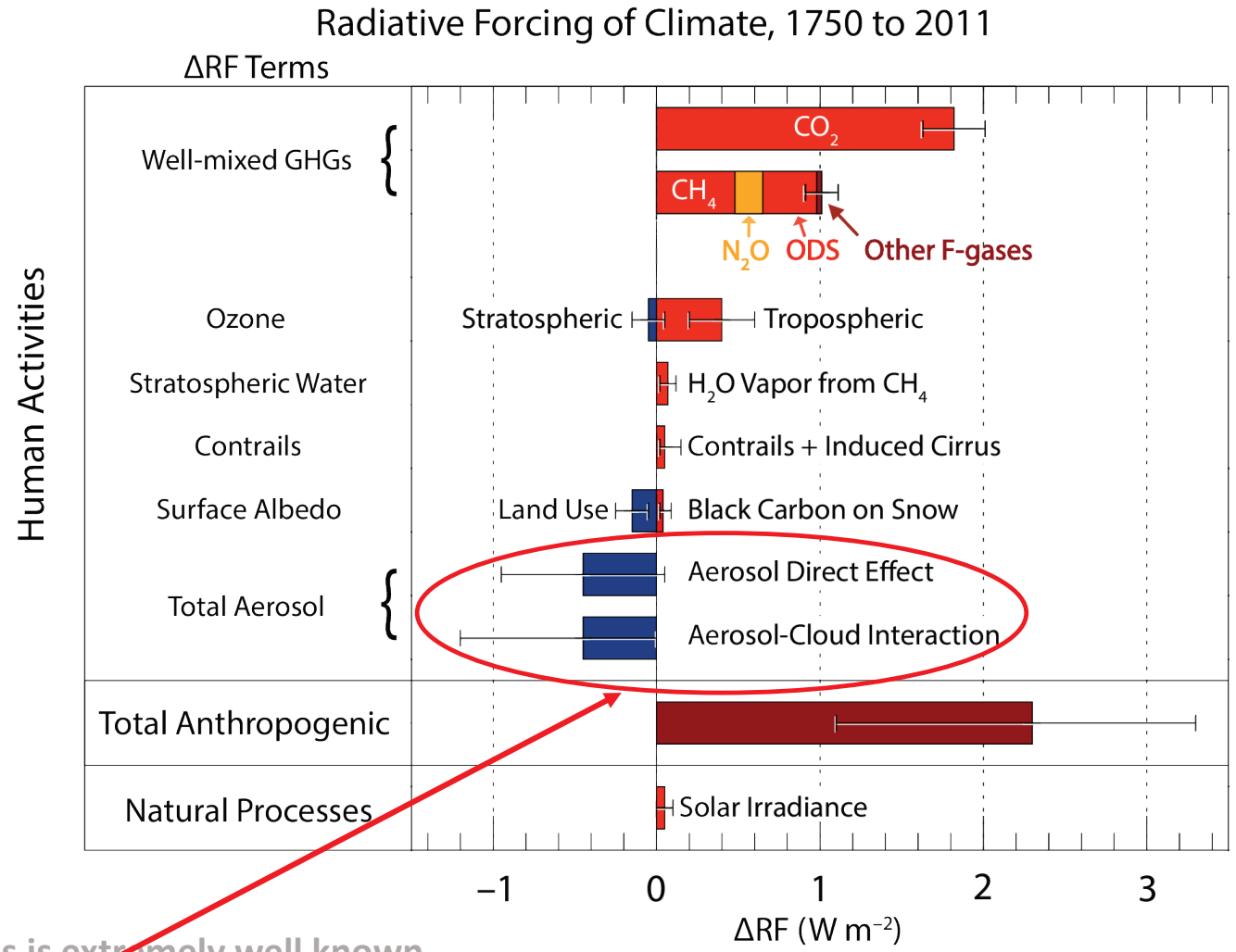
Climate Science 101



ΔRF due to GHGs is extremely well known

Fig 1.4, *Paris Climate Agreement: Beacon of Hope*

Climate Science 101



ΔRF due to GHGs is extremely well known

ΔRF due to aerosols (suspended particulate matter) is not well known.

Fig 1.4, *Paris Climate Agreement: Beacon of Hope*

Three Futures

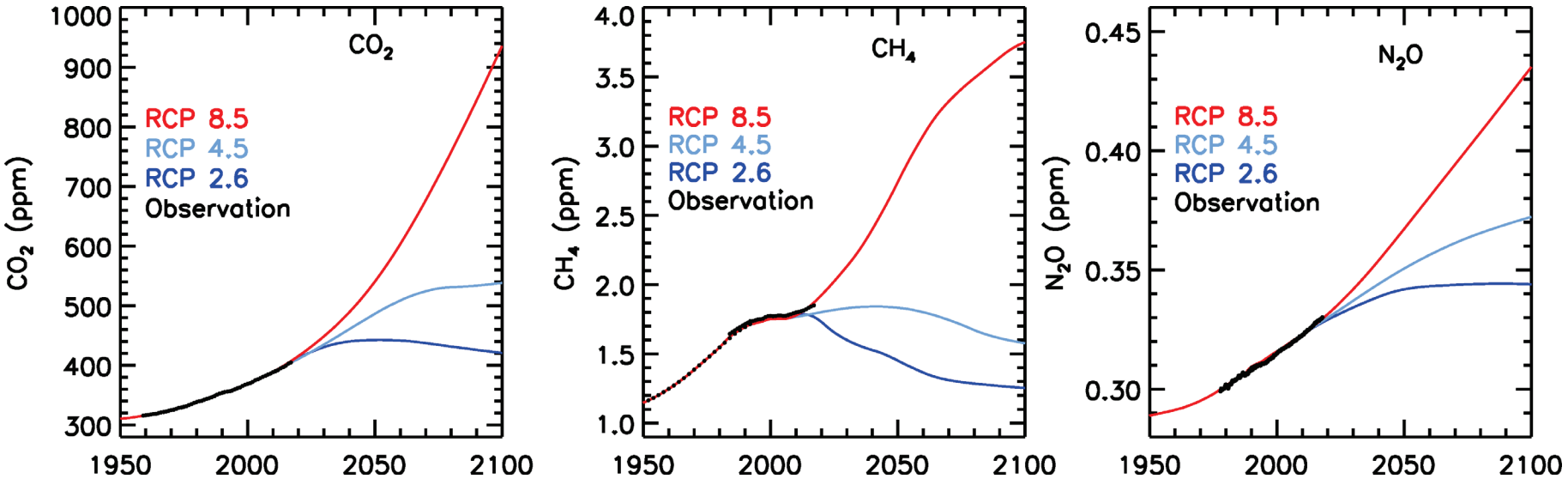


Fig 2.1, update
Paris Climate Agreement: Beacon of Hope

RCP: **R**epresentative **C**oncentration **P**athway
Number represents W m^{-2} RF of climate at end of century

Simple Climate Model

$$\Delta T = \lambda_{BB} (1 + \text{Feedback}) \times (\Delta RF_{GHGs} + \Delta RF_{Aerosols})$$

where

$\lambda_{BB} = 0.3$ K / W m^{-2}

ΔRF_{GHGs} = Rise in RF of climate due to all GHGs

$\Delta RF_{Aerosols}$ = Decline in RF of climate due to human aerosols

Feedback = Net Effect of Changes Due to Water, Lapse Rate, Clouds, Surface Reflectivity, Ocean Circulation, etc.

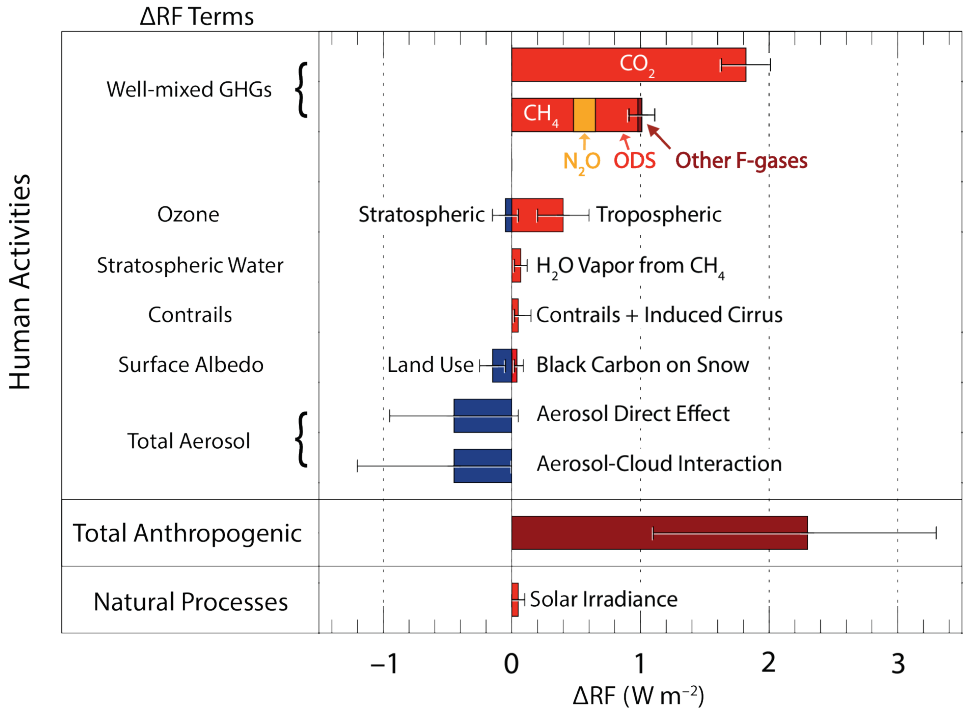


Fig 1.4, Salawitch *et al.*, Paris Climate Agreement: Beacon of Hope, 2017.

Greta Thunberg

Uncertainty in RF due to aerosols is a huge complication

RF due to all GHGs

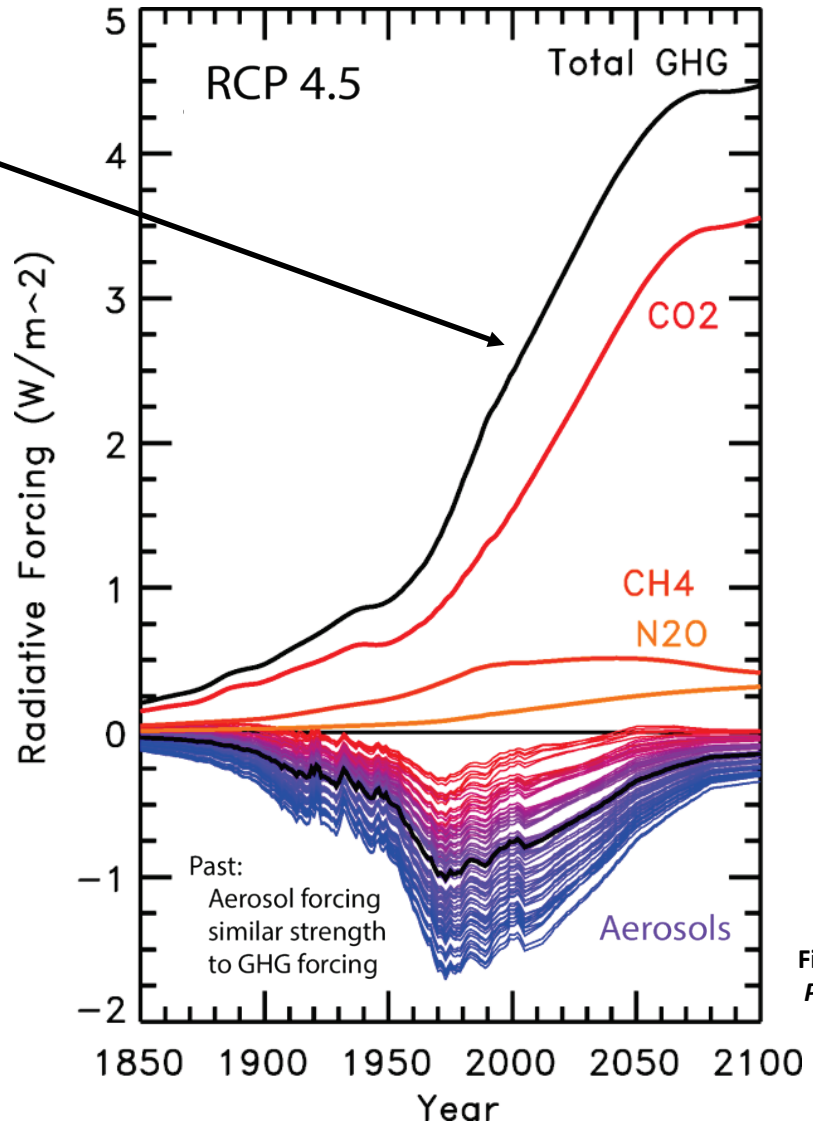


Fig 1.10,
Paris Climate Agreement: Beacon of Hope

Uncertainty in RF due to aerosols is a huge complication

RF due to all GHGs minus RF due to Aerosols, for curve with –0.4 W m^{-2} in year 2011

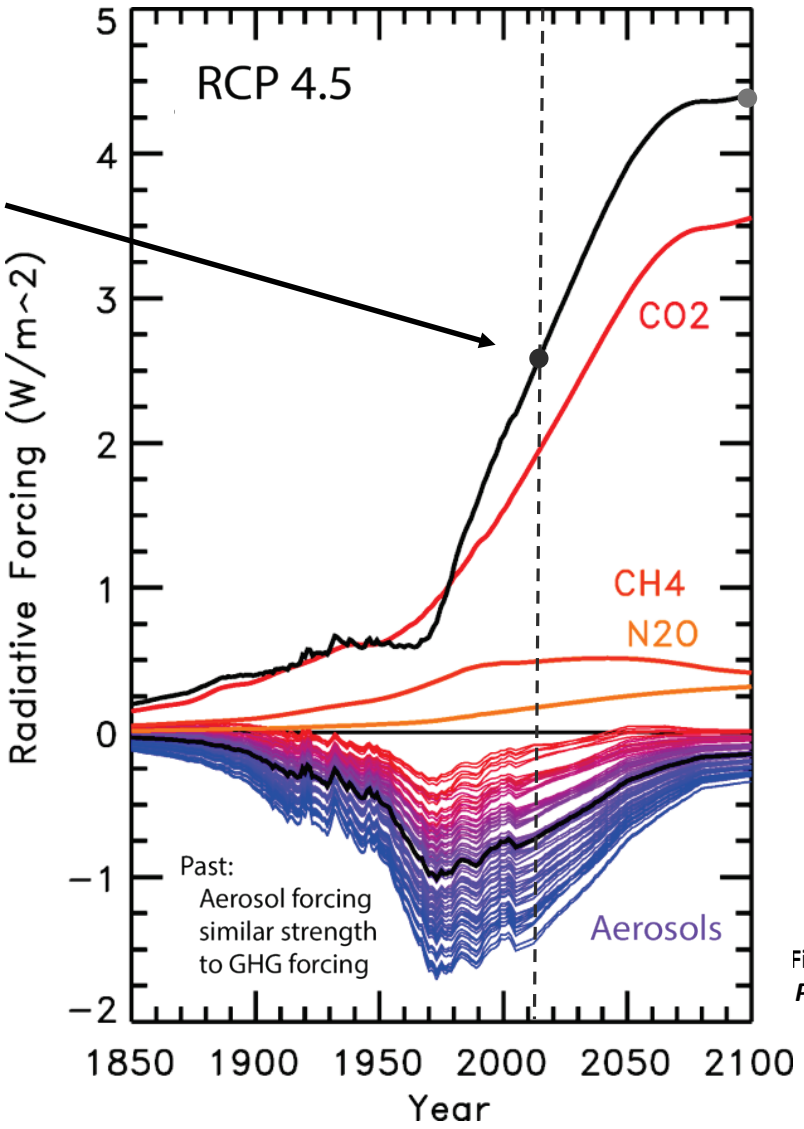


Fig 1.10 modified,
Paris Climate Agreement: Beacon of Hope

27

Uncertainty in RF due to aerosols is a huge complication

RF due to all GHGs minus RF due to Aerosols, for curve with –0.9 W m^{-2} in year 2011

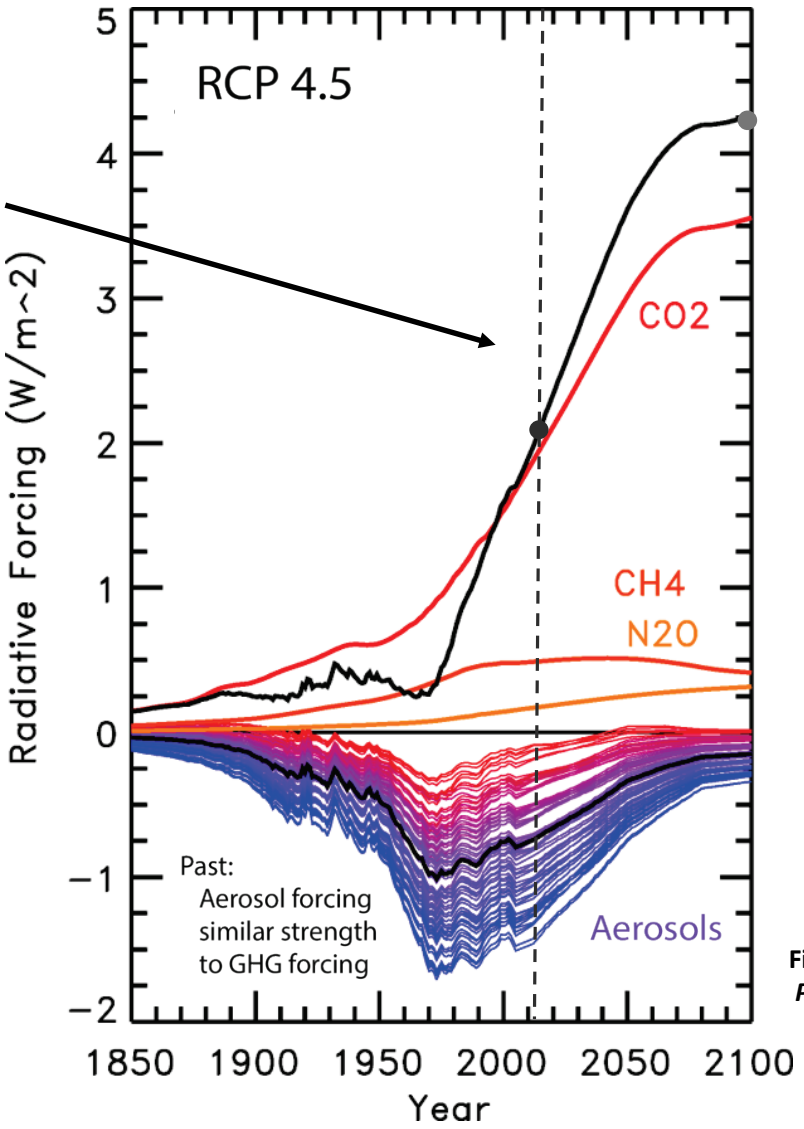


Fig 1.10 modified,
Paris Climate Agreement: Beacon of Hope

Uncertainty in RF due to aerosols is a huge complication

RF due to all GHGs minus RF due to Aerosols, for curve with –1.5 W m^{-2} in year 2011

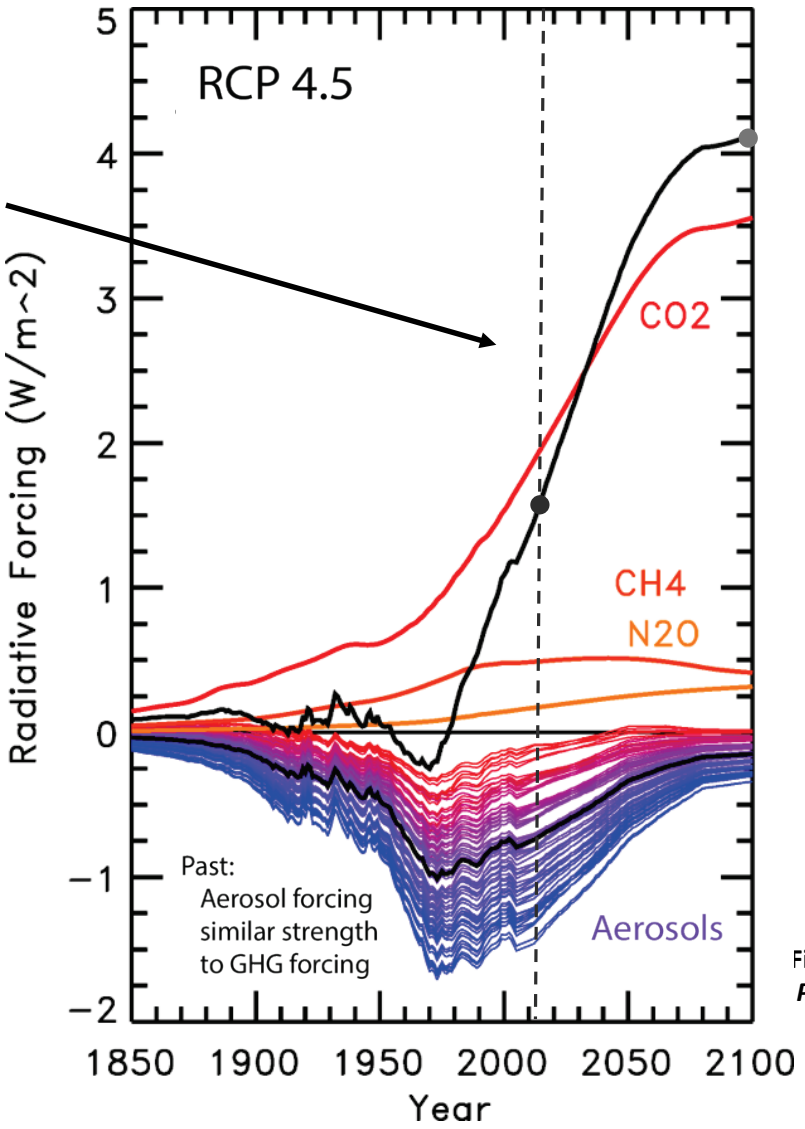
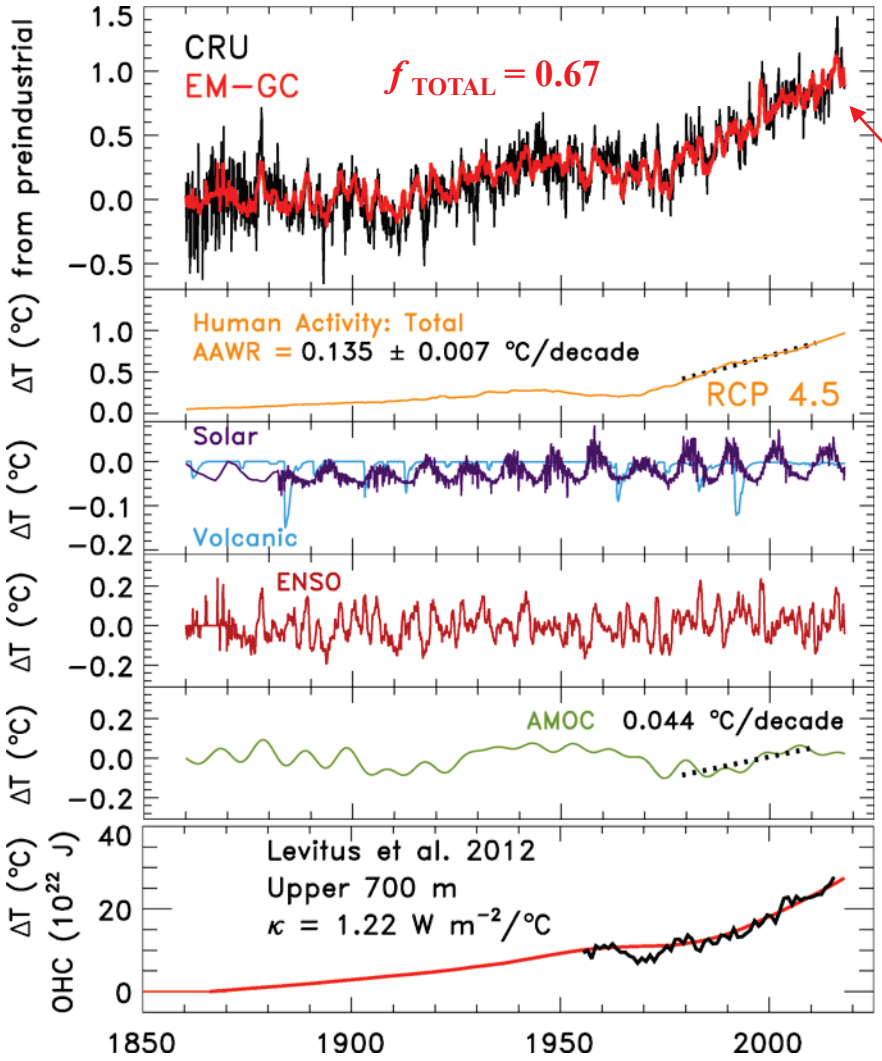


Fig 1.10 modified,
Paris Climate Agreement: Beacon of Hope

29

Empirical Model of Global Climate (EM-GC)



$$\Delta T_{MDL\,i} = (1 + f_{TOTAL})\lambda_{BB}(GHG\ RF_i + LUC\ RF_i + Aerosol\ RF_i) + C_0 + C_1 \times SOD_{i-6} + C_2 \times TSI_{i-1} + C_3 \times ENSO_{i-2} + C_4 \times AMOC_i - \lambda_{BB}\, Q_{OCEAN_i}$$

where:

i = month

$\lambda_{BB} = 0.3\ °C / W\ m^{-2}$

$$1 + f_{TOTAL} = \frac{1}{1 - FB_{\Sigma}\,\lambda_{BB}}$$

FB_{Σ} = Sum of All Feedbacks, i.e.,

$FB_{\Sigma} = FB_{WV} + FB_{LR} + FB_{SURFACE\ ALBEDO} + FB_{CLOUDS}$

in units of $W\ m^{-2}\ °C^{-1}$

Aerosol RF = total RF due to Tropospheric Aerosols

LUC RF = RF due to Land Use Change

SOD = Stratospheric Optical Depth

TSI = Total Solar Irradiance

ENSO = El Niño Southern Oscillation

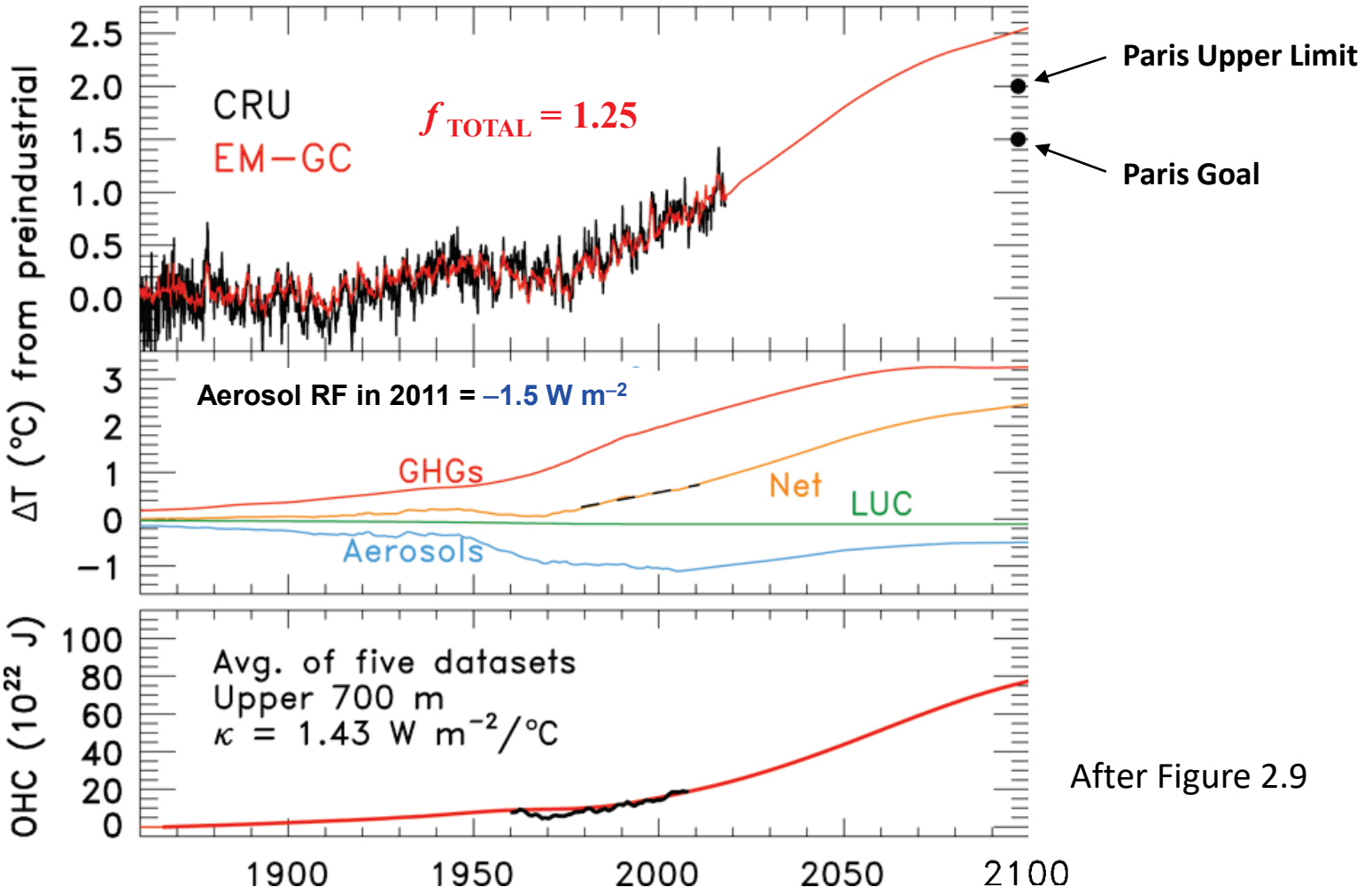
AMOC = Atlantic Meridional Overturning Circ.

Q_{OCEAN} = Ocean heat export =

$\kappa(1 + f_{TOTAL})\{\Delta T_{MDL\,i} - \Delta T_{OCEAN\ SURFACE\ i}\}$

Canty *et al.*, *ACP*, 2013 https://www.atmos-chem-phys.net/13/3997/2013/acp-13-3997-2013.html
updated by Austin Hope & Laura McBride

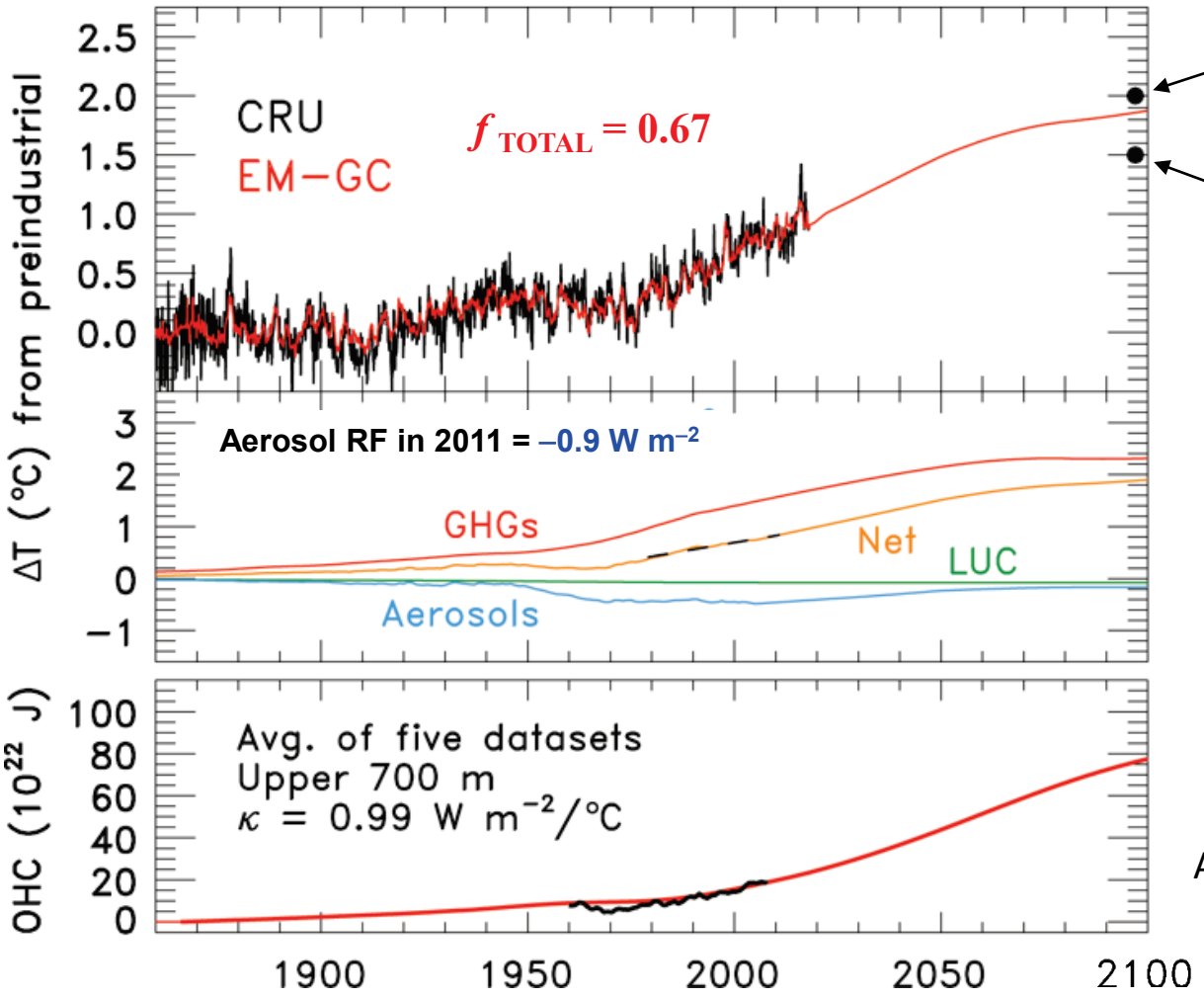
EM-GC Forecast for RCP 4.5 GHG scenario



After Figure 2.9

We assume that whatever value of climate feedback is inferred from the climate record will persist into the future. For Aerosol RF in 2011 of **–1.5 W m^{-2}** & assuming best estimate for H_2O and Lapse Rate feedback is correct, this simulation implies sum of other feedbacks (clouds, surface albedo) must be ***strongly positive***.

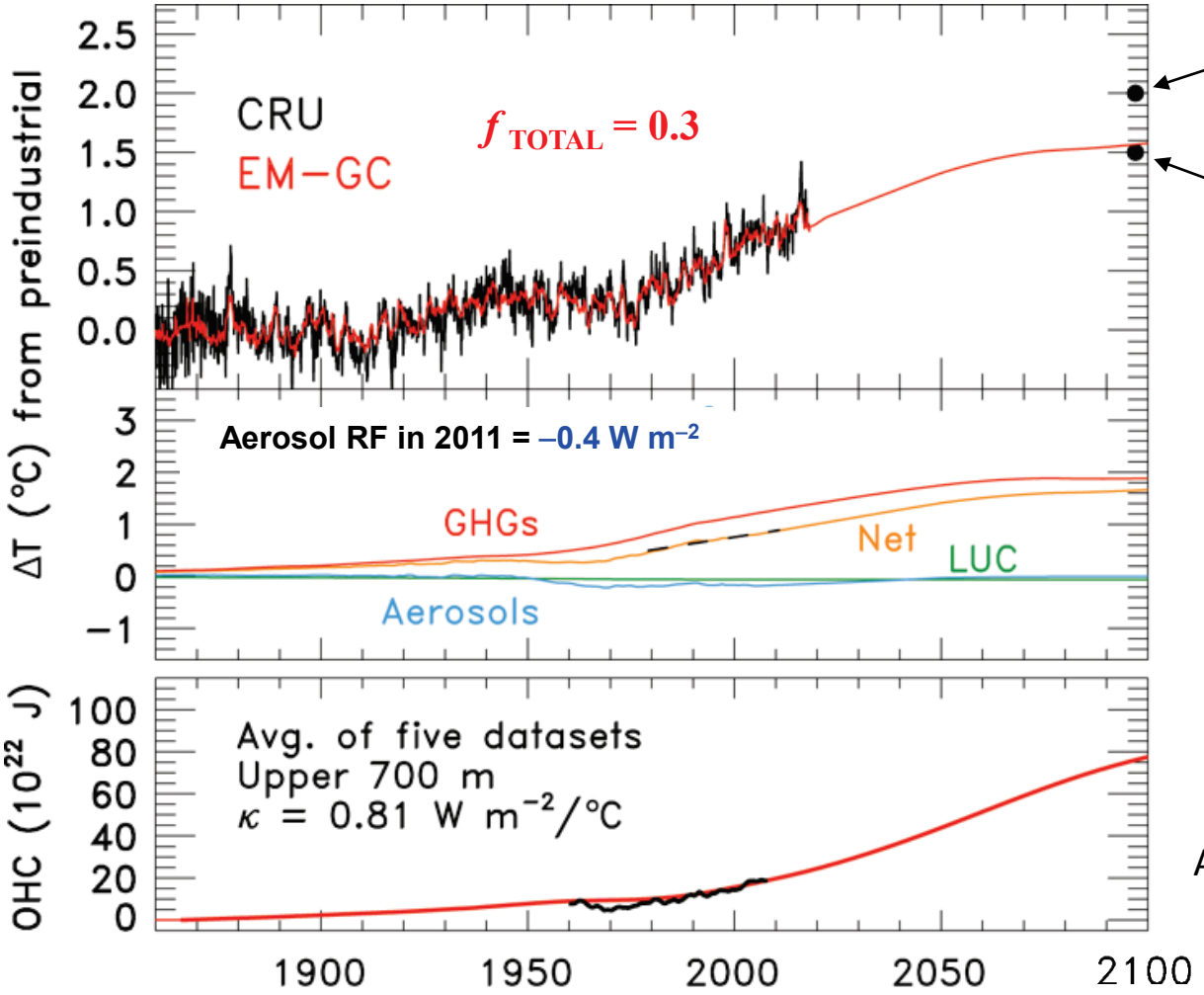
EM-GC Forecast for RCP 4.5 GHG scenario



After Figure 2.9

We assume that whatever value of climate feedback is inferred from the climate record will persist into the future. For Aerosol RF in 2011 of **–0.9 W m^{-2}** & assuming best estimate for H_2O and Lapse Rate feedback is correct, this simulation implies sum of other feedbacks (clouds, surface albedo) must be ***slightly positive***.

EM-GC Forecast for RCP 4.5 GHG scenario



After Figure 2.9

We assume that whatever value of climate feedback is inferred from the climate record will persist into the future. For Aerosol RF in 2011 of **–0.4 W m^{-2}** & assuming best estimate for H_2O and Lapse Rate feedback is correct, this simulation implies sum of <u>other feedbacks</u> (clouds, surface albedo) must be ***negative***.

Uncertainty in RF due to aerosols is a complication that places a fundamental uncertainty on how well future global warming can be forecast

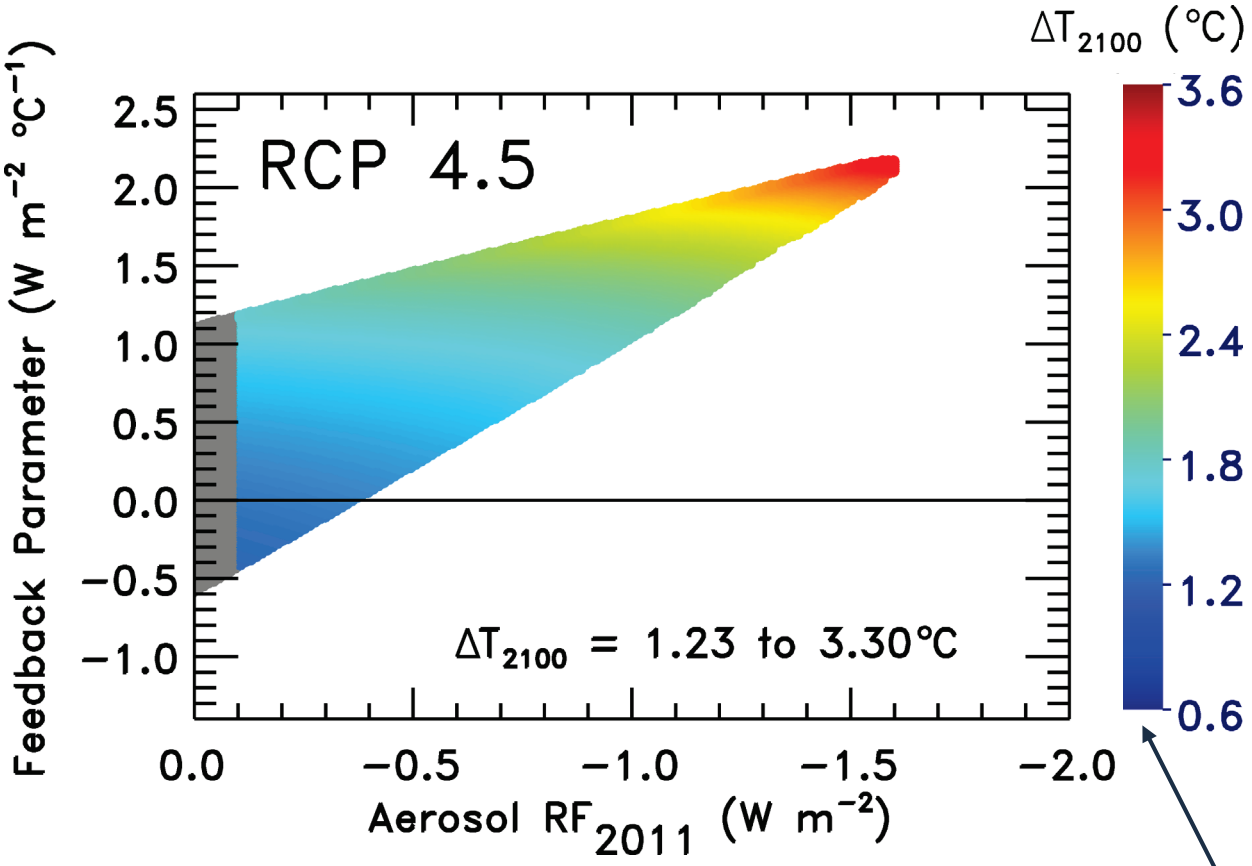


Fig 2.15 (updated) *Paris Climate Agreement: Beacon of Hope*

FB_Σ units W m^{-2} $°C^{-1}$ on EM-GC description slide

ΔT is rise in GMST (Global Mean Surface Temperature) relative to pre-industrial