PROF. DR MICHAELA I. HEGGLIN | HERAEUS SEMINAR | 19 JUNE 2023
FORSCHUNGSZENTRUM JÜLICH | BERGISCHE UNIVERSITÄT WUPPERTAL | UNIVERSITY OF READING

INFORMATION ON CLIMATE CHANGE
FROM MODELS TO OBSERVATIONS

JÜLICH
Forschungszentrum

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INFORMATION ON CLIMATE CHANGE
DO WE NEED TO CHANGE OUR APPROACH?

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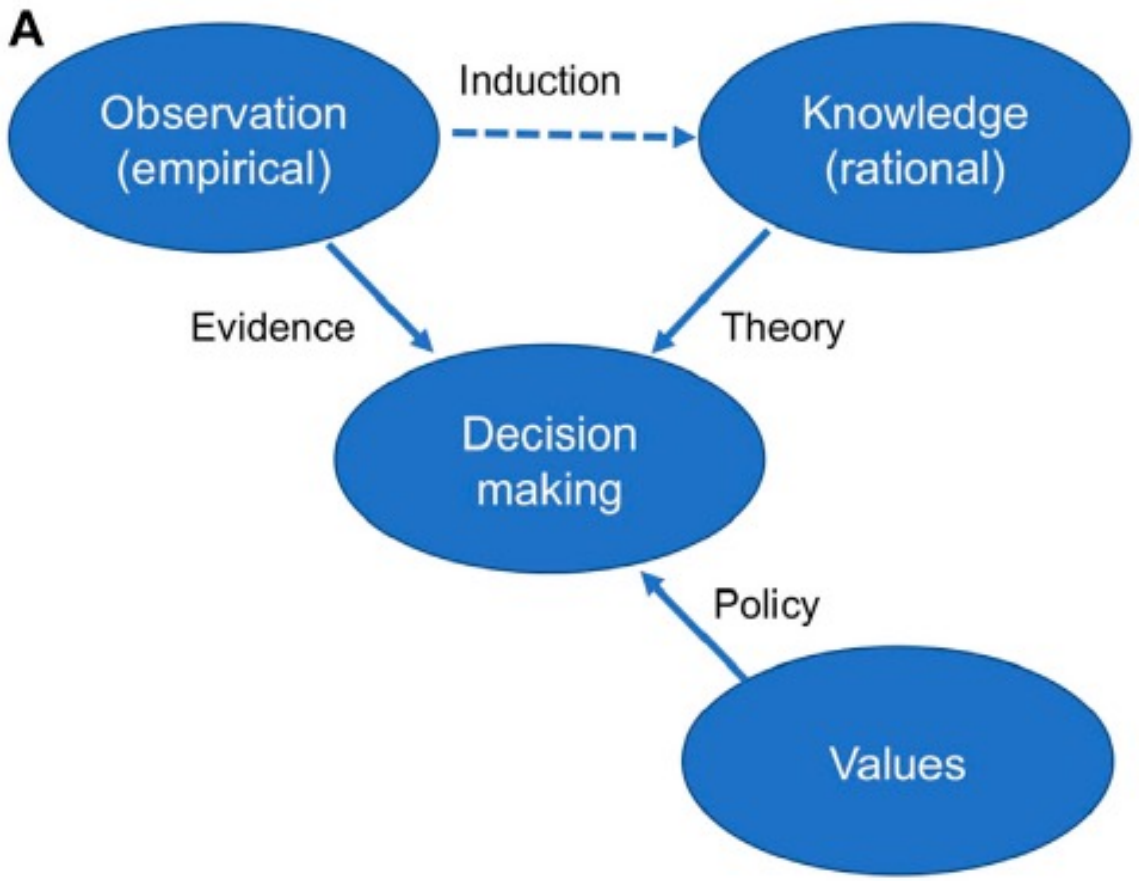
OUTLINE

The use of Earth observations in climate science

- What is the traditional use of Earth observations in climate change science?
- Climate change information from models – What will the future bring?
- The role of Earth observations in capturing climate change – What is the present?
- Transformation of our science approach
- Parallels from the Montreal Protocol (ozone depletion)
- Key points and conclusions

TRADITIONAL SCIENCE APPROACH

Earth observation in climate change science



Traditional approach:

- Moves from the specific to the general (**inductive approach**) to create scientific knowledge.
- Theoretical knowledge **(theory)** informs **decision making**.
- Earth observations (EO) are used as **evidence** for the theory, which places a premium on the credibility of EO.

Hegglin et al., Frontiers of Environmental Sciences 2022

THE CONCEPT OF THE GREENHOUSE EFFECT

Historical development

Joseph Fourier, 1824

- First to introduce the concept of a greenhouse effect.

there exists a physical cause always present which modifies the temperature at the surface of the earth, and gives this planet a fundamental heat, which is both independent of the action of the sun and that internal heat preserved in its own center.

FIRST OBSERVATIONS ON THE ABSORPTION OF LIGHT

Historical development

382 *On the Heat in the Sun's Rays.*

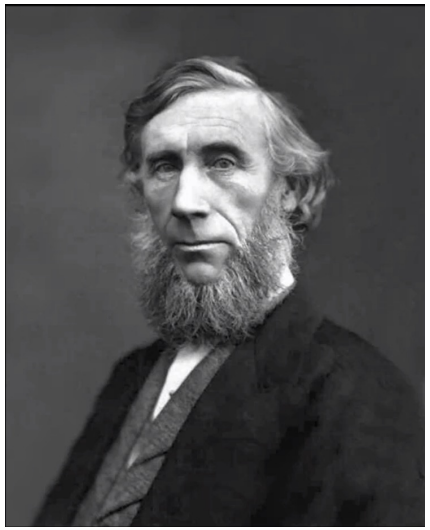
ART. XXXI.—*Circumstances affecting the Heat of the Sun's Rays;* by EUNICE FOOTE.

(Read before the American Association, August 23d, 1856.)

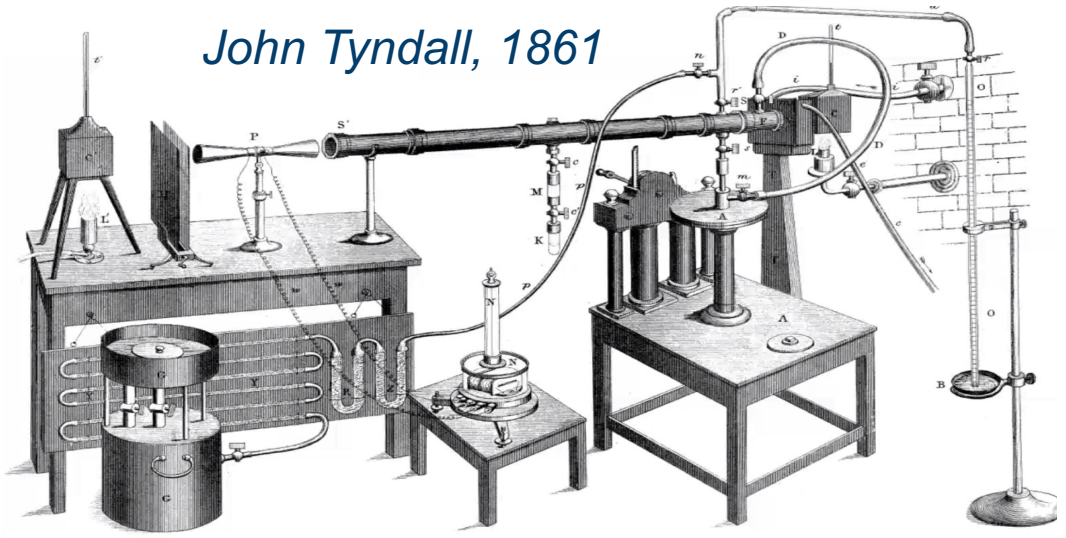
MY investigations have had for their object to determine the different circumstances that affect the thermal action of the rays of light that proceed from the sun.

Eunice Newton Foote, 1856

- Demonstrated the **characteristic** of different gases (greenhouse gases) **to absorb** light (Foote), and infrared radiation (Tyndall).



John Tyndall, 1861



EARLY DETECTION & ATTRIBUTION OF CLIMATE CHANGE

Historical development

Guy Callendar, 1938

- Was the first to show that the **Earth was warming** and related it to an observed increase in CO_2.

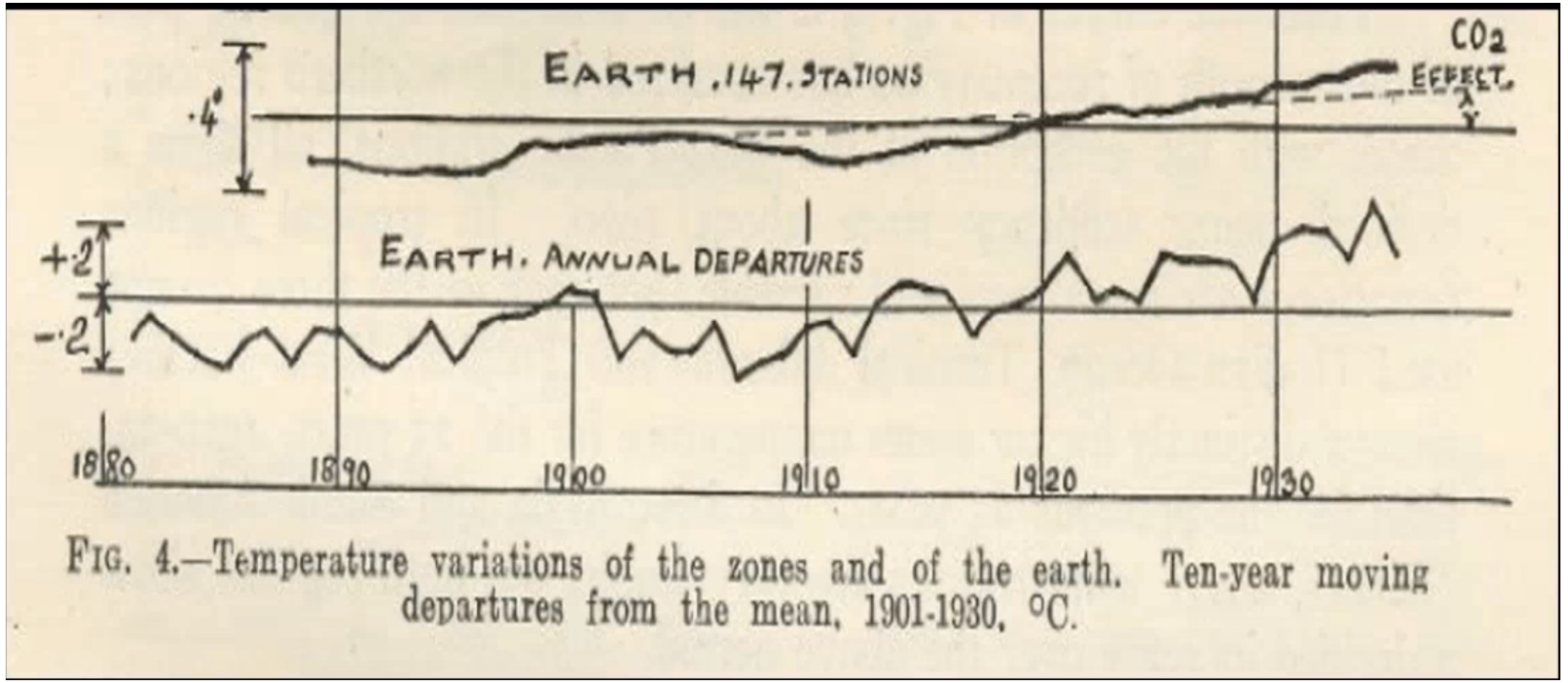


FIG. 4.—Temperature variations of the zones and of the earth. Ten-year moving departures from the mean, 1901-1930. °C.

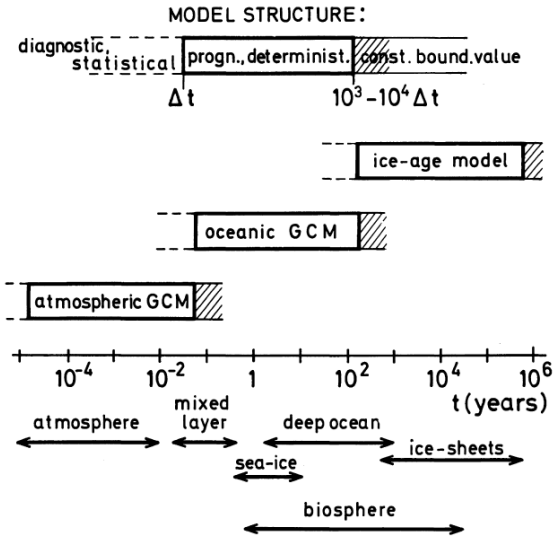
2021 NOBEL PRIZE FOR PHYSICS

*"… for the **physical modelling** of Earth's climate, quantifying variability, and reliably predicting global warming."*

Klaus Hasselmann (along with **Syukuro Manabe** and Giorgio Parisi)

- Showed how weather (which is chaotic) can be incorporated into a model to frame longer-term climate changes.
- Developed statistical techniques that allowed identification of the human-driven part of these warming signals.

→ **Thus laid the basis for today's detection and attribution science!**

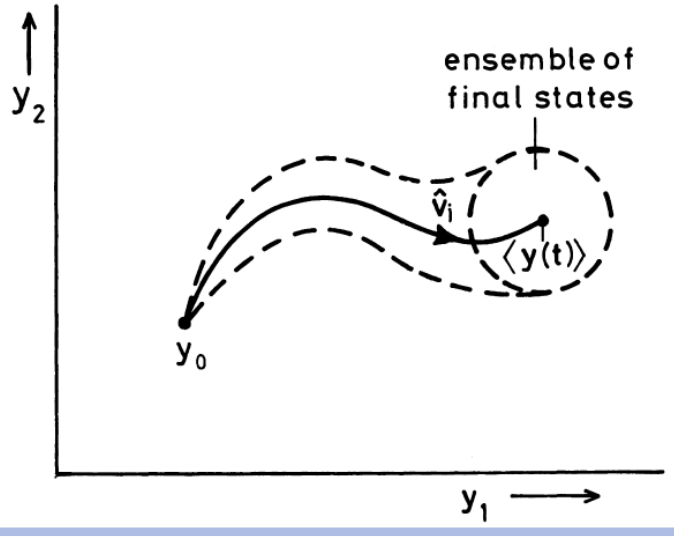


$$\frac{\partial p}{\partial t} + \frac{\partial}{\partial y_i}(v_i p) - \frac{\partial}{\partial y_i}\left(D_{ij}\frac{\partial p}{\partial y_j}\right) = 0$$

(top) Fokker-Planck equation for the climate probability density p(y), determined by mean dispersion and forcing.

(left) Time scales of climatic system and bandwidth covered by particular models.

(right) Evolution of ensemble of climate states in climate phase space y from a given initial state y_0.



***Hasselmann*, Developments in Atmospheric Science 1979**

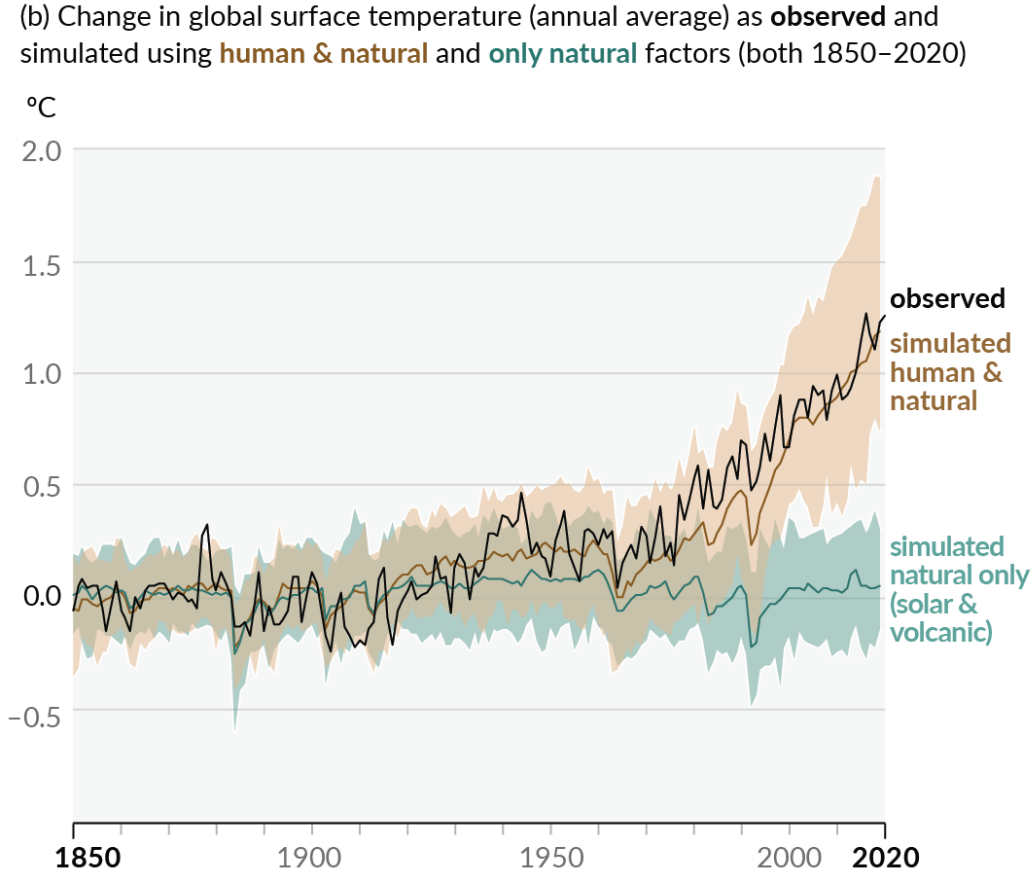
DETECTION AND ATTRIBUTION IN IPCC

From the IPCC Good Practice Guidance Paper on *Detection and Attribution Related to Anthropogenic Climate Change* (Hegerl et al., IPCC 2010)

- Problem: '*Experiment Earth*' does not exist. There is only one realization and observations have long been sparse.

→ Thus:

"To avoid selection bias in studies, it is vital that the data are not preselected based on observed responses, but instead chosen to represent regions / phenomena / timelines in which responses are expected, based on process-understanding."



IPCC AR6 SPM, 2021

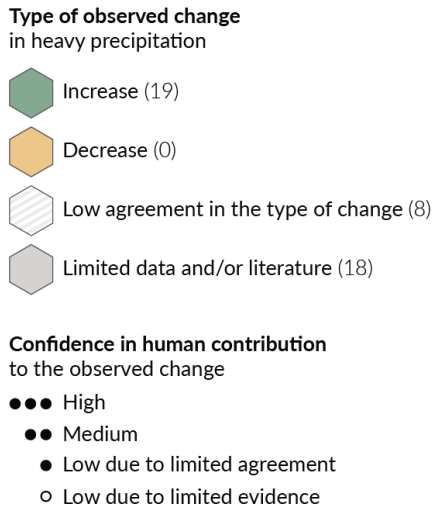
PAST GLOBAL CHANGES IN EXTREME EVENTS

From the Summary for Policymakers (IPCC AR6, SPM, Figure 3)

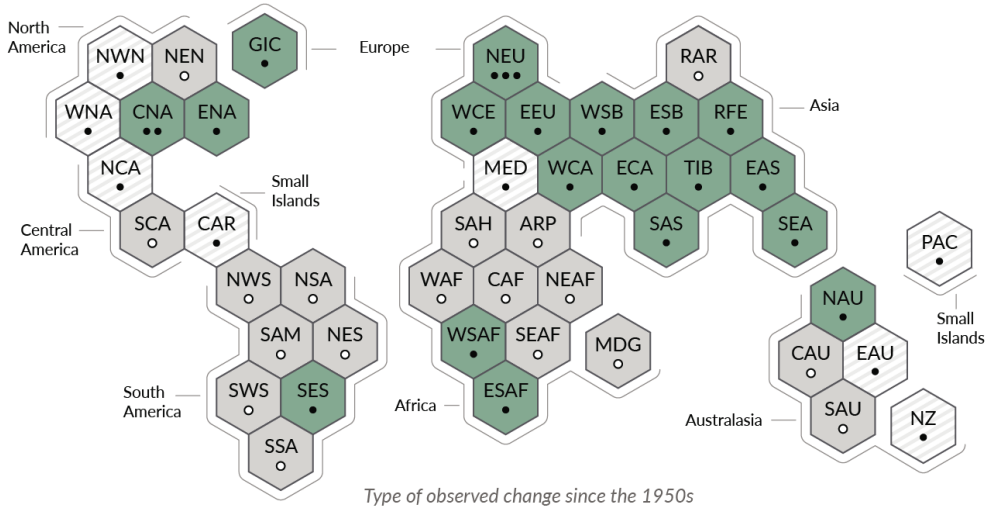
- Leads generally to an overly conservative assessment of climate risk.

  "Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes".

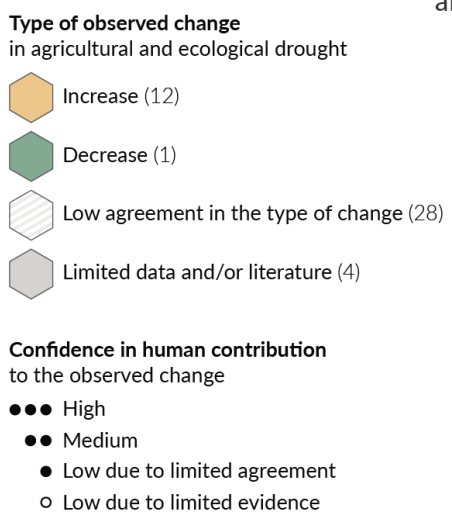
- Shown particularly for hot extremes (the thermodynamics of climate change).
- For **heavy precipitation and droughts**, attribution is less clear due to disagreement between models and/or the lack of evidence (observations).



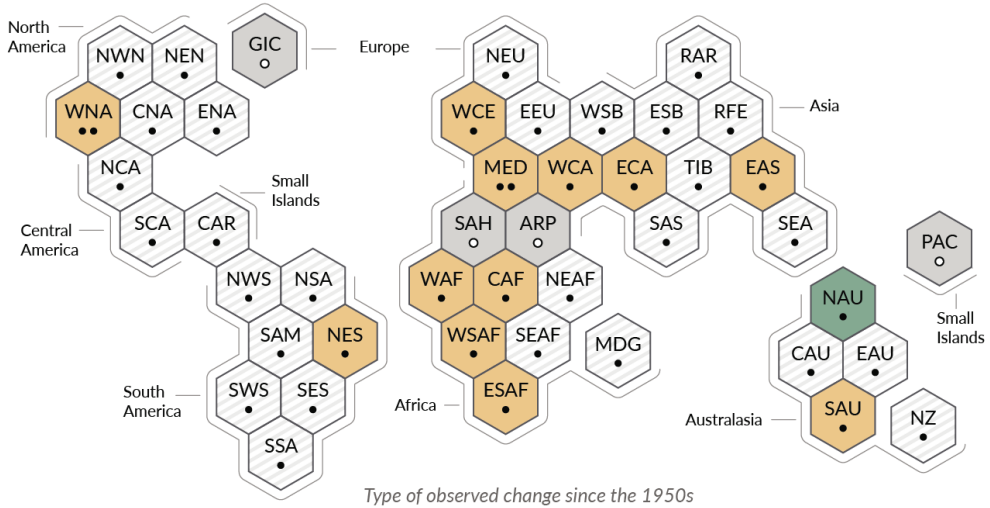
(b) Synthesis of assessment of observed change in **heavy precipitation** and confidence in human contribution to the observed changes in the world's regions



Type of observed change since the 1950s



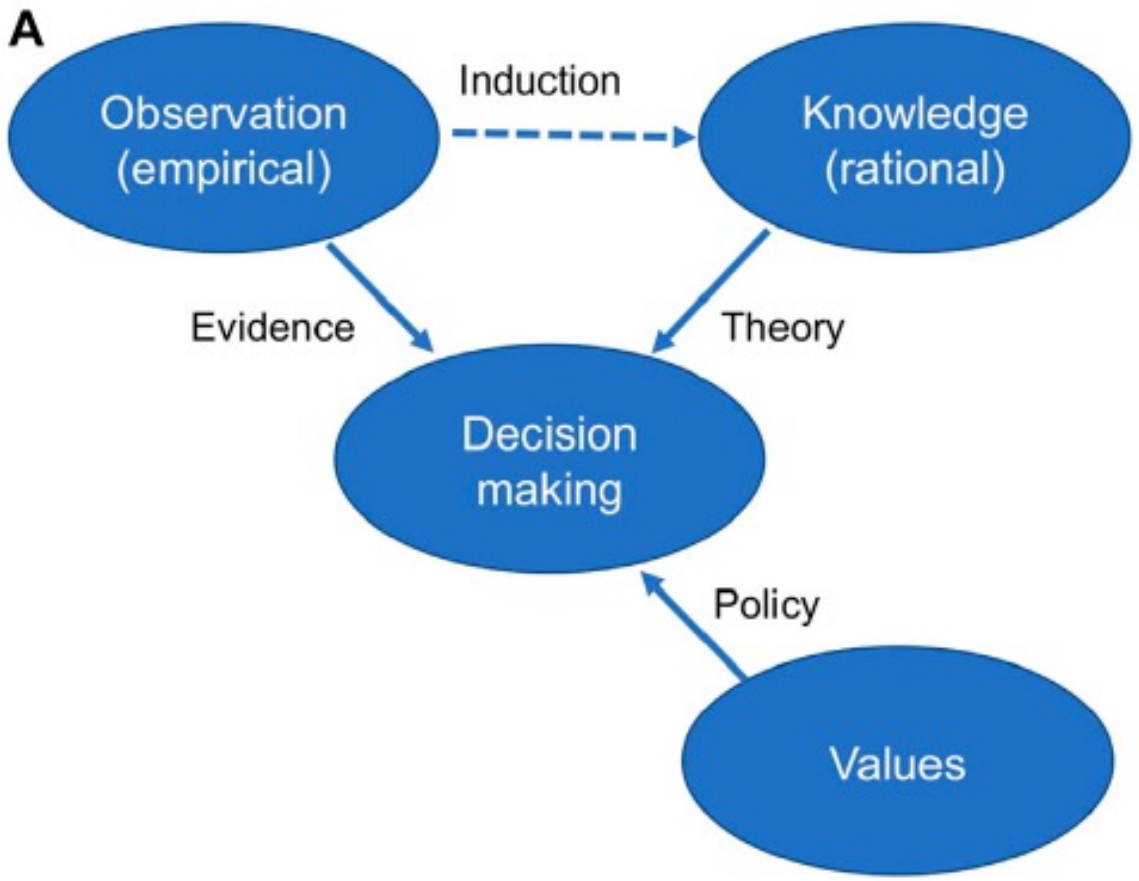
(c) Synthesis of assessment of observed change in **agricultural and ecological drought** and confidence in human contribution to the observed changes in the world's regions



Type of observed change since the 1950s

TRADITIONAL SCIENCE APPROACH

Earth observation in climate change science



Traditional approach:

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- Earth Observation (EO) is used as **evidence** for the theory, which places a premium on the credibility of EO.

→ Thus, *e*vidence from observations for climate change impacts within this framework is hard to come by.

Hegglin et al., Frontiers of Environmental Sciences 2022

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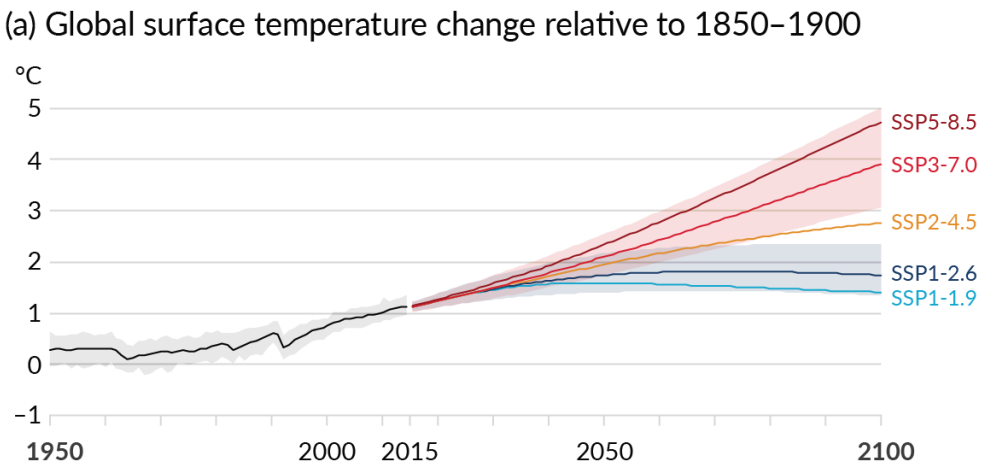
IPCC ON FUTURE CLIMATE CHANGE

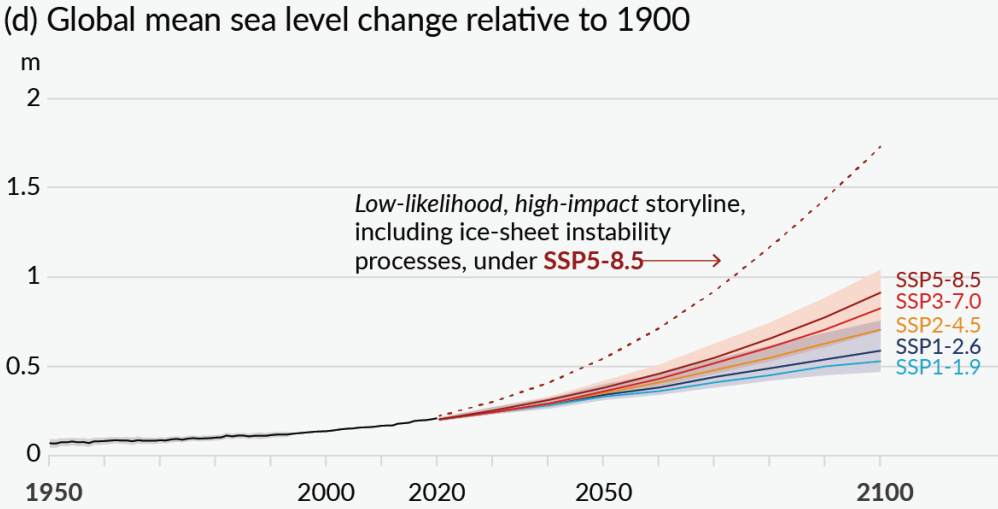
From the IPCC AR6 WGI Summary for Policymakers (Figure 8)

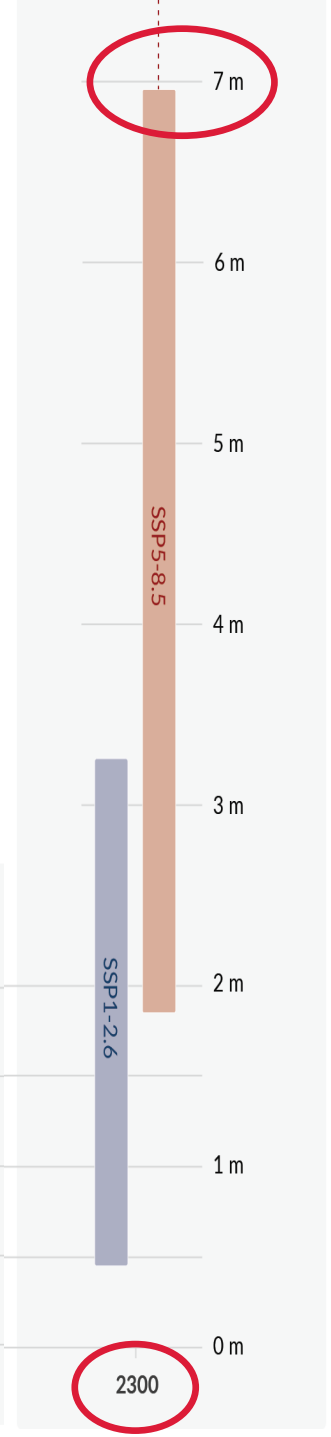
- This then placed the focus on models and future climate changes.

  "Human activities affect all the major climate system components, with some responding over decades and others over centuries."

- Tends to **remove urgency** by referring to 2100 and beyond.
- Makes climate change look **gradual**.







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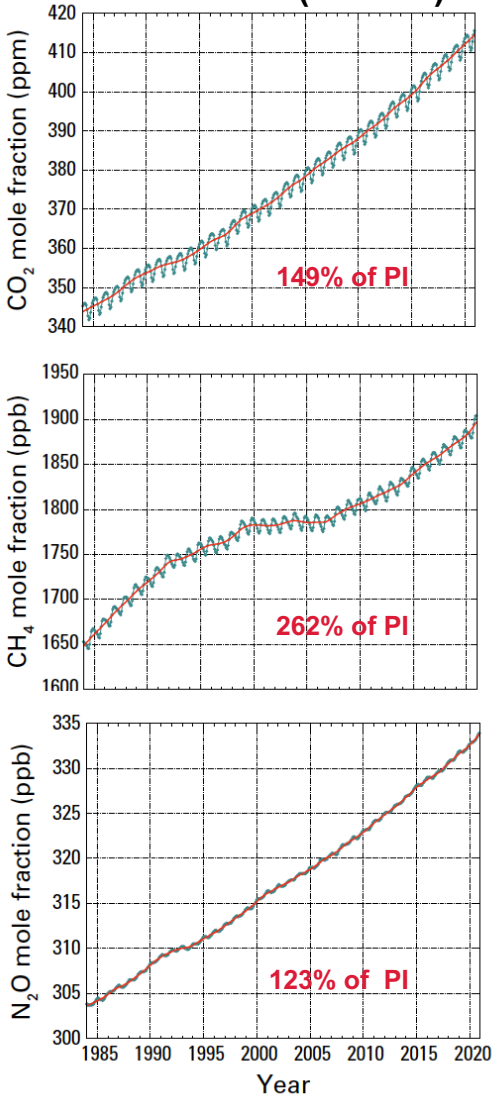
THE OLD APPLICATION OF EARTH OBSERVATIONS

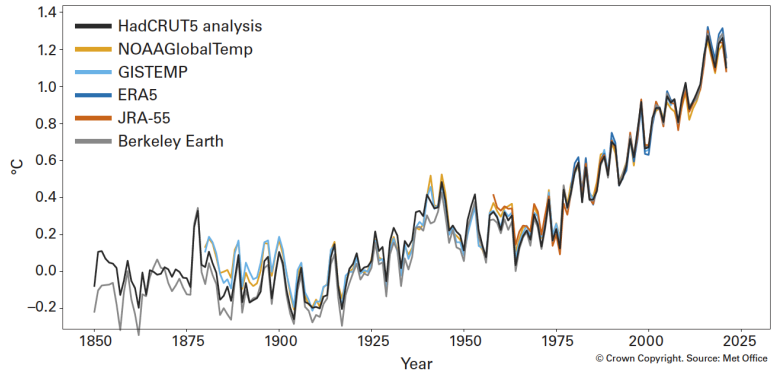
USES GLOBALLY AGGREGATED DATA AS EVIDENCE

The *Big Seven* indicators documenting climate change

Main GHGs (drivers)

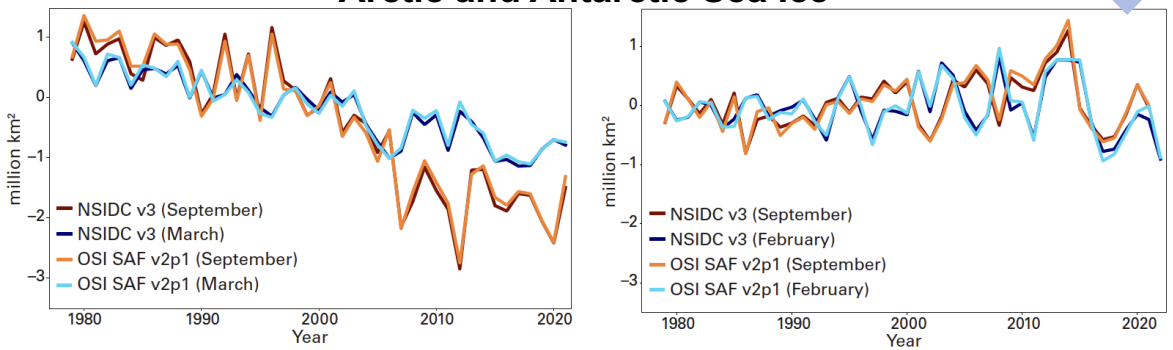


Global Mean Surface Temperature (effect)

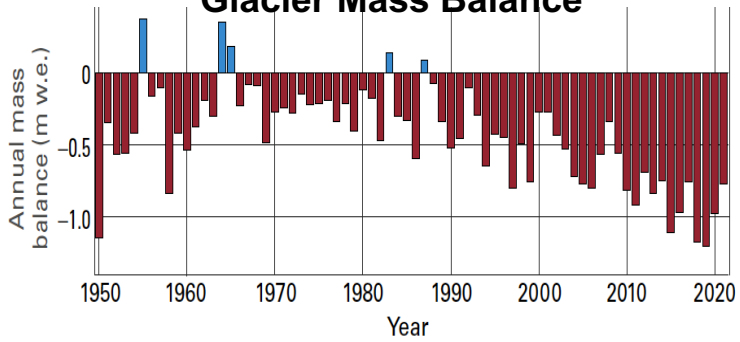


Other Climate Impact Drivers

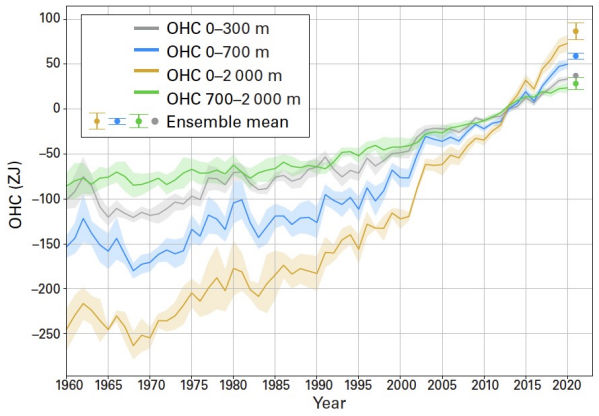
Arctic and Antarctic Sea Ice



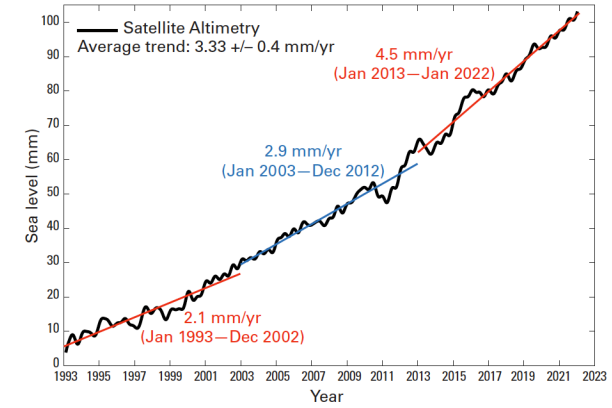
Glacier Mass Balance



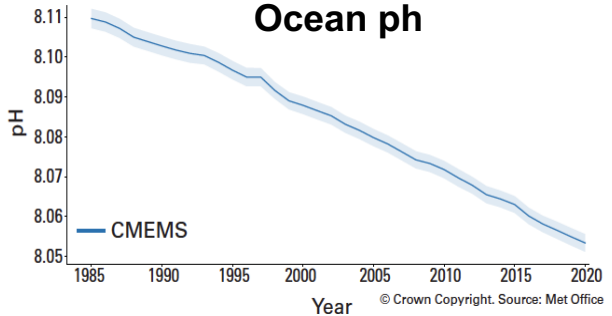
Ocean Heat Content



Sea Level



Ocean ph

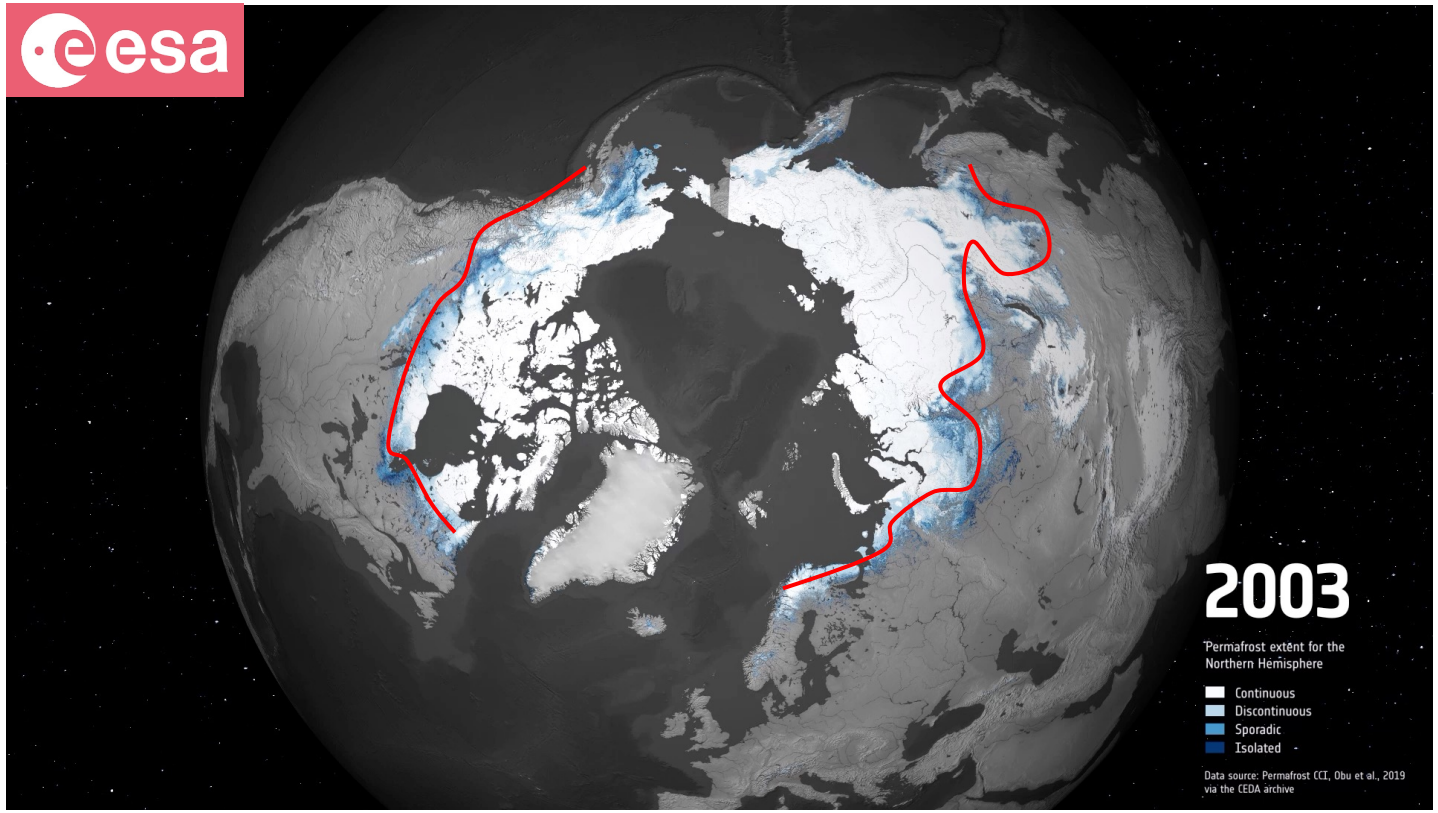


THE NEW APPLICATION OF EO: FROM GLOBAL TO LOCAL

REGIONAL INFORMATION ON CLIMATE CHANGE

Permafrost

- Warming is strongest at high latitudes (polar regions) and high altitudes (mountains).
- Permafrost thawing leads to destabilization of the ground and resulting geohazards.
- Also predicted to release methane stored in the ground – a positive climate feedback.



ESA Permafrost Climate Change Initiative (using land surface temperature and land cover observations)

Obu et al., 2019

REGIONAL INFORMATION ON CLIMATE CHANGE

Deforestation

- Forests are a natural reservoir of carbon.
- Land use change such as deforestation is one of the leading causes for climate change.

Satellite imagery since 1986 reveals the extent of deforestation in the Rondonia region in Brazil between 1986 and 2010.

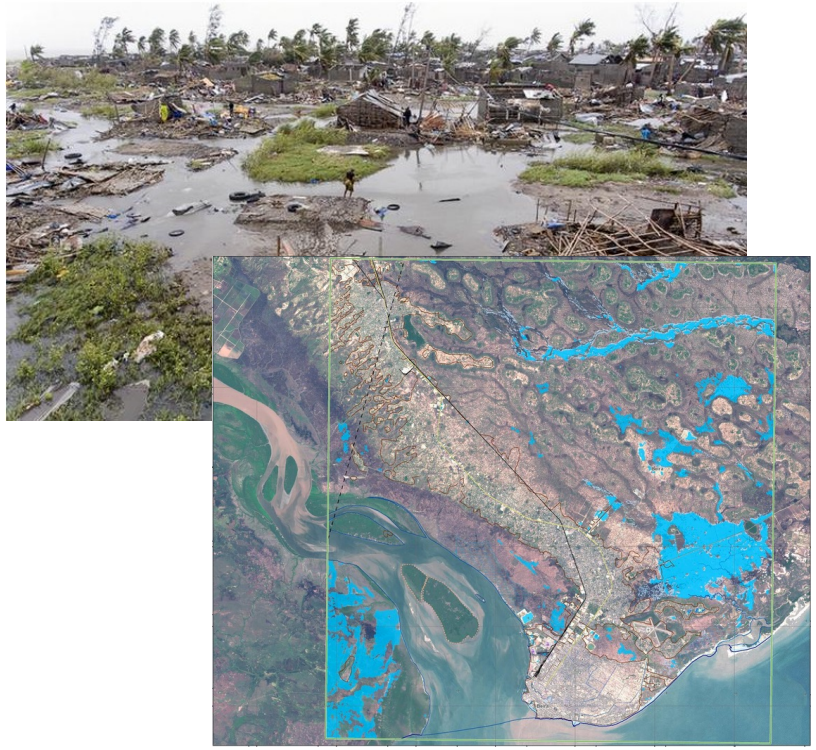
THE NEW APPLICATION OF EO: FROM AGGREGATE TO SINGLE OBSERVATIONS

EXTREME EVENTS

Flooding

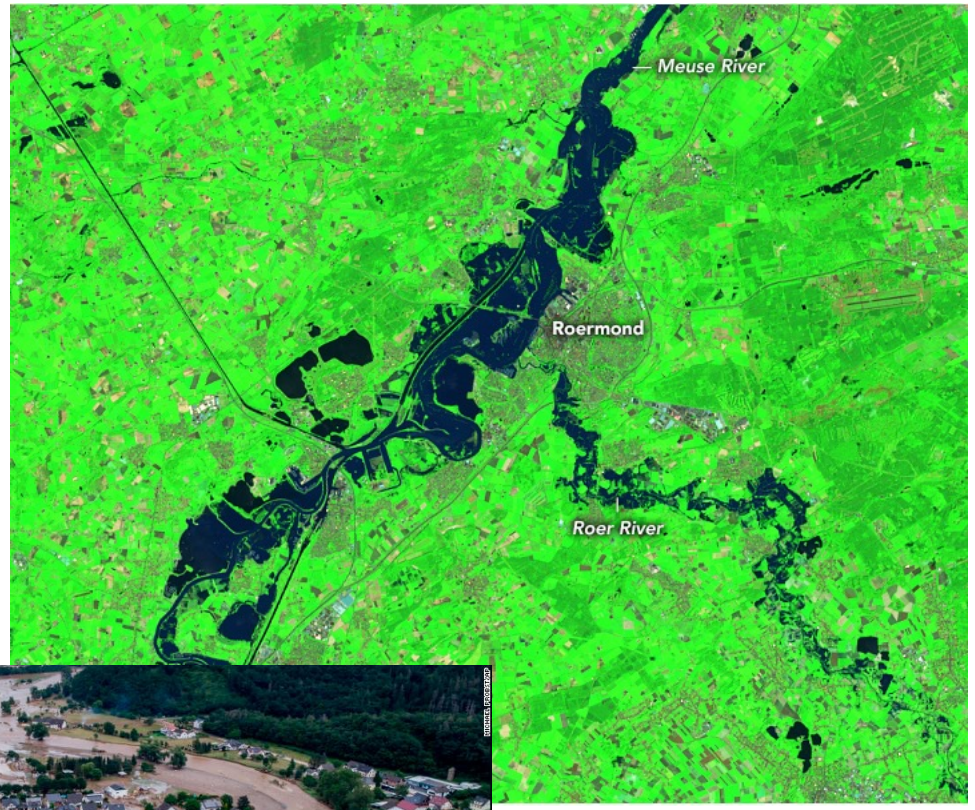
- Extreme events get more frequent and more impactful.
- EO can capture their extent in single pictures.

Cyclone Idai Mozambique 2019



Copernicus Sentinel-1

Floods in Belgium and Germany 2021



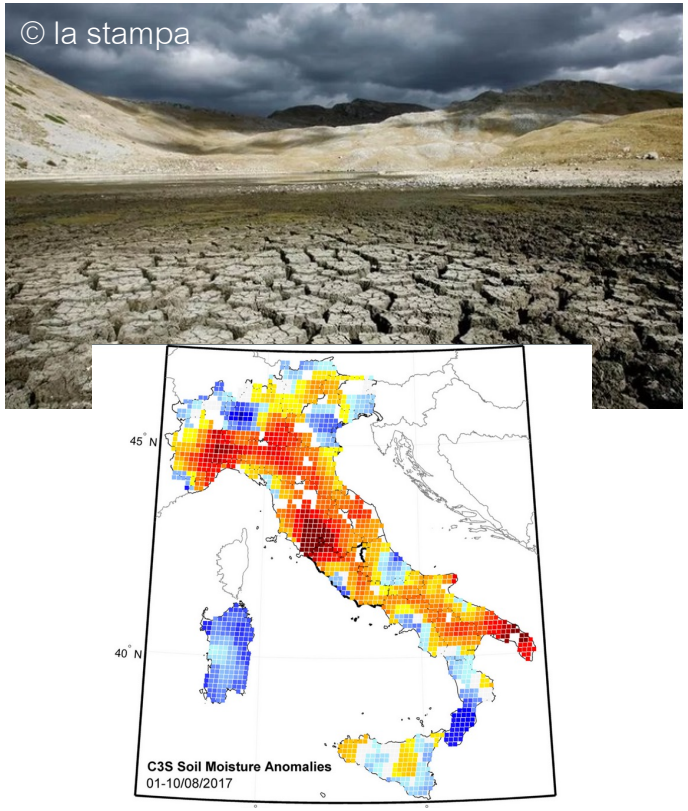
https://earthobservatory.nasa.gov/
(Flooding Belgium/Germany 2021)

EXTREME EVENTS

Droughts and fire

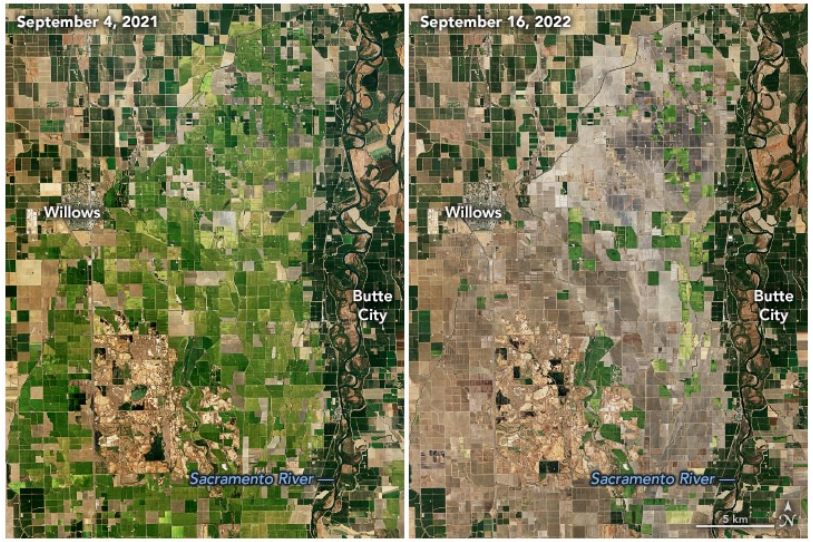
- Affects agriculture and threatens livelihoods (including housing).
- EO can be used for both **disaster risk reduction** and **planning of adaptation**.

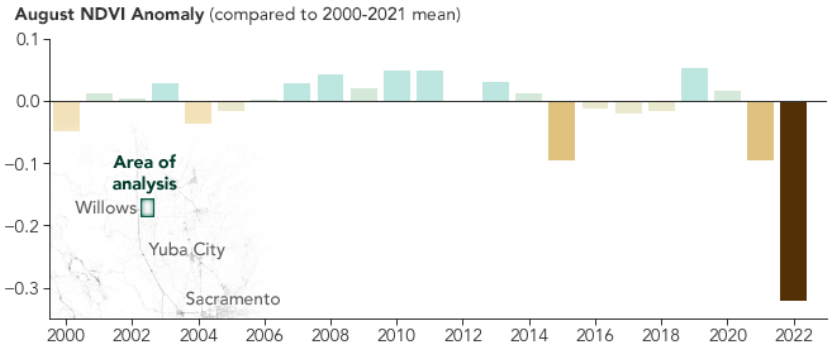
Italy drought 2017



ESA CCI soil moisture

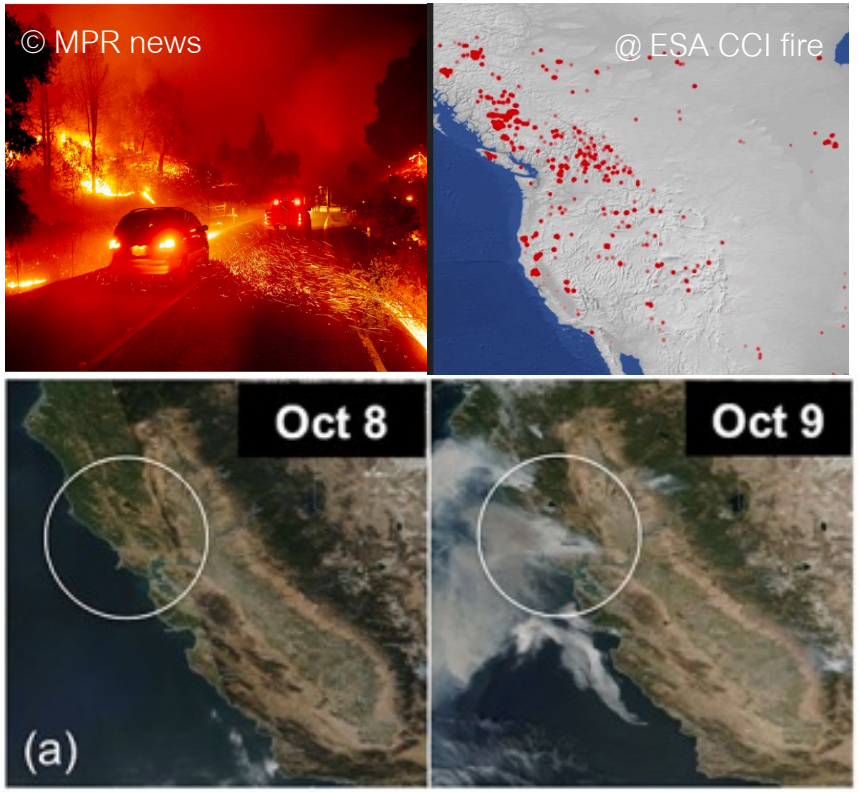
Sacramento valley rice fields 2022





https://earthobservatory.nasa.gov/

California fires 2019 (top) and 2018 (bottom)



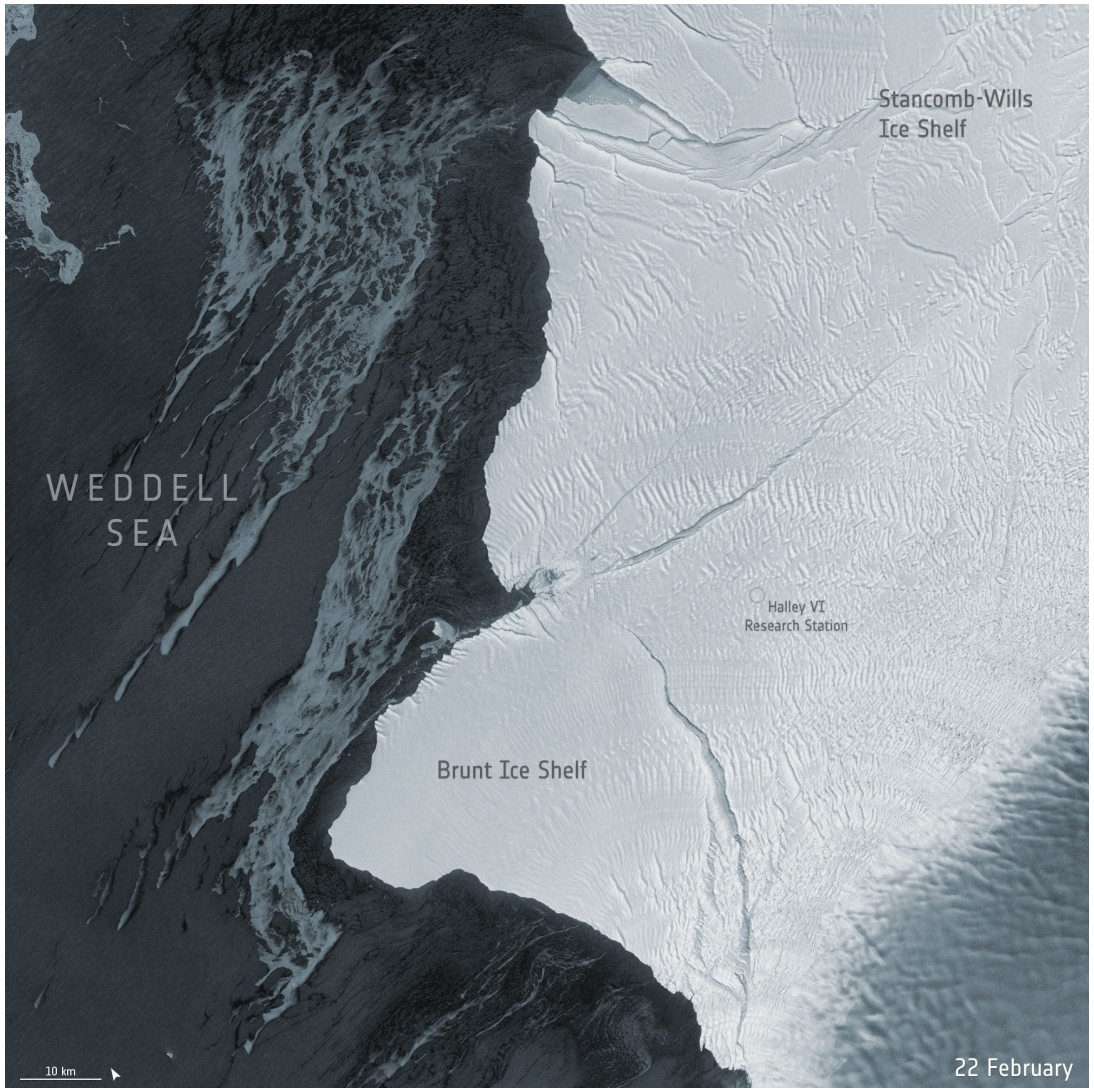
https://earthobservatory.nasa.gov/

THE NEW APPLICATION OF EO: PROCESS-STUDIES IN UNCHARTERED TERRITORIES

PROCESS-STUDIES IN UNCHARTERED TERRITORIES

Ice shelf dynamics

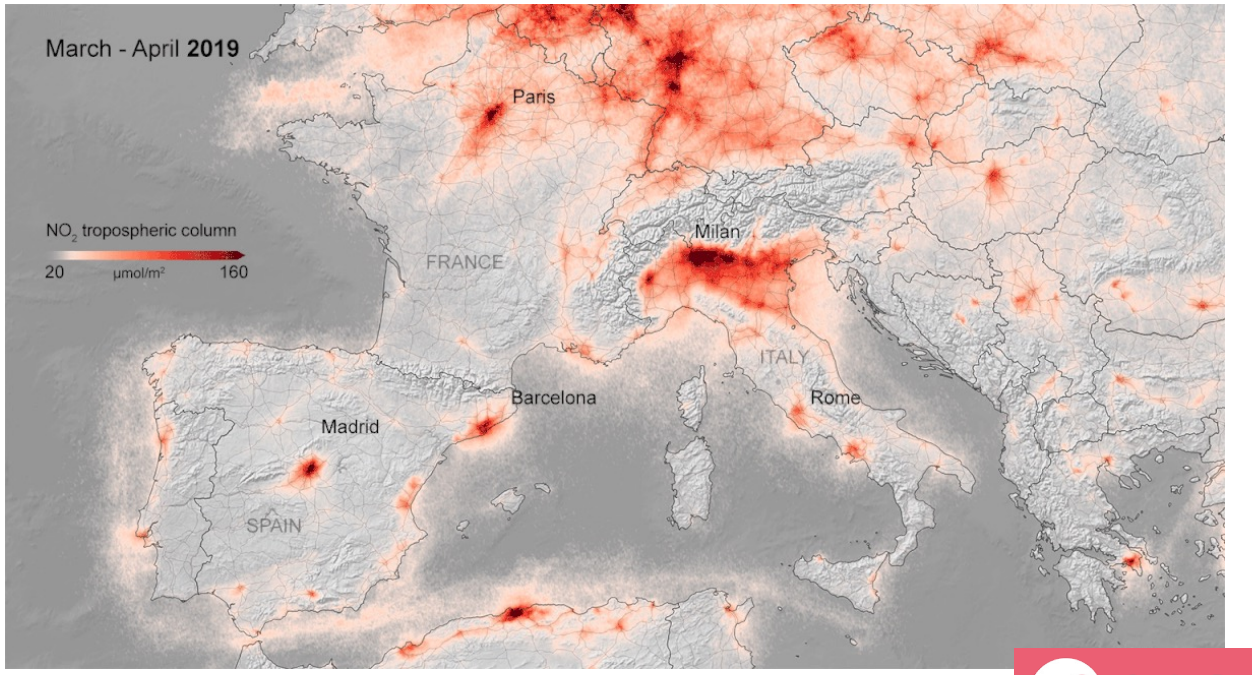
- **Break-off of an iceberg (A-74)** in the Antarctic Weddell Sea, which was the size of Greater London.
- Event is captured by **satellite radar images** which can see through clouds and operate day and night, thus able to see the ground even during polar night.
- Extent of 2021 ice shelf collapse is beyond expectations and **processes are not represented in current models.**
- The Antarctic Ice Sheet contains enough frozen water to raise global sea level by 58 meters.



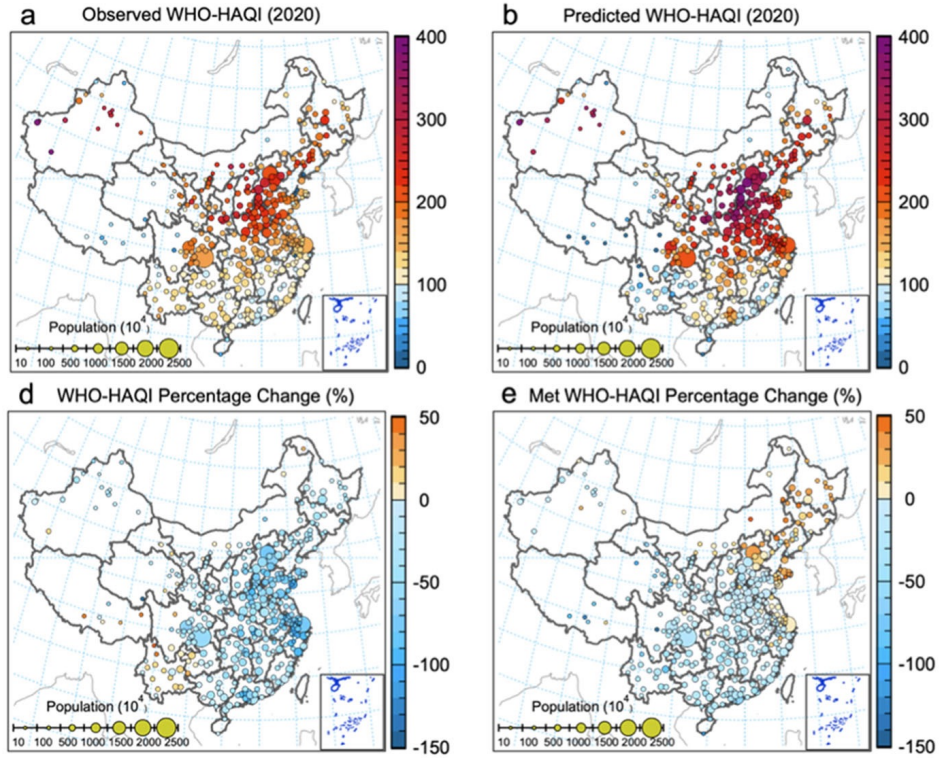
PROCESS-STUDIES IN UNCHARTERED TERRITORIES

A unique experiment of air pollution

- Emissions from fossil fuel burning lead to severe air pollution that kills millions of people each year (WHO).
- Secondary air pollutants (e.g., ozone) are also strong greenhouse gases.
- The 2020 lockdown due to Covid helped benchmark our understanding of atmospheric chemistry and its interactions with meteorology.



Copernicus Sentinel-5P (TROPOMI observations)



Shen, F., M. I. Hegglin et al., npj Climate and Atmospheric Science 2022

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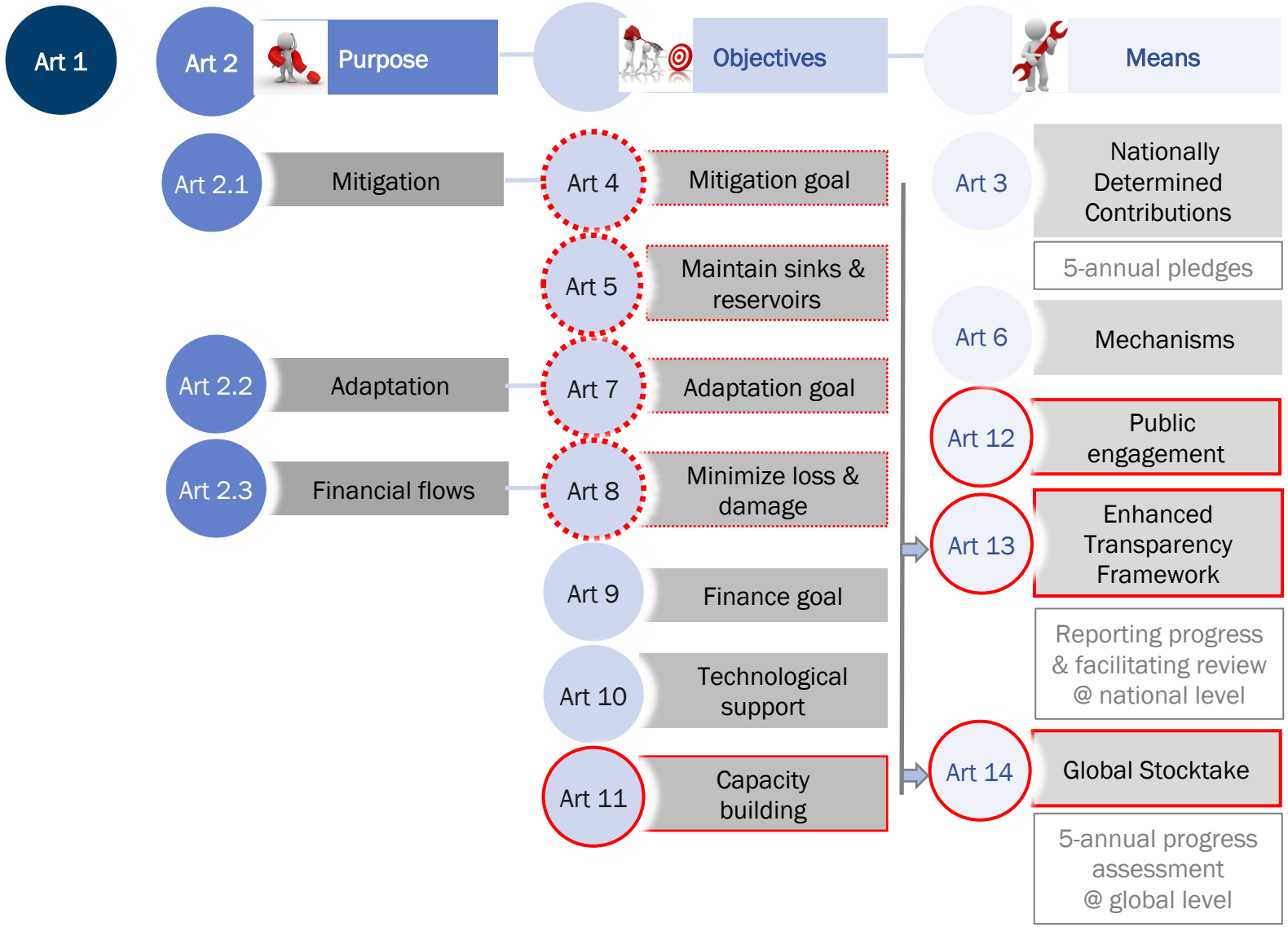
THE NEW APPLICATION OF EO: SUPPORTING THE UNFCCC GLOBAL STOCKTAKE

→ Making our physical and technical knowledge useable for society!

THE UNFCCC PARIS AGREEMENT

Hegglin et al., Frontiers of Environmental Sciences 2022



..... **thematic areas** EO can support
_____ **action pathways** EO can support

- Note, **capacity building** should be seen as a means to an end, and not an end in itself!
- Should be **beyond conventional ideas** of overseas aide.
- **Huge economic benefits** may result from transfer of green technology!

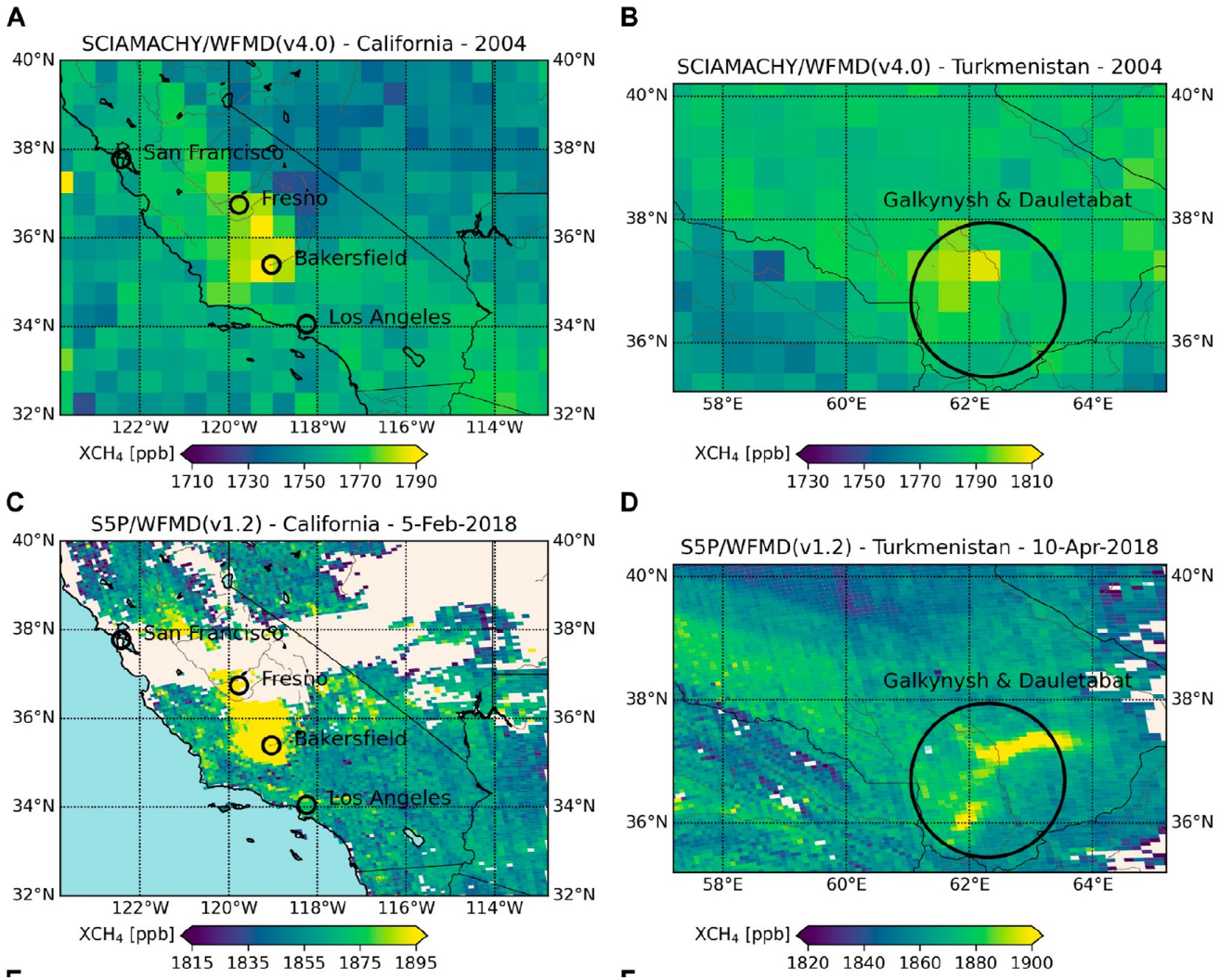
MITIGATION

Hegglin et al., Frontiers of Environmental Sciences 2022

Are our mitigation efforts effective?

EO helps answer this question through its use in top-down emission estimates.

- EO help quantify natural and human sources & sinks on country to continental scales using model-based inversions.
  - → Identifies whether nationally pledges are kept and mitigation mechanisms (e.g., carbon trading) work.
- EO are used to detect CO_2 and CH_4 emission hotspots.
  - → Identifies targeted mitigation opportunities.



SINKS AND RESERVOIRS

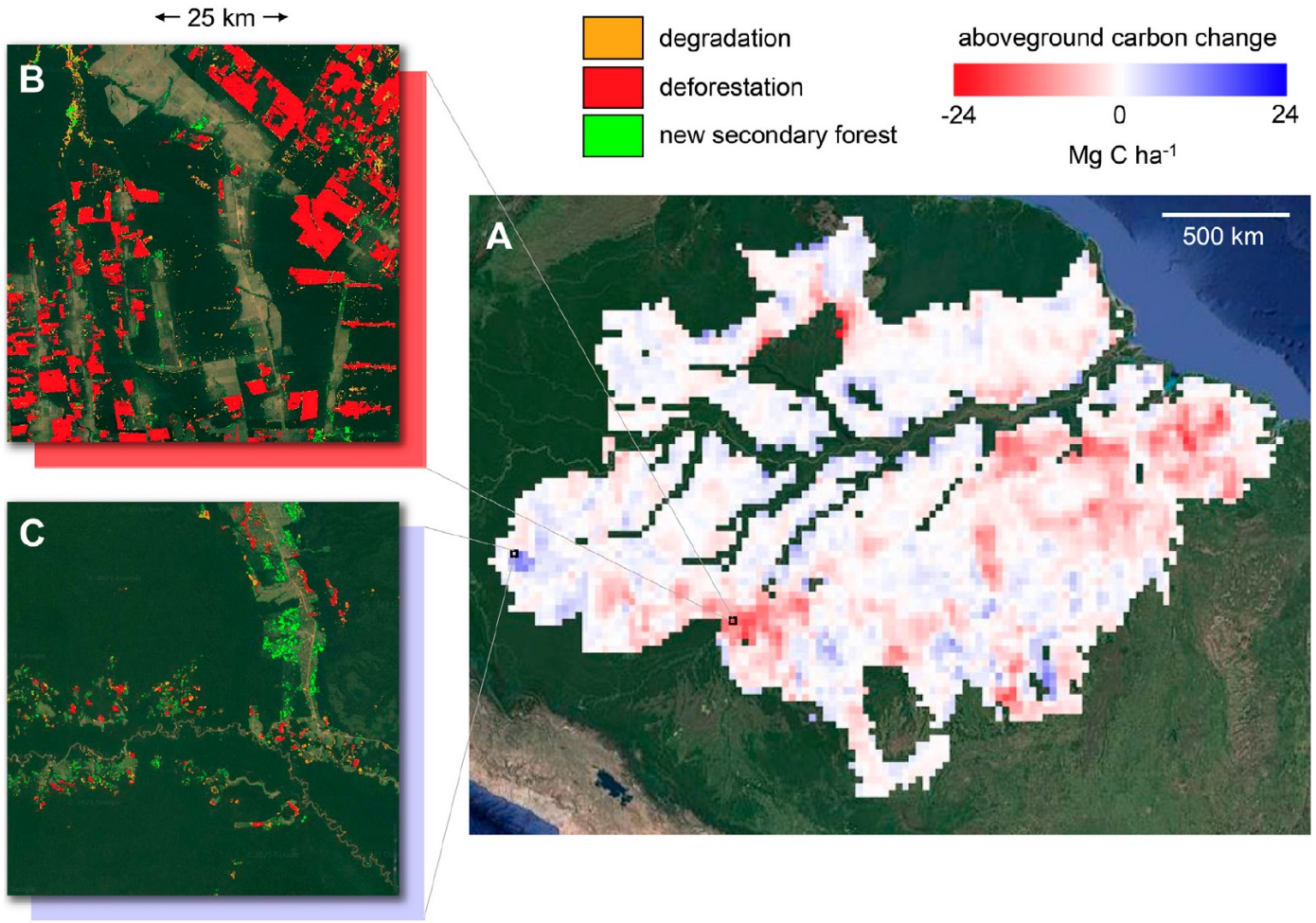
Hegglin et al., Frontiers of Environmental Sciences 2022

Are we maintaining the magnitude of greenhouse gas sinks and reservoirs?

EO helps answer this question by supporting national reporting of land use change at local and global levels.

- Key task is the quantification of the temporal changes and their attribution to natural (e.g., fires, drought, disease) and anthropogenic drivers (e.g., logging, agricultural and urban expansion).

  → Can help verify **effectiveness of carbon offsetting schemes** (e.g., planting trees).

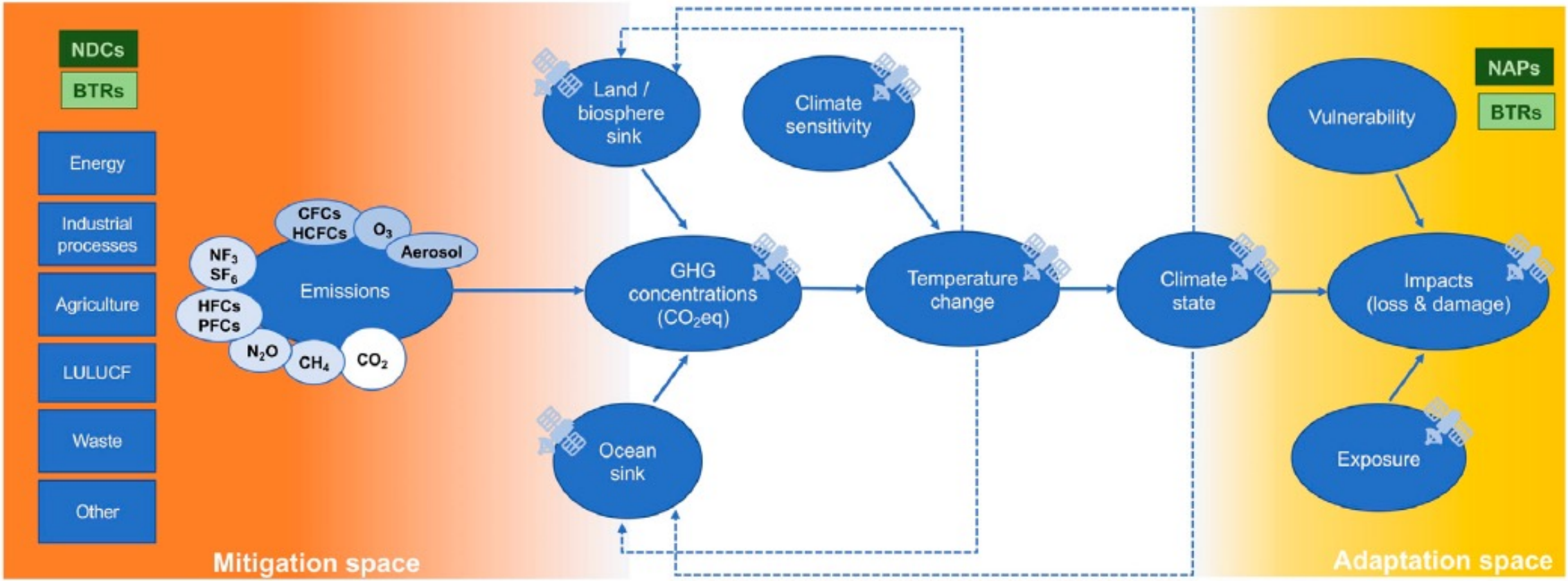


IMPORTANCE OF A SYSTEM PERSPECTIVE

Hegglin et al., Frontiers of Environmental Sciences 2022

The effectiveness of **mitigation efforts** can only be assessed if the full process chain from emissions to temperature change (the Paris target) is known.

Climate adaptation and **loss and damage** can only be assessed if the climate system response to GHG forcings is known.



→ **Cause-effect network** to reflect system-dependencies, helps **attribution** and **avoiding pitfalls**

→ **NEW ROLE FOR MODELS!**

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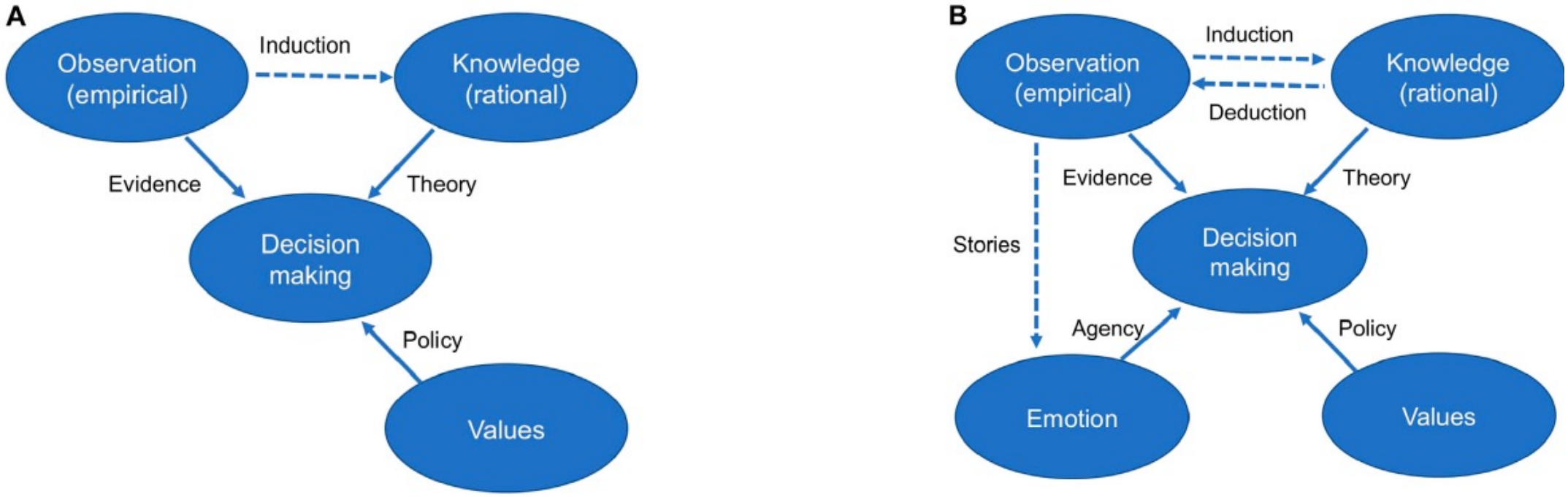
A NEEDED PARADIGM SHIFT IN EO SCIENCE

From an inductive to a deductive approach

Hegglin et al., Frontiers of Environmental Sciences 2022



- In a deductive approach, one moves from the general to the specific to interpret observations.
- EO used to create stories of how climate change is expressing itself in a localized context will not only provide actionable information for adaptation, but also the salience to generate emotions, which are necessary for agency.

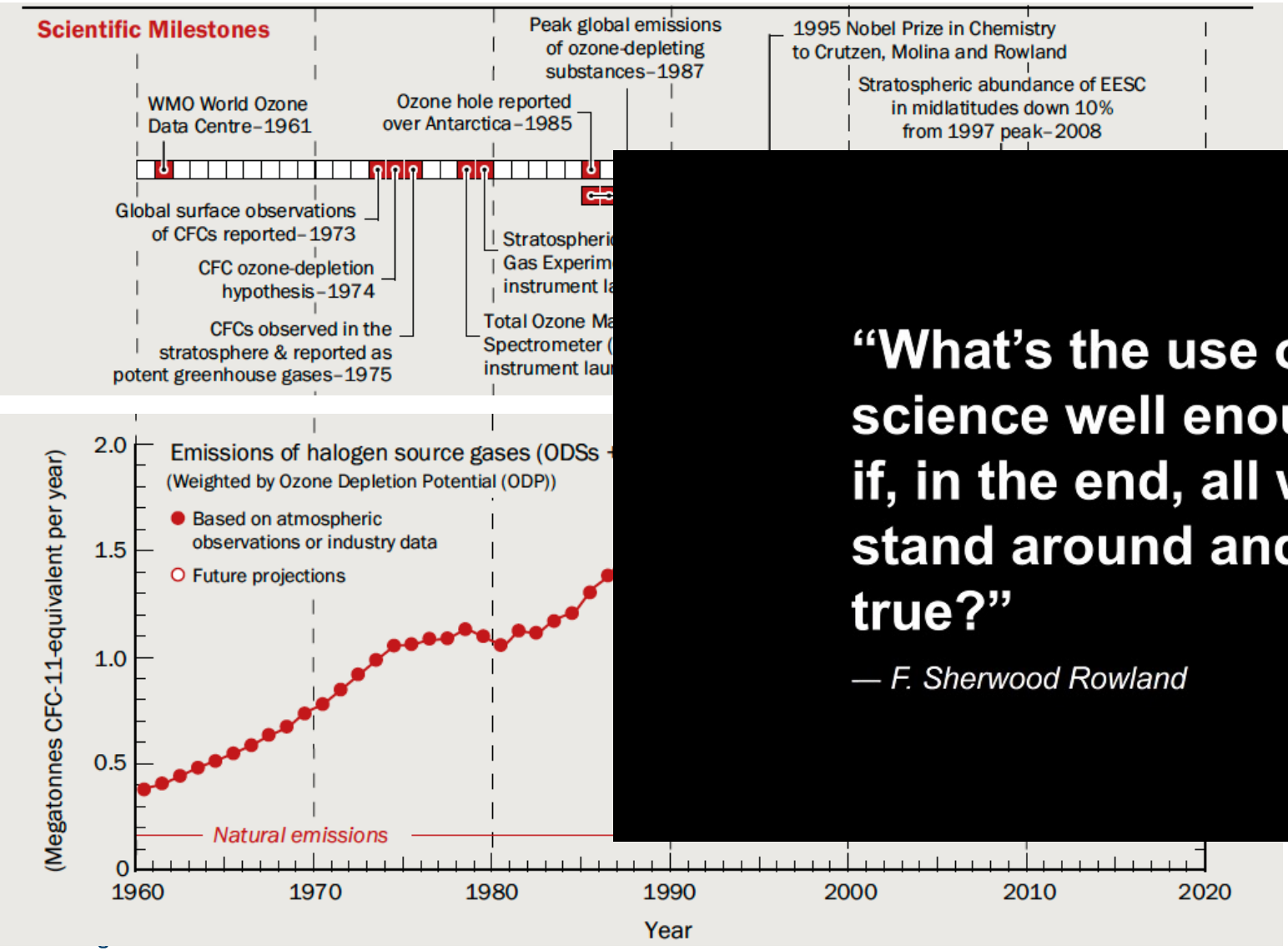
OUTLINE

The use of Earth observations in climate science (and how it was different in ozone science)

- What is the traditional use of Earth observations in climate change science?
- Climate change information from models – What will the future bring?
- The role of Earth observations in capturing climate change – What is the present?
- Transformation of our science approach
- Parallels from the Montreal Protocol (ozone depletion)
- Key points and conclusions

THE ROCKY ROAD TOWARDS THE MONTREAL PROTOCOL

Now hailed as the most successful international treaty to date dealing with an environmental issue



- S. Rowland, 1995 winner of the Nobel Prize in Chemistry and a fervent advocate for political action.

"What's the use of having developed a science well enough to make predictions if, in the end, all we're willing to do is stand around and wait for them to come true?"

— F. Sherwood Rowland

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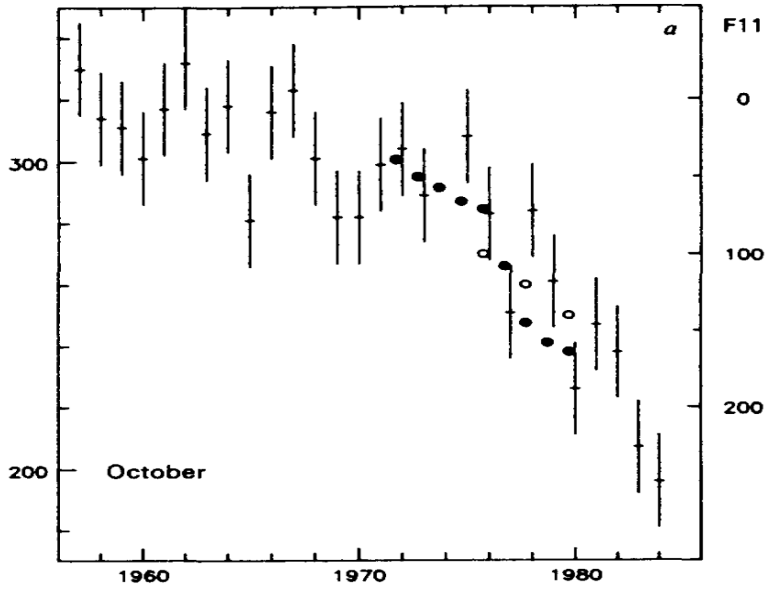
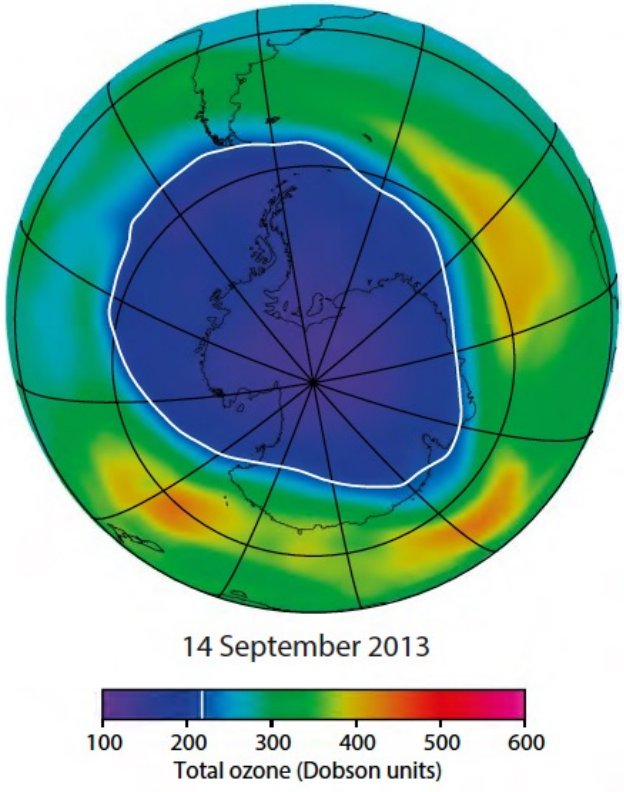
EO MAY HAVE MADE THE DIFFERENCE…

Creation of emotions

- It was not until the Antarctic ozone hole was visualized that people fully realized the global effect releasing CFCs had had on the stratospheric ozone layer.
- The *smoking gun* figure (right) finally established the clear link between chlorine species and ozone loss.

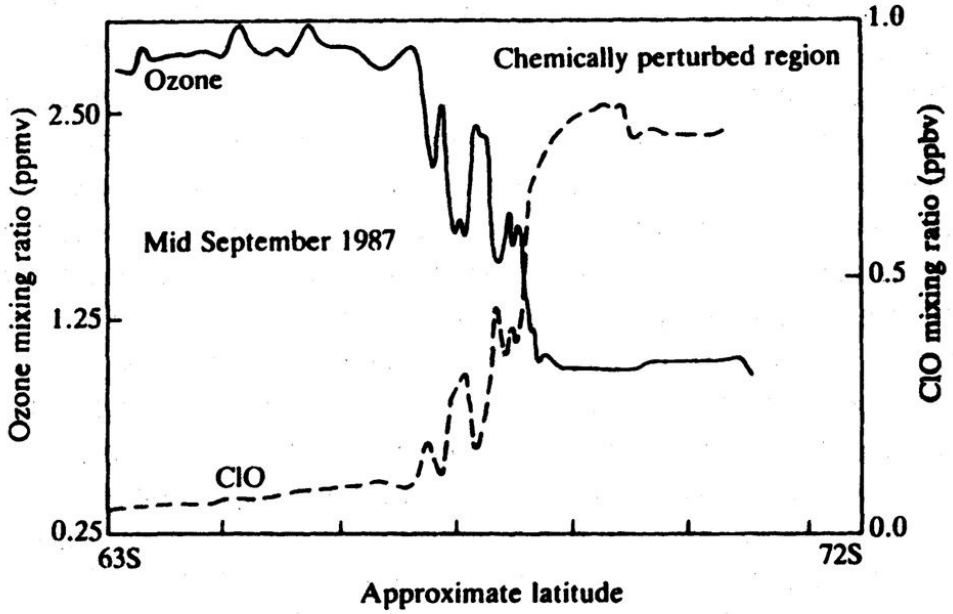
Farman et al., Nature 1985





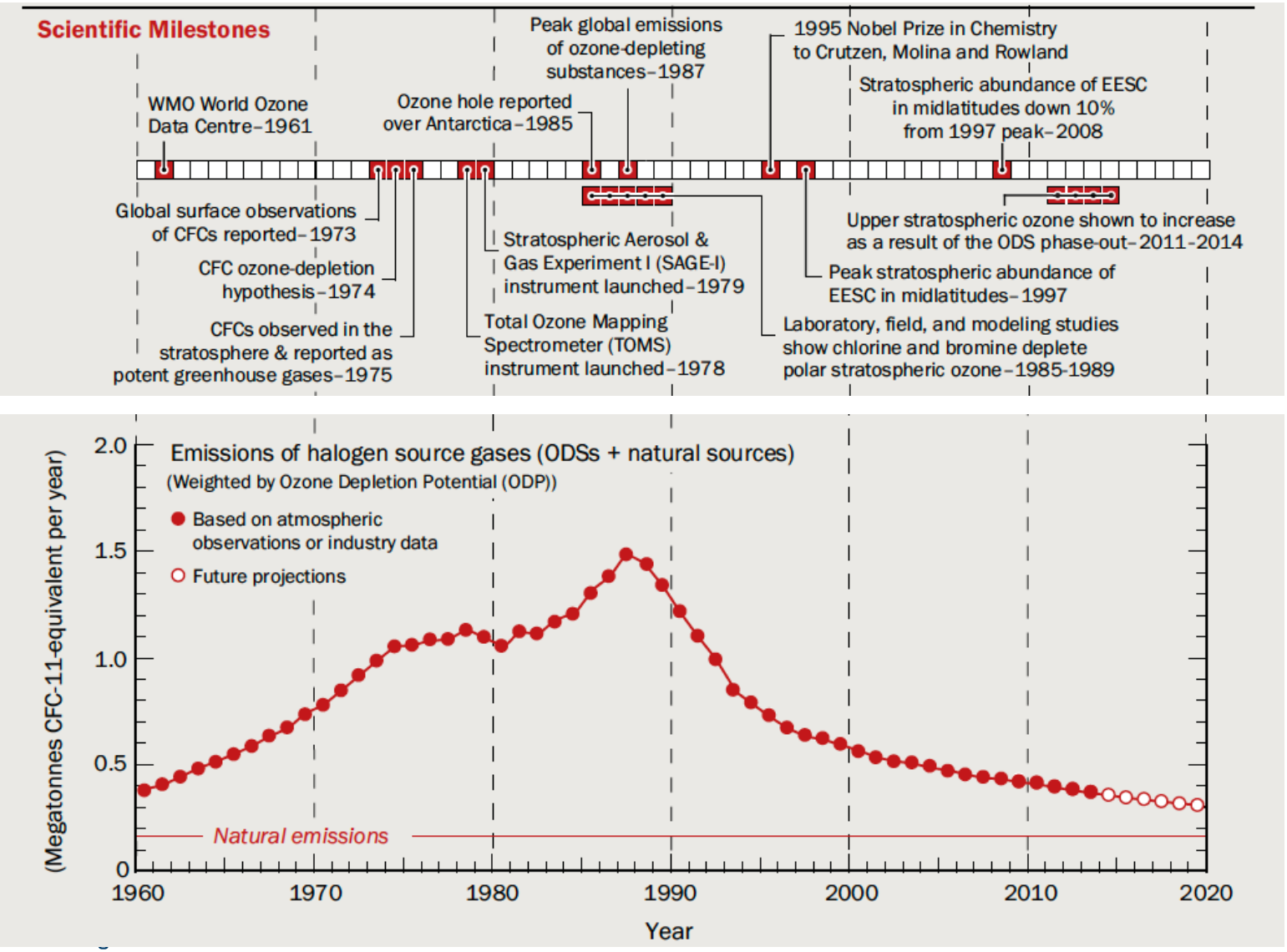
Hegglin et al., WMO/UNEP 20 QAs, 2015

Anderson et al., Science 1991



THE MONTREAL PROTOCOL

Hailed as the most successful international treaty dealing with an environmental issue to date



Hegglin et al., WMO/UNEP 20 QAs, 2015

- The bending of the curve was achieved with the introduction of the Montreal Protocol regulations on the production and use of chlorofluorocarbons (CFCs), with the treaty driven by reaching key scientific milestones.

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CONCLUSIONS

- The science and technology behind EO has made a **huge leap forward** in the 21st century, with innovation on the instrument side as well as an **explosion of operational and private sector** applications.
- Satellite instruments are providing unique observations of key components of the Earth (and climate) system that are essential for our understanding of how the planet is changing, **at both global and local scales.**
- But we need to move away from using EO as proof for climate change to using EO to exemplify and quantify it. This will help to shift the focus from the future to the present, and **make climate change more immediate.**
- The information that is becoming available will have to be exploited in a new and more targeted way, that is to **support the UNFCCC Paris Agreement** in its ambition cycle to combat global climate change.
- EO science (as is green technology science) is standing at the crossroads: it needs a new, **transdisciplinary approach** and enter the dialogue with policymakers, economists, legal experts, and the private sector alike to help accelerate the energy transition and, ultimately, to lead to a just and equitable world.

THANK YOU FOR YOUR ATTENTION!

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Space-based Earth observation in support of the UNFCCC Paris Agreement

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