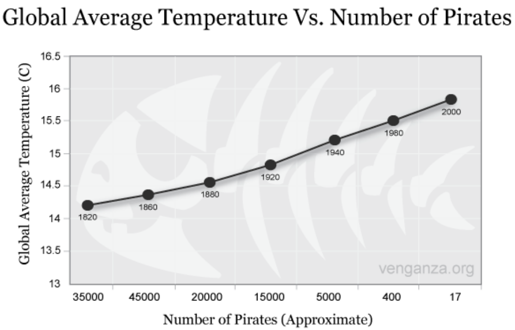
Today's Lecture (Lecture 14): Attribution of anthropogenic climate change



Reference
IPCC AR5, Ch. 10

5.4 – Attribution

How can we tell that the observed warming is anthropogenic?

Time series: We can estimate the history of anthropogenic (GHG, aerosol, ozone depletion) forcings and natural (solar, volcanic) forcings

Spatial distribution: We can estimate the expected pattern (geographic and vertical) of the anthropogenic and natural forcings

What causes uncertainty in attribution?

Internal variability: When internal variability has modes with similar time scales as the anthropogenic effects (decadal–centennial), it can be difficult to distinguish the two (*confounding*)

Model uncertainties: Patterns produced by models have uncertainties

Observational uncertainty – due to limited time series, spatial coverage, instrumental error, instrumental intercomparability

Note: attribution is statistical – not “it’s hot today because of global warming” but “the mean temperature is likely higher because of anthropogenic GHG emissions”.

A sampling of attributions in the IPCC AR5

Uncertainty in the language of IPCC

The IPCC assessment reports use precisely defined terminology for probabilistic projections and confidence estimates:

Virtually certain	99–100% probability
Extremely likely	95–100%
Very likely	90–100%
Likely	66–100%

- It is *extremely likely* that human activities caused more than half of the observed increase in GMST from 1951 to 2010.
- It is *very likely* that anthropogenic forcings have made a substantial contribution to upper ocean warming (above 700 m) observed since the 1970s.
- It is *very likely* that there is a substantial contribution from anthropogenic forcings to the global mean sea level rise since the 1970s
- It is *very likely* that oceanic uptake of anthropogenic carbon dioxide has resulted in acidification of surface waters which is observed to be between -0.0014 and -0.0024 pH units per year.
- It is *very likely* that anthropogenic forcings have made a discernible contribution to surface and subsurface oceanic salinity changes since the 1960s.
- Anthropogenic forcings are *very likely* to have contributed to Arctic sea ice loss since 1979.
- Ice sheets and glaciers are melting, and anthropogenic influences are *likely* to have contributed to the surface melting of Greenland since 1993 and to the retreat of glaciers since the 1960s.
- In land regions where observational coverage is sufficient for assessment, there is *medium confidence* that anthropogenic forcing has contributed to a global-scale intensification of heavy precipitation over the second half of the 20th century.
- There is *low confidence* in attribution of changes in tropical cyclone activity to human influence.

Attribution in four simple steps

1. Historical observational record of a variable of interest (here: temperature)
2. Model reconstructions of the historical record, separately for
   - natural forcings only
   - natural + GHG
   - natural + GHG + other anthropogenic
   - note: internal variability (e.g., El Niño) is not imposed
3. Compare model runs with observational record:
   - Does the combined natural + anthropogenic run match the observational record? (Required to show that the model works.)
   - Does the natural-only run match the record? $\rightarrow$ change attributable to natural forcings
   - Does the natural-only run not match the record? $\rightarrow$ change attributable to anthropogenic forcings
   - In some cases, distinction can be made between the anthropogenic forcings (e.g., GHG-only vs GHG + aerosols)
4. Estimate uncertainty on the model reconstruction (e.g., by running an ensemble of models); use uncertainty to quantify confidence in the statistical sense in the results from step 3

Anthropogenic forcings and their patterns

Greenhouse gases tropospheric warming, stratospheric cooling

Aerosols short-lived $\rightarrow$ regional pattern of cooling (mostly)/heating (absorbing aerosol)

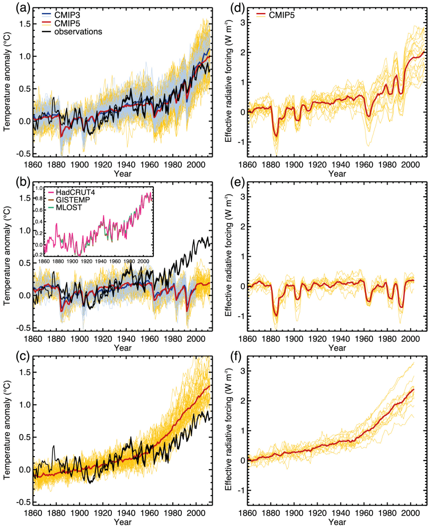
Stratospheric ozone depletion/recovery stratospheric cooling/warming, mostly over the polar regions

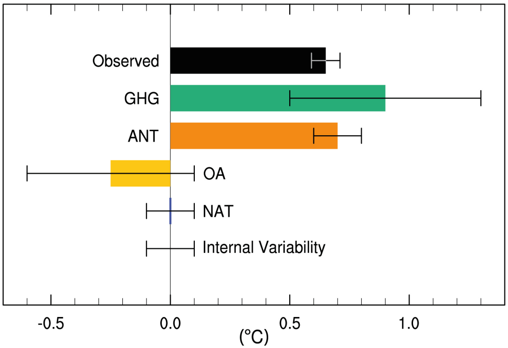
Natural forcings and their patterns

Volcanic eruptions stratospheric warming, tropospheric cooling extending for a few years from well-known dates

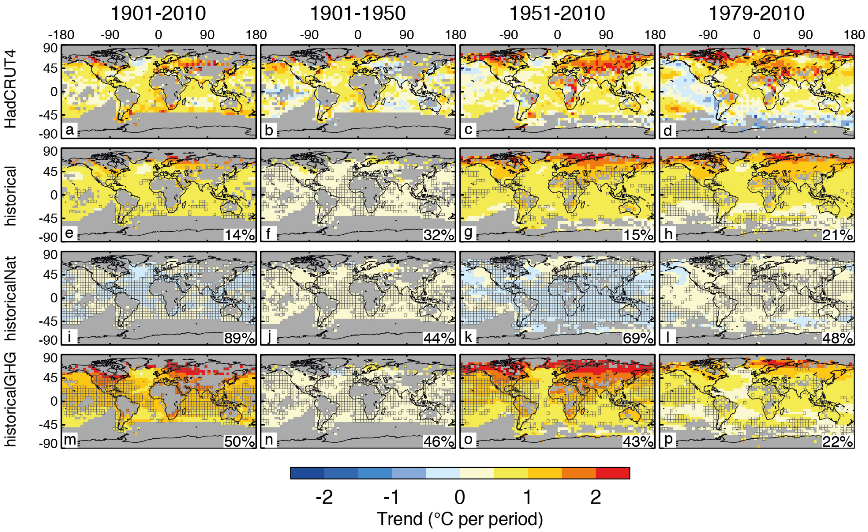
Solar output variability no vertical preference, well measured over the instrumental period

Attribution using global mean surface warming

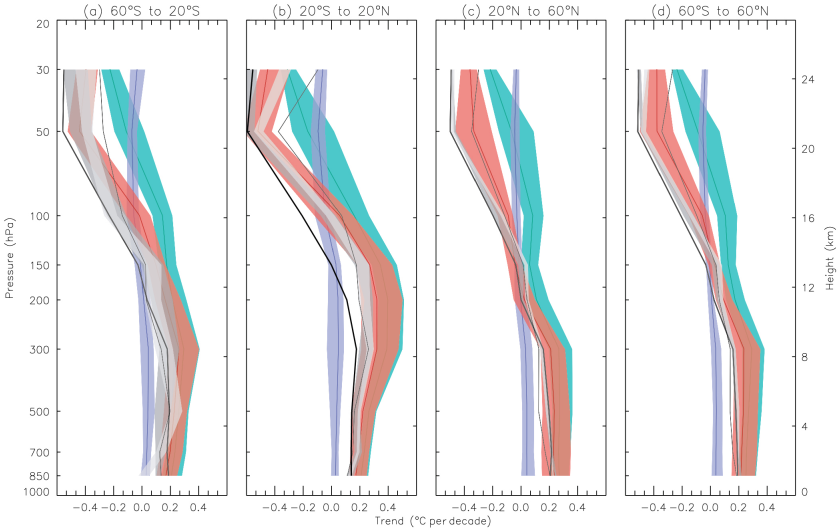




Attribution using the geographic distribution of surface warming



Attribution using the vertical distribution of atmospheric warming



Anthropogenic warming is seen on all continents