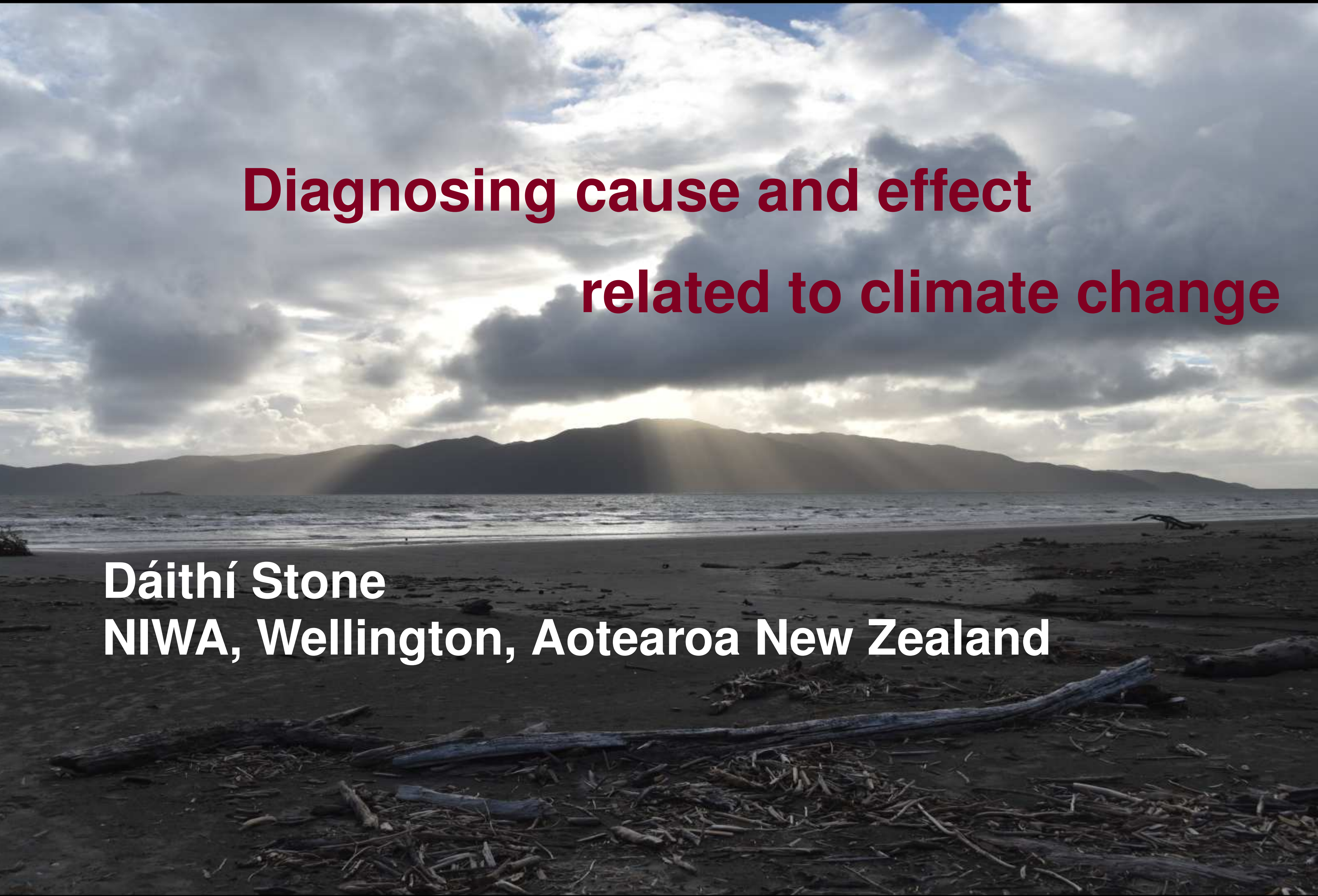


Diagnosing cause and effect related to climate change

Dáithí Stone
NIWA, Wellington, Aotearoa New Zealand

0.1. If a tree falls in a forest and no one is around to hear it, does it make a sound?

- Process-based expectation:
  - Physics says that sound waves have to dissipate the energy of the impact
- Empirical evidence:
  - I have witnessed many trees falling and they all made a sound
  - My friends have witnessed trees falling and they all made a sound
- Conclusion:
  - Yes, of course!

If we emit lots of greenhouse gases, will the planet warm?

- Process-based expectation:
  - Radiative physics says yes (understood for 120 years)
  - Some things not well understood though: what will clouds do?
- Empirical evidence:
  - We have never tried this before
  - Moon, Venus, and Mars are poor case studies
  - Ice cores, etc. unclear on cause-effect relationship in past variations
- Conclusion:
  - Ummm...

0.2. Detection and attribution

Detection and attribution (D&A): is a research process for investigating these sorts of questions about cause and effect

Detection: Is something changing?

Attribution: Why is something changing?

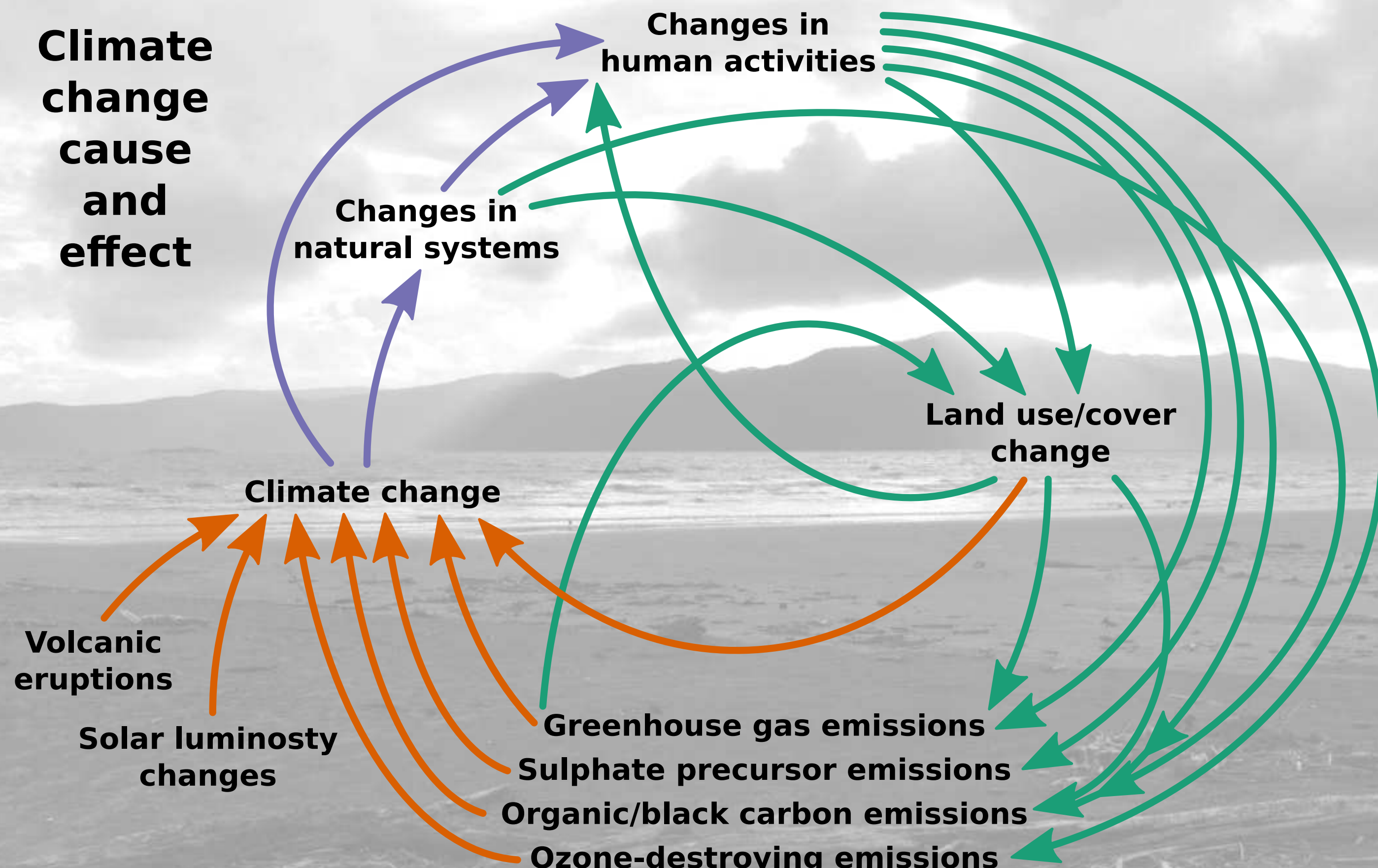
Note:

- D&A sets the strictest requirements of acceptable evidence
- D&A is not the only way to understand the past!

0.3. Outline of these four lectures

1. The detection and attribution of climate change
   - What can we say about cause-effect of past changes in climate?
2. Identifying a human role in extreme weather events
   - What can we say about a human role in a specific recent extreme weather event?
3. Detection and attribution of impacts of climate change
   - What can we say about the effect of past anthropogenic climate change on human, managed, and natural systems?
4. Potential and limitations for using detection and attribution information
   - What is detection and attribution information useful for?

0.4. The wheel of cause and effect involving climate change



Lecture # 1: Orange

Lecture # 2: Orange

Lecture # 3: Purple

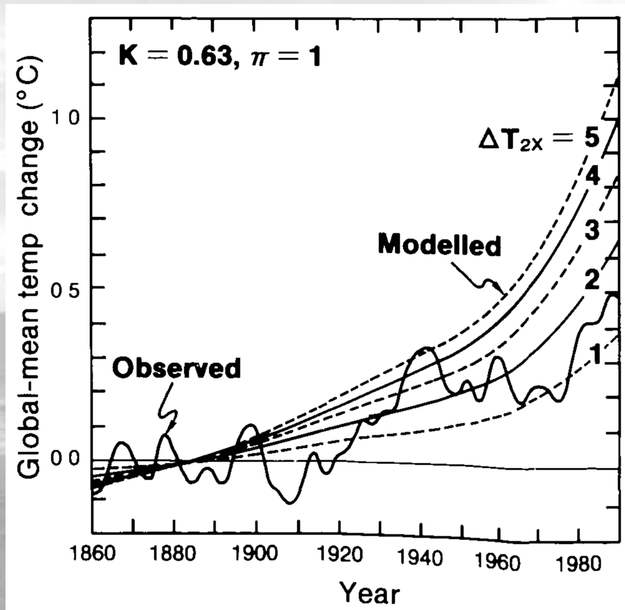
Lecture # 4:

All colours

The detection and attribution of climate change

Dáithí Stone
NIWA, Wellington, Aotearoa New Zealand

1.1. A challenge 30 years ago



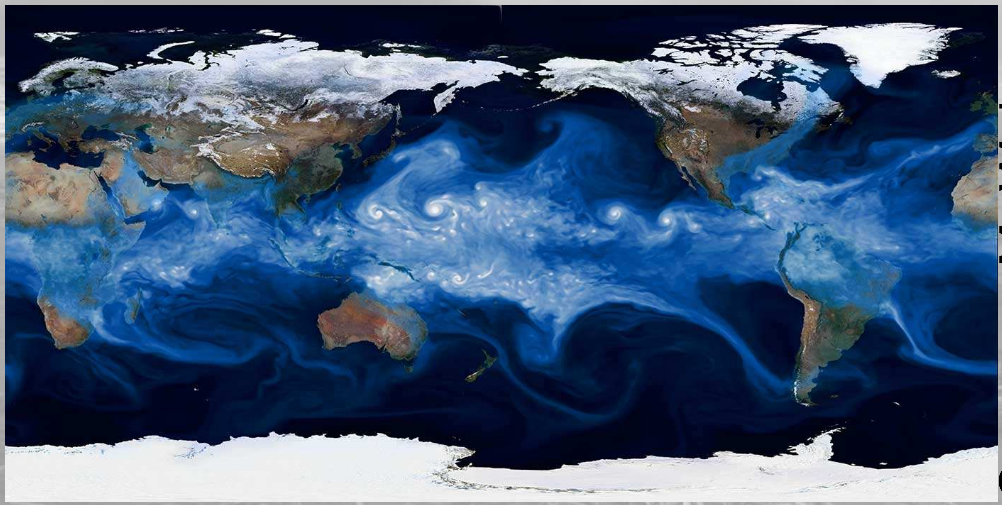
Wigley et alii (1990) (IPCC 1990)

- Physically-based models predict warming
  - But the models are very simple, e.g. $c\frac{dT(t)}{dt} = F(t) - \lambda T(t)$
  - Important parameters are poorly constrained
- Observations show some warming
  - “Global” monitoring network is poor
  - Most of warming occurs before it should
  - Lots of variability
- Best analysis technique little more than “use your eyes”

1.2. Climate models today

Processed-based models are unbelievably more advanced

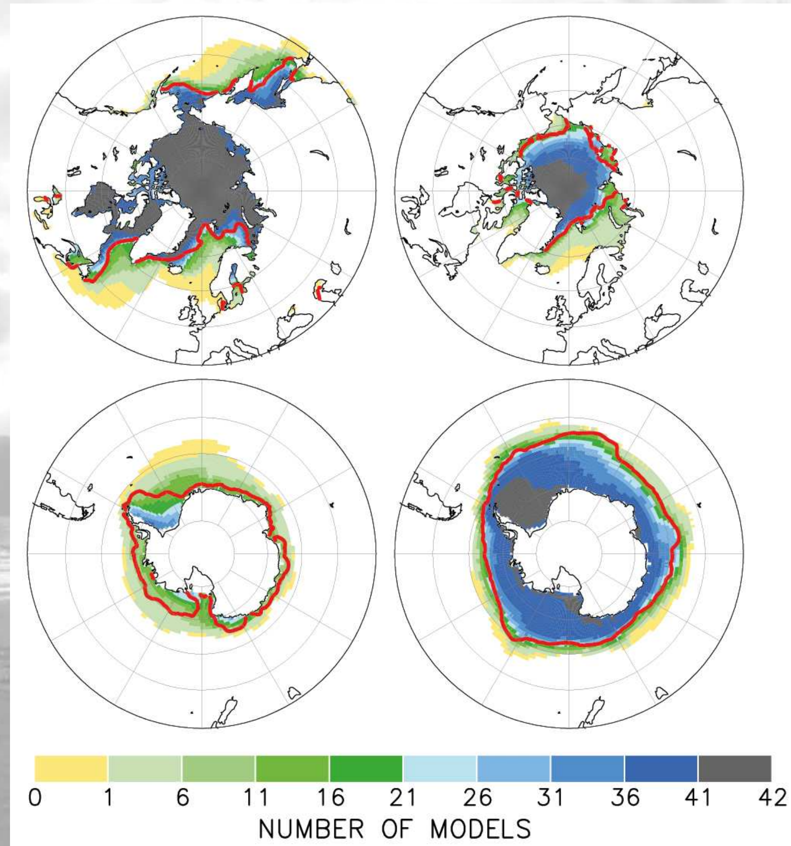
- They produce things we think of as weather
- But important parameters still poorly constrained (e.g. cloud condensation, updraft in convective cells, aerosol chemistry)
- Biases in output: e.g. tropical cyclones avoid land too much
- They do not tell us what is actually happening



Courtesy M. Wehner

Climate model errors/biases

February sea ice coverage September sea ice coverage



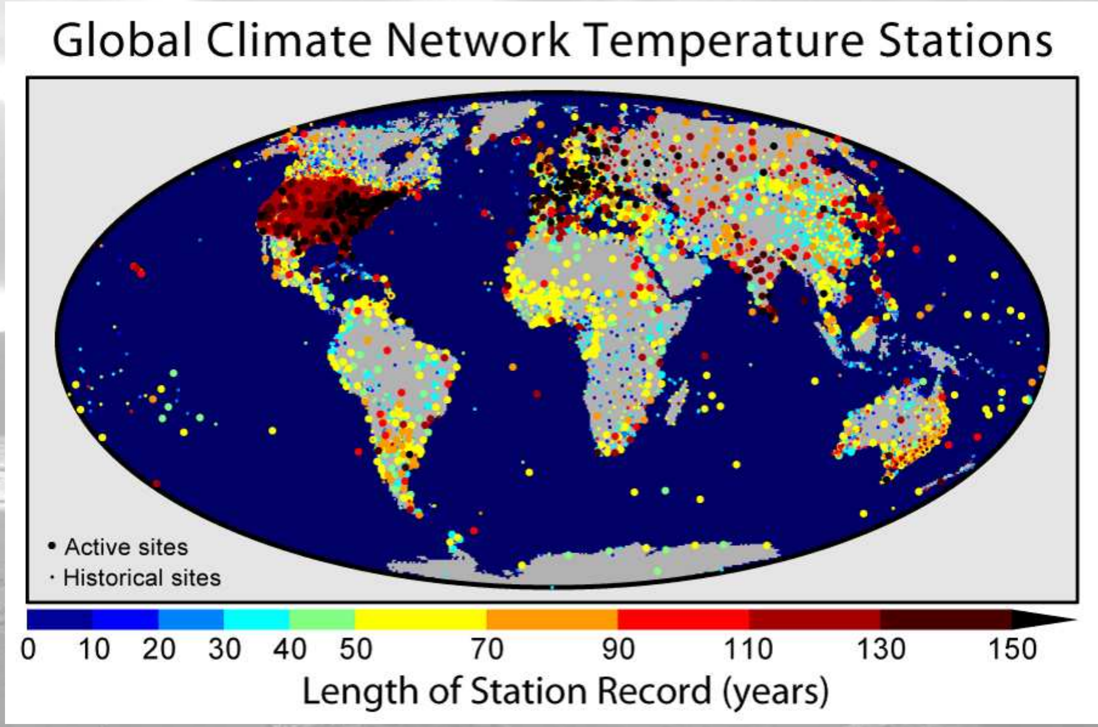
IPCC (2013) (Flato et alii 2013)

Red line is observed coverage (>15% sea ice)

1.3. Climate observations today

Observational products are much more complete

- Major effort digitising old records provides much more global record, going further back in time
- Better understanding of and correction for monitoring discontinuities (e.g. new thermometer type)
- We have three more decades!

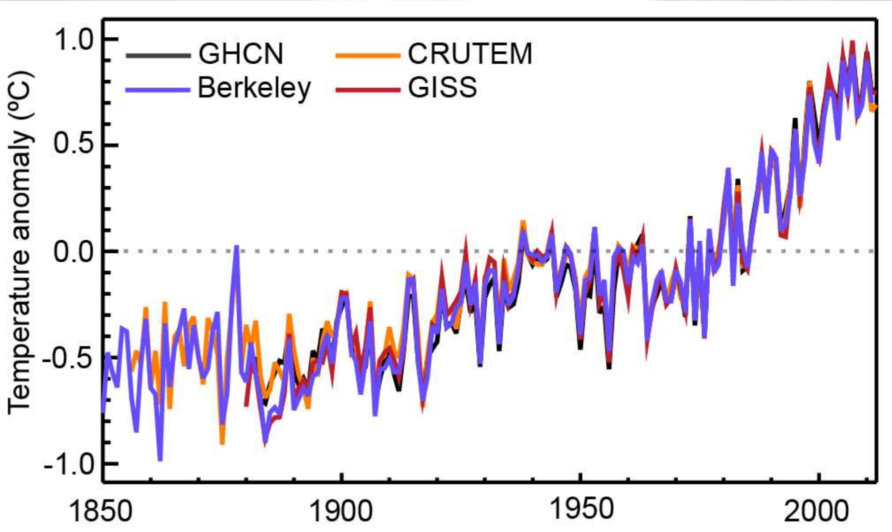


Courtesy R. A. Rohde

What the past three decades give us

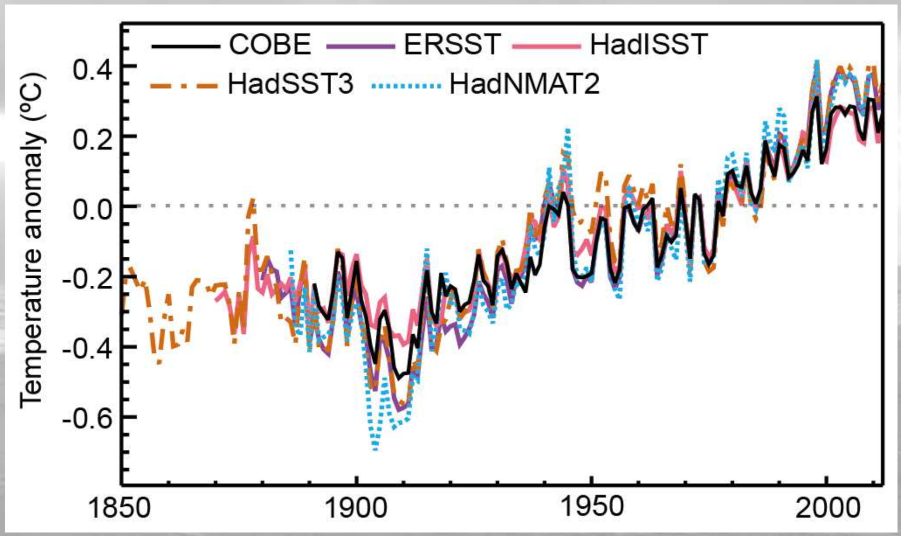
Global annual

temperature over land



Global annual

sea surface temperature

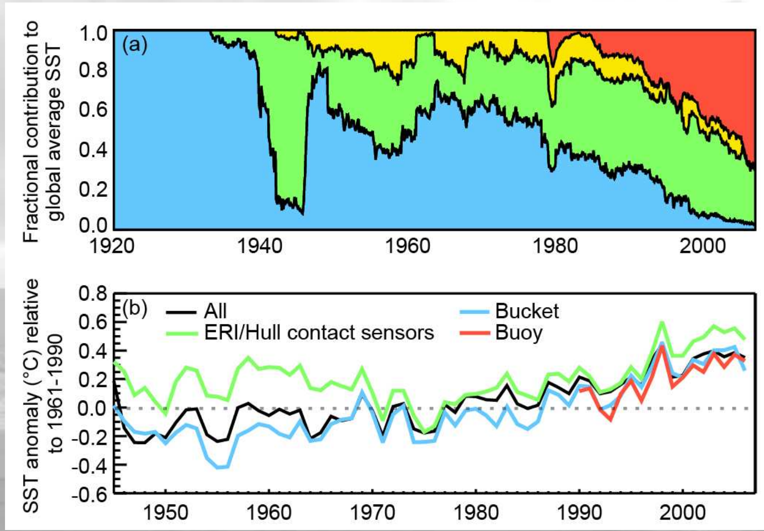


IPCC (2013) (Hartmann et alii 2013)

Is that conclusive?

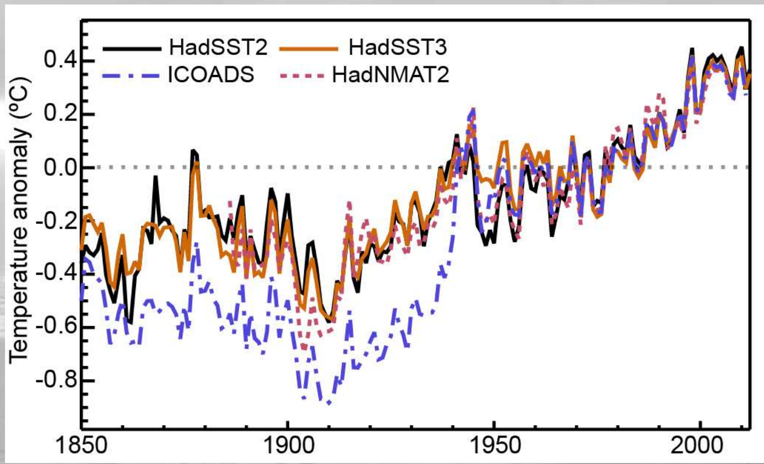
- Uncertainties in these numbers

Ocean temperature measuring method



IPCC (2013) (Hartmann et alii 2013)

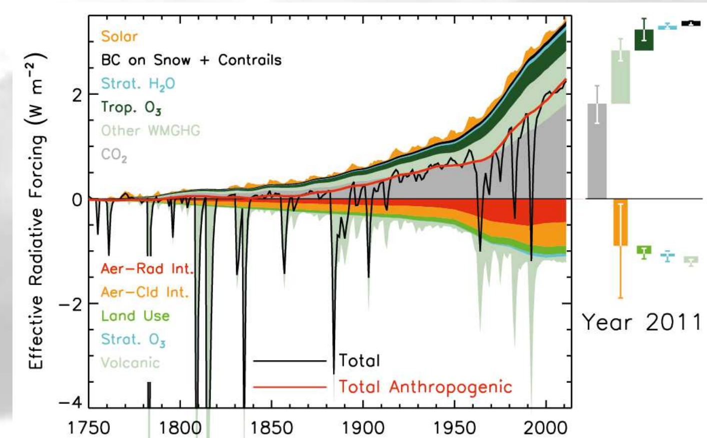
Uncorrected and corrected ocean temperatures



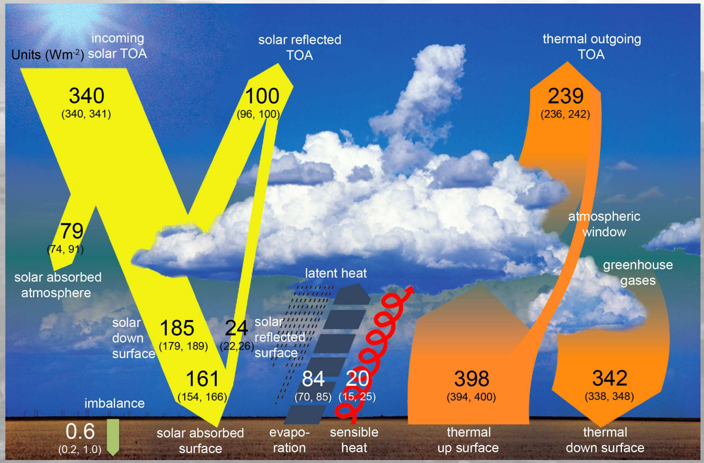
- Other things may be affecting the climate (e.g. sun getting brighter)
  - We have not identified the cause

1.4. Investigator at a crime scene

- We have anthropogenic suspects:
  - Higher atmospheric greenhouse gas concentrations
  - Changes in tropospheric aerosol burdens
  - Destruction of stratospheric ozone
  - Changes in land use and cover
- We have natural (non-human) suspects:
  - Aerosols from volcanic eruptions
  - Changes in solar brightness
- They all have a “motive” (radiative physics)
- Can we prove which committed the crime?
  - Can we find fingerprints?
  - If all guilty: who was the leader?



IPCC (2013) (Myhre et alii 2013)

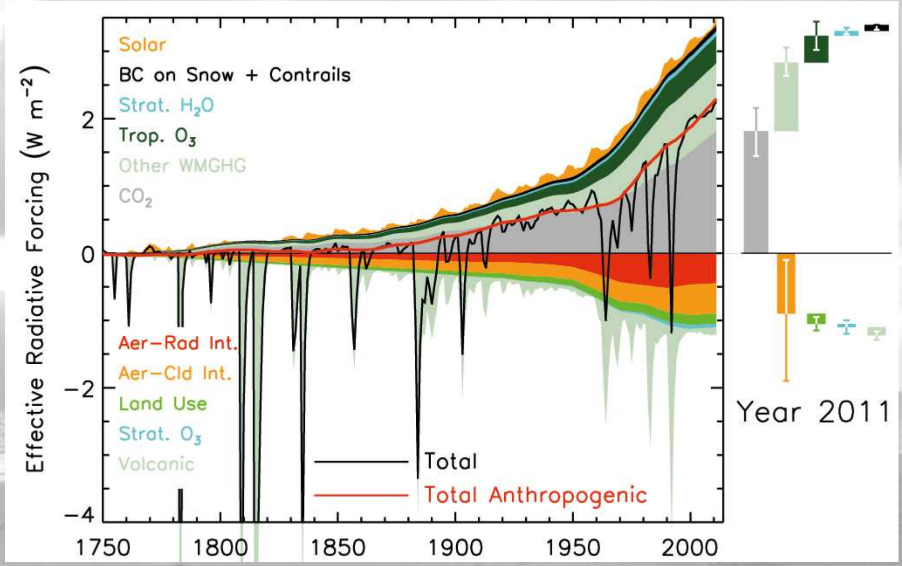


IPCC (2013) (Hartmann et alii 2013)

1.5. Finding a fingerprint

Fingerprints in time

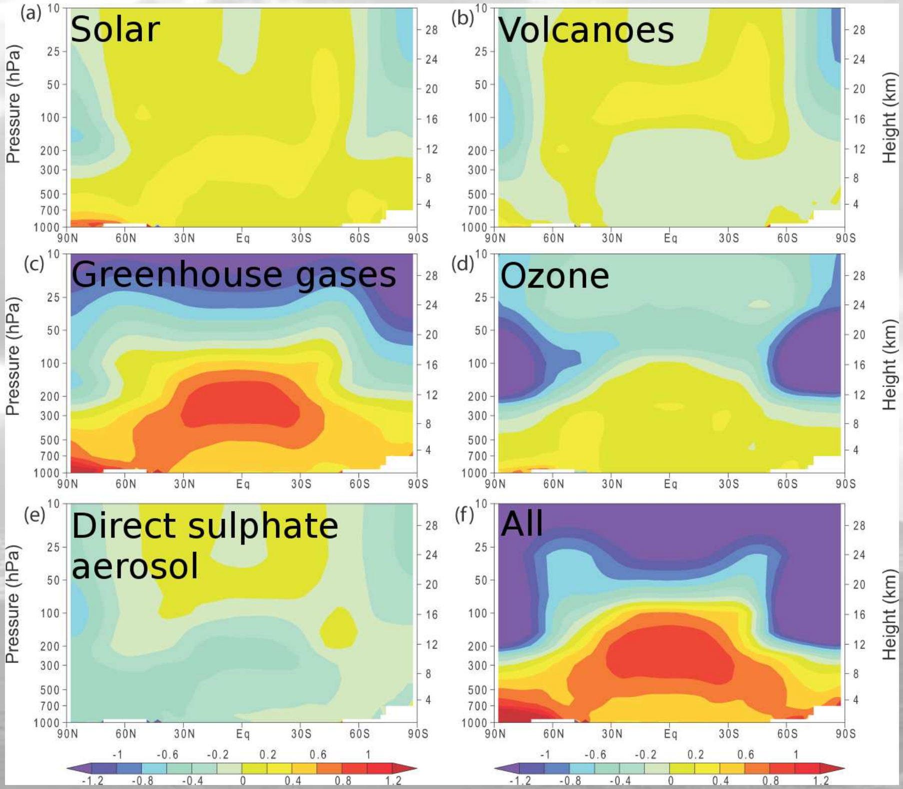
- Expect response to volcanic eruptions to be episodic, coming after eruptions
- Expect response to increasing greenhouse gas concentrations to increase through time



IPCC (2013) (Myhre et alii 2013)

Fingerprints in space and season

- Sulphate aerosols emitted in Northern Hemisphere, so effect is in Northern Hemisphere
- Stratospheric ozone depletion happens in polar spring, so effect on temperature in polar spring
- Greenhouse gases warm surface, cool stratosphere (above 10–20km)
- Greenhouse gases only forcing to increase tropical convection
  - Puts energy (heat) at ∼10km altitude tropics



IPCC (2007) (From Santer et alii 2003)

But the magnitude of that fingerprint might be unclear

- Most important controls on amplitudes are related to cloud responses
  - Climate models represent clouds as 100km$\times$100km$\times$50m blocks
  - Processes internal to clouds represented through crude formulae: not from basic physics and chemistry
  - Fingerprint: Models simulate less rainfall in ocean subtropics and more in ocean tropics, related to change in Hadley cell driven by convection
  - Magnitude: What controls the rate of change of tropical convection?
- Sea ice processes
  - Fingerprint: Climate models have sea ice retreating at the poles. They cannot have it retreating elsewhere!
  - Magnitude: Is the rate of retreat right? What controls that?

1.6. Performing a quantitative analysis

- We will look at multiple linear regression
- There are many other techniques though
- Assume linear additivity: the sum of responses to each individual forcing equals the response to all forcings together
- Then we can set up a linear regression:

$$Y_{obs}[x,t] = \Sigma_{f=forcings}\left(\beta_f \cdot Y_f[x,t]\right) + \nu[x,t]$$

$Y_{obs}[x,t]$: Observed data (dependent variable)

$Y_f[x,t]$: Predicted climate response to forcing f (independent variables)

β_f: Scaling factor on predicted response (regression coefficient)

$\nu[x,t]$: What cannot be explained (residuals)

- Things to note:
  - If $\beta_f = 0$, then we cannot detect the fingerprint in the observed record
  - If $\beta_f = 1$, then we can detect the fingerprint in the observed record at exactly the predicted magnitude
  - If $\beta_f > 0$ but $\beta_f \neq 1$, then we can detect the fingerprint but not at the predicted magnitude
  - If $\beta_f < 0$, then something is wrong (probably with our prediction)

1.7. Application to large-scale surface temperature

The data:

Black: Observations ($Y_{obs}[x,t]$)

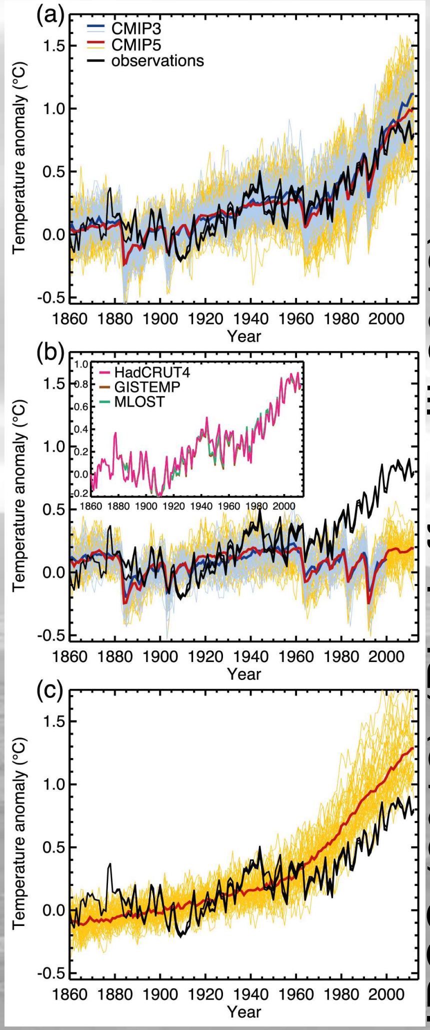
Red, top panel: Simulated response to both anthropenic and natural forcings ($Y_{all}[x,t]$)

Red, middle panel: Simulated response to natural forcings ($Y_{nat}[x,t]$)

Red, bottom panel: Simulated response to anthropogenic forcings ($Y_{ghg}[x,t]$)

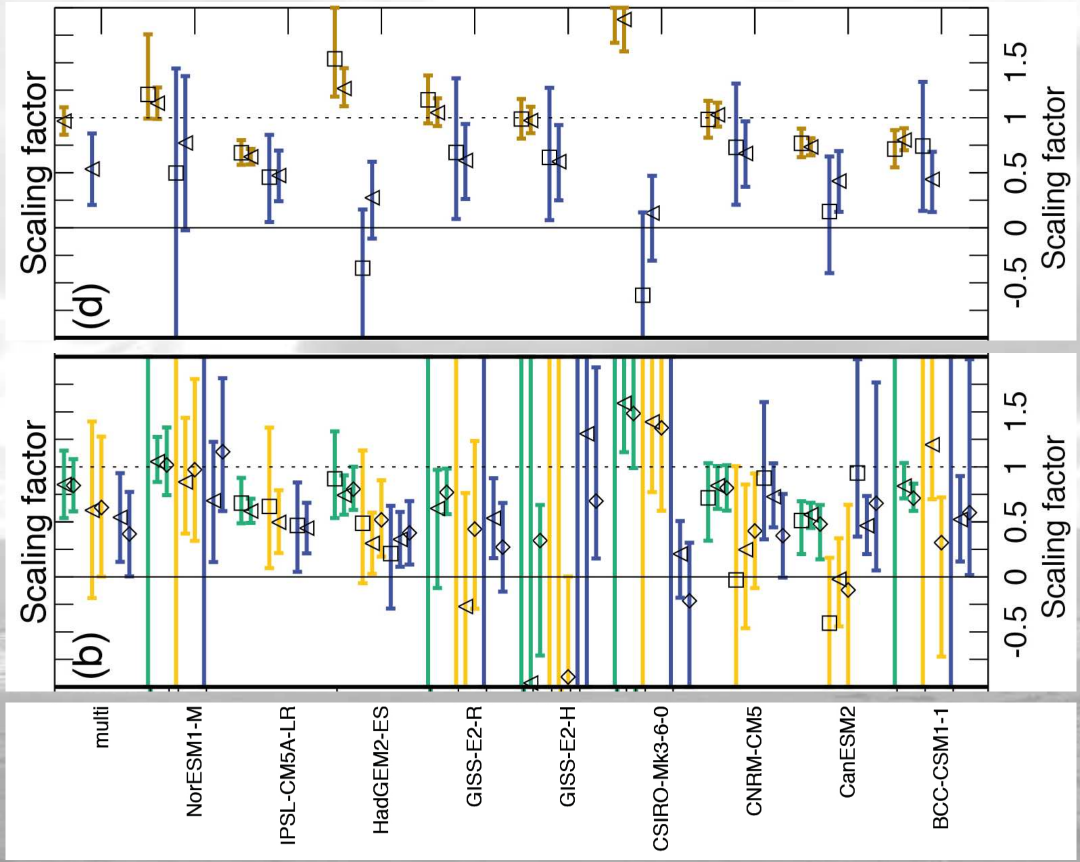
Notes:

- Yellow lines: individual simulations of climate models
- Red lines: average across all simulations (and models)
- Anthropogenic non-greenhouse gas response estimated as $Y_{oth-ant}[x,t] = Y_{all}[x,t] - Y_{nat}[x,t] - Y_{ghg}[x,t]$
- Not shown: large-scale spatial variations



IPCC (2013) (Bindoff et alii 2013)

Regression coefficients



IPCC (2013) (Bindoff et alii 2013)

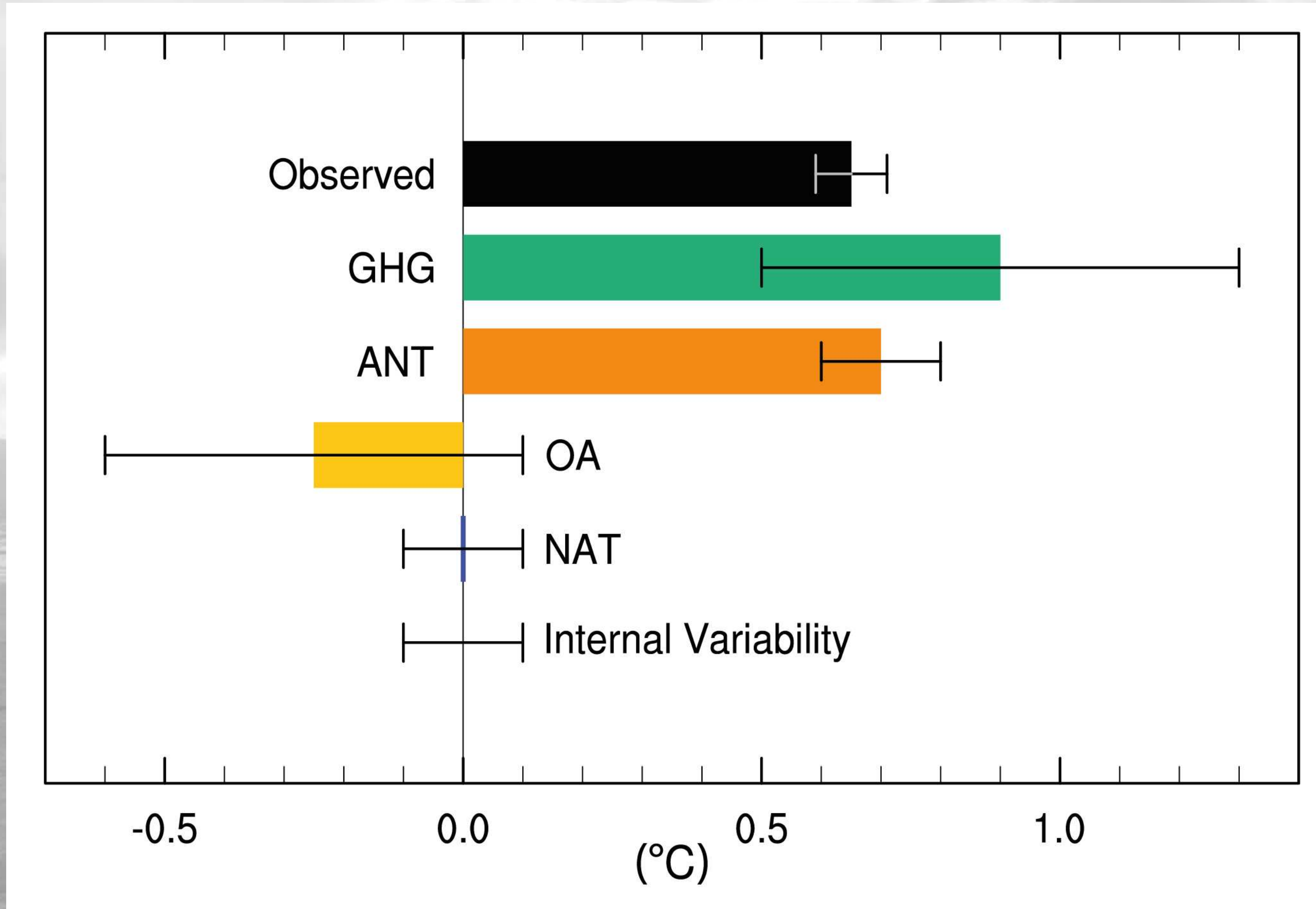
Top: Two-signal (Anthropogenic, Natural) analysis

Bottom: Three-signal (Greenhouse gas, other anthropogenic, natural) analysis

- Many-signal analysis has advantage of not assuming responses to two forcings should have the same bias in models relative to observations
- Many-signal analysis has disadvantage of suffering effective degeneracy
  - With small number of data points (e.g. ten decadal values), the fingerprints are short, so the more fingerprints the more likely two are hard to tell apart
- Also need to check residuals
  - Are they smaller than expected? Maybe our climate models are missing processes behind variability.
  - Are they bigger than expected? Maybe we are neglecting an important forcing.

Attribution: estimating relative importance

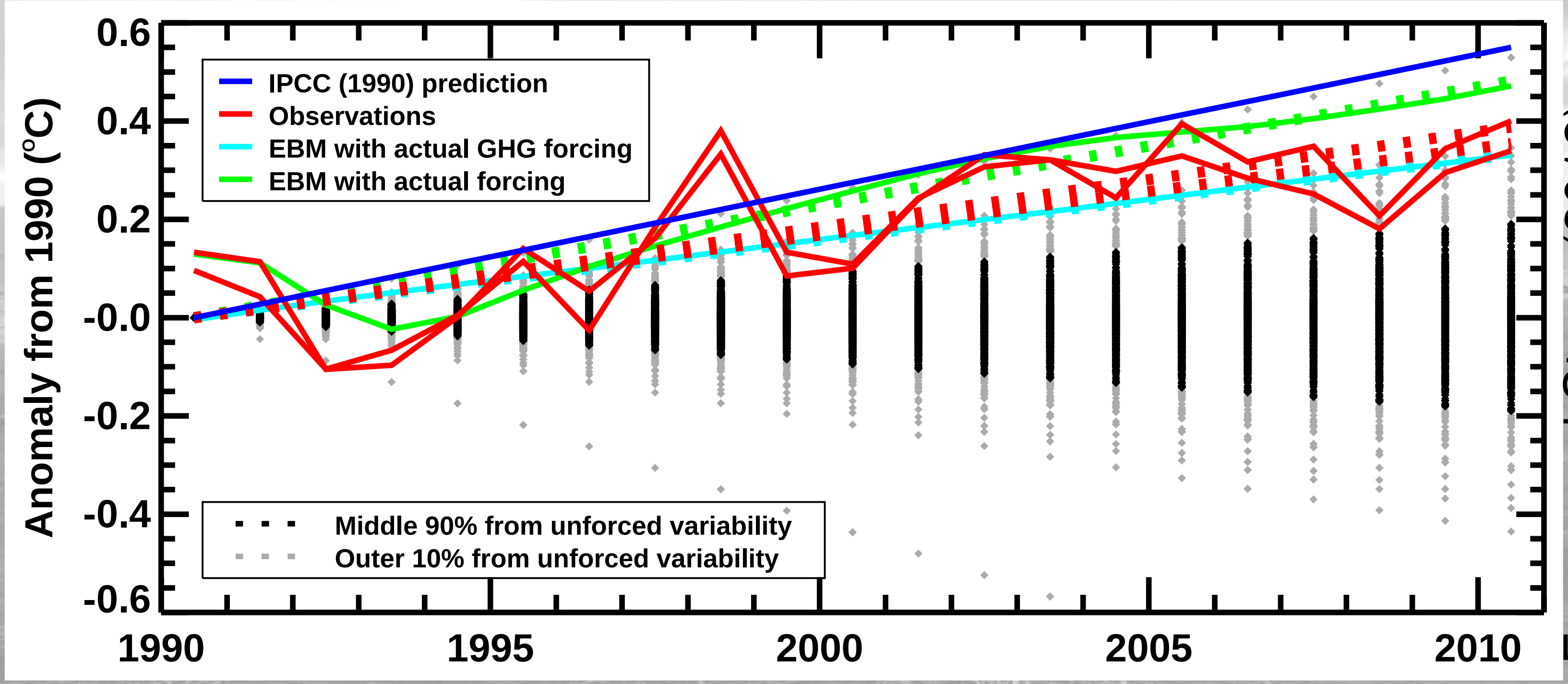
Multiply 1951–2010 simulated global warming trend by regression coefficient:



IPCC (2014) (Bindoff et alii 2013)

1.8. Is there a danger of tuning in hindsight?

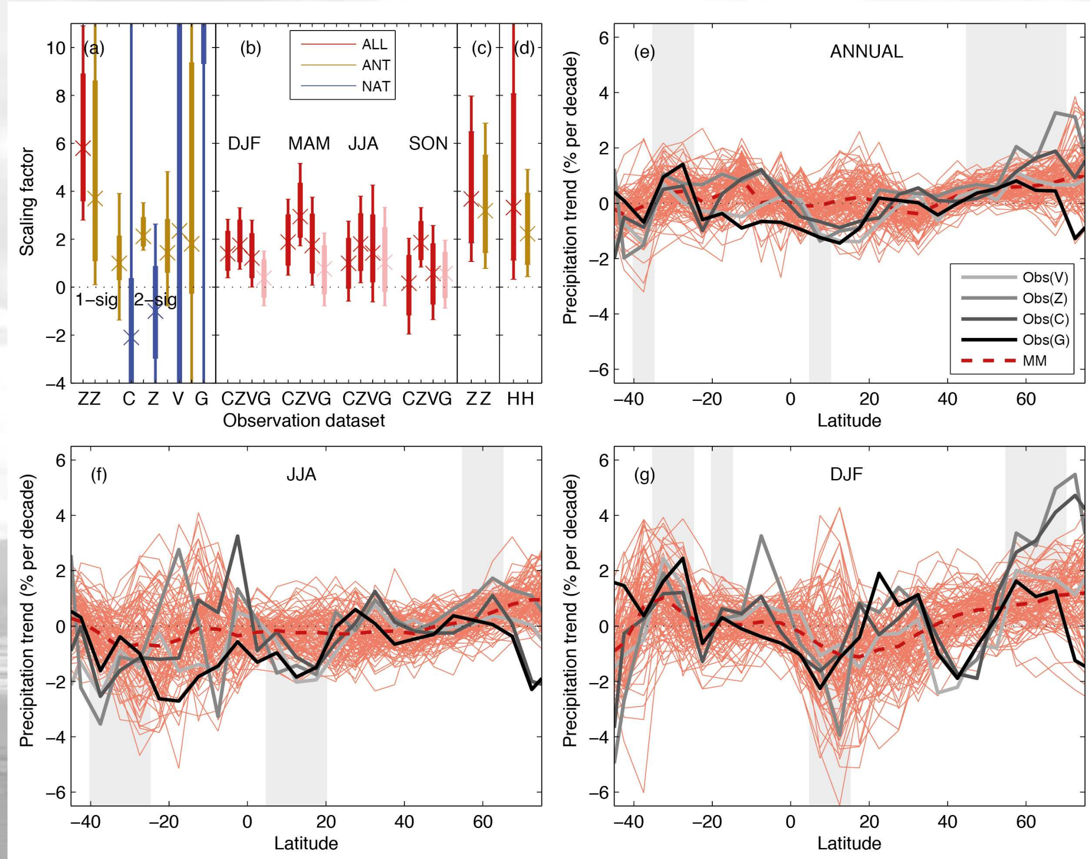
- Yes, but fingerprints help
- We can also now evaluate the IPCC (1990) prediction
- 1990 prediction better than “no change” prediction
  - Even though they missed lots of forcings!



Frame and Stone (2012)

1.9. Application to large-scale land precipitation

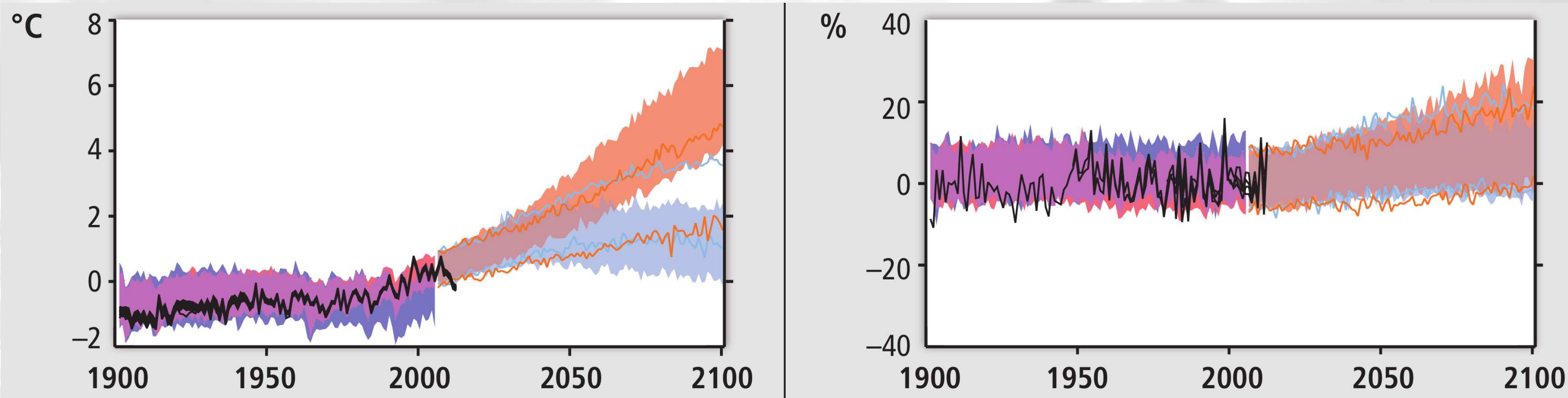
1951–1999 or 1951–2005 trends

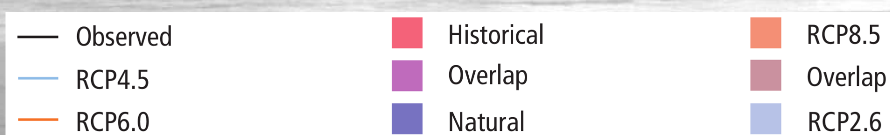


IPCC (2013) (Bindoff et alii 2013)

- Disagreement amongst observational data products
- Simulations and observations agree for seasons but not for year

1.10. Getting more local





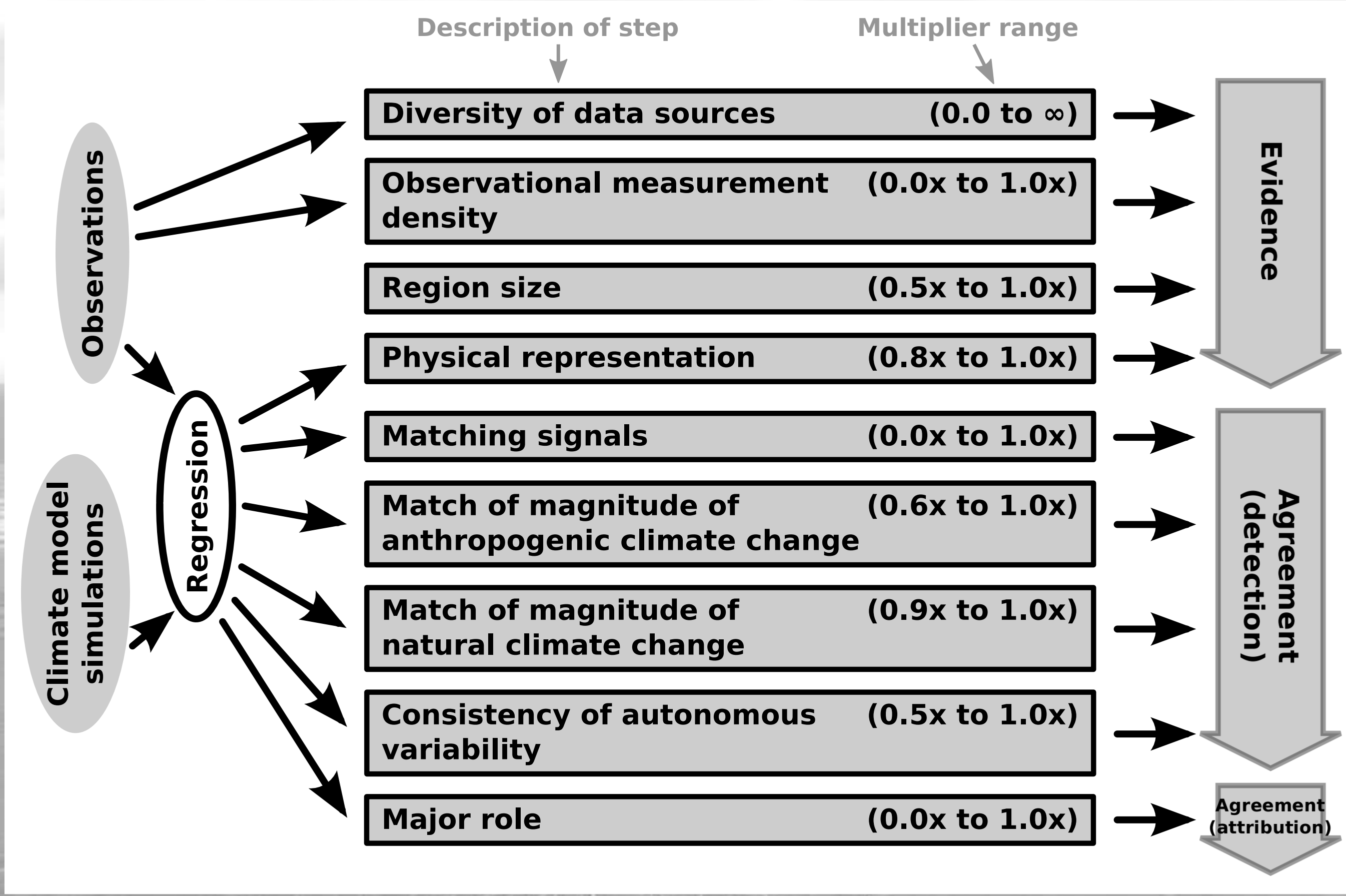
IPCC 2014 (Hijioka et alii 2014)

East Asia (China, Japan, North Korea, South Korea)

- Left: Annual average temperature
- Right: Annual total precipitation

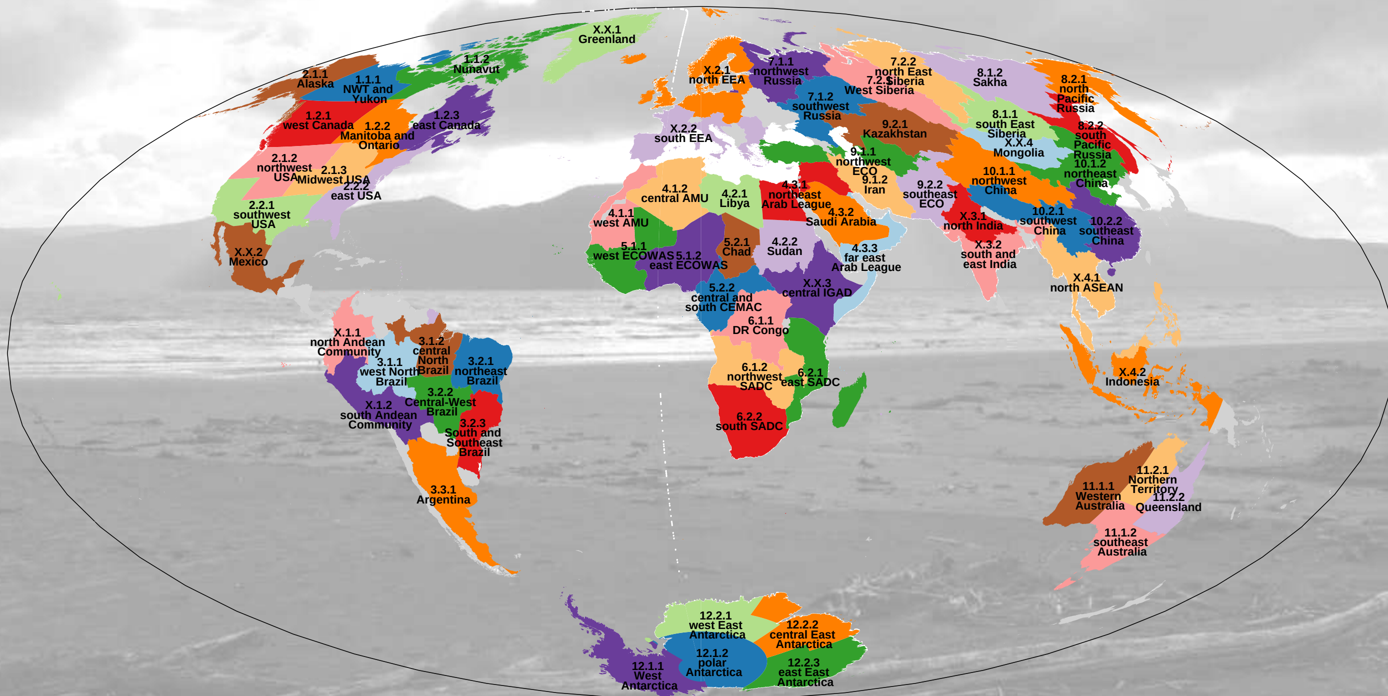
1.11. Building confidence in regional D&A conclusions

A possible algorithm:



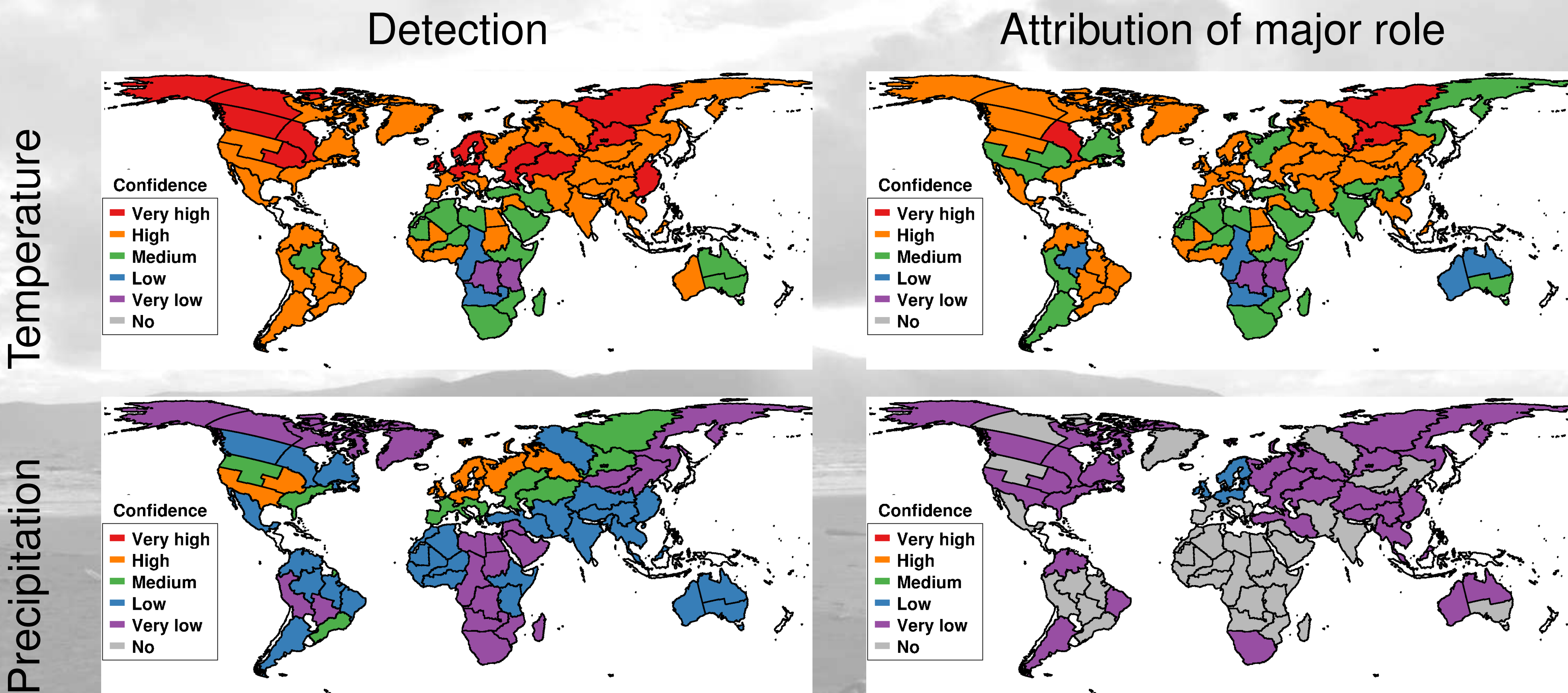
Stone and Hansen (2016)

So what do you think is the main control on confidence in detection of anthropogenic climate change?



Stone (2019)

Confidence in human role, 1961-2010

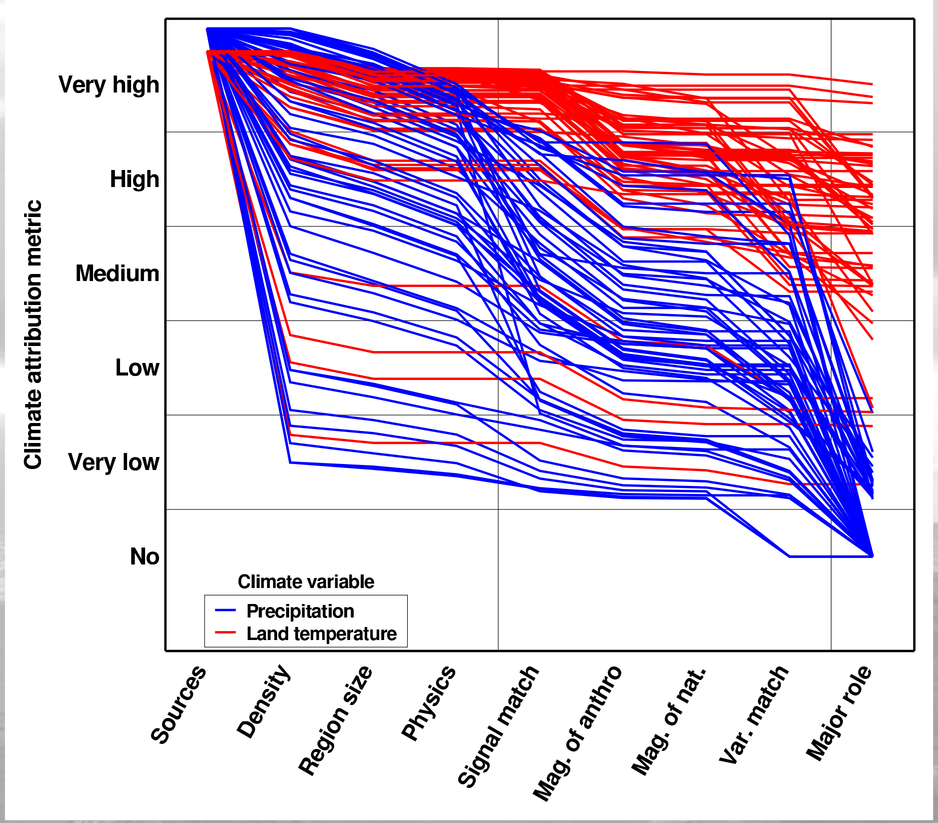


Stone and Hansen (2016)

Controls on regional D&A confidence

Effects of steps on confidence metric

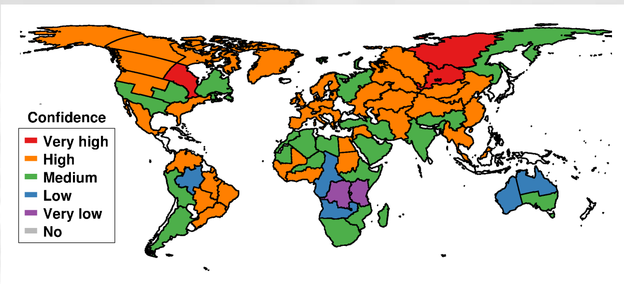
- Observation station density big issue, especially for precipitation (“Density”)
- Fingerprint often not confidently detected for precipitation (“Signal match”)
- Confident conclusion of “Major role” of anthropogenic emissions often not possible
  - For precipitation, probably because it is only indirectly affected



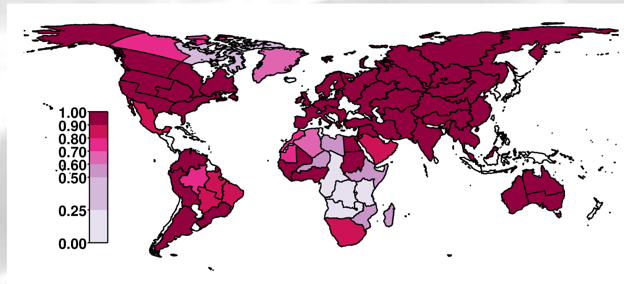
Stone and Hansen (2016)

What matters for temperature attribution?

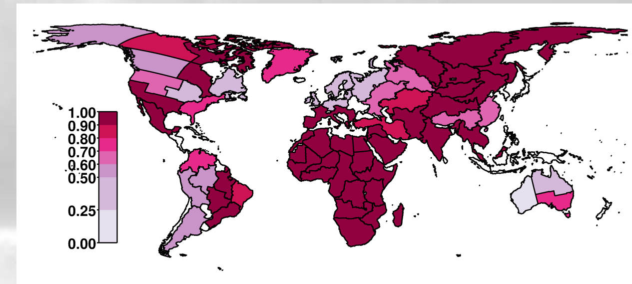
Final confidence



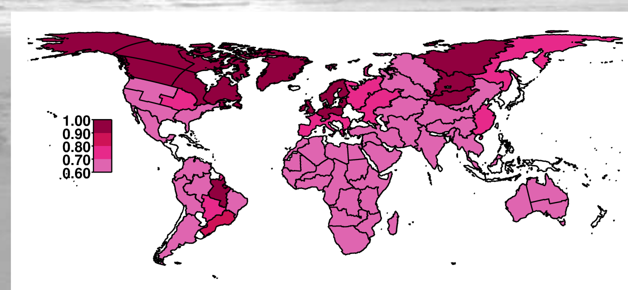
Observational measurement density



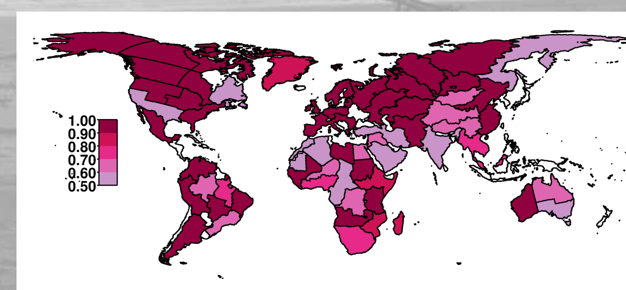
Major role



Match of magnitude of anthropogenic climate change



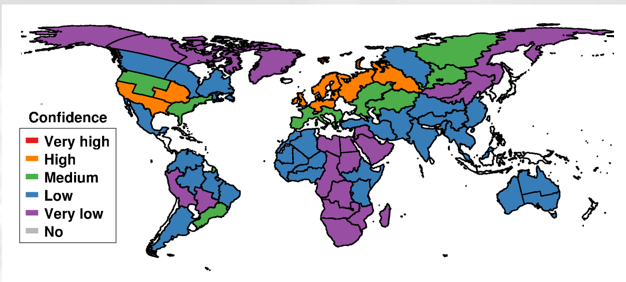
Consistency of autonomous variability



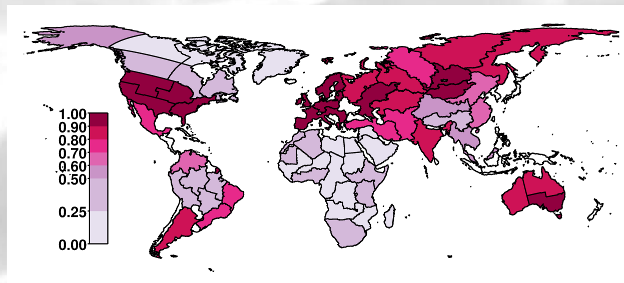
Stone and Hansen (2016)

What matters for precipitation detection?

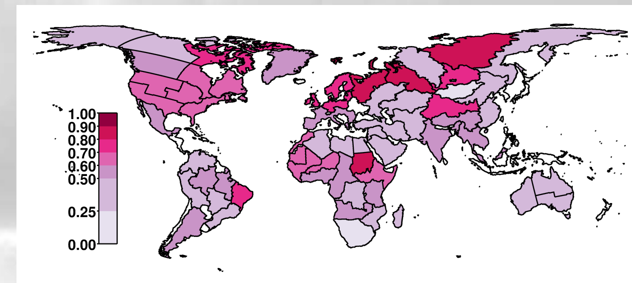
Final confidence



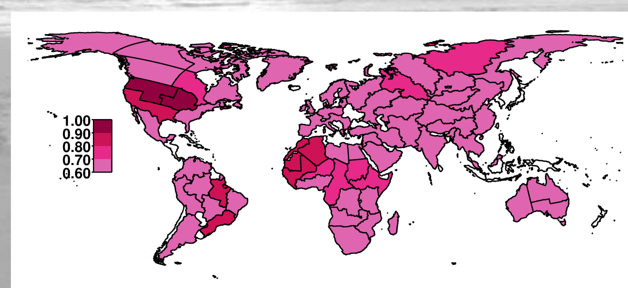
Observational measurement density



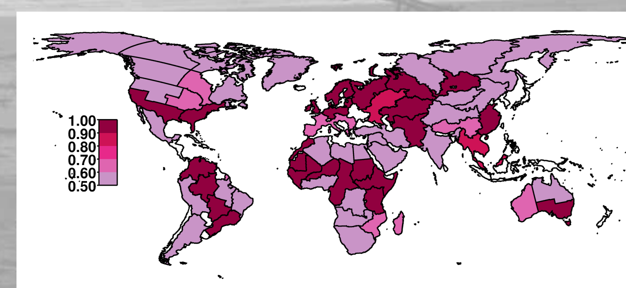
Matching signals



Match of magnitude of anthropogenic climate change



Consistency of autonomous variability



Stone and Hansen (2016)

1.12. Main messages

- As a scientist, you should not blindly believe what climate models tell you
- As a scientist, you should not blindly assume a cause for an observed trend
- Predictions (from climate models) and observations are independent sources of information, and should not agree by chance
- Detection and attribution confronts predictions of past change with observations
- Detection confirms the existence of a changing climate
- Attribution assesses the relative role of various causes
- *Lack of detection of change does not mean change is not occurring!*
  - You may be looking at the wrong measure
  - You may not have sufficient observational data
  - Just because your models a deficient or your observations are incomplete does not mean the world is not changing