Attribution and Detection

Outline

- Definitions of attribution and detection
- Methodologies to separate anthropogenically forced variability from natural variability
- Extreme event attribution
- Challenges faced in attribution studies

Detection and Attribution

- Detection is defined as the process of demonstrating that *climate* or a system affected by climate has changed in some defined statistical sense, without providing a reason for that change. An identified change is detected in observations if its *likelihood* of occurrence by chance due to internal variability alone is determined to be small, for example, <10%.
- Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or an event with a formal assessment of *confidence*.

IPCC Glossary https://www.ipcc.ch/sr15/chapter/glossary/

Why are we interested in attribution?

Attribution studies help to answer the following questions.

- What are the values of ocean initialization?
  - If internal variability does not play an important role, dynamic initialization of coupled GCMs is not critical.
- What physical processes and modes of variability are important for the near-term climate prediction?
- Are the observed changes something transitory due to internal variability or part of a trend that will be amplified due to an anthropogenic forcing?
  - An example: Prolonged drought conditions occurred in western U.S. since the late 1990s. CMIP models suggest that the region will become drier in a warmer climate, but the region is also subject to the impacts of natural decadal variability modes of the Atlantic and Pacific SST.
  - Knowing how much of the drought can be attributed to natural variability vs. climate change could greatly aid water resource managers in developing informed adaptation strategies.

Solomon et al. 2011

Conceptual framework for detection and attribution studies

- The conceptual framework for most detection and attribution studies consists of four elements:
  - relevant observations;
  - the estimated time history of relevant climate forcings (such as greenhouse gas concentrations or volcanic activity);
  - a modeled estimate of the impact of the climate forcings on the climate variables of interest;
  - an estimate of the internal (unforced) variability of the climate variables of interest

Knutson 2017

General types of detection and attribution studies

- There are several general types of detection and attribution studies:
    - attribution of trends or long-term changes in climate variables;
    - attribution of changes in extremes;
    - attribution of weather or climate events;
    - attribution of climate-related impacts;
    - the estimation of climate sensitivity using observational constraints

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Different Attribution Methods

I. Fingerprint-based methods
II. Non-fingerprint based methods
III. Multistep attribution and attribution without detection

I. Fingerprint-based methods

- In the fingerprint-based methods, the observed changes are regressed onto a model-generated response pattern to a particular forcing (or responses to a set of forcings; i.e., fingerprints)

$$y = Xa + u$$

- Where X and y denote the model estimated response patterns to the external forcing(s) and the observed change, respectively; a is a vector of regression scaling factors, with one scaling factor for each fingerprint in matrix X; and u represents internal variability. In other words, the observed change y is regarded as a linear combination of forced signals X and residual internal climate variability u.
  - If the scaling factor for a forcing pattern is determined to be significantly different from zero, a detectable change is identified.
  - If the uncertainty bars on the scaling factor encompass unity, the observed change is consistent with the modeled response, and the observed change can be attributed, at least in part, to the associated forcing agent.
- Fingerprints are based on climate models of various complexities, from simple energy balance models to full earth system models. Statistical approaches range from simple comparisons of observations with model simulations to multi-regression methods.

Hegerl and Zwiers 2011; Knutson et al. 2017

Schematic for the fingerprint methods

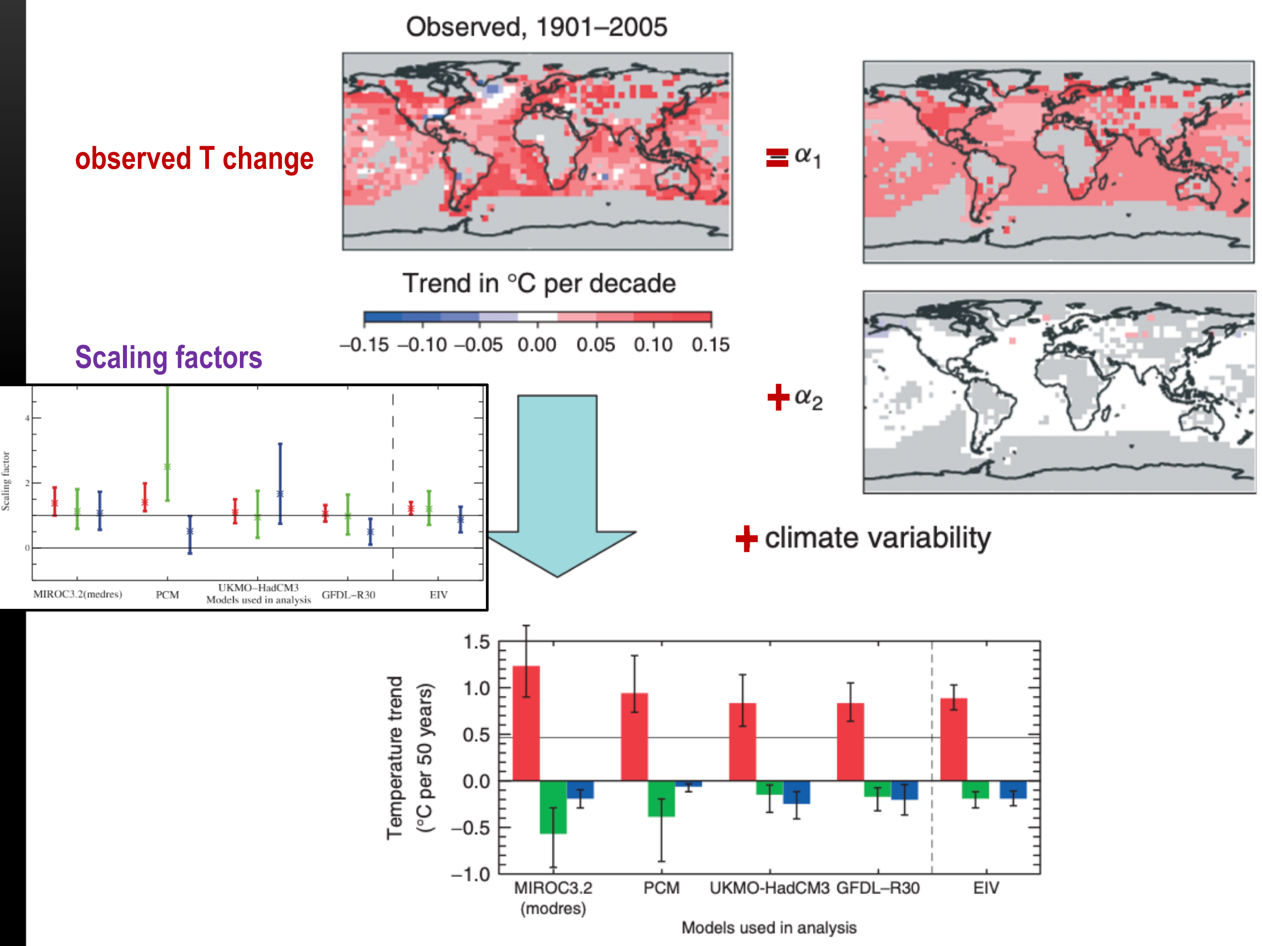

FIGURE 3 | Schematic for detection and attribution. The observed change (shown here: pattern of temperature change over the 20th century, left) is composed of a linear combination of fingerprints for all forcings combined (top, right) and for natural forcings only (center right, this combination allows rescaling of natural vs anthropogenic fingerprints in simulations of the 20th century) plus residual, unexplained variability. The resulting scaling factors and warming per fingerprint can be used to derive contributions to warming such as shown in the bottom panel, labeled panel (c), although in this instance the latter is derived from three fingerprints. It shows attributable warming estimated from a detection and attribution analysis for the 20th century, using a fingerprint of the spatial pattern and time evolution of climate change forced by greenhouse gases (red), other anthropogenic forcing (green), and solar and volcanic forcings combined (blue). The best estimate contribution of each forcing to warming in the 50-year period 1950–1999 is given by the vertical bar and the 5–95% uncertainty in that estimate is given by the black whiskers. The observed trend over that period is shown by a black horizontal line. The different estimates are derived using fingerprints from different models. (Reprinted with permission from Ref 2. Copyright 2007 Cambridge University Press)

- The observed T changes (top, left) can be regarded as a linear combination of fingerprints for different external forcings combined (top, right) and for natural forcings only (center right) and residual, unexplained variability.
- The figure on the middle left shows the scaling factors and the bottom panel shows the different estimates derived using fingerprints from different models.
- In this example the forced responses include three fingerprints: greenhouse gases (red), other anthropogenic forcing (green), and solar and volcanic forcings combined (blue).

Hegerl et al. 2007; Hegerl and Zwiers 2011

Attribution of Global Mean Temperature Trend

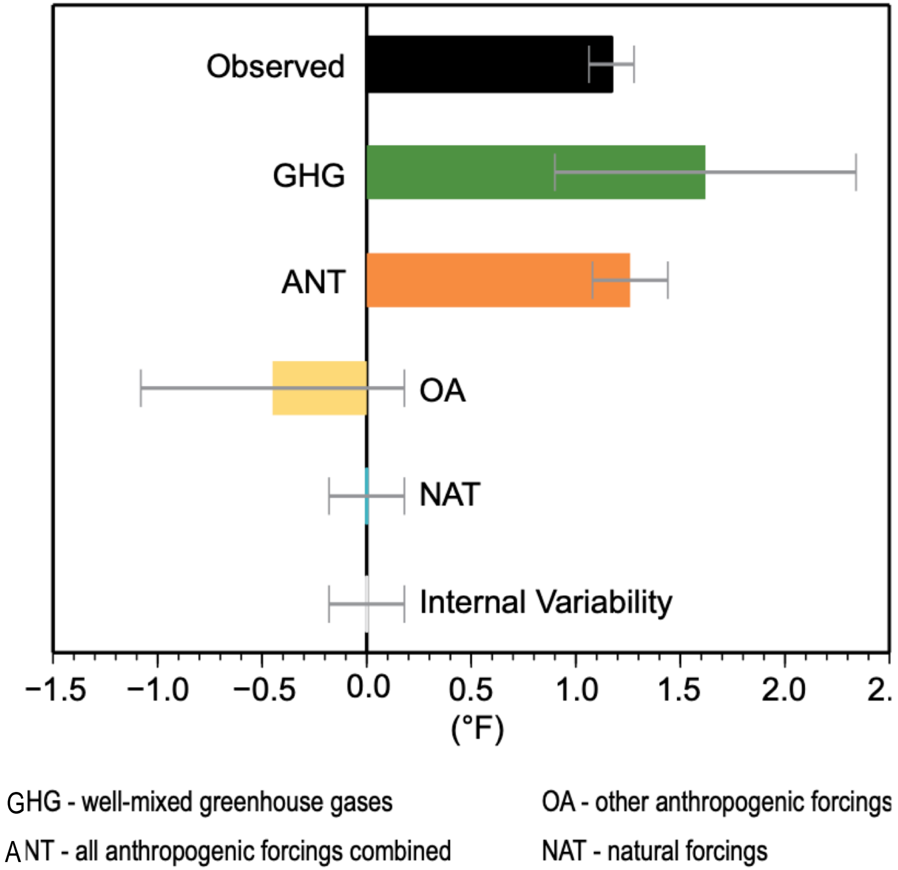

Figure 3.2: Observed global mean temperature trend (black bar) and attributable warming or cooling influences of anthropogenic and natural forcings over 1951–2010. Observations are from HadCRUT4, along with observational uncertainty (5% to 95%) error bars.[62] Likely ranges (bar-whisker plots) and midpoint values (colored bars) for attributable forcings are from IPCC AR5.[1]. GHG refers to well-mixed greenhouse gases, OA to other anthropogenic forcings, NAT to natural forcings, and ANT to all anthropogenic forcings combined. Likely ranges are broader for contributions from well-mixed greenhouse gases and for other anthropogenic forcings, assessed separately, than for the contributions from all anthropogenic forcings combined, as it is more difficult to quantitatively constrain the separate contributions of the various anthropogenic forcing agents. (Figure source: redrawn from Bindoff et al.;[1] © IPCC. Used with permission.)

- The likely range of the anthropogenic contribution to global mean temperature trend over 1951–2010 was 1.1° to 1.4°F, close to the observed warming.
- In contrast, the estimated likely contribution ranges for natural forcing and internal variability were both much smaller (−0.2° to 0.2°F) than the observed warming.

Knutson et al. 2017

II. Non-fingerprint based methods

- Observed changes are compared with natural variability simulations or with simulations including both natural variability and anthropogenic forcing agents. If observations are inconsistent with model simulations using natural forcing only but are consistent with models that incorporate both anthropogenic forcing and natural variability, then the observed changes can be at least partly attributed to anthropogenic forcing.

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Example 1: Trend of Global Mean Temperature

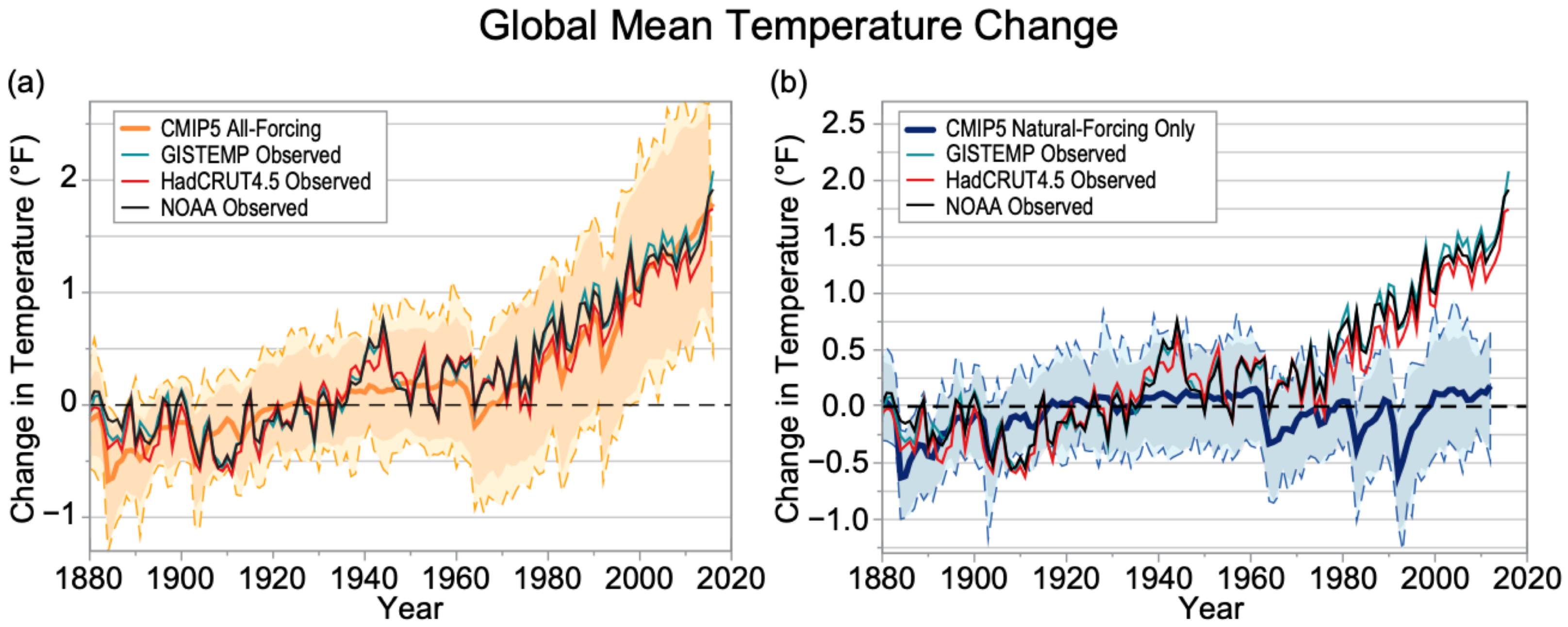

Figure 3.1: Comparison of observed global mean temperature anomalies from three observational datasets to CMIP5 climate model historical experiments using: (a) anthropogenic and natural forcings combined, or (b) natural forcings only. In (a) the thick orange curve is the CMIP5 grand ensemble mean across 36 models while the orange shading and outer dashed lines depict the ±2 standard deviation and absolute ranges of annual anomalies across all individual simulations of the 36 models. Model data are a masked blend of surface air temperature over land regions and sea surface temperature over ice-free ocean regions to be more consistent with observations than using surface air temperature alone. All time series (°F) are referenced to a 1901–1960 baseline value. The simulations in (a) have been extended from 2006 through 2016 using projections under the higher scenario (RCP8.5). (b) As in (a) but the blue curves and shading are based on 18 CMIP5 models using natural forcings only. See legends to identify observational datasets. Observations after about 1980 are shown to be inconsistent with the natural forcing-only models (indicating detectable warming) and also consistent with the models that include both anthropogenic and natural forcing, implying that the warming is attributable in part to anthropogenic forcing according to the models. (Figure source: adapted from Melillo et al.[2] and Knutson et al.[19]).

- The observed temperature trend is inconsistent with models that include only natural forcings (right; blue shading) but is consistent with the model simulations that include both anthropogenic and natural forcings (lef; orange shading).
- The observed global warming is thus attributable in large part to anthropogenic forcings.

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Example 2: Detection and attribution of regional temperature trends

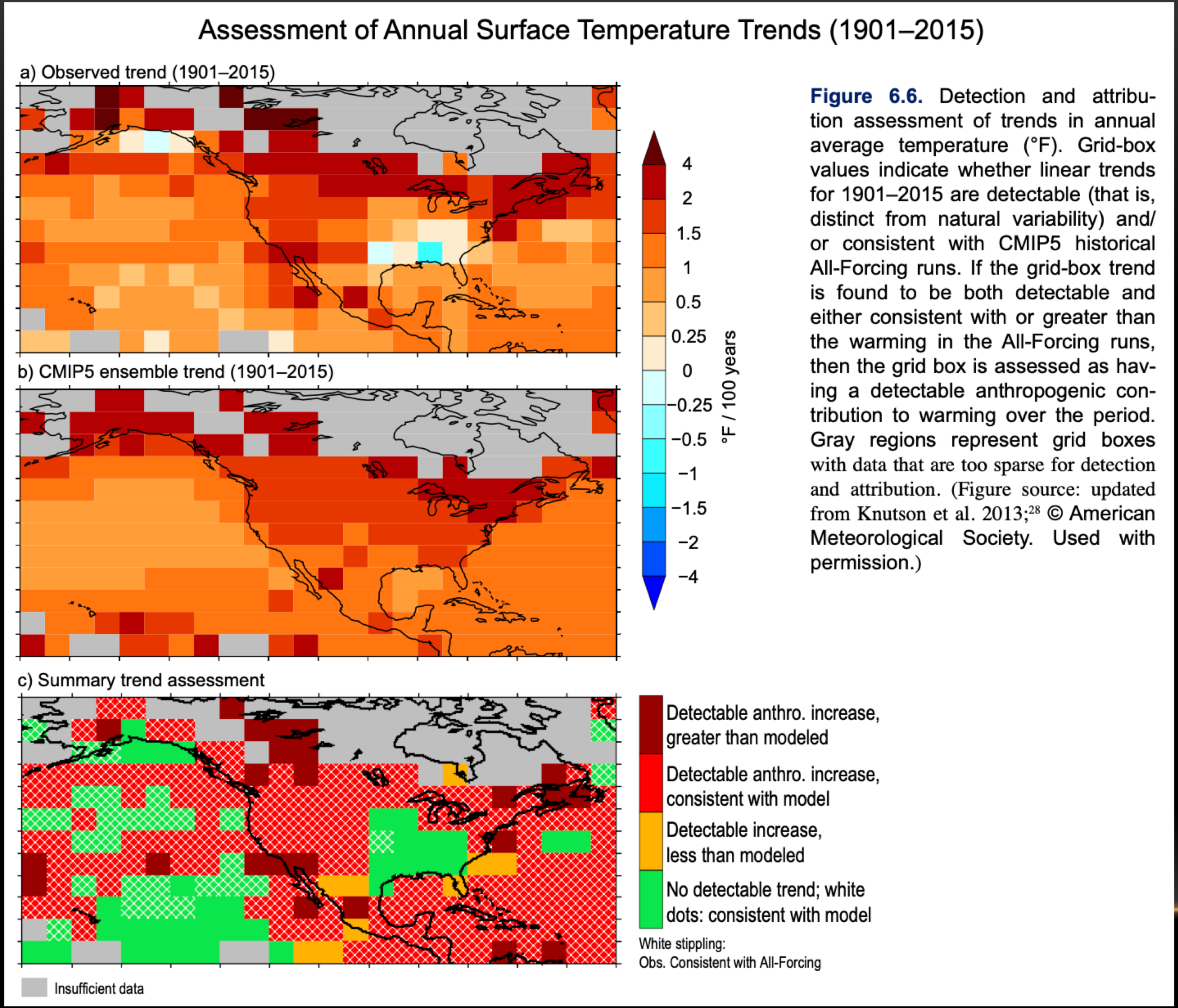

Figure 6.6. Detection and attribution assessment of trends in annual average temperature (°F). Grid-box values indicate whether linear trends for 1901–2015 are detectable (that is, distinct from natural variability) and/or consistent with CMIP5 historical All-Forcing runs. If the grid-box trend is found to be both detectable and either consistent with or greater than the warming in the All-Forcing runs, then the grid box is assessed as having a detectable anthropogenic contribution to warming over the period. Gray regions represent grid boxes with data that are too sparse for detection and attribution. (Figure source: updated from Knutson et al. 2013;[28] © American Meteorological Society. Used with permission.)

- Recall that a detectable trend is a trend that is distinct from natural variability.
- If the trend is found to be both detectable and either consistent with or greater than the warming in the all-forcing runs, then the grid box is assessed as having a detectable anthropogenic contribution to warming over the period, as we can see in many regions in the US and the North Atlantic.

Vose et al. 2017 (Fig. 6.6)

III. Multistep attribution and attribution without detection

- In the multistep approach, (step 1:) the observed change in the variable or event of interest is attributed to a change in climate or other environmental conditions that are closely related to the variable or event of interest, and (step 2:) then the changes in the climate or environmental conditions are separately attributed to an external forcing, such as anthropogenic emissions of greenhouse gases.
  - For example, an attribution statement can be made about hurricanes based on the attributable changes in sea surface temperature (SST) or vertical wind shear, on the basis that higher SST and weaker vertical wind shear are conducive for hurricane activity.
- The multistep approach allows for attribution of a climate change without necessarily detecting a significant change in the occurrence rate of the phenomenon or event itself
  - For example, Murakami et al. (2015) used model simulations to conclude that the very active hurricane season observed near Hawaiʻi in 2014 was at least partially attributable to anthropogenic influence; they also show that there was no clear long-term detectable trend in historical hurricane occurrence near Hawaiʻi in available observations.
  - If an attribution statement is made where there is not a detectable change in the phenomenon itself, then this statement is an example of *attribution without detection.* Such an attribution statement generally has a low confidence than attribution with detection.
- Attribution statements based on the multistep approach are underpinned by a thorough understanding of the link between climate or environmental conditions and the variable or event of interest.

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