Detection and Attribution an Outlook

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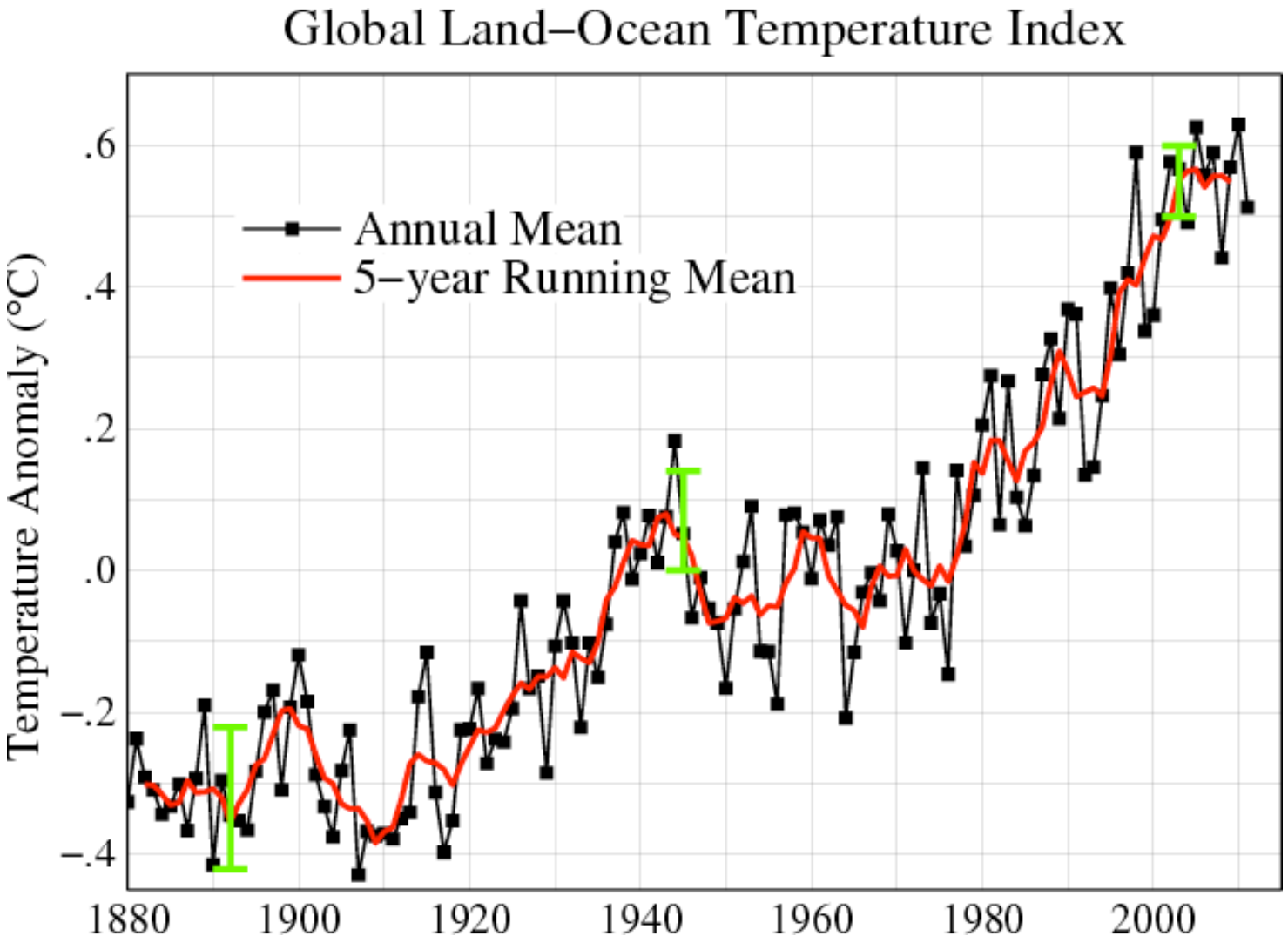
DADA workshop
Buenos Aires, October 15-18 2012

- Detection and Attribution

  - The context: IPCC statements
  - D&A definitions
  - **Non-optimal** and **optimal** approaches
  - Quick look at methodologies at the non-optimal end of the spectrum and an example (Santer et al., 2007)
  - Francis Zwiers to tackle optimal D&A methodology in the next talk.



GISS
Baseline 1951-1980
Last year is 2011 (+0.51C)

IPCC AR4, WG1:

*Warming of the climate system is **unequivocal** as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global mean sea level.*

Of course this statement does not address the causes of the observed warming.

In order to do attribution we need to assess whether the observed changes are

✓ consistent with the expected responses to external forcings

✓ inconsistent with alternative explanations

D&A

- **Detection**: the process of demonstrating that changes in a system's behavior are *statistically significant beyond what can be explained by internal (natural) variability* alone.

- **Attribution**: the process of determining, when possible quantifying, the *relative contribution of multiple factors* that may be responsible for those changes, and *assigning a level of confidence* to this comparative evaluation.

- The factors of interest are external influences, which we distinguish as anthropogenic (GHGs, aerosols, ozone precursors, land use) and natural (volcanic eruptions, solar cycle modulations)

D&A Methodology

D&A methods seek to determine whether an anticipated *signal* (pattern of change) is present in observations

Models play a central role because they are used

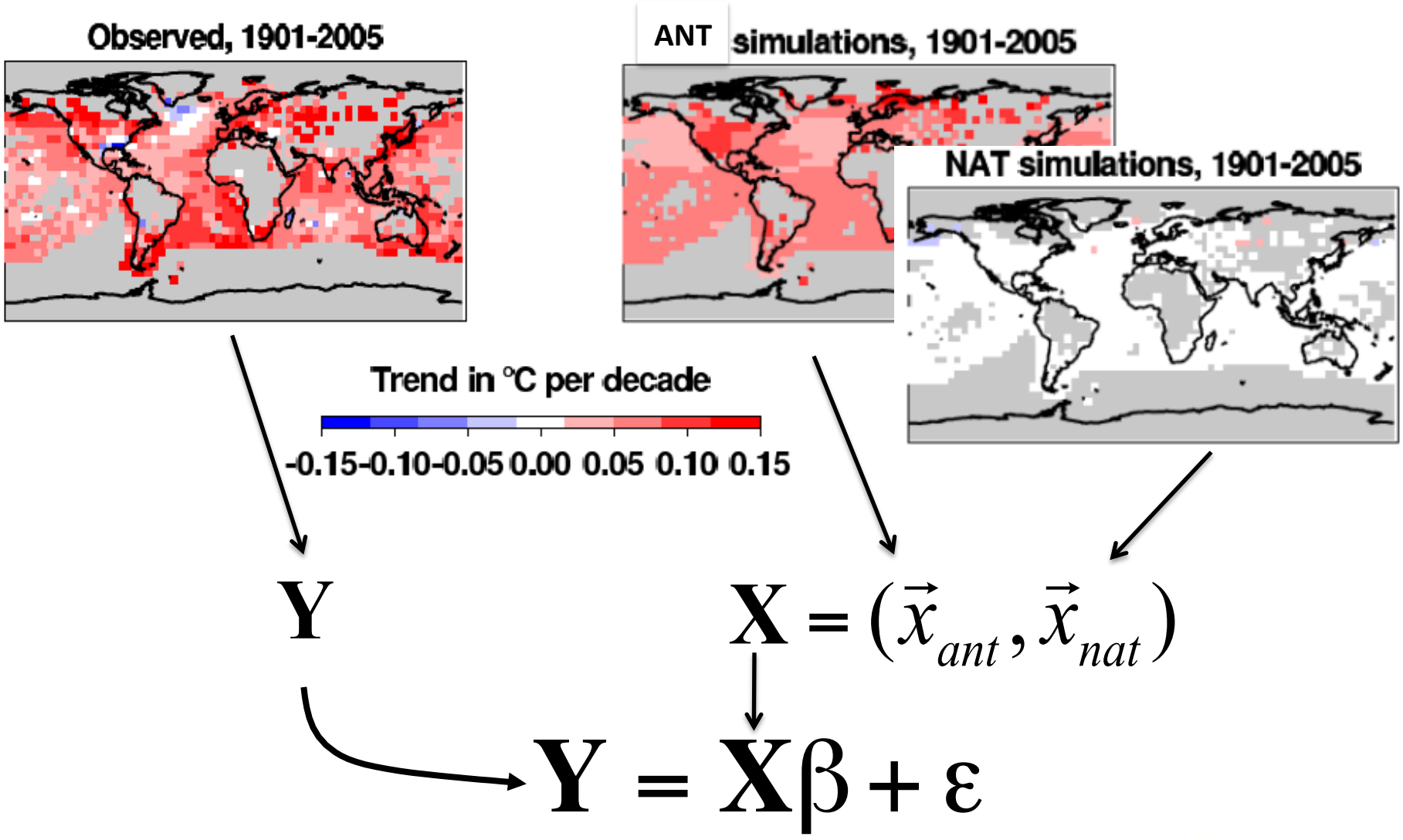
- to estimate the signals, as expected responses to external forcing, and
- to estimate the amplitude of the background internal variability that is also present in observations, the noise.

D&A Methodology

Usually the assumptions are that

- Signal and noise are additive
- Signal components are additive (i.e., the responses to different external forcings add-up linearly)

D&A methods are in most cases variants of linear regression fits



Slide from Gabi Hegerl's presentation at Geneva IPCC WG1/WG2 Meeting on D&A, September 2009

D&A methodology (continued)

A *regression analysis* relates observed and modeled fingerprints (signal characterizations from data and from model output according to separate external forcings) and a *formal hypothesis testing* on the coefficients of the individual modeled fingerprints takes place to

A) Determine that the coefficients are significantly different from zero (it is not all noise) and

B) Estimate the relative magnitude of the coefficients of the anthropogenically forced/naturally forced fingerprints.

D&A methodology (continued)

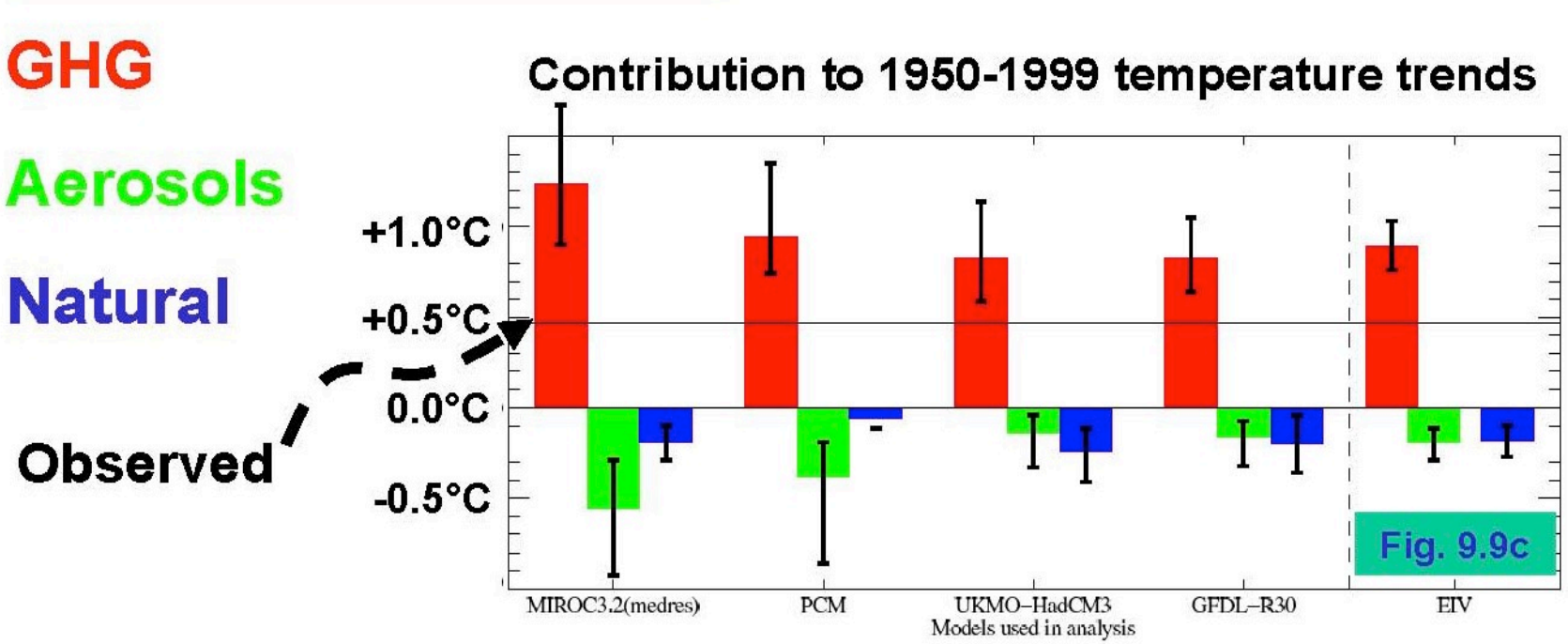
A critical component in the regression analysis is the *error term*, which needs to characterize the behavior of **Y** when left alone (i.e., its internal variability). In most cases, and definitely in the optimal approach to D&A, the error term is *not* assumed to be the realization of a white noise process, and control simulations are used to characterize its covariance structure.

Sources of confidence/uncertainty

Greater confidence is achieved when

- We can separate the contribution to observed changes from individual sources “cleanly”
- We can account for multiple sources of uncertainty (observational and forcing and model uncertainties)
- Models and observations agree on the amplitude of the contributions
- Other explanations can be shown to be not viable
- The internal variability simulated by the model has similar statistical characteristics to the observed

Global Average Surface Air Temperature
AR4 Results

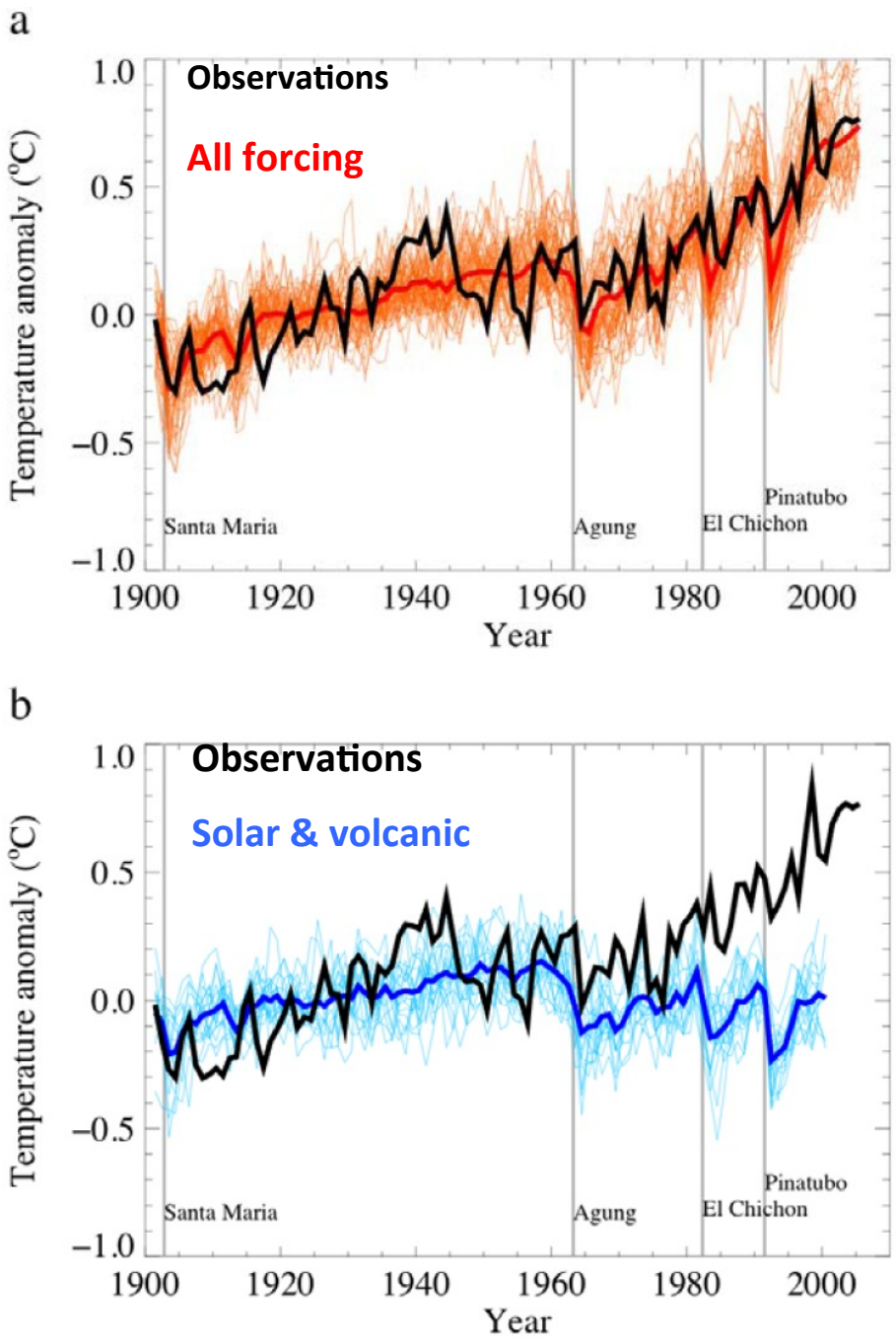


Warming of global Surface Air Temperature during past half century (according to IPCC AR4)

- Cannot be explained without **external** forcing
  Extremely likely (Model variability simulates well observed and paleo variability; changes are very large compared to simulated internal variability; upper ocean warming contributes to support non-internal causes)
- Is not only due to known **natural external** causes
  Very likely (No climate model can reproduce it applying only natural externa forcings; happens at a time when natural forcings would induce cooling)
- **GHGs** have been **dominant** force
  Very likely (Multi-signal D&A analysis robustly estimates larger contribution of GHGs compared to other forcings)
- **GHGs would have caused more warming than observed** without volcanoes and anthropogenic aerosols
  Likely (separation of the responses is uncertain across models)

Non-optimal D&A

For some variables D&A has taken place only qualitatively, by *evaluating the consistency/coherence of the observed changes with the changes modeled* in the presence of anthropogenic/all forcings, as opposed to the changes (or their absence) modeled in the presence of natural-only forcings.


a
Observations
All forcing
Temperature anomaly (°C)
1.0
0.5
0.0
−0.5
−1.0
1900
1920
1940
1960
1980
2000
Year
Santa Maria
Agung
El Chichon
Pinatubo
b
Observations
Solar & volcanic
Temperature anomaly (°C)
1.0
0.5
0.0
−0.5
−1.0
1900
1920
1940
1960
1980
2000
Year
Santa Maria
Agung
El Chichon
Pinatubo

In its more rigorous form, however, non-optimal D&A is still a regression approach

1) Use climate models to estimate "form" of signal
   - Usually the mean F of an ensemble of forced runs
   - Signal could be a pattern of change in space or in space & time, or across multiple variables
2) Estimate amplitude of signal in the observations
   - A scaled inner-product between a normalized signal and observations

$$S = (F^{*}T)/||F||$$

3) Compare S with amplitude of signal in individual forced model runs
4) Compare S with natural variability of signal amplitude in control simulations
   - Calculate amplitude in similar length control run segments
   - Basis for a test of the strength of the signal in the observations
   - Note that model output is processed to match observations
     - It is masked to be "missing" where/when observations are missing, etc.
     - The fact that data are missing may have some impact ... we want to be sure we are not detecting an "aliased" signal
5) Demonstrate that alternative signals are unlikely to be able to explain observed change

Note that in this type of analyses the regression assumes that the covariance matrix is proportional to the identity matrix, therefore these approaches amount to OLS

An example: Santer et al., 2007
D&A of SSTs in cyclogenesis regions

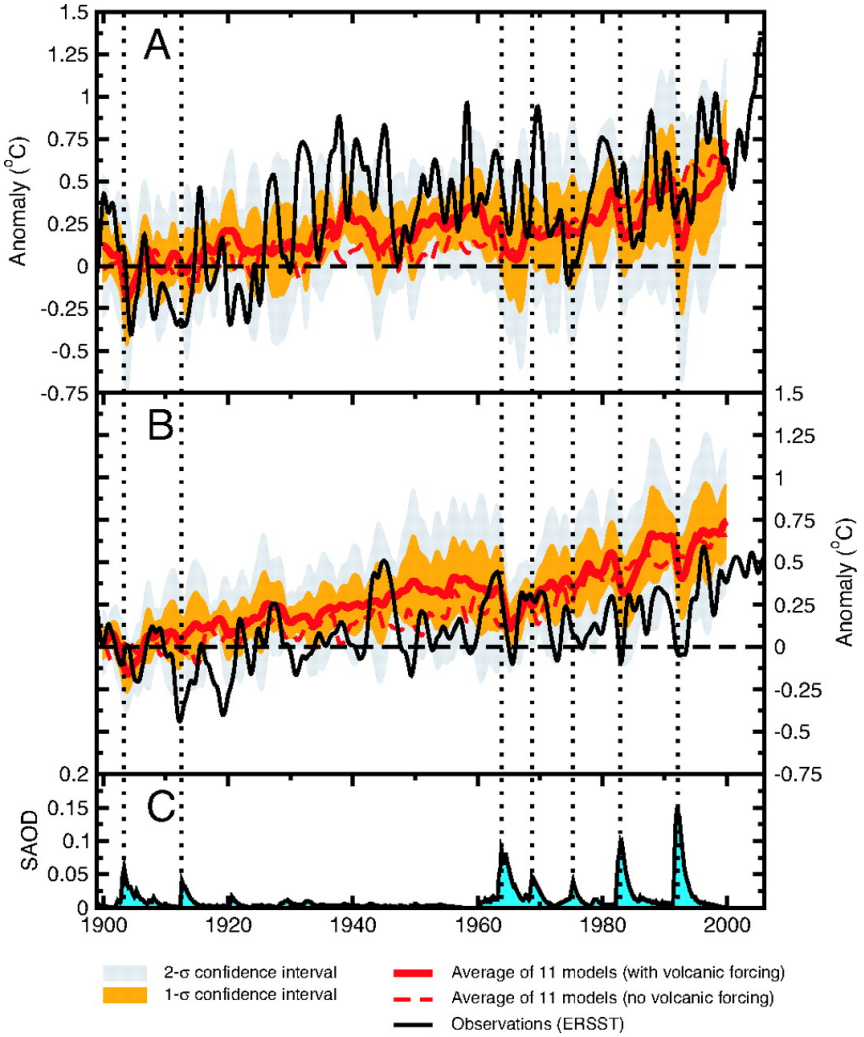
Pacific and Atlantic CR temperature time series are compared to modelled under no external forcings (control simulations) or under 20th century forcings.

Trends are computed for different starting periods from two observationsal products and compared to the distribution of trends obtained from control experiments of 22 different models, finding that in most cases the observed trends are significantly larger than what expected under no external forcings.

Estimates of externally forced components of trends are derived.

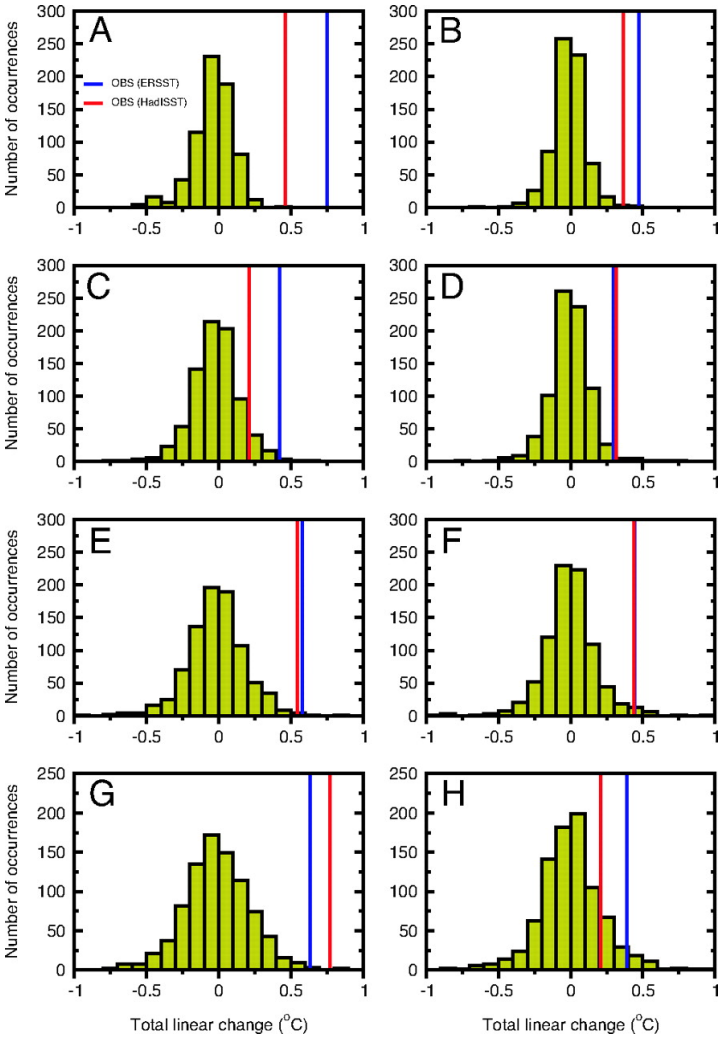
Single forcing experiments from one model are used to apportion the contributions of different external forcings.

Modeled and observed SST changes in tropical cyclogenesis regions and observed changes in stratospheric aerosol optical depth (SAOD).



Santer B D et al. PNAS 2006;103:13905-13910

Comparison between observed and simulated SST changes in the ACR (A, C, E, and G) and PCR (B, D, F, and H).



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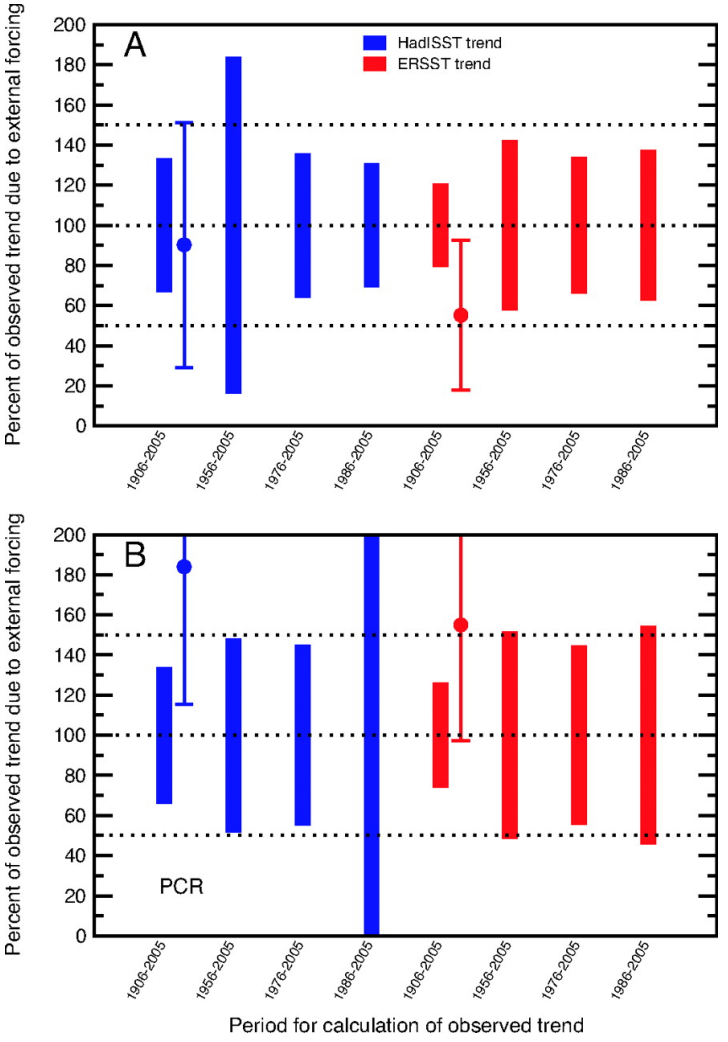
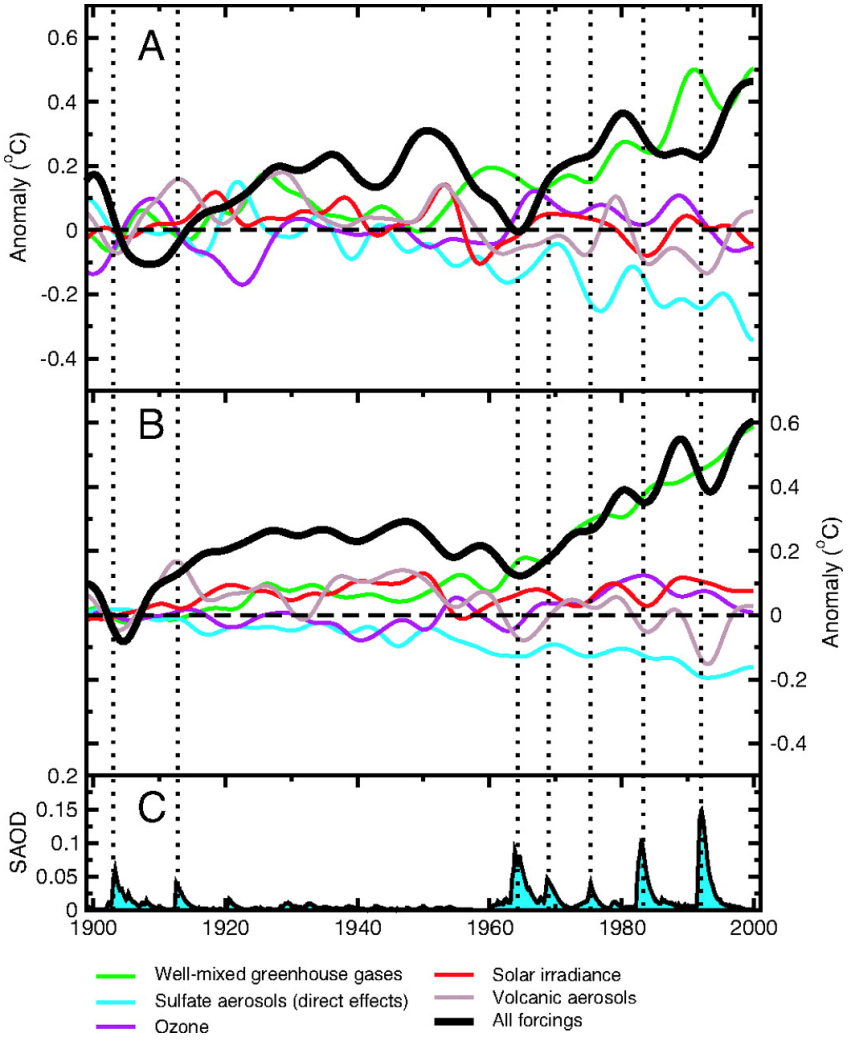
Estimates of the percentage contribution of external forcing to observed SST changes in the ACR (A) and PCR (B).



Santer B D et al. PNAS 2006;103:13905-13910

Contribution of different external forcings to SST changes in tropical cyclogenesis regions.



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Optimal approach to D&A

Floor to Francis!