On the Time-Varying Trend in Global-Mean Surface Temperature

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ACKNOLEDGEMENTS

Wu, Z., Huang, N. E, S. R. Long, C.-K. Peng, 2007: On the trend, detrending, and variability of nonlinear and nonstationary time series. *Proc. Natl. Acad. Sci. USA*. **104**, 14889-14894. doi: 10.1073/pnas.0701020104.

Wu Z., N. E. Huang, J. M. Wallace, B. Smoliak, X. Chen, 2011: On the time-varying trend in global-mean surface temperature. *Clim. Dyn.* **37**, 759-773, DOI: 10.1007/s00382-011-1128-8.

Fu, C., C. Qian, and **Z. Wu**, 2011: Projection of global mean surface air temperature changes in next 40 years: Uncertainties of climate models and an alternative approach. *Science China-Earth Sciences.* **54**, 1400-1406. DOI: 10.1007/s11430-011-4235-9.

A KEY ISSUE

- The Earth's Climate has ever been changing
- Greenhouse gases (especially CO_2) is increasing and the increasing greenhouse gases can lead to a warmer (averaged sense) Earth's climate
- The warming is not spatially uniform. Some regions warm more than others and there can be even cooling regions.
- Therefore, a key issue needs to be addressed are the rate the anthropogentically forced warming and its spatial structure

GREENHOUSE EFFECT AND SLEEPING BEAUTIES

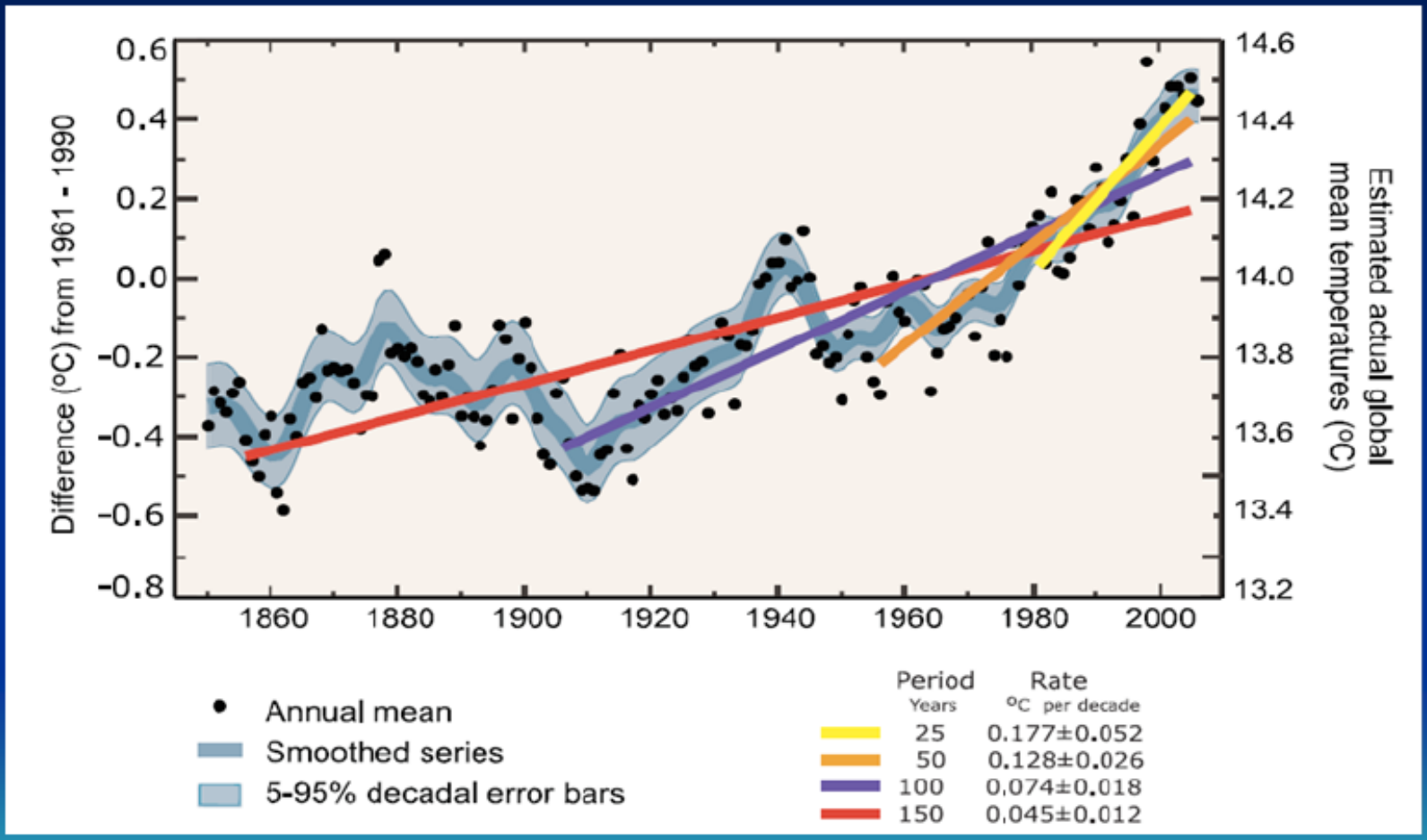
How much change of temperature due to greenhouse gas trapped energy is dependent quite sensitively to how the trapped energy is distributed to different components of the Earth's climate system

A fact: the heat content of a vertical column of atmosphere is equivalent to the heat content of the water of 2.5 meter depth

CONTENT

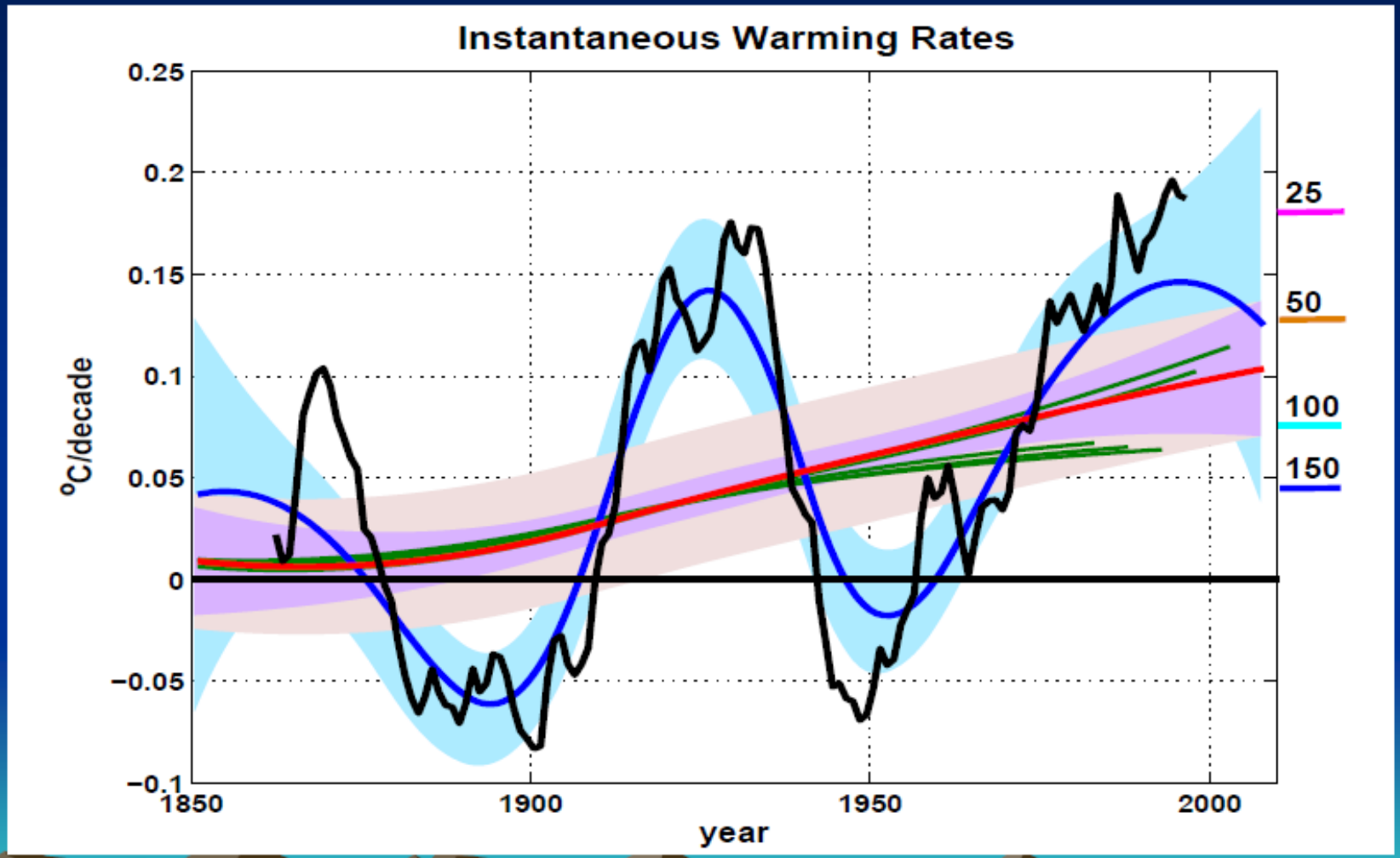
- Trend and Cycles
- Our Estimations of the Trend
- Physical Explanation
- Questions on IPCC AR4
- Conclusions

IPCC AR4 TRENDS



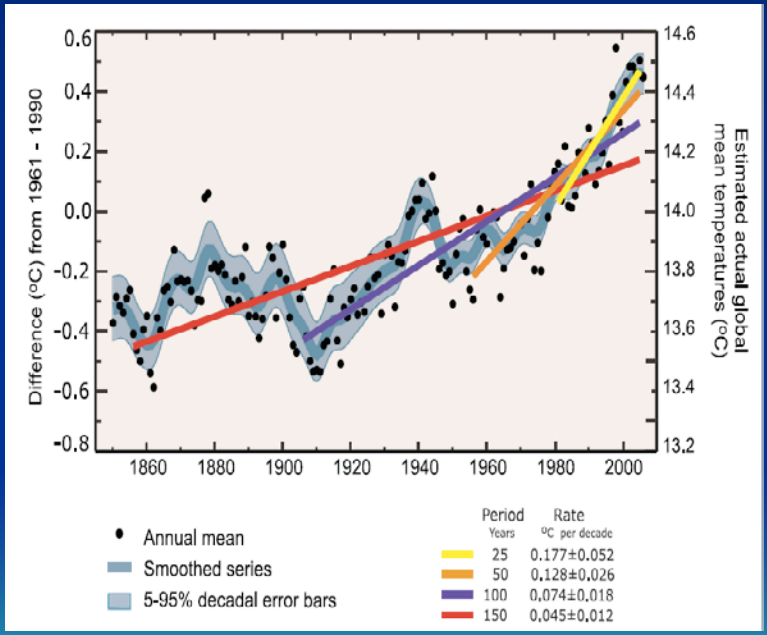
*"…Note that for shorter recent periods, the slope is greater, indicating accelerated warming…" (***FAQ 3.1, Figure 1.** on *p. 253 and* **Figure TS.6** *on p. 37)*

COMPARISON OF TRENDS



THE STATE-OF-THE-ART

- Simple trend – straight line?
- straight lines for subsections of data ?



"One economist's trend is another economist's cycle"

Engle, R. F. and Granger, C. W. J. 1991 *Long-run Economic Relationships*. Cambridge University Press.

CONFUCIUS SAYS

名不正則言不順

言不順則事不成

——孔夫子

TRANSLATION

Without a proper definition,
logical discourse is impossible.
Without logical discourse,
nothing can be accomplished.

Confucius

CONSIDERATIONS RELATING TO TRENDS

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- The trend should be an intrinsic and local property of the data
- Being local, it has to associate with a local length scale, and be valid only within that length span, and be part of a full wave length.
- The method determining the trend should be intrinsic. Being intrinsic, the method for defining the trend has to be adaptive and temporally local.

DEFINITION OF A TREND

Within the given data span, the trend is an intrinsically fitted monotonic function, or a function in which there can be at most one extremum

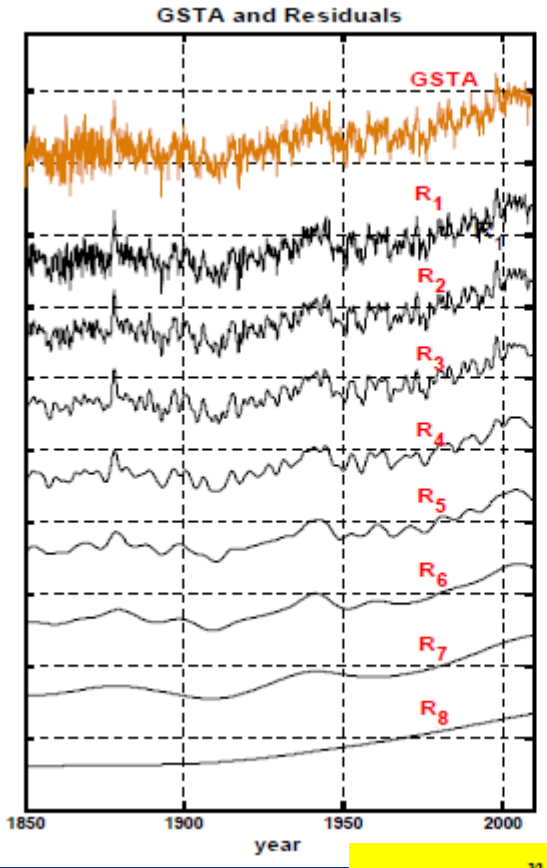
recent years is not more variable than that in the 1800s. The extreme temperature records in the 1990s stand out mainly because the general global warming trend over the whole data length coincides with the warming phase of the 65-year cycle.

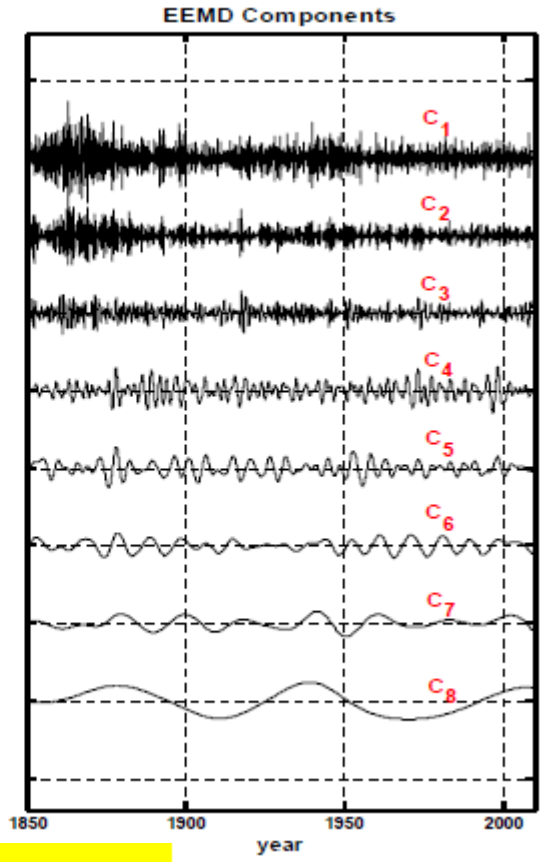
METHOD

- Ensemble Empirical Mode Decomposition
  - Adapive
  - Temporally local
  - Noise-assisted

Wu, Z., and N. E. Huang (2009), Ensemble Empirical Mode Decomposition: a noise-assisted data analysis method, *Advances in Adaptive Data Analysis*, ***1***, 1–41.

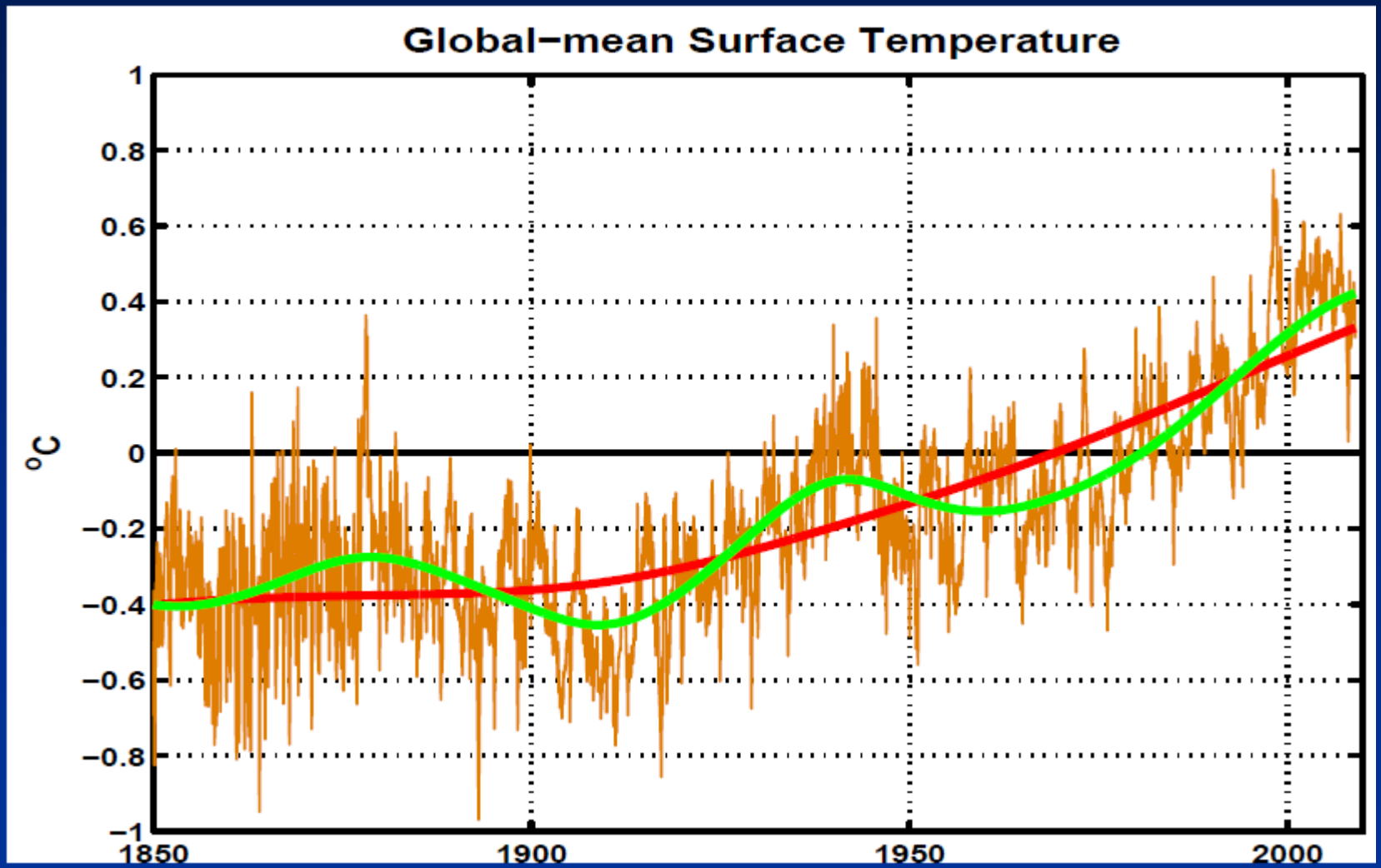
DECOMPOSITION



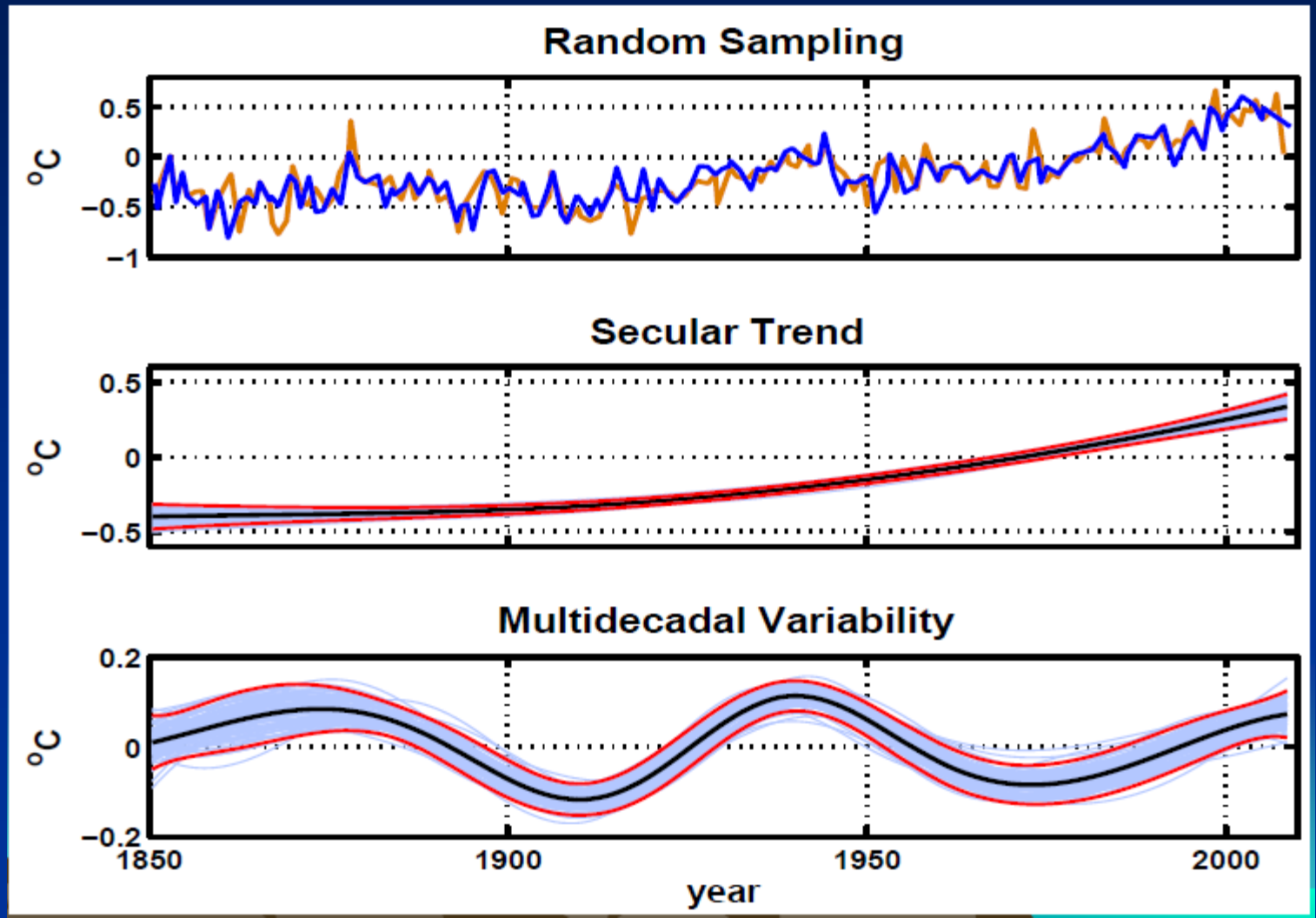


$$x(t) = \sum_{j=1}^{n} c_j(t) + r_n(t)$$

RECONSTRUCTION

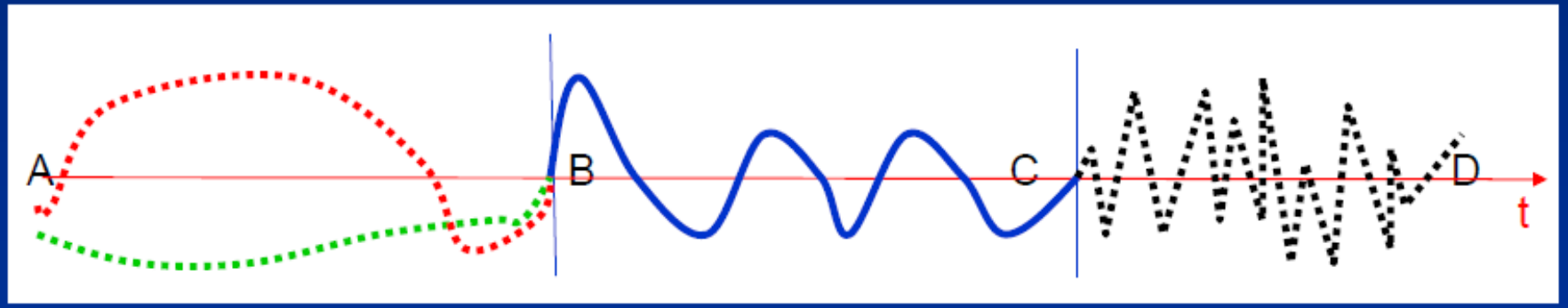


TREND OF NOISY DATA



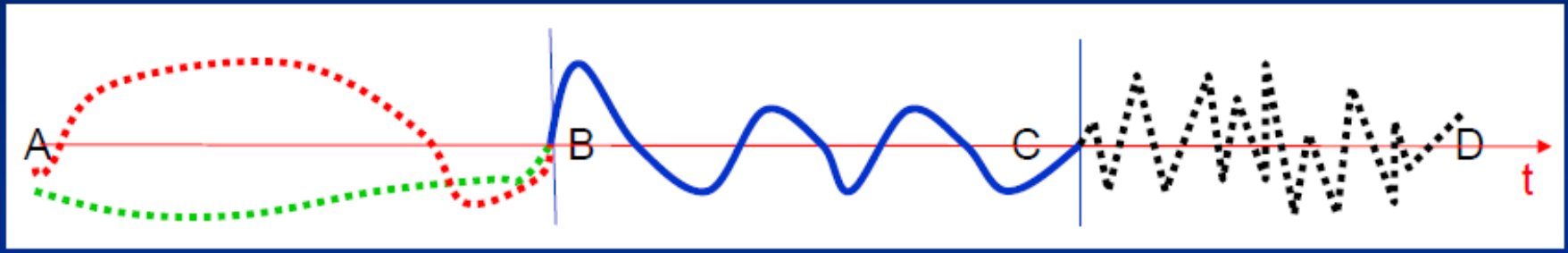
PHYSICAL CONSTRAINTS

1. Later evolution can not change the past
2. What matter to a dynamic system's future evolution are its initial condition boundary condition, and external forcing



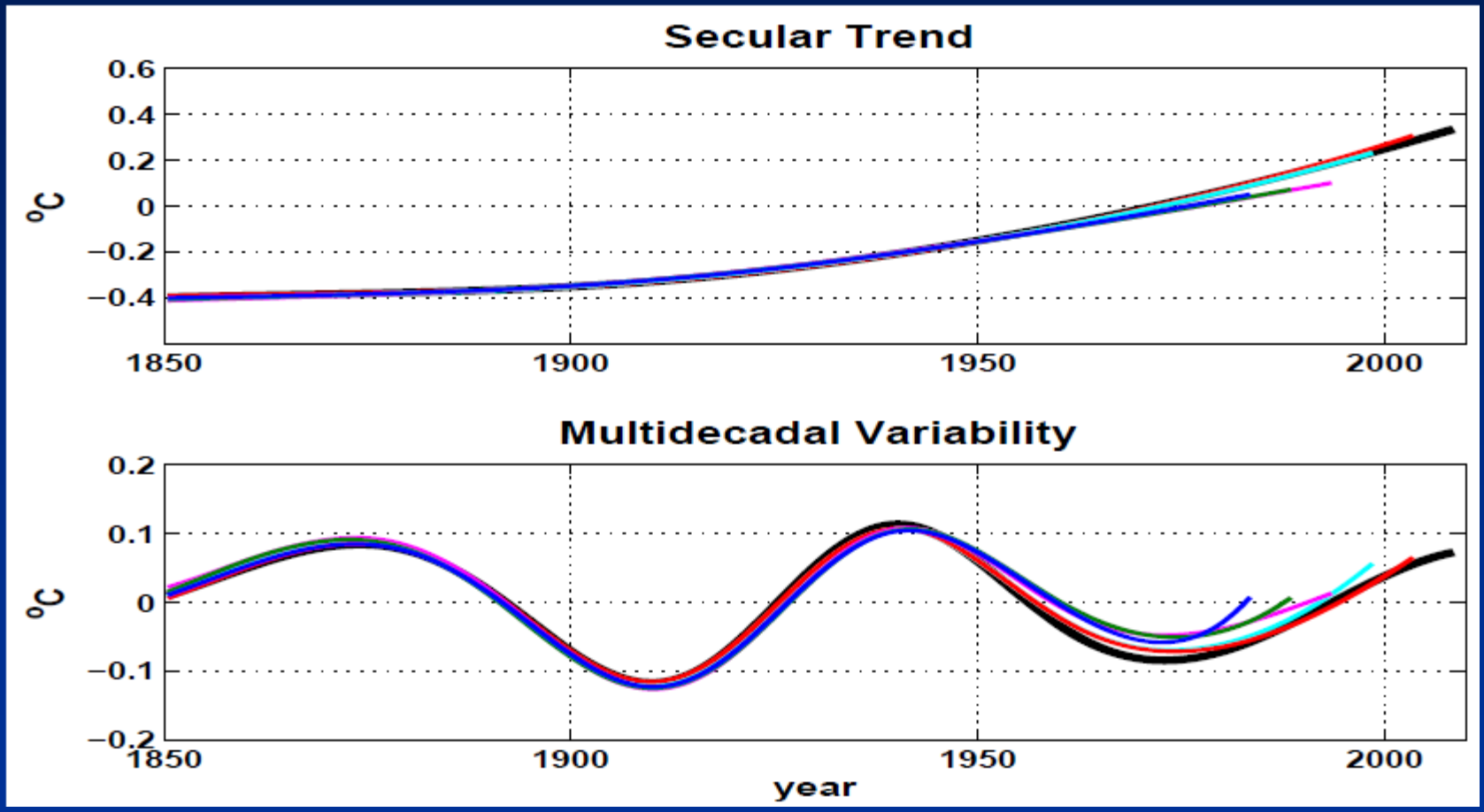
LOCALITY

Suppose that the data ***BC*** contains physically meaningful oscillation (signal) and an analysis method extracts that oscillation. If the data is extended to ***AD*** and the same method is applied to ***AD***, the physically meaningful oscillation within BC should not be changed.

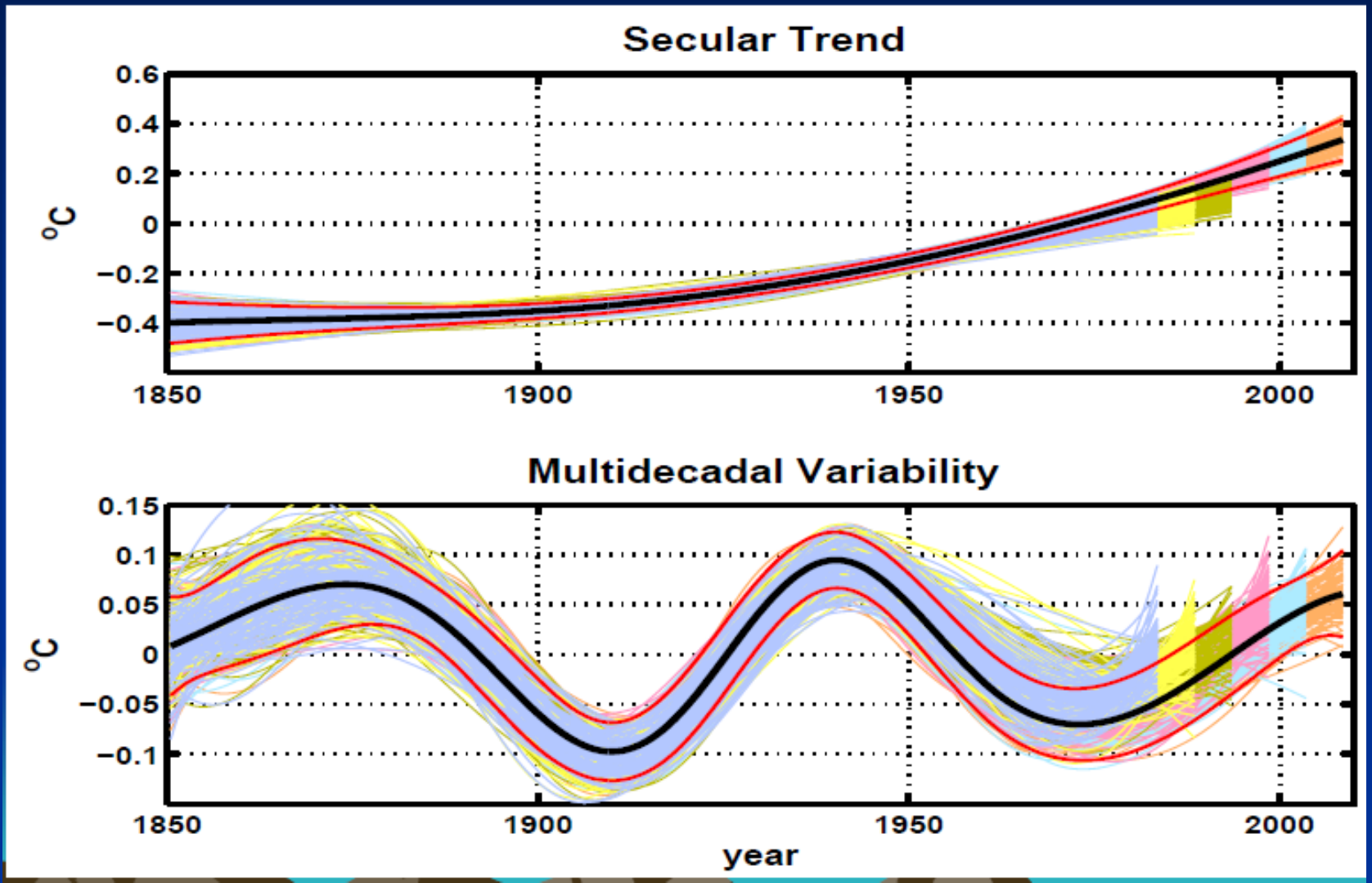


When a scientific data analysis method is designed, "**temporal locality**" should be checked.

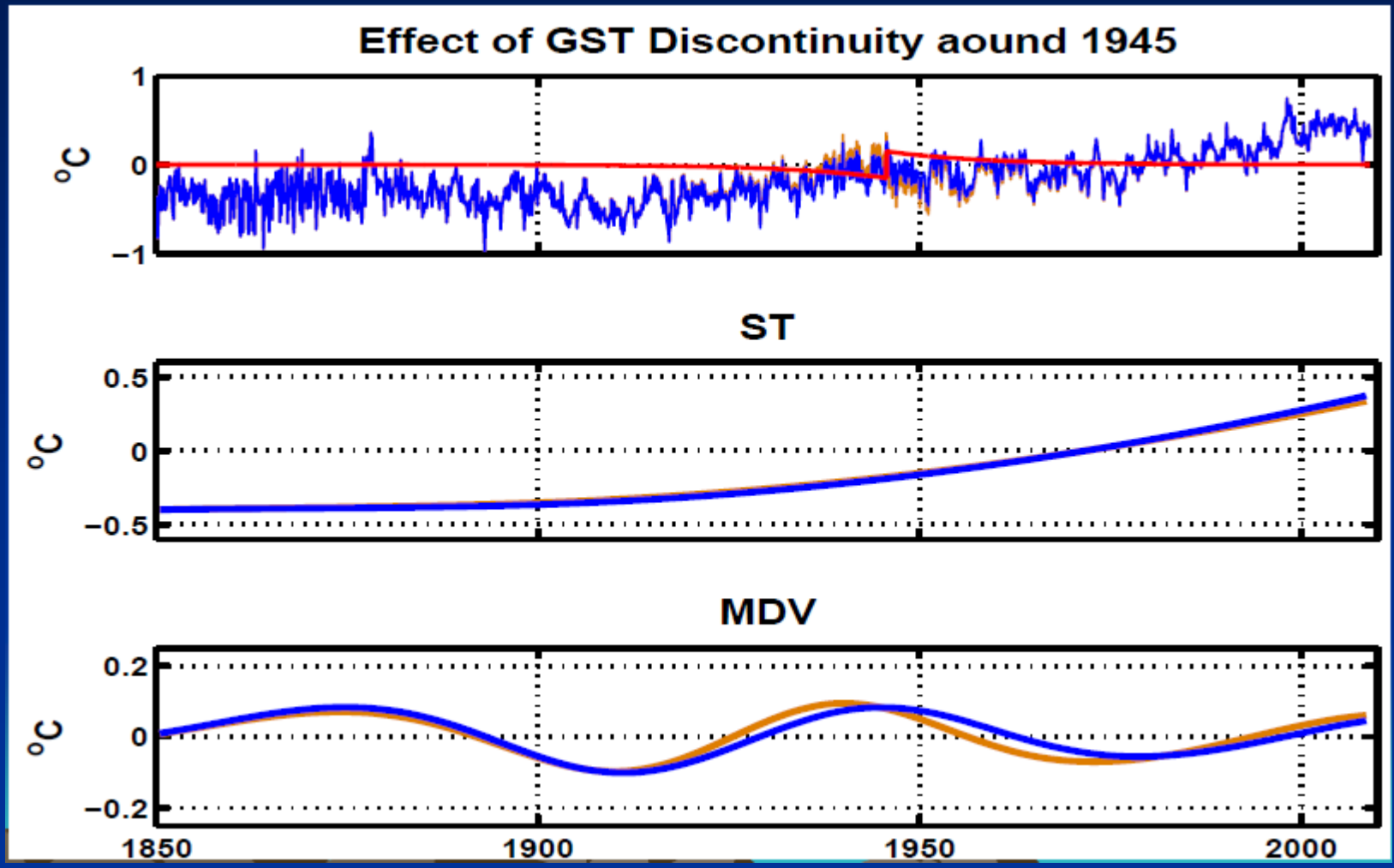
LOCALITY


Secular Trend
0.6
0.4
0.2
0
−0.2
−0.4
°C
1850
1900
1950
2000
Multidecadal Variability
0.2
0.1
0
−0.1
−0.2
°C
1850
1900
1950
2000
year

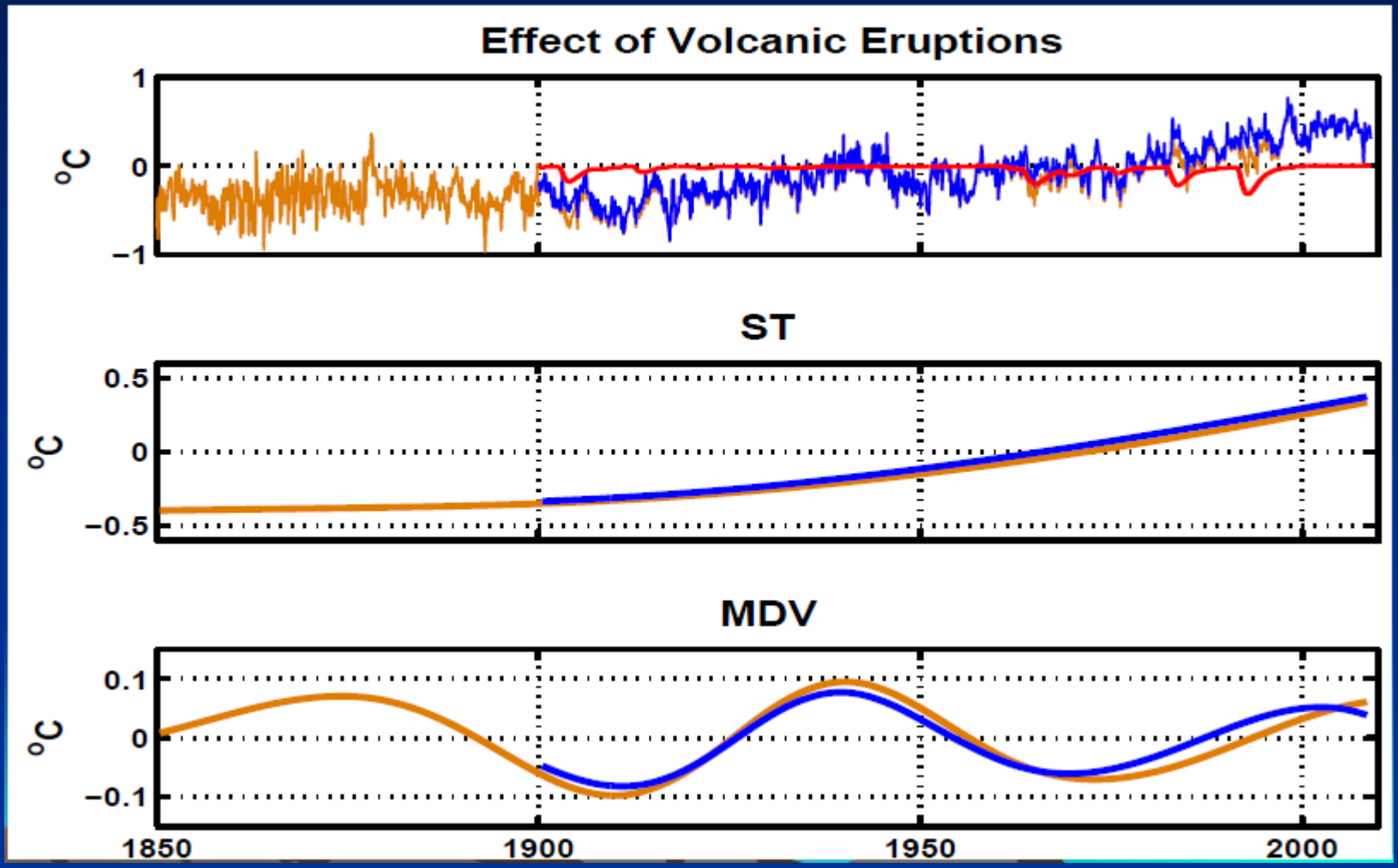
MDV & ST


Secular Trend
0.6
0.4
0.2
0
−0.2
−0.4
°C
1850
1900
1950
2000
Multidecadal Variability
0.15
0.1
0.05
0
−0.05
−0.1
°C
1850
1900
1950
2000
year

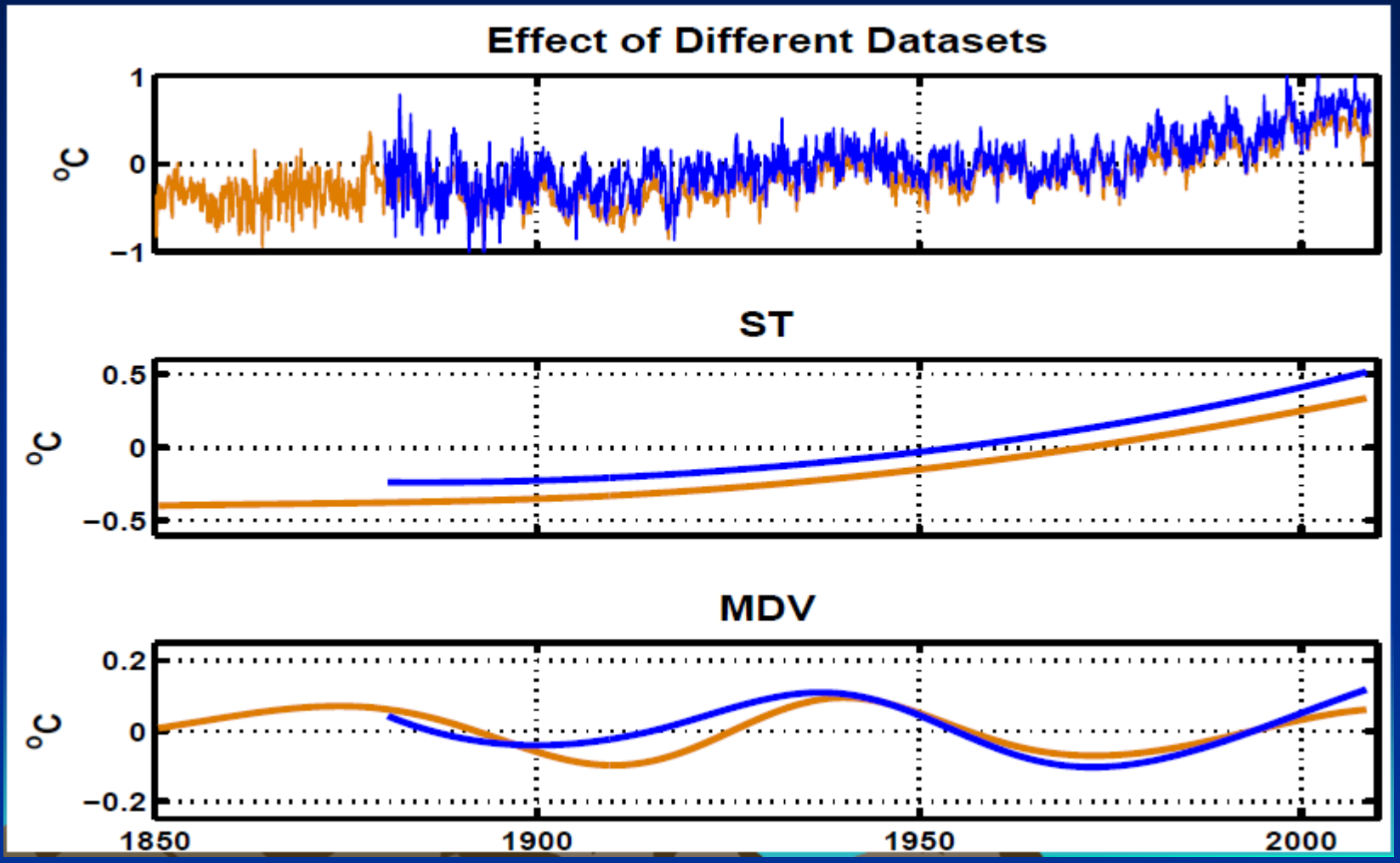
EFFECT OF DATA DISCONTINUITY



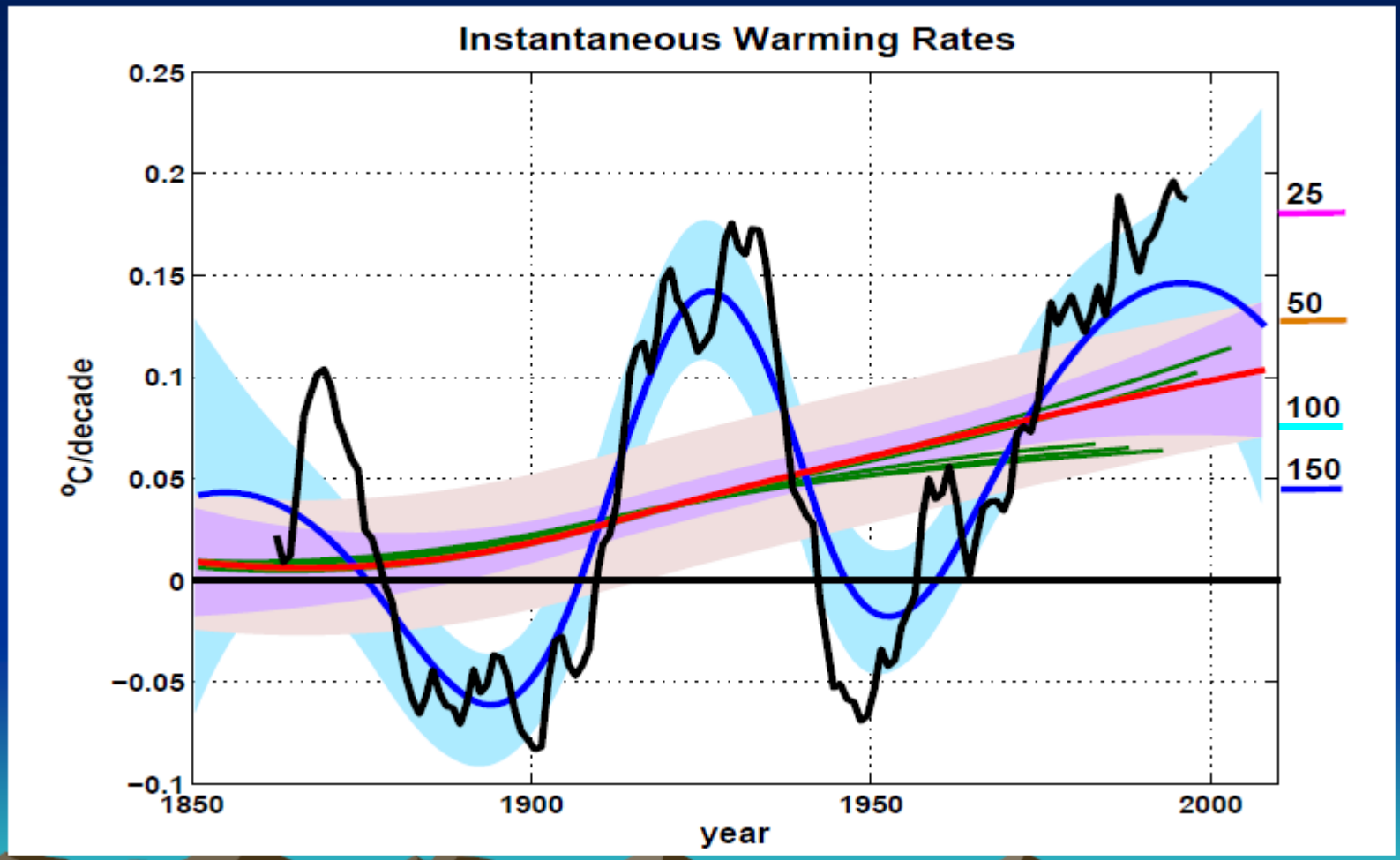
VOLCANIC EFFECT



SENSITIVITY TO DATA SETS



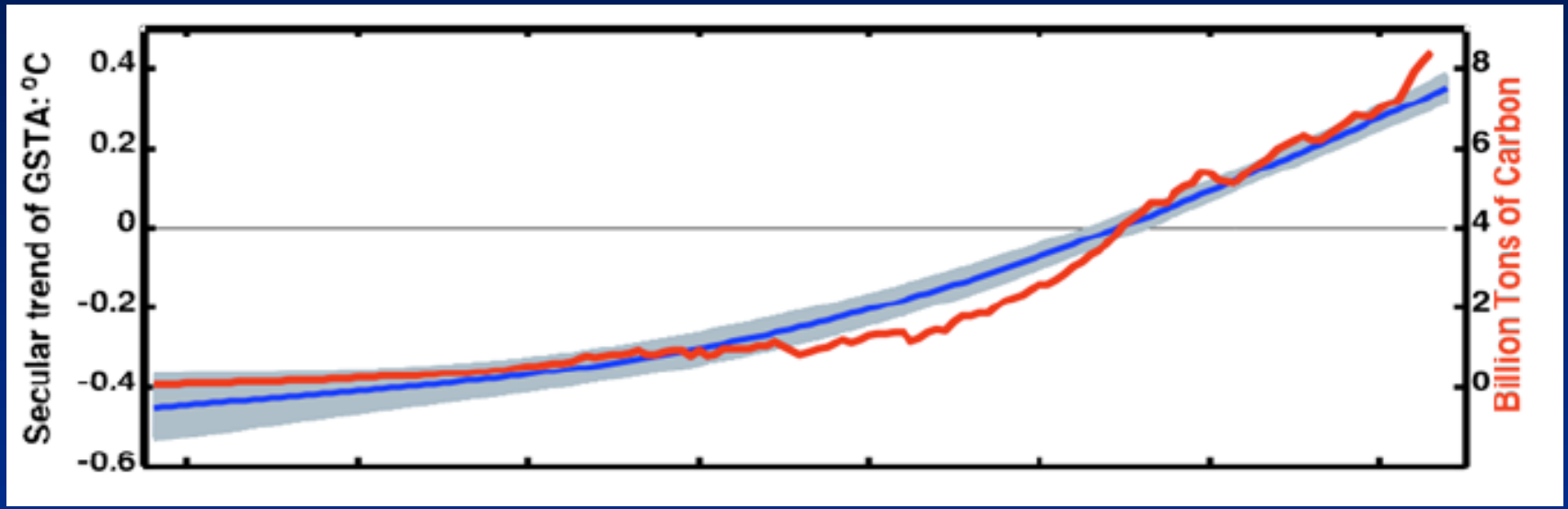
TRENDS & WARMING RATES



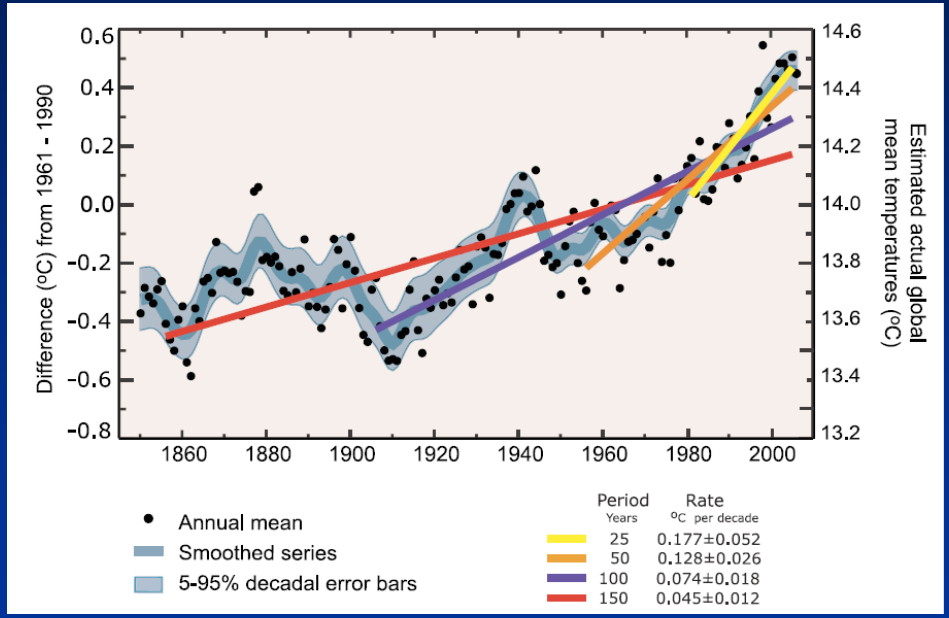
WARMING RATE

	Last 150 years	Last 100 years	Last 50 years	Last 25 years
AR4	0.045±0.012	0.074±0.018	0.128±0.026	0.177±0.052
ST and MDV	0.051±0.040	0.086±0.039	0.105±0.041	0.148±0.051
ST	0.050±0.014	0.067±0.014	0.086±0.018	0.096±0.024

CO2 AND TREND

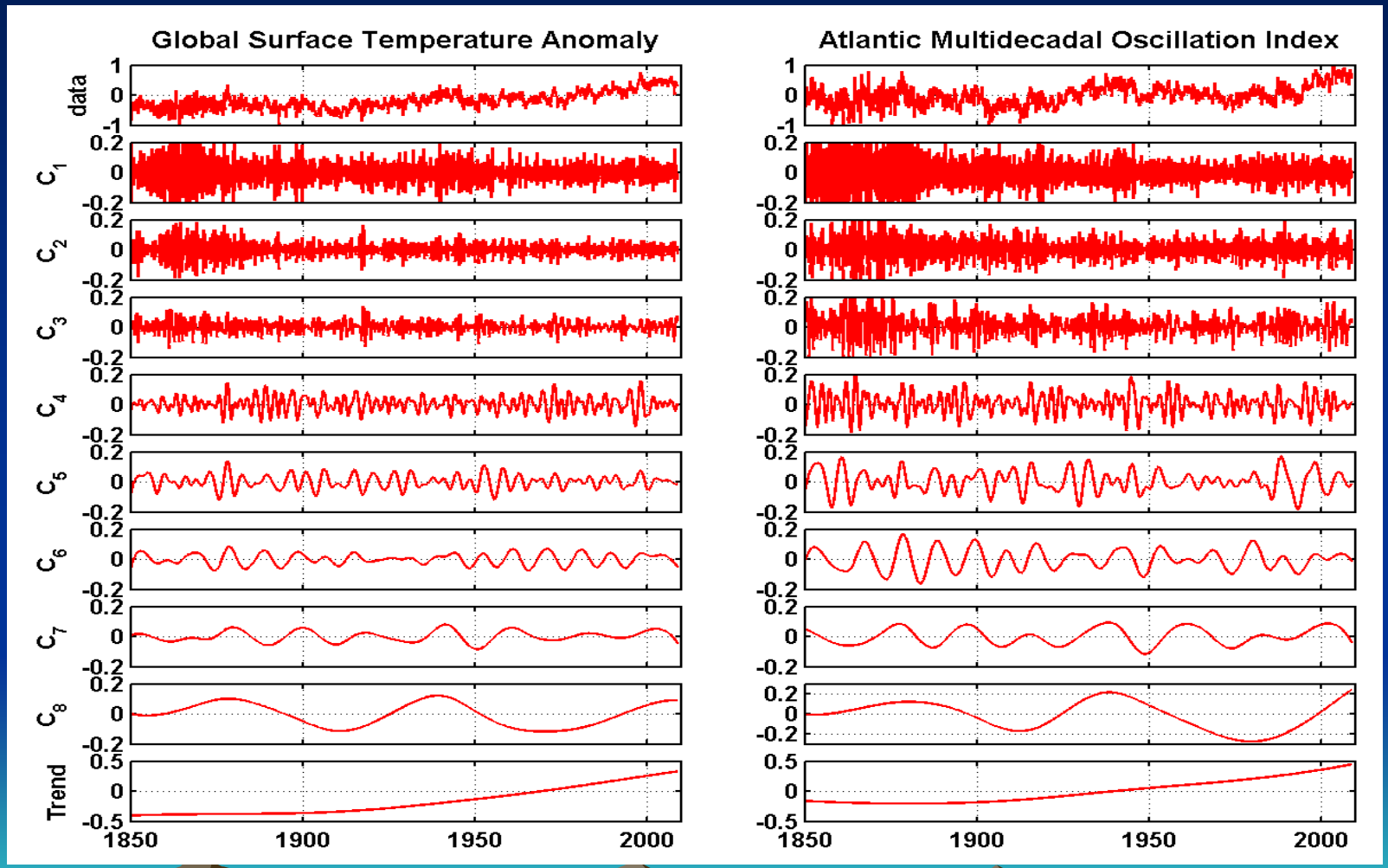


PHYSICAL VIEWS OF TREND vs. CYCLE

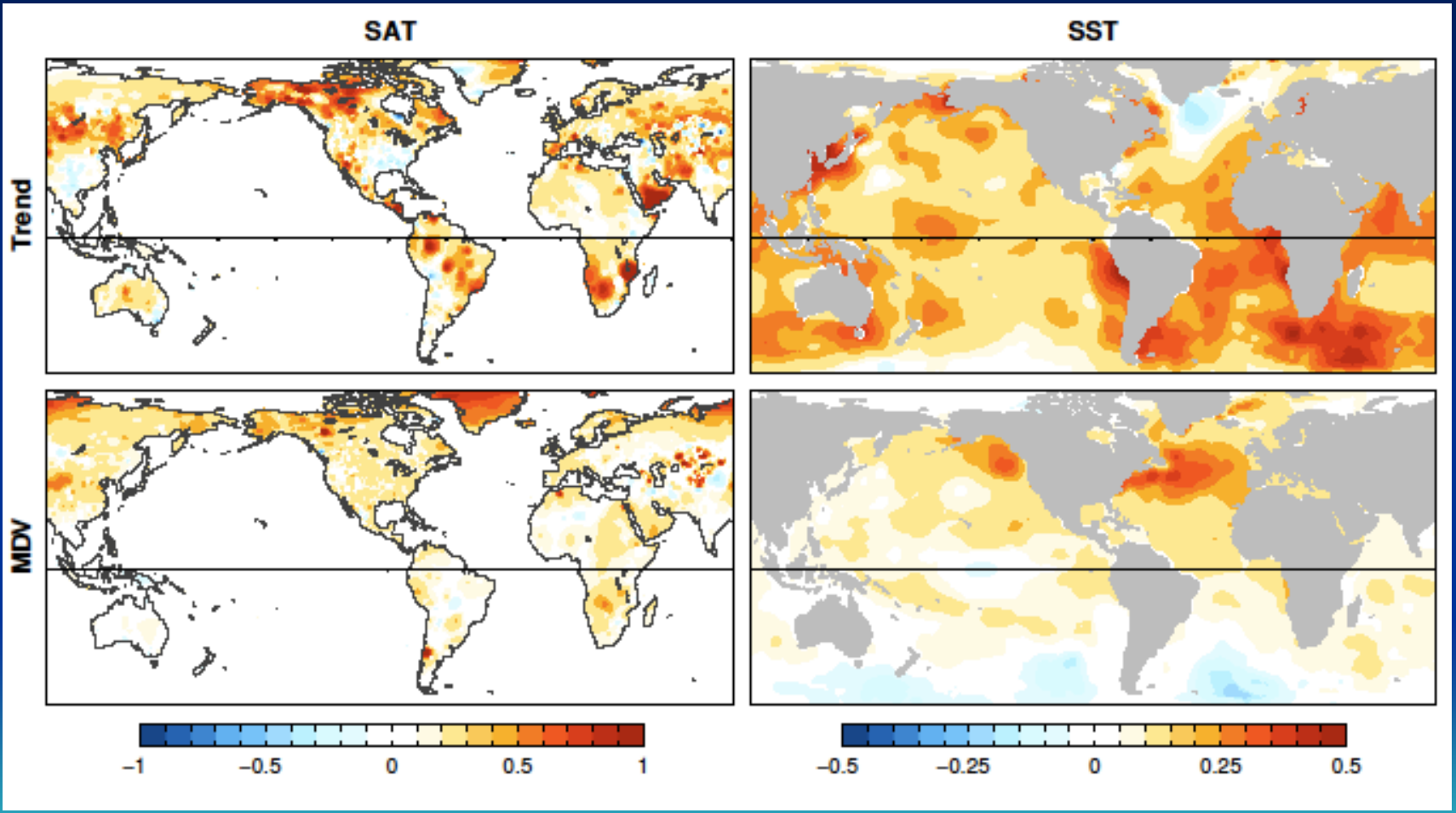


What else might have contributed to the strong warming from 1975 to 1998 other than the greenhouse gases, aerosols or multidecadal variability of the thermohaline circulation?

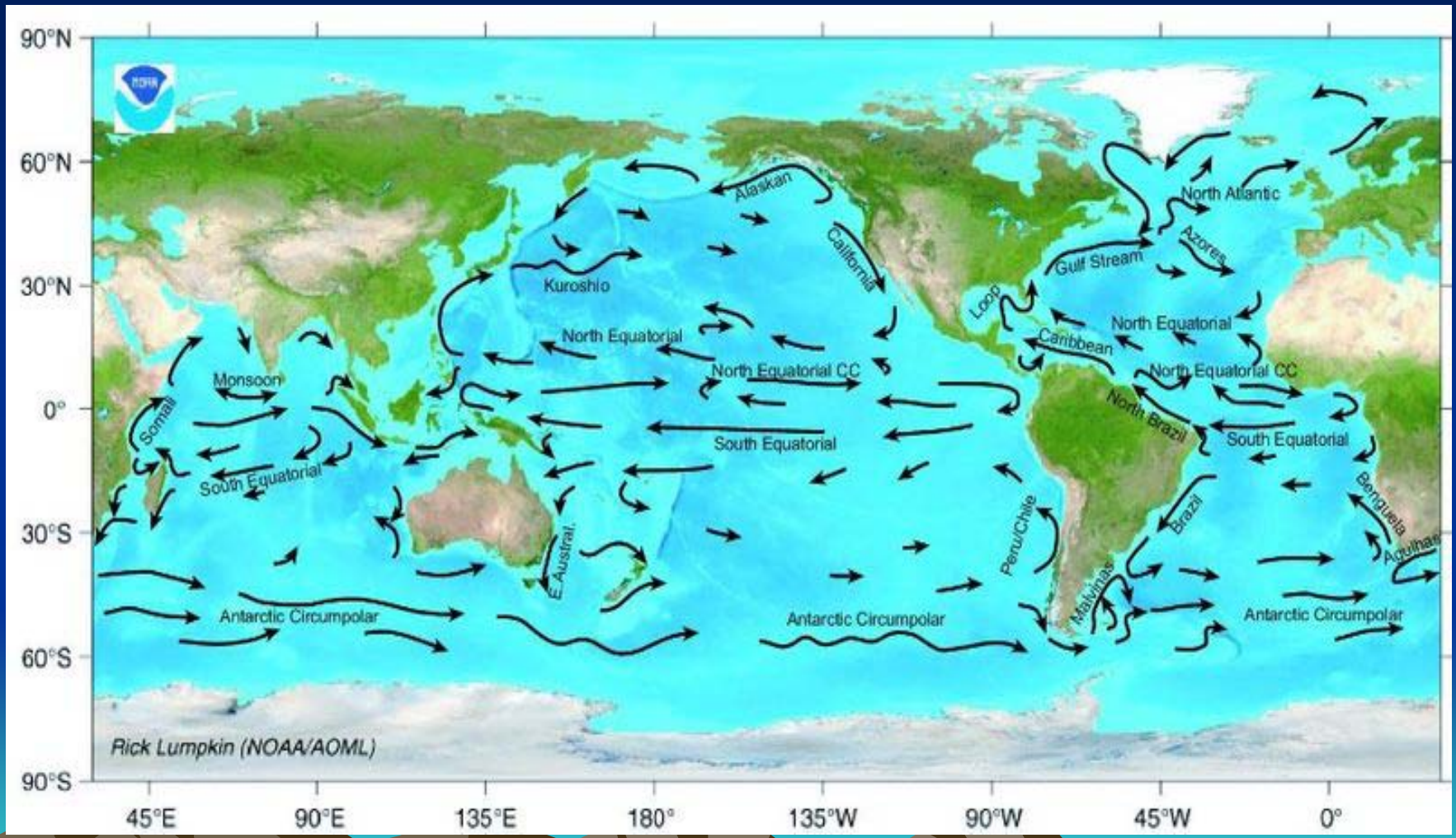
GSTA & AMO INDICES



FINGERPRINTS



WIND-DRIVEN OCEAN CIRCULATION



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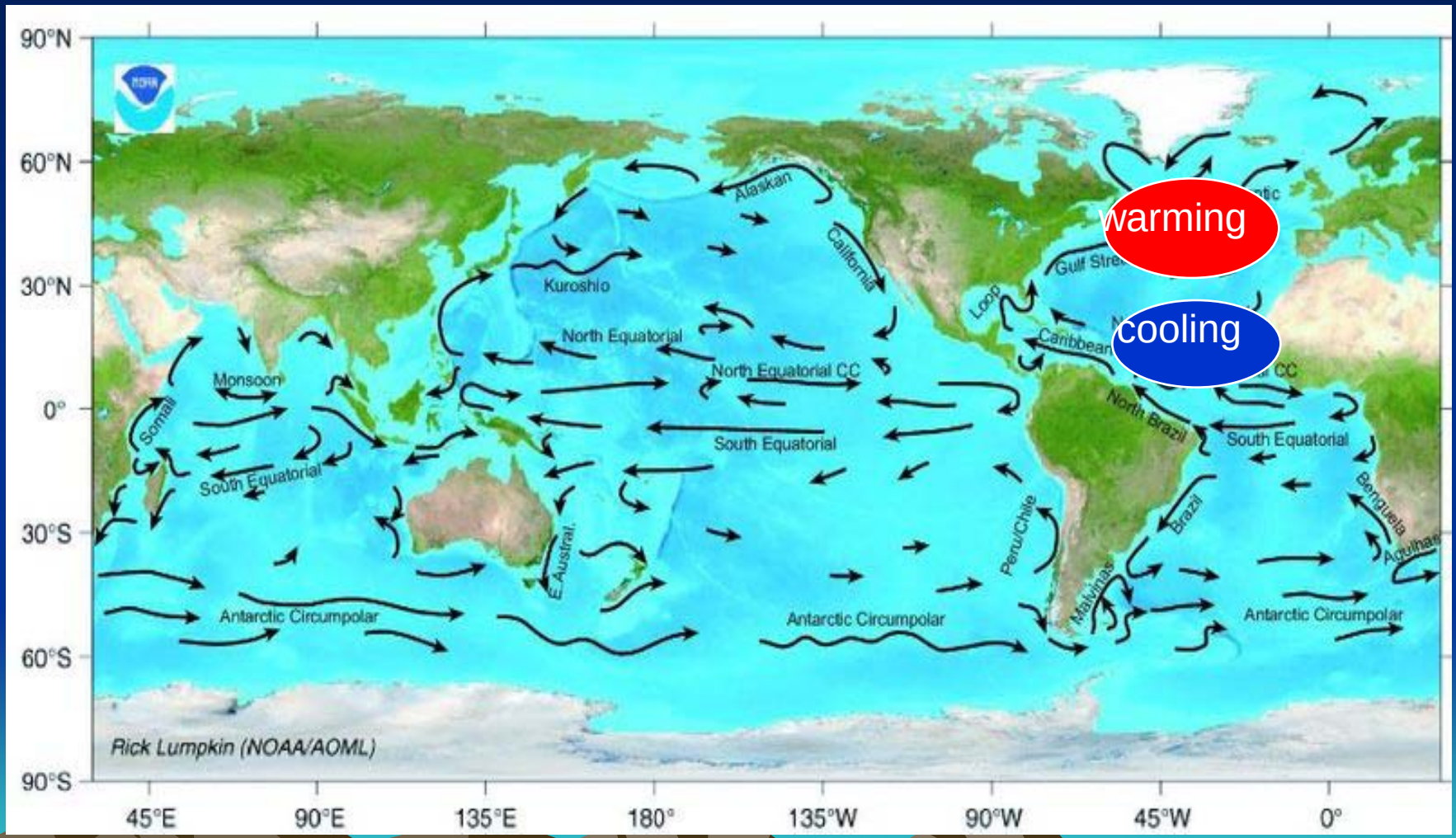
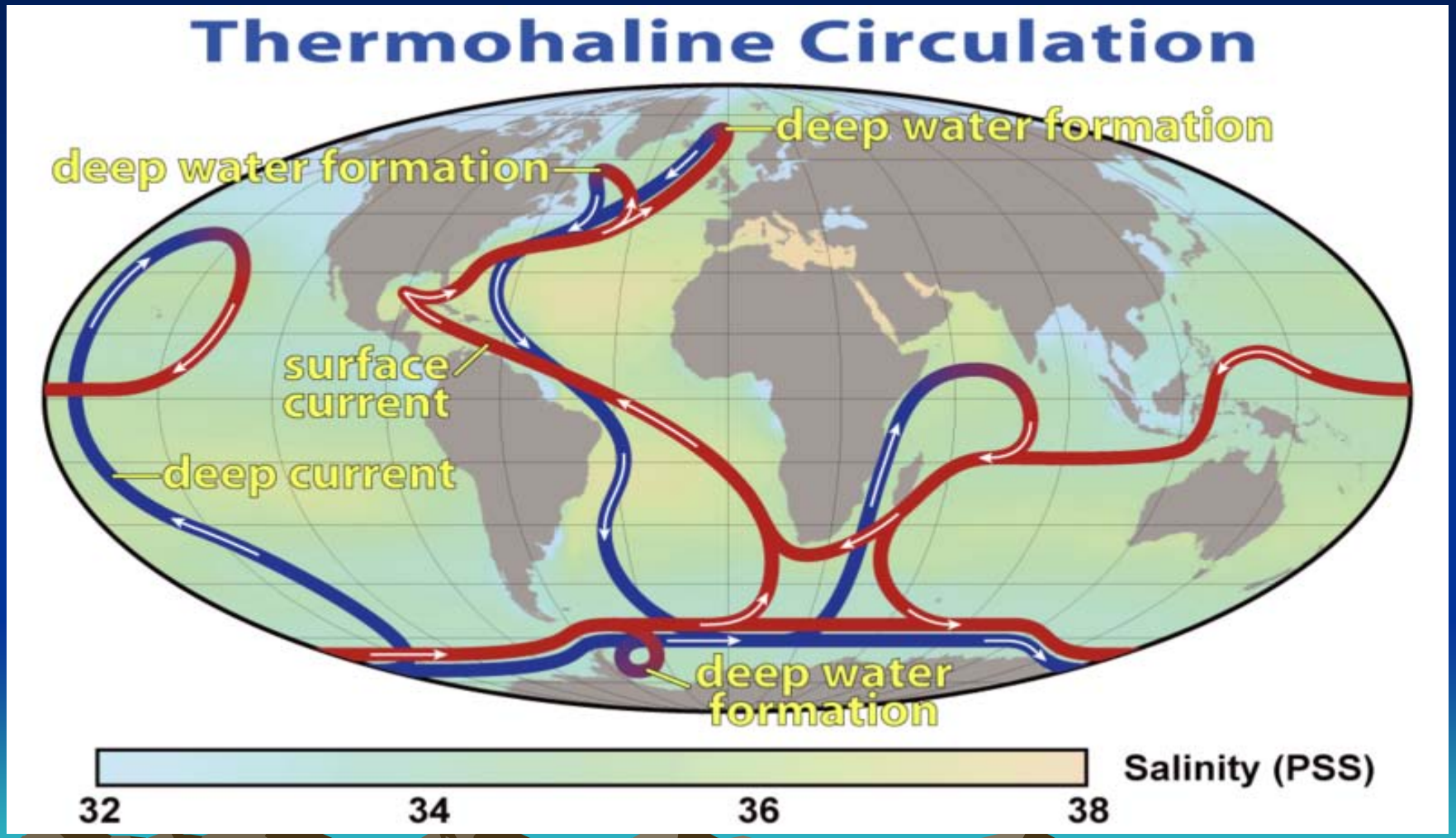
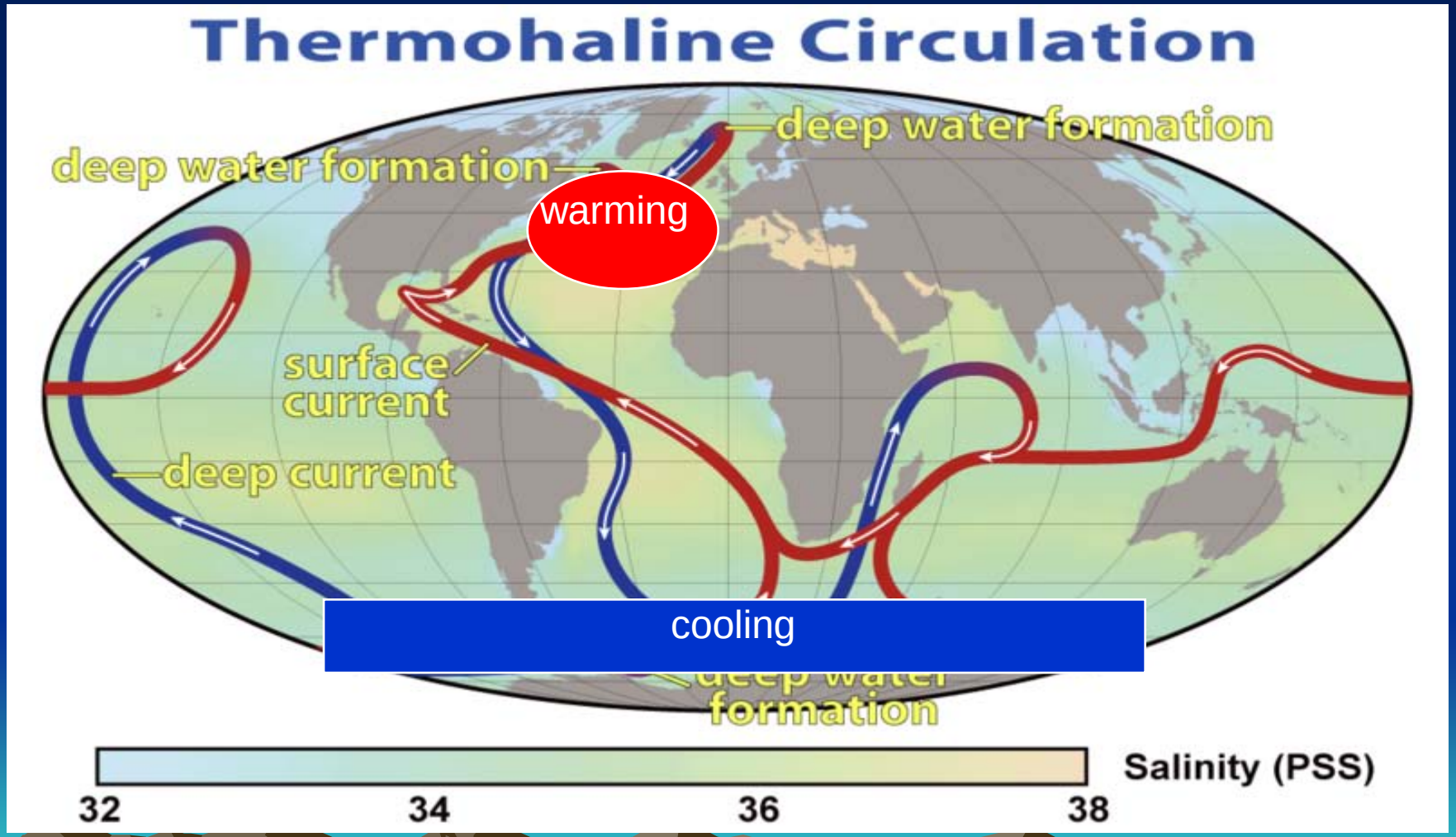


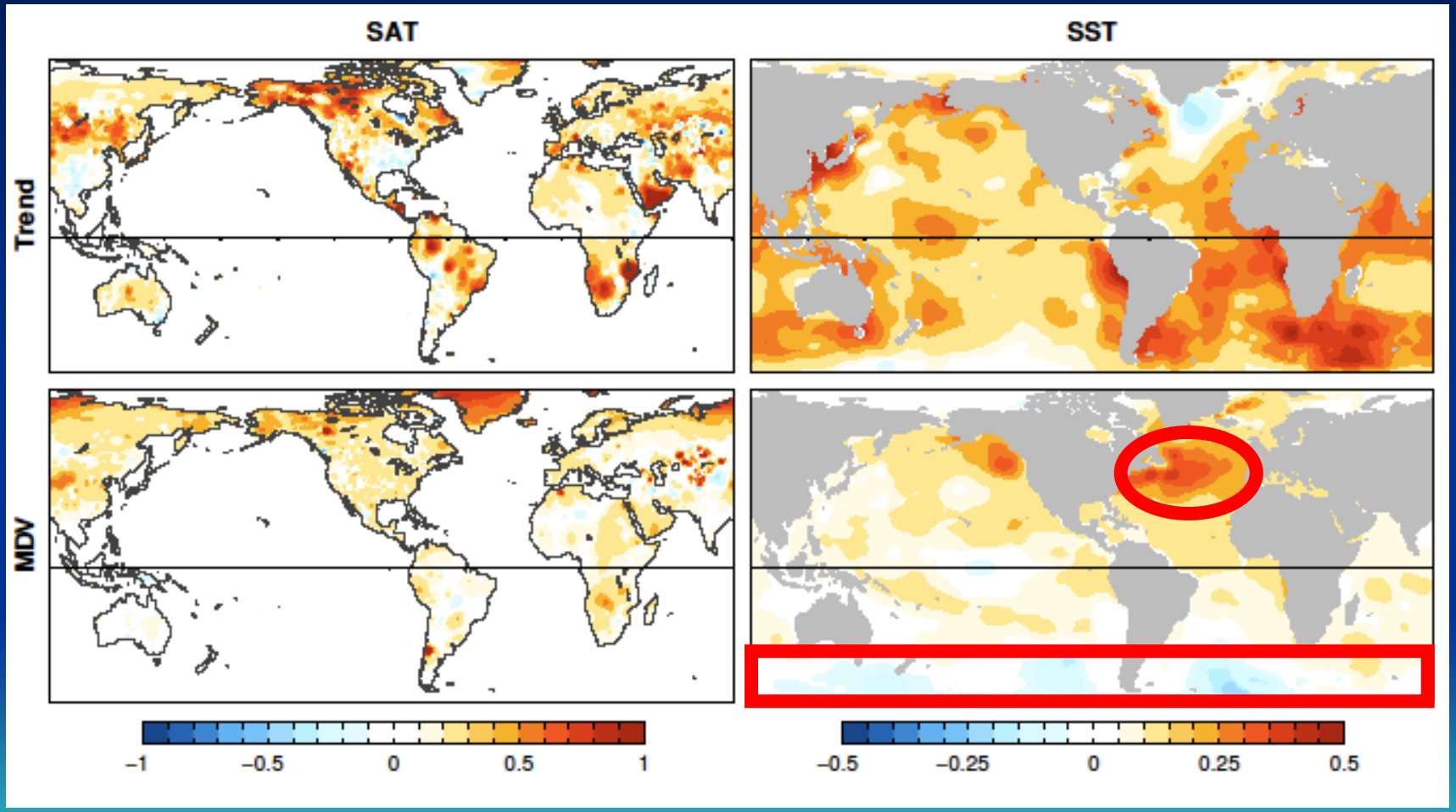
THERMOHALINE CIRCULATION



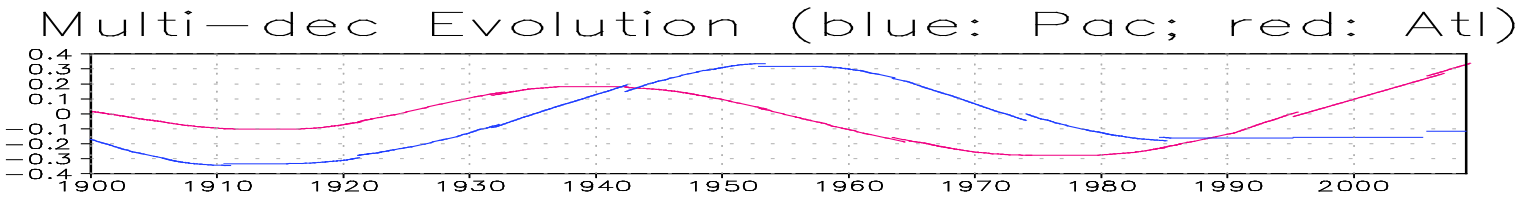
THERMOHALINE CIRCULATION

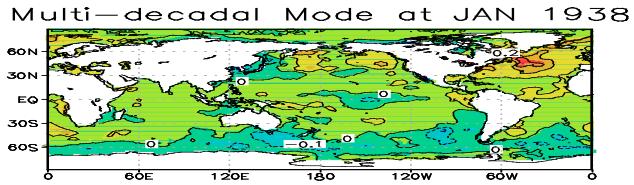


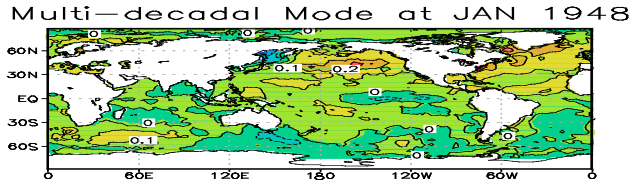
SPATIAL SIGNATURES

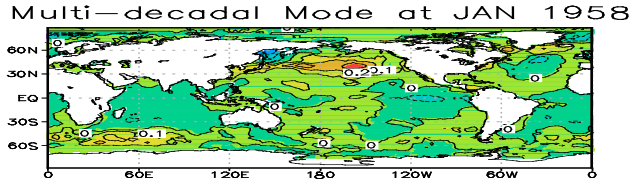


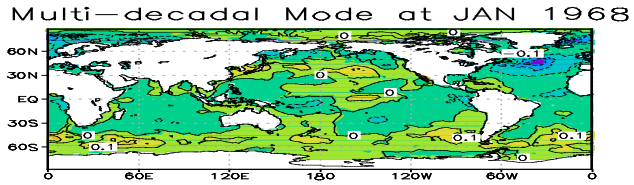
EXAMPLE 3: EVOLUTION OF GLOBAL MEAN SURFACE TEMPERATURE

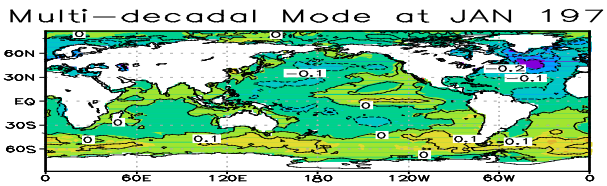


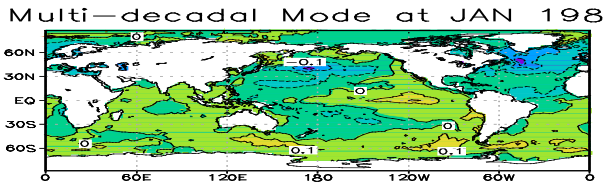


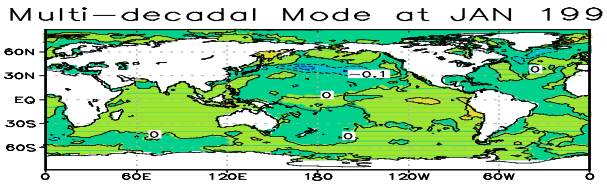


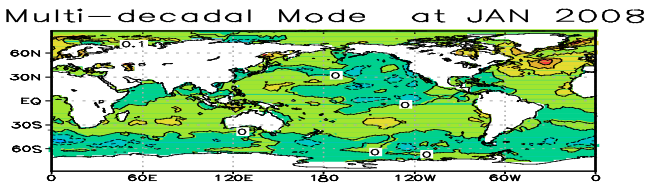












QUESTIONS CONCERNING AR4

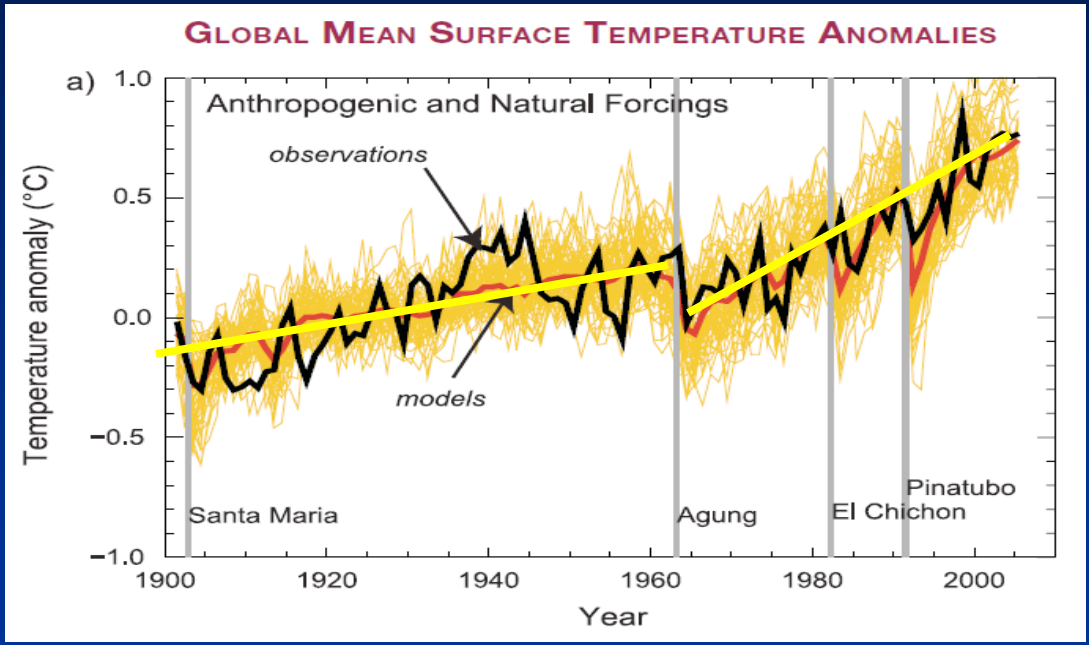
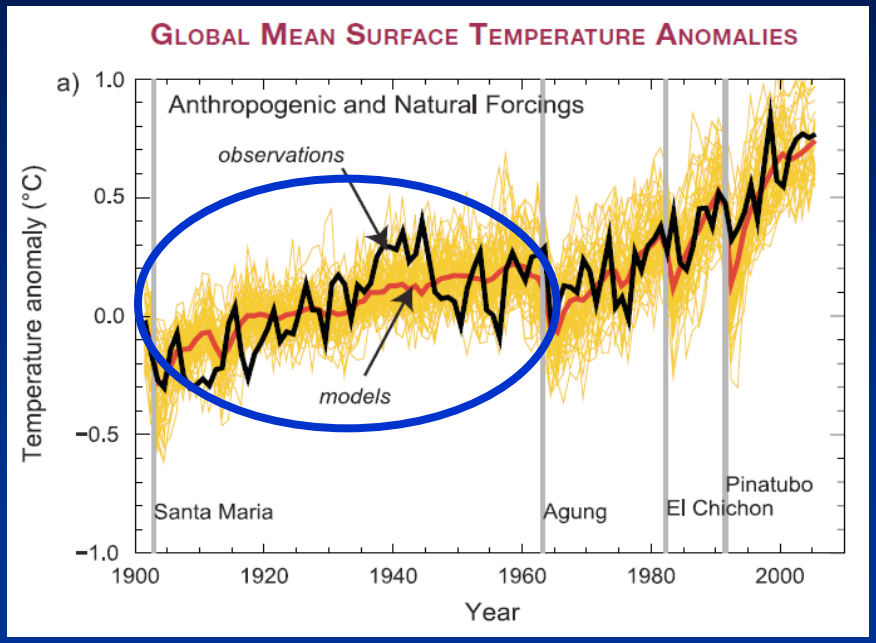


Figure TS.23. (p. 62)

Why there is an apparent discontinuity at 1963 of multi-model ensemble?

QUESTIONS CONCERNING AR4



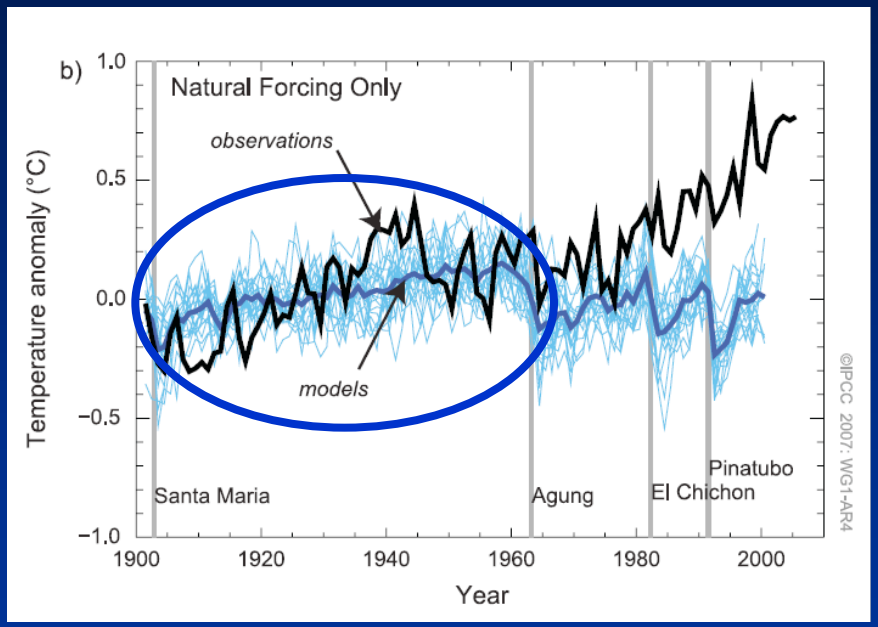
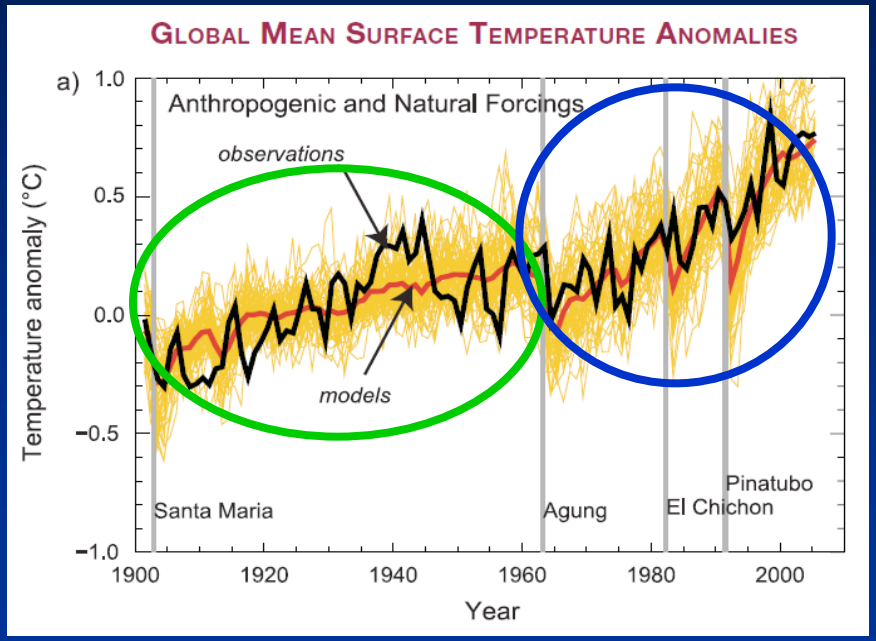


Figure TS.23. (p. 62)

It looks like the anthropogenic forcing played almost little role before 1963 in the ensemble mean (red line in the left panel and blue line in the right panel), but plays dramatic role after 1963. Why does the response to the forcing seem to begin so abruptly?

QUESTIONS CONCERNING AR4



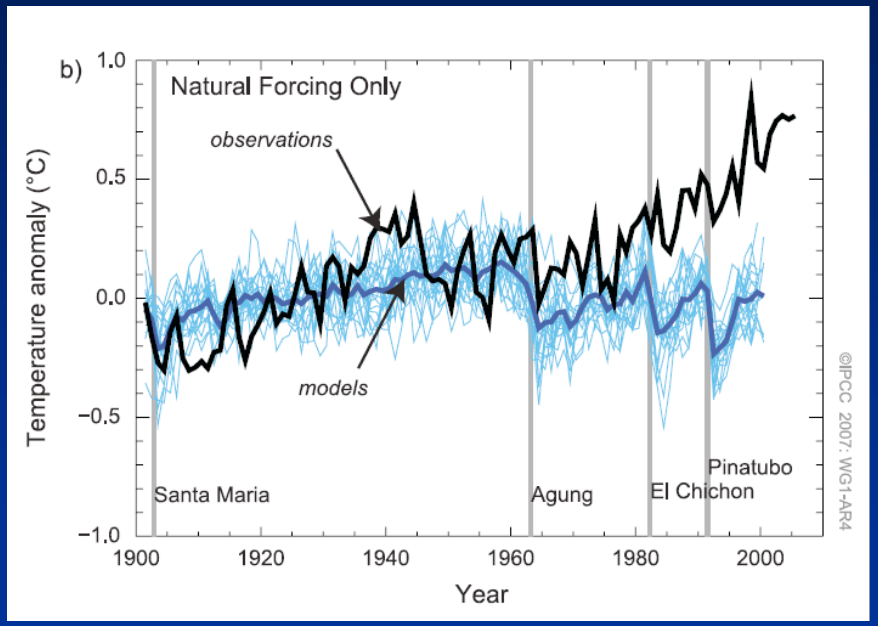
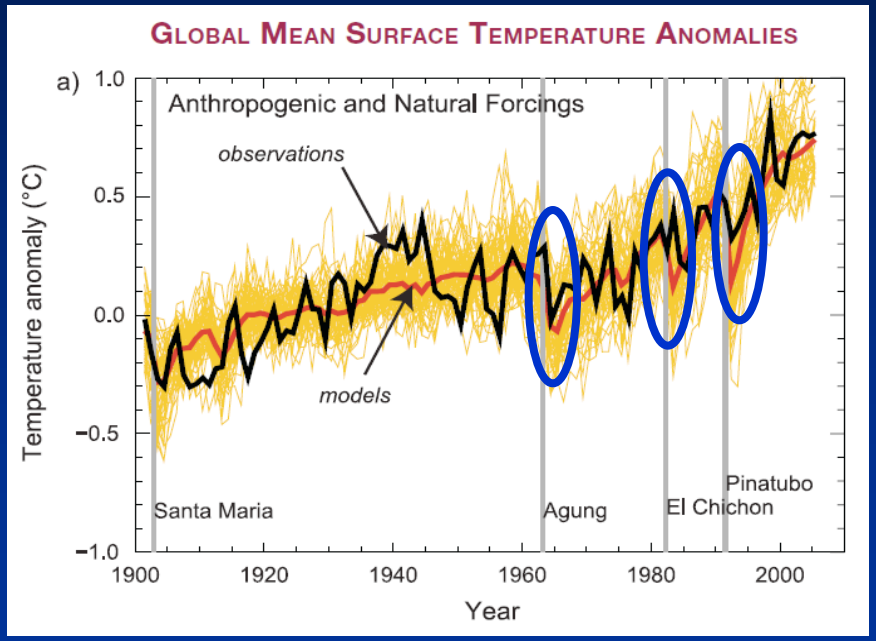


Figure TS.23. (p. 62)

Why do the simulations seem to agree so much better with the observations after 1963?

QUESTIONS CONCERNING AR4



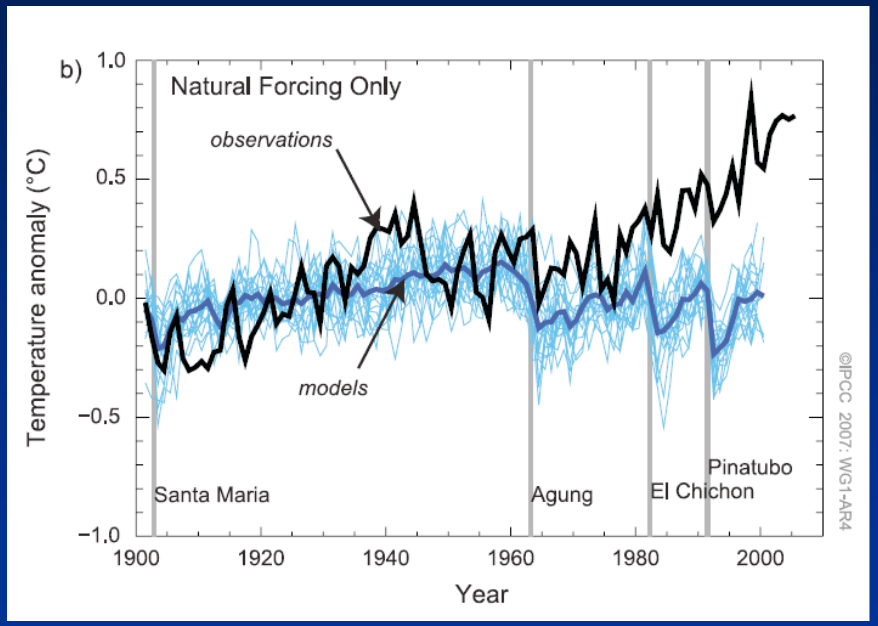
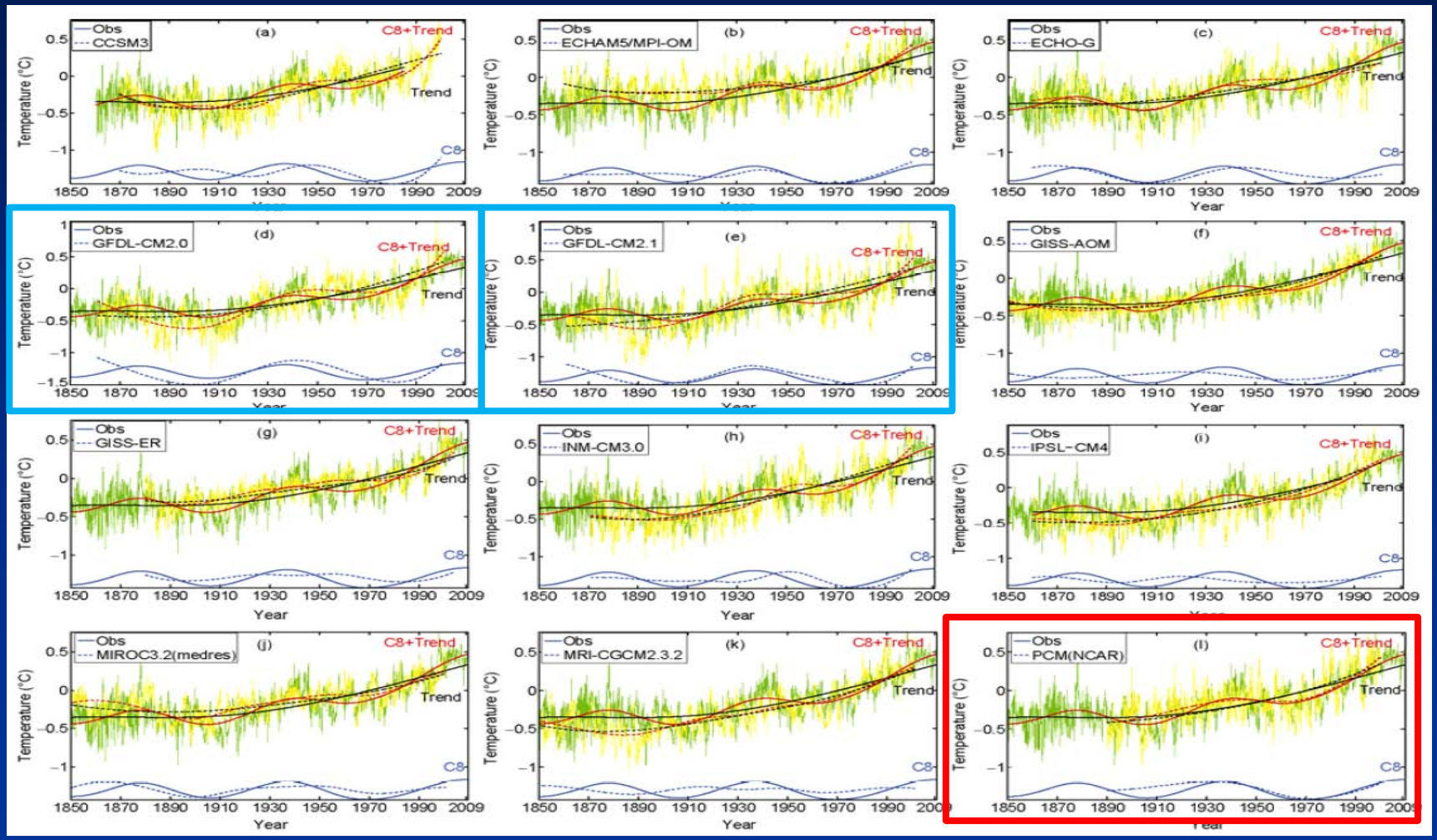


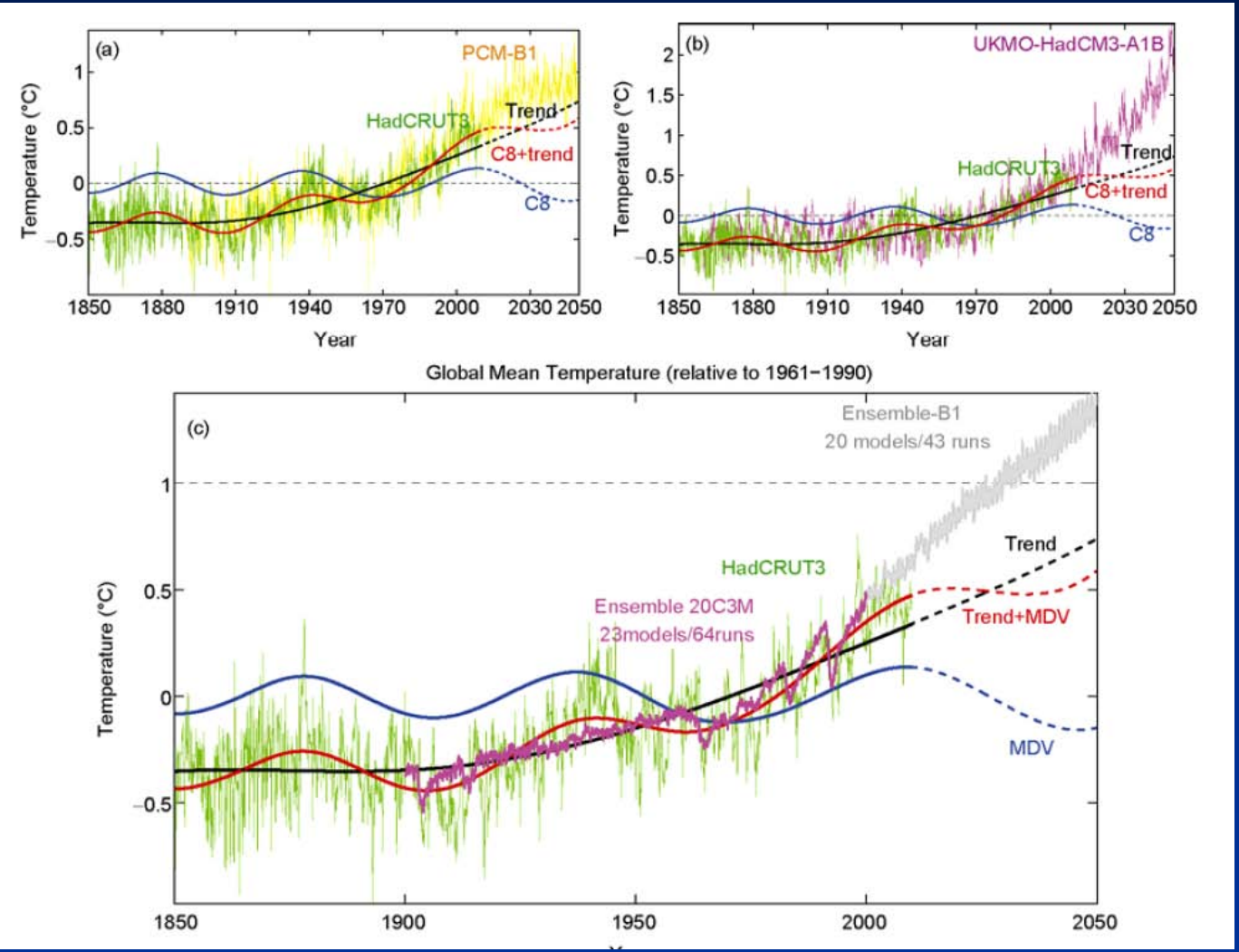
Figure TS.23. (p. 62)

Why is the cooling response to volcanic forcing is at least twice as large in the multi-model ensemble as in the observations

CMIP3 MODELS



PROJECTIONS OF FUTURE



CMIP3 MODEL PROBLEMS

- **Kiehl (2007):**

  "***The total anthropogenic forcing for a wide range of climate modes differs by a factor of two and that the total forcing is inversely correlated to climate sensitivity.***"

- **Knitti (2008):**

  "***Since most models do not incorporate the aerosol indirect effects, model agreement with observations may be partly spurious. The incorporation of more detailed aerosol effects in future models could lead to inconsistencies between simulated and observed past warming, unless the effects are small or compensated by additional forcings***."

WARMING RATE

	Last 150 years	Last 100 years	Last 50 years	Last 25 years
AR4	0.045±0.012	0.074±0.018	0.128±0.026	0.177±0.052
ST and MDV	0.051±0.040	0.086±0.039	0.105±0.041	0.148±0.051
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A FEW POINTS

- **The short term global warming trends are dominated by the AMO signal.**
- **GSTA is correlated with the AMO time series on all timescales.**
- **The multi-decadal oscillation likely originates in the Atlantic overturning circulation**
- **The claim that the rate of global warming is accelerating cannot be justified on the basis of an analysis of trends with an arbitrary time span, such as 25 years**

A QUOTE AT THE END

“Every age has ridiculed the one before it, and accused it of having generalized too naively. Descartes pitied the Ionians; Descartes, in his turn, makes us smile. No doubt, our children will some day laugh at us.”

--- Henry Poincaré