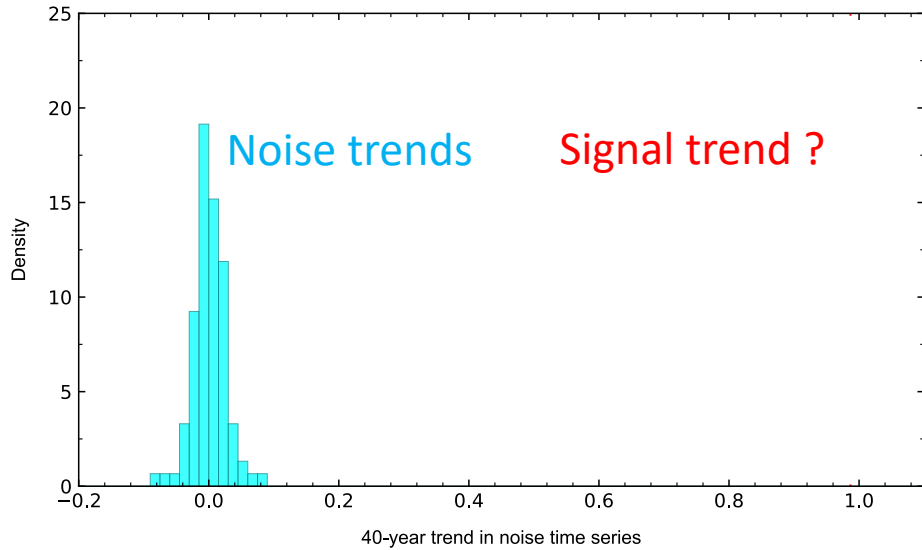
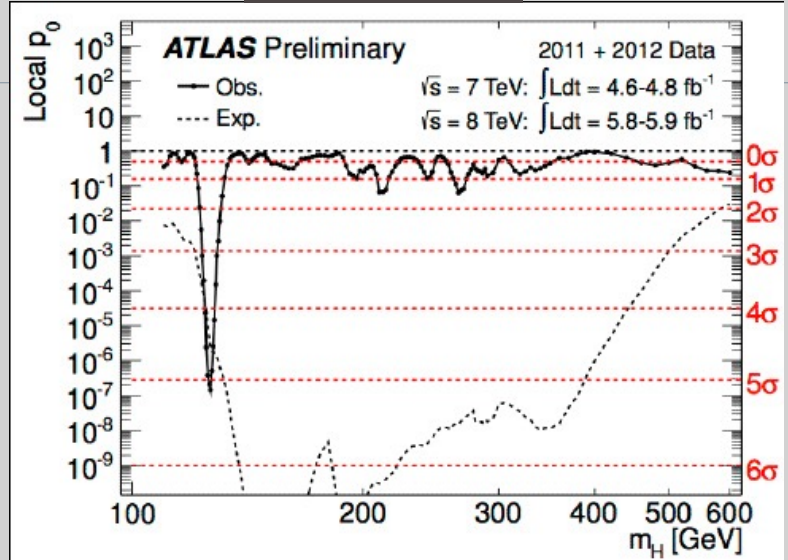


Climate Change



Higgs Boson



5-sigma : Is Climate Change More Detectable than the Higgs Boson ?

Laurent Terray, CNRS/Cerfacs/IRD

Thanks to: **Ben Santer** (LLNL)

Rencontres de Noirmoutier

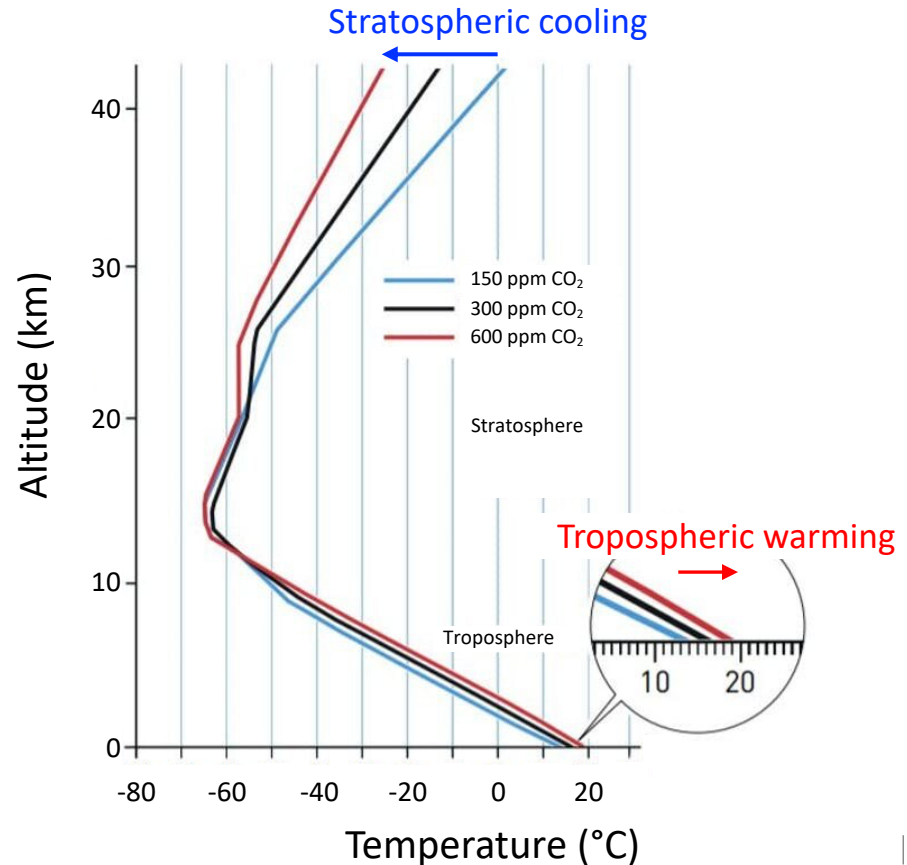
June 1st –5th, 2026

Climate change fingerprint: Prediction and Detection

Thermal Equilibrium of the Atmosphere with a Given Distribution of Relative Humidity

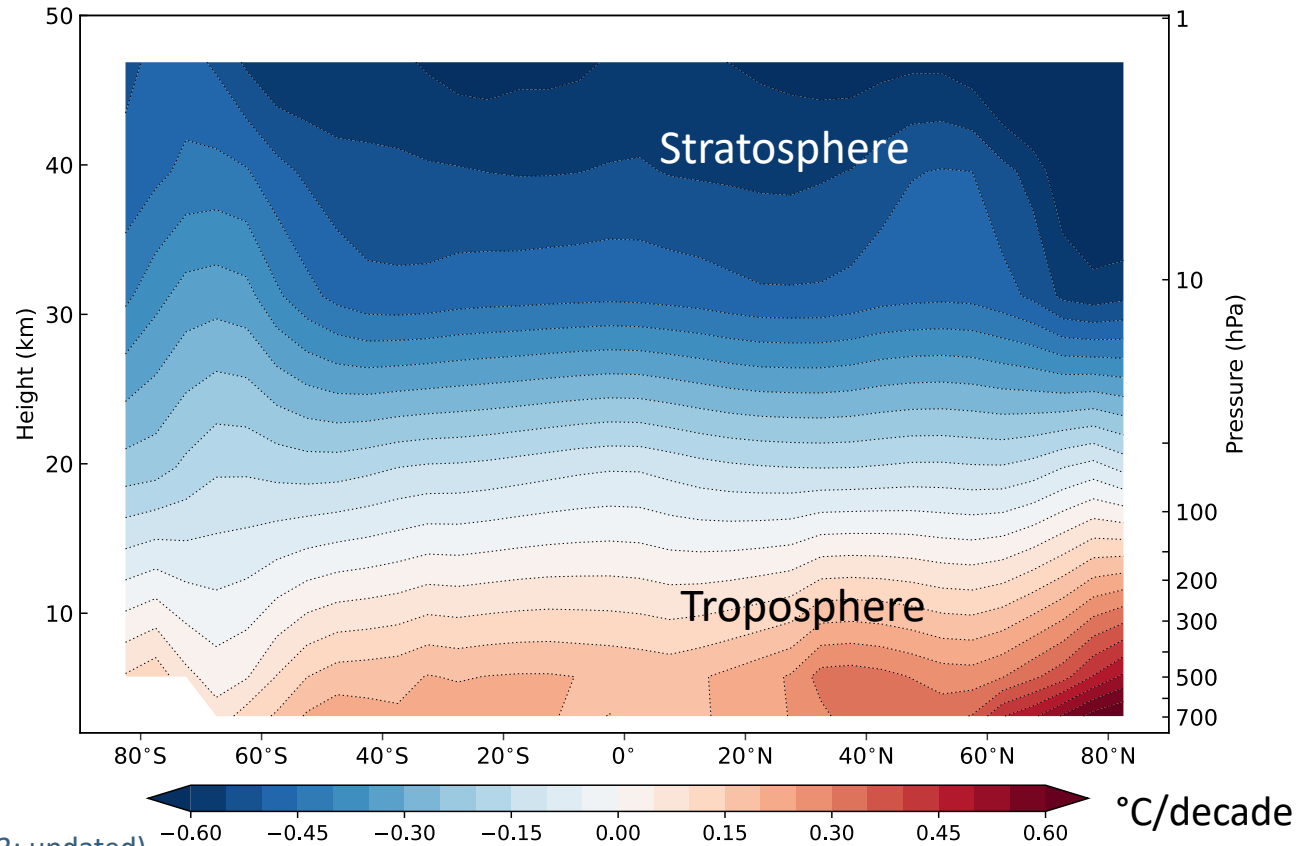
SYUKURO MANABE AND RICHARD T. WETHERALD

Geophysical Fluid Dynamics Laboratory, ESSA, Washington, D.C.
(Manuscript received 2 November 1966)



Manabe's "Climate change fingerprint" is in the satellite temperature data

Temperature trend
over
1986 to 2025



Not so easy ... Climate system varies at all time scales !

Stochastic climate models

Part I. Theory

By K. HASSELMANN, *Max-Planck-Institut für Meteorologie, Hamburg, FRG*

(Manuscript received January 19; in final form April 5, 1976)



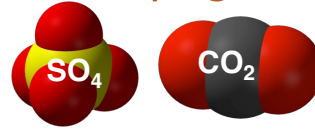
« Short-term weather variability leads to long-term climate variability »

« The slow components (e.g the Ocean) integrate weather variability on daily to monthly time scales into climate variability on annual to multidecadal time scales »

Note: The 2021 Nobel prize was awarded to both **Suki Manabe** and **Klaus Hasselmann** "for the physical modelling of Earth's climate, quantifying variability and reliably predicting global warming"

Detection of climate change due to human influence ?

- Identify a robust fingerprint pattern of *anthropogenic* forcing for atmospheric temperature

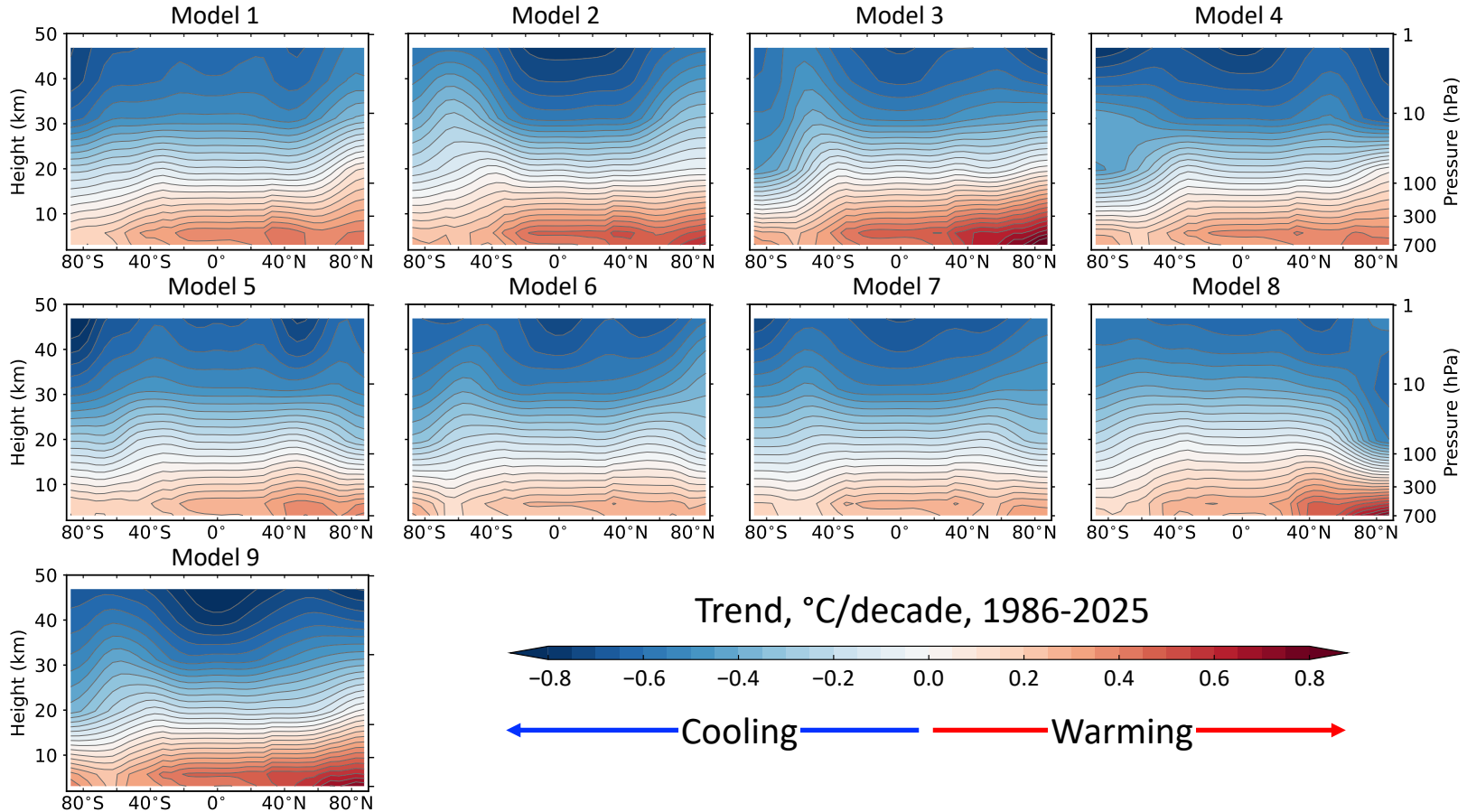


- Search for an increase in spatial pattern similarity between recent atmospheric temperature observations and the fingerprint (index I_S^{Obs})
- Need a null hypothesis H_0 : define a World without us (counterfactual world) and derive the distribution of the similarity index (I_S^{Noise}) in this World
- Assess how (un)likely it is to get I_S^{Obs} under H_0

Detection ingredients

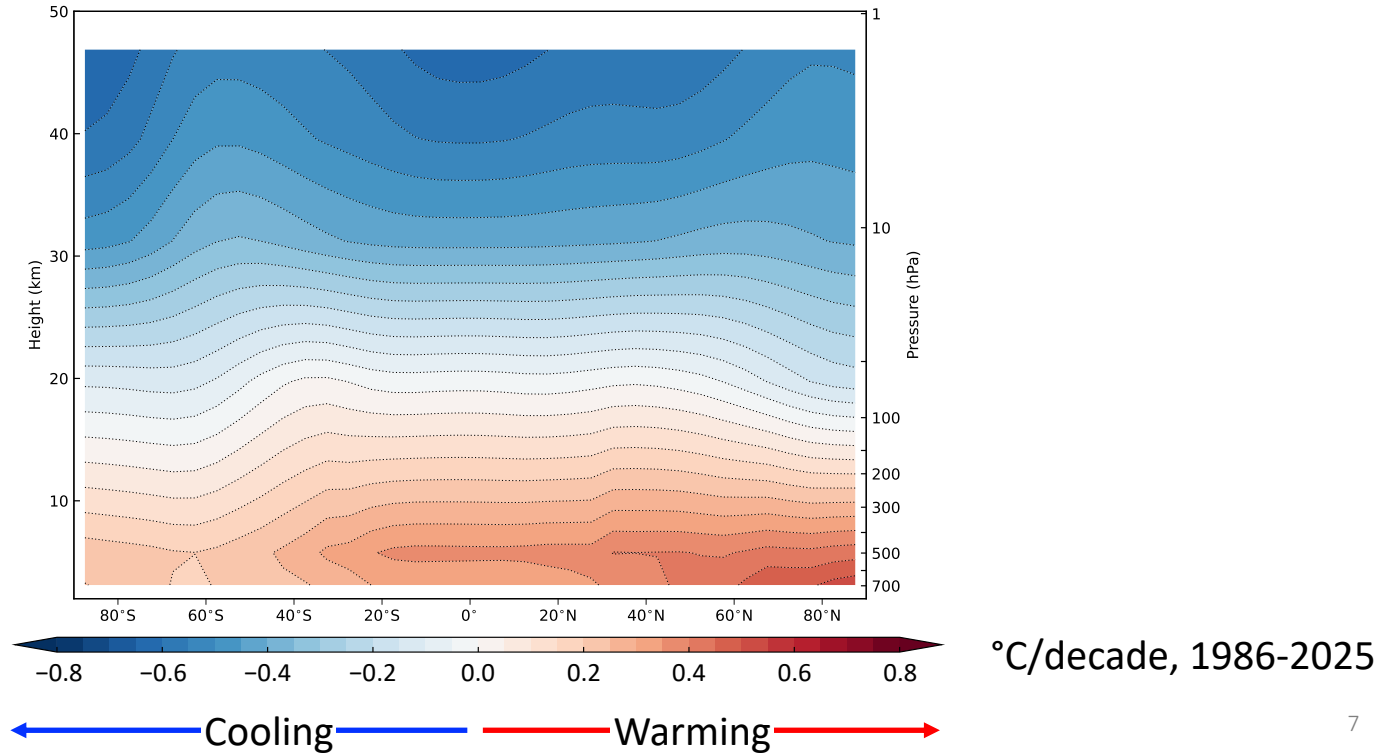
- Observations: annual zonal mean atmospheric temperature $T(\theta, z, t)$ with $t = 1986, \dots, 2025$
- Model-based:
 1. Anthropogenic temperature fingerprint $F(\theta, z)$: derived from historical simulations
 2. The World without us: simulated temperature from long control simulations $T_c(\theta, z, t)$

How to get the “vertical fingerprint” $F(\theta, z)$?



$F(\theta, z)$: Multimodel Mean Trend

$$F(\theta, z) = 1/M \sum_{i=1}^M trend_i(\theta, z)$$



Detection algorithm

1. Project temperature observations T on the fingerprint F

$$Z_{Obs}(t) = \sum_{\theta=1}^{N_{\theta}} \sum_{z=1}^{N_z} T(\theta, z, t) \cdot F(\theta, z)$$

$t = 1986, \dots, 2025$

2. Fit a linear trend to $Z_{Obs}(t)$



Index $I_S^{Obs} = \text{trend@slope}$


Detection algorithm

3. Project World without us temperature on the fingerprint

$$Z_c(t) = \sum_{\theta=1}^{N_\theta} \sum_{z=1}^{N_z} T_c(\theta, z, t) \cdot F(\theta, z)$$

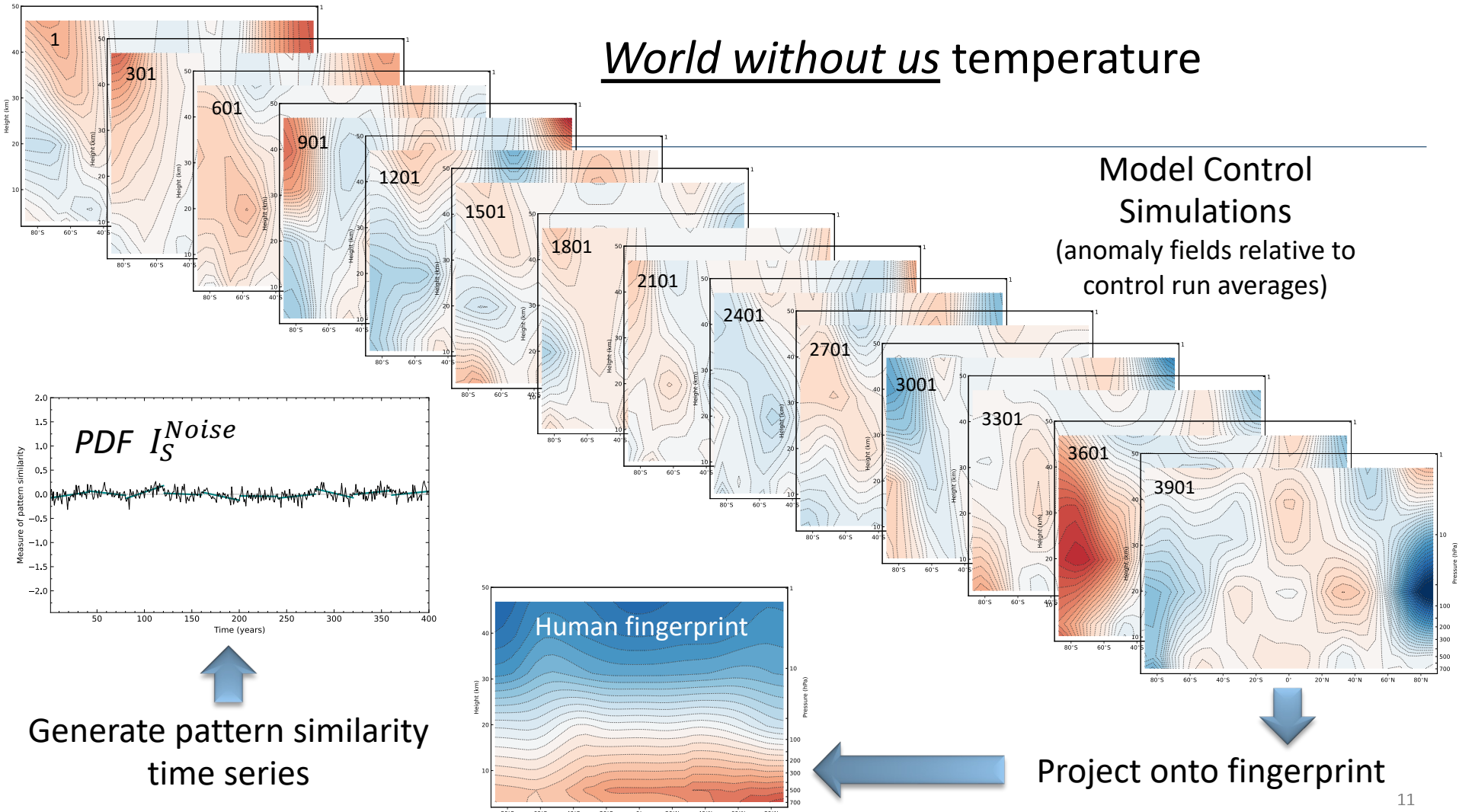
$t = 1, \dots, O(1000s)$

4. Fit linear trends to the N_c non-overlapping 40-year chunks of $Z_c(t)$

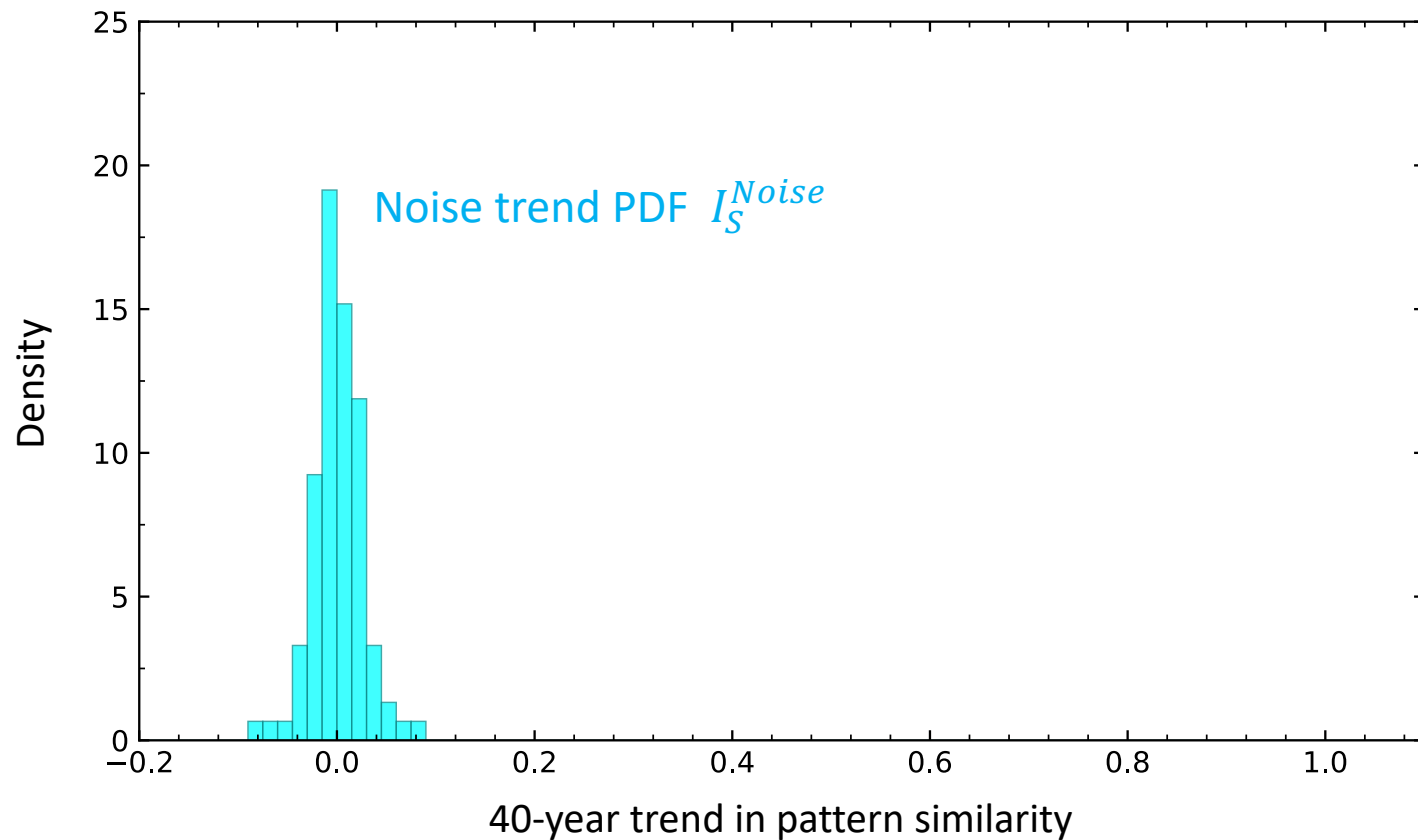
 $I_S^{Noise} = \text{pdf}(\text{trend@slope}, i = 1, \dots, N_c)$

World without us temperature

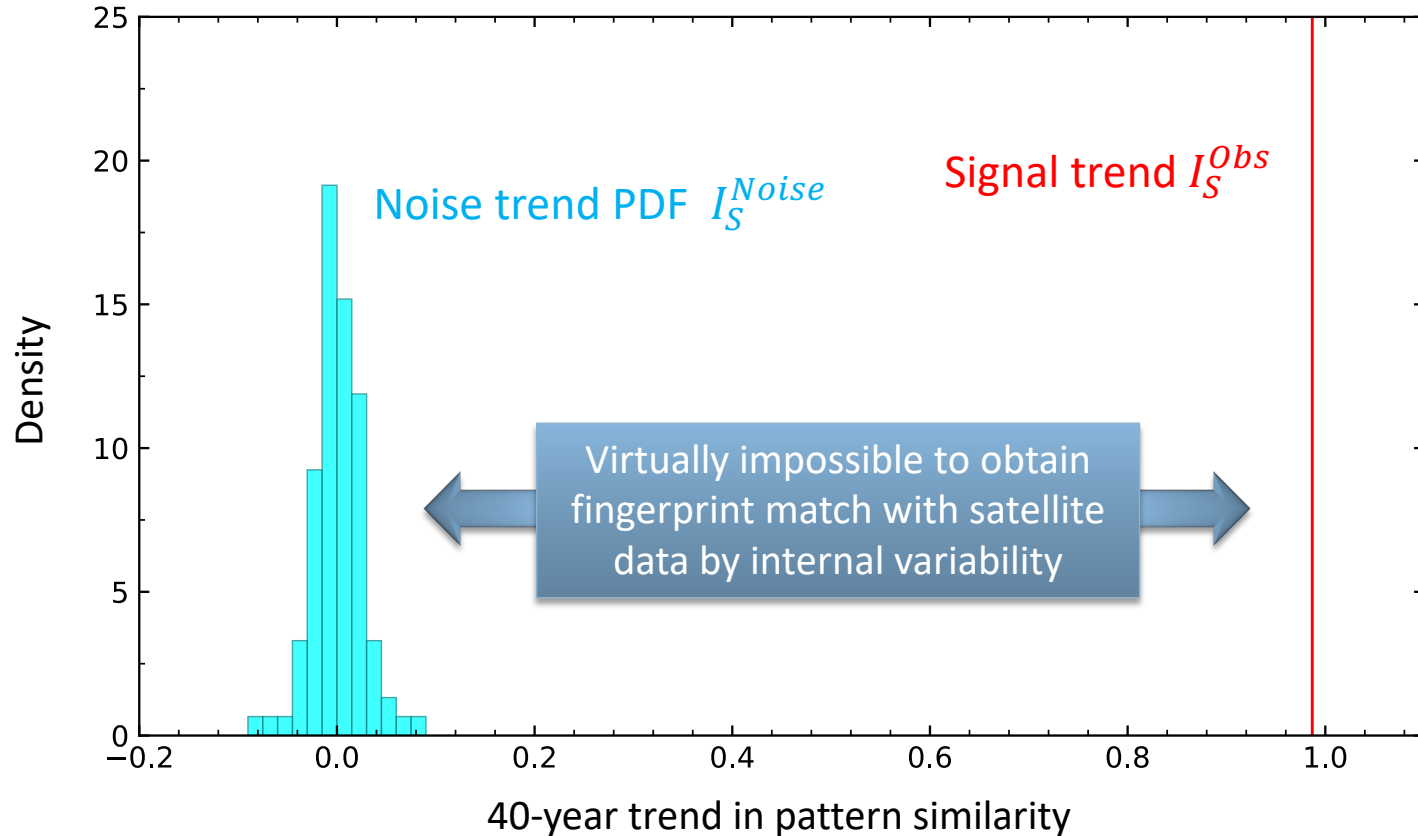
Model Control Simulations
(anomaly fields relative to control run averages)



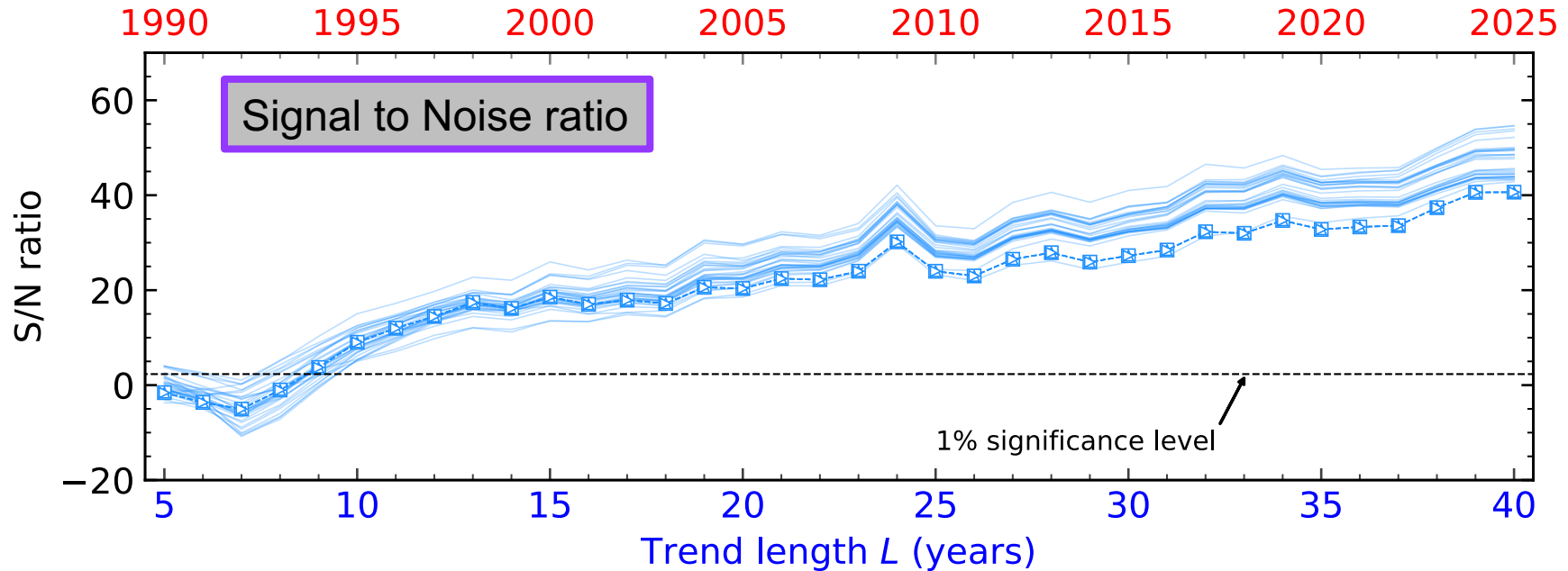
“Vertical fingerprint” results




“Vertical fingerprint” results



When was the signal first detectable ? Early detection was possible in 1995 !



Summary

- Changes in the vertical structure of atmospheric temperature are a key piece of evidence for human effects on global climate
- Upper stratosphere cooling is key to robust detection (40-sigma !)
- The Higgs boson and climate change are two nice examples of *predictive science*
- Two different detection problems !
- Higgs: Low SNR problem, direct sampling of the counterfactual world (no Higgs)
- Climate change: the one-Earth problem  Structural model uncertainty

Additional slides

Summary of the Statistical Model:

- T : temperature observations, function of space(s) and time(t)

$$T_{s,t} = m_s + \psi_{s,t}^{ANT} + \varepsilon_{s,t}$$

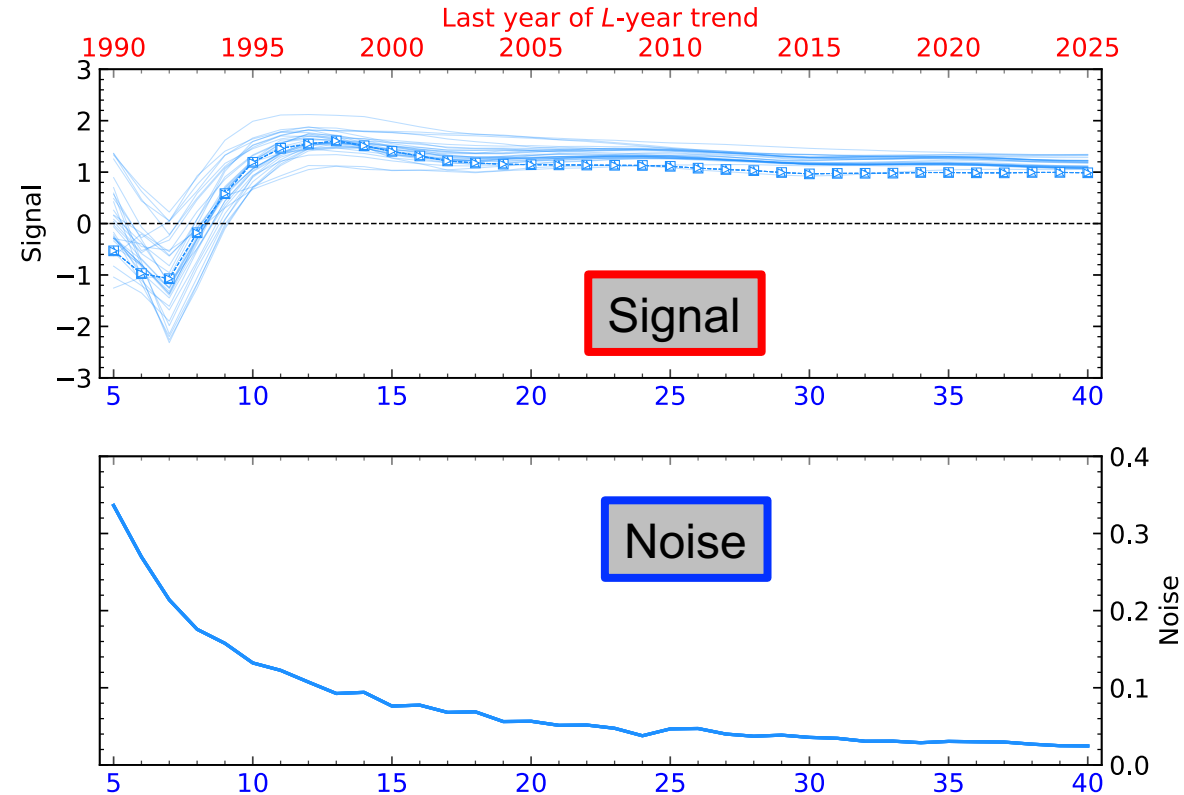
- Separability assumption of ANT forcing : $\psi^{ANT} = g(s) \cdot \mu(t)$

$$T_{s,t} = m_s + g_s \cdot \mu_t + \varepsilon_{s,t}$$

- Time filter: linear trend over a L -year period:

$$T'_{s,L} = \beta_L \cdot g_s + \eta_{s,L} \quad \boxed{\text{Test:}} \quad \begin{cases} H_0 : \ll \beta_L = 0 \gg \\ H_1 : \ll \beta_L > 0 \gg \end{cases}$$

When was the signal first detectable ?



Why is fingerprint detection so clear?

