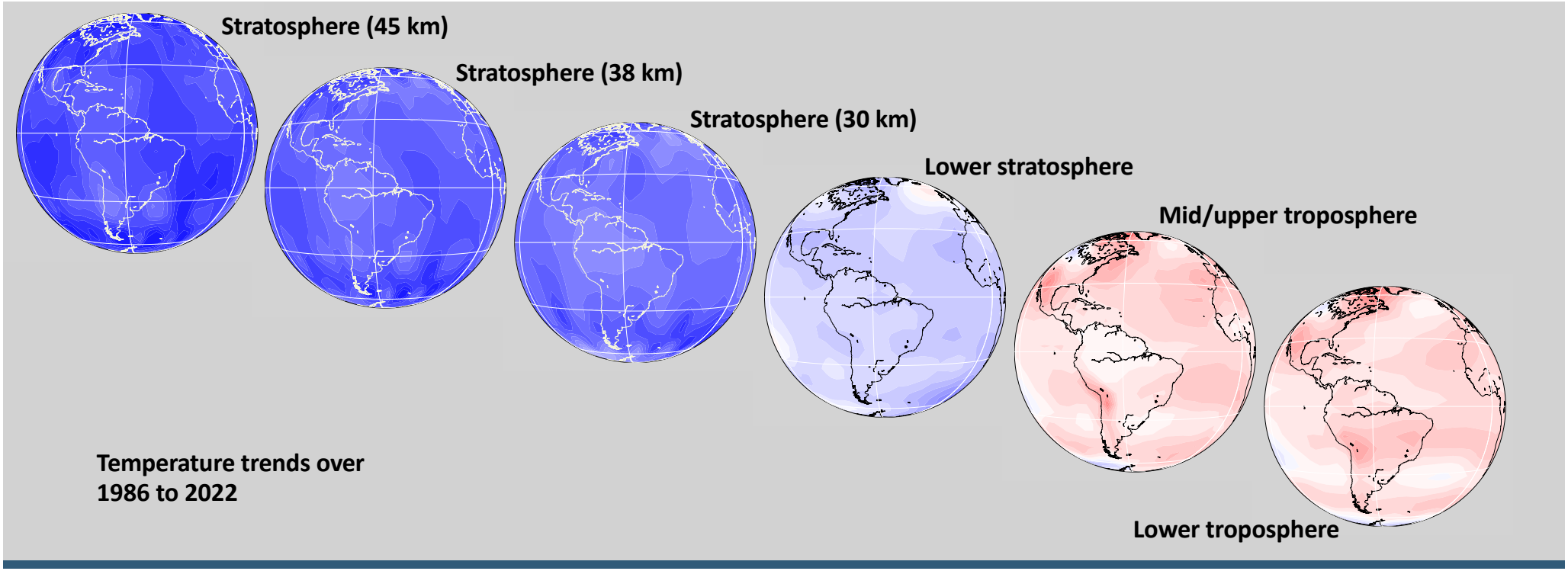

Exceptional Stratospheric Contribution to Human Fingerprints on Atmospheric Temperature

Ben Santer*, Stephen Po-Chedley, Lilong Zhao, Cheng-Zhi Zou, Qiang Fu, Susan Solomon, David Thompson, Carl Mears, and Karl Taylor

*Woods Hole Oceanographic Institution & UCLA

Univ. of Utah Atmospheric Sciences Seminar
Sept. 27, 2023

Structure

- Introduction
- Relevant history
- Extending “vertical fingerprinting” to the upper stratosphere
  - Global mean changes
  - Pattern analysis
- Conclusions

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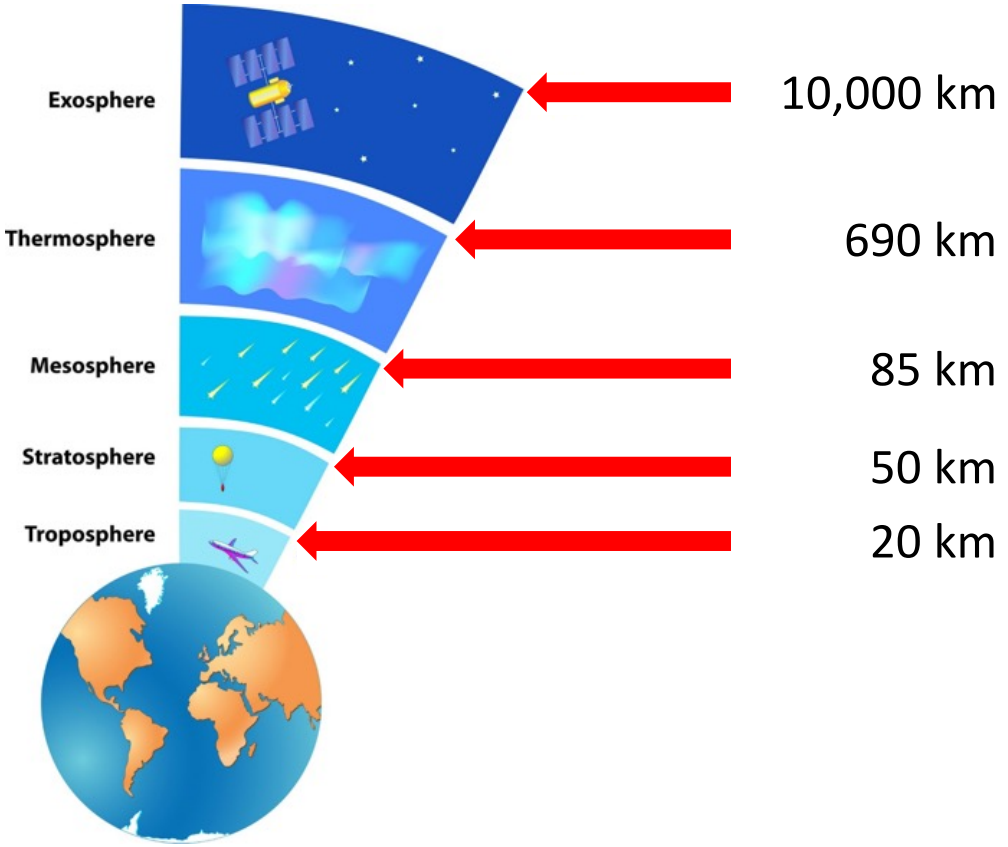
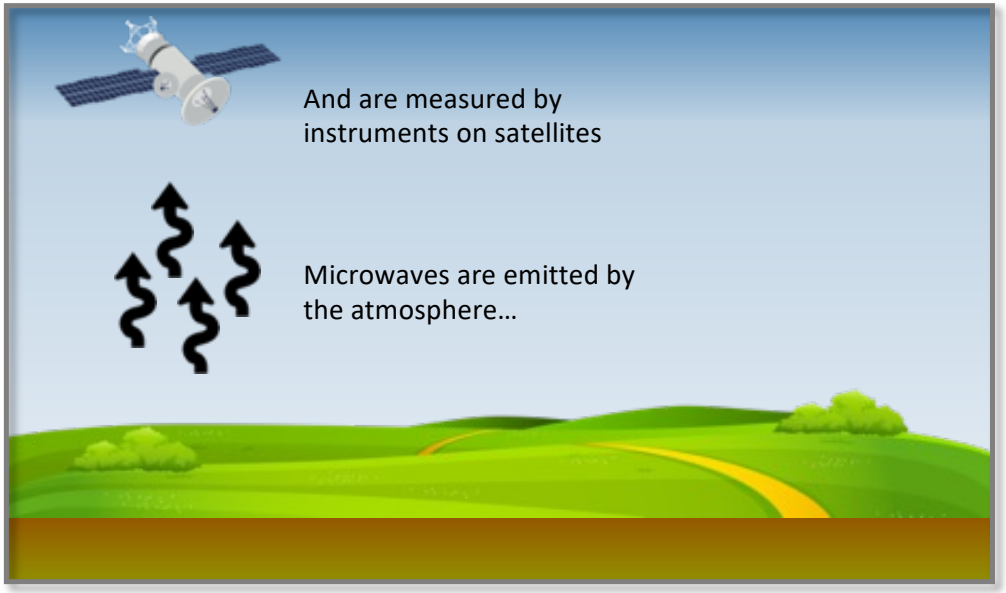
Layers of Earth's atmosphere

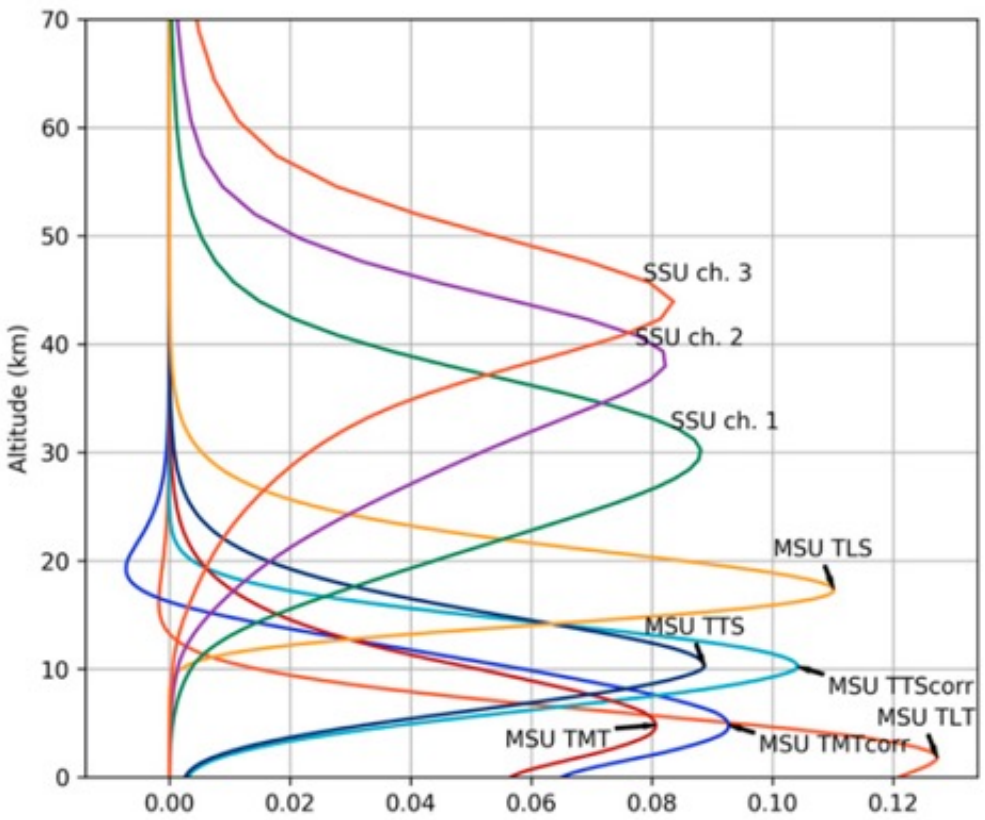


Measuring atmospheric temperature from space



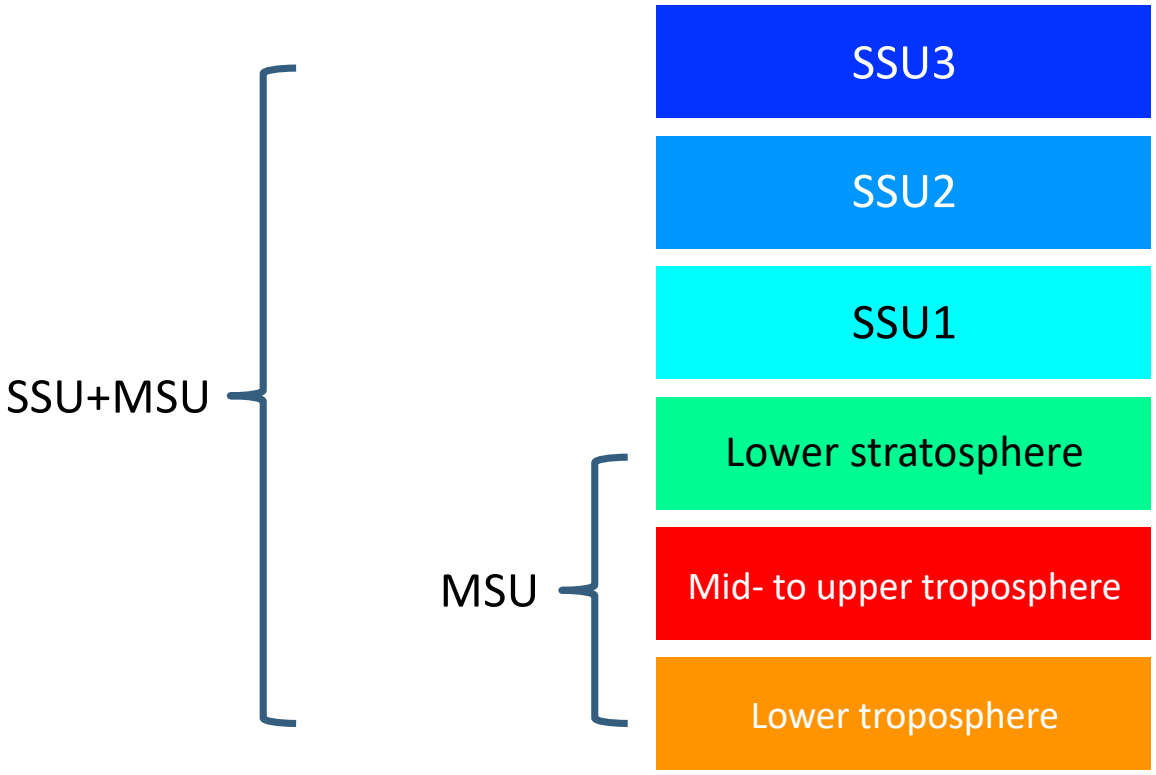
- Higher temperatures = More microwave emissions from oxygen molecules
- By choosing different microwave frequencies, different atmospheric layers can be measured

Atmospheric layers of interest in this talk



Source: Steiner et al., J. Climate (2020)

We consider different sets of atmospheric layers



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Manabe: Predicting climate change

"…physical modelling of Earth's climate, quantifying variability and reliably predicting global warming"

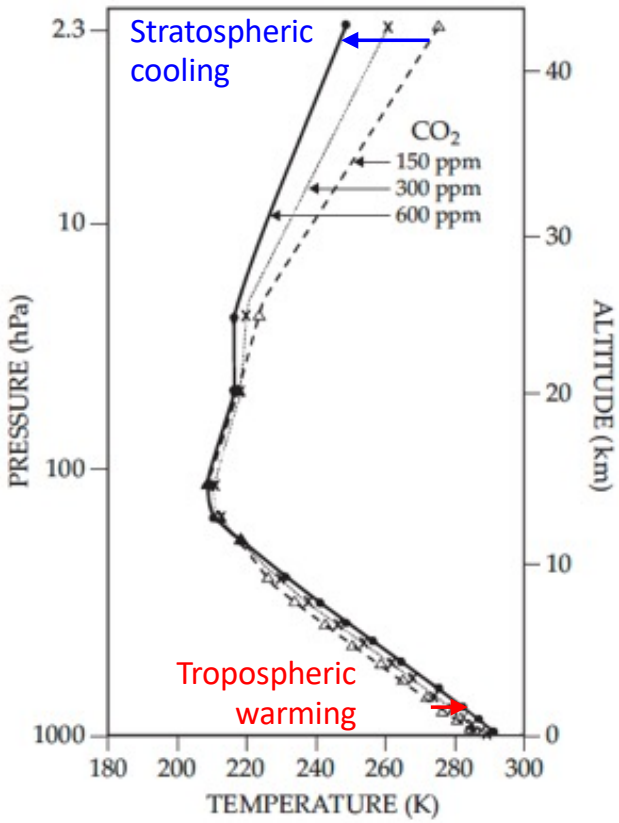
Manabe and Wetherald (1967)

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

SYUKURO MANABE AND RICHARD T. WETHERLAND

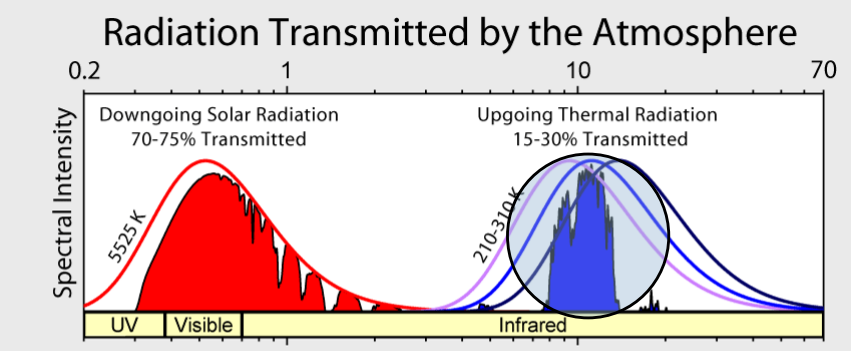
Geophysical Fluid Dynamics Laboratory, ESSA, Washington, D.C.

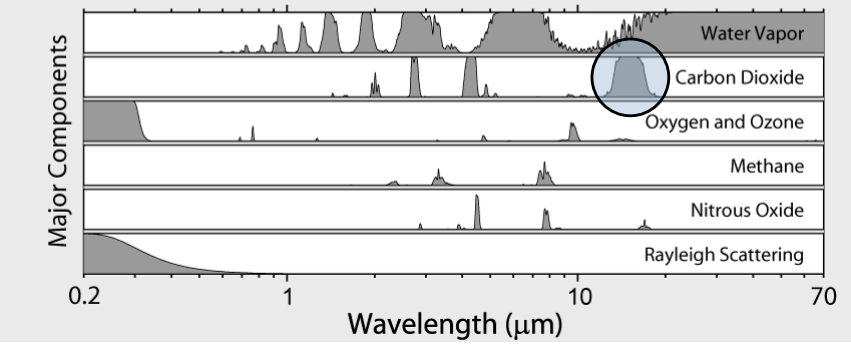
(Manuscript received 2 November1966)



Source: Manabe and Wetherald, J. Atmos. Sci. (1967)

Why does increased CO_2 cool the stratosphere?





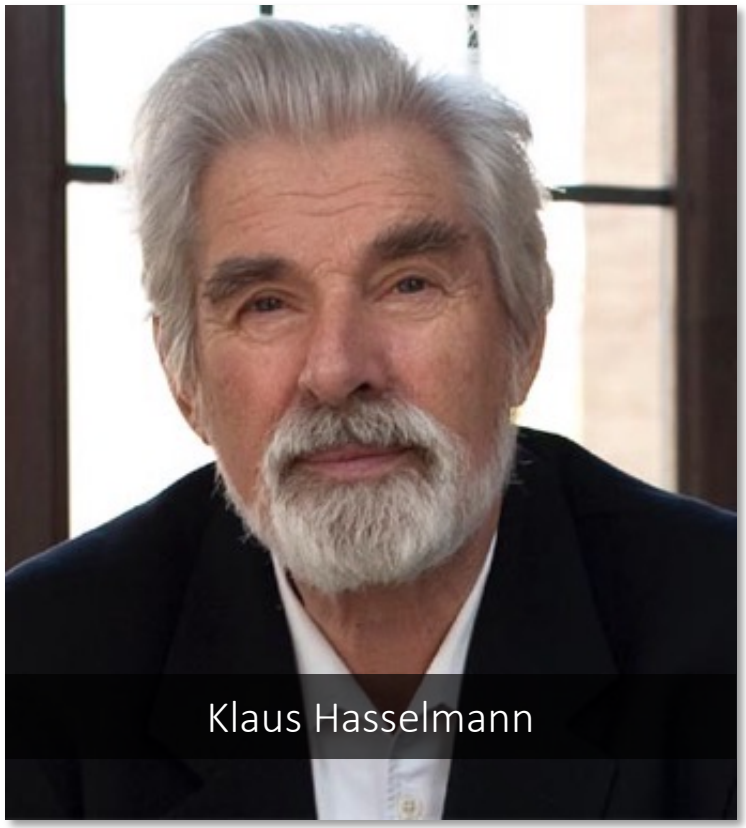
Key point: "The largest absorption band of carbon dioxide is not far from the maximum in the thermal emission from ground, and it partly closes the window of transparency of water; hence its major effect".

Why does increased CO_2 cool the stratosphere?*

- Concentrations of CO_2 are increasing throughout atmosphere; CO_2 absorbs and emits IR
- Whether increased CO_2 warms or cools a given atmospheric layer depends on whether the net change (increased absorption vs increased emission) is positive or negative
- Increasing tropospheric CO_2 makes it more difficult for IR to reach the stratosphere or above
- "Extra stratospheric CO_2 molecules then see less radiation to absorb coming up, but they are totally happy emitting more – half of which goes up into space. So the net effect is less absorption and more emittence, and thus they give a cooling. The effect is larger the further up you go."

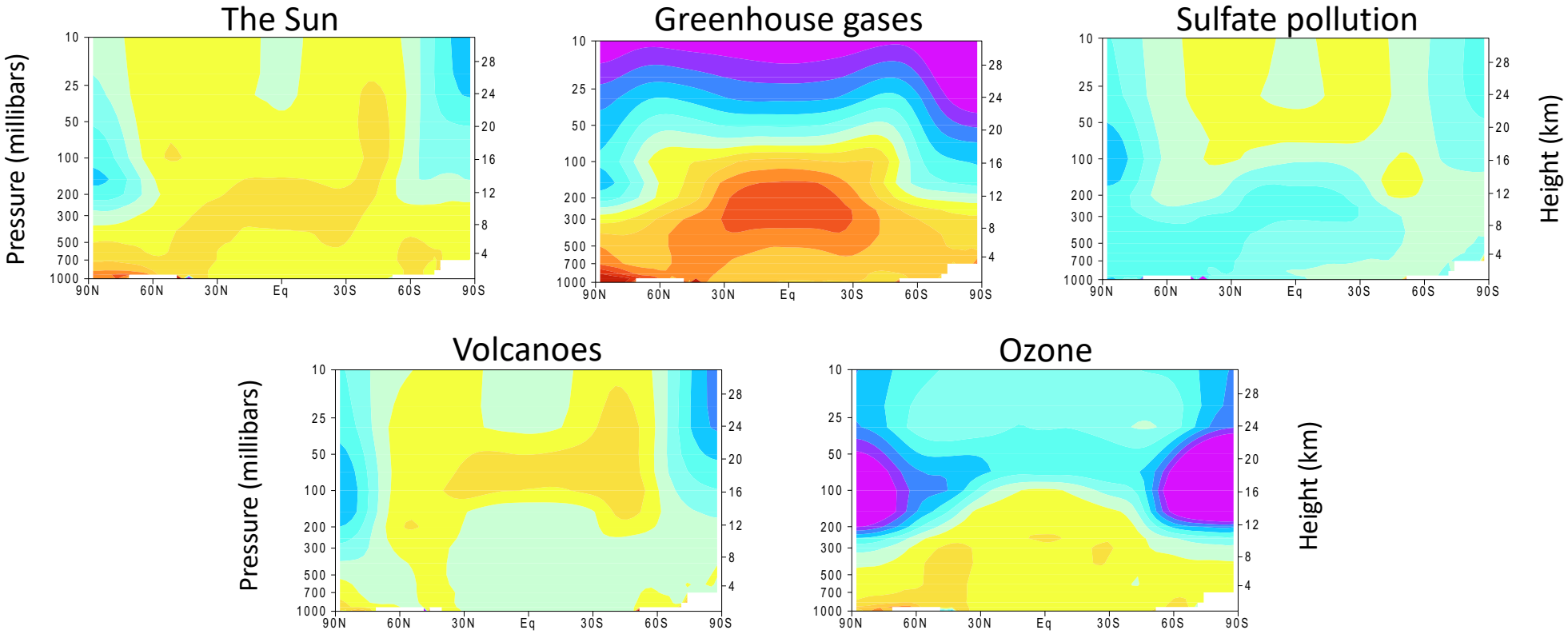
https://www.realclimate.org/index.php/archives/2023/05/cmip6-not-so-sudden-stratospheric-cooling/

Hasselmann: The power of patterns


Klaus Hasselmann

"…methods for identifying specific signals, fingerprints, that both natural phenomena and human activities imprint in the climate"

Natural and human fingerprints on climate



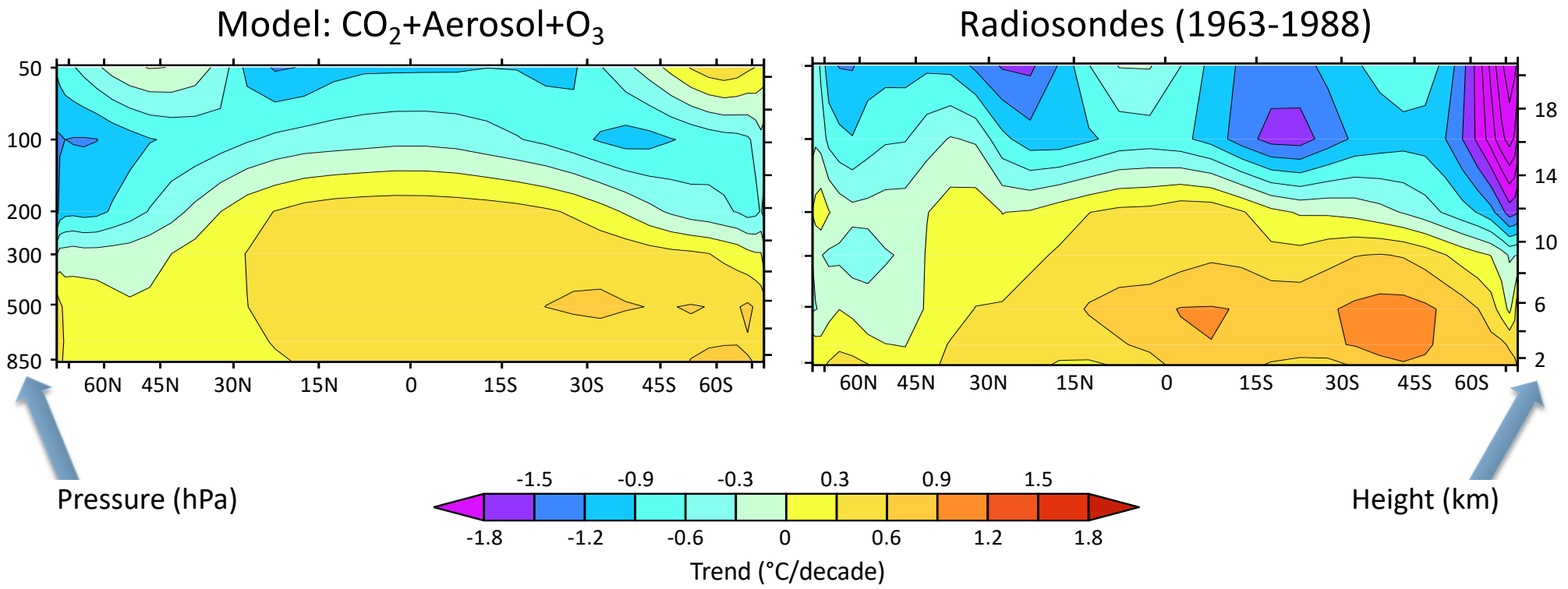
Vertical fingerprinting: Santer et al. (1996)

A search for human influences on the thermal structure of the atmosphere

B. D. Santer*, K. E. Taylor*†, T. M. L. Wigley‡, T. C. Johns§, P. D. Jones‖, D. J. Karoly¶, J. F. B. Mitchell§, A. H. Oort#, J. E. Penner†, V. Ramaswamy#, M. D. Schwarzkopf#, R. J. Stouffer# & S. Tett§

"…we have identified a component of the observational record that shows a statistically significant similarity with model predictions..."

Vertical fingerprinting: Santer et al. (1996)



Source: Santer et al., Nature (1996)

Thompson et al. (2012)

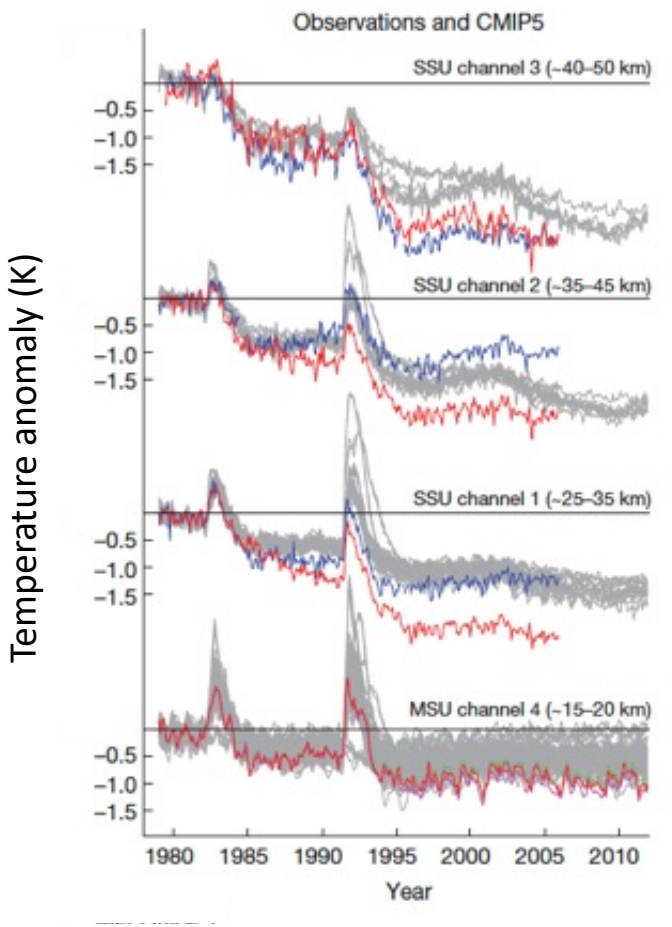
The mystery of recent stratospheric temperature trends

David W. J. Thompson[1], Dian J. Seidel[2], William J. Randel[3], Cheng-Zhi Zou[4], Amy H. Butler[5], Carl Mears[6], Albert Osso[7], Craig Long[5] & Roger Lin[5]

"Stratospheric temperature trends play an important part in allowing us to distinguish between the climate responses to natural and anthropogenic forcings"

Source: Thompson et al., Nature (2012)

Thompson et al. (2012)



NOAA STAR
Met. Office
CMIP5

Source: Thompson et al., Nature (2012)

Santer et al. (2013)

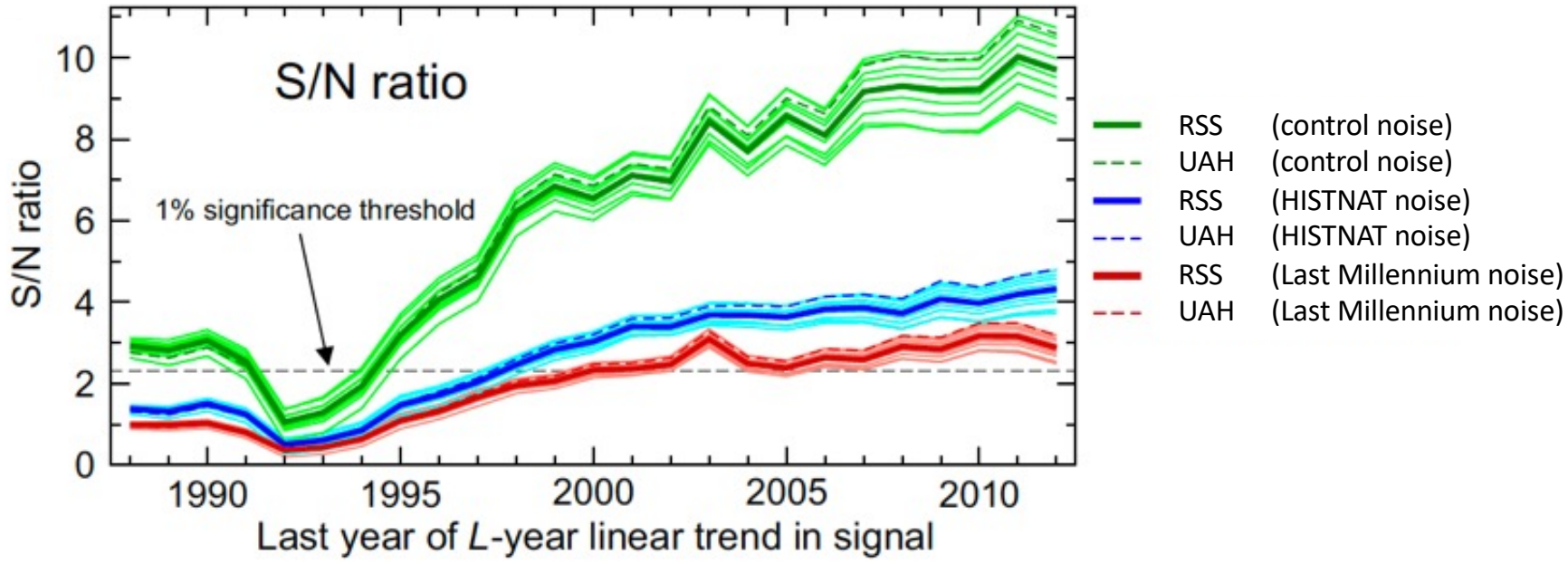
Human and natural influences on the changing thermal structure of the atmosphere

Benjamin D. Santer[a,1], Jeffrey F. Painter[a], Céline Bonfils[a], Carl A. Mears[b], Susan Solomon[c], Tom M. L. Wigley[d,e], Peter J. Gleckler[a], Gavin A. Schmidt[f], Charles Doutriaux[a], Nathan P. Gillett[g], Karl E. Taylor[a], Peter W. Thorne[h], and Frank J. Wentz[b]

"We detect a human influence signal in all cases, even if we test against natural variability estimates with much larger fluctuations in solar and volcanic influences than those observed since 1979"

Source: Santer et al., PNAS (2013)

Santer et al. (2013)



Source: Santer et al., PNAS (2013)

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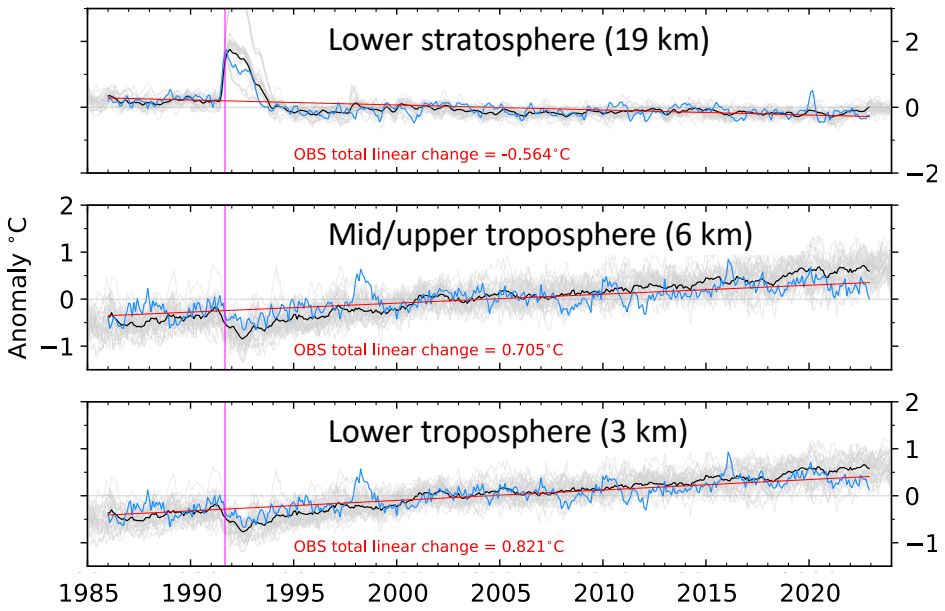
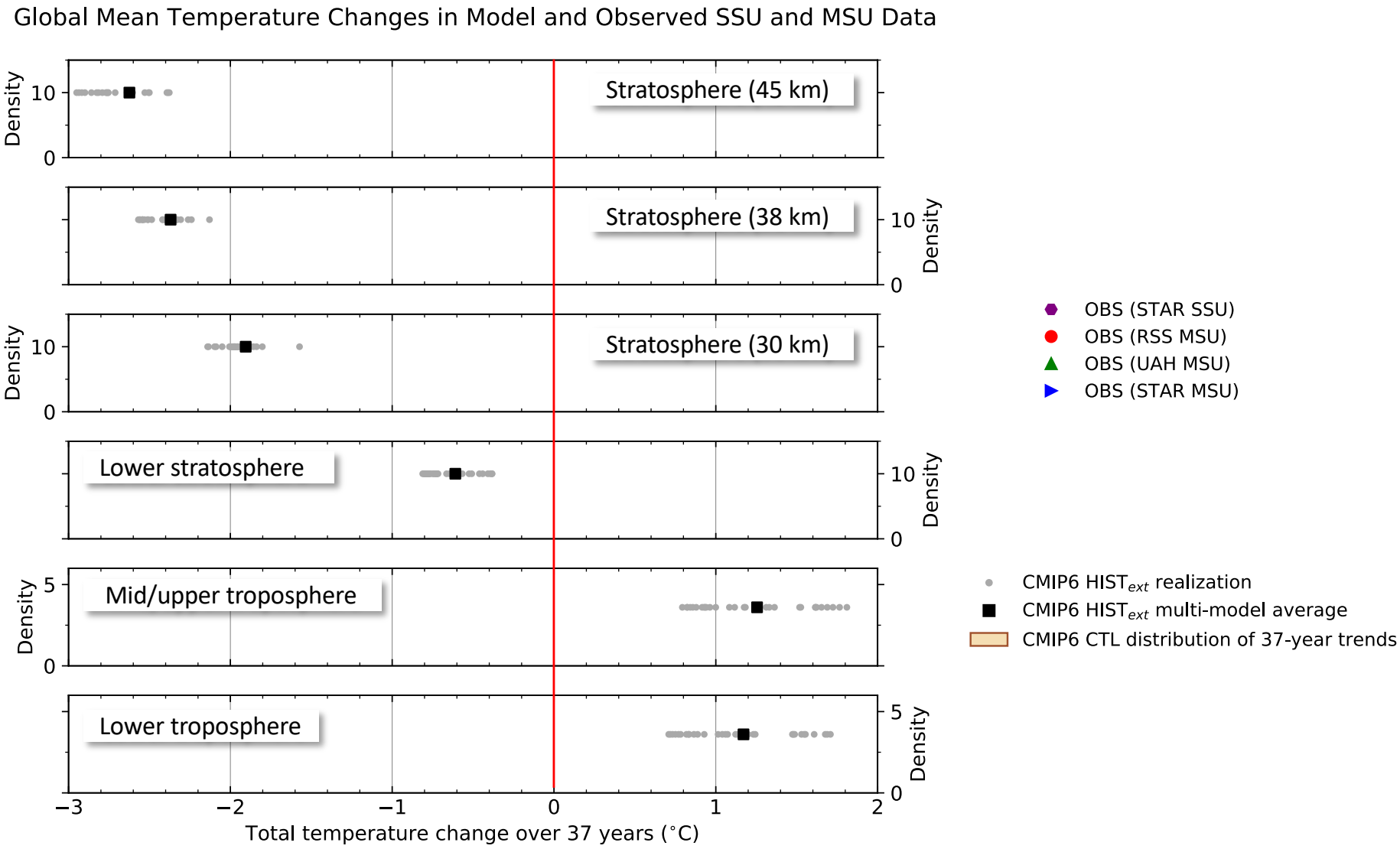
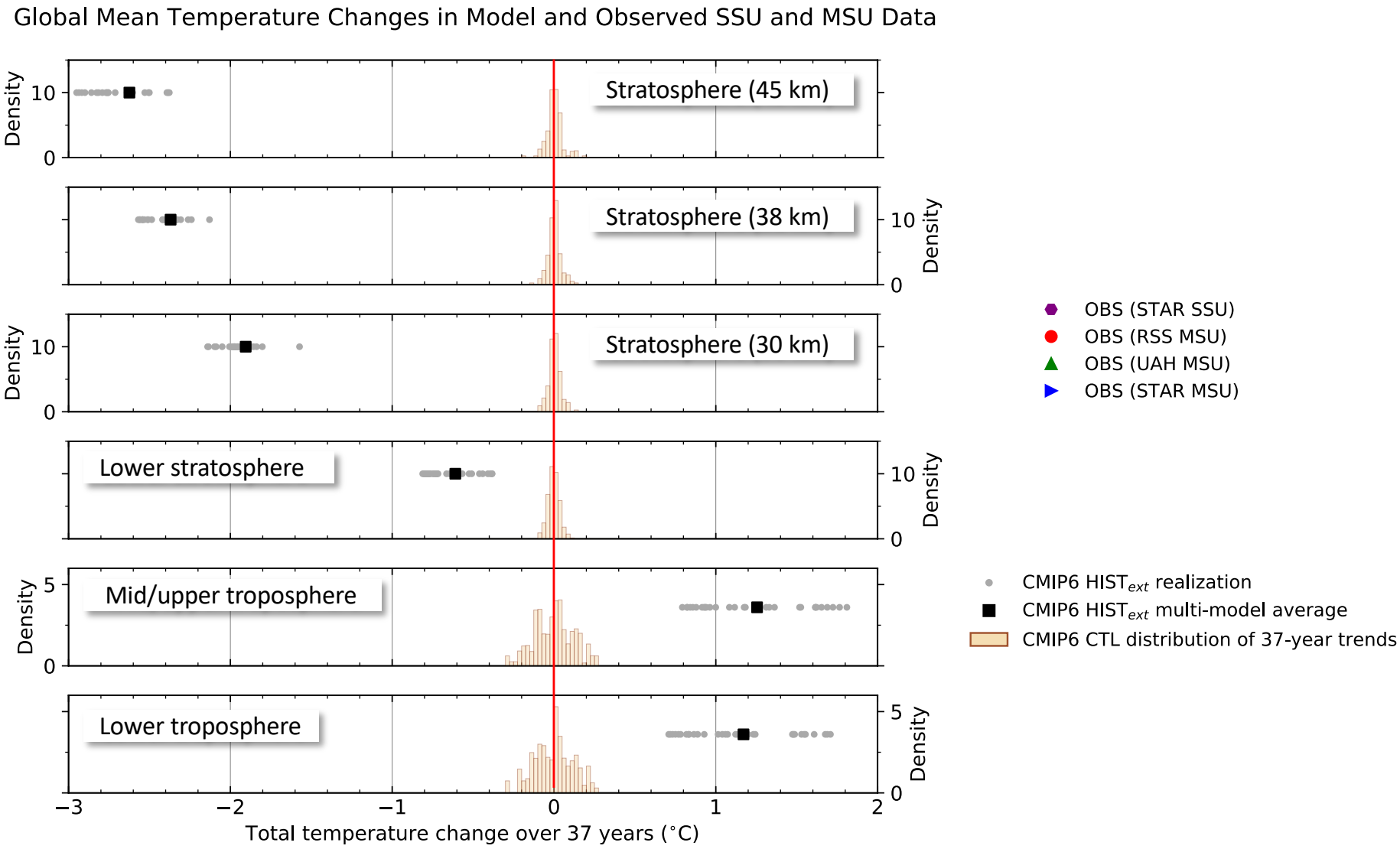
Global-mean temperature changes in models and observations



Observations Multi-model average Model realization


Global Mean Temperature Changes in Model and Observed SSU and MSU Data
Stratosphere (45 km)
Stratosphere (38 km)
Stratosphere (30 km)
Lower stratosphere
Mid/upper troposphere
Lower troposphere
Density
Total temperature change over 37 years (°C)
OBS (STAR SSU)
OBS (RSS MSU)
OBS (UAH MSU)
OBS (STAR MSU)
CMIP6 HIST$_{ext}$ realization
CMIP6 HIST$_{ext}$ multi-model average
CMIP6 CTL distribution of 37-year trends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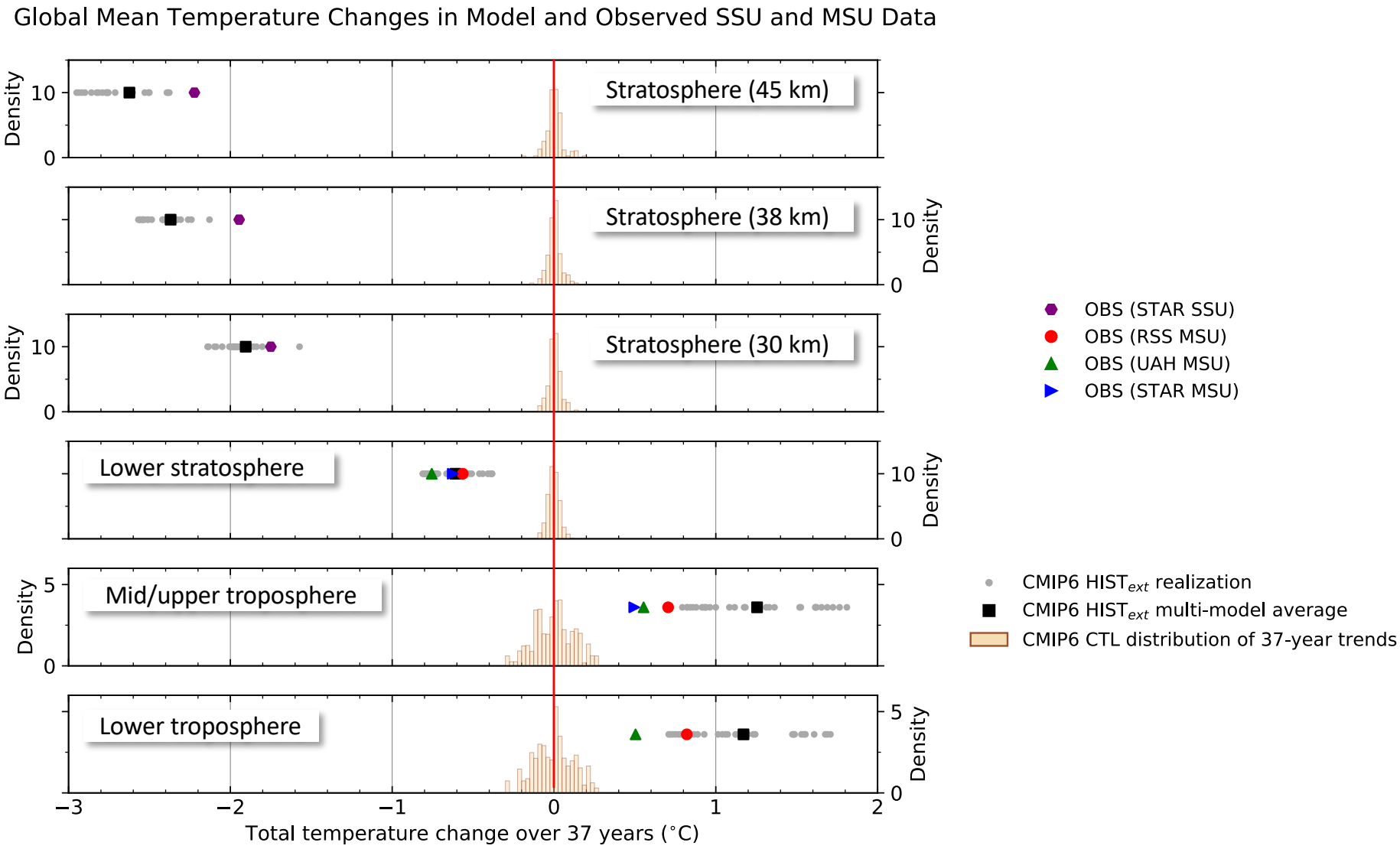
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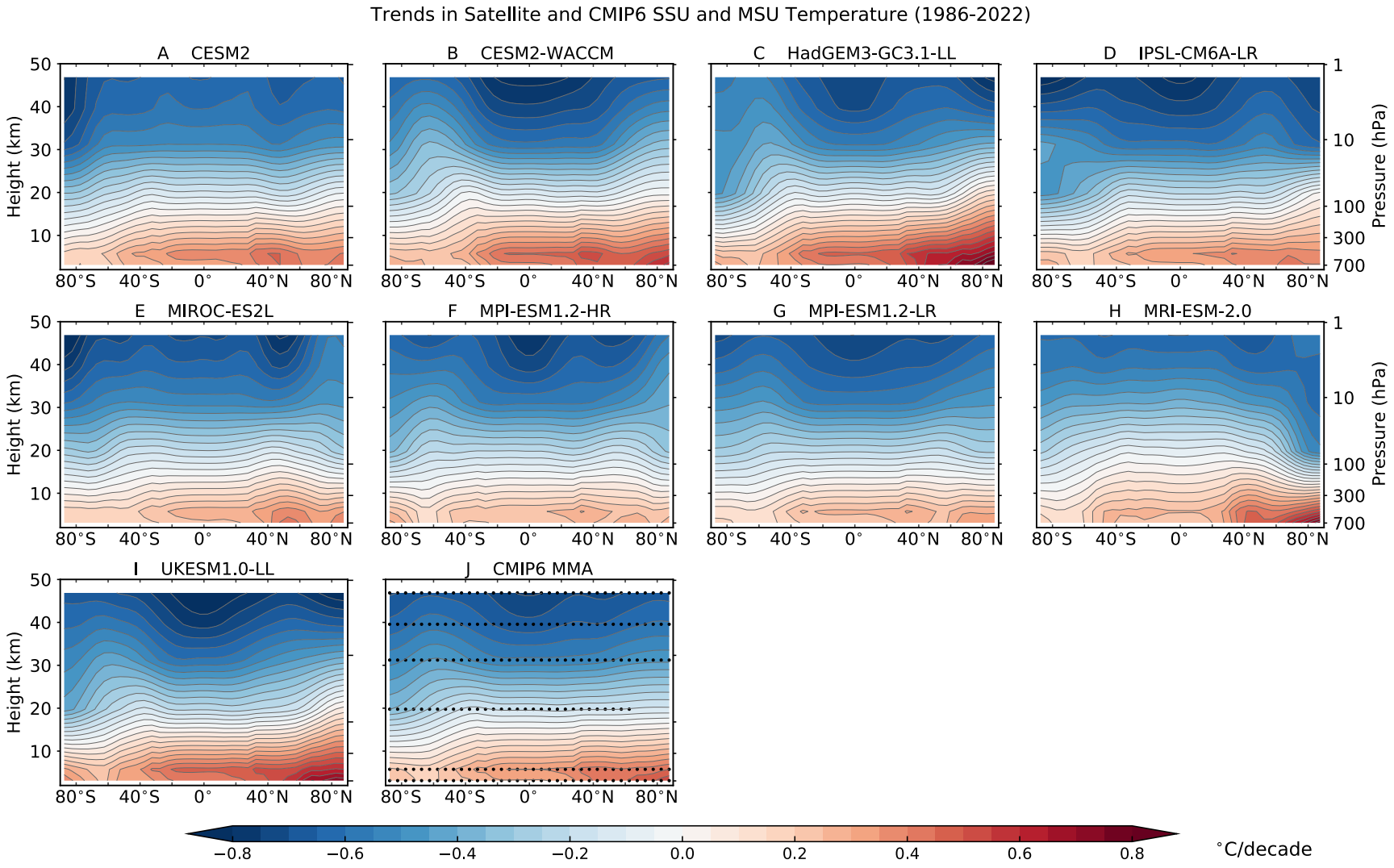
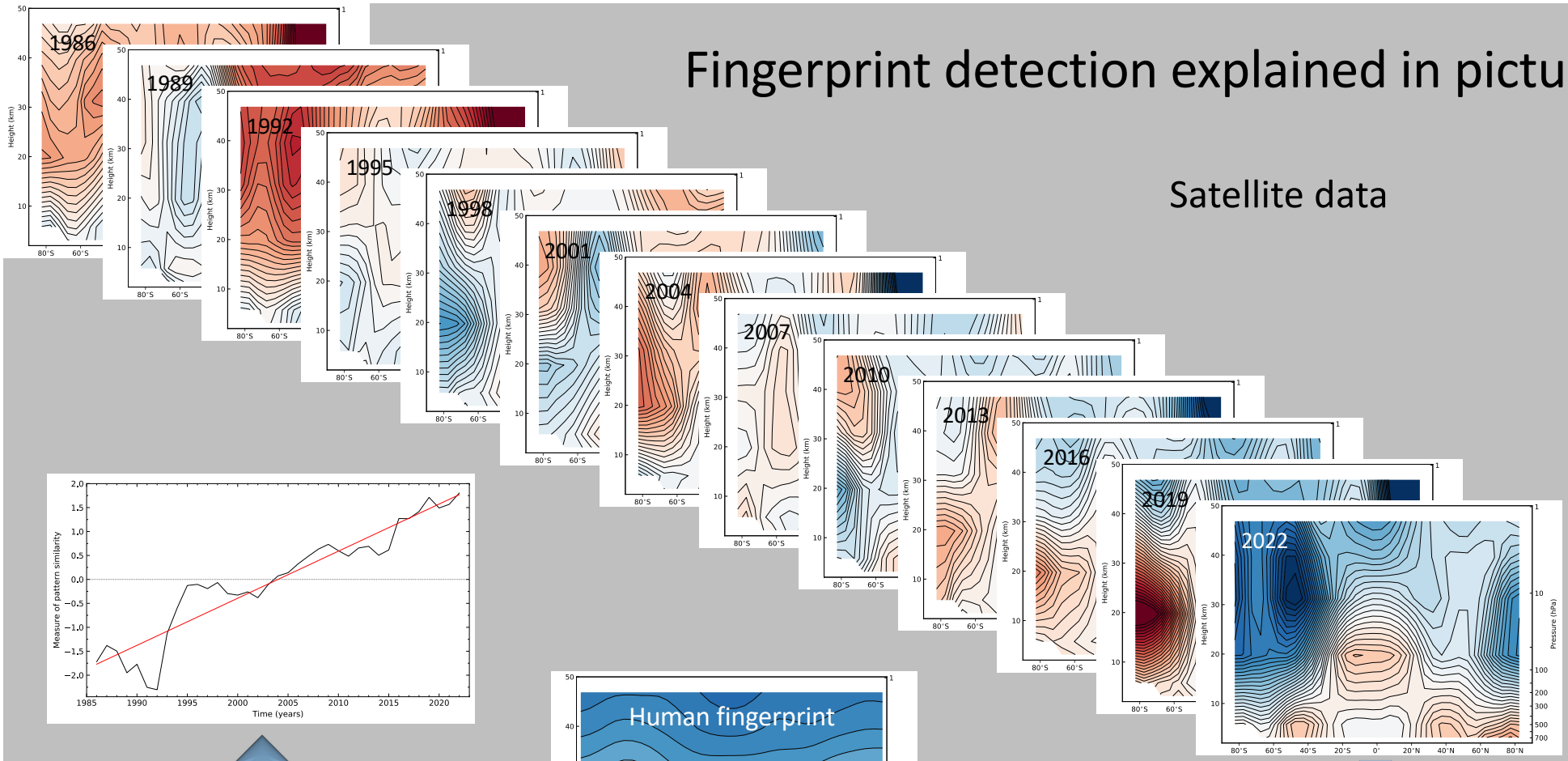
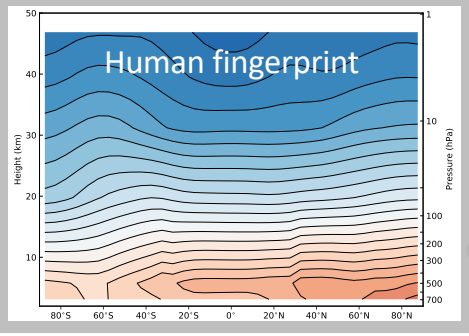

Trends in Satellite and CMIP6 SSU and MSU Temperature (1986-2022)
A CESM2
B CESM2-WACCM
C HadGEM3-GC3.1-LL
D IPSL-CM6A-LR
E MIROC-ES2L
F MPI-ESM1.2-HR
G MPI-ESM1.2-LR
H MRI-ESM-2.0
I UKESM1.0-LL
J CMIP6 MMA
Height (km)
Pressure (hPa)
80°S 40°S 0° 40°N 80°N
−0.8 −0.6 −0.4 −0.2 0.0 0.2 0.4 0.6 0.8
°C/decade

Fingerprint detection explained in pictures

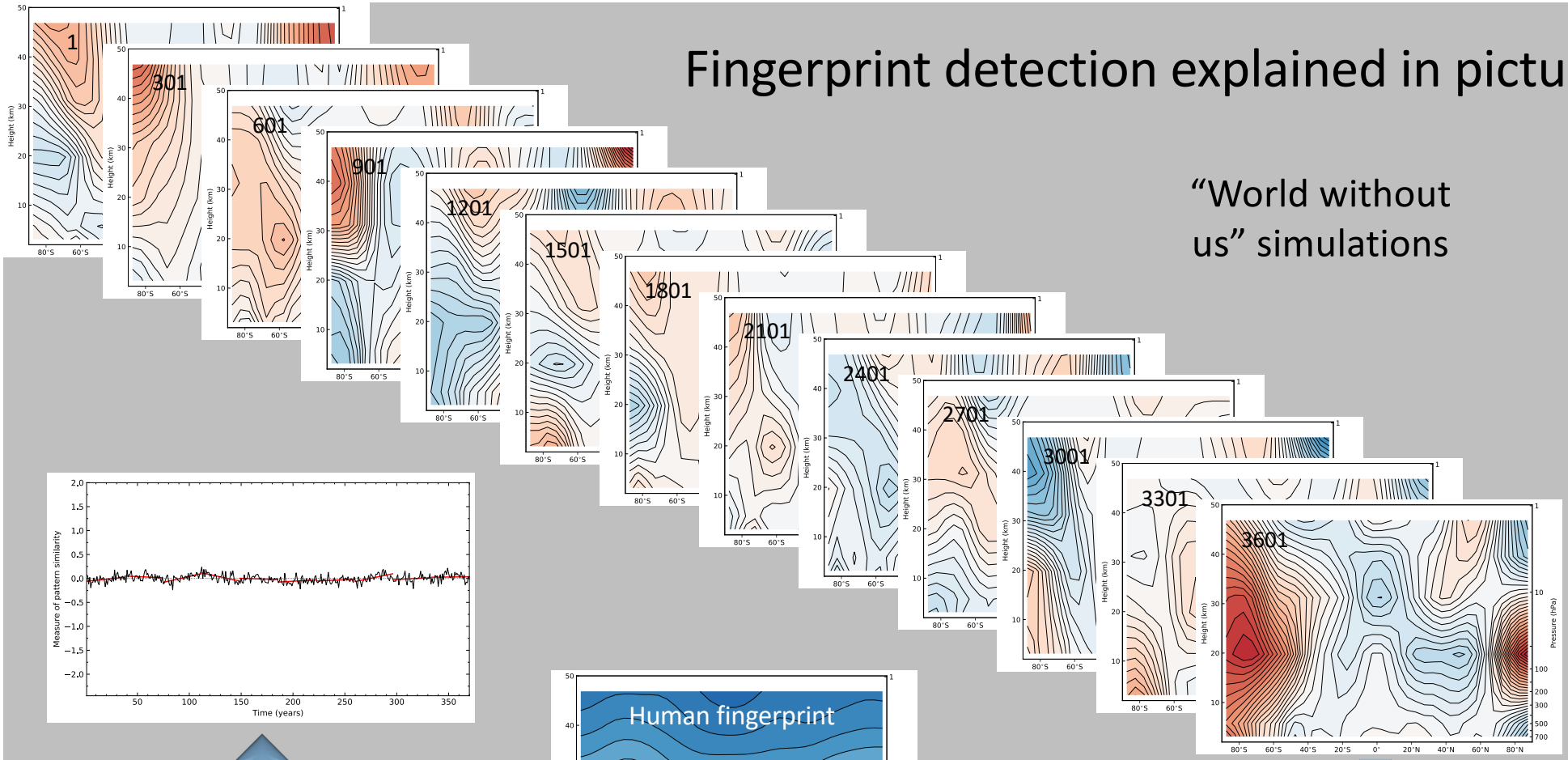


Generate pattern similarity time series



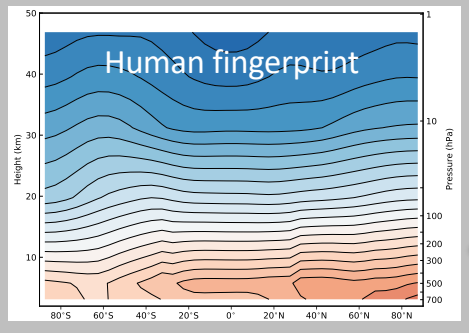
Compare with fingerprint

Fingerprint detection explained in pictures



"World without us" simulations

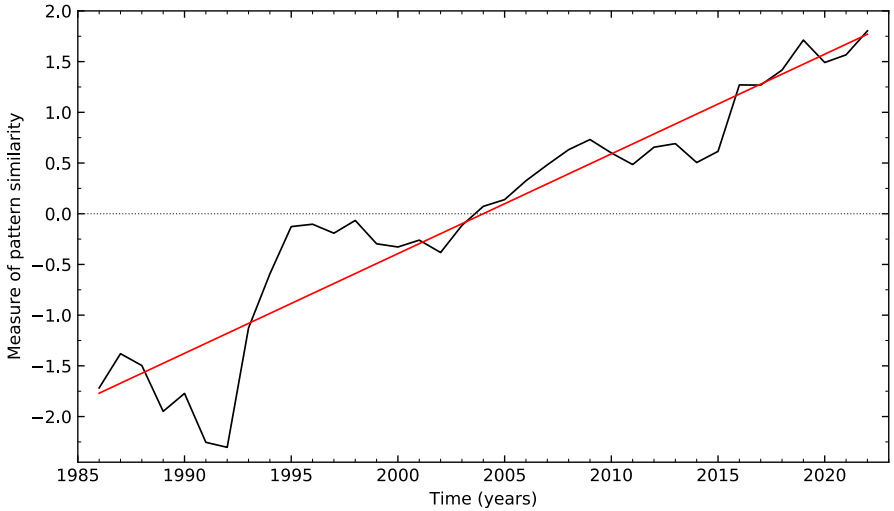
Generate pattern similarity time series



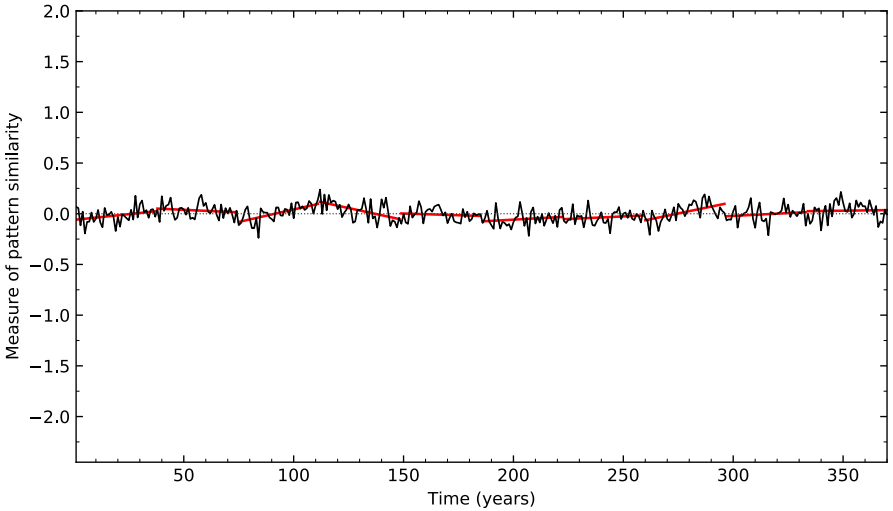
Compare with fingerprint

Fingerprinting explained…

Similarity between human fingerprint and satellite data

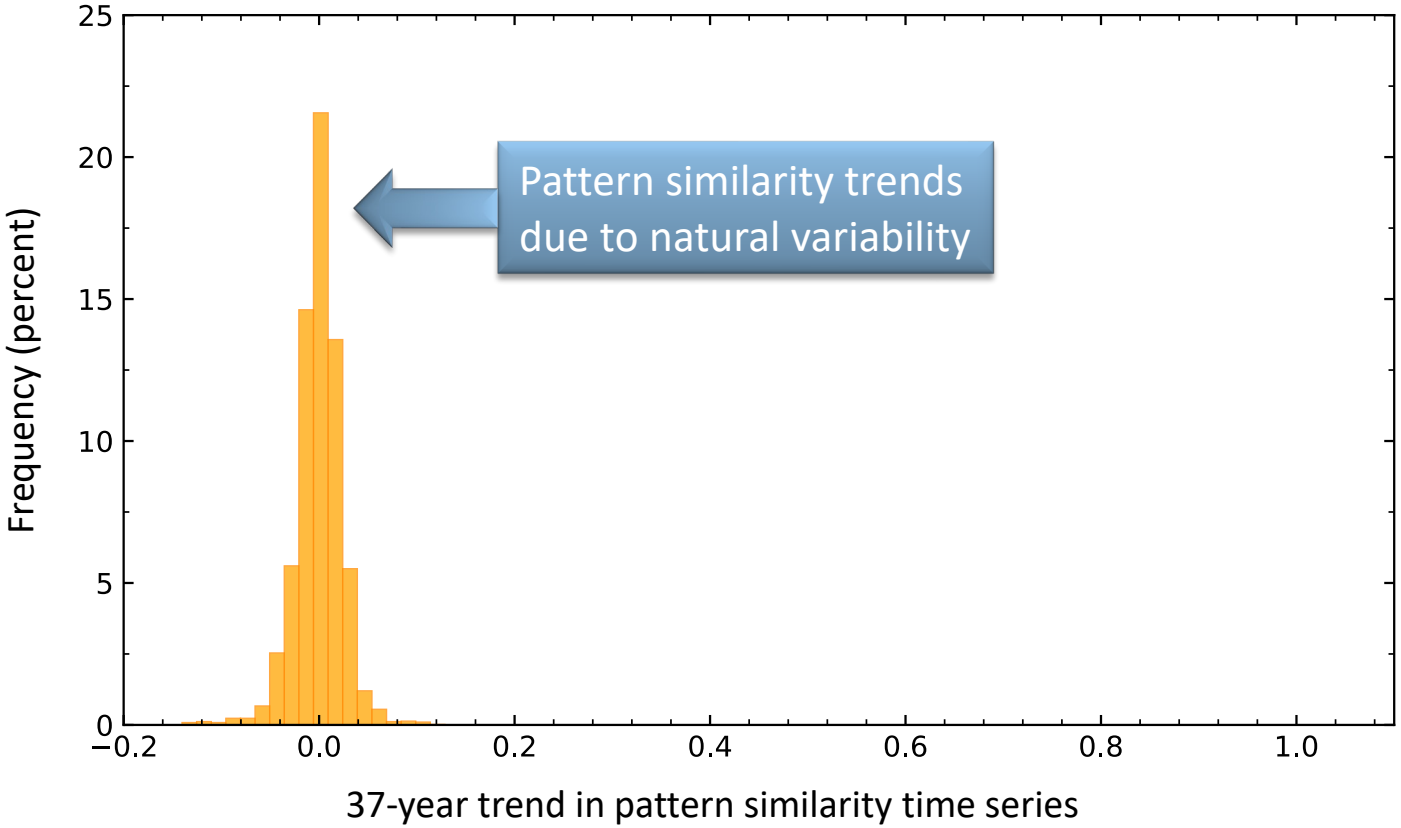


Similarity between human fingerprint and model “world without us” runs



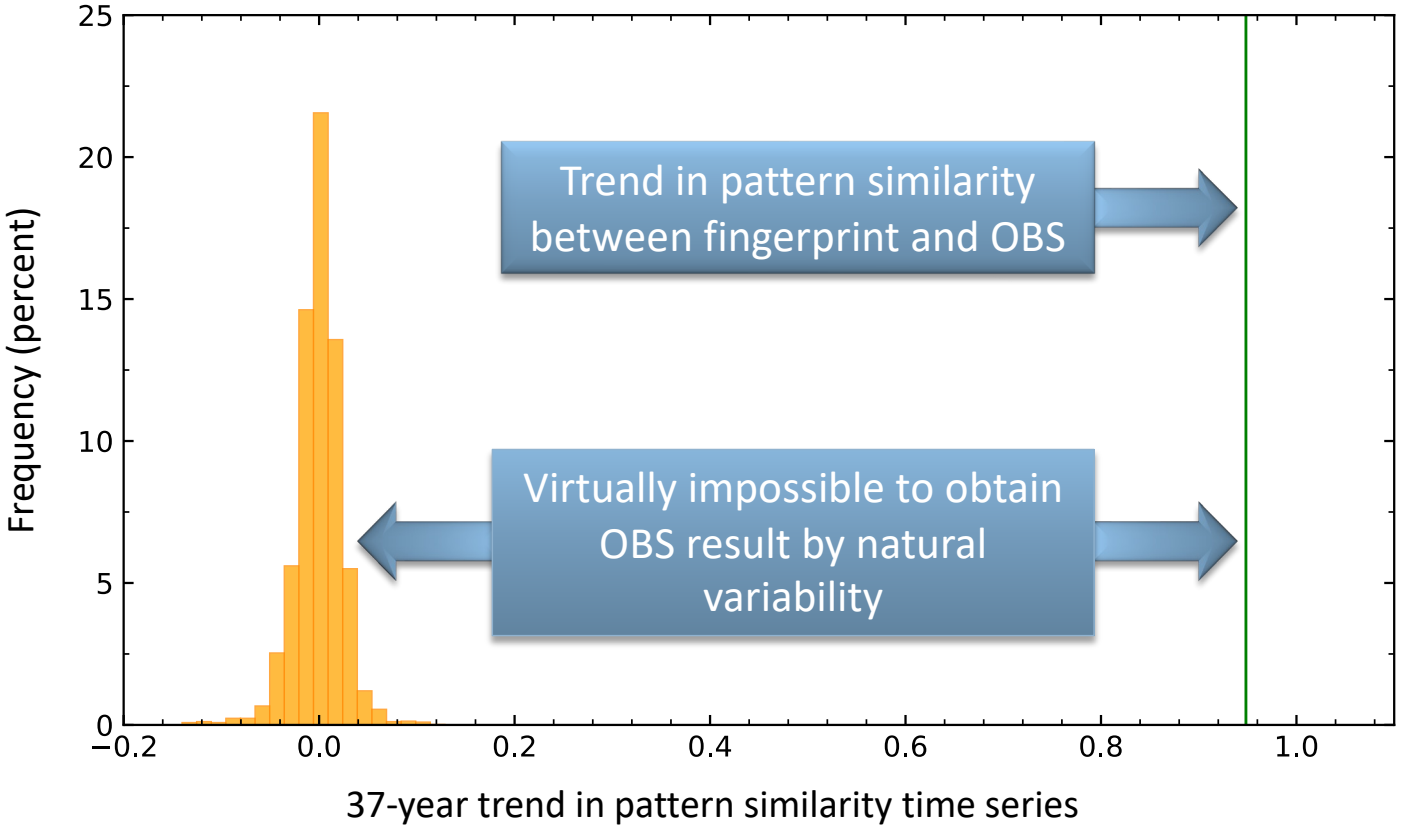
Source: Santer et al., PNAS (2023)

Fingerprinting explained…



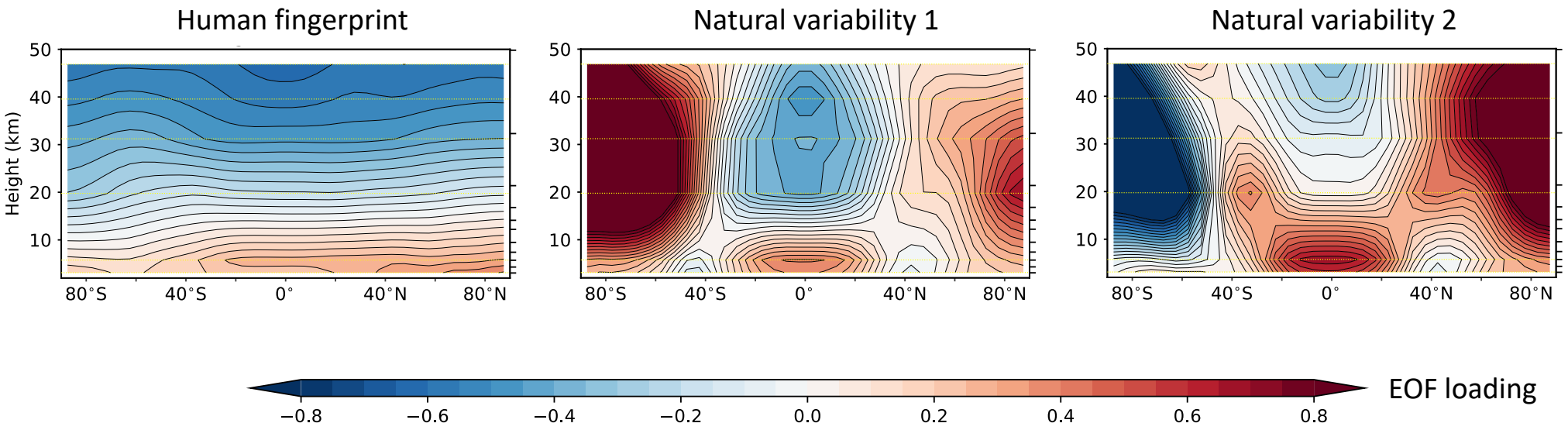
Source: Santer et al., PNAS (2023)

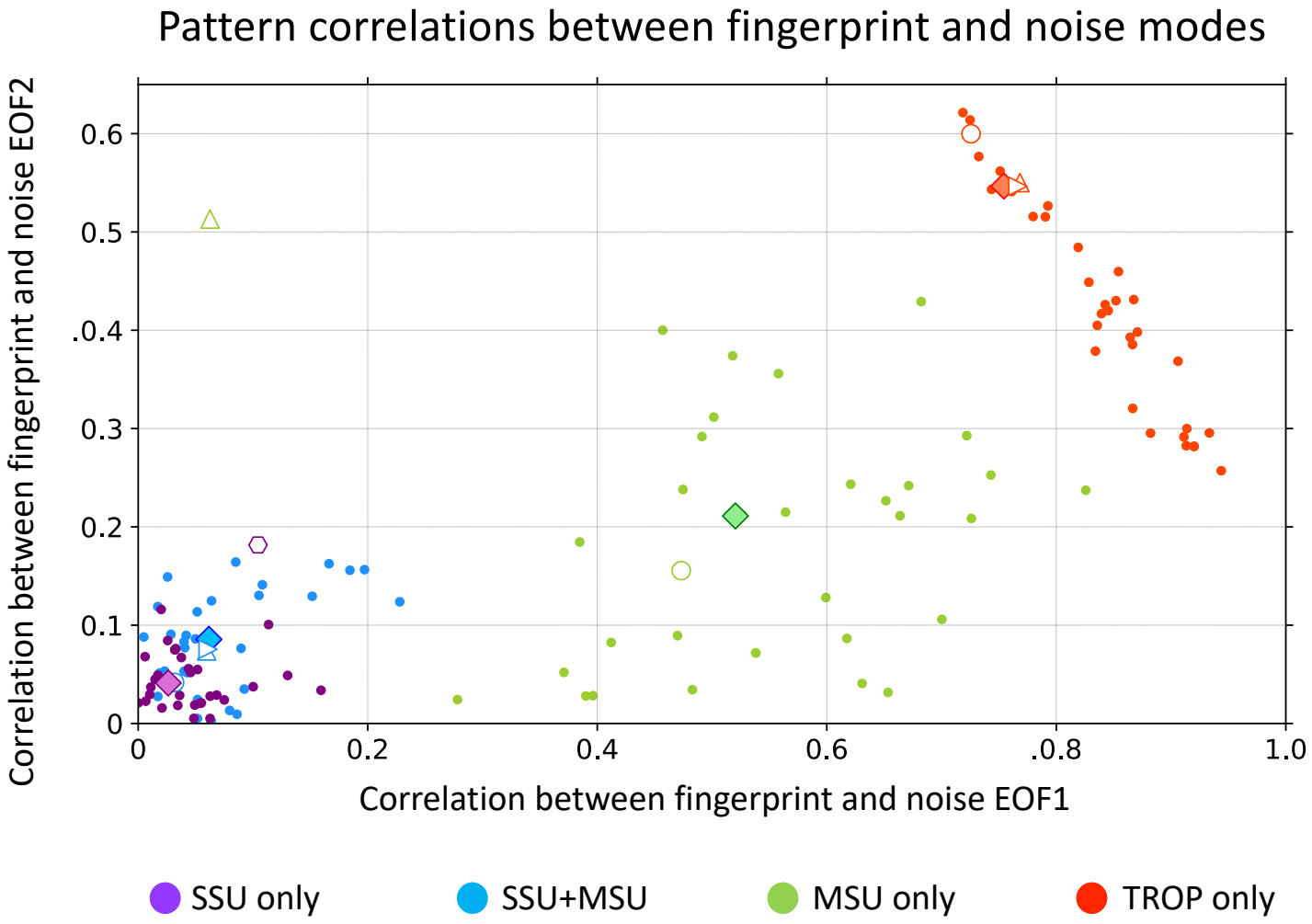
Fingerprinting explained…



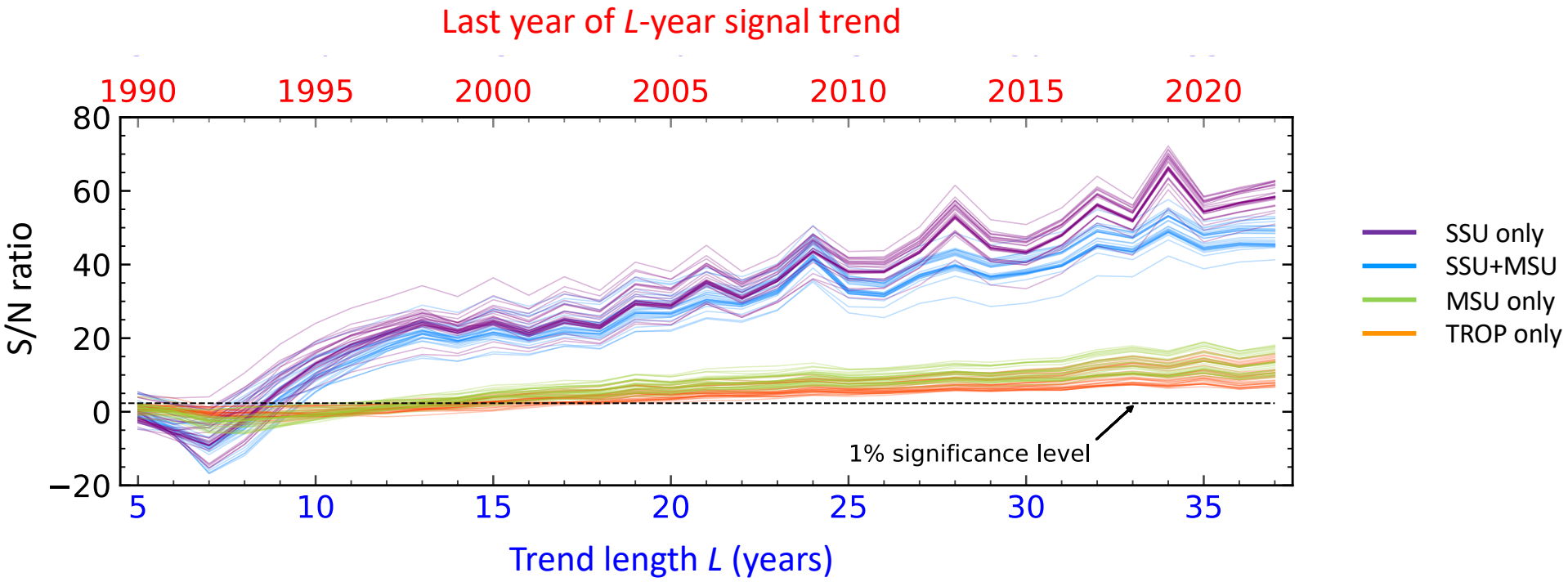
Source: Santer et al., PNAS (2023)

Why do we obtain this result?



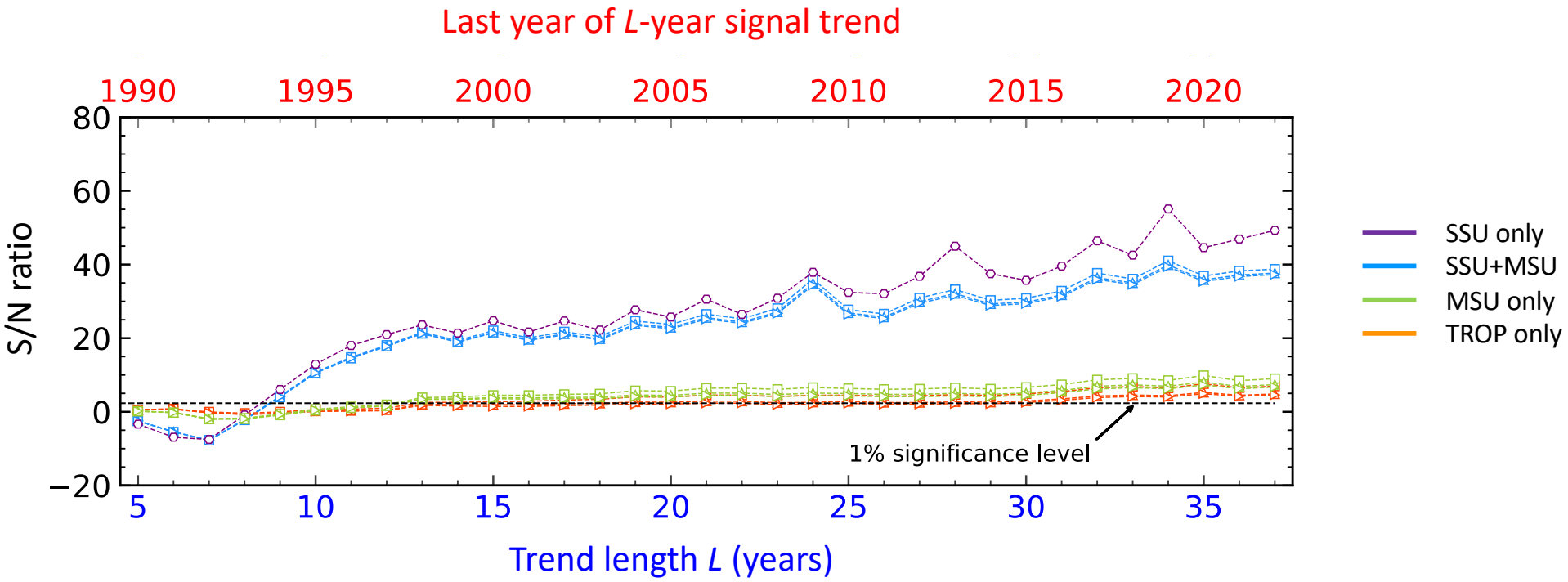

Pattern correlations between fingerprint and noise modes
Correlation between fingerprint and noise EOF2
0.6
0.5
.0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
.0.8
1.0
Correlation between fingerprint and noise EOF1
SSU only
SSU+MSU
MSU only
TROP only

Signal-to-noise in different atmospheric regions: Searching in models



Source: Santer et al., PNAS (2023)

Signal-to-noise in different atmospheric regions: Searching in satellite data



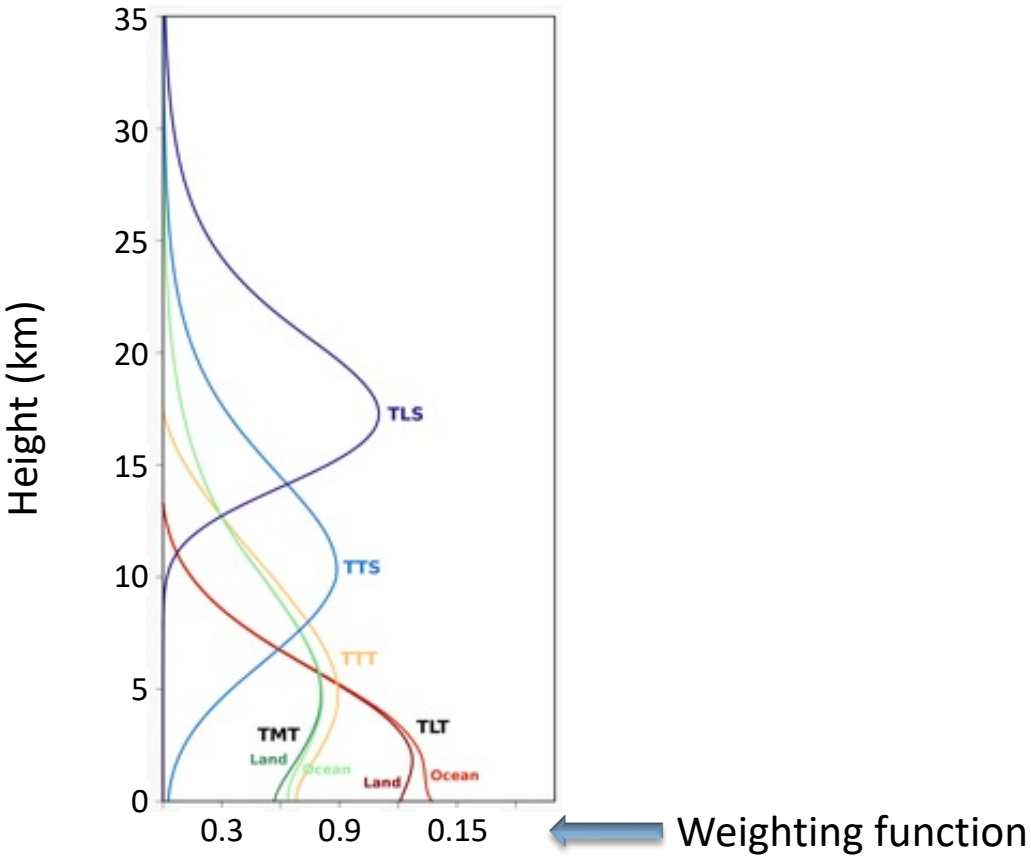
Source: Santer et al., PNAS (2023)

Conclusions

- Tropospheric warming and lower stratospheric cooling has long been recognized as a key fingerprint of human effects on climate
- This fingerprint neglected information from the mid- to upper stratosphere ($S_{25\text{-}50}$)
- Including $S_{25\text{-}50}$ temperature information improves the detectability of a human fingerprint by a factor of five:
  - The $S_{25\text{-}50}$ layer samples the large cooling signal from human-caused CO_2 increases, has low natural variability, and is spatially distinct from patterns of natural variability in $S_{25\text{-}50}$
- It is now virtually impossible for natural causes to explain satellite-measured trends in the thermal structure of Earth's atmosphere

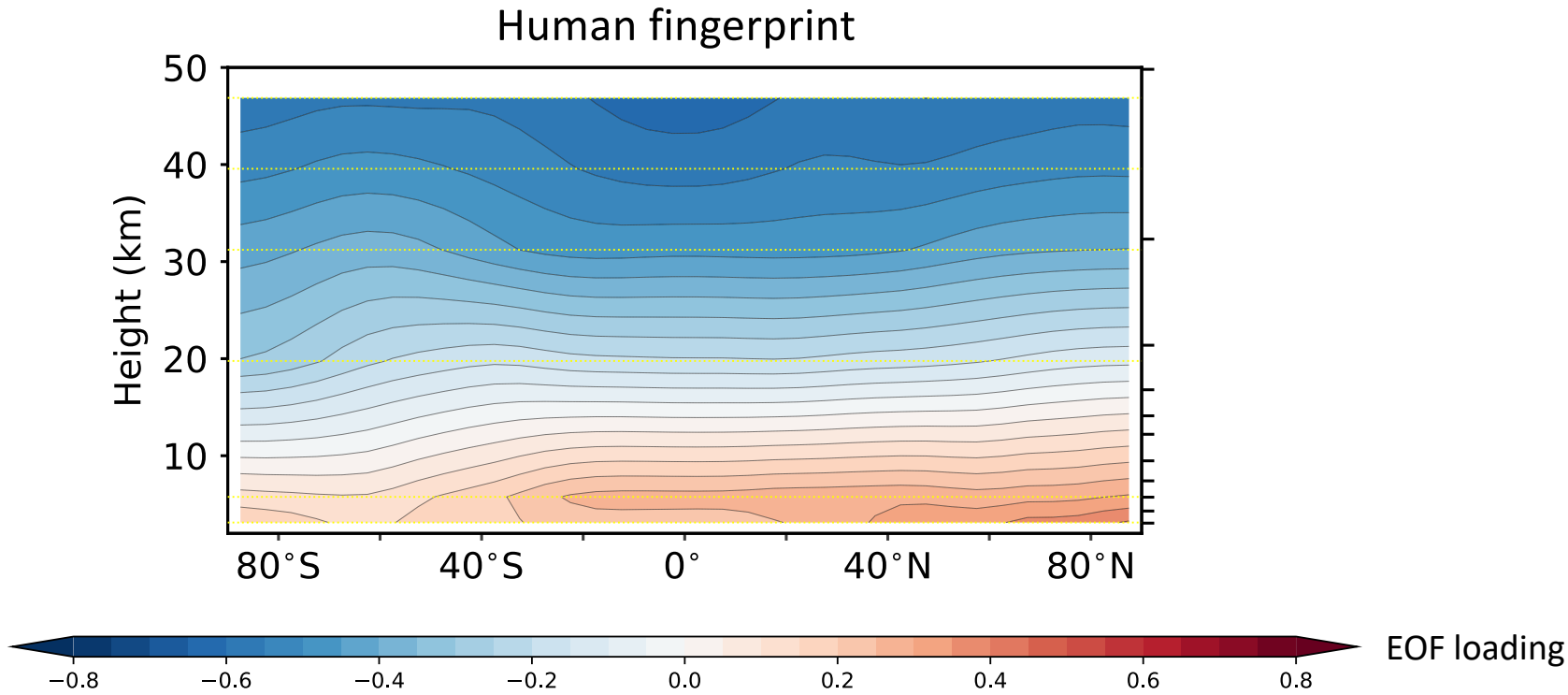
- EXTRA SLIDES

Atmospheric layers of interest in this talk



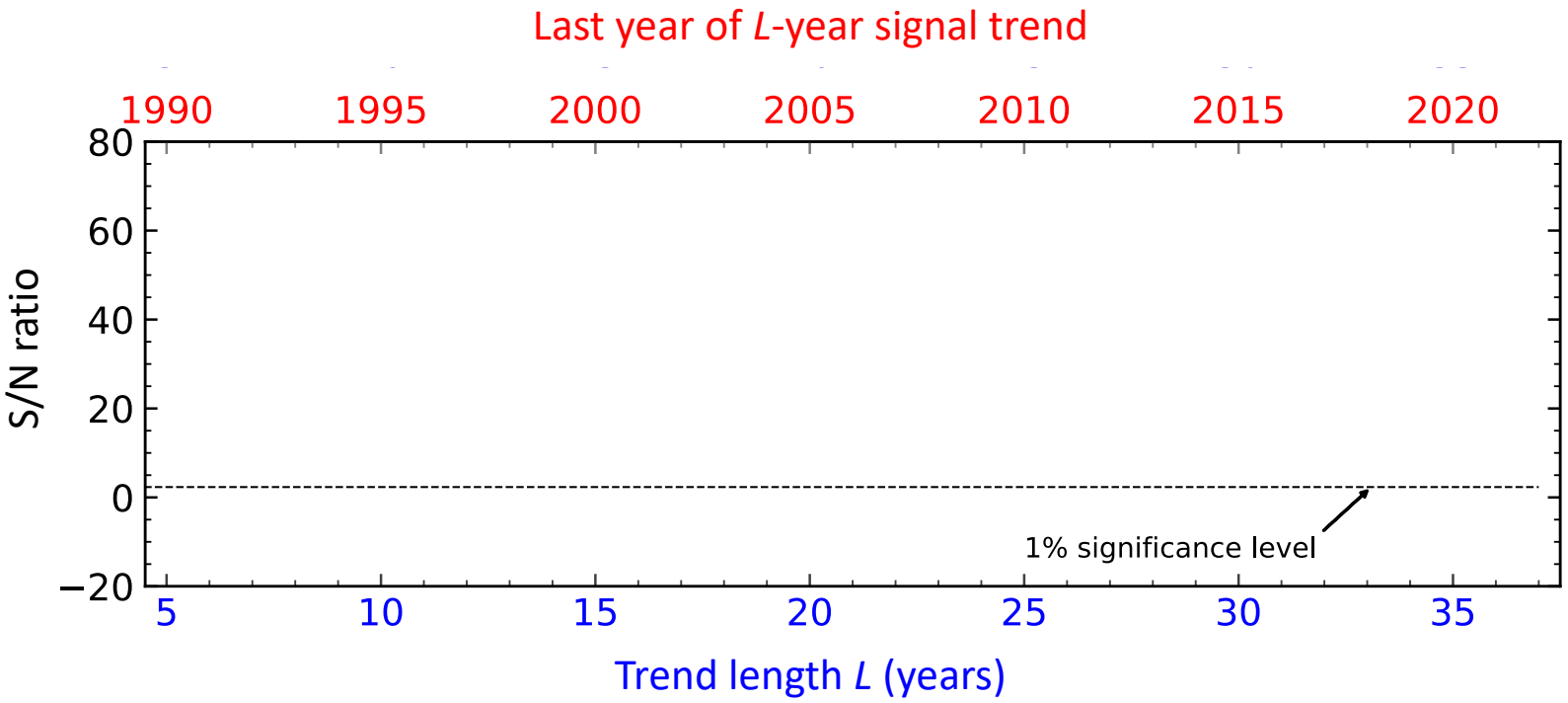
Source: ftp://ftp.ssmi.com/msu/weighting_functions

We search for a human fingerprint in satellite data and in model historical runs – and on multiple timescales



Source: Santer et al., PNAS (2023)

Signal-to-noise in different atmospheric regions: Searching in models



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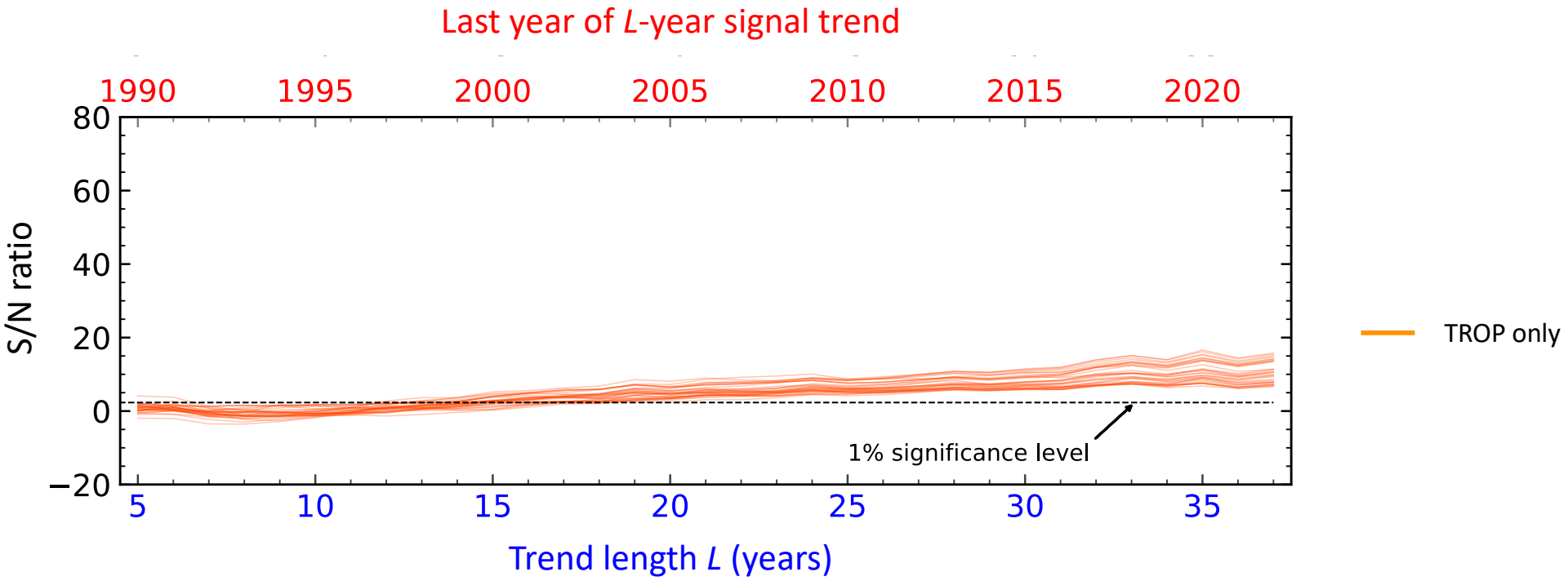
Signal-to-noise in different atmospheric regions: Searching in models



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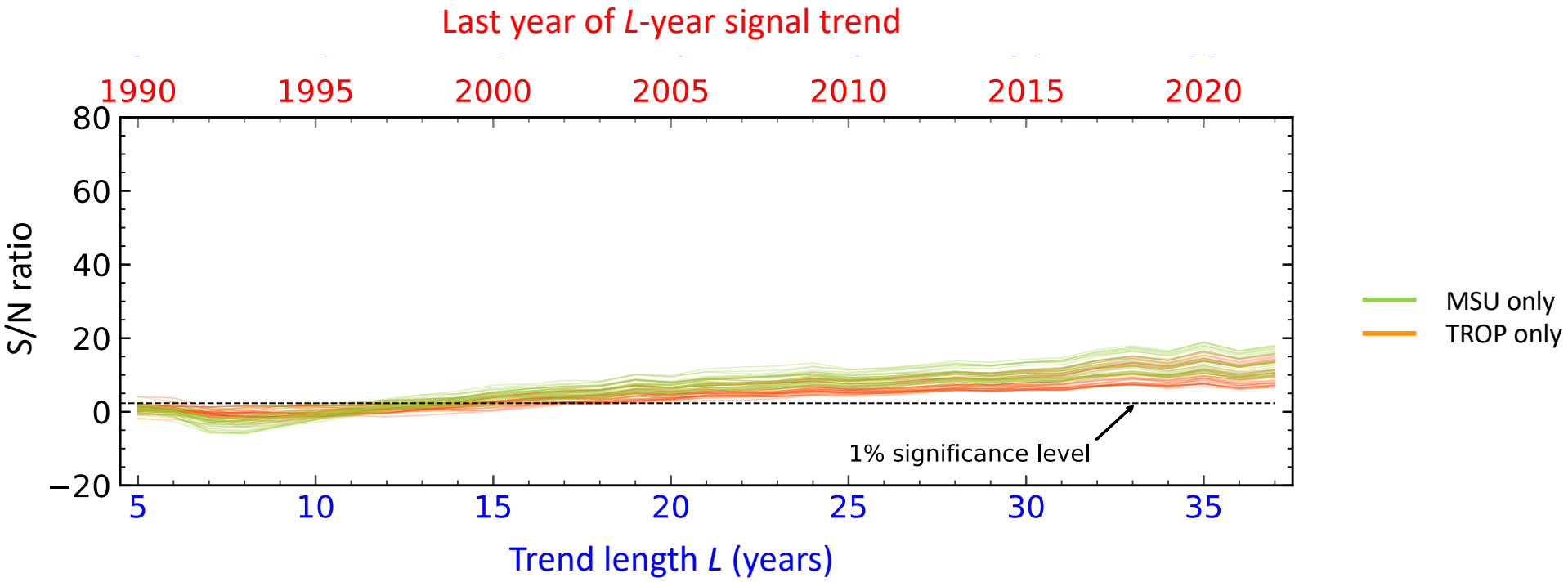
Signal-to-noise in different atmospheric regions: Searching in models



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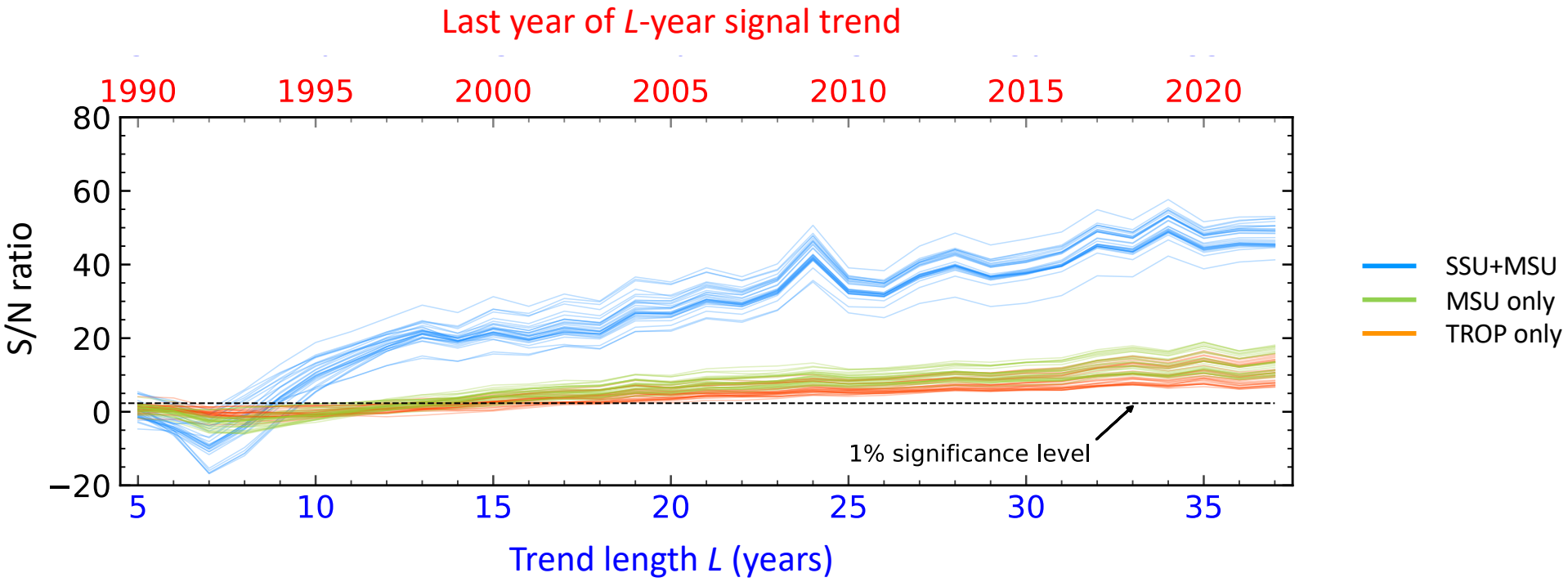

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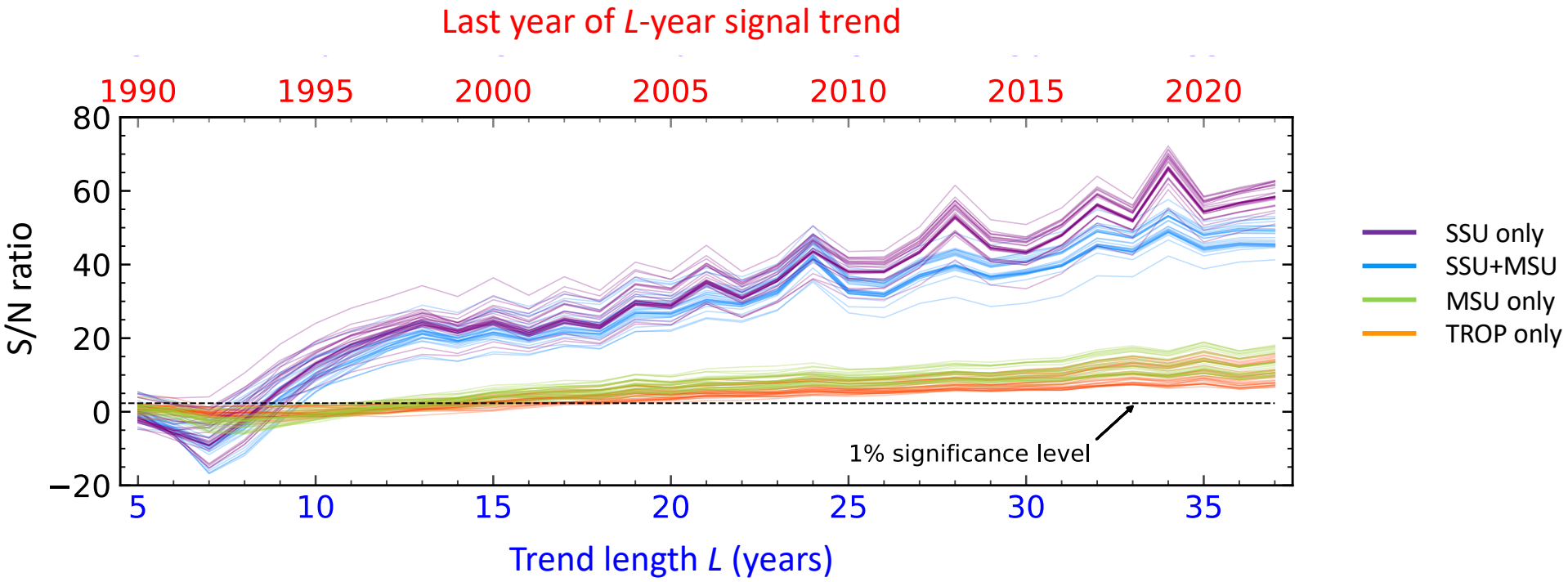
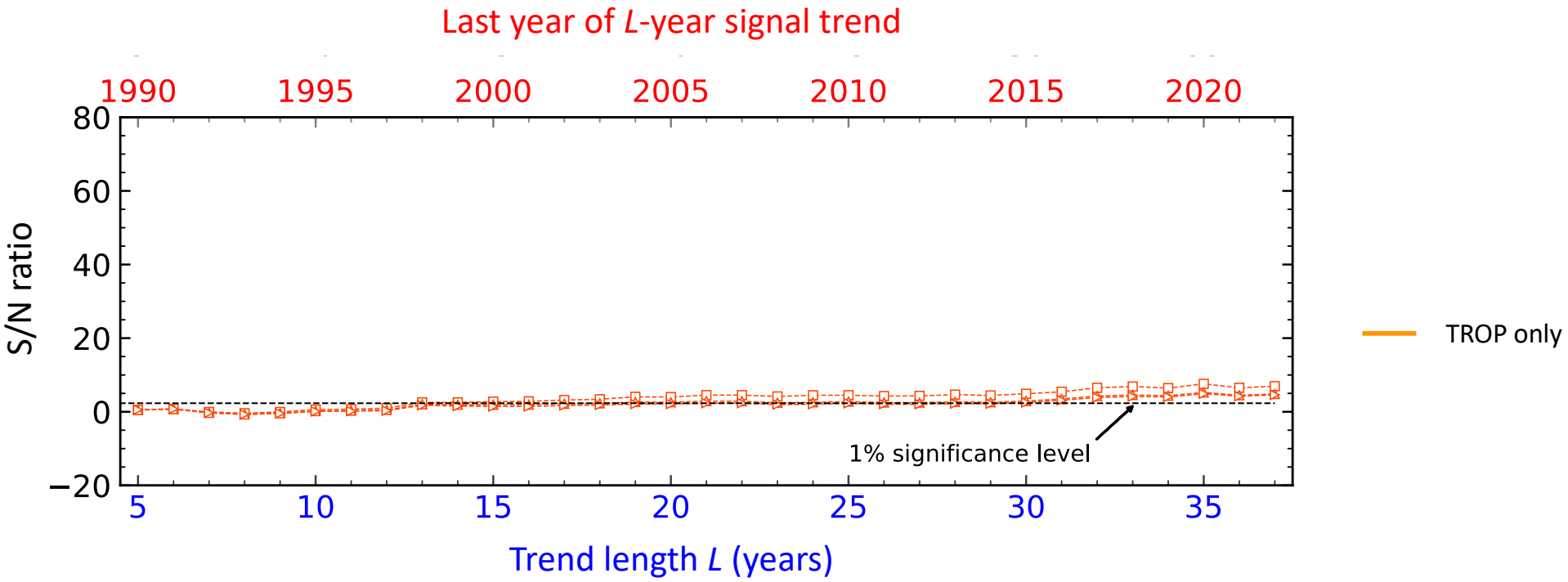
Signal-to-noise in different atmospheric regions: Searching in models



Source: Santer et al., PNAS (2023)

Signal-to-noise in different atmospheric regions: Searching in satellite data



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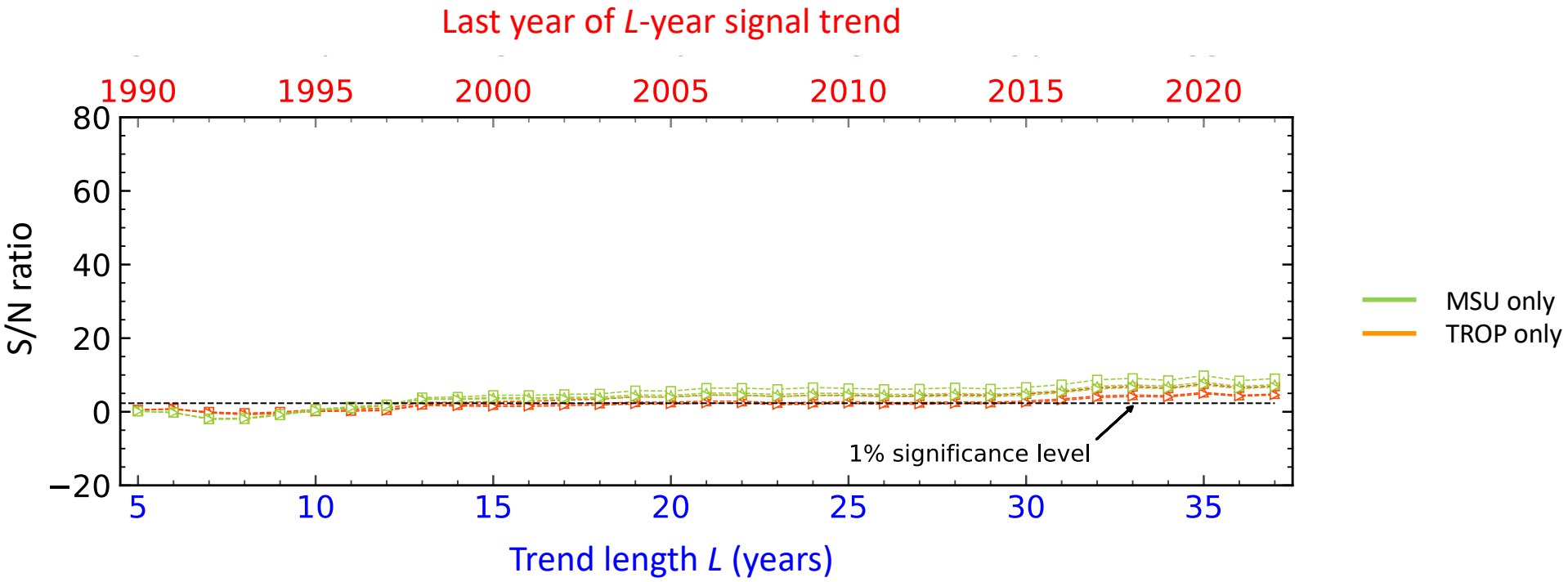
Signal-to-noise in different atmospheric regions: Searching in satellite data



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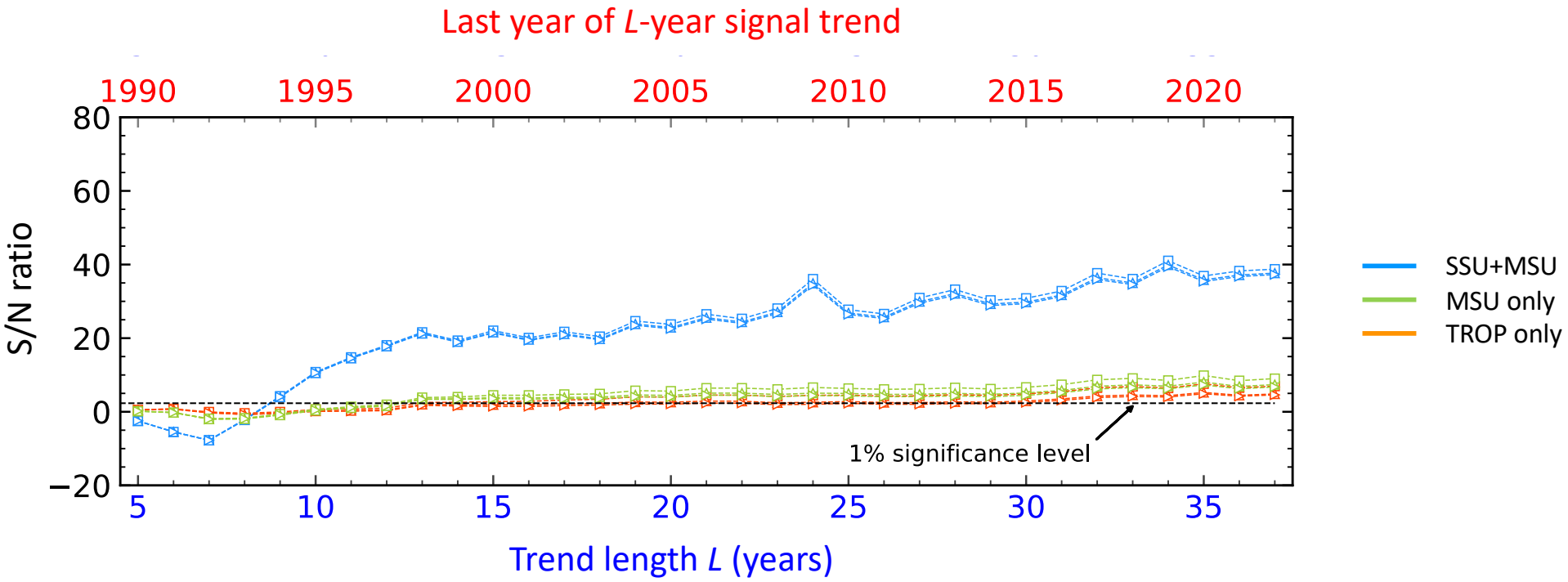
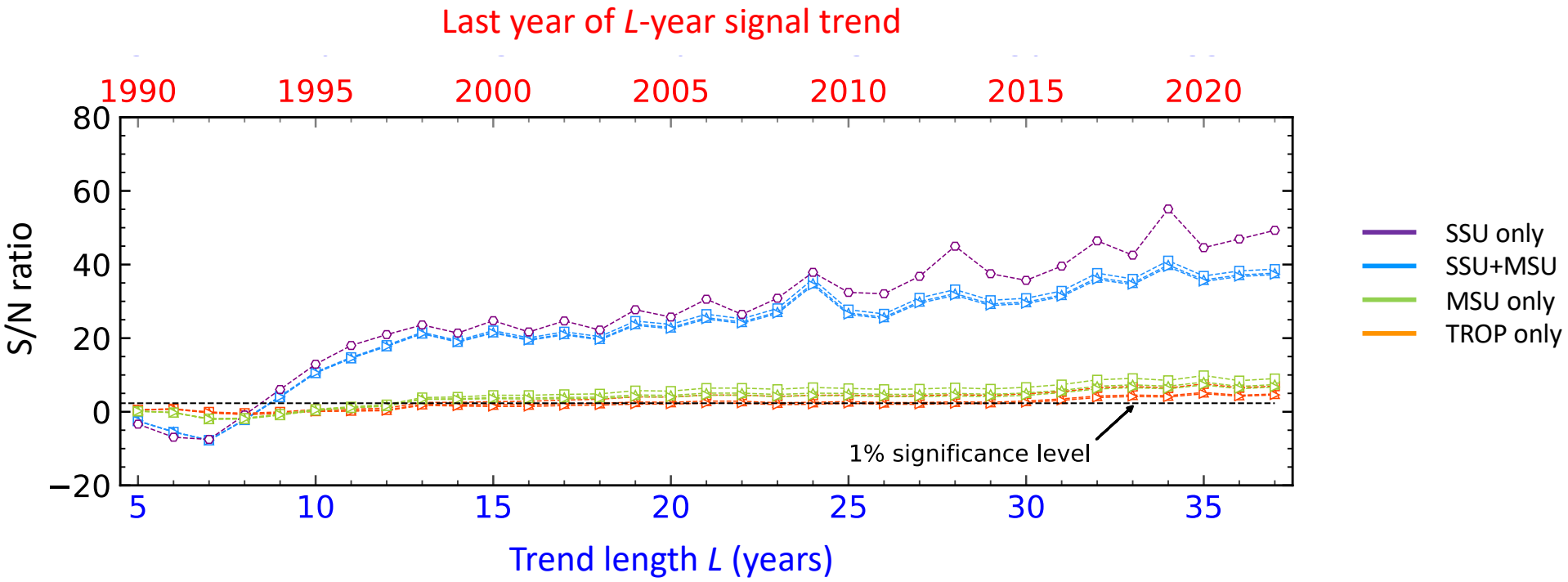


Source: Santer et al., PNAS (2023)

Signal-to-noise in different atmospheric regions: Searching in satellite data



Source: Santer et al., PNAS (2023)