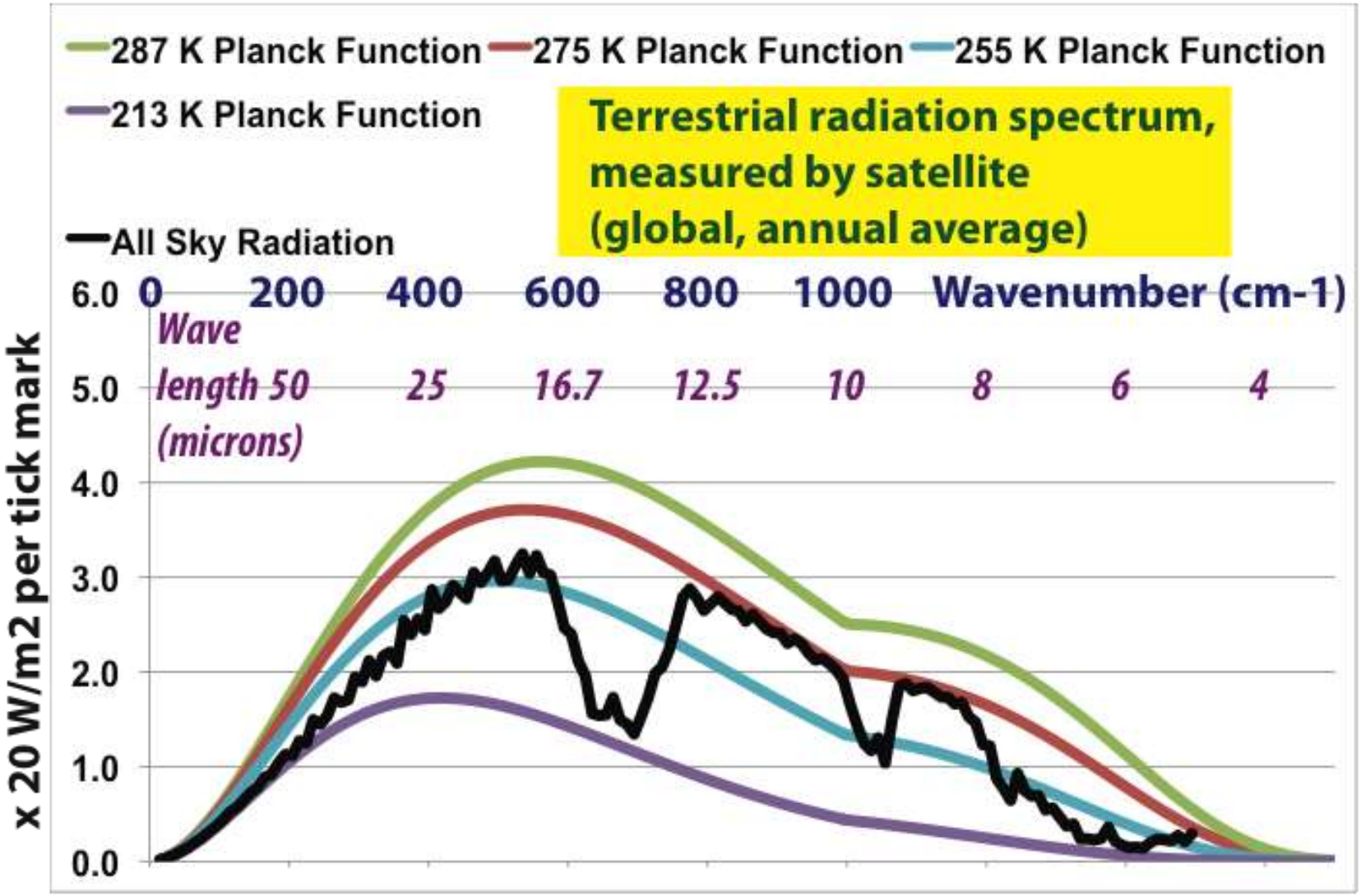
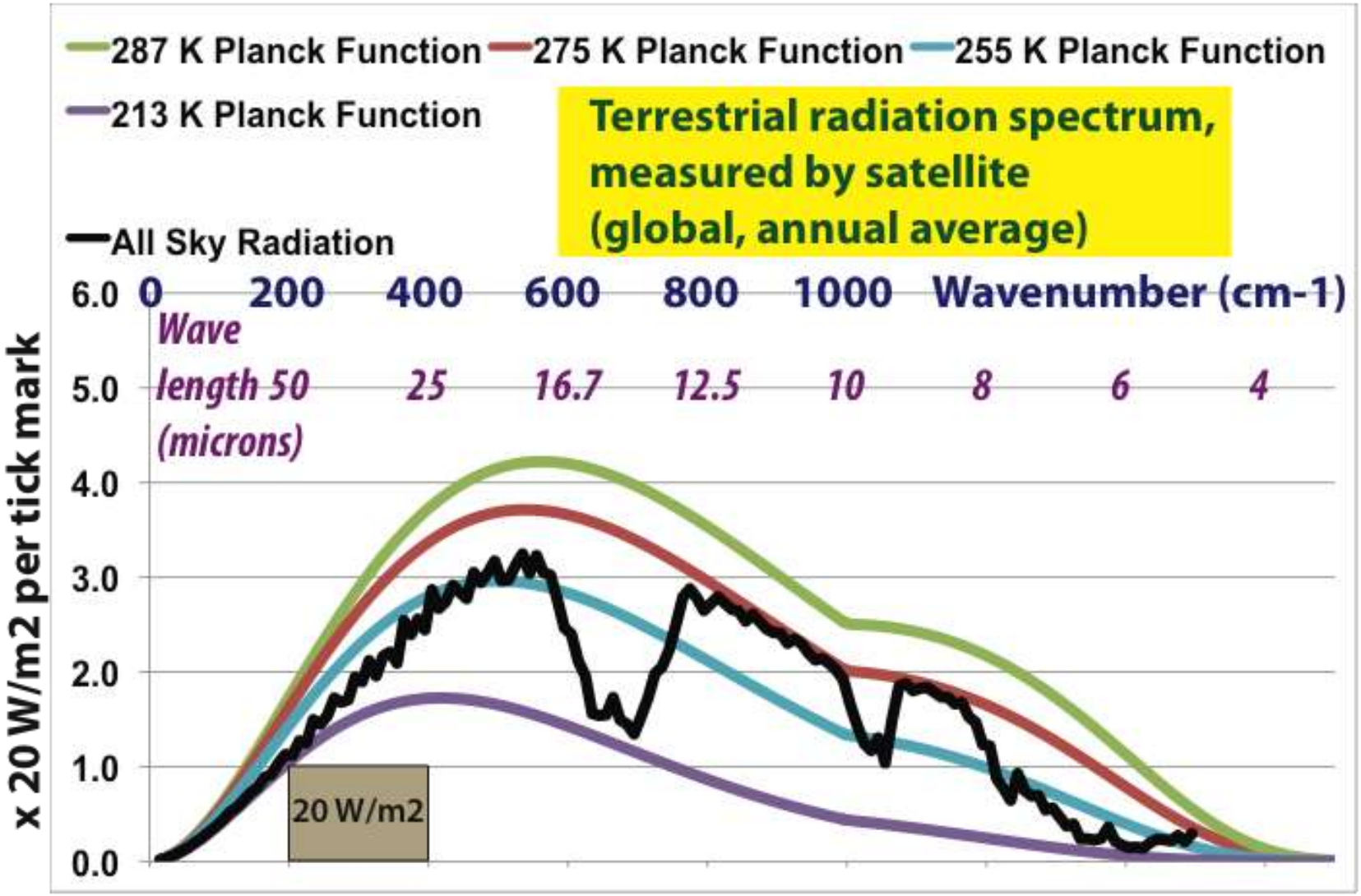
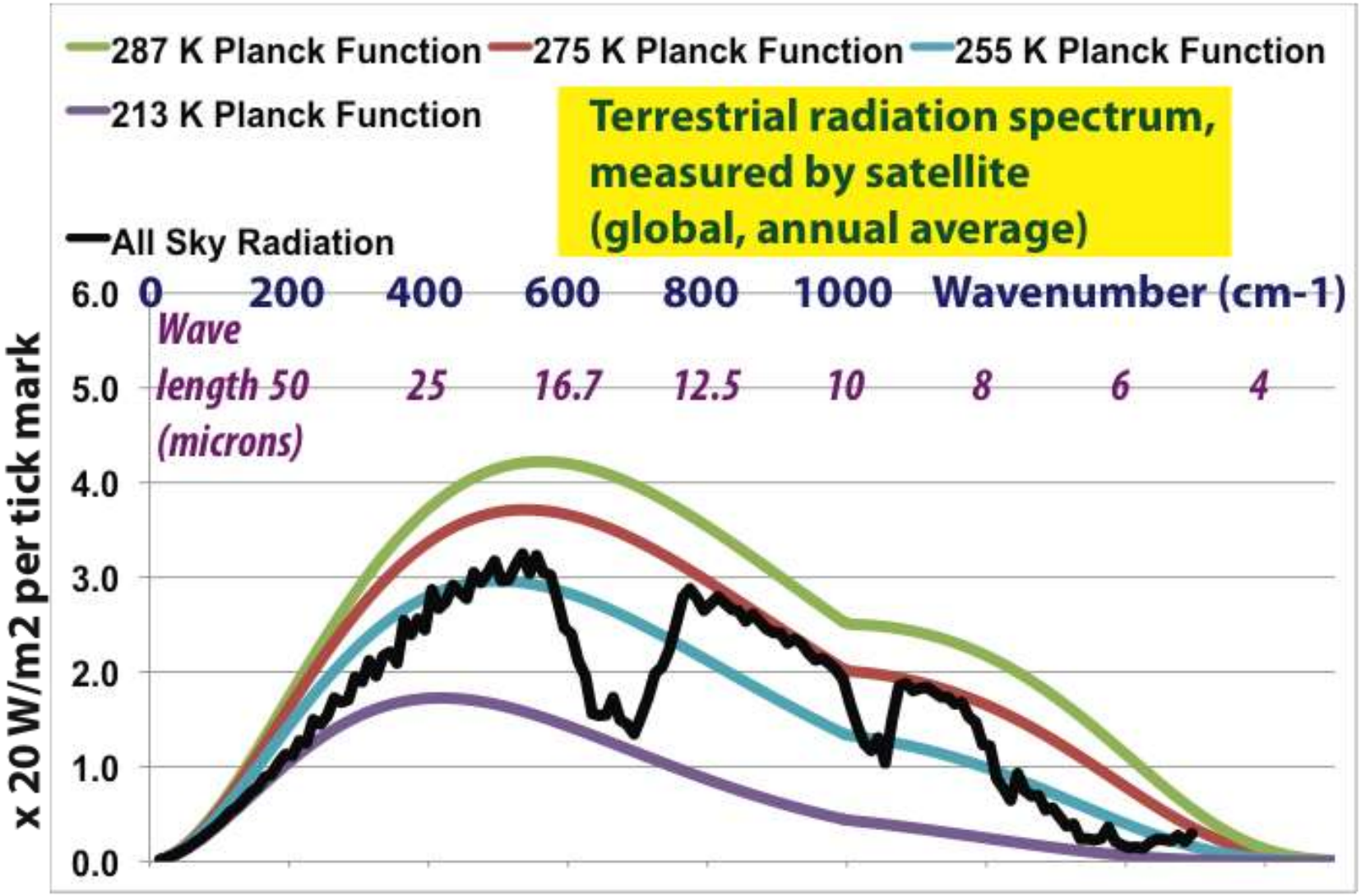
The Essential Story of Climate Change

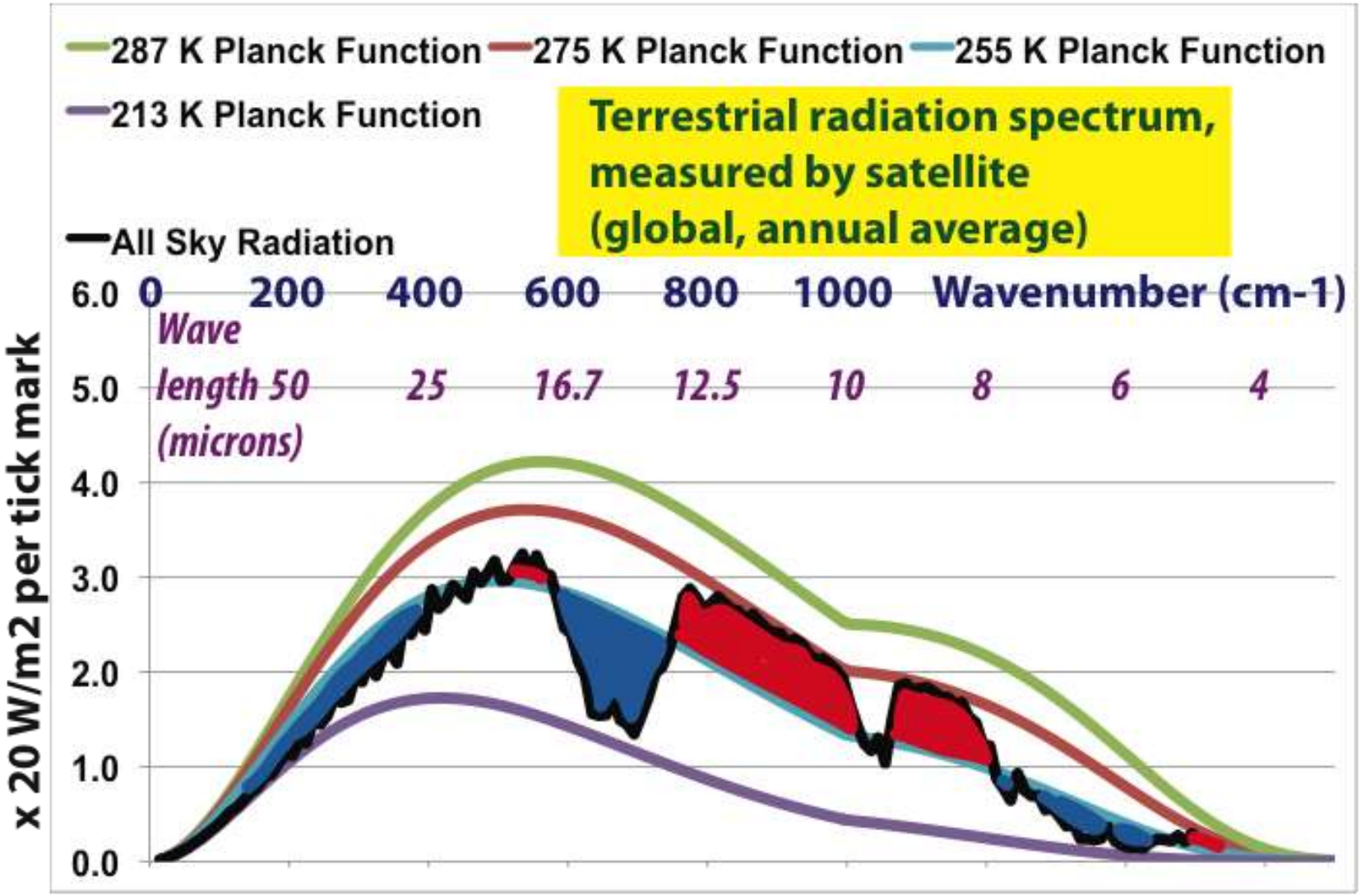
John W. Nielsen-Gammon

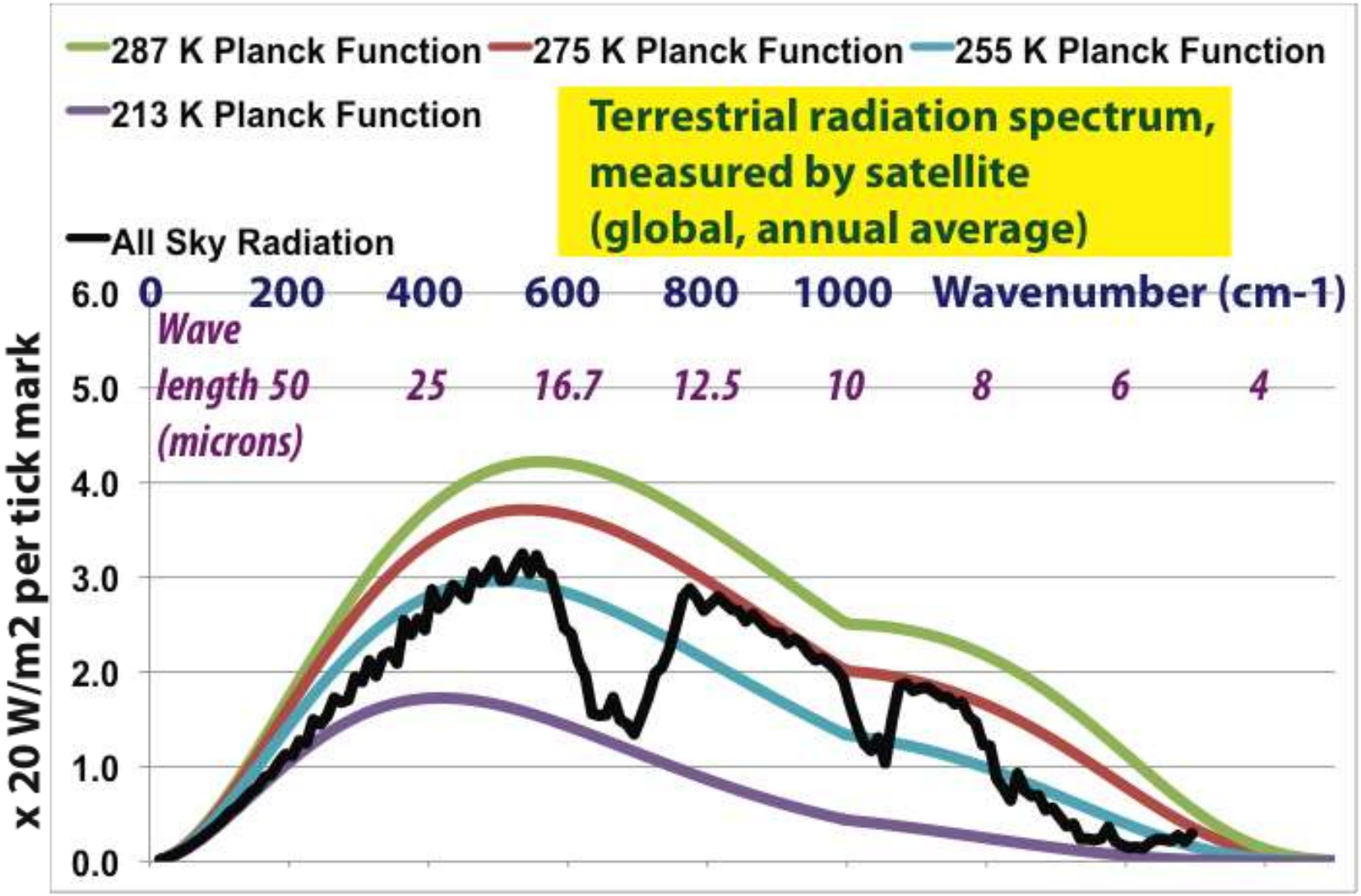
Texas A&M University

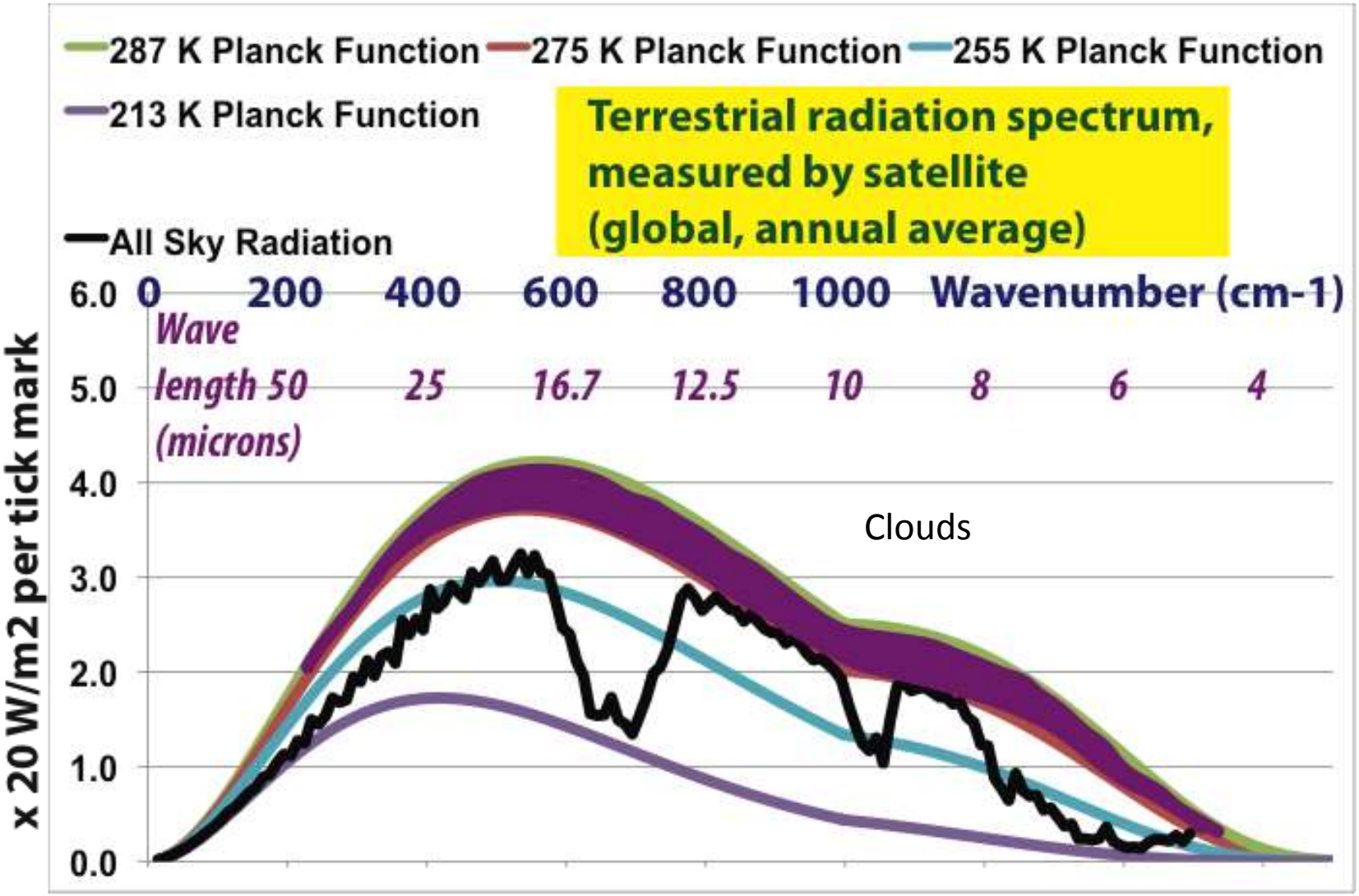

287 K Planck Function
275 K Planck Function
255 K Planck Function
213 K Planck Function
All Sky Radiation
Terrestrial radiation spectrum, measured by satellite (global, annual average)
x 20 W/m2 per tick mark
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
200
400
600
800
1000
Wavenumber (cm-1)
Wave length (microns)
50
25
16.7
12.5
10
8
6
4

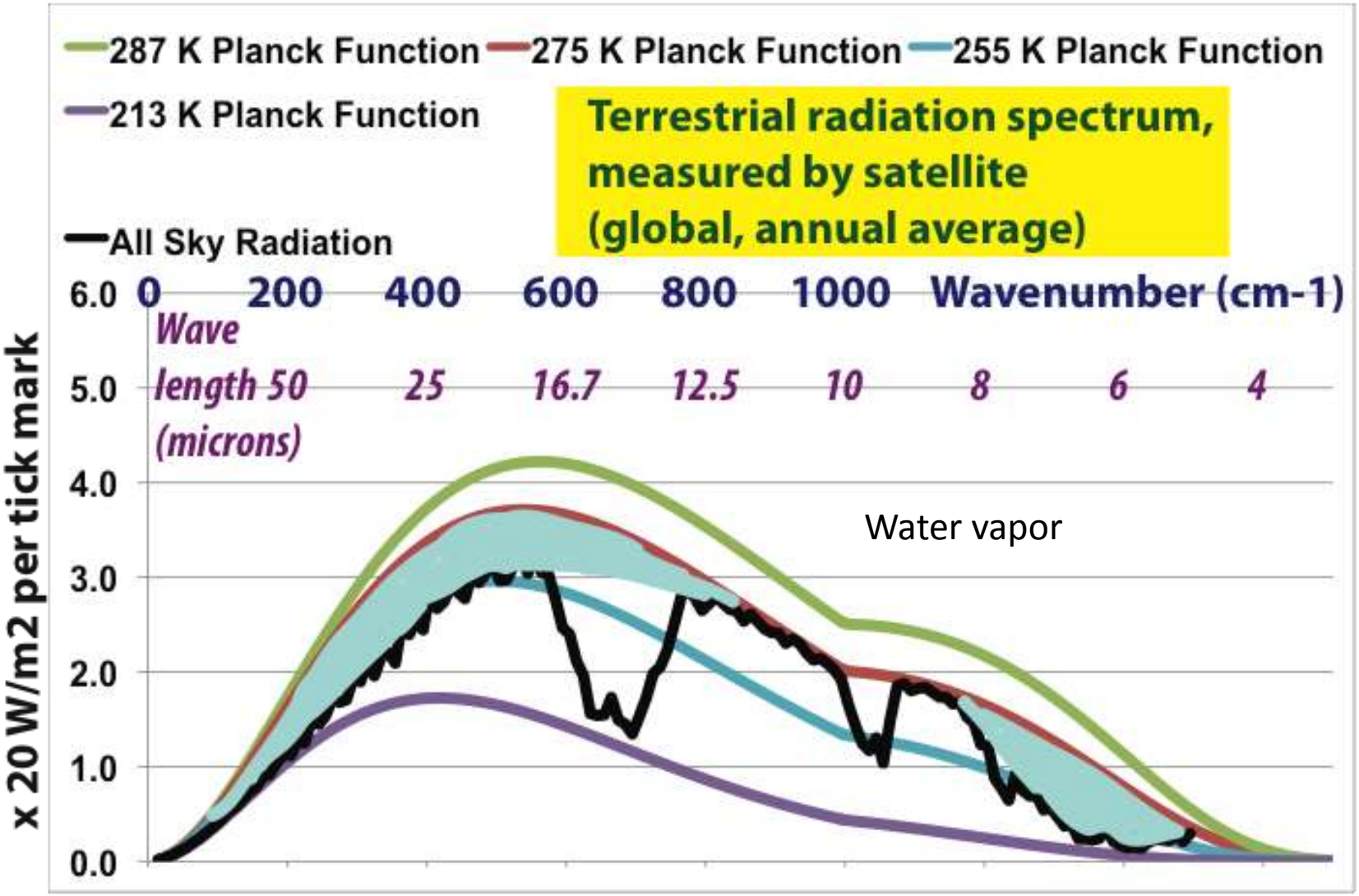

287 K Planck Function
275 K Planck Function
255 K Planck Function
213 K Planck Function
All Sky Radiation
Terrestrial radiation spectrum, measured by satellite (global, annual average)
x 20 W/m2 per tick mark
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
200
400
600
800
1000
Wavenumber (cm-1)
Wave length (microns)
50
25
16.7
12.5
10
8
6
4
20 W/m2

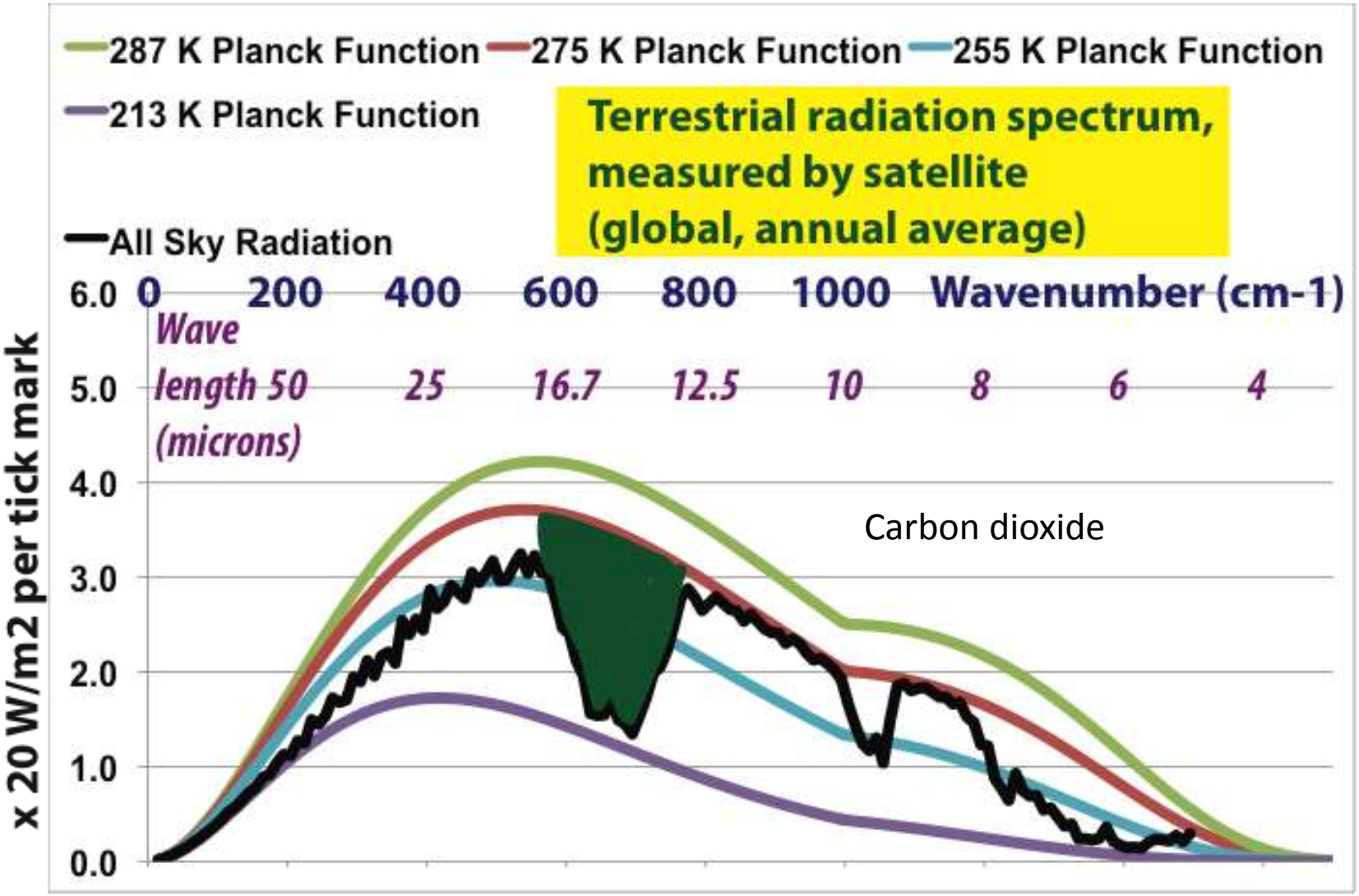

287 K Planck Function
275 K Planck Function
255 K Planck Function
213 K Planck Function
All Sky Radiation
Terrestrial radiation spectrum, measured by satellite (global, annual average)
x 20 W/m2 per tick mark
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
200
400
600
800
1000
Wavenumber (cm-1)
Wave length (microns)
50
25
16.7
12.5
10
8
6
4

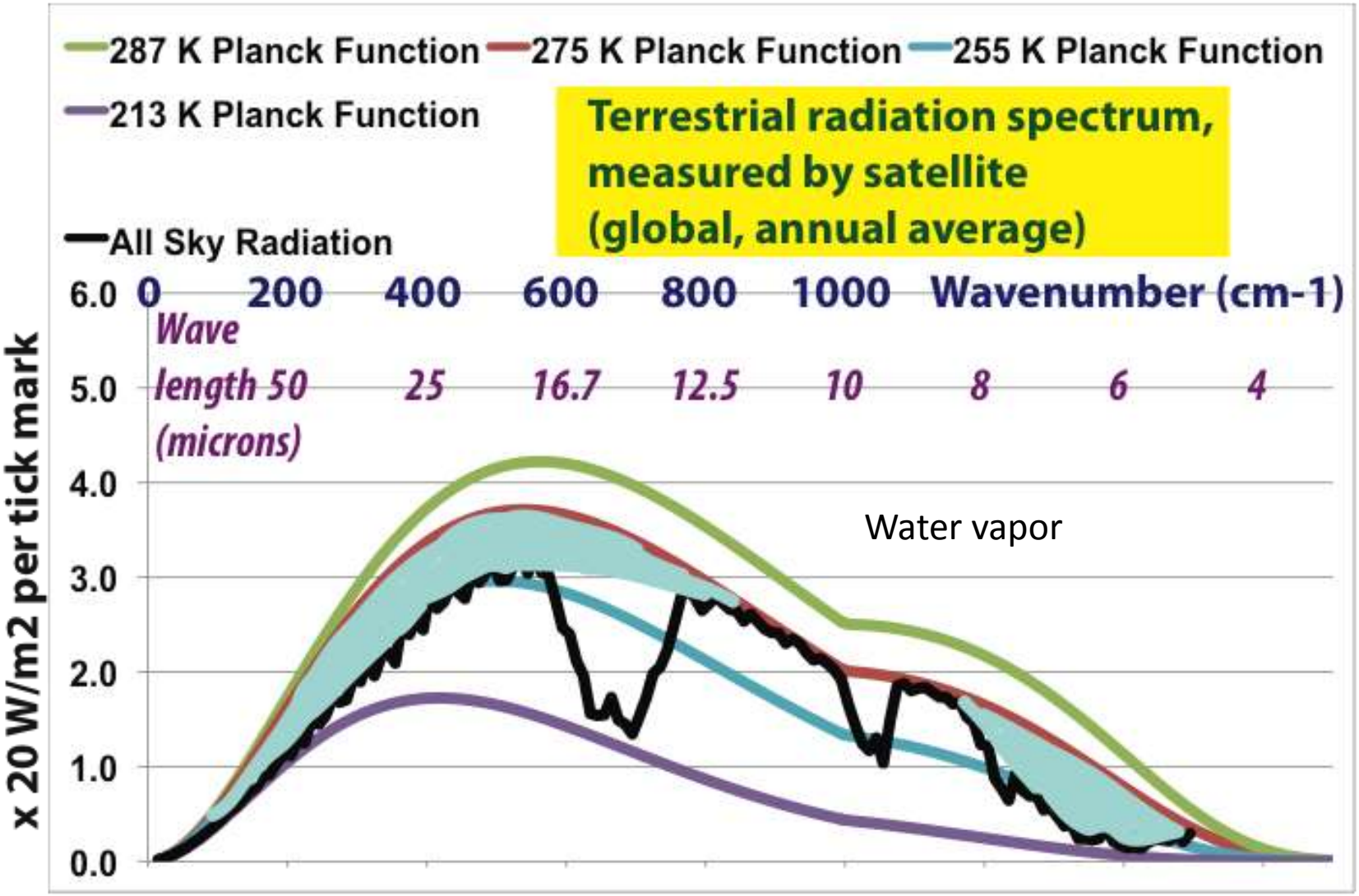

287 K Planck Function
275 K Planck Function
255 K Planck Function
213 K Planck Function
All Sky Radiation
Terrestrial radiation spectrum, measured by satellite (global, annual average)
x 20 W/m2 per tick mark
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
200
400
600
800
1000
Wavenumber (cm-1)
Wave length (microns)
50
25
16.7
12.5
10
8
6
4

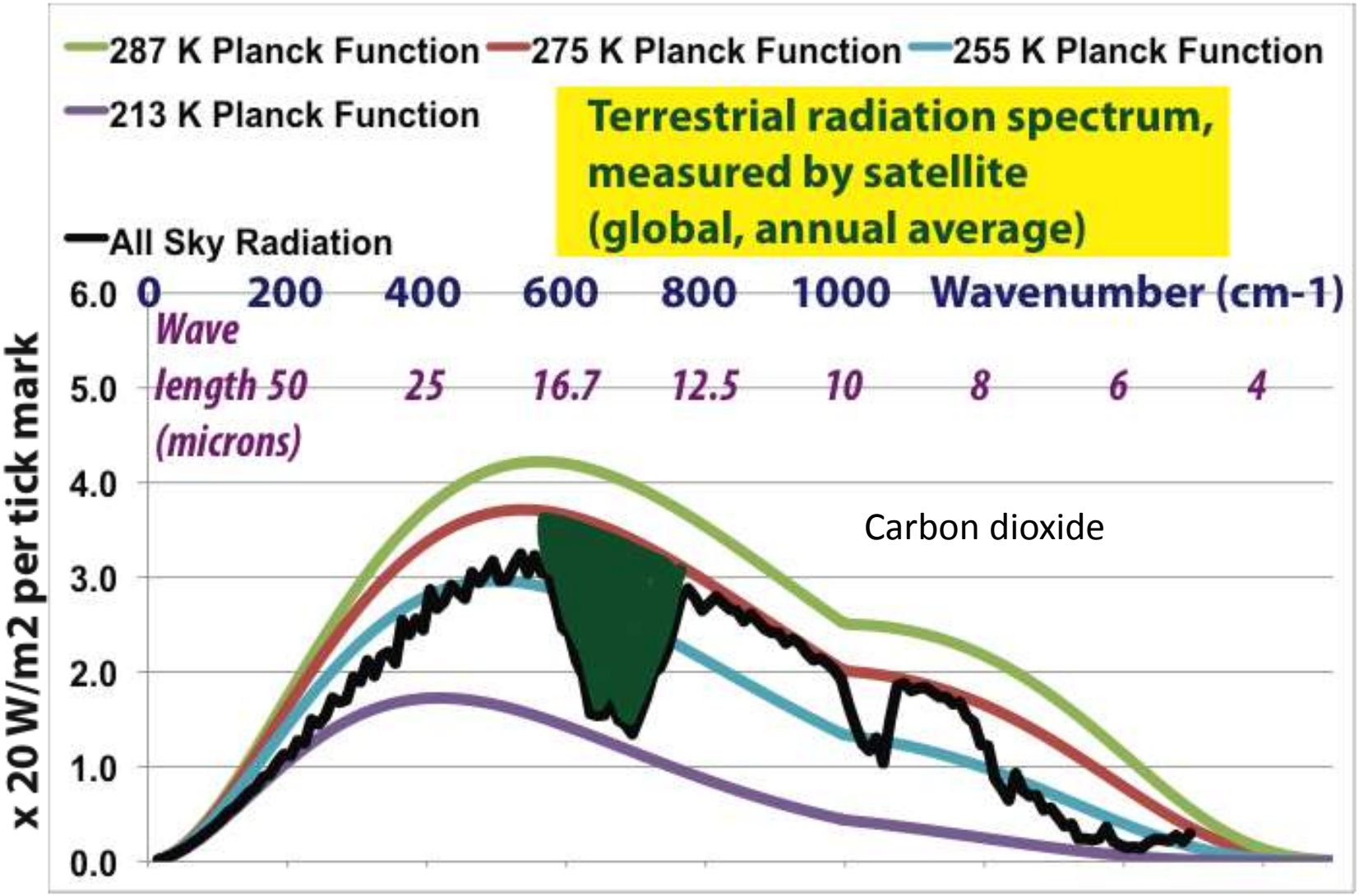

287 K Planck Function
275 K Planck Function
255 K Planck Function
213 K Planck Function
All Sky Radiation
Terrestrial radiation spectrum, measured by satellite (global, annual average)
x 20 W/m2 per tick mark
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
200
400
600
800
1000
Wavenumber (cm-1)
Wave length (microns)
50
25
16.7
12.5
10
8
6
4

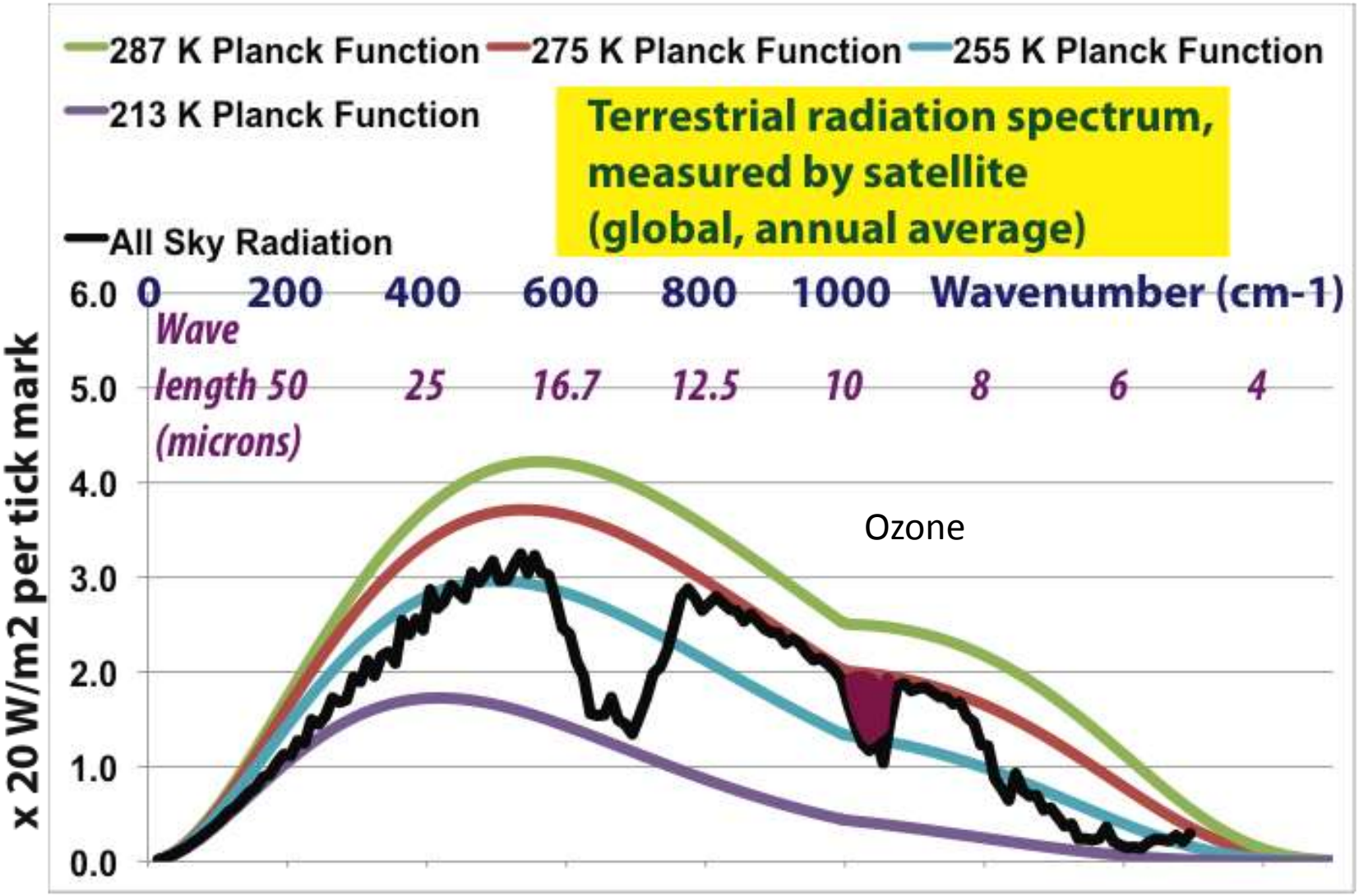

287 K Planck Function
275 K Planck Function
255 K Planck Function
213 K Planck Function
Terrestrial radiation spectrum, measured by satellite (global, annual average)
All Sky Radiation
6.0
5.0
4.0
3.0
2.0
1.0
0.0
x 20 W/m2 per tick mark
0
200
400
600
800
1000
Wavenumber (cm-1)
Wave length (microns)
50
25
16.7
12.5
10
8
6
4
Clouds

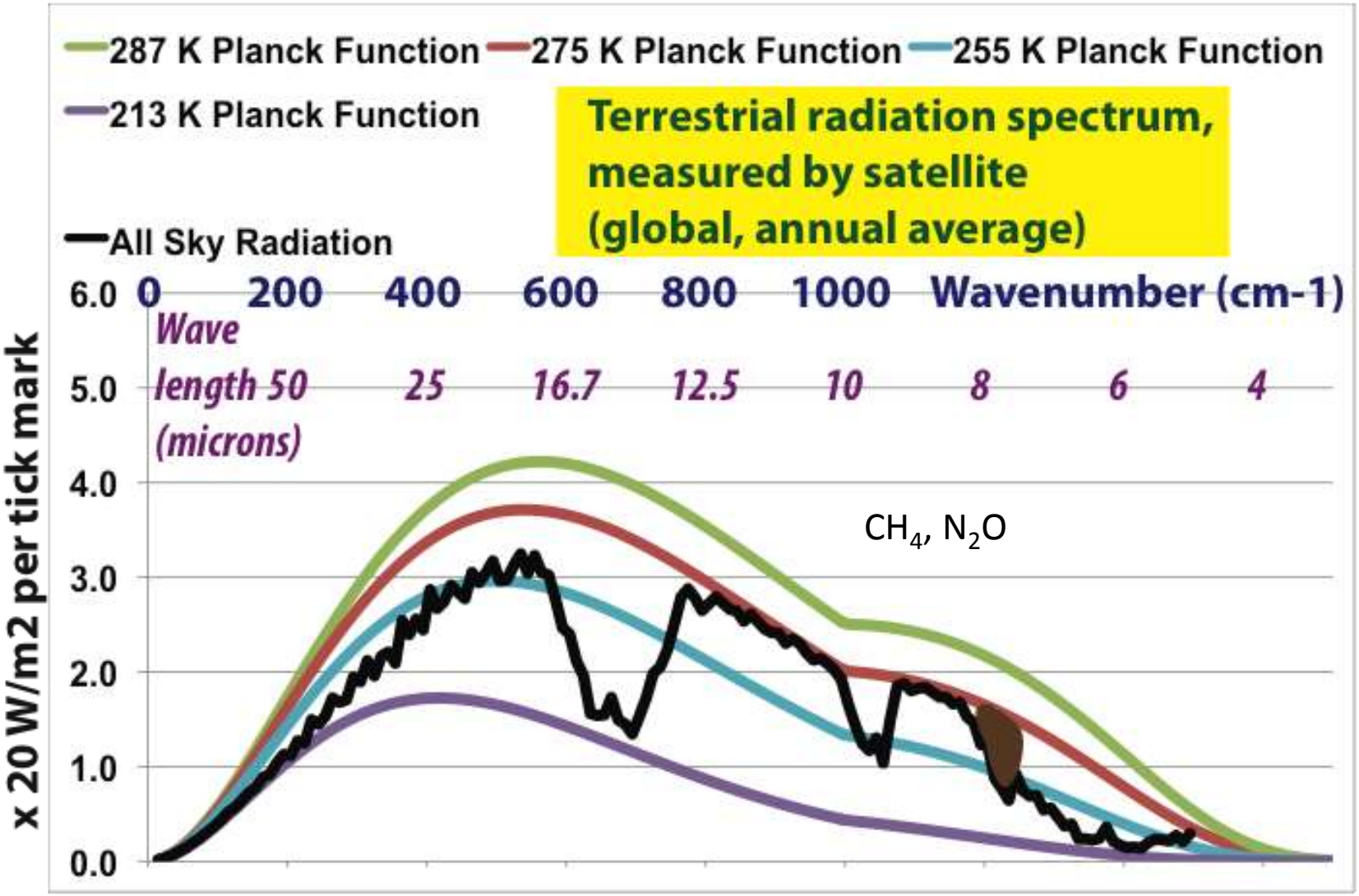

287 K Planck Function
275 K Planck Function
255 K Planck Function
213 K Planck Function
Terrestrial radiation spectrum, measured by satellite (global, annual average)
All Sky Radiation
x 20 W/m2 per tick mark
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
200
400
600
800
1000
Wavenumber (cm-1)
Wave length (microns)
50
25
16.7
12.5
10
8
6
4
Water vapor


287 K Planck Function
275 K Planck Function
255 K Planck Function
213 K Planck Function
Terrestrial radiation spectrum, measured by satellite (global, annual average)
All Sky Radiation
x 20 W/m2 per tick mark
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
200
400
600
800
1000
Wavenumber (cm-1)
Wave length (microns)
50
25
16.7
12.5
10
8
6
4
Carbon dioxide


287 K Planck Function
275 K Planck Function
255 K Planck Function
213 K Planck Function
Terrestrial radiation spectrum, measured by satellite (global, annual average)
All Sky Radiation
x 20 W/m2 per tick mark
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
200
400
600
800
1000
Wavenumber (cm-1)
Wave length (microns)
50
25
16.7
12.5
10
8
6
4
Water vapor


287 K Planck Function
275 K Planck Function
255 K Planck Function
213 K Planck Function
Terrestrial radiation spectrum, measured by satellite (global, annual average)
All Sky Radiation
x 20 W/m2 per tick mark
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
200
400
600
800
1000
Wavenumber (cm-1)
Wave length (microns)
50
25
16.7
12.5
10
8
6
4
Carbon dioxide


287 K Planck Function
275 K Planck Function
255 K Planck Function
213 K Planck Function
All Sky Radiation
Terrestrial radiation spectrum, measured by satellite (global, annual average)
x 20 W/m2 per tick mark
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
200
400
600
800
1000
Wavenumber (cm-1)
Wave length (microns)
50
25
16.7
12.5
10
8
6
4
Ozone

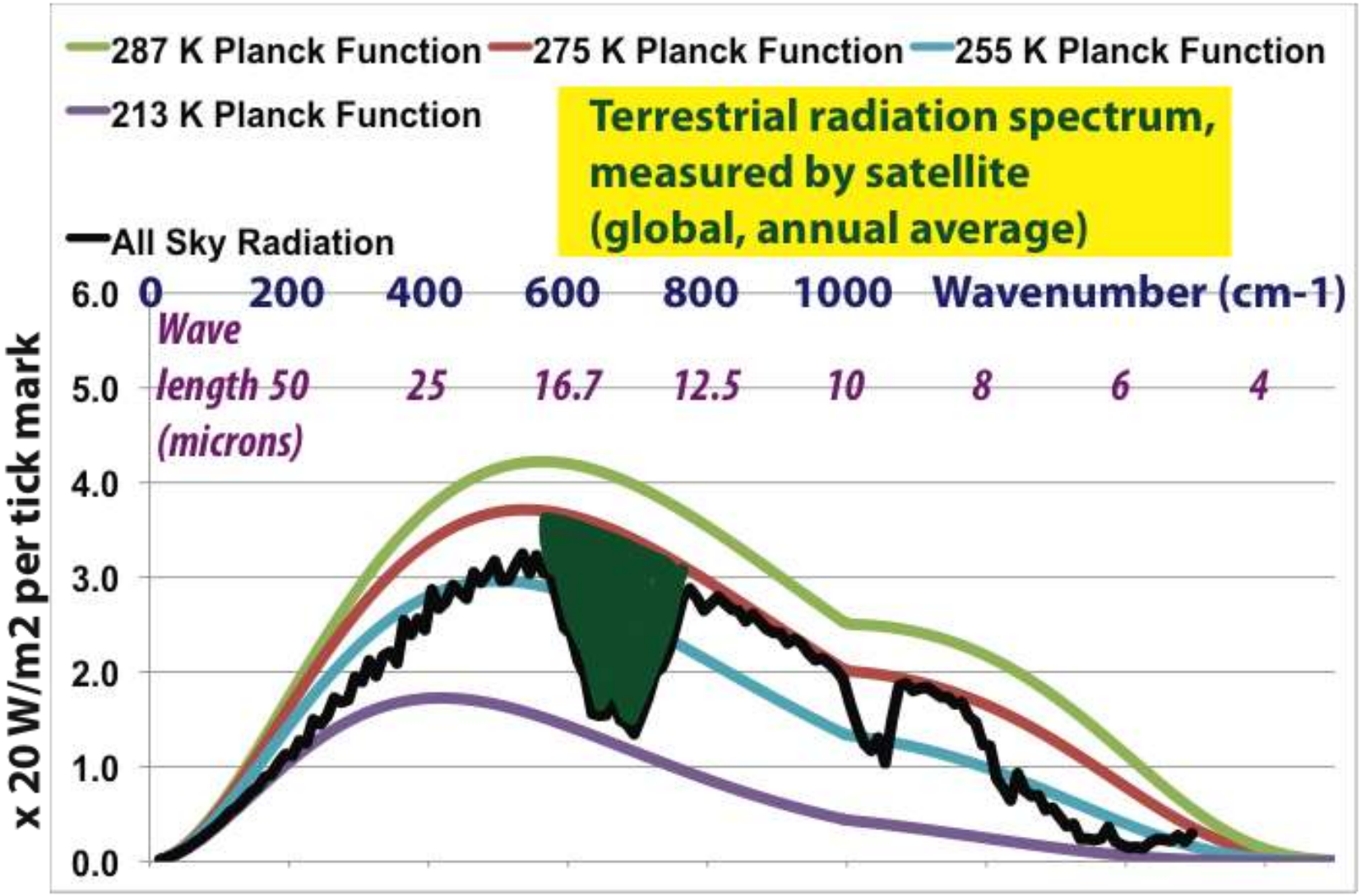

287 K Planck Function
275 K Planck Function
255 K Planck Function
213 K Planck Function
All Sky Radiation
Terrestrial radiation spectrum, measured by satellite (global, annual average)
x 20 W/m2 per tick mark
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
200
400
600
800
1000
Wavenumber (cm-1)
Wave length (microns)
50
25
16.7
12.5
10
8
6
4
CH_4, N_2O

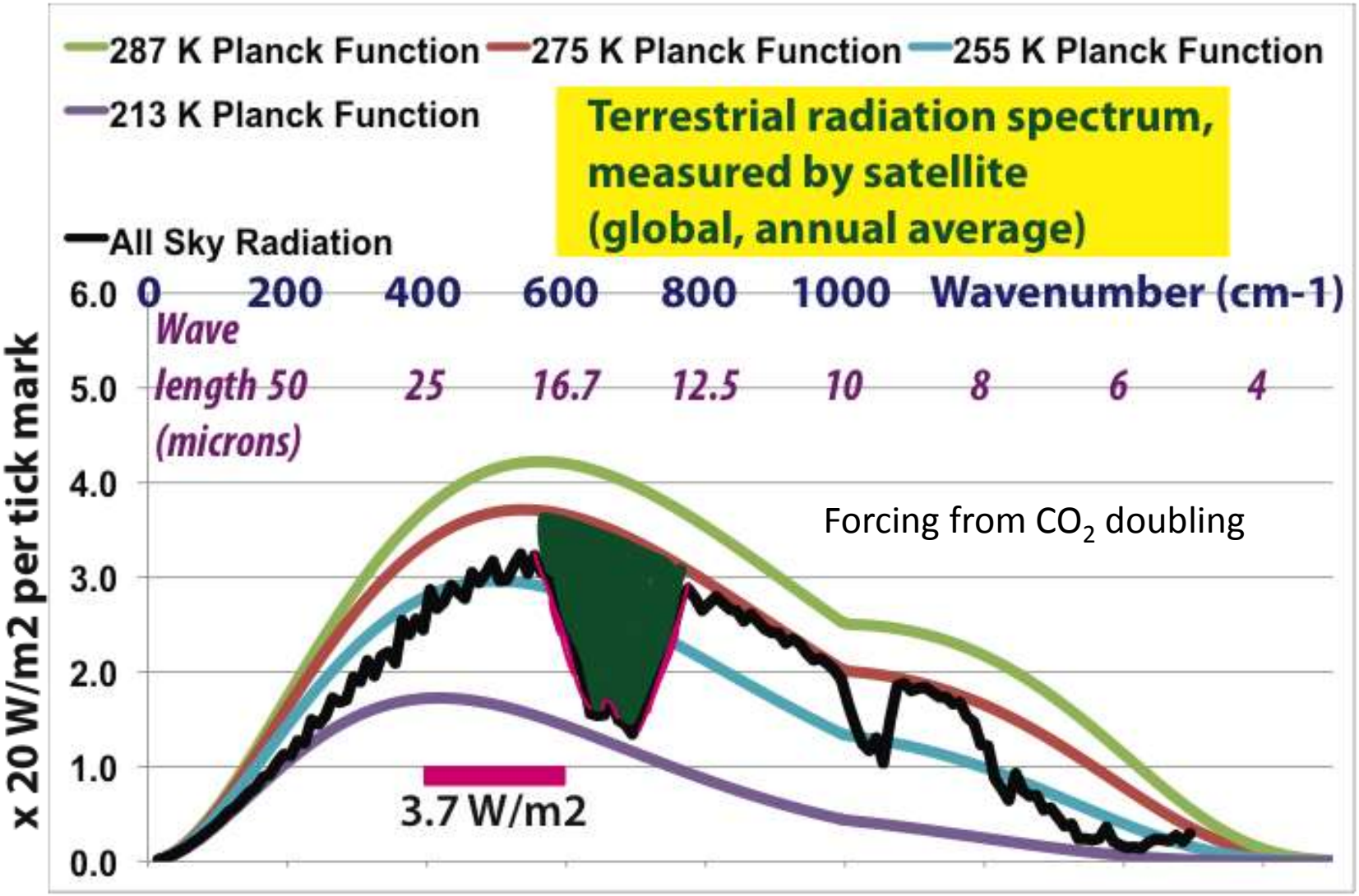
Reducing Earth's energy loss

- Water vapor: ~50%
- Carbon dioxide: ~19%
- Other Tyndall gases: ~7%
- Clouds: ~24%
  - But clouds also reduce Earth's energy absorption

Thermodynamic Coupling

- Earth's surface: net energy gain from space
- Earth's troposphere: net energy loss to space
- If the atmosphere cooled as much as it wants to, it would be unstable
- Heat transfer from Earth to troposphere and within troposphere keeps it near stability threshold


287 K Planck Function
275 K Planck Function
255 K Planck Function
213 K Planck Function
All Sky Radiation
Terrestrial radiation spectrum, measured by satellite (global, annual average)
x 20 W/m2 per tick mark
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
200
400
600
800
1000
Wavenumber (cm-1)
Wave length (microns)
50
25
16.7
12.5
10
8
6
4

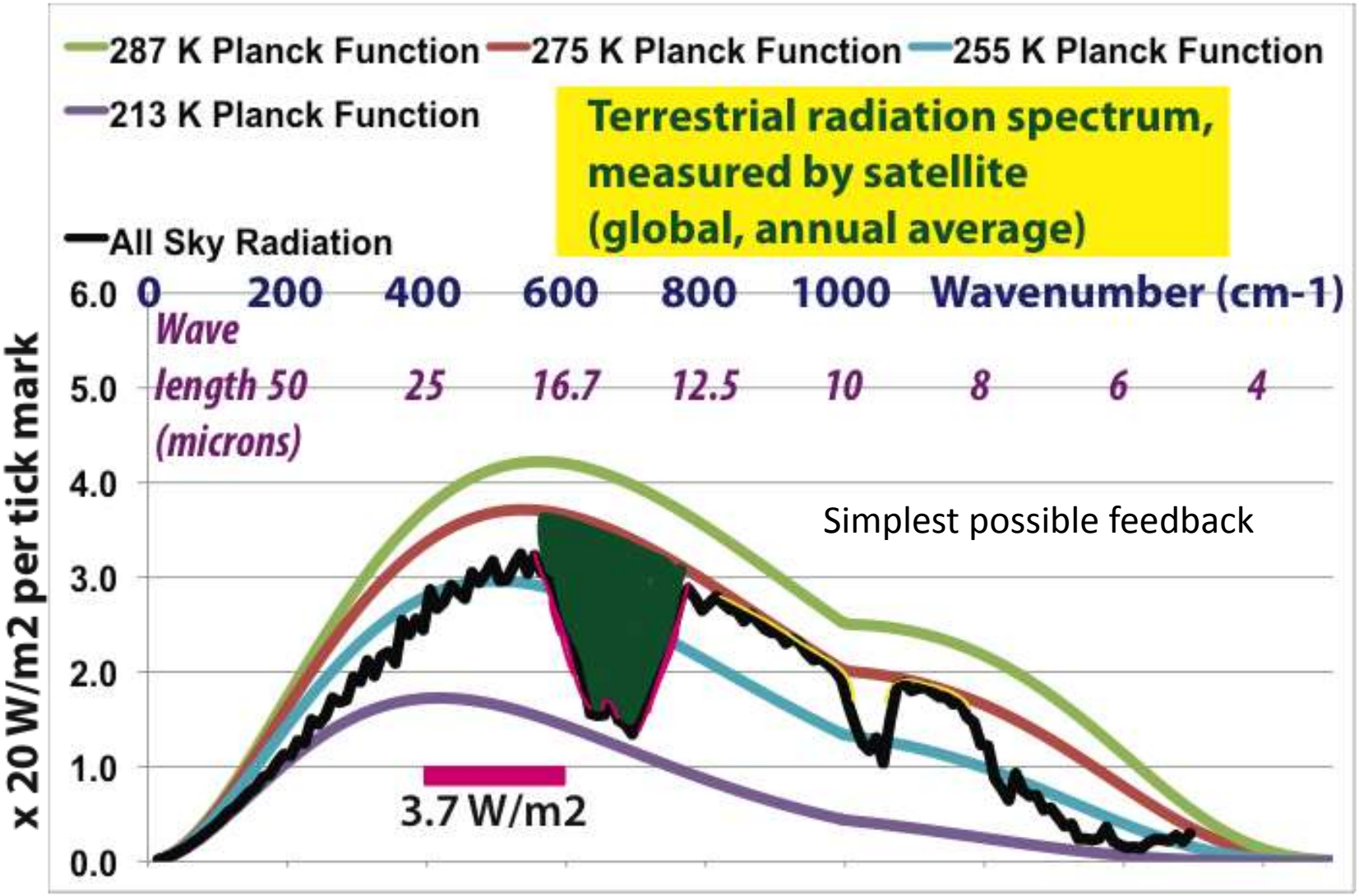

287 K Planck Function
275 K Planck Function
255 K Planck Function
213 K Planck Function
All Sky Radiation
Terrestrial radiation spectrum, measured by satellite (global, annual average)
x 20 W/m2 per tick mark
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
200
400
600
800
1000
Wavenumber (cm-1)
Wave length (microns)
50
25
16.7
12.5
10
8
6
4
Forcing from CO_2 doubling
3.7 W/m2

Forcing & Feedbacks

- More heat in or less heat out
  - Climate system gains heat
  - Climate system warms
  - Outgoing radiation increases
  - Climate system approaches new equilibrium

Forcing & Feedbacks

- More heat in or less heat out
  - Climate system gains heat
  - Climate system warms
  - Outgoing radiation increases
    - Radiative characteristics of climate system change in response to warming
    - Increase of outgoing radiation speeds up or slows down
  - Climate system approaches new equilibrium


287 K Planck Function
275 K Planck Function
255 K Planck Function
213 K Planck Function
All Sky Radiation
Terrestrial radiation spectrum, measured by satellite (global, annual average)
x 20 W/m2 per tick mark
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
200
400
600
800
1000
Wavenumber (cm-1)
Wave length (microns)
50
25
16.7
12.5
10
8
6
4
Simplest possible feedback
3.7 W/m2

The Key Questions

- What is the size of the feedbacks?

The Key Questions

- What is the size of the feedbacks?
  - Does this depend on the type of forcing?

The Key Questions

- What is the size of the feedbacks?
  - Does this depend on the type of forcing?
  - Does this depend on the state of the climate?

The Key Questions

- What is the size of the feedbacks?
  - Does this depend on the type of forcing?
  - Does this depend on the state of the climate?
- What are the future forcings?

The Key Questions

- What is the size of the feedbacks?
  - Does this depend on the type of forcing?
  - Does this depend on the state of the climate?
- What are the future forcings?
- What else happens?

The Key Questions

- What is the size of the feedbacks?
  - Does this depend on the type of forcing?
  - Does this depend on the state of the climate?
- What are the future forcings?
- What else happens?
  - Rainfall, storms, sea level, pH

The Key Questions

- What is the size of the feedbacks?
  - Does this depend on the type of forcing?
  - Does this depend on the state of the climate?
- What are the future forcings?
- What else happens?
  - Rainfall, storms, sea level, pH
  - Spatial pattern of changes

A funny thing happened on the way to the public…

- Observations = good
- Climate models = bad

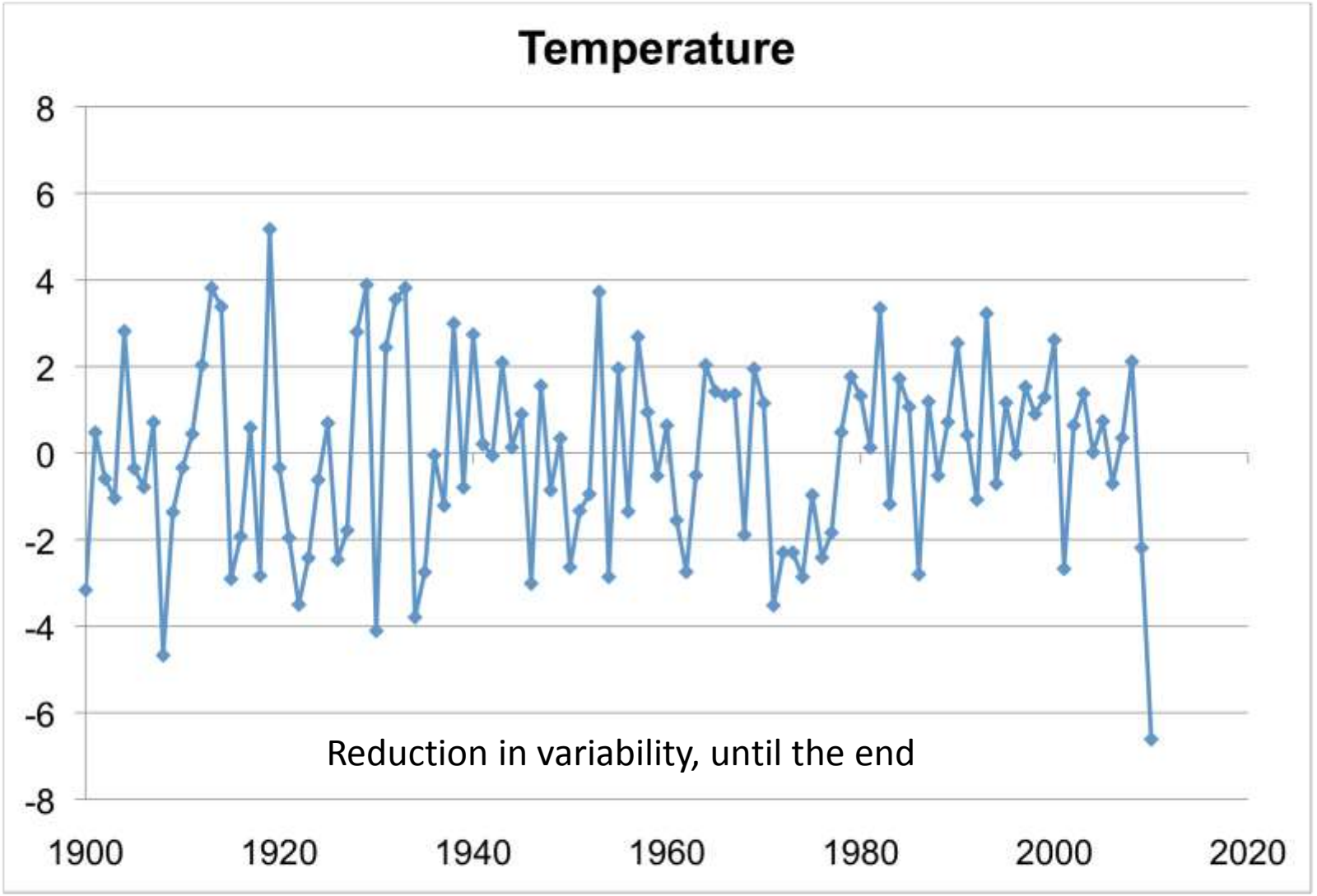
- What’s a model?

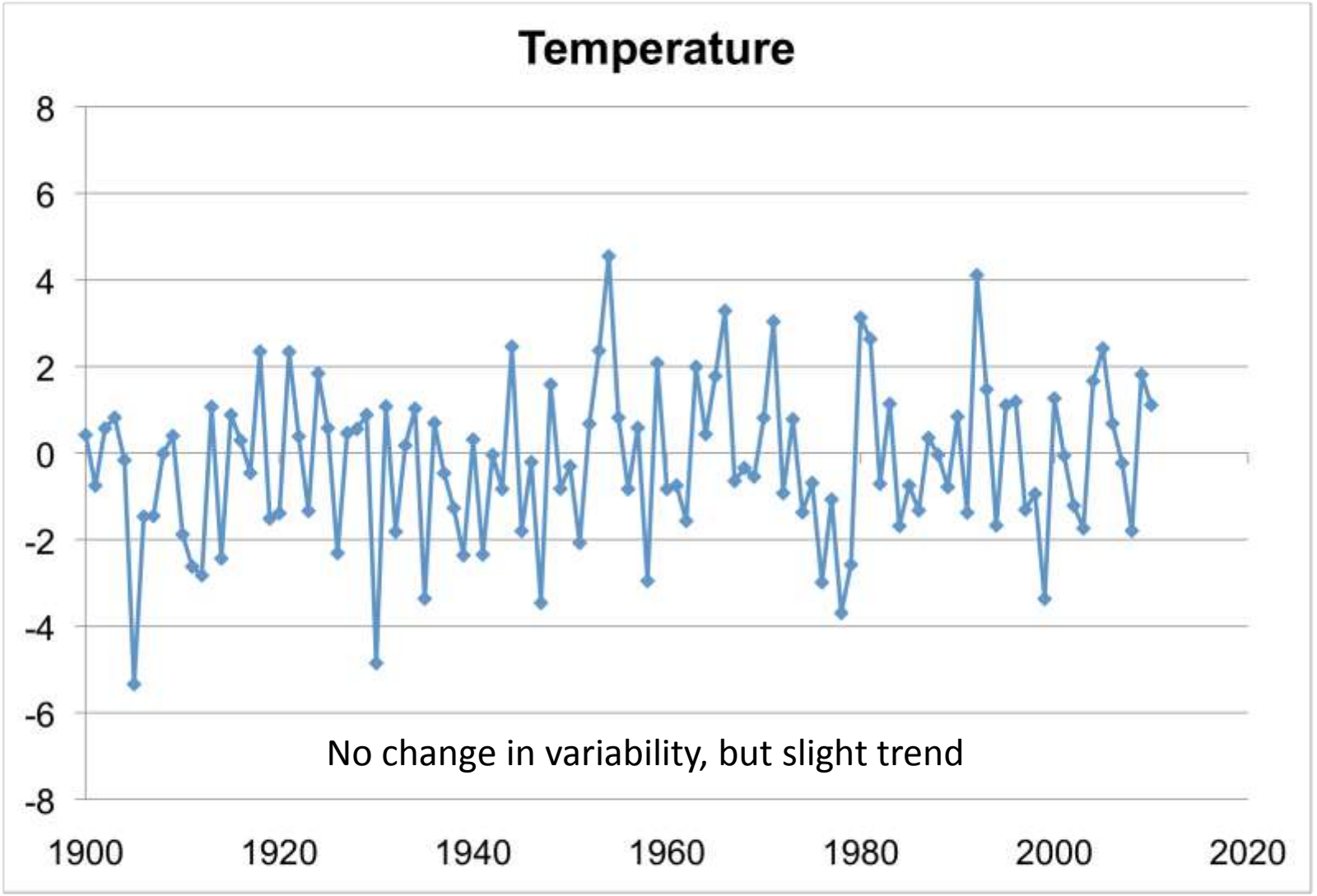
- What’s a model?

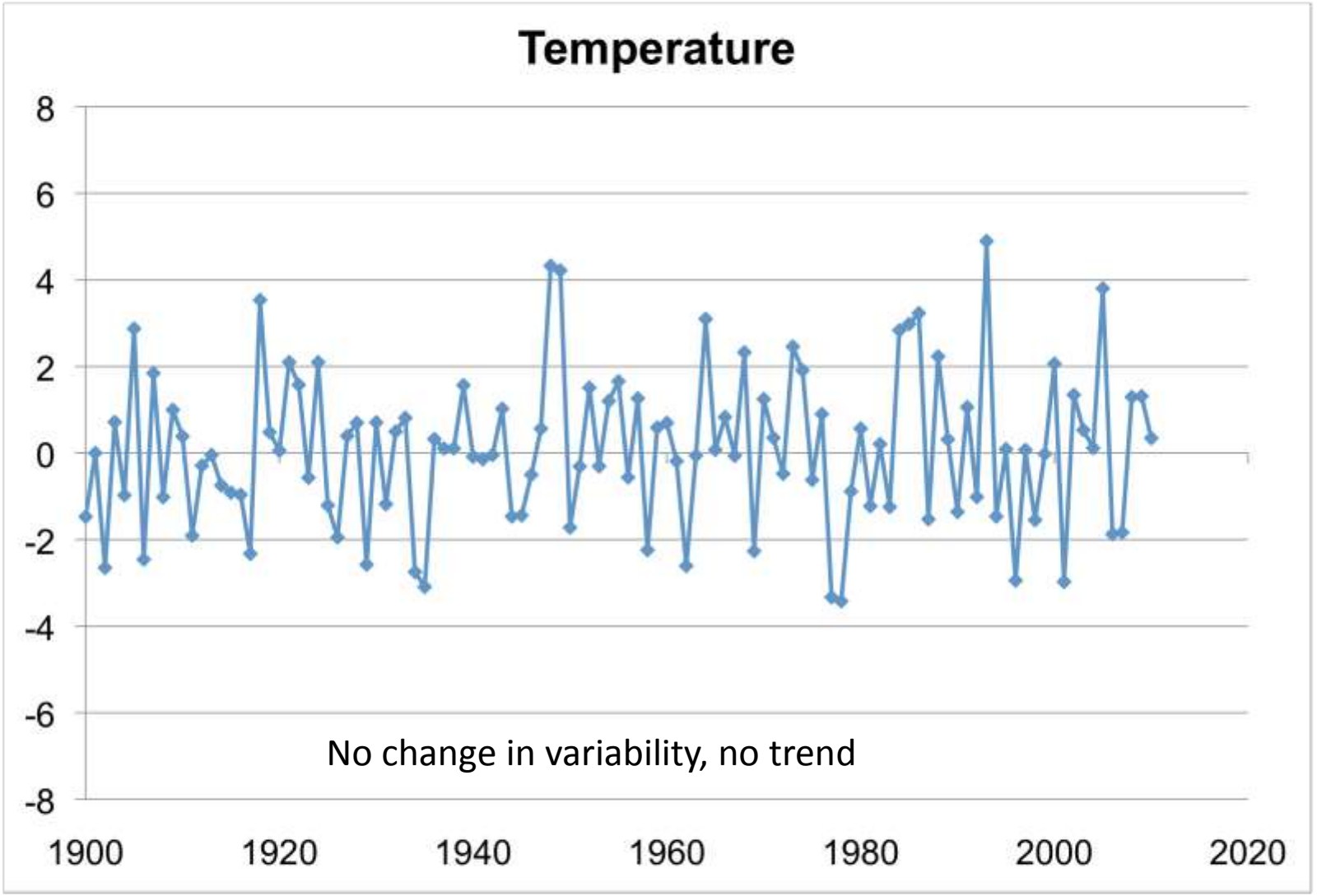
- What's a model?

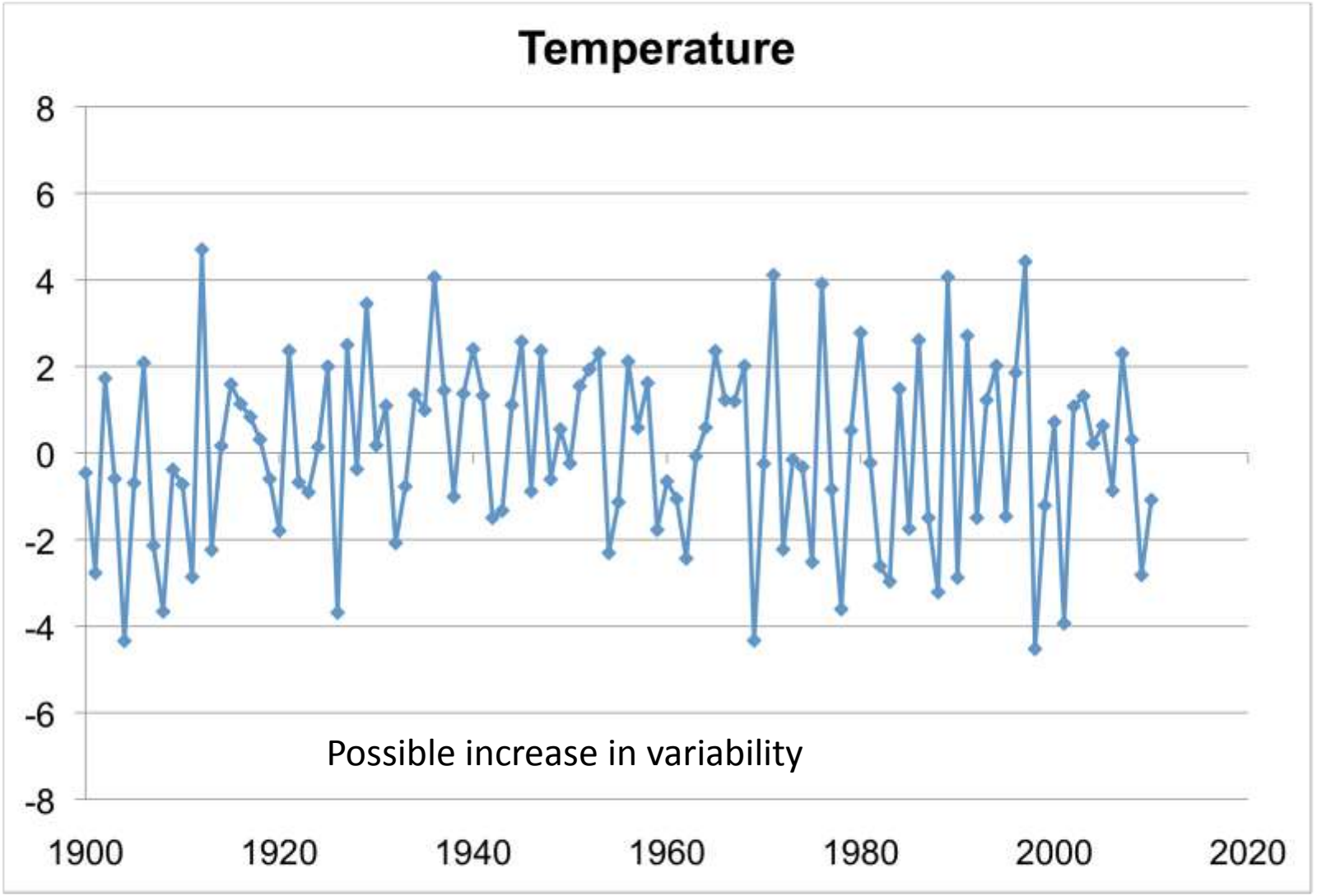
But in reality…

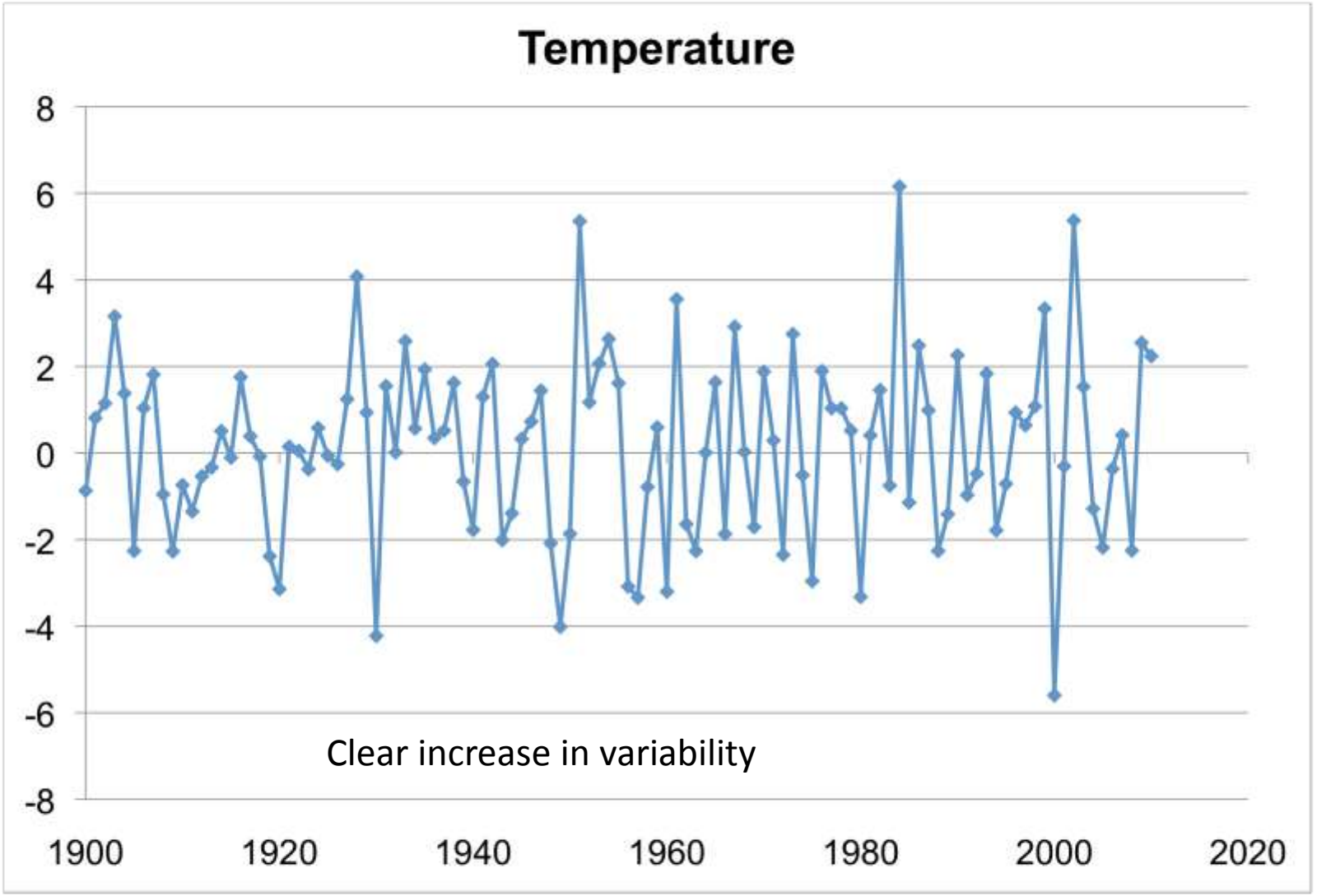
- Observations show concurrence in the real world
- Climate models show cause and effect in worlds very similar to our own


Temperature
8
6
4
2
0
-2
-4
-6
-8
1900
1920
1940
1960
1980
2000
2020
Reduction in variability, until the end


Temperature
8
6
4
2
0
-2
-4
-6
-8
1900
1920
1940
1960
1980
2000
2020
No change in variability, but slight trend


Temperature
8
6
4
2
0
-2
-4
-6
-8
1900
1920
1940
1960
1980
2000
2020
No change in variability, no trend


Temperature
8
6
4
2
0
-2
-4
-6
-8
1900
1920
1940
1960
1980
2000
2020
Possible increase in variability


Temperature
8
6
4
2
0
-2
-4
-6
-8
1900
1920
1940
1960
1980
2000
2020
Clear increase in variability

Telling the secret…

- All 5 time series were generated from random, stationary Gaussian noise
  - These were the first five time series I produced

Telling the secret…

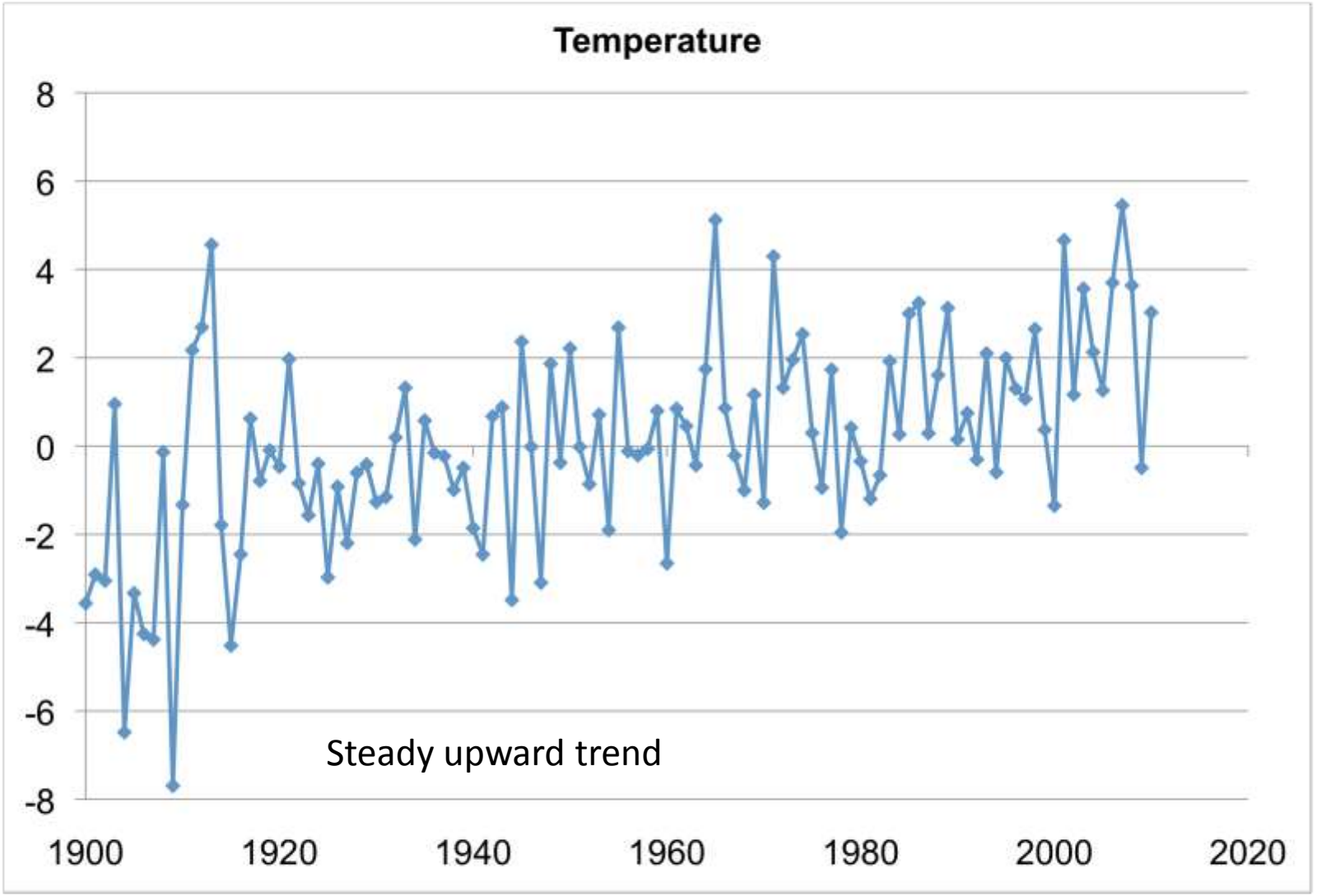
- All 5 time series were generated from random, stationary Gaussian noise
- There was no trend, and the variability did not change

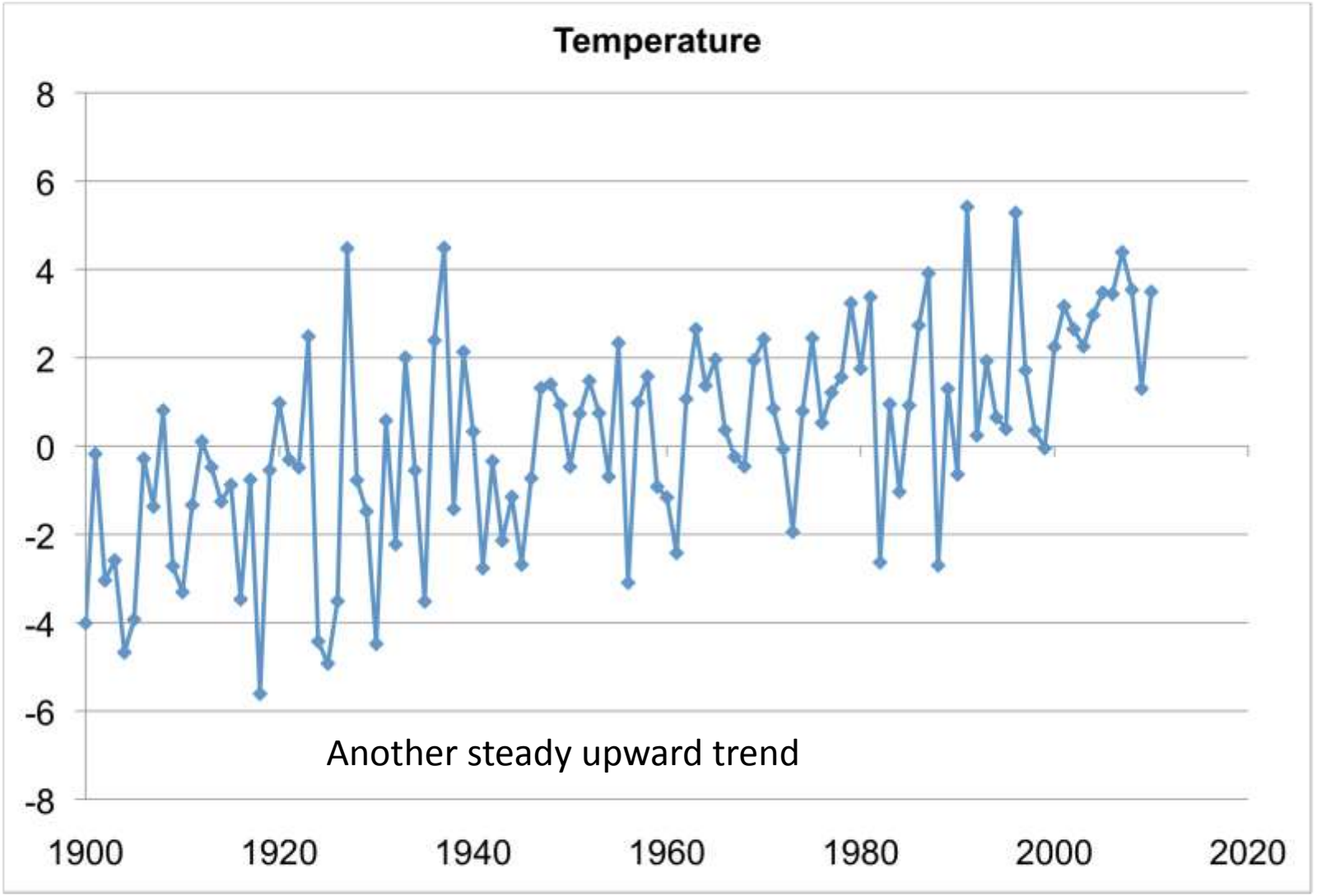
Telling the secret…

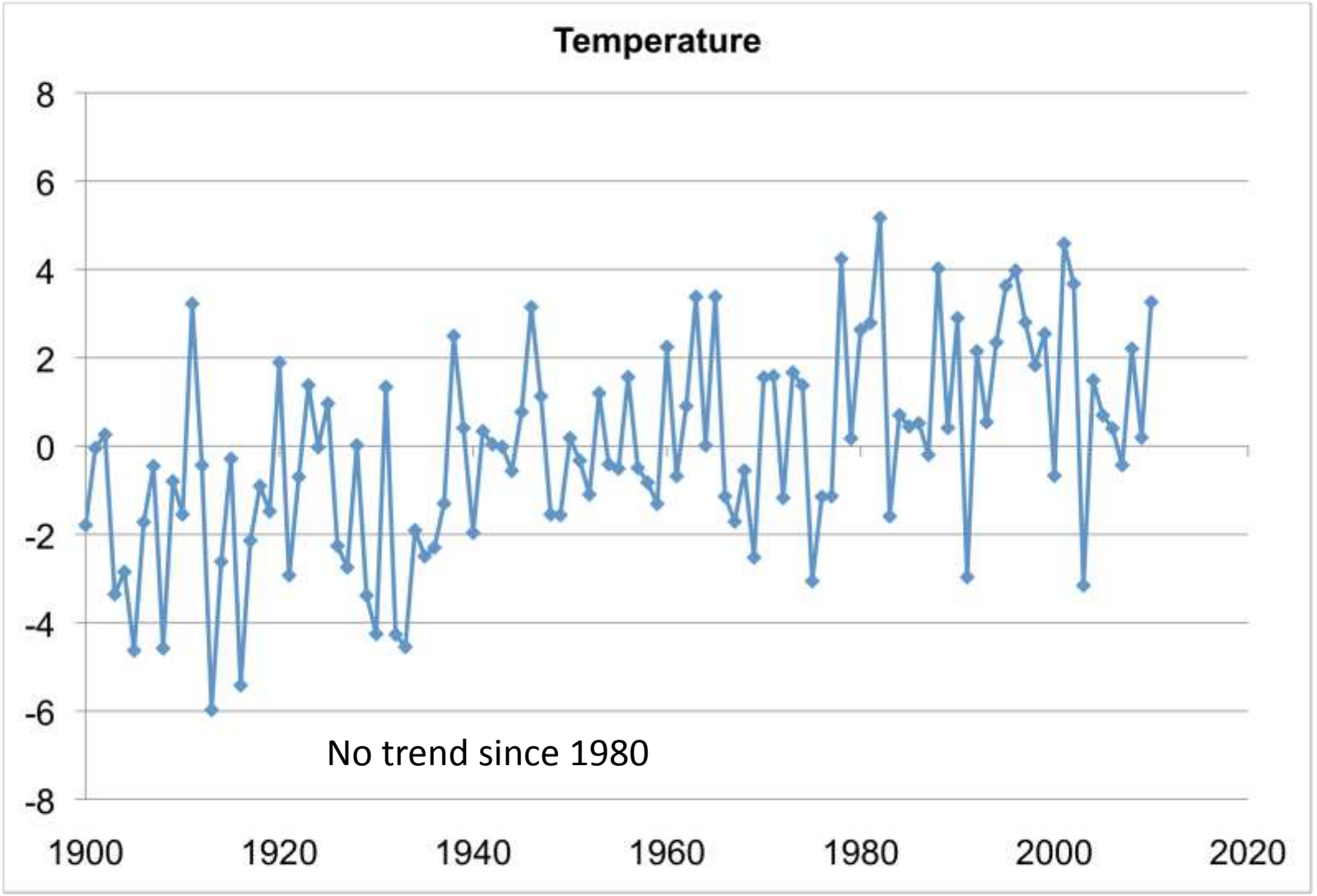
- All 5 time series were generated from random, stationary Gaussian noise
- ~~There was no trend, and the variability did not change~~
- There really were changes in variability

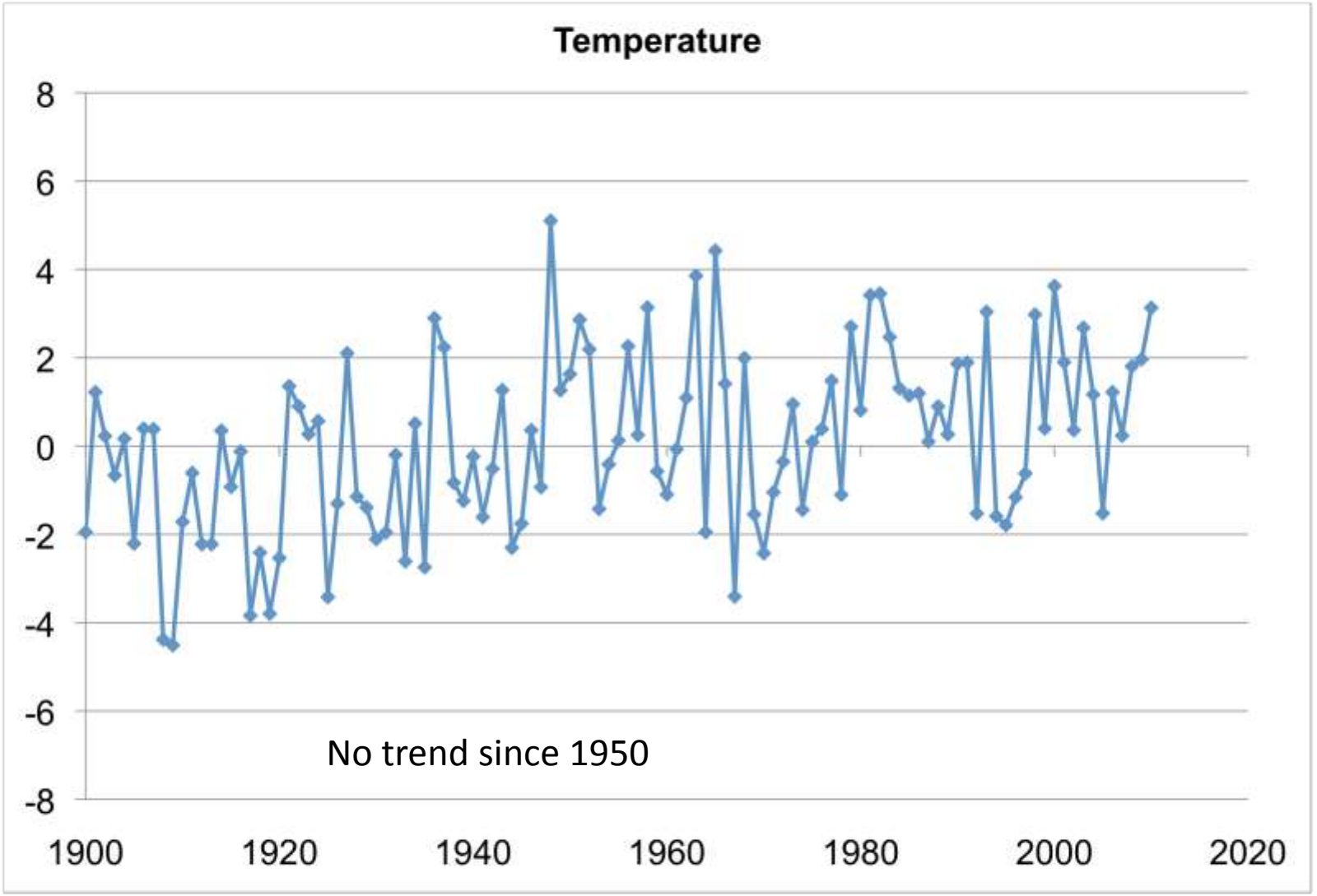
Telling the secret…

- All 5 time series were generated from random, stationary Gaussian noise
- ~~There was no trend, and the variability did not change~~
- There really were changes in variability
- The expected variability (based on the process generating the data) did not change


Temperature
8
6
4
2
0
-2
-4
-6
-8
1900
1920
1940
1960
1980
2000
2020
Steady upward trend


Temperature
8
6
4
2
0
-2
-4
-6
-8
1900
1920
1940
1960
1980
2000
2020
Another steady upward trend


Temperature
8
6
4
2
0
-2
-4
-6
-8
1900
1920
1940
1960
1980
2000
2020
No trend since 1980


Temperature
8
6
4
2
0
-2
-4
-6
-8
1900
1920
1940
1960
1980
2000
2020
No trend since 1950

Bet you can guess…

- All four statements are accurate

Bet you can guess…

- All four statements are accurate
- But the data points were generated from a combination of random noise and a steady, long-term trend

Bet you can guess…

- All four statements are accurate
- But the data points were generated from a combination of random noise and a steady, long-term trend
- Based on the generating process, the expected value of each point is higher than the expected value of the preceding point

Back to reality…

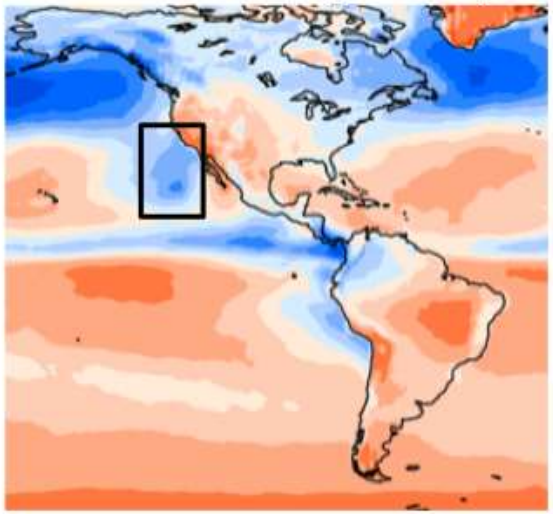
- Observations show concurrence in the real world
- Climate models show cause and effect in worlds very similar to our own
- Physical analysis, through climate models and comparison with observations, is essential

Californian stratocumulus

Shortwave cloud forcing (W/m^2) = **Net $SW_{all\ sky}$ - Net $SW_{clear\ sky}$**

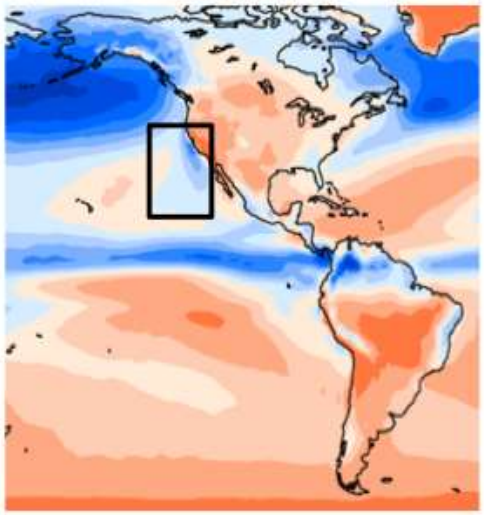
- Tells us something about the cloud cooling effect
- The more negative, the more cooling effect

Observations (CERES)



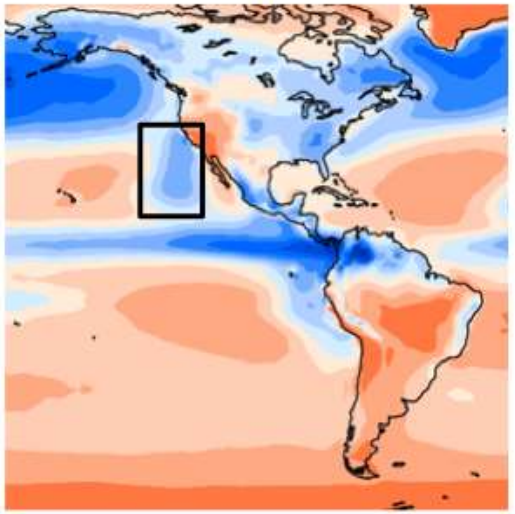
Cooling effect on the ocean

CAM4

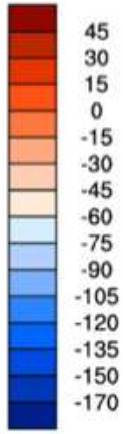


Not enough cooling and cloud too close to the coast

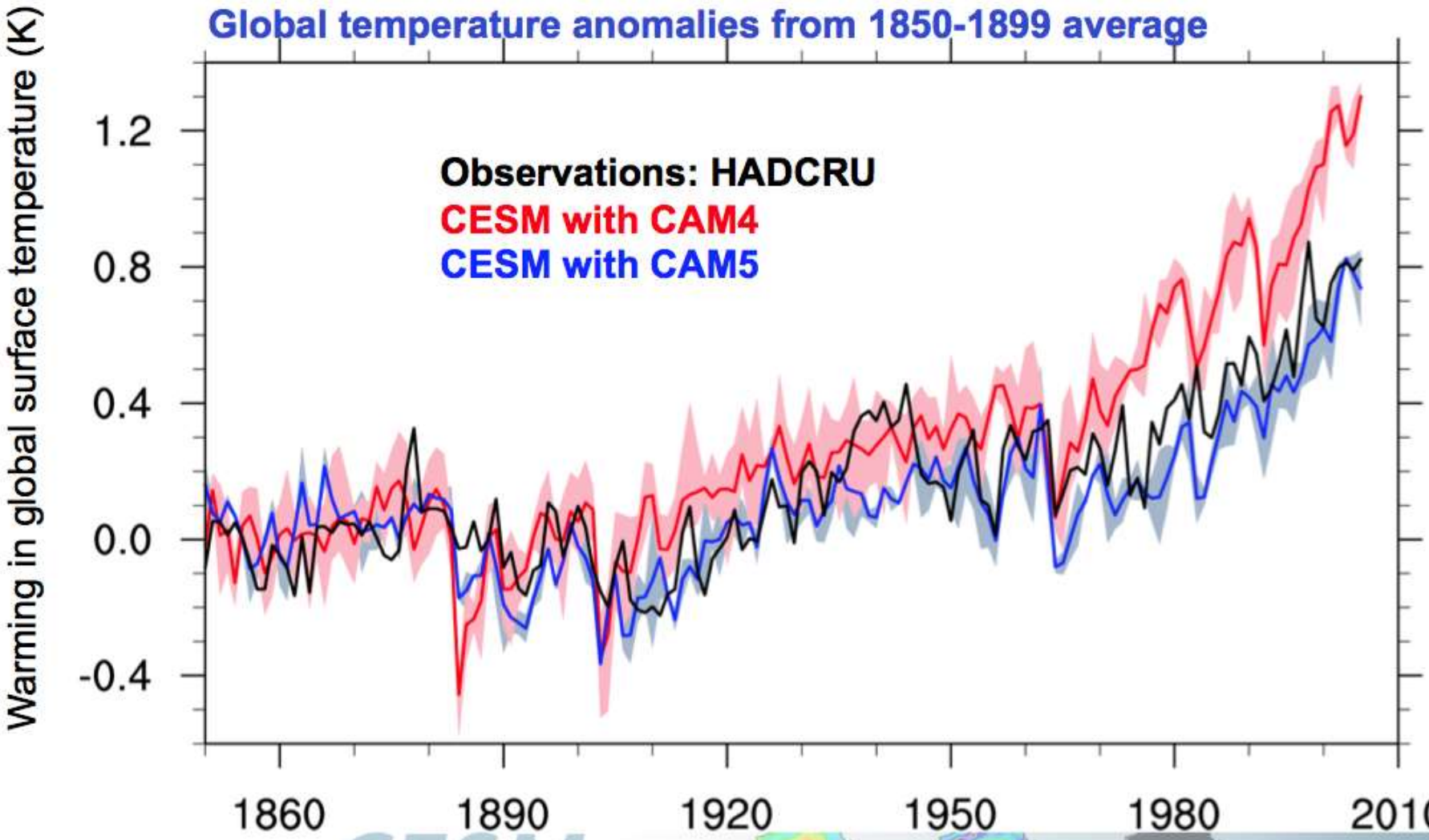
CAM5.1

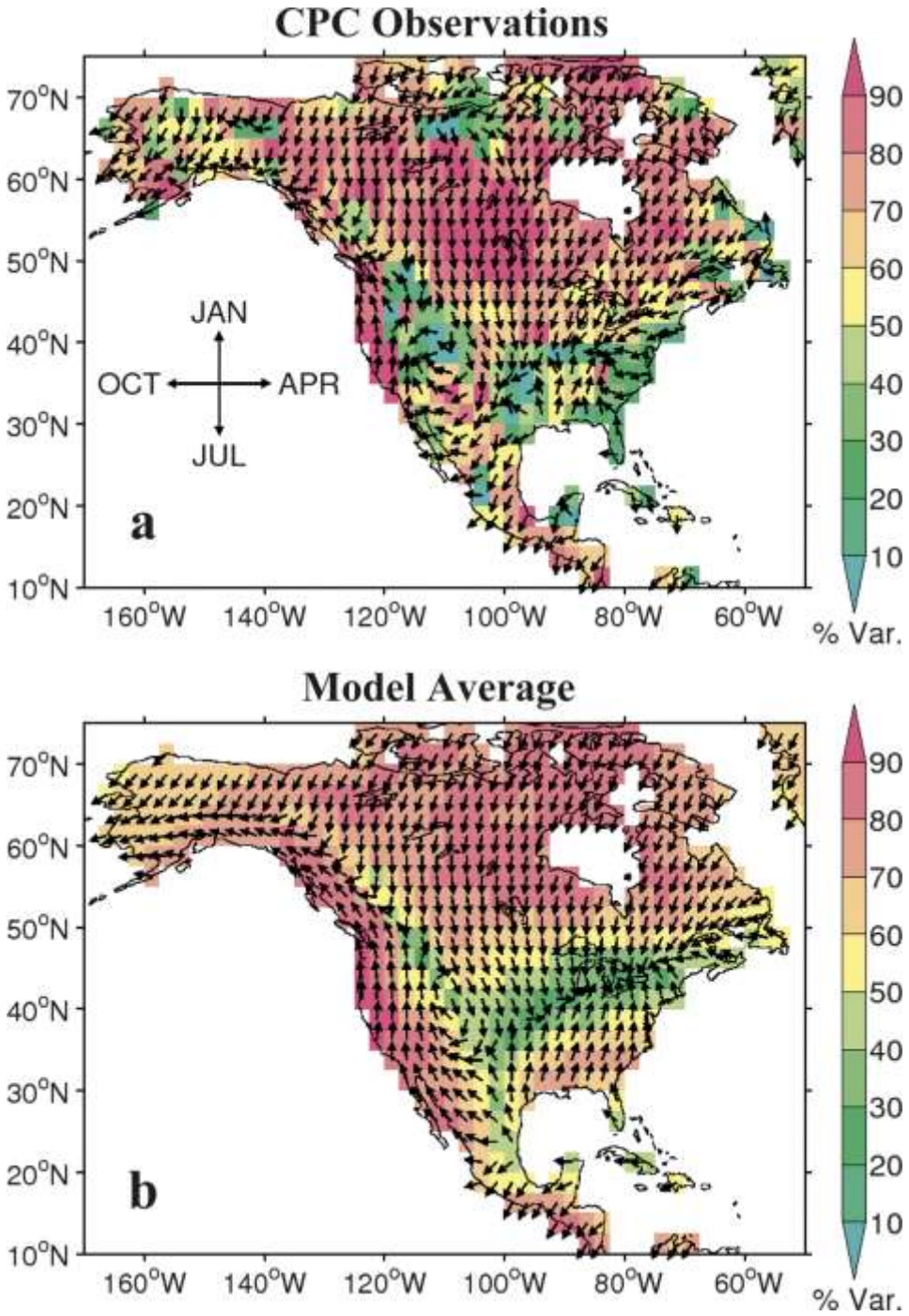


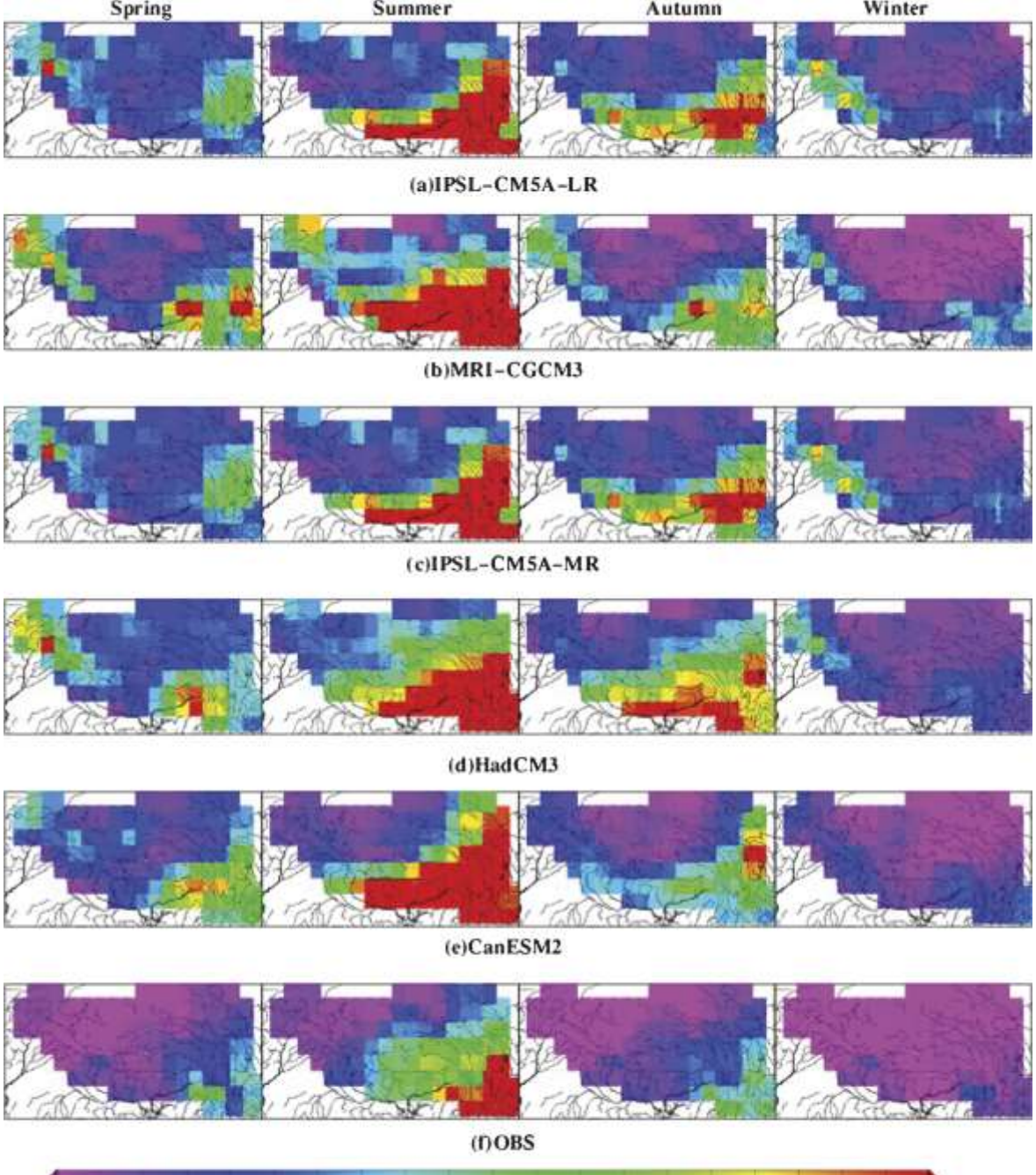
Major improvement



Warming over the 20th century




CPC Observations
70°N
60°N
50°N
40°N
30°N
20°N
10°N
160°W
140°W
120°W
100°W
80°W
60°W
JAN
OCT
APR
JUL
a
90
80
70
60
50
40
30
20
10
% Var.
Model Average
b
90
80
70
60
50
40
30
20
10
% Var.



Seasonal precipitation spatial distribution for 5 GCM with the least bias,for the TP

Summary

- Carbon dioxide's role in the radiation budget is well established
- Relative importance is easier to pin down than specific consequences
- Climate models are widely misunderstood but are essential when used properly