Introduction: Climate & Climate Change

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PEKING UNIVERSITY

Outline

- Current climate
- Climate change in the Industrial Era
- Radiative forcings and climate feedbacks

致谢：本课件中部分资料来自李成才老师（特别是关于辐射的部分）。

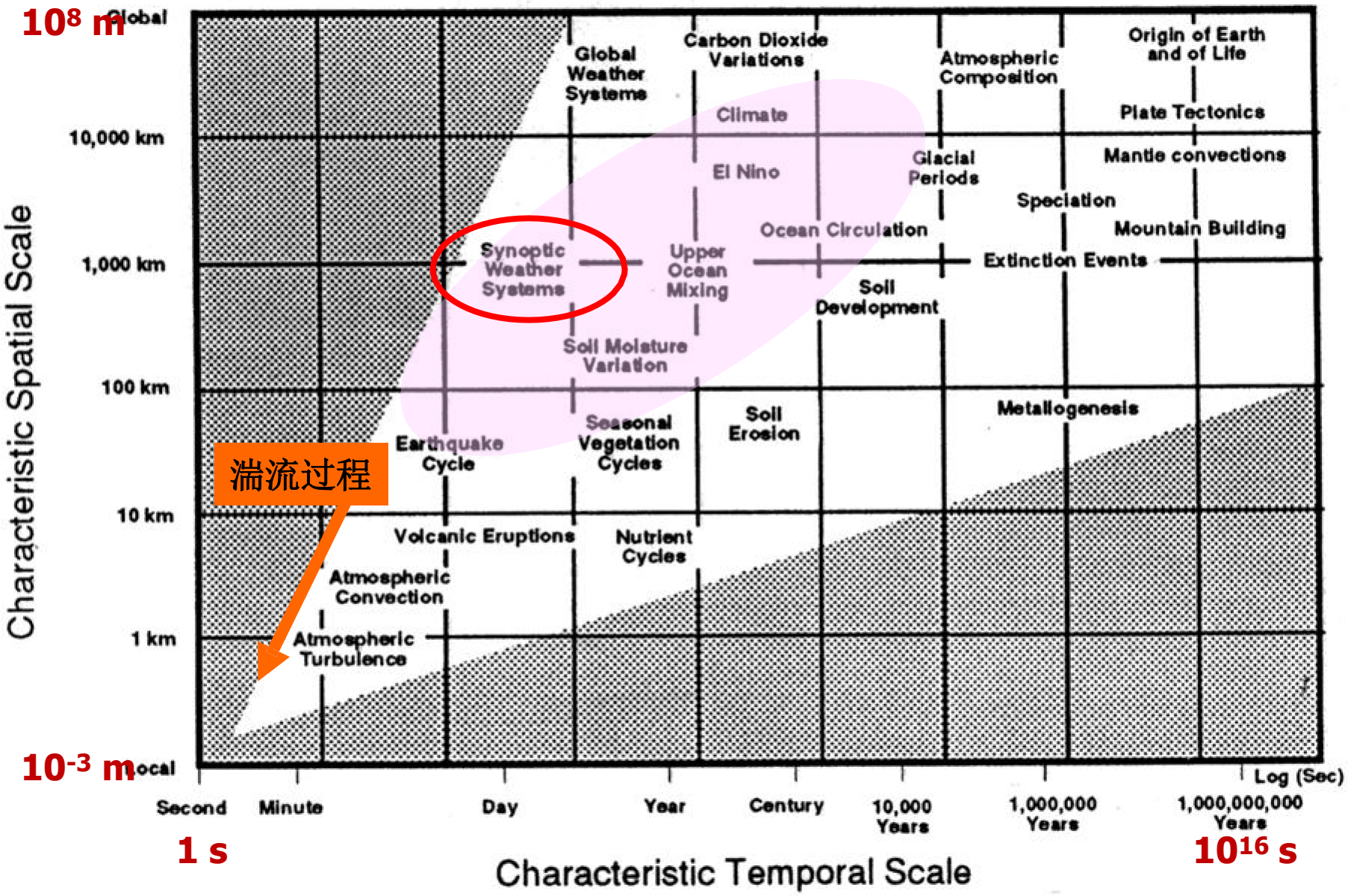
气候

- 气候系统：一个复杂的、各部分相互作用的系统，包括大气、陆地表面、冰雪、海洋和其它水体以及生物
- 传统/狭义上，气候通常被描述为从数月到数百万年的一段时间内（通常采用30年的时间段）的气温、降水、风等气象变量的平均值及变率



我们最关心的问题：气候系统的变化、原因（自然强迫、内部变率、人类活动）、对相关自然和人文环境的影响、以及未来气候变化和应对

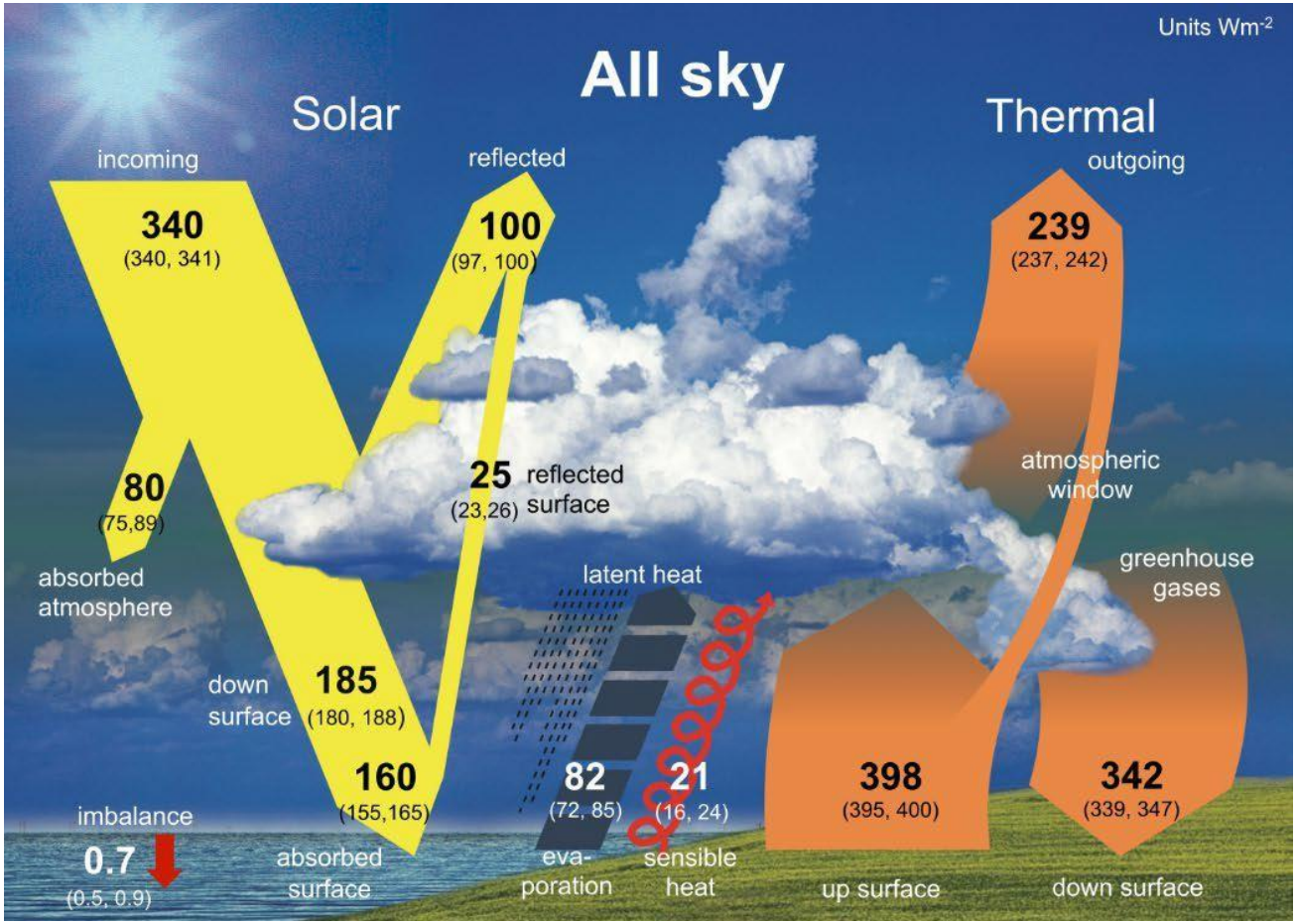
Spatiotemporal Scales in the Earth Climate System



Spatiotemporal Scales in the Atmosphere

	Scale	Name
20,000 km (weeks)	Planetary	Global circulation
2,000 km (1 week)	Synoptic	Synoptic (e.g., cyclone)
200 km (1 day)	Meso-α	Mesoscale (e.g., TC)
20 km (hours)	Meso-β	Mesoscale (e.g., supercell)
2 km (mins)	Meso-γ	Mesoscale (convection)
200 m (mins)	Micro-α	Boundary-layer turbulence
20 m (secs)	Micro-β	Surface-layer turbulence
2 m (secs)	Micro-γ	Inertial subrange turbulence
2 mm (secs)	Micro-δ	Fine-scale turbulence
Air molec. (< 1 sec)	Molecular	Viscous dissipation subrange

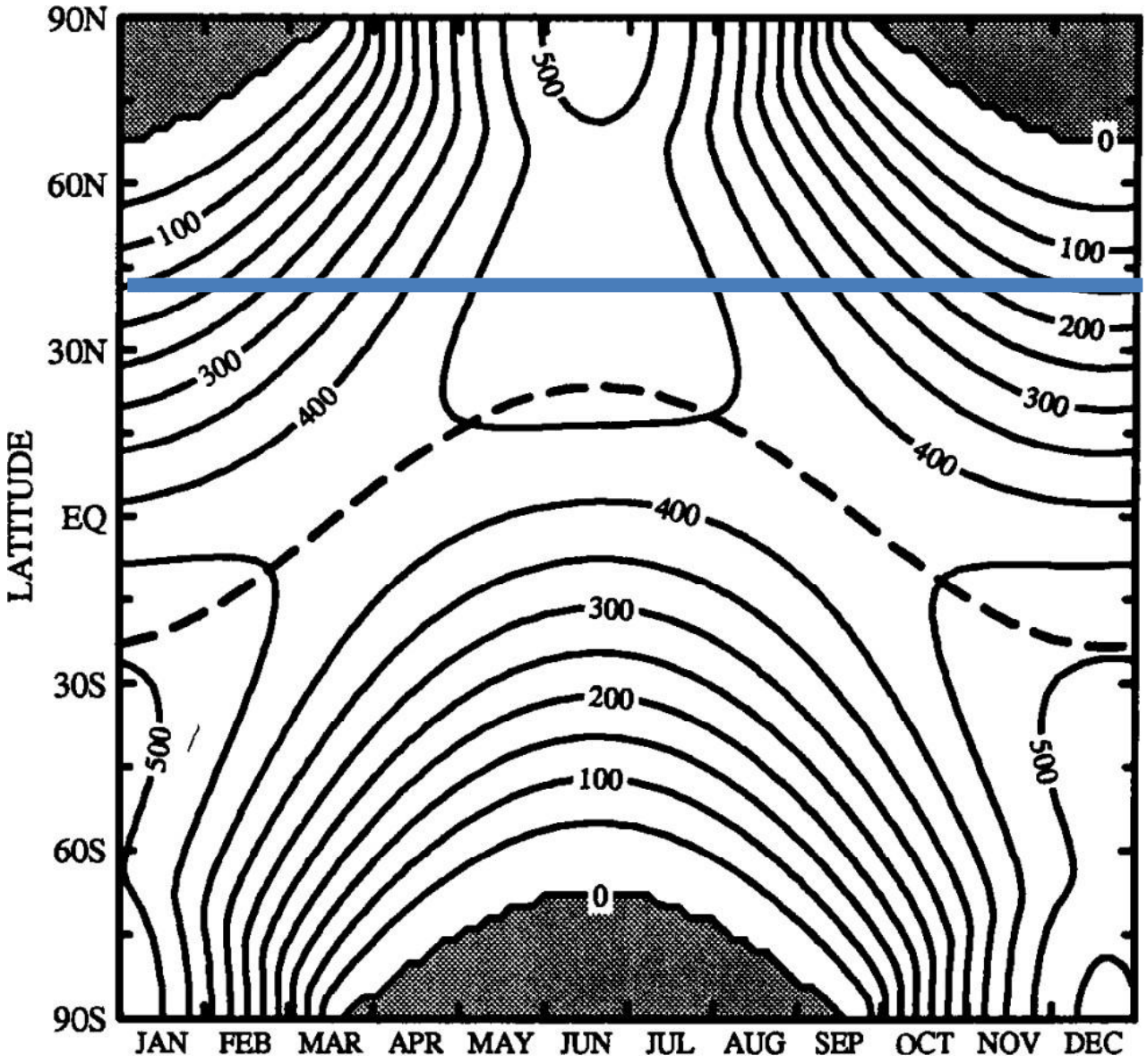
Earth Energy Budget (in Early 21st Century)



IPCC, 2021

- Energy balance: Atmosphere 80+(398-40)+21+82-342-(239-40), Surface 160+342-398-21-82, Earth TOA 340-100-239
- Planetary albedo: ~29% (surface 7%, atmosphere 22%)

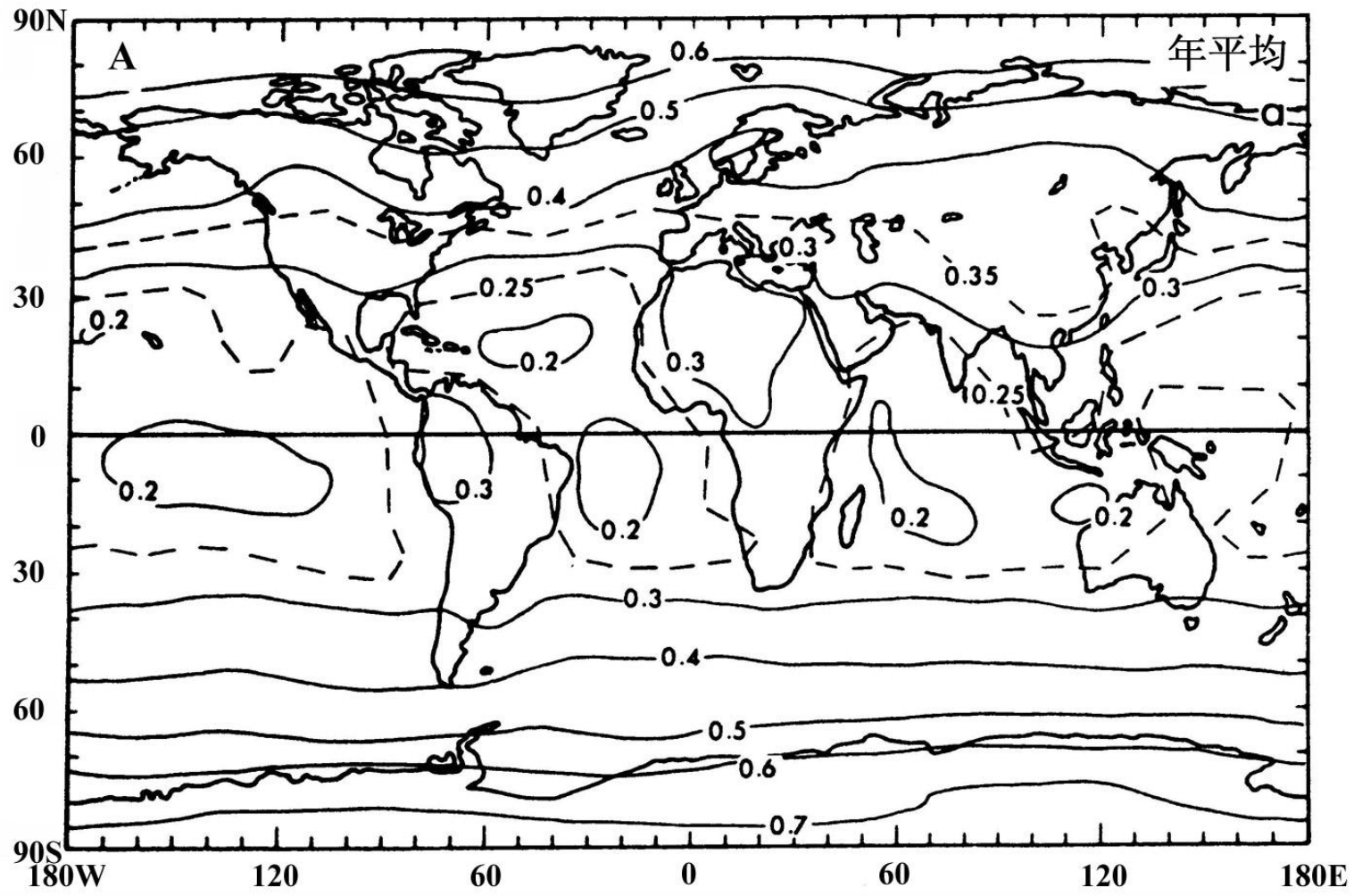
Top-Of-Atmosphere Incident Solar Radiation: F_{SW}



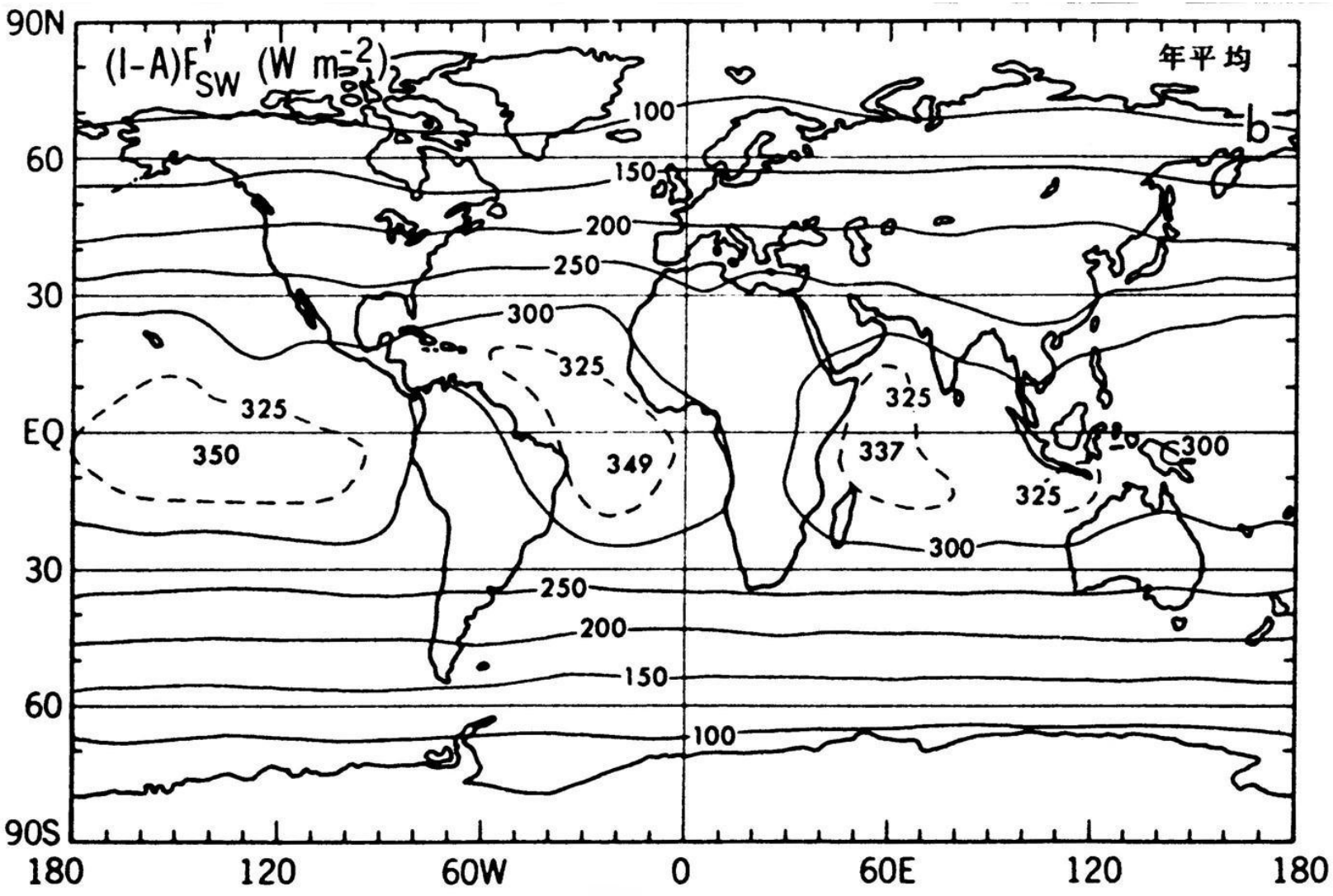
Beijing:
150-500 w/m²

15S-15N:
350-450 w/m²

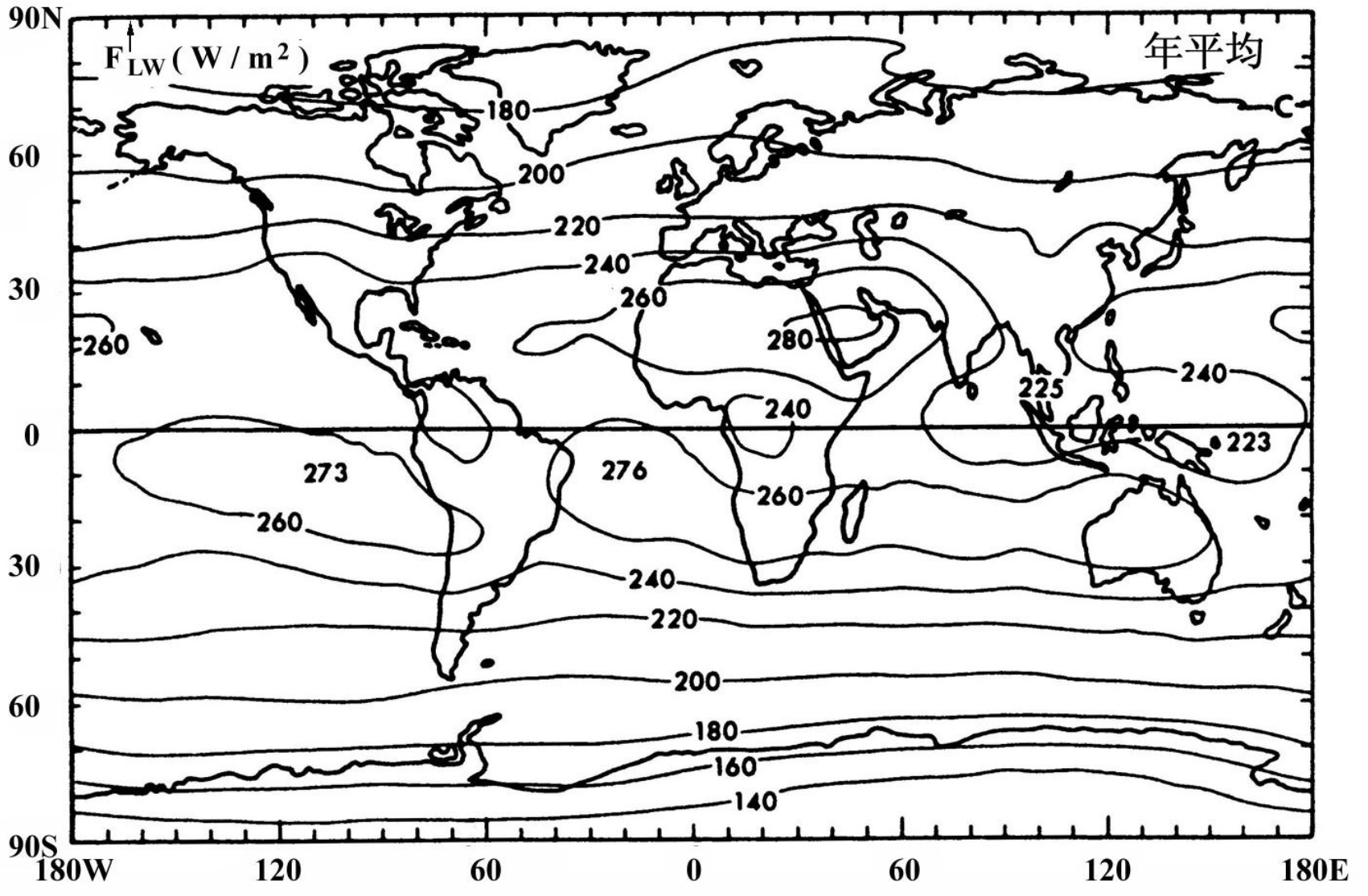
Planetary Albedo (at TOA): *R*



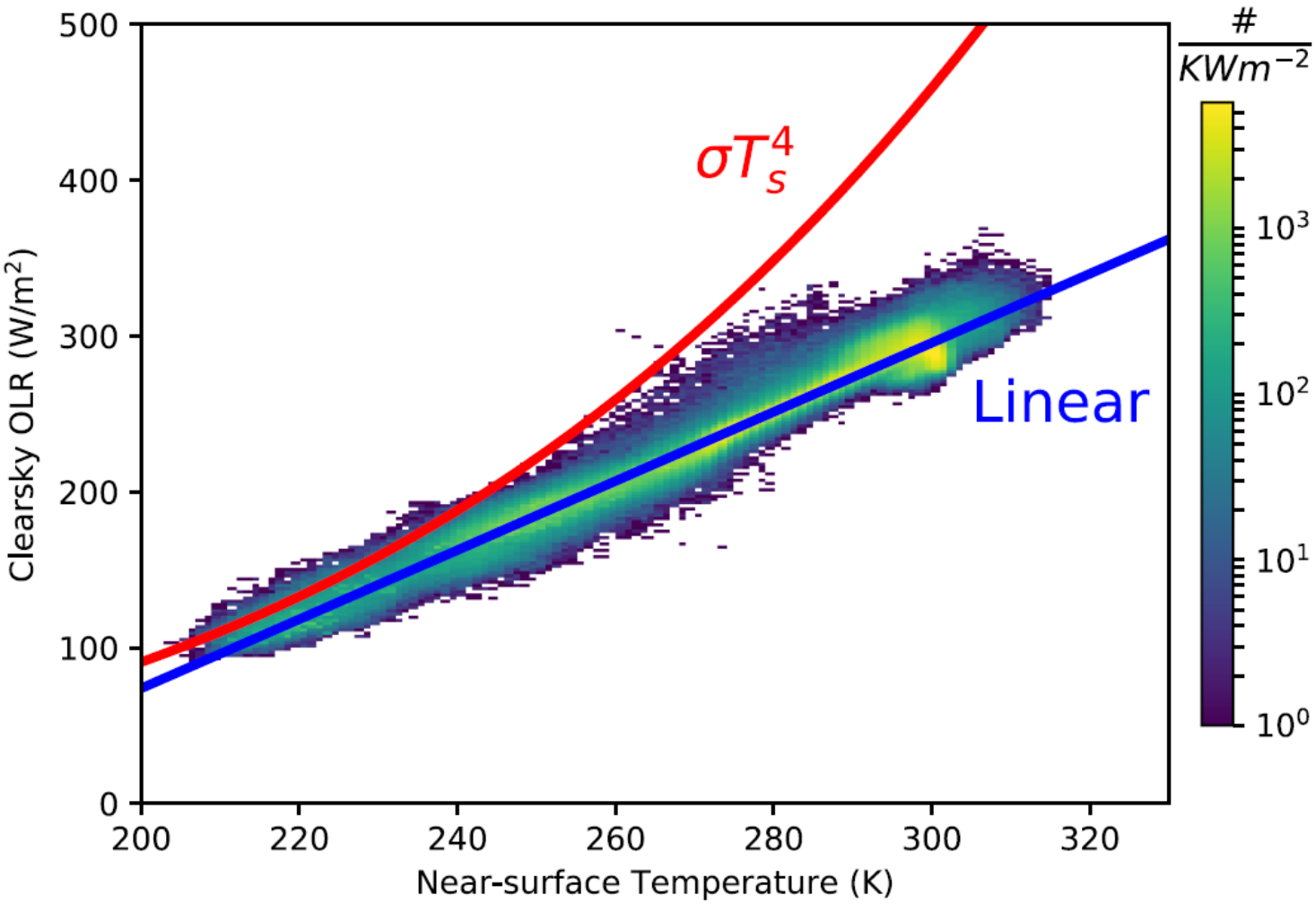
TOA Net Downward Solar Radiation: $(1 - R)\, F_{SW}$



TOA Upward Longwave Radiation: F_{LW}

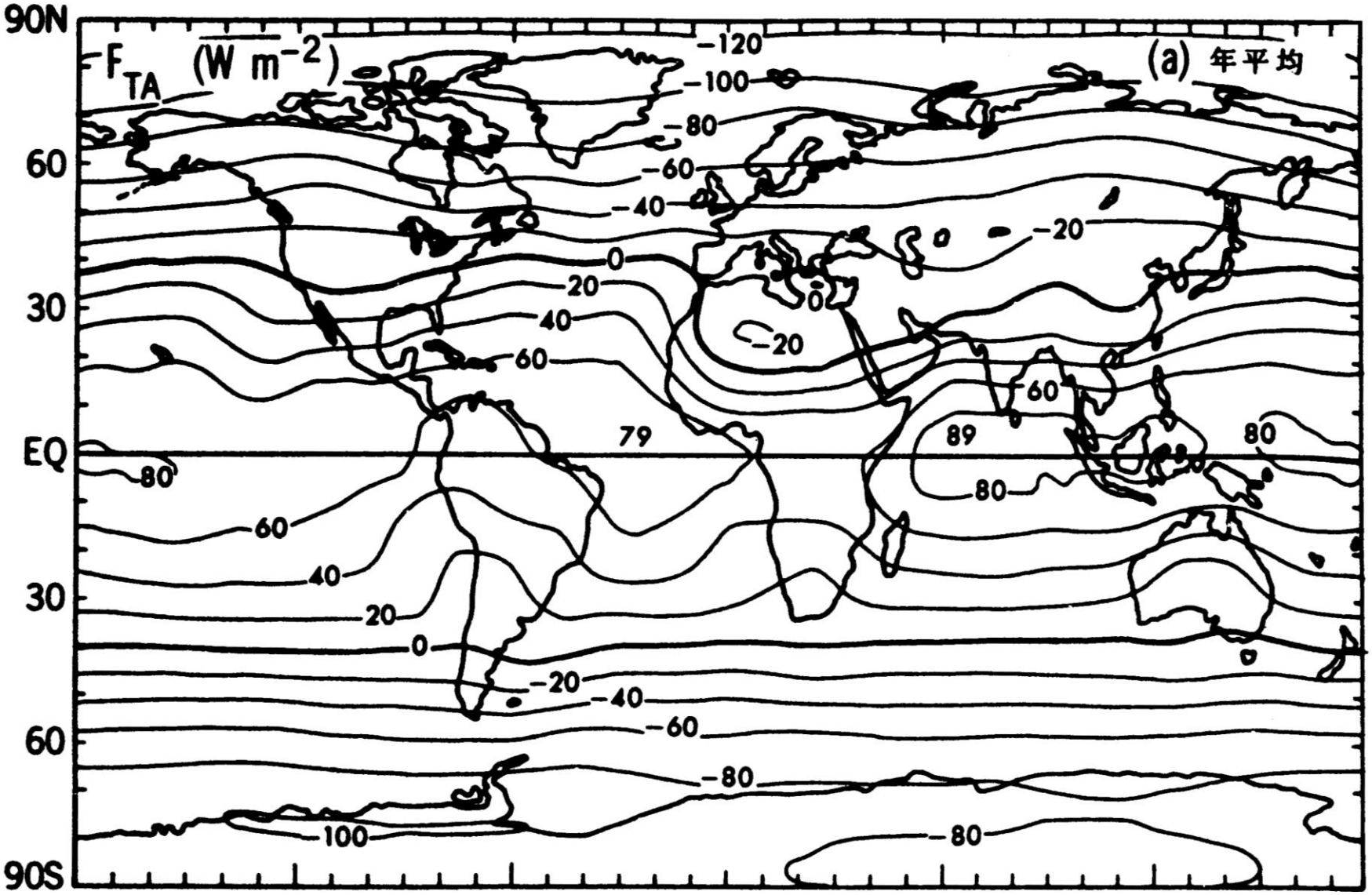


F_{LW} As a Linear Function of Surface Temperature

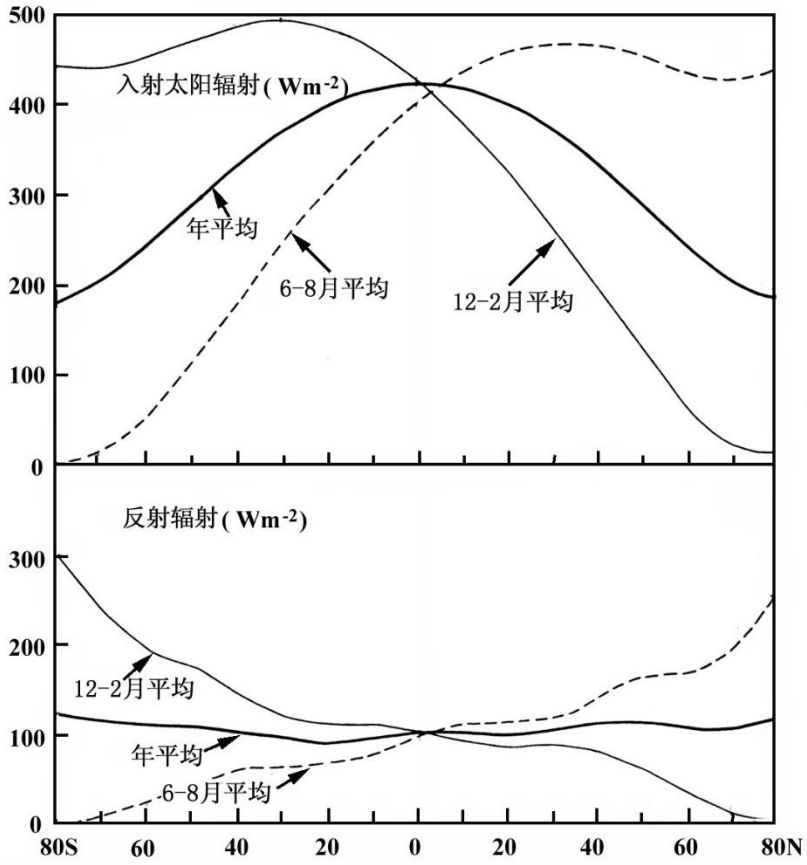


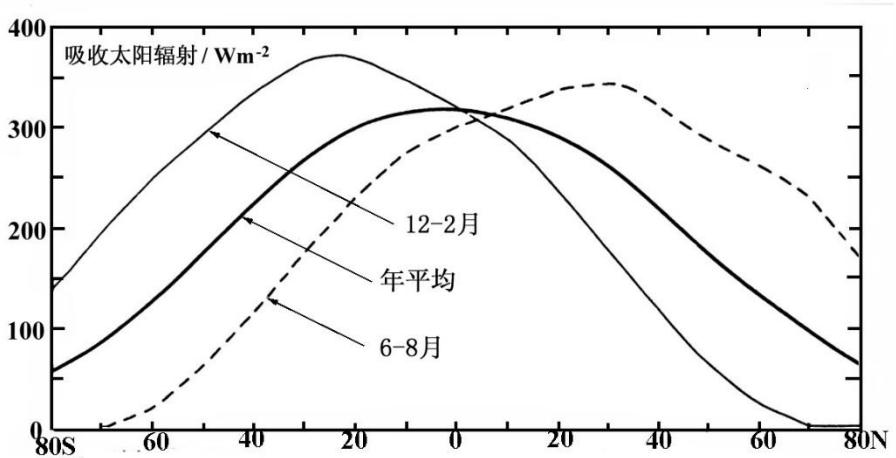
Koll et al., 2018, PNAS

TOA Net Radiation: F_{TA}

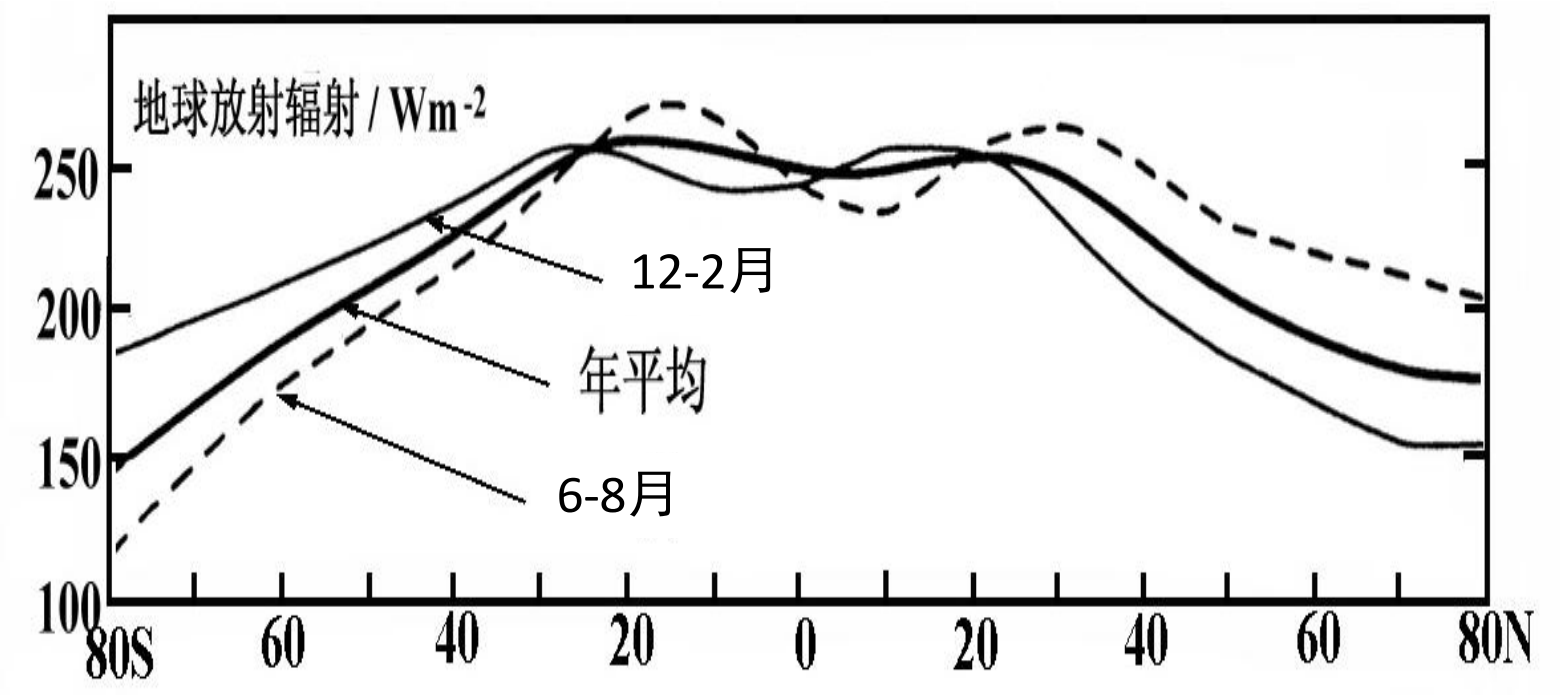


TOA Solar Radiation: Meridional Distribution



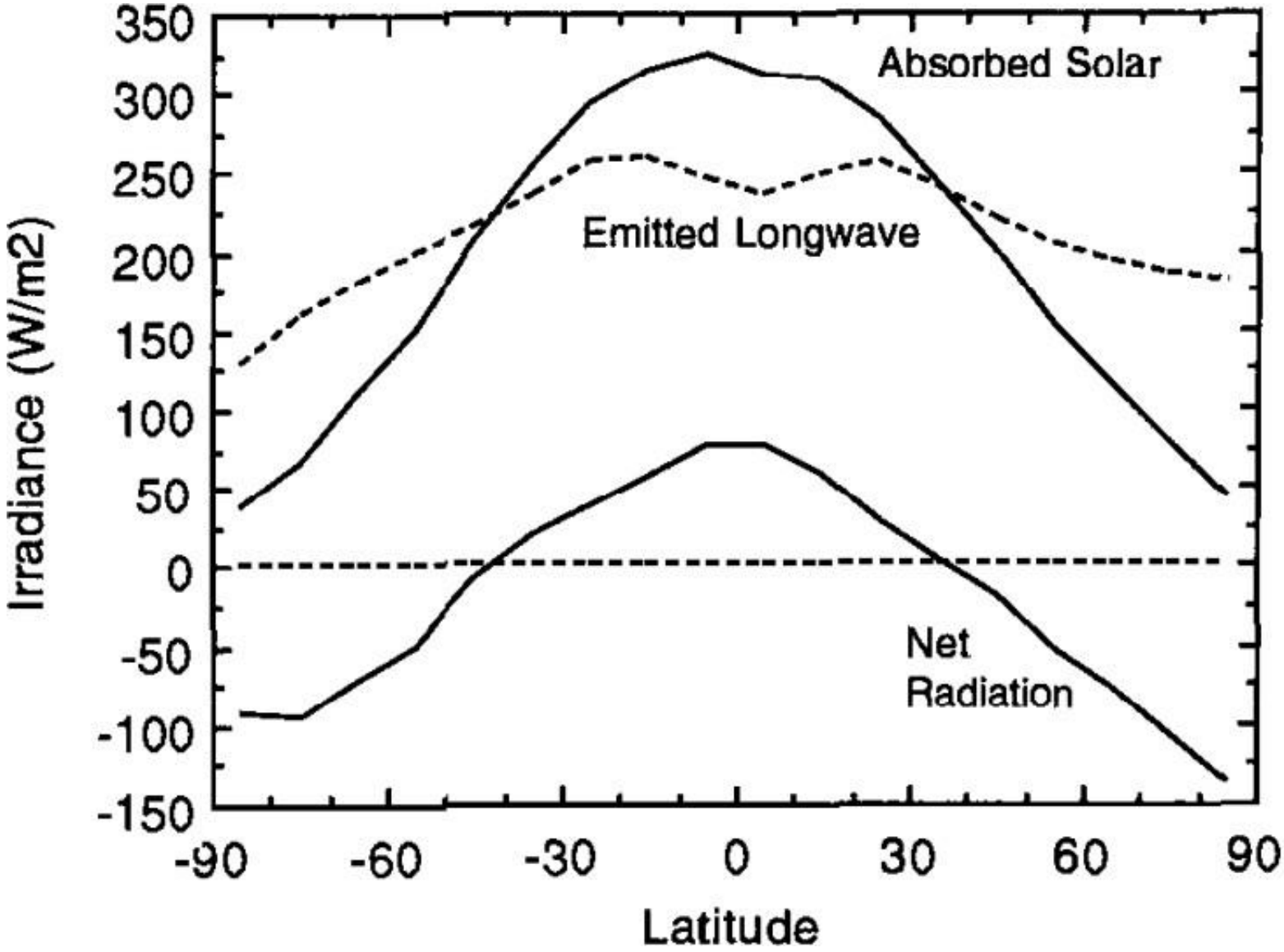


TOA Upward Longwave Radiation: Meridional Distribution

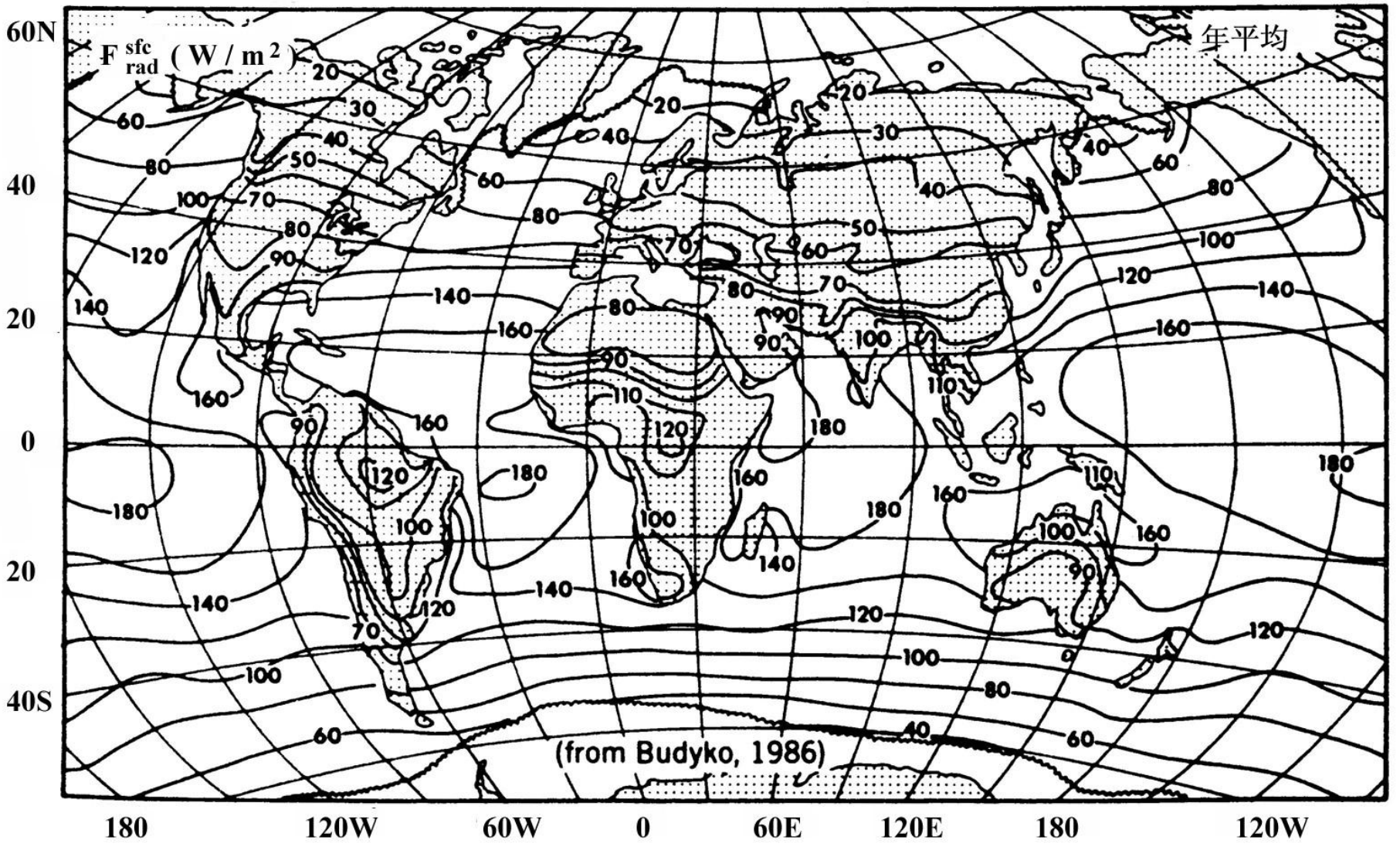


- **High values of about 250 w/m² in 30S-30N**
- **Higher values in northern than southern polar regions**
- **Weaker meridional gradient than solar radiation**

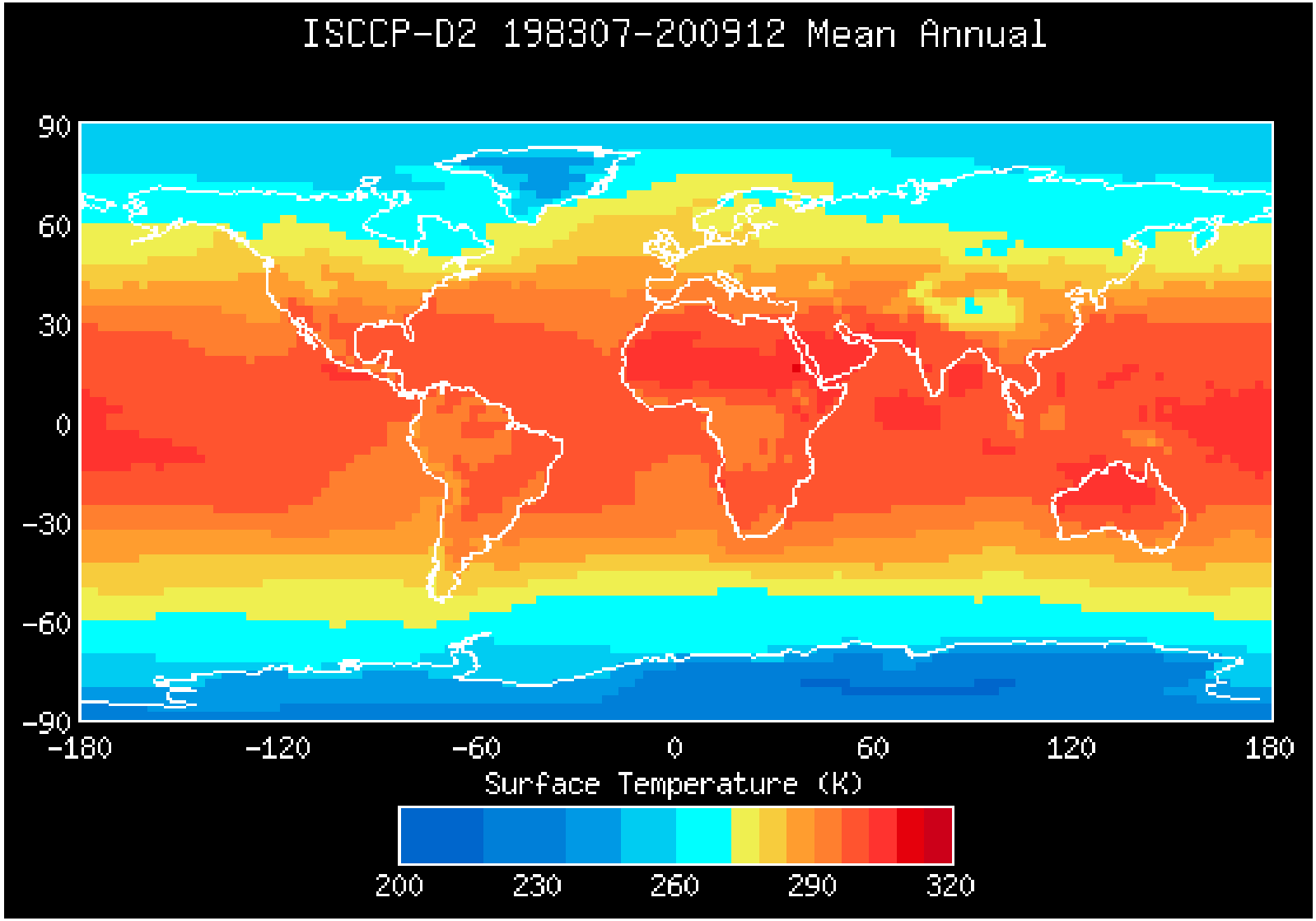
TOA Net Flux (Solar + Longwave): Meridional Distribution



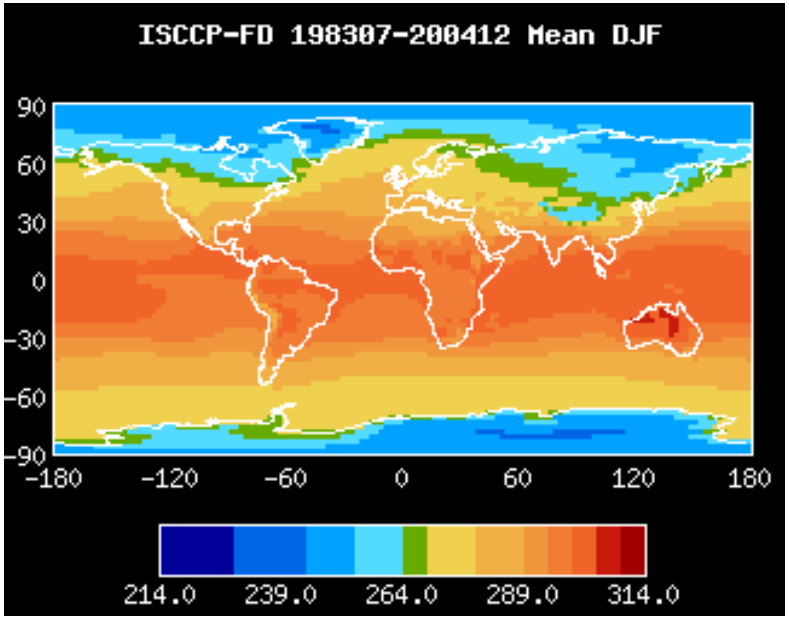
Surface Net (Solar + Longwave) Flux

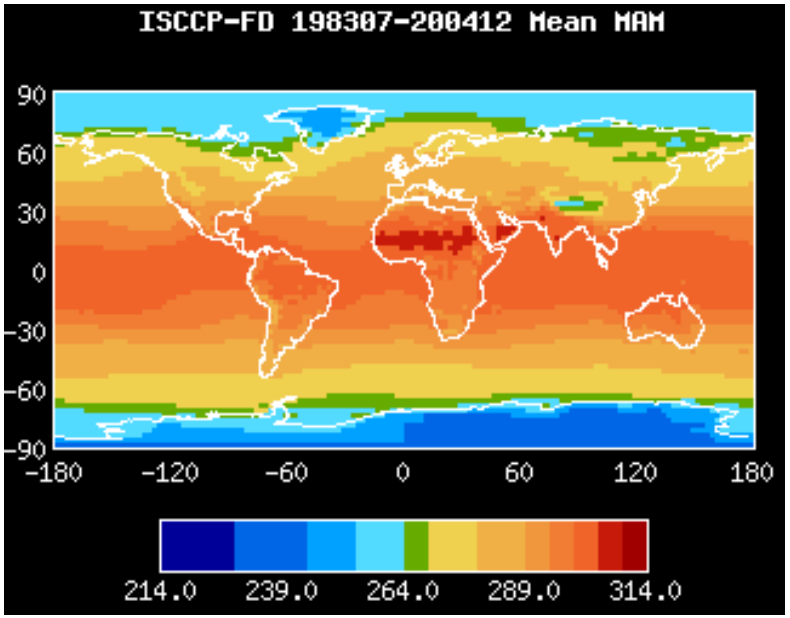


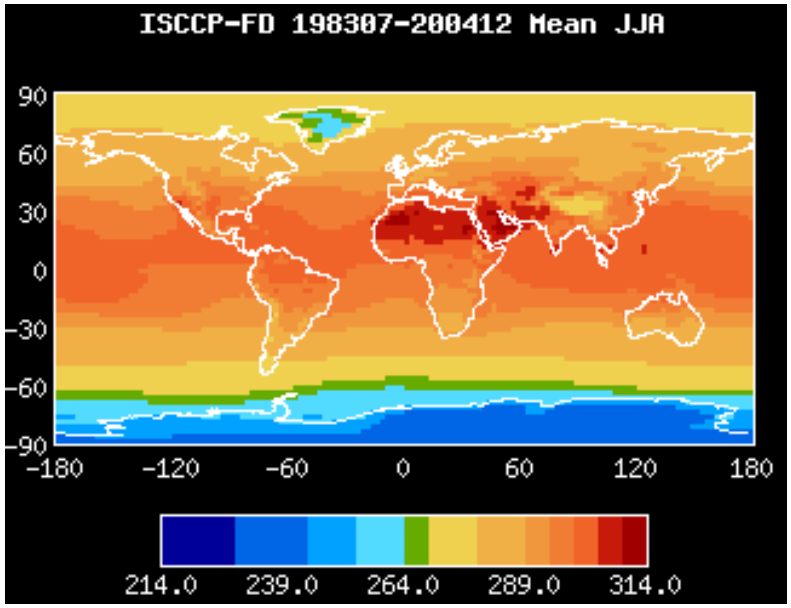
Global Surface Temperature: 1983-2009

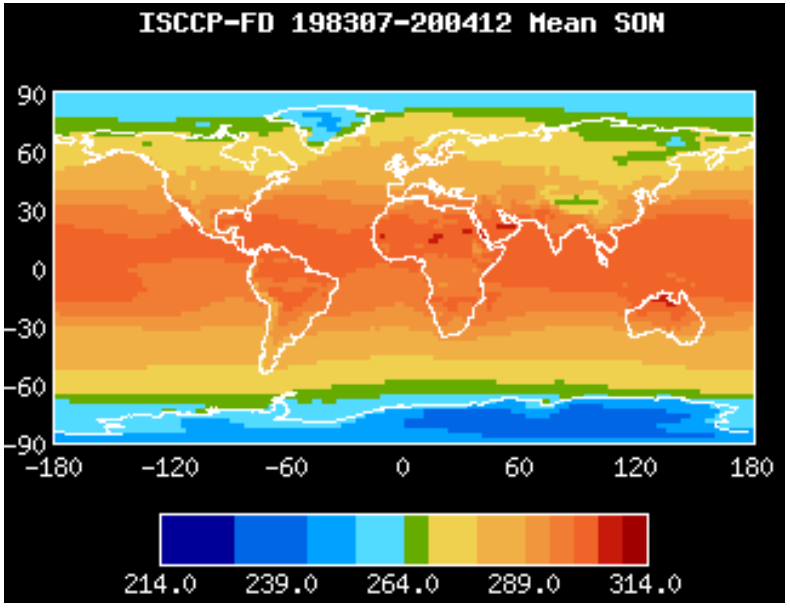


Global Seasonal Surface Temperature: 1983-2004

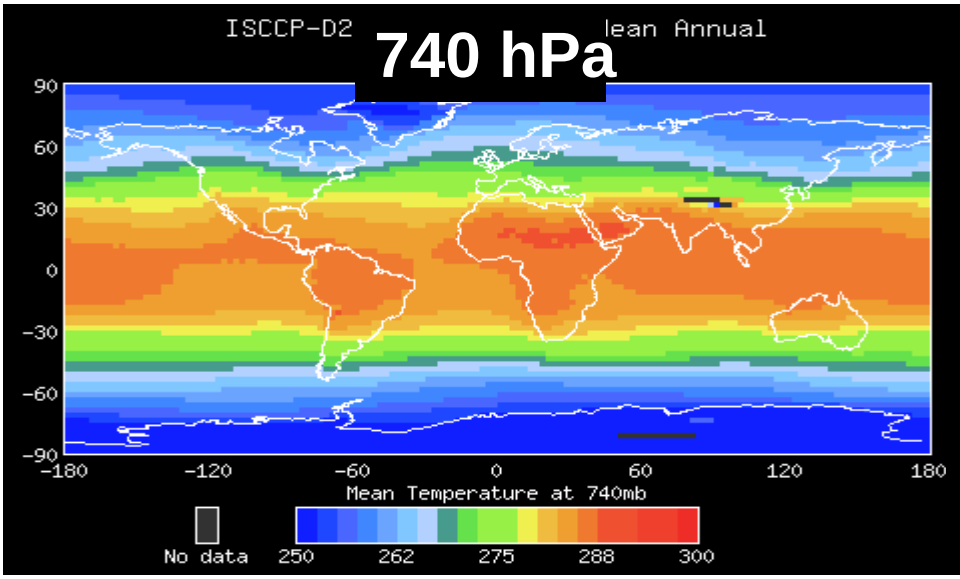


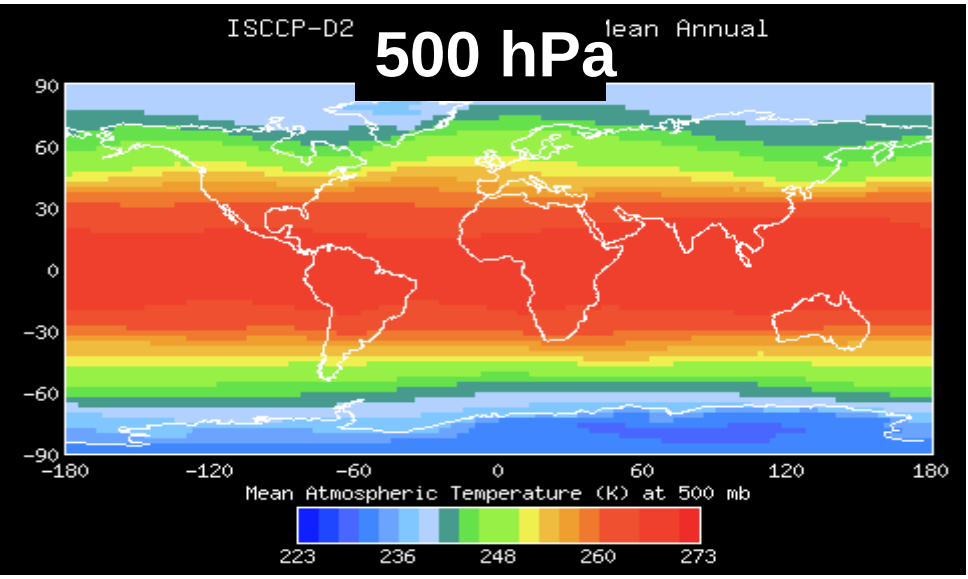


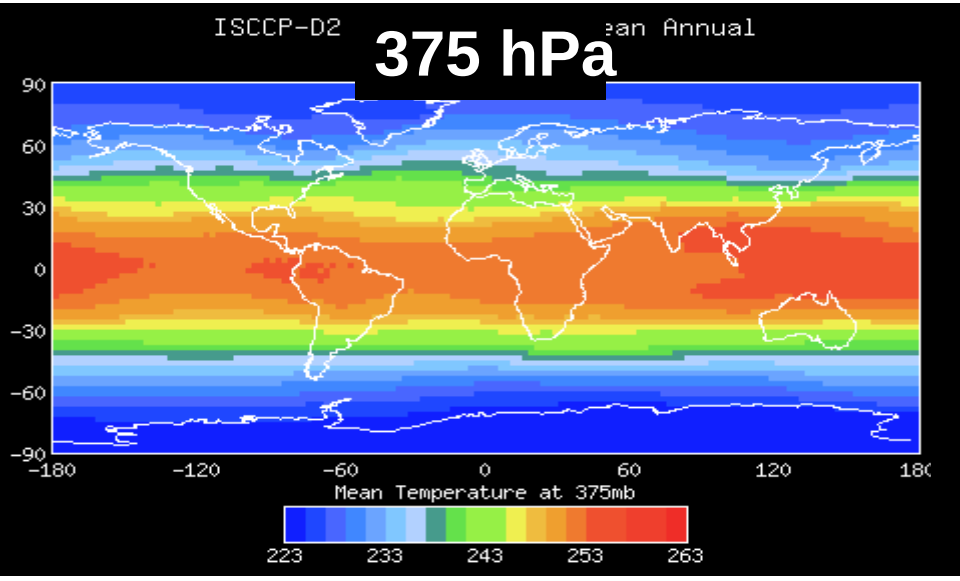


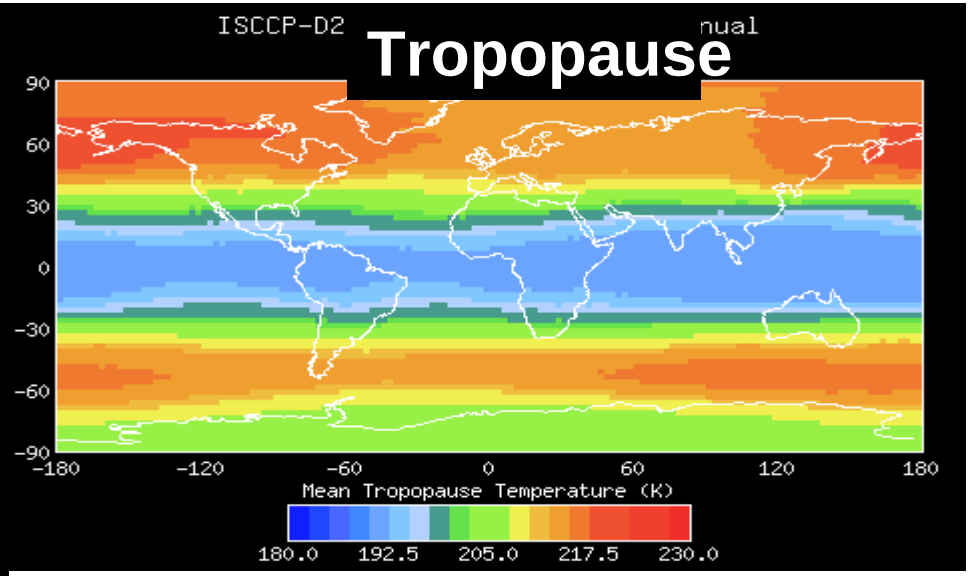


Tropospheric Air Temperature: 1983-2009

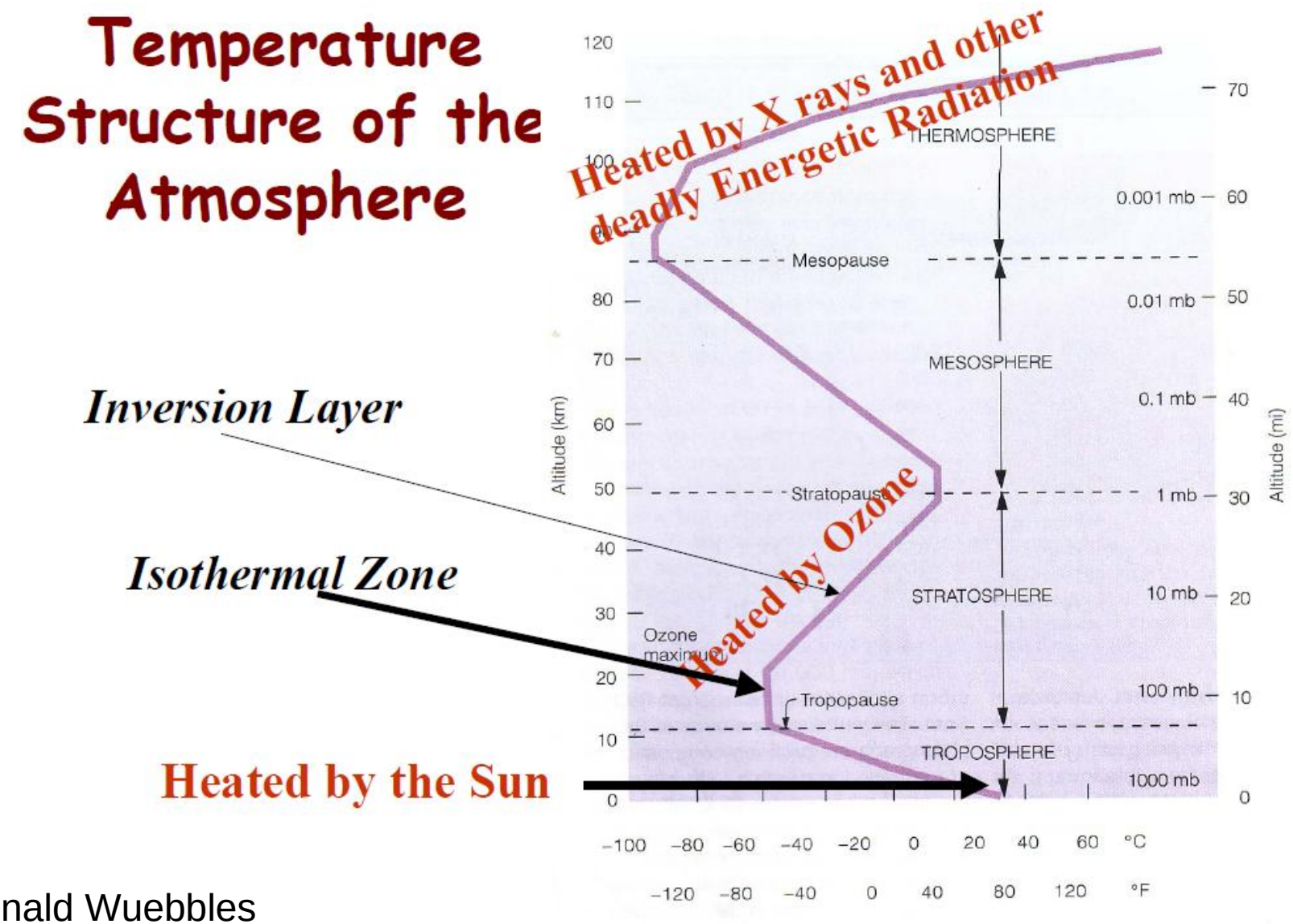






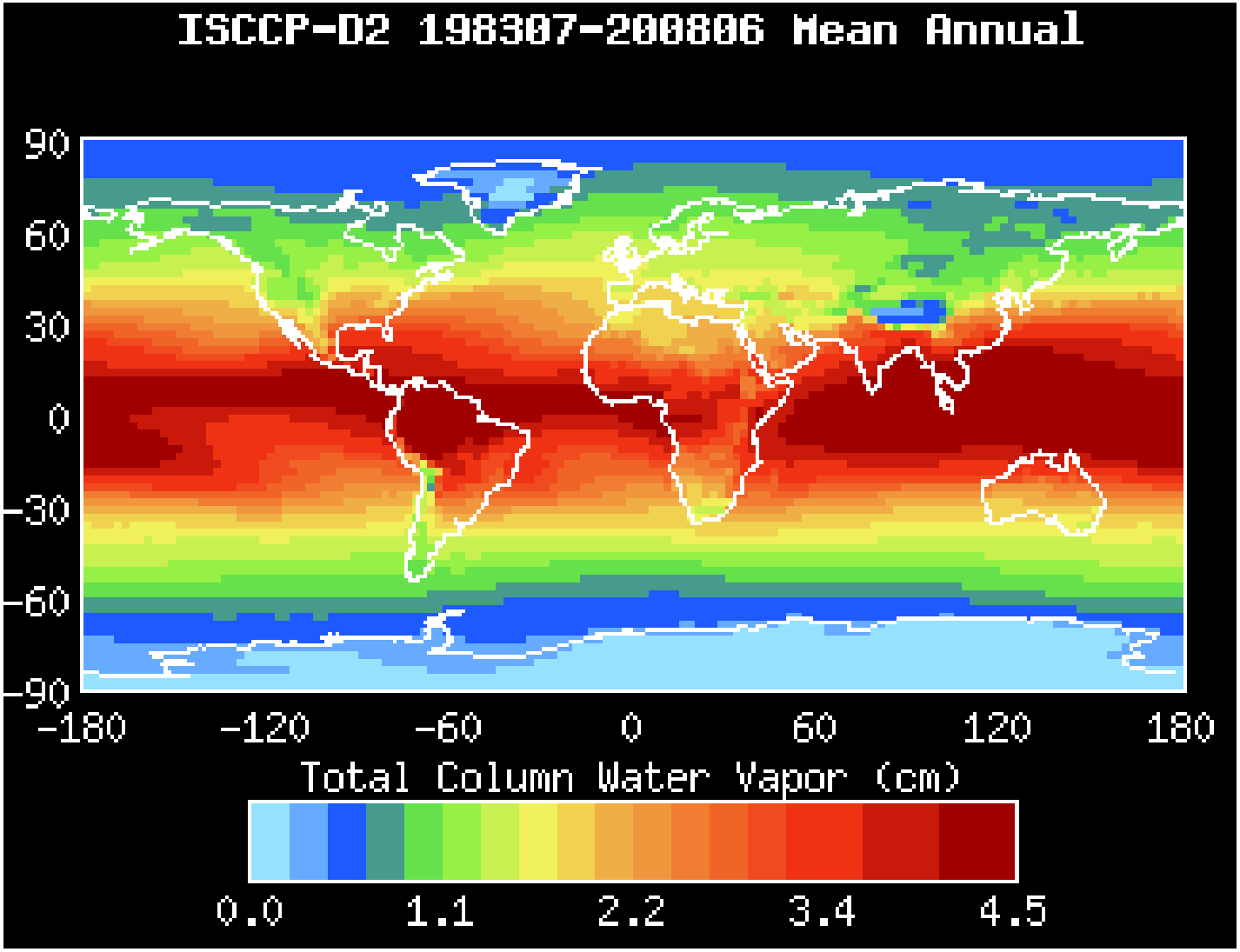


Vertical Distribution of Air Temperature and Its Drivers

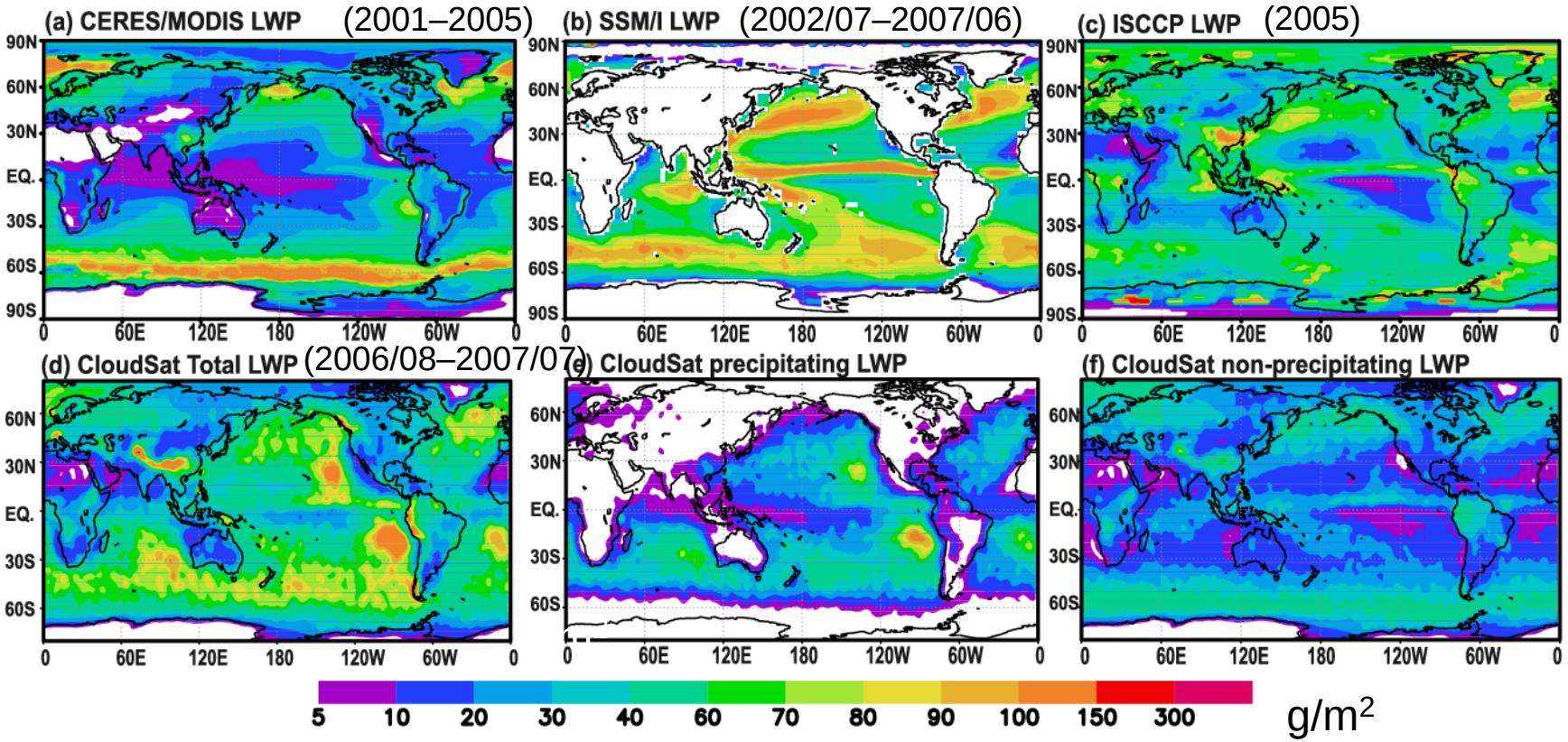


Donald Wuebbles

Global Water Vapor Content: 1983-2008

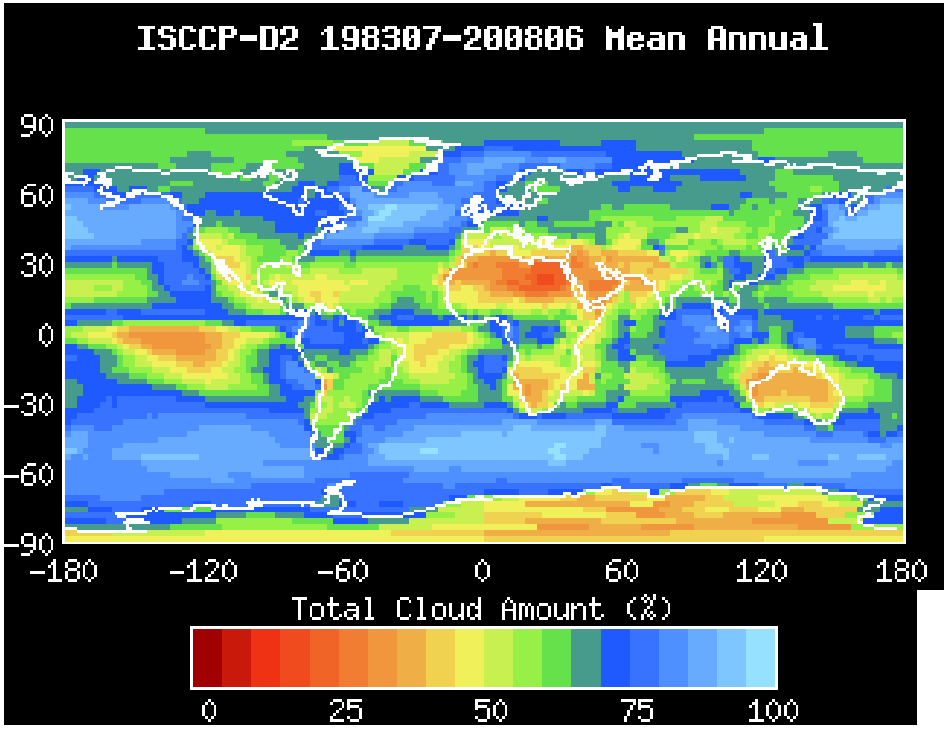


Global Cloud Water Content: 1983-2008

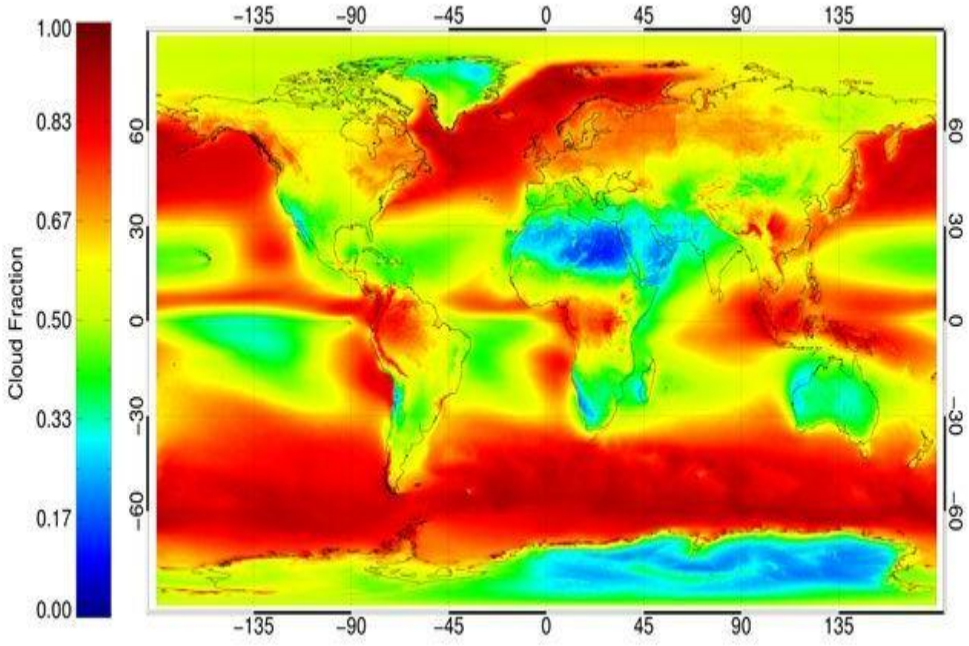


1 mm ~ 1000 g/m^2

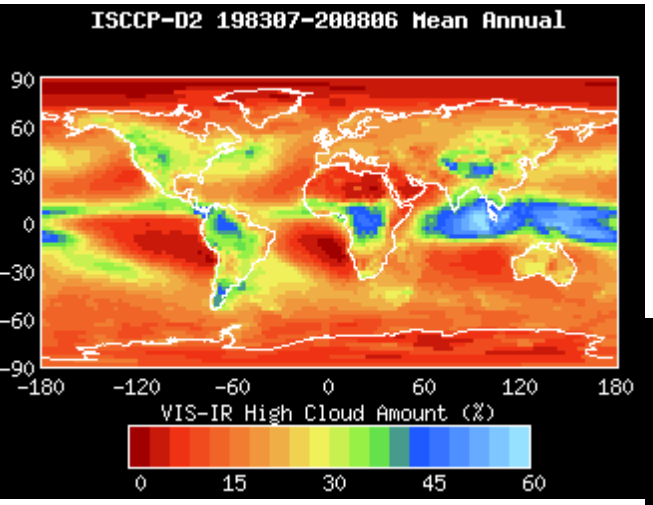
Global Cloud Cover



CLARA-A2 (1982-2015)

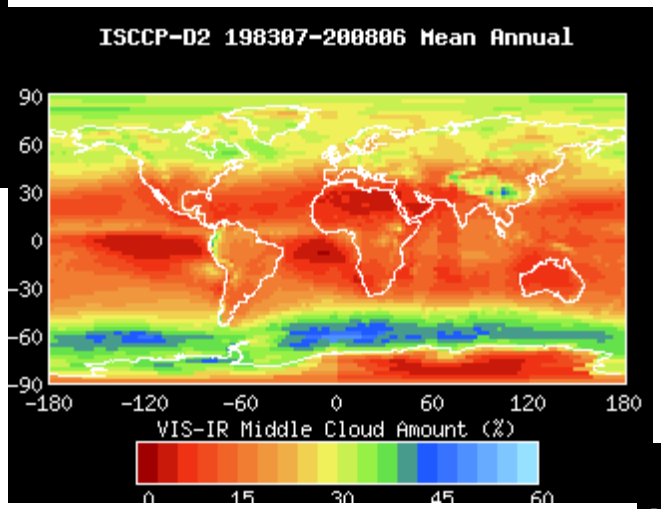


Global Cloud Cover at Different Heights: 1983-2008

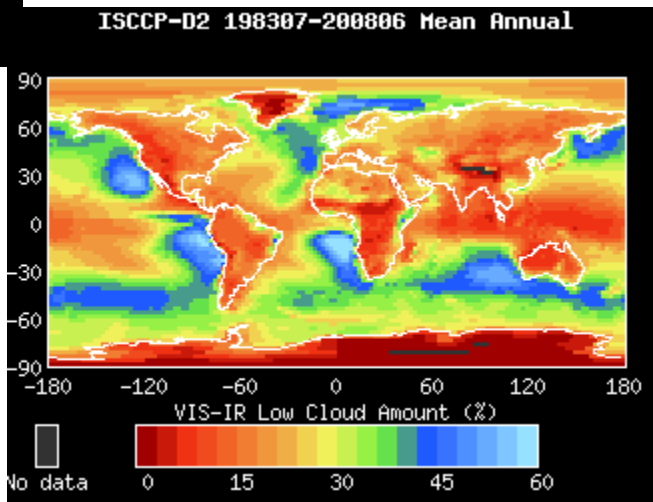


High cloud (< 440 hPa)

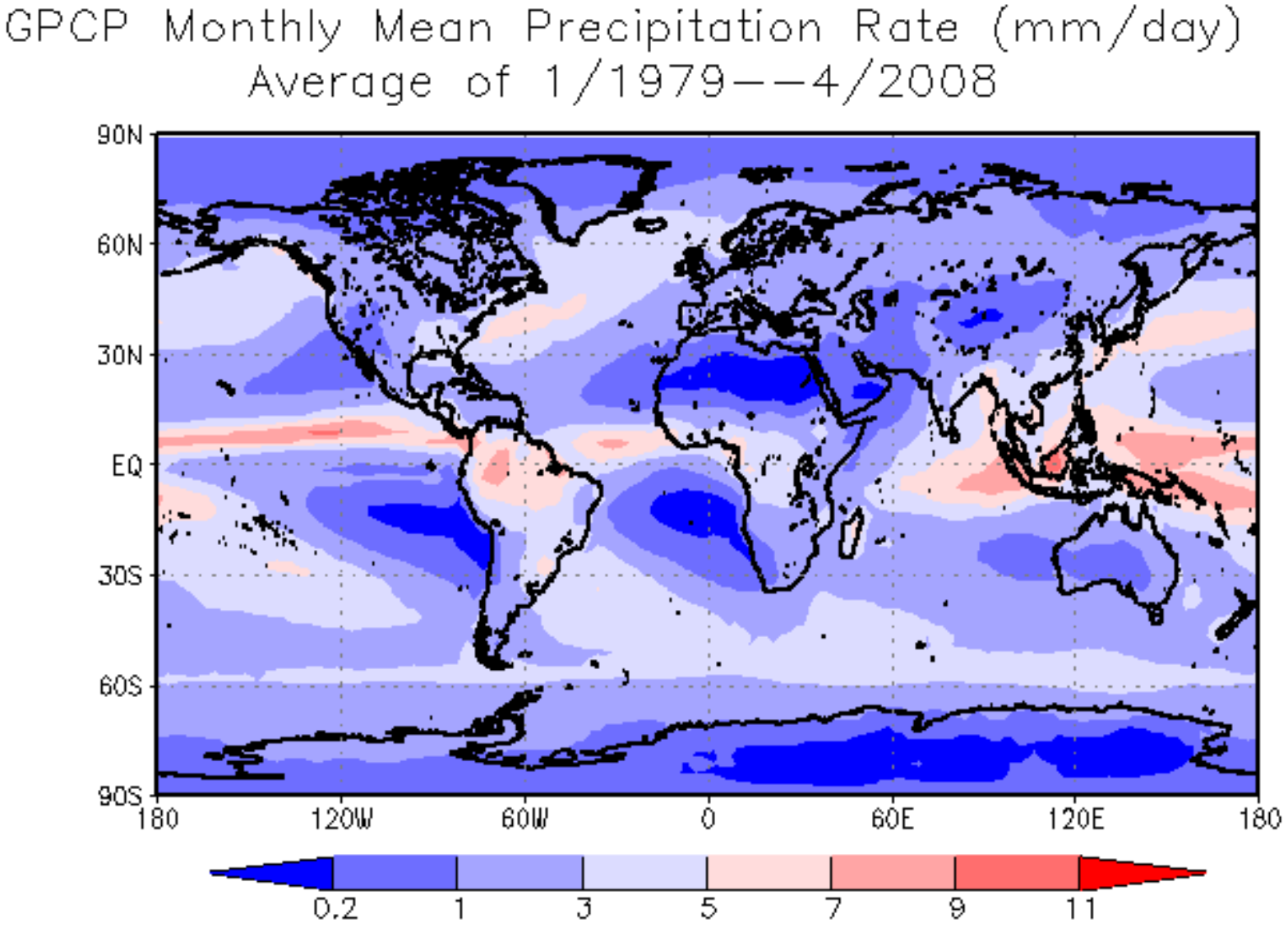
Middle cloud (440–680 hPa)



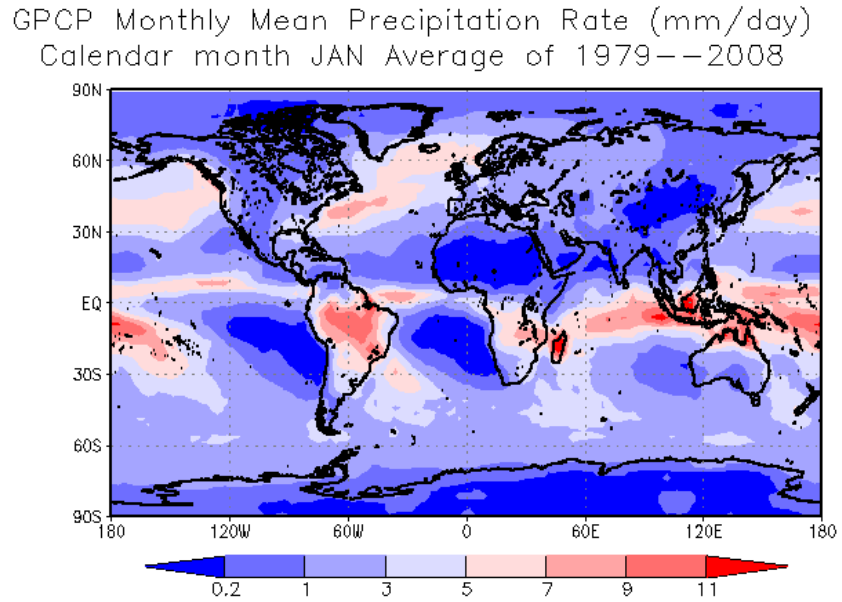
Low cloud (> 680 hPa)

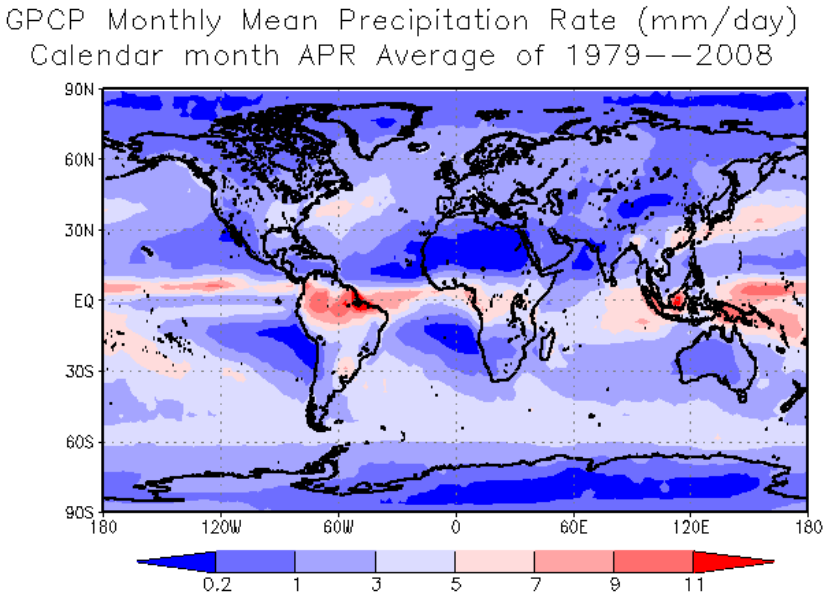


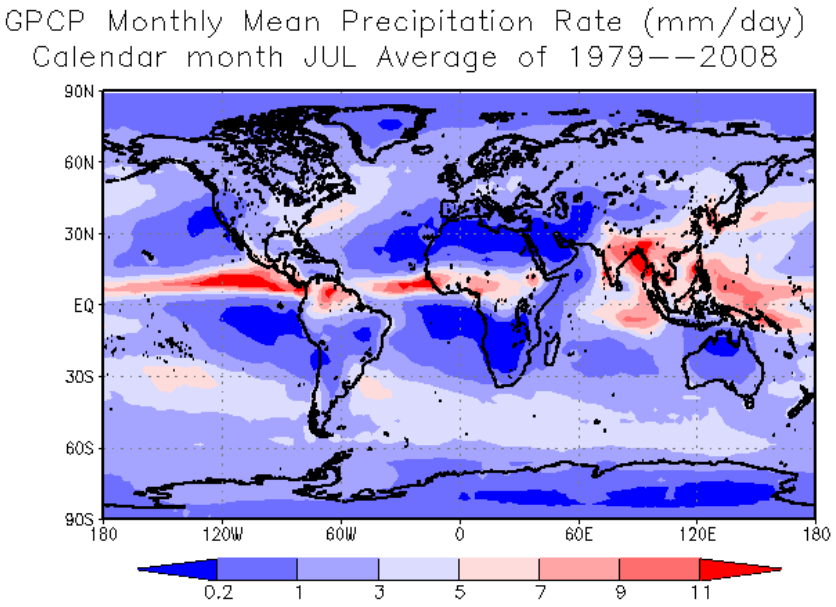
Global Precipitation: 1979-2008

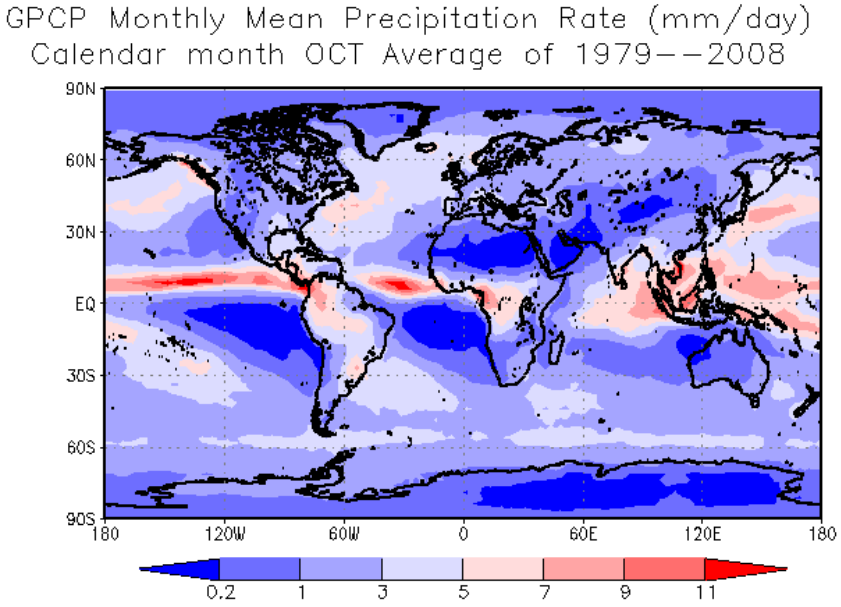


Global Seasonal Precipitation: 1979-2008







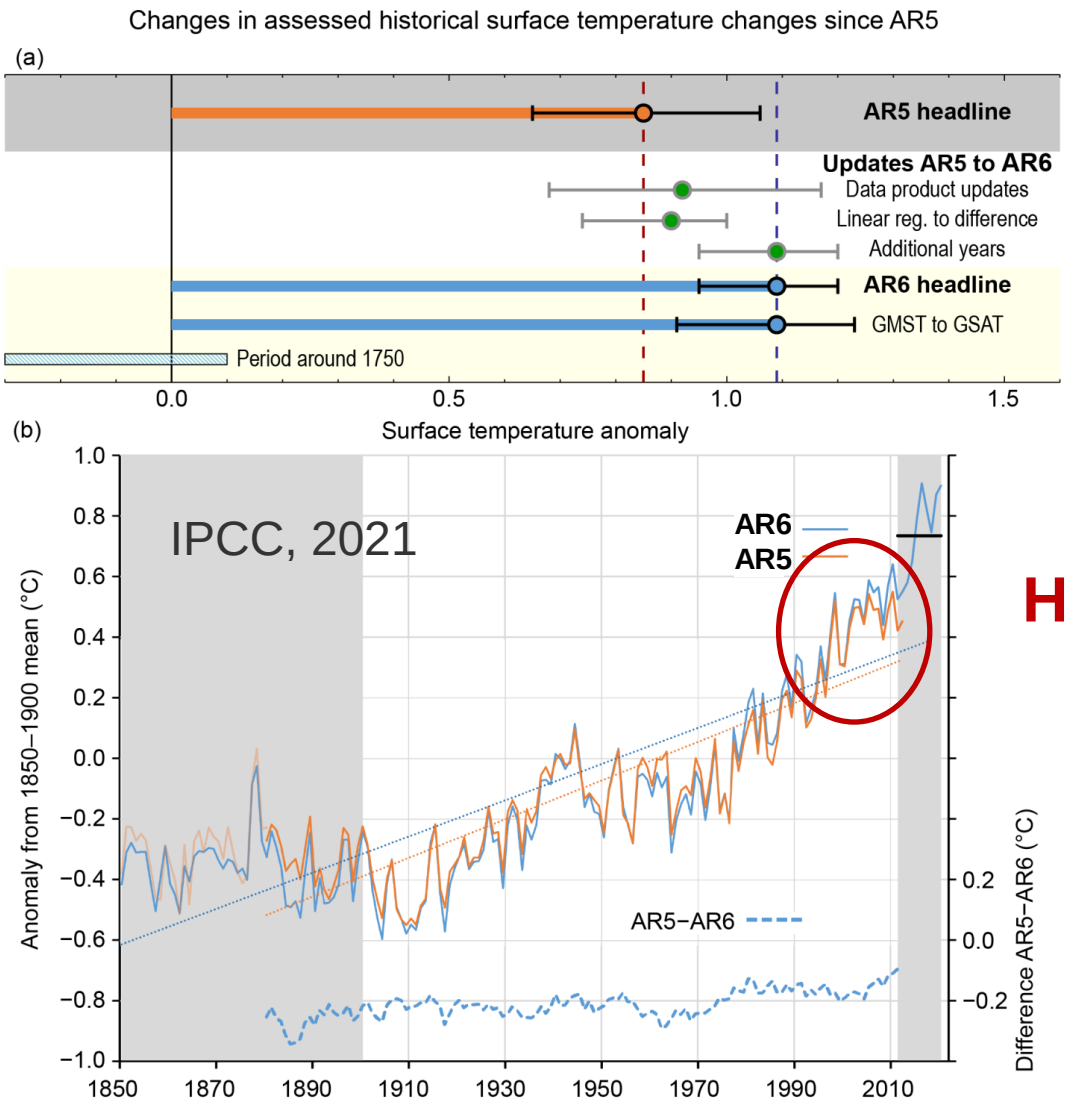


Global Warming

2022

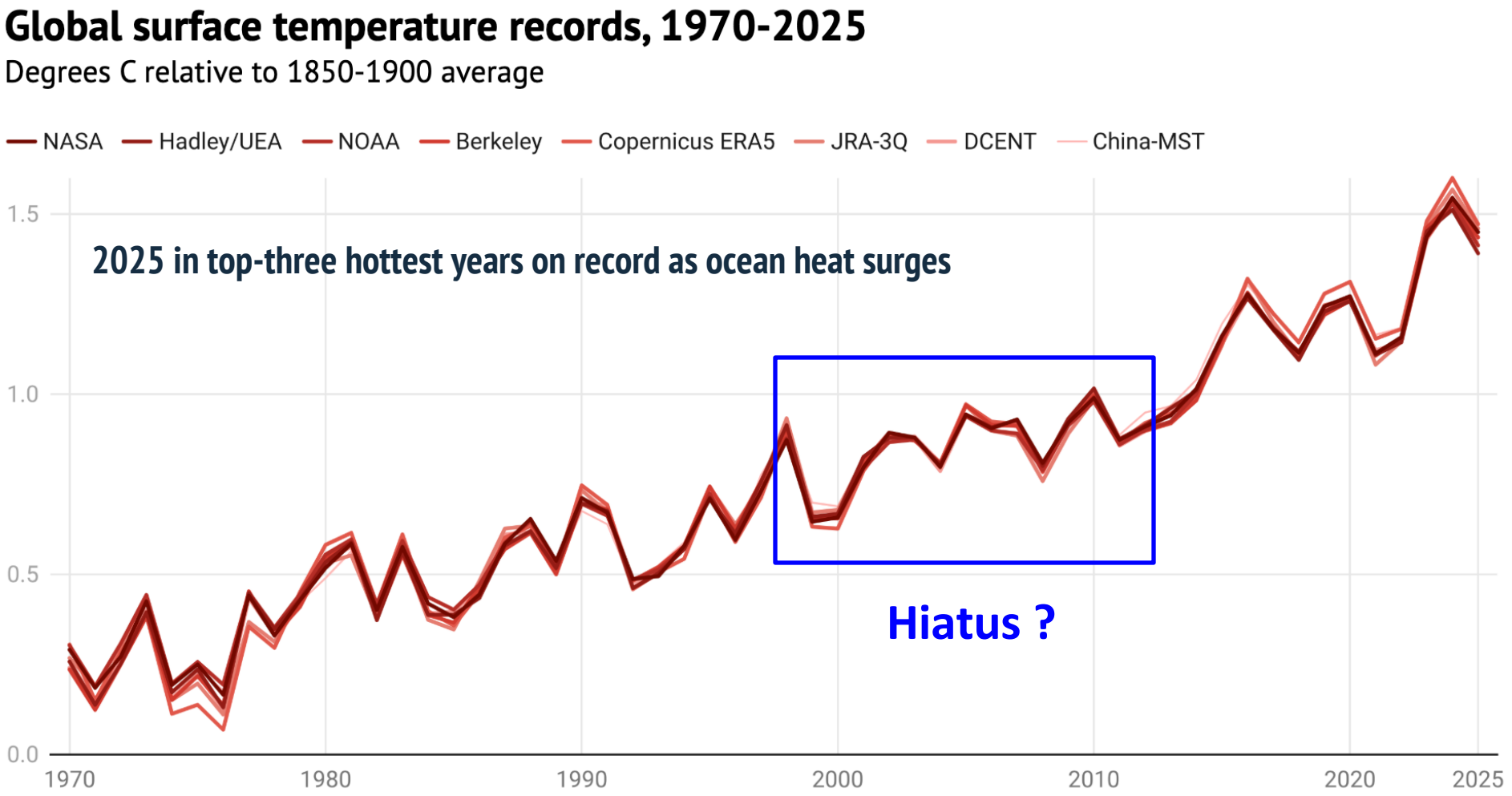


Global Temperature Change In Industrial Era



Hiatus

Global Temperature Change In Industrial Era

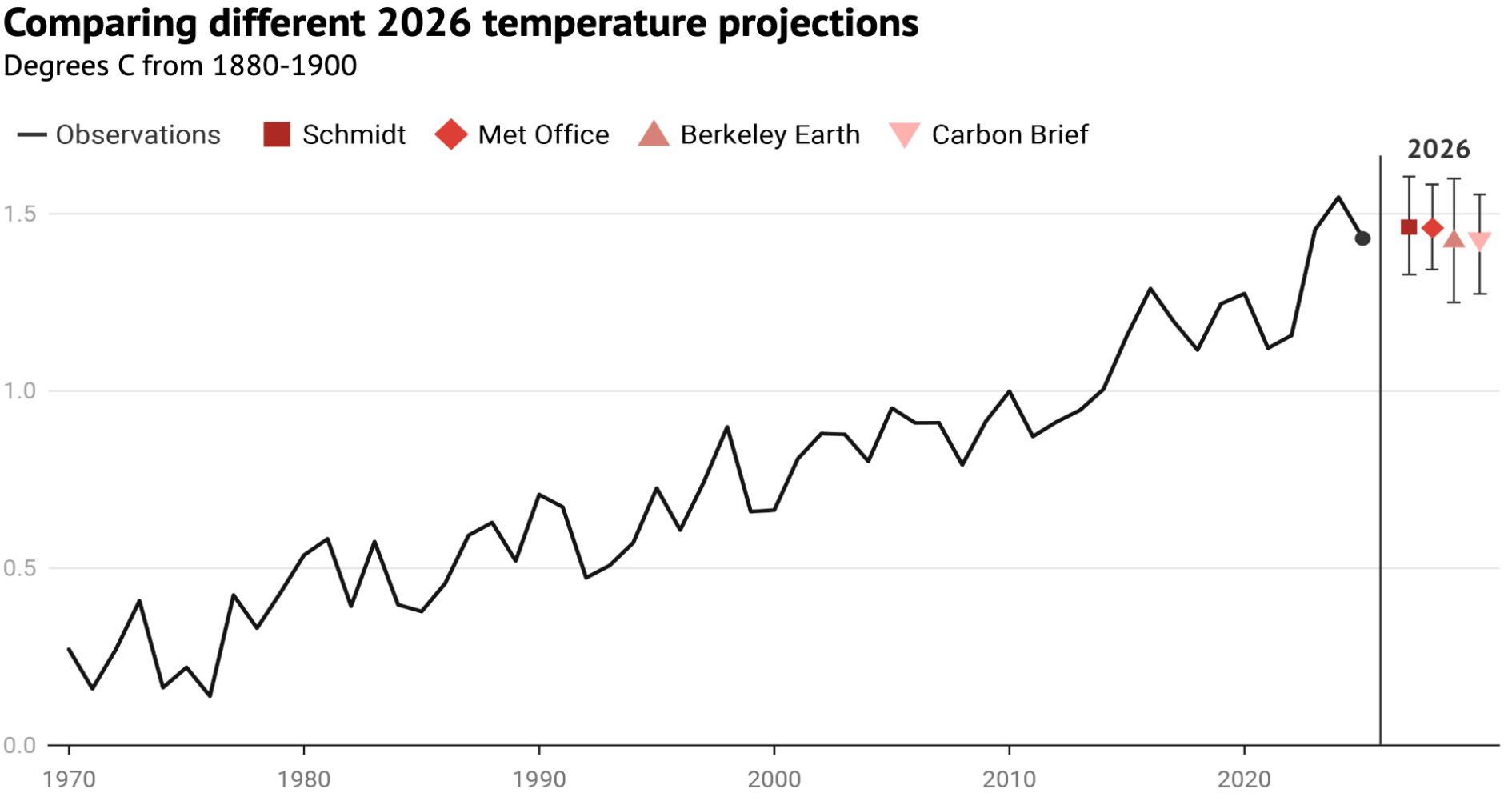


Source: NASA GISTEMP, NOAA GlobalTemp, Hadley/UEA HadCRUT5, Berkeley Earth, Copernicus ERA5, JRA-3Q, DCENT and China-MST

CarbonBrief
CLEAR ON CLIMATE

https://www.carbonbrief.org/state-of-the-climate-2025-in-top-three-hottest-years-on-record-as-ocean-heat-surges-9

Global Temperature Change In Industrial Era

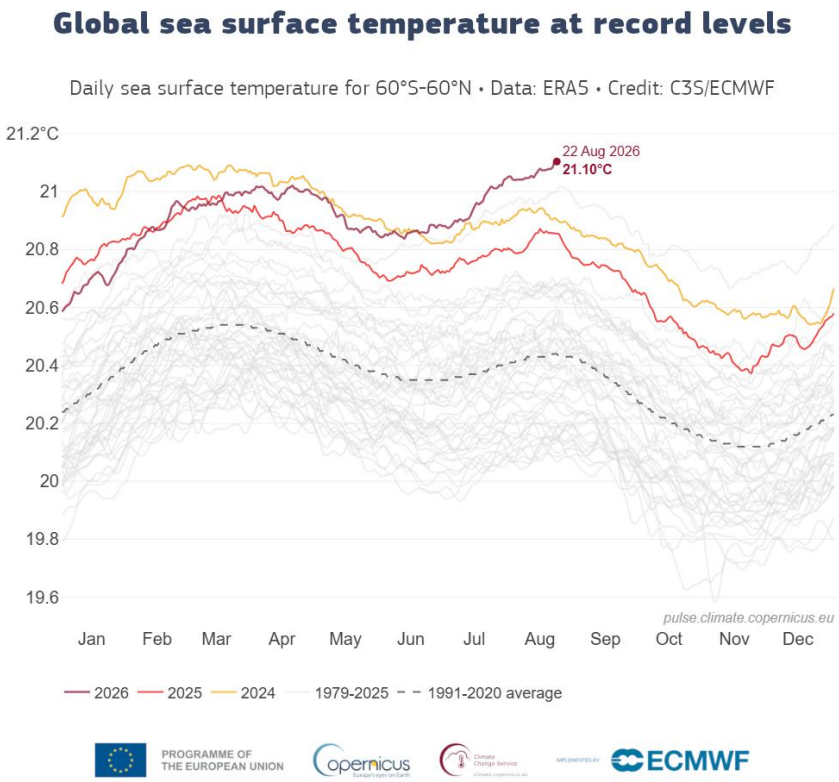


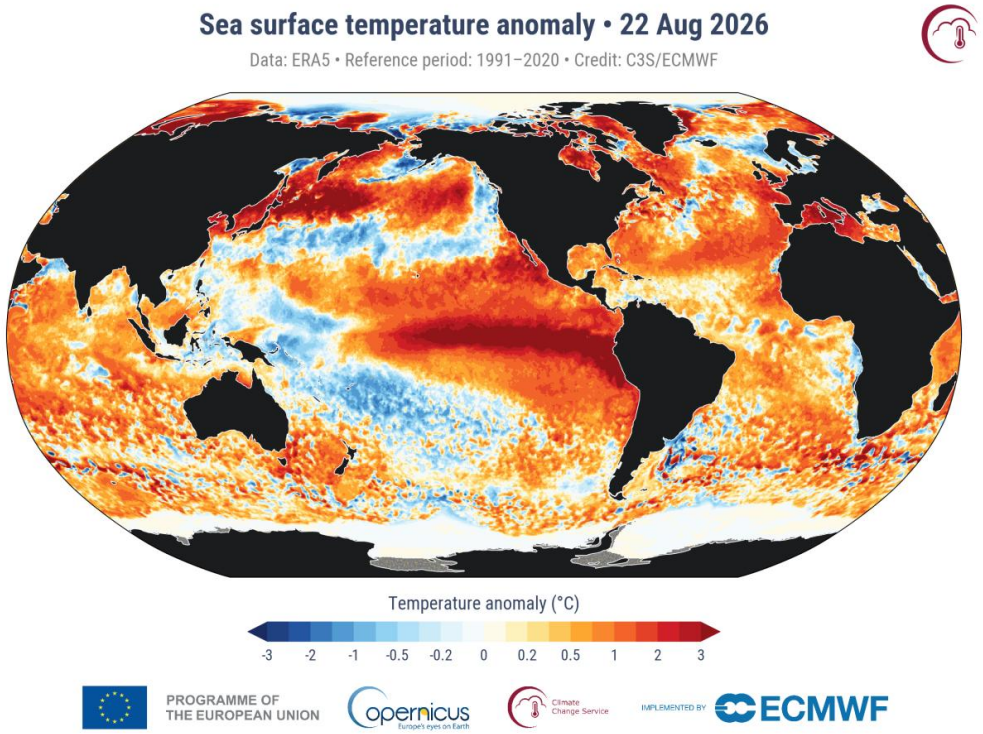
Source: NASA, NOAA, Hadley/UAE, Copernicus, JRA-3Q, DCENT, China-MST, UK Met Office, Schmidt, Berkeley Earth, Carbon Brief analysis

CarbonBrief
CLEAR ON CLIMATE

https://www.carbonbrief.org/state-of-the-climate-2025-in-top-three-hottest-years-on-record-as-ocean-heat-surges-9

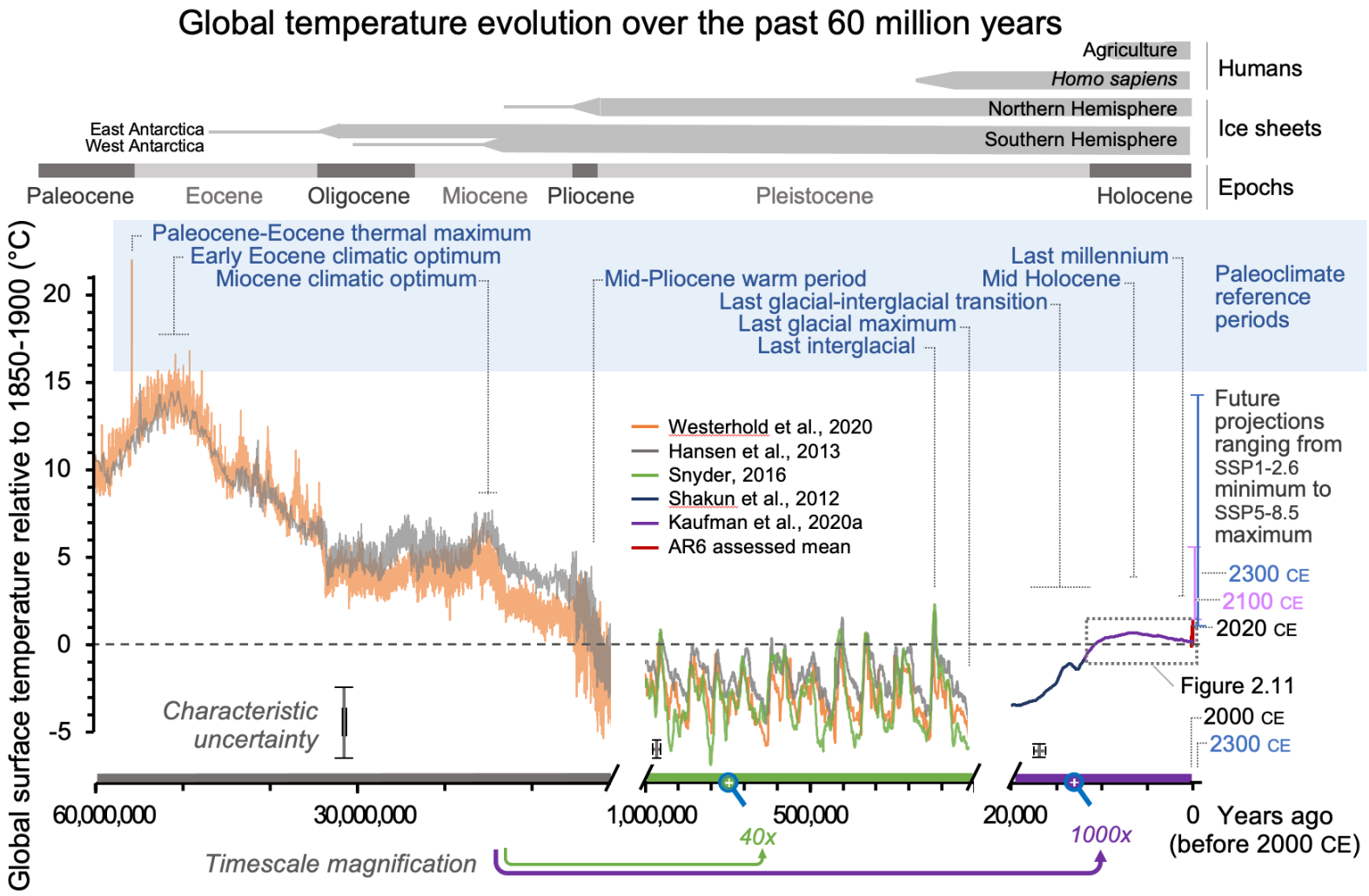
Global Sea Surface Temperature at Record Levels





https://climate.copernicus.eu/copernicus-daily-global-sea-surface-temperature-breaks-2024-record

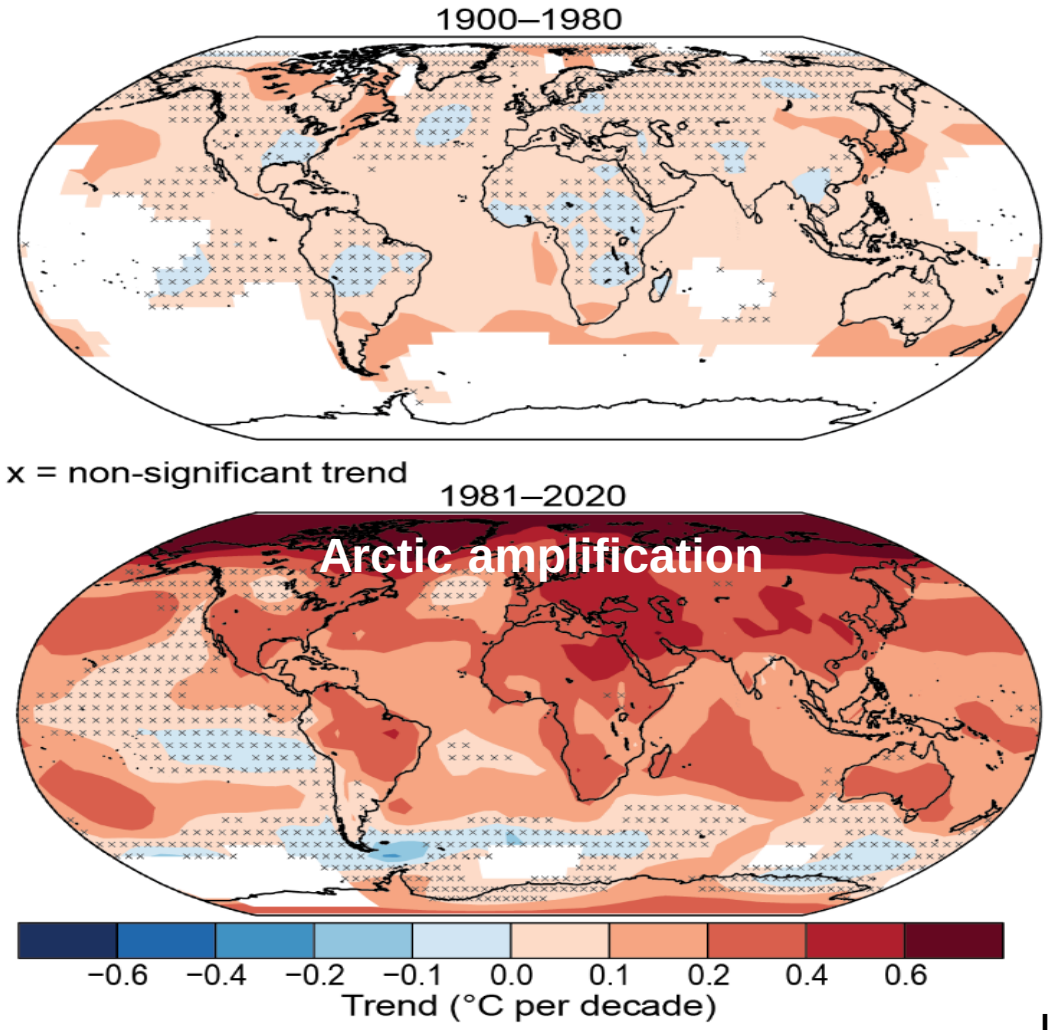
Global Temperature Evolution



Paleocene 古新世；Eocene 始新世；Oligocene 渐新世；
Miocene 中新世；Pliocene 上新世；Pleistocene 更新世；
Holocene 全新世；Quaternary 第四纪

IPCC, 2021

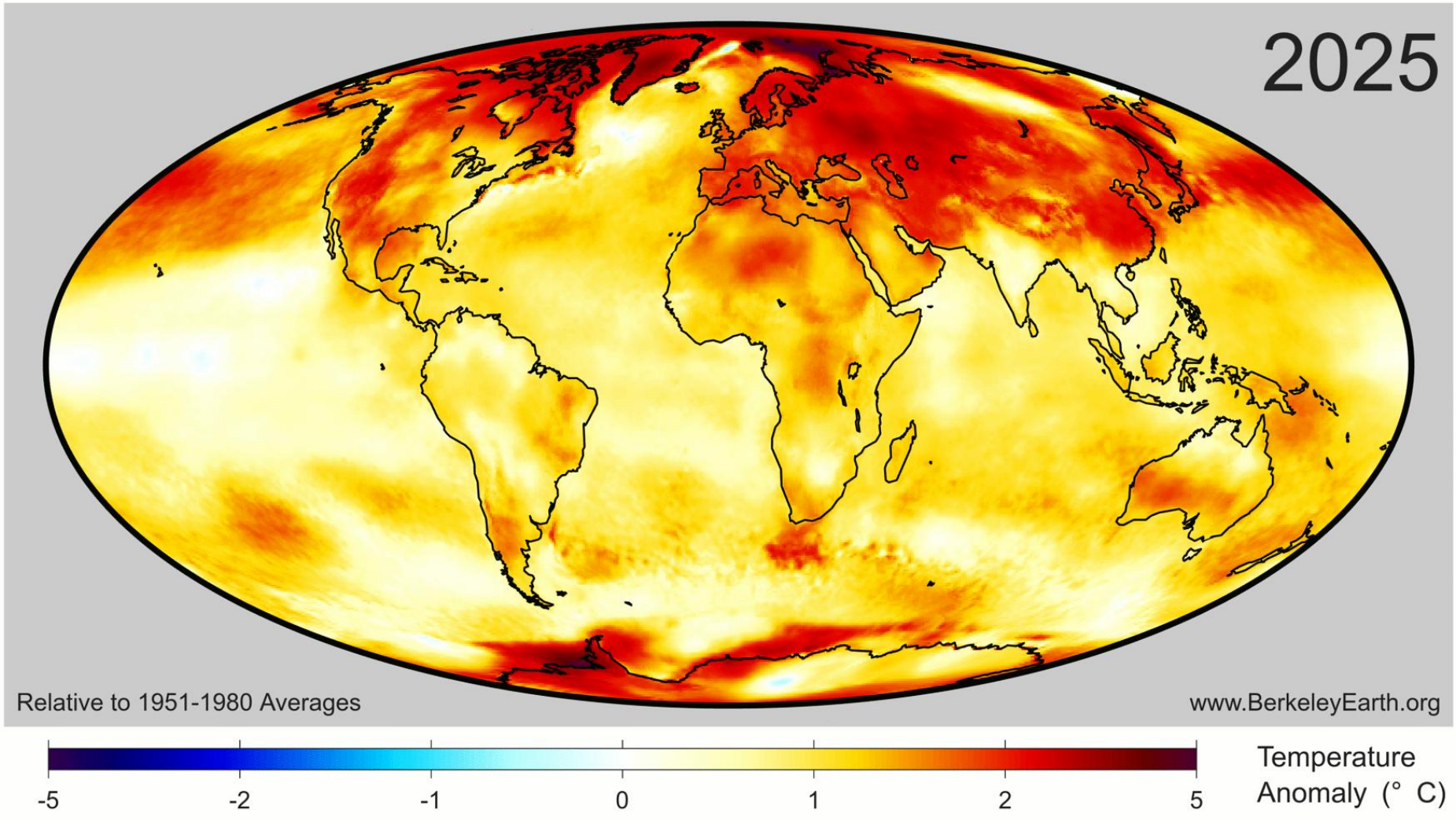
Global Temperature Trend: Spatial Heterogeneity



IPCC, 2021

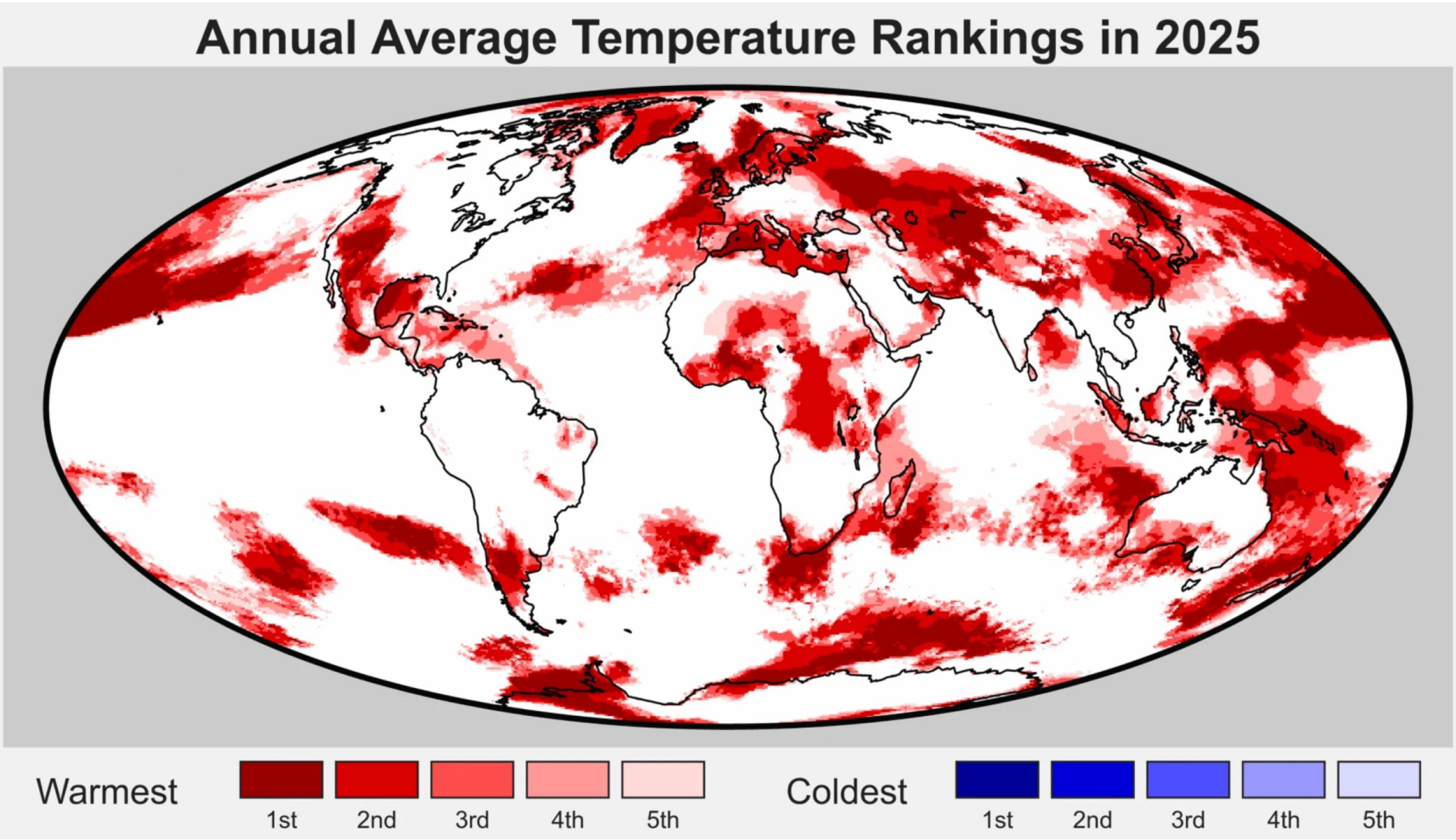
Jim Hansen: ΔT variability and biodiversity?

Global Temperature Anomaly: 2025



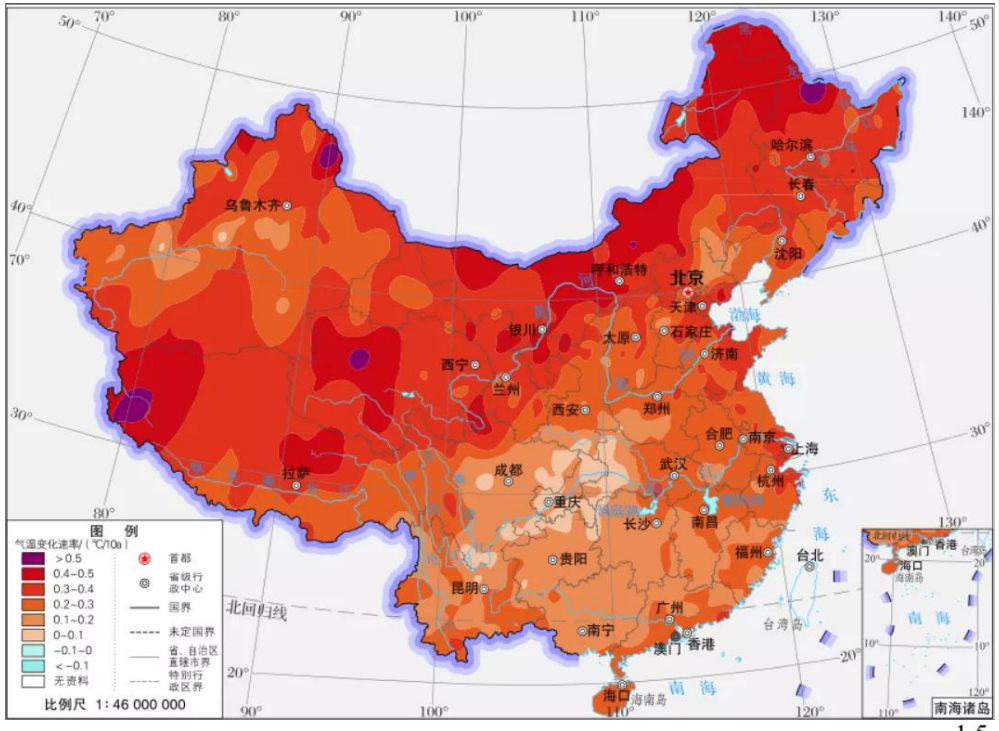
https://www.carbonbrief.org/state-of-the-climate-2025-in-top-three-hottest-years-on-record-as-ocean-heat-surges-9

Global Temperature Anomaly: 2025



https://www.carbonbrief.org/state-of-the-climate-2025-in-top-three-hottest-years-on-record-as-ocean-heat-surges-9

China Temperature Anomaly: 1901-2020

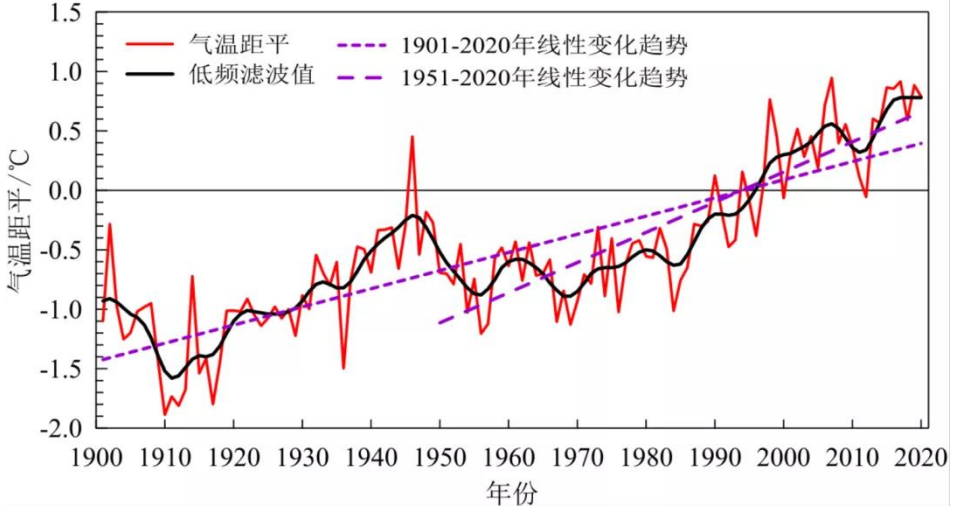


中国气候变化蓝皮书（2021）

- 中国是全球气候变化的敏感区和影响显著区，升温速率明显高于同期全球平均水平。
- 1951~2020年，中国地表年平均气温呈显著上升趋势，升温速率为0. 26℃/10年。
- 近20年是20世纪初以来的最暖时期，1901年以来的10个最暖年份中，除1998年，其余9个均出现在21世纪。

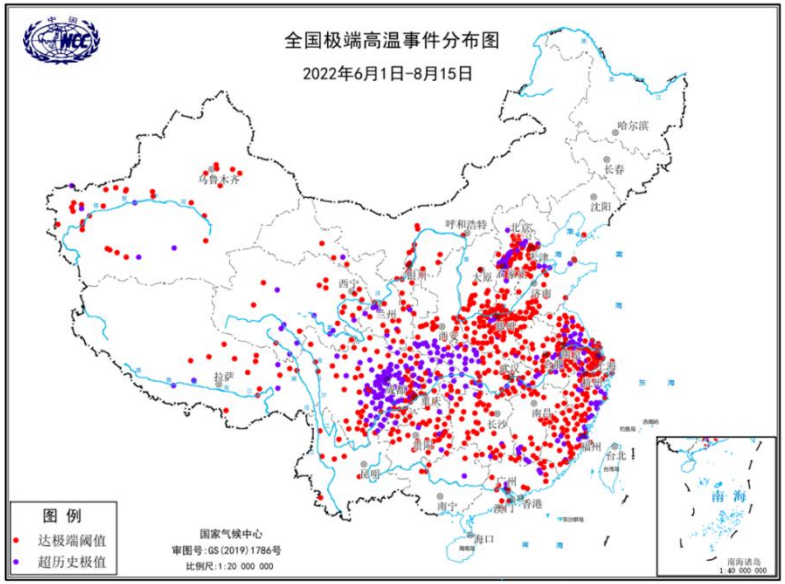
中国气候变化蓝皮书（2024）

- 2023年，我国地表平均气温较常年值偏高0.84℃，为1901年以来的最暖年份

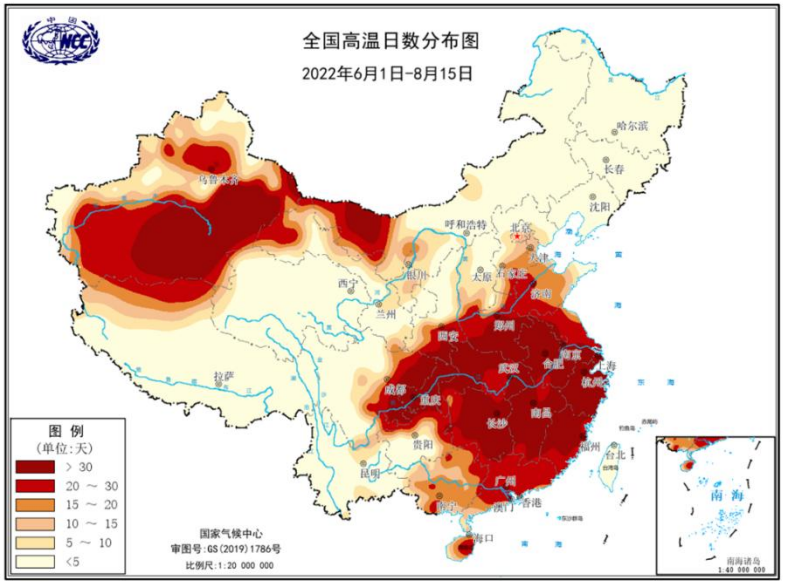


Heatwave in 2022 in China

极端高温事件（6月1日-8月15日）



高温日数（6月1日-8月15日）

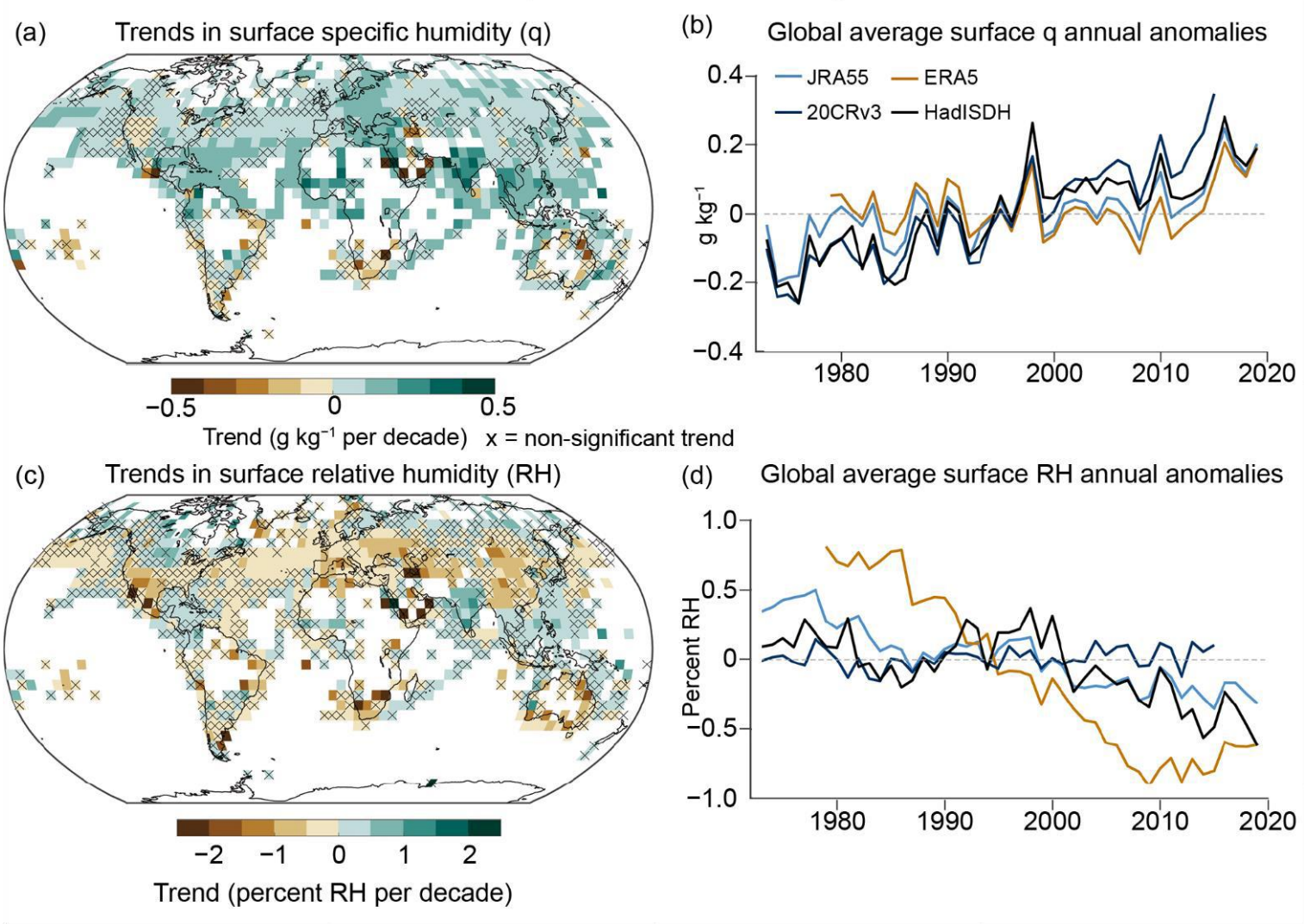


国家气候中心：

综合考虑高温热浪事件的平均强度、影响范围和持续时间，从今年6月13日开始至8月17日的区域性高温事件**综合强度已达到1961年有完整气象观测记录以来最强**

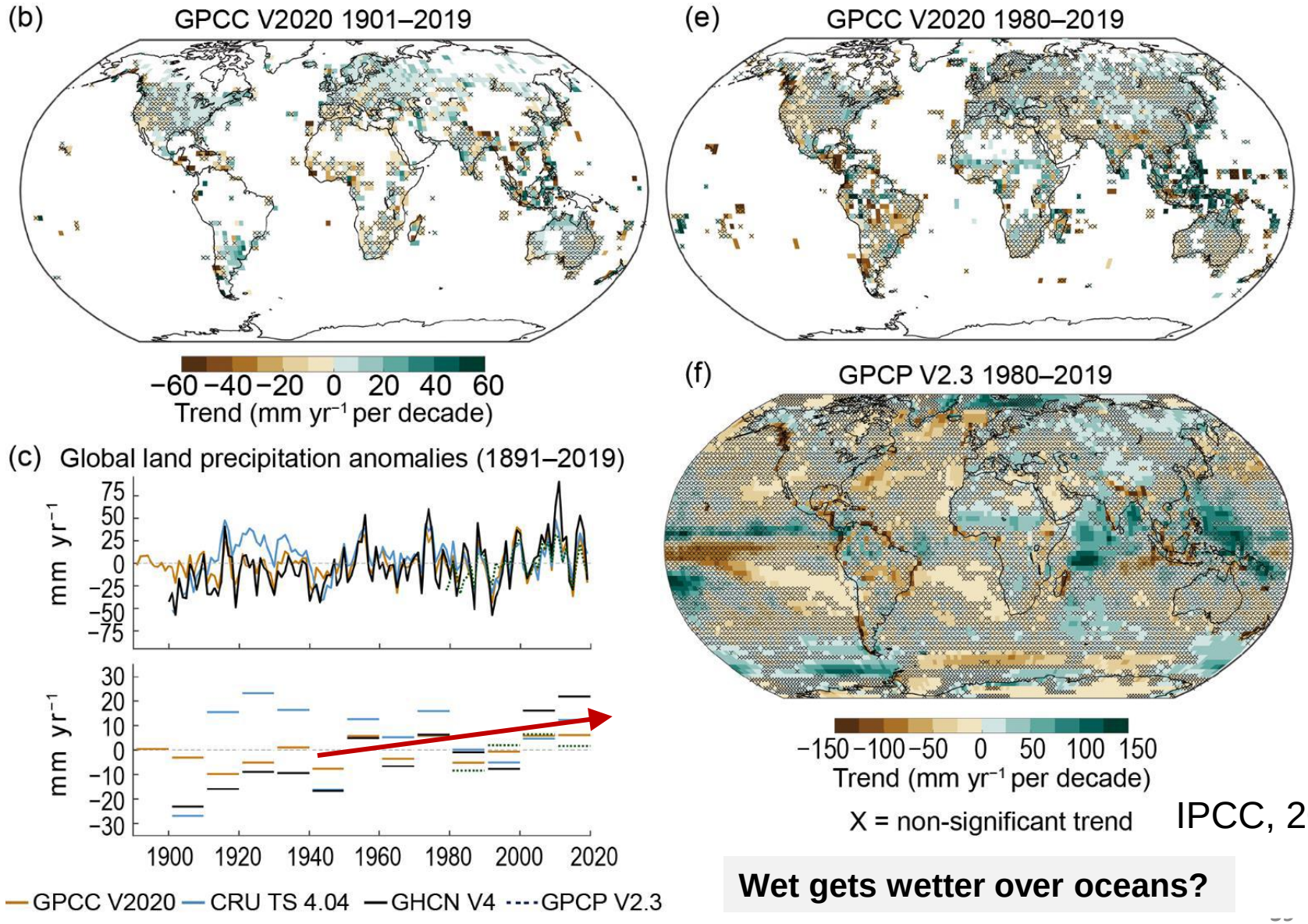


Humidity Change: 1973–2019



IPCC, 2021

Global Precipitation Anomaly: 1901–2019

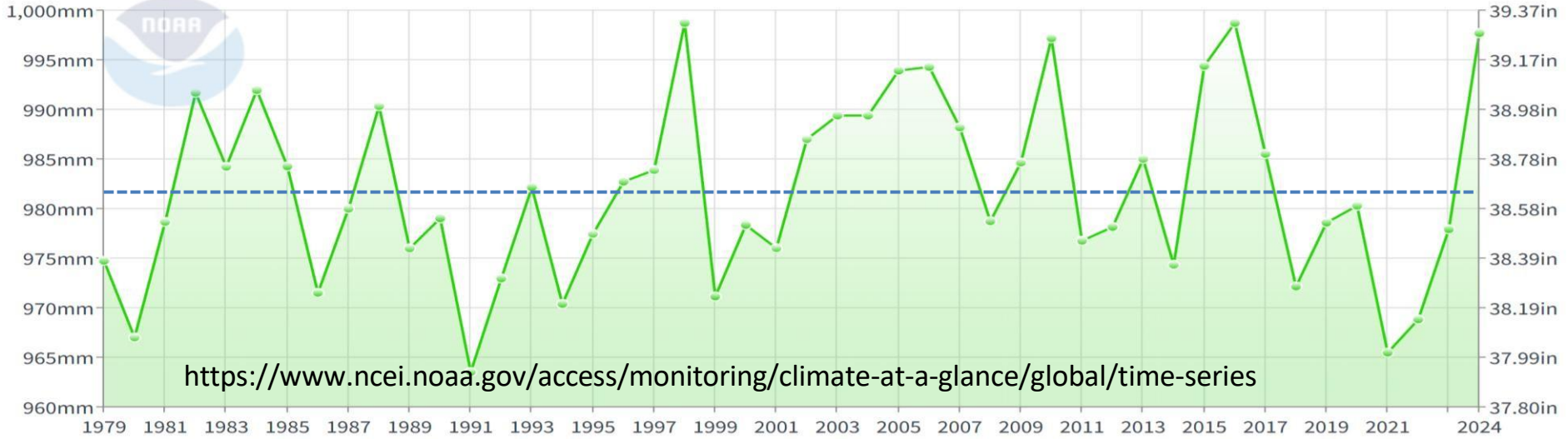


IPCC, 2021

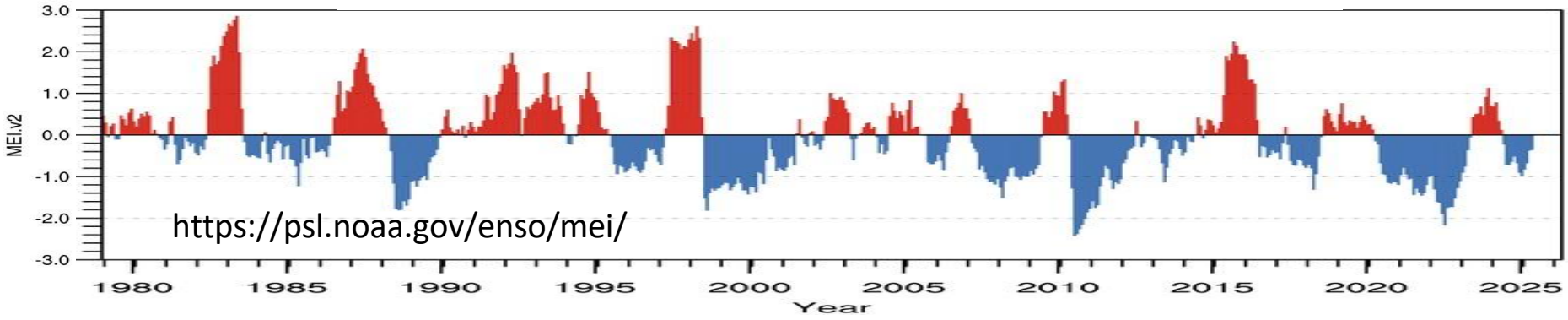
Wet gets wetter over oceans?

Global Precipitation Anomaly: 1979–2024

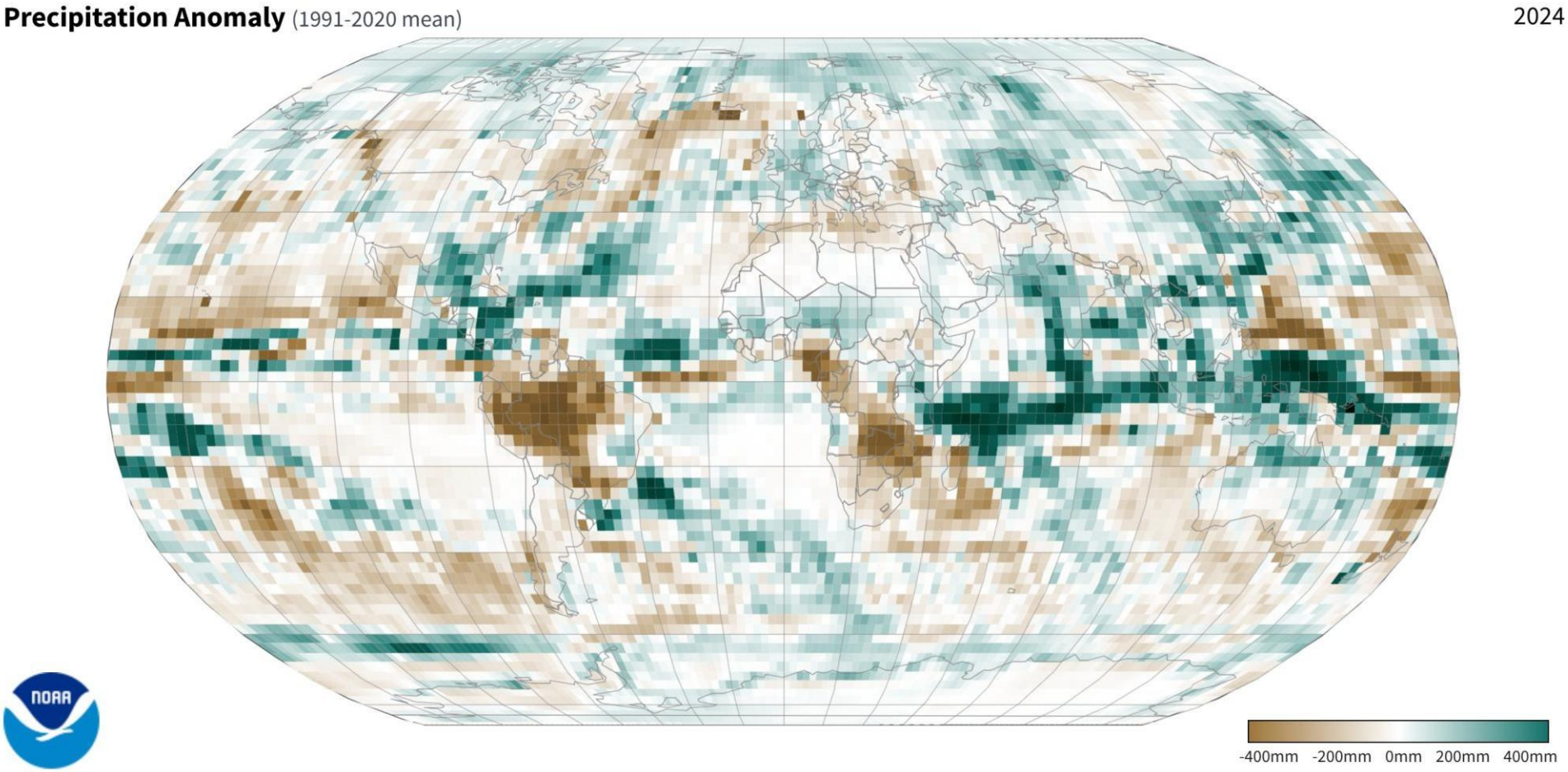
Global land and ocean annual precipitation



Multivariate ENSO index v2 using JRA3Q

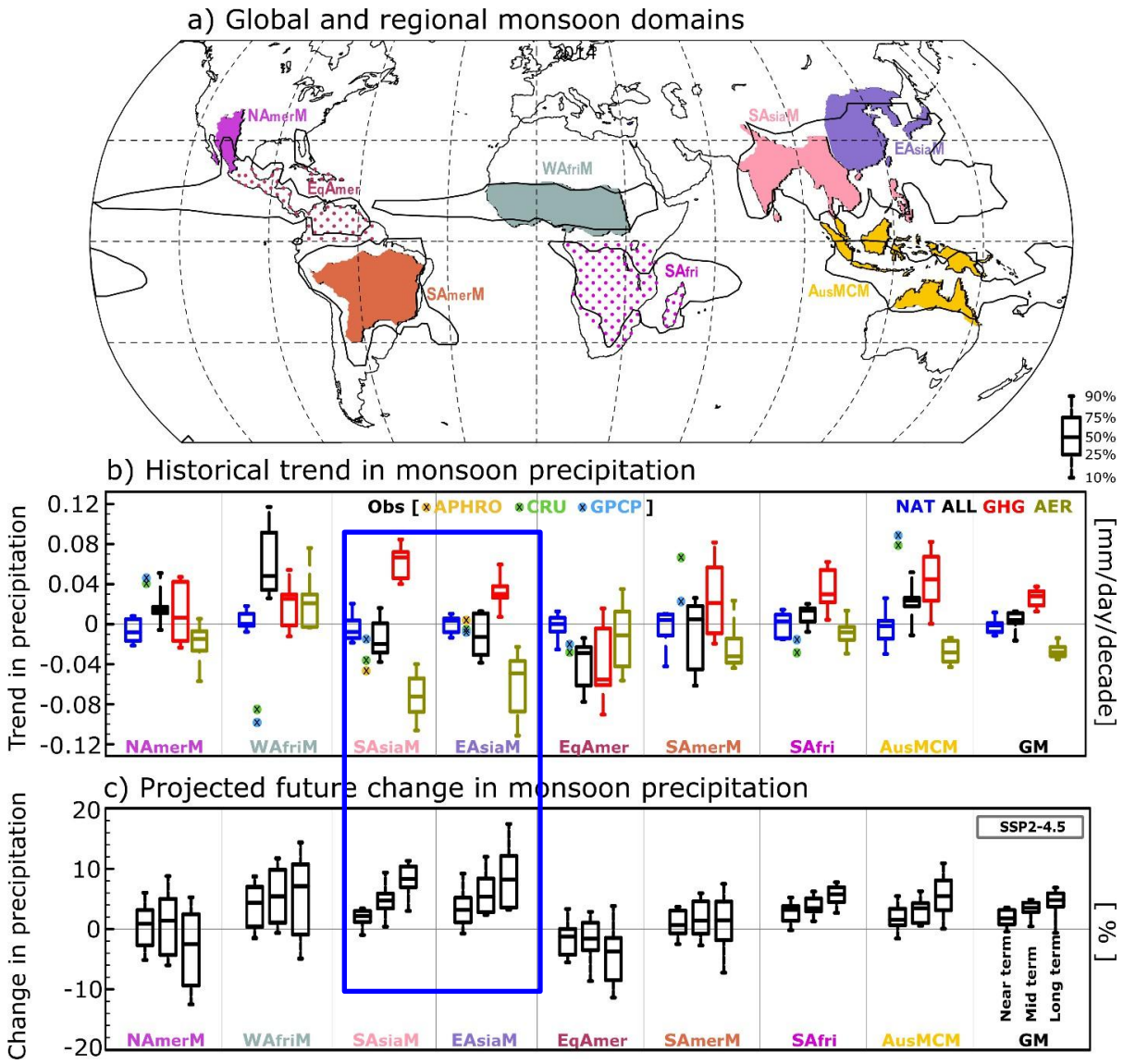


Global Precipitation Anomaly: 2024



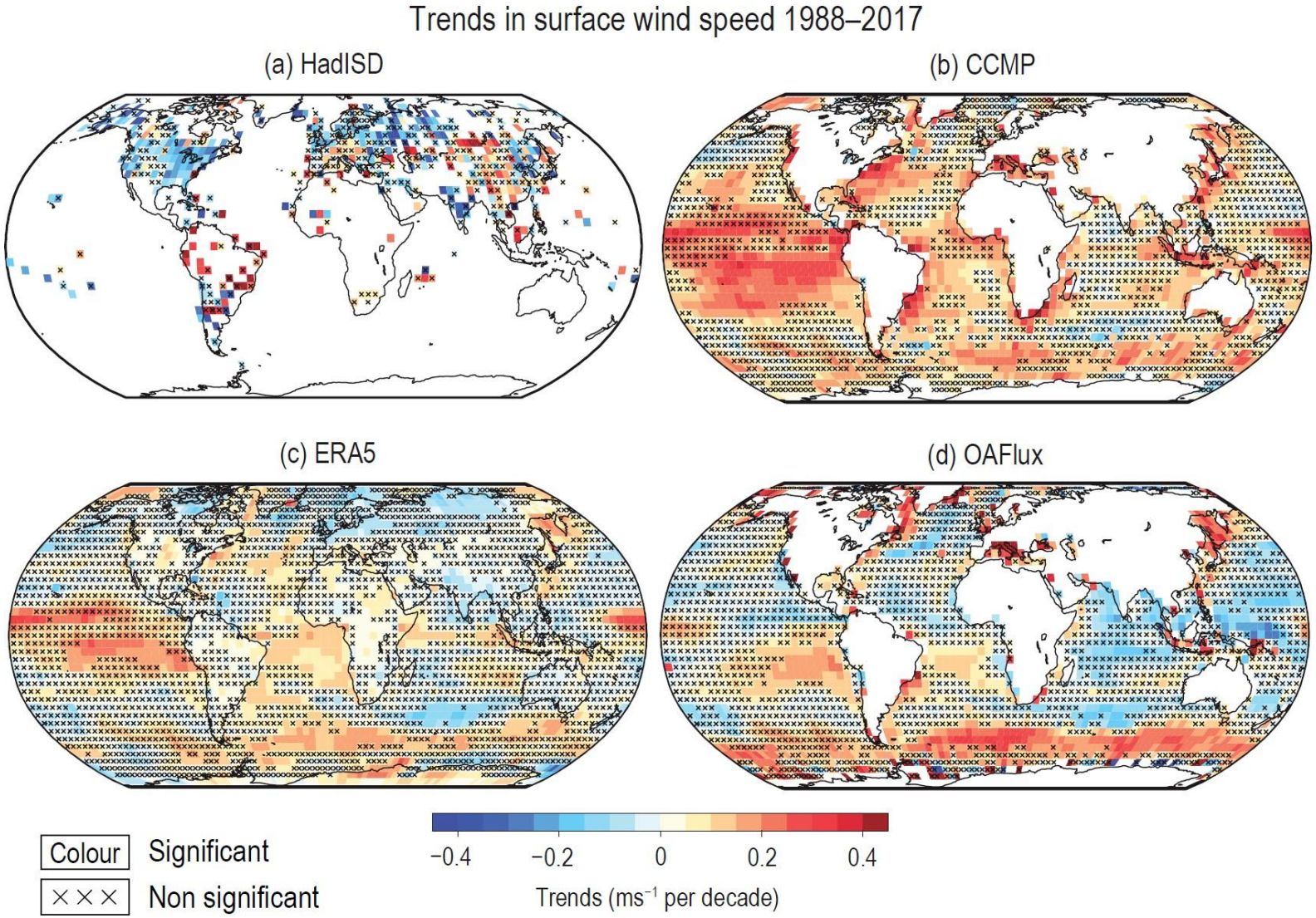
https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/global/mapping

Changes in Global Monsoon Precipitation



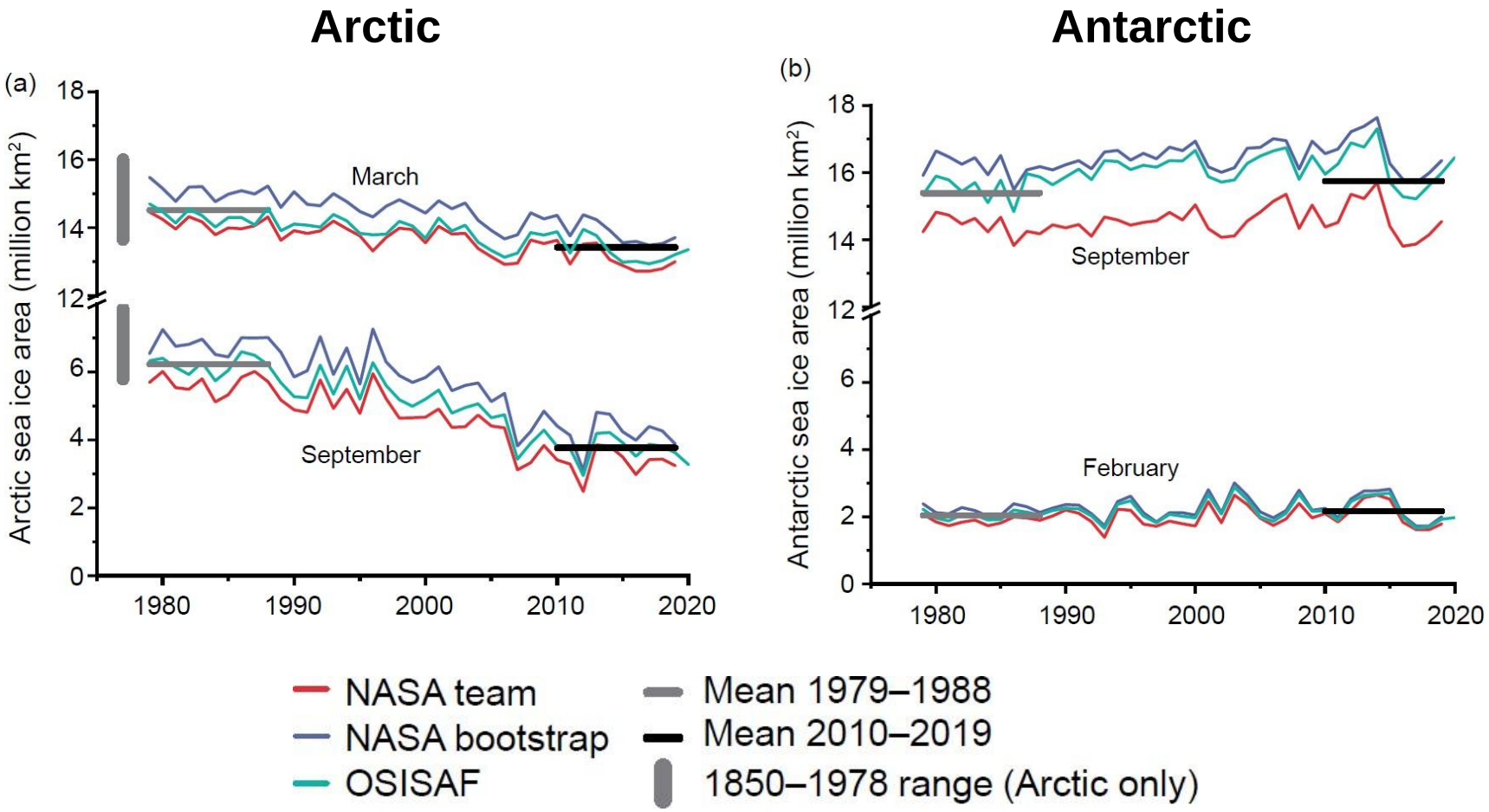
IPCC, 2021

Surface Wind Speed Change: 1988–2017



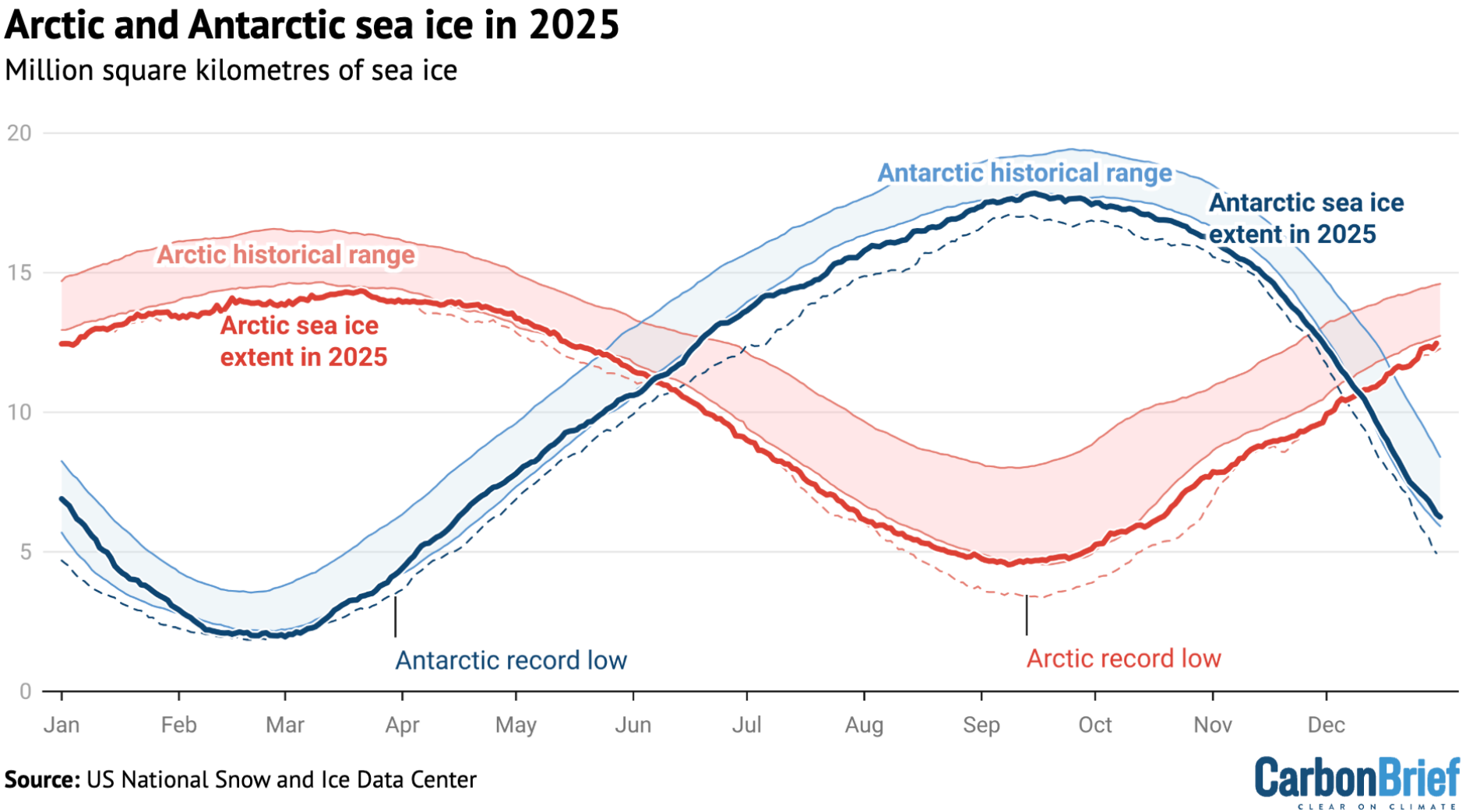
IPCC, 2021

Sea Ice Change



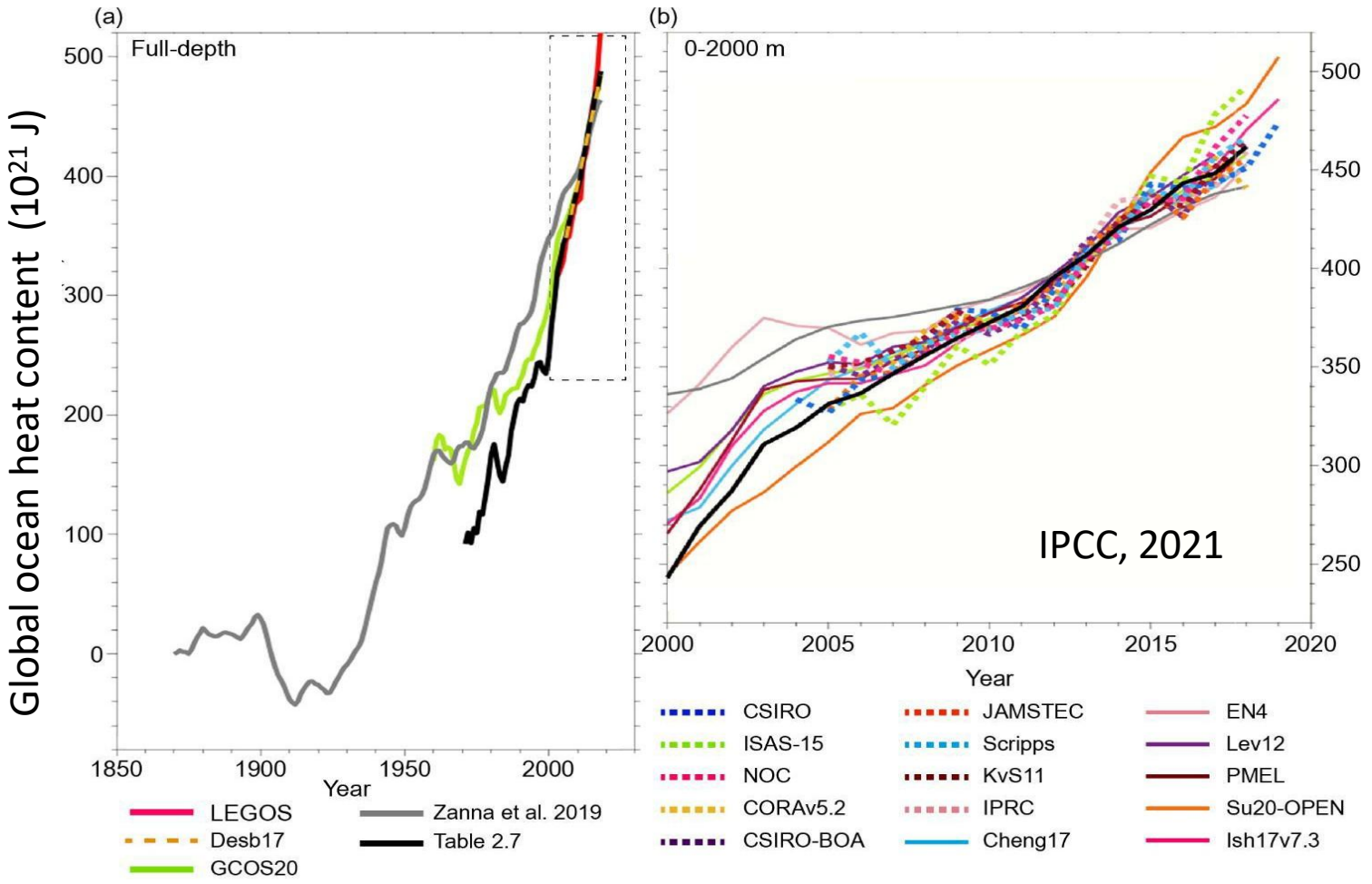
IPCC, 2021

Sea Ice Change in 2025



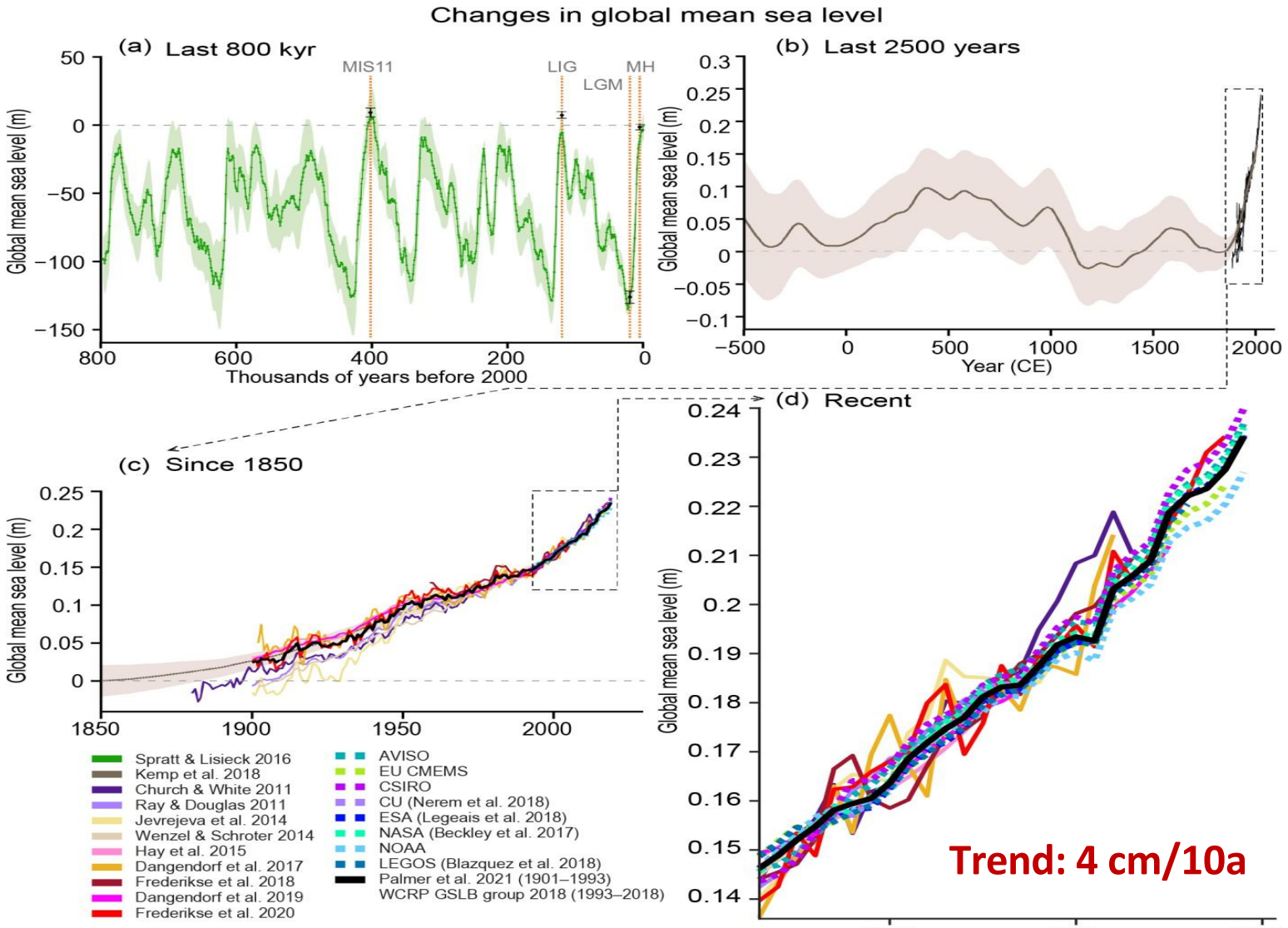
https://www.carbonbrief.org/state-of-the-climate-2025-in-top-three-hottest-years-on-record-as-ocean-heat-surges-9

Ocean Heat Content Change



- World energy consumption in 2019: ~ 5.5×10^{20} J
- Radiative forcing for 1750–2019: 2.7 w/m^2 = 4.3×10^{22} J/yr

Sea Level Change



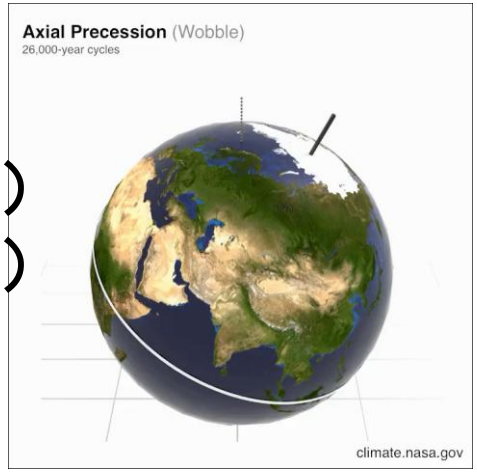
Contributors to sea level rise:
https://youtu.be/Q15gTMXjwCc

IPCC, 2021

影响气候的因子

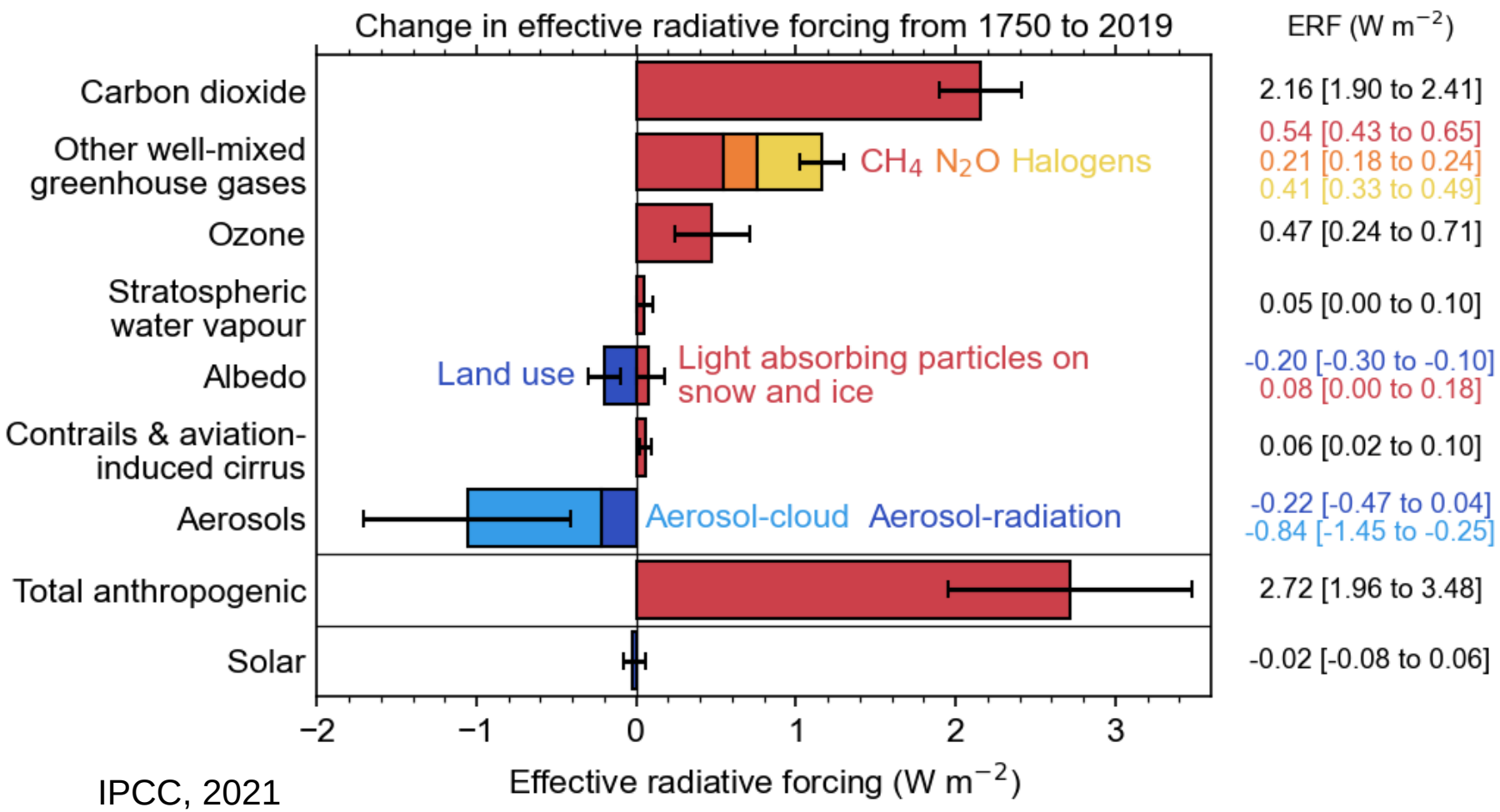
改变地球的辐射平衡有三种最基本的方法：
1. 改变TOA入射的太阳辐射
2. 改变反射的太阳辐射
3. 改变地球向外的长波辐射

- 内部变率：气候系统自身动态演化
- 自然（外部）因素：
  - 地质运动（板块运动、火山活动、陨石等）
  - 地球轨道变化（偏心率、黄赤交角、岁差）
  - 太阳活动（太阳黑子等）
- 人为强迫：
  - 长寿命温室气体：CO_2、CH_4、N_2O、halocarbons
  - O_3（与NO_x、CO、VOC相关）
  - 气溶胶：BC、OC、sulfate、nitrate、ammonium、dust
  - 土地利用和植被类型改变
- 反馈过程：热力、动力、碳循环等



Effective Radiative Forcing

What is ERF? [Concentration based]

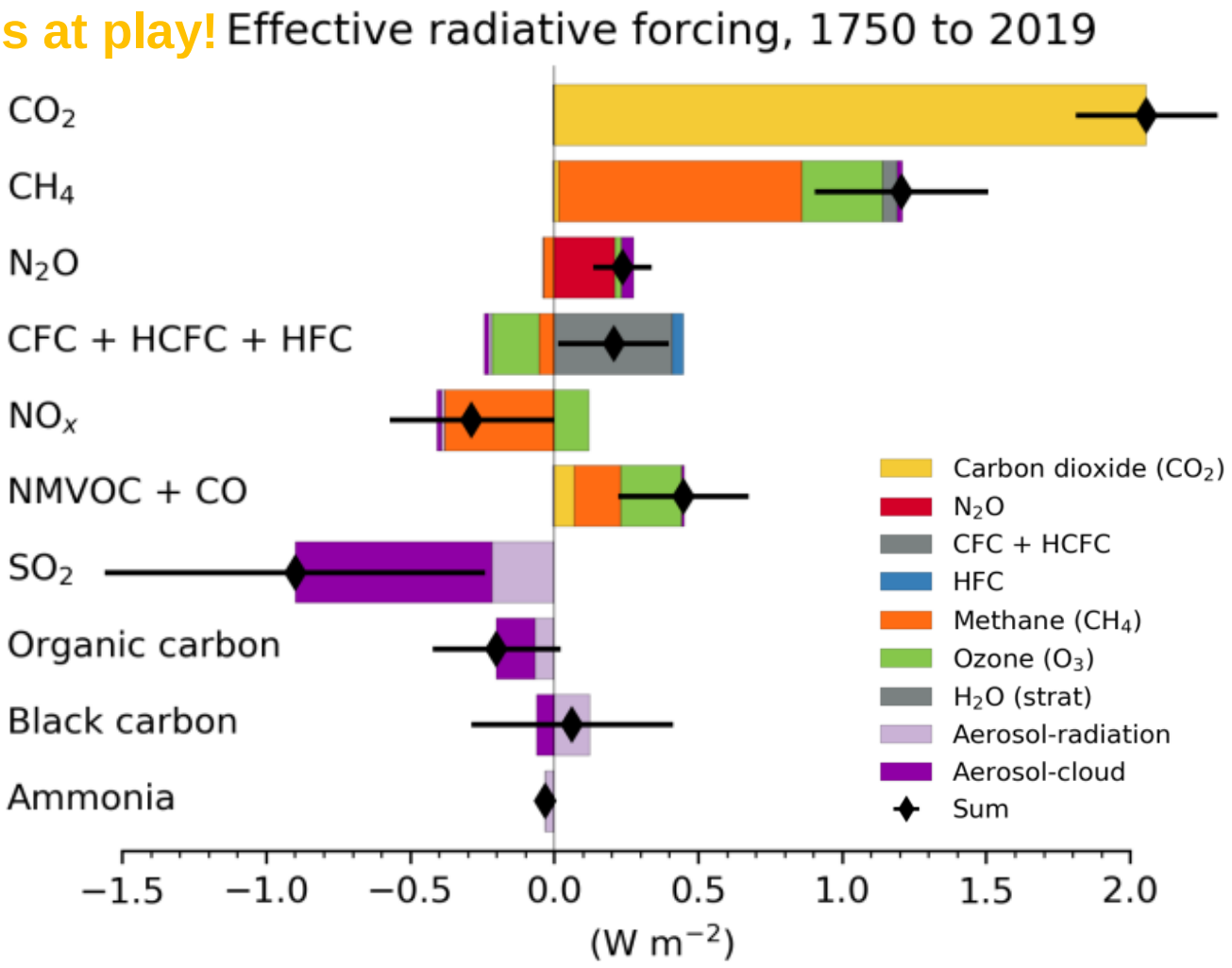


IPCC, 2021

Effective Radiative Forcing

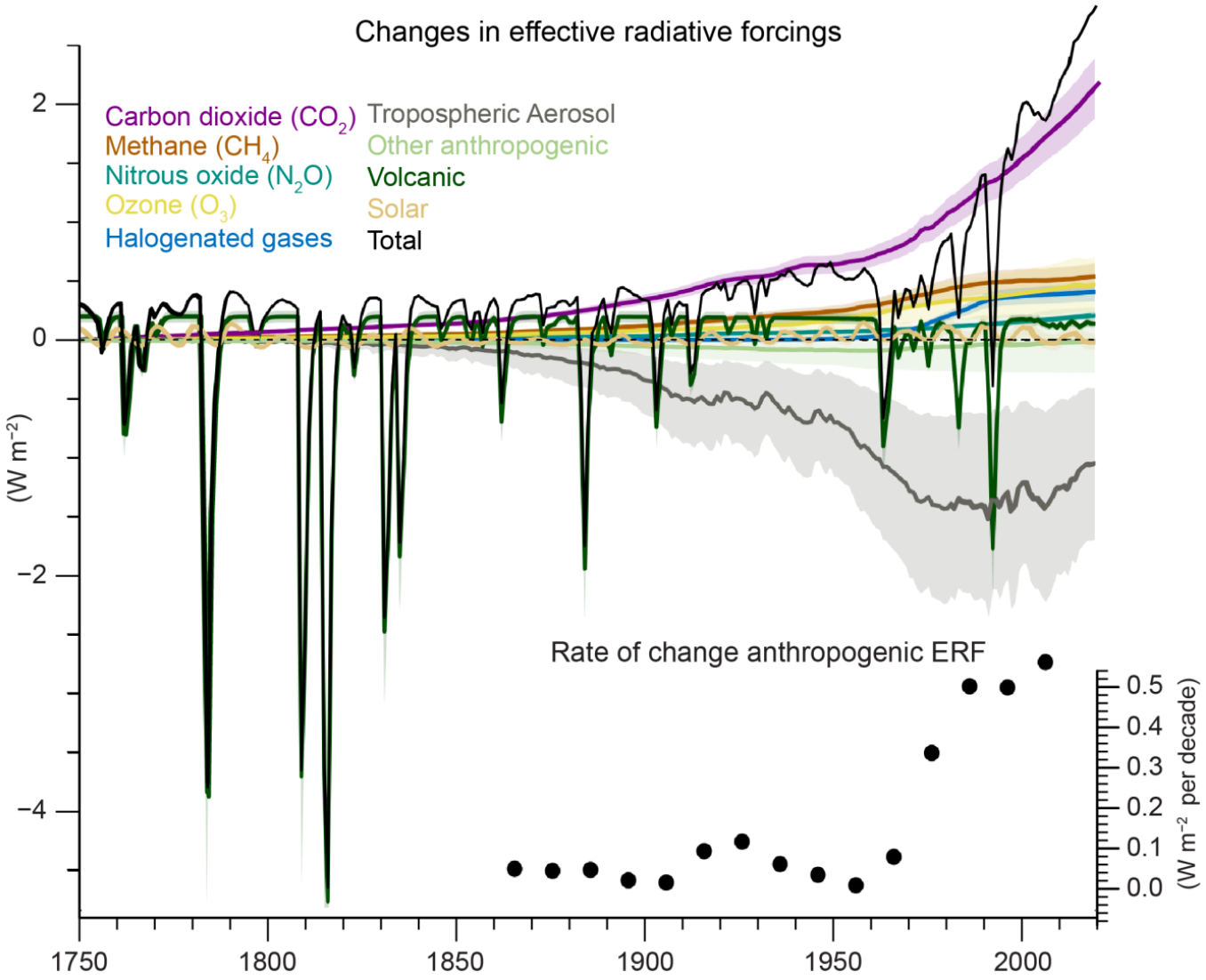
Climate-chemistry interactions at play!

[Emission based]



IPCC, 2021

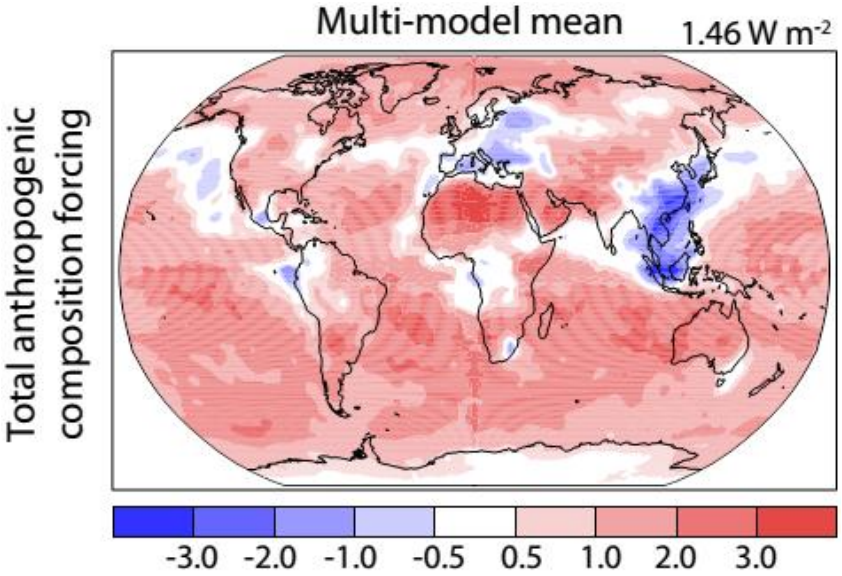
Effective Radiative Forcing



IPCC, 2021

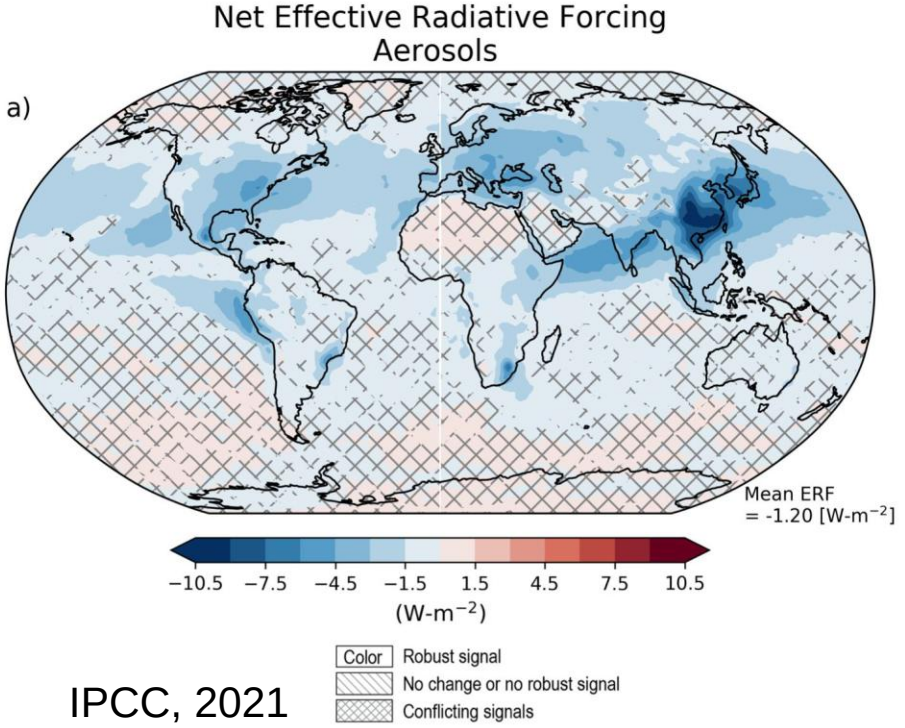
Radiative Forcing: Spatial Distribution

Total RF: 1850–2000



IPCC, 2013

Aerosol ERF: 1850–[1995-2014 mean]



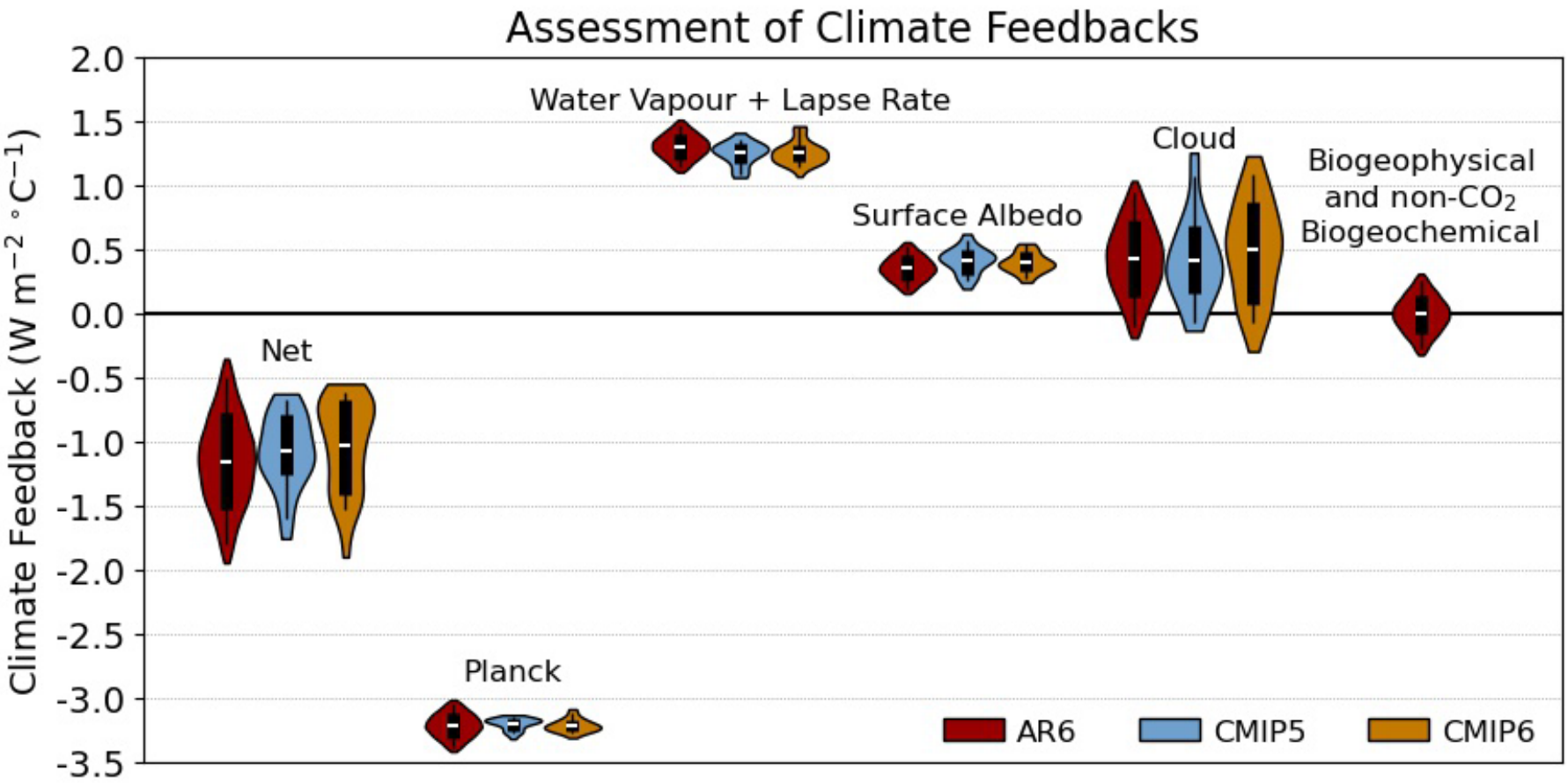
IPCC, 2021

与气候变化相关的反馈过程

- 温度（热辐射）：（-）
- 水汽：温室效应（+）
- 温度递减率：（-）
- 冰雪圈：返照率（+）
- 云水：返照率（-）、温室效应（+）
- 海洋：CO_2含量（+,-）、AMOC（?）
- 生物圈：光合作用（-）、呼吸（+）、生物物理、生物化学

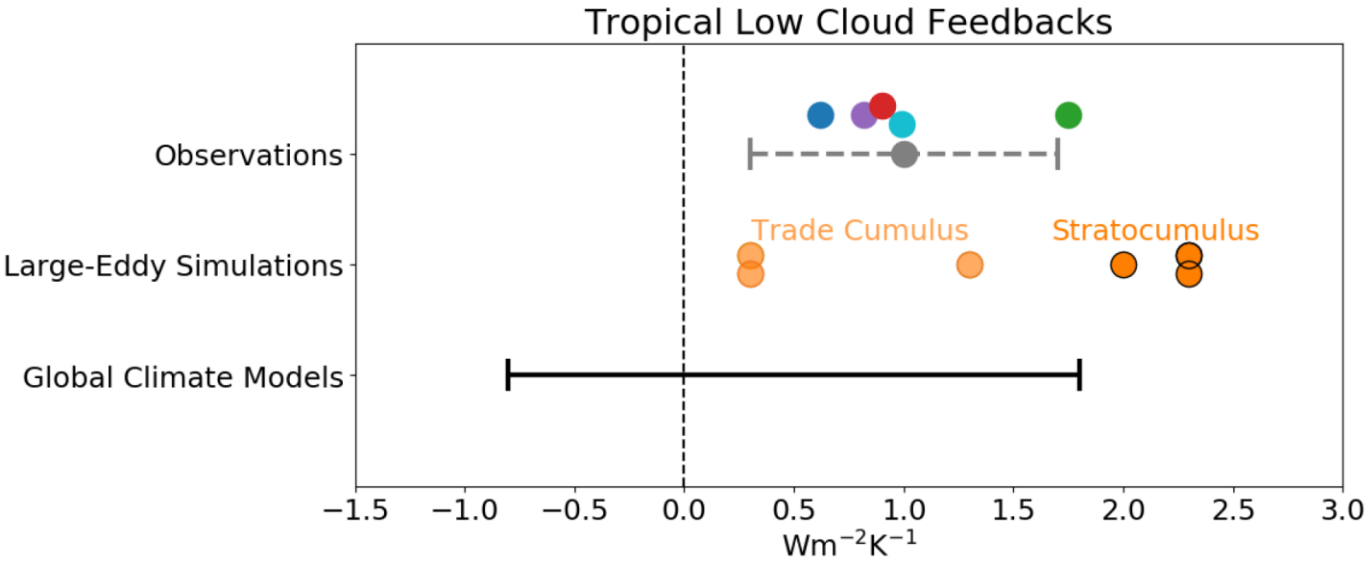


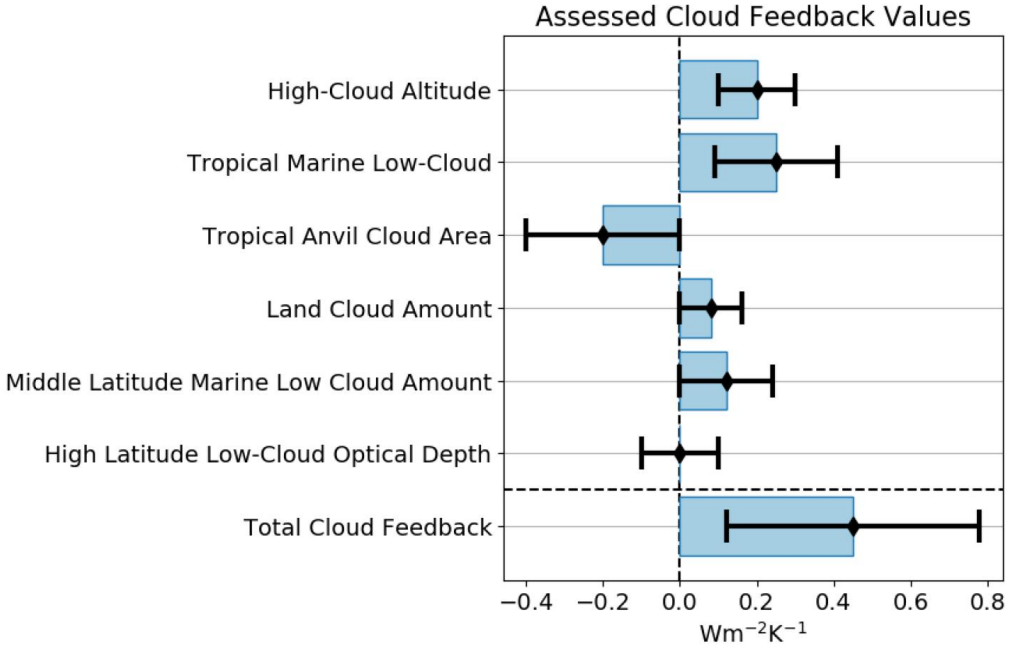
Summary of Feedbacks



IPCC, 2021

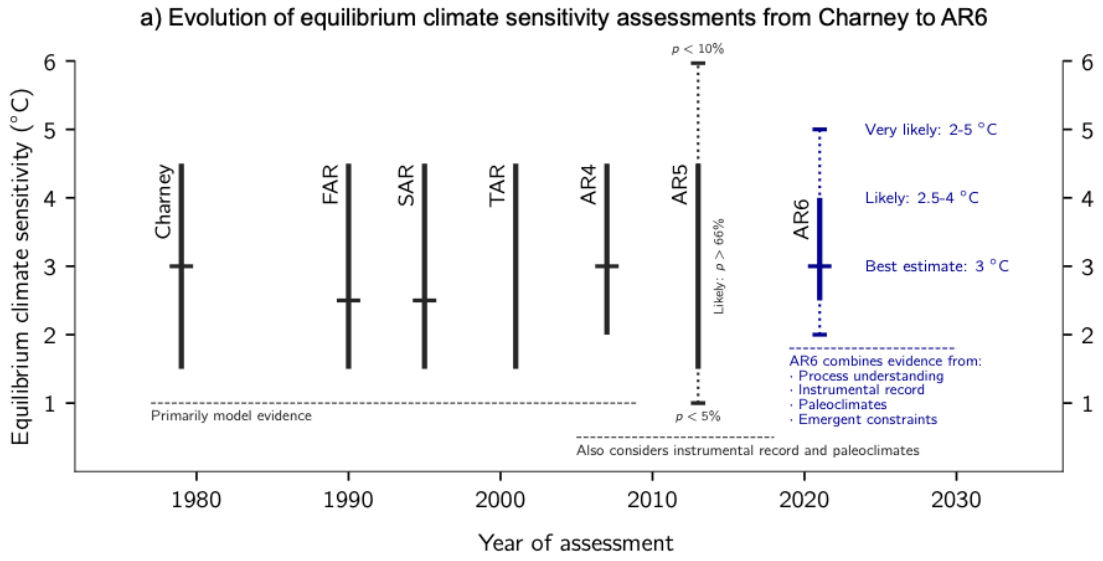
Cloud Feedbacks

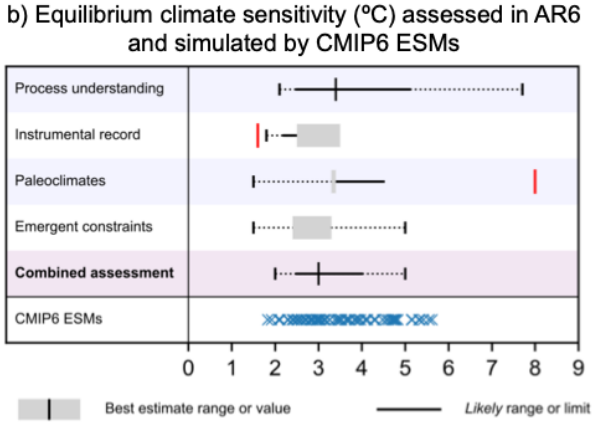


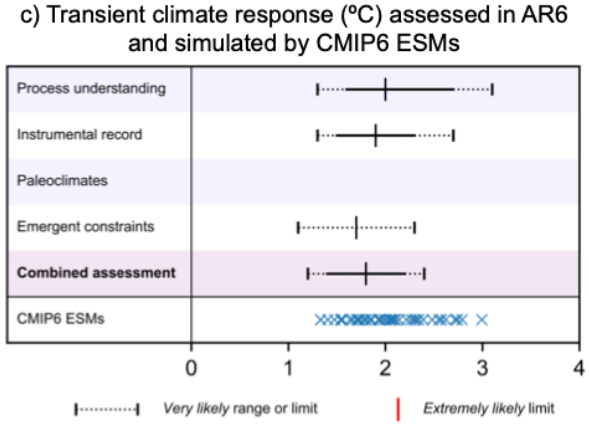


Sherwood et al., 2020 RoG

Climate Sensitivity







Science 125

$$F = -\lambda \Delta T$$

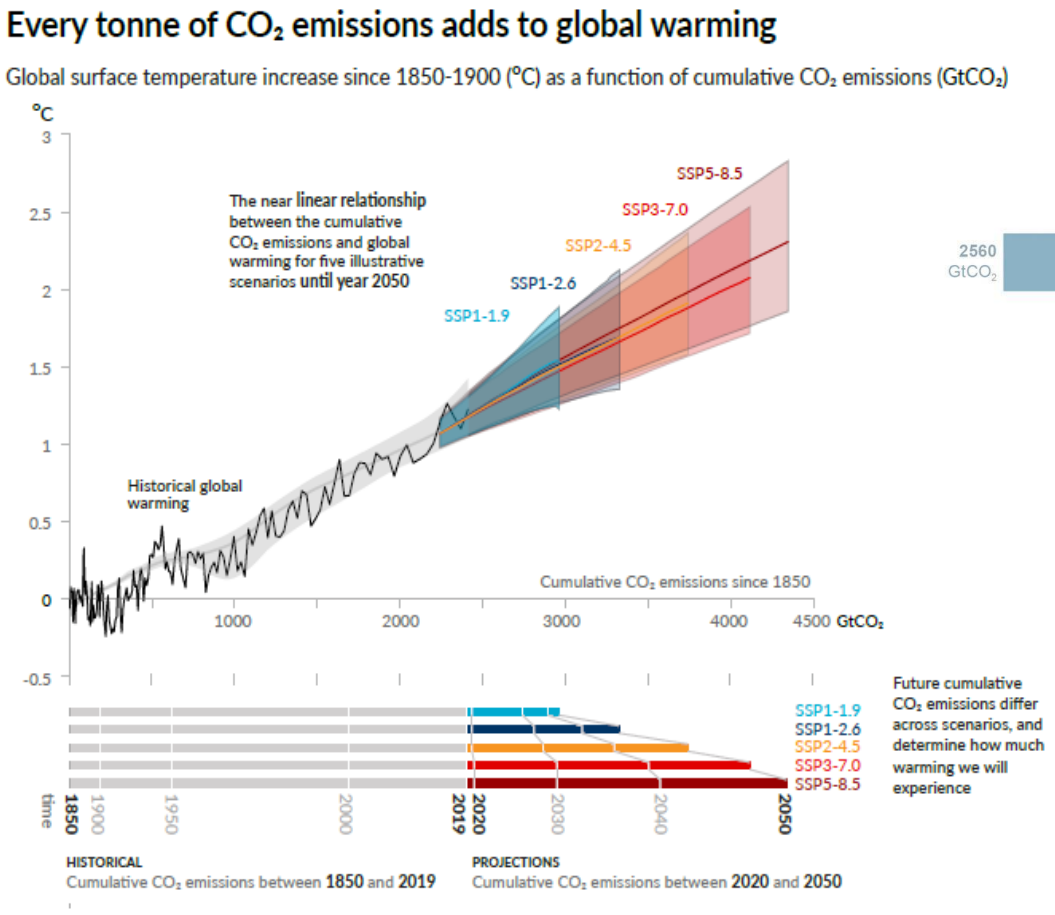
Instantaneous forcing = 3.7 w m^{-2} with 2 x CO_2

T increment at new equilibrium

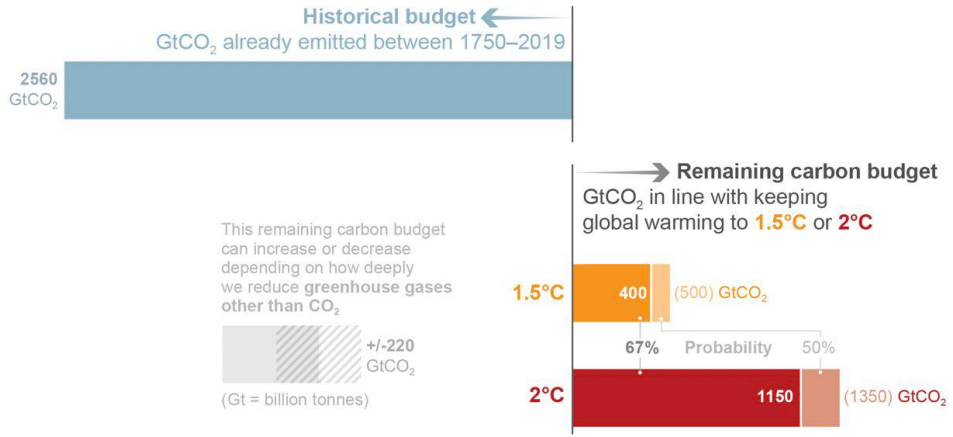
Total Feedback

IPCC, 2021

Cumulative CO_2 Emissions and Warming



Carbon budget



IPCC, 2021

思考题

讨论：地表气温的日变化、云和气溶胶的影响

讨论：气候变化与极端天气的关系

讨论：气溶胶对气候的影响的不确定性及原因

讨论：云反馈作用的不确定性及原因

讨论：气候-化学相互作用及生物圈影响

讨论：碳中和背景下污染-气候协同控制