

*Past and Future Climates*  
*Astronomical, Solar, and Anthropogenic Forcing*  
*Strategies for Future Space and Modeling Research*

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- 
- The background of the slide is a vibrant illustration of space. A young boy with spiky yellow hair, wearing a green tunic and a red bow tie, stands on a small, light blue, spherical planet. The planet has a few small red flowers and a small grey structure. The background is a deep blue night sky filled with numerous yellow stars of various sizes and several yellow planets or moons. The overall style is reminiscent of the classic children's book 'The Little Prince'.
- **Climates of the past**
  - **Solar variability and climate**
  - **Future Climate(s)**
  - **Future strategies**
  - **Conclusion (s)**

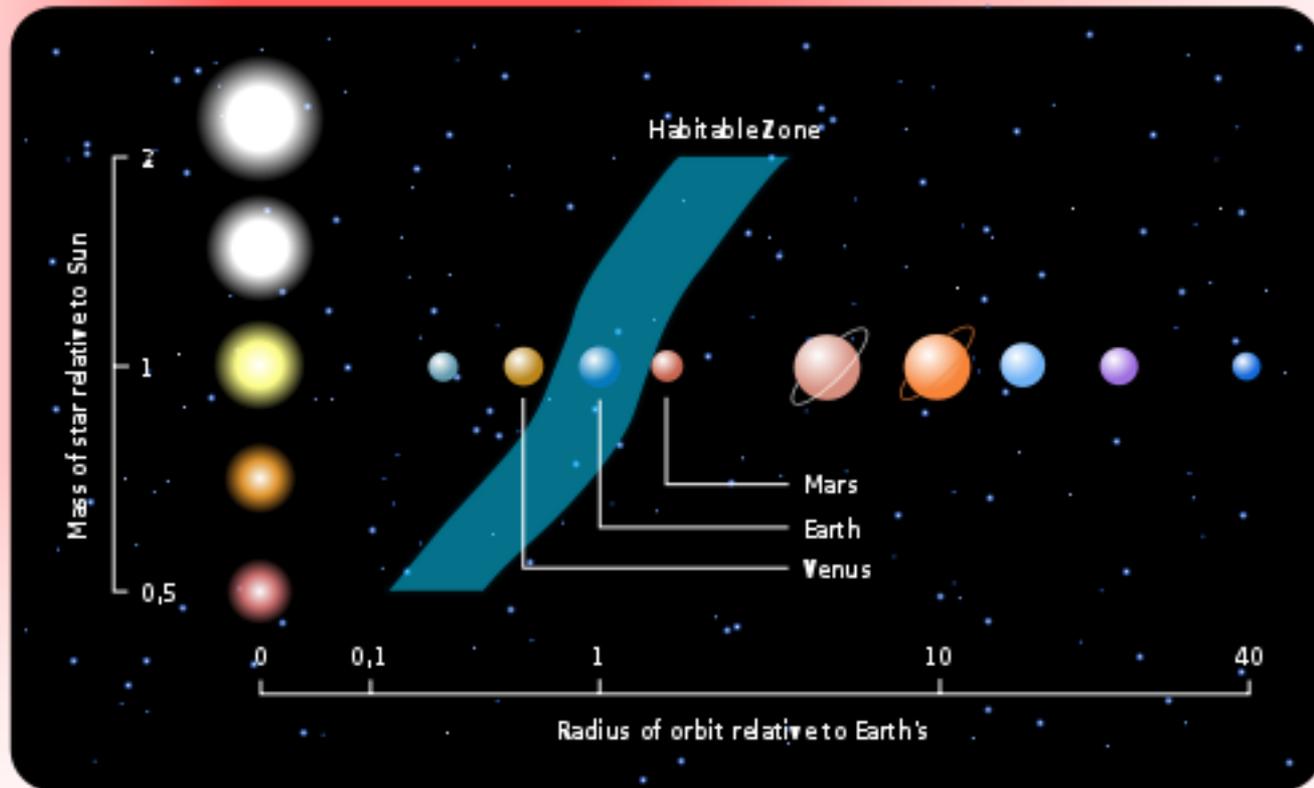
# The Earth Climate

The Earth climate is one of the most difficult phenomenon to understand (and of course model and forecast (if ever possible) because it is determined by the influence of a variable Sun on an unstable planet involving a large number of interacting phenomena. It is a chaotic concept!

This is illustrated by the increasingly overabundant literature on global warming and its causes, not all self-consistent, even though peer reviewed and apparently intelligent!

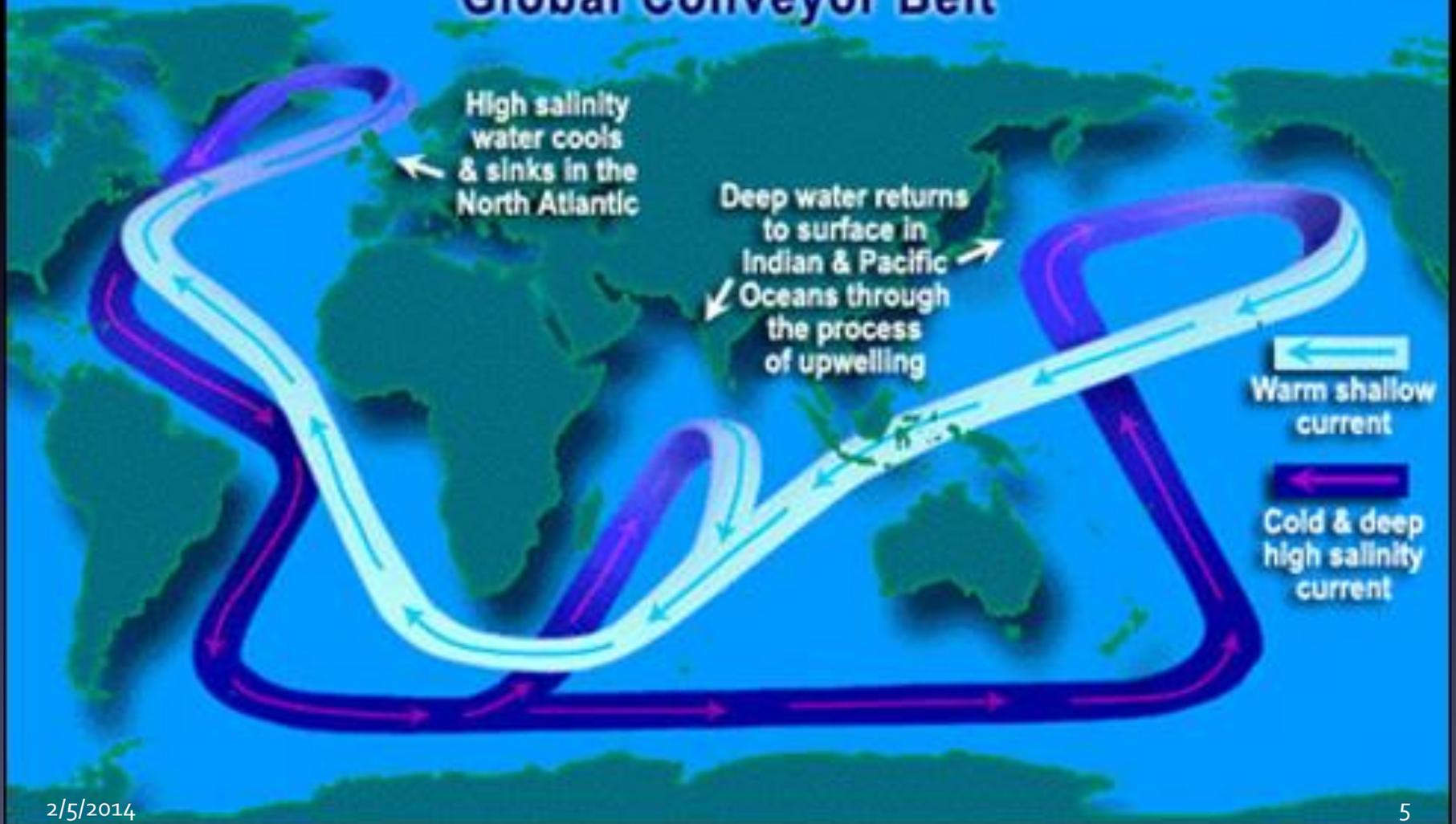
Climate science is typically an interdisciplinary field that includes nearly all fields of modern science from astronomy to life science and sociology through chemistry, aerodynamics, fluid physics, magnetism, solid state physics, thermodynamics and geophysics.

# The Earth-Sun System

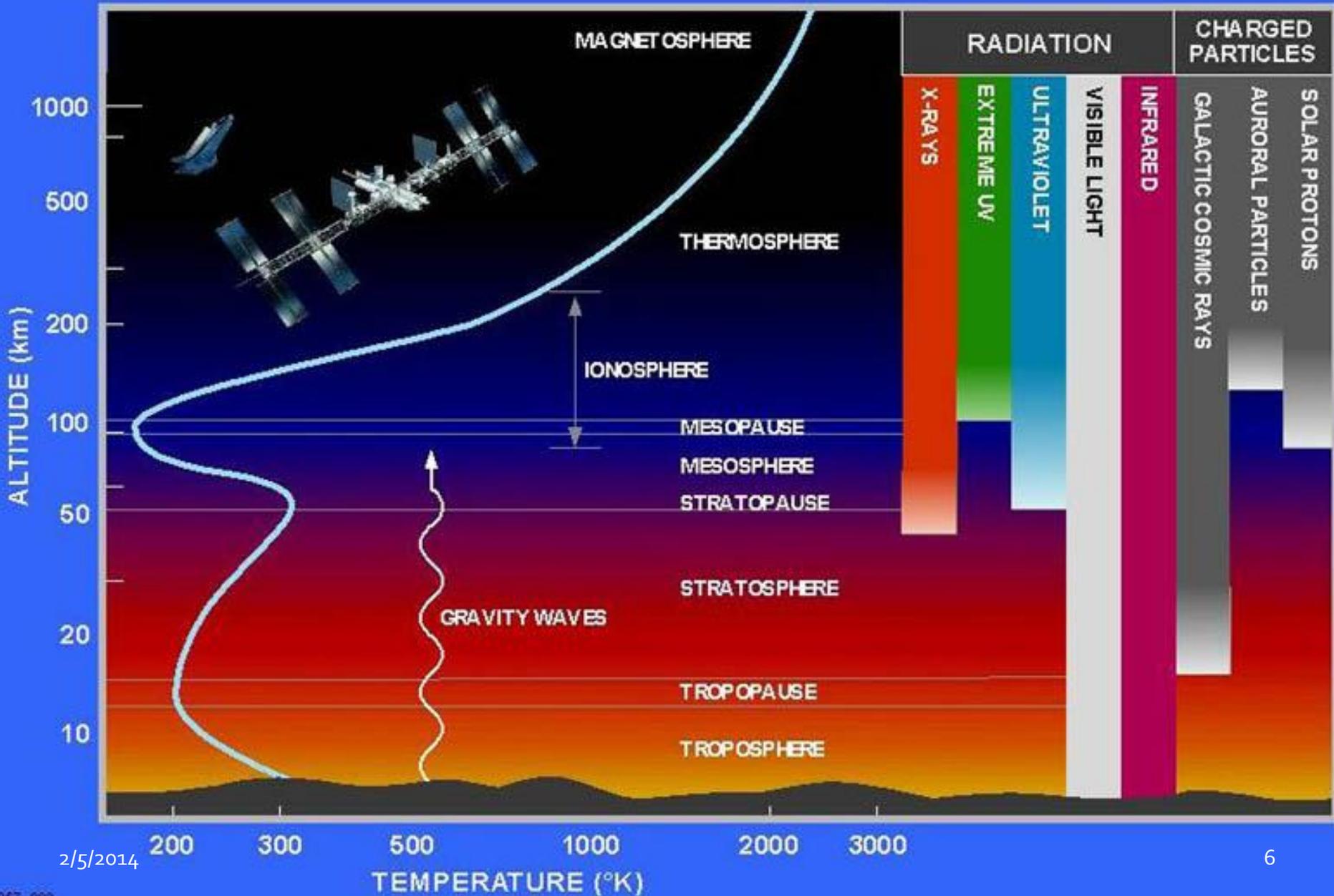


# A variable water planet

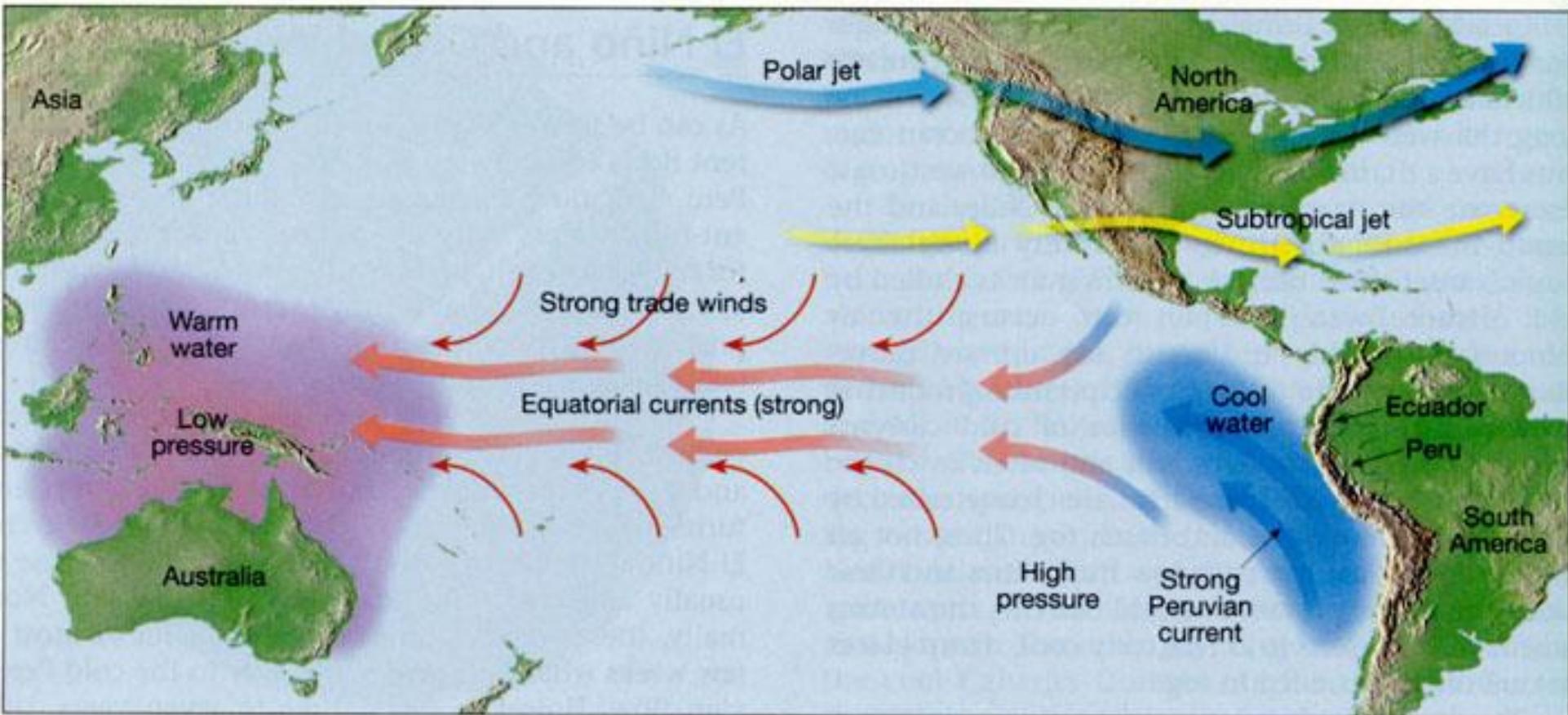
## Generalized model of thermohaline circulation: "Global Conveyor Belt"



# The Earth atmosphere



# Ocean/atmosphere interactions PDO/ENSO

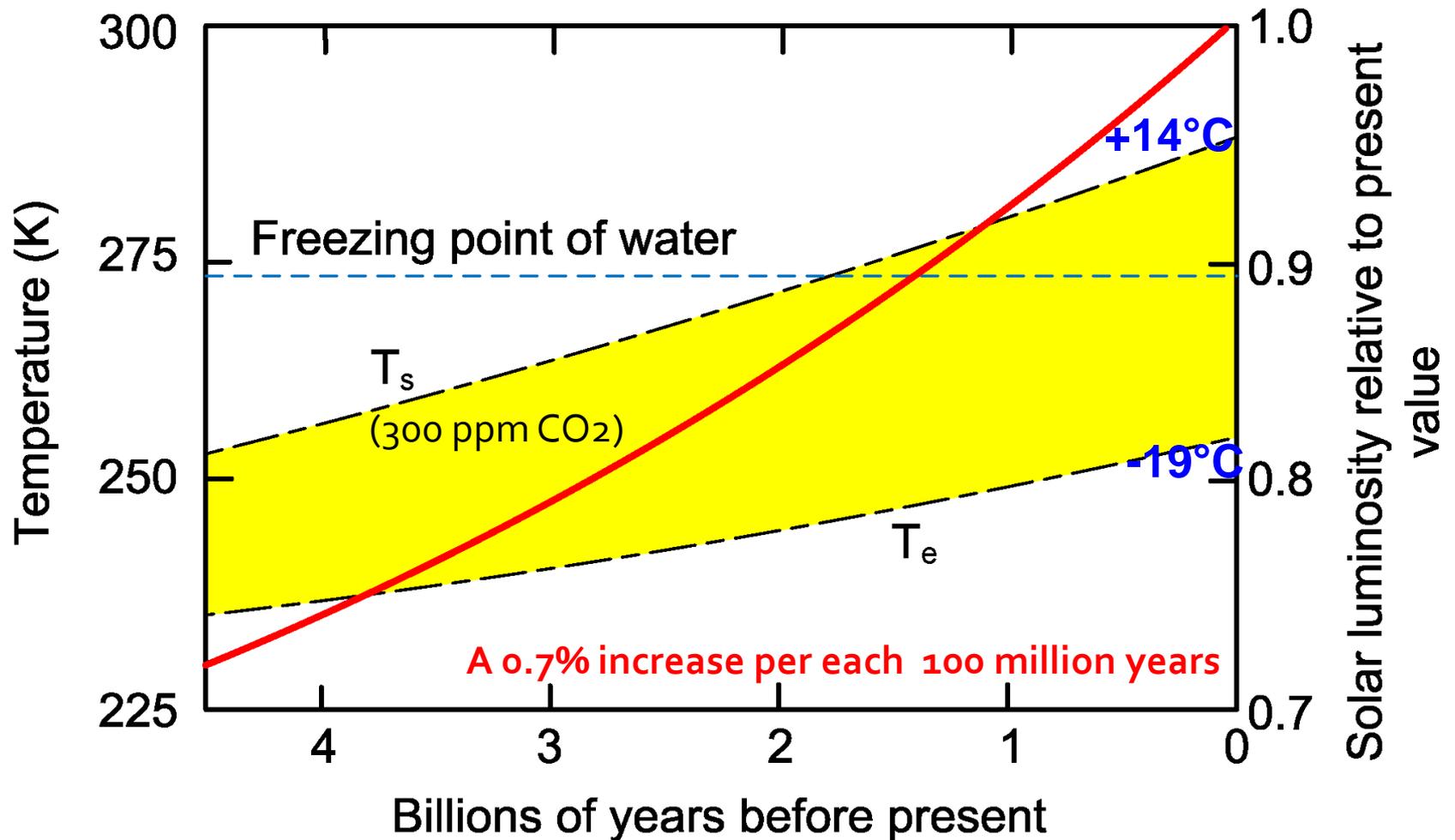


# Main factors affecting the paleoclimate (4.5 By-1My BP)

Among these we find:

- Solar radiation forcing
- Volcanism and the outgassing of Earth interior modifying the atmosphere
- Astronomical parameters: obliquity of the Earth with respect to the ecliptic plane
- Plate tectonics
- The albedo of the solid Earth, the oceans ice sheets and the atmosphere (clouds and aerosols),
- The greenhouse effect
- Oceanic and atmospheric circulation

# Long-term solar forcing

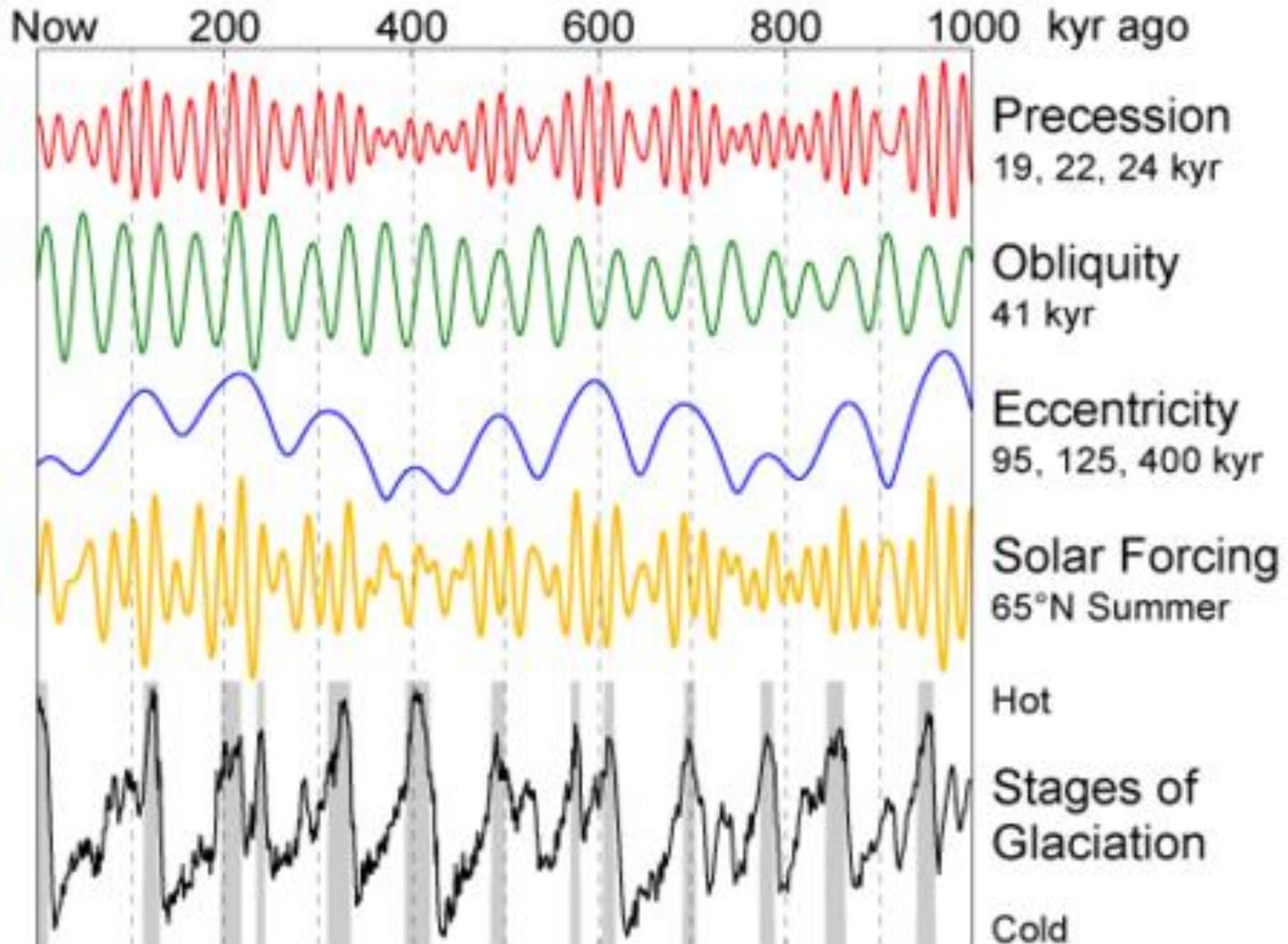




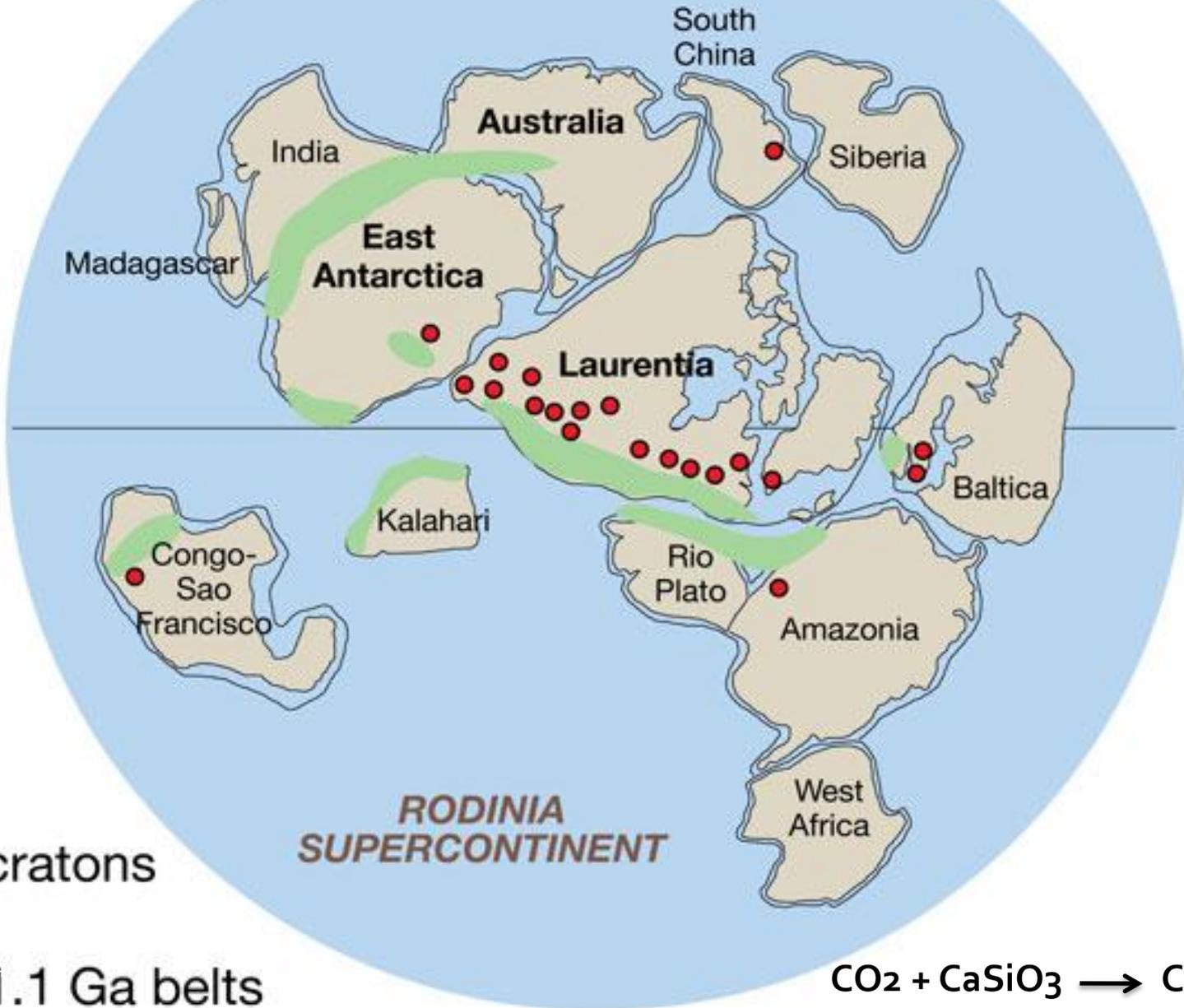
# Astronomical and Orbital Forcing

Milutin Milankovitch

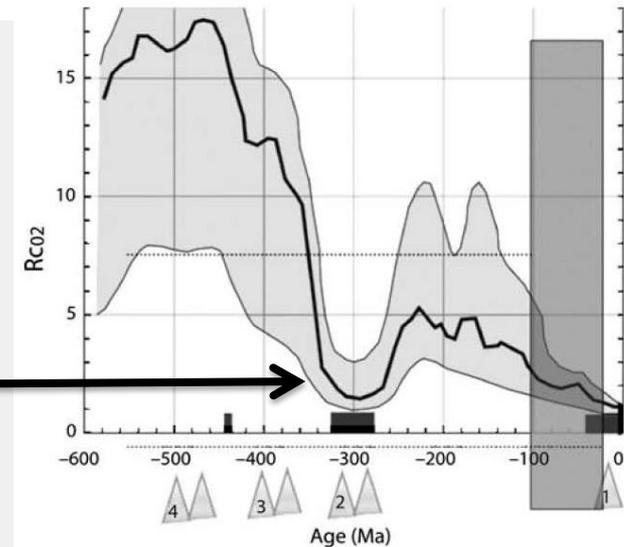
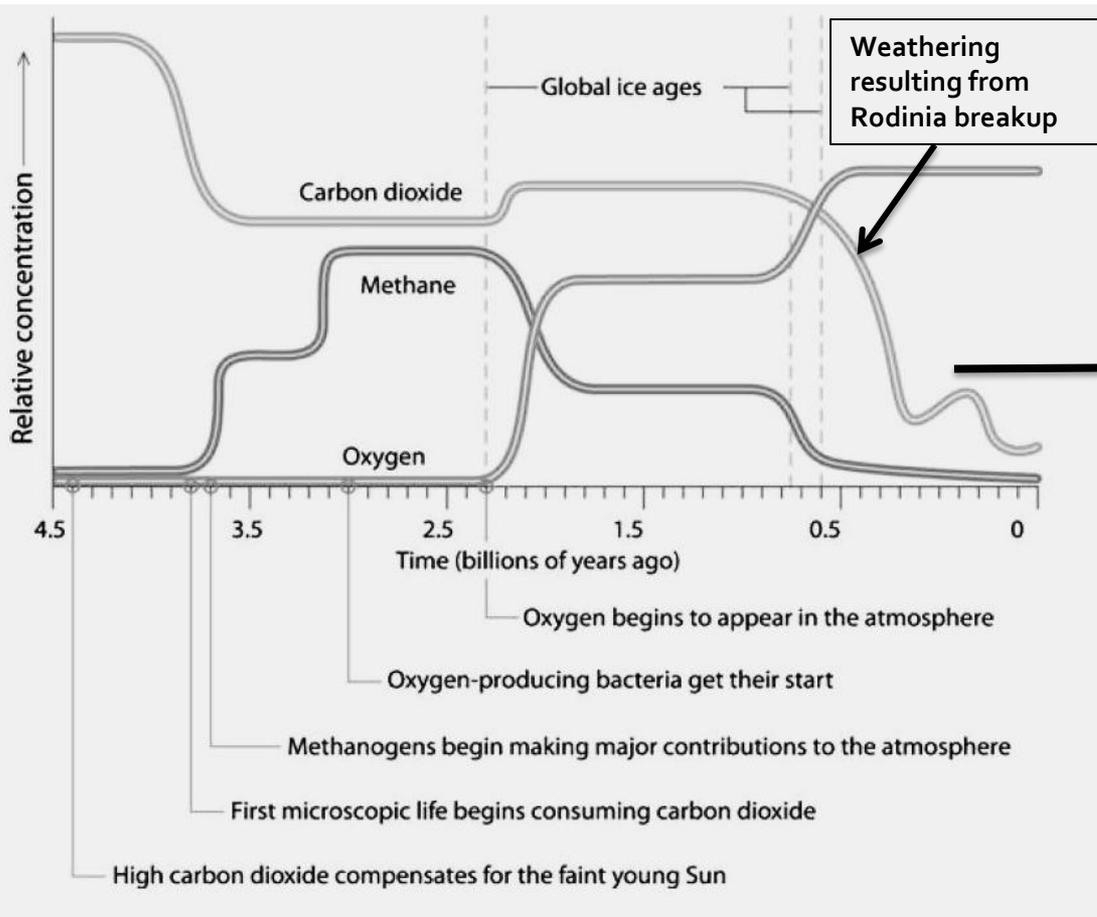
1879-1958



# Plate tectonics



# Crucial role of CO<sub>2</sub>, CH<sub>4</sub>, O<sub>2</sub> in paleoclimate change

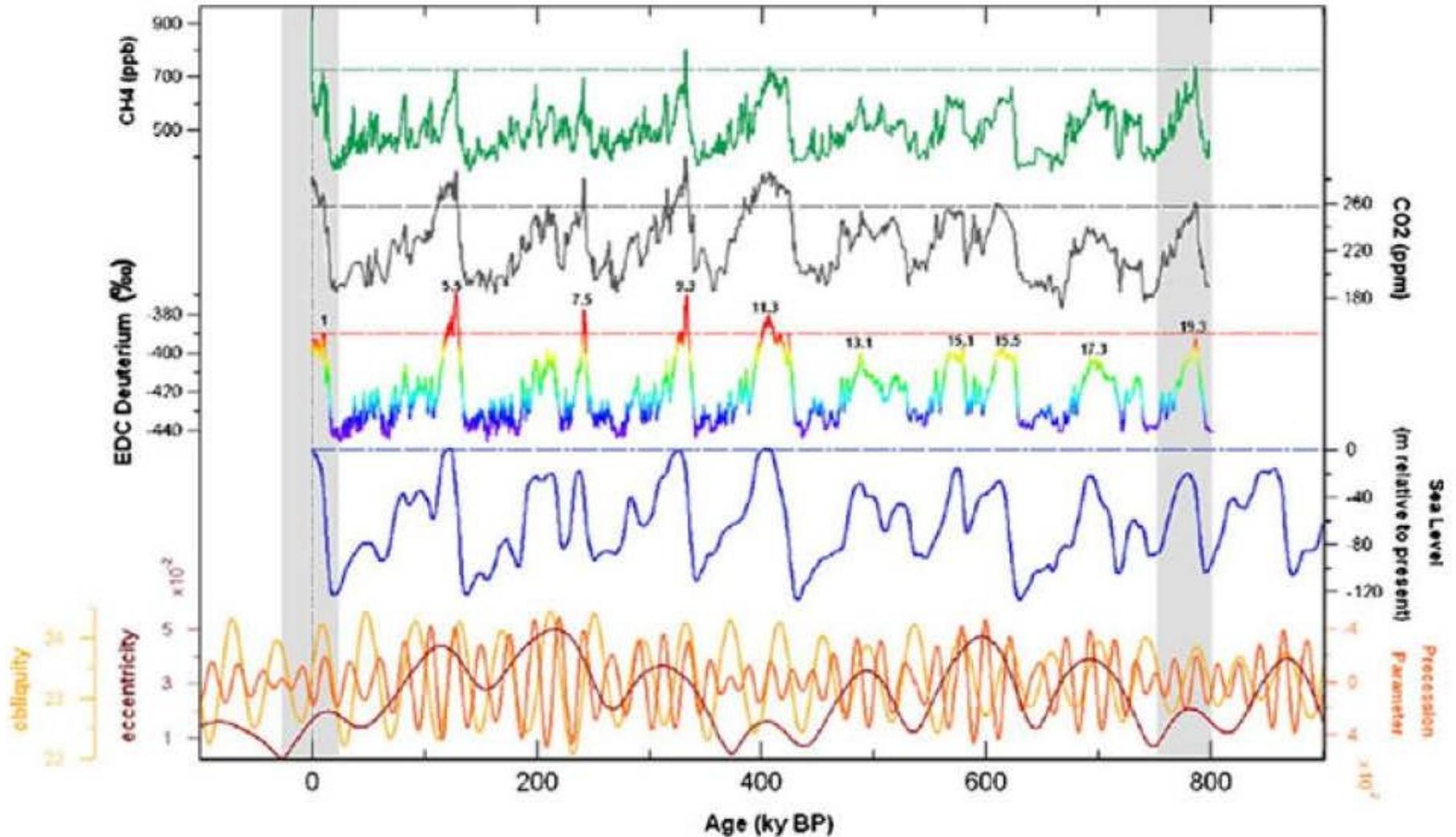


CH<sub>4</sub> (mostly of biogenic origin) is destroyed by O<sub>2</sub> (mostly of biogenic origin)

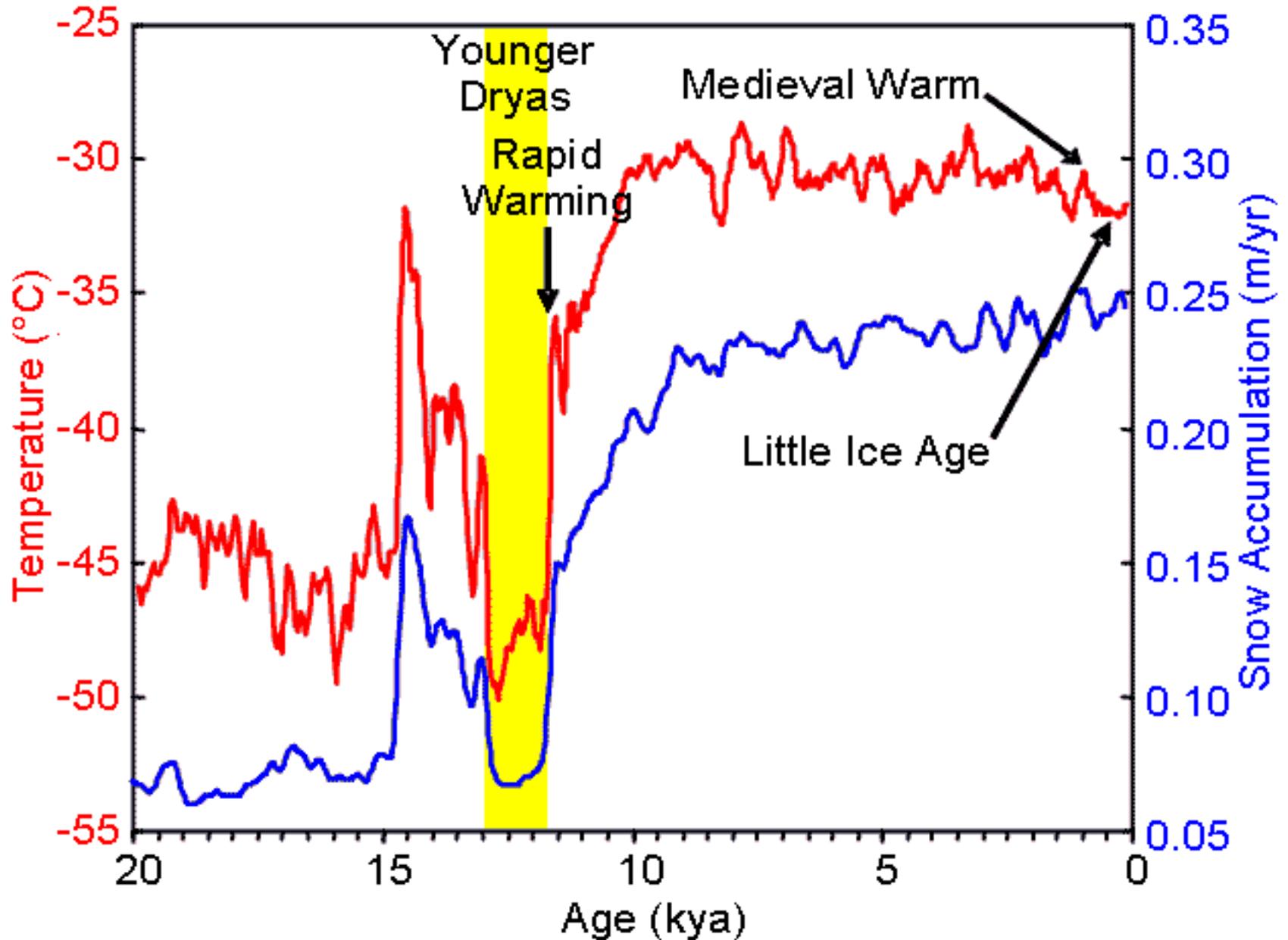


CO<sub>2</sub> sink is due to methanogenic archaea and to the weathering (water rain and formation of silicates)

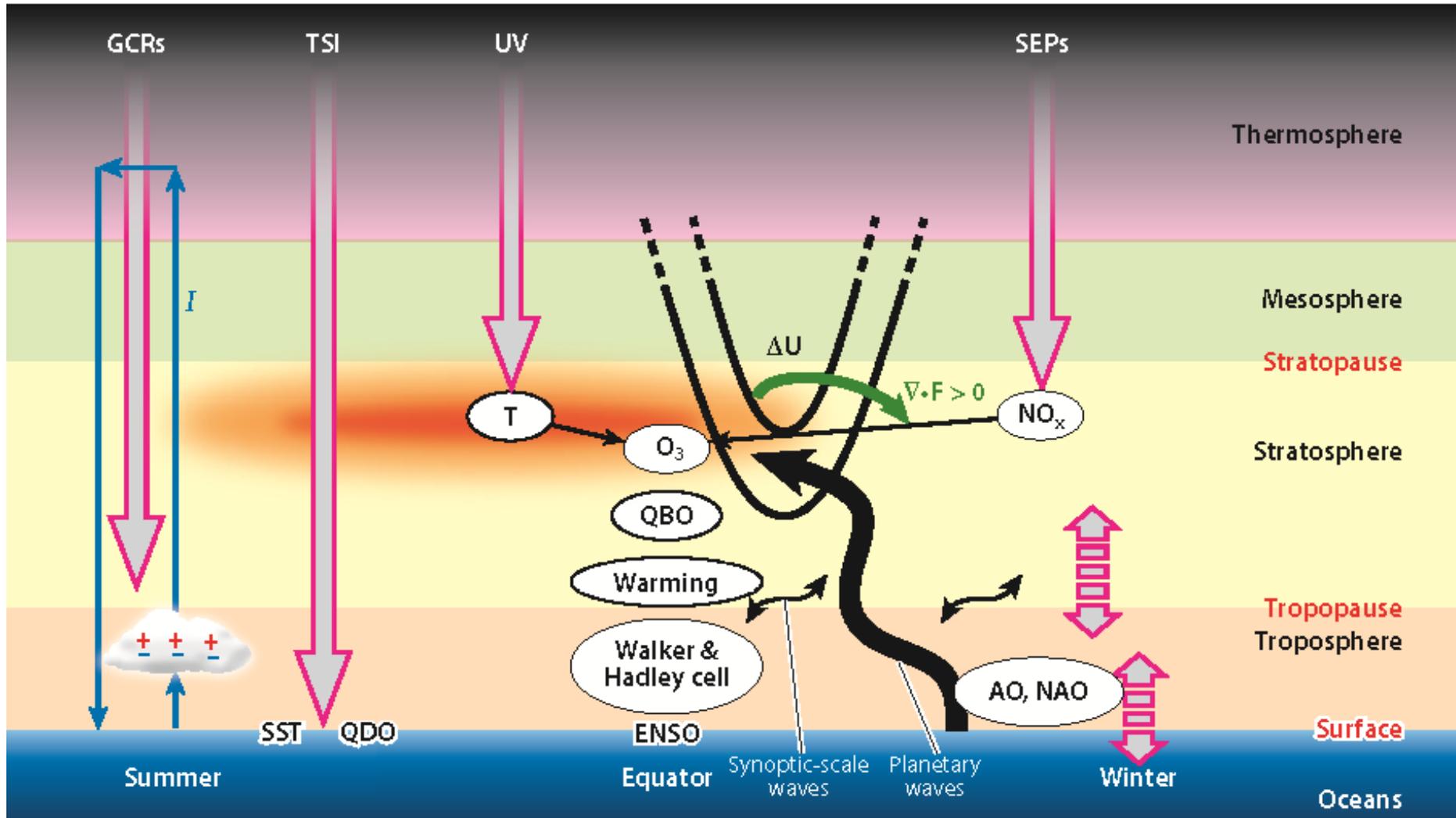
# Forcing factors since 1 My



# Zooming on the Holocene Climate

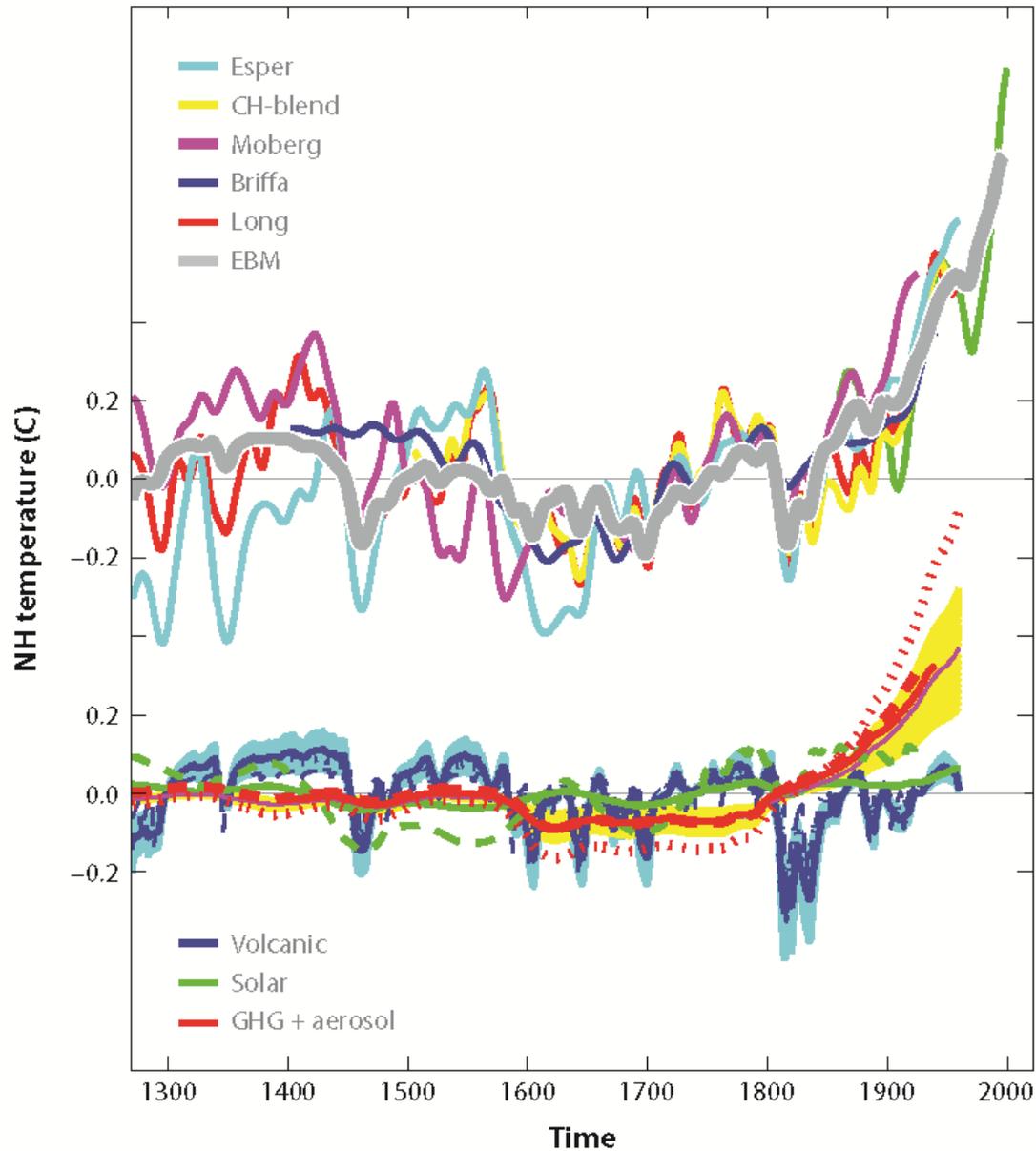


# Solar variability and climate



Reprinted by S. Solanki in his Annual Review 2013 from Gray et al. (2010).

# Reconstructed temperature over last millennium

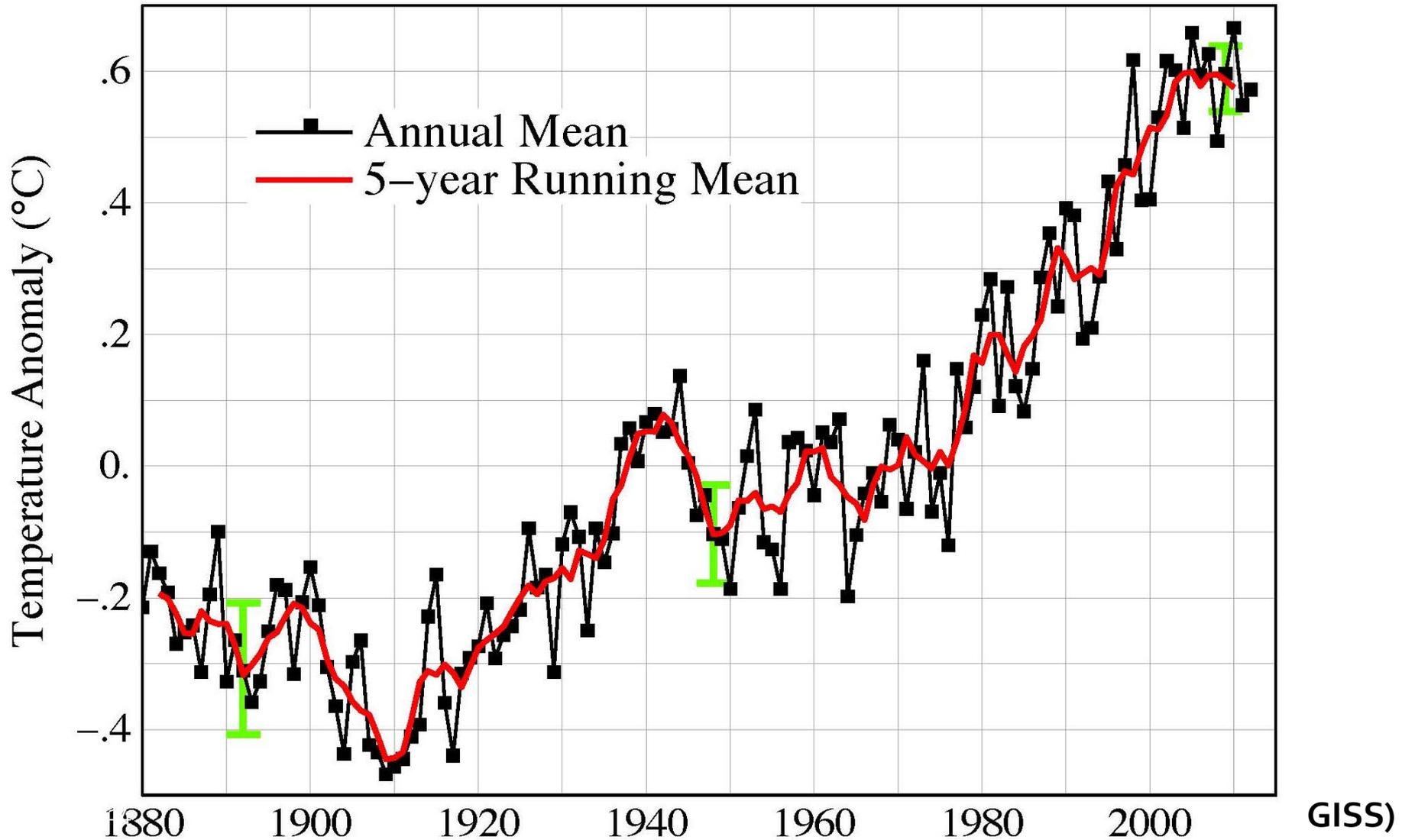


S. Solanki et al., Ann. Rev. Astron. Astroph. 2013

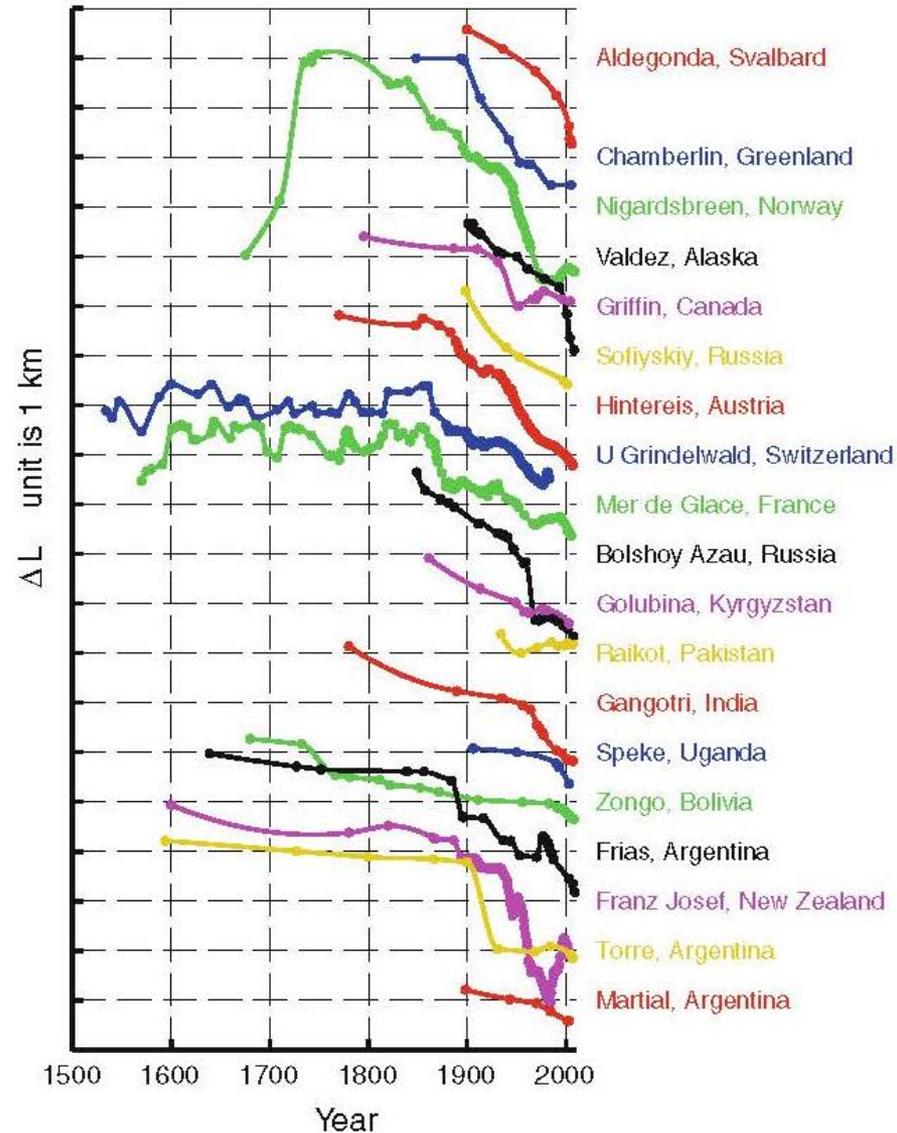
# Sea Level Rise, 1880-2013

# The Earth is getting warmer

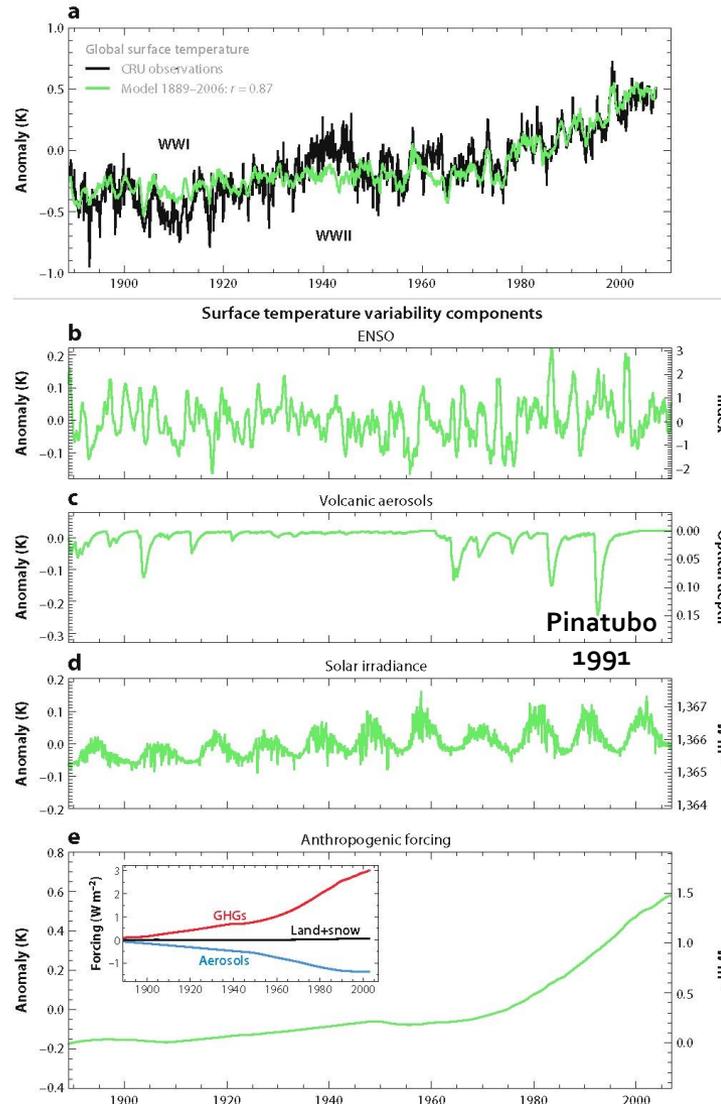
## Global Land–Ocean Temperature Index



# Glacier length records

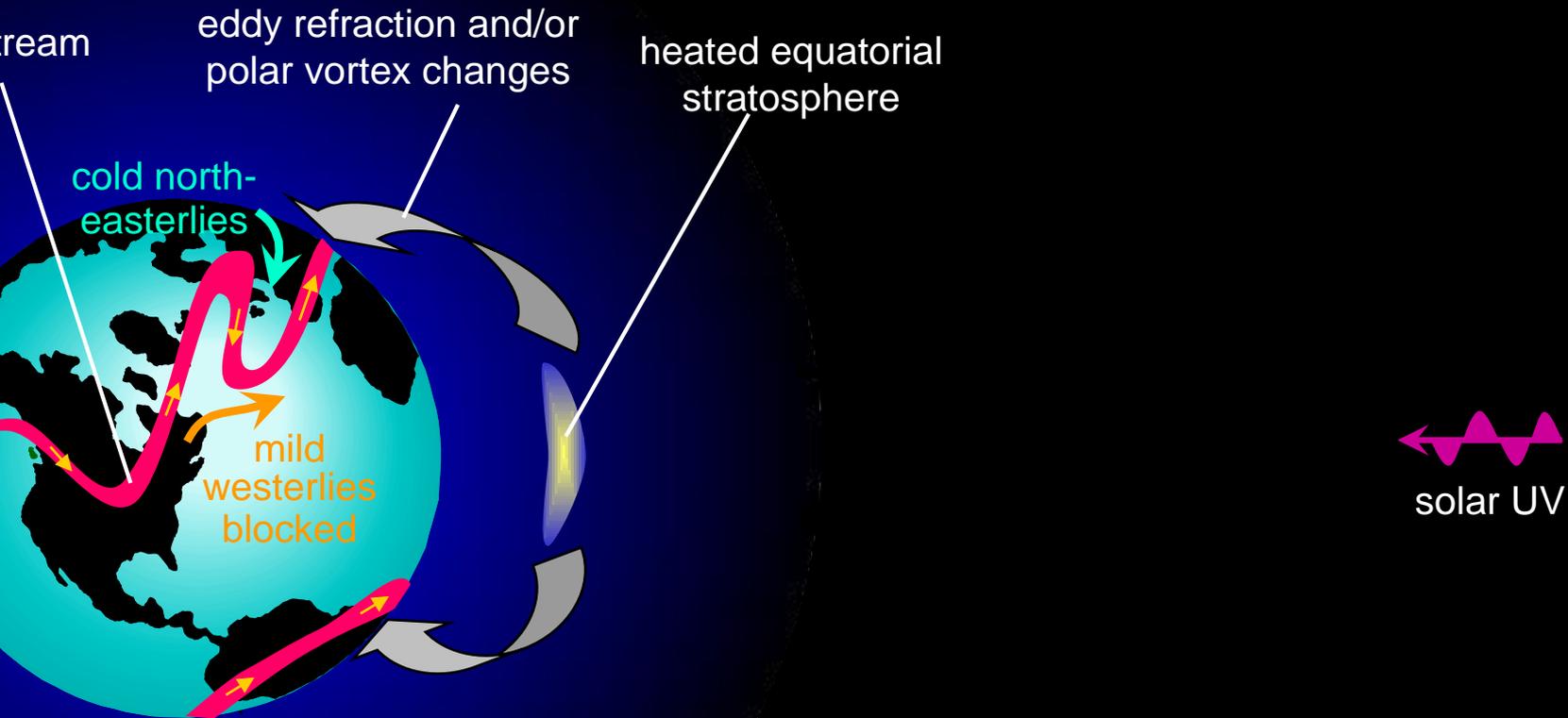


# Global mean surface temperature and its main regression components as of 1880 (Solanki et al)

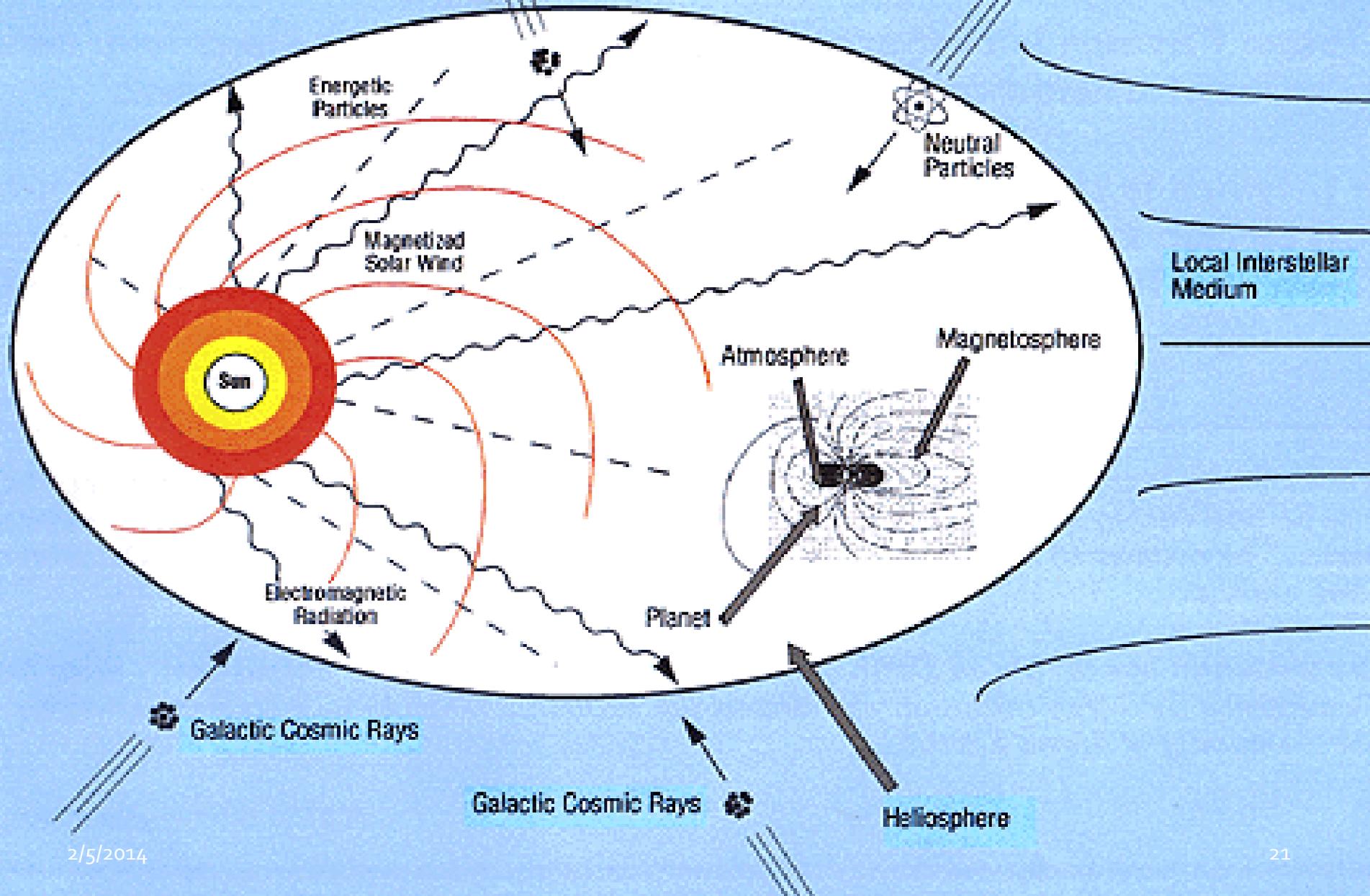


Annu. Rev. Astro. Astrophys. 2013.51:11-351. Downloaded from www.annualreviews.org by University of Bern on 12/04/13. For personal use only.

# Indirect solar forcing: UV irradiance variability



# Sun's magnetic variability



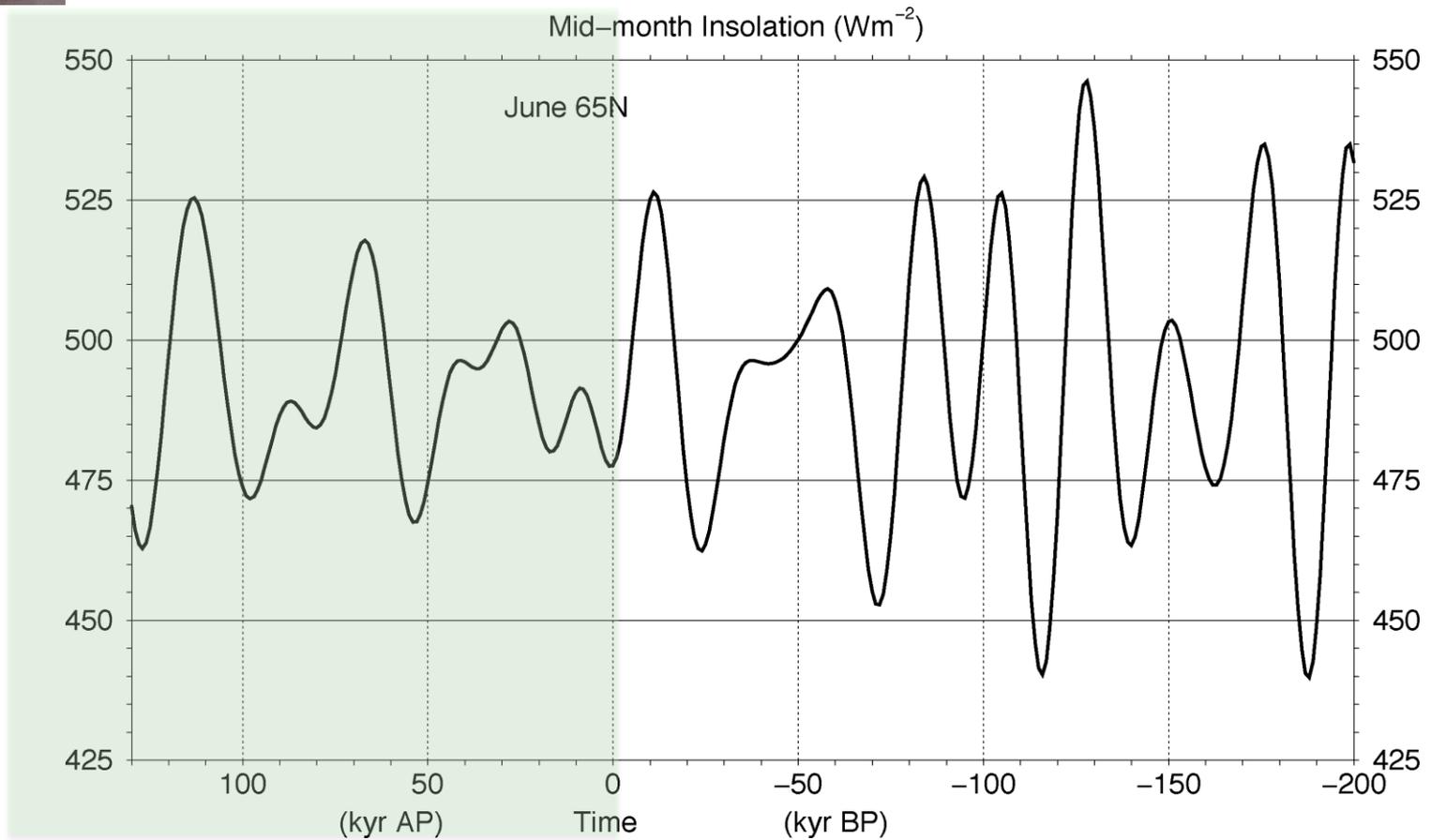
# Cosmic rays and formation of clouds/aerosols



The "CLOUD"  
experiment at  
CERN

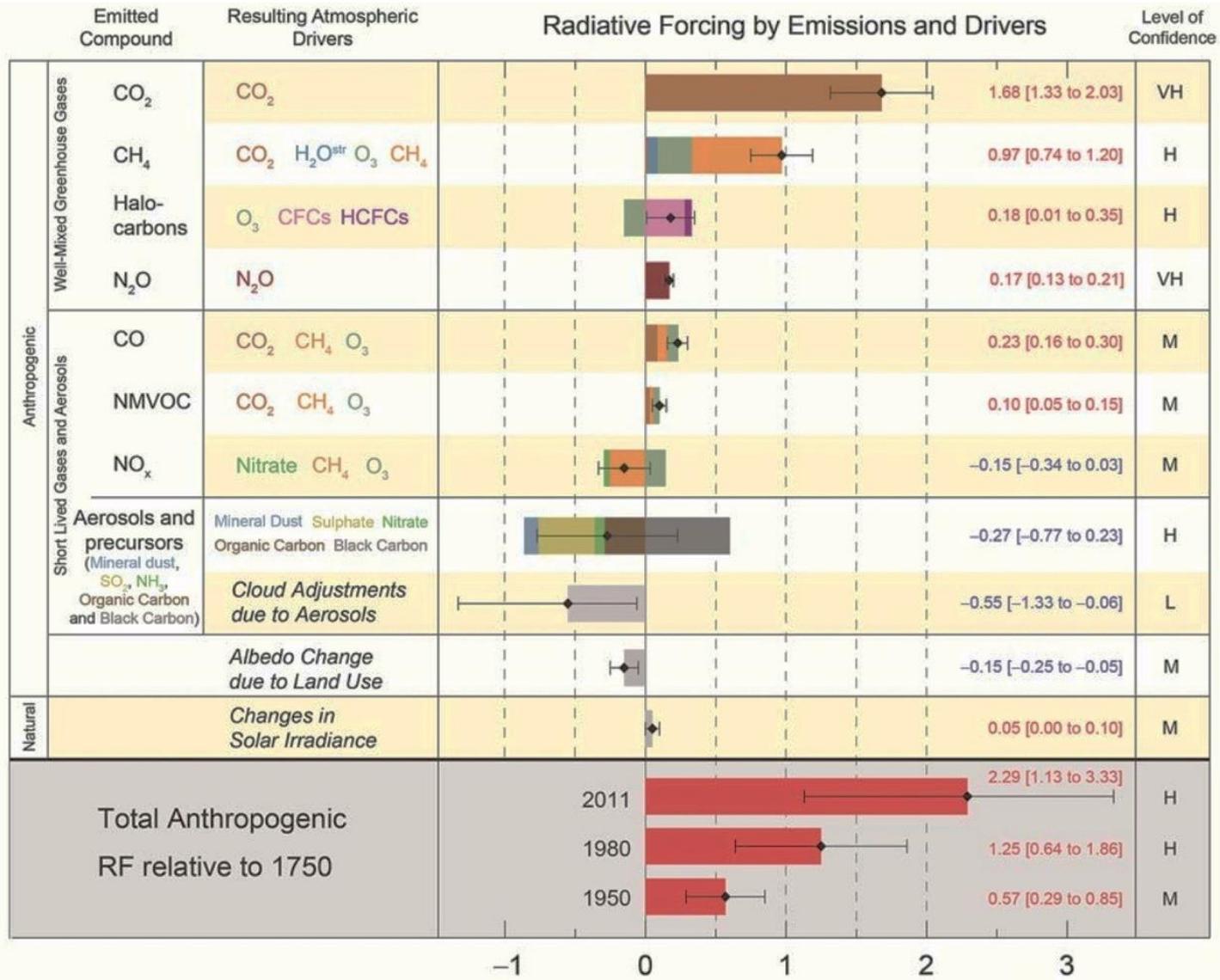


# Future climate

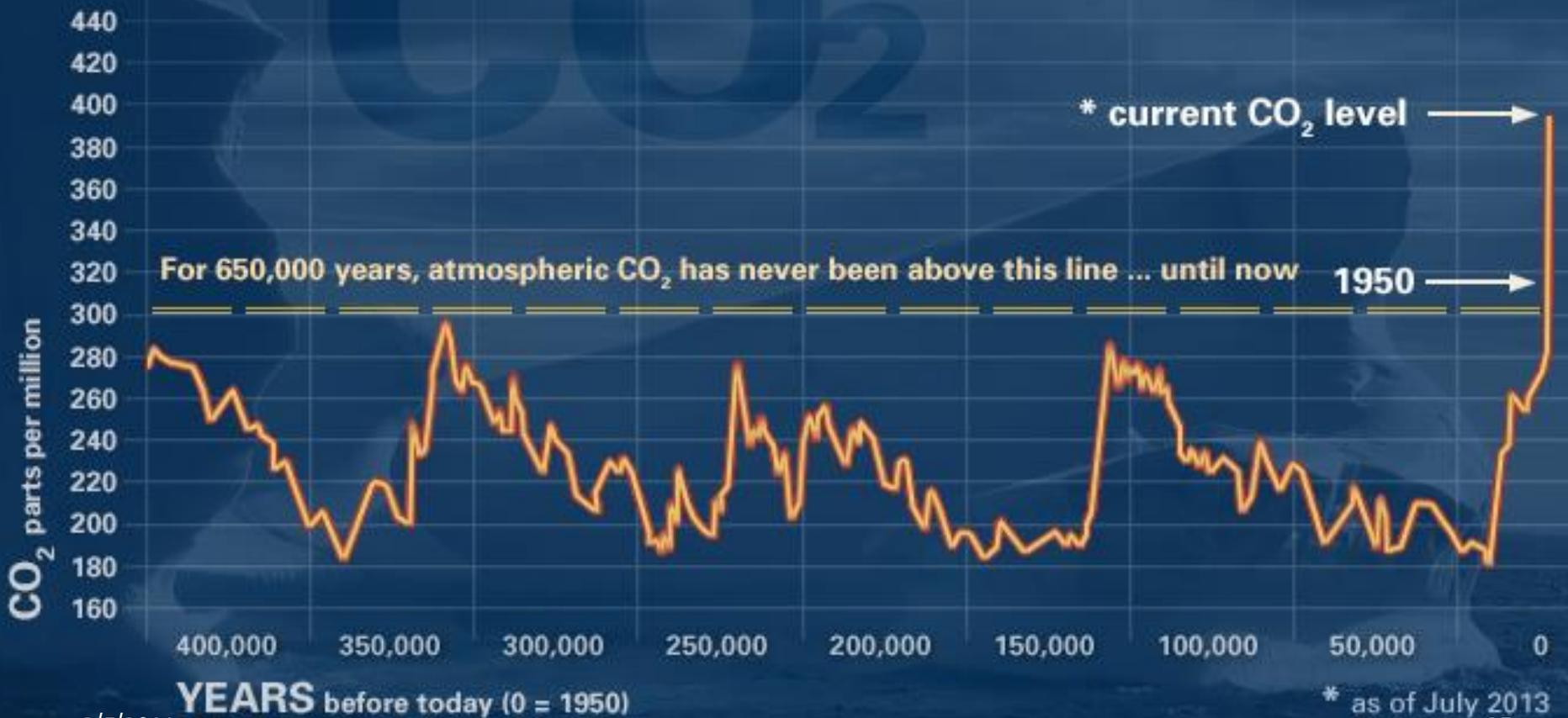


# Near-term future

## Anthropogenic Forcing (W/m<sup>2</sup>)

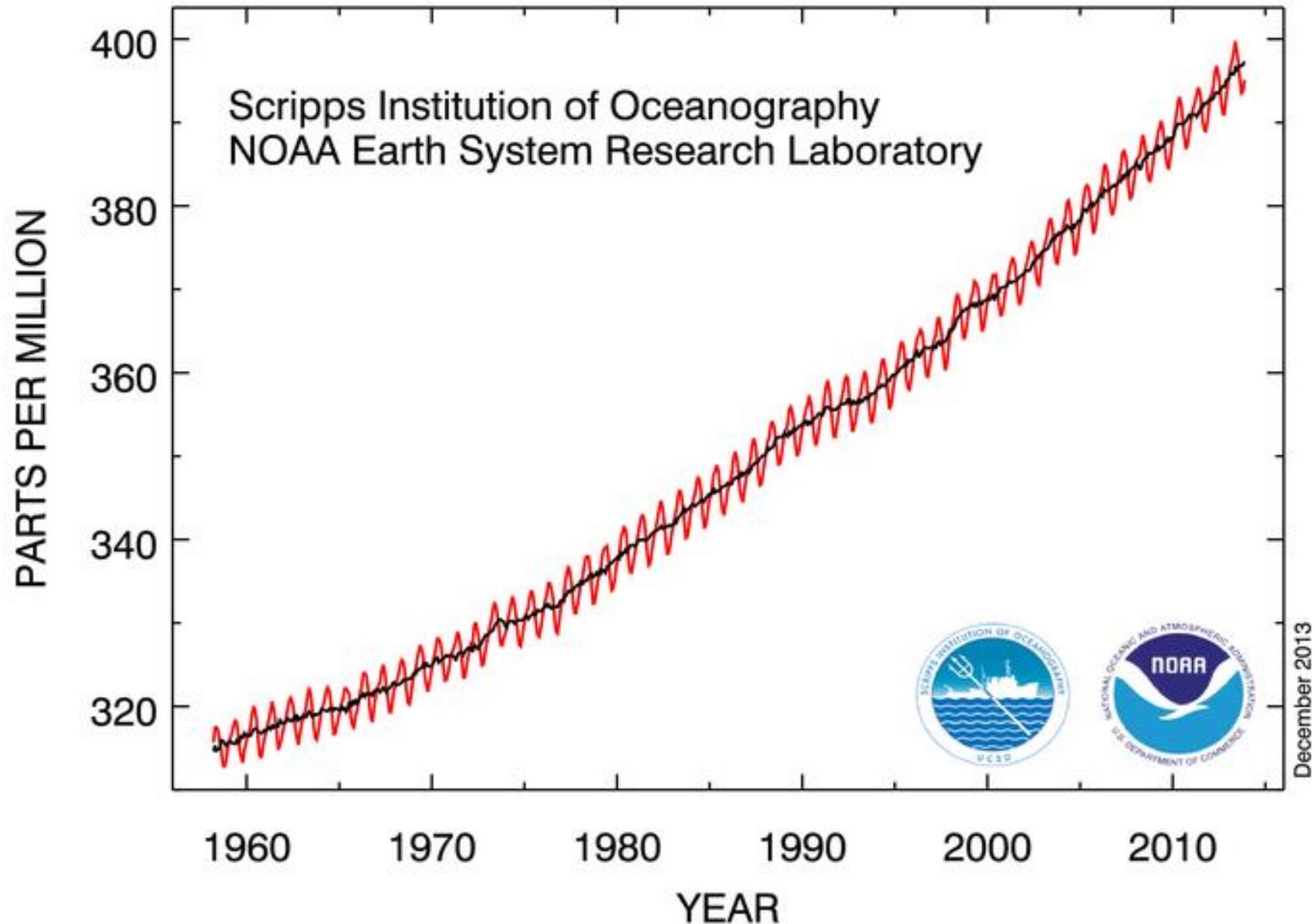


# Atmospheric CO<sub>2</sub>



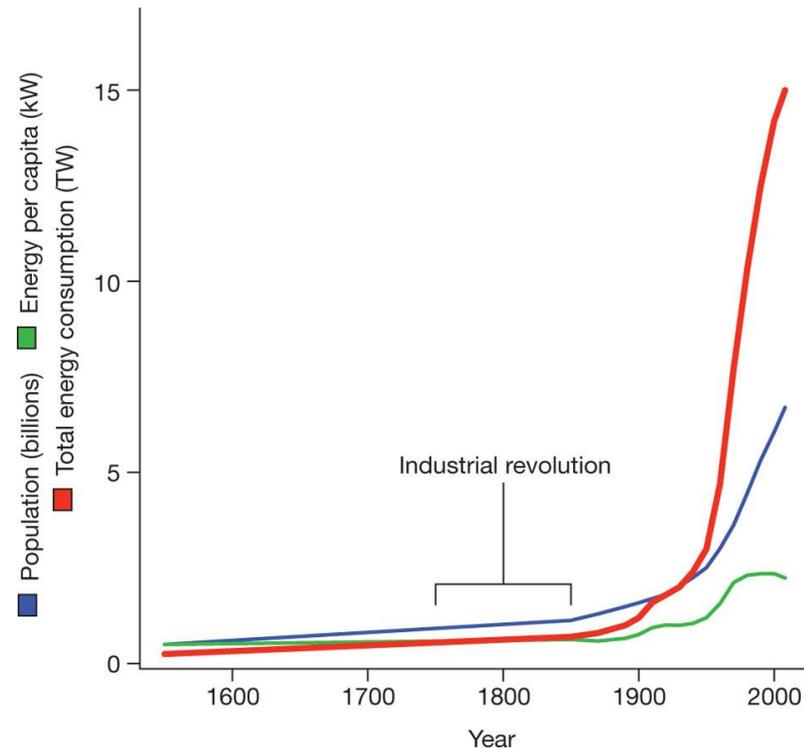
# Anthropogenic Forcing

## Atmospheric CO<sub>2</sub> at Mauna Loa Observatory



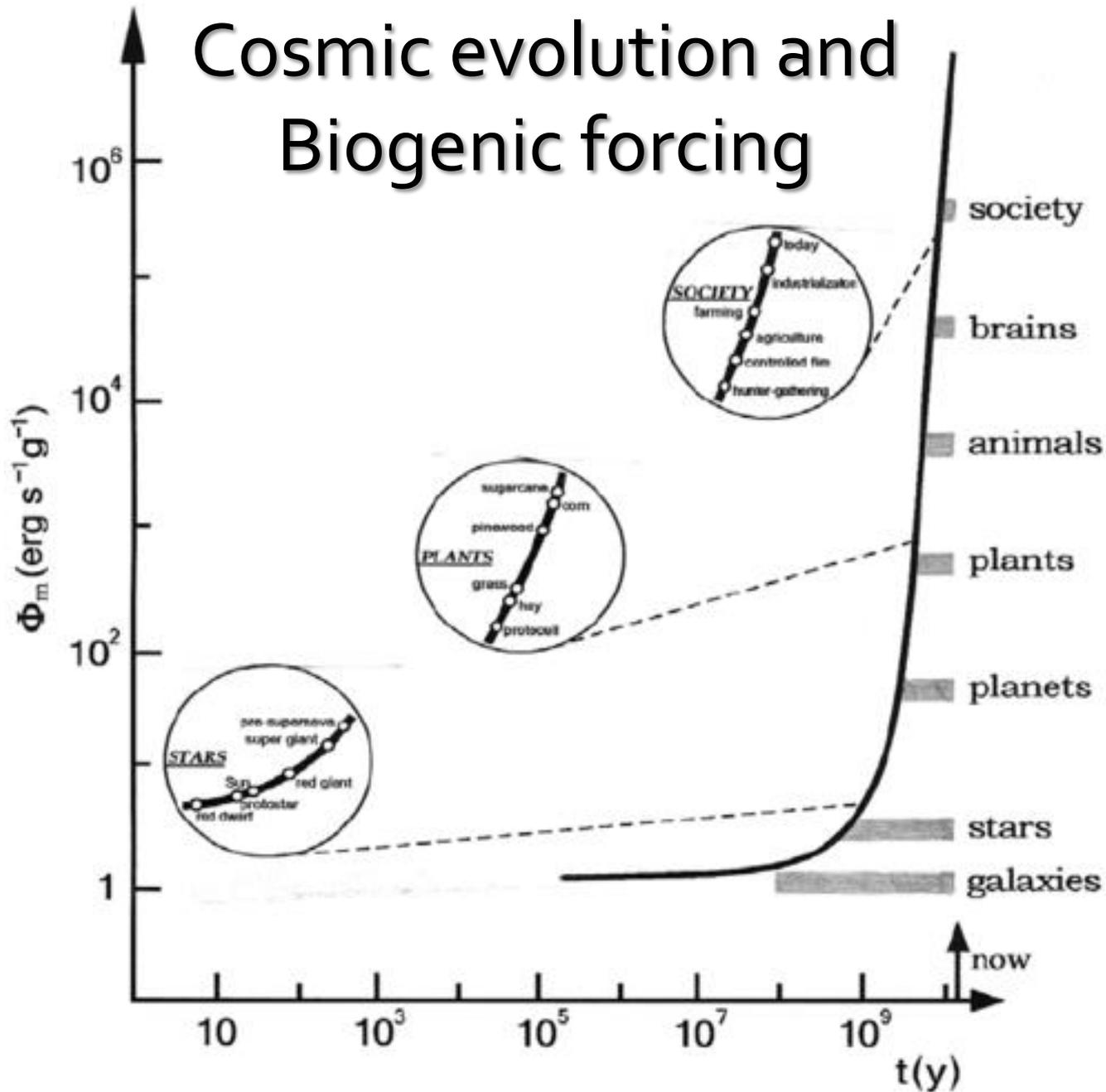
# Anthropogenic Forcing

History of growth in world population and environmental impact of *Homo sapiens*, indicated by its surrogates, per capita and total human energy use.



P R. Ehrlich *et al.* *Nature* **486**, 68-73 (2012) doi:10.1038/nature11157

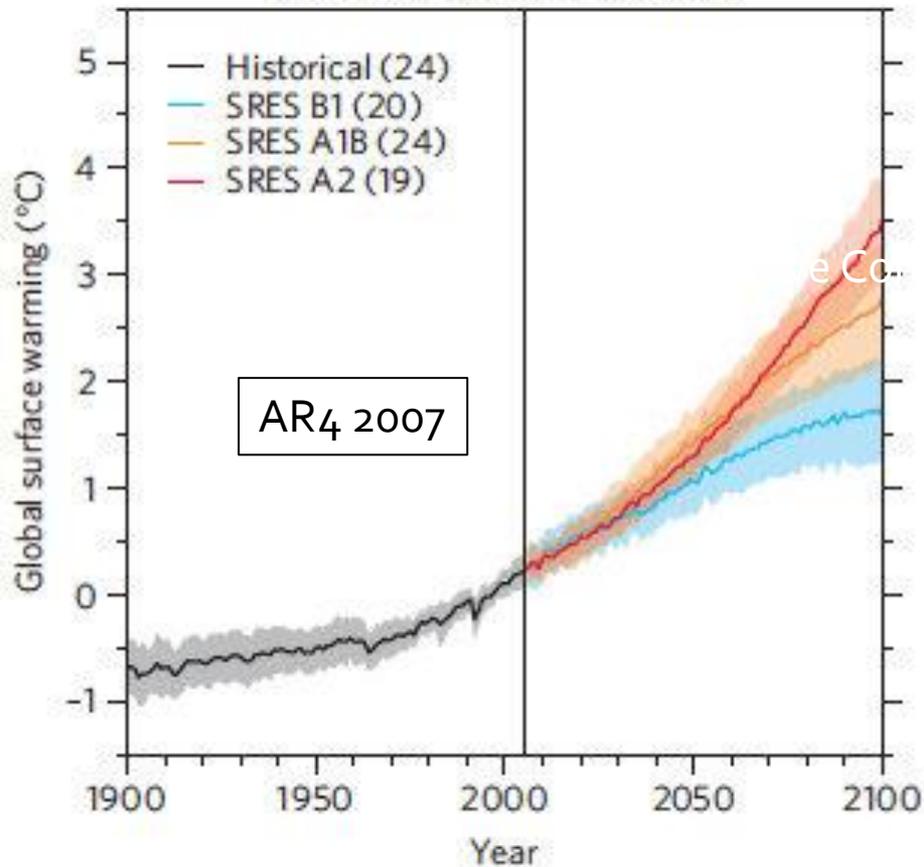
# Cosmic evolution and Biogenic forcing



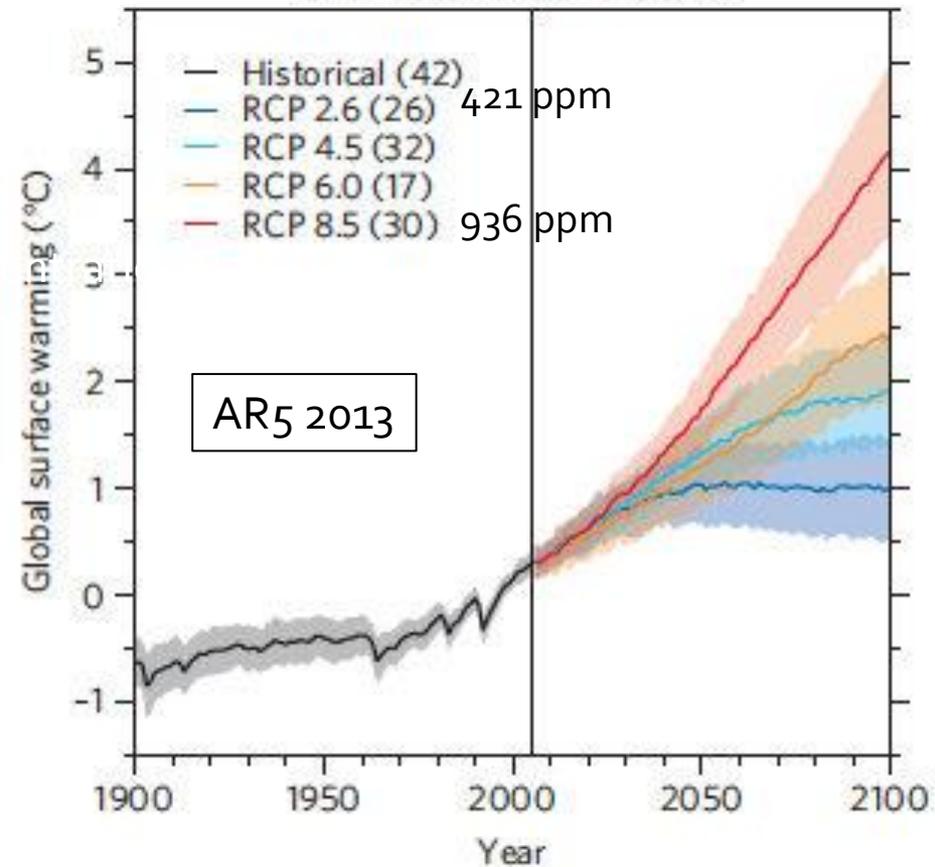
# IPCC

## future Earth surface temperatures

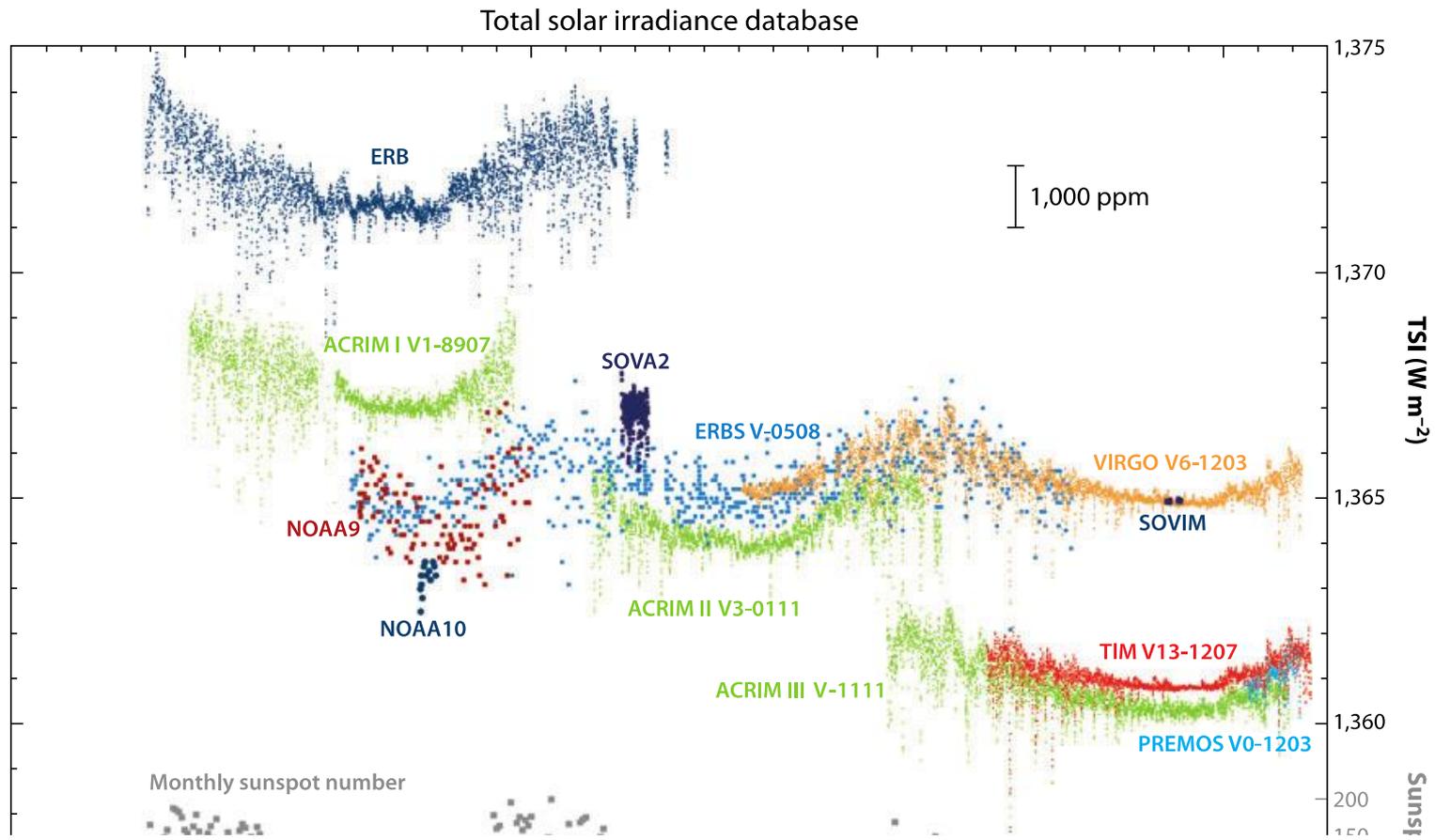
CMIP3 models, SRES scenarios



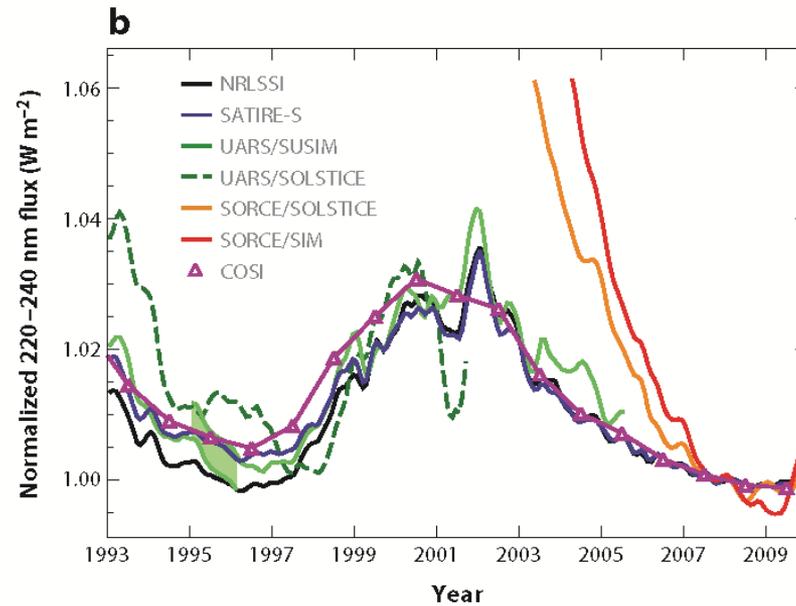
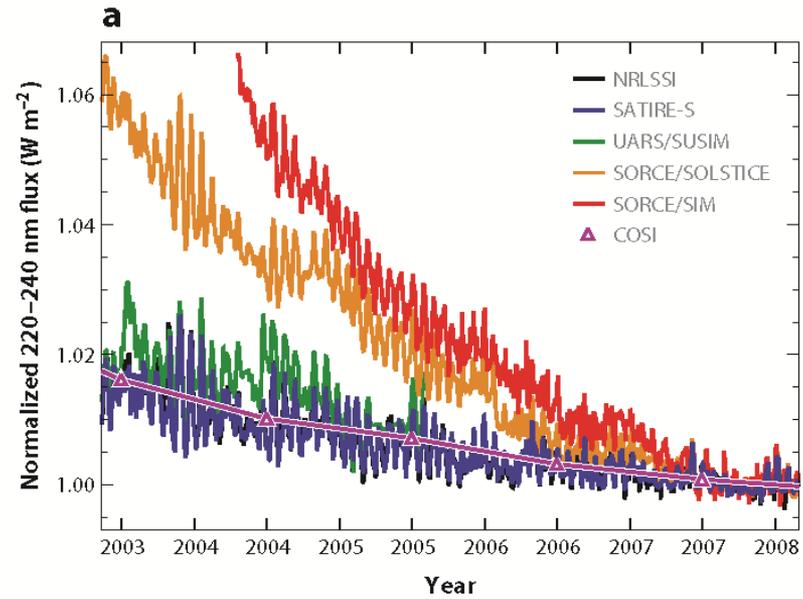
CMIP5 models, RCP scenarios



# Uncertainties

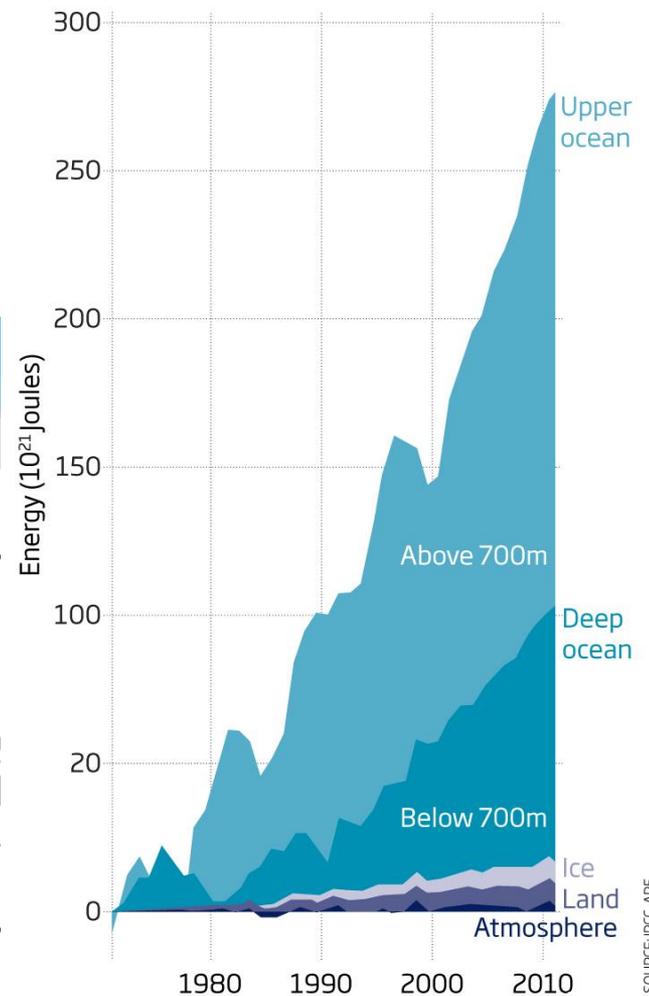
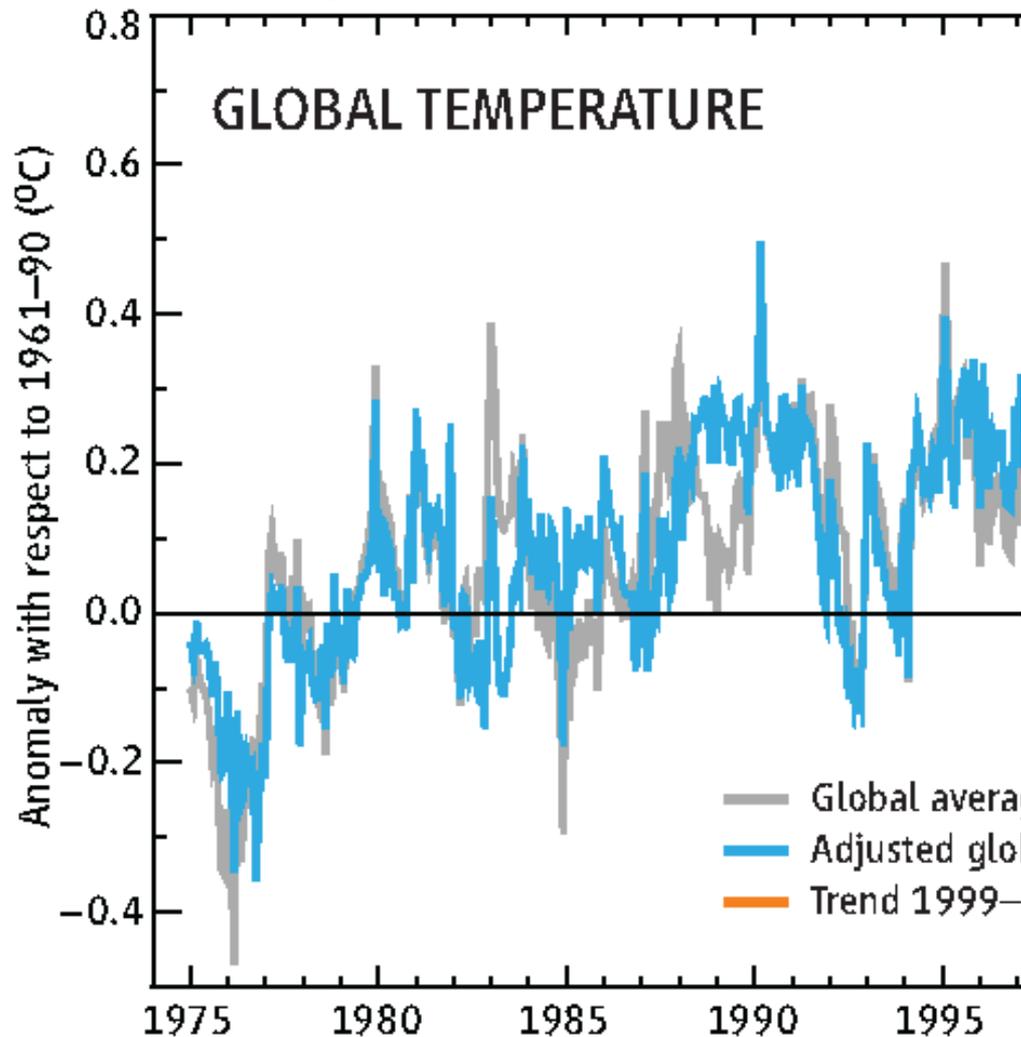


# Uncertainties



# Anomalies

## Has global warming stopped?



# Future strategies

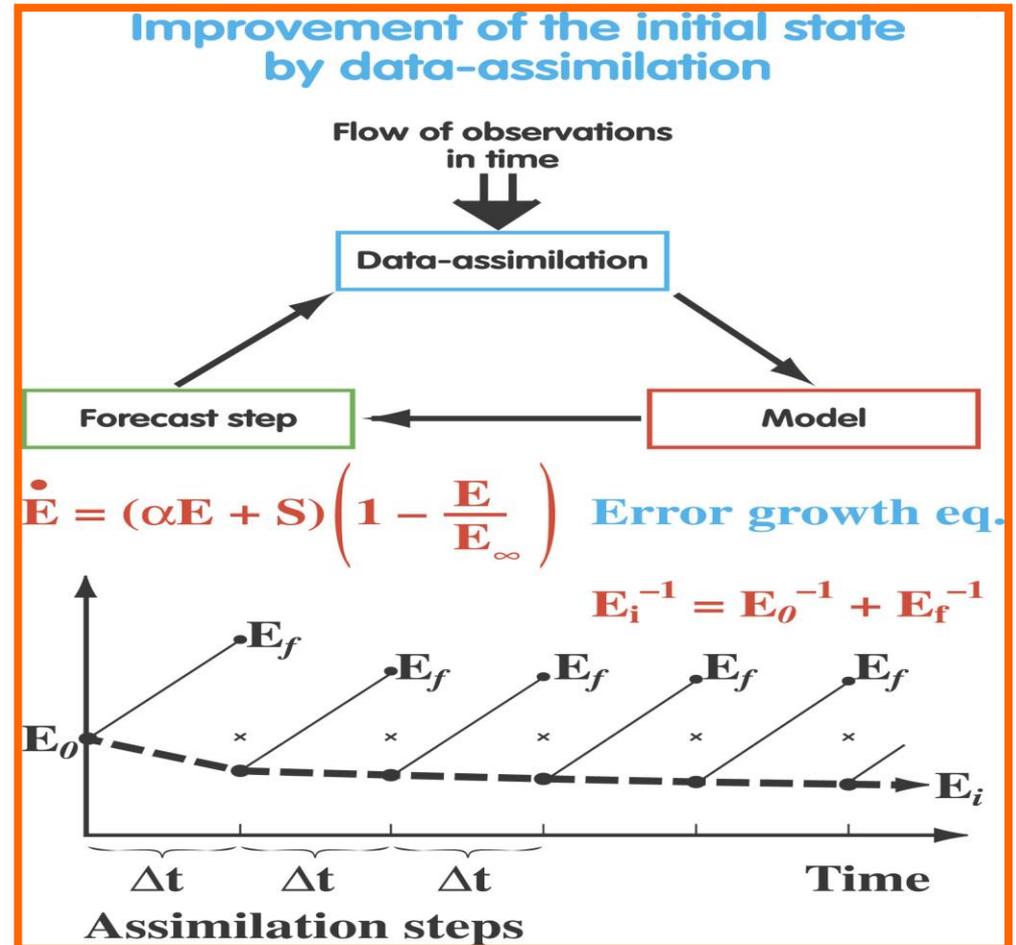
- **Many more observations,**
- **Much more improved modeling,**
- **Ensured continuity in data gathering over time scales which are meaningful to climate science, i.e. decades.**

# Modeling the climate

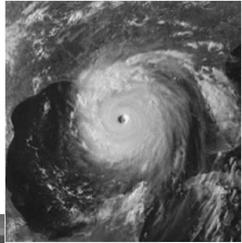
## Principle of error reduction in data assimilation

- Prediction is not just very difficult,
- Exact predictions are impossible.

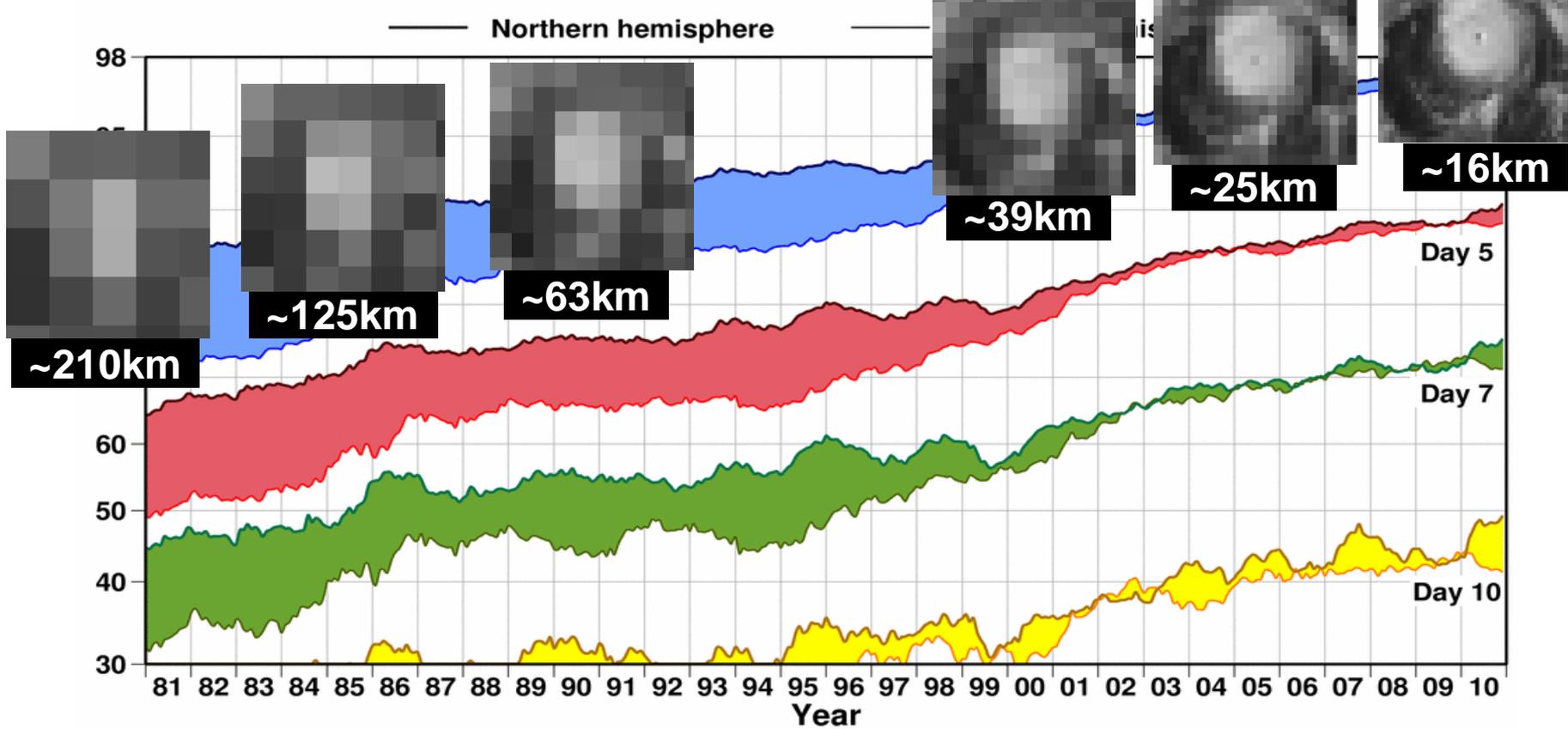
- Individual weather systems 3 - 12 days
- General weather situation 7 - 30 days
- Climate anomalies (El Nino) 3-12 months



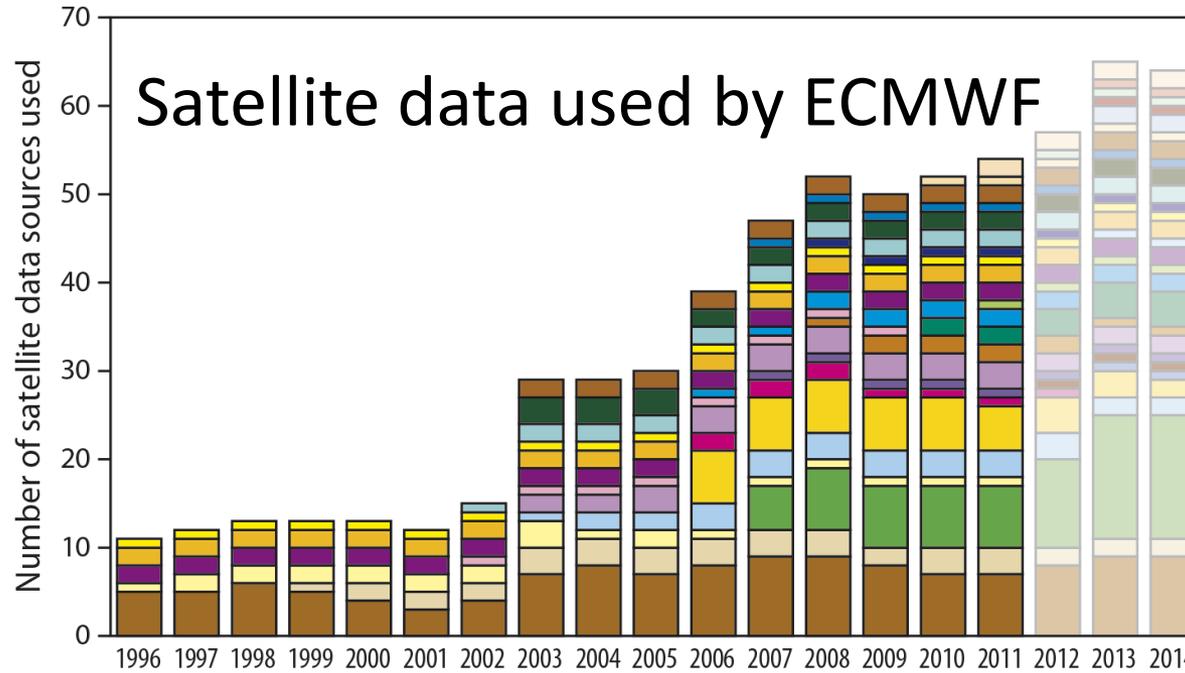
# Evolution of weather forecast skill



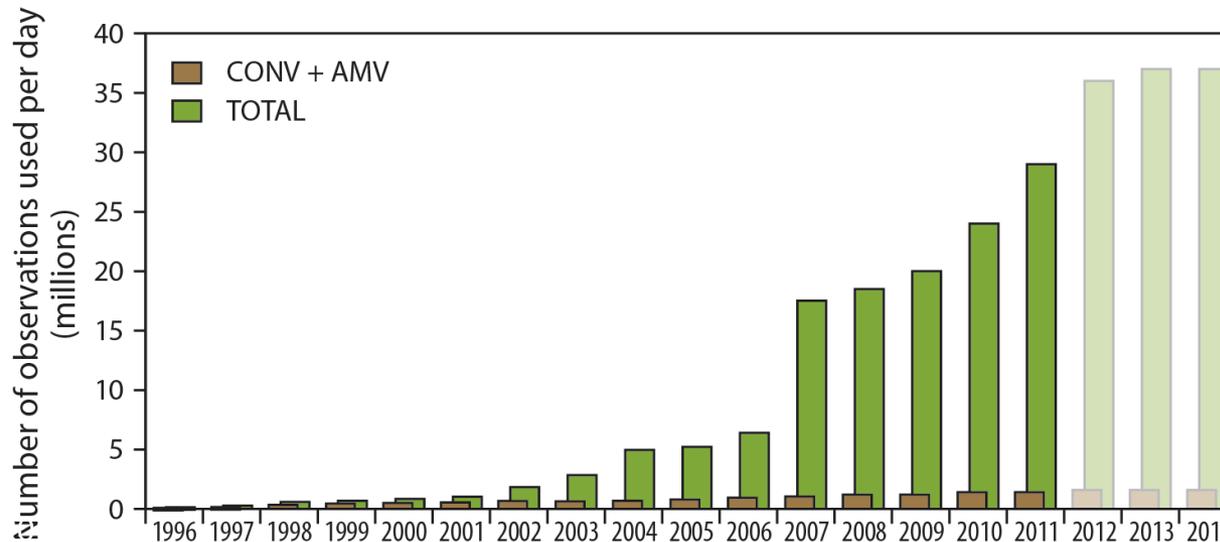
Anomaly correlation (%) of ECMWF 500hPa height anomalies



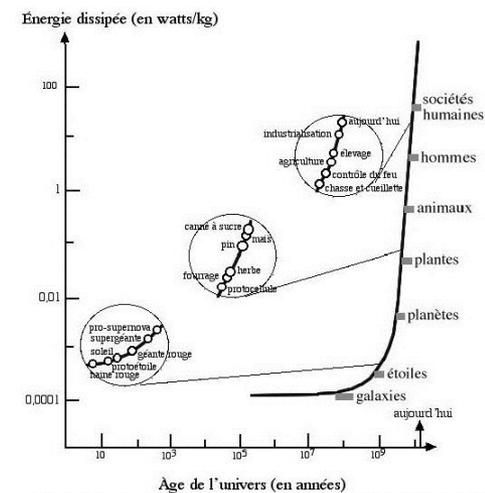
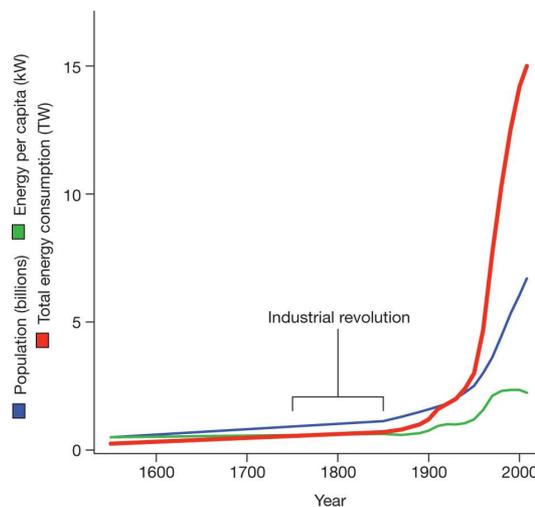
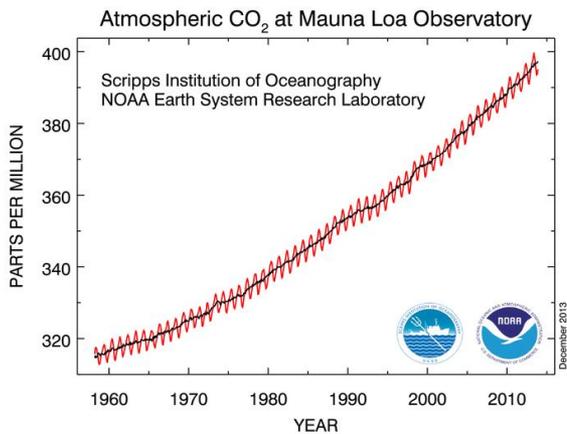
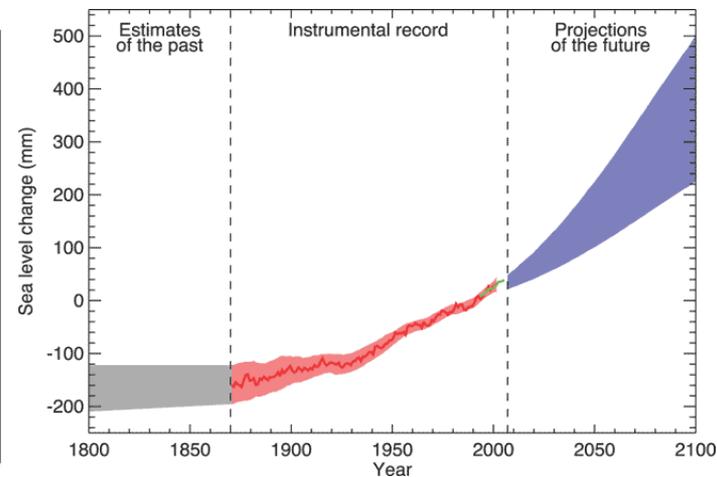
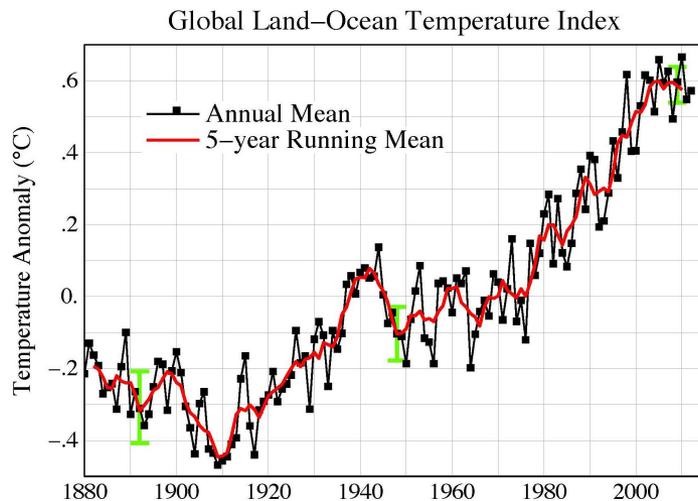
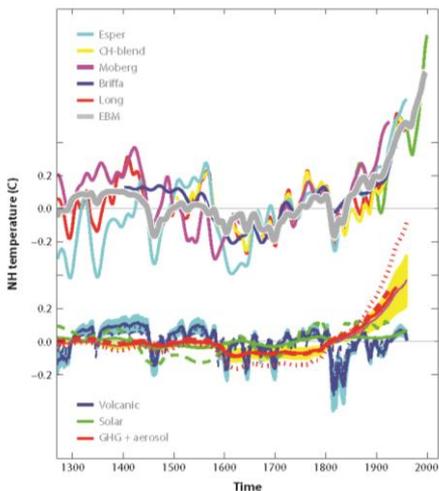
# Importance of satellites for weather forecasting



- Megha Tropiques
- Sentinel 3
- GOSAT
- ADM Aeolus
- EarthCARE
- SMOS
- TERRA/AQUA AMV
- GMS/MTSAT Rad
- GOES Rad
- METEOSAT Rad
- FY-2C/D AMV
- GMS/MTSAT AMV
- GOES AMV
- HY-2A
- METEOSAT AMV
- Oceansat
- JASON-1/2/3
- QuikSCAT
- FY-3A/B
- AURA
- AQUA
- TRMM
- GCOM-W/C
- CHAMP/GRACE
- TERRASAR-X/SAC-C
- COSMIC
- ENVISAT
- ERS-1/2
- METOP
- DMSP
- NOAA



# Conclusions



# Conclusion

Reducing the present uncertainties affecting our evaluation of climate evolution can only come through much expanded, internationally coordinated observational assets, both at the small-scale process level, and at large-scale circulation changes. It involves:

- The design and deployment of new instruments on the ground, at sea and in space;
- The maintenance of crucial *in-situ* and satellite observing systems.
- These should be accompanied by rigorous approaches to synthesize the heterogeneous data streams into a coherent dynamic framework

# Conclusion

Sustaining such observations over sufficiently long periods to provide records of useful quality for climate research is a serious inter-generational challenge

**But who is in  
Thank you!  
charge?**