Long Term Observations of Earth's Upper Atmosphere

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Outline

- The golden age of atmospheric science
- Science in the modern age
- Continued observations of the upper atmosphere
- Science and operational needs
- Priorities for the future – that need to be started now!

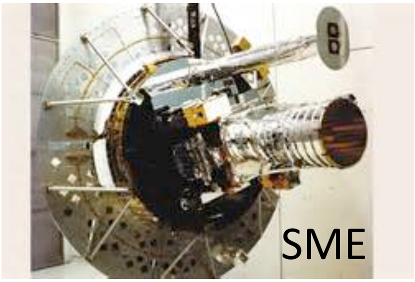
The Golden Age of Upper Atmospheric Science 1975 - Present

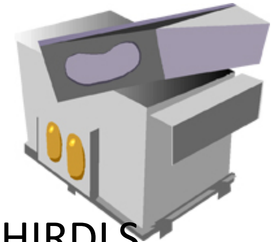
- Concerns over the ozone layer prompted development of satellite measurement of ozone, thermal structure, related chemistry, and dynamics
- Experimental techniques involve both limb and nadir observations
  - Limb both solar occultation and thermal emission
  - Nadir is backscatter ultraviolet (e.g. SBUV, TOMS)
- Multiple U. S. and International instruments and missions flown over past 40 years to understand stratosphere, mesosphere, and lower thermosphere/ionosphere

What makes the Upper Atmosphere Interesting and Worthy of Study?

- Blend of classical photochemistry and aeronomy
  - Ozone is still the main radiative drive in the mesosphere and up to 90 km
  - Solar UV variability and particle precipitation influence thermal structure and composition
- Climate change
  - Expect M/LT to cool with increasing carbon dioxide
- Non-Equilibrium Radiative Transfer
  - ALL heating and cooling processes occur far removed from Local Thermodynamic Equilibrium (LTE) above ~ 65 km
- Atomic species become significant
  - Low density means long lifetimes for atomic oxygen and oxygen
  - Remarkable influence on the energy budget of the 80-100 km region and above
- The E-region, 105-140 km, is the "heat sink" for the entire atmosphere up to the exobase – controls climate change in thermosphere/ionosphere
  - Ultimately determines density at satellite orbits

Upper Atmosphere Satellite Instruments and Missions




HIRDLS

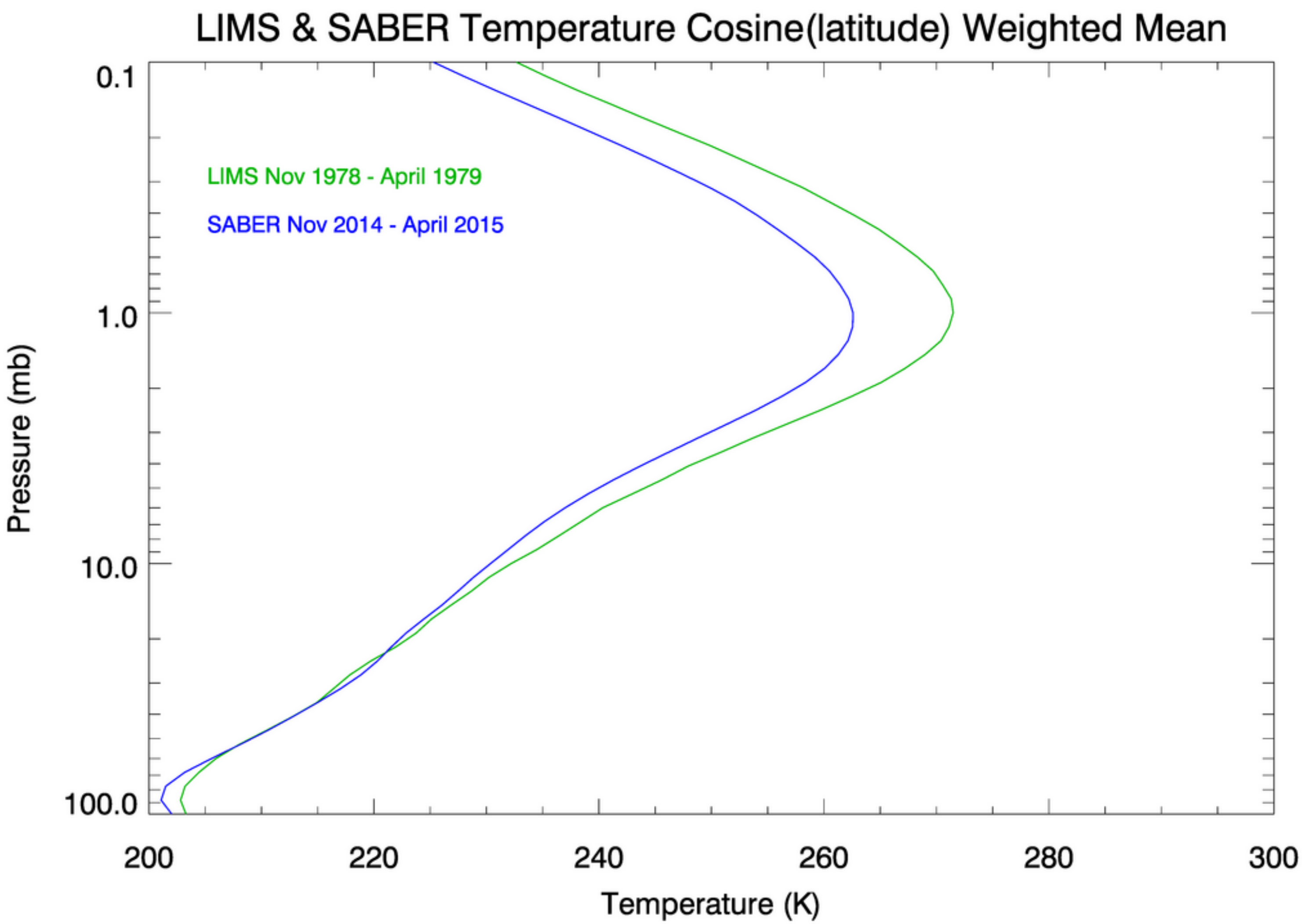
- 1970's
  - LRIR, LIMS, AE, SAM
- 1980's
  - DE-1, DE-2, SAGE-II, SME
- 1990's
  - UARS, POAM
- 2000's
  - Aura, TIMED, Envisat, ODIN, SciSat, SAGE-III, AIM, SMILES
- 2010's
  - SAGE III on ISS (2016 launch)
- 2020's ????
  - No missions in preparation for middle atmosphere science

A gap in thermal structure and chemical composition measurements after 2020 is almost assured

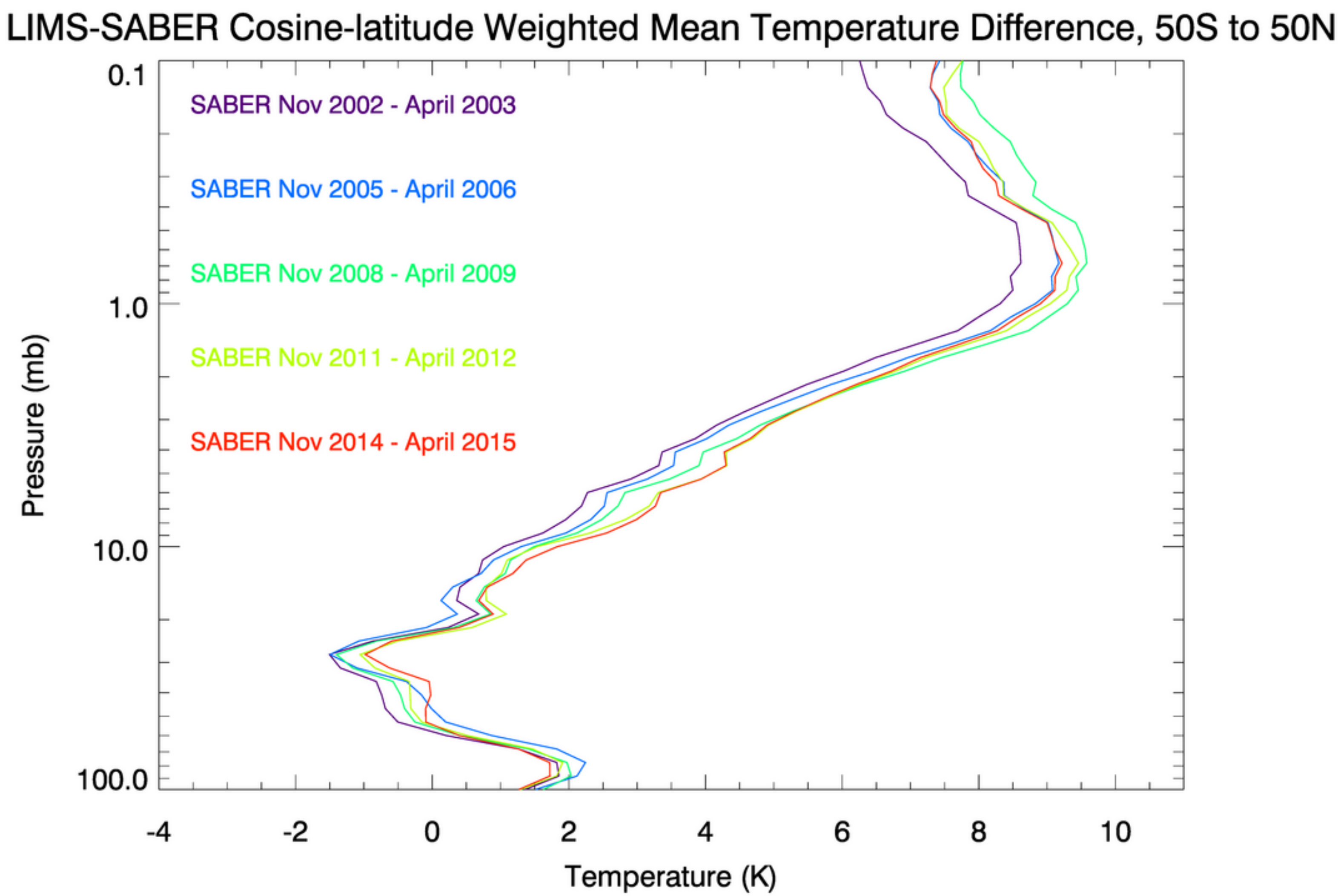
Selected Long-Term Observations

- Stratospheric Temperature 1978 – 2015
- Mesospheric Carbon Dioxide
- Thermospheric energy balance

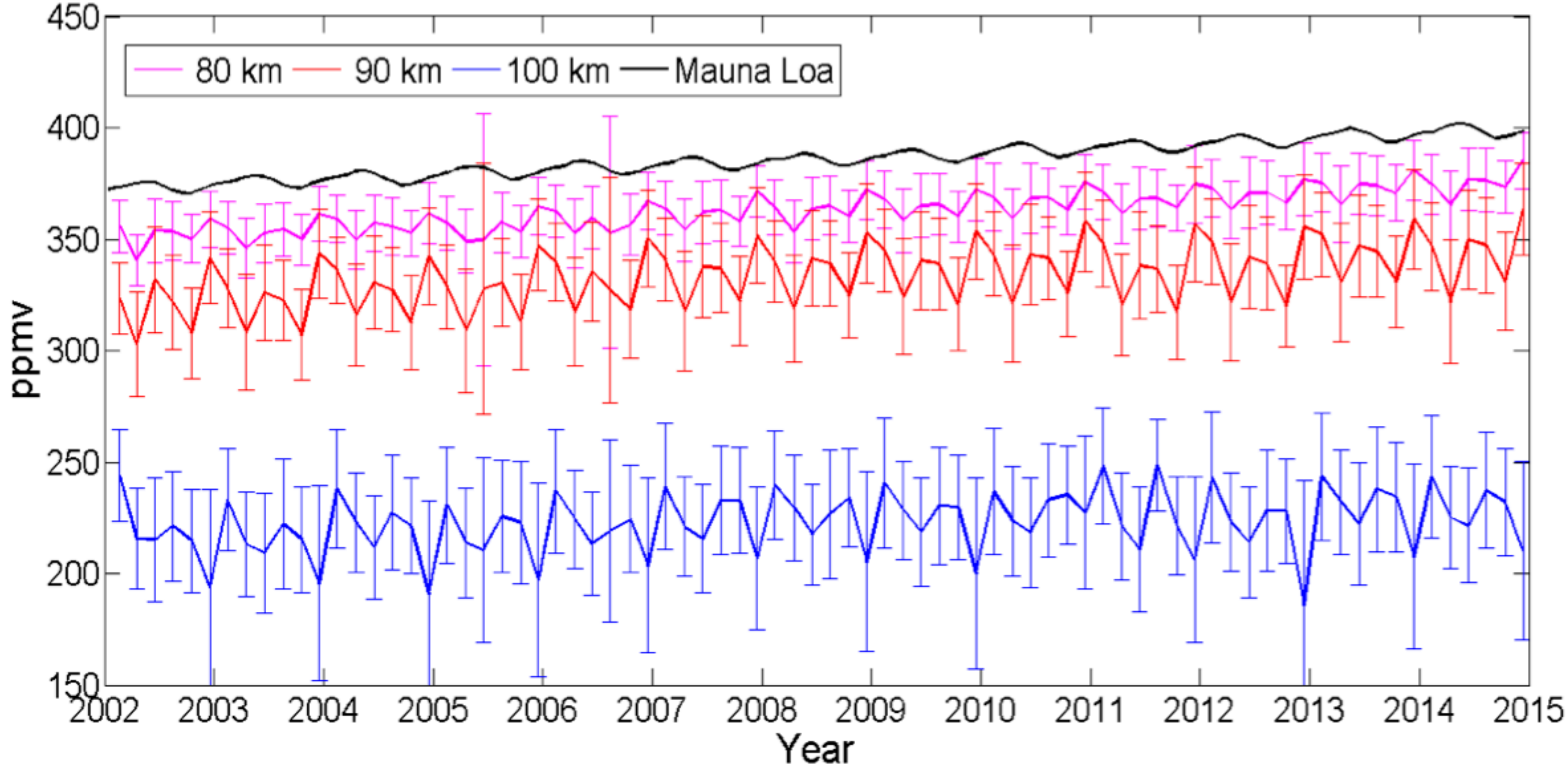
Stratospheric Temperature Change 1978/79 to 2014/15



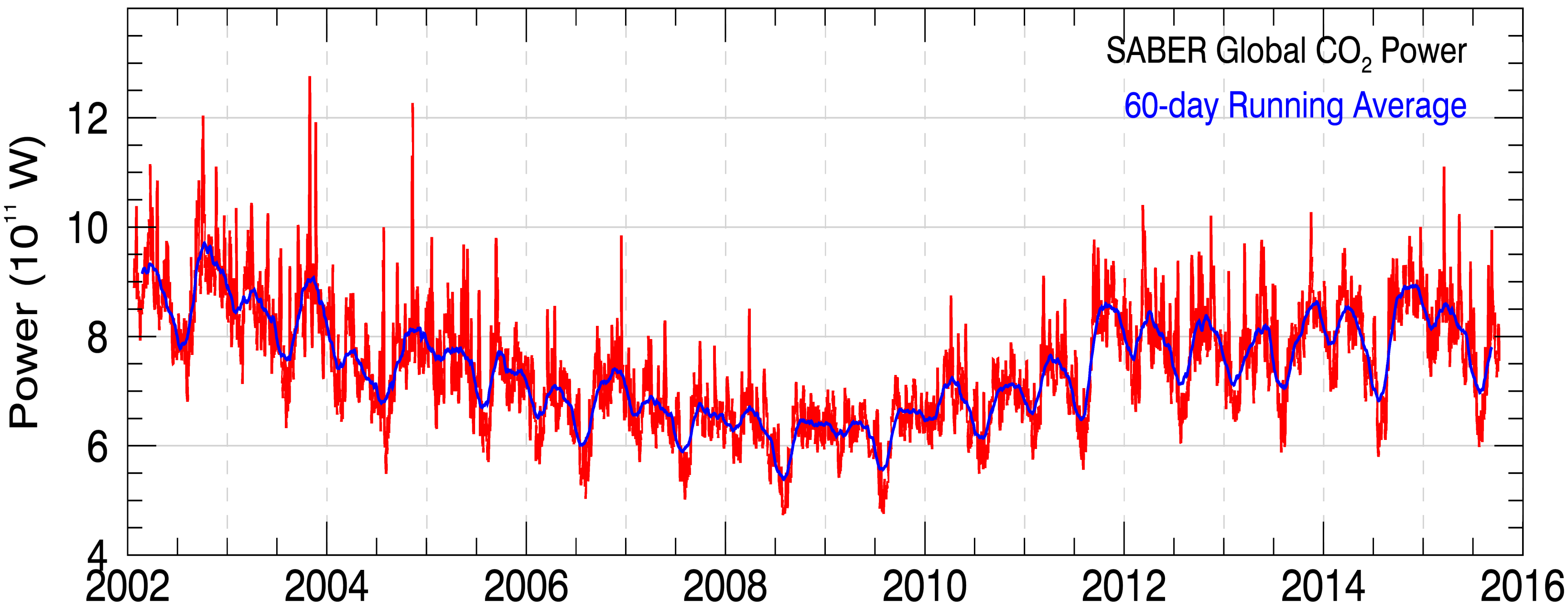
Stratospheric Temperature Differences



Time Series of Upper Mesosphere and Lower Thermosphere Carbon Dioxide 2002-2015



Global Radiative Cooling by CO_2 (W) 100 km to 140 km
2002 – 2015 : 5000 days of data



Global Radiative Cooling by NO (W) 100 km to 140 km
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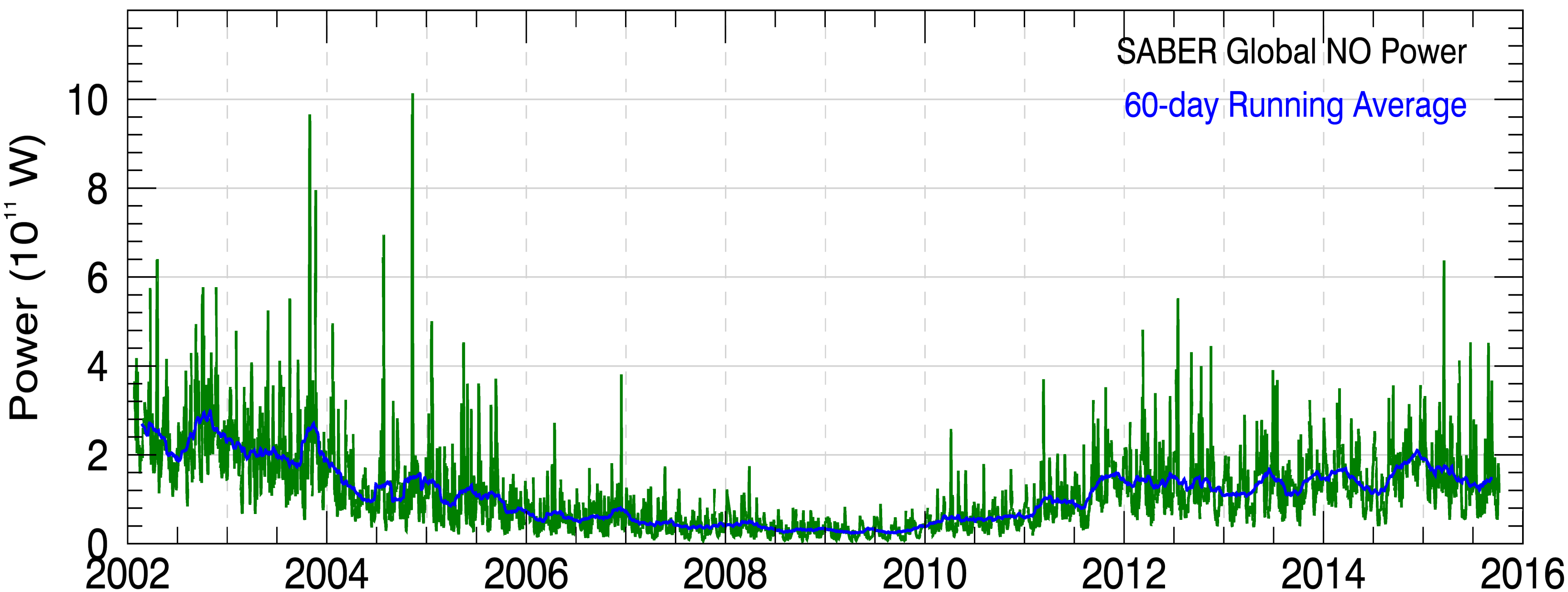
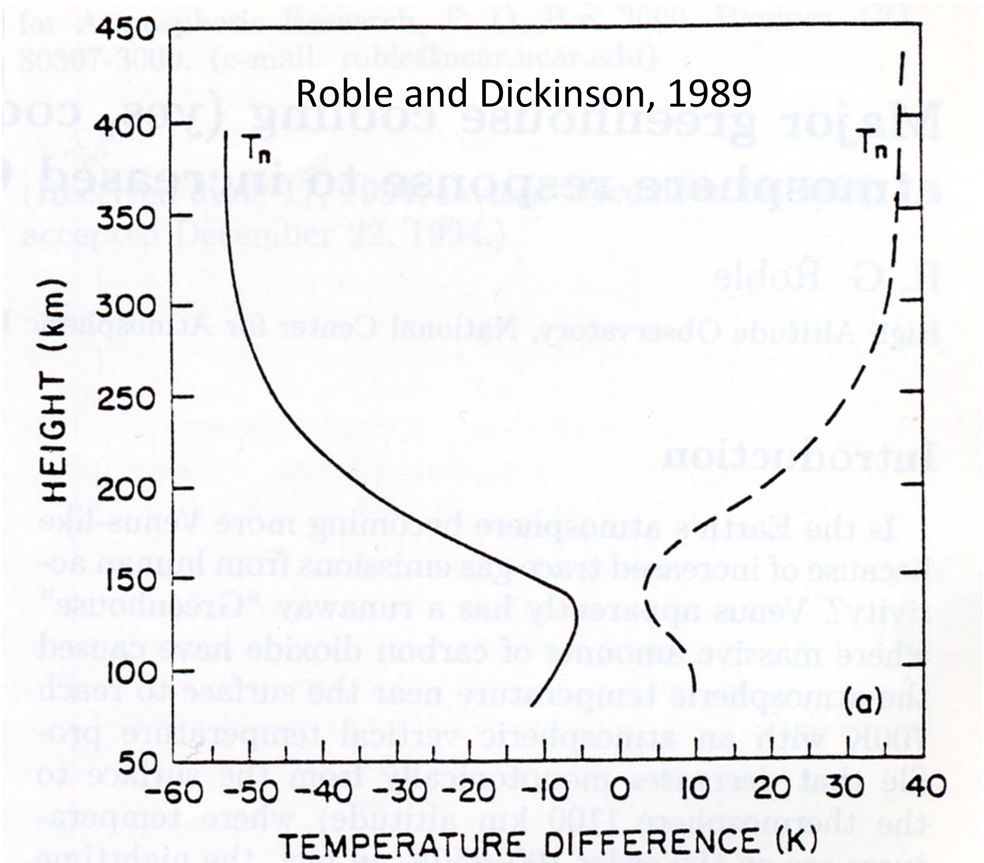


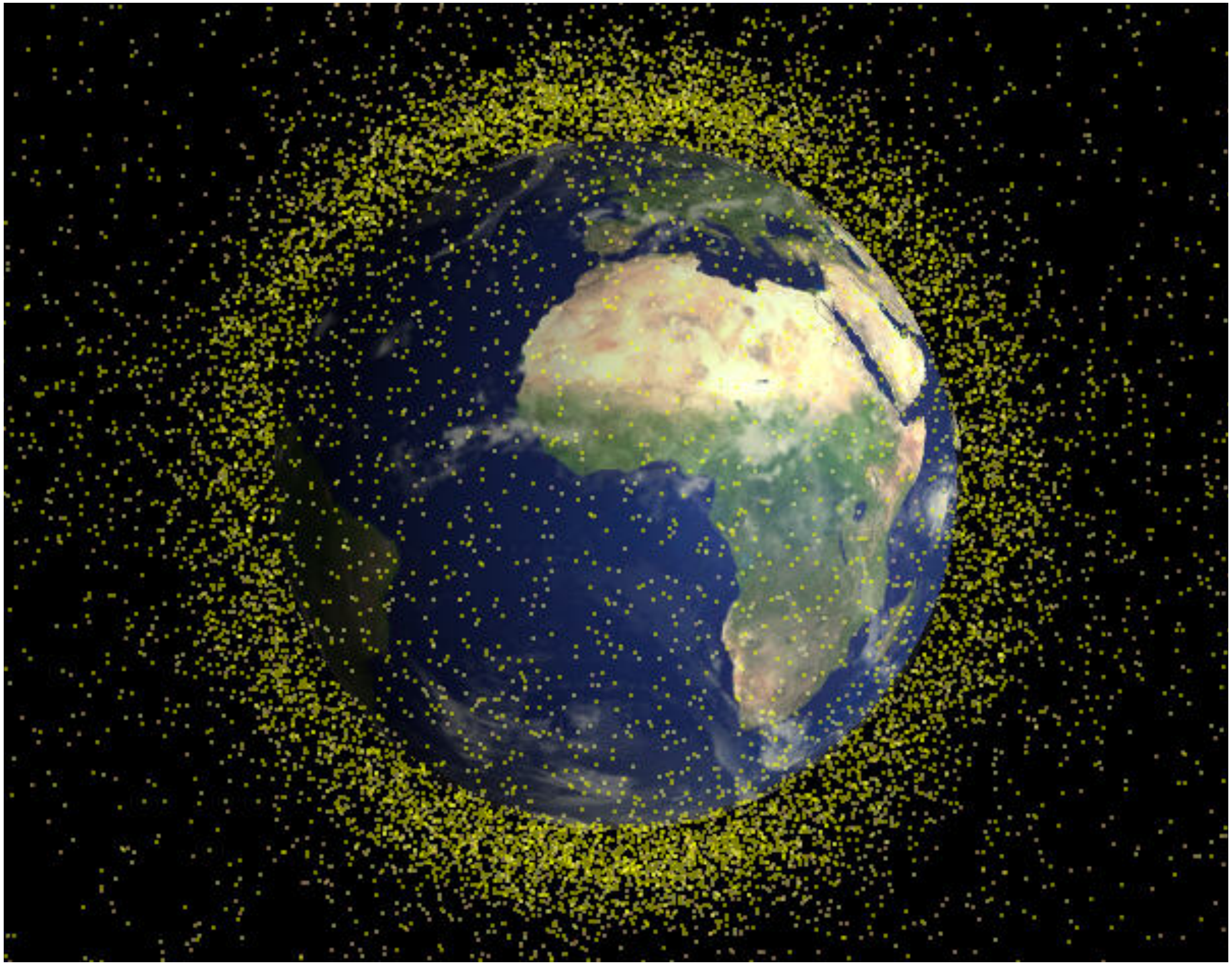
Name one good reason why we need to continue to measure the mesosphere and thermosphere

Global Cooling due to Increasing CO_2



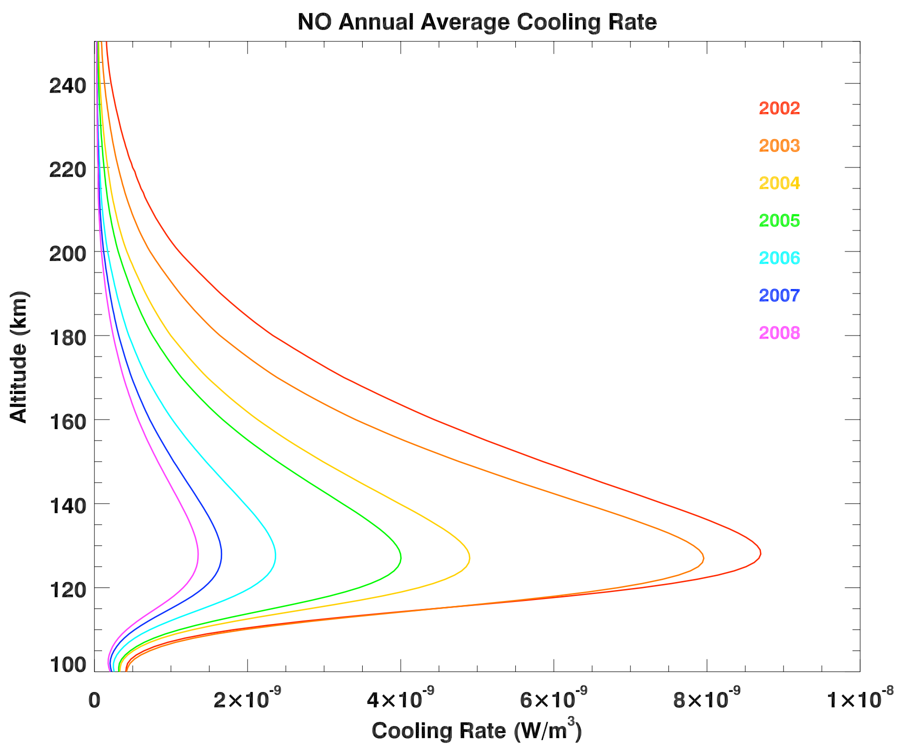
Increasing CO_2 → More IR emission/cooling by CO_2
Reduced temperatures → Reduced Density → Reduced Orbital Drag
Translates to longer lifetime for satellites – *and space debris*

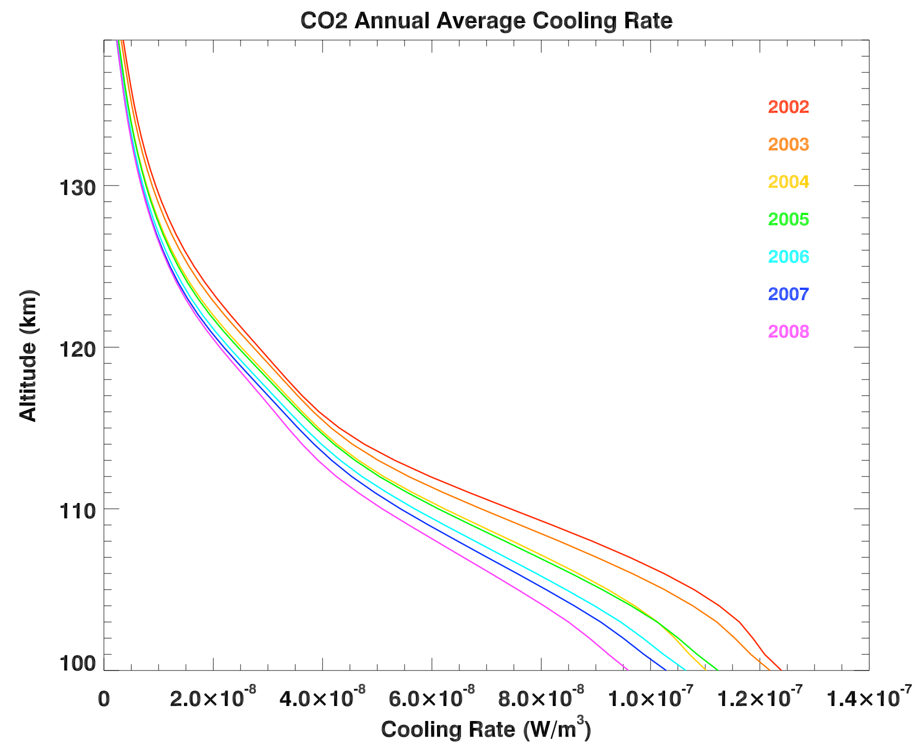
How about 10^8 good reasons?



NASA Orbital Debris Program Office

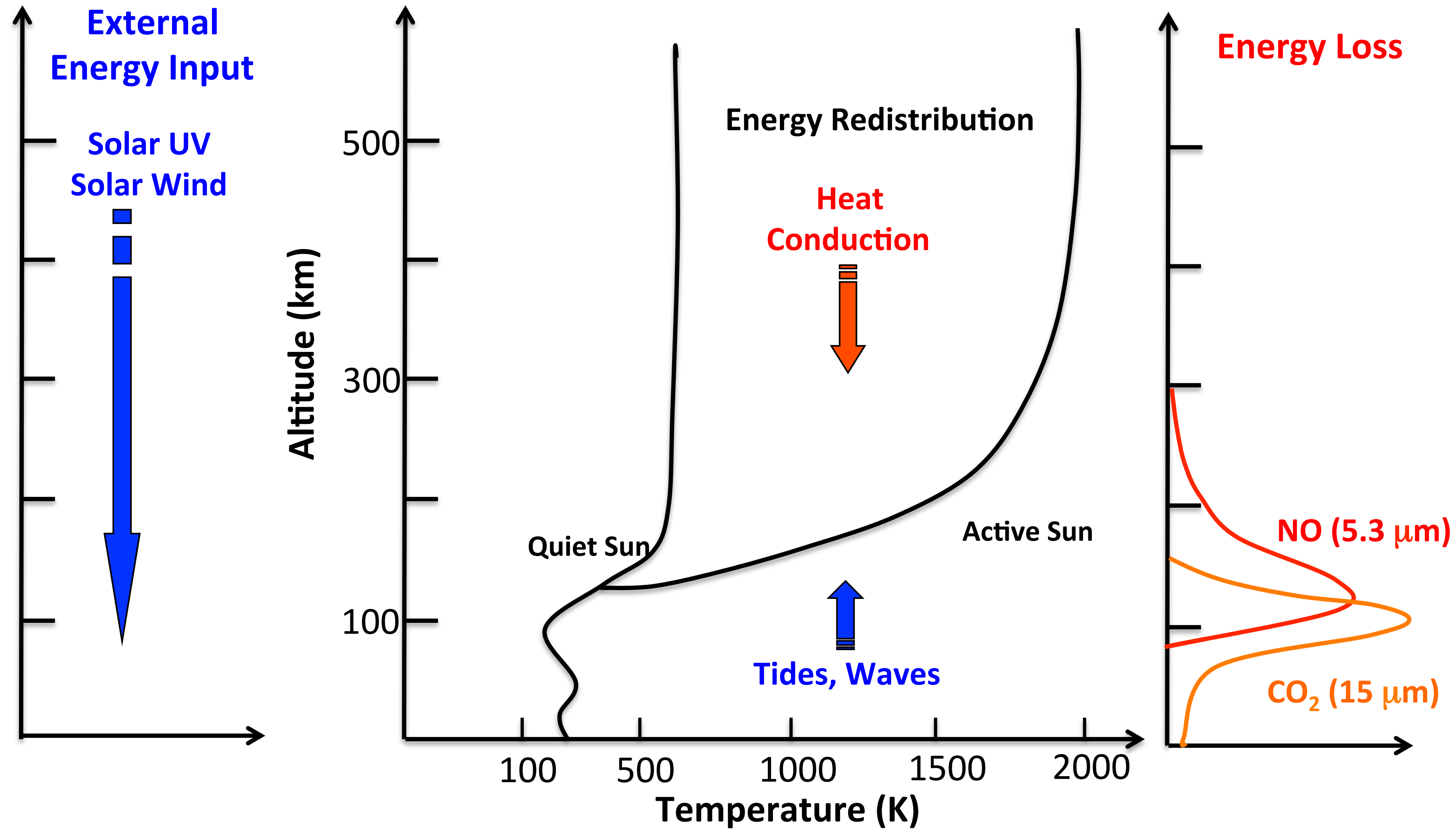
How does the Atmosphere Cool Above 140 km?





Infrared Radiation is Effective Only below 140 km

Thermosphere Energy Balance – The E-Region Heat Sink

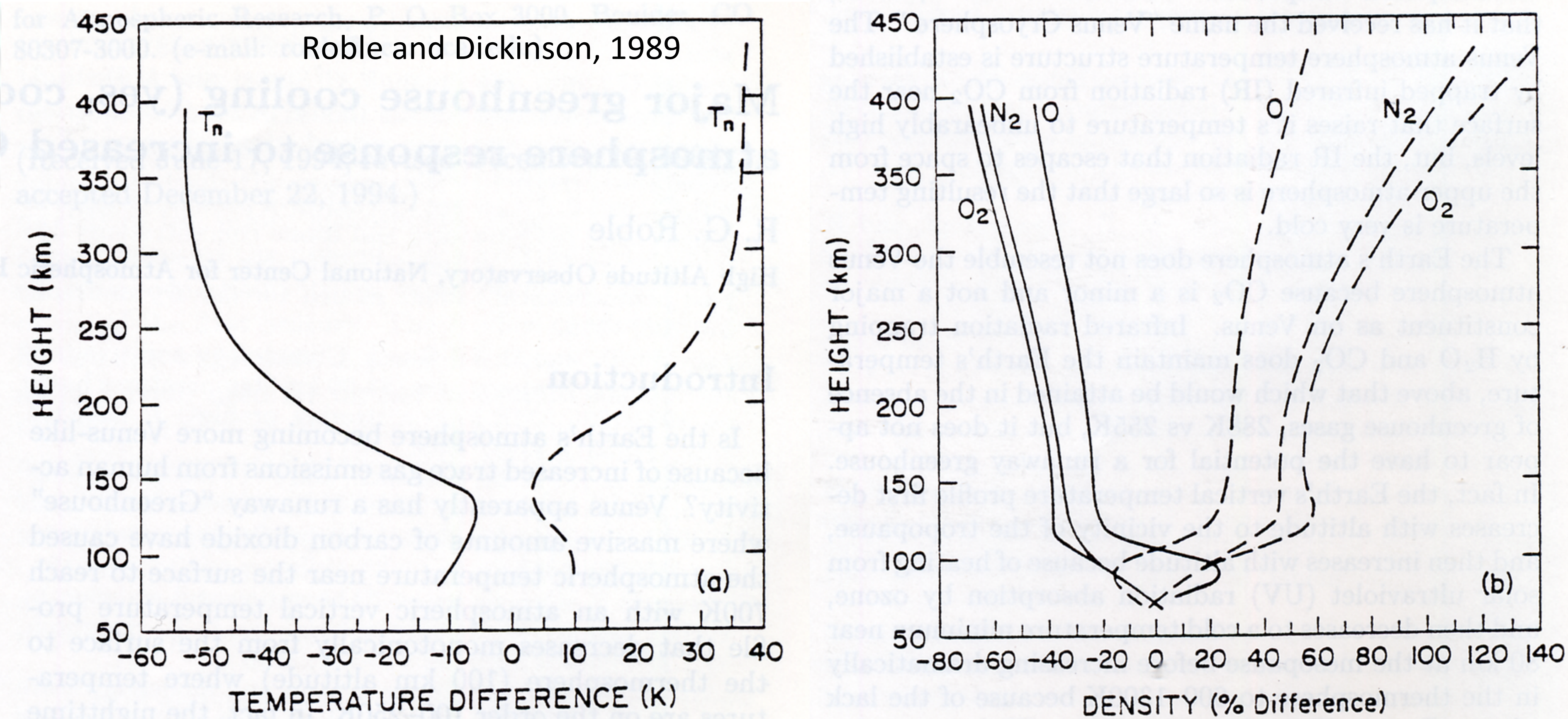


Summary

- Long, illustrious history of observations of Earth's stratosphere, mesosphere, and thermosphere
- Presently facing a gap in measurements in near future
- Critical to understand thermal structure and energy balance of E-region, the "heat sink" of the upper atmosphere
- Long term evolution due to CO_2 increase controlled by radiative cooling in the E-region
- Technology now exists to measure T, O in E-region, and to study its coupling to above and below
- These measurements are a priority to understanding the future of satellite operations and climate change aloft

Backups

Global Cooling due to Increasing CO_2



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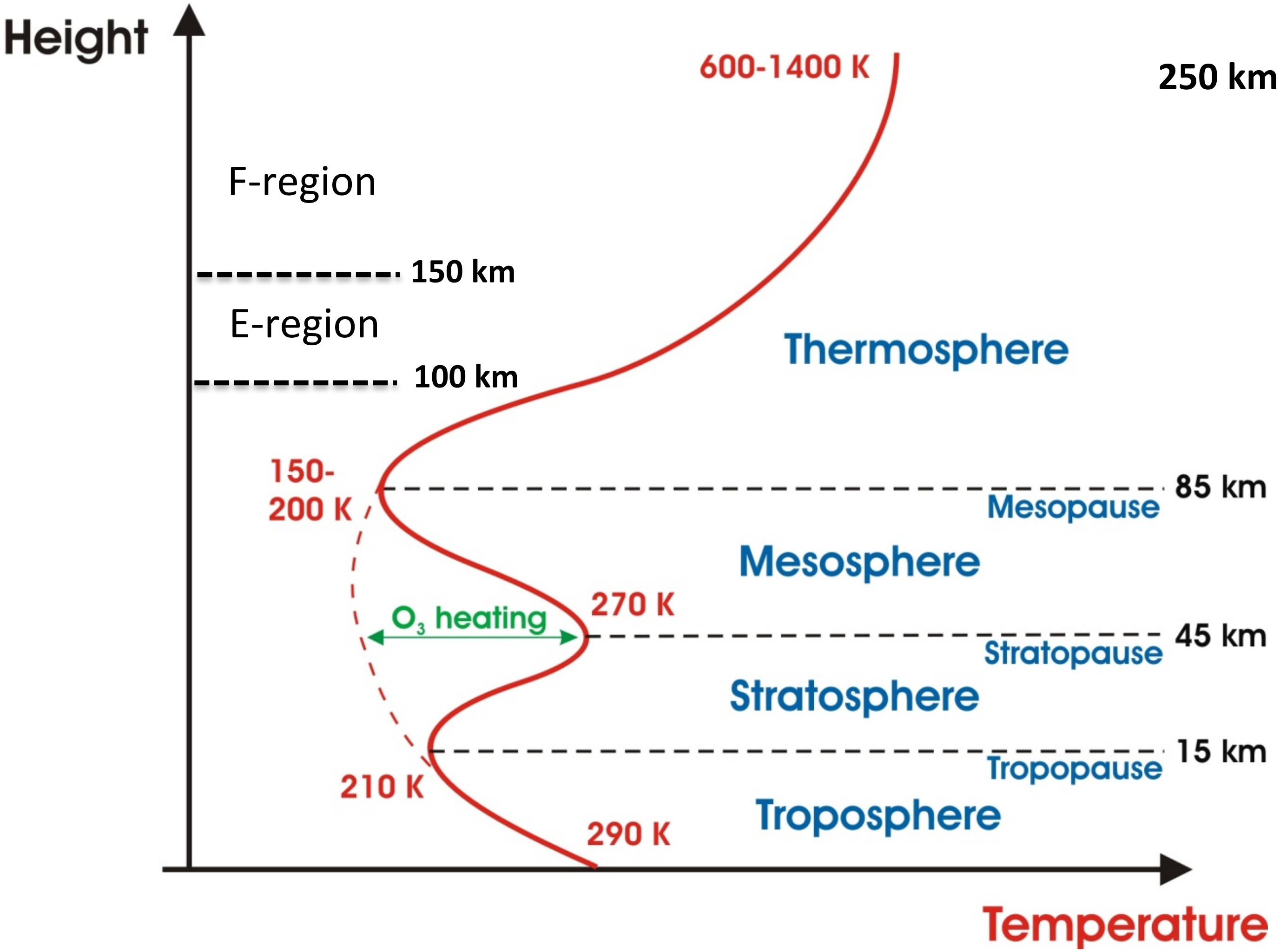
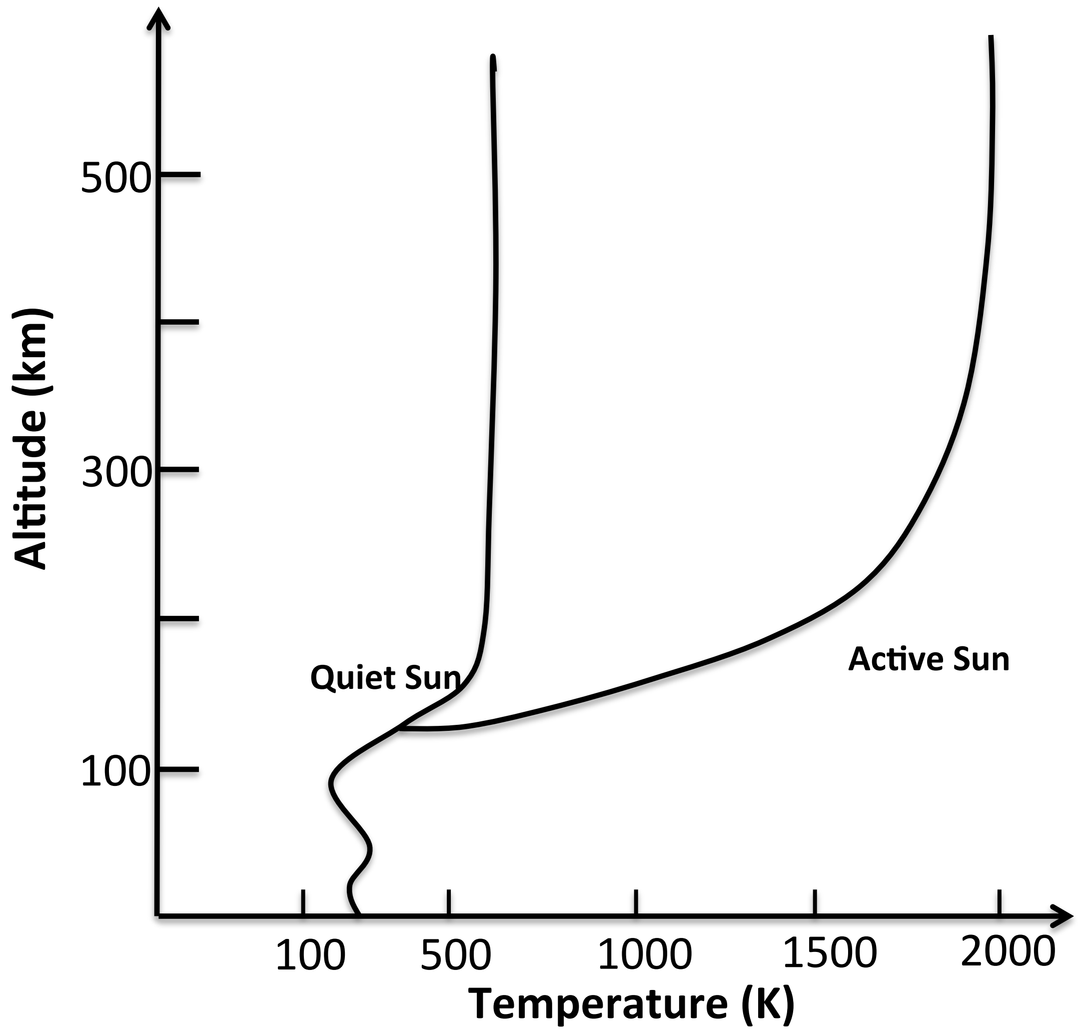
Regions in Earth's Atmosphere

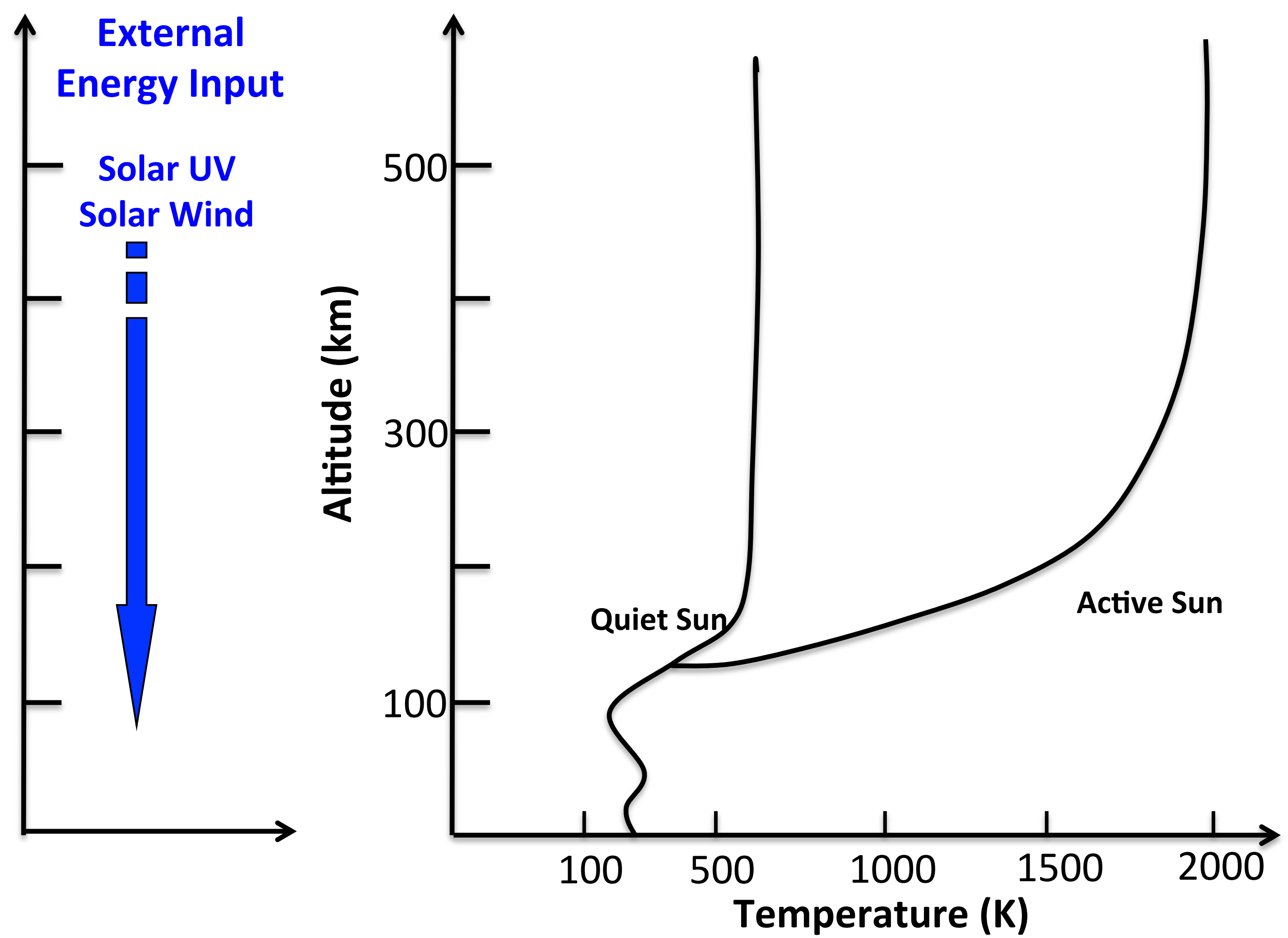


Thermosphere Energy Balance – Thermal Structure

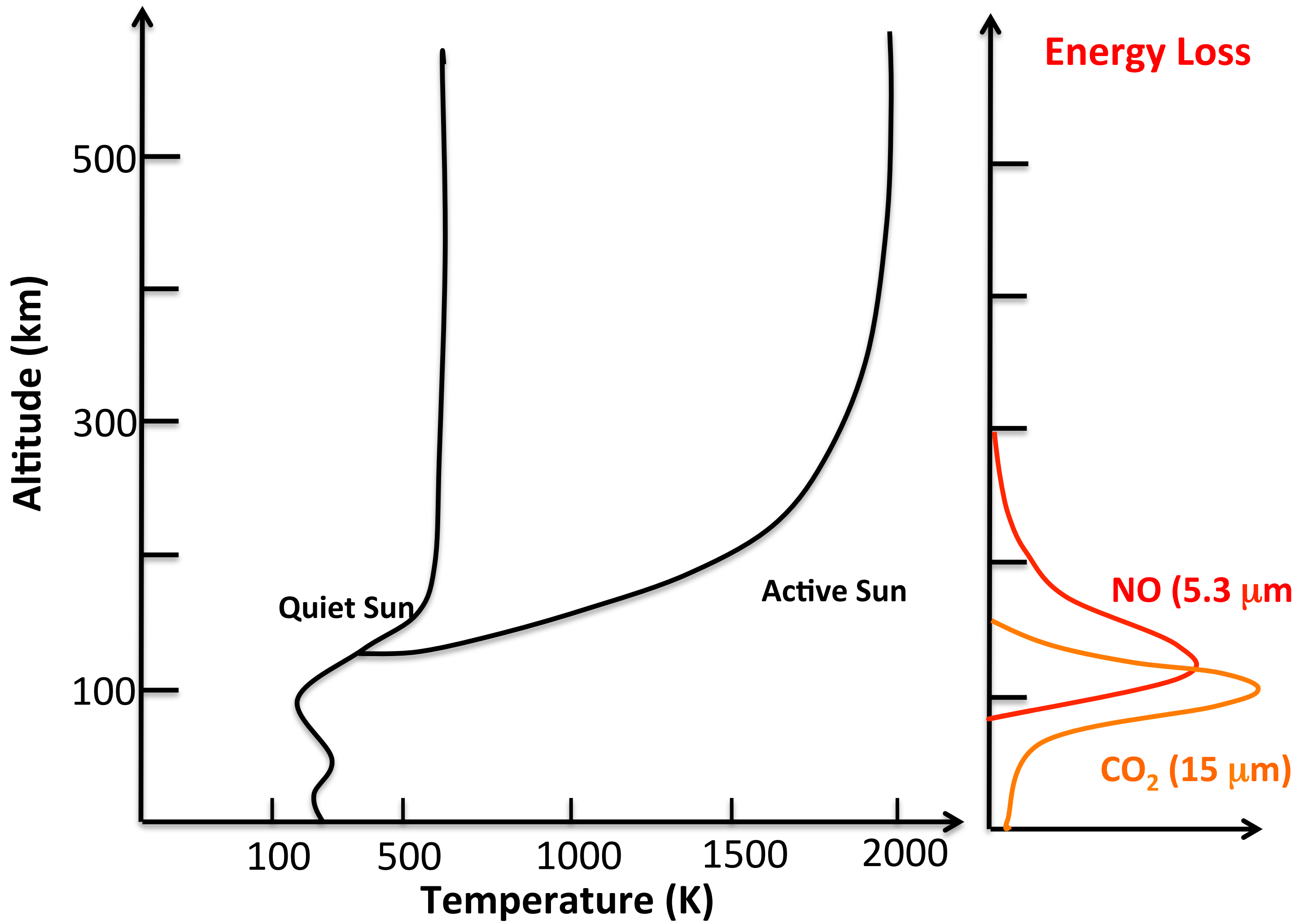


Banks and Kockarts, 1973

Thermosphere Energy Balance – Energy Inputs



Thermosphere Energy Balance – Energy Outputs



Thermosphere Energy Balance – Energy Redistribution