British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Response of the Earth's environment to solar radiative forcing

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British Antarctic Survey

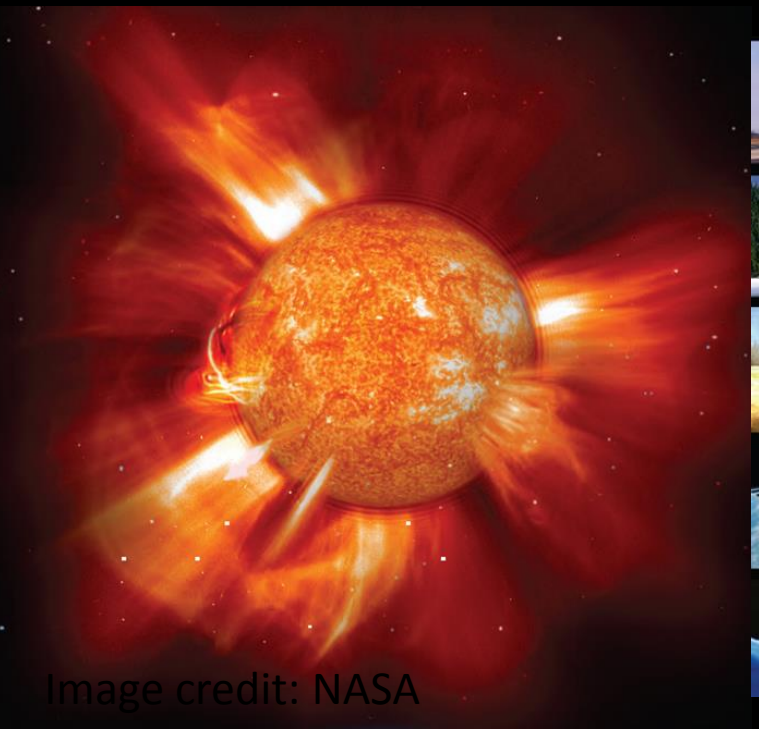


Image credit: NASA

Outline

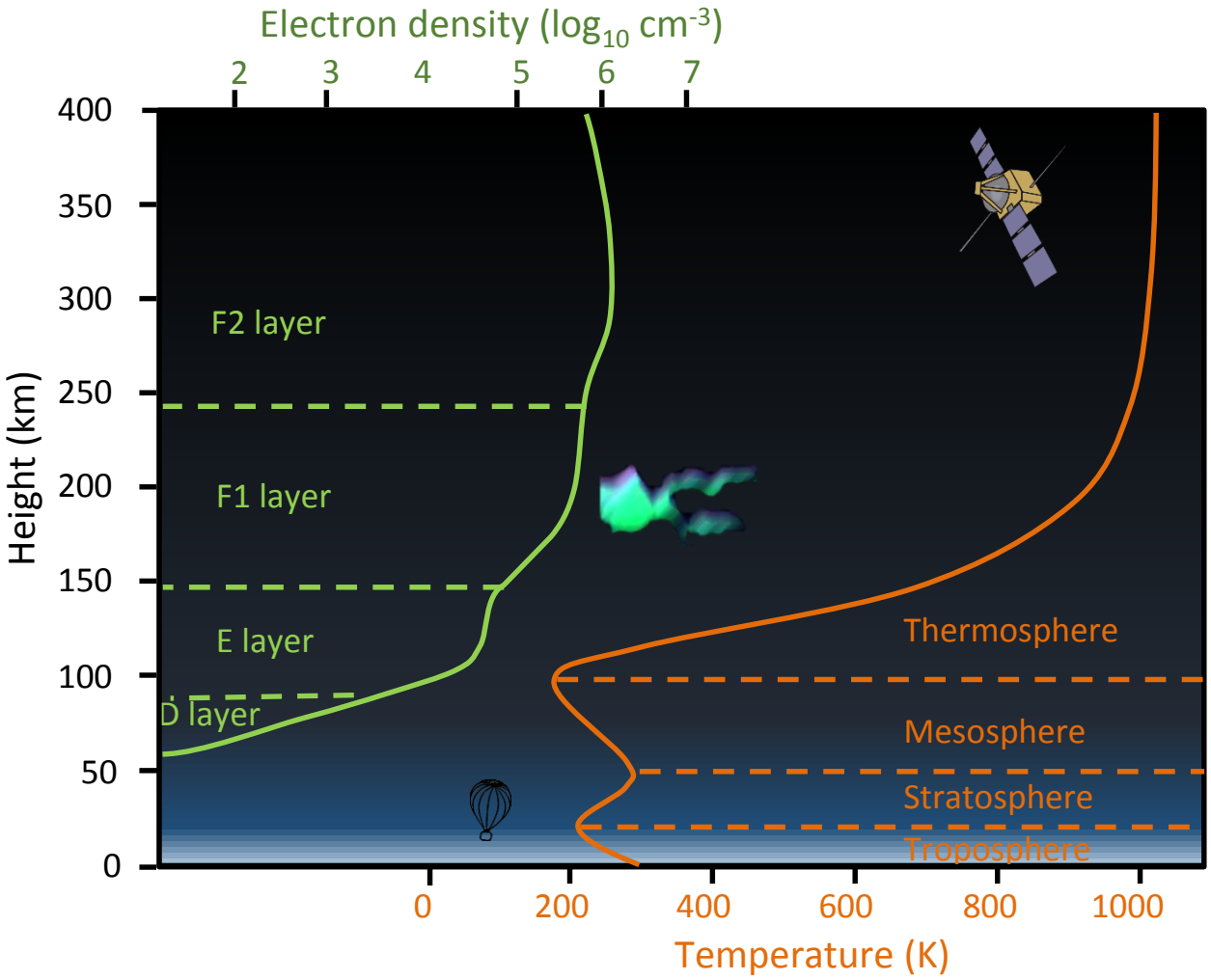
This lecture

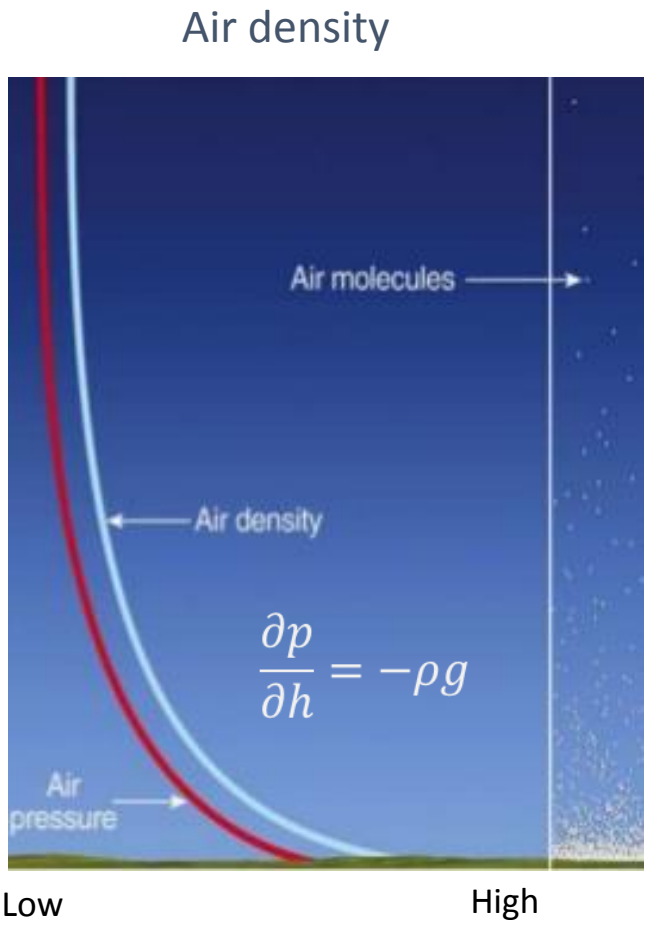
- Intro to atmosphere structure and processes
- Absorption of solar radiation
- Atmosphere composition
- Energy balance
- Ionization
- Conductivity
- Low latitude currents

Next lecture

- Effects of variations in solar radiative forcing (examples)
- High-latitude currents
- Coupling to magnetosphere

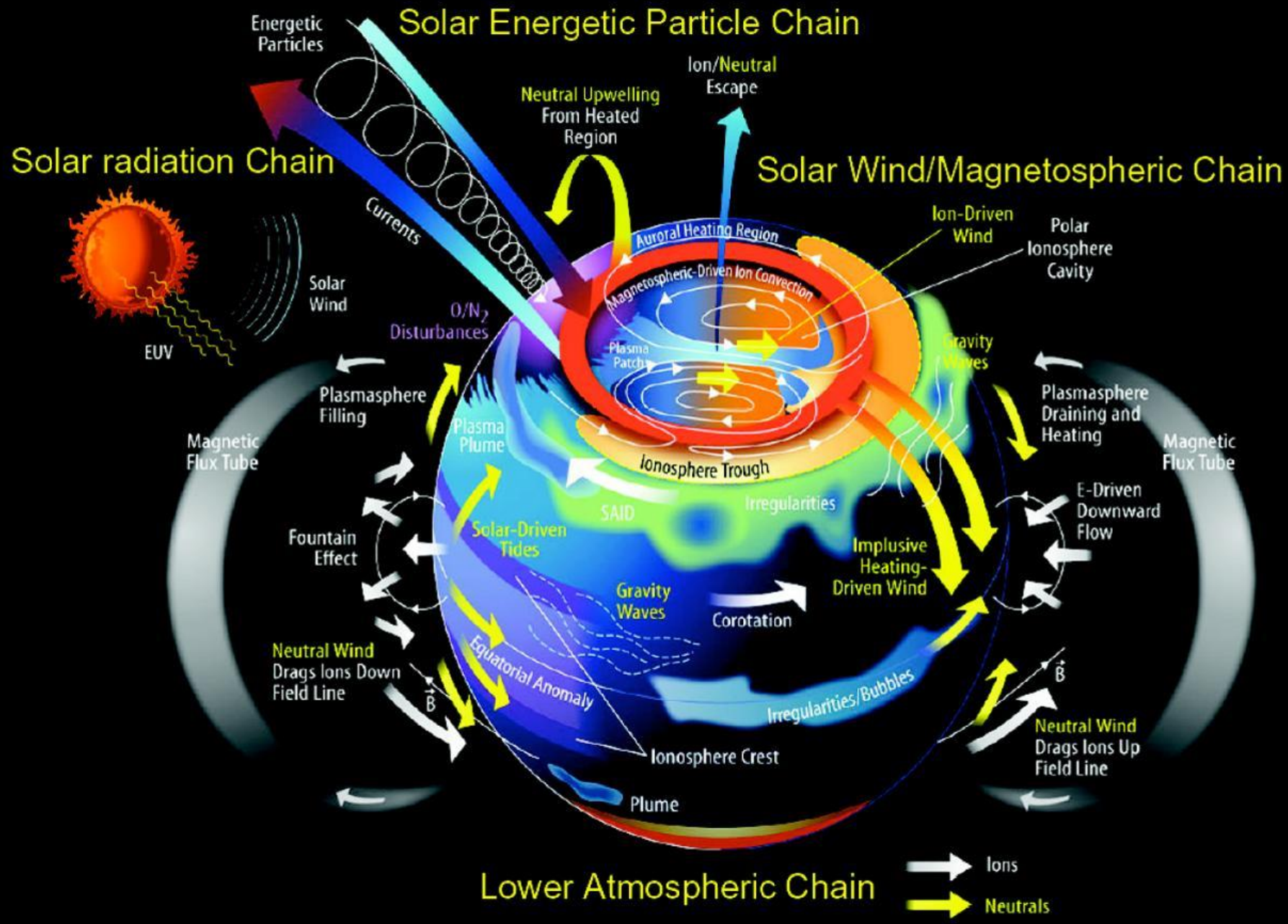
Vertical structure of the atmosphere



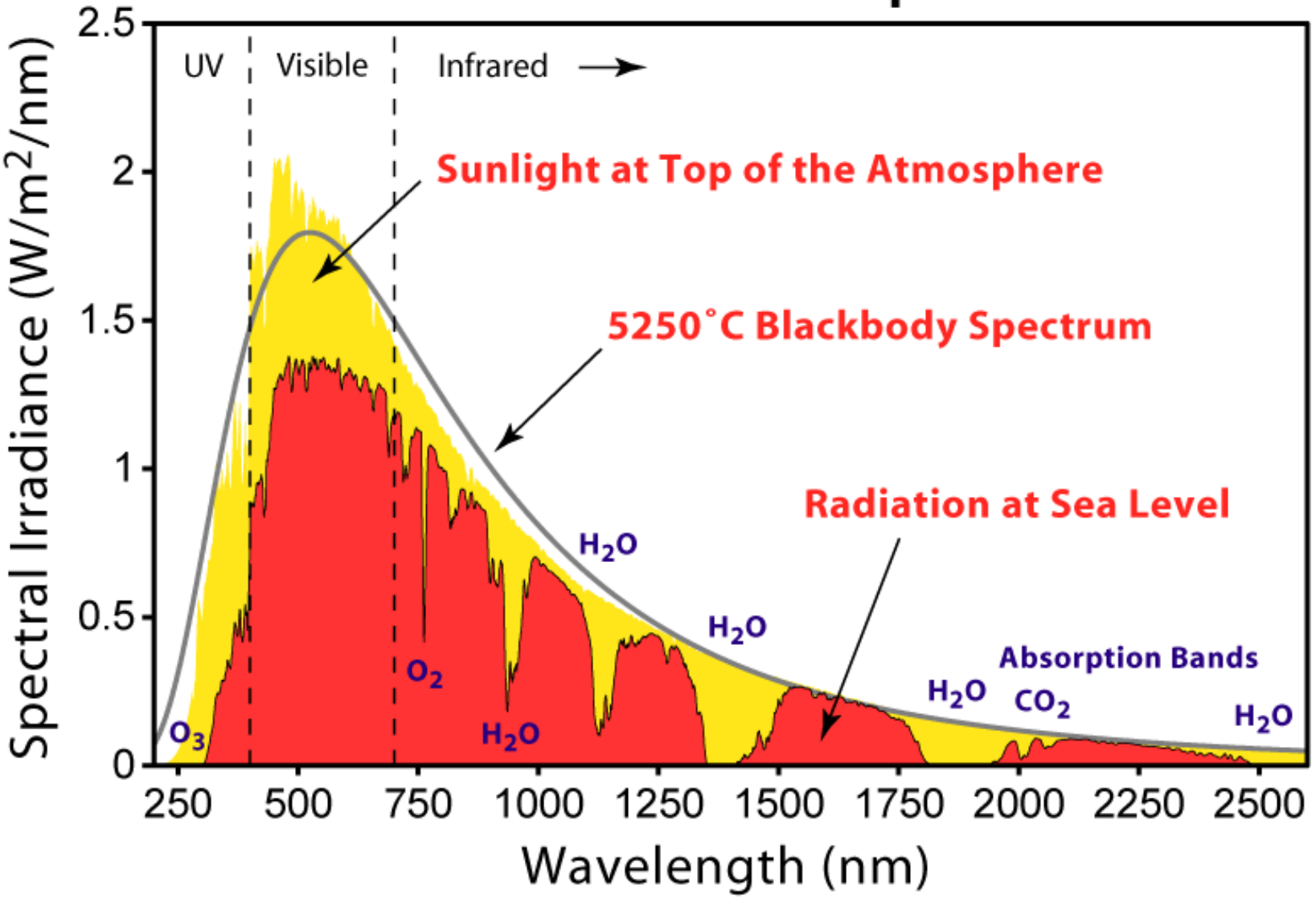


scale height $H = \frac{RT}{Mg}$

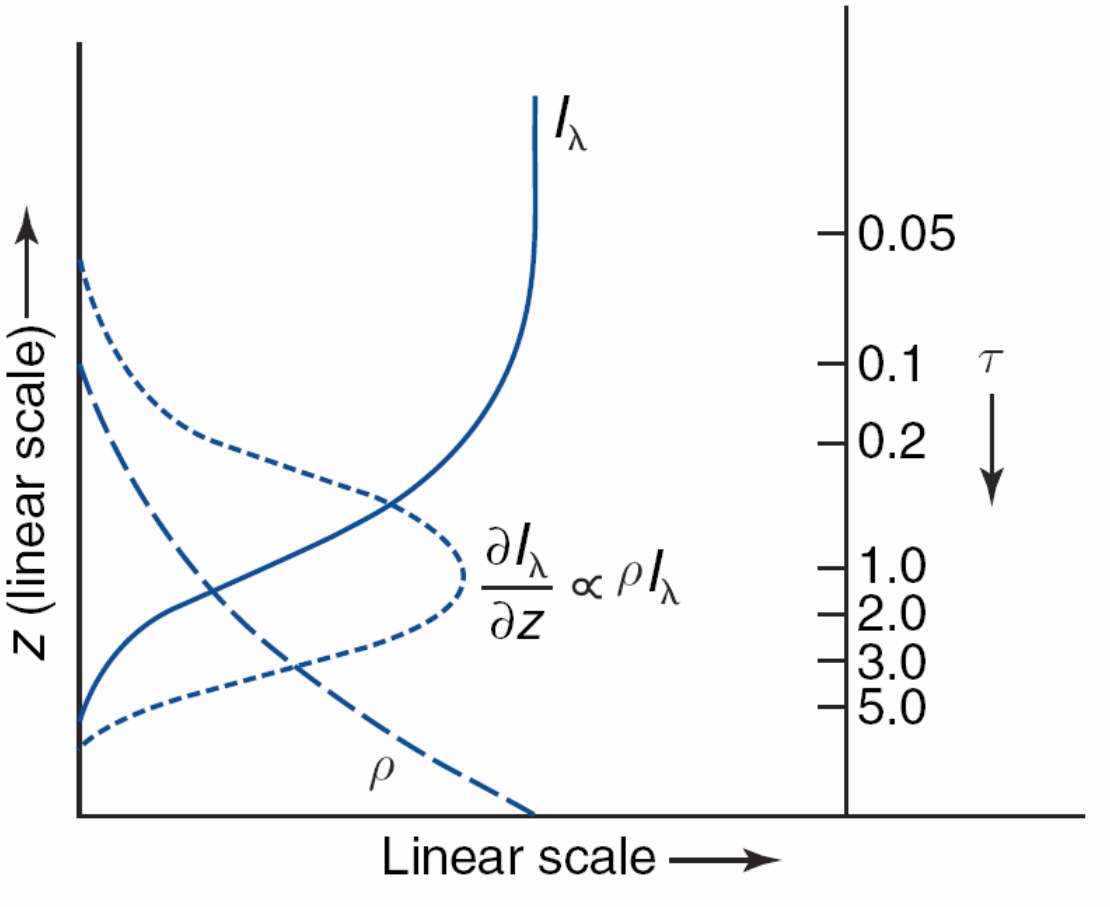
Terrestrial Atmosphere ITM Processes



Solar Radiation Spectrum



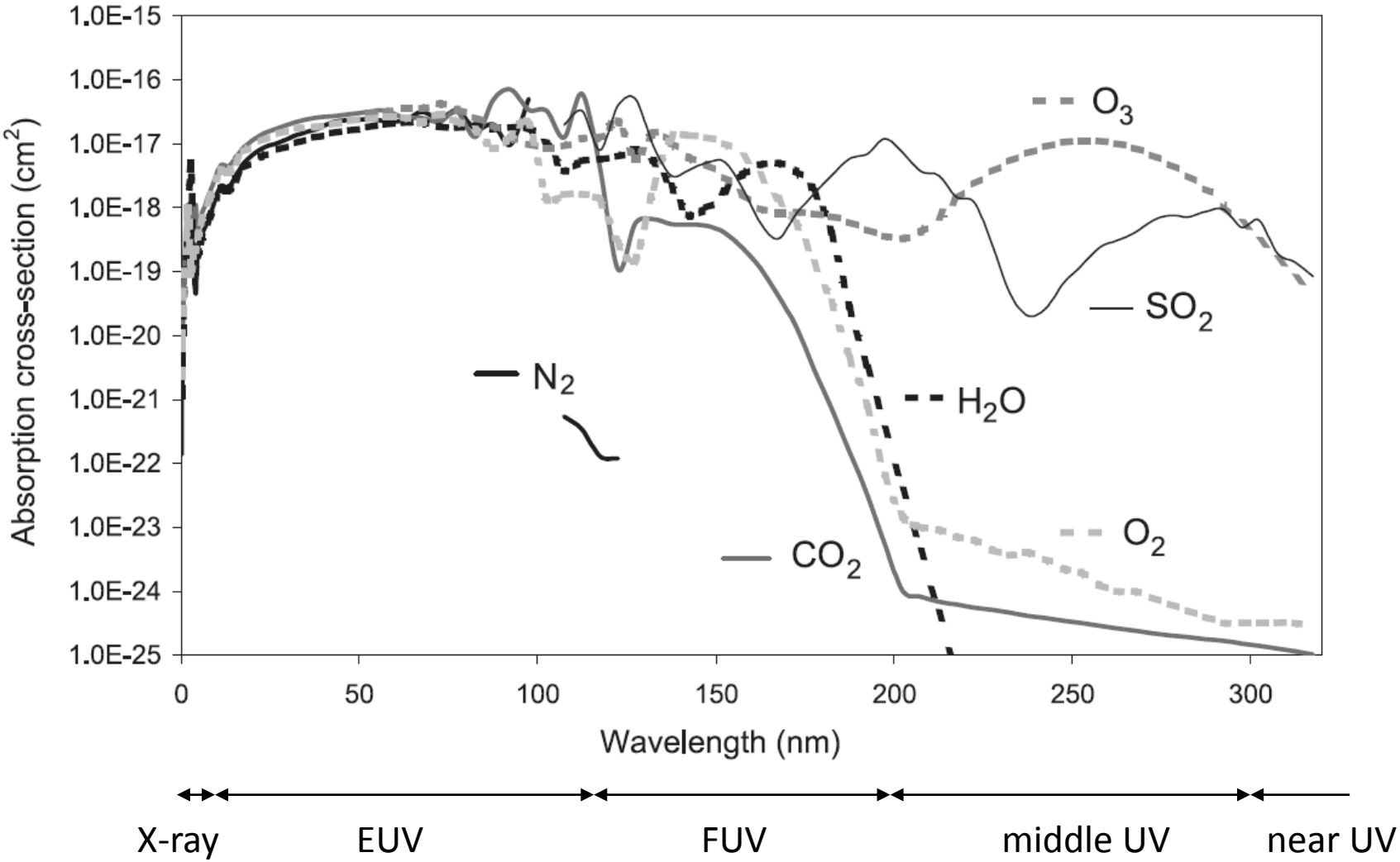
Absorption of solar radiation



Balance between

- Intensity of incoming solar radiation
- Atmosphere density

Atmospheric absorption cross-sections



From Cnossen et al. (2007)

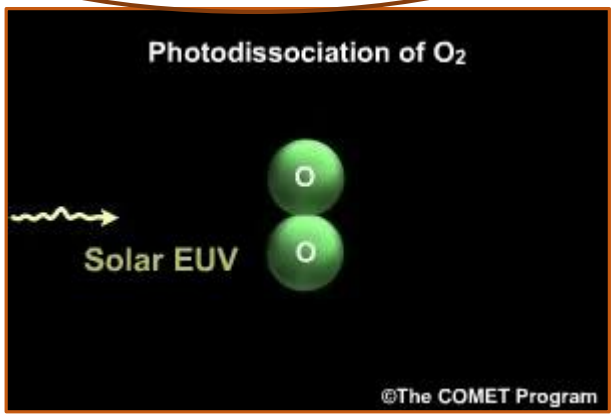
What happens with absorbed solar energy?

EUV photon

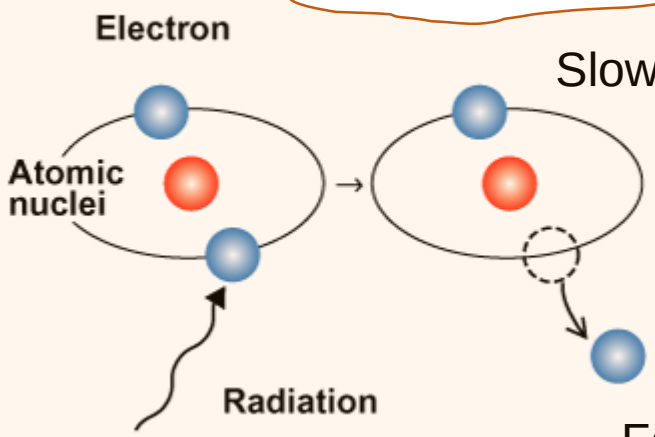
Photo-ionization

Photo-dissociation

Excitation



He atom



EUV photon

Fast electron (photo-electron)

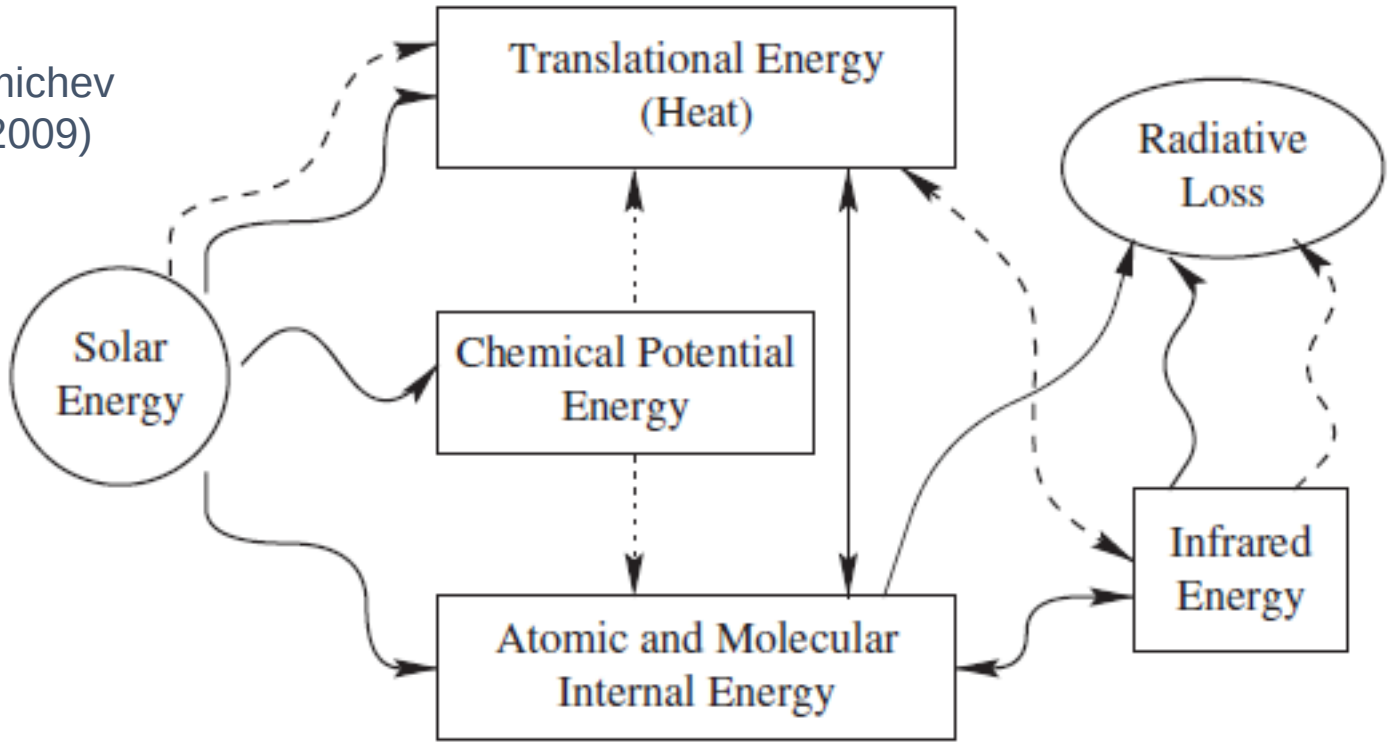
Chemical reactions

Heating

Radiative loss (cooling)

Transformation of radiative energy

From Fomichev (JASTP, 2009)



LTE radiative processes

non-LTE radiative processes

non-LTE chemical processes

non-LTE kinetic processes

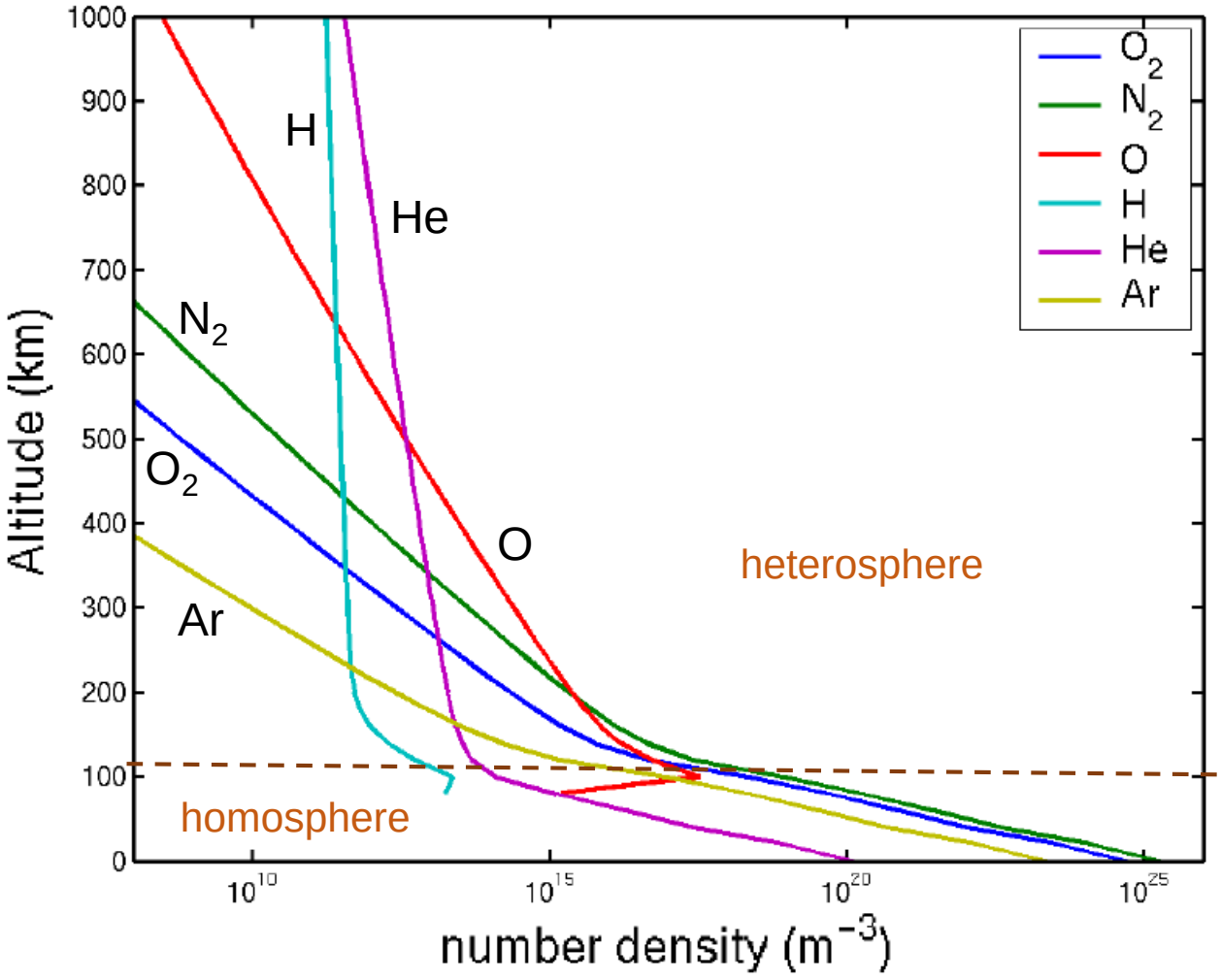
LTE = local thermodynamic equilibrium

Energy Thresholds for Processes

Species	Dissociation (Å)	Dissociation (eV)	Ionization (Å)	Ionization (eV)
H			911.75	13.6
He			504.27	24.58
O			910.44	13.62
O_2	2423.7	5.11	1027.8	12.06
N_2	1270.4	9.76	796	15.57
NO	1910	6.49	1340	9.25

From *Heubner et al., Astrophys. Space Sci*., 195, 1-294, 1992

Neutral atmosphere composition



Important minor species:

NO (nitric oxide)

CO_2 (carbon dioxide)

O_3 (ozone)

turbopause
(balance between molecular and eddy diffusion)

Absorption of solar radiation within the atmosphere

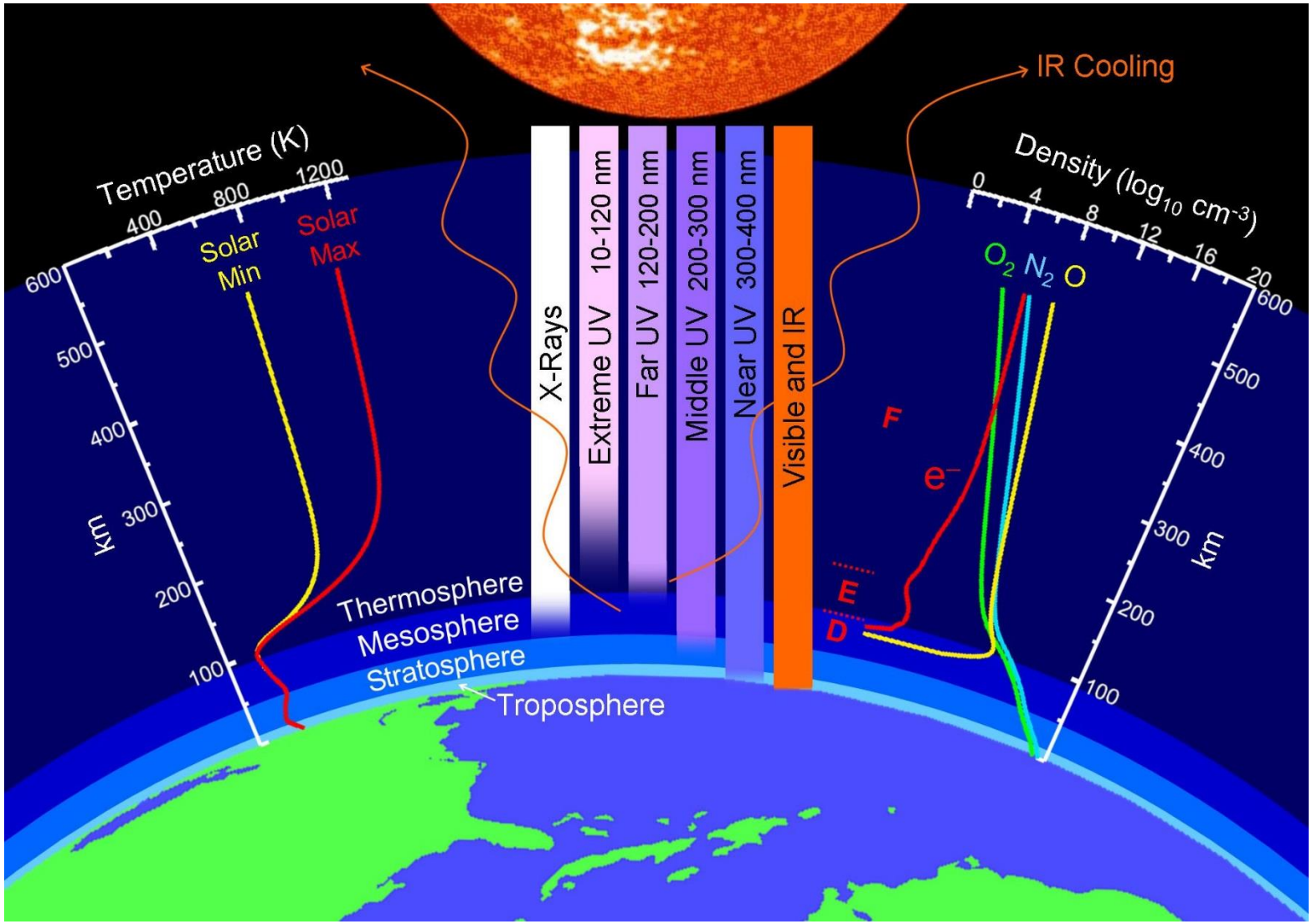
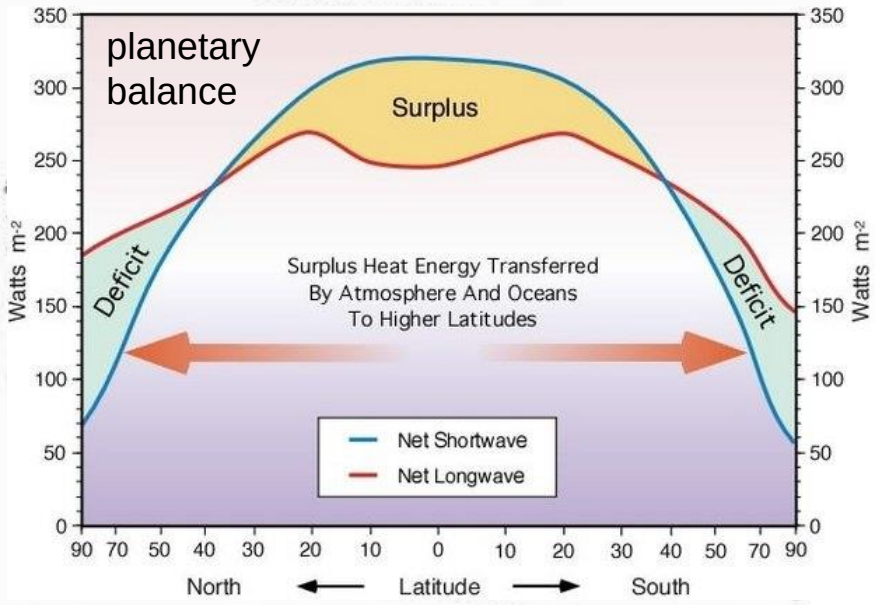


Image credit: John Emmert/NRL

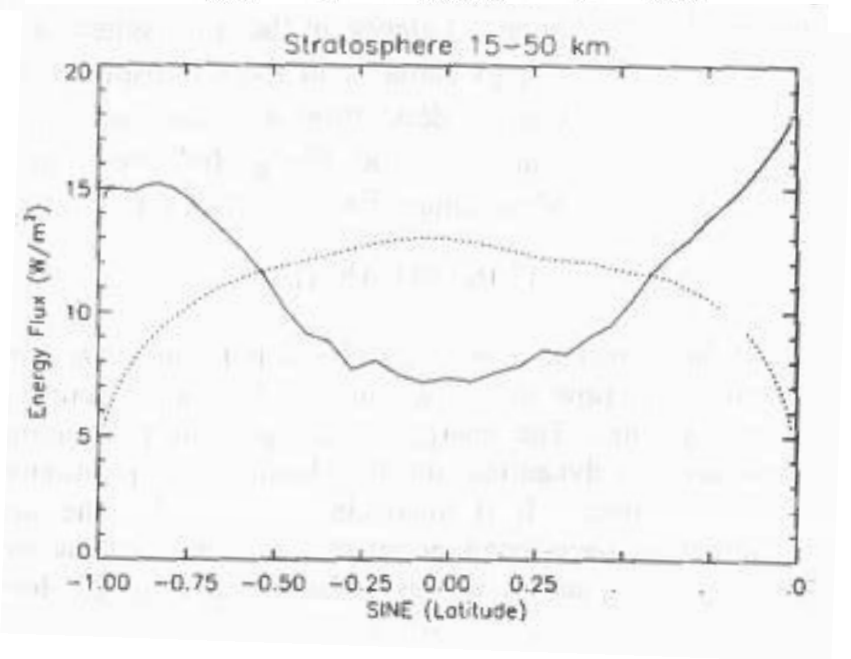
Energy balance in the atmosphere

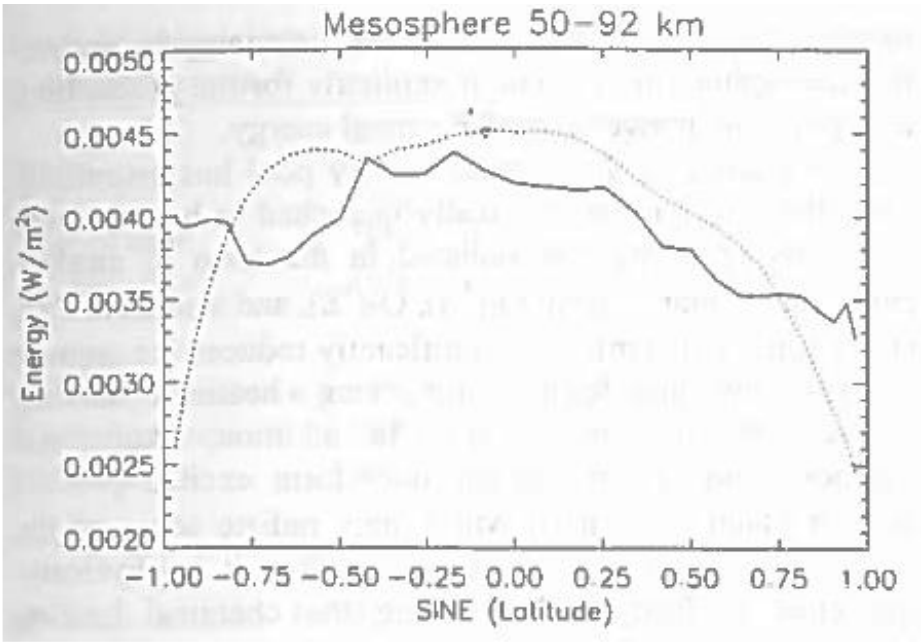


zonal mean absorbed solar radiation

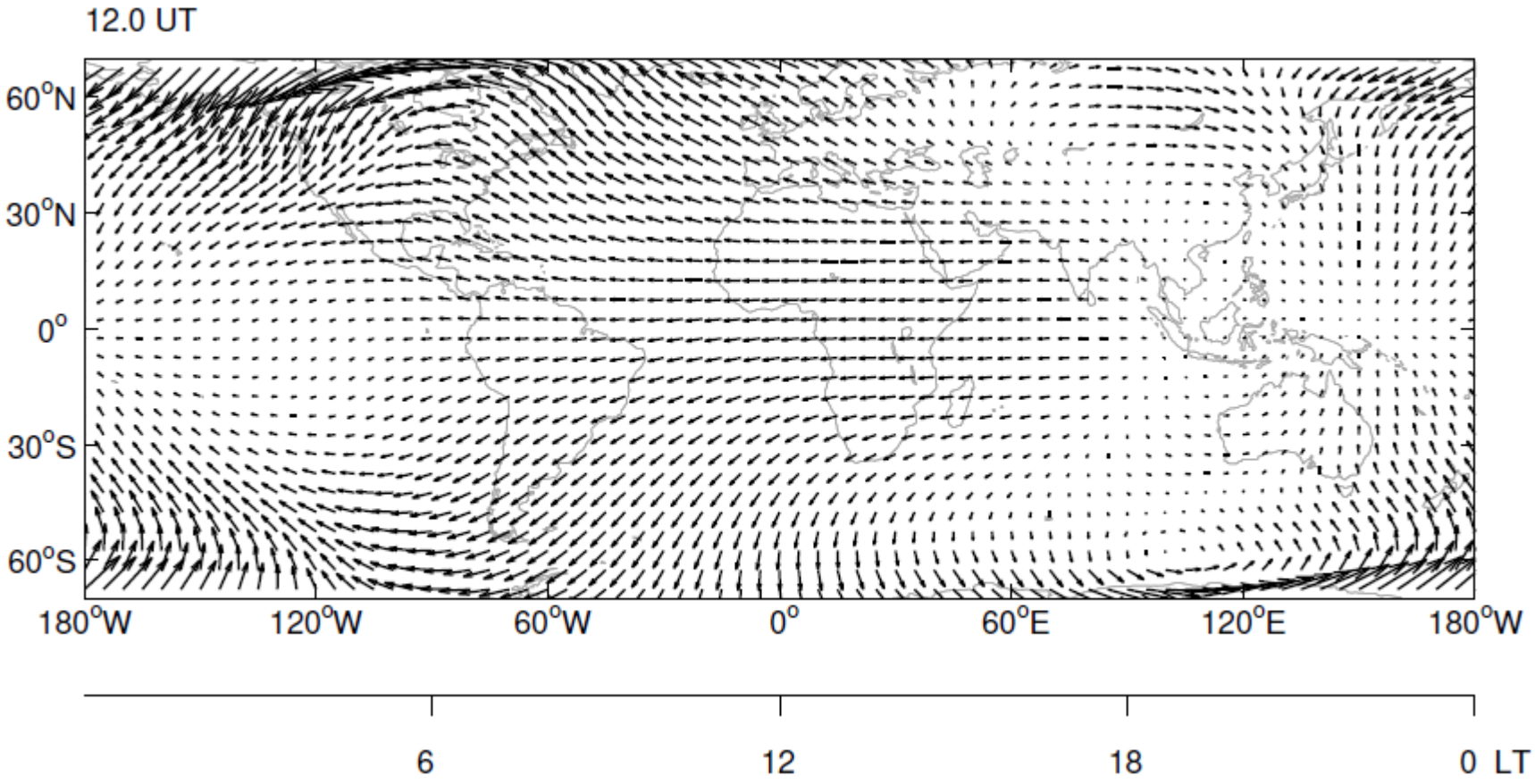
zonal mean outgoing infrared radiation

From Mlynczak (2000)

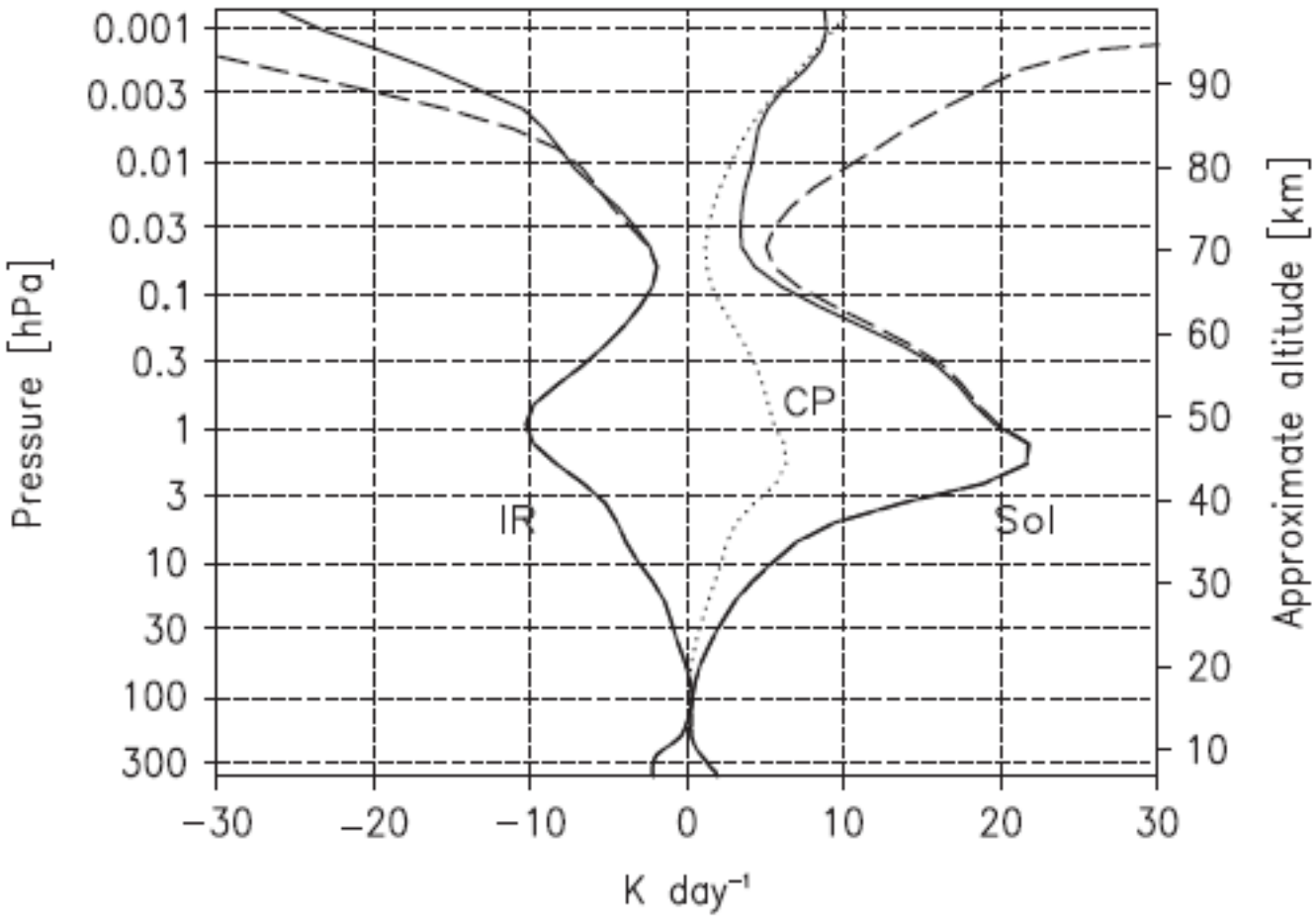




Winds in the thermosphere



Radiative energy terms in the middle atmosphere



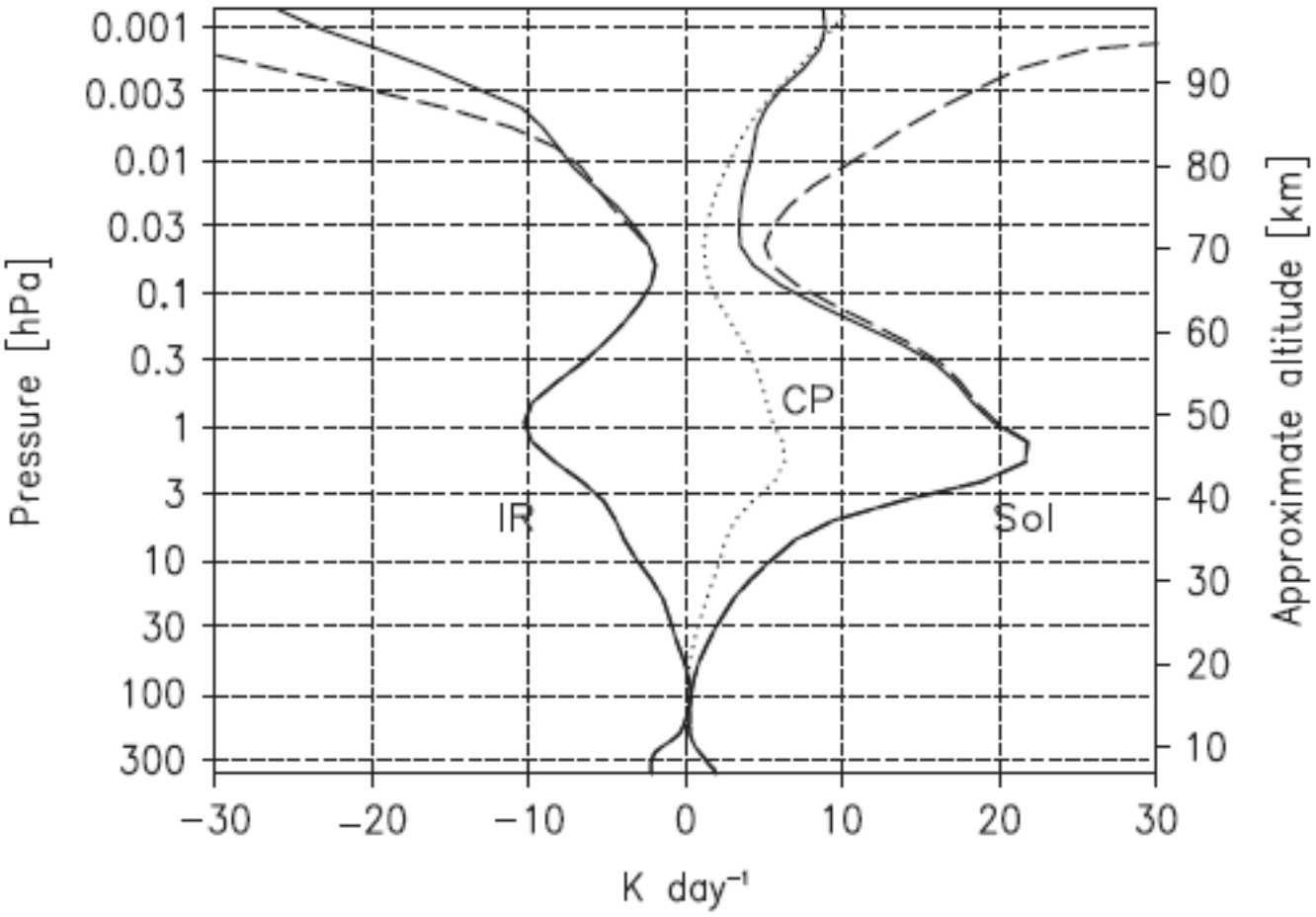
IR = infrared cooling
CP = chemical heating
Sol = solar heating

——— LTE

- - - - - non-LTE

From Fomichev (JASTP, 2009)

Radiative energy terms in the middle atmosphere



What latitude?

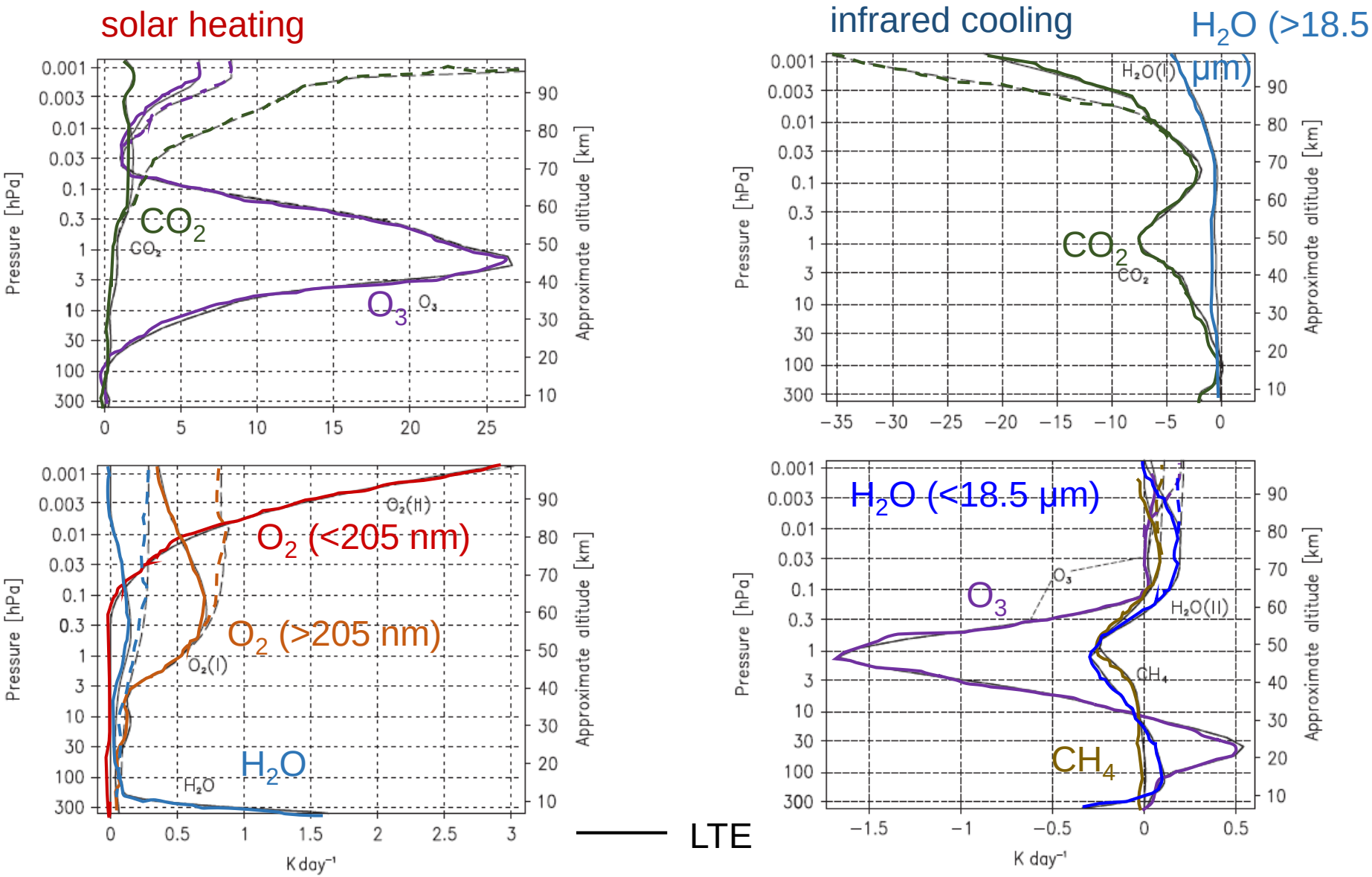
IR = infrared cooling
CP = chemical heating
Sol = solar heating

——— LTE

- - - - - non-LTE

From Fomichev (JASTP, 2009)

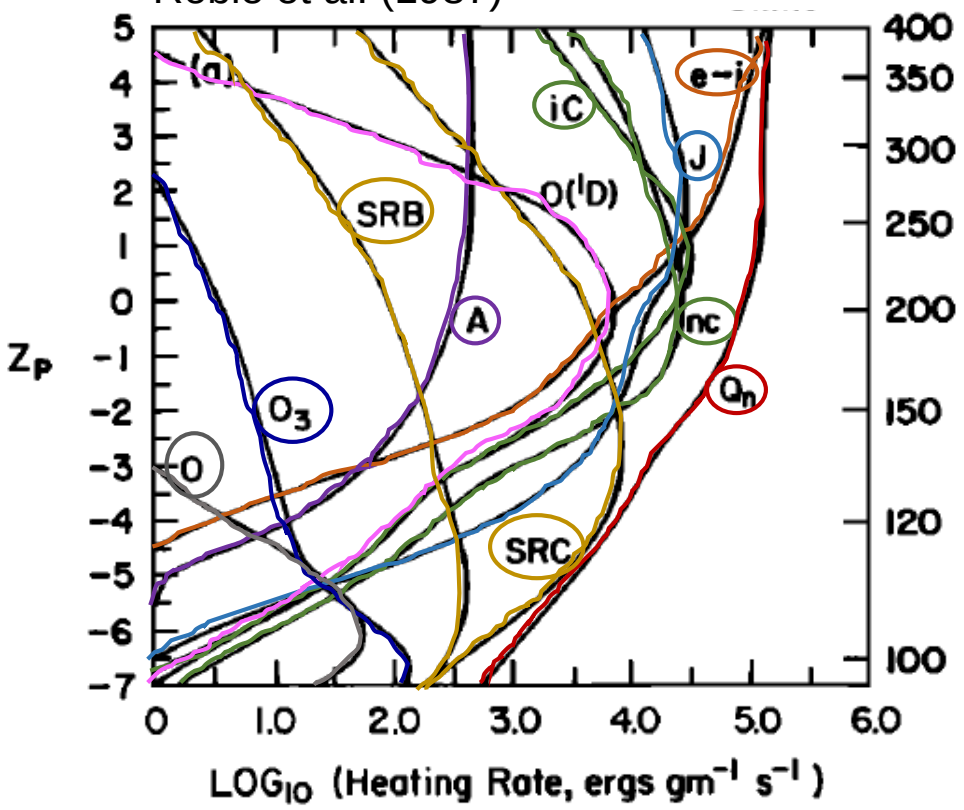
Middle atmosphere radiative heating and cooling

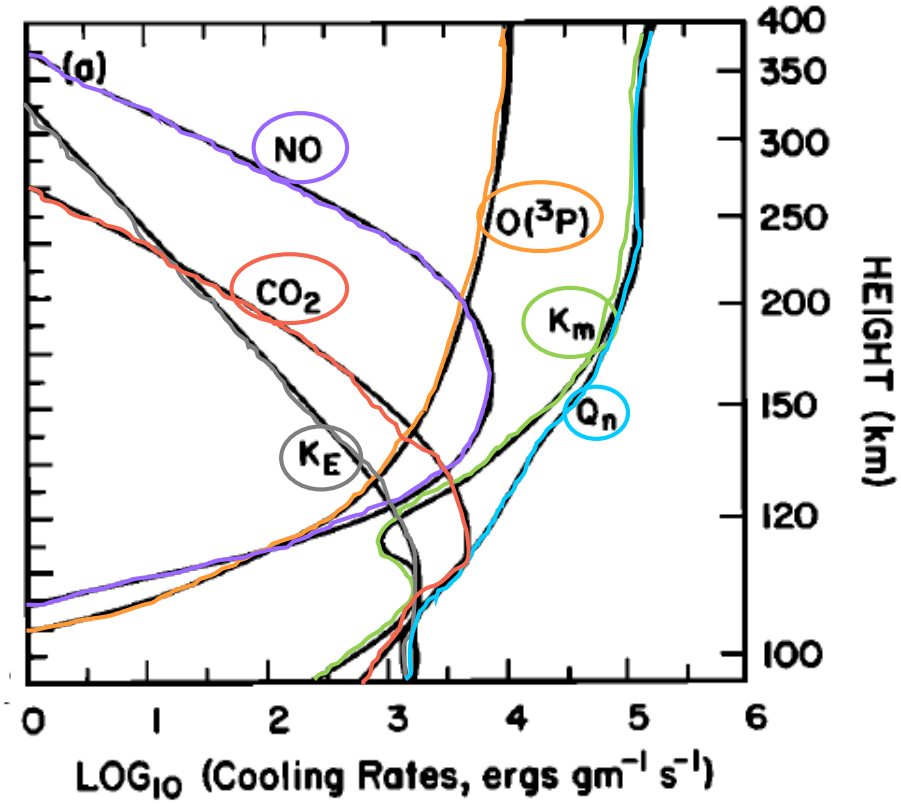


From Fomichev (JASTP, 2009)

Thermosphere heating and cooling rates (solar min)

Roble et al. (1987)





O_2 absorption

exothermic chemical reactions

total neutral heating

O_3 absorption

collisions with ions/electrons

quenching of O(1D)

O recombination

Joule heating

auroral particle precipitation

NO 5.3 μm emission

total neutral cooling

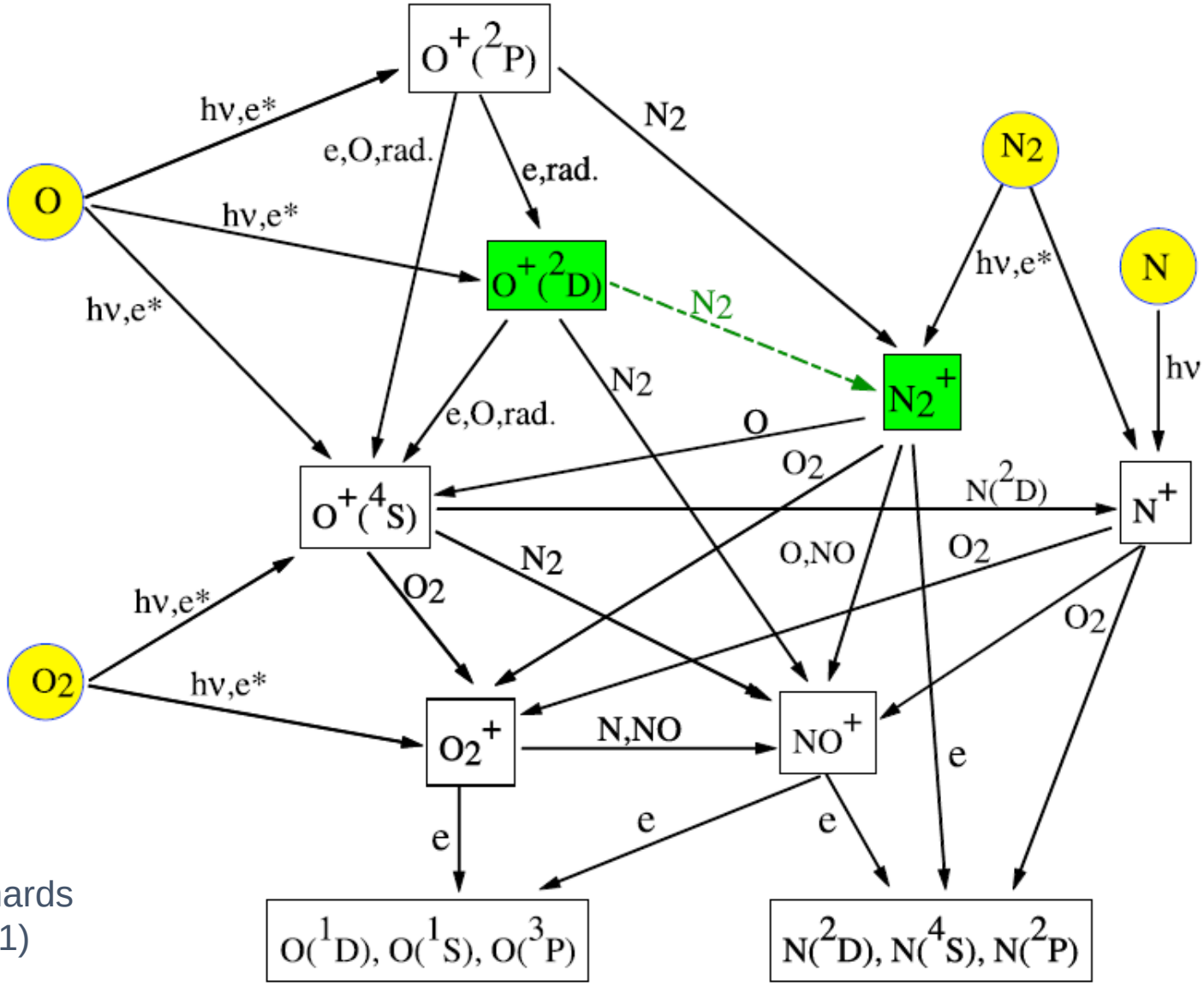
CO_2 15 μm emission

atomic oxygen cooling

molecular thermal conduction

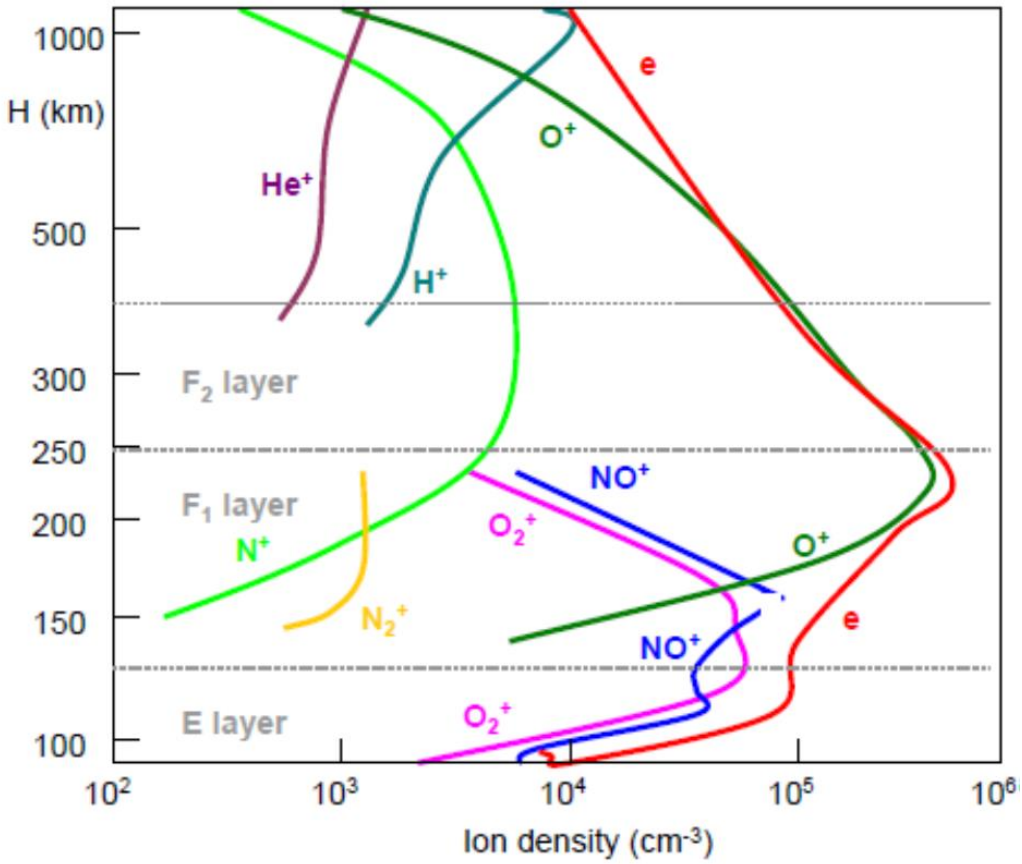
eddy thermal conduction

Photochemistry in the upper atmosphere



From Richards (JGR, 2011)

Ionosphere composition

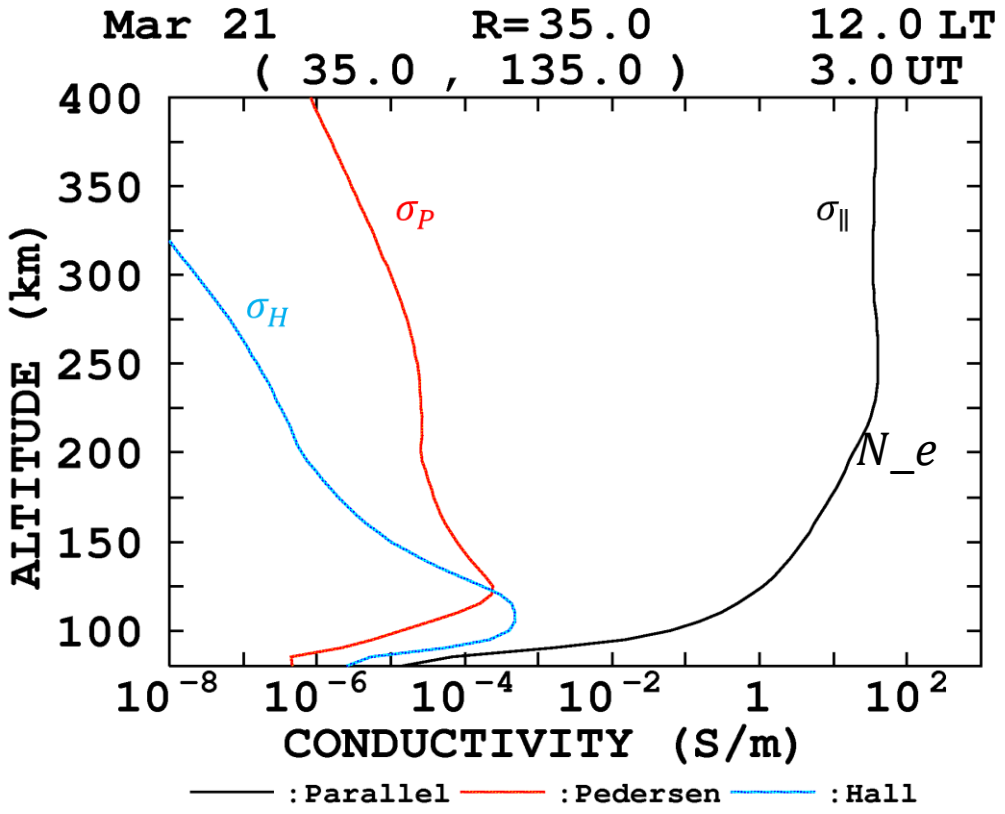


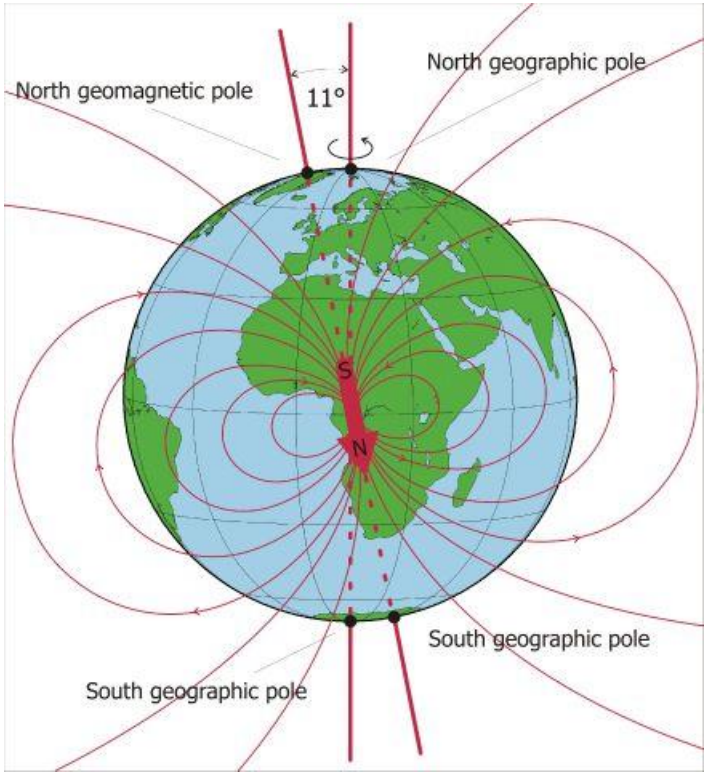
Major species: O_2^+, NO^+, and O^+

Molecular ions dominate < ~150 km; approximate photo-chemical equilibrium

O+ dominant > ~200 km

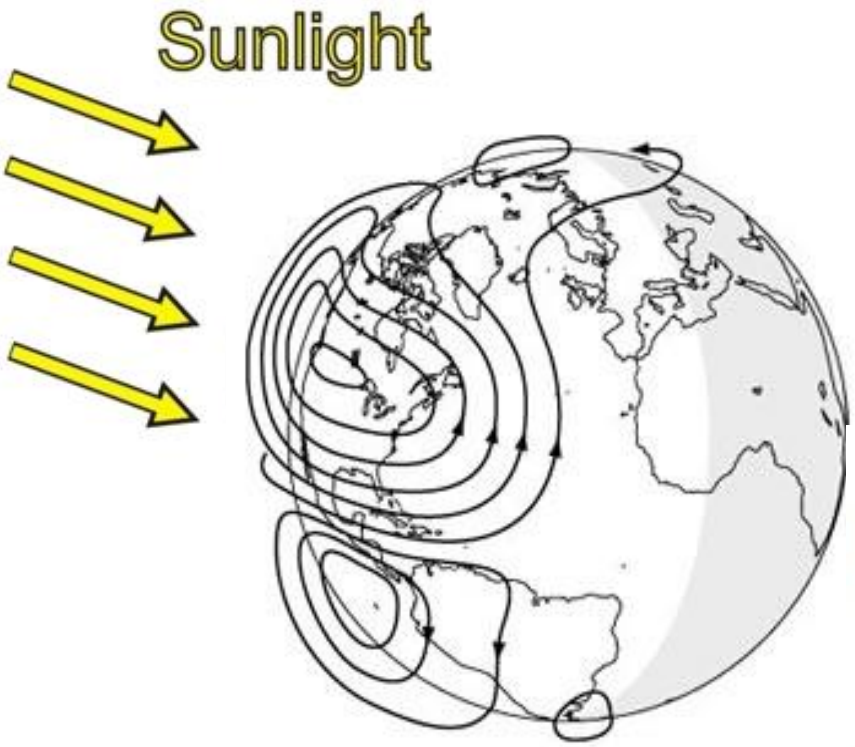
Conductivity of the ionosphere





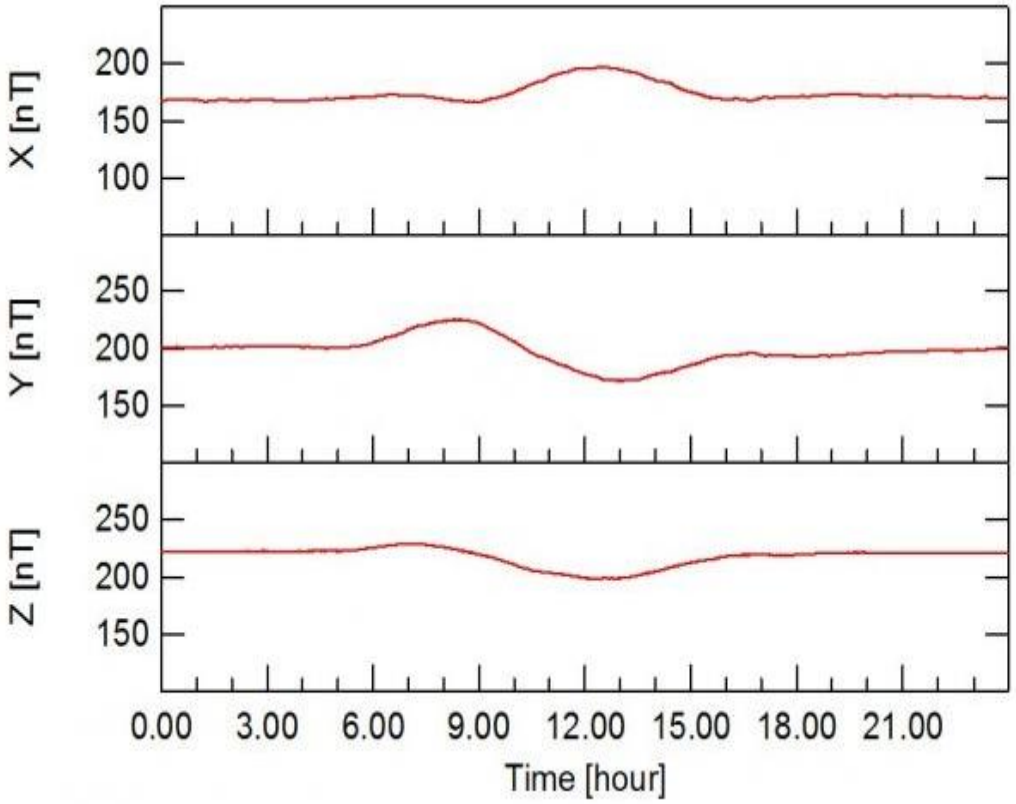
$$\sigma_\parallel = \frac{N_e e^2}{m_e(\nu_{en\parallel} - \nu_{ei\parallel})}$$

Solar quiet (Sq) current system



Winds drive currents

Observations from l'Aquila



Currents perturb the magnetic field

Summary

- Solar activity affects…
  - Heating and cooling processes throughout the atmosphere
  - Pressure gradients and winds
  - Composition
  - Ionization
  - Conductivity
  - Currents in the ionosphere

- These processes also interact with each other!