Laurea in Ingegneria per l'Ambiente ed il Territorio

CAMBIAMENTI CLIMATICI E ADATTAMENTI NEGLI ECOSISTEMI E NELLE SOCIETÀ

Docenti

Salvatore Pappalardo

Daniele Codato

Alessandro Ceppi (Politecnico di Milano)

Supporto didattico

Edoardo Crescini

- 6 CFU
- 48 ore
- 102 ore di studio individuale

Outline

- #Stripe su eventi estremi
- Impatti cc sulla stagionalità (emisfero boreale)
- Atmosfera: ruolo, struttura, composizione
- Bilancio radiativo terrestre

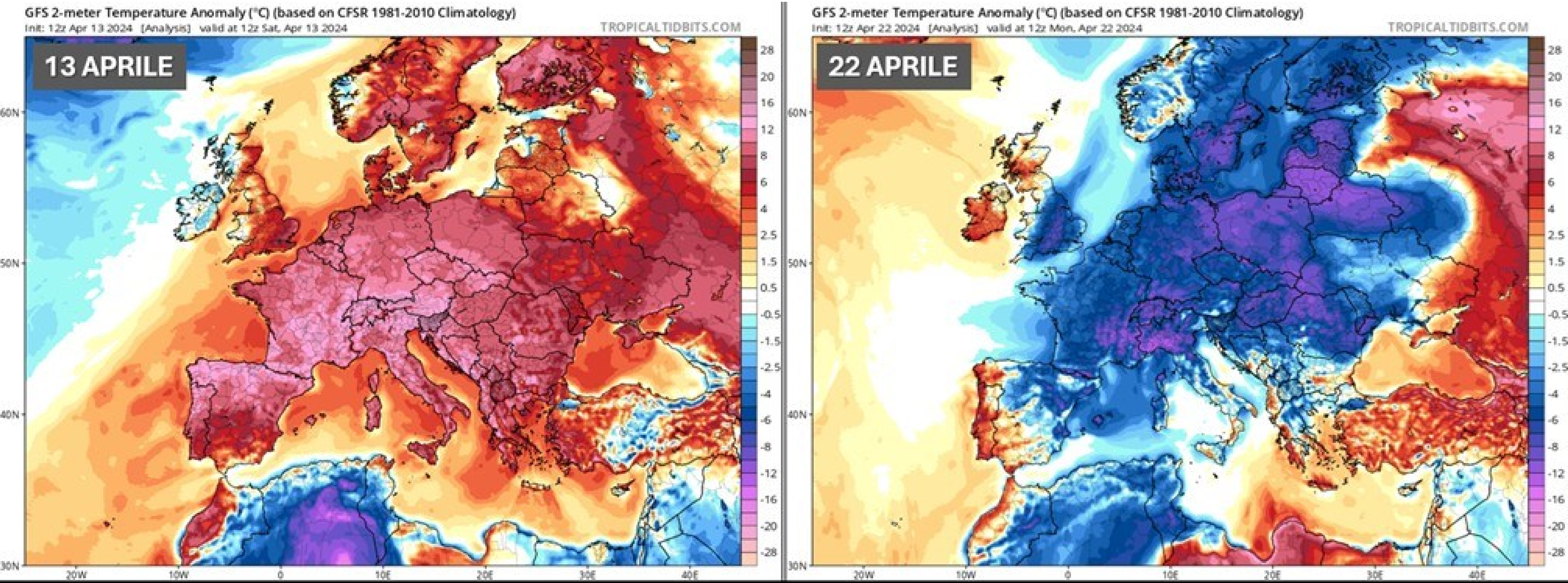

Fig. 1 – Il salto termico: da temperature fino a 12-15 °C sopra la media a temperature fino a 9-12 °C sotto la media

Andrea Corigliano
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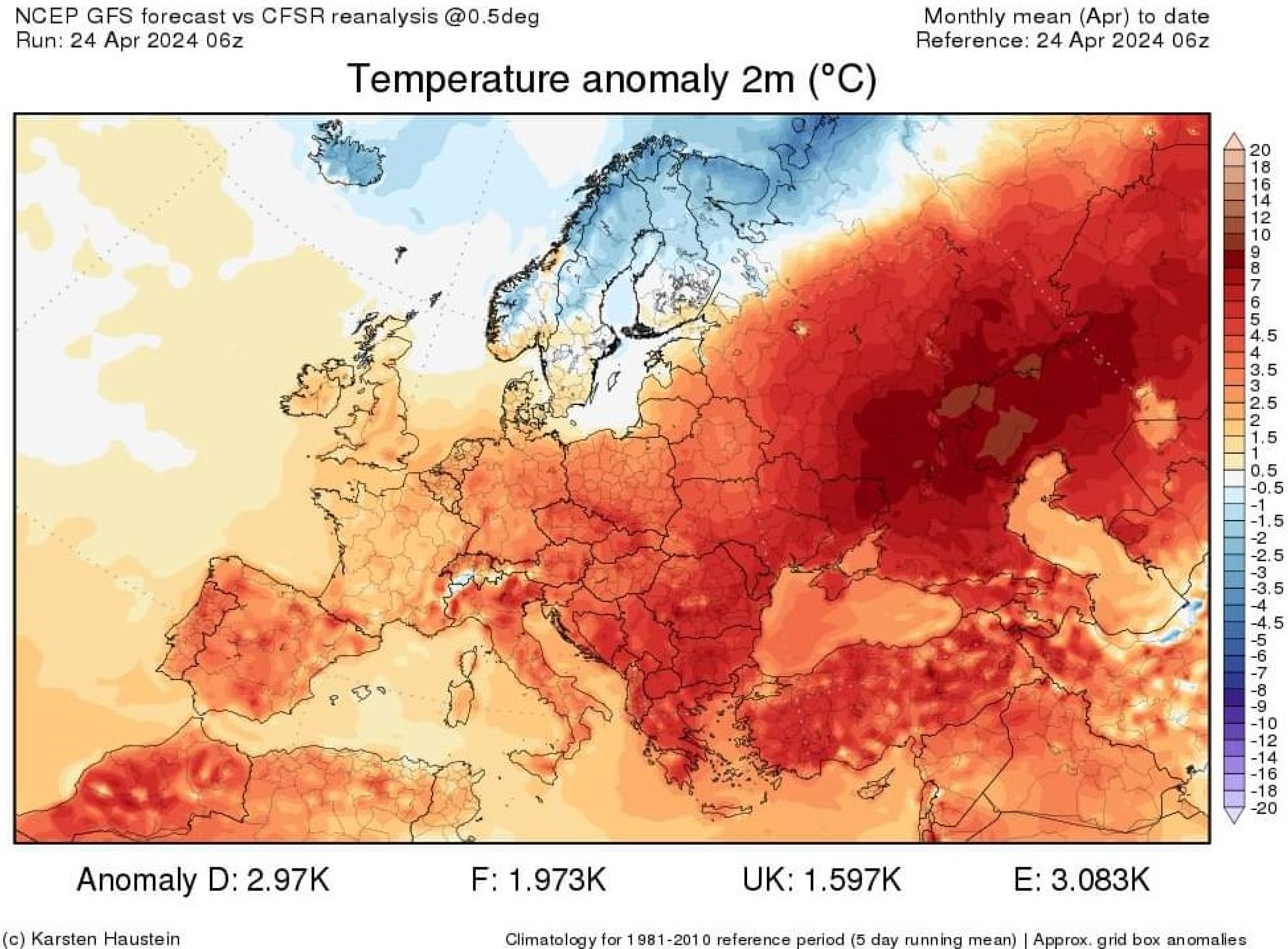

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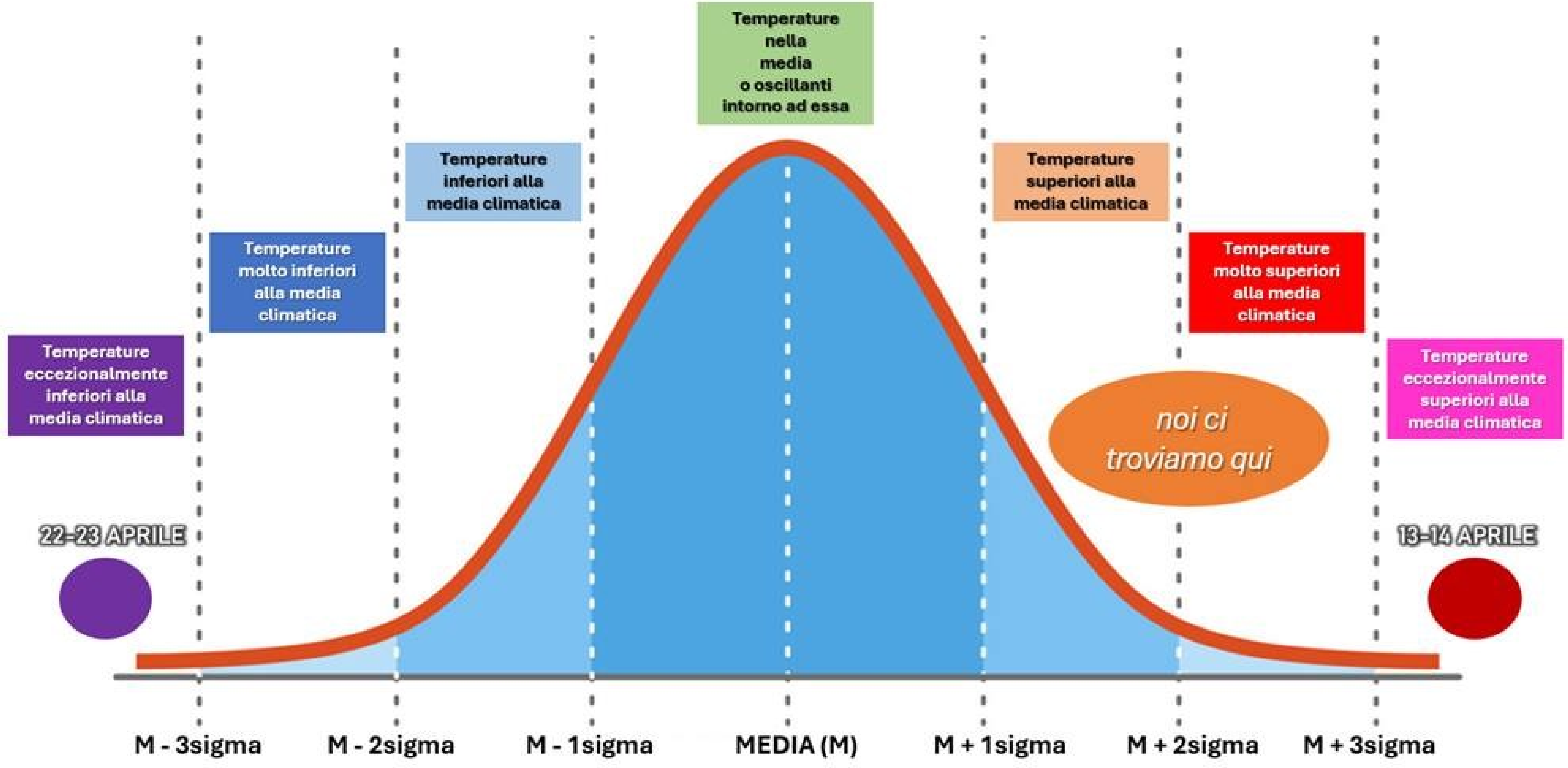

Fig. 2 – La distribuzione gaussiana e collocamento delle due fasi estreme

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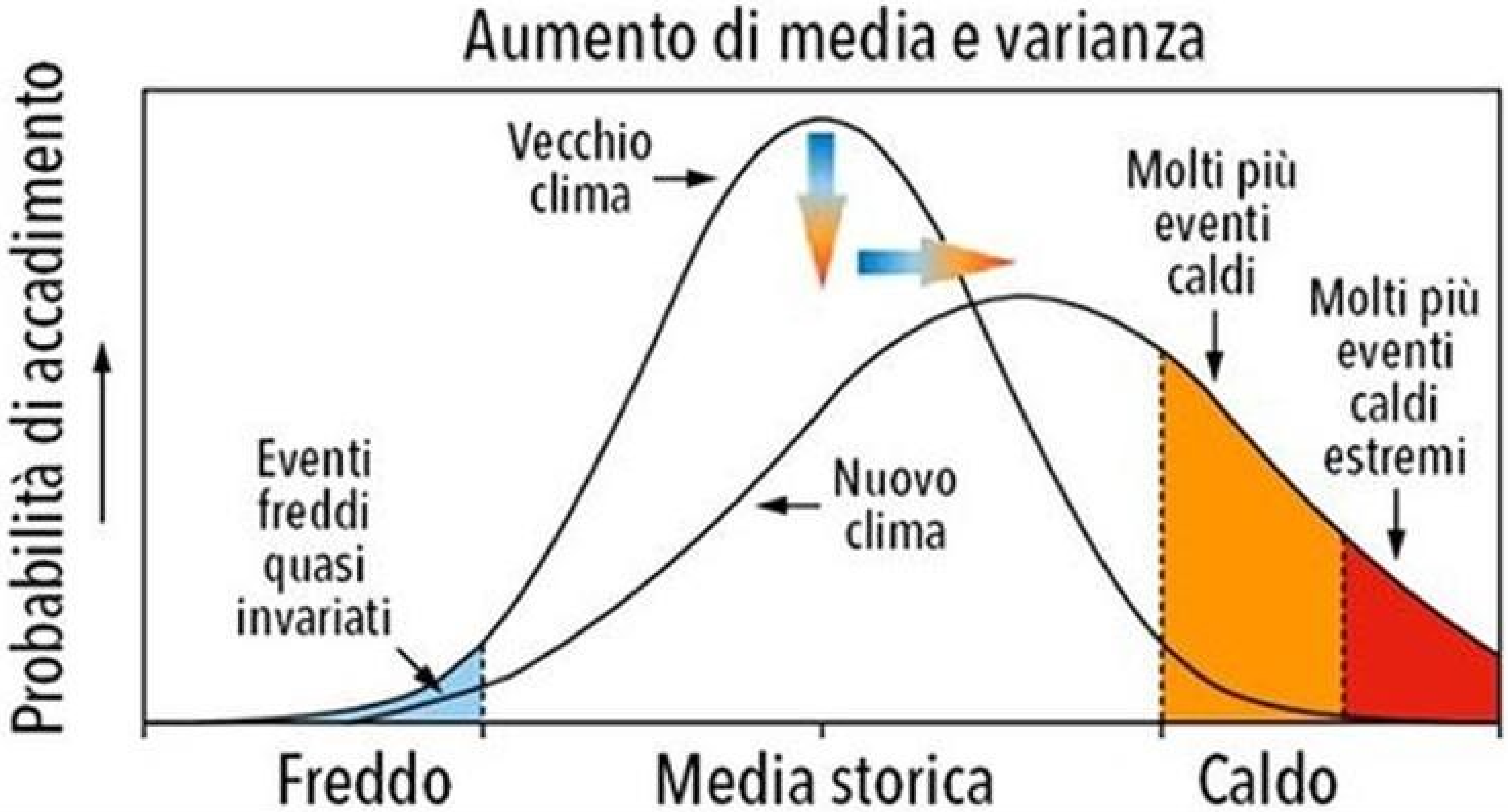

Fig. 4 – La differenza tra il «vecchio clima» e il «nuovo clima»

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Geophysical Research Letters

RESEARCH LETTER
10.1029/2020GL091753

Changing Lengths of the Four Seasons by Global Warming

Jiamin Wang[1,2], Yuping Guan[2], Lixin Wu[3,4], Xiaodan Guan[1], Wenju Cai[3,4,5], Jianping Huang[1], Wenjie Dong[6,7], and Banglin Zhang[8]

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Jiamin Wang and Yuping Guan contributed equally to this work.

Key Points:

- Climate change has driven longer and hotter summers, shorter and warmer winters, shorter springs and autumns
- The onsets of spring and summer are advanced, while the onsets of autumn and winter are delayed
- Such changes in four seasons can be mainly attributed to greenhouse-warming, and will be amplified under the business-as-usual scenario

Supporting Information:

- Supporting Information S1
- Movie S1

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Citation:

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Abstract How long will the four seasons be by 2100? Increasing evidence suggests that the length of a single season or in regional scales has changed under global warming, but a hemispherical-scale response of the four seasons in the past and future remains unknown. We find that summer in the Northern Hemisphere midlatitudes has lengthened, whereas winter has shortened, owing to shifts in their onsets and withdrawals, accompanied by shorter spring and autumn. Such changes in lengths and onsets can be mainly attributed to greenhouse-warming. Even if the current warming rate does not accelerate, changes in seasons will still be exacerbated in the future. Under the business-as-usual scenario, summer is projected to last nearly half a year, but winter less than 2 months by 2100. The changing seasonal clock signifies disturbed agriculture seasons and rhythm of species activities, more frequent heat waves, storms and wildfires, amounting to increased risks to humanity.

Plain Language Summary A series of phenomena such as early flowering of plants and early migratory birds are suggesting that the traditional four seasons may have changed. We focus on how the four seasons changed during 1952–2011 and will change by the end of this century in the warming

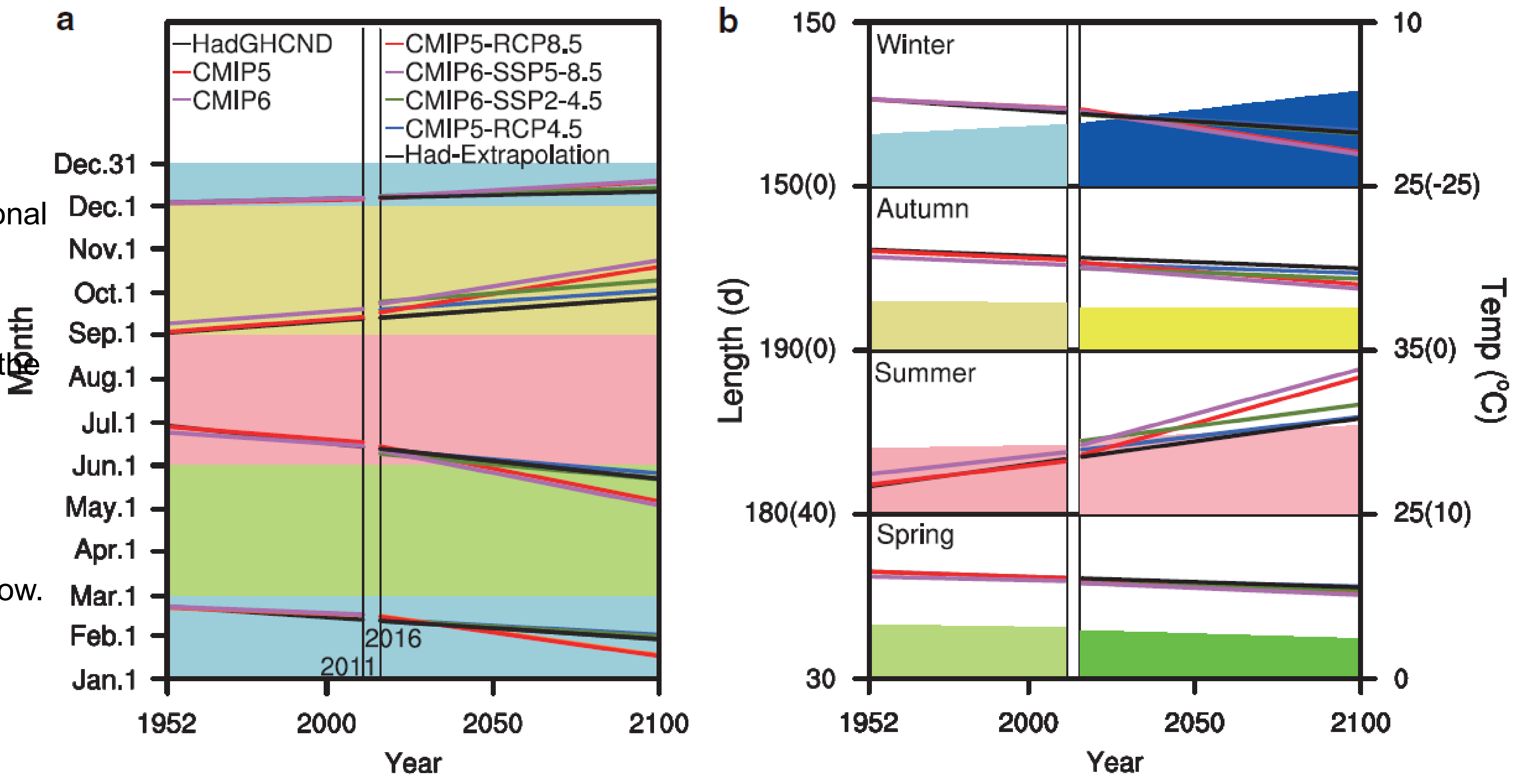
Ipotesi:
GHG stiano influendo sui ritmi stagionali

Segnali?

Changes in season:
1) Contrazione e dilatazione delle stagioni
2) *Shift* dell'entrata delle stagioni (*onset*)

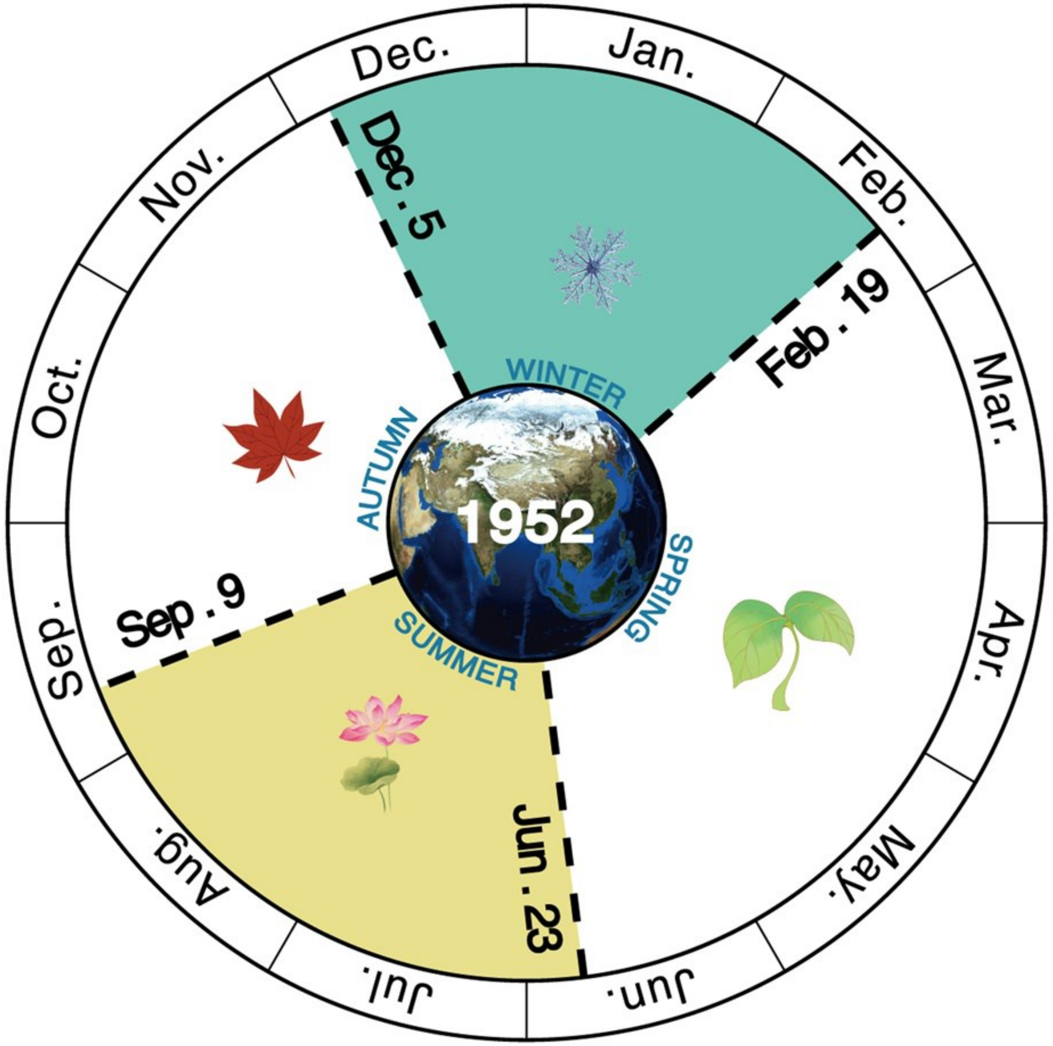
Elaborazioni e simulazioni di scenario al 2100 (RCP 4.5, RCP 8.5)

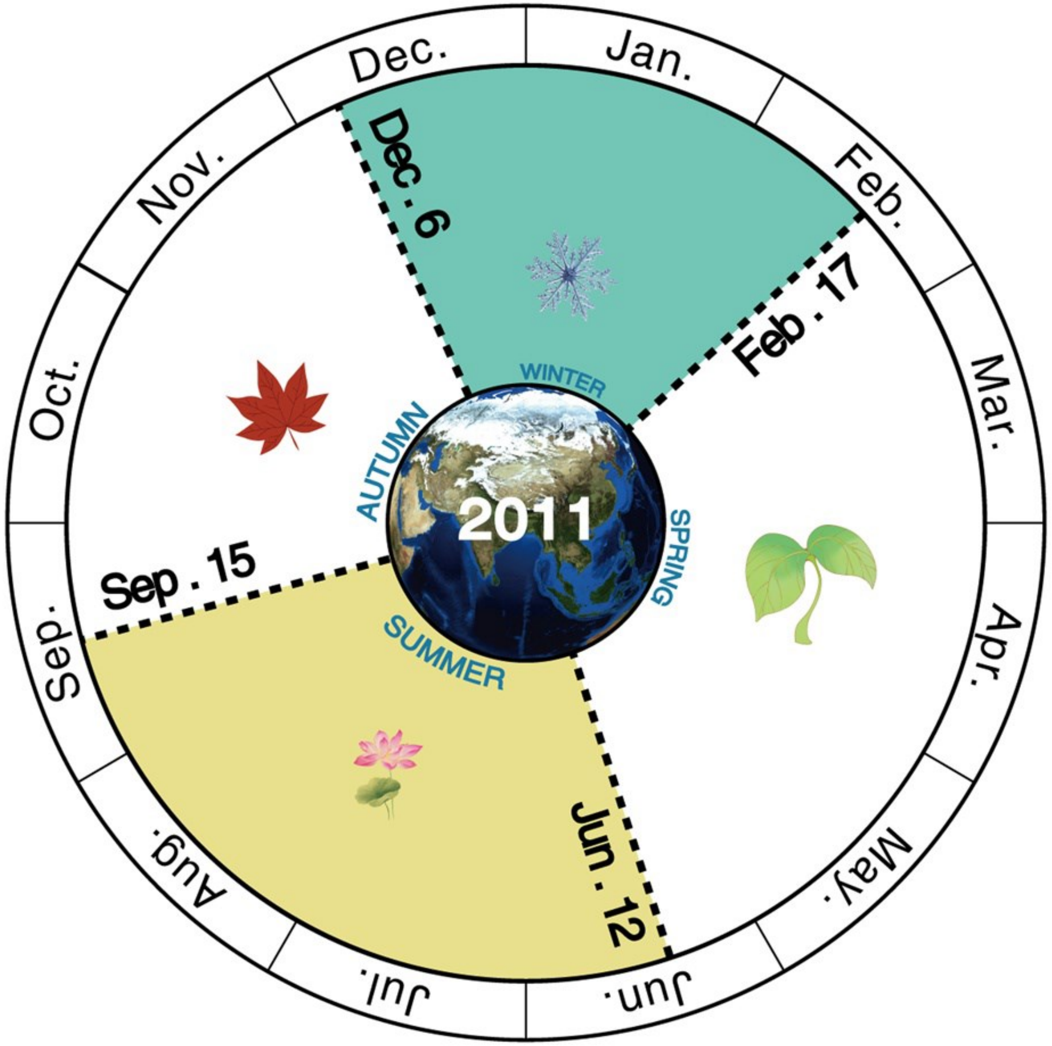
Figure 4. Temporal trends for onsets, lengths and temperatures of the four seasons during the period of 1952–2011 (historical) and 2016–2100 (future). (a) Onsets are shown in (a).
The shading denotes the range of traditional seasons (green: spring, pink: summer, khaki: autumn, blue: winter). (b) Lengths and temperatures are shown in (b) The curve is the length trend, and shading is the temperature trend from HadGHCND and RCP8.5 (trends for others are listed in Table S3). The labels on the Y axis in parentheses indicate coordinates of the graph above, and labels outside the parentheses indicate the coordinates below. HadGHCND, Hadley Centre's Global Historical Climatology Network Daily; RCP, representative concentration pathways.



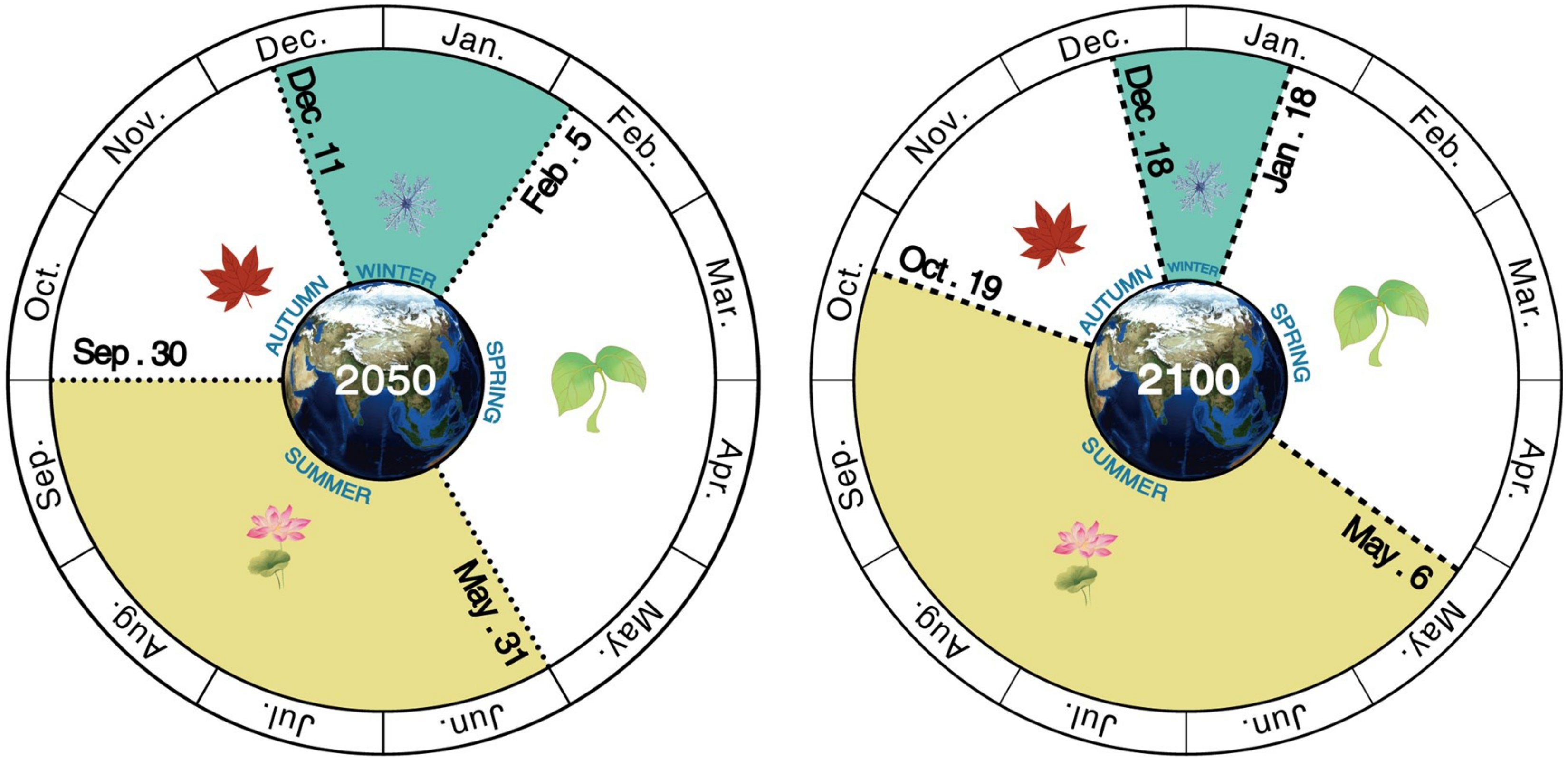
RCP 4.5: confermato il trend osservato nella serie storica (‘longer summer and shorter winter will become the new normal in the 21st century’)

Elaborazioni e simulazioni di scenario 1952-2011





Elaborazioni e simulazioni di scenario al 2100 (RCP 8.5)



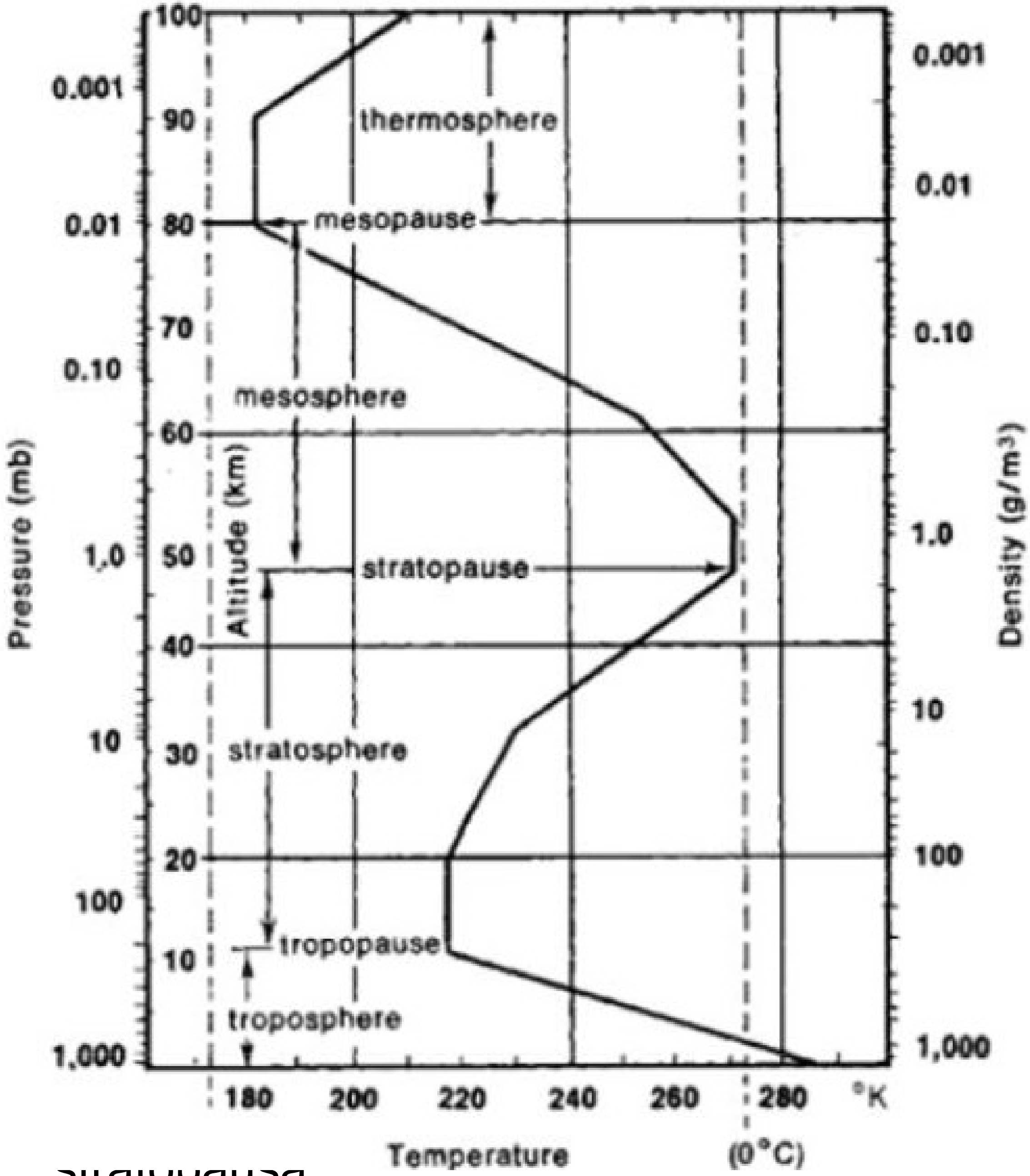
RCP 8.5 (*busines-as-usual scenario*): 166 gg (estate), 31 gg (inverno)

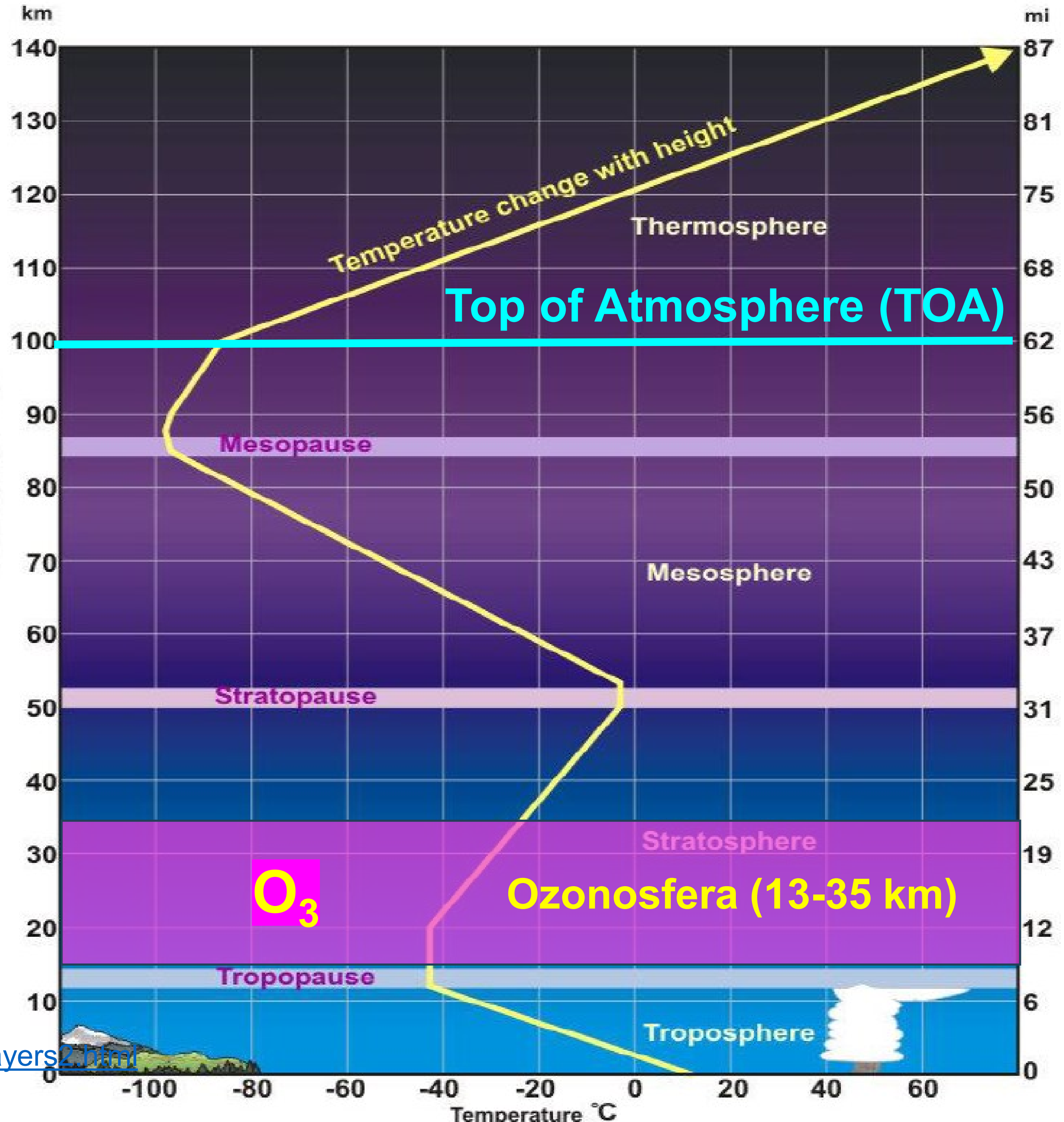
- Estati molto più lunghe e più calde, inverni più corti e più caldi, primavere ed autunni più corti
- Primavera ed estate cominceranno 1 mese prima (rispetto al 2011), autunno e inverno anticipo di 1 mese
- 6 mesi di estate, meno di 2 mesi di inverni
- Gli impatti più importanti ricadranno sull'economia agricola, sui sistemi ecologici (biodiversità) e sulla salute umana

L’ATMOSFERA

L'ATMOSFERA

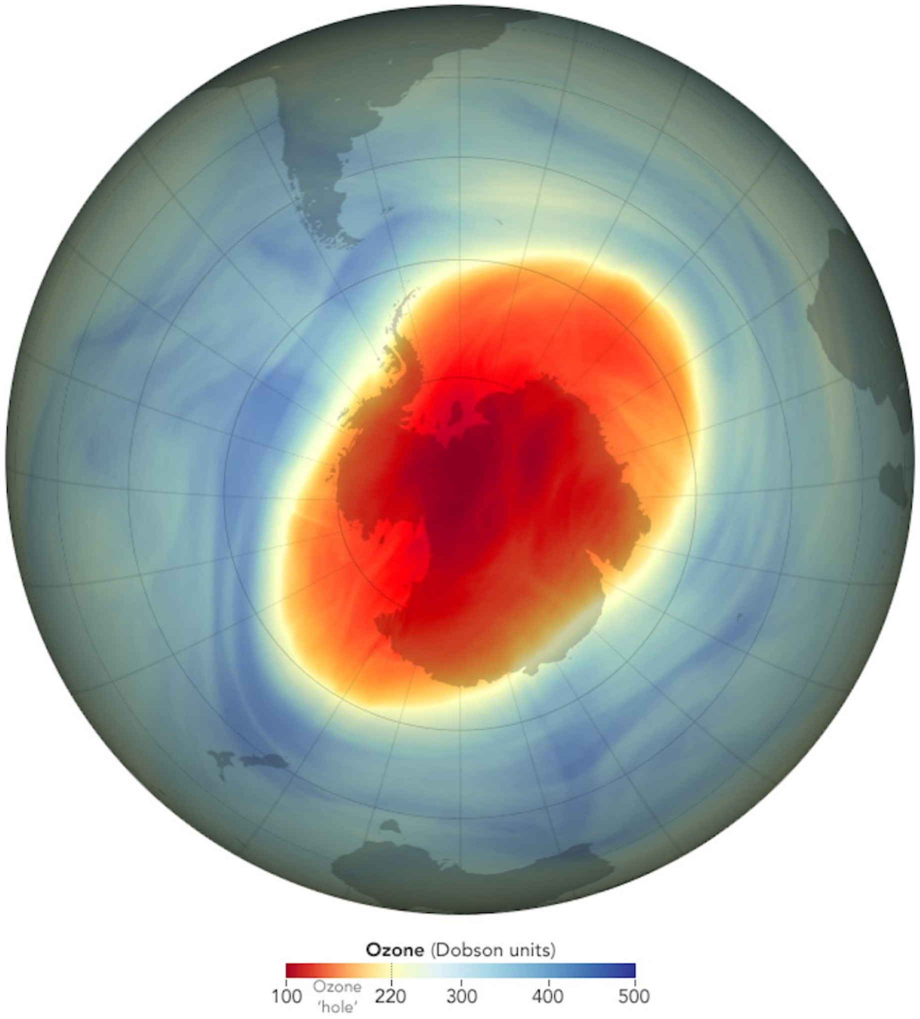
https://www.metoffice.gov.uk/weather/climate/climate-explained/earths-atmosphere

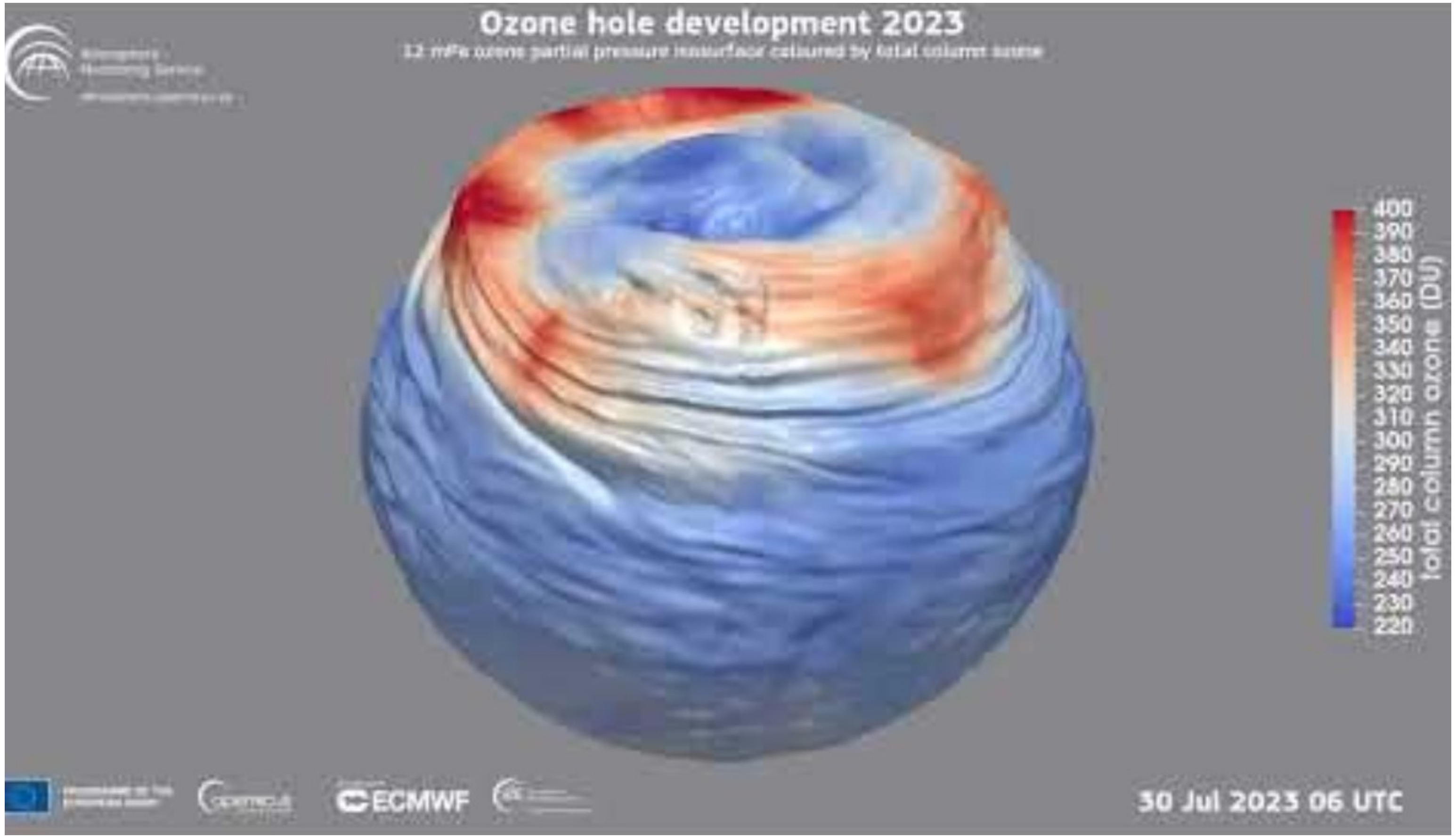




stratopausa

https://www.nasa.gov/mission_pages/sunearth/science/atmosphere-layers2.html

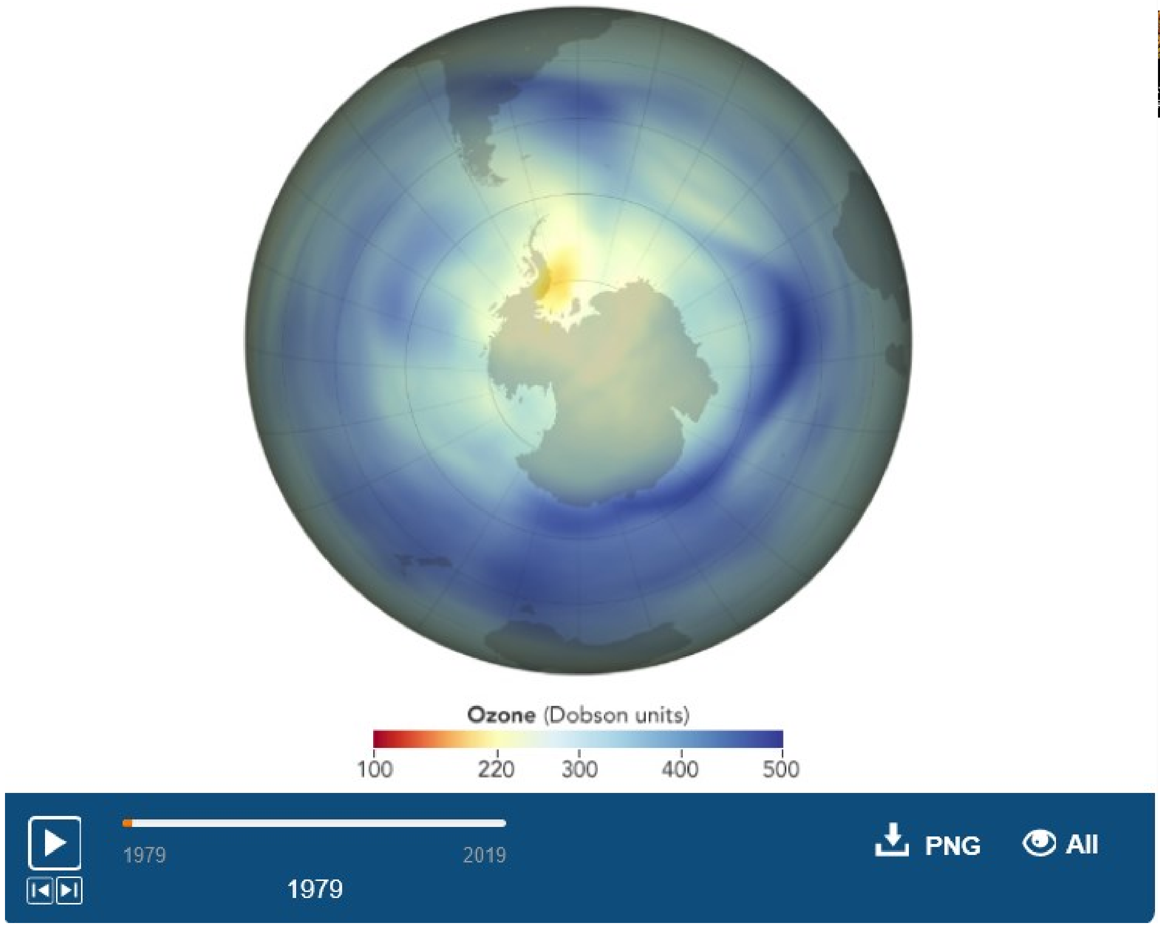




https://www.youtube.com/watch?v=6fOVCS5apNM

https://earthobservatory.nasa.gov/world-of-change/Ozone

Protocollo di Montreal (1987, 1989)

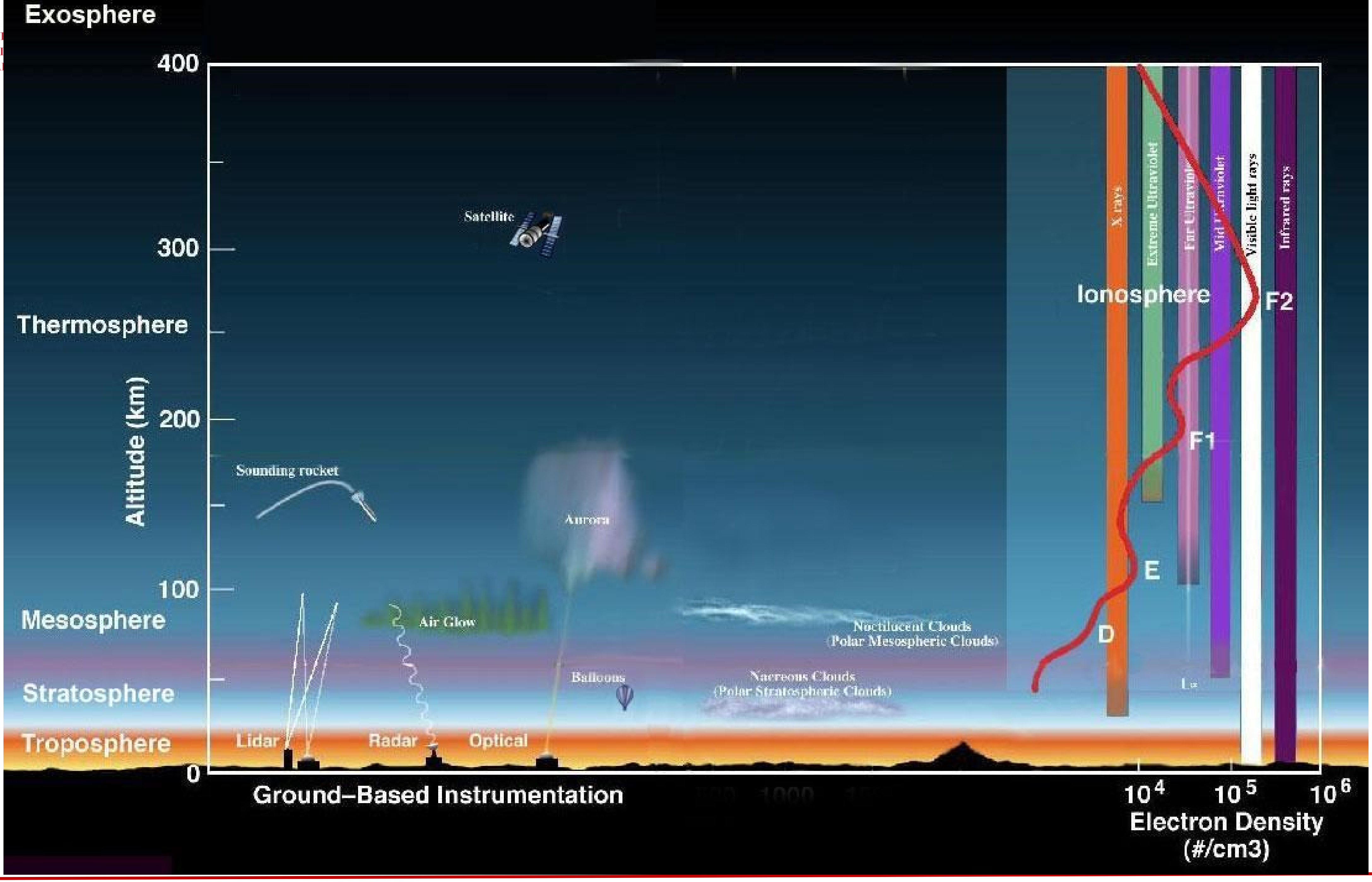


https://earthobservatory.nasa.gov/world-of-change/Ozone

https://earthobservatory.nasa.gov/features/videos/the-ozone-hole

https://www.nasa.gov/missions/aura/ozone-hole-continues-shrinking-in-2022-nasa-and-noaa-scientists-say/

https://www.youtube.com/watch?app=desktop&v=lBu3vltczRw


Exosphere
400
300
Thermosphere
Altitude (km)
200
100
Mesosphere
Stratosphere
Troposphere
0
Satellite
Sounding rocket
Aurora
Air Glow
Noctilucent Clouds
(Polar Mesospheric Clouds)
Balloons
Nacreous Clouds
(Polar Stratospheric Clouds)
Lidar
Radar
Optical
Ground–Based Instrumentation
X rays
Extreme Ultraviolet
Visible light rays
Infrared rays
Ionosphere
F2
F1
E
D
10 4
10 5
10 6
Electron Density
(#/cm3)

La troposfera

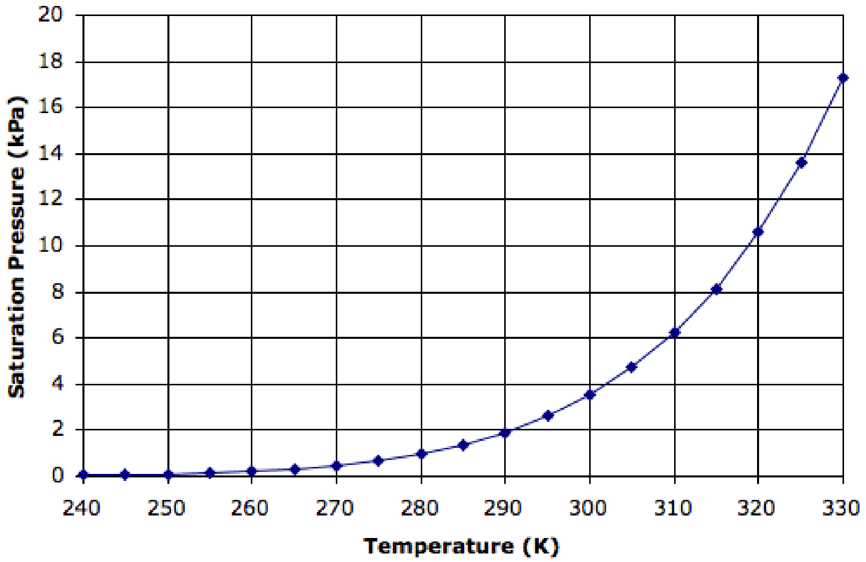
- Dalla superficie fino a circa 12 km, ma è variabile in funzione del tempo e dello spazio: in media 12 km (8 km in corrispondenza dei poli e 18 km all'equatore) (dal greco *τροπος*: girare)
- Nel profilo termico verticale la T diminuisce (in media ~0.6 °C 100 m di altitudine)
- Il tempo meteorologico (quasi tutto) si verifica in atmosfera
- Rappresenta l'80% della massa dell'atmosfera
- Salvo il contenuto in vapore acqueo, la composizione dell'atmosfera è essenzialmente uniforme
- Tra troposfera e stratosfera si verificano pochissima scambi (eruzioni)

Com'è fatta l'atmosfera?

Constituent	Chemical formula	Molecular weight ($^{12}C = 12$)	Fraction by volume in dry air	Total mass (g)
Total atmosphere		28.97		5.136×10^{21}
Dry air		28.964	100.0 %	5.119×10^{21}
Nitrogen	N_2	28.013	78.08 %	3.87×10^{21}
Oxygen	O_2	31.999	20.95 %	1.185×10^{21}
Argon	Ar	39.948	0.934 %	6.59×10^{19}
Water vapor	H_2O	18.015	Variable	1.7×10^{19}
Carbon dioxide	CO_2	44.01	353 ppmv[a]	$\sim 2.76 \times 10^{18}$
Neon	Ne	20.183	18.18 ppmv	6.48×10^{16}
Krypton	Kr	83.80	1.14 ppmv	1.69×10^{16}
Helium	He	4.003	5.24 ppmv	3.71×10^{15}
Methane	CH_4	16.043	1.72 ppmv[a]	$\sim 4.9 \times 10^{15}$
Xenon	Xe	131.30	87 ppbv	2.02×10^{15}
Ozone	O_3	47.998	Variable	$\sim 3.3 \times 10^{15}$
Nitrous oxide	N_2O	44.013	310 ppbv[a]	$\sim 2.3 \times 10^{15}$
Carbon monoxide	CO	28.01	120 ppbv	$\sim 5.9 \times 10^{14}$
Hydrogen	H_2	2.016	500 ppbv	$\sim 1.8 \times 10^{14}$
Ammonia	NH_3	17.03	100 ppbv	$\sim 3.0 \times 10^{13}$
Nitrogen dioxide	NO_2	46.00	1 ppbv	$\sim 8.1 \times 10^{12}$
Sulfur dioxide	SO_2	64.06	200 pptv	$\sim 2.3 \times 10^{12}$
Hydrogen sulfide	H_2S	34.08	200 pptv	$\sim 1.2 \times 10^{12}$
CFC-12	CCl_2F_2	120.91	480 pptv[a]	$\sim 1.0 \times 10^{13}$
CFC-11	CCl_3F	137.37	280 pptv[a]	$\sim 6.8 \times 10^{12}$

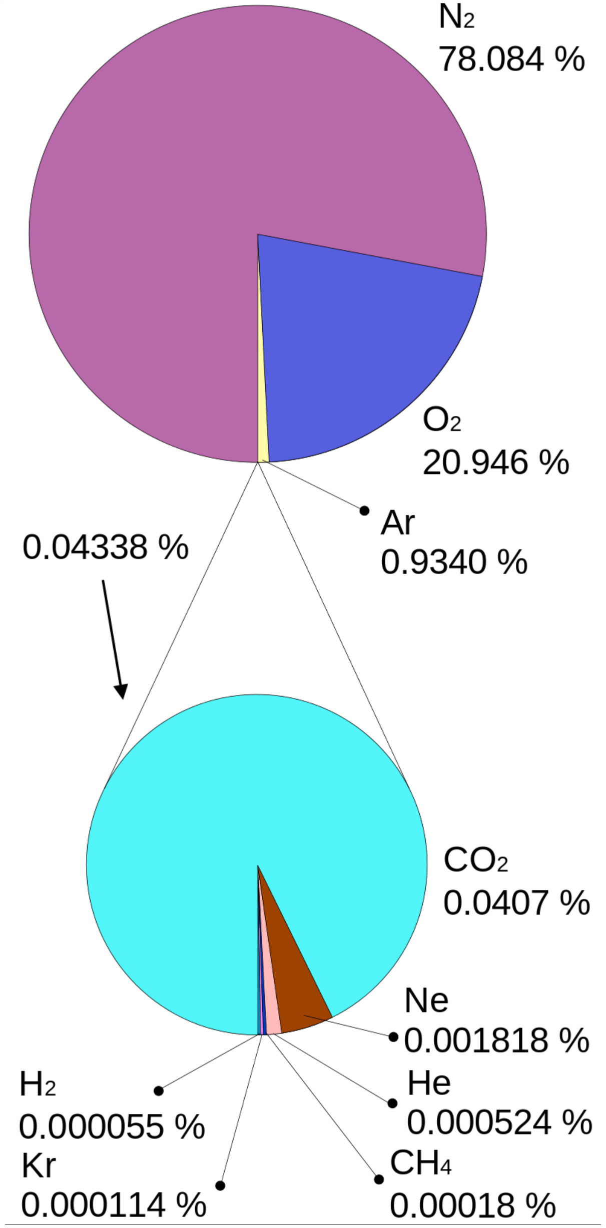
Composizione chimica dell'atmosfera

Equazione di Clausius-Clapeyron



Composizione chimica dell’atmosfera

Constituent	Percent by Volume	Concentration in Parts Per Million (PPM)
Nitrogen (N_2)	78.084	780,840.0
Oxygen (O_2)	20.946	209,460.0
Argon (Ar)	0.934	9,340.0
Carbon dioxide (CO_2)	0.036	360.0
Neon (Ne)	0.00182	18.2
Helium (He)	0.000524	5.24
Methane (CH_4)	0.00015	1.5
Krypton (Kr)	0.000114	1.14
Hydrogen (H_2)	0.00005	0.5



https://www.ux1.eiu.edu/~cfjps/1400/atmos_origin.html

GreenHouse Gases (GHG) – i gas ad effetto serra

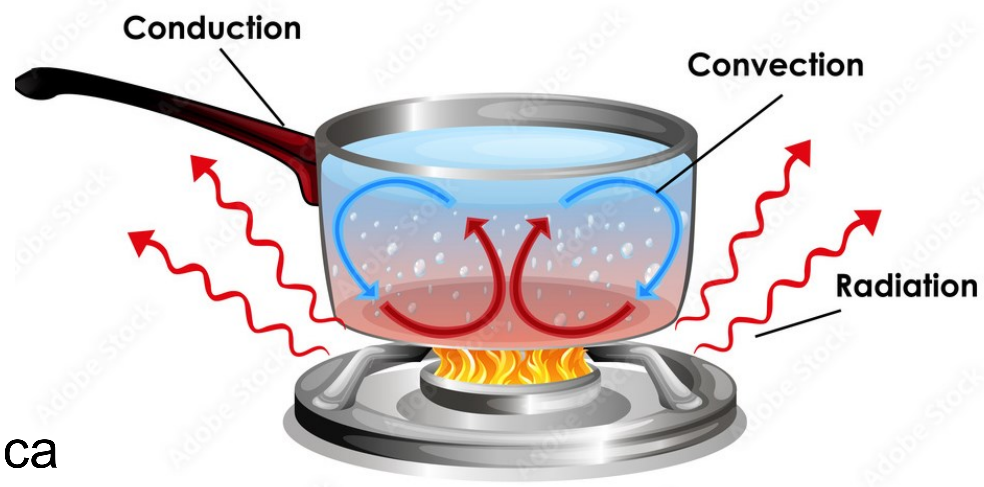
Gas	Pre-1750 tropospheric concentration	Recent tropospheric concentration	Absolute increase since 1750	Percentage increase since 1750	Increased radiative forcing (W/m^2)
Biossido di carbonio (CO_2)	280 ppm	395.4 ppm	115.4 ppm	41.2%	1.88
Metano (CH_4)	700 ppb	1893 ppb / 1762 ppb	1193 ppb / 1062 ppb	170.4% / 151.7%	0.49
Protossido di azoto (N_2O)	270 ppb	326 ppb / 324 ppb	56 ppb / 54 ppb	20.7% / 20.0%	0.17
Ozono troposferico (O_3)	237 ppb	337 ppb	100 ppb	42%	0.4

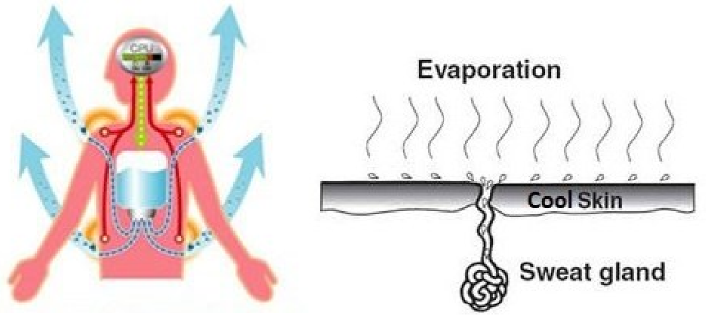
(Bagliani, 2019)

Il bilancio energetico terrestre

Bilancio radiativo terrestre: scambi di energia termica

1. **Conduzione:** gradiente di temperatura in un solido o fluido (contatto)
2. **Convezione:** trasmissione di calore tra una superficie ed un fluido (liquido, gas) in movimento
3. **Irraggiamento:** trasmissione di energia sotto forma di onde elettromagnetiche, senza un mezzo interposto
4. **Passaggi di stato dell'acqua**: i) **assorbimento** energia termica (calore latente) nei passaggi da solido a liquido (fusione), da liquido a gassoso (evaporazione), da solido a liquido (fusione); ii) **cessione calore** latente nei passaggi inversi: condensazione, congelamento, deposizione





Irraggiamento

*Emissione di onde elettromagnetiche di frequenza proporzionale alla loro temperatura: **quando la temperatura sale, la frequenza della luce emessa aumenta***

- corpi vicini 0 K emettono onde radio
- corpi molto freddi irradiano microonde
- **i corpi a T ambiente emettono infrarossi**
- **i corpi molto caldi emettere luce visibile**

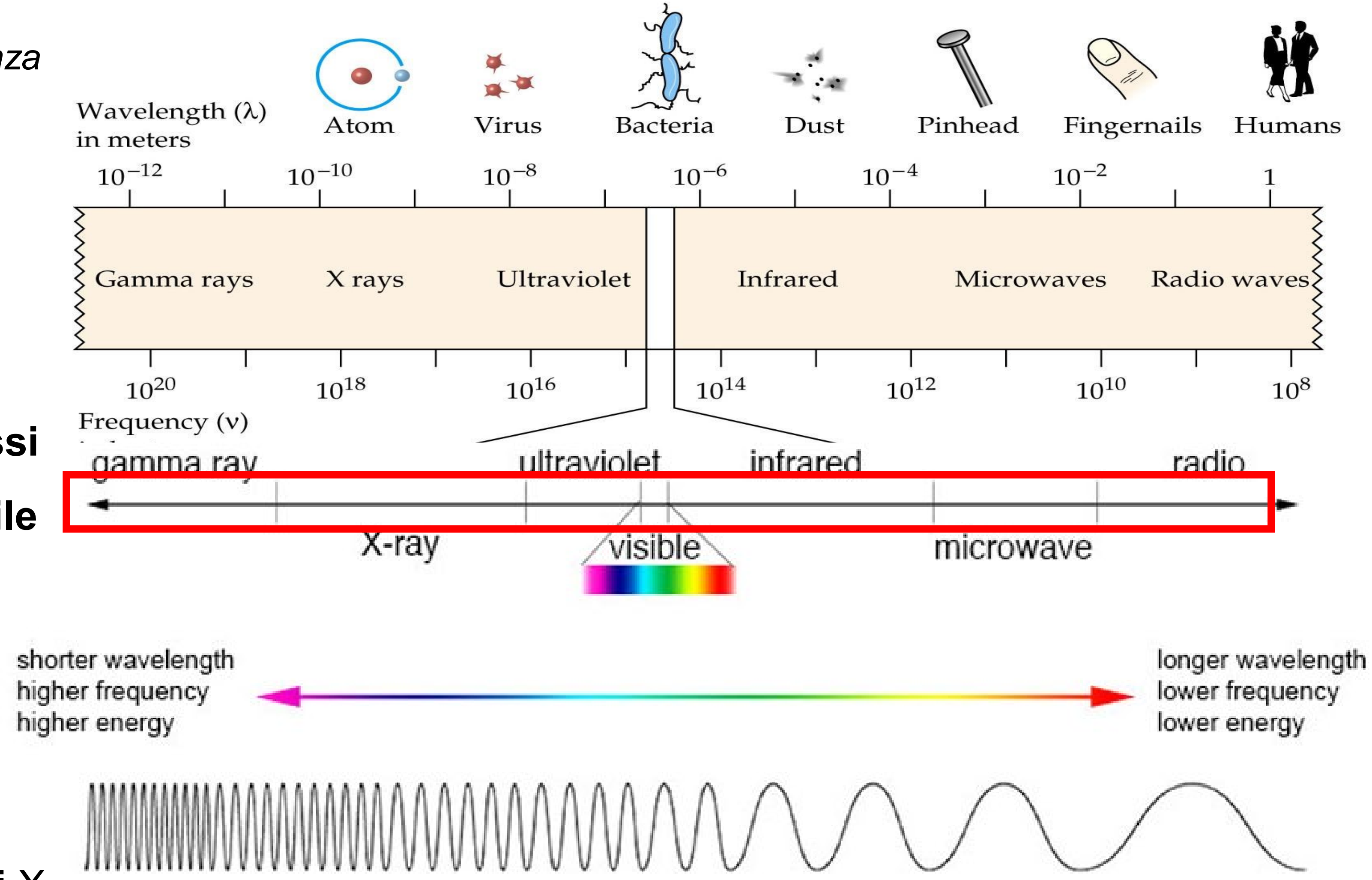
\- dapprima rossa (T calor rosso, 700 C°)

\- bianca (T calor bianco, circa 1200 C°)

- corpi ancora più caldi emettono

nell'ultravioletti

- i plasmi stellari (T 10^6 °C) emettono raggi X



Sistema terra:
Isolato?
Chiuso?
Aperto?

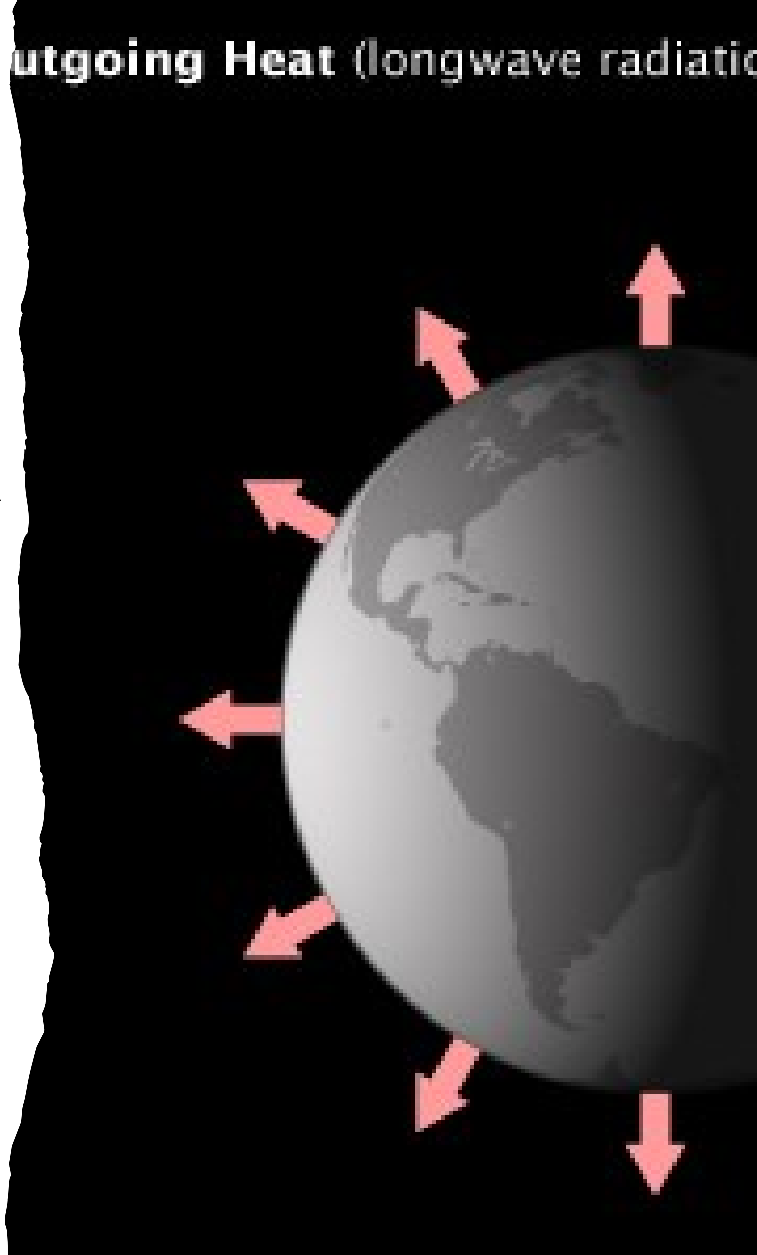
Bilancio radiativo terrestre

Il bilancio radiativo terreste è dato dalla differenza tra la quantità di energia **in entrata** nel “Sistema Terra” e la quantità di energia **in uscita** dal “Sistema Terra”

E_{in} = radiazione solare assorbita dalla Terra
E_{out} = radiazione riflessa + radiazione riemessa nello spazio dalla Terra.

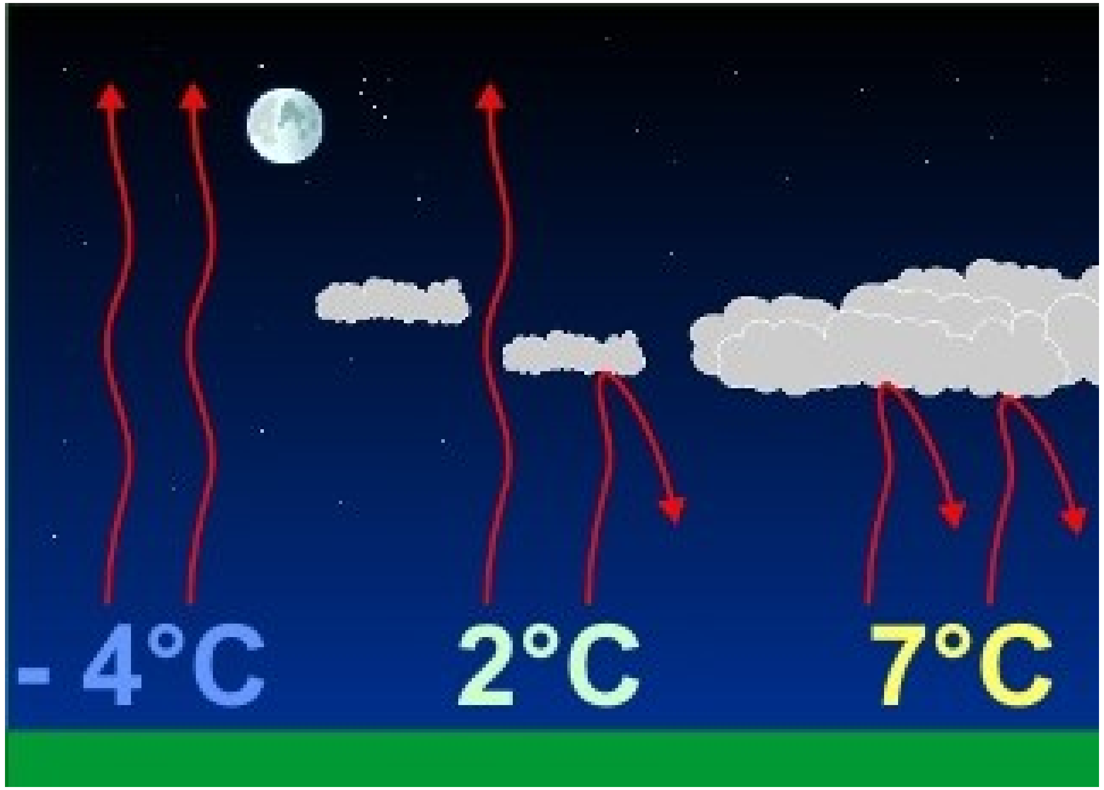
$$E_{tot} = E_{in} - E_{out}$$

- Terra in parte riflette (30%) in parte assorbe (70%) l’energia.
- Energia assorbita viene riemessa come radiazione infrarossa

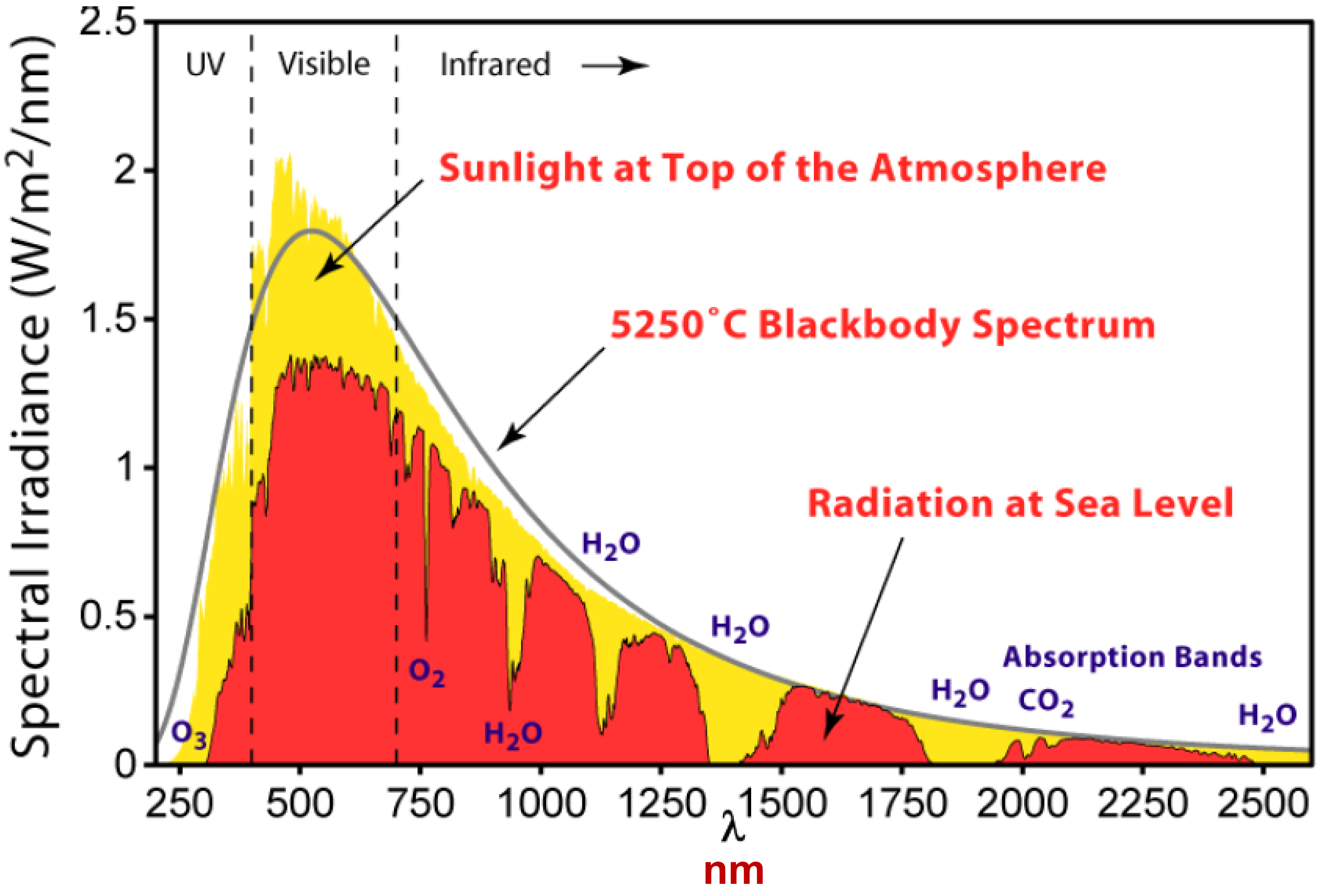


>0 si riscalda
<0 si raffredda
se costante non varia

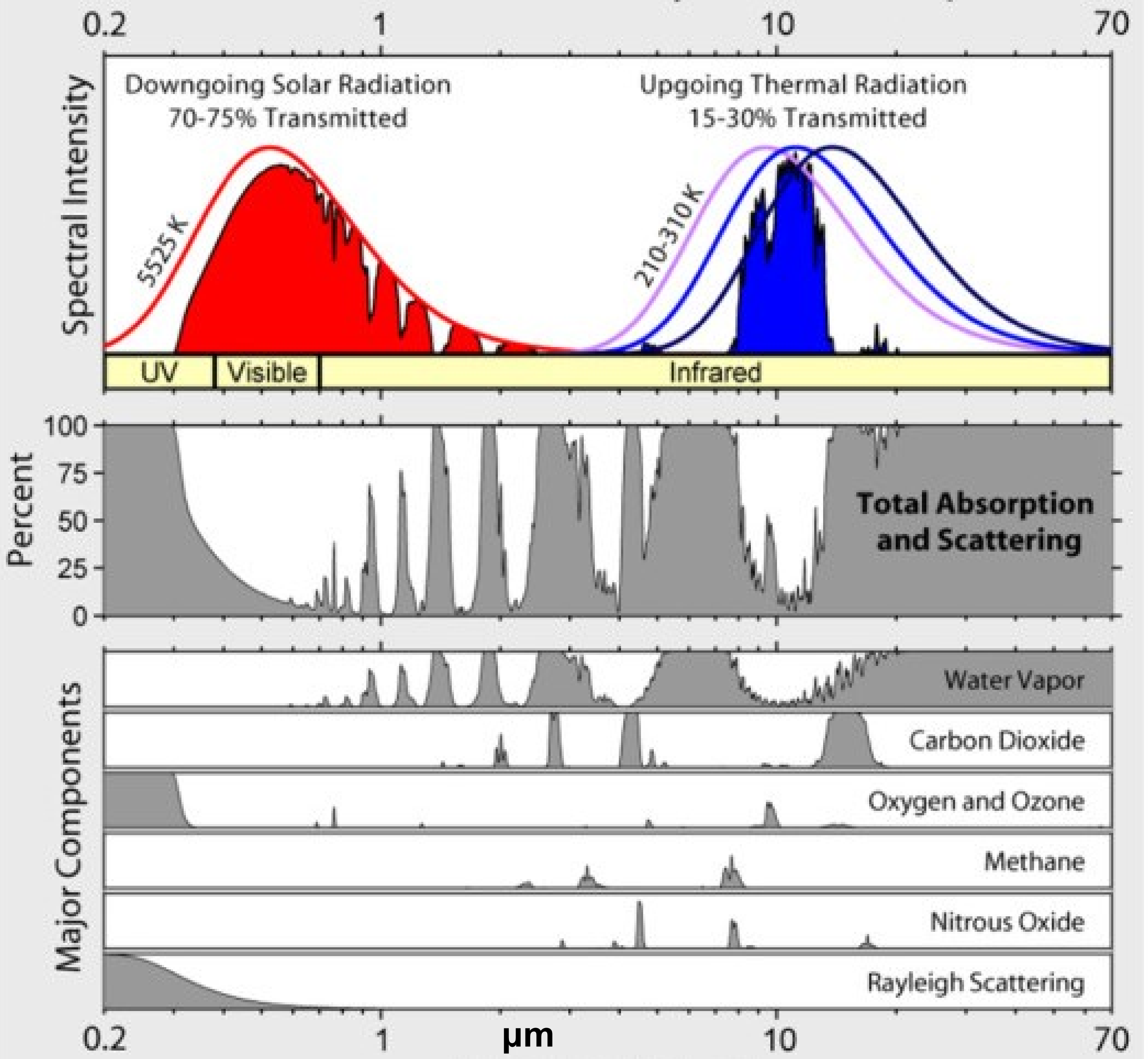
Bilancio energetico: effetto serra



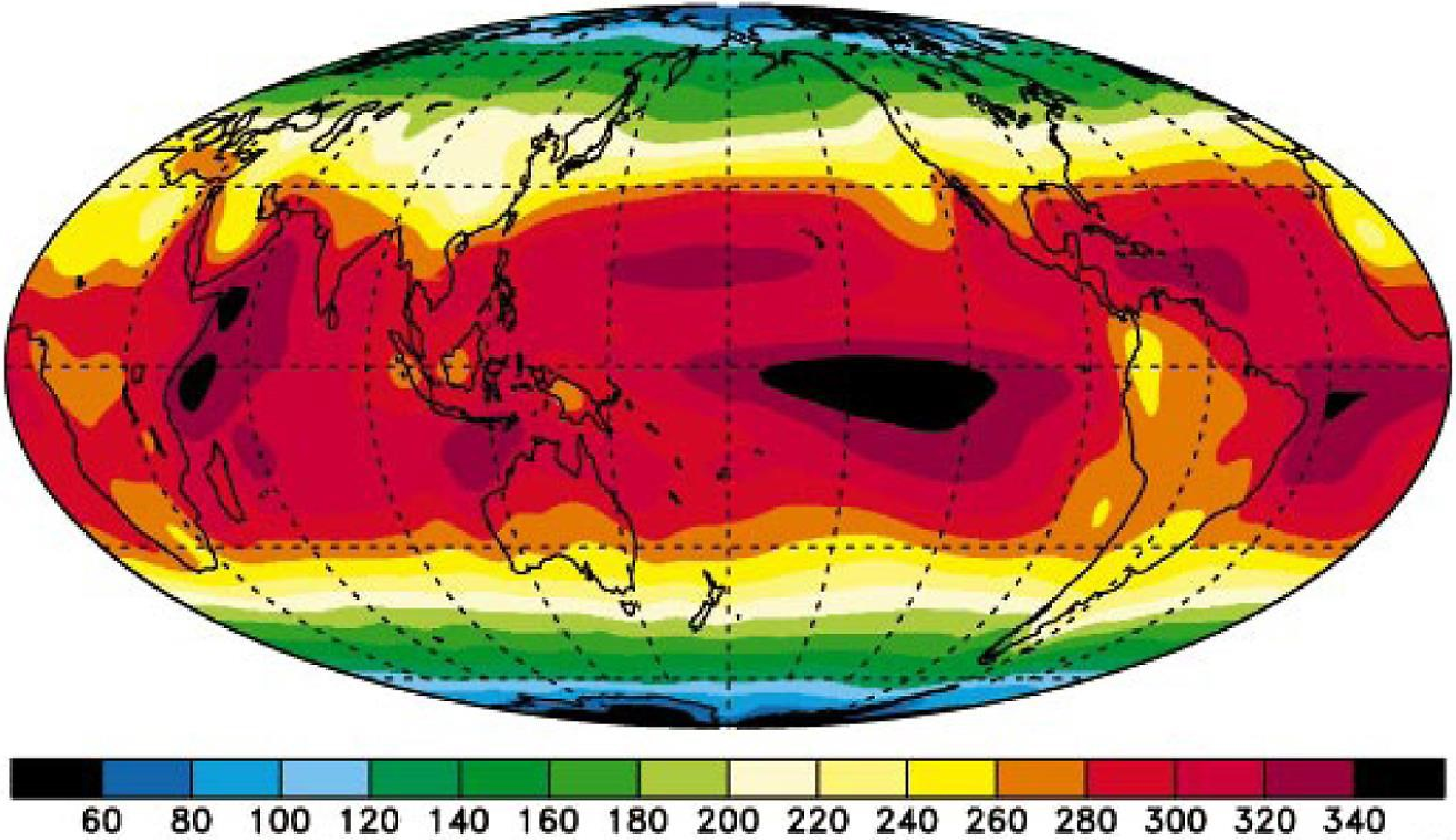
Atmospheric Absorption (*downgoing*)



Radiation *downgoing* and *upgoing*



La radiazione infrarossa in ***entrata*** nel sistema Terra (assorbita)



Annual mean net incoming solar radiation at the top of the atmosphere that is absorbed by the Earth (in W m-2). Figure from Trenberth and Stepaniak (2003)

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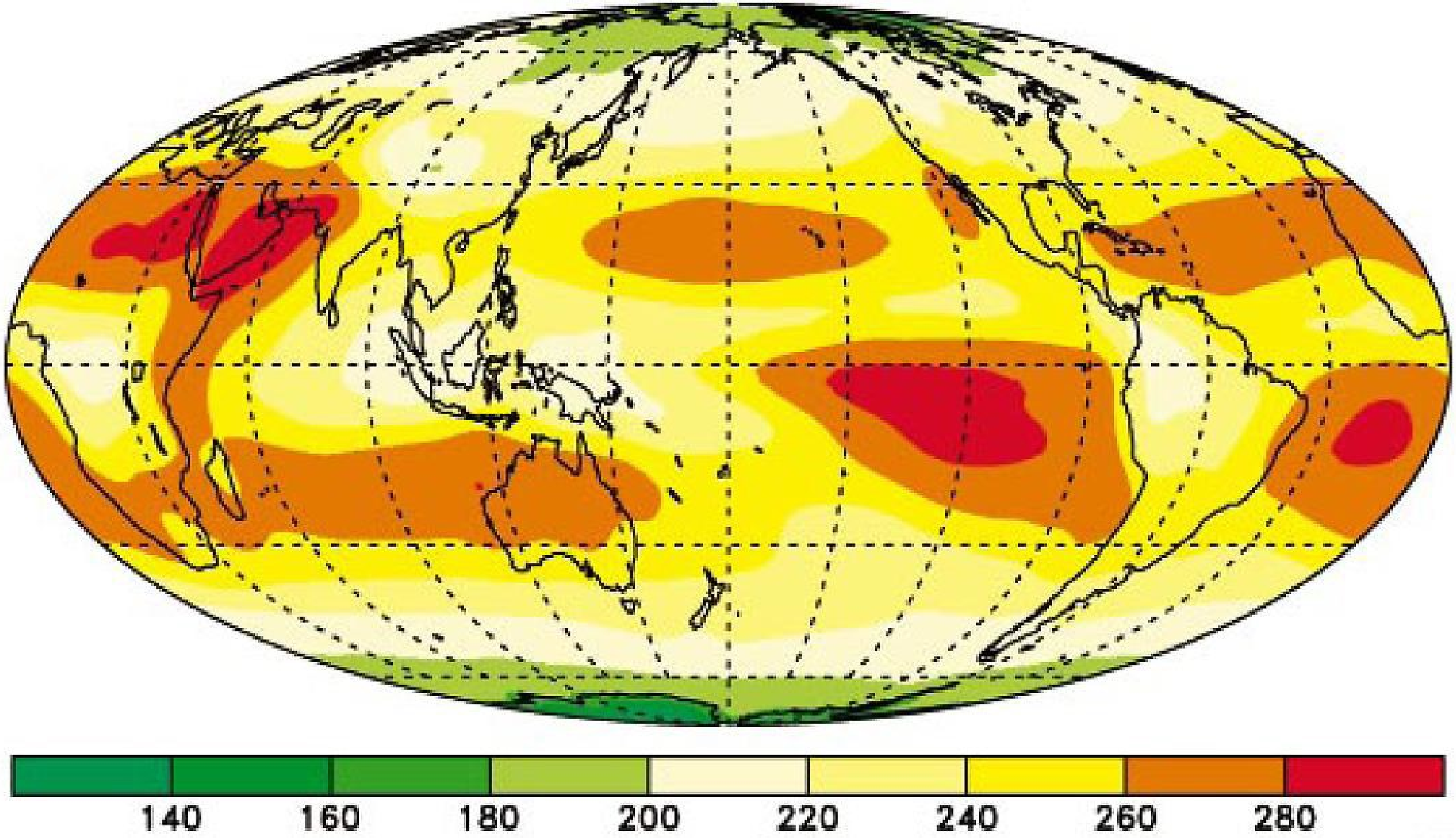
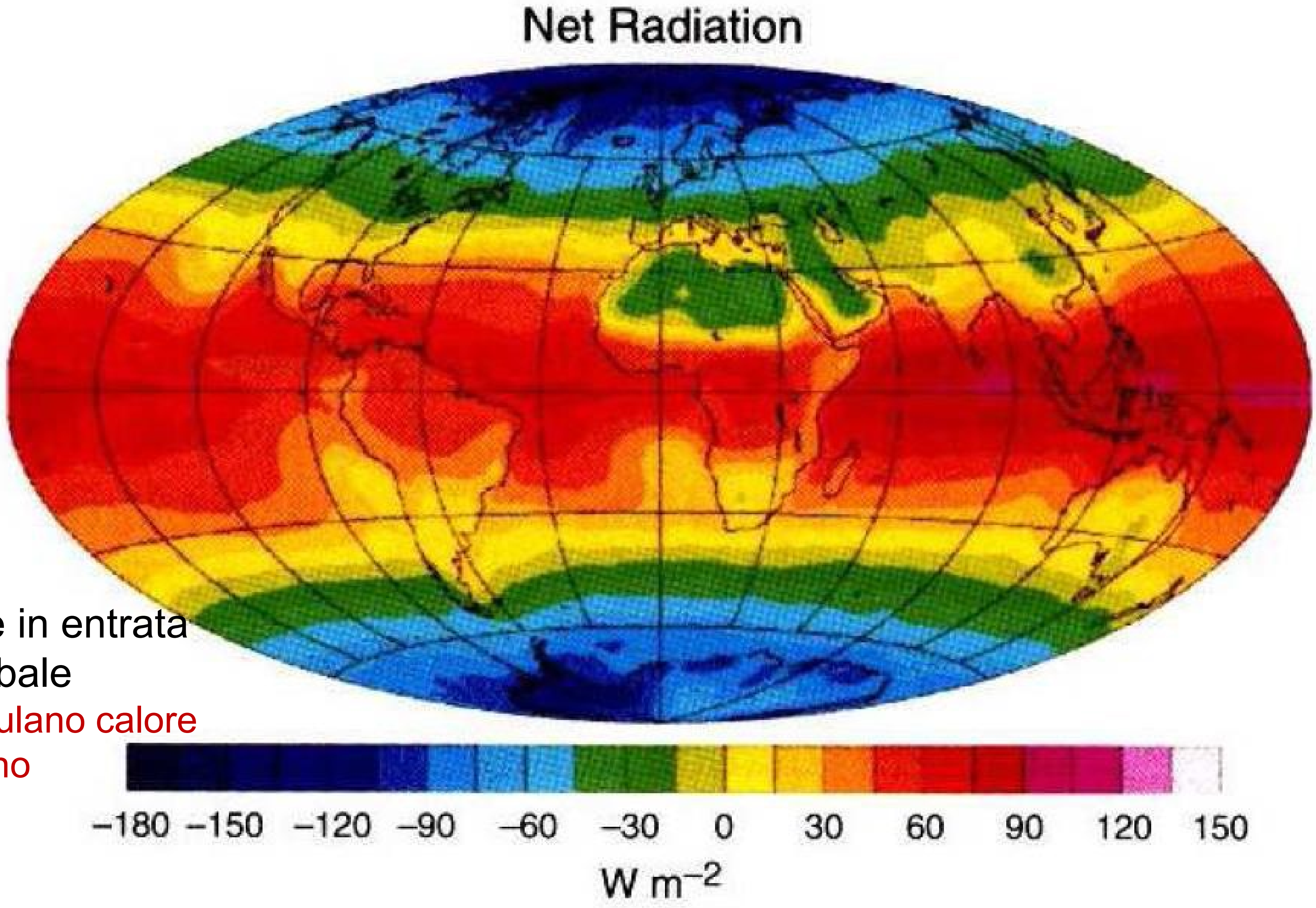
La radiazione infrarossa in ***uscita*** nel sistema Terra (emessa)



Net annual mean outgoing longwave radiation at the top of the atmosphere (in W m-2). Figure from Trenberth and Stepaniak (2003)



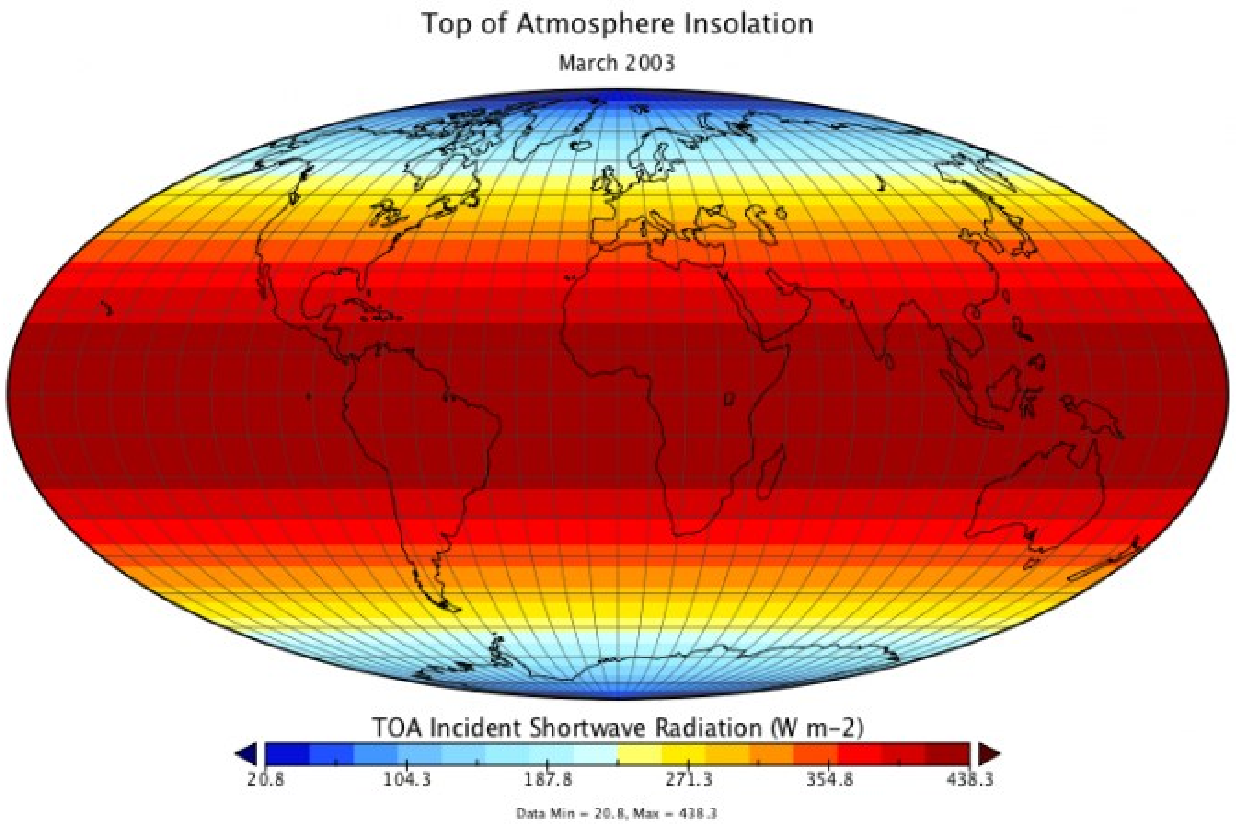
Radiazione netta

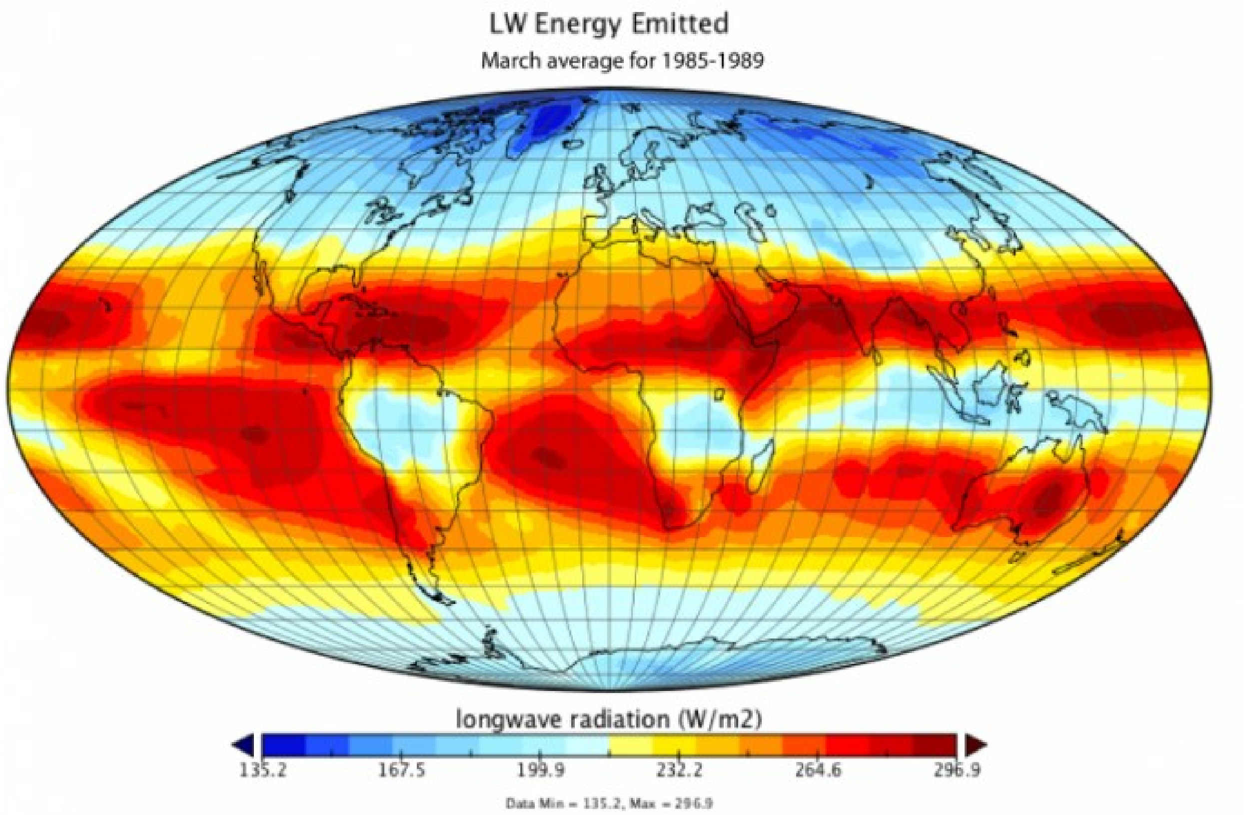
Bilancio tra la radiazione in entrata ed in uscita su scala globale

Le zone equatoriali accumulano calore

Le zone polari si raffreddano

Variabilità del clima: energia termica e trasporto di calore

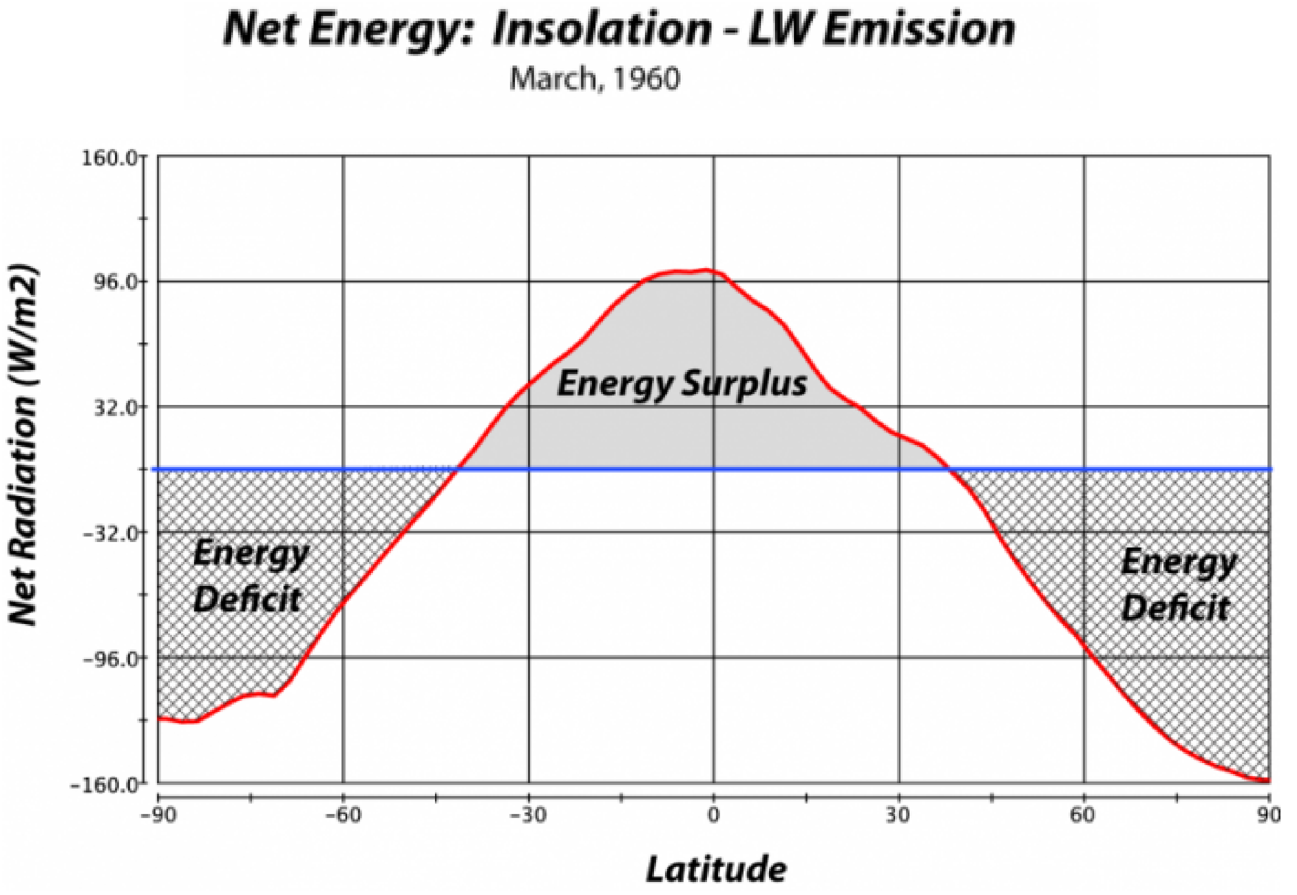


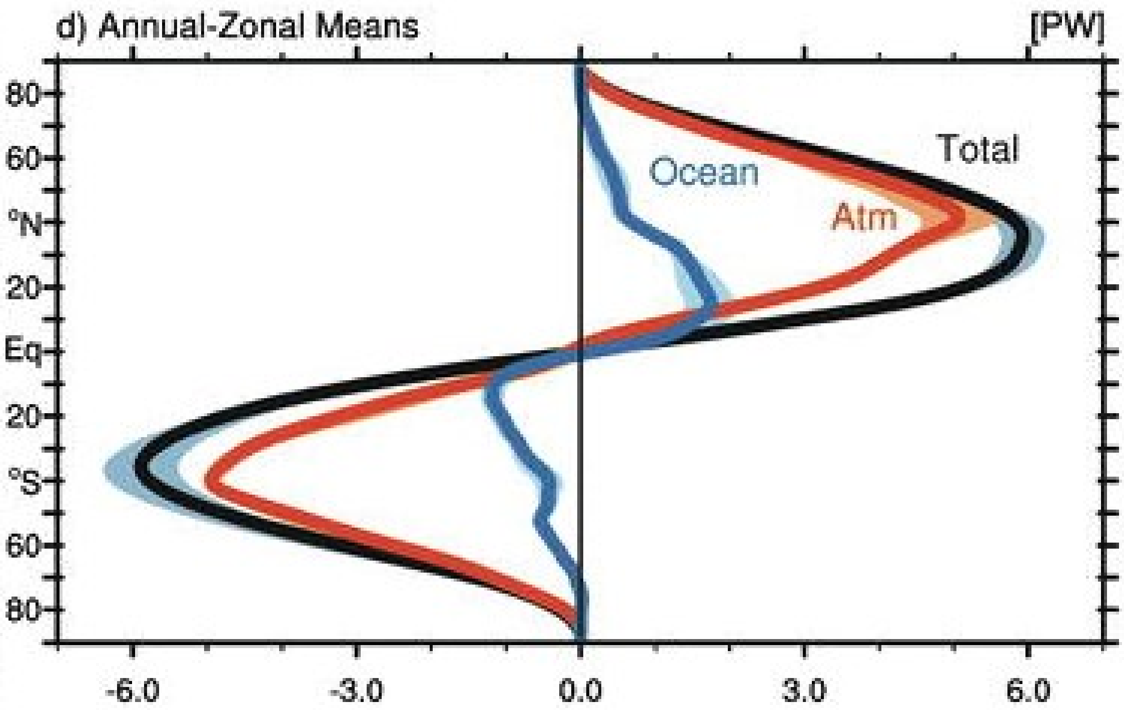


L'energia termica viene ridistribuita dalle basse alle alte latitudini grazie ai processi di trasporto nell'atmosfera (venti) e nell'oceano (correnti

https://www.e-education.psu.edu/earth103/node/1007

Il motore del sistema climatico: bilancio e flussi di calore

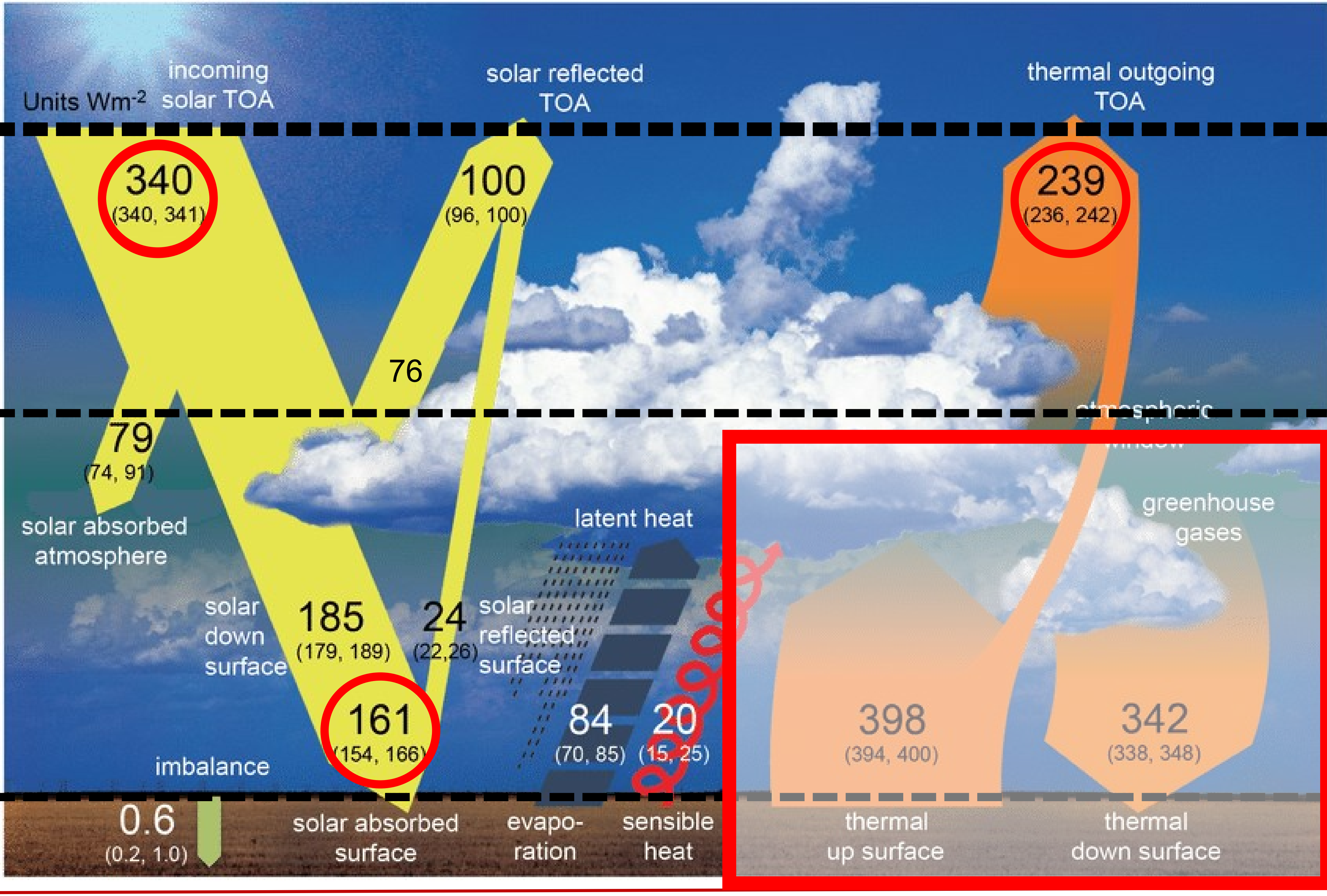




The median annual mean transport by latitude for the total (gray), atmosphere (red), and ocean (blue) accompanied with the associated range (shaded).

The insolation reaching the surface averaged over March 1960, from NASA's ERBE experiment.
Credit: David Bice Penn State University is licensed under CC BY-NC-SA 4.0

Bilancio energetico terrestre

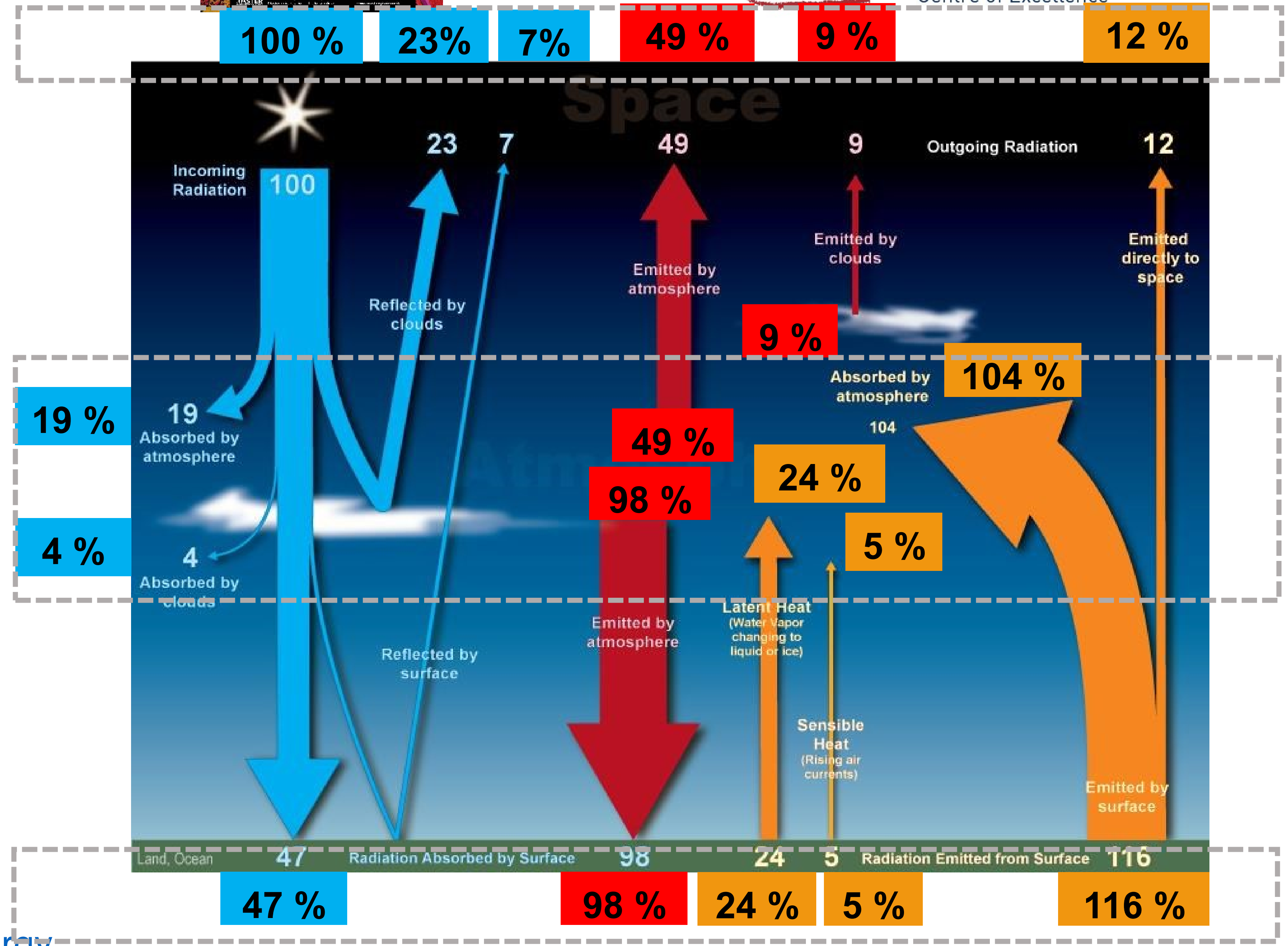


Bilancio energetico terrestre

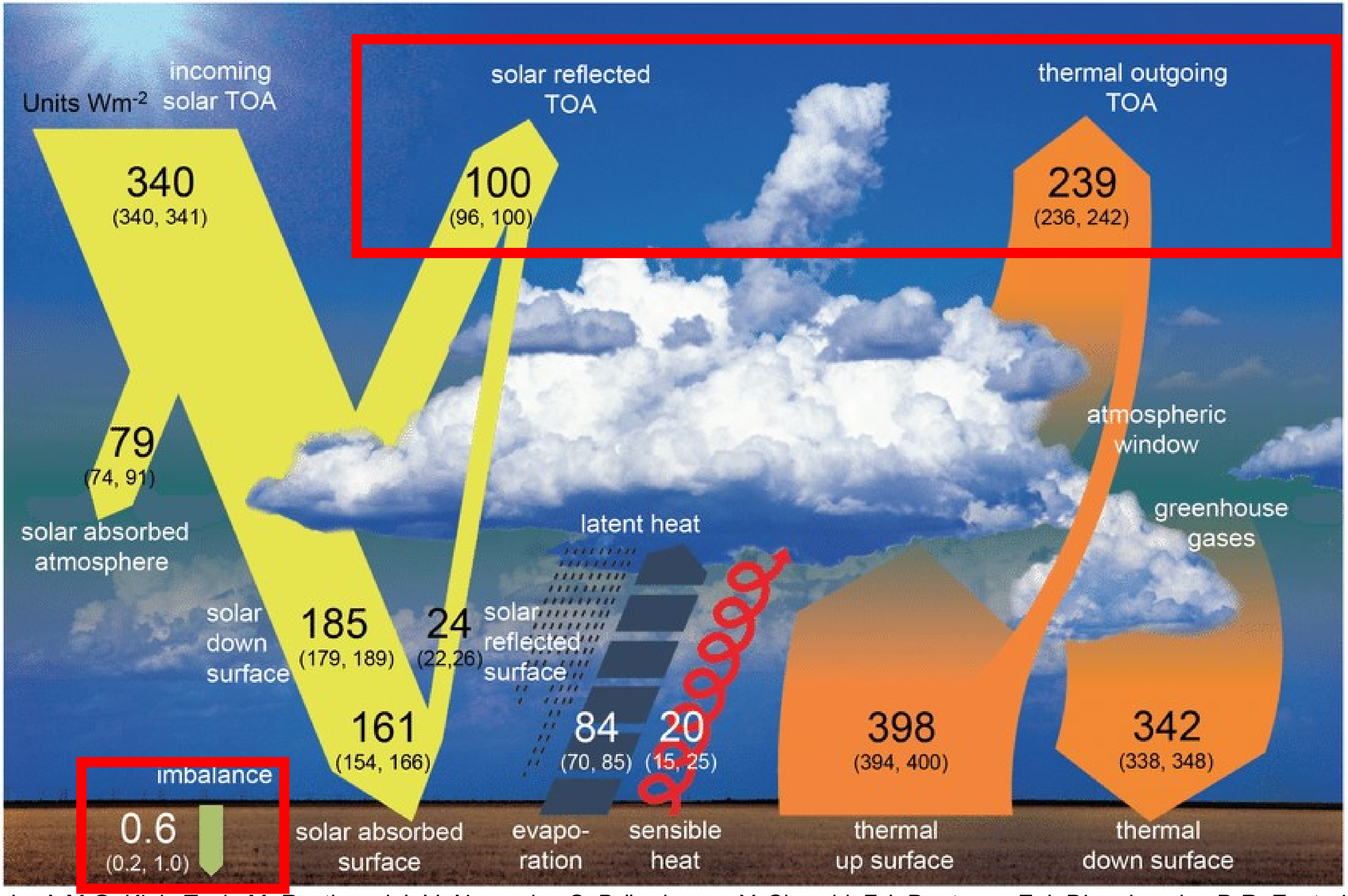
In 100% | out -100%

In 156% | out -156%

In 145% | out -145%



https://www.weather.gov/jetstream/energy



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Bilancio energetico terrestre: *in a nutshell*

Quantità media di energia al **TOA** (Top Of Atmosphere) è circa **340 Watt m^{-2}**
Sulla superficie terrestre (terre e oceani) arrivano **161 Watt m^{-2}**

Tale energia (centrata **sulla luce visibile**) viene:
- **riflessa**: **30%** del totale (da atmosfera 27%, nubi (3%)
- **assorbita: 70%** del totale, atmosfera (19%), nubi (4%), superficie terrestre (47%)

L'energia assorbita viene riemessa come radiazione infrarossa

(Bagliani, 2019)

Cosa potrebbe surriscaldare ulteriormente il sistema Terra?

UNIVERSITÀ DEGLI STUDI DI PADOVA

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RESEARCH LETTER

10.1002/2015GL063514

Key Points:
- The Earth is heated both by thermal energy and by CO_2 greenhouse effect
- Time scales and ratios of warming from thermal versus CO_2 are quantified
- Approximately 1% of net anthropogenic climate forcing from direct thermal emissions

Supporting Information:
- Texts S1–S4, Figure S1, and Table S1

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Time scales and ratios of climate forcing due to thermal versus carbon dioxide emissions from fossil fuels

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Abstract The Earth warms both when fossil fuel carbon is oxidized to carbon dioxide and when greenhouse effect of carbon dioxide inhibits longwave radiation from escaping to space. Various important time scales and ratios comparing these two climate forcings have not previously been quantified. For example, the global and time-integrated radiative forcing from burning a fossil fuel exceeds the heat released upon combustion within 2 months. Over the long lifetime of CO_2 in the atmosphere, the cumulative CO_2-radiative forcing exceeds the amount of energy released upon combustion by a factor >100,000. For a new power plant, the radiative forcing from the accumulation of released CO_2 exceeds the direct thermal emissions in less than half a year. Furthermore, we show that the energy released from the combustion of fossil fuels is now about 1.71% of the radiative forcing from CO_2 that has accumulated in the atmosphere as a consequence of historical fossil fuel combustion.

1. Introduction

The Earth is heated both when reduced carbon is oxidized to carbon dioxide and when outgoing longwave radiation is trapped by carbon dioxide in the atmosphere (CO_2 greenhouse effect) [*Washington*, 1972; *Nordell*, 2003; *Block et al.*, 2004; *Chaisson*, 2008; *Flanner*, 2009; *Ma et al.*, 2011; *G. J. Zhang et al.*, 2013; *X. Zhang et al.*, 2013]. The purpose of this study is to improve our understanding of time scales and relative magnitudes of climate forcing increase over time from pulse, continuous, and historical CO_2 and thermal emissions. We aim to (1) improve our understanding of time scales and relative magnitudes of the forcing increase over time due to pulse fossil fuel combustion thermal and CO_2 emissions; (2) identify for a pulse emission the crossover time when warming from CO_2 exceeds warming from thermal; and (3) understand how this affects cumulative forcing from thermal and CO_2 emissions since the Industrial Revolution.

In converting energy from chemical/physical energy to thermal energy and from thermal energy to electrical

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Variabilità del clima terrestre*

- Sistema terra in equilibrio dinamico (*steady state*)
- **Perturbazioni che possono alterare il bilancio energia: forzanti radiativi**
- Provenienza spaziale: esogeni (esterni) endogeni (interni)
- Causalità: naturali o antropogenici

*Variazione dello stato medio (*SD, frequency*) che descrivono il clima su tutte le scale temporali e spaziali (IPCC)

Evoluzione e cambi del clima sono legati ai *climate forcing* (forzanti radiativi)