Physical and Dynamical Climatology

Theoretical framework for application in the Indonesian maritime continent

Yamaguchi University (relayed to University of Udayana); 14, 21, 28 June and 5 July 2024

http://aoe.scitec.kobe-u.ac.jp/~mdy/MCC/

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1. Introduction: Earth's tropical atmosphere and ocean (June 14)
2. Conservation laws and basic equations (June 14)
3. Atmospheric vertical structure: Radiative-convective equilibrium (June 14)
4. Mean zonal and meridional circulations (June 21)
5. Equatorial waves (June 28)
6. Convection: Why can't we predict rainfall? (July 5)

Textbook:

- Yamanaka, 2017: Theoretical meteorology in the tropics, *Sri Lanka J. Meteor. Spec. Issue,* **2**, 3-126. https://doi.org/10.13140/RG.2.2.32479.36002

Additional reading:

- Yamanaka, 2016: Physical climatology of Indonesian maritime continent: An outline to comprehend observational studies. *Atmos. Res*., **178-179,** 231-259. https://www.researchgate.net/publication/299417525
- Yamanaka et al., 2018: Maritime continent coastlines controlling Earth's climate, *Prog. Earth Planet. Sci*.,**5**, 21. https://www.researchgate.net/publication/324219399
- Yamanaka, 2019: Climate-biogeosphere-humanosphere interaction, *ISQUAR*, Lecture 4. https://www.researchgate.net/publication/331977496

http://aoe.scitec.kobe-u.ac.jp/~mdy/MCC/

Physical and Dynamical Climatology

Theoretical framework for application in the Indonesian maritime continent

Updated: (slides) 4 June 2023; (text) 15 August 2017

(Old revisions: 27 April 2022; 14 June 2021; 17 June 2020; 24 April 2019; 4 July 2018; 9 Jun 2017: 6 Jun 2016; 17 Jun 2015; 23 Jun 2014; 24 Jun 2013; 10 May 2012; 18 Oct 2011; 19 Aug 2011)

Textbook: "***Theoretical Meteorology in the Tropics***" may be downloaded here.
Additional readings: "***Physical Climatology of the Indonesian Maritime Continent***" may be downloaded here or here;
"***Maritime Continent Coastlines Controlling Earth's Climate***" may be downloaded here or here;
"***Climate-Biogeosphere-Humanosphere Interaction***" may be downloaded here.

- **1. Introduction: Earth's tropical atmosphere and ocean** (6 June 2023) [slides] [text]
- **2. Conservation laws and basic equations** (6 June 2023) [slides] [text]
- **3. Atmospheric vertical structure: Radiative-convective equilibrium** (6 June 2023) [slides] [text]
  - 3.1. Radiative equilibrium
  - 3.2. Radiative-convective equilibrium
  - 3.3. Moisture effect
  - 3.4. Log-pressure coordinate
- **Eight essentials of Chaps. 1 - 3** [slides]
- **4. Mean zonal and meridional circulations** (7 June 2023) [slides] [text]
  - 4.1. Trade wind (Equatorial easterly)
  - 4.2. Potential vorticity conservation and inertial instability
  - 4.3. Hadley circulation
  - 4.4. Monsoon circulation
  - 4.5. Brewer-Dobson circulation
- **5. Equatorial waves** (8 June 2023) [slides] [text]
  - 5.1. Classification of waves in geophysical fluids
  - 5.2. Zonal-vertical (Walker) circulation
  - 5.3. Atmosphere-ocean interaction and El Nino-southern oscillation (ENSO)
  - 5.4. Wave-mean flow interaction and quasi-biennial oscillation(QBO)
- **6. Convection: Why can't we predict rainfall?** (9 June 2023) [slides] [text]

https://doi.org/10.13140/RG.2.2.32479.36002
https://www.researchgate.net/publication/320346992

Terjemahan bahasa Indonesia akan dilakukan oleh Dr. Sulaiman BRIN.

Theoretical Meteorology in the Tropics[1]

Manabu D. Yamanaka[2]

Japan Agency for Marine-earth Science and Technology (JAMSTEC) Yokosuka 237-0061, Japan

Contents

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[1]Short-term Expert Training Course on Weather Forecasting I, JICA–Sri Lanka Department of Meteorology Improving of Meteorological Observation, Weather Forecasting & Dissemination Project, 21 November – 1 December 2016
[2]Professor Emeritus, Kobe University

Atmospheric Research 178–179 (2016) 231–259

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Atmospheric Research

https://doi.org/10.1016/j.atmosres.2016.03.017
https://www.researchgate.net/publication/299417525

Invited Review Article

Physical climatology of Indonesian maritime continent: An outline to comprehend observational studies

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Yamanaka et al. Progress in Earth and Planetary Science (2018) 5:21
https://doi.org/10.1186/s40645-018-0174-9

Progress in Earth and Planetary Science

REVIEW | Open Access

Maritime continent coastlines controlling Earth's climate

Manabu D. Yamanaka[1,2*], Shin-Ya Ogino[1], Pei-Ming Wu[1], Hamada Jun-Ichi[1,3], Shuichi Mori[1], Jun Matsumoto[1,3] and Fadli Syamsudin[4]

Introduction
- Tropical rainfall in the global climate
- The global energy/water cycle and the maritime continent
- JEPP-HARIMAU and SATREPS-MCCOE projects

Review
- Diurnal cycle observed around the IMC coastlines
- Local rainfall as a function of coastal distance
- Regional rainfall as a function of "coastline density"
- Consistency with the global water budget
- Control of the global climate

Conclusions

International School on Equatorial Atmosphere (ISQUAR; 18–22 March 2019, LAPAN Bandung)

https://www.researchgate.net/publication/331977496

ISQUAR Lecture 4

Climate-biogeosphere-humanosphere interaction

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Project Researcher, Research Institute for Humanity and Nature

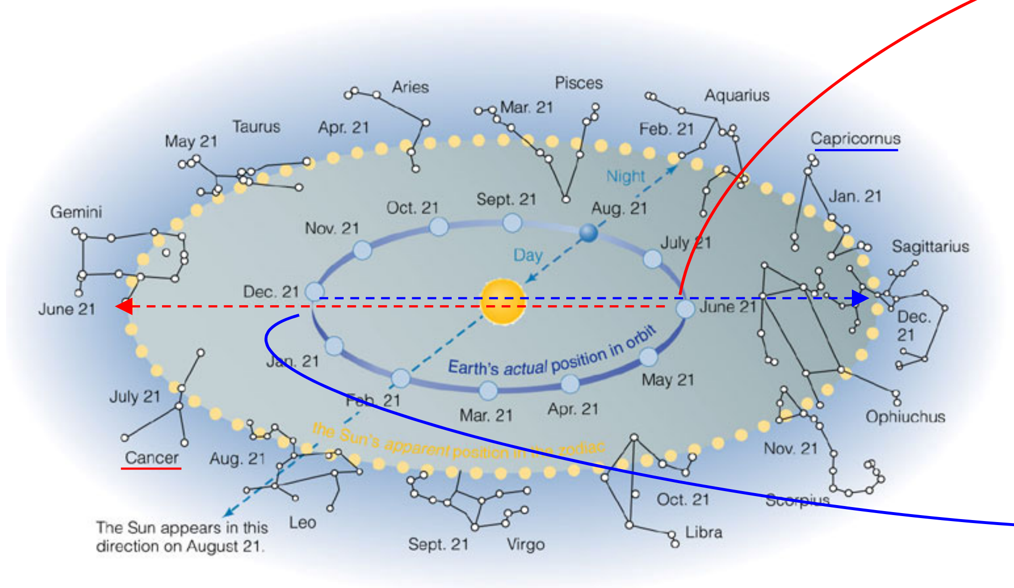
Visiting Scientist, Japan Agency for Marine-Earth Science and Technology

Professor Emeritus, Kobe University

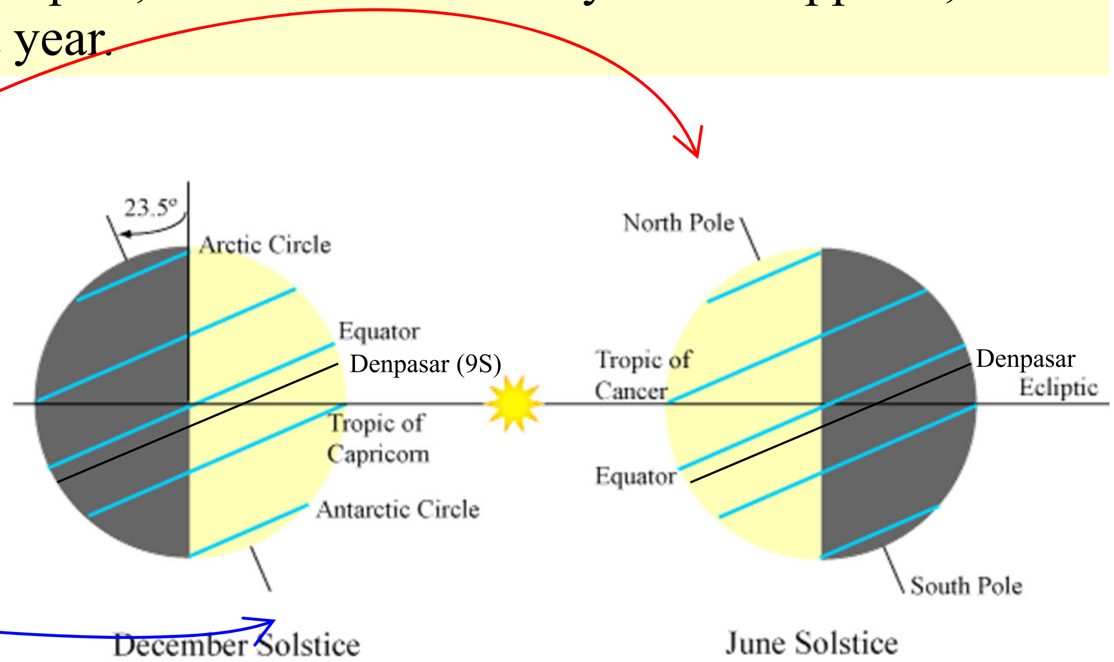
The equatorial coastal rainfall is dependent directly on sea-land heat contrast. The sea surface temperature varies through atmosphere-ocean interactions such as El Niño-southern oscillation (ENSO) over the Pacific and Indian-Ocean dipole mode (IOD) occurring respectively after and before late 2018. The land surface heating by sunshine before the noon makes the rainy season in each hemispheric summer (twice near the equator), and this (as well as nighttime cooling) is dependent on the land surface properties. The resultant rainfall sustains the biosphere, which is partly used as the humanosphere. The human activities affect the land surface as well as the greenhouse and parasol effects. An important issue is the sustainable development of the Indonesian peatland accumulating massive carbon and causing serious forest fire under less rainfall with a strong El Niño event.

1. Introduction: Earth's tropical atmosphere and ocean

- Recognition of the nature including our planet Earth was started at first as description of locality of ground and sky by geography and astronomy (geodesy), and then understood theoretically using generalized laws of physics.
- Greek and Roman scientists pioneered the first category, and among them **Eratosthenes** (c. 275 – c.194 BC), Hipparchus (c.190 – c.120 BC) and Ptolemaeus (c. AD 83 – c. 168) recognized the *Tropic of Cancer* and the *Tropic of Capricorn* as the northern and southern latitudinal limits over Earth where Sun can arrive in the zenith on each solstice, and as those of Sun on the celestial sphere (cf. Chapter 4, § 6.1).
- The low-latitude region around the equator between the both Tropics became called "tropics" geographically until the great voyage ages. For insolation in the tropics the annual cycle amplitude is weaker than in the extratropics, and a semi-annual cycle also appears, because Sun is located in the zenith twice a year.

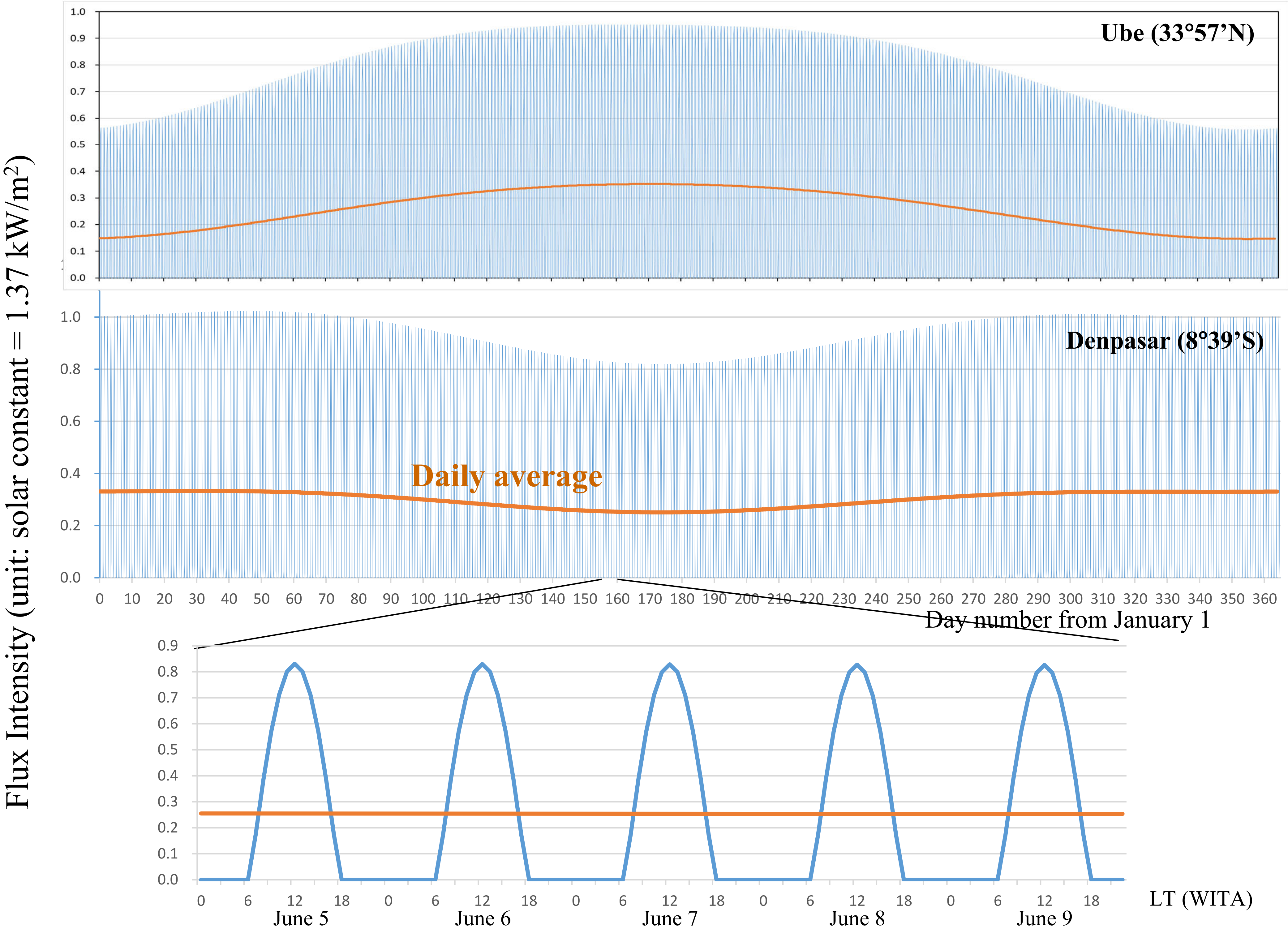


(Pearson Education, 2004: http://www.newton.ac.uk/about/art-artefacts/newton-portrait)



(Astronomy Dept., Univ. of Michigan: https://dept.astro.lsa.umich.edu/resources/ugactivities/Labs/seasons/SeasonsIntrotroppics.html)

Solar heating: northern middle latitude (Ube) & southern low latitude (Denpasar)



- Many textbooks of theoretical, physical or dynamical meteorology described almost only on the mid-latitudes; such as geostrophic winds, extratropical cyclones, fronts and their practical application tools called weather maps, but these concepts are almost useless in the tropics.
- Chapters of tropical meteorology are used mainly for tropical cyclones, although they appear actually in subtropics and very rarely in the central tropics near the equator (cf. Section 6.3).
- In the equatorial region or low latitudes with solar-energy input (excess) and almost horizontal Earth's rotation, forced convective motions in vertical planes are more essential rather than unstable horizontally vortical motions dominant in the middle/latitudes (Chapter 4).

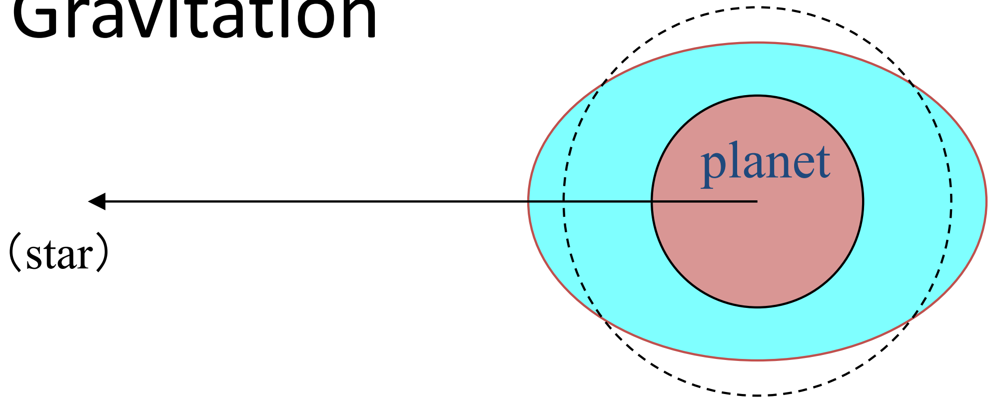
- On one hand, because of delayed/limited establishment of observation network over developing countries and broader oceans, improvement of the geographical description aspect is still necessary.
- On the other hand, as well as the above-mentioned dynamical features, interannual/ intraseasonal interactions with open oceans and water cycles with rainforest lands have been requesting establishment of the physical aspect of tropical meteorology and climatology as a rather new paradigm. This is the author's major motivation to prepare this lecture.

- Borderless combination of the two aspects is also required by recent computer-network innovations, sustainability crisis (environmental damages with continuous development) and extraterrestrial/extrasolar knowledge expansions.
- Now geographical observers study numerical physical model output, and atmospheric physicists study advanced geographical observations and geography of other planets.

Two major forcings of star on planet

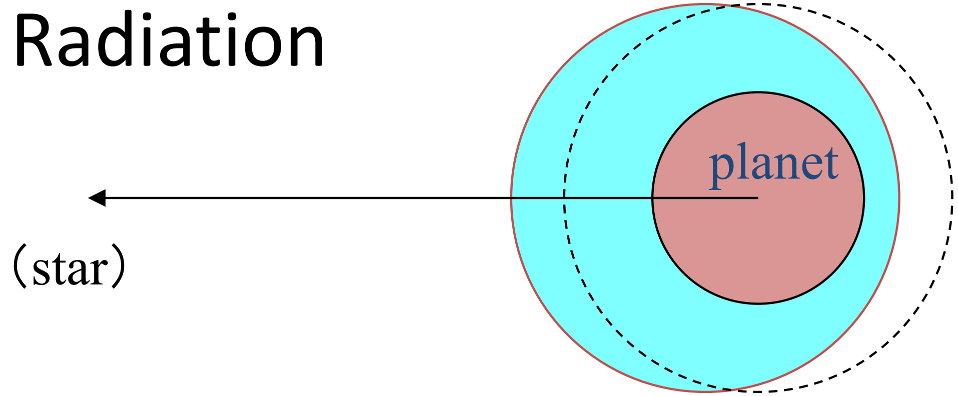
Both $\propto$ (distance)$^{-2}$, but planetary response is different

- Gravitation



Balanced with
revolutional centrifugal force
Revolutional orbit (Kepler's laws)
⇒ Stellar distance
⇒ Stellar radiation, annual length
Oceanic tides, planetary tides

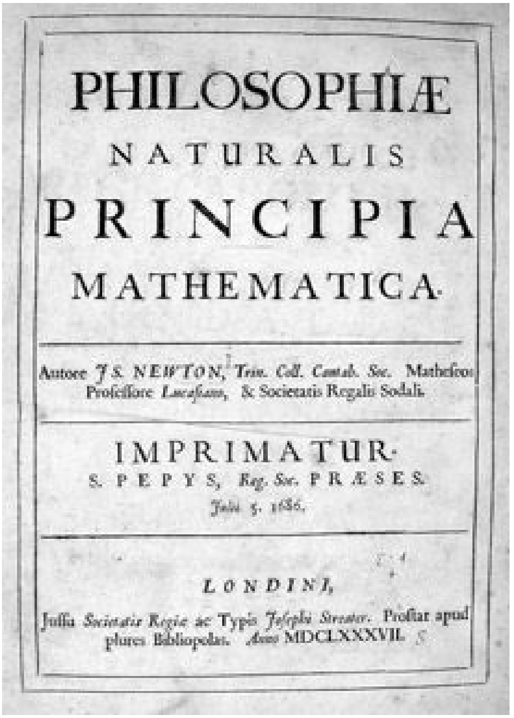
- Radiation



Balanced with planetary IR cooling
- Time scale ≫ rotation
  ⇒Meridional differential heating
- Time scale ～ rotation
  ⇒Zonal diffrential heating
  Atmospheric tides

Sir Isaac Newton (1642 – 1726/27)

(http://www.newton.ac.uk/about/art-artefacts/newton-portrait)



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore J S. NEWTON, Trin. Coll. Cantab. Soc. Matheseos Professore Lucasiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu Societatis Regiæ ac Typis Josephi Streater. Prostat apud plures Bibliopolas. Anno MDCLXXXVII.

Principles of Natural Philosophy (1687, 1713, 1726)

1. NEWTON'S THEORY OF A FLATTENED EARTH

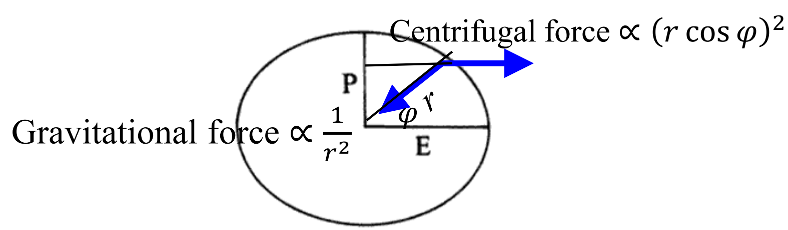
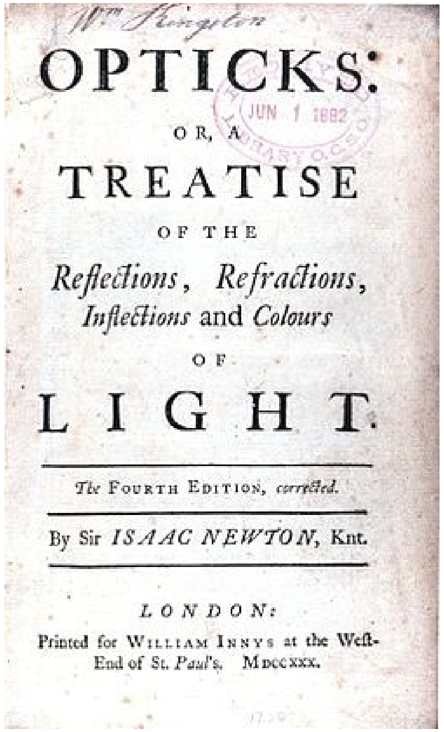


Figure 1. Meridian of a flattened ellipsoid of revolution.

(Gredenberg, 1995)

$$\frac{E-P}{P} = \frac{1}{298}$$



OPTICKS:
OR, A
TREATISE
OF THE
Reflections, Refractions, Inflections and *Colours*
OF
LIGHT.

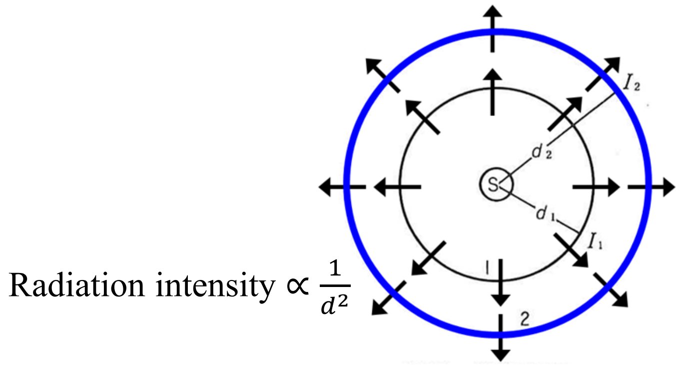
The Fourth Edition, corrected.

By Sir ISAAC NEWTON, Knt.

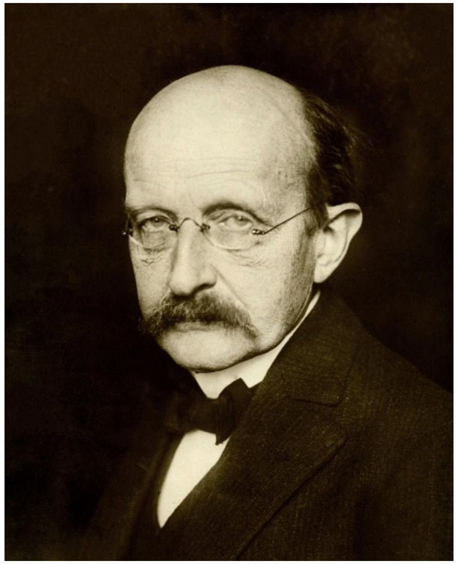
LONDON:
Printed for William Innys at the West-End of St. Paul's. MDCCXXX.

Opticks: Or, a Treatise of the Reflexions, Refractions, Inflexions and Colours of Light (1704)

Geometrical optics
Light wave



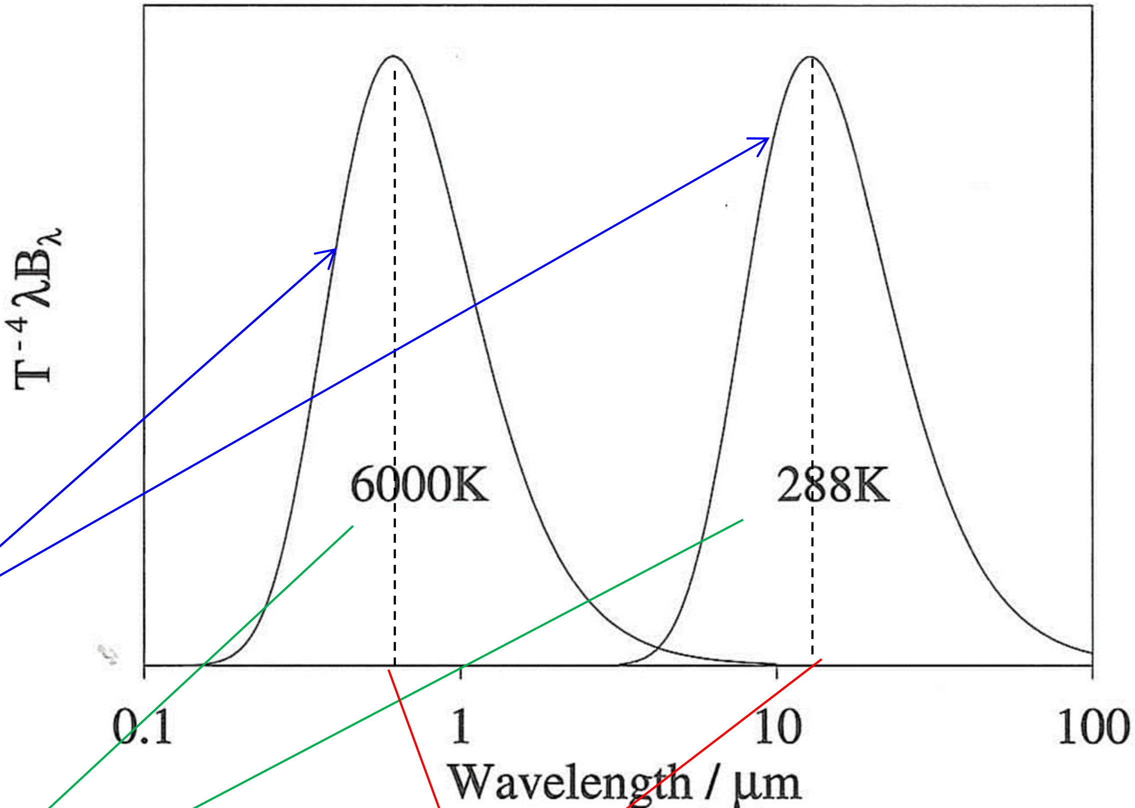
The distance^{-2} law



Max Planck (1858-1947)

http://www.gahetna.nl/collectie/afbeeldingen/fotocollectie/zoeken/weergave/detail/start/2/tstart/0/q/zoekterm/Planck

Black Body Radiation Law (1900)



(Andrews, 2000, Chapter 3

"Energy(-density) flux" (energy per unit time and unit area) for electromagnetic waves radiated (with unit solid angle and unit wavelength interval) from a "black body" with temperature T:

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5\{\exp[hc/(\lambda kT)] - 1\}}$$

(λ: wavelength, c: light speed, k: Boltzmann constant, h: Planck constant).

(Integration (area) → Energy flux intensity)

Stefan-Boltzmann's law

$$B(T) \equiv \int_{2\pi} \int_0^\infty B_\lambda(T) d\lambda \Big|_{\text{upward}} d\omega = \sigma T^4$$

(σ=5.67×10^{-8} J s^{-1} m^{-2} K^{-4})

(Differentiation (peak) → Maximum mode wavelength)

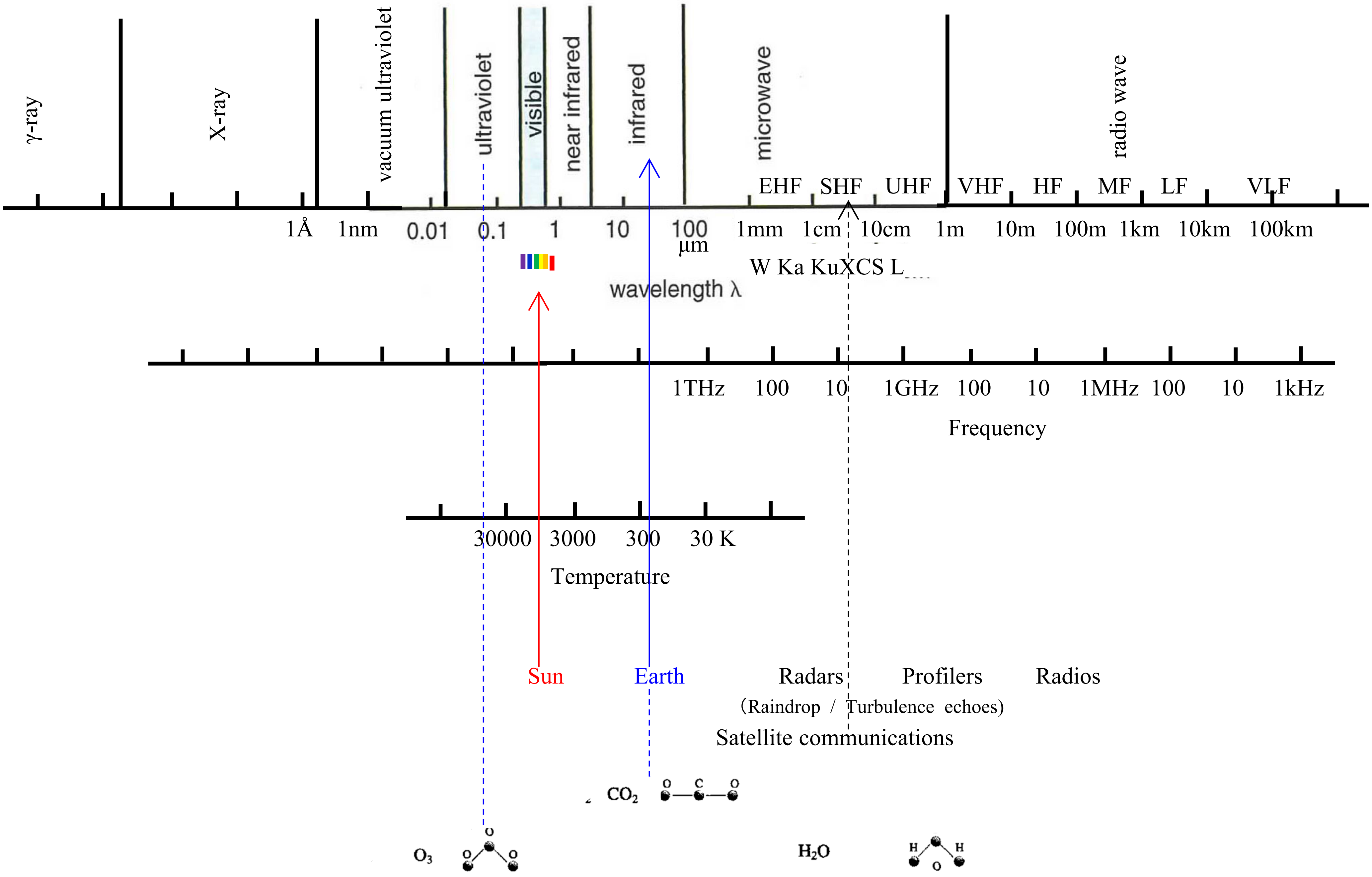
Wien's law

$$\lambda_{\max}[\mu\text{m}] = \frac{2897}{T\ [\text{K}]}$$

(→ Exercise 1-2)

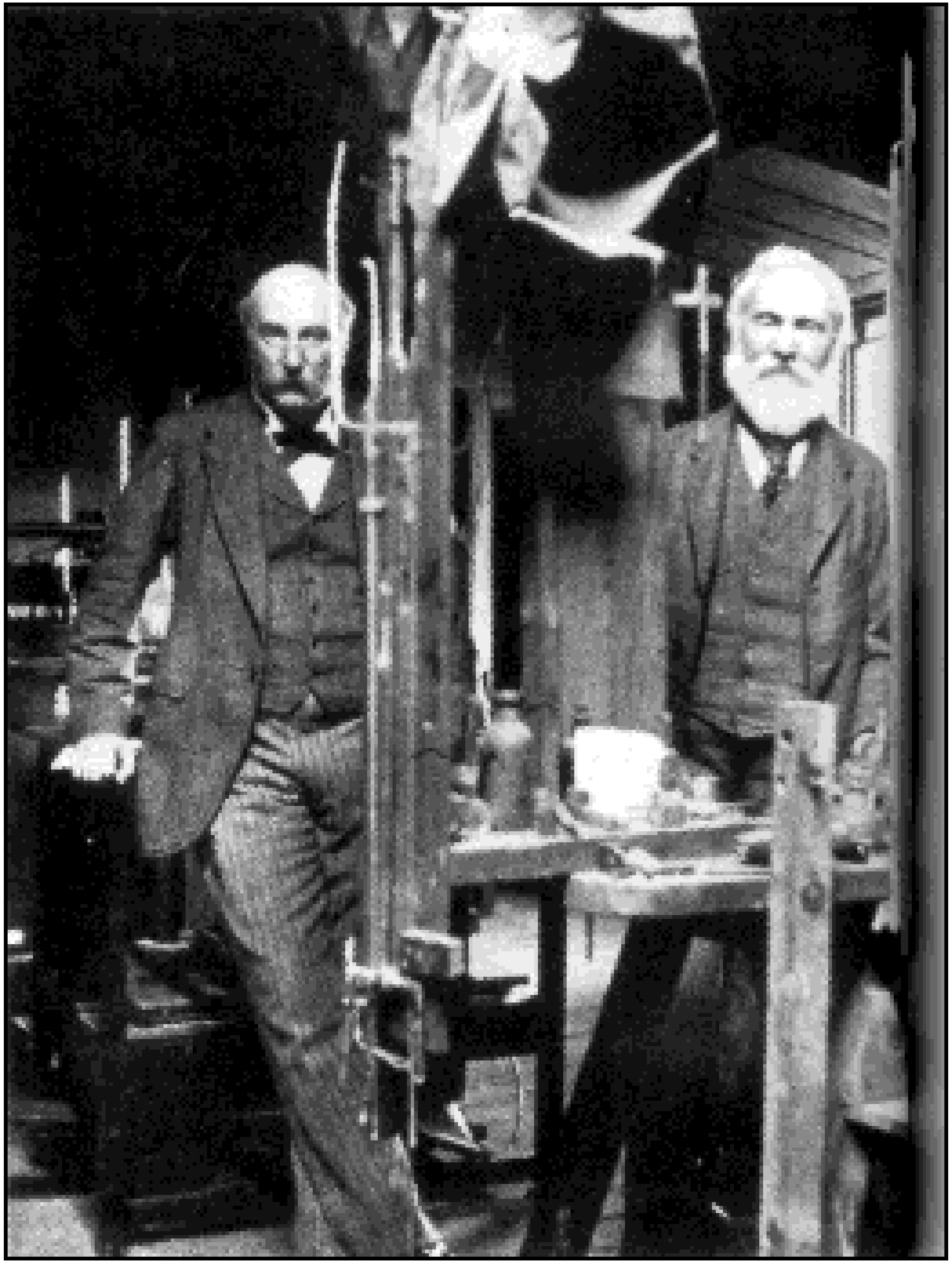
Electromagnetic waves

Wavelength × Frequency = Light Speed = 300,000 km/s



Lord Rayleigh
John William Strutt

(1842-1919)

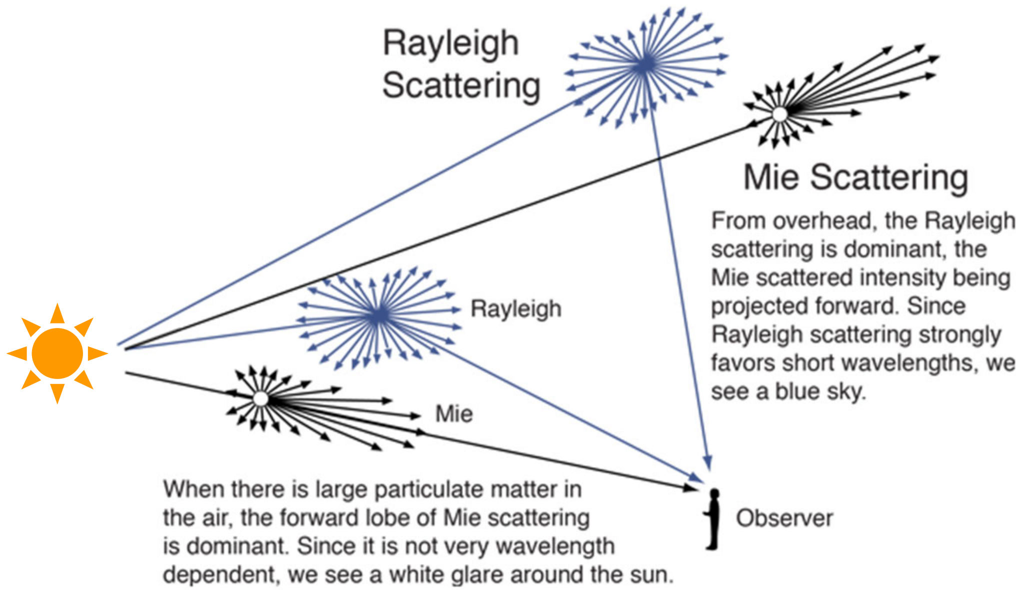


Lord Kelvin
William Thomson
(1824- 1907)

Why sky is blue?

Shorter wavelength (violet) => Particle (Mie) scattering

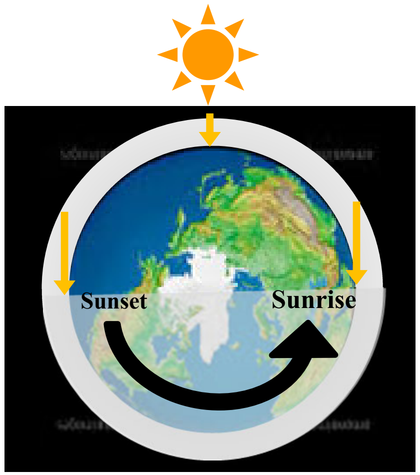
Blue color light => Molecule (Rayleigh) scattering



(http://hyperphysics.phy-astr.gsu.edu/hbase/atmos/blusky.html)

Longer wavelength (yellow, red) => Less scattering along a long optical path with low solar angle (sunrise/sunset)

Evening (sunset) glow



Morning (sunrise) glow

Climate = heating/cooling balance

- Solar radiation (with visible light):
  energy input (heating) to Earth

- Earth’s radiation (with infrared wave):
  energy output (cooling) of Earth

Solar heating – Infrared cooling equilibrium

$$I \times \pi r^2 = \sigma T_{\mathrm{earth}}^4 \times 4\pi r^2$$

$$\Rightarrow T_{\mathrm{earth}} = \left(\frac{I}{4\sigma}\right)^{1/4} \fallingdotseq 230\ \mathrm{K}$$

$\fallingdotseq -40°\mathrm{C}$ too cool !

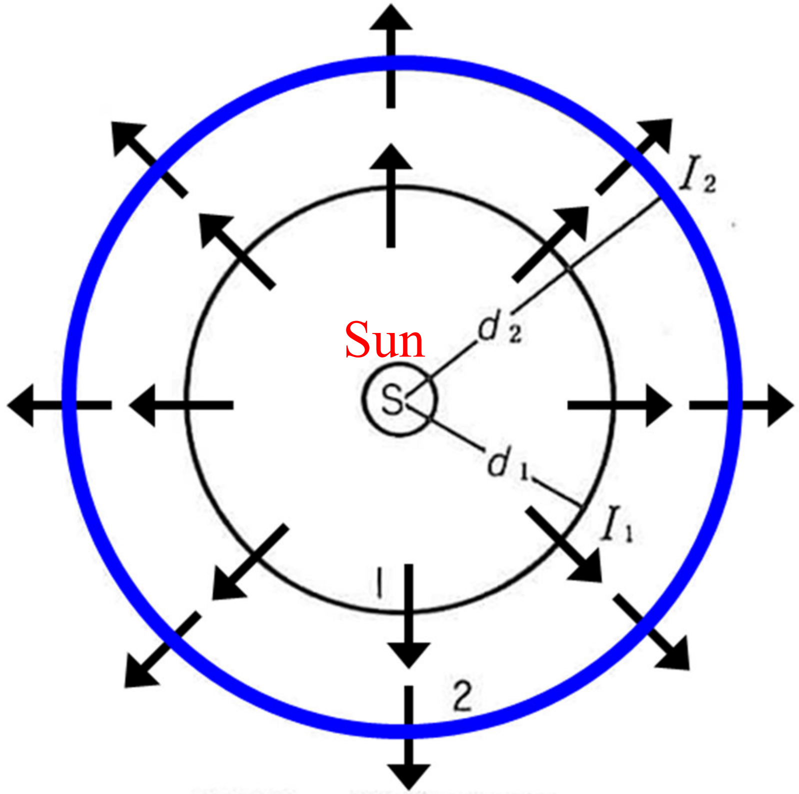
⇒ Greenhouse effect is needed

Solar radiation wavelength (Wien's law)

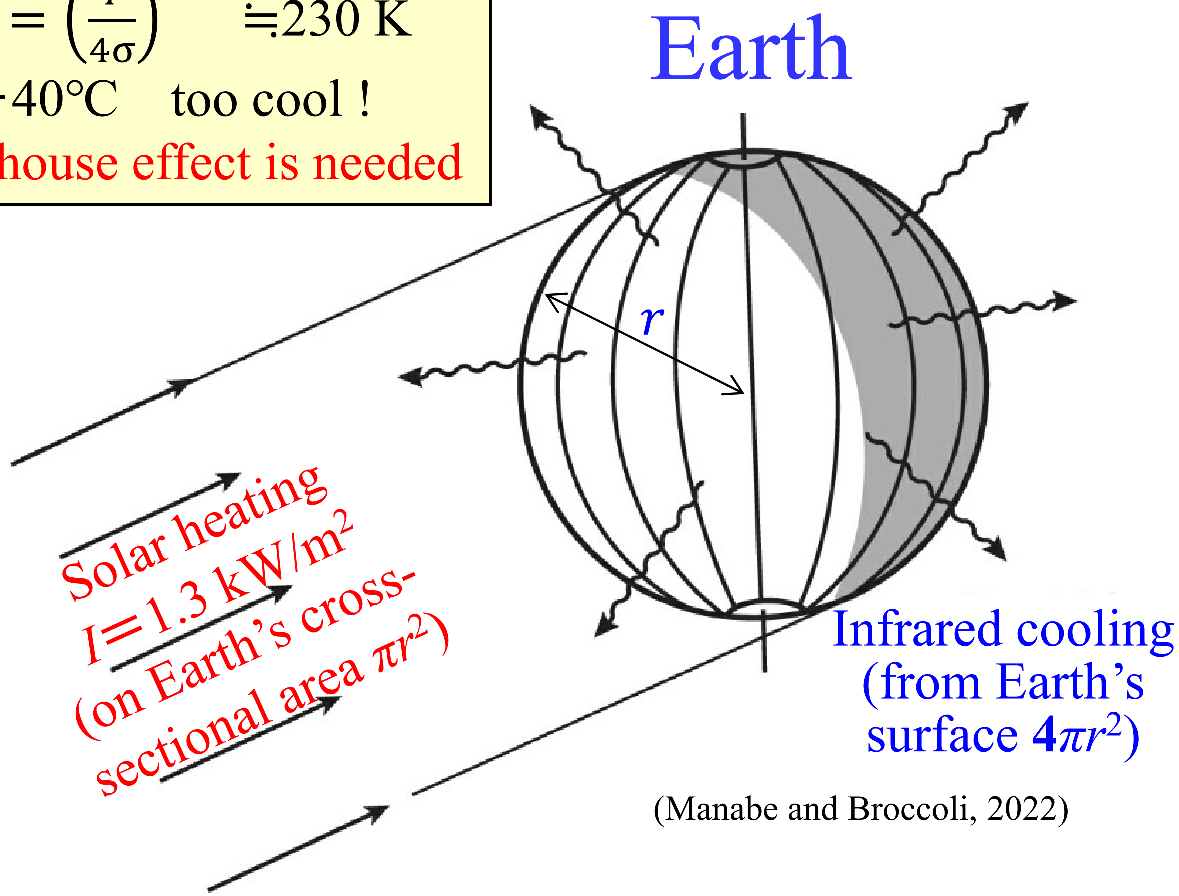
$$\lambda \fallingdotseq \frac{3000}{T_{\mathrm{sun}}} \fallingdotseq \frac{3000}{6000\ \mathrm{K}} \fallingdotseq 0.5\mu\mathrm{m}$$

Solar "surface" radiation intensity
(Stefan-Boltzmann law)

$$I_{\mathrm{solar\ surface}} = \sigma T_{\mathrm{sun}}^4$$



Irradiated spherical surface ∝ Distance^2
⇒ Solar heating weakened with (solar distance)$^{-2}$



(Manabe and Broccoli, 2022)

Earth's radiation wavelength (Wien's law)

$$\lambda \fallingdotseq \frac{3000}{T_{\mathrm{earth}}} \fallingdotseq \frac{3000}{300\ \mathrm{K}} \fallingdotseq 10\ \mu\mathrm{m}$$

Earth's "surface" radiation intensity
(Stefan-Boltzmann law)

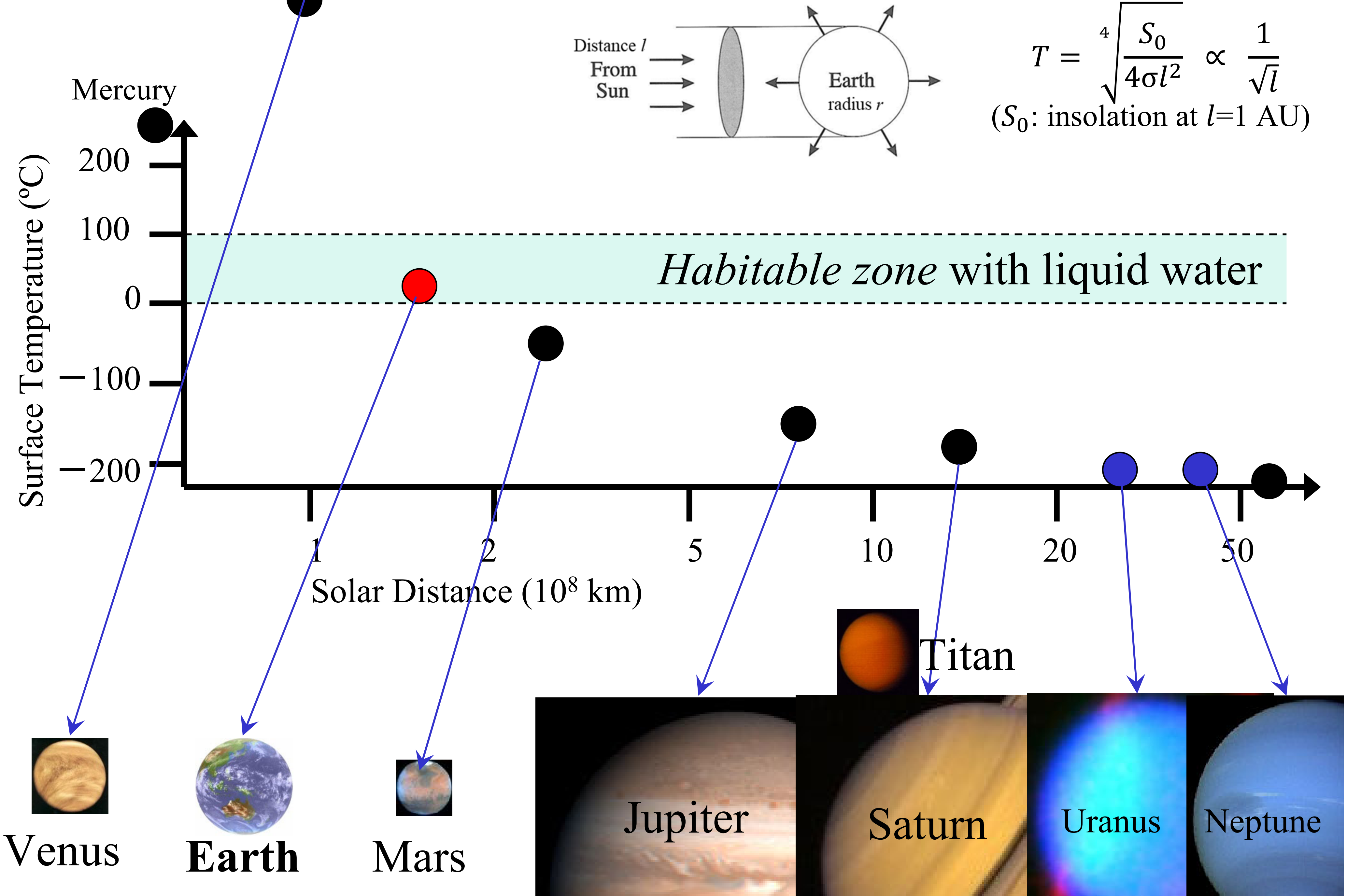
$$I_{\mathrm{earth's\ surface}} = \sigma T_{\mathrm{earth}}^4$$

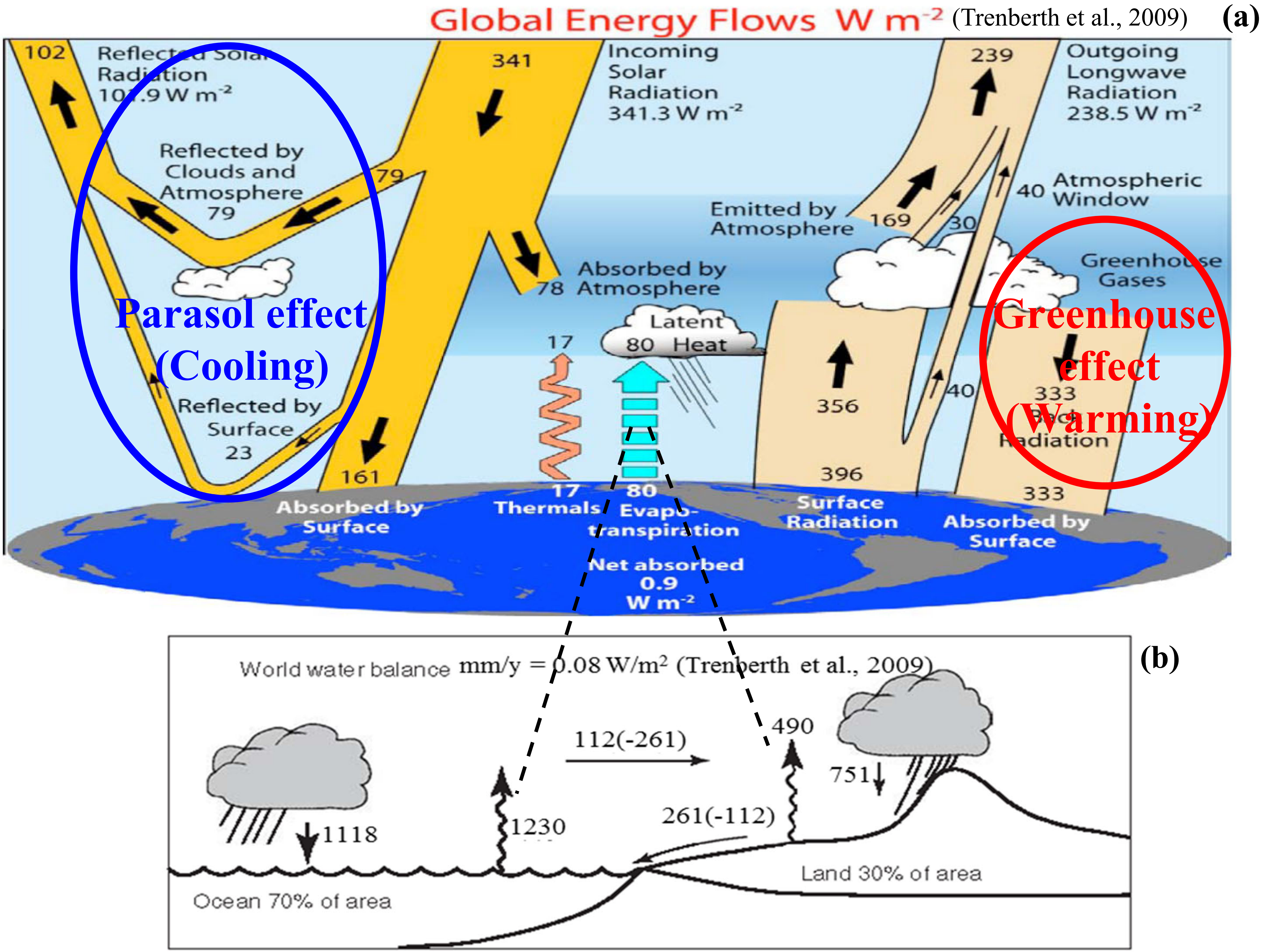
“0-dimensional” radiative “equilibria” for Solar-system planets

$$\frac{S_0}{l^2} \cdot \pi r^2 = \sigma T^4 \cdot 4\pi r^2$$

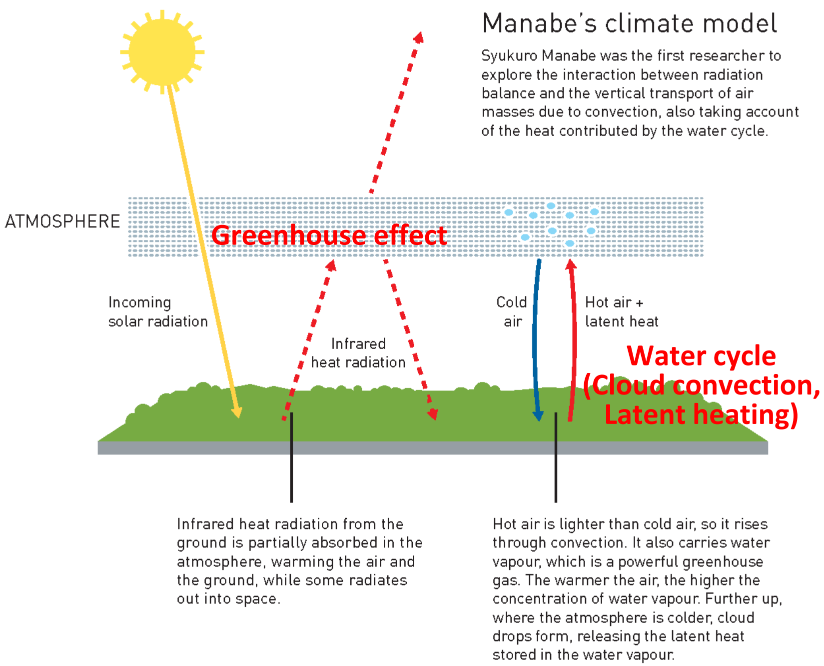
$$T = \sqrt[4]{\frac{S_0}{4\sigma l^2}} \propto \frac{1}{\sqrt{l}}$$

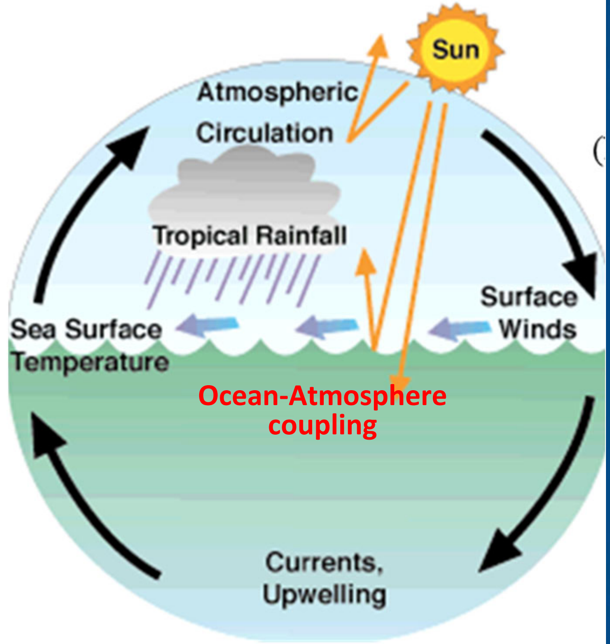
(S_0: insolation at l=1 AU)





Global Energy Flows W m⁻² (Trenberth et al., 2009)
(a)
102
Reflected Solar Radiation
Incoming Solar Radiation 341.3 W m⁻²
341
239
Outgoing Longwave Radiation 238.5 W m⁻²
Reflected by Clouds and Atmosphere 79
79
Atmospheric Window
40
Emitted by Atmosphere
169
30
Absorbed by Atmosphere
78
Greenhouse Gases
Parasol effect (Cooling)
Greenhouse effect (Warming)
17
Latent 80 Heat
356
40
333
Radiation
Reflected by Surface 23
161
396
333
17 Thermals
80 Evapo-transpiration
Absorbed by Surface
Surface Radiation
Absorbed by Surface
Net absorbed 0.9 W m⁻²
(b)
World water balance mm/y = 0.08 W/m² (Trenberth et al., 2009)
112(-261)
490
751
1118
1230
261(-112)
Land 30% of area
Ocean 70% of area

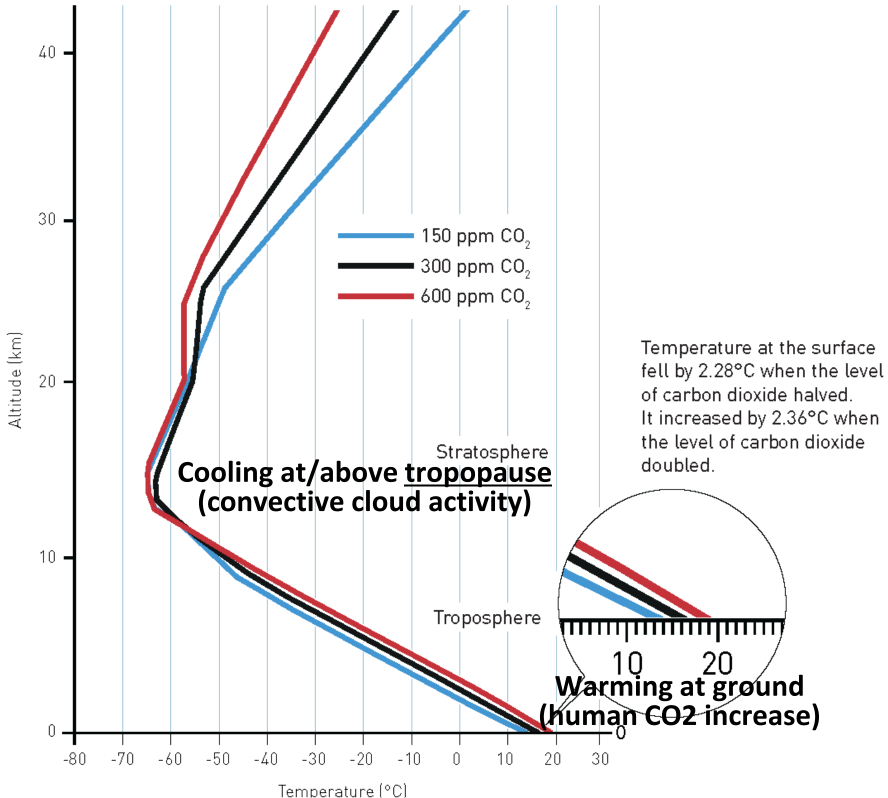




Carbon dioxide heats the atmosphere

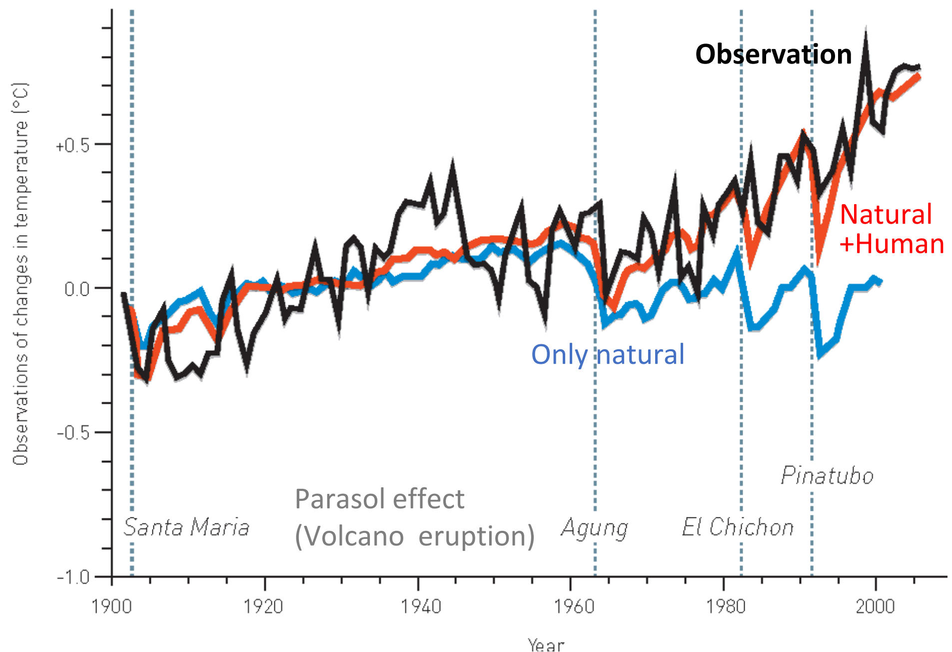
©Johan Jarnestad/The Royal Swedish Academy of Sciences
https://www.nobelprize.org/prizes/physics/2021/press-release/

Increased levels of carbon dioxide lead to higher temperatures in the lower atmosphere, while the upper atmosphere gets colder. Manabe thus confirmed that the variation in temperature is due to increased levels of carbon dioxide; if it was caused by increased solar radiation, the entire atmosphere should have warmed up.



Identifying fingerprints in the climate

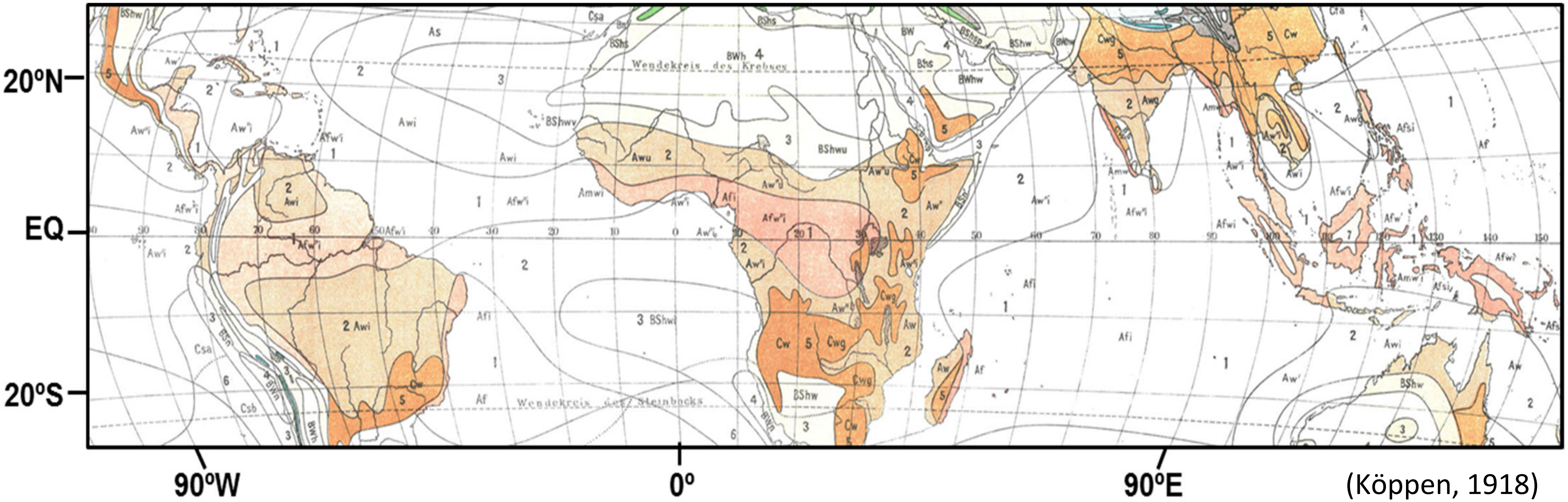
Klaus Hasselmann developed methods for distinguishing between natural and human causes (fingerprints) of atmospheric heating. Comparison between changes in the mean temperature in relation to the average for 1901–1950 (°C).



Tropical climate in global geography

Wladimir Peter Köppen (1846 – 1940)

- Köppen's (1918) climate classification
  - temperature: sensible (radiative) heating
  - rainfall: latent heating .
- Rainfall: a flux quantity (per area per time)
  - Horizontal scale: rain gage, radar, …
  - Temporal: hourly, daily, monthly, annual
  - Individually short-lived small clouds
  - Organized into multiple scale structures
- Tropical climate (*A*): rainforest (*Af*), savanna (*Aw*)
  - vegetation: seasonal–annual and 10^2–10^3 km



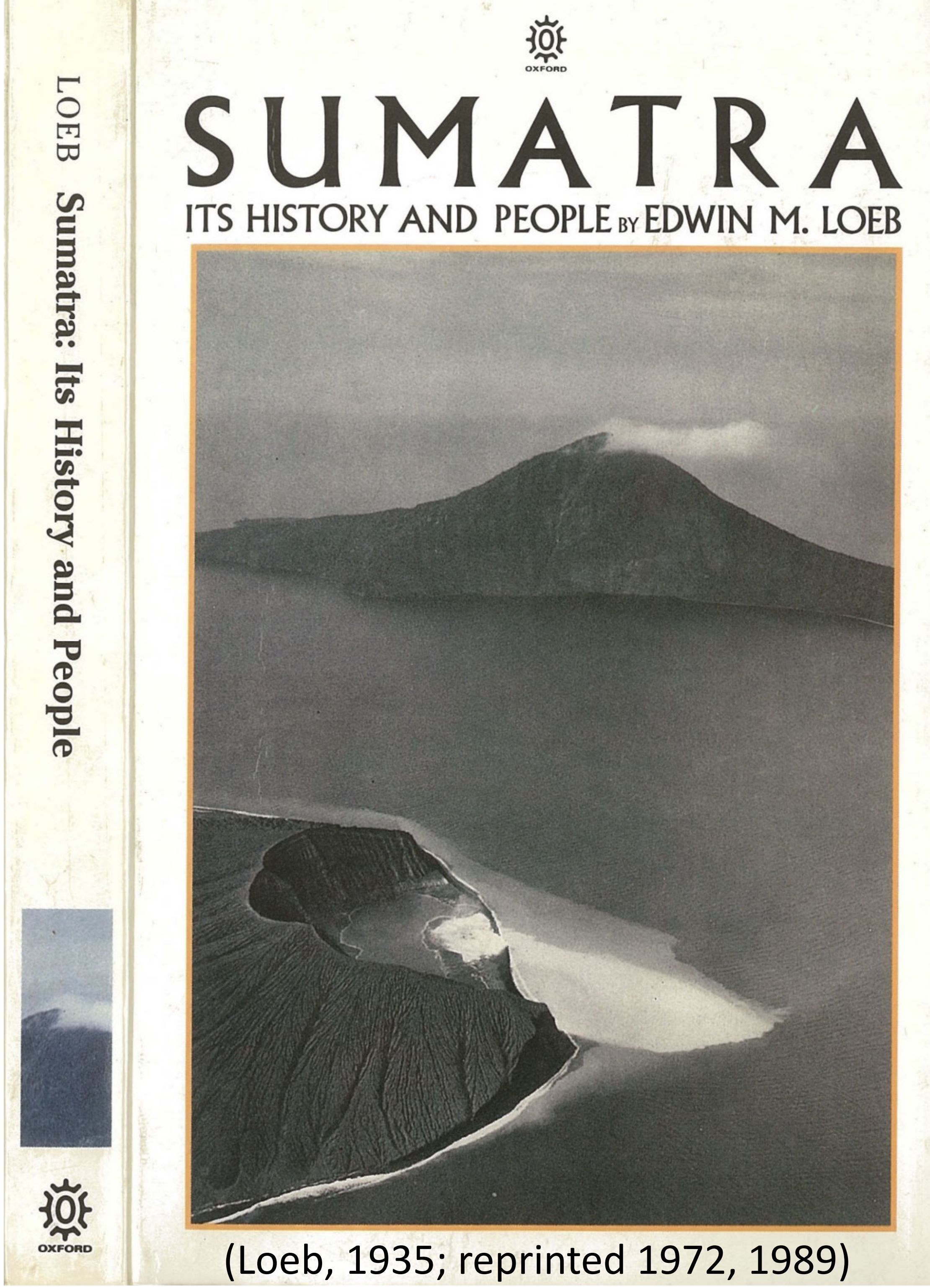
(Köppen, 1918)

(Köppen, 1918)

Köppen's *Af* : min. monthly rain ≥ 60 mm (annual >> 720 mm/year)

low-lat. S.America, Africa, "East Indies"

excluded inland of Sumatera, Kalimantan and Papua



(Loeb, 1935; reprinted 1972, 1989)

http://aoe.scitec.kobe-u.ac.jp/~mdy/library/books/Loeb-Sumatra

victims.

History. — The pre-European history of Sumatra is of great importance for the understanding of the complex native cultures of European contact. Unfortunately no uniformity exists in the interpretation of original sources, even among such competent scholars as Krom and Ferrand. Ferrand was one of the first historians to show that it was Sumatra and not Java which gave an early impetus to the expansion of Hindu civilization in Insulinde.

Śrîvijaya in the Palembang River valley in Sumatra was colonized by Hindus at an early date; perhaps between the first and second century A. D. At any rate like Cambodia and Champa, this empire was in full cultural development in the seventh century.

Actually the first Hindu kingdom mentioned in Sumatra was that of Malayu (Malay-Land) in Djambi in 644 A. D. A short time afterwards, however, the kingdom of Śrîvijaya was powerful enough to conquer Malayu and Banka, gain a foothold on the Malay Peninsula and come into close contact with Java. The Chinese royal edict of 695 mentions ambassadors of Śrîvijaya. This kingdom was already the chief one of Sumatra, and held Malayu as a subject state.

The first use of the name Sumatra occurred in 1017. The man who at that time was king of Sumatra (Śrîvijaya) sent ambassadors, a letter, and slaves to China. The treasures consisted of clothing, ivory, and Sanskrit books. The Chinese called this king "haji Sumatra

bhūmi", the king of the land of Sumatra. Krom does not accept any of the explanations as yet given for this name. Most writers believe that the word "Sumatra" is derived from the word "Samudra", which is the Sanskrit name for the sea, and also for a later kingdom in Atjeh. In this case Sumatra is "Sea-land". But Krom claims that it is peculiar to call an island Sea-land, and besides, that this name is of later use than the name Sumatra.

The initial cause of the fall of Śrîvijaya is said by Krom to have been two expeditions of conquest sent by Candrabhana, then king of Śrîvijaya. Candrabhana landed in Ceylon in the year 1251. He pleaded friendship, stating "We are all Buddhists". Then, treacherously, he reduced the native cities to ruins. Some years later the conqueror returned again to the island, but this time he was forced to flee, leaving his harem behind. Among the treasures which the vanquished were forced to leave in Ceylon were mentioned: royal insignia, shell trumpets, parasols, and kettle drums.

Due to this weakening of the power of Śrîvijaya, Krtanagara, king of Singasari in Java, thought that the auspicious moment had

ROLE OF A TROPICAL "MARITIME CONTINENT" IN THE ATMOSPHERIC CIRCULATION [1]

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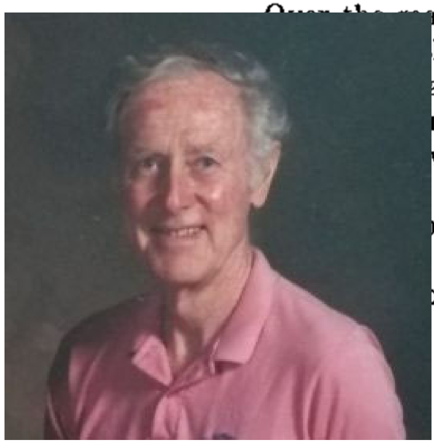
ABSTRA

Thunderstorm frequency and amount of moisture above
South America and Africa and the "maritime continent" of
amount of heat for export than do equatorial oceanic regions.
aritime continent in January 1963, heat gen
hrough conversion of potential to kinetic en
anuary 1964 *drought* over the maritime cont
r troposphere, associated with inefficient pole
western Pacific and southeast Asia fluctuate b

posphere over the maritime continent in wi
circulation, the proposed Marshall Island e
include winter.



(1921 - 2017)

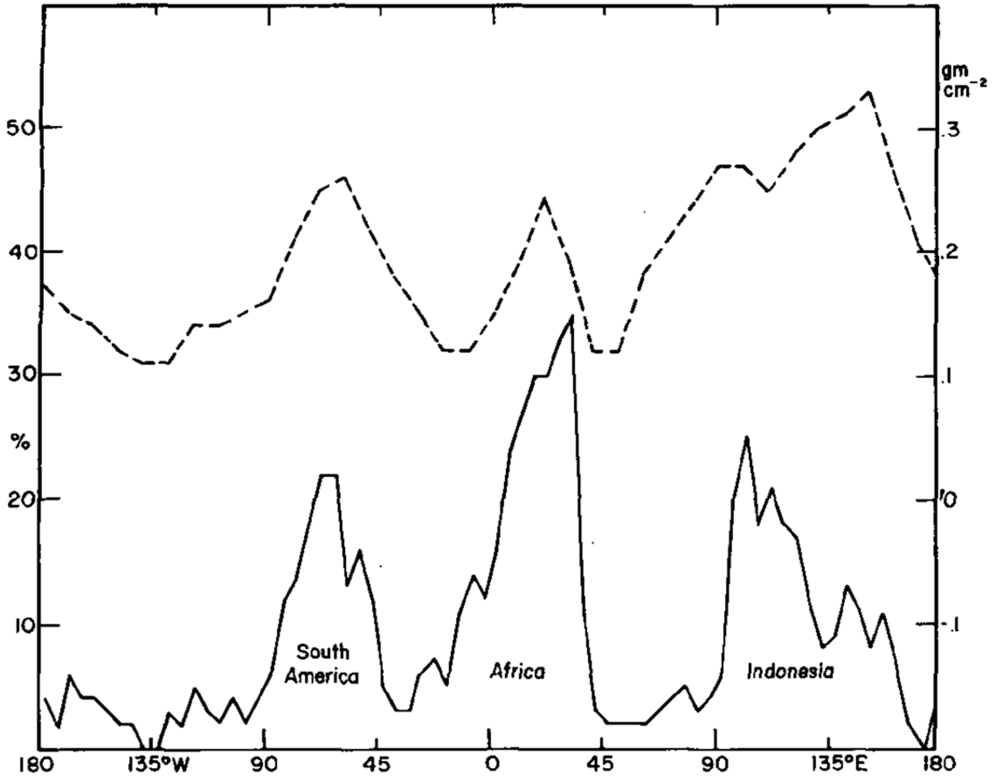


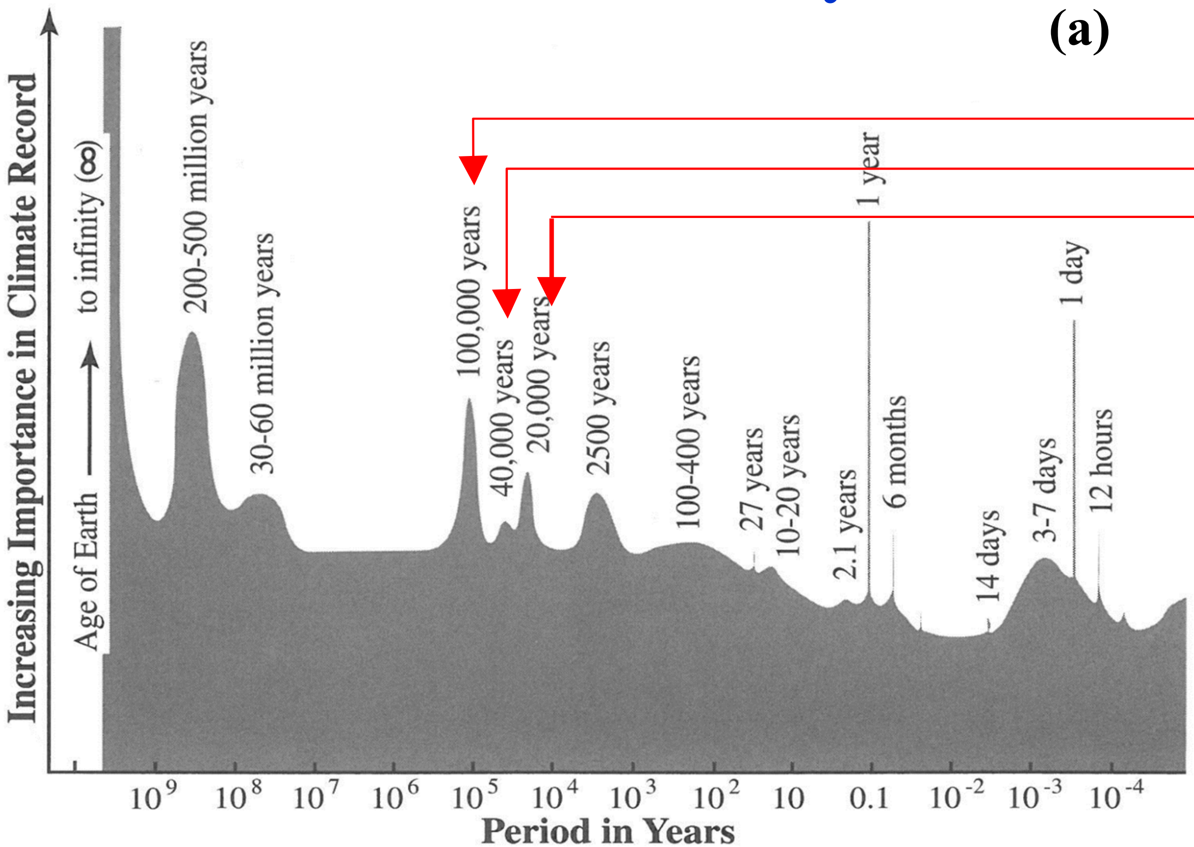
FIGURE 1.—The equatorial belt between 10°N. and 10°S. Annual percentage of days with thunder by 5° long. intervals (solid line). Based on Braak [2], World Meteorological Organization [13], [14]. Mass of water vapor in gm. cm.$^{-2}$ above 500 mb. by 10° long. intervals (dashed line). Averages of February, April, and June 1962, from Raschke and Bandeen [10].

1. INTRODUCTION

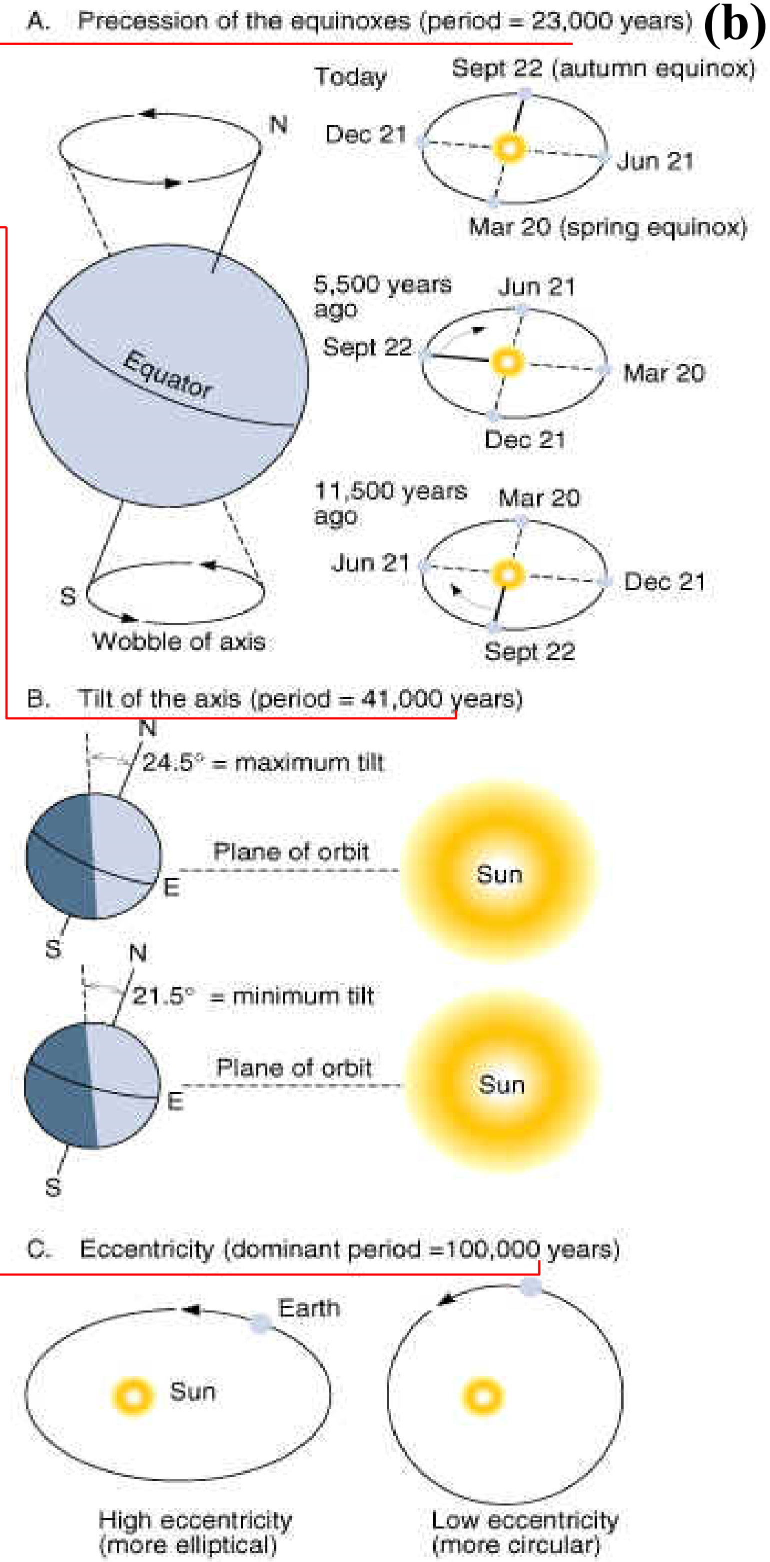
Since World War II, students of tropical meteorology, particularly in the United States, have concentrated on the oceanic Tropics. The valuable results stemming from their investigations are epitomized in an excellent text (Riehl [11]). However, scientific arguments for continuing to emphasize the oceanic Tropics, i.e., freedom from orographic distortion, tropical hurricane generation, importance of air-sea interaction processes, and relatively uni-

Insolation variability

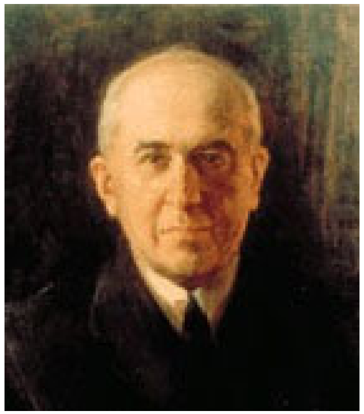
(a)



(b)



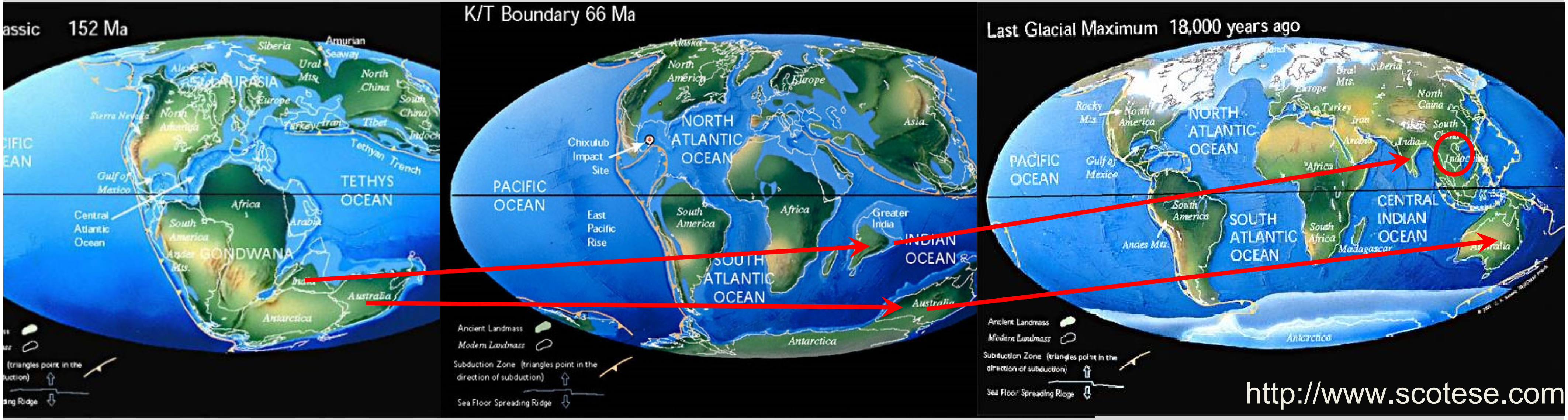
(c)



Milutin Milanković (1879 –1958)

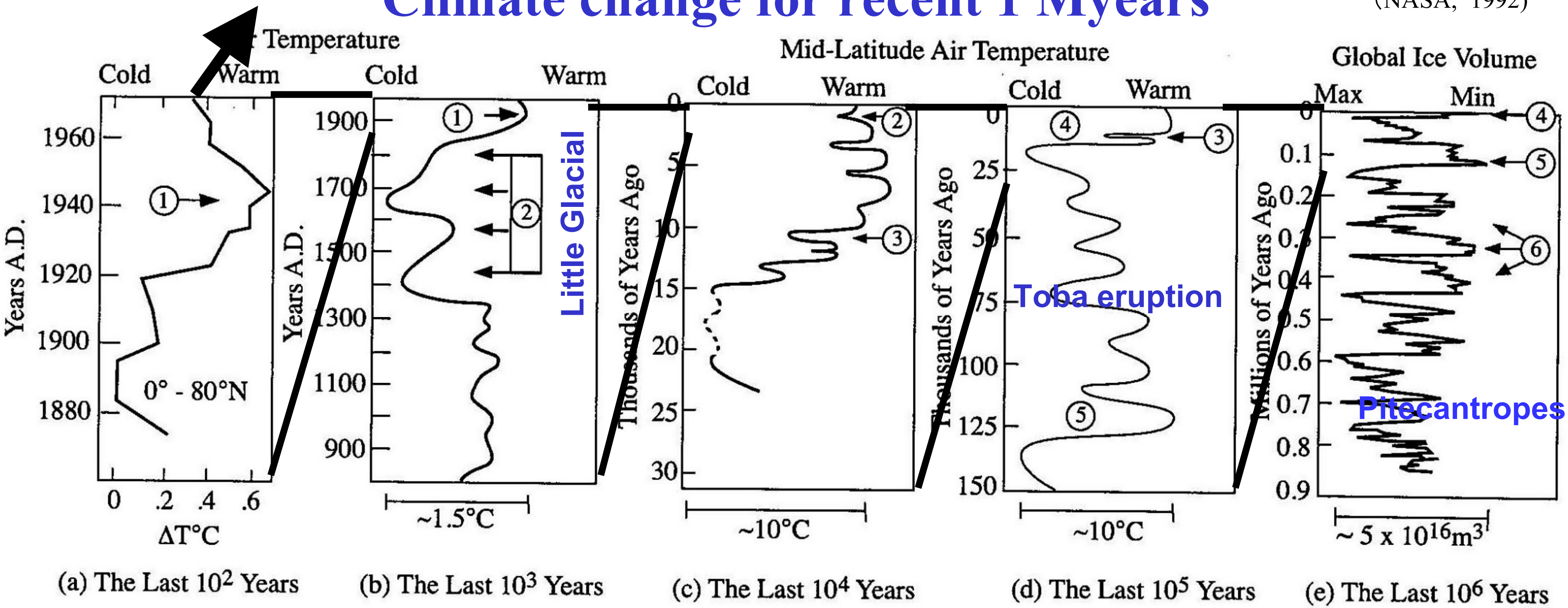
(d)

Ocean/Continent ~ 7:3 has been conserved for recent 400 Myears



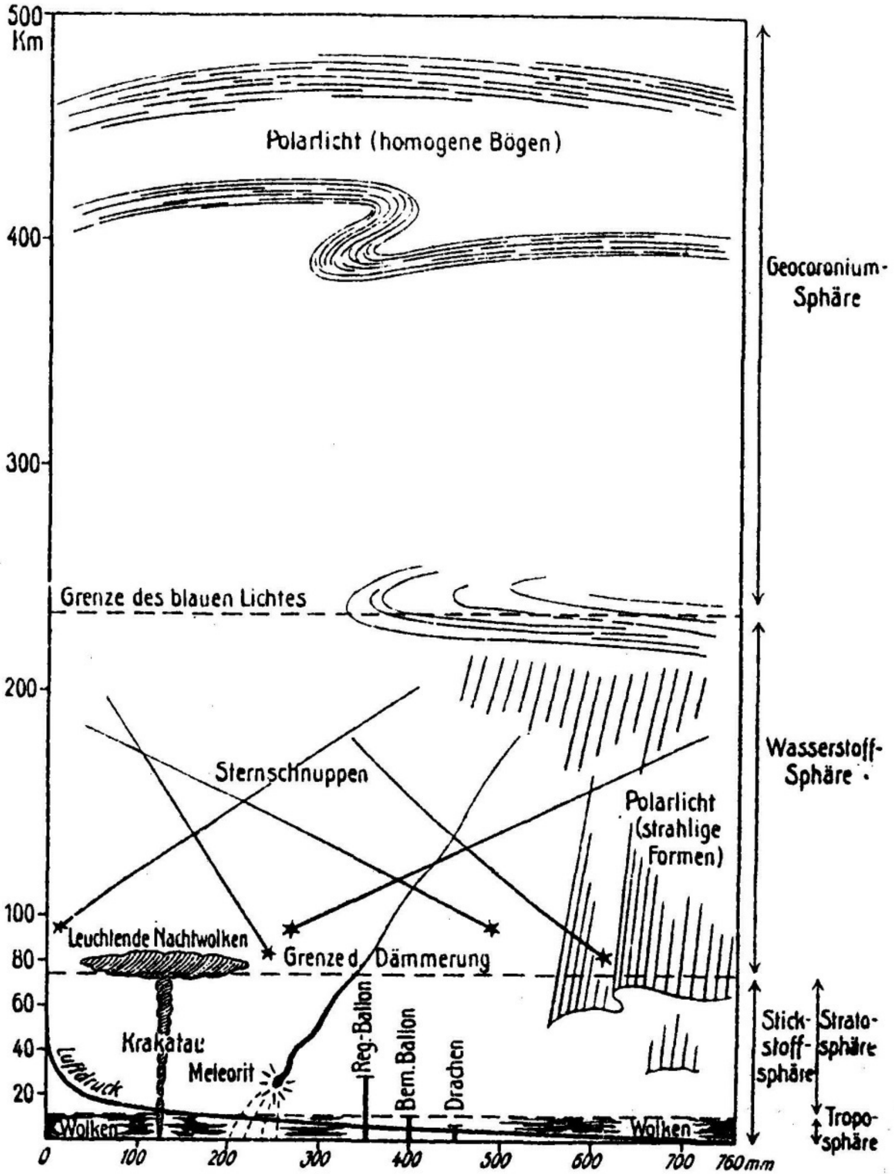
Climate change for recent 1 Myears

(NASA, 1992)



Alfred Lothar Wegener (1880 –1930)

(http://www.bildindex.de/bilder/fm426294a.jpg)

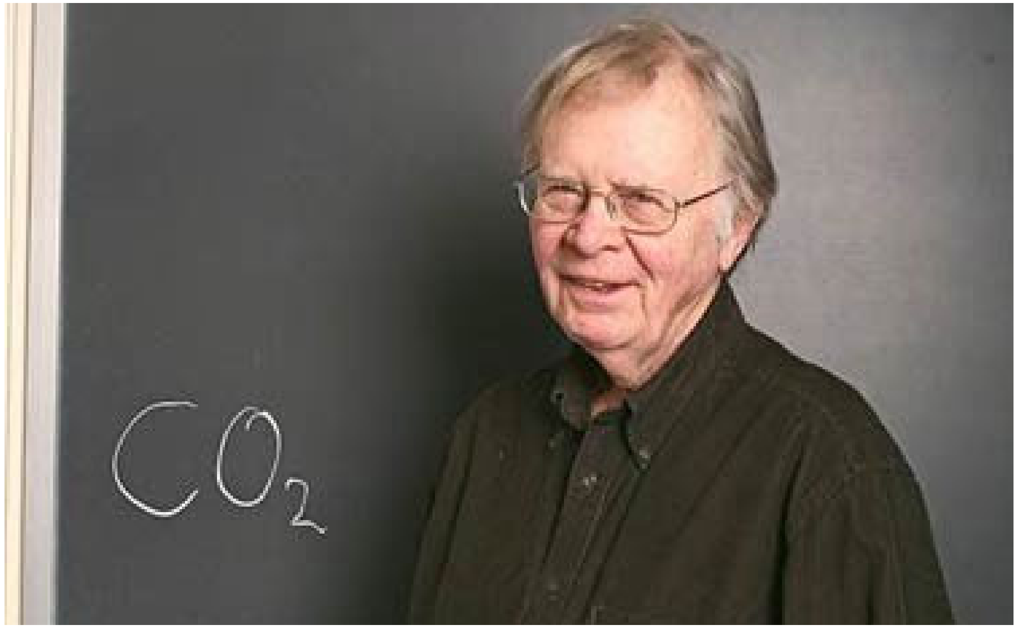


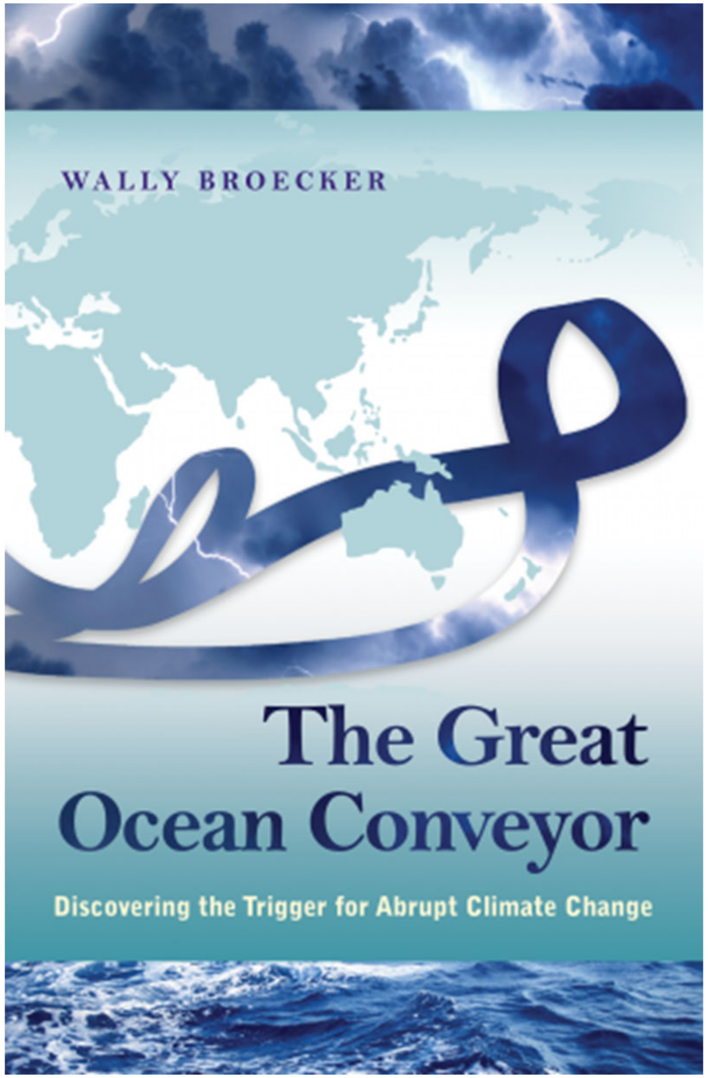
(Wegener, 1911: *Thermodynamik der Atmosphäre*; 松野, 1982より孫引き）

- 1905: Doctorate in astronomy. Work for aeronomy. .
- 1910: Conceiving of an idea of "continent drift"
- 1915: Publication of a book on the idea. Marriage.
- 1919-23: Paleoclimatology with father-in-law Köppen
- 1924: Professor at University of Glaz
- 1930 (aged 50): Died during Greenland expedition.

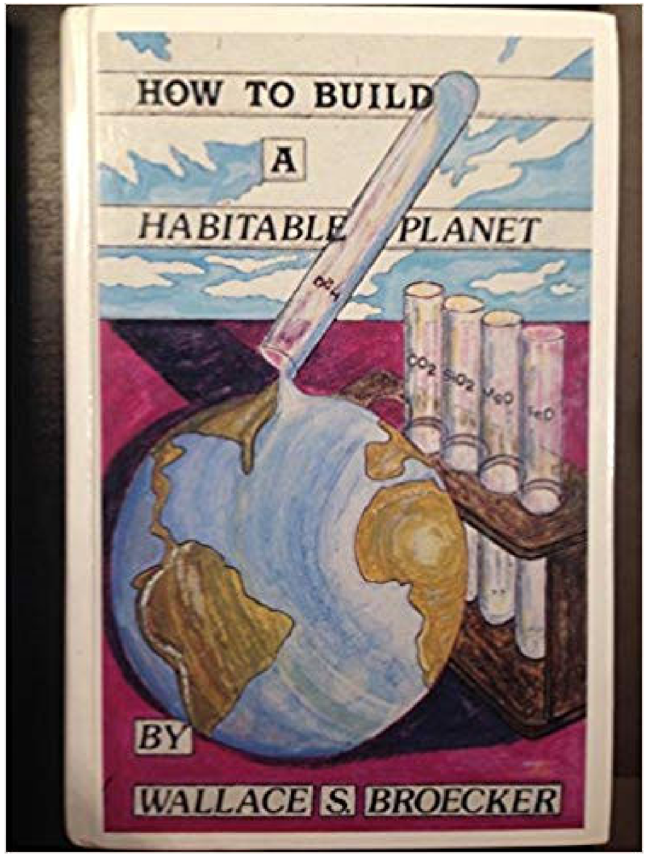
Wallace Smith Broecker
(1931 – Feb 19, 2019)

"Grandfather of climate science"
Popularized "Global warming" (1975)
Concept of "Ocean conveyor" (1982)

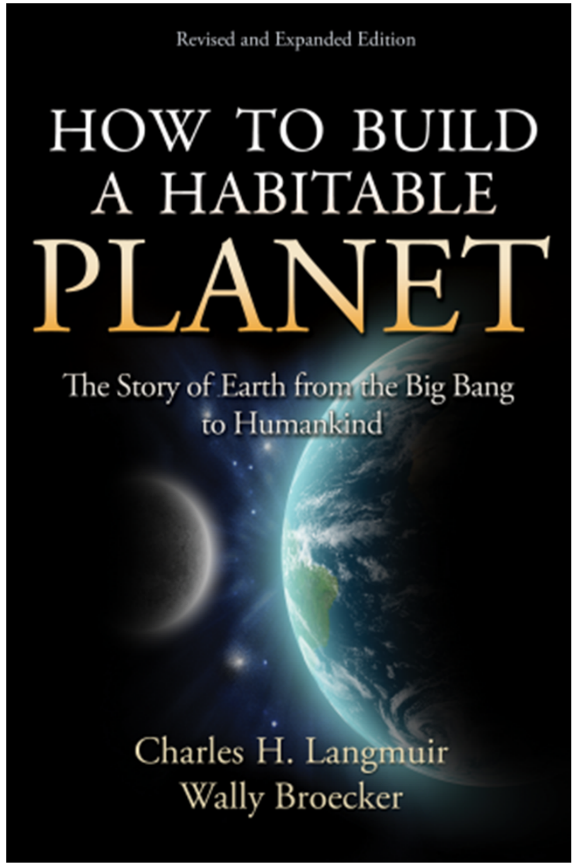




(2010) https://press.princeton.edu/titles/9162.html

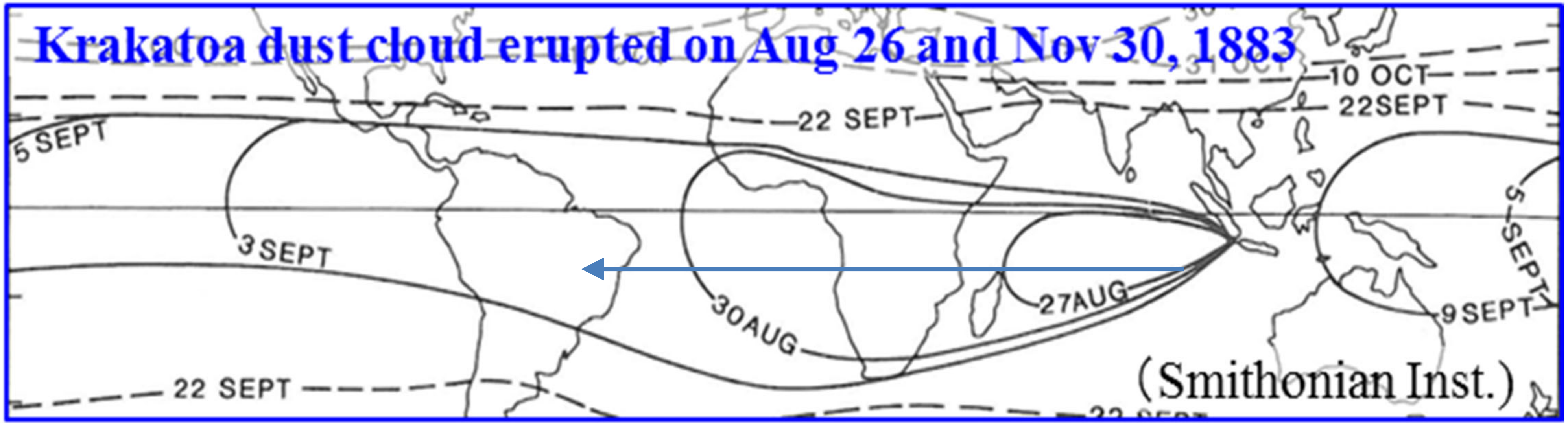


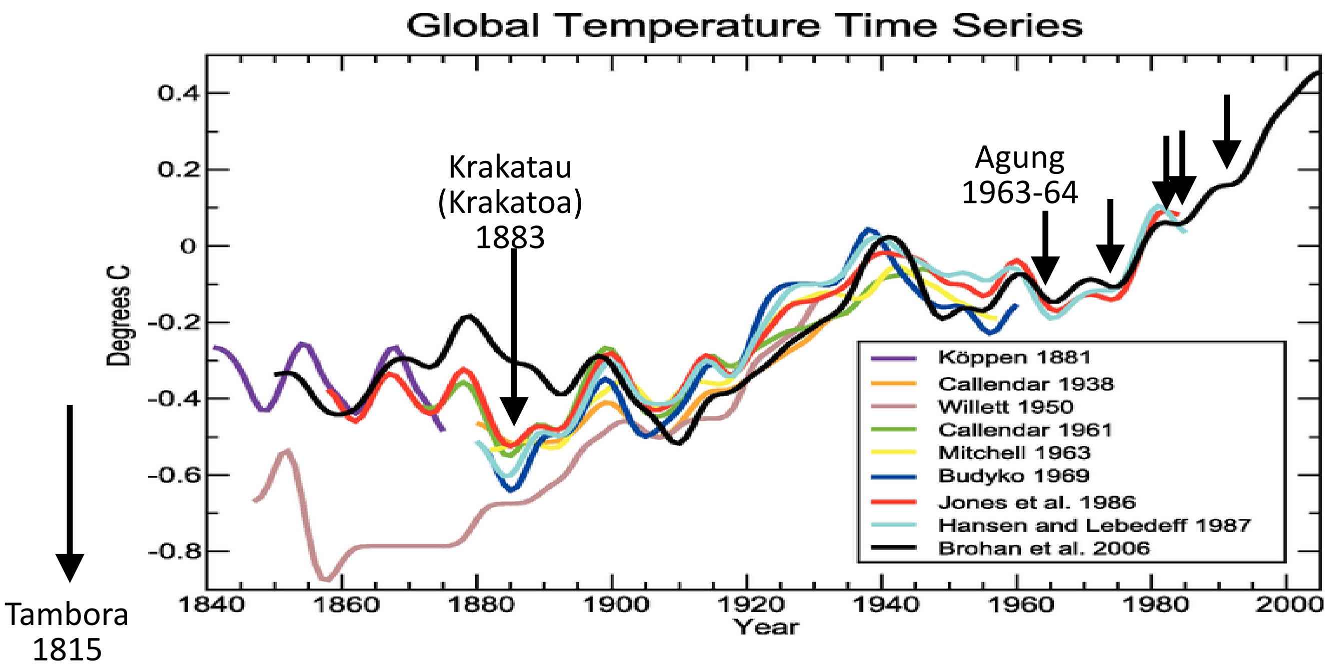
(1988) https://press.princeton.edu/titles/9162.html

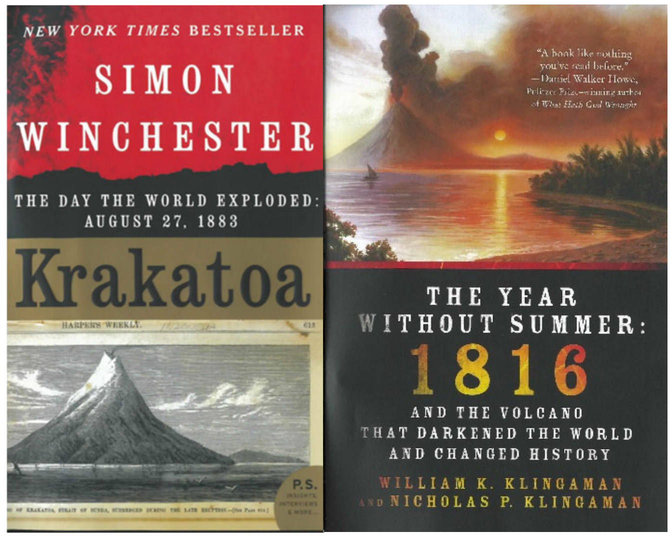


(2012) https://press.princeton.edu/titles/9691.html

Volcano ashes transported by stratospheric zonal flow







(Toba 75,000 year ago; … ; Tambora 1815; Krakatau 1883; …. ; Agung 1963-64; ……)

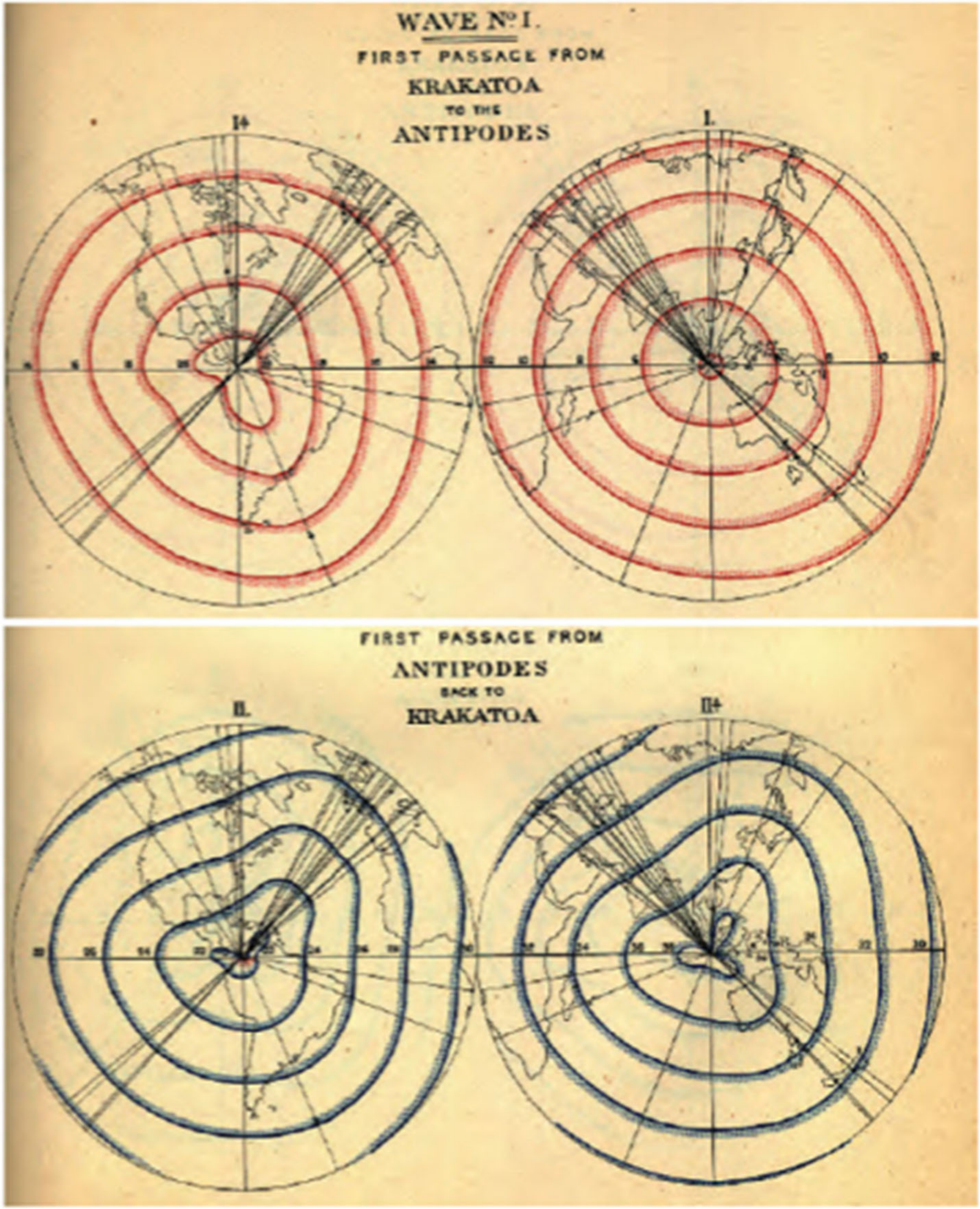


Figure 2.17 The first two of a series of figures included in the Royal Society report on Krakatoa (Symons, 1888) illustrating the progression of the pressure wave from the explosion as it propagated around the world and back several times. The innermost red contour surrounding Krakatoa labeled "4" in the top right map corresponds to the position of the wave at 0400 UTC, minutes after the explosion. Successive contours radiating outward from Krakatoa in the top right panel and inward toward the antipodal point in the top left panel are at two-hour intervals 0600, 0800, . . . , 2000 UTC. Hence, the signal traveled halfway around the world in slightly over 16 hours. Subsequent blue-green contours 22, 24, . . . , 38 in the bottom panels show the wave returning to its point of origin. From Strachey (1988).