Physical and Dynamical Climatology

Theoretical framework for application in the Indonesian maritime continent

Yamaguchi University (relayed to University of Udayana), 14 – 16 June 2021

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

Manabu D. Yamanaka

Senior Researcher, Research Institute for Humanity and Nature (RIHN) /
Visiting Researcher, JAMSTEC / Professor Emeritus, Kobe University
mdy@chikyu.ac.jp, mdy@jamstec.go.jp, mdy@kobe-u.ac.jp

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 15)
5. Equatorial waves (June 15)
6. Convection: Why can't we predict rainfall? (June 16)

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

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

Theoretical Meteorology in the Tropics[1]

Manabu D. Yamanaka[2]

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

Contents

[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

Manabu D. Yamanaka

Department of Coupled Ocean–Atmosphere–Land Processes Research (DCOP), Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 2-15 Natsushima-cho, Yokosuka 237-0061, Japan
Department of Planetology, Graduate School of Science, Kobe University, 1-1 Rokkodai-cho, Kobe 657-8501, Japan

Contents

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

https://www.researchgate.net/publication/324219399

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

ISQUAR Lecture 4

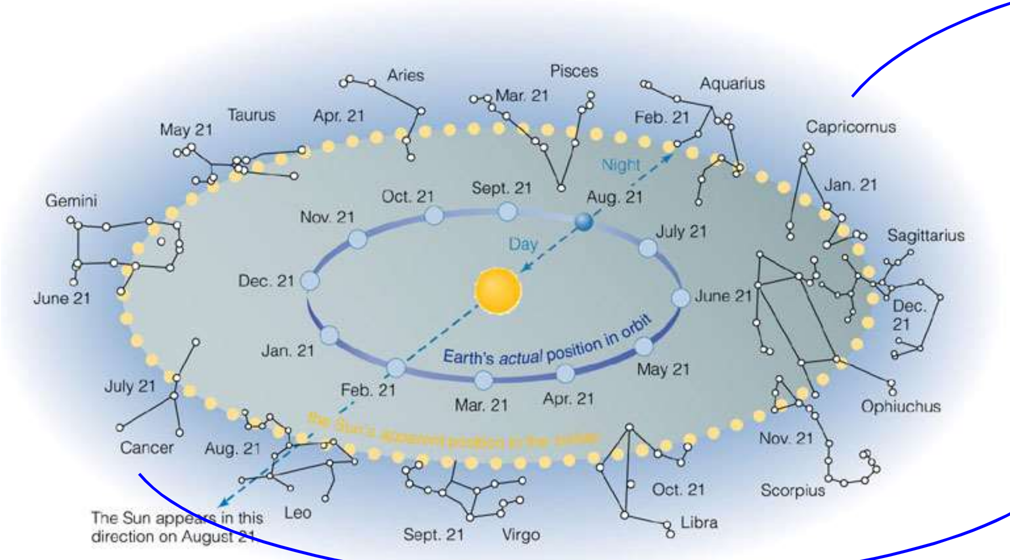
Climate-biogeosphere-humanosphere interaction

Manabu D. Yamanaka
Project Researcher, Research Institute for Humanity and Nature
Visiting Scientist, Japan Agency for Marine-Earth Science and Technology
Professor Emeritus, Kobe University

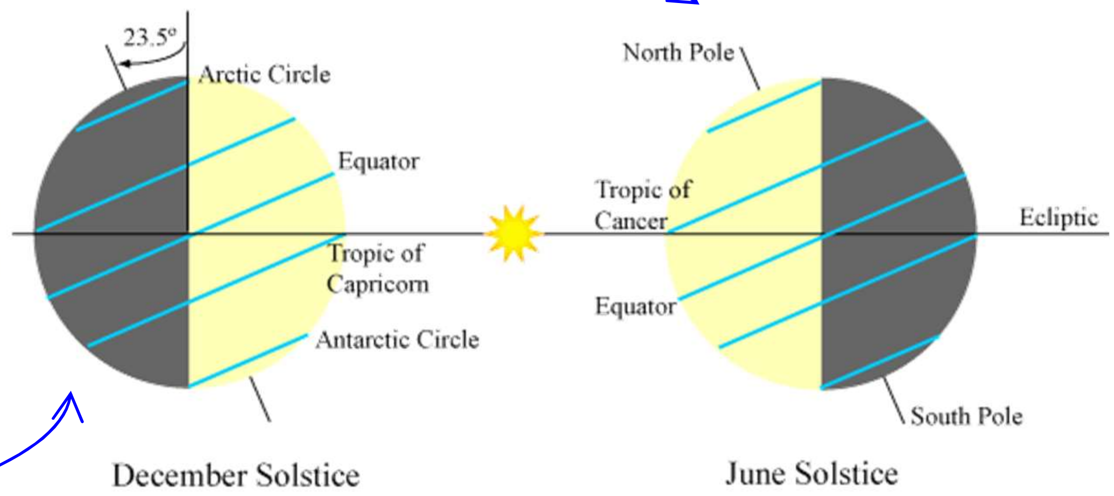
The equatorial coastal rainfall is dependent directly on sea-land heat contrast. The sea surface temperature varies through atmosphere-ocean interactions such as El Niño-southern oscillation (ENSO) over the Pacific and Indian-Ocean dipole mode (IOD) occurring respectively after and before late 2018. 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 surely 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, or those of Sun over the celestial sphere (cf. Chapter 4, Section 6.1).
- The low-latitude region around the equator between the both Tropics became called "tropics" geographically until the great voyage ages.



(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)

- 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).

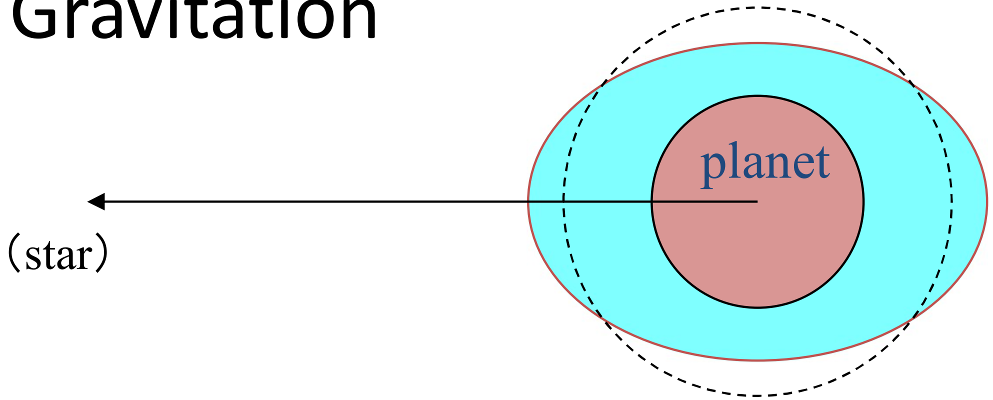
- On one hand, because of delayed/limited establishment of observation network over developing countries and broader oceans, improvement of the geographical description aspect is still necessary.
- On the other hand, as well as the above-mentioned dynamical features, interannual/ intraseasonal interactions with open oceans and water cycles with rainforest lands have been requesting establishment of the physical aspect of tropical meteorology 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

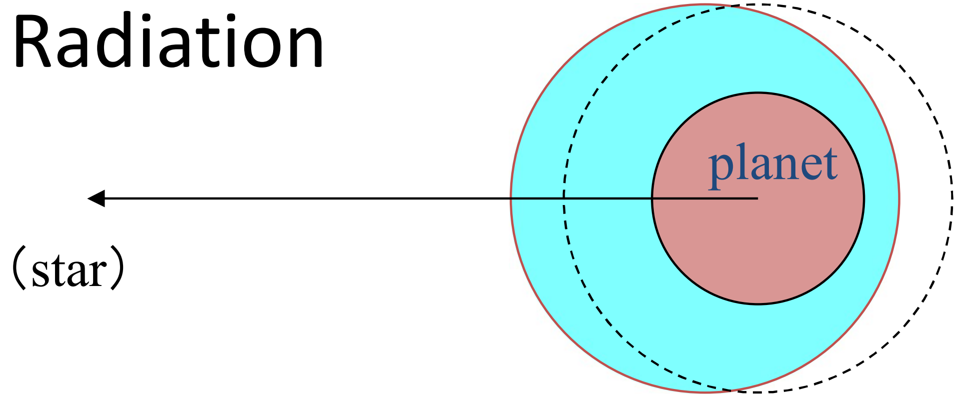
Both $\propto$ (distance)$^{-2}$, but planetary response is different

- Gravitation



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

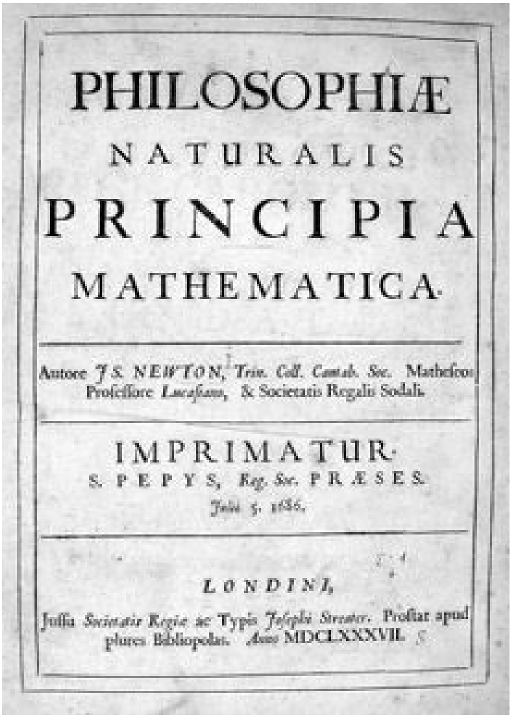
- Radiation



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 *JS. 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)

I. NEWTON'S THEORY OF A FLATTENED EARTH

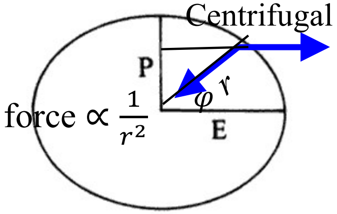
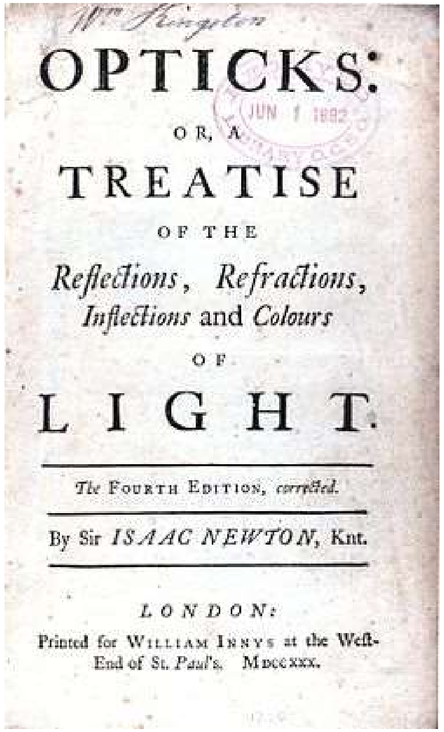


Figure 1. Meridian of a flattened ellipsoid of revolution.

(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.

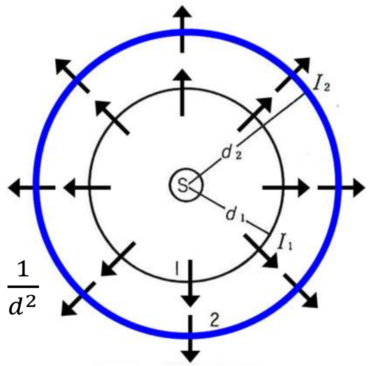
LONDON:

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

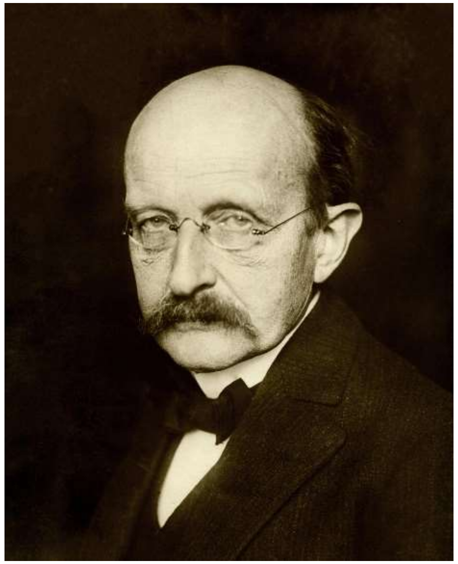
Light wave



Radiation intensity $\propto \frac{1}{d^2}$

The distance^{-2} law

Max Planck (1858-1947)



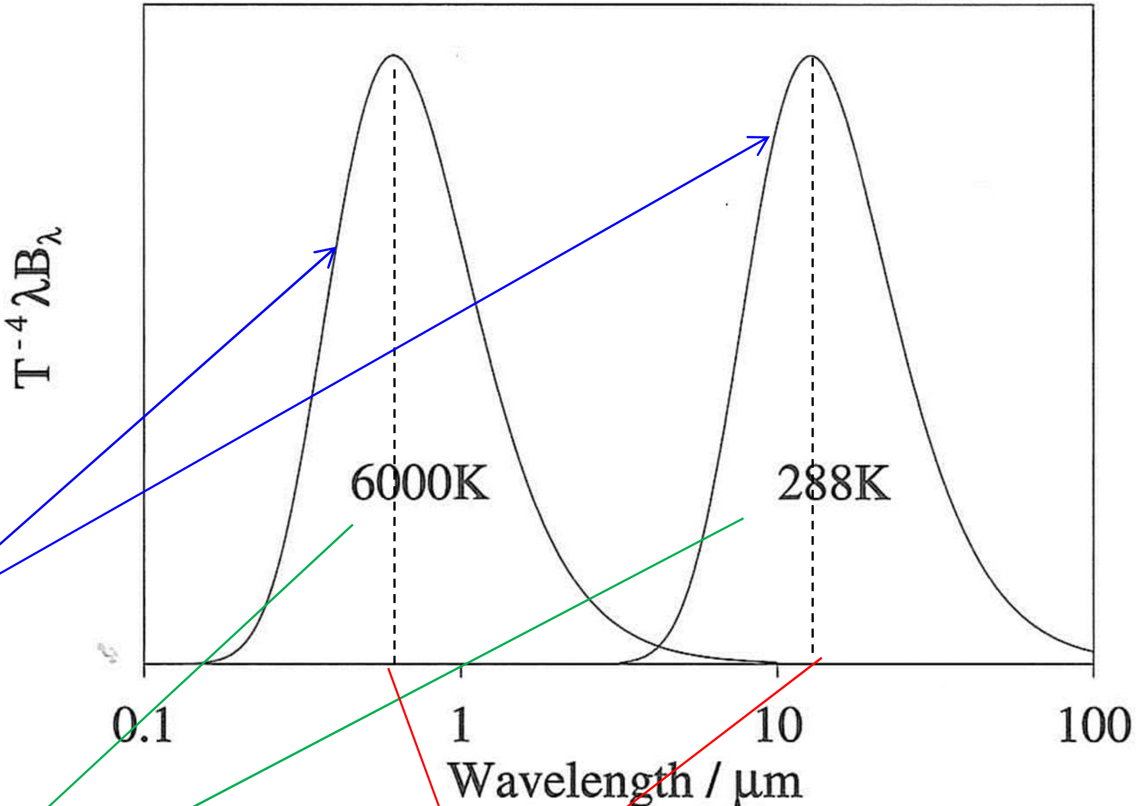
http://www.gahetna.nl/collectie/afbeeldingen/fotocollectie/zoeken/weergave/detail/start/2/tstart/0/q/zoekterm/Planck

Black Body Radiation Law (1900)

"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).



(Andrews, 2000, Chapter 3

(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})

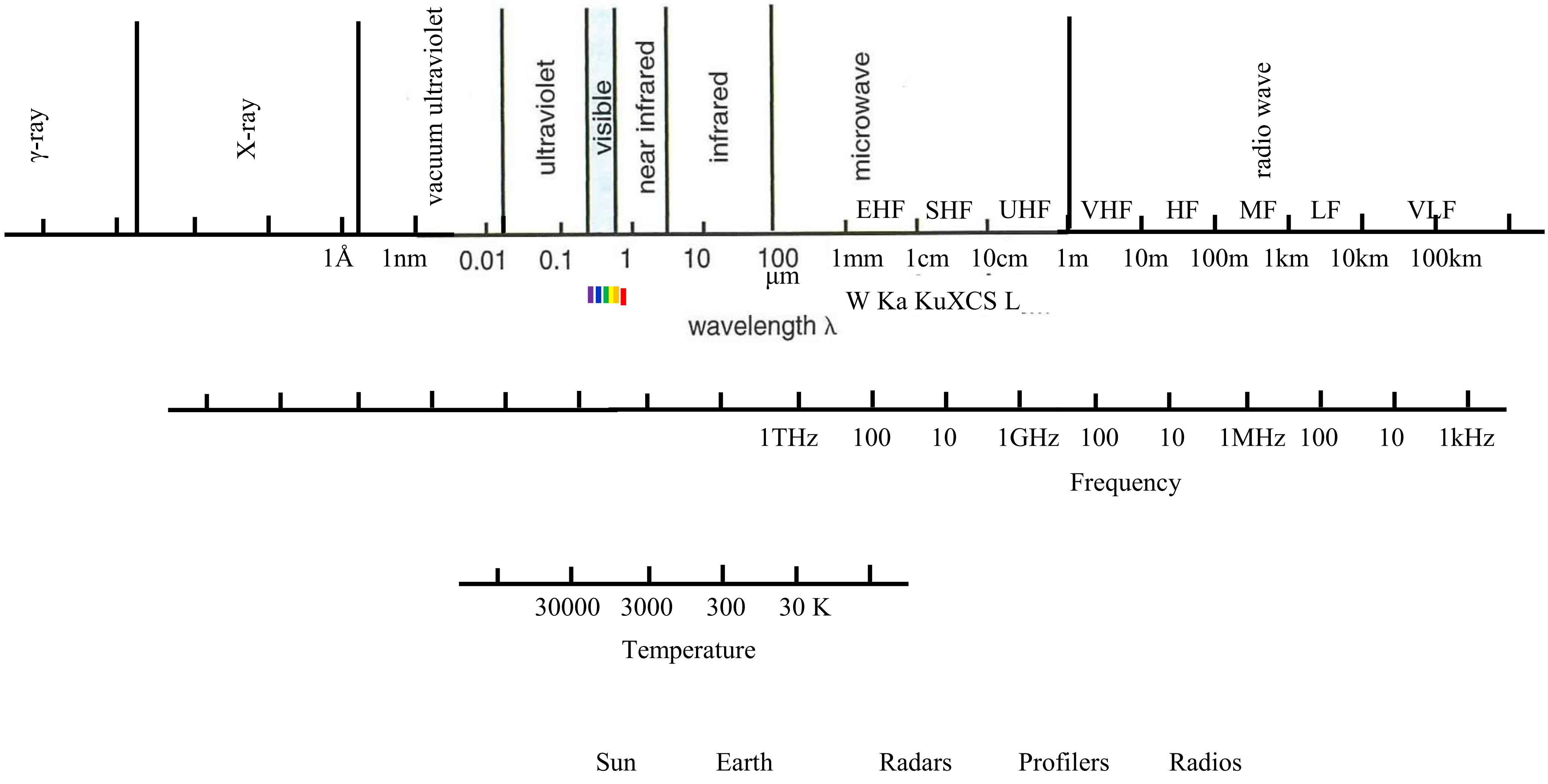
(Differentiation (peak) → Maximum mode wavelength)

Wien's law

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

(→ Exercise 1-2)

Electromagnetic waves



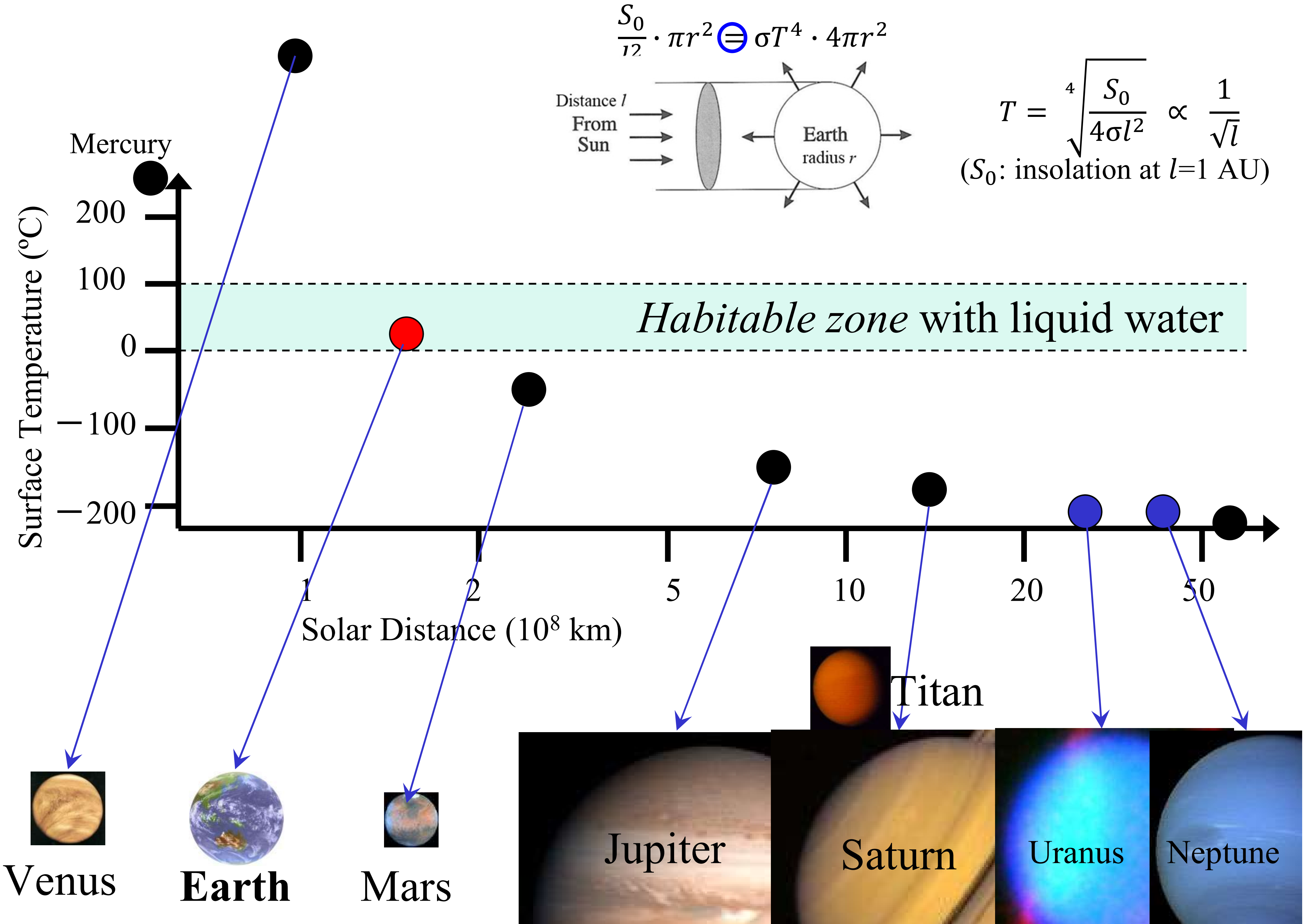
Wavelength × Frequency = Light Speed = 300,000 km/s

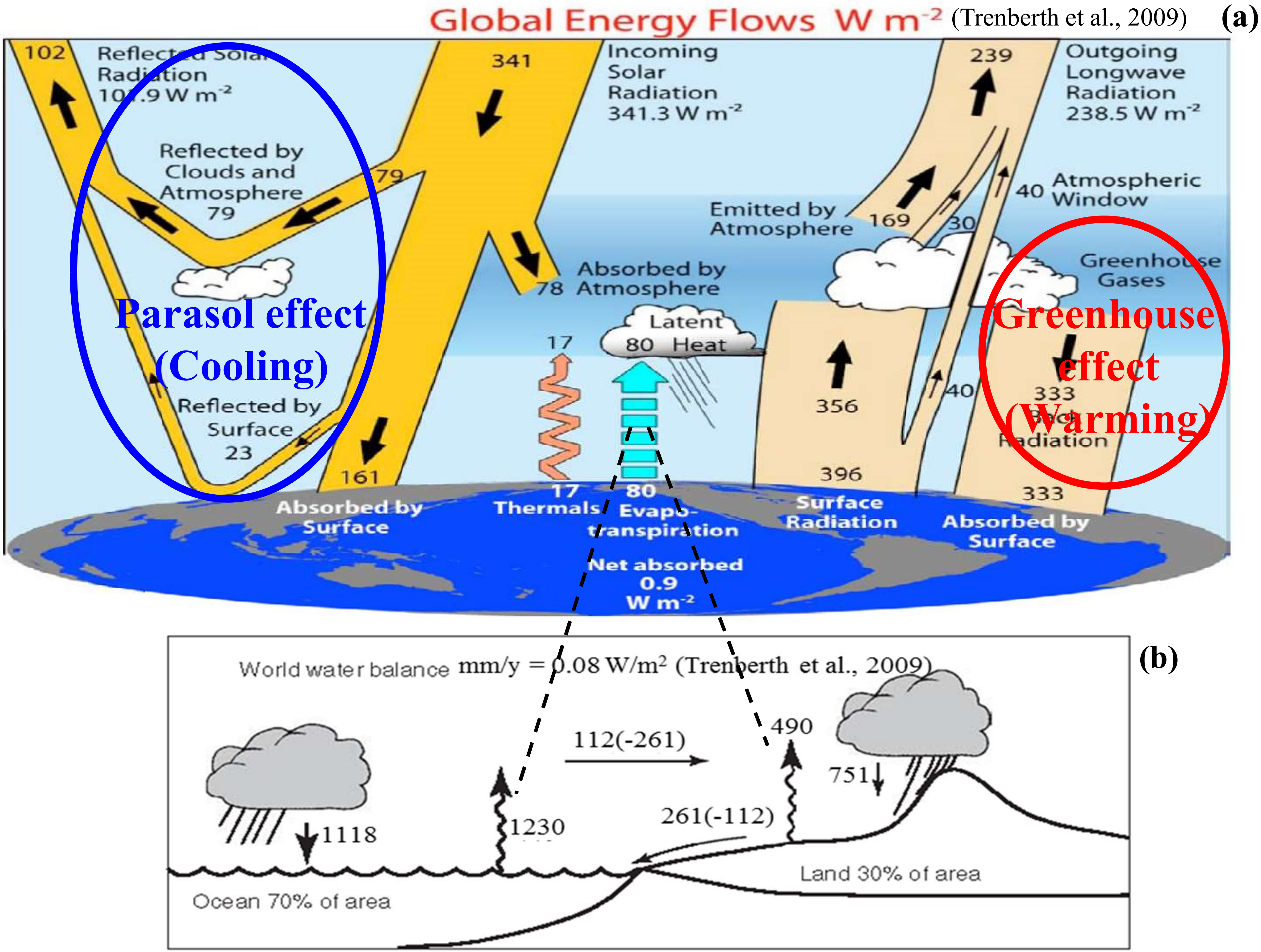
Climate = heating/cooling balance

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

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

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

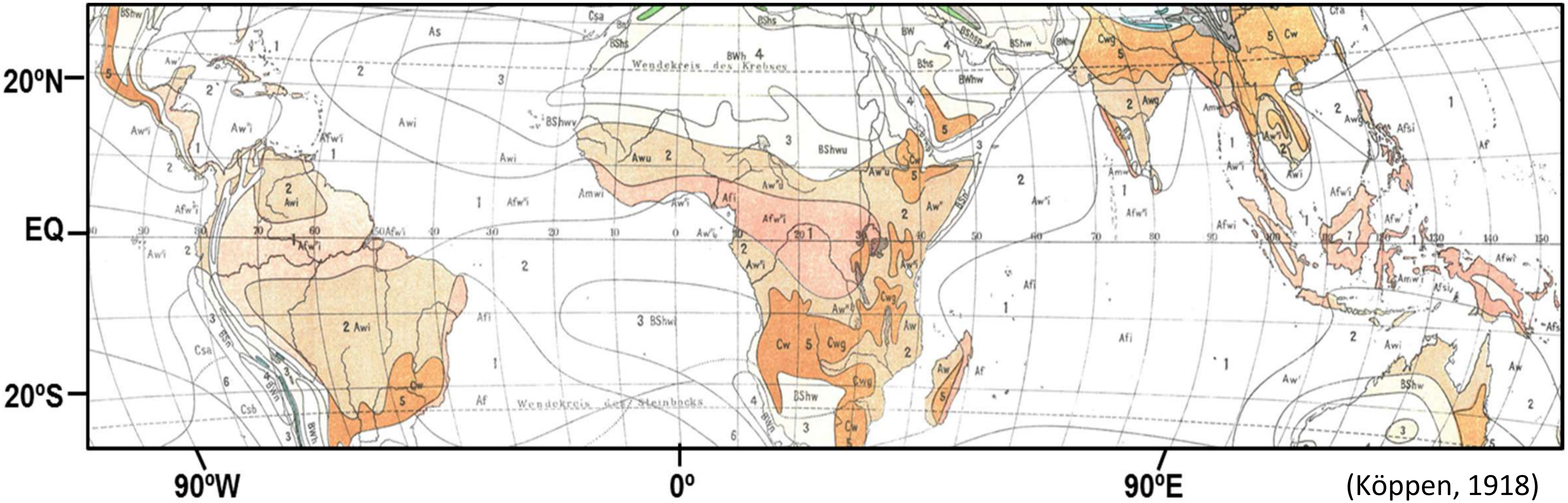



Global Energy Flows W m⁻² (Trenberth et al., 2009)
(a)
102
Reflected Solar Radiation 101.9 W m⁻²
341
Incoming Solar Radiation 341.3 W m⁻²
239
Outgoing Longwave Radiation 238.5 W m⁻²
Reflected by Clouds and Atmosphere 79
79
40 Atmospheric Window
Emitted by Atmosphere
169
30
Absorbed by Atmosphere
78
Greenhouse Gases
Parasol effect (Cooling)
Greenhouse effect (Warming)
17
Latent 80 Heat
356
40
333
Back Radiation
Reflected by Surface 23
161
17
80
396
333
Absorbed by Surface
Thermals
Evapo-transpiration
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

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



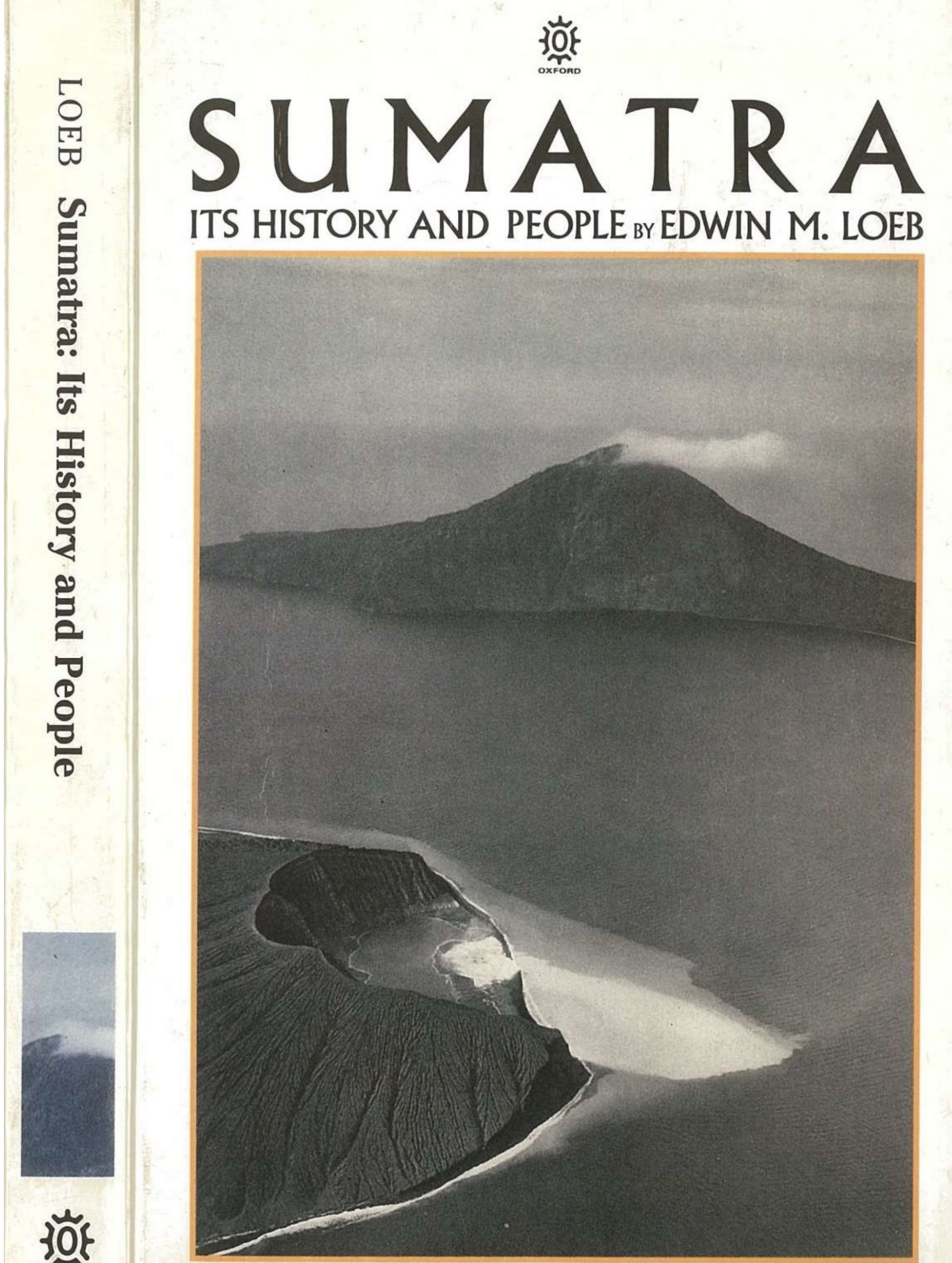
(Köppen, 1918)

(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]

C. S. RAMAGE

Department of Geosciences, Univers

ABSTR

Thunderstorm frequency and amount of moisture abo
South America and Africa and the "maritime continent"
amount of heat for export than do equatorial oceanic regio
Over the maritime continent in January 1963, heat ge
northward and through conversion of potential to kinetic
jet stream. In January 1964 *drought* over the maritime co
heat in the upper troposphere, associated with inefficient p
winters over the western Pacific and southeast Asia fluctuat
1964.
Since the troposphere over the maritime continent in w
the extratropical circulation, the proposed Marshall Island
be rescheduled to include winter.

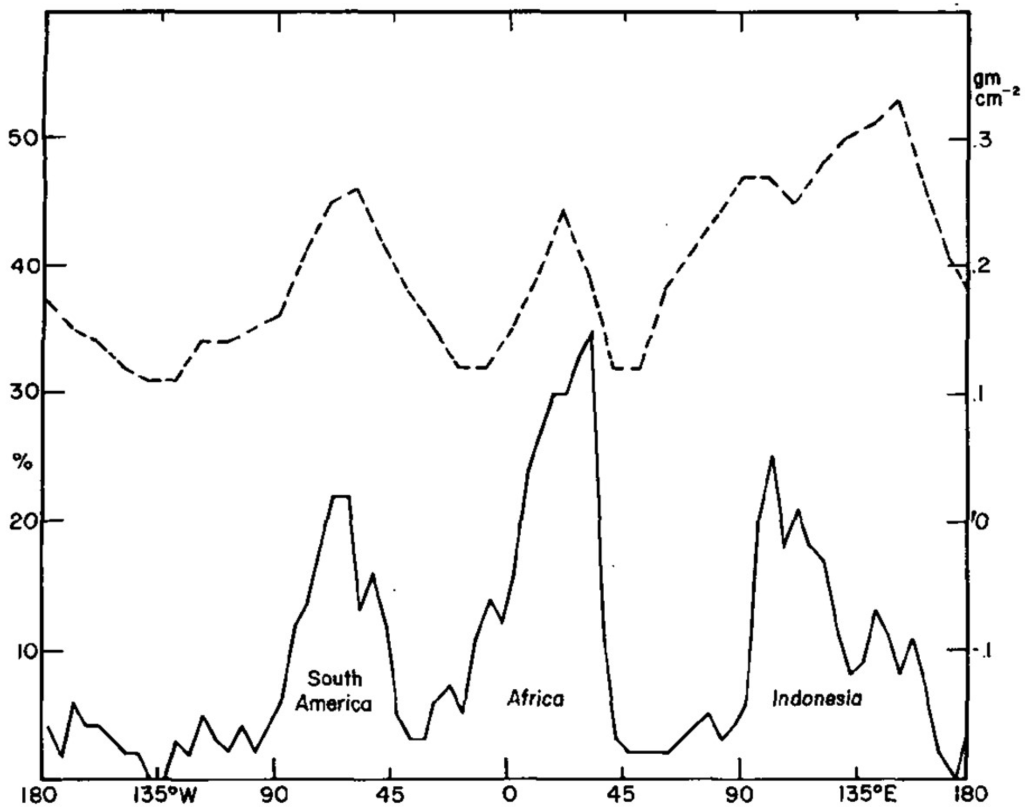
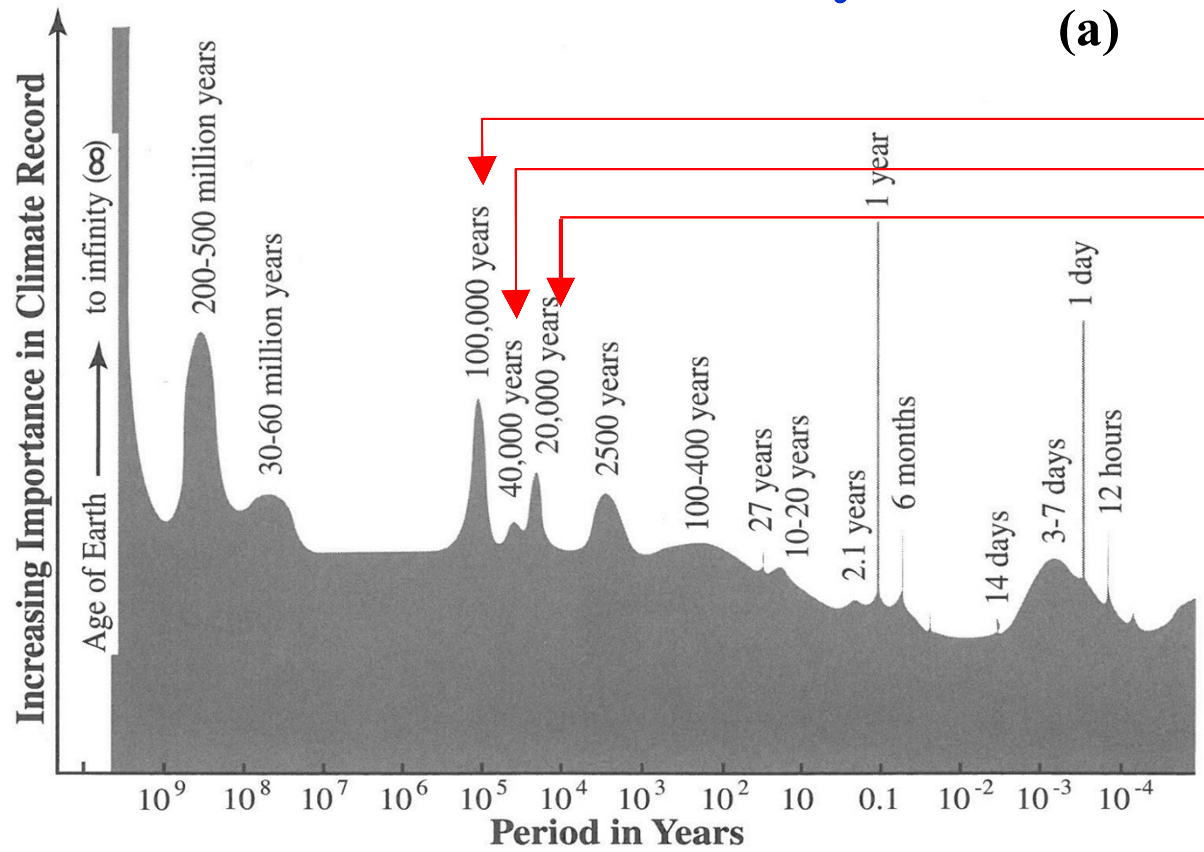
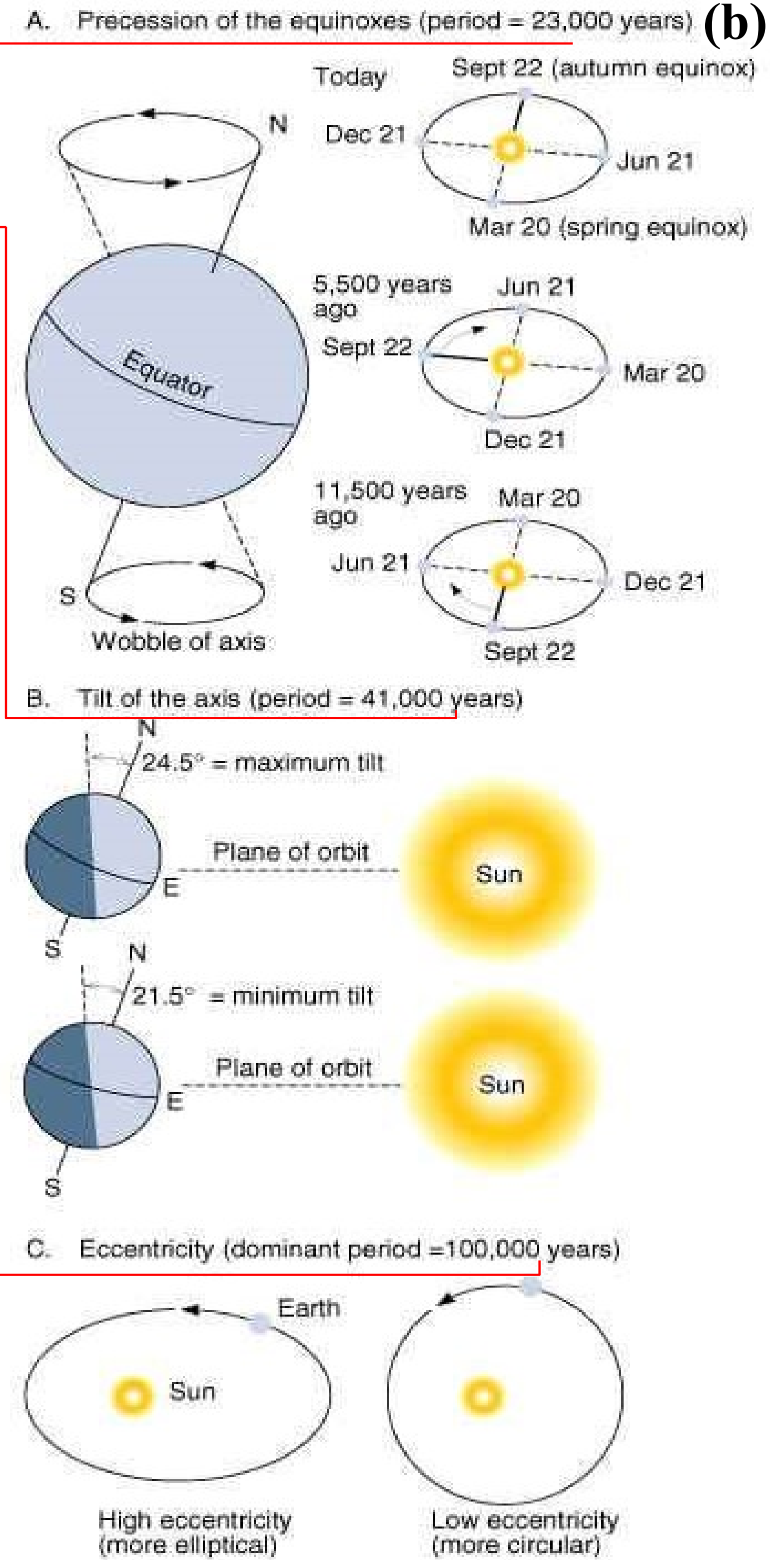


FIGURE 1.—The equatorial belt between 10°N. and 10°S. Annual percentage of days with thunder by 5° long. intervals (solid line). Based on Braak [2], World Meteorological Organization [13], [14]. Mass of water vapor in gm. cm.$^{-2}$ above 500 mb. by 10° long. intervals (dashed line). Averages of February,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

Schroeder **Ramage** Hamilton Stevens Barnes
(Past Chiars of Dept. of Meteorology, U. Hawaii; Jan 2007)

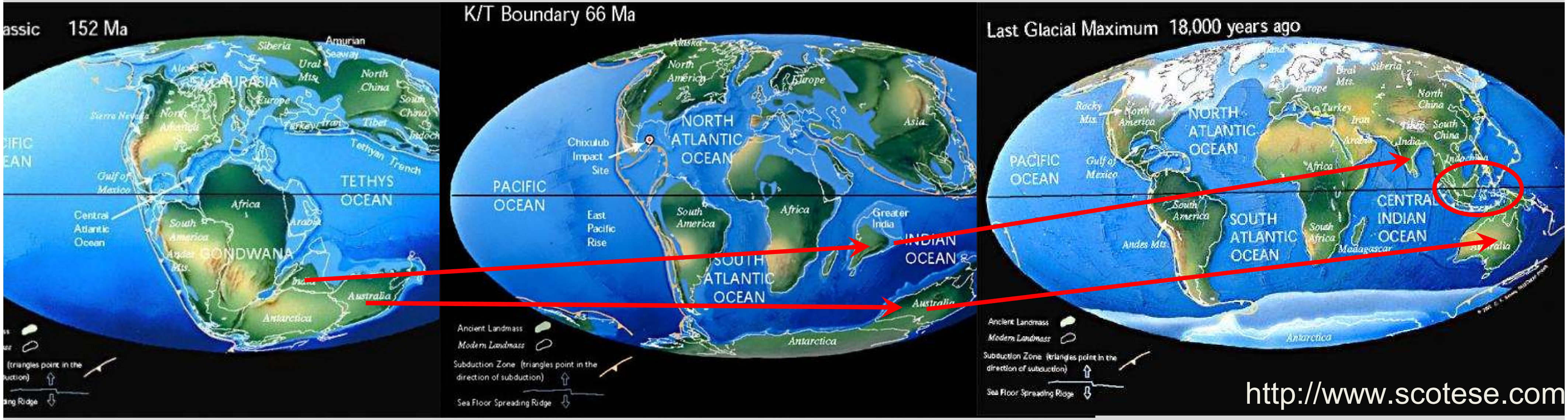
Insolation variability





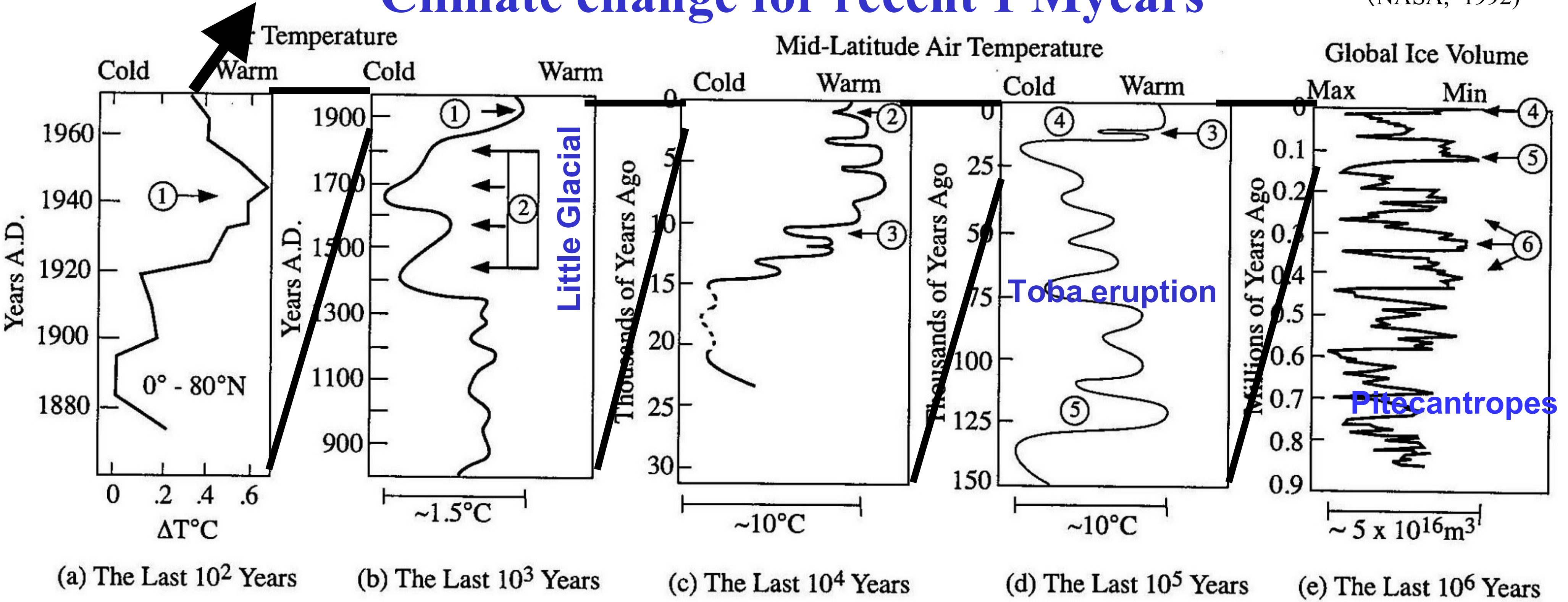
Milutin Milanković (1879 –1958)

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



Climate change for recent 1 Myears

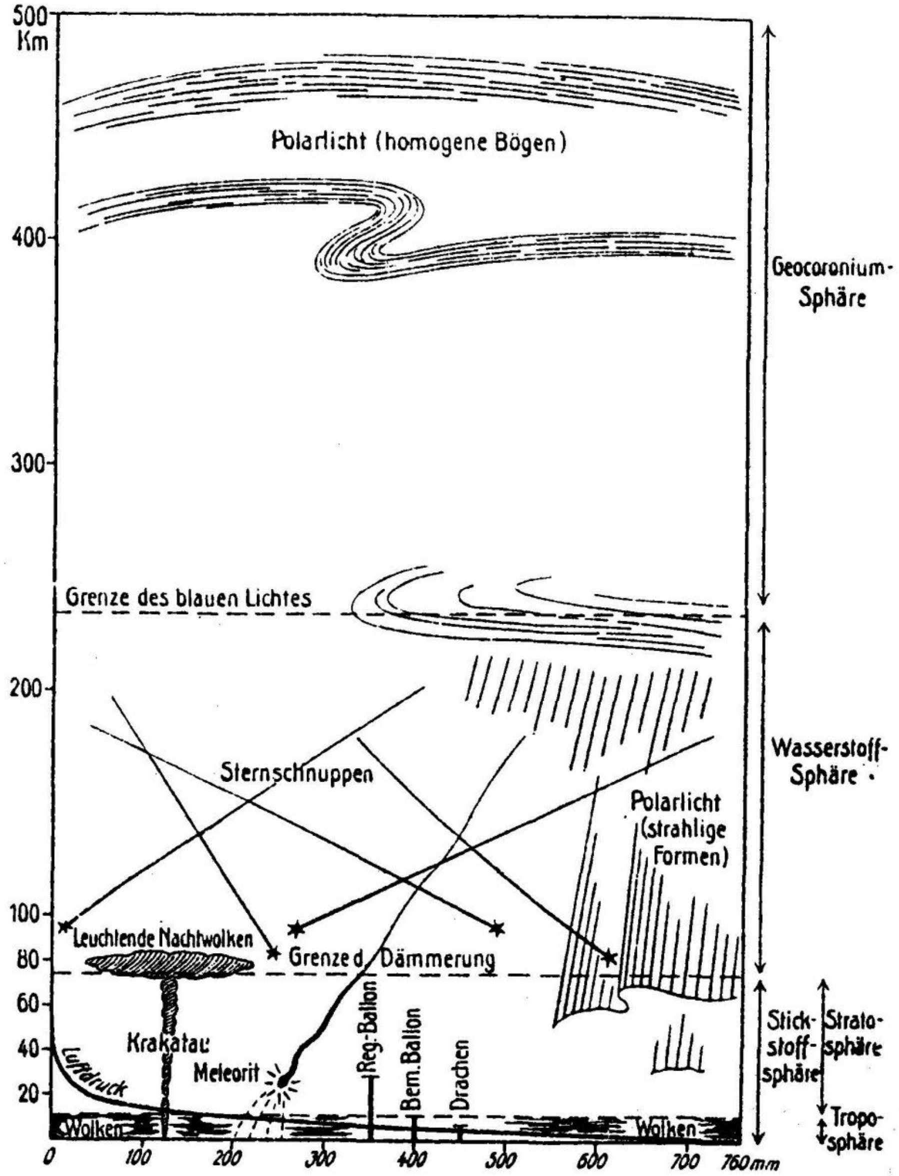
(NASA, 1992)



Alfred Lothar Wegener (1880 –1930)

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

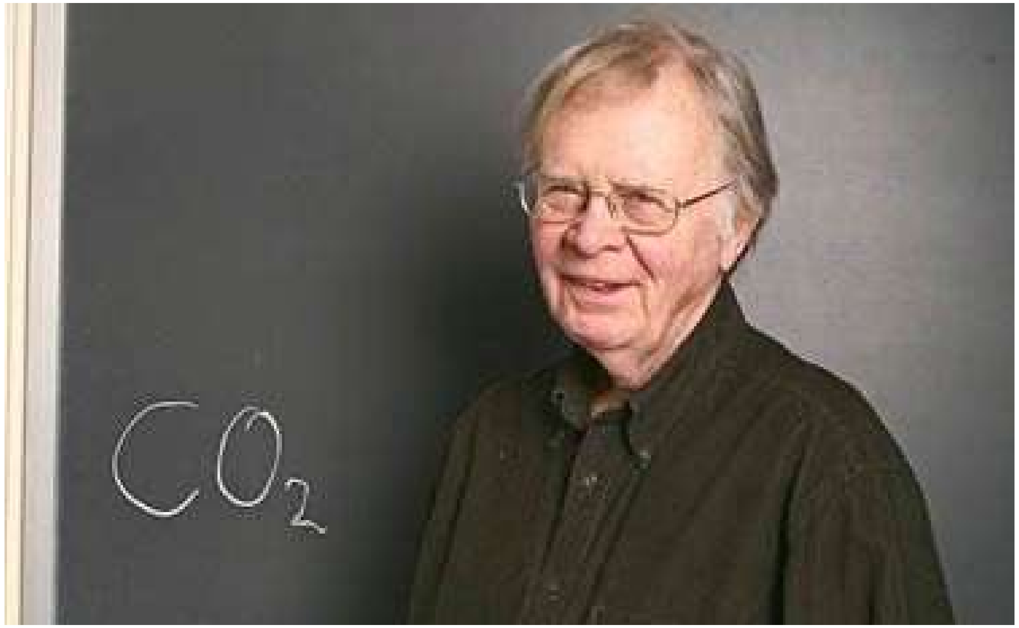
- 1905: Doctorate in astronomy. Work for aeronomy. .
- 1910: Conceiving of an idea of "continent drift"
- 1915: Publication of a book on the idea. Marriage.
- 1919-23: Paleoclimatology with father-in-law Köppen
- 1924: Professor at University of Glaz
- 1930 (aged 50): Died during Greenland expedition.

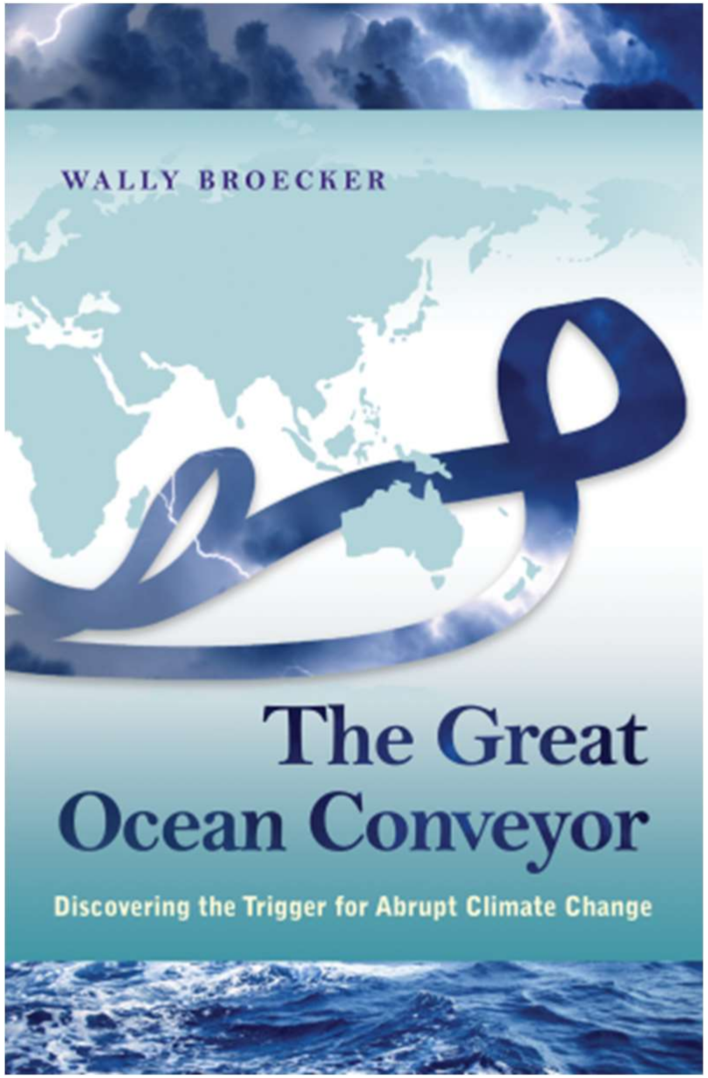


(Wegener, 1911: *Thermodynamik der Atmosphäre*; 松野, 1982より孫引き)

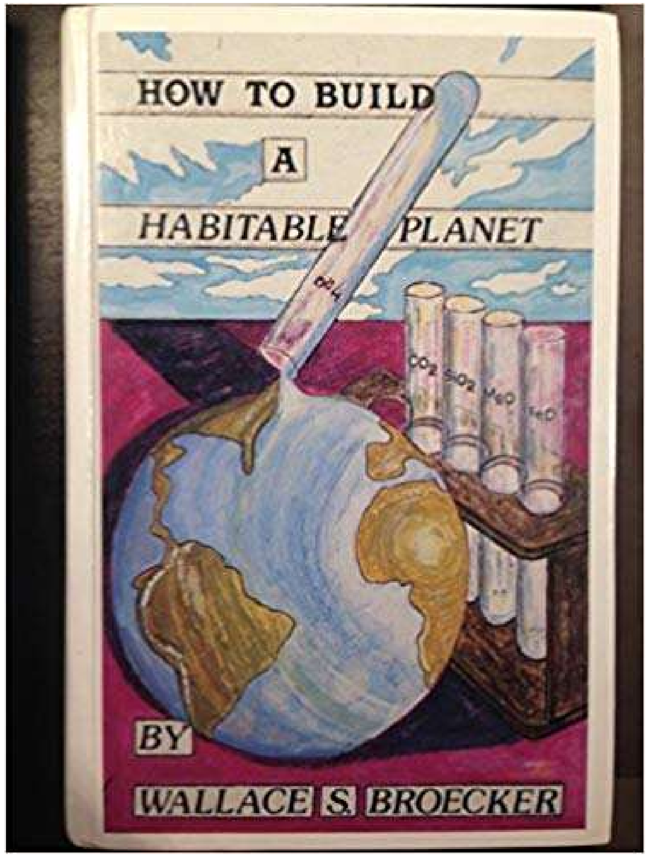
Wallace Smith Broecker (1931 – Feb 19, 2019)

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

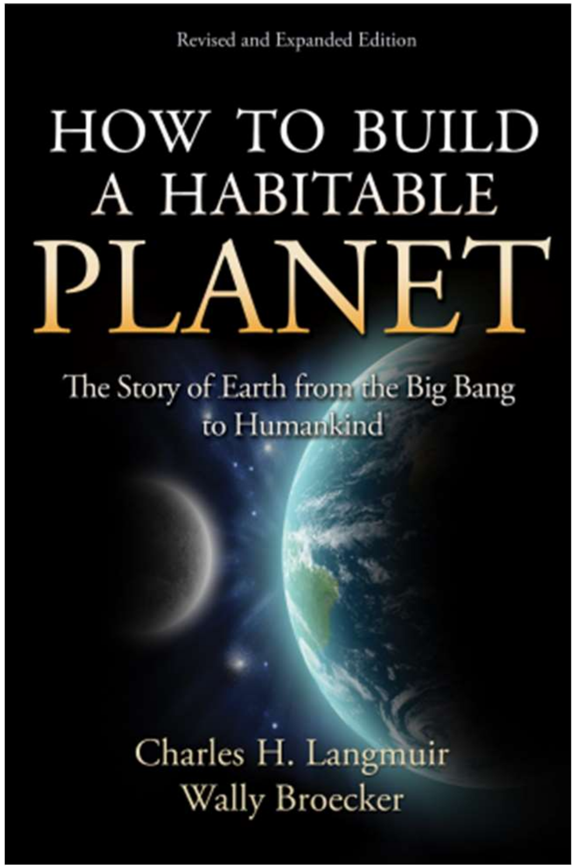




(2010) https://press.princeton.edu/titles/9162.html

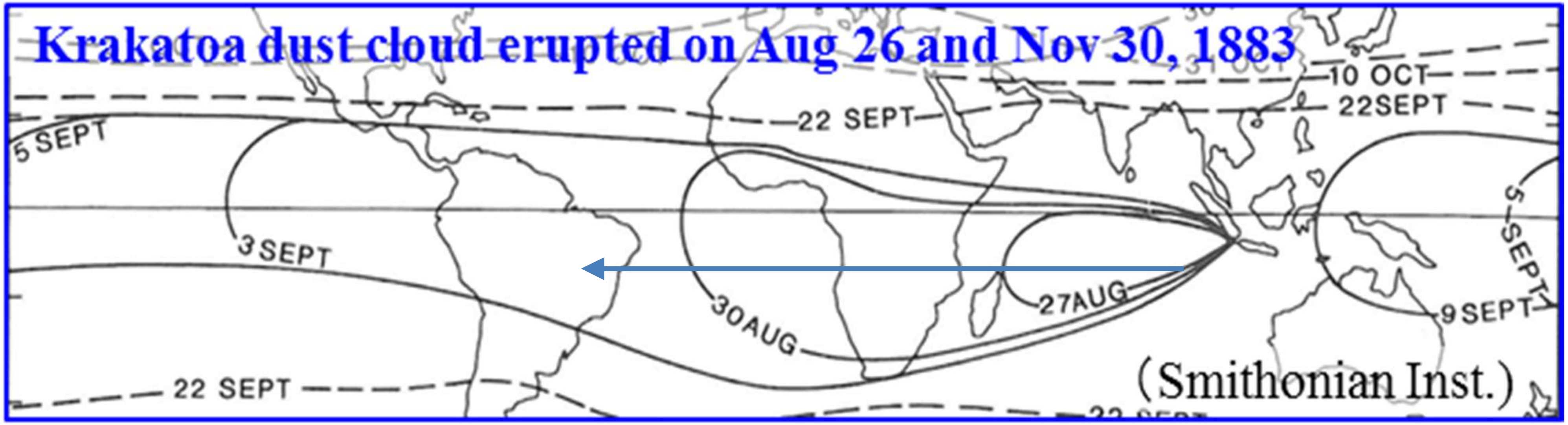


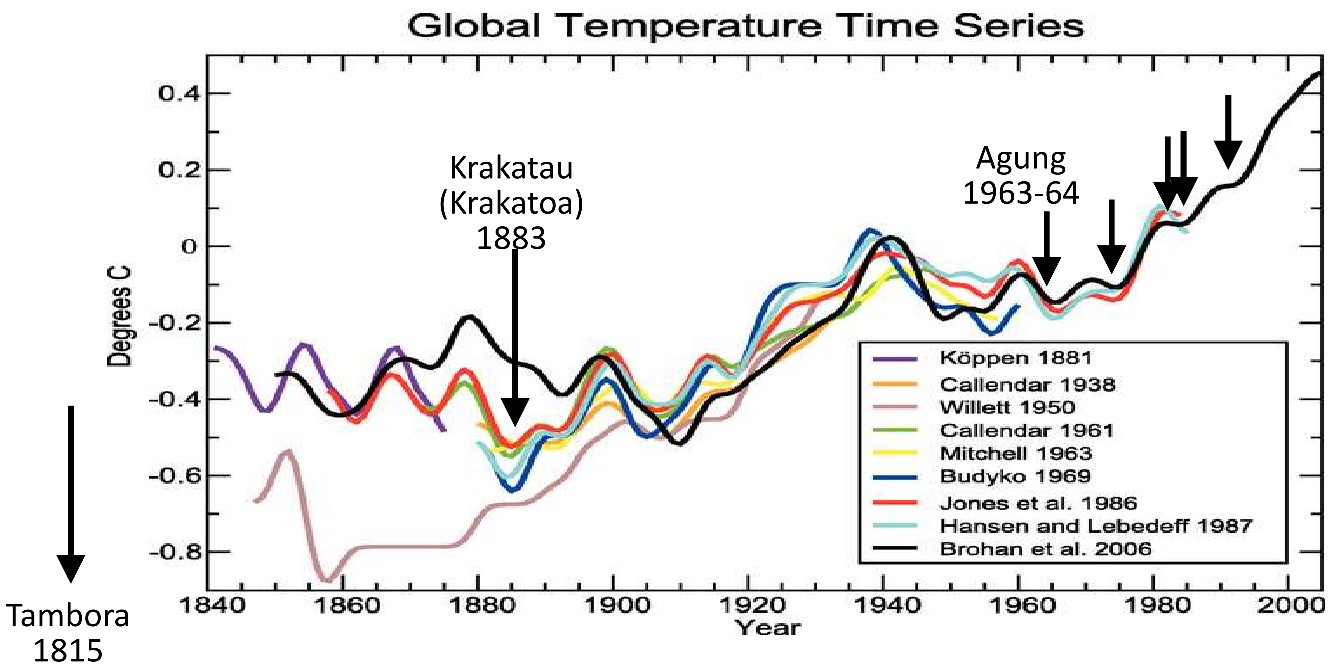
(1988) https://press.princeton.edu/titles/9162.html

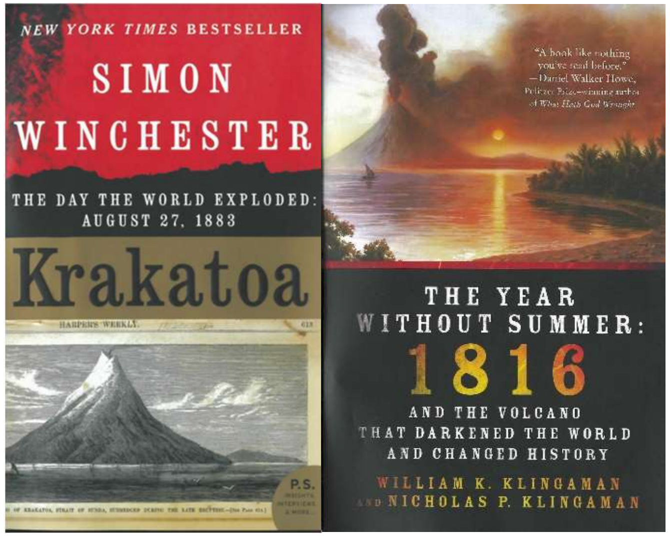


(2012) https://press.princeton.edu/titles/9691.html

Volcano ashes transported by stratospheric zonal flow







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