

Fizyka Procesów Klimatycznych Chmury

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<https://epic.gsfc.nasa.gov/?date=2025-04-14>

Image Information

epic_1b_20250414114331

Processing Version: 03

Distance to Earth: 977,551 miles

Distance to Sun: 92,256,650 miles

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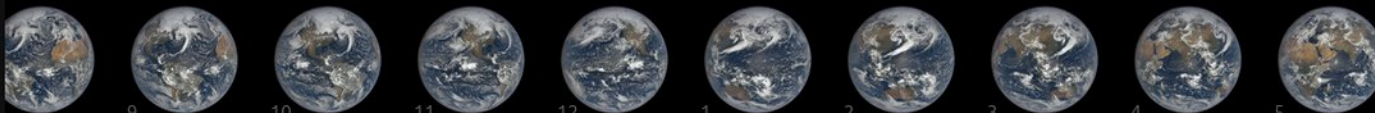
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Showing 7 of 12. 2025-04-14

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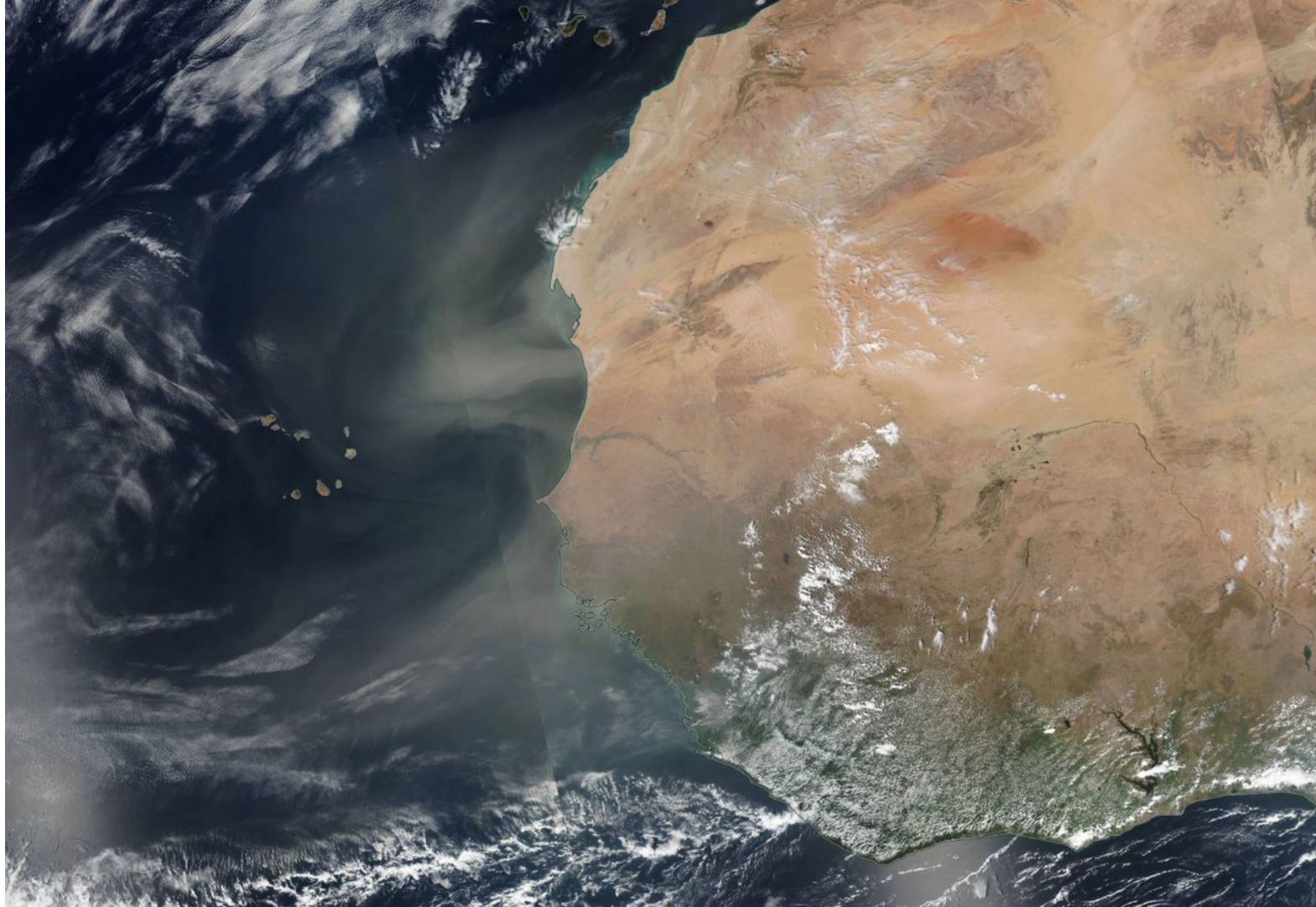
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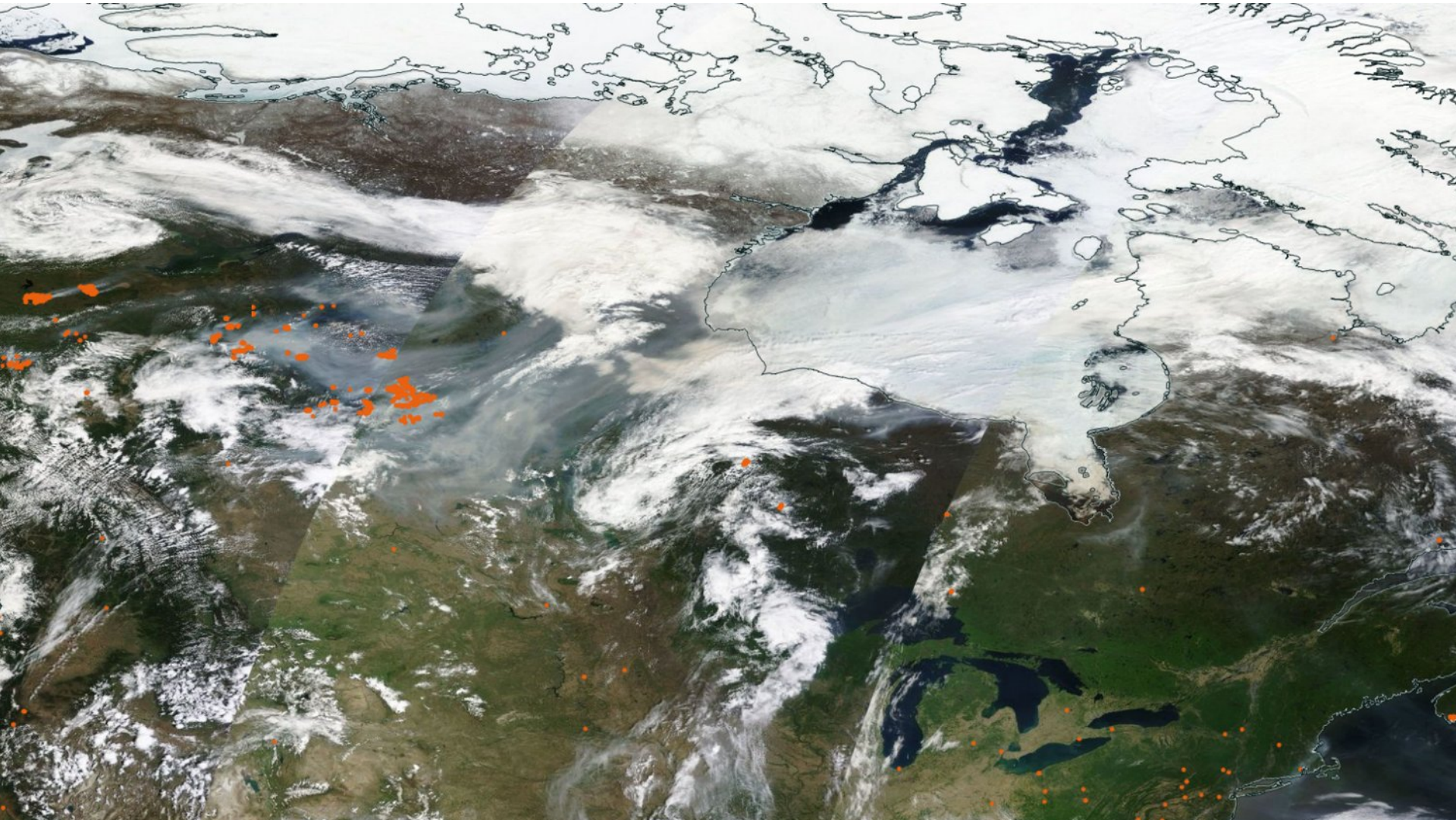
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Aerozole







Chmury

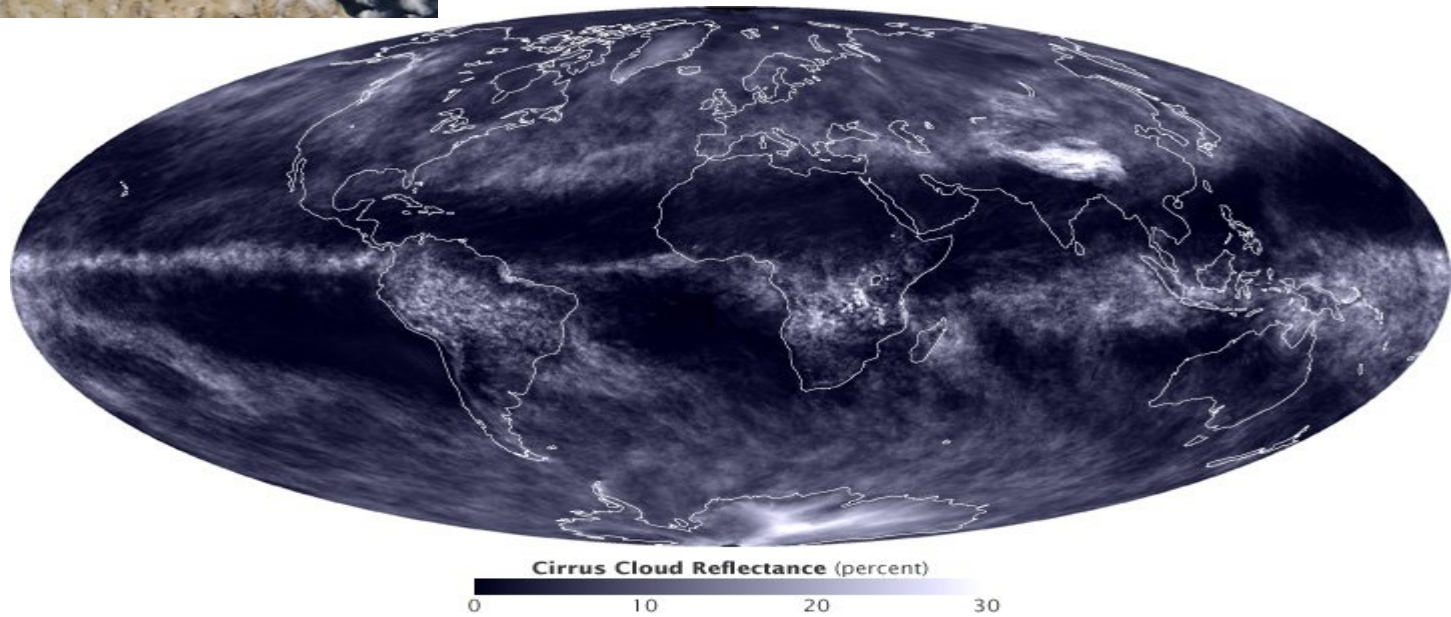


Chmury niskie:
dominuje efekt albedo





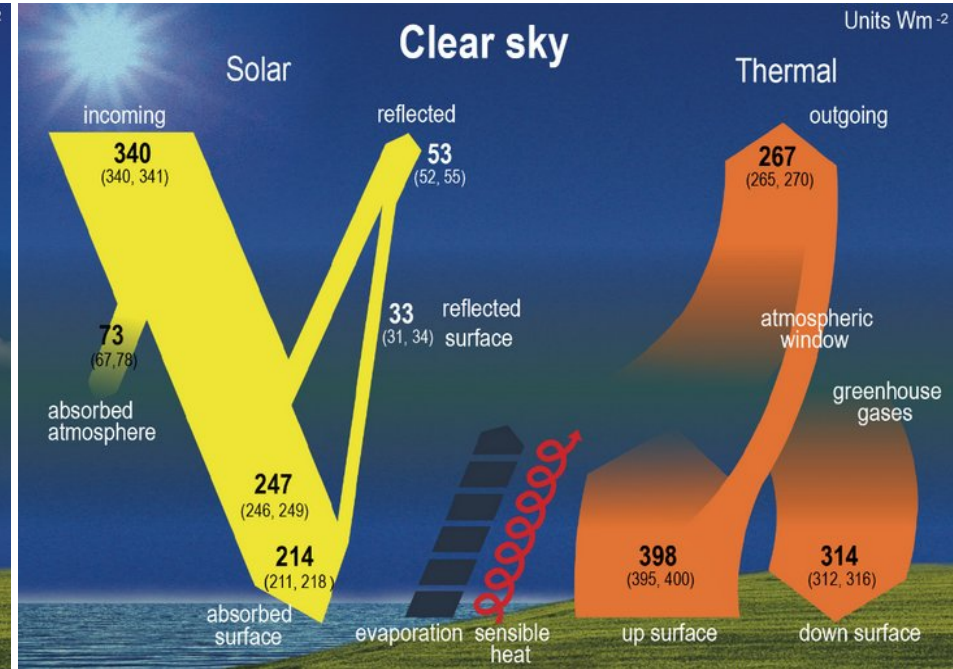
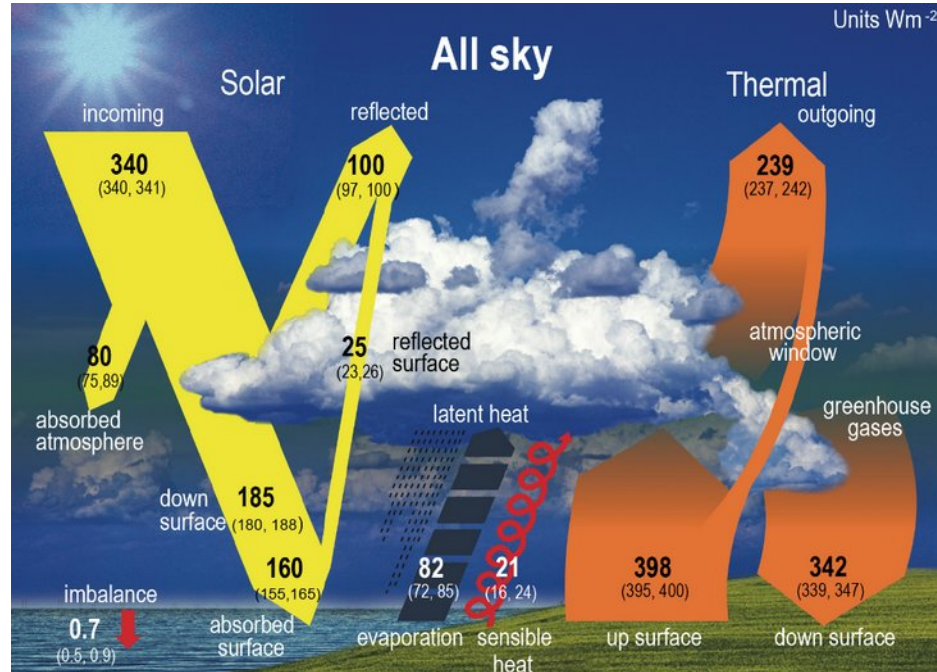
Chmury wysokie: ważny zarówno efekt cieplarniany
jak i albedo



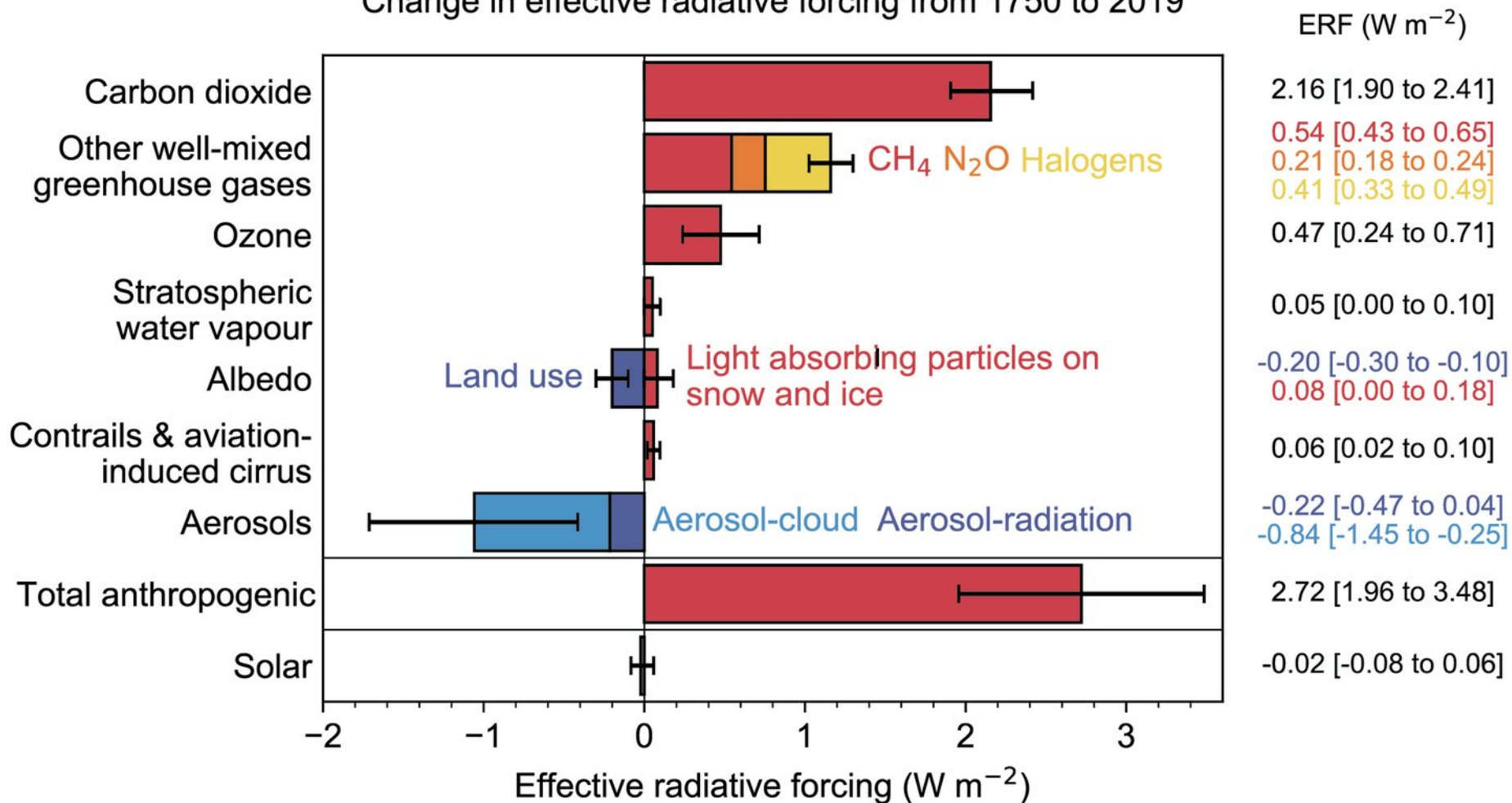
Chmury rozbudowane w pionie: ważne wszystkie efekty



Schematic representation of the global mean energy budget of the Earth (left panel), and its equivalent without considerations of cloud effects (right panel).



Change in effective radiative forcing from 1750 to 2019



Wróćmy do chmur...

Woda w atmosferze – domieszka do tzw. „powietrza suchego” występuje w trzech stanach skupienia – stałym, ciekłym i gazowym.

Przejścia pomiędzy tymi stanami mają swoje nazwy i tak – między stanem stałym i ciekłym topnienie i zamarzanie; między stanem ciekłym i gazowym – parowanie i kondensacja; między stanem gazowym a stałym – sublimacja i resublimacja.

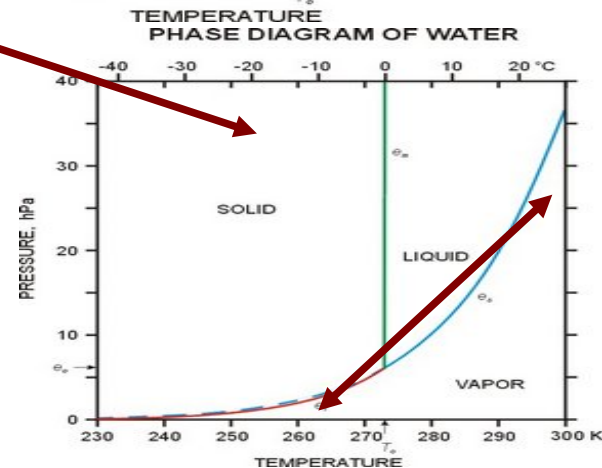
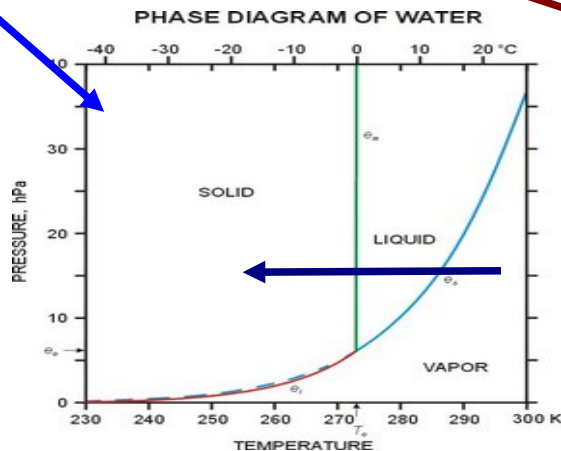
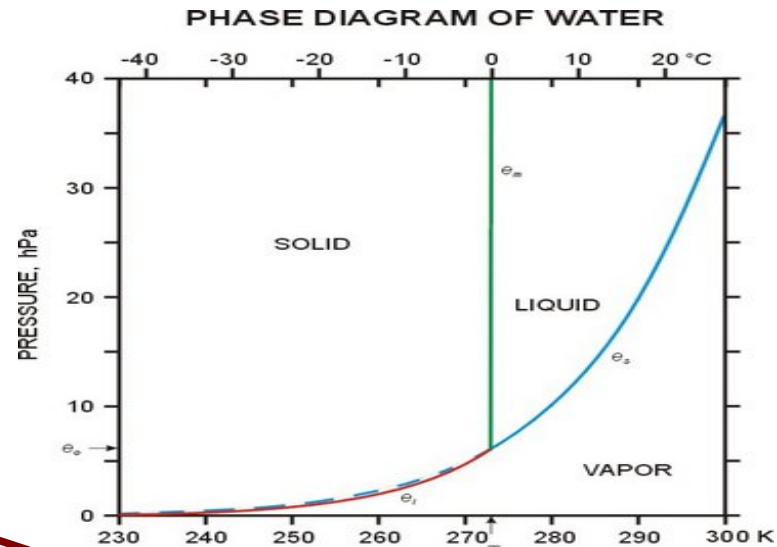
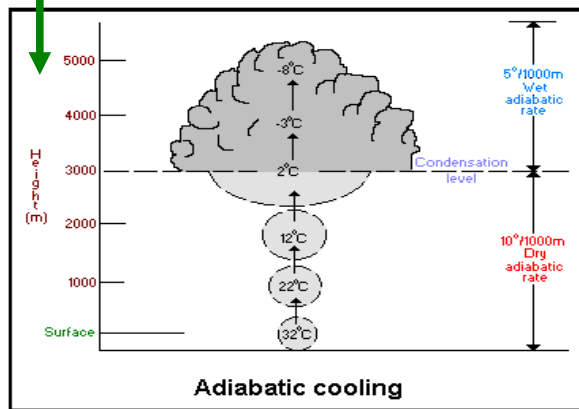


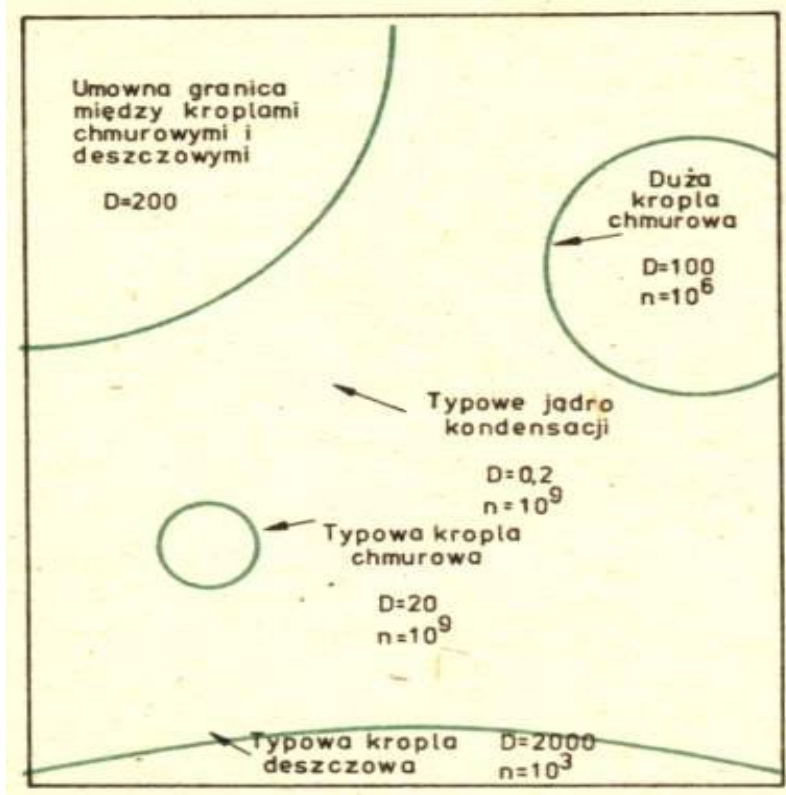
Chmury powstają zawsze tam, gdzie temperatura powietrza ma niższą wartość niż temperatura punktu rosy, co umożliwia przemianę fazową – kondensację obecnej w powietrzu pary wodnej.

Procesy fizyczne prowadzące do kondensacji pary wodnej obecnej w powietrzu:
rozprężanie adiabatyczne (np. w ruchach wstępujących);

ochładzanie izobaryczne (radiacyjne, przez przewodnictwo);

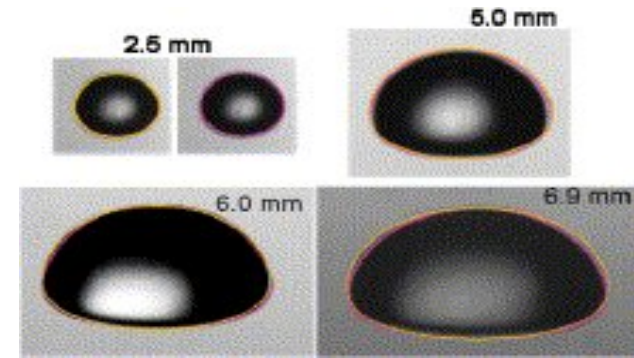
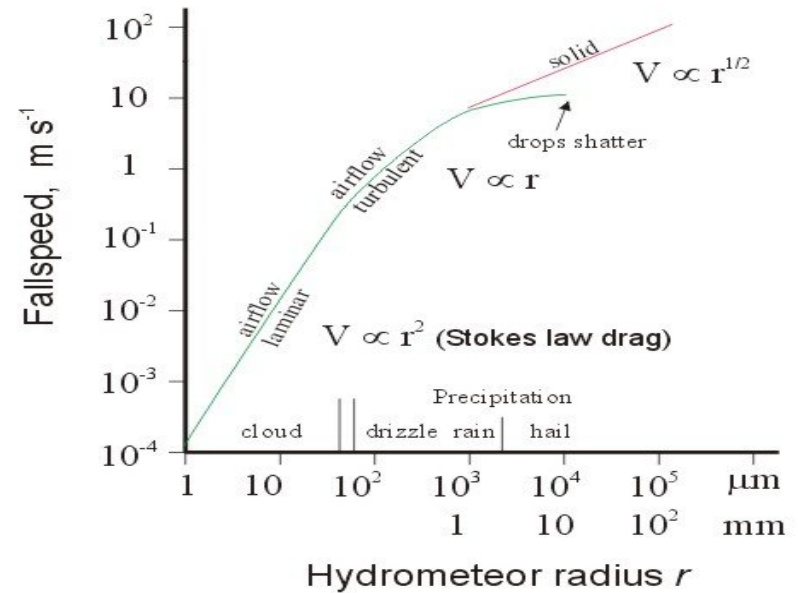
mieszanie izobaryczne.





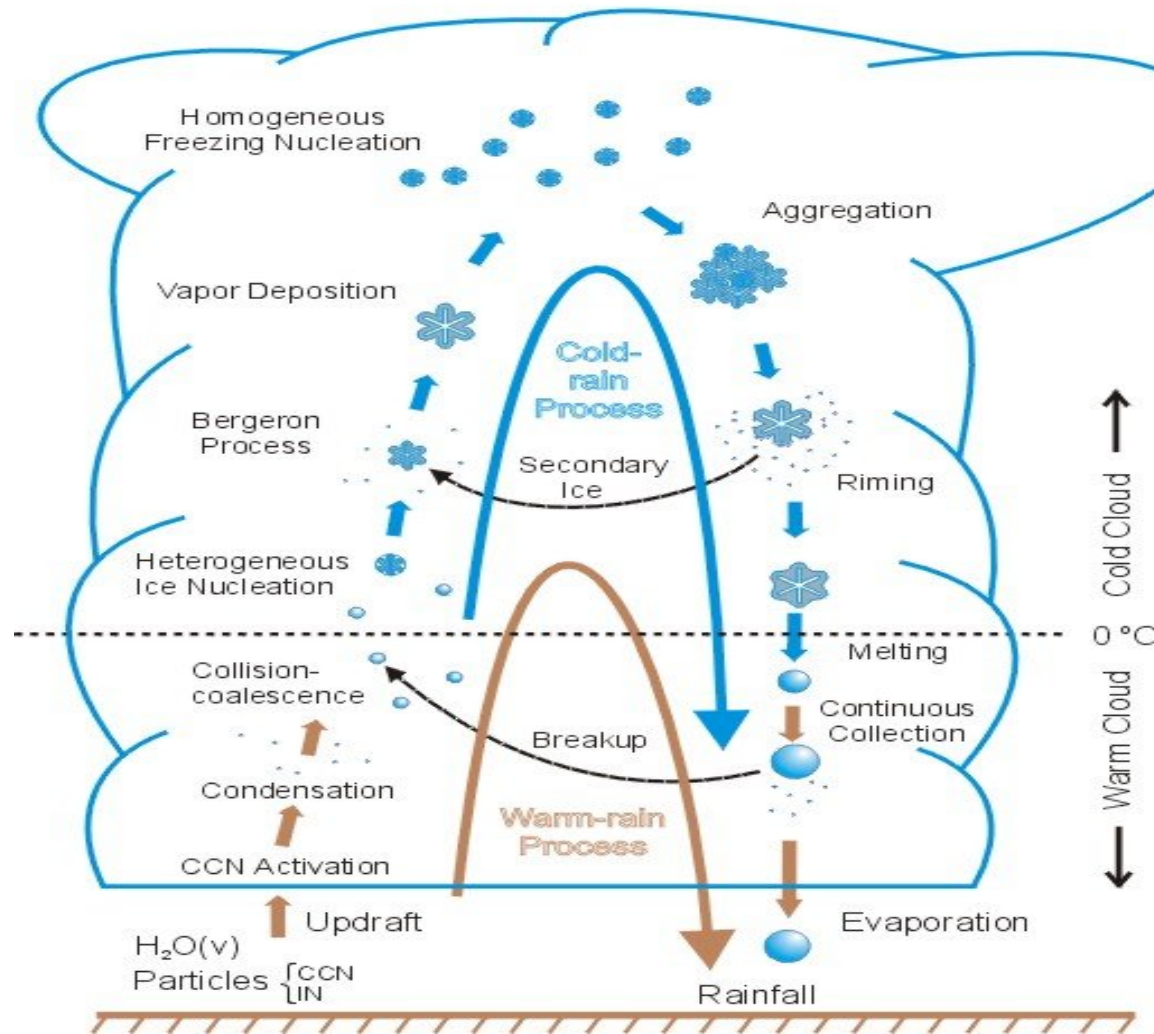
KROPLE CHMUROWE I OPADOWE

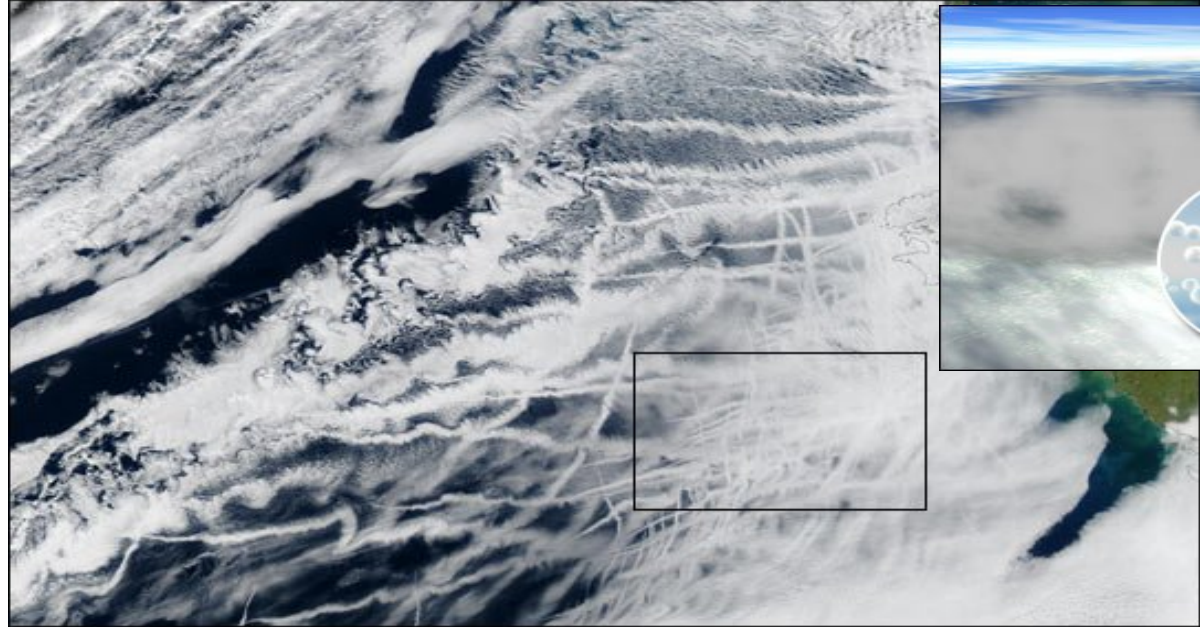
CLOUD-PARTICLE FALLSPEEDS



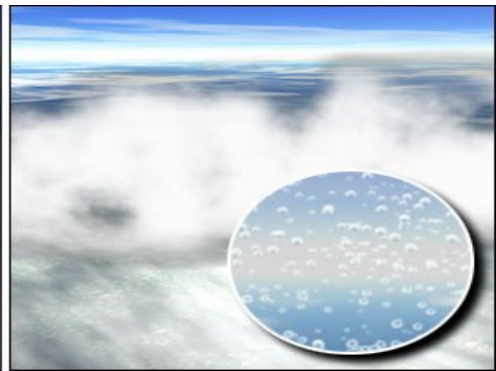
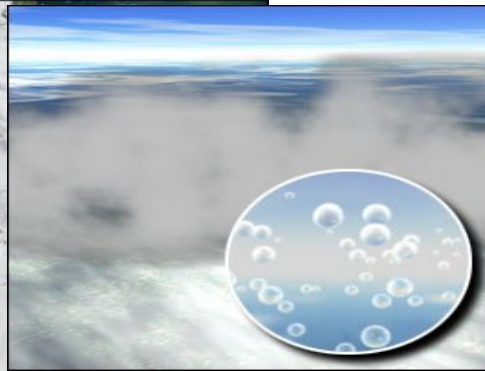
PRECIPITATION MECHANISMS

Mechanizmy opadowe





True Color

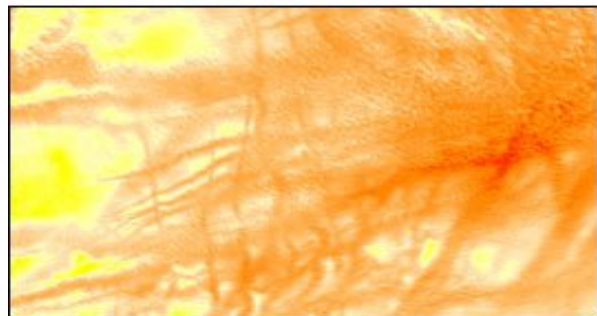


Wpływ aerozolu na budowę chmur (rozmiar kropelek)

i w konsekwencji na ich właściwości radiacyjne:

tzw. pośrednie efekty aerozolowe:

- pierwszy (albedo chmur)
- drugi (czas życia chmur).



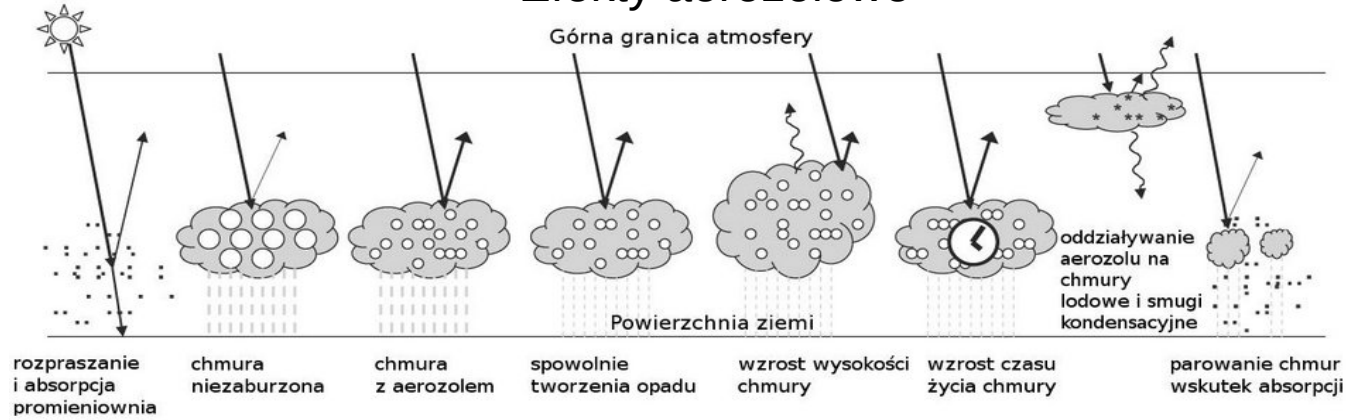
Optical Thickness



Effective Particle Radius (μm)



Efekty aerozolowe



Efekt bezpośredni

Pierwszy efekt pośredni

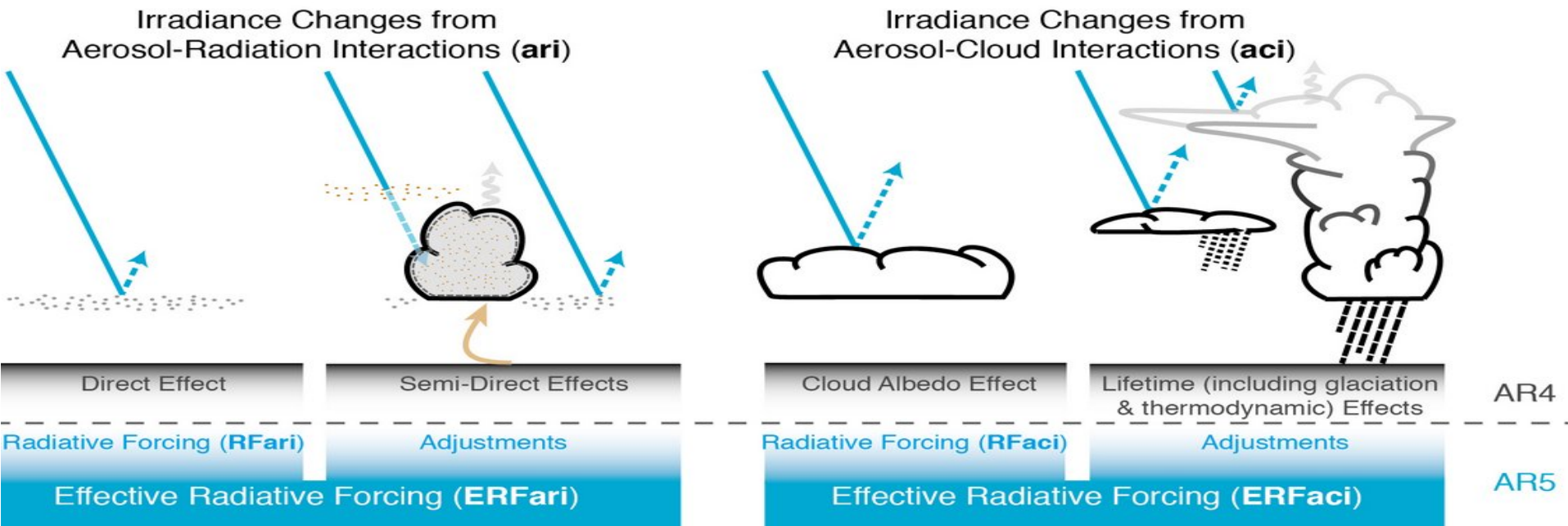
Drugi efekt pośredni

Efekt pół-bezpośredni

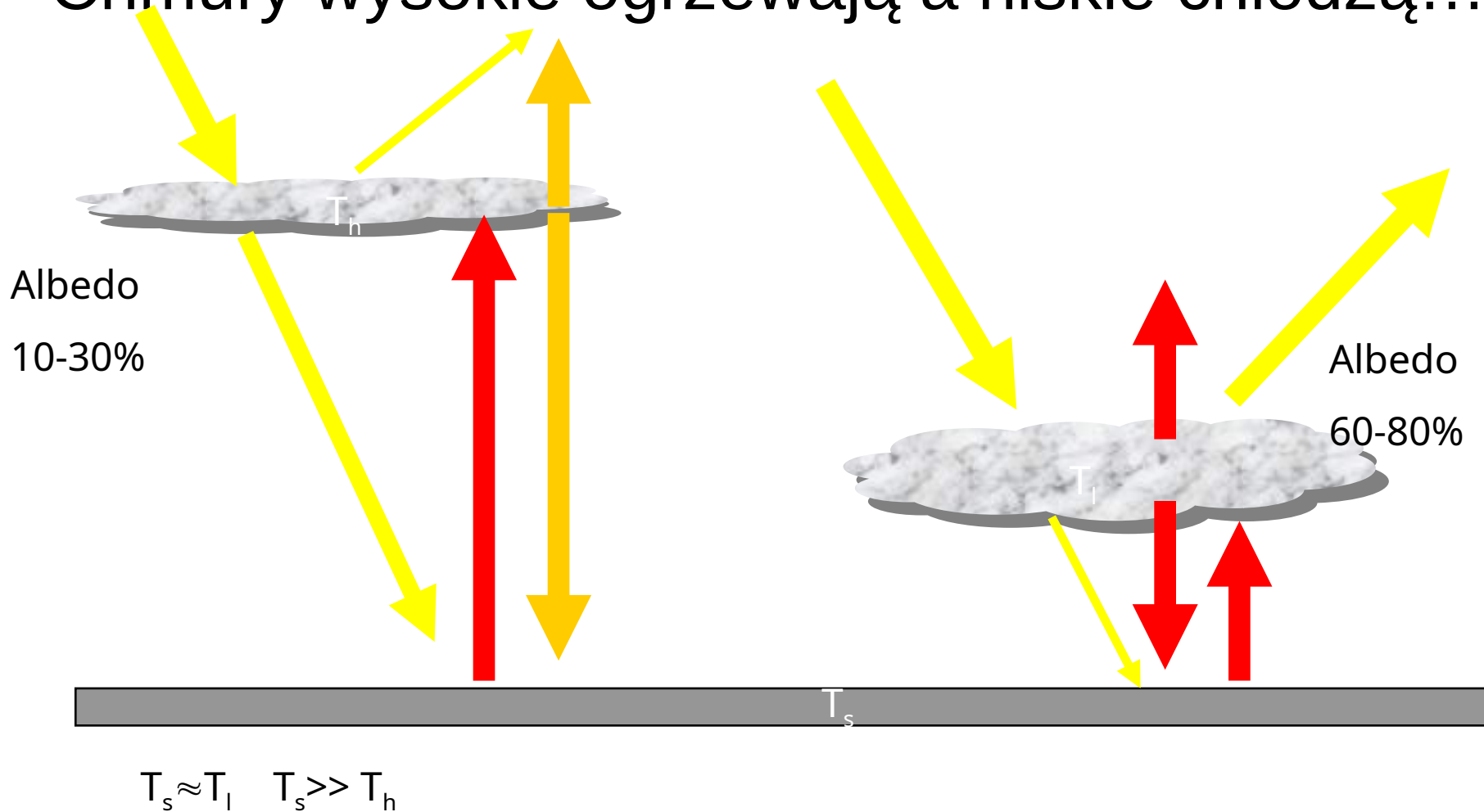
Efekt Twomeya

Efekt Albrechta

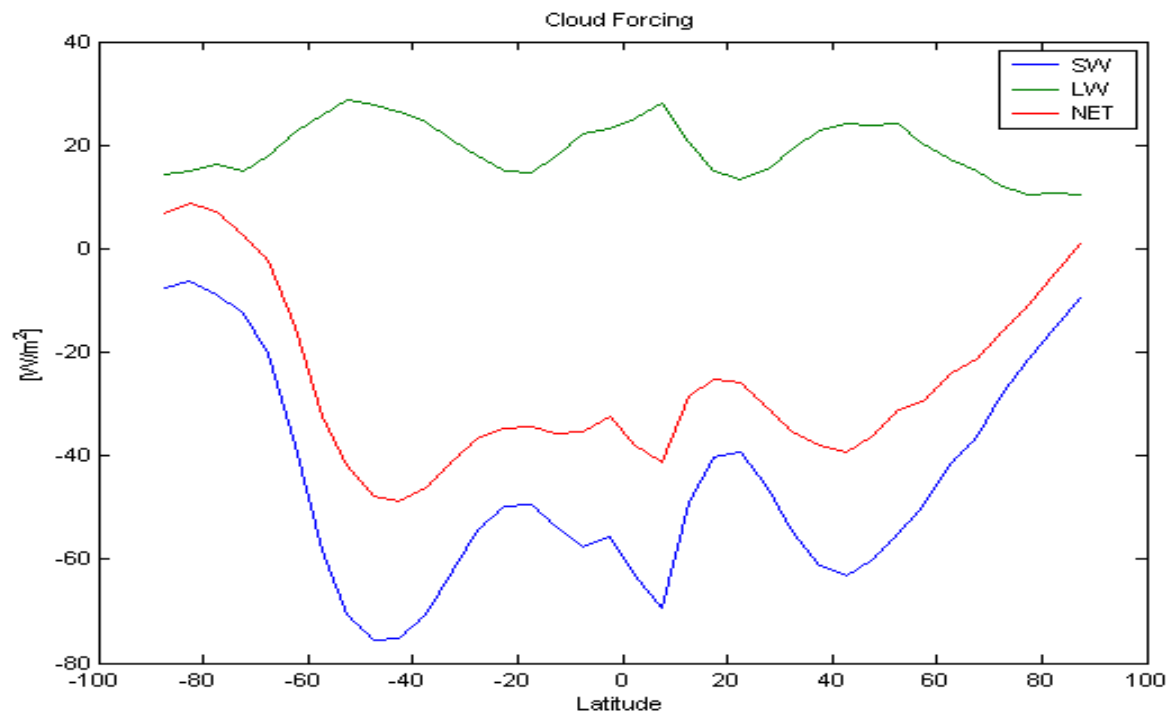
Efekty aerozolowo-chmurowe wg. V Raportu IPCC

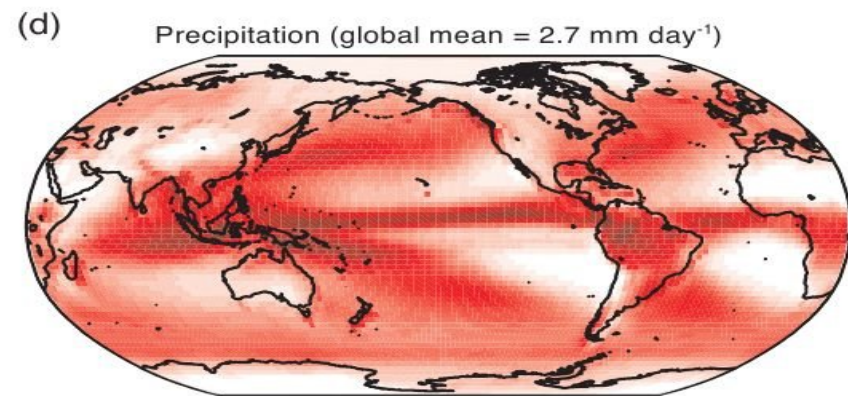
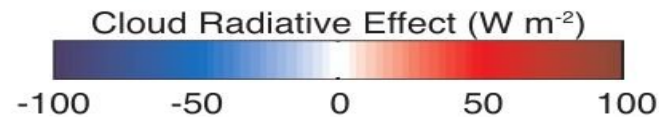
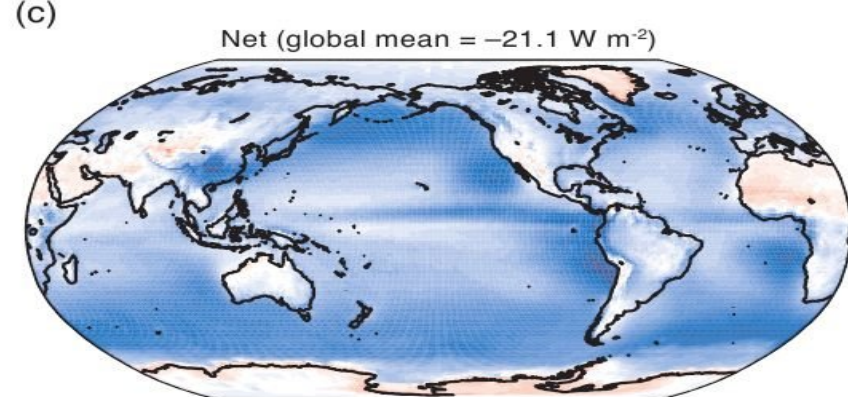
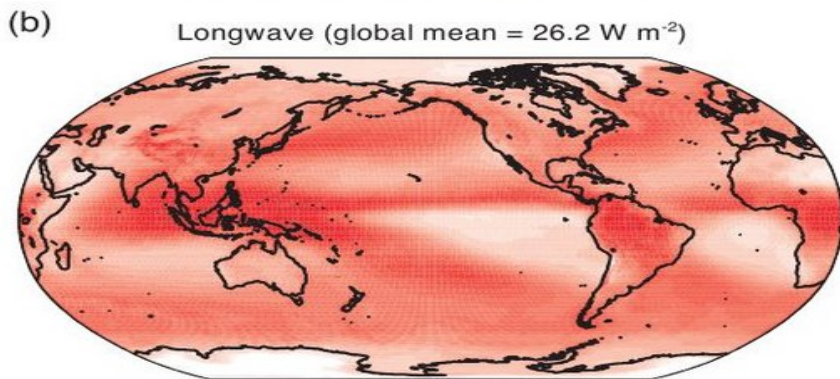
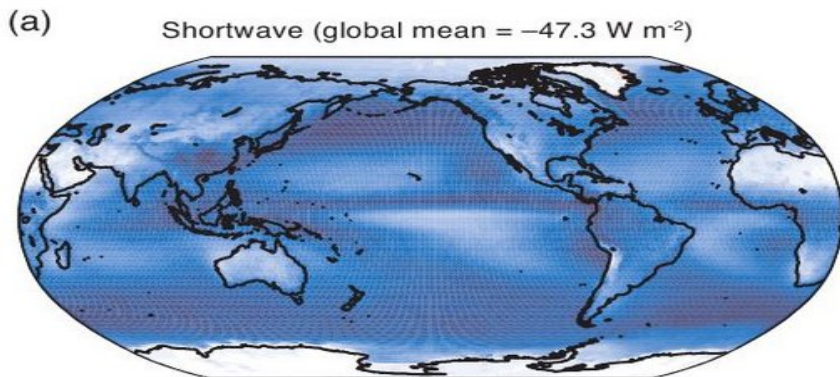


Chmury wysokie ogrzewają a niskie chłodzą...



Wymuszanie radiacyjne chmur

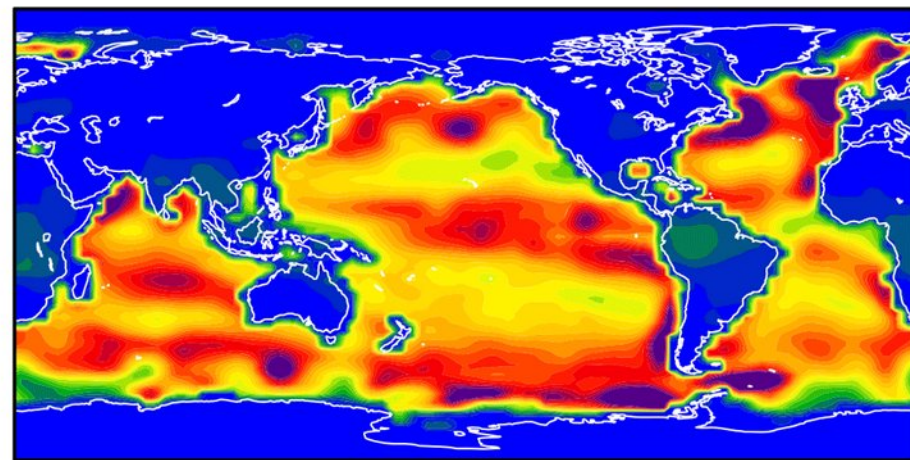
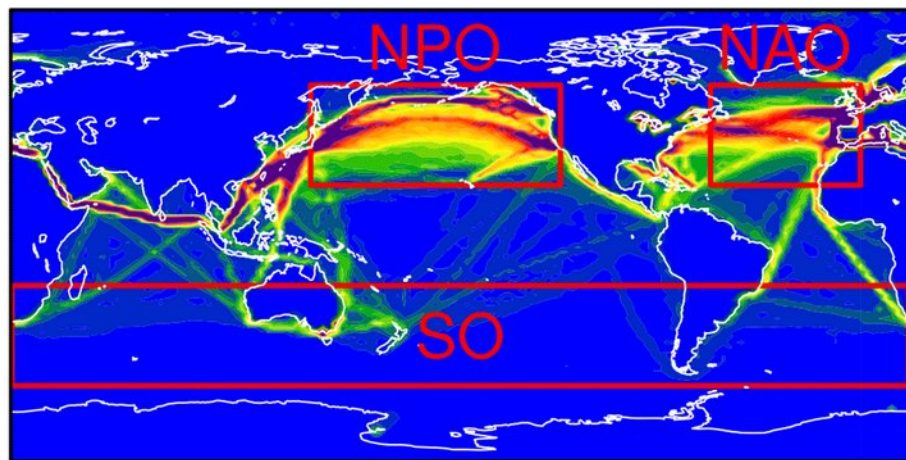




Chmury i ich rola w procesach
radiacyjnych i klimatycznych

(a) Shipping SO_2

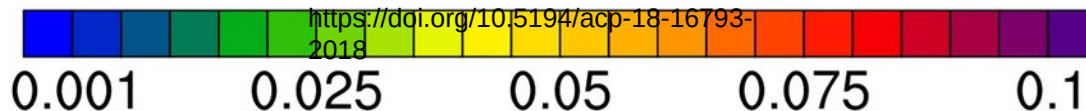
(b) DMS



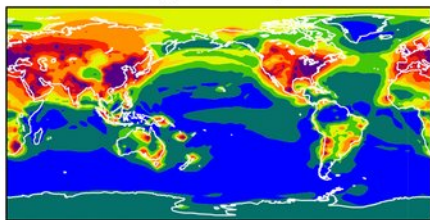
5.4 Tg S yr⁻¹

(g S m⁻² yr⁻¹)

18.2 Tg S yr⁻¹



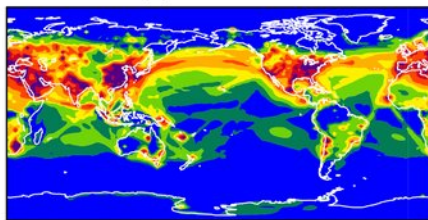
Spatial patterns of annual means of sulfur emissions (g S m⁻² yr⁻¹) from
(a) international shipping and
(b) natural DMS in the simulation at the reference emission level.

(a) Total SO₂

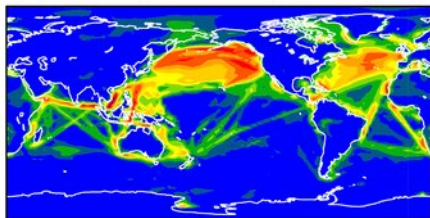
(p.p.b.v.)



(d) Total sulfate



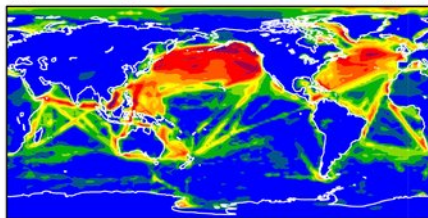
(p.p.t.v.)

(b) Percentage of total SO₂ from shipping

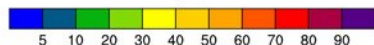
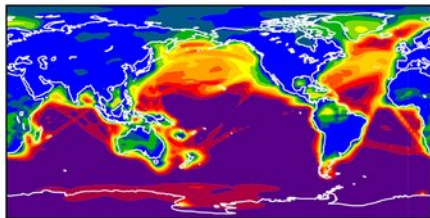
(%)



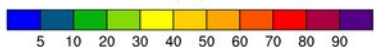
(e) Percentage of total sulfate from shipping



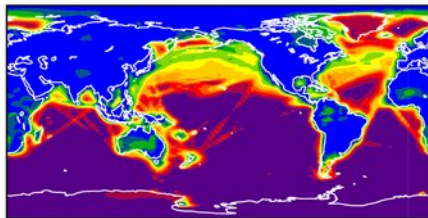
(%)

(c) Percentage of total SO₂ from DMS

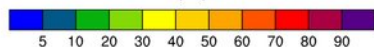
(%)



(f) Percentage of total sulfate from DMS



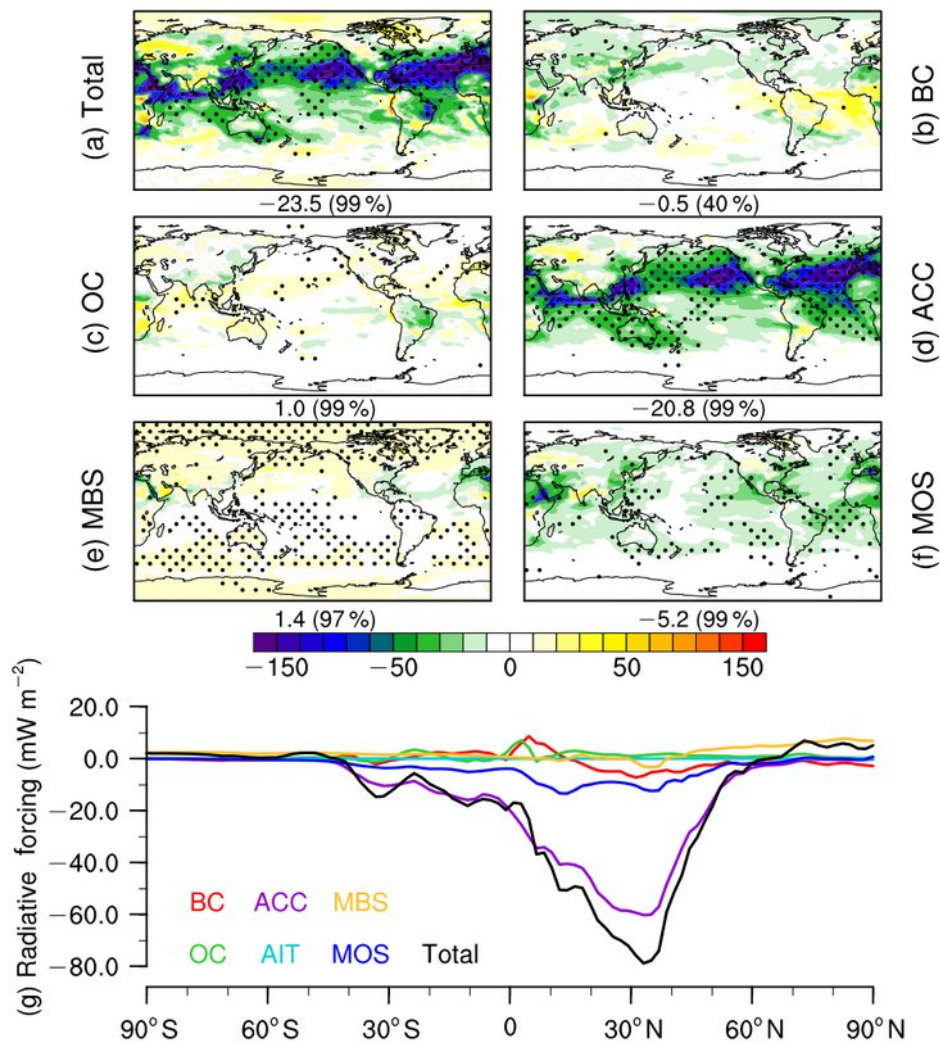
(%)



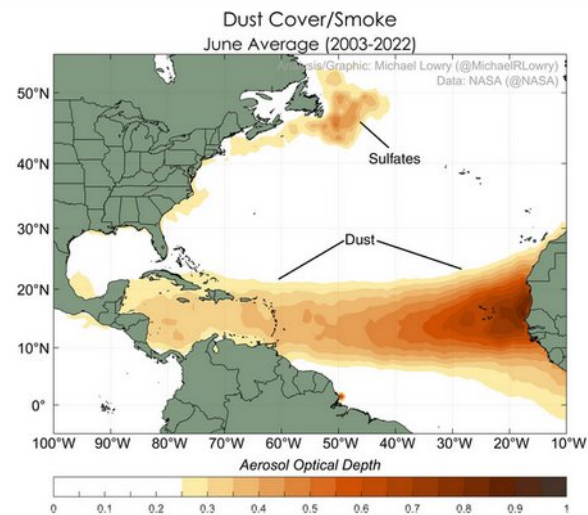
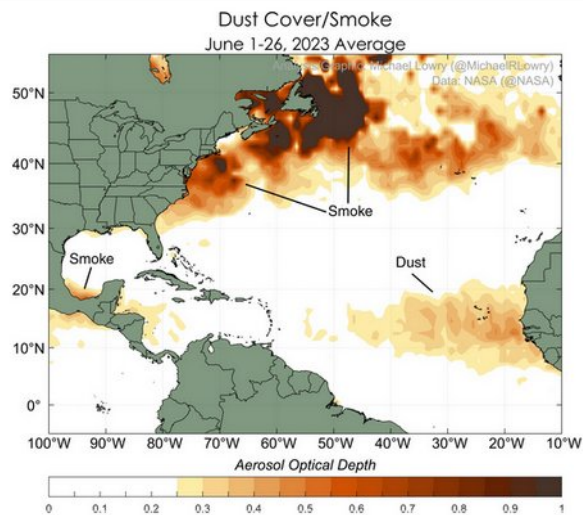
Spatial patterns of
(a) annual mean concentrations of total SO₂ (parts per billion by volume; ppbv).

Panels (b, c) show, respectively, the contributions of shipping emissions and natural DMS to total SO₂ in the lowest model layer.

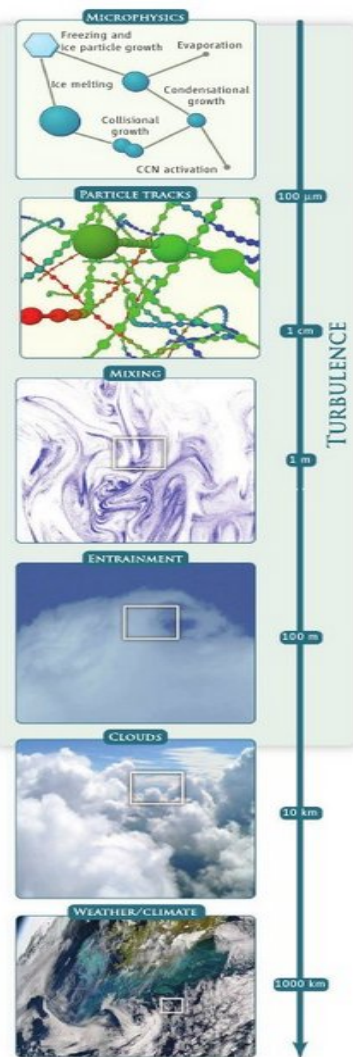
Panels (d)–(f) are the same as (a)–(c), but for sulfate aerosols.



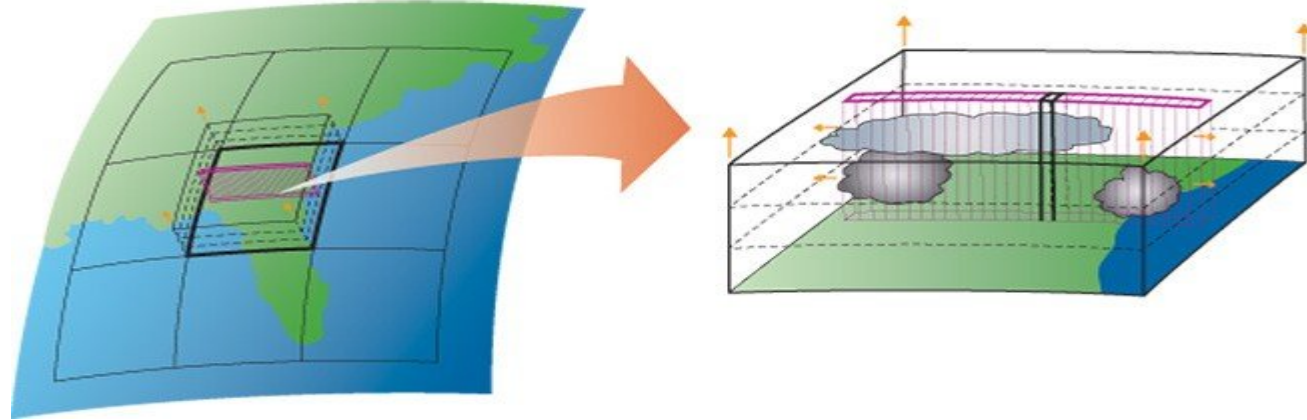
Simulated direct radiative effect (DRE; mW m^{-2}) of ISE at the TOA by MARC. The DRE is calculated as the difference between simulation results with and without ISE (i.e., ShipRef_DMSRef minus ShipZero_DMSRef) and averaged over the 30-year period of simulations at all-sky conditions. Panels (a)–(f) show the spatial patterns of DRE due to ISE with the global mean differences and the associated significant levels indicated by the numbers below each panel, and panel (g) shows the meridional variations in zonal mean DRE for various aerosol types from ISE and their total effects.



Comparison of June dust in 2023 (left) to the typical dust cover (2003-2022).
NASA via Berkeley Earth



Jak sobie radzimy z problemami?
 „Multiscale modeling” - modelowanie wieloskalowe,
 superparametryzacje, GIGA-LES, ILES,
 explicit cloud-resolving....

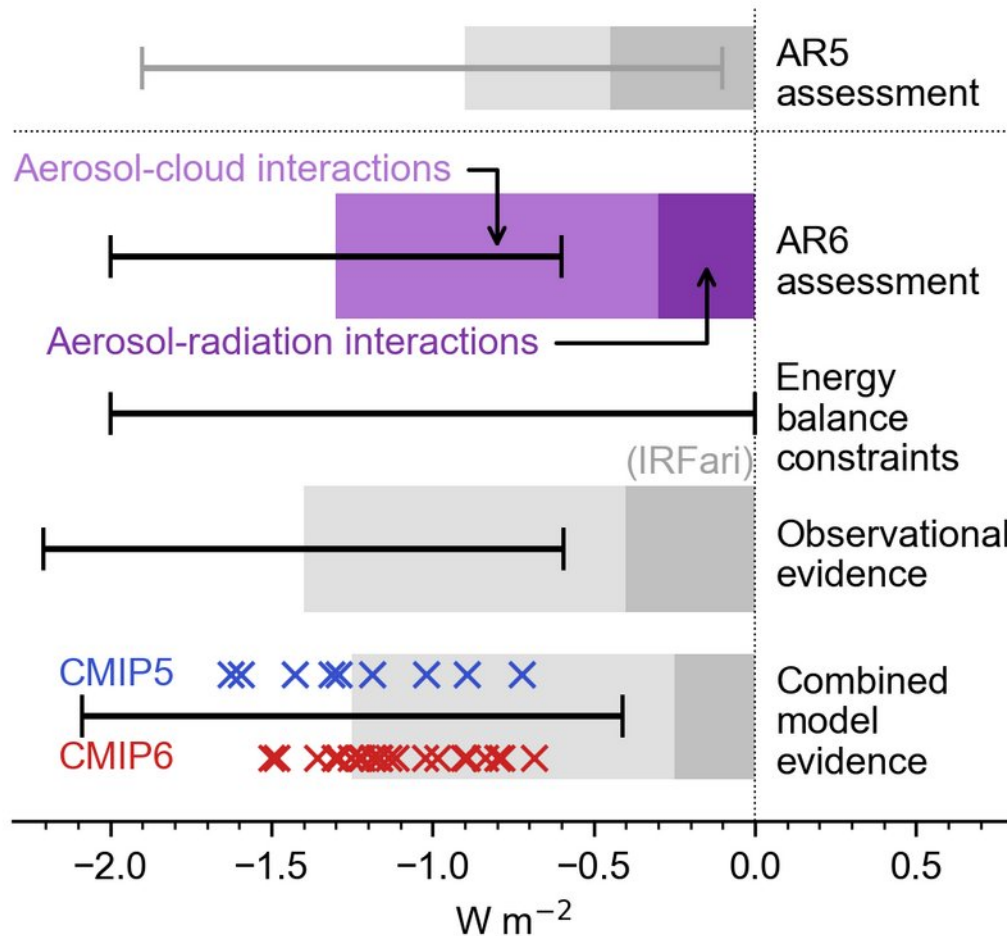


Bodenschatz, E., S.P. Malinowski, R.A. Shaw, F. Stratmann, 2010: Can We Understand Clouds without Turbulence? *Science*, **327**, 970 – 971.

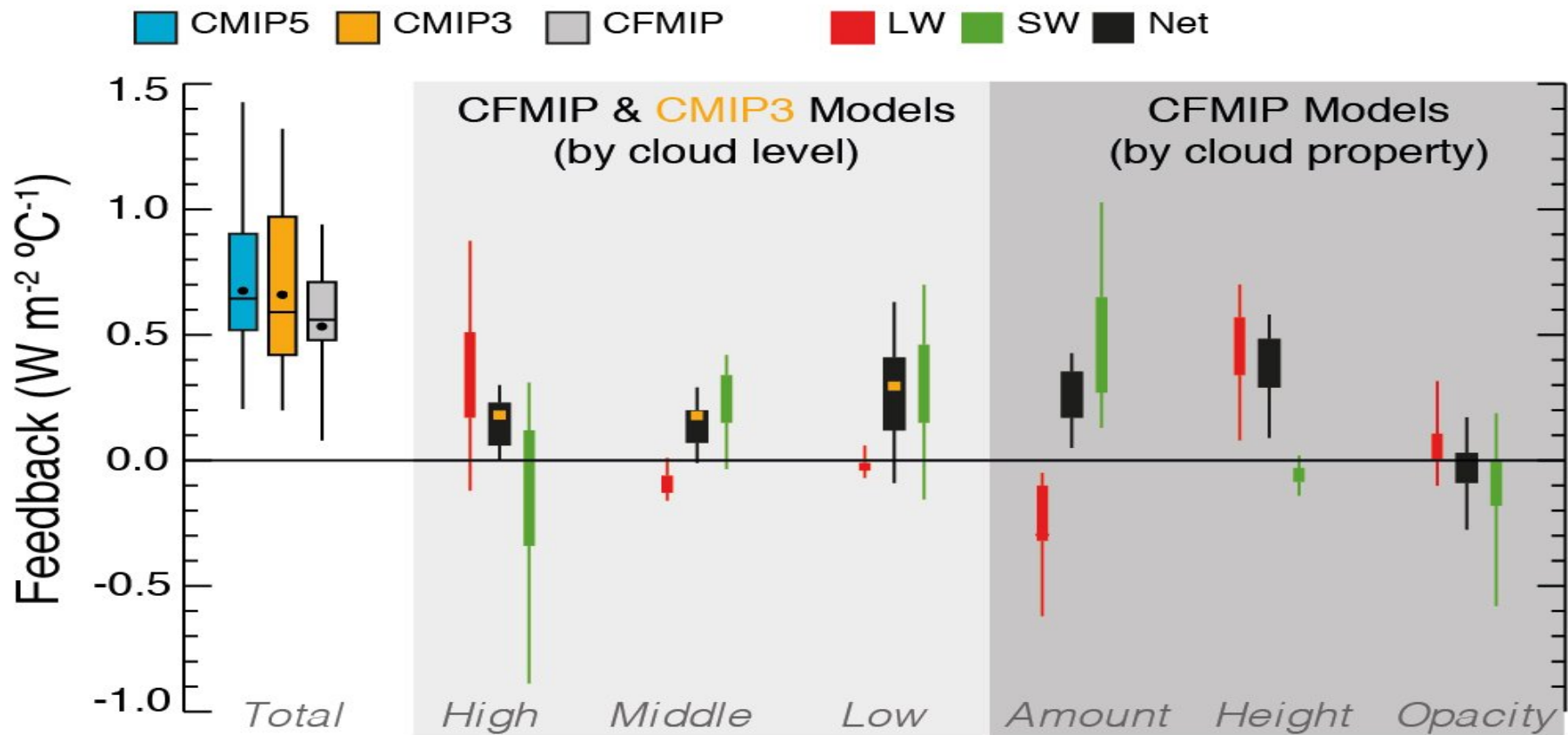
Randall D.A., Khairoutdinov M., Arakawa A., Grabowski W.W., 2003: Breaking the cloud parameterization deadlock . *Bull. Amer. Meteorol. Soc.*, **84**, 1547-1564.

I wiele wiele innych....

Aerosol effective radiative forcing



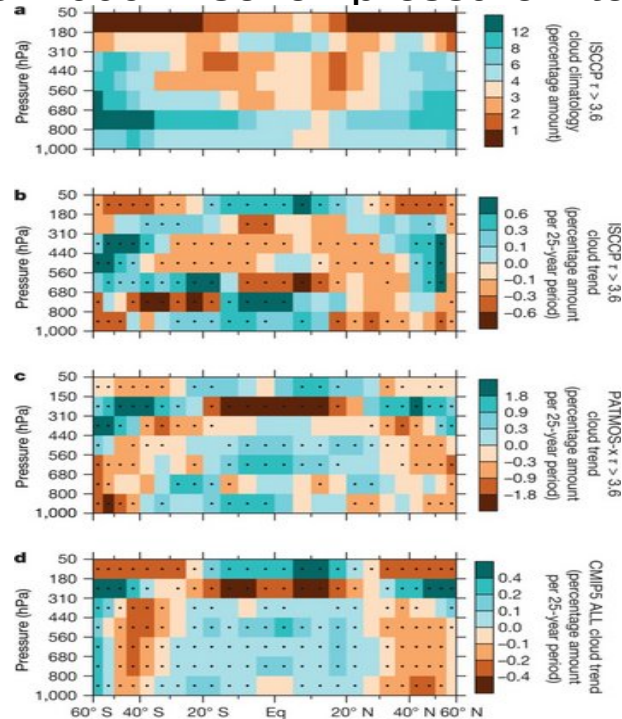
Net aerosol effective radiative forcing (ERF) from different lines of evidence. The headline AR6 assessment of -1.3 [-2.0 to -0.6] W m^{-2} is highlighted in purple for 1750–2014 and compared to the AR5 assessment of -0.9 [-1.9 to -0.1] W m^{-2} for 1750–2011. The evidence comprising the AR6 assessment is shown below this: energy balance constraints [-2 to 0 W m^{-2} with no best estimate]; observational evidence from satellite retrievals of -1.4 [-2.2 to -0.6] W m^{-2} ; and climate model-based evidence of -1.25 [-2.1 to -0.4] W m^{-2} .



Efekty sprzężeń związanych z chmurami wskutek z zmian koncentracji CO₂ w atmosferze.

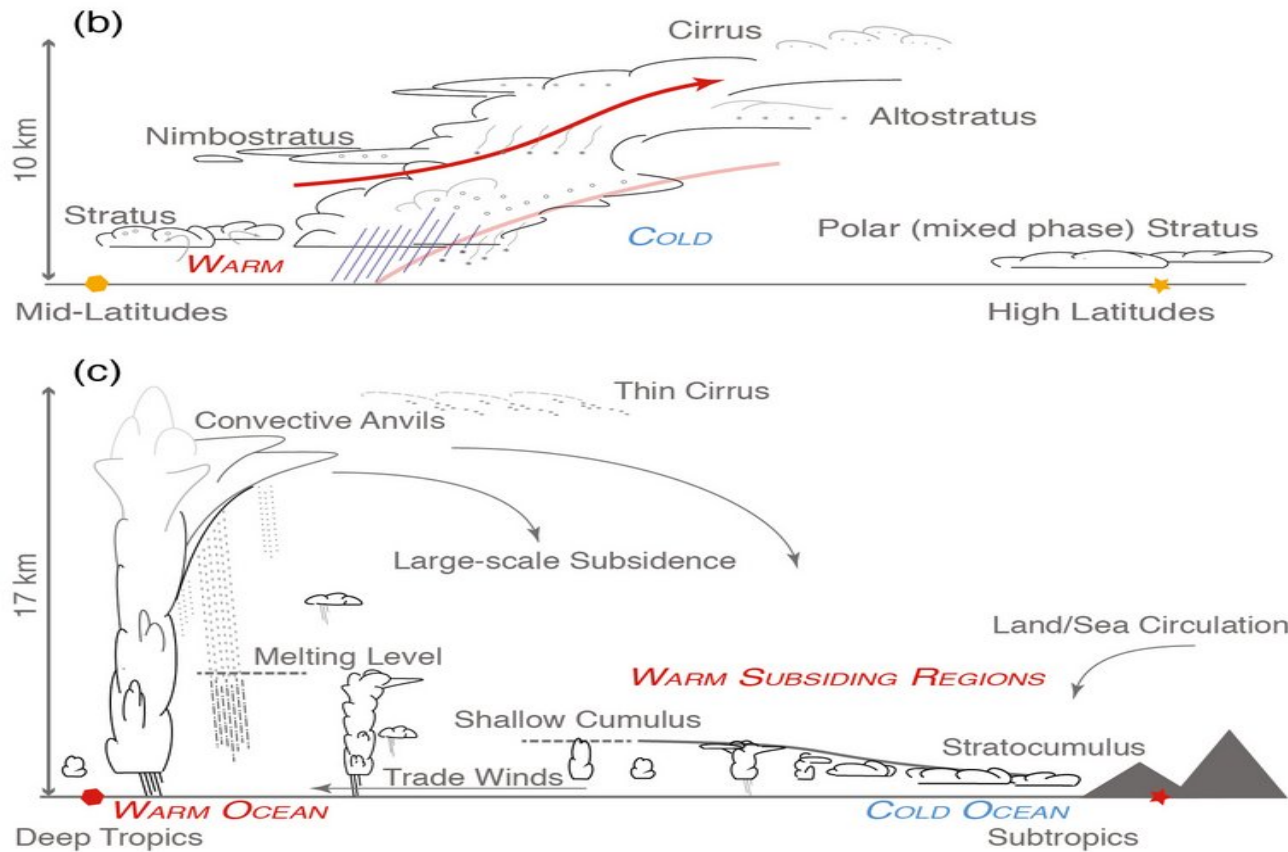
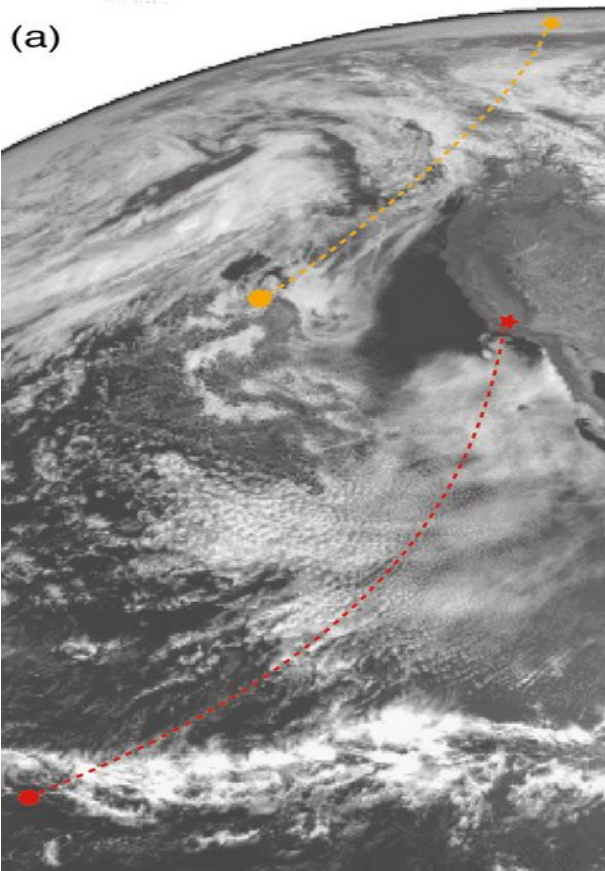
Zonal mean change in observed and simulated cloud amount during the period 1983–2009 in seven pressure intervals

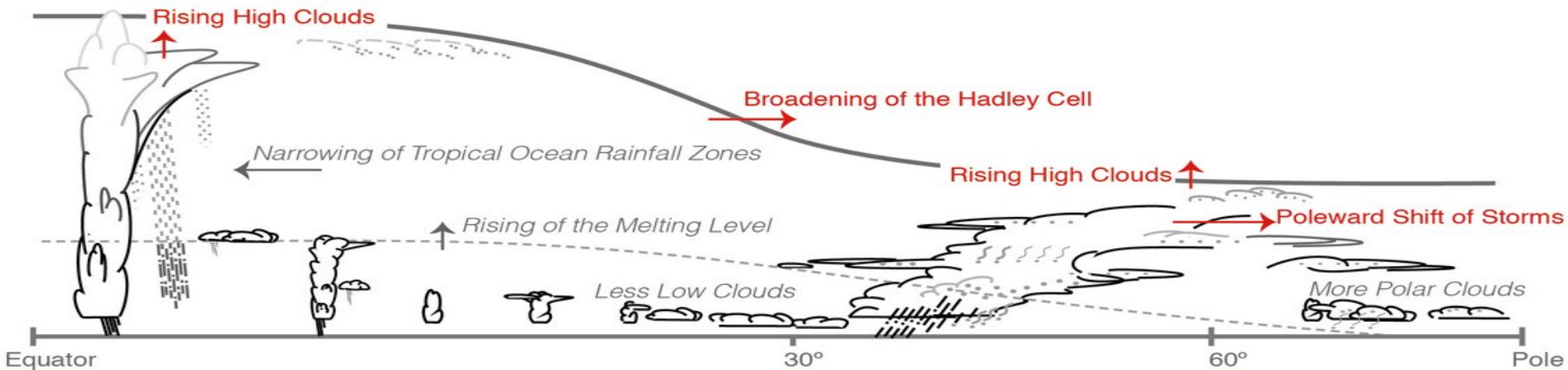
Układy chmur przesuwają się w kierunku biegunów i w górę, co wzmacnia ocieplenie klimatu.



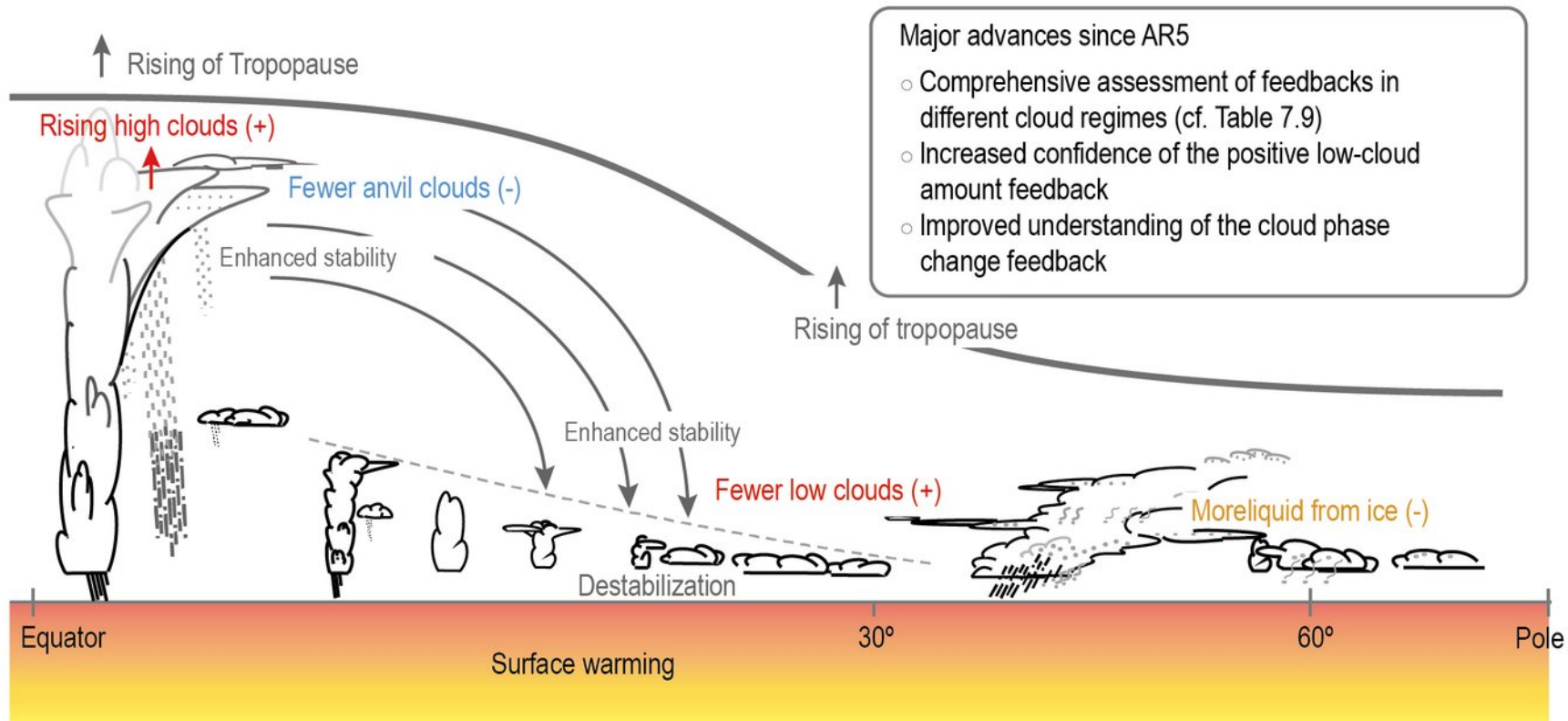
J R Norris et al. *Nature* 1–4 (2016) doi:10.1038/nature18273

Chmury i aerozole, a ściślej cykl hydrologiczny wpływają nie tylko na strumienie radiacyjne, ale i na dynamikę atmosfery i oceanu.



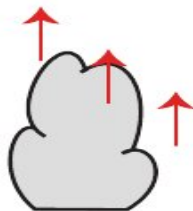


Zmiany w strukturze i dynamice atmosfery związane ze zmianami zachmurzenia na ocieplającej się Ziemi.

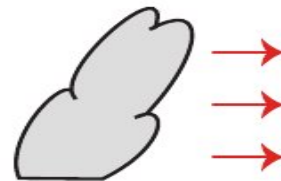
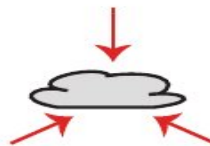


Greenhouse Warming

Tropics



Mid-latitudes



Cloud Response

High clouds rise as troposphere deepens, increasing difference between cloud top and surface temperature.

Reduction in mid- and low-level cloudiness (left). Shift of cloudy storm tracks poleward into regions with less sunlight (right).

Feedback Mechanism

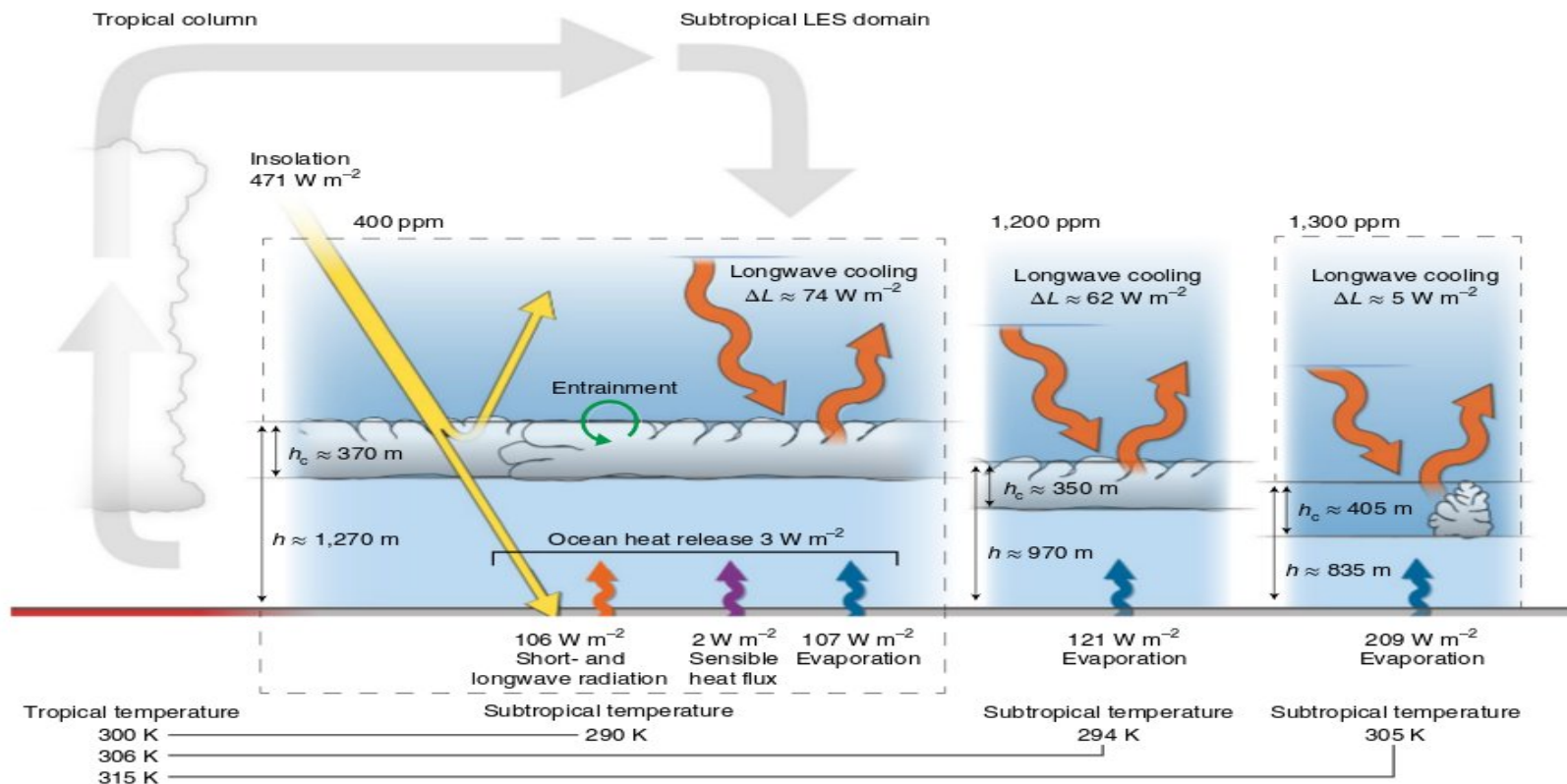
High clouds more effectively trap infrared radiation, increasing surface warming.

Less sunlight reflected by clouds back to space, increasing surface warming.

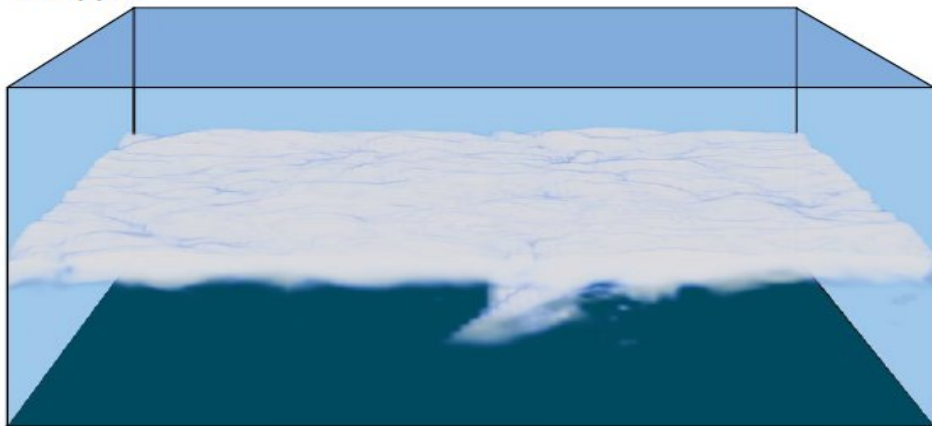
Zmiany w zachmurzeniu ocieplającej się planety – schematycznie.

Morskie chmury: nowo odkryte sprzężenie zwrotne destabilizujące klimat Ziemi.

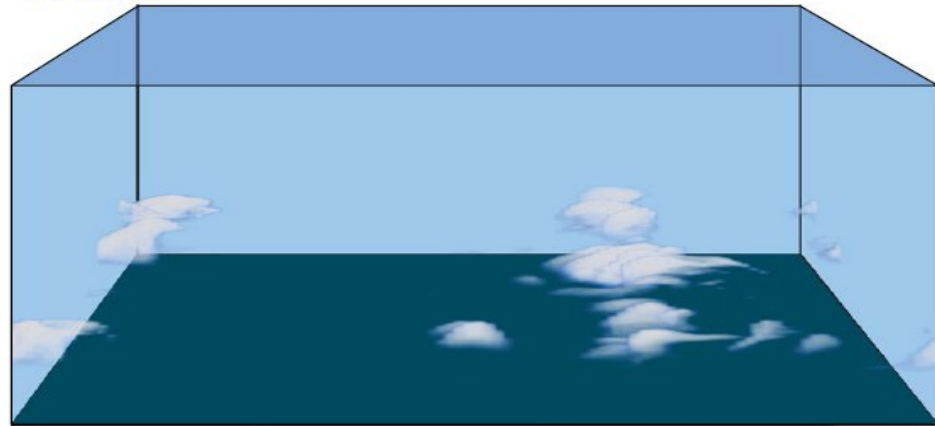




400 ppm

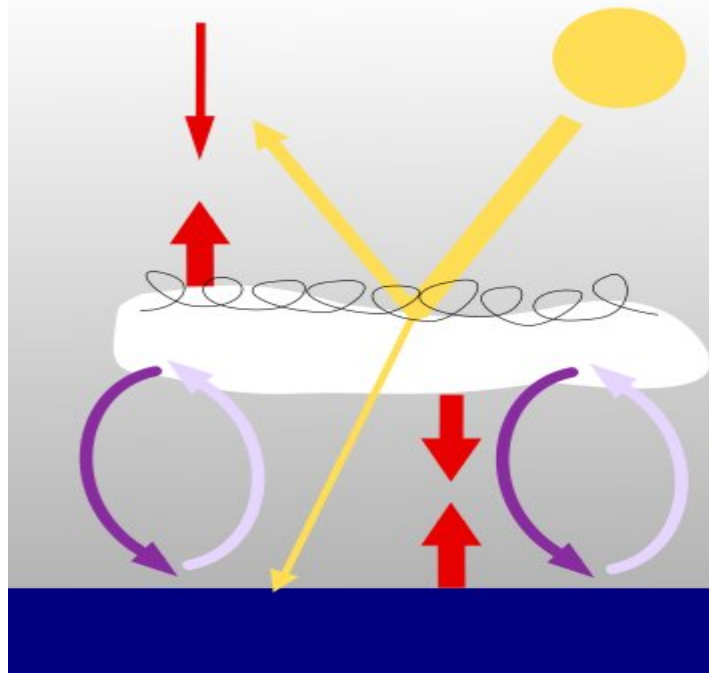


1,600 ppm

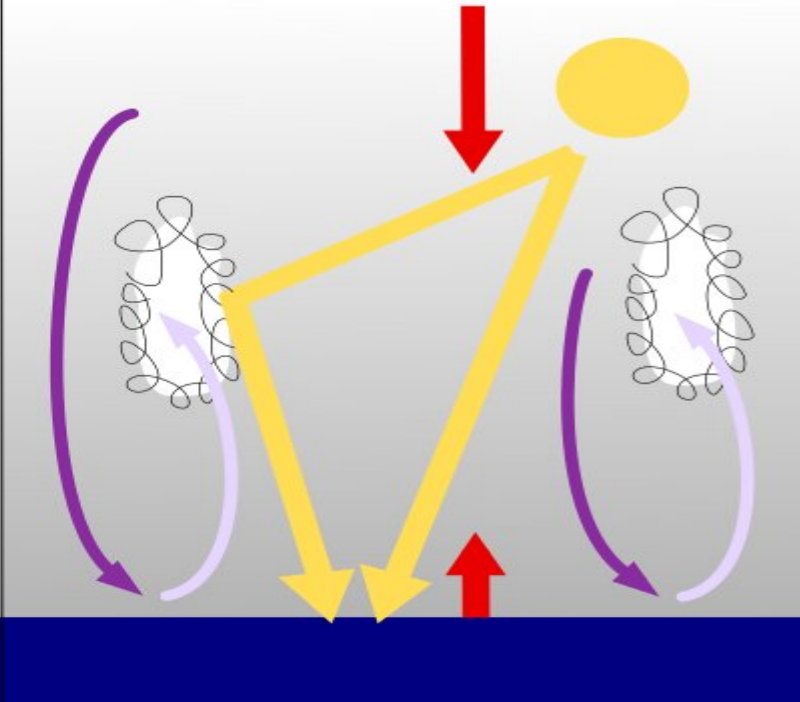


Wyniki symulacji zachmurzenia w rejonie podzwrotnikowym przy różnych średnich koncentracjach dwutlenku węgla. Po lewej – 400 ppm (stan obecny, ze średnią temperaturą powierzchni morza w tym rejonie ok. 17°C), po prawej – 1600 ppm (możliwy stan przyszły, ze średnią temperaturą morza w

400 ppm CO₂



1600 ppm CO₂



Schemat zmian w bilansie energii i właściwości morskiej warstwy granicznej atmosfery nakrytej chmurą stratocumulus w sytuacji, gdy koncentracja CO₂ w atmosferze wzrośnie z wartości obecnych (ok. 400 ppm) do ok. 1600 ppm. (przyszłe stulecie w scenariuszu Biznes-jak-zwykle) Proste żółte linie ze strzałkami schematycznie pokazują bilans promieniowania słonecznego, czerwone – promieniowania podczerwonego (cieplnego). Fioletowe strzałki ilustrują transport konwekcyjny (mieszanie wskutek konwekcji) w dolnych warstwach atmosfery: pokazują, że przy konwekcji stratocumulusowej wymiana pary wodnej i wody ograniczona jest do płytkiej warstwy pokrytej chmurami, w przeciwieństwie do sytuacji z konwekcją cumulusową, gdzie mieszanie i transport pary wodnej z powierzchni oceanu obejmuje znacznie głębszy obszar

Nierównowaga energetyczna narasta nie tylko dlatego, że **rośnie efekt cieplarniany**,

ale także dlatego, że **spada albedo** naszej planety,

gdyż **maleje zawartość aerozolu**, **zmieniają się chmury**, **zmniejsza się powierzchnia lodu**.

RESEARCH ARTICLE | GLOBAL WARMING

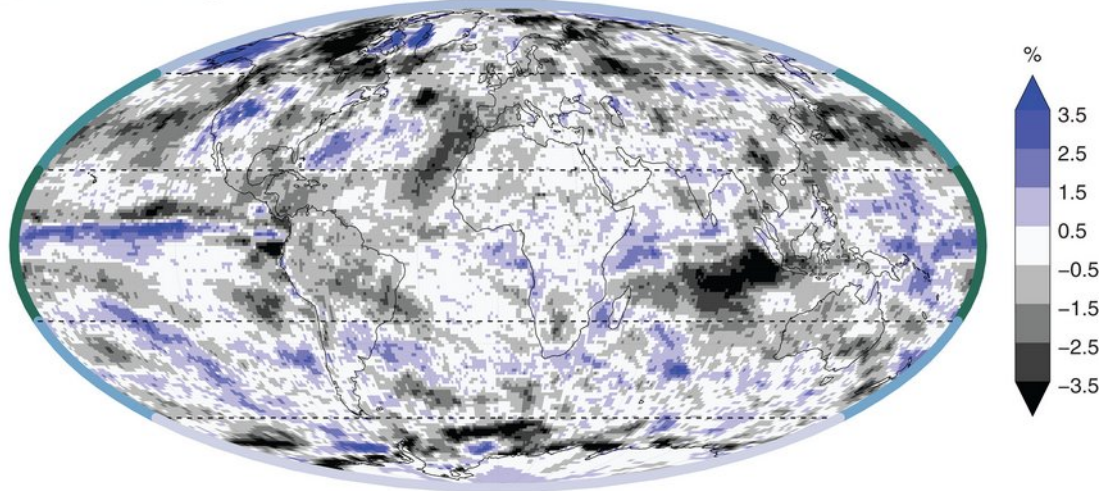
f X in

Recent global temperature surge intensified by record-low planetary albedo

HELGE F. GOESSLING · THOMAS RACKOW · AND THOMAS JUNG · Authors Info & Affiliations

SCIENCE • 5 Dec 2024 • Vol 387, Issue 6729 • pp. 68-73 • DOI: 10.1126/science.ado7280

A CERES Planetary Albedo Anomaly 2023



B Contributions to Global-Mean Temperature Anomaly 2023

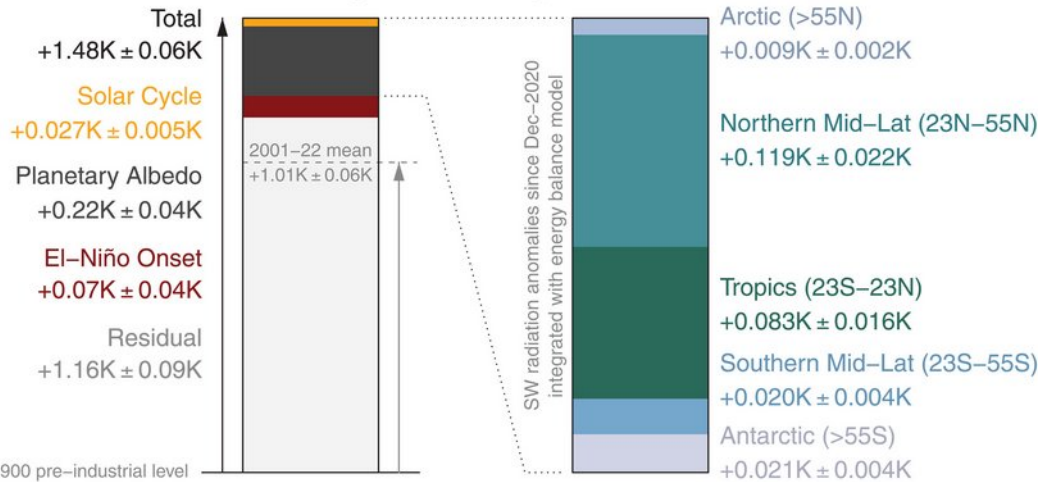
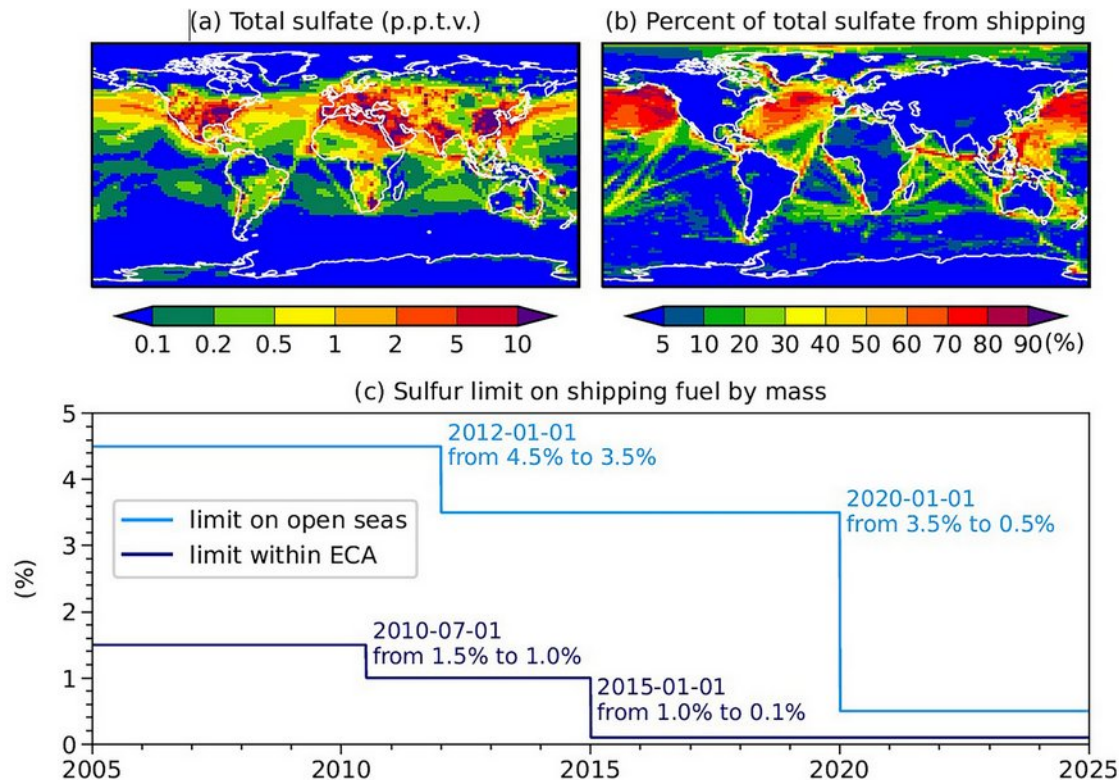


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Figure S5. Sulfate aerosols and sulfur limit on emissions, p.p.t.v. = parts per trillion by volume.**



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James E. Hansen, Pushker Kharecha, Makiko Sato, George Tselioudis, Joseph Kelly, Susanne E. Bauer, Reto Ruedy, Eunbi Jeong, Qinjian Jin, Eric Rignot, Isabella Velicogna, Mark R. Schoeberl, Karina von Schuckmann, Joshua Amponsem, Junji Cao, Anton Keskinen, Jing Li & Anni Pokela

<https://doi.org/10.1080/00139157.2025.2434494>

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03 February 2025

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Figure 6. Earth's albedo (reflectivity, in percent), seasonality removed.**

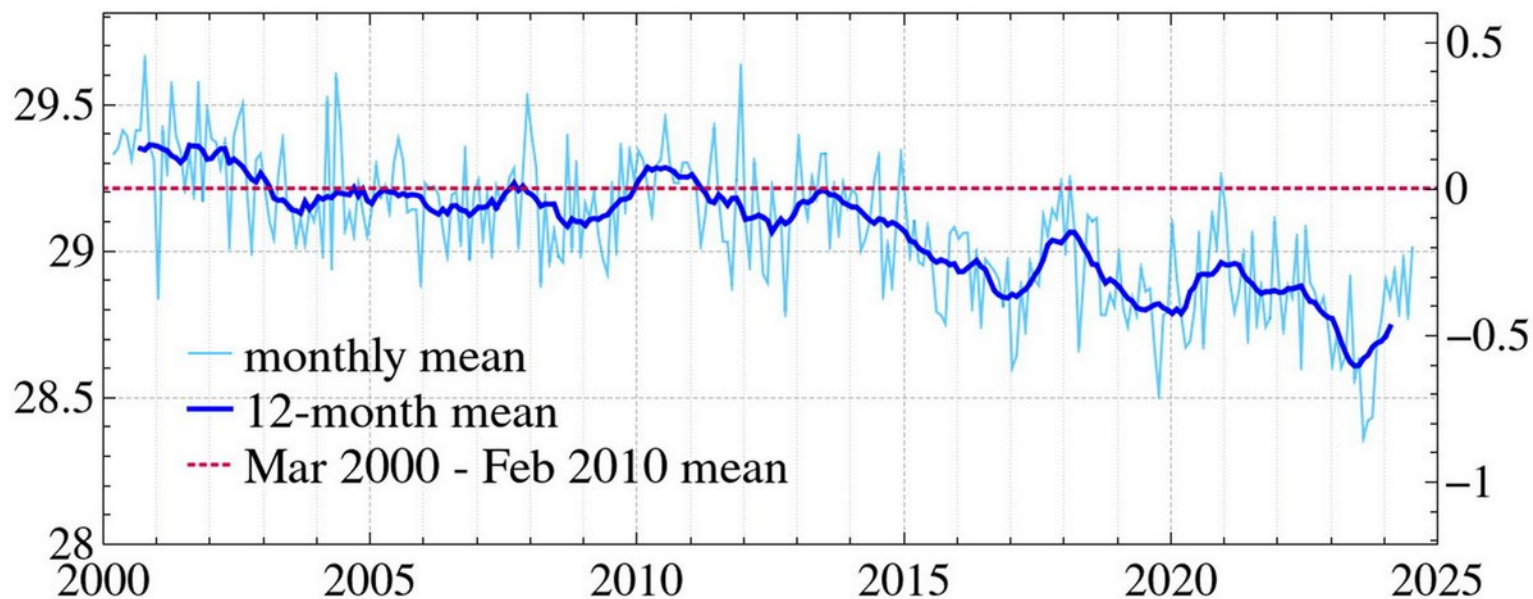
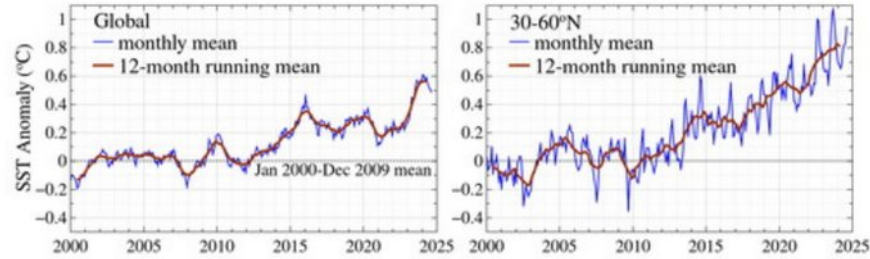
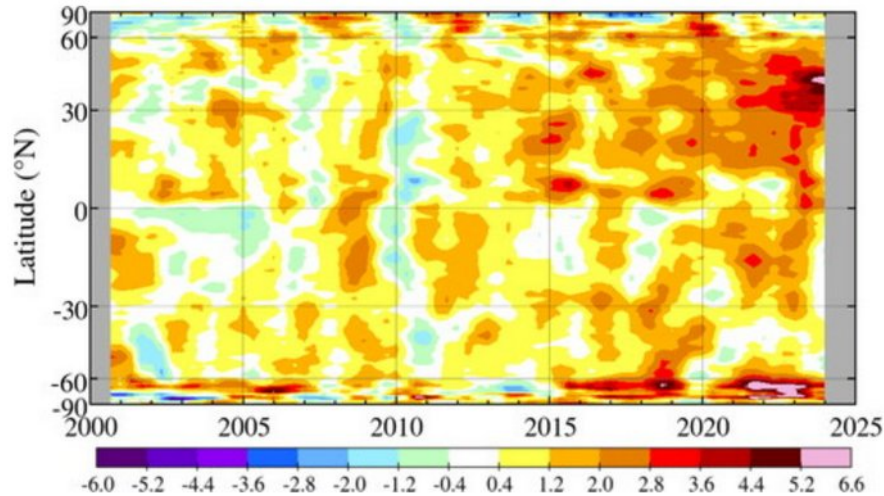


Figure 11. Global and 30-60°N Sea Surface Temperature anomalies.**

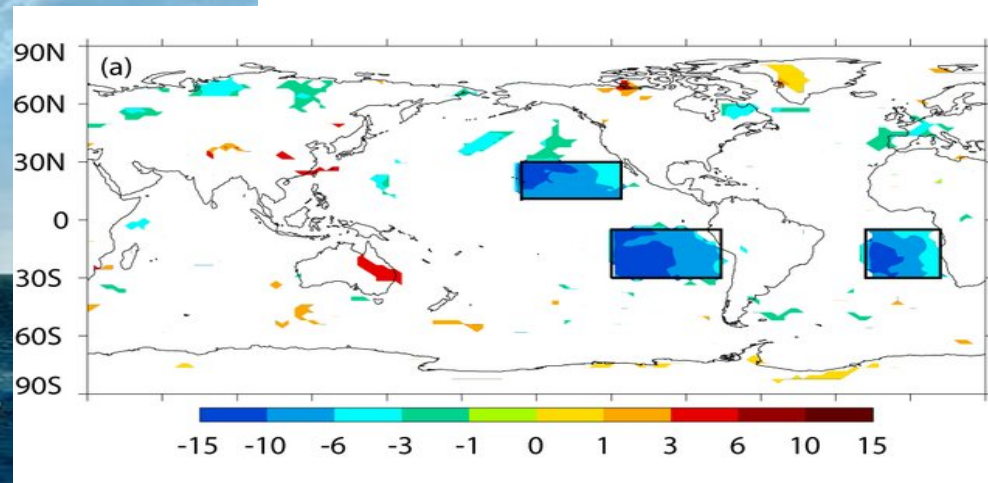
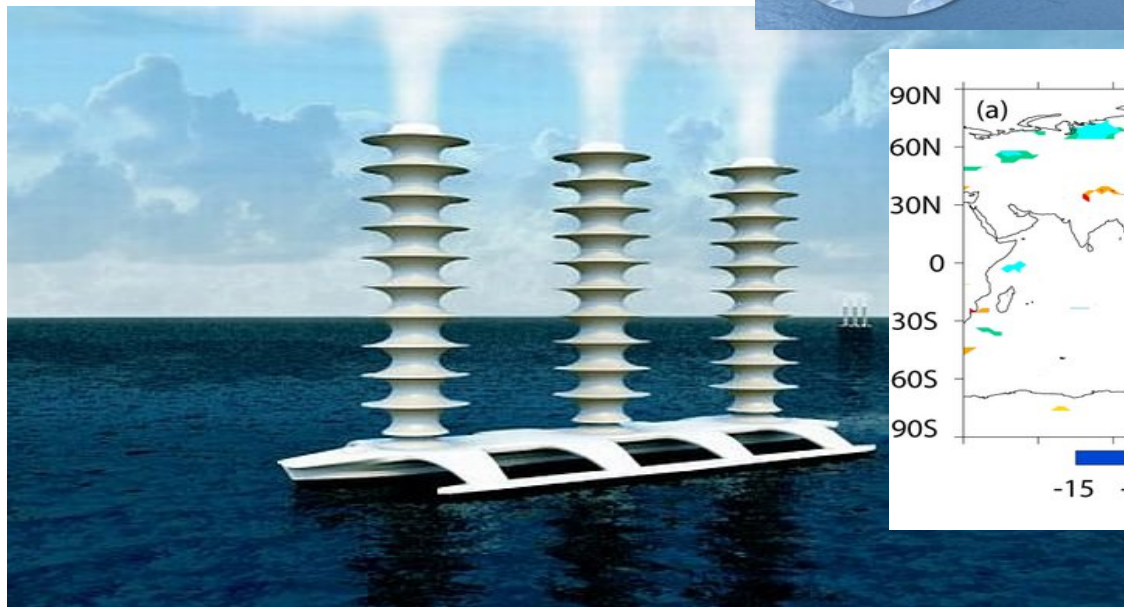
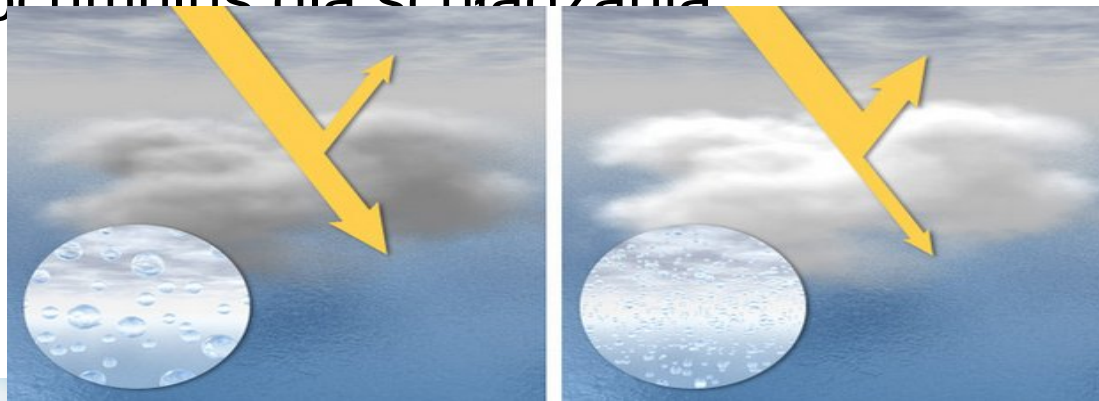


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Figure 12. Zonal-mean Earth energy balance over ocean (W/m^2).**



„Wybielanie” chmur stratocumulus dla schładzania
planety?





Robert Wood

Professor, Atmospheric
Sciences, Univ. of Washington

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Publications in process, not yet submitted:

The impact of the interaction of cloud microphysics and macro-physics with large-scale circulation on stratocumulus-to-cumulus transition. Je-Yun Chun, Robert Wood, Peter N. Blossey, and Sarah J. Doherty, 2024: To be submitted to Atmospheric Chemistry and Physics

Evaluation of E3SM version 2 marine boundary layer clouds over the northeast Pacific during the CSET Campaign. Kyoung Ock Choi, Philip J. Rasch, Robert Wood, Sarah J. Doherty, 2024: To be submitted to Journal of Geophysical Research - Atmospheres

Submitted, in review:

A protocol for model intercomparison of impacts of Marine Cloud Brightening Climate Intervention. Philip J. Rasch, Haruki Hirasawa, Mingxuan Wu, Sarah Doherty, Robert Wood, Hailong Wang, Andy Jones, James Haywood, Hansi Singh, 2024, submitted to Geoscientific Model Development (GMD).

[Aggressive aerosol mitigation policies reduce chances of keeping global warming to below 2C](#). Robert Wood, Mika. A. Vogt, and Isabel. L. McCoy. Manuscript submitted to Earth's Future, October 2023.

[Exploring ship track spreading rates with a physics-informed Langevin particle parameterization](#). Lucas A. McMichael, Michael J.

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