FGB ITB Future Science and Technology Talk #8
26 Juli 2024

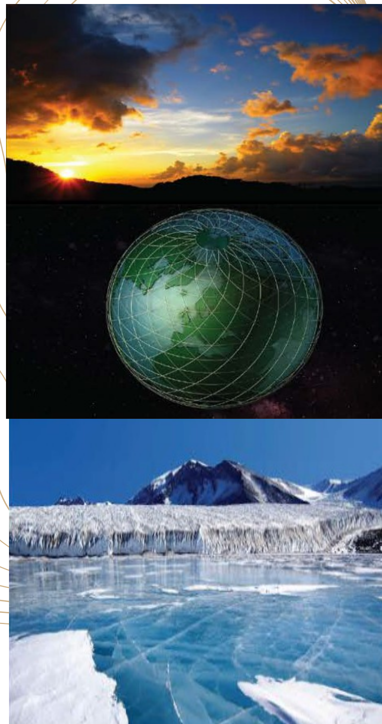
Image credit: WRCP theme slide

Perubahan Iklim: Tantangan Sains Saat Ini dan Masa Depan

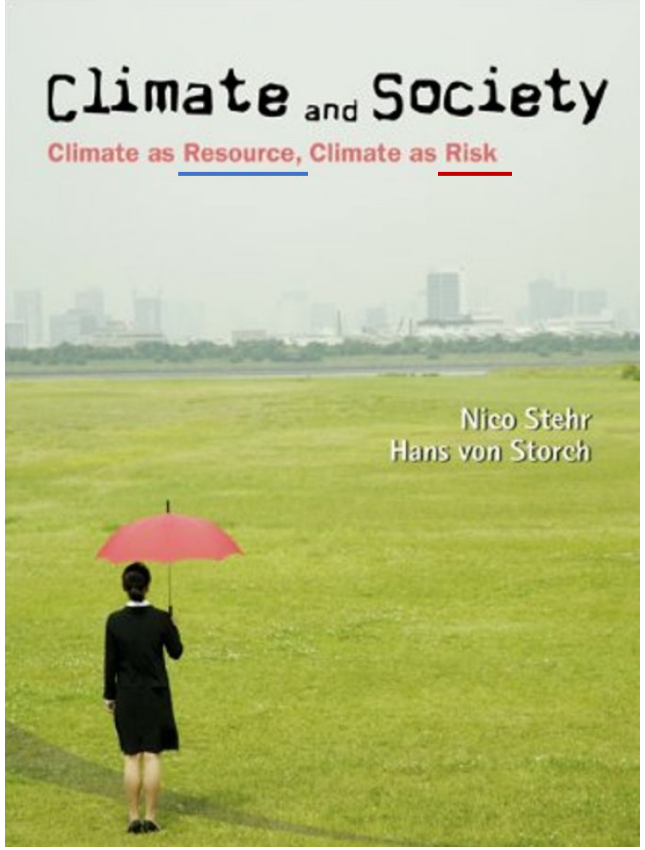
oleh:

Tri Wahyu Hadi

Kelompok Keahlian Sains Atmosfer
Fakultas Ilmu dan Teknologi Kebumian
Institut Teknologi Bandung



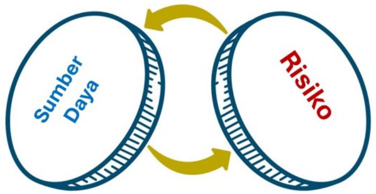
Iklim dalam Masyarakat Modern

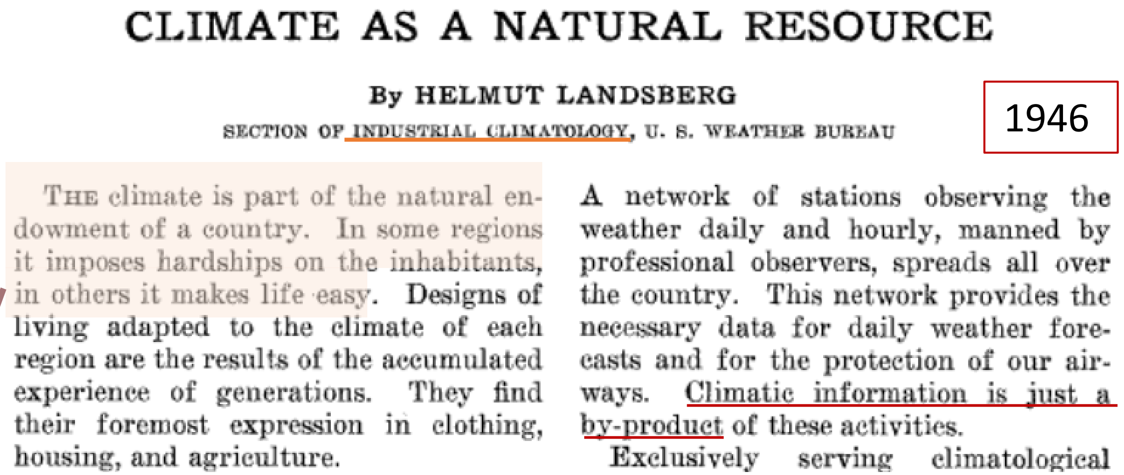


CLIMATE AND SOCIETY
Climate as Resource, Climate as Risk

Keunggulan komparatif?

One of the messages of this book is that the scientific subject matter "climate" should not only be located within the domain of natural sciences, but also within the realm of the social sciences and humanities. This is even more valid when the public and policy-makers have to be advised how to deal with suggestions and warnings prompted by scientific climate research.





CLIMATE AS A NATURAL RESOURCE

By HELMUT LANDSBERG

SECTION OF INDUSTRIAL CLIMATOLOGY, U. S. WEATHER BUREAU

1946

THE climate is part of the natural endowment of a country. In some regions it imposes hardships on the inhabitants, in others it makes life easy. Designs of living adapted to the climate of each region are the results of the accumulated experience of generations. They find their foremost expression in clothing, housing, and agriculture.

A network of stations observing the weather daily and hourly, manned by professional observers, spreads all over the country. This network provides the necessary data for daily weather forecasts and for the protection of our airways. Climatic information is just a by-product of these activities.

Exclusively serving climatological

Today we are on very much more certain ground when we assert that the climate is not determining, but more or less conditioning, social processes.

Competitiveness prevails…

Bagaimana dengan Risiko?

Iklim Seperti yang (Mungkin) Anda Tahu

1) Climate in a narrow sense is usually defined as the **"average weather,"** or
2) more rigorously, as the statistical description in terms of the **mean** and **variability** of relevant quantities over a period of time ranging from months to thousands of years.

ON THE CLIMATE OF AND METEOROLOGICAL RESEARCH IN THE NETHERLANDS INDIES

by

C. BRAAK, Ph.D.*

Dept. of Climatology, Royal Meteorological Observatory, De Bilt, Netherlands; late Director of the Royal Magnetical and Meteorological Observatory, Batavia.

Added to this seasonal variation are the local differences, which are relatively large on account of the mountainous character of the country, which makes rainfall and cloudiness to a high degree dependent upon the direction of the wind. Moreover, in successive years differences occur in the force of the monsoons which are closely connected with the general air-circulation. Consequently the differences between the seasons may vary appreciably, so that in some years the farmer will wait in vain for the dry season, whereas in other years he will look out for months and months for the first good shower.

* Reprinted from "Science in the Netherlands East Indies," pp. 50–64 (Amsterdam: Kon. Ak. Wet., I.C.O. Committee, 1929).

Climate Variability

Not (yet) Climate Change !

Kajian Iklim dalam Geografi (Indonesia)

LAND EN VOLK VAN SUMATRA

DOOR

C. LEKKERKERKER.

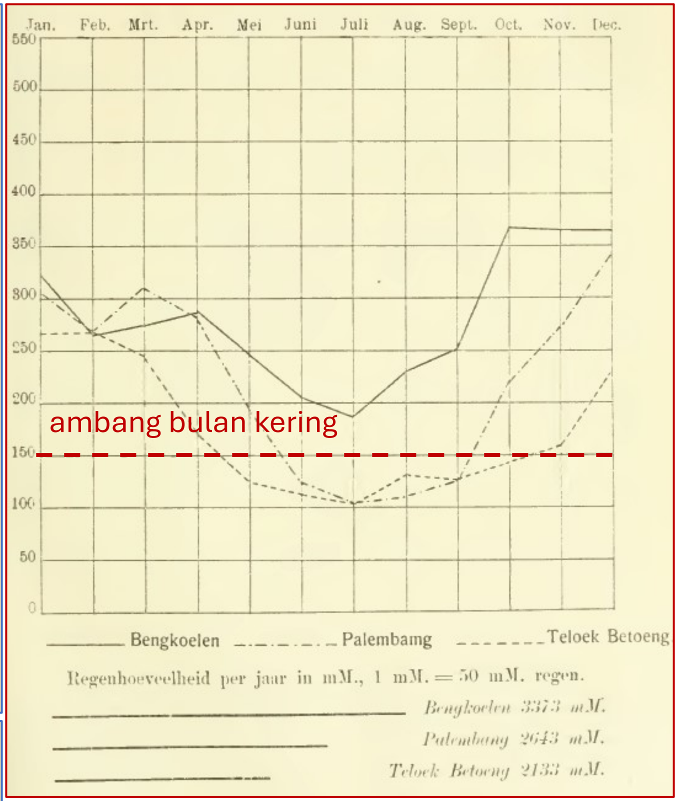
Oud-Inspecteur van het Inlandsch onderwijs in Nederlandsch-Indië, Archivaris van het Bali-Instituut.

Met 32 platen, 1 kaart en 4 graphische voorstellingen.

(Bekroond antwoord op een prijsvraag van het Koloniaal Instituut.)

N. V. BOEKHANDEL EN DRUKKERIJ VOORHEEN E. J. BRILL — LEIDEN. 1916.

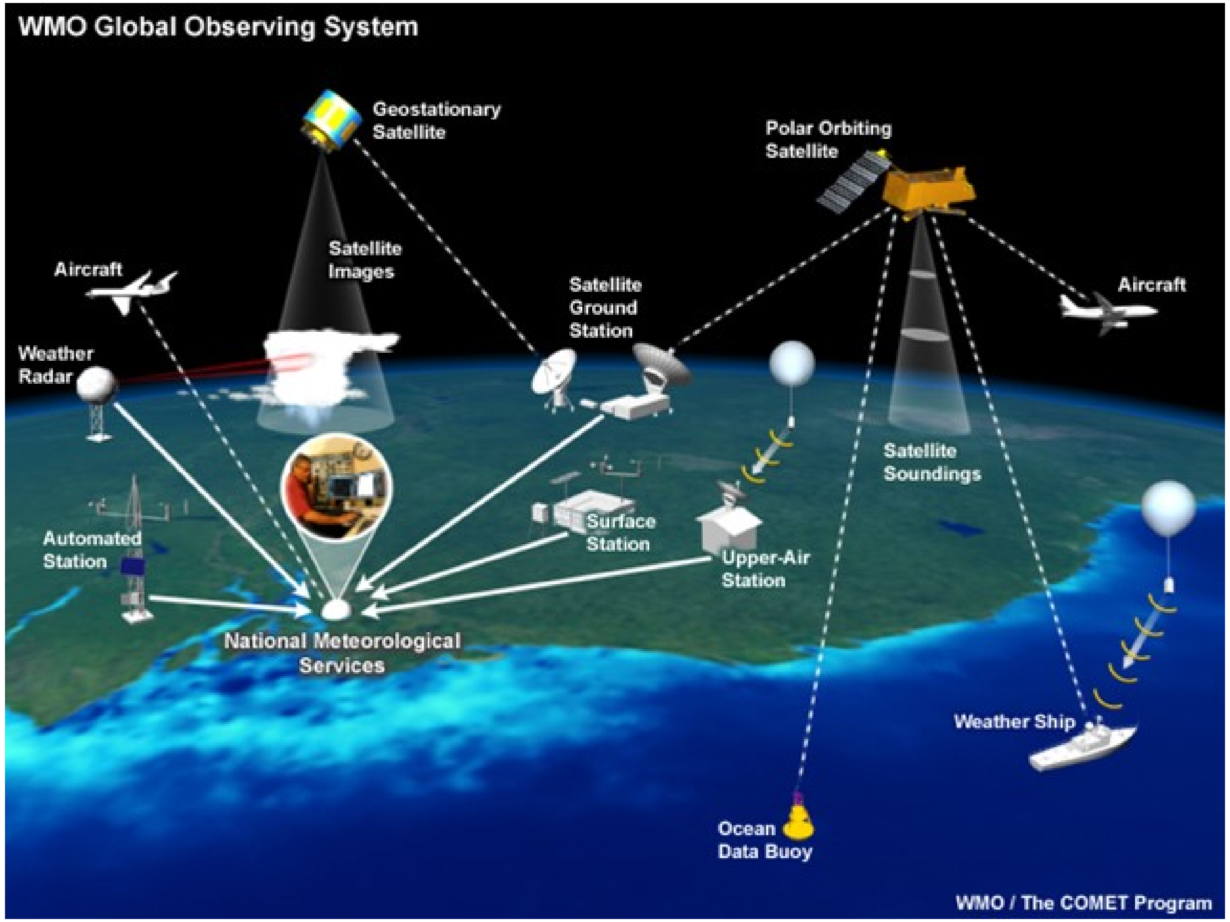
IV. KLIMAAT, BODEM EN DIERENWERELD.



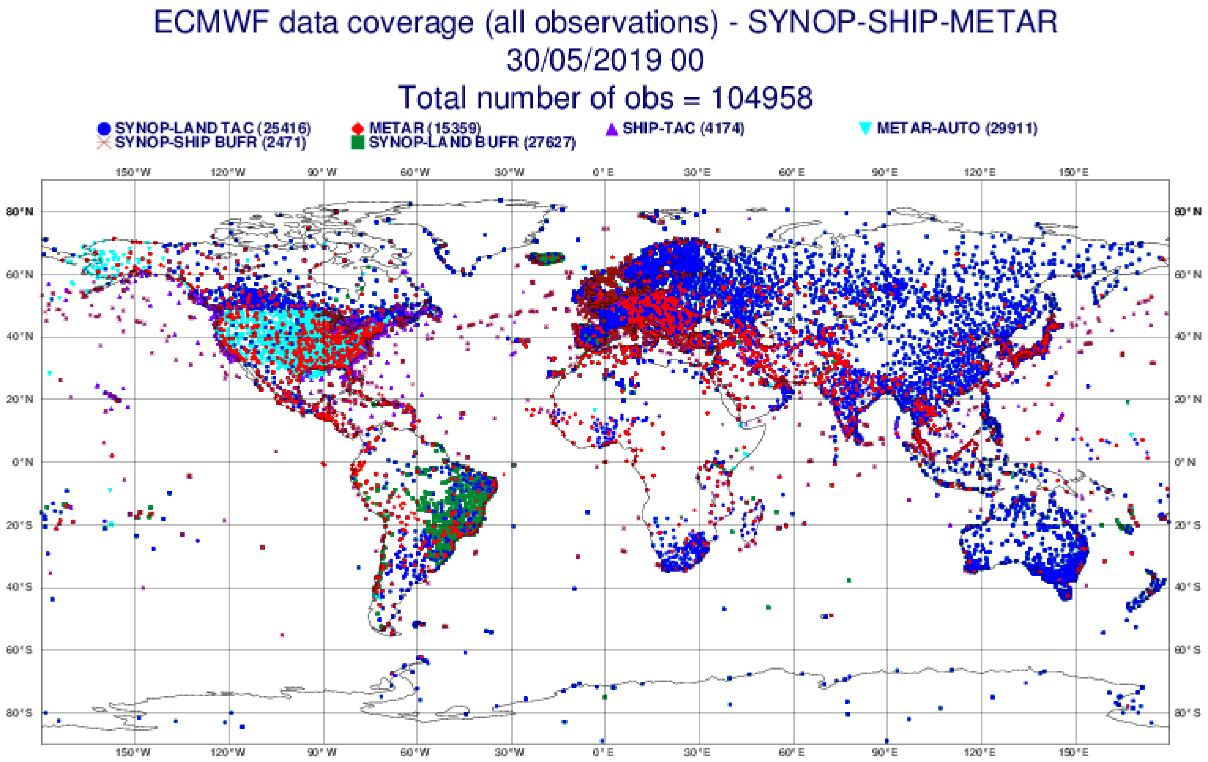
Regen.

Van de klimaatsfactoren is voor een tropisch land die van den regen wel de meest belangrijke. Hoeveel regen valt er en hoe is de hoeveelheid over het jaar verdeeld? Dit zijn voor den landbouwer wel de voornaamste klimaatsvragen.

Observasi Cuaca/Iklim



Source: https://uls.climate.copernicus.eu



Source: ECMWF SYNOP-SHIP-METAR data coverage

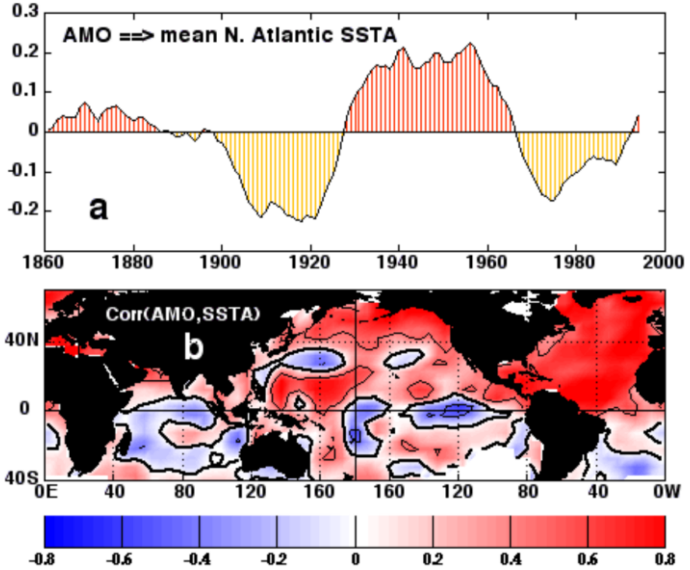
- Observasi cuaca/iklim merupakan upaya kerjasama global dengan biaya yang sangat besar
- **Berbagai teknologi** terus (menjadi tantangan untuk) dikembangkan untuk mendapatkan data pengamatan dengan akurasi lebih tinggi dan biaya lebih murah

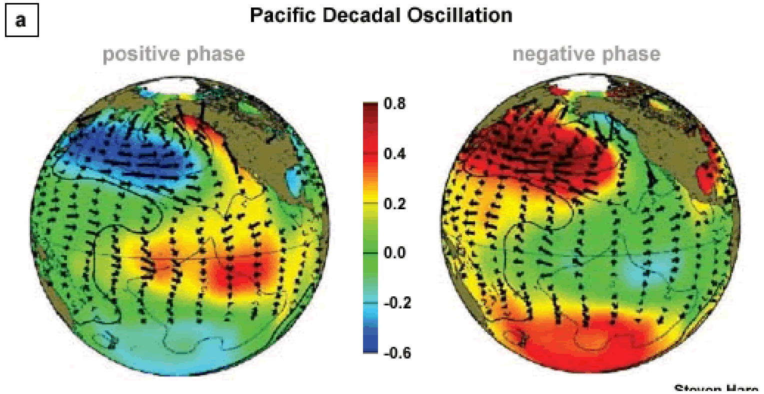
Issues:

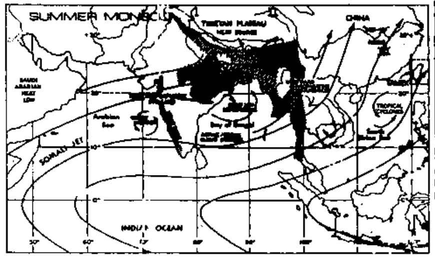
- ***Availability, Accessibility, and Quality***
- ***Large amount of (structured big) data***

Identifikasi dan Pemantauan Variabilitas Iklim

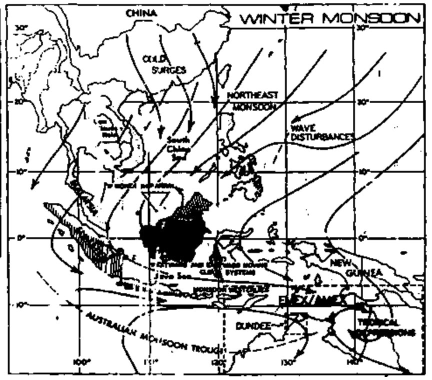
Multi-decadal

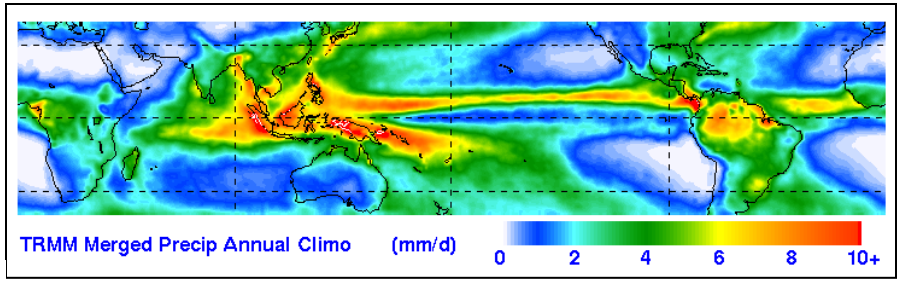


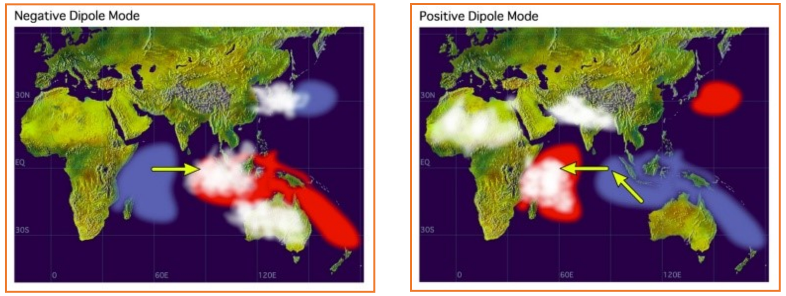




Monsoon (Annual Cycle)

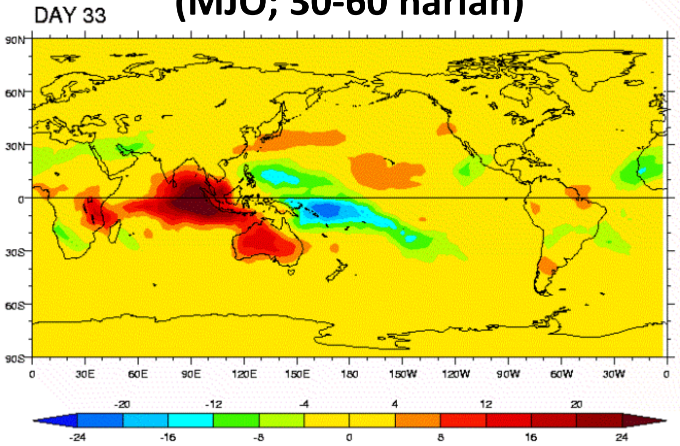


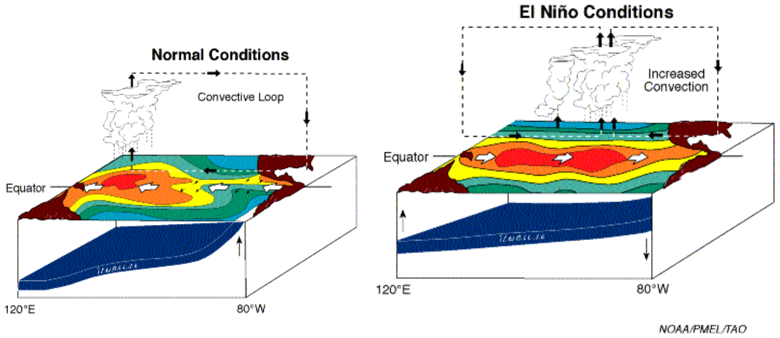




Indian Ocean Dipole (IOD; interannual)

Madden-Julian Oscillation (MJO; 30-60 harian)





El Nino Southern-Oscillation (ENSO; interannual)

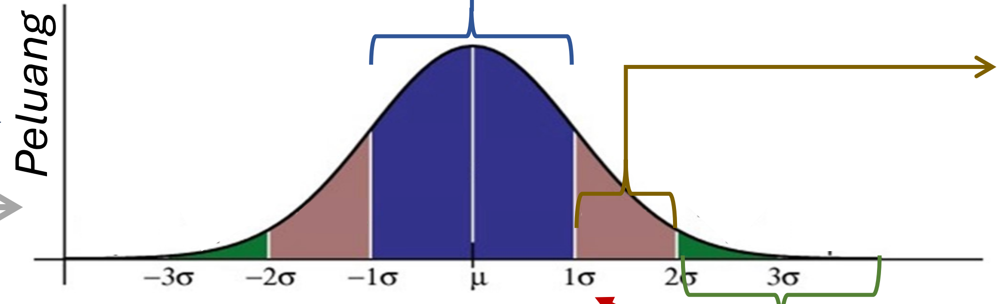
AND MORE

Images from various internet sources

Variabilitas Iklim dan Risiko Iklim

Every opportunity comes with risks; risks come from uncertainty (NOT ambiguity)

(ilustrasi)



Normal (nilai yang diharapkan → *opportunity*)
→ sistem akan bekerja sesuai rancangan/rencana

Atas/bawah-normal (gangguan yang dapat ditolerir)
→ kinerja sistem akan menurun tetapi dapat diintervensi
→ **Hazard** dan **Risiko Iklim**

mean

standard deviation (as uncertainty measure)

variability

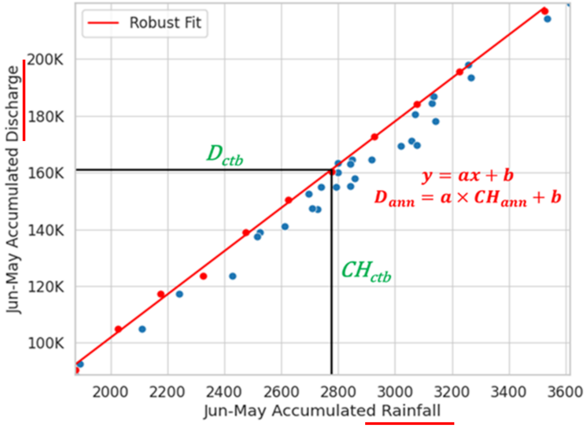
Ekstrem (rendah/tinggi) → memicu bencana
→ sistem berhenti bekerja
→ **Hazard** dan **Risiko bencana**

Datal klim

Observasi

Simulasi Model Iklim

Model Dampak Iklim (*Climate Impact Models*)



Aplikasi Statistika sederhana?

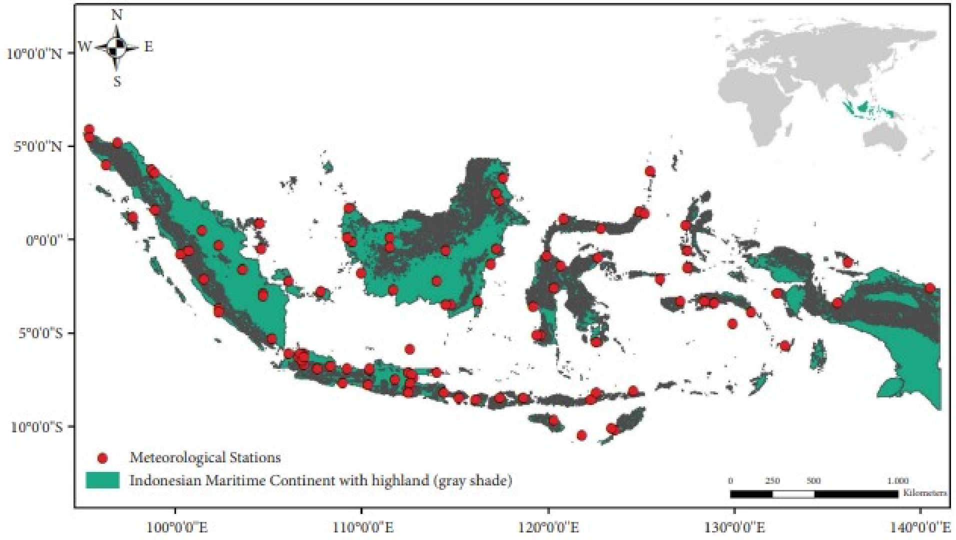
Ketakstasioneran Data Deret Waktu Iklim

Research Article

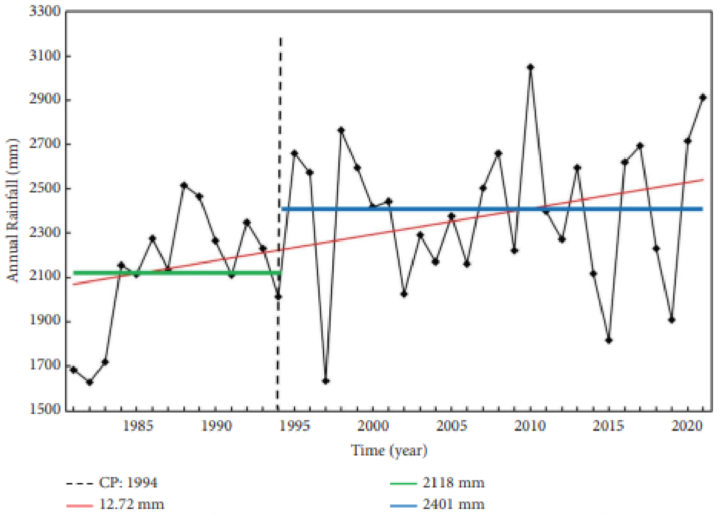
Nonstationary Changes in Annual Rainfall over Indonesia's Maritime Continent

Gian Gardian Sudarman,[1,2] Tri Wahyu Hadi,[3] Nining Sari Ningsih,[4] Ardhasena Sopaheluwakan,[2] Muhammad Ridho Syahputra,[3] and Fiolenta Marpaung[5]

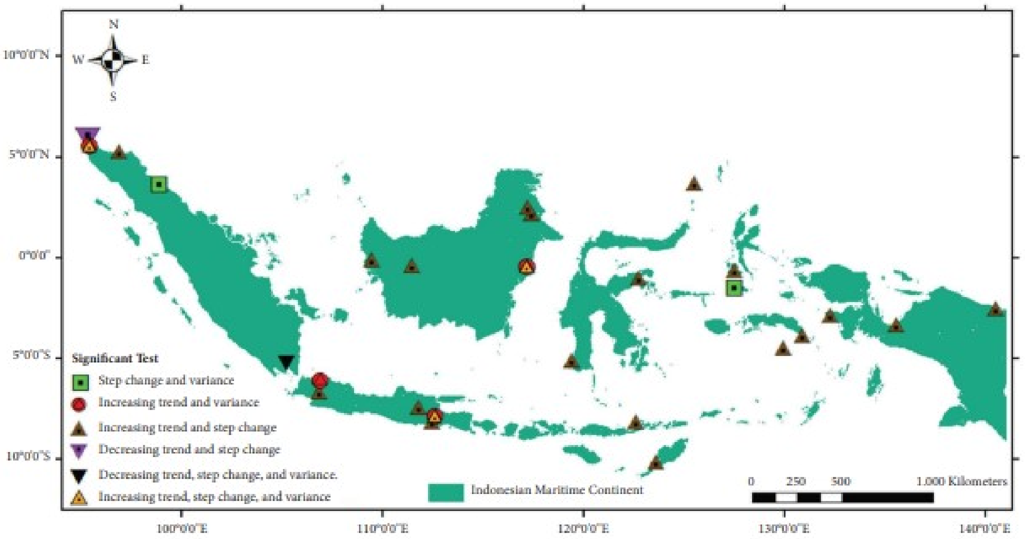
Advances in Meteorology
Volume 2024, Article ID 9392844, 11 pages
https://doi.org/10.1155/2024/9392844



Analisis:
Trend,
Step-change, and
Change in
Variance



Weak to strong non-stationarity



Bagaimana menentukan "normal" , anomali, periode ulang, dengan deret waktu non-stasioner?

Model Iklim

Pendekatan I: *from the parts to the whole*

The problem of weather prediction, considered from the viewpoints of mechanics and physics

VILHELM BJERKNES

translated from German and edited by ESTHER VOLKEN[1] and STEFAN BRÖNNIMANN[2*]

Original citation:
BJERKNES, V., 1904: Das Problem der Wettervorhersage, betrachtet vom Standpunkte der Mechanik und der Physik. – Meteorol. Z. **21**, 1–7.
DOI 10.1127/0941-2948/2009/416

If it is true, as any scientist believes[E1], that subsequent states of the atmosphere develop from preceding ones according to physical laws, one will agree that the necessary and sufficient conditions for a rational solution of the problem of meteorological prediction are the following:

1. *One has to know with sufficient accuracy the state of the atmosphere at a given time.*
2. *One has to know with sufficient accuracy the laws according to which one state of the atmosphere develops from another.*

The governing equations of the atmospheric motions

Hukum ke-2 Newton tentang gerak

Pers. Navier-Stokes

$$\vec{a} = \frac{\vec{F}}{m} \quad \Rightarrow \quad \frac{D\mathbf{U}}{Dt} = -2\boldsymbol{\Omega} \times \mathbf{U} - \frac{\mathbf{1}}{\rho}\boldsymbol{\nabla} p + \mathbf{g} + \mathbf{F}_r$$

g. Coriolis; g. grad. tekanan; *gravity*; *g. gesekan dan lainnya*

Hukum kekekalan massa (pers. Kontinuitas)

$$\frac{1}{\rho}\frac{D\rho}{Dt} + \boldsymbol{\nabla} \cdot \mathbf{U} = 0$$

divergensi/konvergensi aliran

Hukum kekekalan energi (termodinamika atmosfer)

$$c_v \frac{DT}{Dt} + p\frac{D\alpha}{Dt} = J$$

laju pemanasan diabatik

Non-linear dynamical equations

Persamaan diferensial parsial (PDP) :
masalah **syarat awal** dan **syarat batas**

prediksi cuaca — *prediksi iklim*

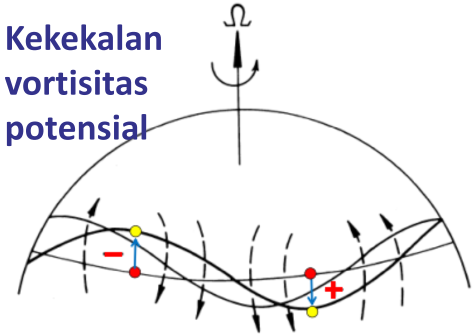
Global Circulation Model (GCM): The 1st Milestone

Persamaan prognostic dan metode numerik:

$$\frac{du(t)}{dt} = F(t) \quad \Rightarrow \quad u^{n+1} = u^n + \int_{n\Delta t}^{(n+1)\Delta t} F(u,t)\, dt$$

Gelombang planeter sebagai sumber prediktabilitas cuaca

Kekekalan vortisitas potensial



$$\left(\frac{\partial}{\partial t} + \overline{u}\frac{\partial}{\partial x}\right)\nabla^2\psi' + \beta\frac{\partial \psi'}{\partial x} = 0$$

Solusi: $\psi' = \mathrm{Re}\left[\Psi \exp(i\phi)\right]$

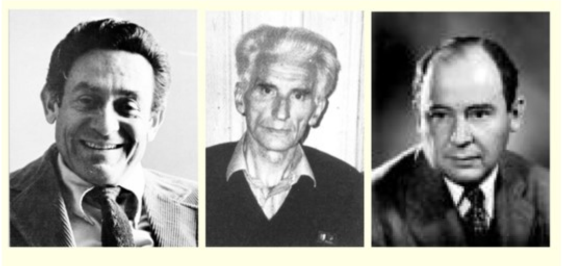
$$\phi = kx + ly - \nu t$$

Numerical Integration of the Barotropic Vorticity Equation

By J. G. CHARNEY, R. FJÖRTOFT[1], J. von NEUMANN
The Institute for Advanced Study, Princeton, New Jersey[2]

(Manuscript received 1 November 1950)

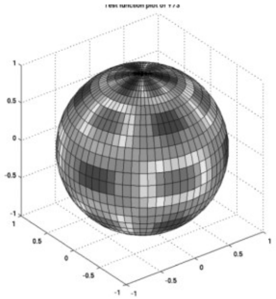
Tellus, Vol. 2, 1950, pp 237–254



CARL-GUSTAF ROSSBY
1898–1957

Global spectral model

Sinya pada permukaan bola di waktu *t*

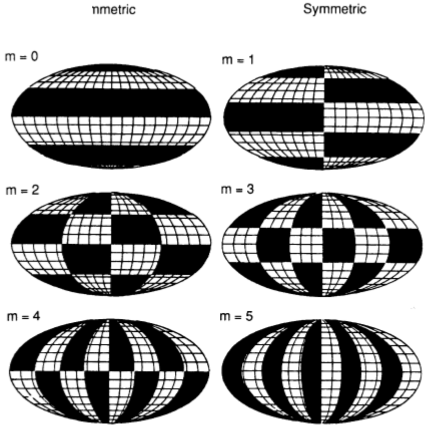


Analysis

Synthesis

$$\xi(\lambda, \mu) = \sum_{m=-M}^{M} \sum_{n=|m|}^{N(m)} \xi_n^m P_n^m(\mu) e^{im\lambda}$$

Spherical harmonics basis function



BVE example

$$\frac{d\psi_n^m}{dt} = \frac{2\Omega i m}{n(n+1)}\psi_n^m - \frac{a^2}{n(n+1)} F_n^m$$

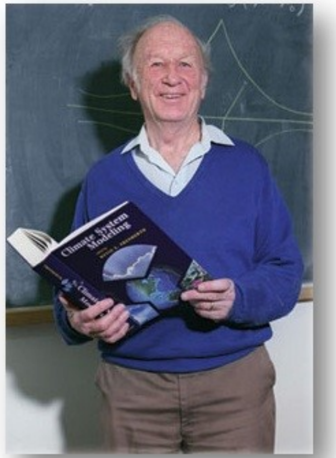
$$\psi_n^m(t+\Delta t) = \psi_n^m(t-\Delta t) + 2\Delta t \frac{d\psi_n^m}{dt}$$

Predict the future value of each spectral coefficient

Dasar Pengembangan *Numerical Weather Prediction* (NWP)

Global Circulation Model (GCM): More Milestones

Sistem **non-linear**



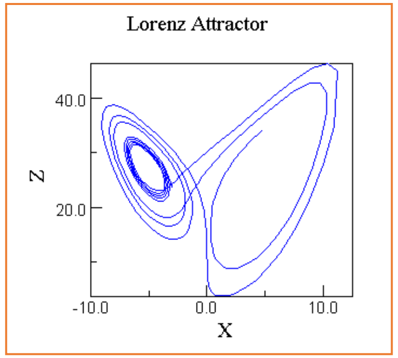
Edward Norton Lorenz
(1917–2008)

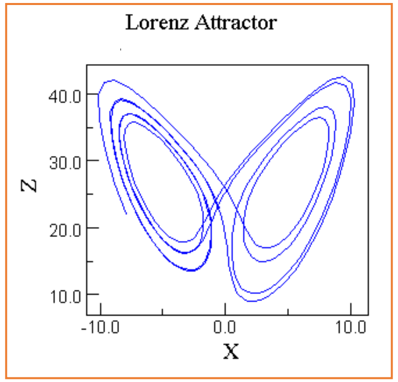
Image credit:
https://www.armstrongeconomics.com/research/economic-thought/by-topic/chaos-theory/

$$\frac{dx}{dt} = \sigma(y - x)$$

$$\frac{dy}{dt} = rx - y - xz$$

$$\frac{dz}{dt} = xy - bz$$

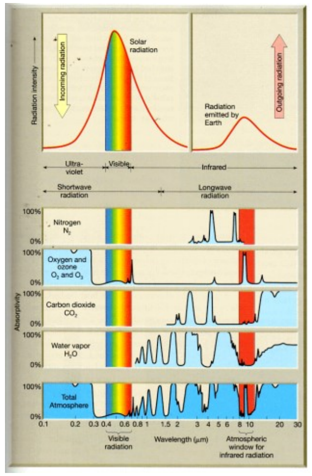




Sensitifitas terhadap nilai awal
→ perilaku chaos (Lorenz, 1963) → *butterfly effect*
→ Batasan terhadap prediktabilitas atmosfer

Karena nilai awal "pasti" mengandung kesalahan, maka ketidakpastian prediksi tidak dapat dihilangkan tetapi harus dapat dikuantifikasi → long-range climate prediction

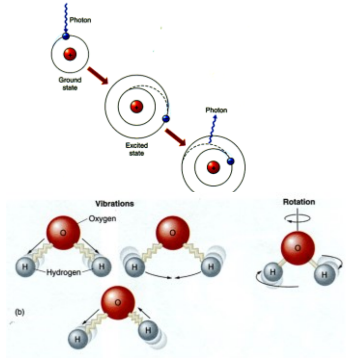
Energi radiasi



https://www.ess.uci.edu/~yu/

$E_v = h\nu$

Selective absorption



Thermal Equilibrium of the Atmosphere with a Given Distribution of Relative Humidity

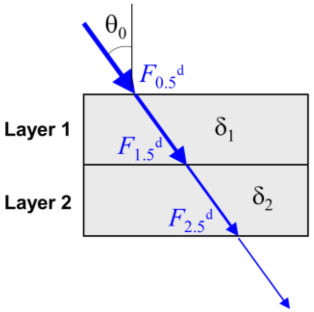
SYUKURO MANABE AND RICHARD T. WETHERALD

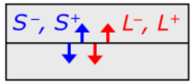
Geophysical Fluid Dynamics Laboratory, ESSA, Washington, D. C.

(Manuscript received 2 November 1966)

Source: https://cerncourier.com/a/2021-nobel-prize-recognises-complexity/

Radiative Transfer, Radiative Equilibrium, and Radiative Forcing



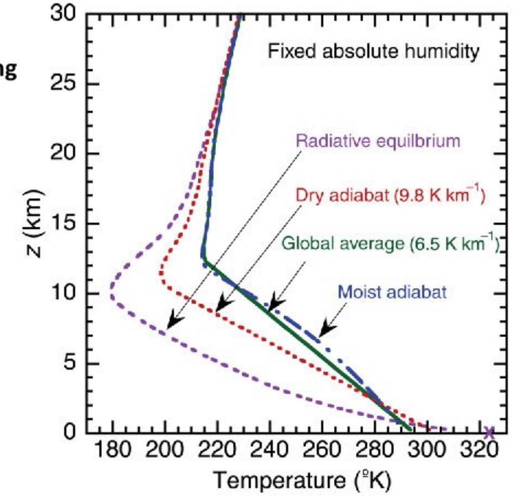


Fluxes / irradiances between model levels
Net flux $R_n = S^- - S^+ + L^- - L^+$

Laju pemanasan

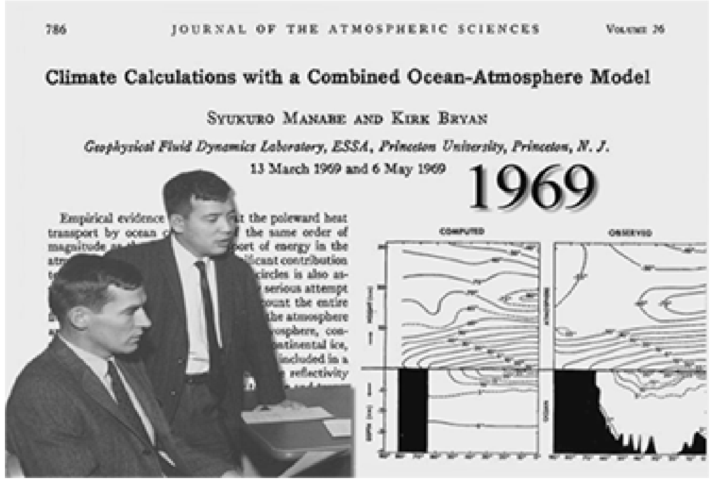
$$\frac{D\bar{\theta}}{Dt} = \frac{1}{\rho C_p}\frac{\partial R_n}{\partial z} + latent + \cdots$$

Radiative-Convective Model



Efek perubahan komposisi atmosfer terhadap iklim dapat dihitung dalam model iklim

Global Climate Model and Earth System Model



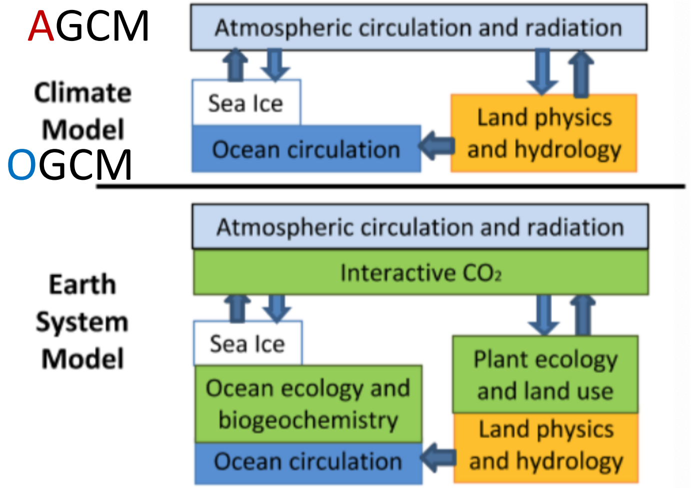
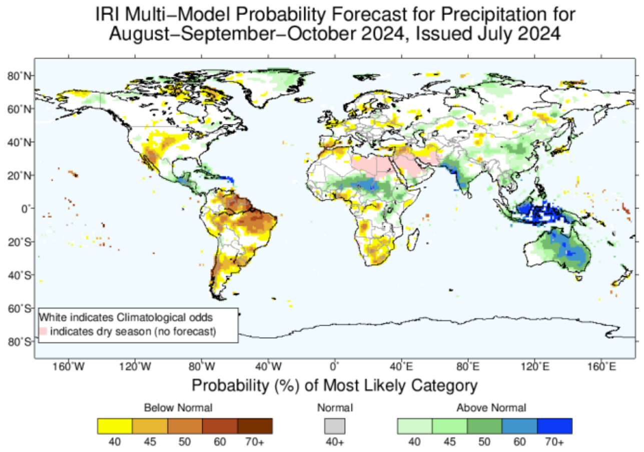


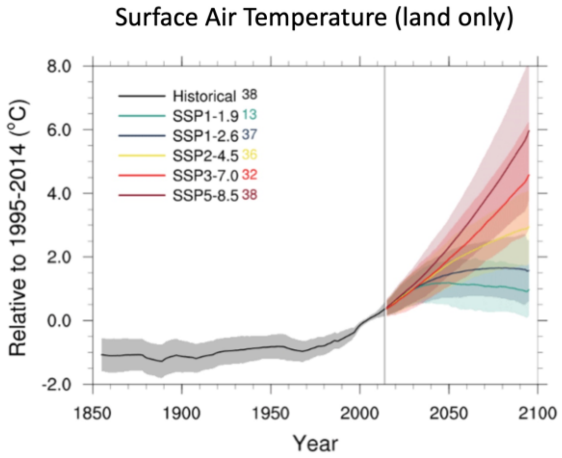
Figure based on SOCCOM

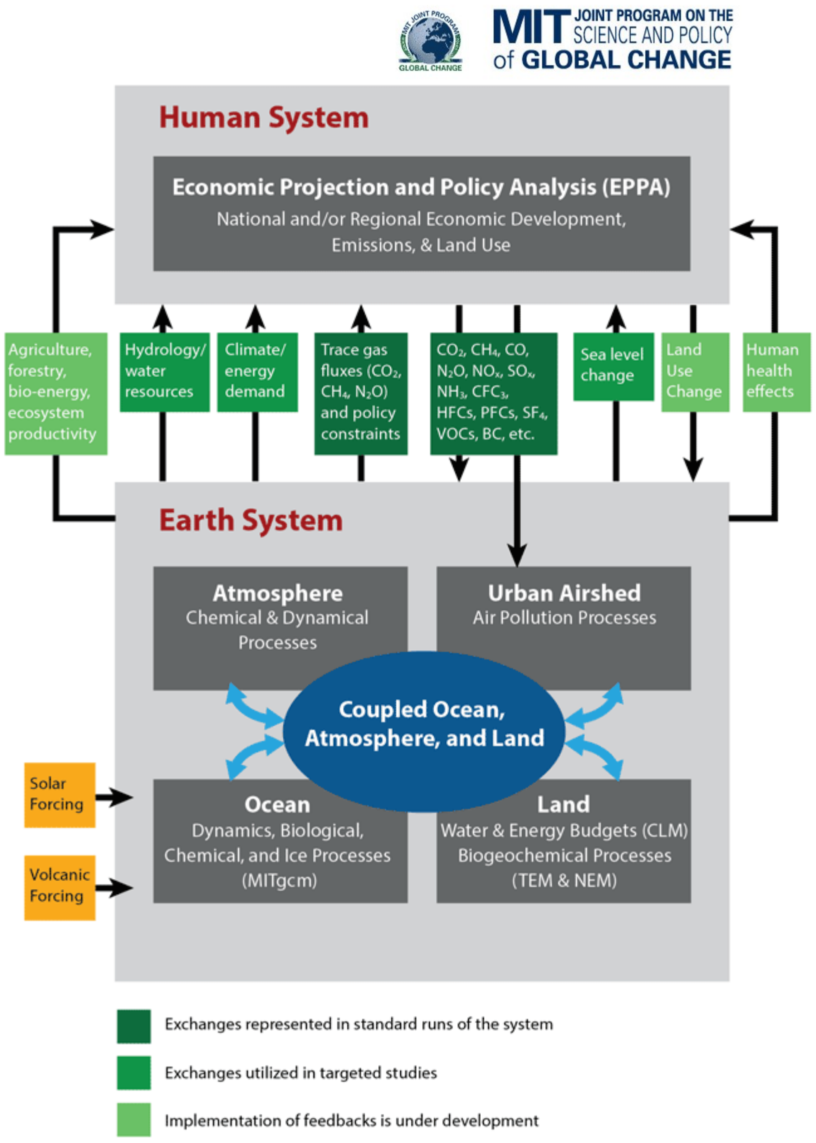
Ever growing complexity !

(Seasonal) Climate Forecast



Climate Projection





Kebutuhan Sumberdaya Komputasi

NOAA completes upgrade to weather and climate supercomputer system

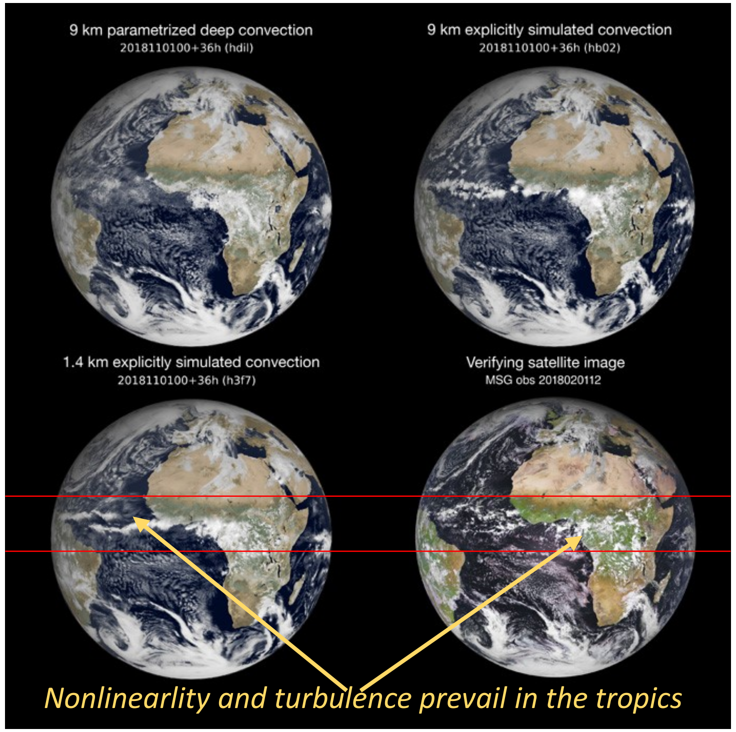
August 10, 2023

With this upgrade, the twin supercomputers, located in Manassas, Virginia, and Phoenix, Arizona, now operate at a speed of 14.5 petaflops each, and together, the forecast system can process 29 quadrillion calculations per second.

https://www.noaa.gov/news-release/noaa-completes-upgrade-to-weather-and-climate-supercomputer-system

ECMWF

Total number of compute nodes	7,020	7,680
Total number of GPIL nodes	208	448
Total memory	0.9 PiB	2.1 PiB
Total number of cores	260,208	1,040,384



WORLD METEOROLOGICAL ORGANIZATION
Weather Climate Water

Kilometre-Scale Modelling of the Earth System: A New Paradigm for Climate Prediction

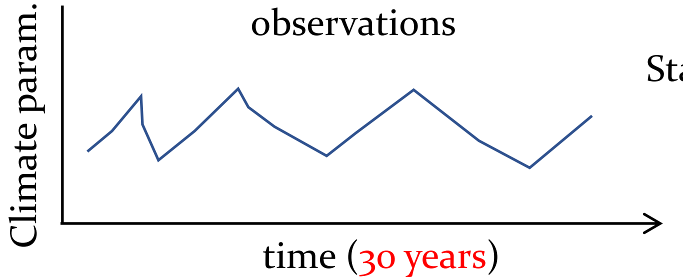
MAGAZINE ARTICLE

30 November 2023

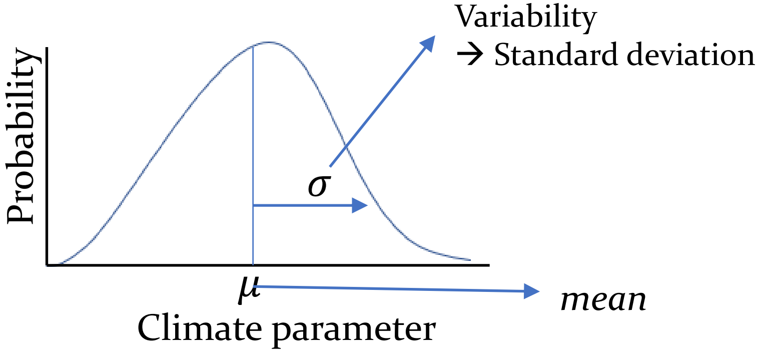
Untuk menjalankan model cuaca dan iklim terkini selalu diperlukan “top-tier super- computer”

Hazard Iklim dan Perubahan Iklim

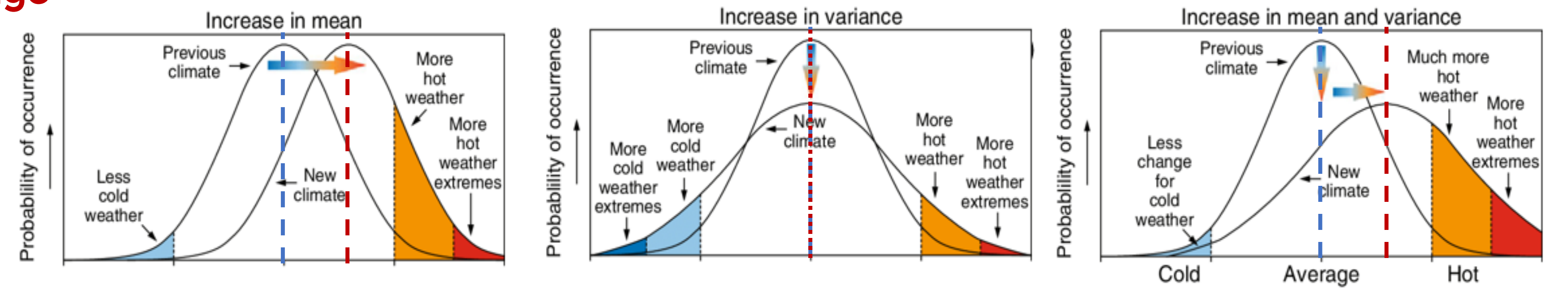
Kembali ke statistik



Climate



Climate Change

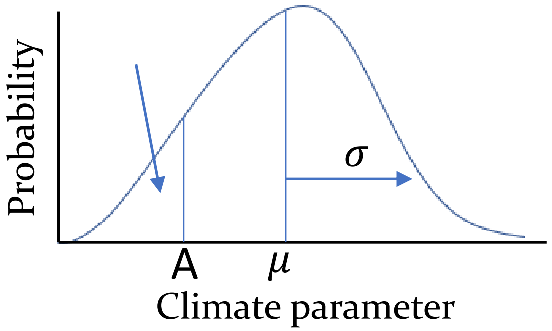


Modified from Figure 2.32 in the Intergovernmental Panel on Climate Change, Working Group I report (2001) (Benson et al., 2012; Climatic Change. 112. 299-323. 10.1007/s10584-011-0212-8.)

Pertanyaan yang relevan?

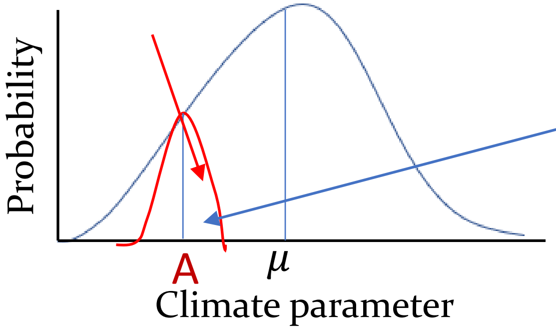
Iklim historis (baseline)

e.g., peluang nilai kurang dari (ambang batas) A?



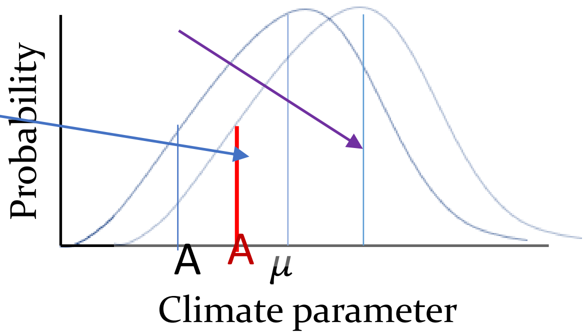
Prediksi musim
(Seasonal forecast)
3 bulan – 1 tahun ke depan

Peluang nilai di sekitar A?



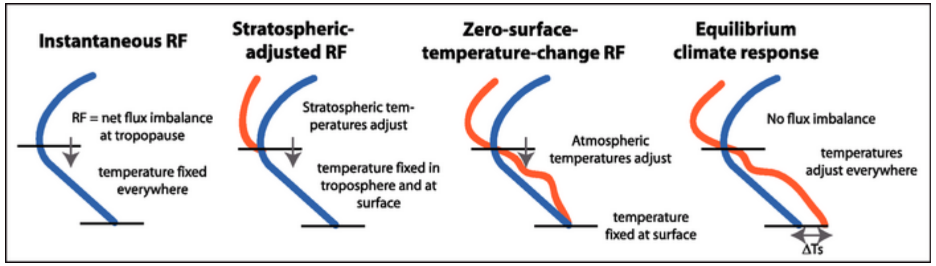
Ensemble model

Pdf berubah? Seberapa besar dan bagaimana peluangnya?

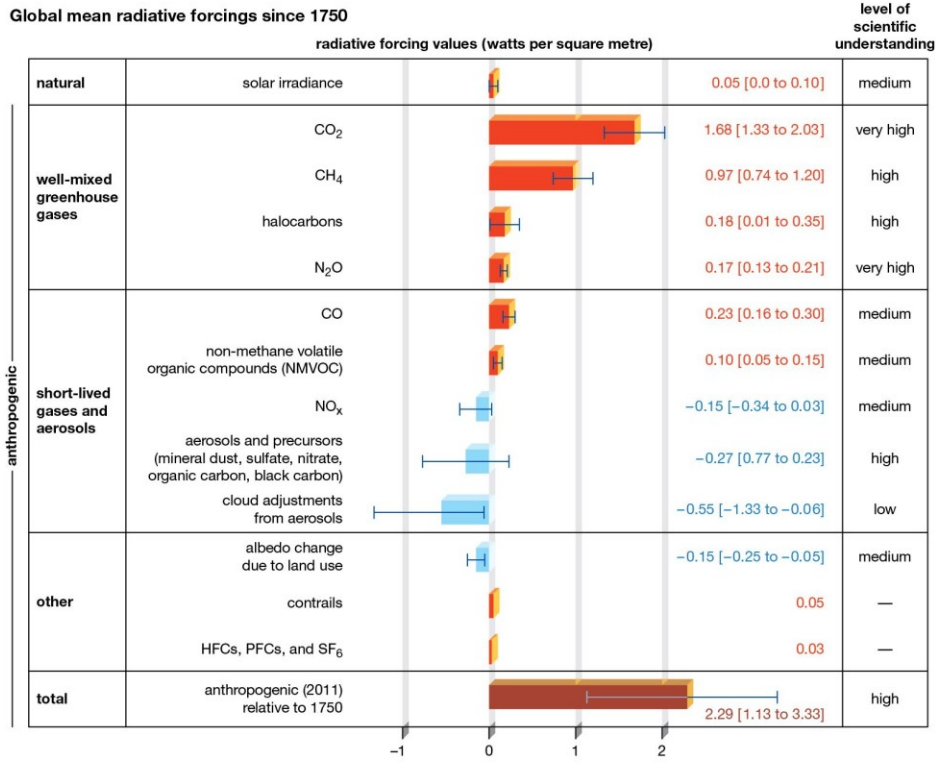


Bottom-up: long historical 2x30-year data; Top-down: climate projection for the next 30 – 100 years

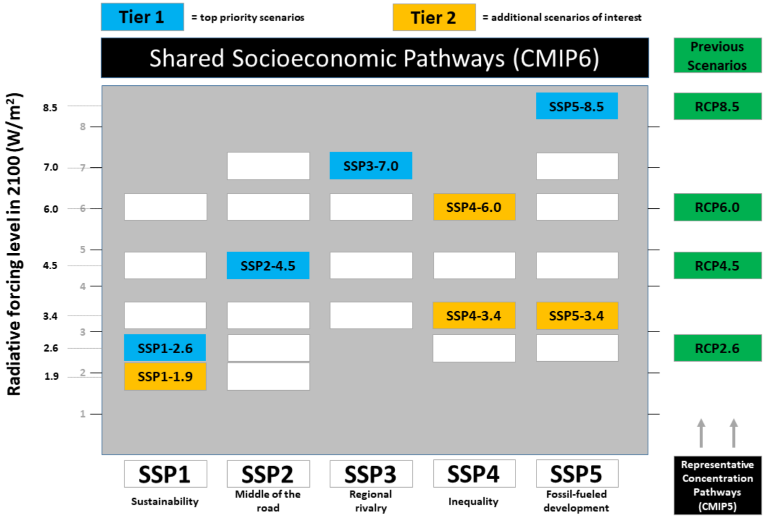
Radiative Forcing

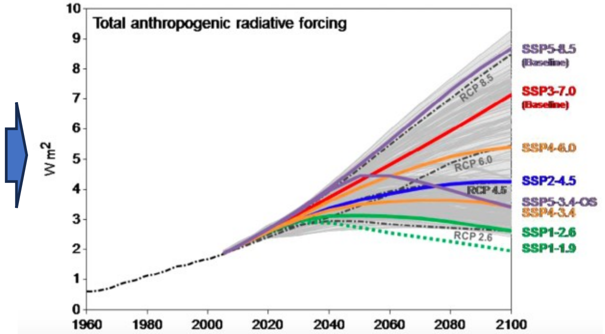


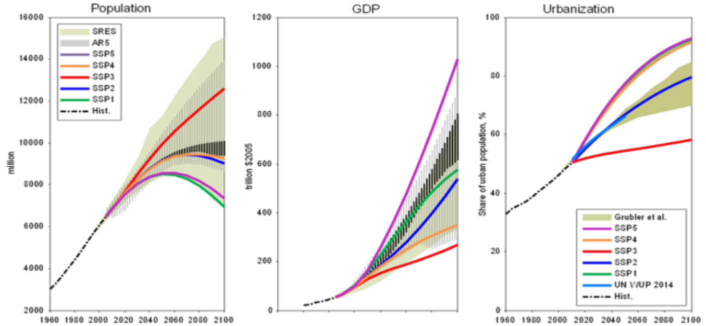
Radiative forcing, defined as the net flux imbalance at the tropopause, is shown by an arrow. The horizontal lines represent the surface (lower line) and tropopause (upper line). The unperturbed temperature profile is shown as the blue line and the perturbed temperature profile as the red line. (IPCC)



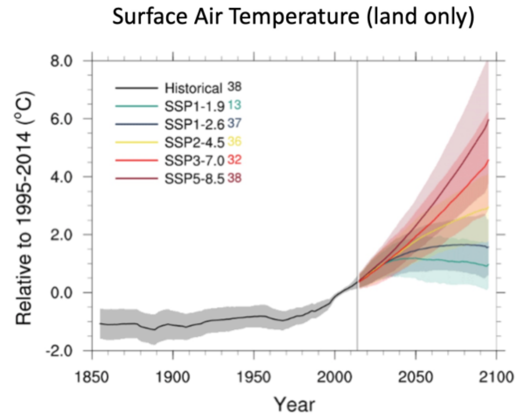
Source: Intergovernmental Panel on Climate Change, *Climate Change 2014: The Physical Science Basis*, "Summary for Policymakers."







Human dimension (NOT physical science)



Mitigasi dan Adaptasi PI

TCFD | TASK FORCE ON CLIMATE-RELATED FINANCIAL DISCLOSURES

Disclose the organization's governance around climate-related risks and opportunities.

Mainstreaming ke dalam industri global

Perdebatan Panjang tentang
Pemanasan Global

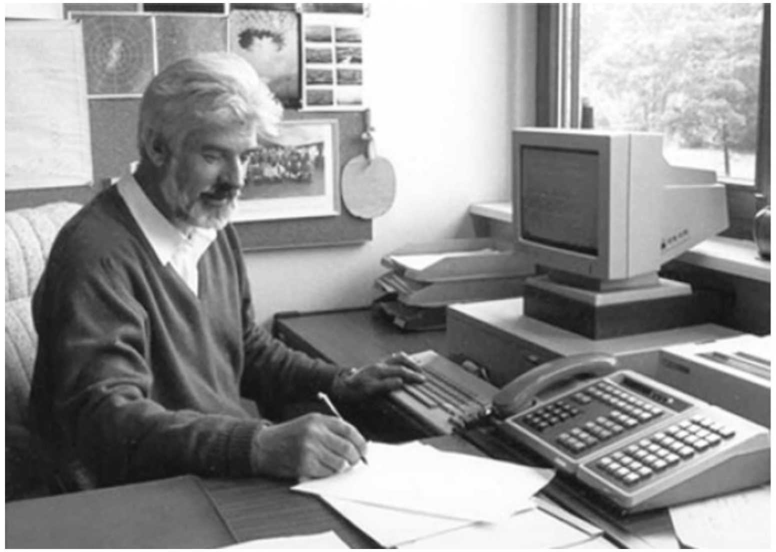
Optimal Fingerprints for the Detection of Time-dependent Climate Change

K. HASSELMANN
Max-Planck-Institut für Meteorologie, Hamburg, Germany

(Manuscript received 24 August 1992, in final form 17 March 1993)

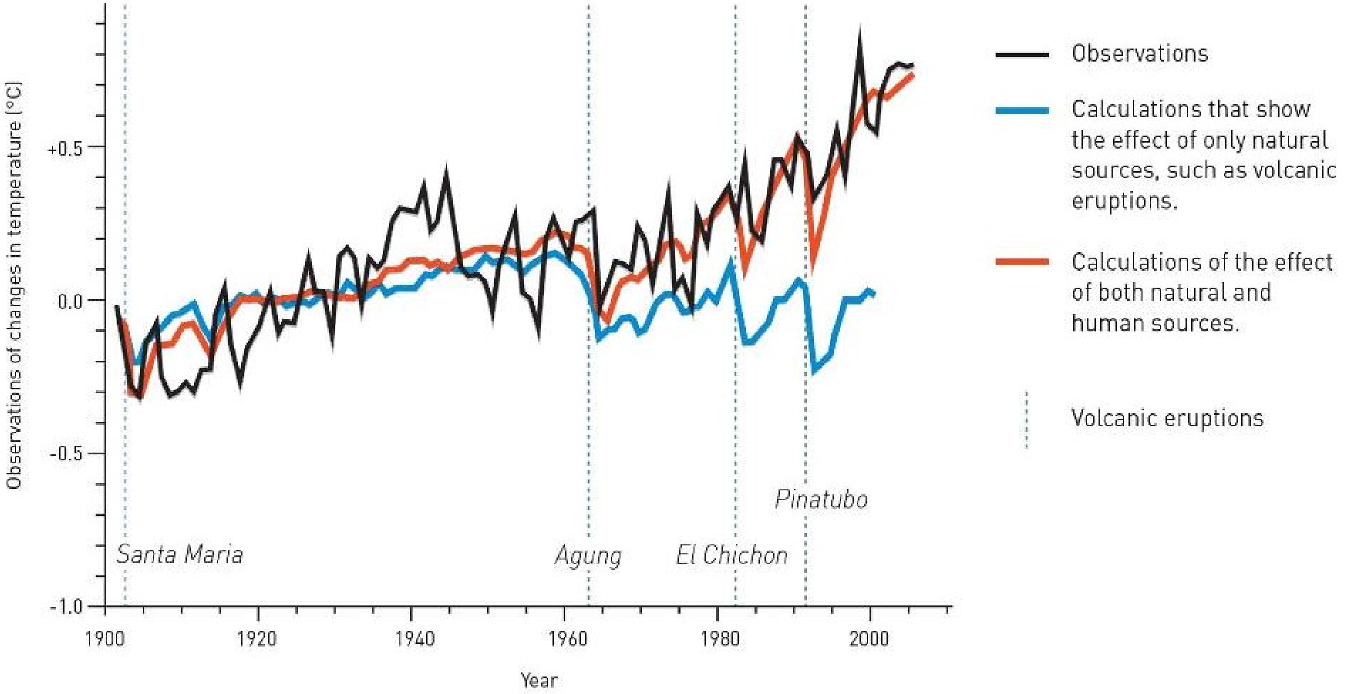
JOURNAL OF CLIMATE

DOI: https://doi.org/10.1175/1520-0442(1993)006<1957:OFFTDO>2.0.CO;2



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).



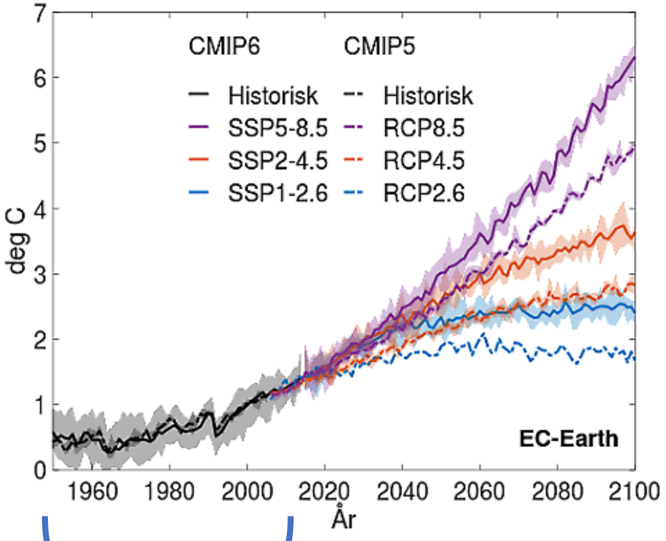
Source: https://www.cmcc.it/article/nobel-prize-in-physics-awarded-scientists-who-shed-light-on-climate

Informasi Proyeksi Perubahan Iklim

FGB ITB Future Science and Technology Talk #8
26 Juli 2024

Evaluasi model iklim

Coupled model	CMIP	Atmos. model	Ocean model	Hist. run ID	References	Complexity	Affinity	MAE
ACCESS1-0	5	HadGAM2, 192 × 144, 38 lv	NOAA/GFDL MOM4p1, 360 × 300, 50 lv	r1i1p1	Bi et al. (2013)	2222002000	Mixed	0.53
ACCESS1-3	5	UM7.3-approx. GA1, 192 × 144, 38 lv	NOAA/GFDL MOM4p1, 360 × 300, 50 lv	r1i1p1	Bi et al. (2013)	2222002000	Mixed	0.63
ACCESS-CM2	6	UM10.6-GA7.1, 192 × 144, 85 lv	ACCESS-OM2 (GFDL-MOM5), 360 × 300, 50 lv	r1i1p1f1	Bi et al. (2020)	2222002000	Mixed	0.60
ACCESS-ESM1-5	6	UM7.3-approx. GA1, 192 × 145, 38 lv	ACCESS-OM2 (GFDL-MOM5), 360 × 300, 50 lv	r1i1p1f1 + 1	Ziehn et al. (2020)	2222122020	Mixed	0.61
AWI-ESM-1-1-LR	6	ECHAM6.3.04p1, 192 × 96, 47 lv	FESOM 1.4, 126 859 wet nodes (unstructured mesh), 46 lv	r1i1p1f1	Semmler et al. (2020)	2222220100	JRA-55	0.78
BCC-CSM1.1	5	BCC-AGCM2.1, 128 × 64 (T42), 26 lv	GFDL-MOM4, 360 × 232, 40 lv	r1i1p1	Wu et al. (2013, 2014)	2222221120	None	1.0
BCC-CSM2-MR	6	BCC-AGCM3-MR, 320 × 160, 46 lv	GFDL-MOM4, 360 × 232, 40 lv	r1i1p1f1	Wu et al. (2019)	2222221120	None	0.88
CanESM2	5	CanAM4, 128 × 64, 35 lv	CanOM4, 256 × 192, 40 lv	r1i1p1	Chylek et al. (2011)	2222222021	JRA-55	0.79
CCSM4	5	CAM4, 288 × 192, 26 lv	POPv2, 384 × 320, 60 lv	r6i1p1	Gent et al. (2011)	2222221000	ERA-Interim	0.95
CMCC-CM	5	ECHAM5, 480 × 240, T159, 31 lv	OPA8.2-ORCA2, 31 lv	r1i1p1	Scoccimarro et al. (2011)	2222000000	JRA-55	0.61
CMCC-CM2-SR5	6	CAM5.3, 288 × 192, 30 lv	NEMO3.6-ORCA1, 50 lv	r1i1p1f1	Cherchi et al. (2019)	2222002000	ERA-Interim	0.55
CMCC-ESM2	6	CAM5.3, 288 × 192, 30 lv	NEMO3.6-ORCA1, 50 lv	r1i1p1f1	Cherchi et al. (2019)	2222022020	ERA-Interim	0.55
CNRM-CM5	5	ARPEGE-Climat v5.2.1 256 × 128, 31 lv	NEMO3.2-ORCA1, 42 lv	r1i1p1	Voldoire et al. (2013)	2222101100	Mixed	0.60
CNRM-CM6-1	6	ARPEGE 6.3 256 × 128, 91 lv, T127 Gr 24572 gb	NEMO3.6-ORCA1, 75 lv	r1i1p1f2 + 2	Voldoire et al. (2019)	2222101100	Mixed	0.63
CNRM-CM6-1-HR	6	ARPEGE 6.3, 720 × 360, 91 lv, T359 Gr 181724 gb	NEMO3.6-ORCA025, 75 lv	r1i1p1f2	Voldoire et al. (2019)	2222101100	Mixed	0.68
CNRM-ESM2-1	6	ARPEGE 6.3, 720 × 360, T127 Gr 24572 gb, 91 lv	NEMO3.6-ORCA1, 75 lv	r1i1p1f2	Séférian et al. (2019)	2222222220	Mixed	0.65
CSIRO-MK3.6	5	AGCM v7.3.8, 192 × 96, T63 spectral, 18 lv	GFDL MOM2.2, 192 × 189, 31 lv	r1i1p1	Collier et al. (2011)	2222000000	ERA-Interim	1.04
EC-Earth-2.3	5	IFS (modified cy31R1), 320 × 160, T159L62, 62 lv	Modified NEMO2-ORCA1, 42 lv	r12i1p1	Hazeleger et al. (2011)	2222001000	ERA-Interim	0.49
EC-Earth3	6	IFS (IFS cy36r4), 512 × 256, T255L91 Gr, 91 lv	NEMO3.6-ORCA1, 75 lv	r1i1p1f1 + 16	Döscher et al. (2021)	2222101000	ERA-Interim	0.41
EC-Earth3-Veg	6	IFS (IFS cy36r4), 512 × 256, T255L91 Gr, 91 lv	NEMO3.6-ORCA1, 75 lv	r1i1p1f1	Döscher et al. (2021)	2222221000	ERA-Interim	0.41
EC-Earth3-Veg-LR	6	IFS (IFS cy36r4), 320 × 160, T159L62 Gr, 62 lv	NEMO3.6-ORCA1, 75 lv	r1i1p1f1	Döscher et al. (2021)	2222221000	ERA-Interim	0.40
EC-Earth3-AerChem	6	IFS (IFS cy36r4), 512 × 256, T255L91 Gr, 91 lv	NEMO3.6-ORCA1, 75 lv	r1i1p1f1 + 16	Döscher et al. (2021)	2222102000	ERA-Interim	0.41
EC-Earth3-CC	6	IFS (IFS cy36r4), 512 × 256, T255L91 Gr, 91 lv	NEMO3.6-ORCA1, 75 lv	r1i1p1f1 + 16	Döscher et al. (2021)	2222221020	ERA-Interim	0.41
FGOALS-g2	5	GAMIL2, 128 × 60, hybrid, 26 lv	LICOM2, 360 × 196, tripolar grid, 1/2° in the tropics, 30 lv	r1i1p1	Li et al. (2013)	2222101000	JRA-55	1.17
FGOALS-g3	6	GAMIL3, 180 × 80, hybrid, 26 lv	LICOM3, 360 × 218, tripolar grid, 30 lv	r1i1p1	Li et al. (2020)	2222111000	Mixed	0.80
GFDL-CM3	5	AM3p9, 144 × 90, C48L48, 48 lv	MOM4p1, 360 × 200, tripolar grid, 1/3° at Equator, 50 lv	r1i1p1	Griffies et al. (2011)	2222222200	Mixed	0.61
GFDL-CM4	6	GFDL-AM4.0.1, 360 × 180, cubed sphere, c96, 33 lv	GFDL-MOM6, 1440 × 1080, tripolar 0.25° grid, 75 lv	r1i1p1f1	Held et al. (2019)	2222222210	Mixed	0.58
GISS-E2-H	5	GISS-E2, 144 × 90, 40 lv	HYCOM, 1 × cos(lat) tripolar grid north of 58° N, Mercator below, 26 lv	r6i1p1	Schmidt et al. (2014)	2222101100	ERA-Interim	0.82
GISS-E2-R	5	GISS-E2, 144 × 90, 40 lv	Russel Ocean, 288 × 180, regular lat–long, 32 lv	r1i1p1	Schmidt et al. (2014)	2222101100	ERA-Interim	0.78
GISS-E2-1-G	6	GISS-E2.1, 144 × 90, 40 lv	GISS Ocean, 288 × 180, regular lat–long, 32 lv	r1i1p1f1	Kelley et al. (2020)	2222101100	None	0.75
HadGEM2-CC	5	HadGAM2, 192 × 145, N96L60, 60 lv	HadGOM2, 360 × 216, 40 lv	r1i1p1	Collins et al. (2011)	2222222120	Mixed	0.63
HadGEM2-ES	5	HadGAM2, 192 × 145, N96L38, 38 lv	HadGOM2, 360 × 216, 40 lv	r1i1p1 + 1	Collins et al. (2011)	2222222220	Mixed	0.57
HadGEM3-GC31-MM	6	UM10.6-GA7.1, 432 × 324, N216L85, 85 lv	NEMO-HadGEM3-GO6.0-eORCA025, 75 lv	r1i1p1f3	Roberts et al. (2019)	2222002000	Mixed	0.45
IITM-ESM	6	IITM-GFSv1, 192 × 94, 64 lv	MOM4p1, 360 × 200, tripolar, primarily 1° grid, 50 lv	r1i1p1f1	Swapna et al. (2015)	2222101020	Mixed	0.81
INMCM4	5	INM-CM4 atmosphere model, 180 × 120, 21 lv	INM-CM4 ocean model, 360 × 360, 40 lv	r1i1p1	Volodin et al. (2010)	2222220010	JRA-55	0.77
IPSL-CM5A-LR	5	LMDZ4v5, 96 × 95, 39 lv	NEMO3.2-ORCA2, 31 lv	r1i1p1 + 5	Dufresne et al. (2013)	2222221110	None	0.98
IPSL-CM5A-MR	5	LMDZ4v5, 144 × 143, 39 lv	NEMO3.2-ORCA2, 31 lv	r1i1p1	Dufresne et al. (2013)	2222221110	None	0.95
IPSL-CM6A-LR	6	LMDZ NPv6, 144 × 143, N96L79, 79 lv	NEMO-OPA-eORCA1.3, 75 lv	r1i1p1f1 + 17	Boucher et al. (2020)	2222221111	Mixed	0.72
KIOST-ESM	6	GFDL-AM2.0, 192 × 96, 32 lv	GFDL-MOM5.0, 360 × 200, tripolar nominal 1° grid, 52 lv	r1i1p1f1	Pak et al. (2021)	2222221120	JRA-55	0.84
MIROC5	5	MIROC-AGCM6, 256 × 128, T85L40, 40 lv	COCO4.5, 256 × 224, 50 lv	r1i1p1	Watanabe et al. (2010)	2222102000	ERA-Interim	0.91
MIROC-ESM	5	MIROC-AGCM 2010, 128 × 64, T42L80, 80 lv	COCO3.4, 256 × 192, 44 lv	r1i1p1	Watanabe et al. (2011)	2222222020	JRA-55	1.06
MIROC6	6	CCSR AGCM, 256 × 128, T85L81, 81 lv	COCO4.9, 360 × 256, tripolar primarily 1° grid, 63 lv	r3i1p1f1	Tatebe et al. (2019)	2222102000	Mixed	0.77
MIROC-ES2L	6	CCSR AGCM, 128 × 64, T42L40, 40 lv	COCO4.9, 360 × 256, tripolar primarily 1° grid, 63 lv	r5i1p1f2 + 1	Hajima et al. (2020)	2222022020	None	1.14
MPI-ESM-LR	5	ECHAM6, 192 × 96, T63L47, 47 lv	MPIOM, 256 × 220, bipolar grid with 1.5° at Equator, 40 lv	r1i1p1	Giorgetta et al. (2013)	2222220020	JRA-55	0.66
MPI-ESM-MR	5	ECHAM6, 192 × 96, T63L95, 95 lv	MPIOM, 802 × 404, tripolar grid with 0.4° at Equator, 40 lv	r1i1p1	Giorgetta et al. (2013)	2222220020	JRA-55	0.72
MPI-ESM1.2-LR	6	ECHAM6.3, 192 × 96, T63L95, 47 lv	MPIOM1.63, 360 × 256, bipolar grid, 1.5° at Equator, 40 lv	r1i1p1f1 + 9	Mauritsen et al. (2019)	2222221020	JRA-55	0.66
MPI-ESM1.2-HR	6	ECHAM6.3, 384 × 192, T127L95, 95 lv	MPIOM1.63, 802 × 404, tripolar grid, 0.4° at Equator, 40 lv	r1i1p1f1 + 9	Müller et al. (2018)	2222221020	JRA-55	0.57
MPI-ESM1.2-HAM	6	ECHAM6.3, 192 × 96, T63L95, 47 lv	MPIOM1.63, 256 × 220, bipolar grid, 1.5° at Equator, 40 lv	r1i1p1f1	Mauritsen et al. (2019)	2222222120	JRA-55	0.75
MRI-ESM1	5	GSMUV-110120oc, 320 × 160, TL159L48, 48 lv	MRICOM-3-0, 368 × 364, tripolar primarily 0.5 × 1.0° grid, 51 lv	r1i1p1	Yukimoto et al. (2011)	2222122220	ERA-Interim	0.65
MRI-ESM2.0	6	MRI-AGCM3.5, 320 × 160, TL159L80, 80 lv	MRICOM-4-4, 364 × 360, tripolar primarily 0.5 × 1.0° grid, 61 lv	r1i1p1f1 + 4	Yukimoto et al. (2019)	2222112210	ERA-Interim	0.57
NESM3	6	ECHAM v6.3, 192 × 96, T63L47, 47 lv;	NEMO3.4-ORCA1, 46 lv	r1i1p1f1 + 4	Cao et al. (2018)	2222221000	None	0.71
NorESM1-M	6	CAM4-Oslo, 144 × 96, f19L26, 26 lv;	MICOM-noresm-ver1-gx1v6, 384 × 320, 53 lv	r1i1p1	Bentsen et al. (2013)	2222122000	JRA-55	0.87
NorESM2-LM	6	CAM-Oslo, 144 × 96, 32 lv;	MICOM. 384 × 360, 1.0° at Equator, 70 lv	r1i1p1f1 + 2	Seland et al. (2020)	2222122120	Mixed	0.74
NorESM2-MM	6	CAM-Oslo, 288 × 192, 32 lv;	MICOM, 384 × 360, 1.0° at Equator, 70 lv	r1i1p1f1 + 1	Seland et al. (2020)	2222122120	ERA-Interim	0.54
SAM0-UNICON	6	CAM5.3 with UNICON, 288 × 192, 30 lv	POP2D, 320 × 384, 60 lv	r1i1p1f1	Park et al. (2019)	2222222000	ERA-Interim	0.60
TaiESM 1.0	6	TaiAM1, 288 × 192, 30 lv	POP2, 320 × 384, 60 lv	r1i1p1f1	Lee et al. (2020)	2222222000	Mixed	0.58



- Membandingkan keluaran *historical simulation* dengan data observasi (*reanalysis*)
- Fokus pada "kelaikgunaan" (BUKAN "akurasi") model
- Evaluasi dilakukan dengan berbagai macam metrik

A circulation-based performance atlas of the CMIP5 and 6 models for regional climate studies in the Northern Hemisphere mid-to-high latitudes

Swen Brands

https://gmd.copernicus.org/articles/15/1375/2022/

Evaluasi model iklim untuk wilayah Indonesia

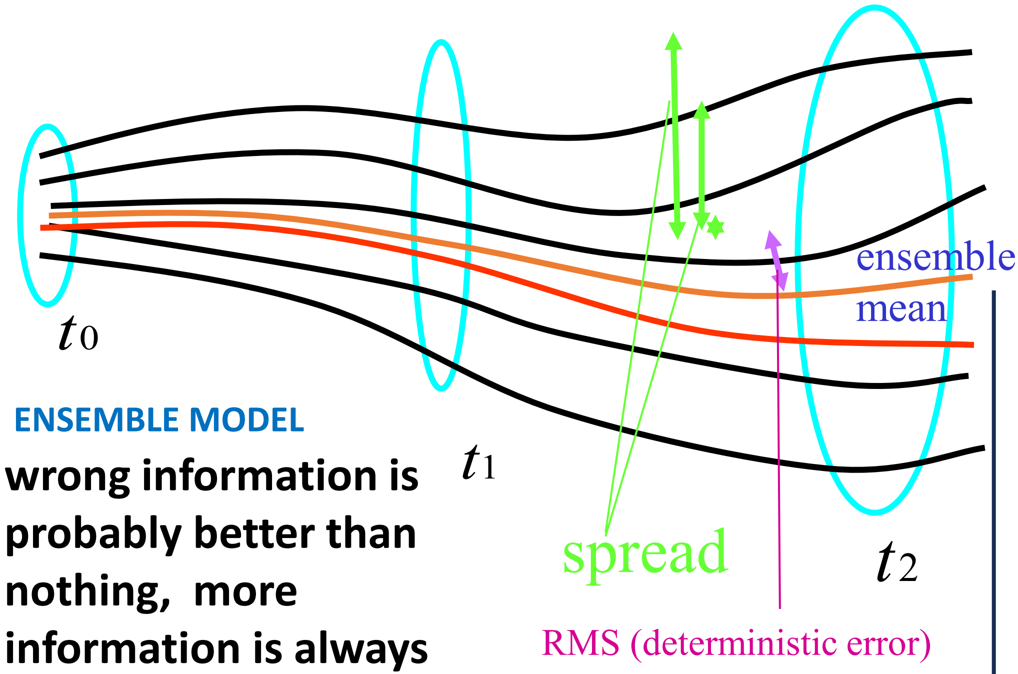
	BCC-CSM1-1	CanESM2	CNRM-CM5	FGOALS-g2	GFDL-CM3	GFDL-ESM2M	INM-CM4	IPSL-CM5	MIROC5	MPI-ESM-LR	MRI-CGCM3	NorESM1-M
Trend_ME	18	14	21	16	4	1	6	3	23	10	11	13
Trend_STDE	15	5	1	10	11	3	16	6	17	24	20	4
Trend_SKWE	19	8	12	17	18	5	13	2	11	15	6	22
Trend_KURTE	15	21	14	22	12	8	2	11	6	19	7	20
Var_ME	16	11	10	2	19	24	6	7	8	12	4	22
Var_STDE	13	10	3	9	17	20	4	2	22	24	11	16
Var_SKWE	12	11	22	23	20	15	10	21	7	2	3	18
Var_KURTE	12	15	24	19	22	8	14	23	10	4	1	20
Rank-sum (1)	120	95	107	118	123	84	71	75	104	110	63	135
Overall-rank (1)	17	9	12	16	19	8	6	7	11	14	4	22
CMIP5 - CMIP6 (1)												
ANN_Amp	20	9	1	10	13	12	14	6	17	21	24	11
SEMI-ANN_Amp	21	17	1	19	8	7	2	11	18	15	24	5
ANN_Phase	19	8	2	11	7	1	9	21	23	24	17	6
SEMI-ANN_Phase	1	22	18	12	9	20	13	17	16	21	11	24
MJO,IOD, & ENSO	15	22	2	7	19	4	9	18	1	10	23	24
Rank-sum (2)	76	78	24	59	56	44	47	73	75	91	99	70
Overall-rank (2)	18	19	**2**	11	10	4	6	16	17	23	24	14
CMIP5 - CMIP6 (2)												
Rank-sum (1+2)	196	173	131	177	179	128	118	148	179	201	162	205
Overall-rank (1+2)	20	14	7	15	16	4	**2**	9	16	21	10	22
CMIP5-CMIP6 (1+2)												

	BCC-CSM2-MR	CanESM5	CNRM-CM6-1	FGOALS-g3	GFDL-CM4	GFDL-ESM4	INM-CM5	IPSL-CM6	MIROC6	MPI-ESM1-2-HR	MRI-ESM2	NorESM2-LM
Trend_ME	7	2	5	20	17	15	9	8	12	24	22	19
Trend_STDE	8	9	23	2	12	13	21	14	19	7	18	22
Trend_SKWE	14	3	21	1	10	16	9	24	20	4	7	23
Trend_KURTE	9	1	10	4	17	18	3	24	16	5	13	23
Var_ME	1	3	17	14	13	20	5	9	21	23	18	15
Var_STDE	7	1	14	8	5	12	6	15	23	19	21	18
Var_SKWE	4	13	19	1	17	16	5	24	6	8	9	14
Var_KURTE	5	17	11	2	18	13	7	21	6	9	3	16
Rank-sum (1)	55	49	120	52	109	123	65	139	123	99	111	150
Overall-rank (1)	**3**	**1**	17	**2**	13	19	5	23	19	10	15	24
CMIP5 - CMIP6 (1)	14	8	-5	14	6	-11	1	-16	-8	4	-11	-2
ANN_Amp	16	15	2	22	4	8	5	7	19	23	18	3
SEMI-ANN_Amp	20	6	9	23	4	14	16	3	12	22	13	10
ANN_Phase	14	15	18	16	4	5	13	22	20	3	10	12
SEMI-ANN_Phase	6	7	10	8	2	3	14	19	23	15	4	5
MJO,IOD, & ENSO	13	8	11	20	5	14	16	21	12	17	6	3
Rank-sum (2)	69	51	50	89	19	44	64	72	86	80	51	33
Overall-rank (2)	13	8	7	22	**1**	4	12	15	21	20	8	**3**
CMIP5 - CMIP6 (2)	5	11	-5	-11	9	0	-6	1	-4	3	16	11
Rank-sum (1+2)	124	100	170	141	128	167	129	211	209	179	162	183
Overall-rank (1+2)	**3**	**1**	13	8	4	12	6	24	23	16	10	19
CMIP5-CMIP6 (1+2)	17	13	-6	7	12	-8	-4	-15	-7	5	0	3

Femmy Marshita B (Tesis Magister, ITB, 2022)

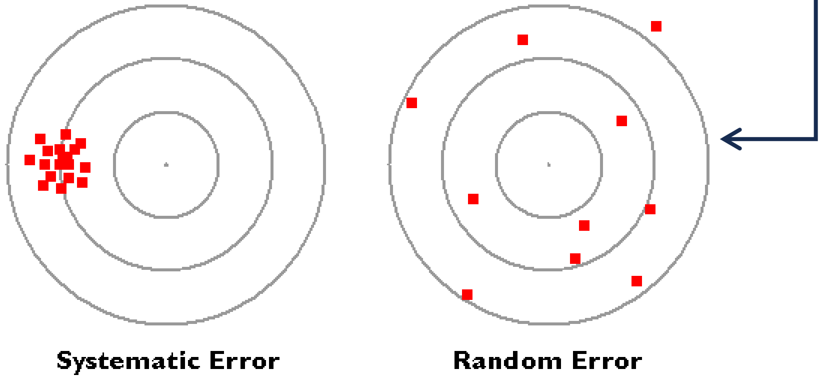
Model versi CMIP6 (yang terbaru) TIDAK SELALU lebih baik daripada model yang sama versi (lamanya) CMIP5

Risiko adalah informasi probabilistik



ENSEMBLE MODEL

wrong information is probably better than nothing, more information is always for the better



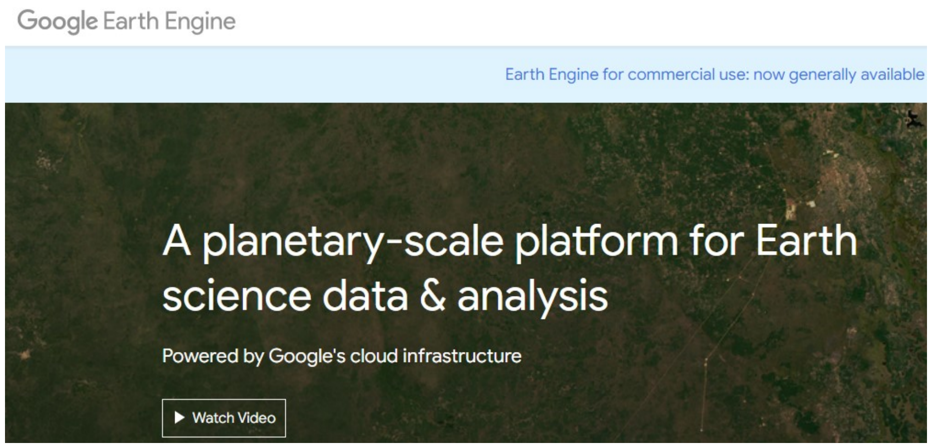
Upaya perbaikan informasi + permasalahannya

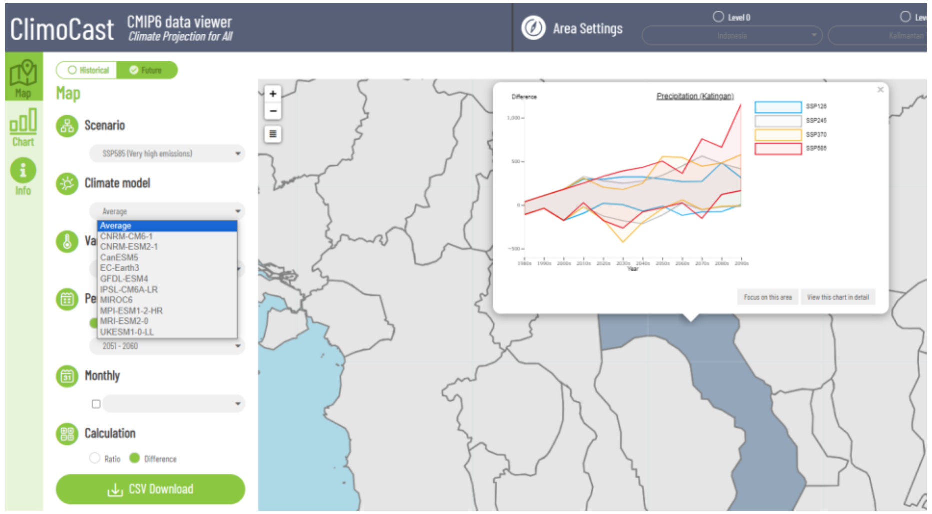
Downscaling and bias-correction contribute considerable uncertainty to local climate projections in CMIP6

David C. Lafferty[1] and Ryan L. Sriver[1]

npj Climate and Atmospheric Science (2023)6:158; https://doi.org/10.1038/s41612-023-00486-0

Berlomba Berbagi Data dan Informasi?





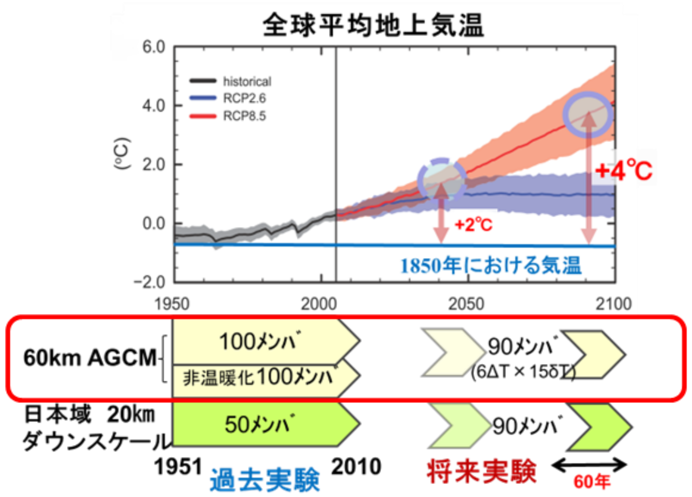
DIAS
Data Integration & Analysis System

d4PDF Data Download System

Home › d4PDF Data Download System

https://diasjp.net/en/service/d4pdf-data-download/

https://www.miroc-gcm.jp/d4PDF/design.html



Large ensemble simulation

Practical Climate Modeling

Bagaimana mengolah data keluaran model prediksi/proyeksi iklim global menjadi informasi yang mudah digunakan oleh pengambil keputusan

Metode "DELTA" untuk proyeksi

Nilai (persen) perubahan =

$$\Delta I = \frac{I_{mod\_future} - I_{mod\_historical}}{I_{mod\_historical}} \times 100\%$$

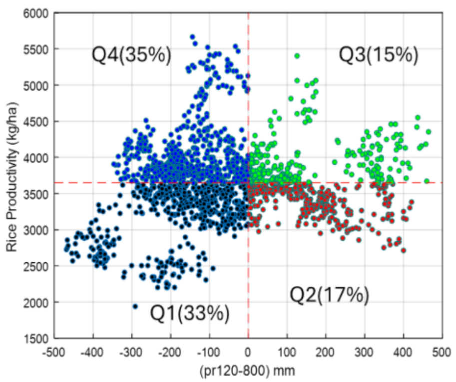
Dapat diterapkan tanpa kalibrasi!

Semakin banyak data dan informasi iklim digunakan dalam pengambilan keputusan di masyarakat, semakin baik untuk kita semua.

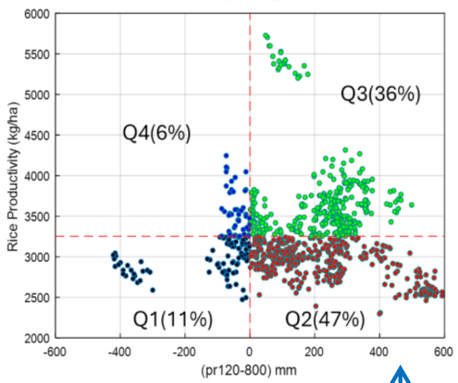
Practical Climate Modeling (Contoh Kasus):
Proyeksi Produksi Padi

Korelasi deviasi curah hujan dari nilai ambang dengan produksi padi

MH

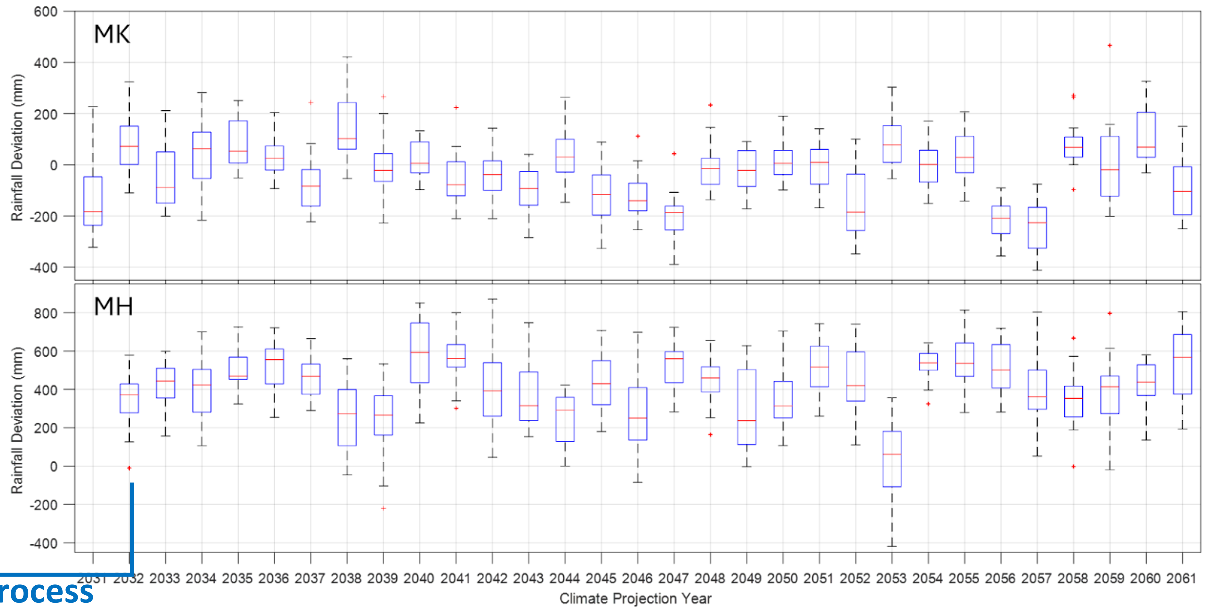


MK



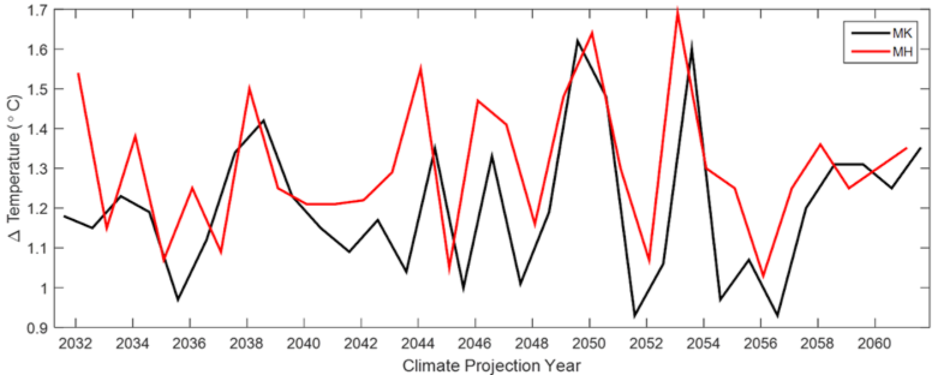
Database hasil simulasi *crop yield* dari data iklim historis menggunakan model APSIM oleh **Dr. Elza Surmaini dkk.** (BRIN)

Proyeksi Deviasi CH Musim Tanam



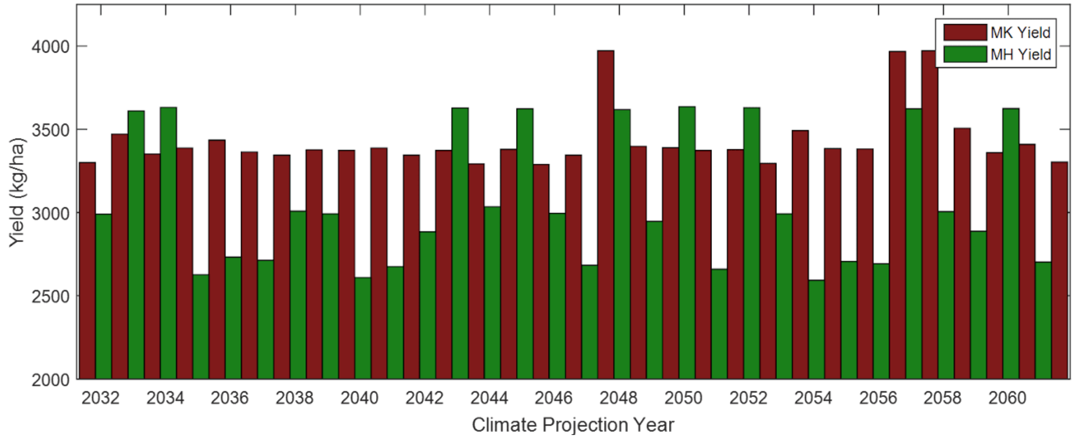
Look up process

Proyeksi kenaikan temperatur musim tanamam



Efek peningkatan temperatur berdasarkan model regresi

Proyeksi produktivitas padi



Fluktuasi dan potensi penurunan produksi MH lebih tinggi

Iklim Seperti yang (Mungkin) Anda BELUM Tahu

$$M_r = \frac{a^3}{g}\int_p\int_\lambda\int_\varphi u\cos^2\varphi\,d\varphi\,d\lambda\,dp,$$

$$M_\Omega = \frac{a^4\Omega}{g}\int_\lambda\int_\varphi p_s\cos^3\varphi\,d\varphi\,d\lambda,$$

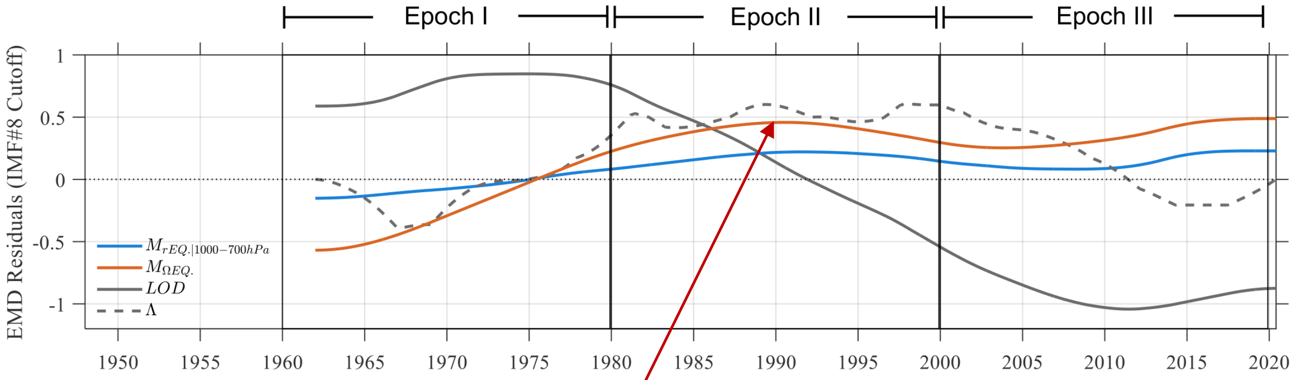
Bervariasi sebagai fungsi dari kecepatan angin zonal dan tekanan permukaan

$M = M_{atm} + M_{ocean} + M_{ice} + M_{crust} + M_{mantle} + M_{core}$ = const.

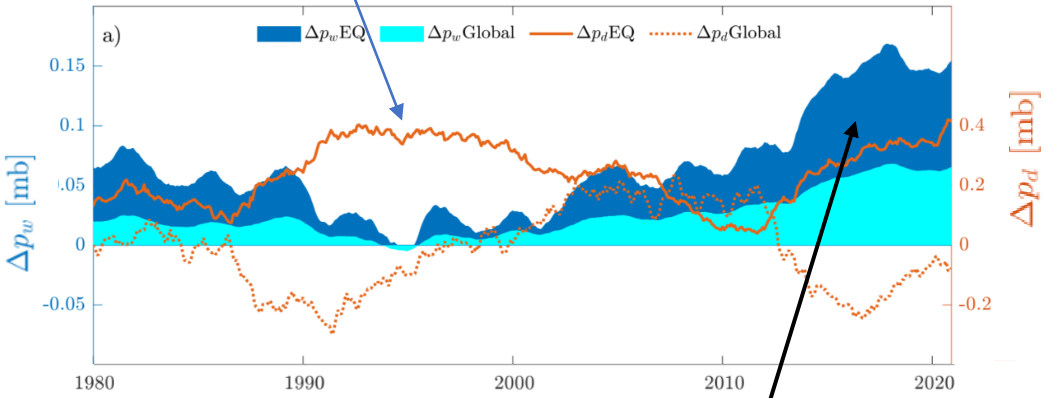
(Oort, 1989)

Perubahan laju rotasi bumi padat (*crust*) diukur sebagai perubahan panjang hari atau Length of Day (LOD)

Modeling angular momentum interactions among earth's components?



Peningkatan signifikan dari nilai M_Ω akibat peningkatan tekanan permukaan di wilayah ekuator vs. *acceleration of crustal rotation*



moistening of the tropical atmosphere (troposphere)
(Wirid Birastri, ongoing doctoral research)

dan Tentu Saja.... AI

https://www.weforum.org/agenda/2023/12/ai-weather-forecasting-climate-crisis/

WORLD ECONOMIC FORUM

EMERGING TECHNOLOGIES

AI can now outperform conventional weather forecasting – in under a minute, too

Dec 14, 2023

- GraphCast
- QuickClim
- ClimaX
- ACE
- Etc.

The ultimate goal, says Schneider, is **to create digital models of Earth's systems**, **partly powered by AI**, that can simulate all aspects of the weather and climate down to **kilometre scales**, **with great accuracy and at lightning speed**. We're not there yet, but advocates say this target is now in sight.

NEWS FEATURE | 26 March 2024

How AI is improving climate forecasts

Researchers are using various machine-learning strategies to speed up climate modelling, reduce its energy costs and hopefully improve accuracy.

By Carissa Wong

The first approach involves developing **machine-learning models called emulators**, which produce the same results as conventional models without having to crank through all the mathematical calculations.

In the second approach, researchers are **using AI** in a more fundamental way, **to power the guts of climate models**. These 'foundation' models can later be tweaked to perform a wide range of downstream climate- and weather-related tasks.

A third approach is **to embed machine-learning components inside physics-based models** to produce hybrid models

Nature **628**, 710-712 (2024)
doi: https://doi.org/10.1038/d41586-024-00780-8

Kilas Balik 20 Tahun ke Belakang

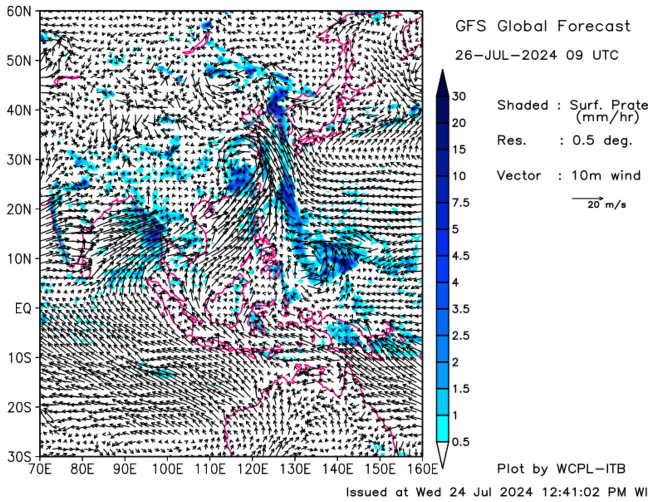
Memperkenalkan Kuliah Prediksi Cuaca Numerik di Kurikulum Program Studi S1 Meteorologi 2003

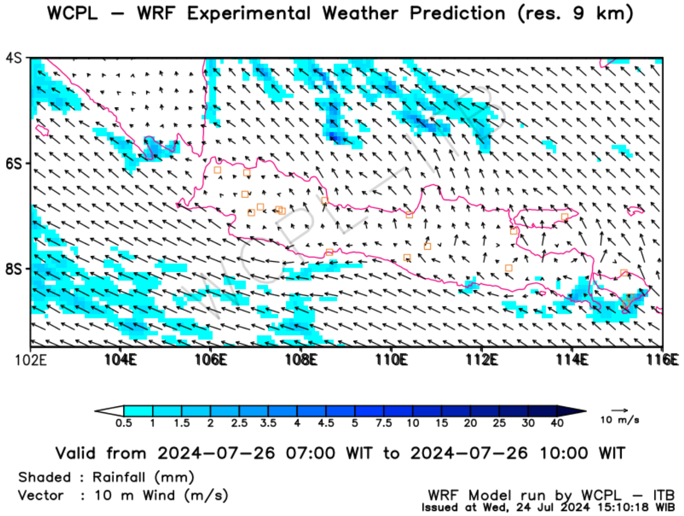
HPC (PC Cluster) pertama, 2006,
8 compute node, total 8 core

HPC konfigurasi terbaru ,
2023
Server-1: 64 core
Server-2: 40 core (80 thread)

Weather forecast – Downscaling experiment

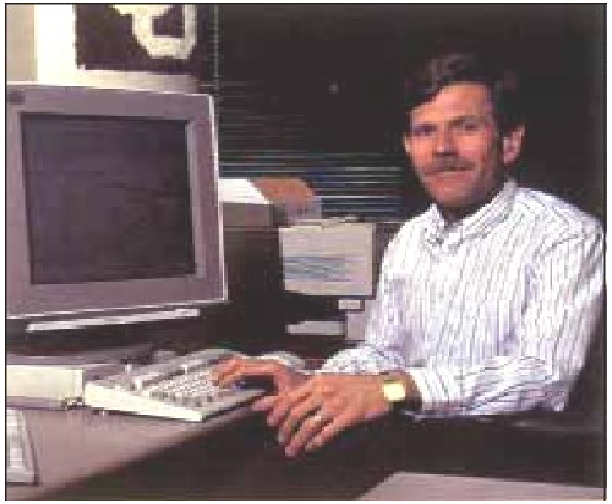
http://weather.meteo.itb.ac.id/





- **Kurang memadai** untuk menjalankan model cuaca dan iklim global
- Pemanfaatan **difokuskan untuk pendidikan** (Praktikum dan Tugas Akhir) bagi **mahasiswa S1**
- **Pengelolaan** dan pengembangan **oleh dosen-dosen muda**
- Lebih banyak **mengembangkan metode** prediksi dan proyeksi iklim menggunakan **"statistical downscaling"** (data-driven empirical model & post-processing output model global) → *Constructed Analogue*, *Bayesian Model Averaging*, dll. → *hybrid models with AI (machine learning)*.

Tuntutan, Tantangan, "Tentengan", Tuntunan (?)



Kelvin K. Droegemeier (1993) is an associate professor of meteorology at the University of Oklahoma :

"Meteorology encompasses mathematics, physics, thermodynamics, aerodynamics, computer science and other disciplines," he says. "I find the combination of these elements and their application to the atmosphere intriguing and rewarding."

"Reports that say that something hasn't happened are always interesting to me, because as we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns- the ones we don't know we don't know."

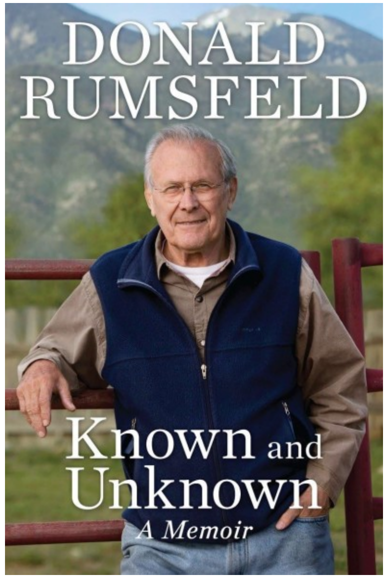


Image credit: https://www.amazon.com/Known-Memoir-Donald-Rumsfeld/

An expert is someone who knows the boundaries of knowing and not knowing (IMHO)

ITB, melalui FGB, selayaknya dapat memandu pengembangan kepakaran yang bersifat lintas keilmuan agar lebih sinergis dalam menjawab berbagai permasalahan terkait Iklim global dan dampaknya terhadap pembangunan Bangsa Indonesia di masa depan.

Terimakasih