An Introduction to Radiative Forcing in Climate Change

Tatsuya Seiki @ Tomita team

AICS Cafe 2012/1/13

Self-introduction

断絶の2000年

	Before 2000	After 2000
部活	無し	ワンダーフォーゲル部
趣味	漫画	漫画、登山、沢登り、ボルダリング

1981年：北海道札幌市にて誕生
2000年：北海道から出たくて上京＋東京工業大学入学
2004年：雲が好きだったので修士から衛星観測の研究室＠東京大学に編入
2010年：雲の数値モデルで学位（理学）取得

登った百名山（３５個）

利尻岳、大雪山、トムラウシ山、十勝岳、鳥海山、会津駒ヶ岳、那須岳、男体山、日光白根山、両神山、雲取山、甲武信ヶ岳、金峰山、瑞牆山、富士山、谷川岳、草津白根岳、四阿山、浅間山、巻機山、白馬岳、五竜岳、鹿島槍ヶ岳、水晶岳、鷲羽岳、槍ヶ岳、穂高岳、常念岳、蓼科山、赤岳、甲斐駒ケ岳、鳳凰山、塩見岳、光岳、石鎚山

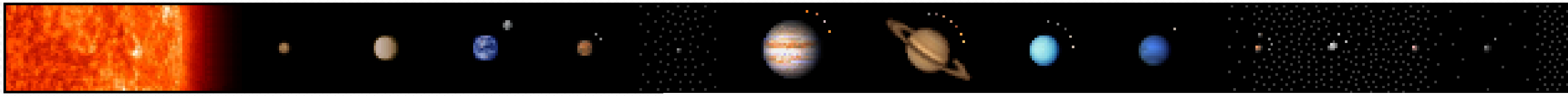
Cloud in Climate Study

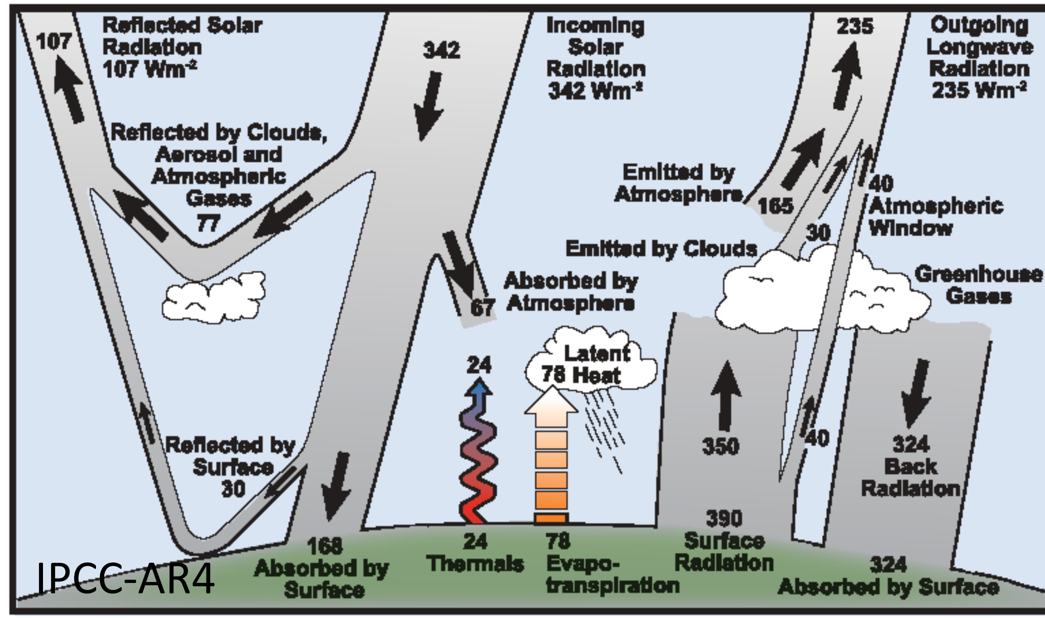
Various clouds = various brightness = different efficiencies of light-scattering (cooling the Earth)

	Thin	Mid	Thick
High	巻雲 Cirrus	巻層雲 Ciro-stratus	積乱雲 Cumulonimbus
Mid	高積雲 Alto-cumulus	高層雲 Alto-stratus	乱層雲 Nimbostratus
Low	積雲 Cumulus	層積雲 stratocumulus	層雲 stratus

Radiative Forcing and Climate Change

Radiative Forcing





Radiative Forcing:

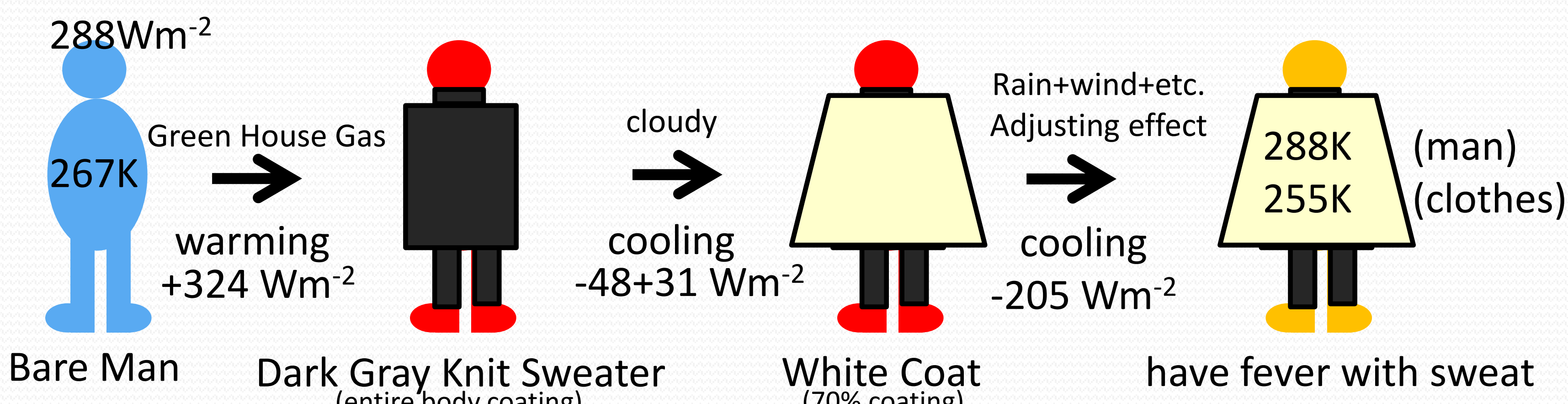
- Contribution to energy balance
- Concept to assess global warming

Equilibrium condition

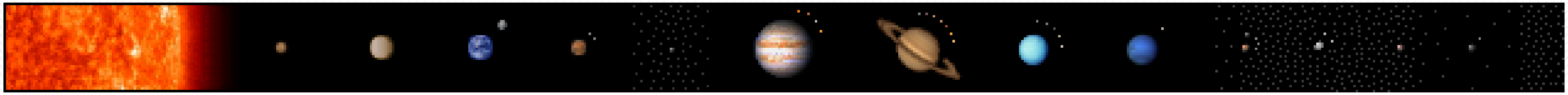
$$\pi r_E^2 (1-\alpha) S_{sun} \quad = \quad 4\pi r_E^2 \sigma T^4$$

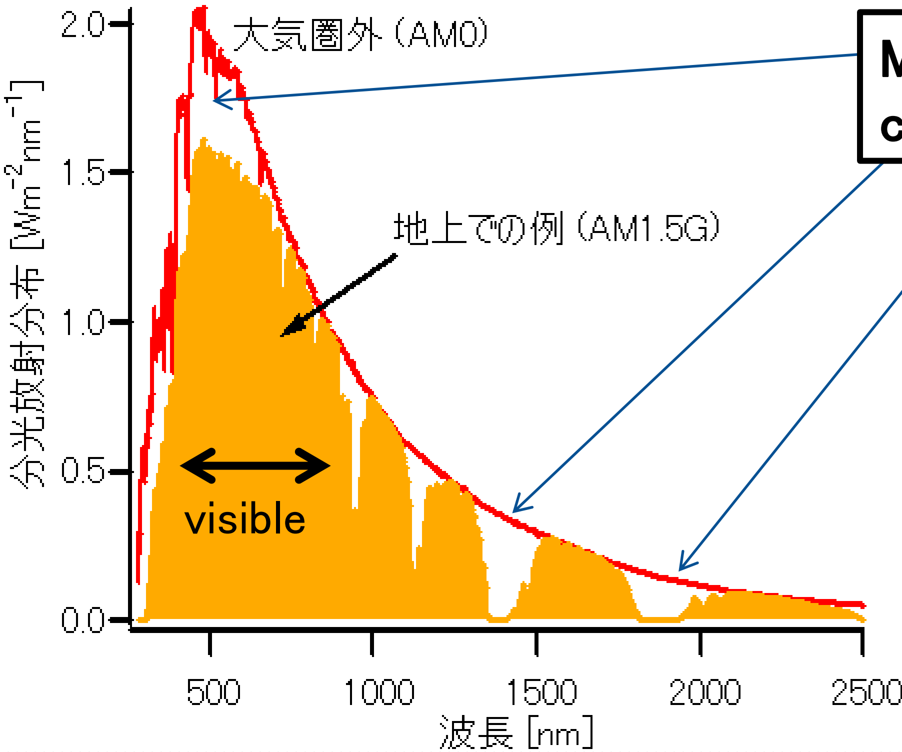
Equilibrium + perturbation

$$\pi r_E^2 (1-\alpha) S_{sun} + \delta E \;=\; 4\pi r_E^2 \sigma (T+\delta T)^4$$

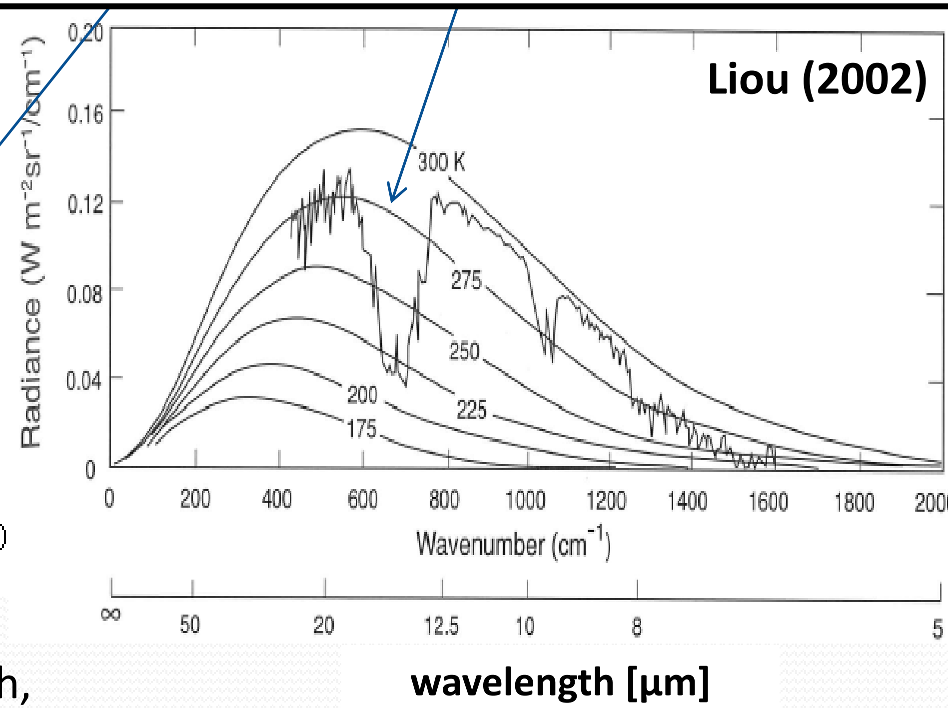


Radiative Forcing (by wavelength)





Missing energy comes from gas absorption
c.f.) CO_2, H_2O, O_3

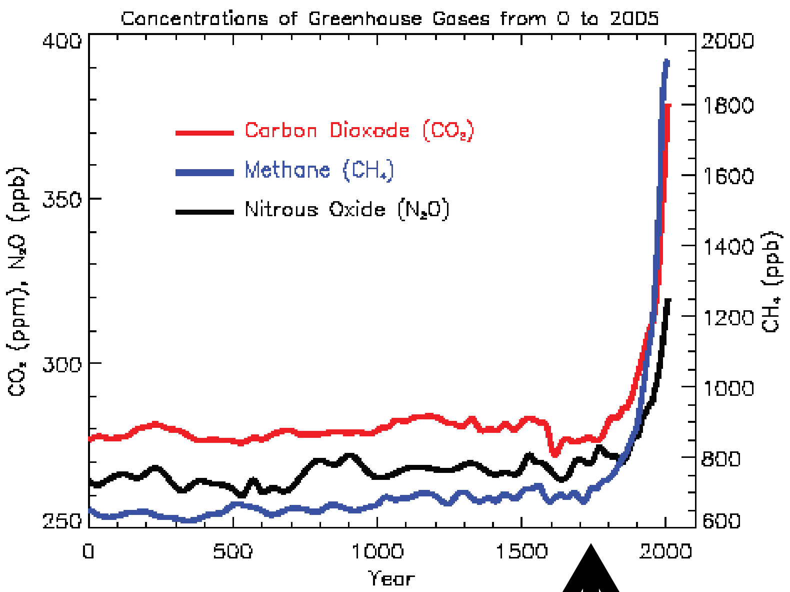


Radiative energy flux depends on wavelength,
while optical properties of atmospheric gases/particles depends on wavelength.

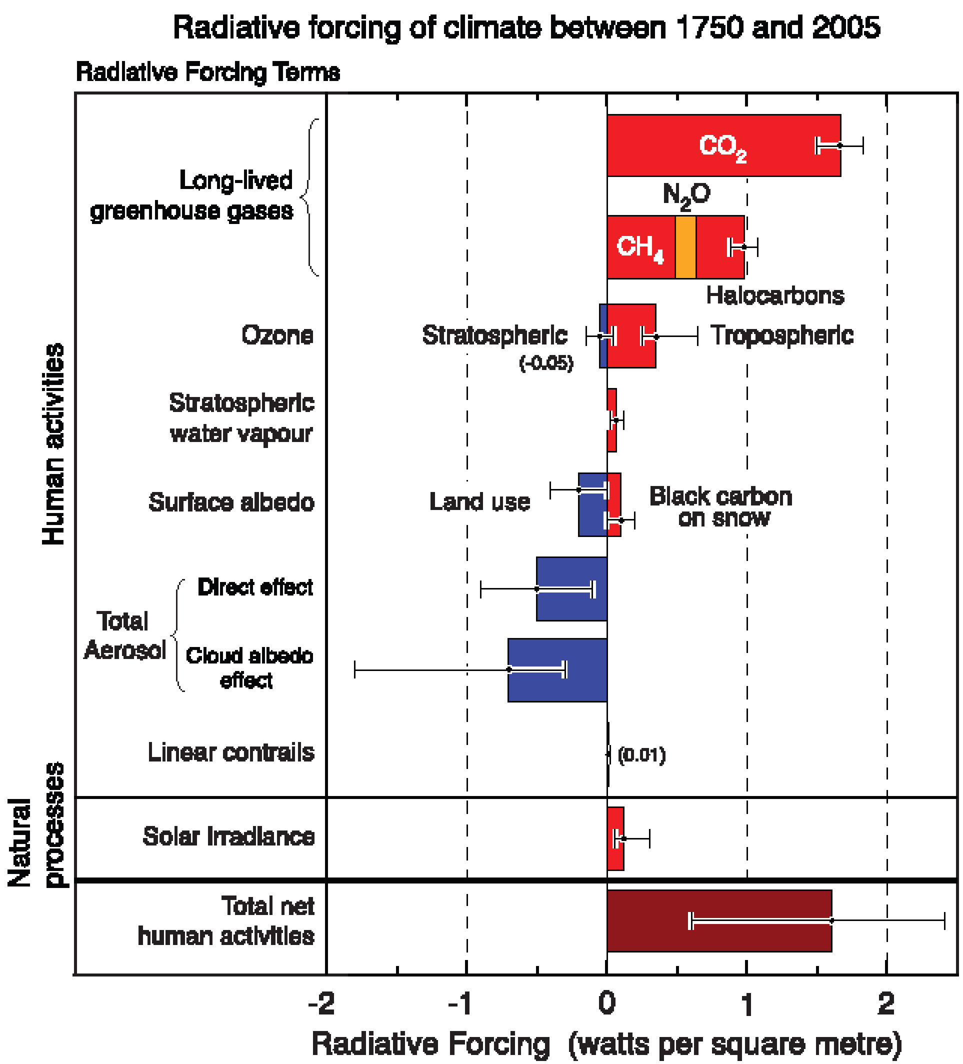
$$B_\lambda(T) = \frac{2hc^2}{\lambda^5\left(e^{hc/k_B\lambda T} - 1\right)}$$

- ✓ Energy flux from Solar beam: H_2O, O_3, Cloud, Aerosol
- ✓ Energy flux from Earth heat: H_2O, CO_2, CH_4, N_2O, O_3, Cloud

Anthropogenic Radiative Forcing



Industrial Revolution: Steam Engine by Newcomen, 1712; Watt, 1769



Human activities role as an additional radiative forcing into climate systems after 1700s. Greenhouse gases have strong impact to heat the Earth with less uncertainties, while aerosols has strong impact to cool the Earth with much uncertainties.

Aerosol Radiative Forcing

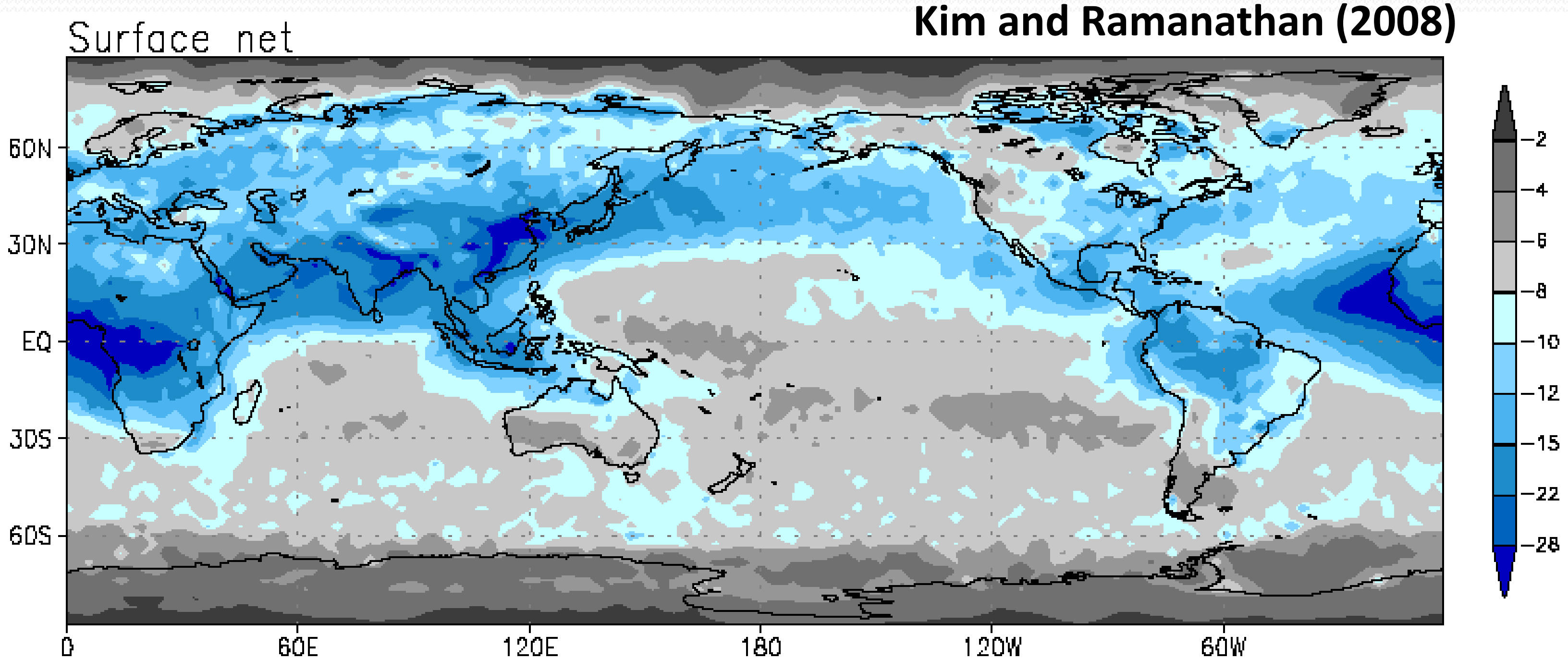
2007.6.17-21, Beijing (photo by Seiki)

At Beijing, it is likely to be foggy even though it is not cloudy.
Aerosols (Atmospheric Pollution) overcast sky to decrease energy exp(-1) near the ground, particularly around industrial regions.

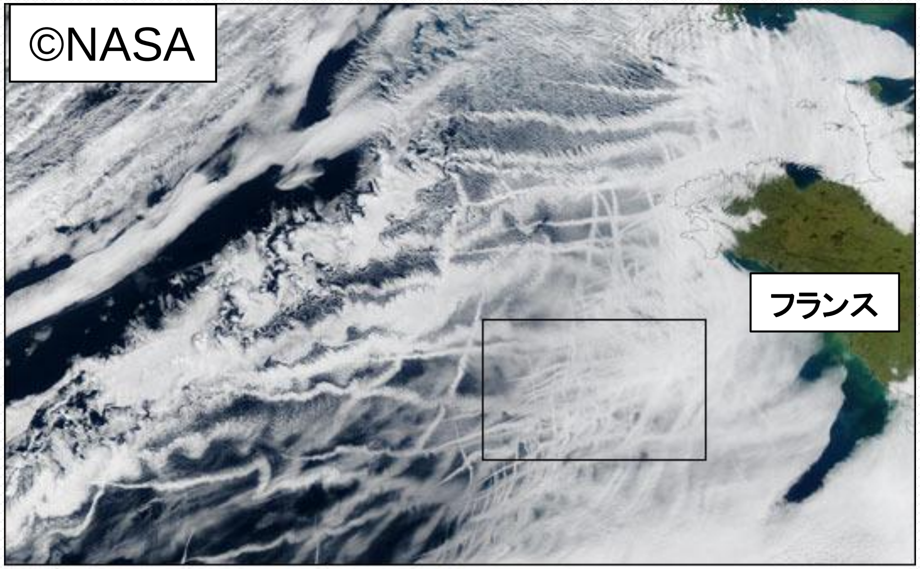
Global dimming by Aerosols

Aerosol radiative forcing at the surface by multi-satellite/ground observations.

Kim and Ramanathan (2008)



Aerosol Indirect Radiative Forcing



True Color

典型的な雲

$1 m^{-2}$あたりの質量～ 50～100 $g\ m^{-2}$

太陽光の散乱～雲の 断面積(πr^2) に比例

50gの水滴一個だと半径は2.3cm
断面積は$16.4 cm^2$
➔$1 m^2$の地面のうち、0.164%しか覆われない

海上の雲粒の典型的な大きさ～ 20×10^{-6} m

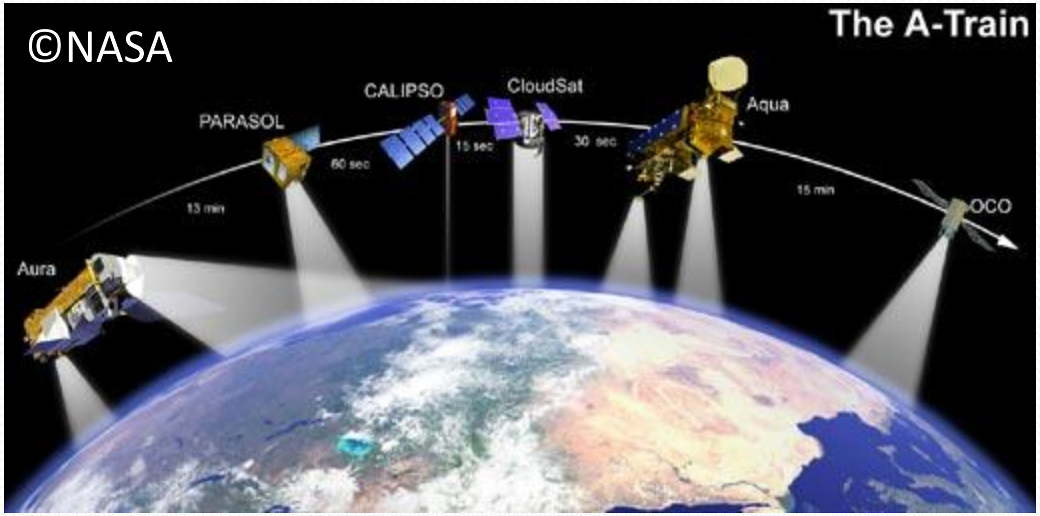
➔粒子数は1.5×10^9個、断面積は～ 1.88 m^2

➔188%も雲が覆う！

粒子サイズが1/2になると断面積は2倍になる!

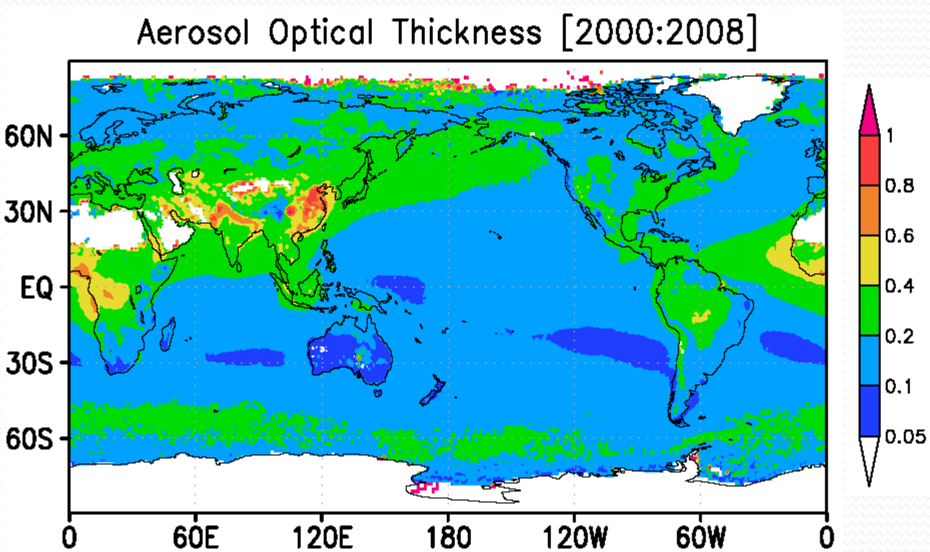
人間の産業活動は硫酸などのエアロゾル(大気汚染物質)を大量に排出し、
エアロゾルが水蒸気をまとって多量の雲凝結核となる。
エアロゾルが多い地域では雲粒が小さくなって太陽光を反射しやすくなっている

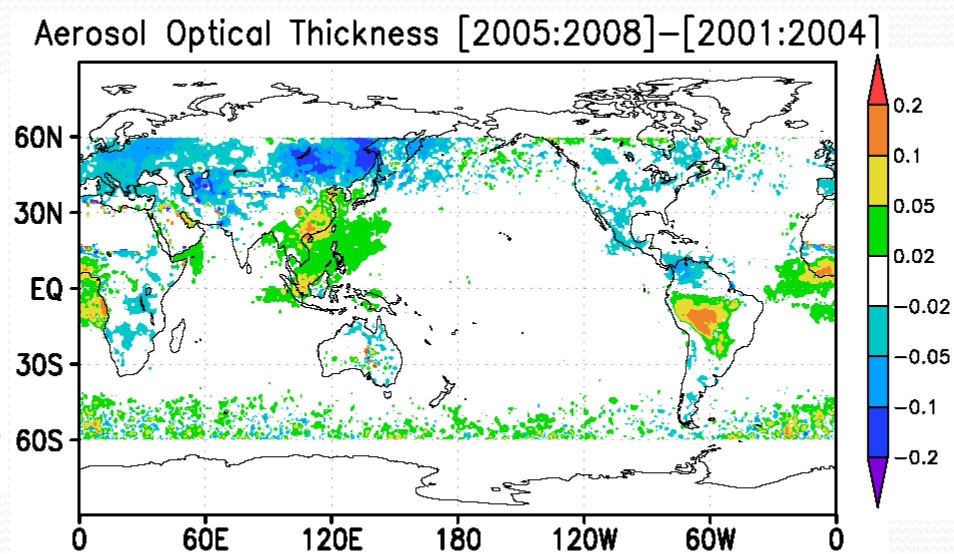
Aerosols Distribution by Satellites



After 1980s, NASA has led observation projects using satellite remote sensing. (e.g., ISCCP, ERBE, A-Train)

We can estimate radiative forcing by Cloud and aerosols quantitatively.
➔ Improving Climate Models

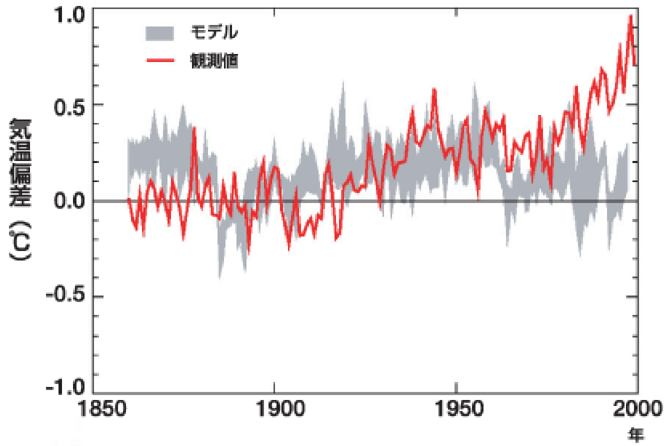




MODIS/Aqua-Terra

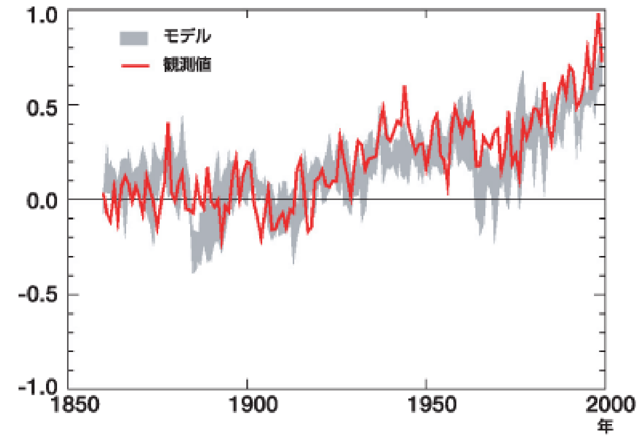
Global Warming Projection

（a）自然起源



自然起源の応答（太陽放射や火山噴火）だけでは、
20世紀後半の温暖化は説明できない。

（c）自然起源 ＋ 人為起源



すべての人為起源と自然起源の因子を複合させると、
過去140年間の観測値とモデル計算が最もよく説明
される。

B1「持続的発展型社会シナリオ」

・環境の保全と、経済の発展を地球規模で両立する。

A1T： 非化石エネルギー源を重視(新エネルギーの大幅な技術革新)

B2「地域共存型社会シナリオ」

・地域的な問題解決や世界の公平性を重視し、経済成長はやや低い。

・環境問題等は、各地域で解決が図られる。

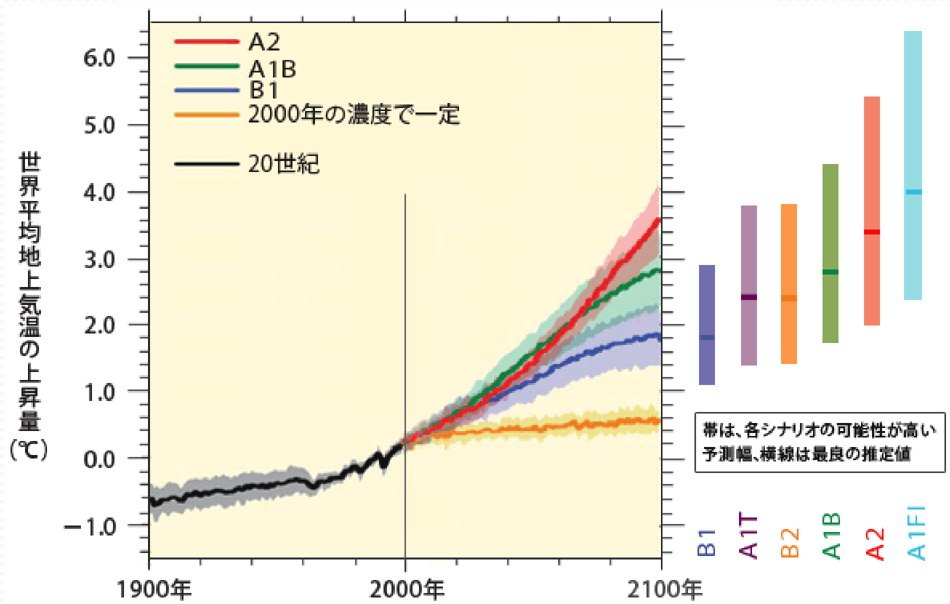
A1B：各エネルギー源のバランスを重視

A2「多元化社会シナリオ」

・世界経済や政治がブロック化され、貿易や人・技術の移動が制限。

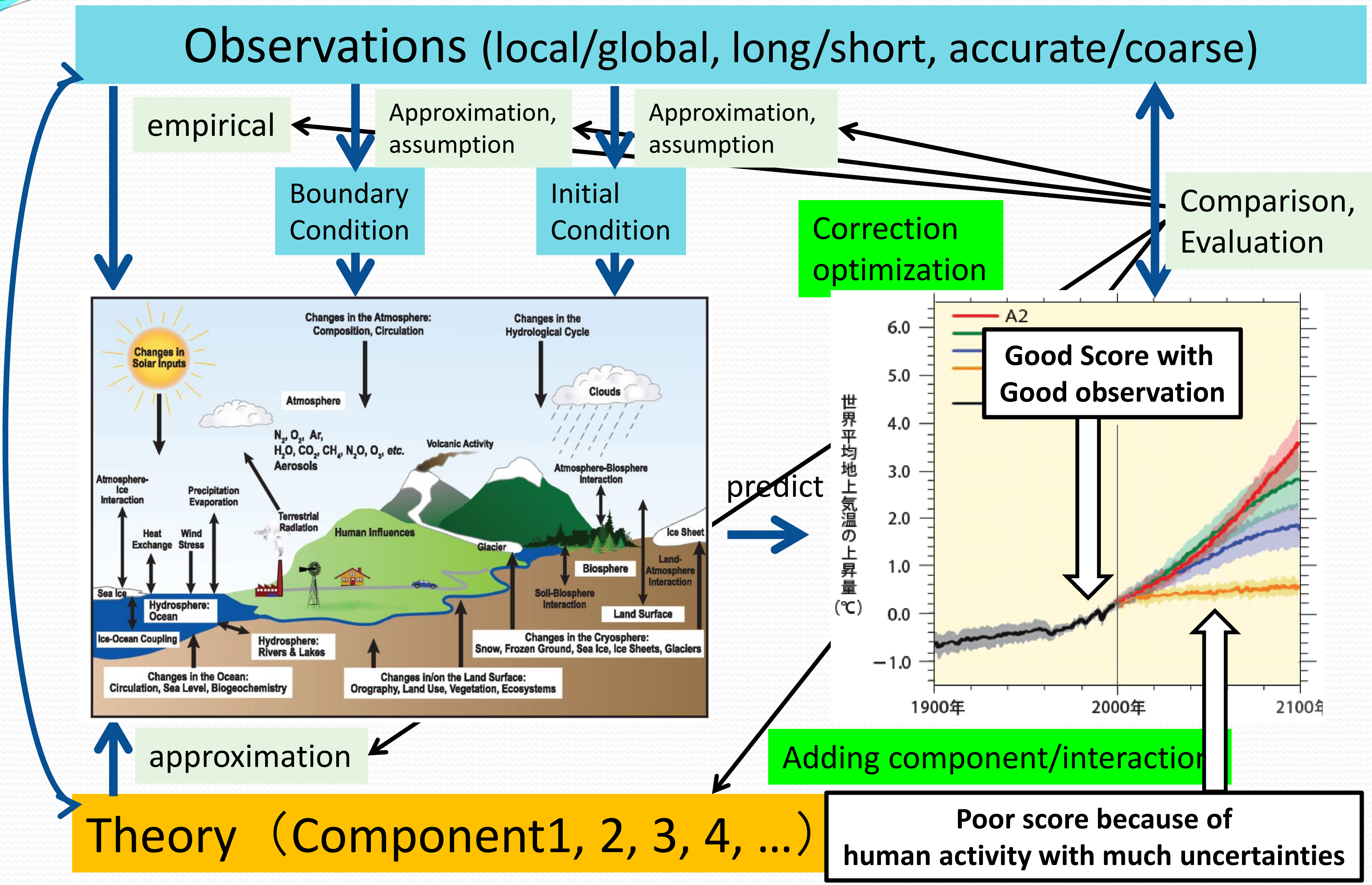
・経済成長は低く、環境への関心も相対的に低い。

A1FI：化石エネルギー源を重視

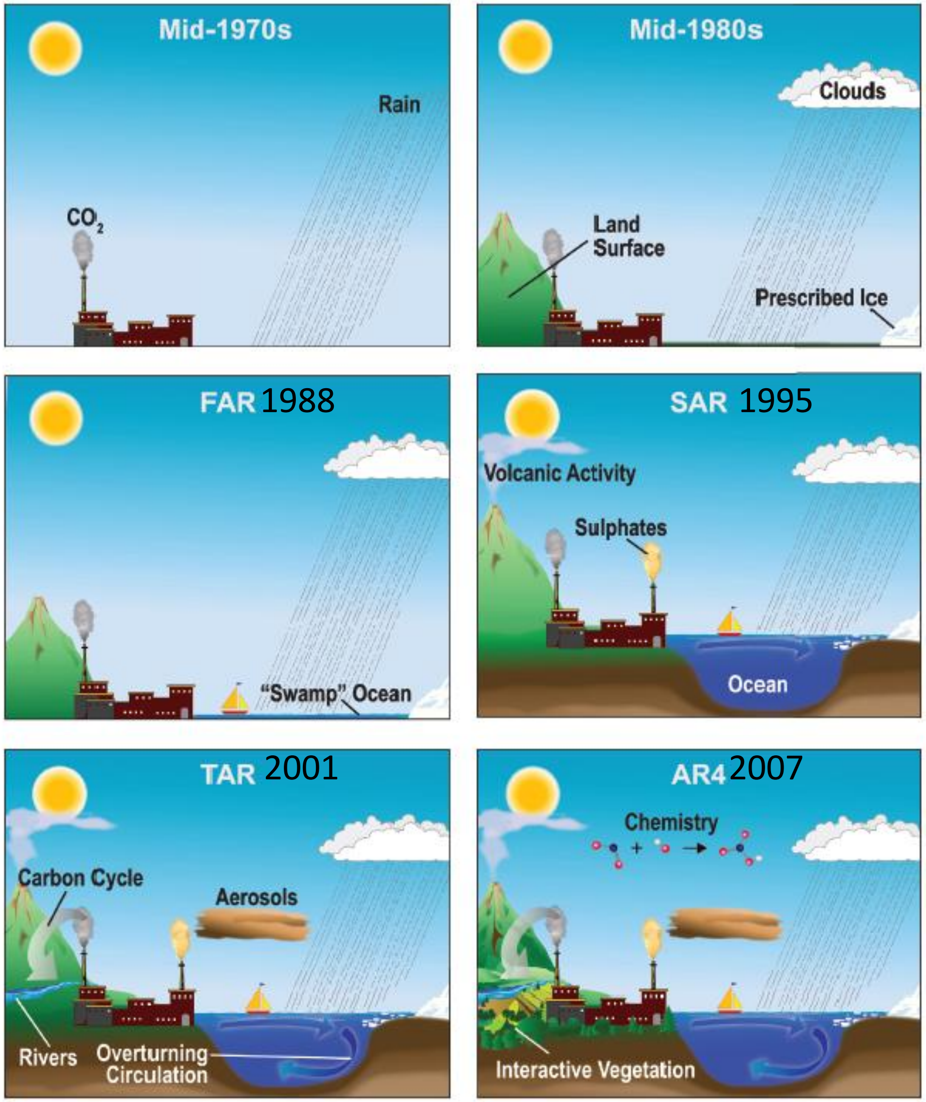


General Circulation Model

General Circulation Models (GCMs)



Development of GCMs

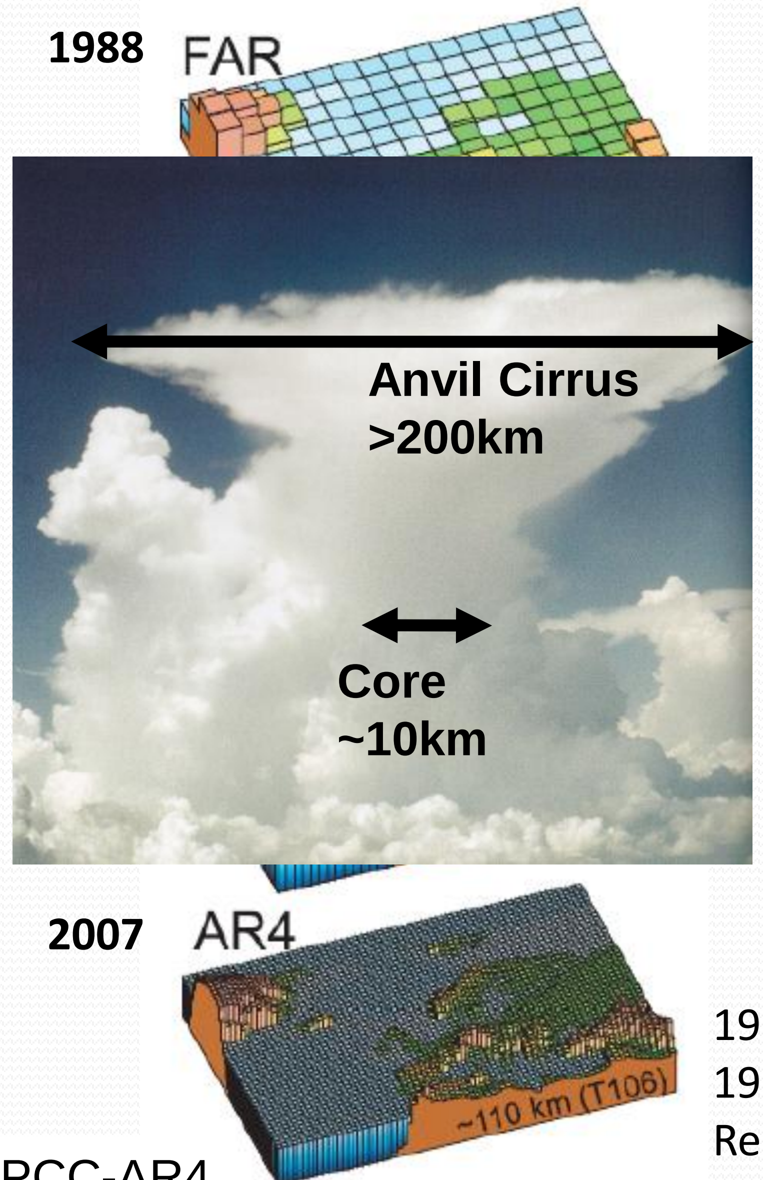


General Circulation Models contain:

- Geophysical Fluid Dynamics (fluid+thermo+gravity+Coriolis+salinity)
    - Atmospheric circulation
    - Oceanic circulation
    - Phase change/Latent heat
        - **Vapor ⇔cloud,rain**
        - Sea-water ⇔ sea-ice, salinity
- Land Surface
    - Vegeration, urbanization, cultivation
    - River
    - Soil (heat/water transport)
    - Ice-sheet
- Radiation (e.g., Solar Incidence)
    - Gas absorption
    - Rayleigh Scattering
    - **Mie Scattering by Cloud, Aerosol**
- Chemistry (e.g., ozone hole)
    - Chemical Reaction
    - **Wet deposition**
    - Emission

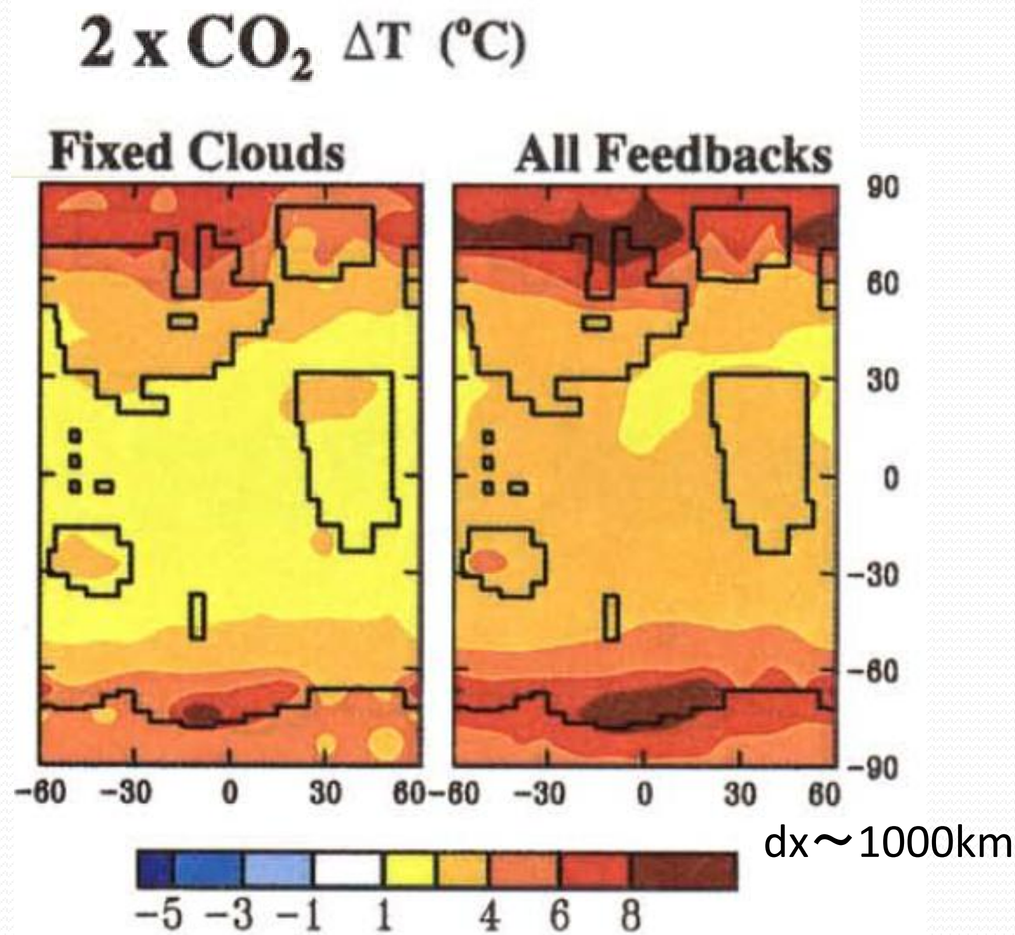
Advances in Simulation

1988



2007

IPCC-AR4



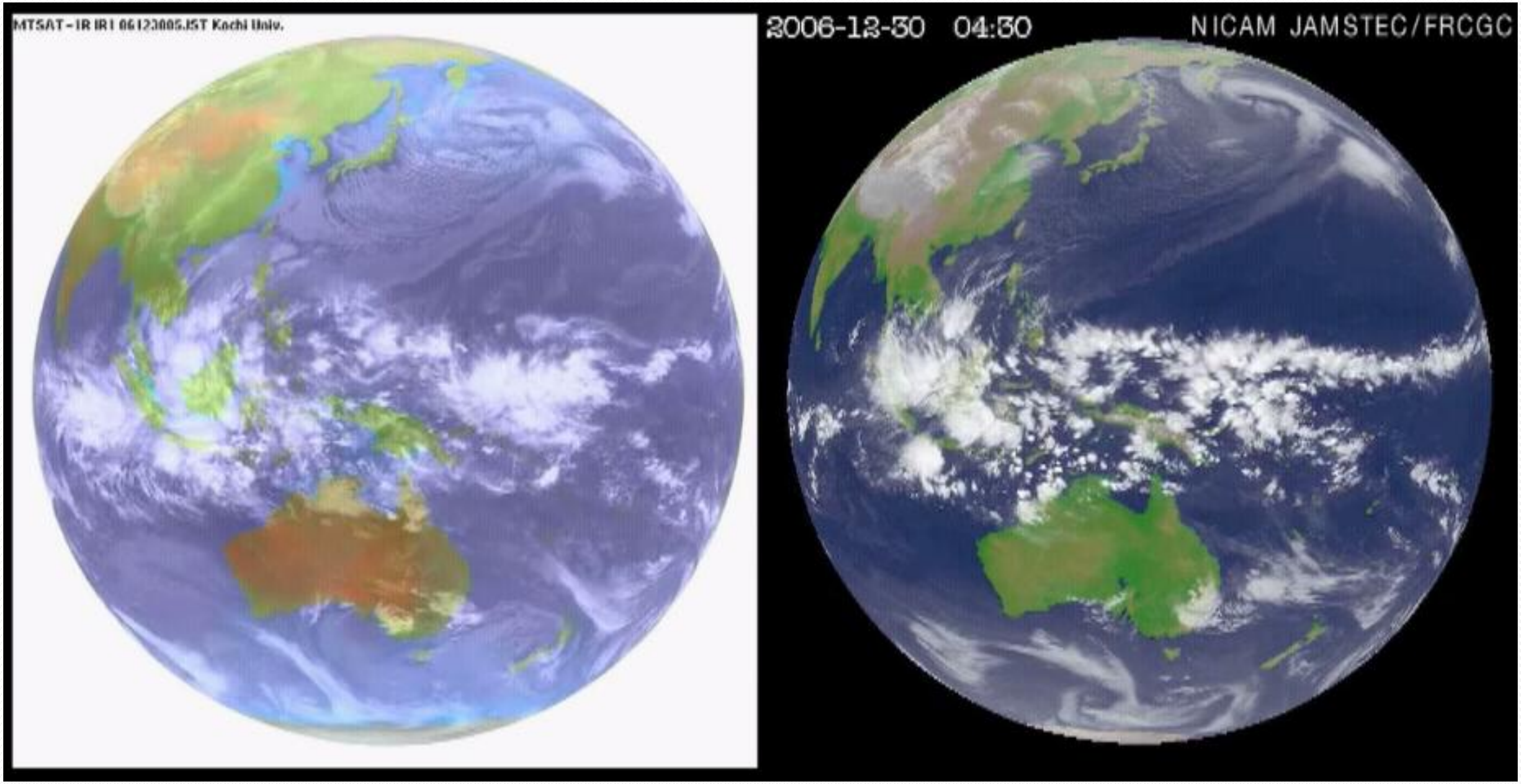
Hansen et al. (1997)

1988, Dr. James Hansen@NASA suggest Global Warming
1988, IPCC is established
Recently, it is found that poorly resolved cloud causes the most severe error in climate change.

Global Cloud Resolution Model, NICAM @ The Earth Simulator, Japan

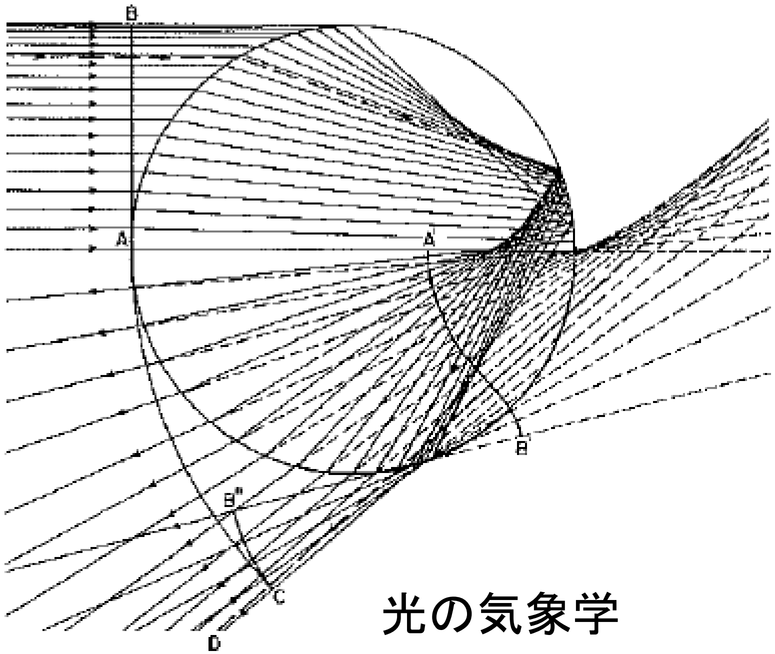
Reproduction of Madden Jullian Oscillation (Miura et al., 2007)

➔horizontal resolution=3.5km (⇔30000 times heavier than conventional ones: dx～110km)



Cloud Optical Properties (classic)

Descartes Rainbow is introduced in “Discourse on Method (方法序説)”(1637)



光の気象学

color	purple	yellow	red
m_{water}	1.3435	1.3341	1.3318
θ_i (deg)	58.80	59.35	59.48
θ(deg)	40.58	41.91	42.25

Snell’s law: refraction theory

$$\frac{\sin\theta_A}{\sin\theta_B} = \frac{v_A}{v_B} = \frac{m_A}{m_B}$$

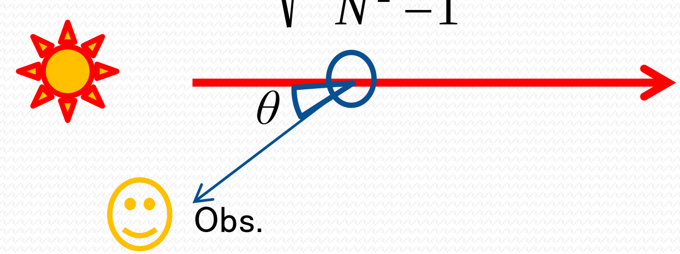
m:refractive index

Application of Maxwell’s law to sphere

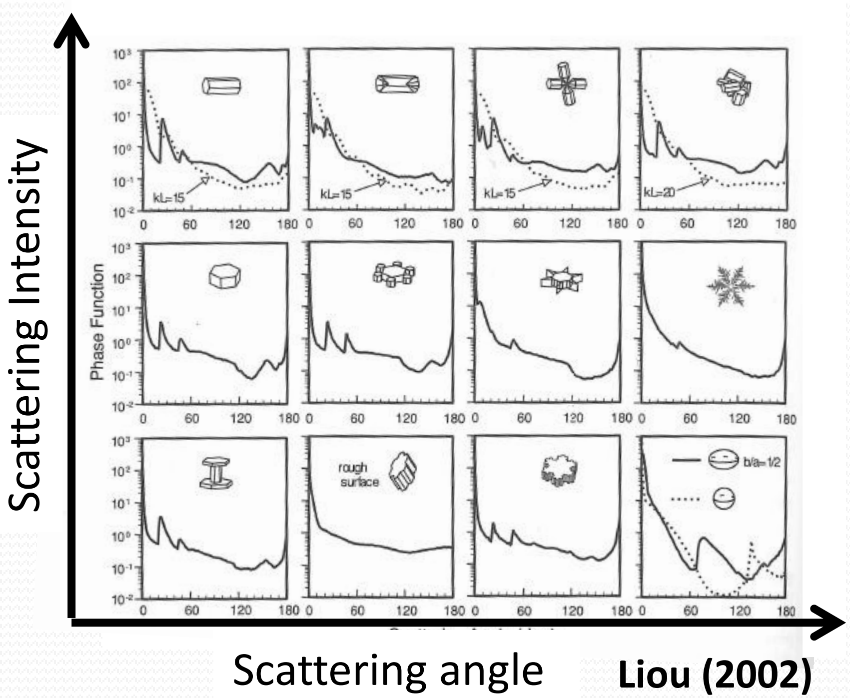
$$E_l^r = R_l E_l^i, \qquad E_l^t = T_l E_l^i,$$
$$E_r^r = R_r E_r^i, \qquad E_r^t = T_r E_r^i.$$
$$s.t.$$
$$R_r = \frac{\cos\theta_i - m\cos\theta_t}{\cos\theta_i + m\cos\theta_t}, \qquad R_l = \frac{m\cos\theta_i - \cos\theta_t}{m\cos\theta_i + \cos\theta_t},$$
$$T_r = \frac{2\cos\theta_i}{\cos\theta_i + m\cos\theta_t}, \qquad T_l = \frac{2\cos\theta_i}{m\cos\theta_i + \cos\theta_t}.$$

Deriving a major angle to concentrate energy fluxes after Nth refractions.

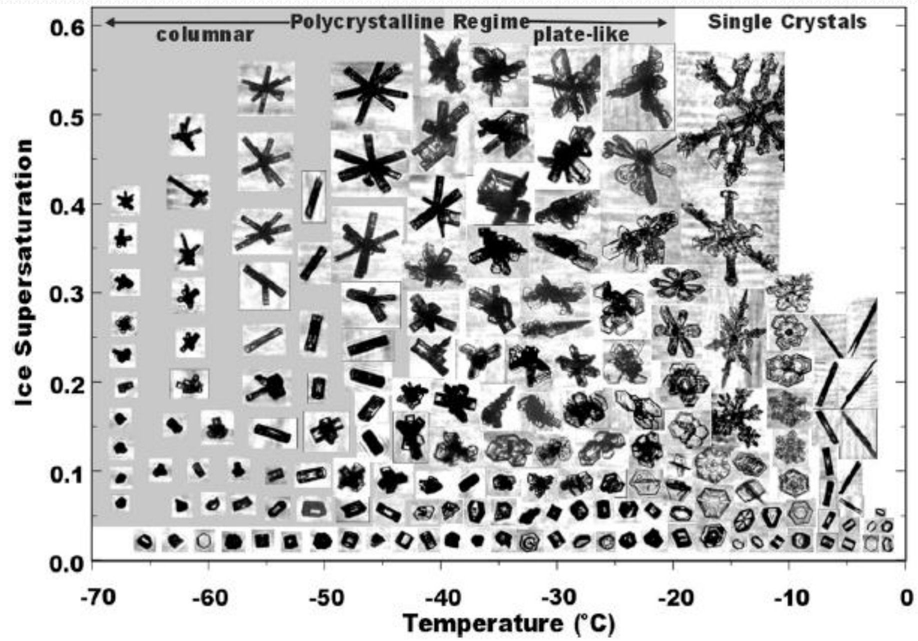
$$\theta_i = \cos^{-1}\sqrt{\frac{m_{water}^2 - 1}{N^2 - 1}}$$



Cloud Optical Properties (advanced)



Liou (2002)



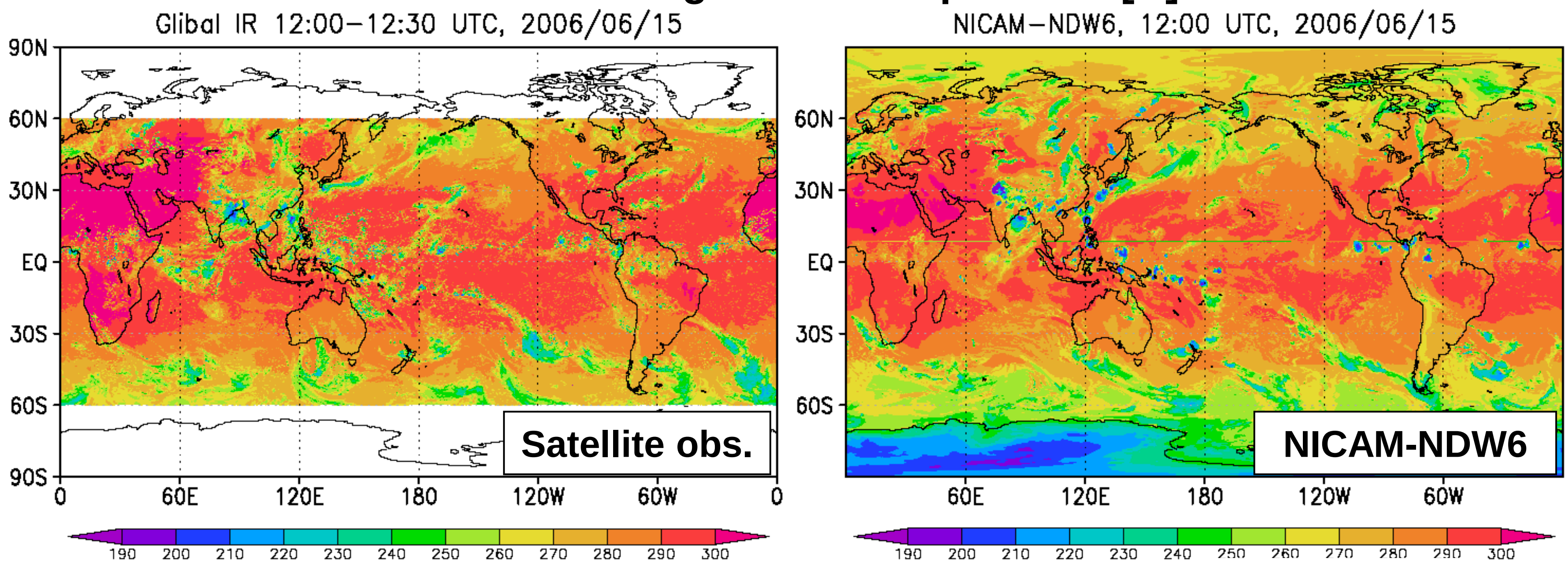
Bailey and Hallett (2010)

<u>Current topics of my research</u>

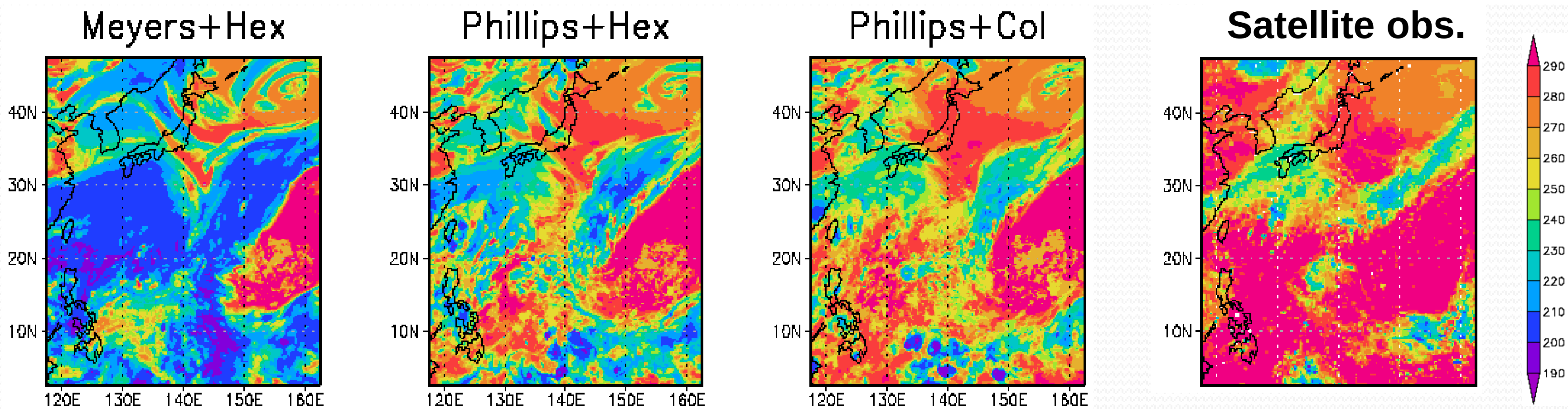
1. Ice Nucleation Modeling:
   Aerosol/Supercooled liquid water ➔ Ice Crystals
2. Estimation of the Impact of Non-sphericity of ice crystals

Global Simulation (now undergoing)

Infrared Brightness Temperature [K]



Differences by schemes



Ice Nucleation Scheme: Meyers et al. (1992) or Phillips et al. (2006)

Ice Crystal Shape: Hexagonal Plate (Hex) or Hexagonal Column (Col)

Climate Simulation in the Future (unlimited…)

None knows the sufficient spatial resolution,
and the sufficient combination of cloud/aerosol interaction.
(Do uncertainties converge or not in the future ?)

- GCMs need fine spatial resolution to resolve cloud as much as possible.
  - dx~3.5km is the finest at this moment.
  - ➔dx>1km is challenging in the next step (more than 3.5^3 times heavier)

- It is better to treat many species of cloud/aerosol particle as much as possible.
  - ➔Cost~N^2 x M^2: N/M is the number of cloud/aerosol. (N=5, M=24 at this moment)