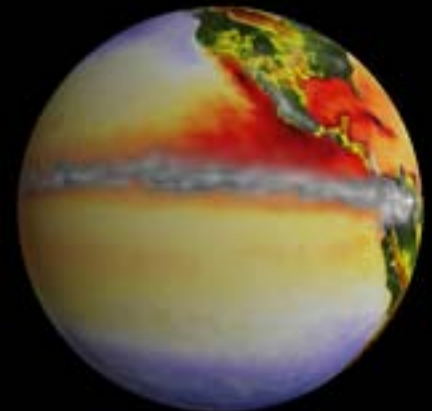


神戸大学 2008.6.14

人為起源要因による気候変動とその周辺
Anthropogenic climate change and
some issues

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東京大学気候システム研究センター
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進行する全球規模の環境汚染



インドとバングラデシュ域の大気汚染：ヒマラヤ山脈からの伏流水で肥沃なインド・ガンジー地峡帯から流れ出す大気汚染エアロゾル。水供給の変化は？

大西洋の航跡雲：船舶の航行に伴って発生する航跡雲（大西洋の例）：船から発生する汚染物質で、数百キロメートルに及ぶ大きな変化が起っている。雲の変化は？

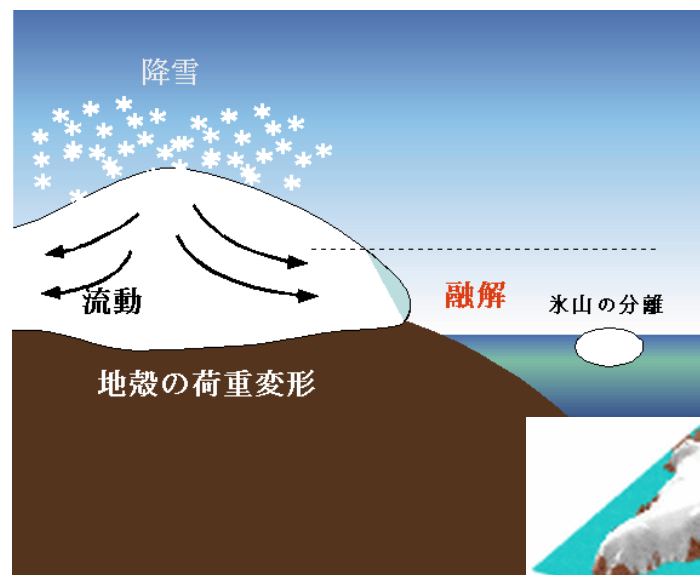
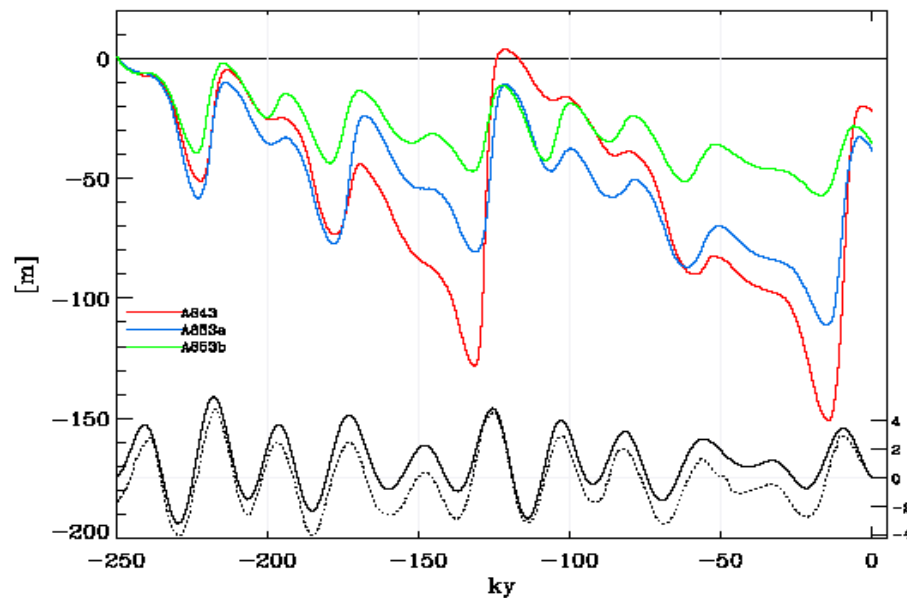
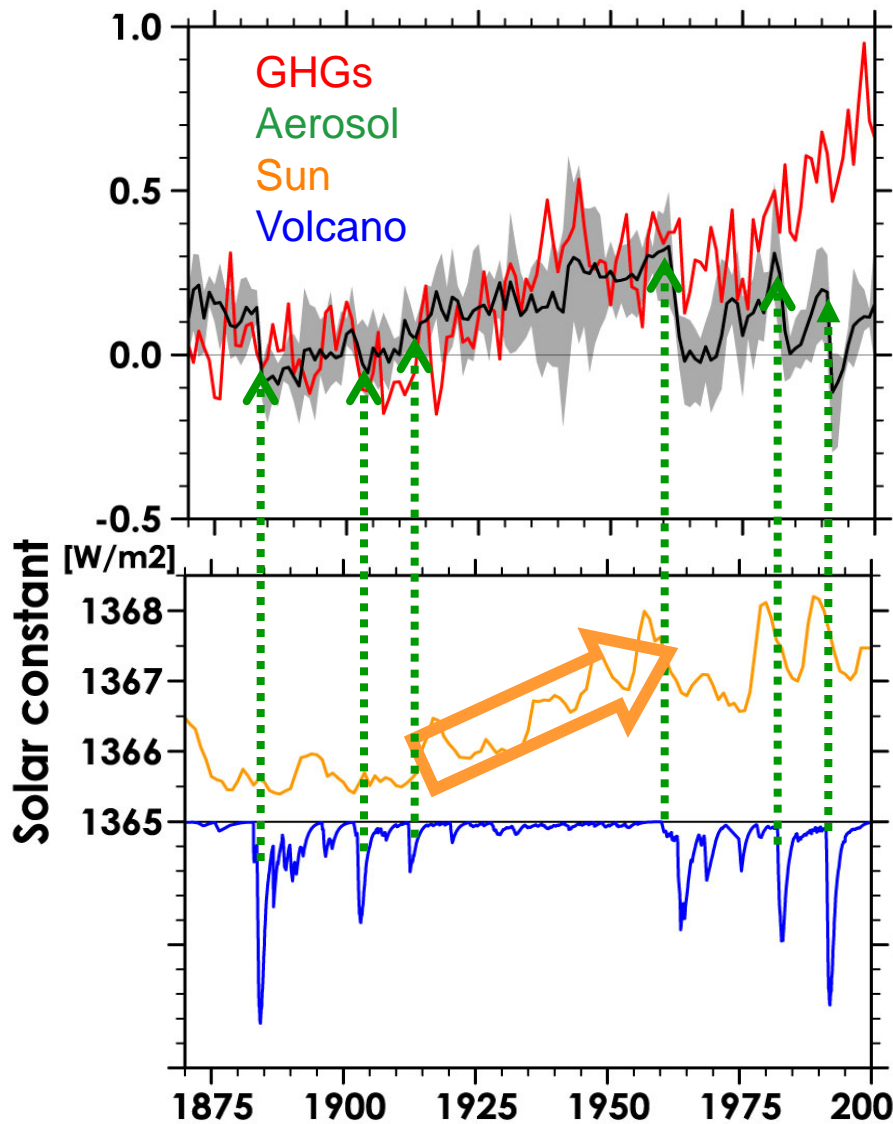


湾岸戦争と油井火災 1991年



Various time scales and mechanisms for Earth's climate change

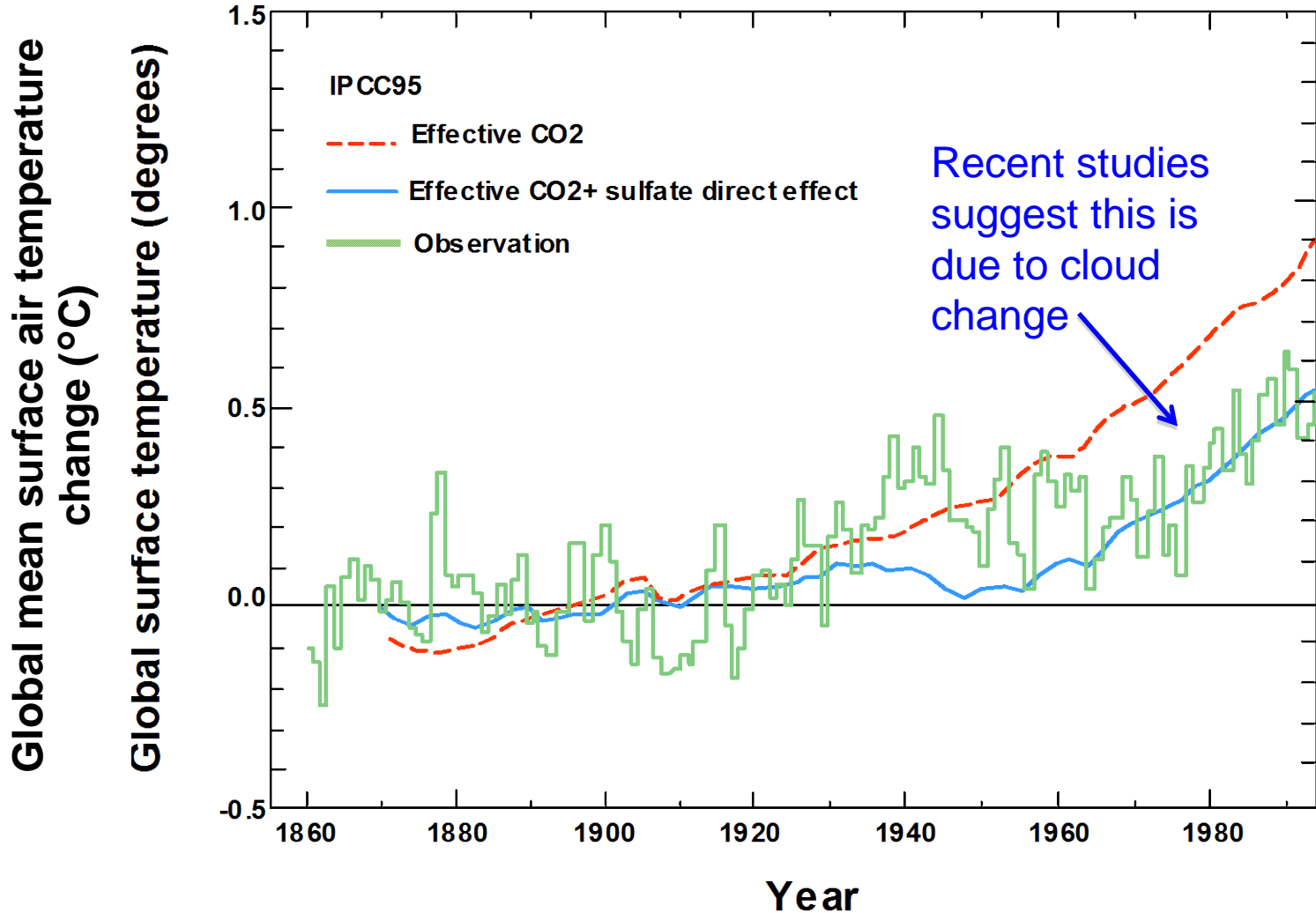
Orbital change
+ Crust response
+ CO₂



yr0000

Complex atmospheric physics

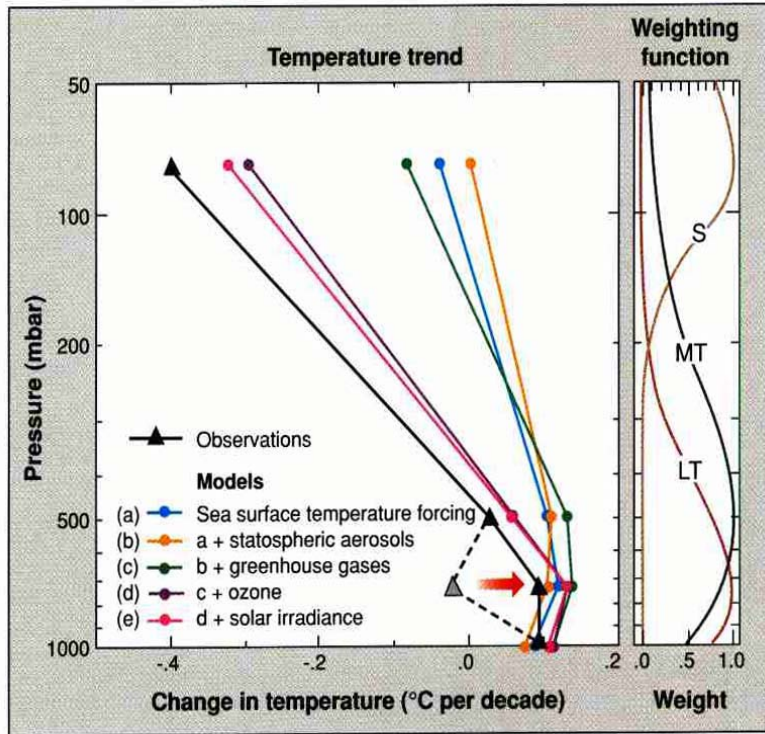
- Mitchell et al. (Nature 1989): CO₂ and Climate: Missing feedback, ice particles
- Mitchell et al. (Nature 1995): sulphate aerosols
- Takemura et al. (JGR2005, GRL2006)



レッスン 1

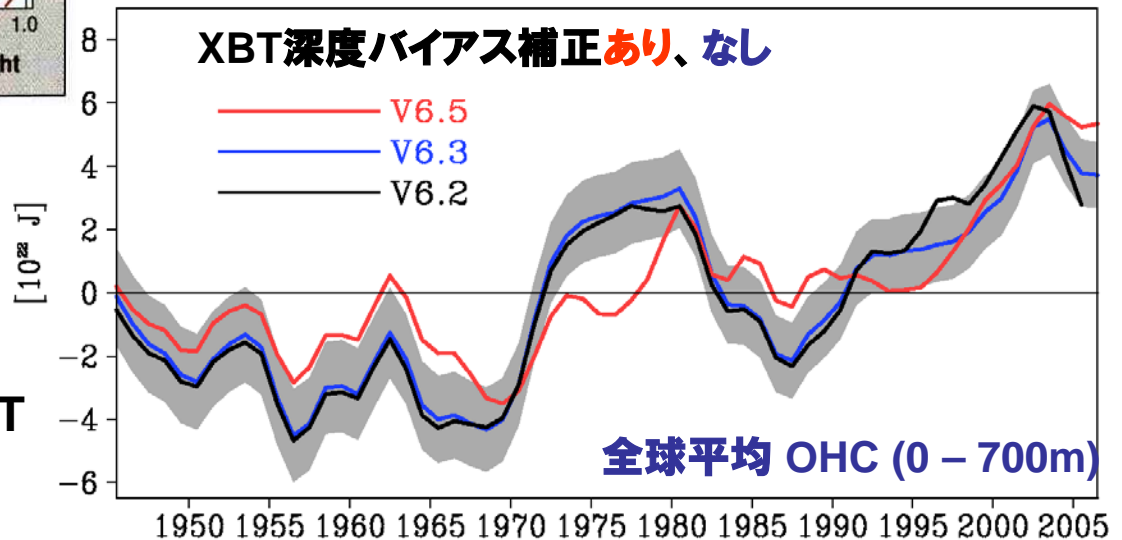
- 気候系の変化メカニズムは非常に複雑である。
- Handwavingは通用しない
- 詳細な、物理・化学・地球物理プロセスのモデリングが必要
 - 研究者の連携が重要
 - 情報流路構築のためのプラットフォームとしての気候・環境モデル
 - コンピューターリソースが必要
- 執拗な検証作業が必要
 - 相関は関連とは違う：容易に間違えを起こす
 - 地上・衛星観測システムの確立が重要
 - 様々なデータ復元が必要

Disputes in data analysis



- Spencer and Christy (Science 1990):
NOAA/MSU ch2 brightness temp
- Hansen et al. (Science 1998)

Global (60S–60N) Annual Mean Heat Content relative to 1961–2000 average, err: 1σ

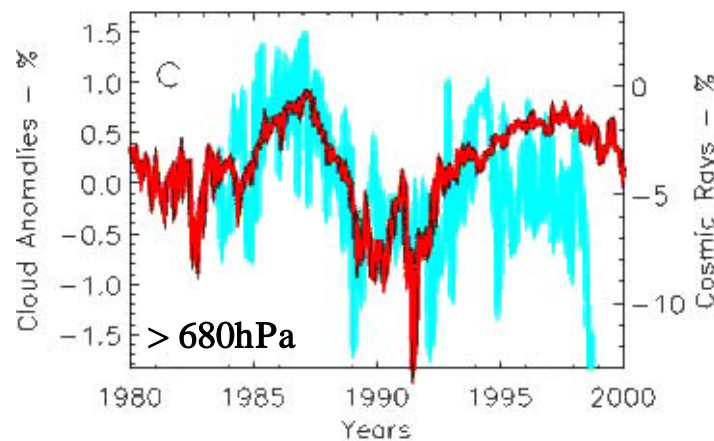
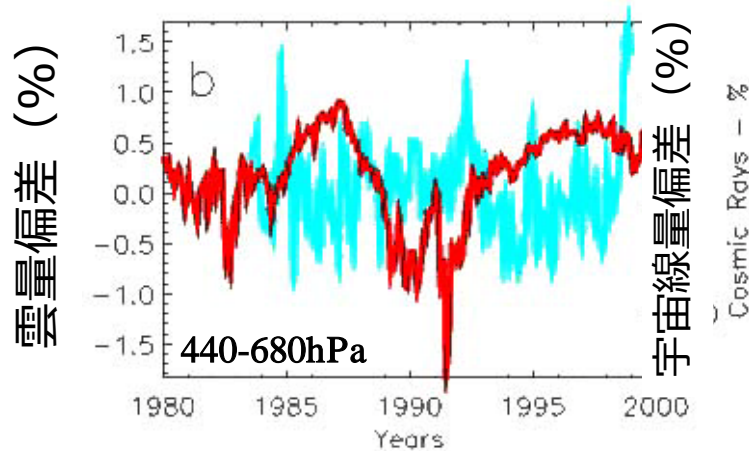


Lyman et al. (2007): Argo & XBT
 Ishii and Kimoto (2008)

不確実な気候変化要因

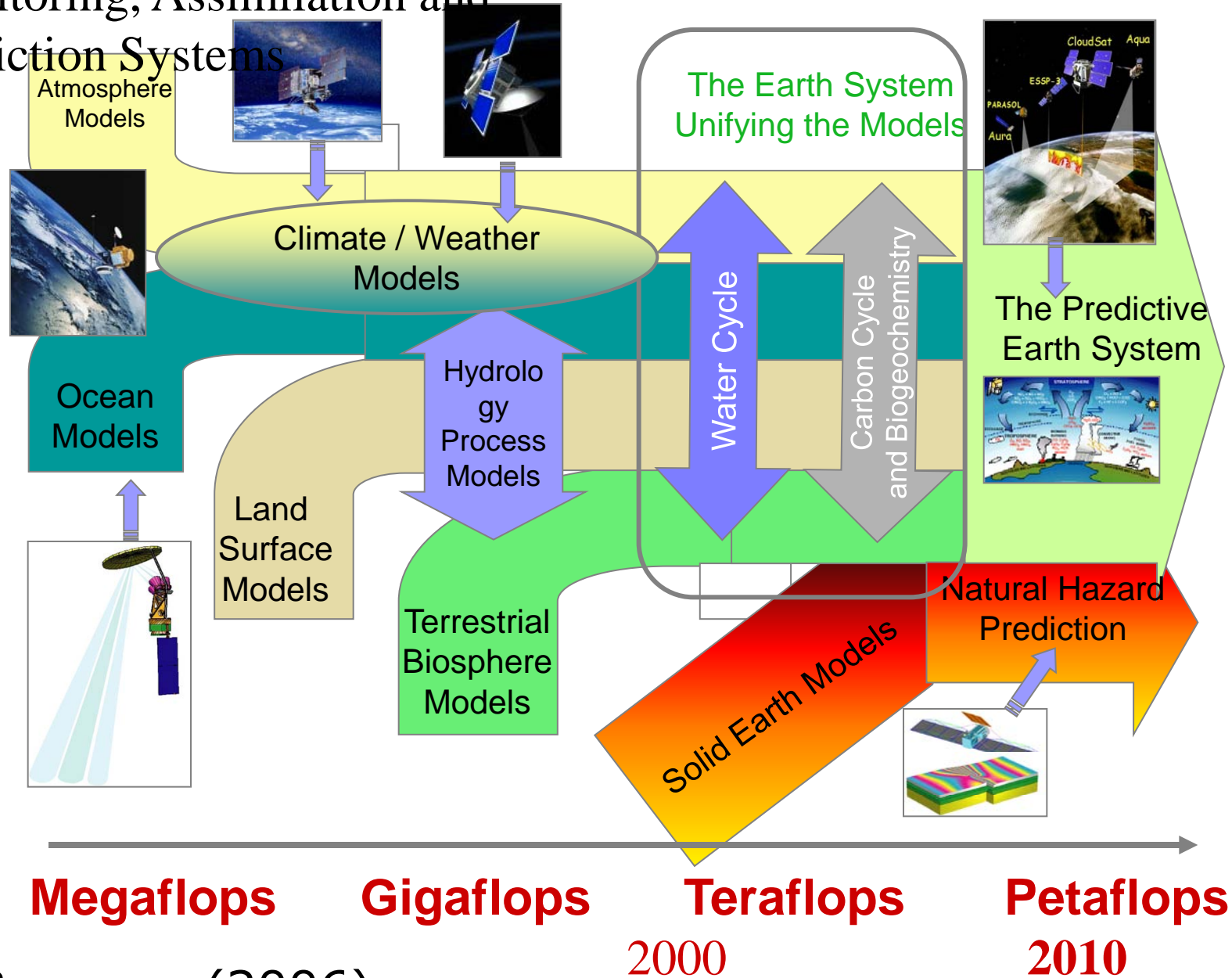
IPCC-AR4 (2007)

要因	証拠	合意度	不確実度	研究の現状
太陽照度	B	不十分	低い	過去25年間の観測、プロキシデータとの関係、オゾンの間接効果
火山性エアロゾル	A	不十分	低い	エルチチョンとピナツボ観測、プロキシデータとの関係要
メタン酸化以外成層圏水蒸気	C	不十分	非常に低い	理論的説明不足
灌漑起原対流圏水蒸気	C	不十分	非常に低い	全球規模の把握不足
上層雲への航空機影響	C	不十分	非常に低い	飛行機雲の巻雲への変質過程不明
宇宙線	C	不十分	非常に低い	いくつかの実験的証拠と観測がある、微物理モデルによると可能性あり、物理メカニズムが不明
その他の表面過程	C	不十分	非常に低い	いくつかのモデル研究と関連過程の証拠あり、放射強制力評価困難



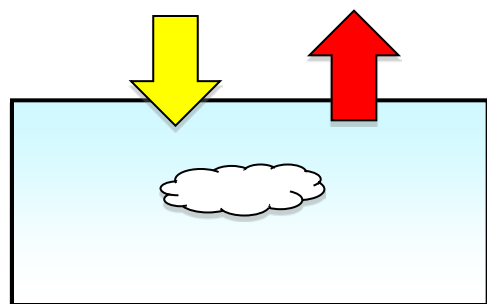
Marsh&Svensmark (2001)

Towards Operational Earth System Monitoring, Assimilation and Prediction Systems



気候系の摂動

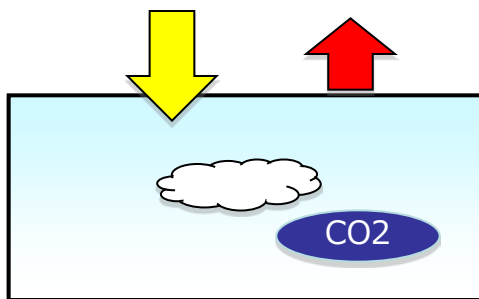
太陽放射 = 地球熱放射



T_s

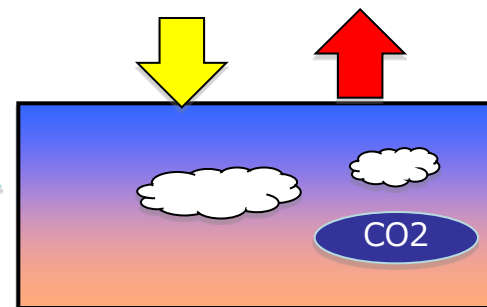
放射強制力 ΔF :
温室効果、日傘効果等

SW > LW



T_s

SW = LW



$T_s + \Delta T_s$

気候感度

$$\delta F(e, T_s, \{q_n\}) = \frac{\partial F}{\partial e} \Delta e + \left\{ \frac{\partial F}{\partial T_s} + \sum_n \frac{\partial F}{\partial q_n} \frac{\partial q_n}{\partial T_s} \right\} \Delta T_s \rightarrow 0$$

放射収支

ΔF

放射強制力

気候変化

$$\Delta T_s = \lambda \Delta F$$

$$\lambda = -1 / \left\{ \frac{\partial F}{\partial T_s} + \sum_n \frac{\partial F}{\partial q_n} \frac{dq_n}{dT_s} \right\}$$

$$\lambda_0 = \frac{1}{2(1+t)\sigma T_s^3} = 0.29$$

$$F = \sigma T_s^4$$

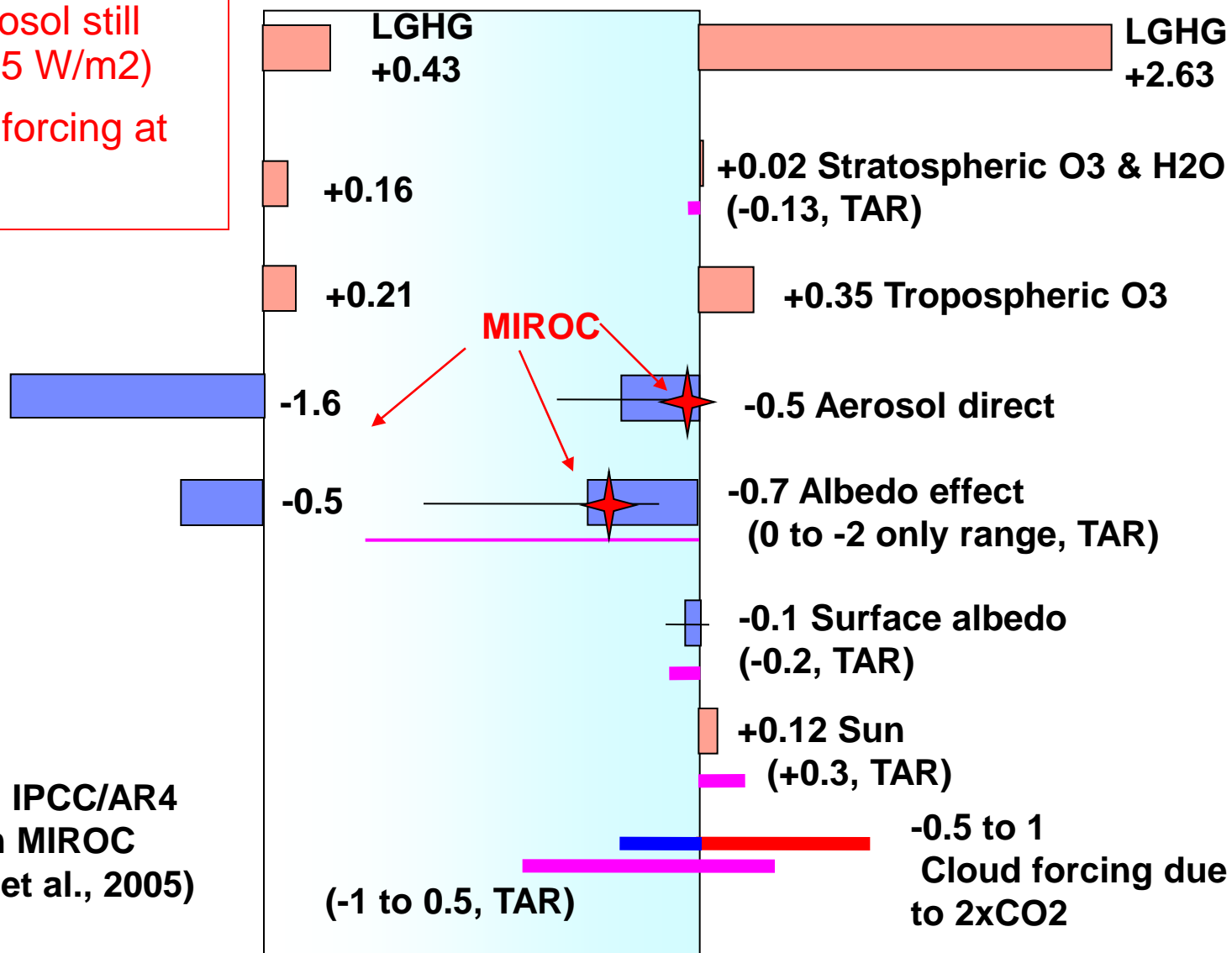
IPCC90	λ	λ
フィードバック	GFDL	GISS
雲、雪反射率固定	0.43	0.50
+雲フィードバック	0.50	0.80
+雪反射フィードバック	1.00	1.05

Radiative forcings since 1750

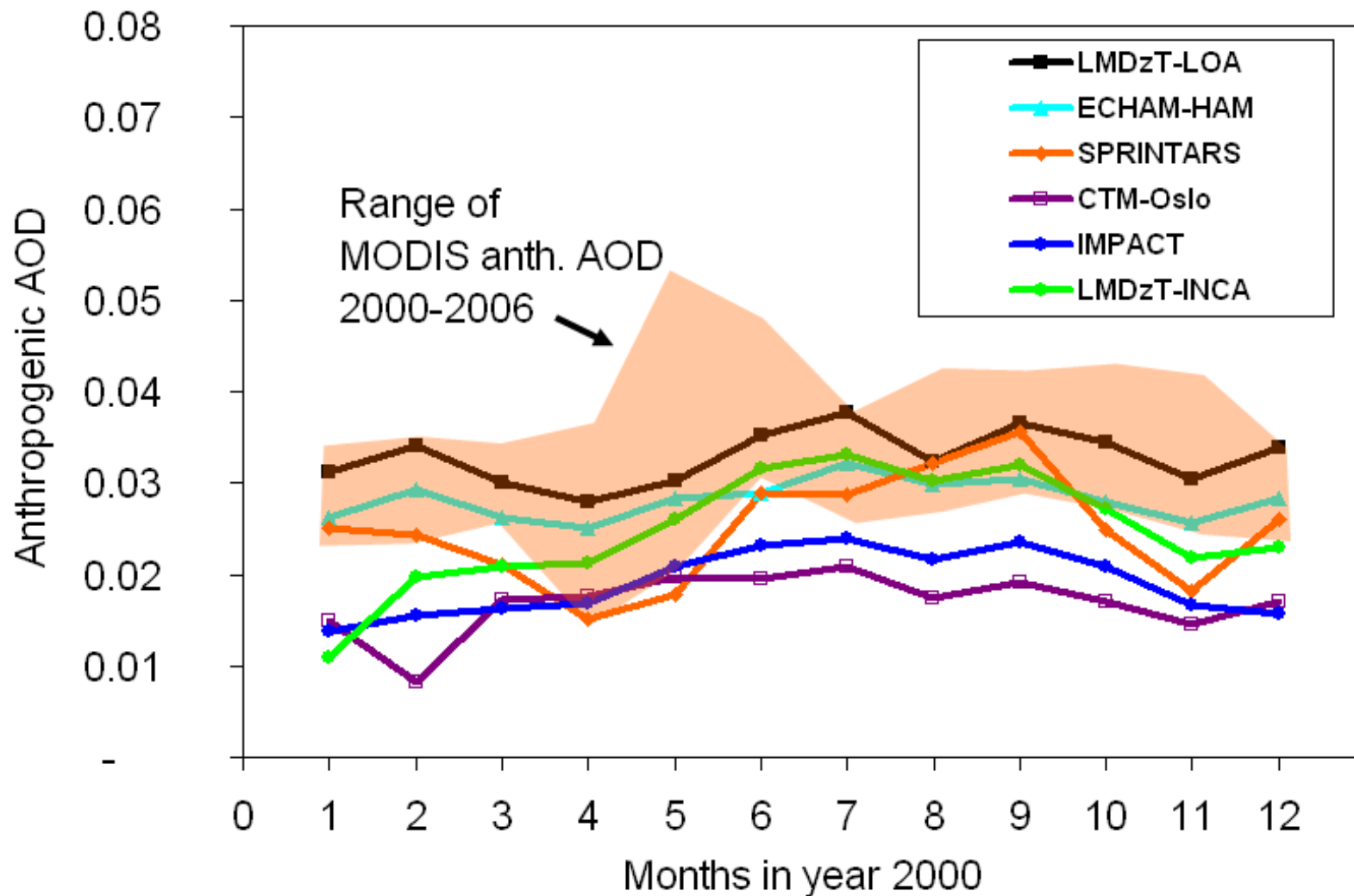
BOA

TOA (Tropopause)

- Cloud and aerosol still uncertain ($\pm 0.5 \text{ W/m}^2$)
- Large aerosol forcing at surface



Global monitoring and simulation of aerosols



- Model underestimation of AOT
- SSA evaluation is important for RF

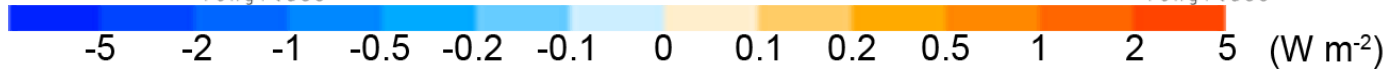
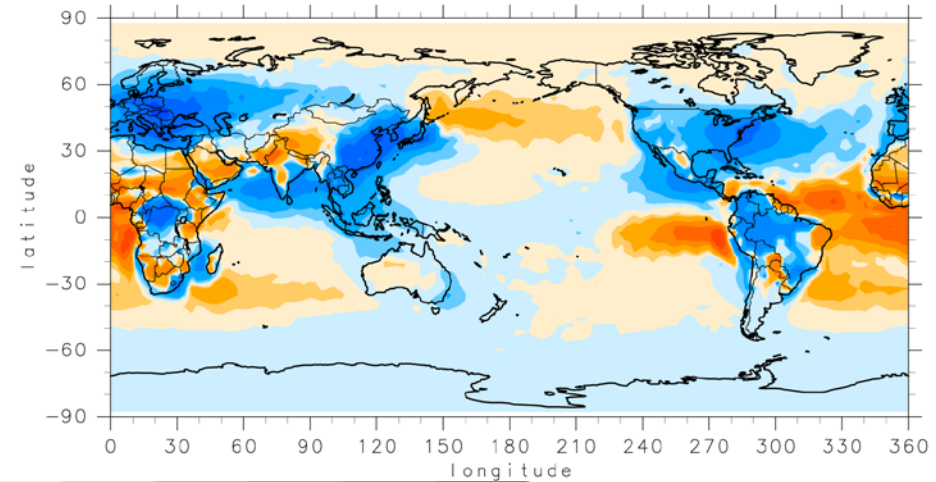
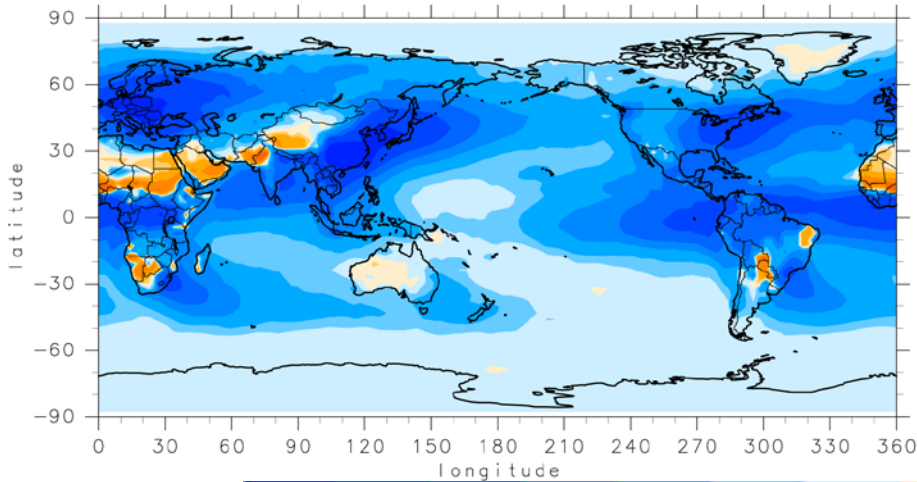
Nakajima and Schulz (FIAS2008)

Aerosol direct forcing by MIROC/AGCM+SPRINTARS

- Uncertainty of about 0.5 W/m^2 due to stratification
- Boundary layer modeling and hygroscopic growth modeling

Clear-skyAVG. -0.70 W m^{-2}

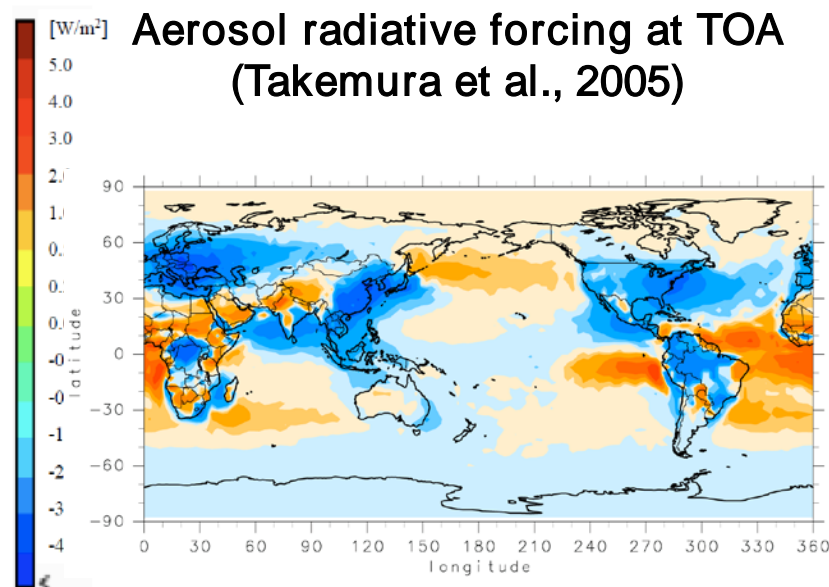
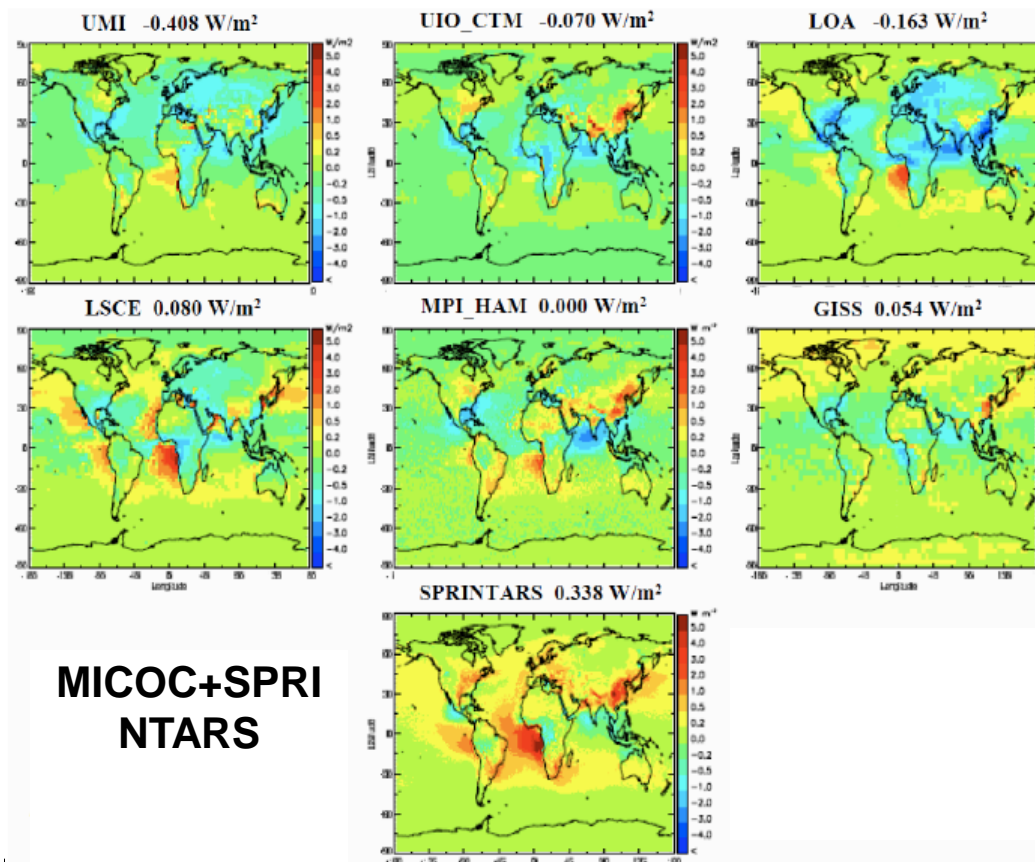
All-skyAVG. -0.04 W m^{-2}



TOA Radiative Forcing	Tropopause (W m^{-2})		Surface (W m^{-2})	
	All-sky	Clear-sky	All-sky	Clear-sky
BC	+0.42	+0.22	-0.75	-0.95
OC	-0.26	-0.48	-0.35	-0.55
Sulfate	-0.20	-0.44	-0.16	-0.36
Total	-0.04	-0.70	-1.26	-1.86

Tekemura et al. (JGR2005)

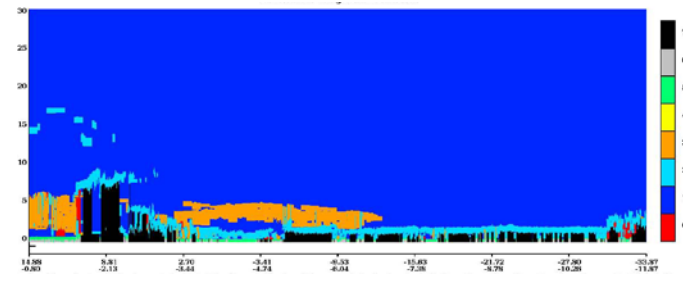
AEROCOM comparison of direct *ARF* at TOA in cloudy sky condition (Schulz et al., 2006)



- Positive *RF* over clouds cancel negative *RF* in clear sky (Clear sky: -0.70 Wm^{-2} vs all sky: -0.04 Wm^{-2}).
- But aerosol *RF* over clouds largely depend on models.
- MIROC simulates more absorbing aerosols above clouds than other GCMs.

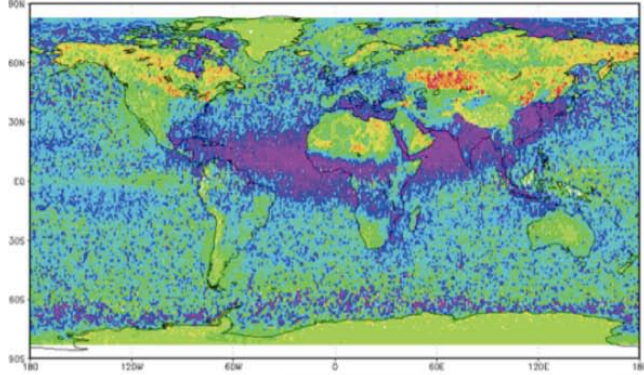
CALIPSO lidar detection of clouds and aerosols

(E. Oikawa, 2009;
Courtesy NASA-CALIPSO team)



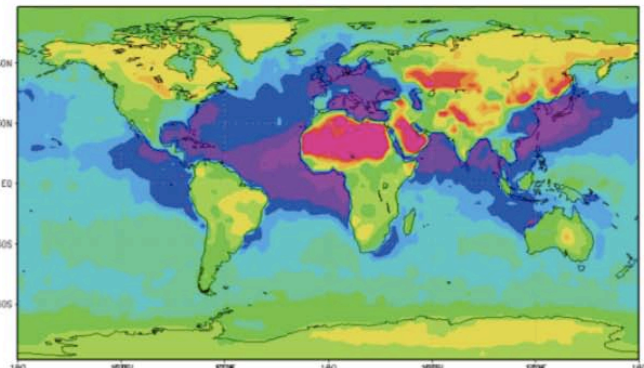
CALIPSO ARF (晴天大気)

Global -3.64W/m^2 , Ocean -4.08W/m^2



SPRINTARS ARF (晴天大気)

全球平均： -2.56W/m^2 、海上： -3.77W/m^2



Clear sky

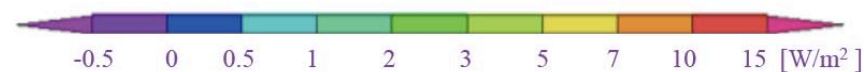
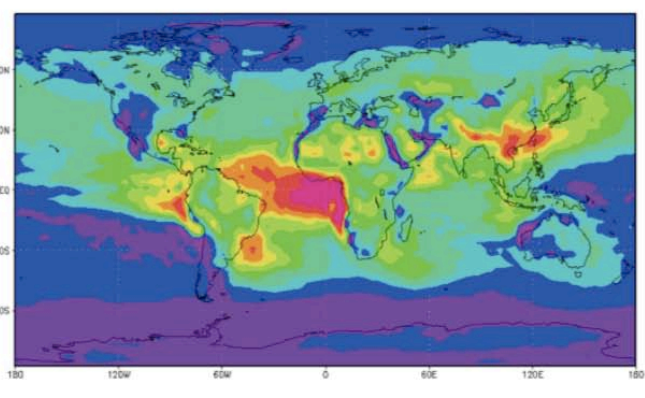
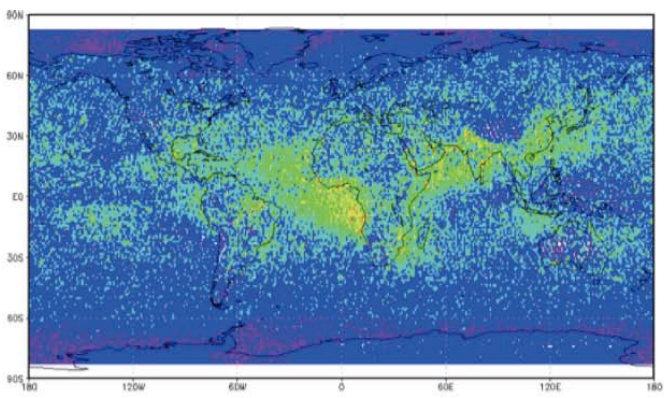
CALIPSO ARF

$+0.57\text{ W/m}^2$

SPRINTARS ARF

$+1.33\text{ W/m}^2$

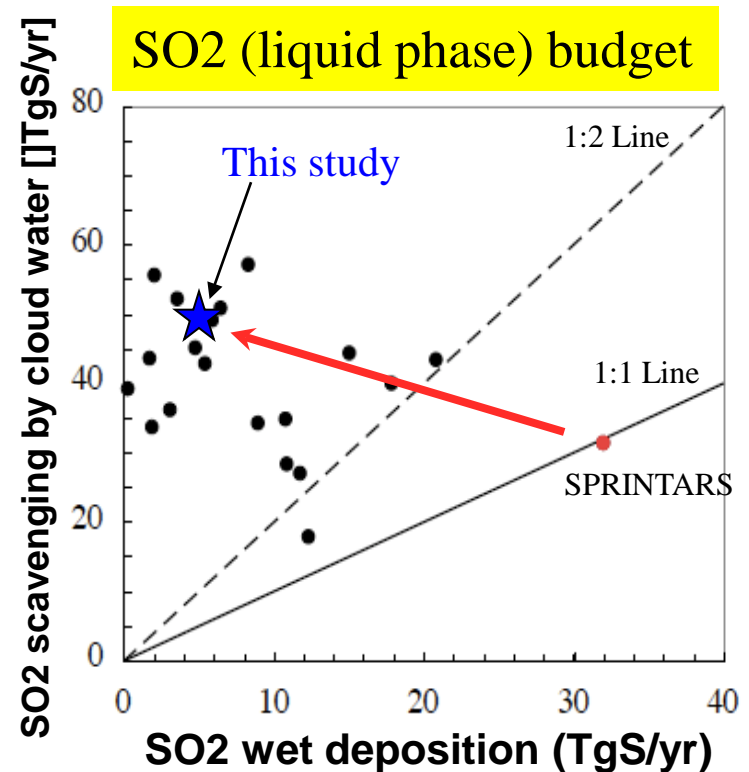
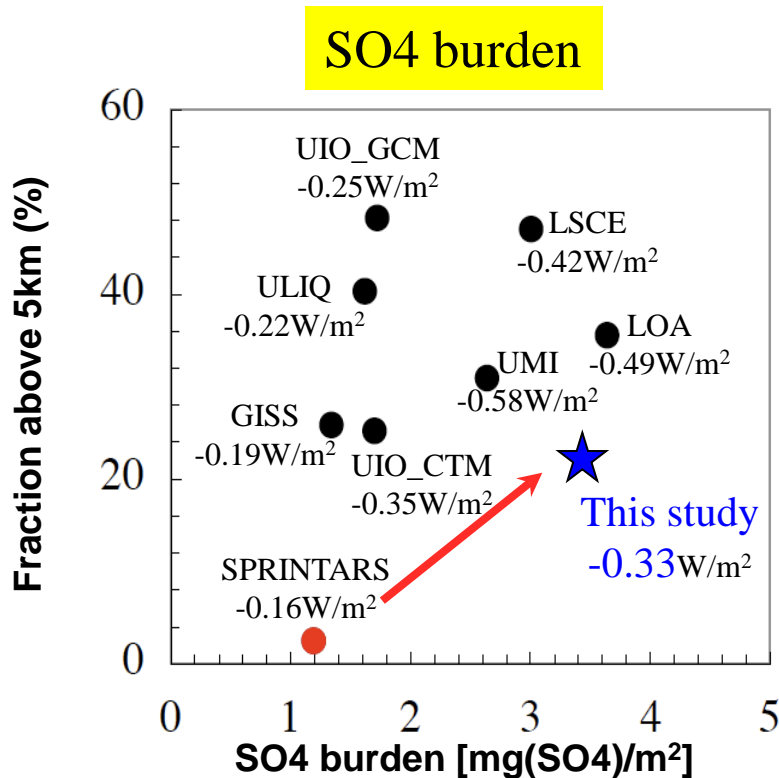
Overcast



Some updates in SPRITARS sulfate process

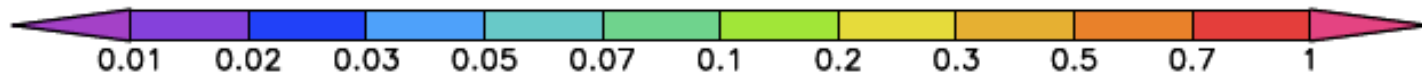
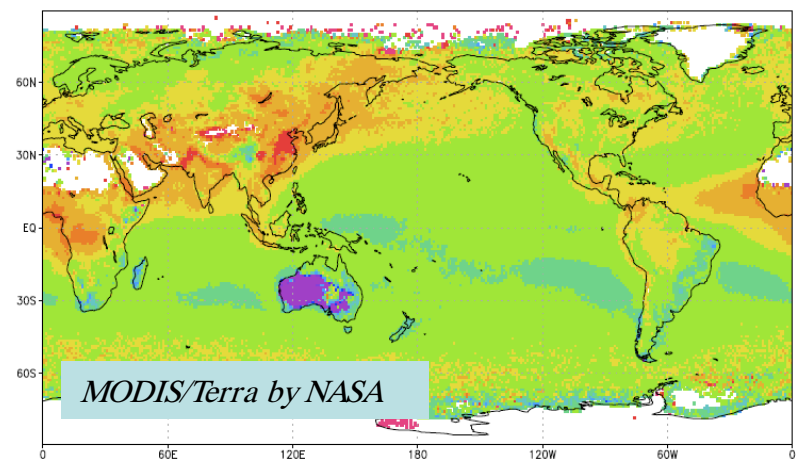
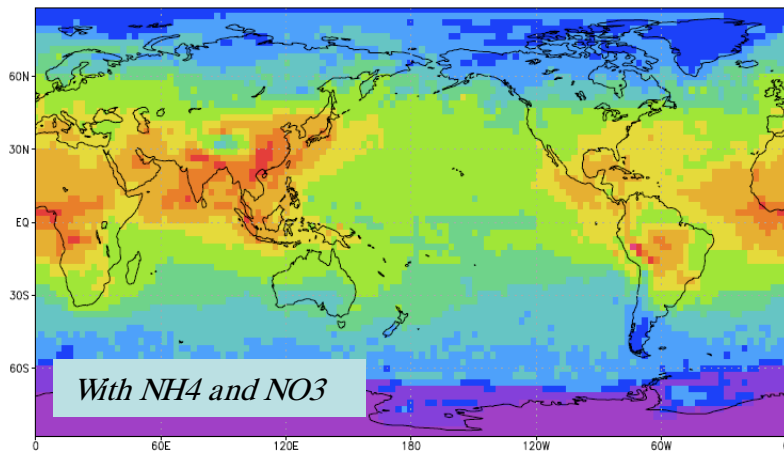
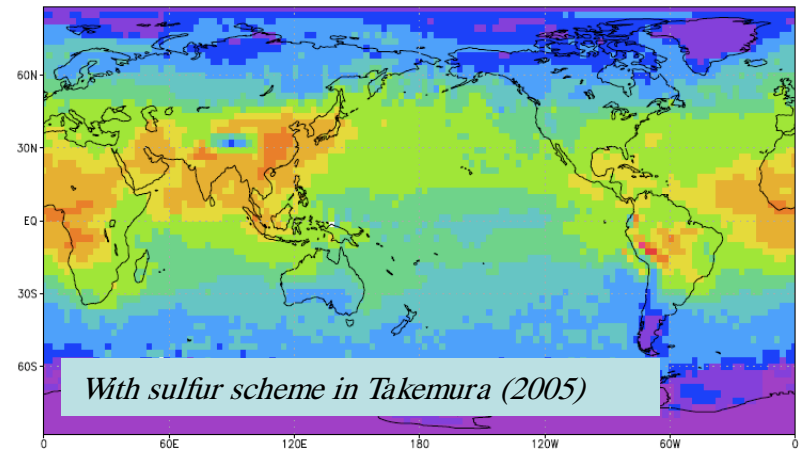
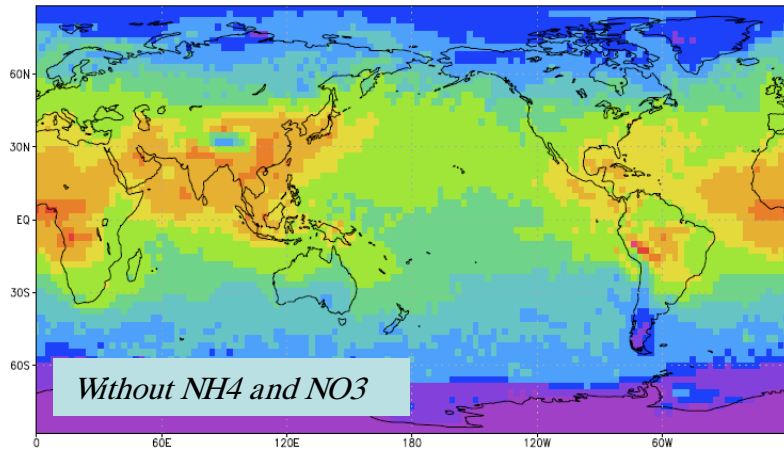
D. Goto (2009)

S ¹	N ²	ADE (W/m ²)
New	New	-0.62(SO₄+NH₄+NO₃)
New	-	-0.33(SO₄)
Standard	-	-0.23(SO₄)
IPCC-AR4		-0.5(SO ₄ +NH ₄ +NO ₃)
AeroCom ³		-0.35(SO ₄)



Using Schulz et al. (2006) and Textor et al. (2007)

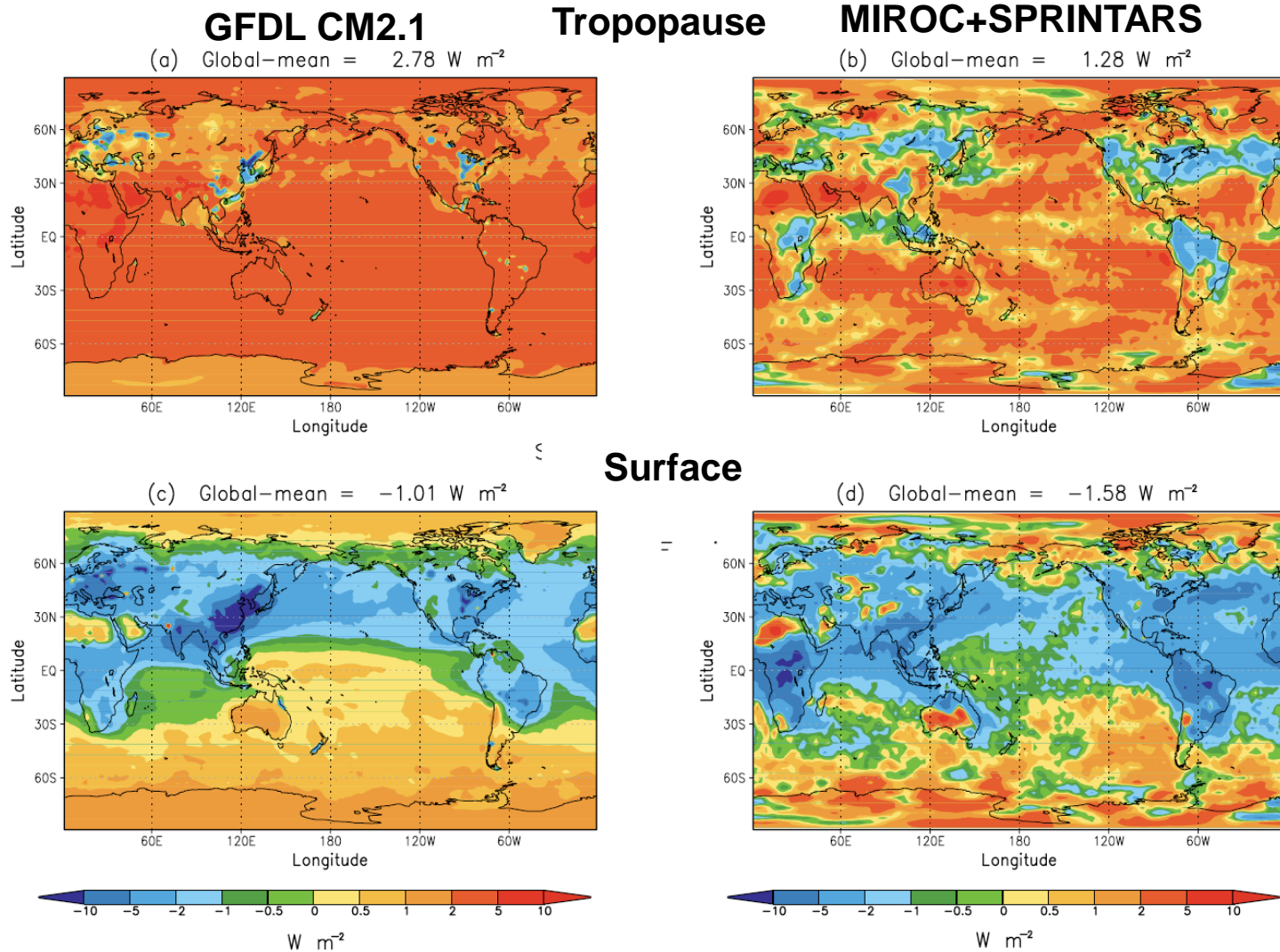
Annual mean aerosol optical thickness



Surface cooling

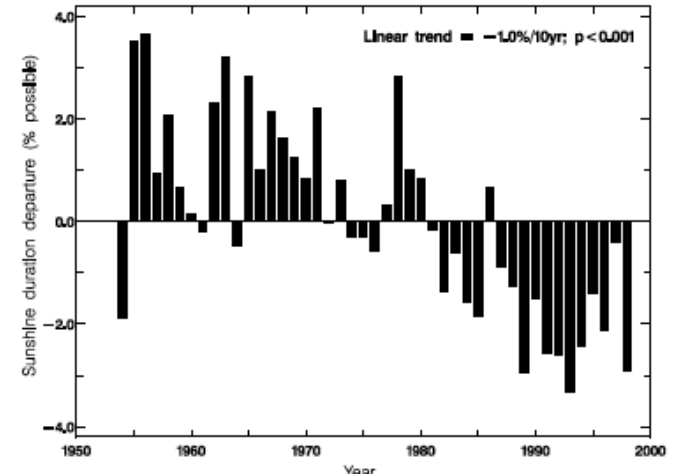
- Convection; SST modulation; Monsoon circulation: Precipitation change

Natural + anthropogenic RF between 1860-2000



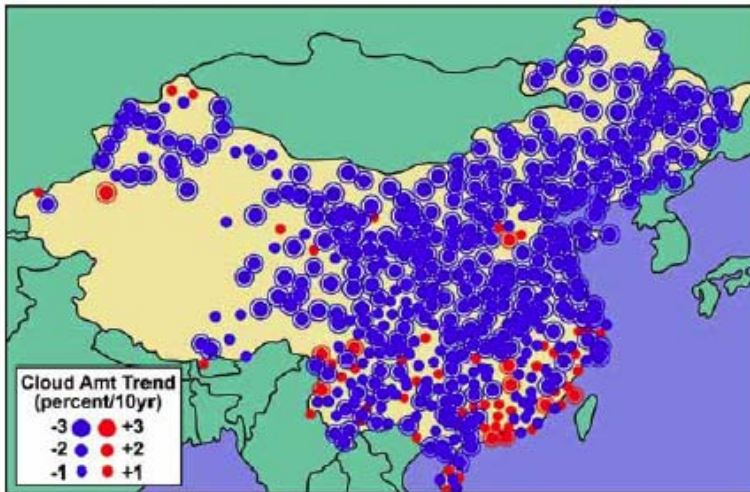
Cloudiness and sunshine in China

All site mean

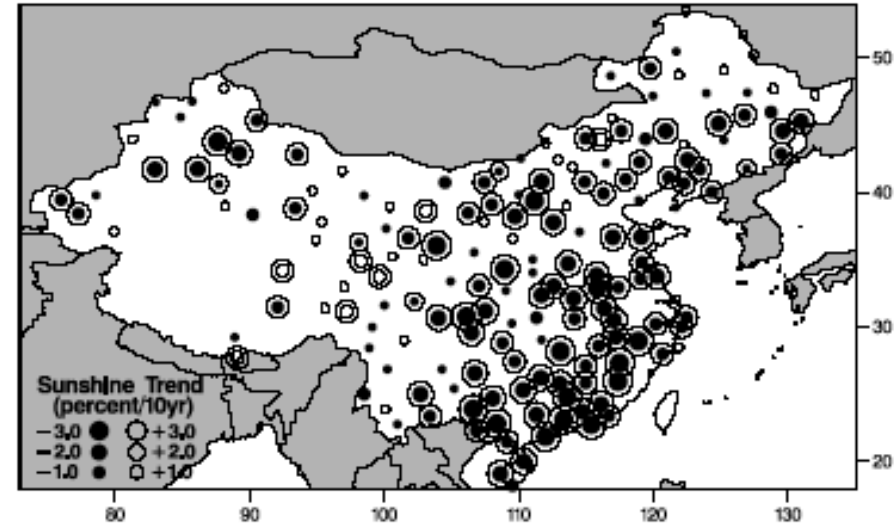


■ Inconsistency?

Trends in annual mean total cloud cover (%/10yr) for 1954-2001 [Qian et al., 2006]



Trend in the annual mean sunshine duration in 1954-1998 (Kaiser & Qian, 2002)



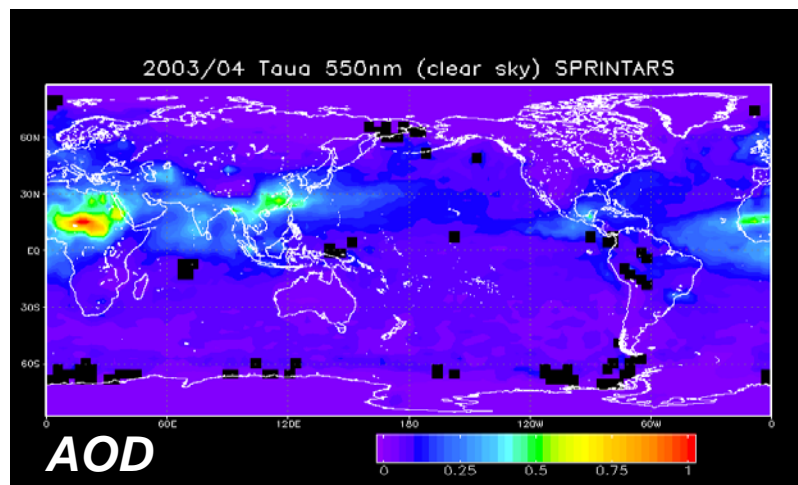
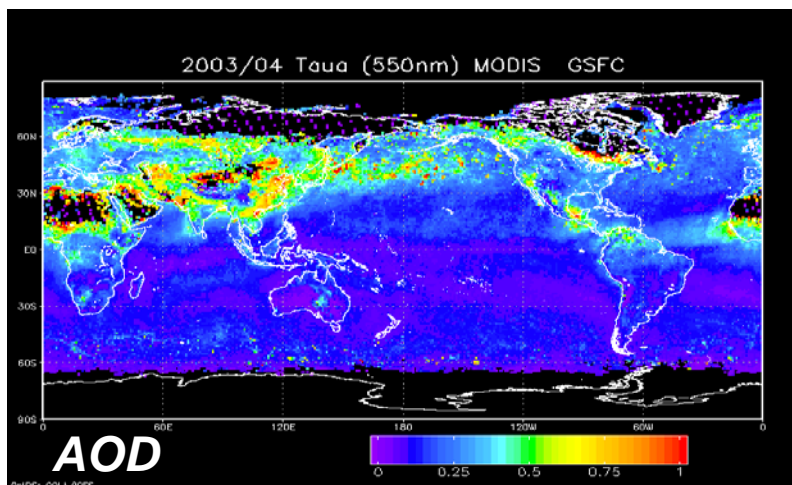
全球規模の大気汚染とそのシミュレーション

- 観測によるモデル検証に膨大な労力 (IPCCは20年)

TERRA-MODIS衛星観測

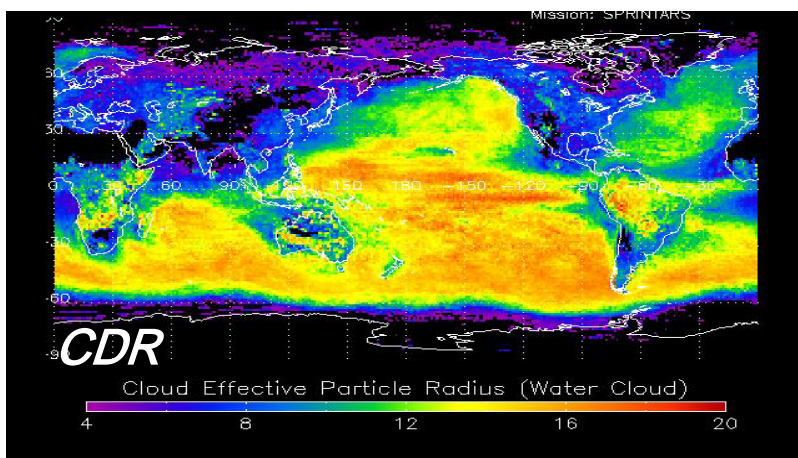
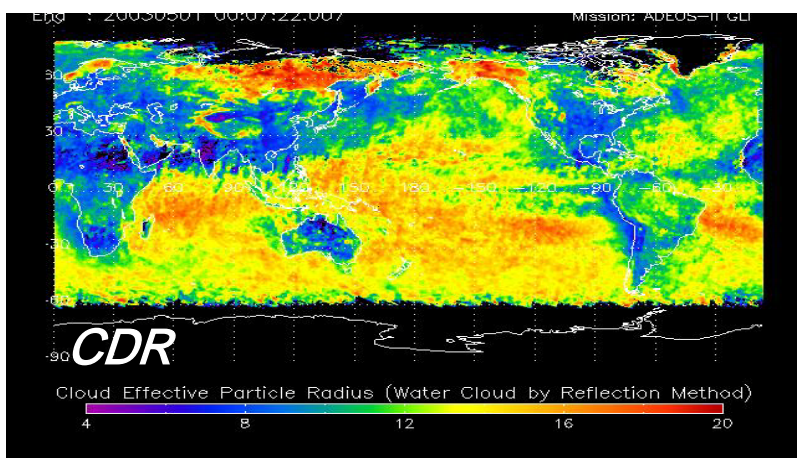
MIROC+SPRINTARSモデル

エアロゾル
光学的厚さ



2003 April

水雲粒
半径
(ミクロン)

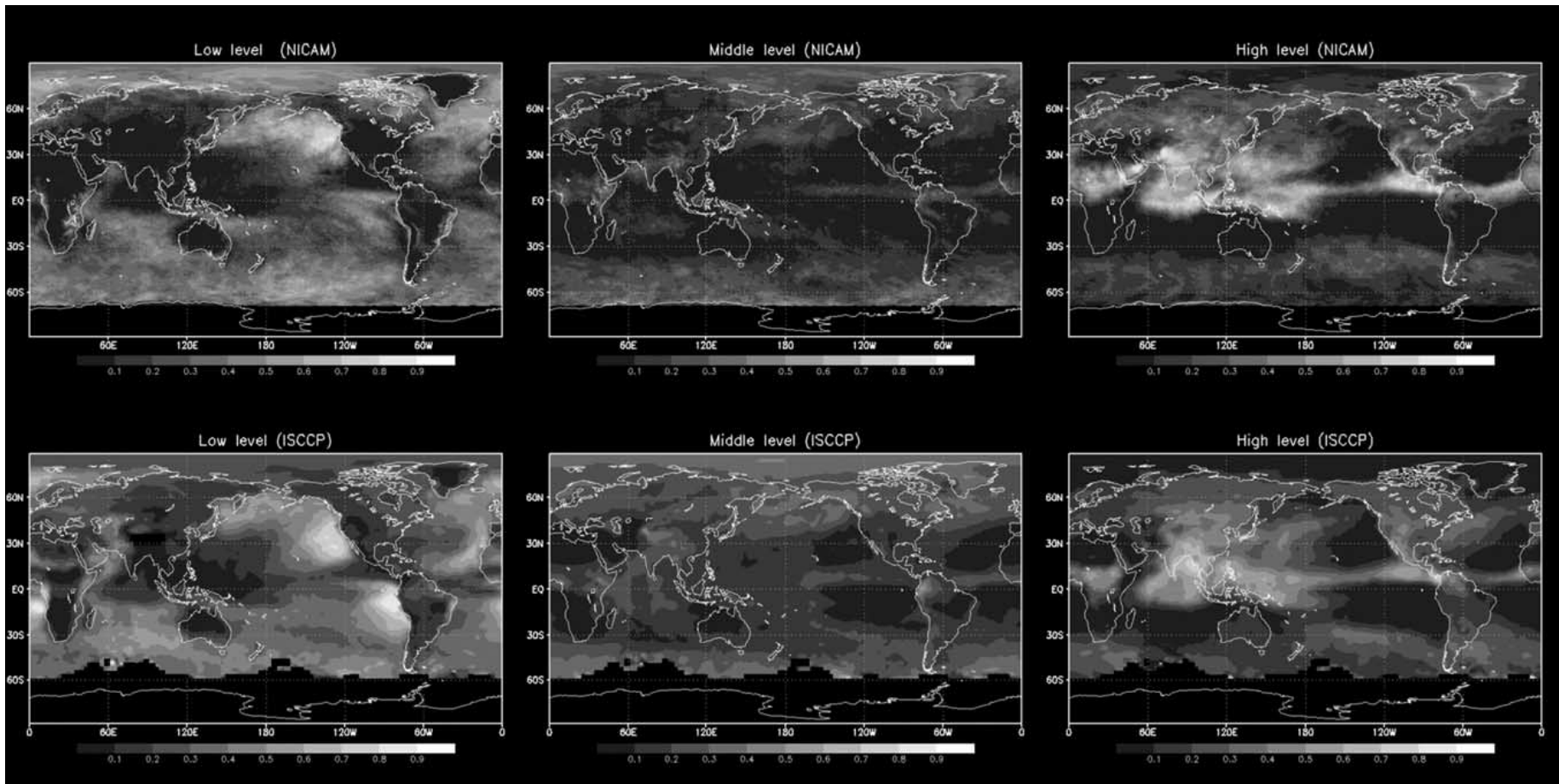


下層雲

中層雲

上層雲

NICAM

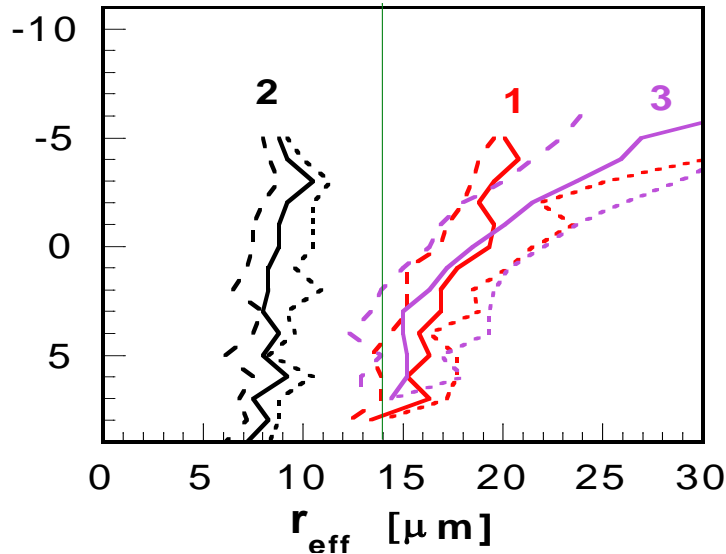


ISCCP

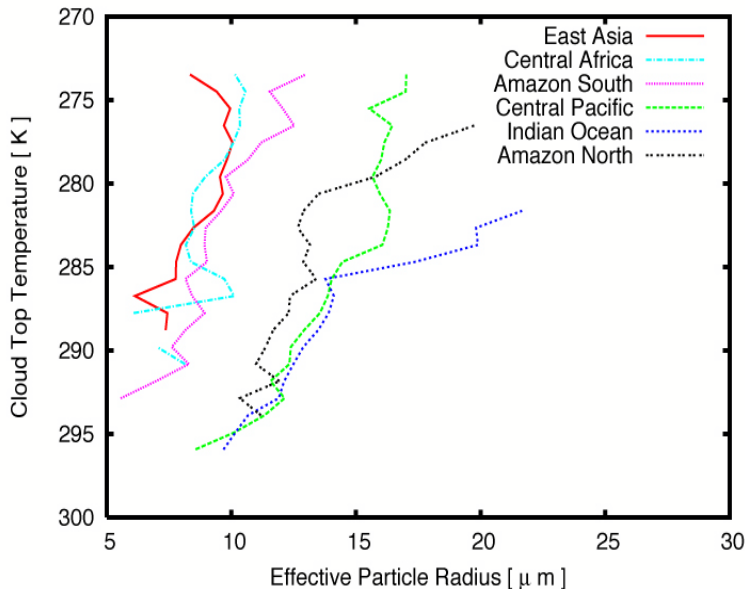
Vertical growth pattern of cloud droplets in convective system

AVHRR
T14

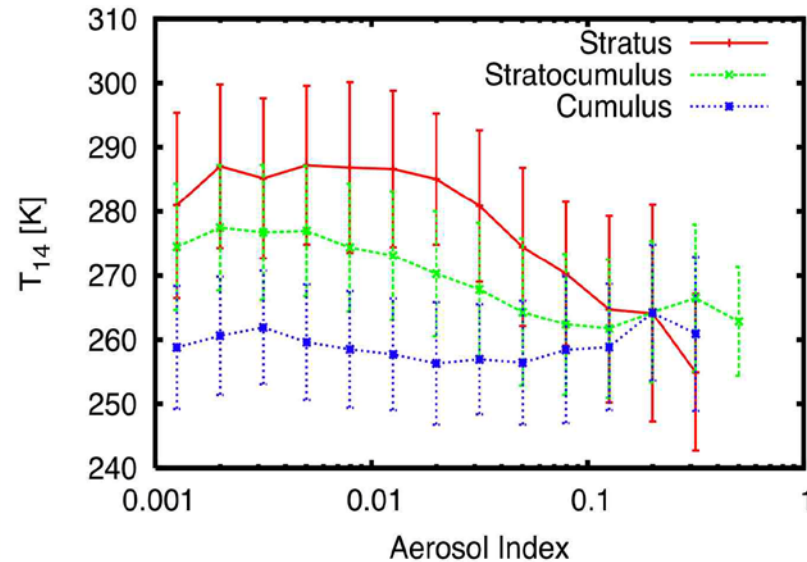
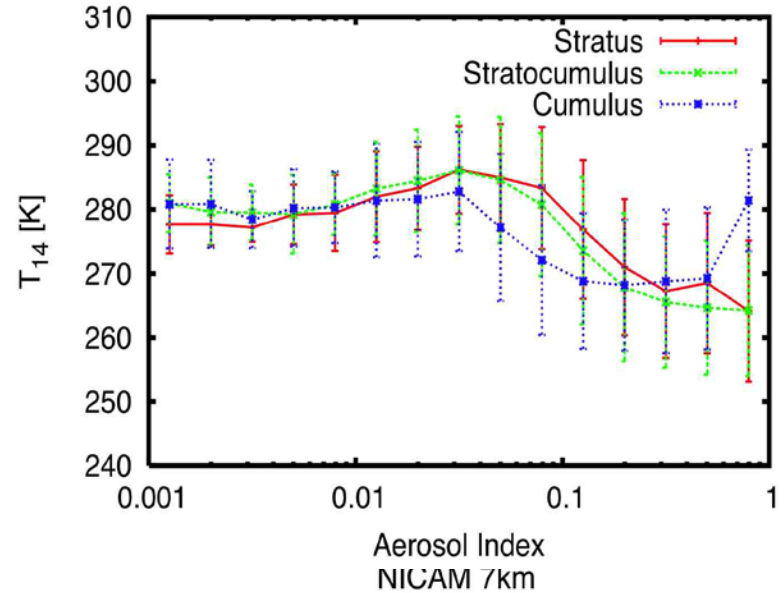
Rosenfeld (Science 2000)



NICAM
T14



MODIS



Conclusions

- Large negative forcing at TOA and BOA by anthropogenic aerosols, but 50% model uncertainties (0.5 W/m² at TOA)
- Large indirect effect at TOA; Suppress warming by 30%
- Large uncertainties both by observation and modeling
 - Model underestimation of AOT
 - Land clouds difficult to model
 - High resolution model with aerosol interaction developed
- Large direct effect at BOA
 - This effect continues another 30 years with large uncertainties in scenario, so that we have to monitor.
 - SST&LST loops start working for precipitation change; Cloud and precipitation changes need GHG and aerosol effects
- High resolution modeling and active remote sensing are promising