Nov 13-17, 2023
EarthCARE Science and VAlidation WS, Frascati

The path of the EarthCARE mission development toward understanding global radiation, cloud, and aerosol interaction

-Long winding road (dialogue w Thorsten)-

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Acknowledgments: JMAG, ScienceTeam, Space agencies

I am an old man ... going to talk old stories...

... Once upon a time...

Climate change issues

- **Stern report (2006): Global warming of 2 - 3℃ will cause damage corresponding to 0-3% of GDP**
- **Climate Change Adaptation Act, Japan (2018)**
- **JMA new warning notice Level-5 （2019）: *Residents in the target area are encouraged to take immediate actions to save lives***
- **2018 July: West Japan heavy rain, 200 dead**
- **2019 Oct.: Super Typhoon#19, Category-5; 88 dead, 4000 in evacuation life**
- **2023: Word record of warming "Era of global warming ends, Era of global boiling has arrived " UN Chief**

(The Guardian Digital)

- **S. Manabe won the Nobel Prize in Physics 2011: a Physics Committee member said 'Climate modeling is physics' in the press conference**

Prof. S. Manabe

Hokuriku Shinkansen super express trains in the Chikuma-river flooding

Mabi town, Oda-river flood

Long winding road of EarthCARE mission

Boyle's law 1662

Industrial revolution mid 17C

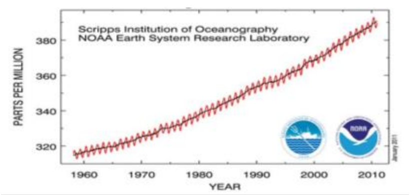
Hadley circulation 1735

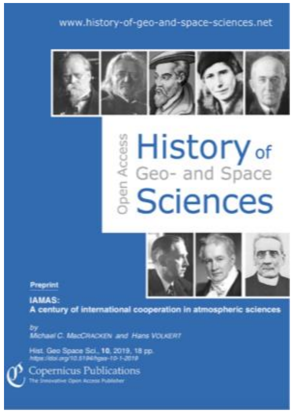
IUGG:100th anniversary 2019

Fourier, radiation effect 1824

IMO 1879

Arrhenius, global warming 1896





IUGG 1919

IGY 1957-58

TIROS-1 meteorol. satellite 1960

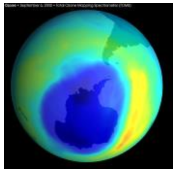
CO2 monitoring at Mauna Loa 1958

Graeme sent us an email for CPR meeting 1993 May

Global warming GCM, Manabe, Wetherald 1975

ESSP sat cost caps...

Ozone hole, Farman et al 1985



Joint CloudSat-MDS/Atmos-B mtg 1997

Earth radiation budget, Ice cloud

TRMM 1997

ESA Granada review1: Earth Explores 4 missions to two (GOCE, ADM) 1999

Crutzen, Molina, Rowland: Nobel Prize in Chemistry 1995

MTPE/TERRA 1999

ERM

CLOUDSAT, CALIPSO 2006

ESA Granada review2: EarthCare selected 2001

Hurricane Katrina 2005
Extreme weather increase

GPM Core 2014

Doppler
Aerosol and cloud

Aeolus/Aladin 2018

Manabe, Hasselmann, Parisi, Nobel Prize in Physics 2021

EarthCARE launch

Back in early 1990s

- **UK WCRP/GEWEX, 1993: Concept for a spaceborne cloud radar system**

- Brown, P.R.A., A.J. Illingworth, A.J. Heymsfield, G.M. McFarquhar, K.A. Browning, and M. GOsset, 1995: The role of spaceborne millimeter-wave radar in the global monitoring of ice cloud. J. Appl. Meteorol., 34, 2346-2366.

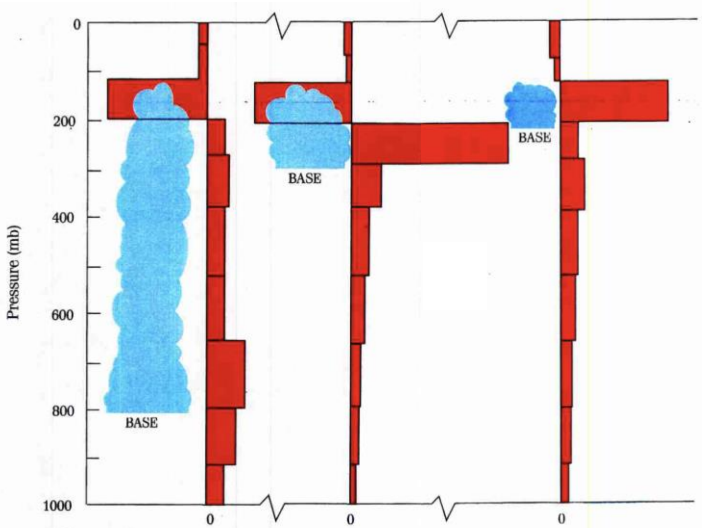


Fig. 2 The diagram shows greatly differing vertical profiles of the infra-red heating of the atmosphere by a complete overcast of cloud with cloud-top at 125 mb, depending on the height of the cloud base. (Slingo & Slingo, 1989).

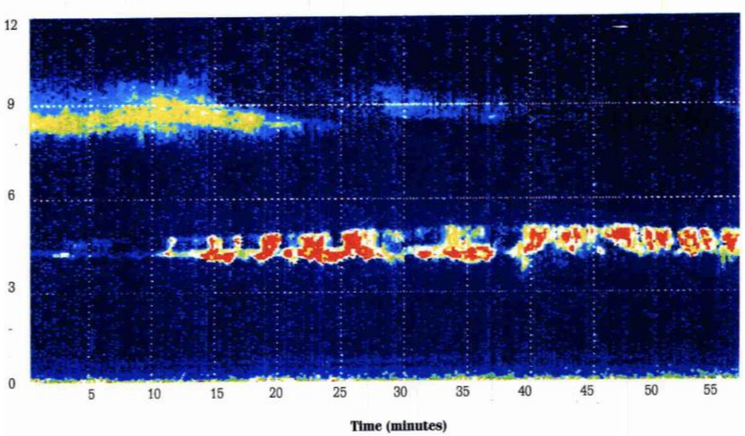
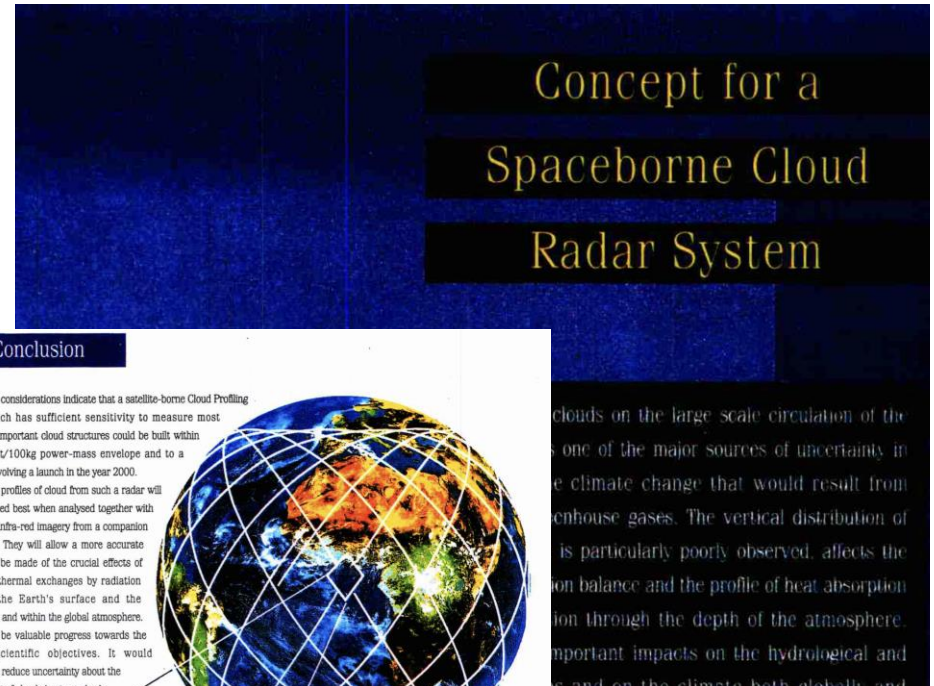
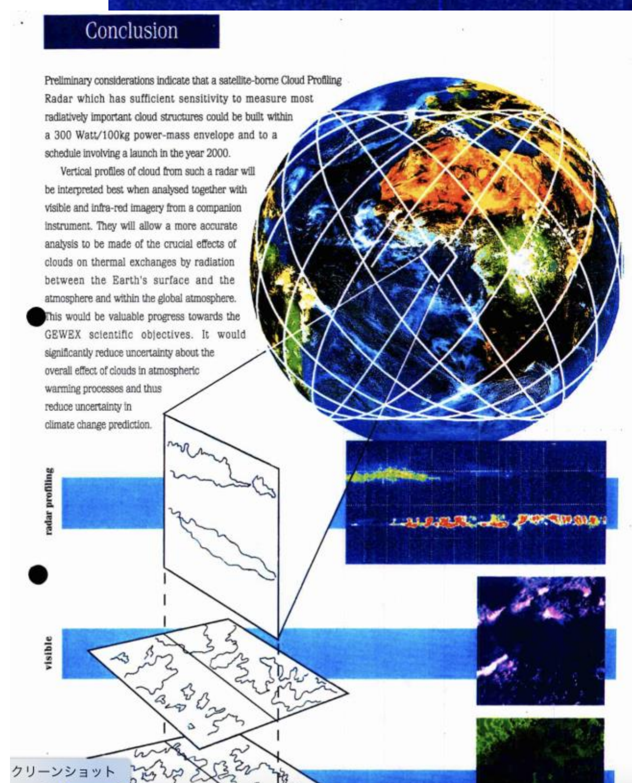


Fig. 7 Time-height record from a ground based 94 GHz (3mm) radar showing multiple cloud layers (courtesy of Prof T Ackerman, Pennsylvania State University)



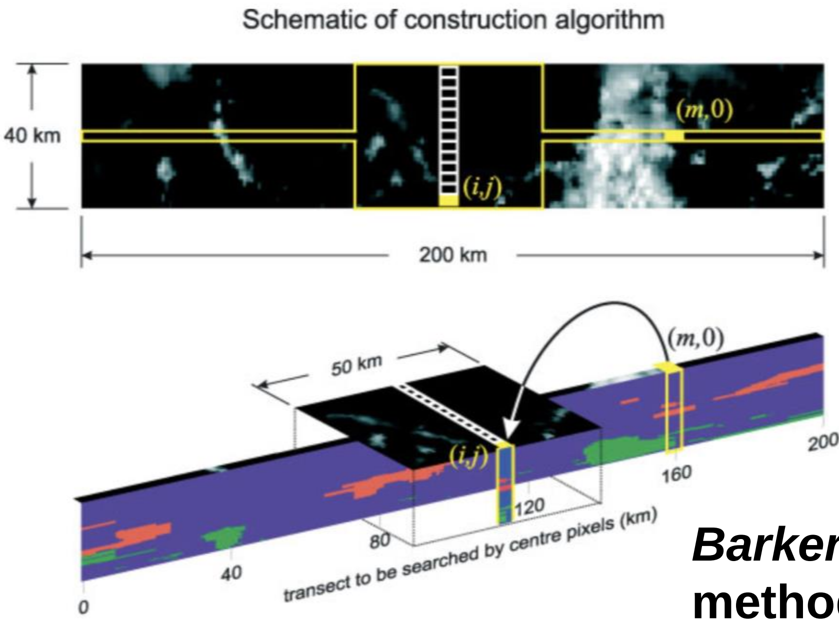


Conclusion

Preliminary considerations indicate that a satellite-borne Cloud Profiling Radar which has sufficient sensitivity to measure most radiatively important cloud structures could be built within a 300 Watt/100kg power-mass envelope and to a schedule involving a launch in the year 2000.

Vertical profiles of cloud from such a radar will be interpreted best when analysed together with visible and infra-red imagery from a companion instrument. They will allow a more accurate analysis to be made of the crucial effects of clouds on thermal exchanges by radiation between the Earth's surface and the atmosphere and within the global atmosphere. This would be valuable progress towards the GEWEX scientific objectives. It would significantly reduce uncertainty about the overall effect of clouds in atmospheric warming processes and thus reduce uncertainty in climate change prediction.

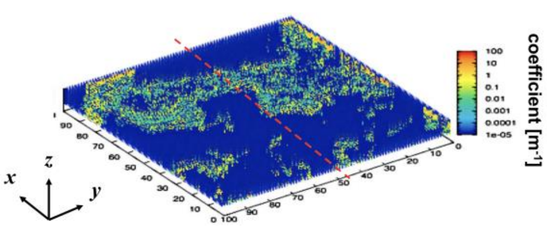
3D Earth Radiative energy Budget (ERB)

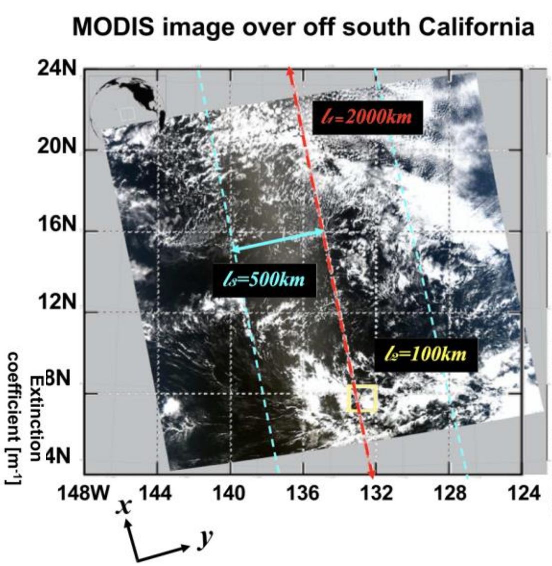


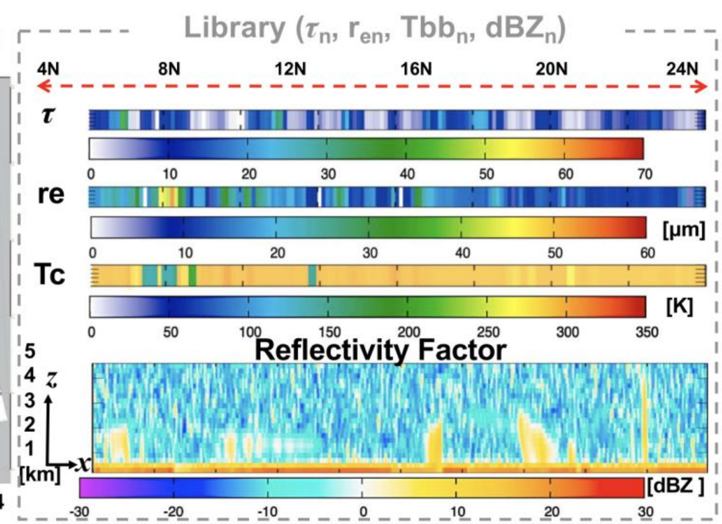
- **Error in two stream method: < ~10Wm-2 *(Barker+, 2015)***
- **3D effect: SW 200%~, LW 20%~ *(Marshak&Davis. 2005)***
- ***Jakub&Mayer. (2016*): 3D effect helps warm cloud organization, 10 stream 3D RT in LES**

***Barker+ (J.Q.R. Meteorol. Soc., 2011)*: A methodology for 3D scene construction**

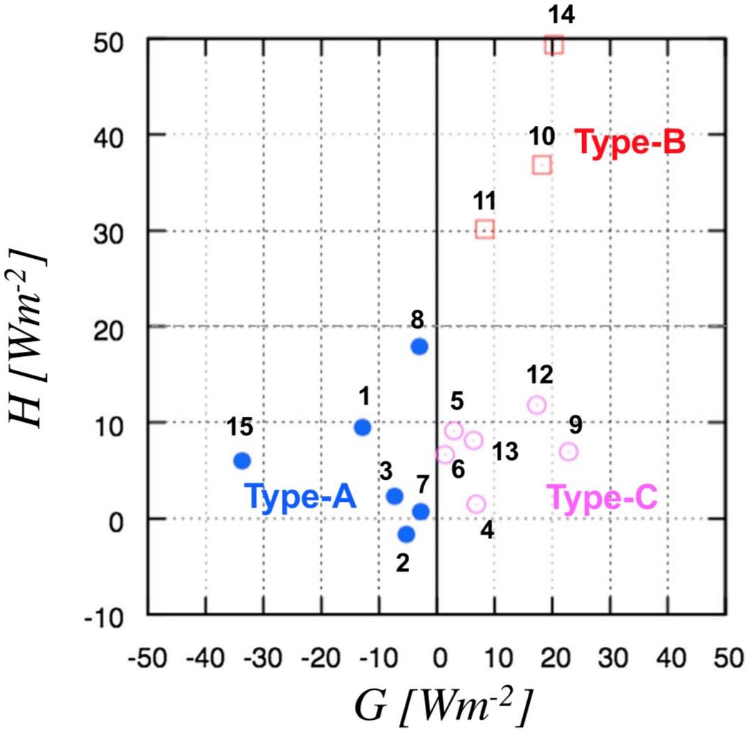
***Okata+ (JGR'17)* added cloud microphysics from imager (COT, RE, Tc)**





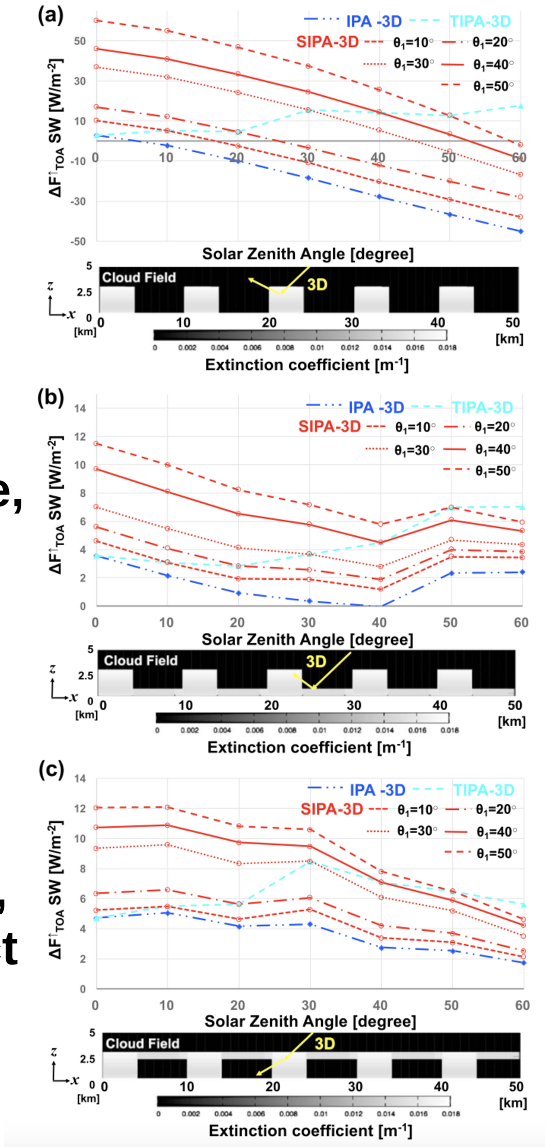


Cloud parameters under the CLOUDSAT orbit. 2007.07.02.22:30



ISS photo

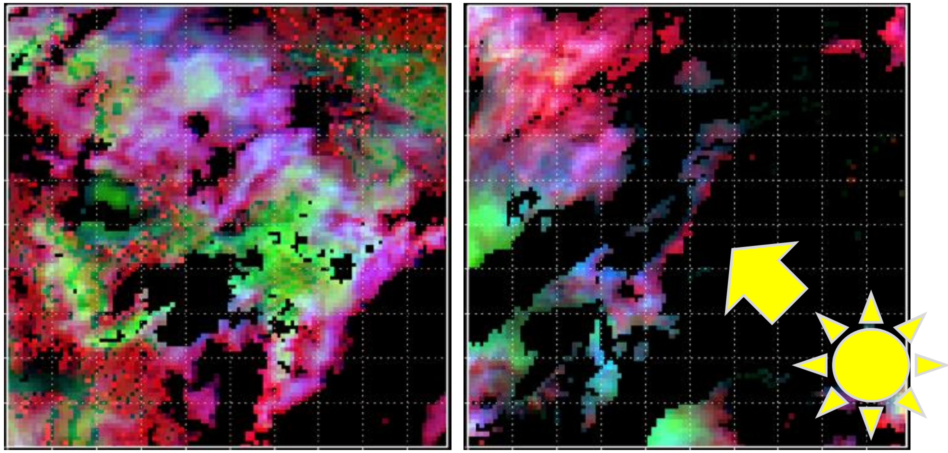
Clear-sky obscuring effect IPA, TIPA approx.



Upper-cloud roughened type, bright sides

$$G \equiv [\Delta F_{\mathrm{IPA}}(60°) - \Delta F_{\mathrm{IPA}}(0°)]$$

$$H \equiv [\Delta F_{\mathrm{TIPA}}(\theta_{04}) - \Delta F_{\mathrm{TIPA}}(\theta_{03})] - [\Delta F_{\mathrm{TIPA}}(\theta_{02}) - \Delta F_{\mathrm{TIPA}}(\theta_{01})]$$



Low-cloud roughened type, light guide effect

Okata+ (JGR'17)

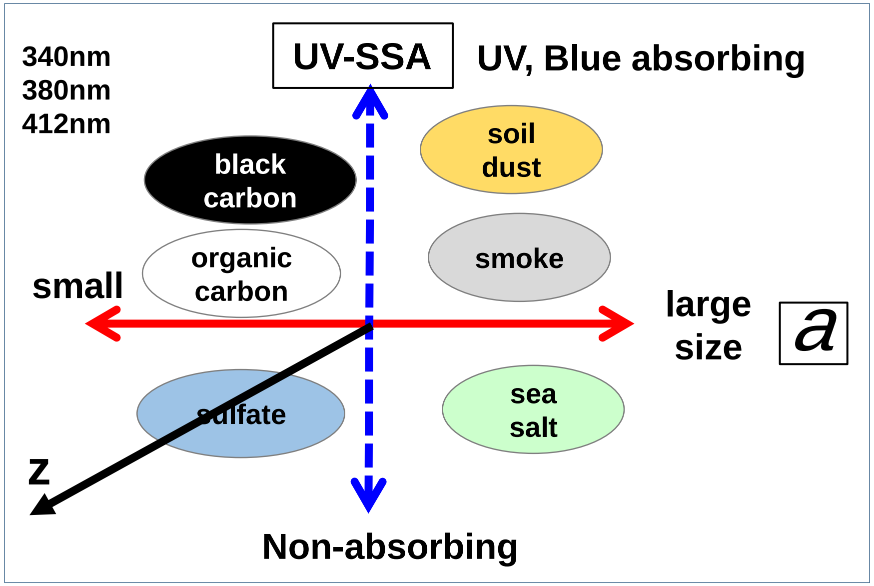
Aerosol characterization from satellites

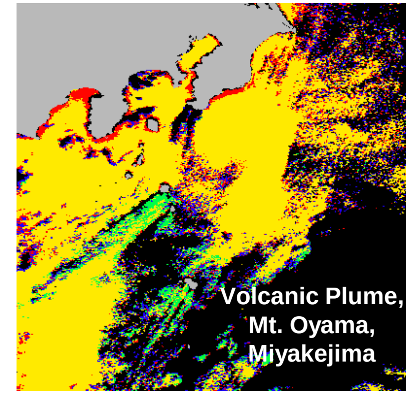
AVHRR: AOT&AE
(Higurashi+, JC'00)

MODIS: Deep blue
(Hsu+, JGR'13)

2D, Polarization:
POLDER, POLDER2, PARASOL
(Herman+, JGR'97; Dubovik+, AMT'11)

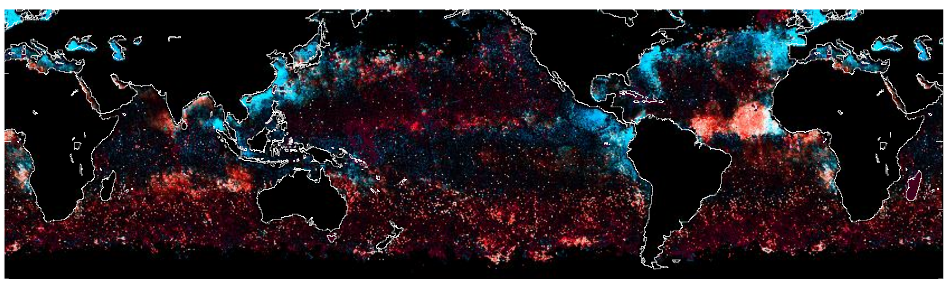
3D: CALIPSO Lidar
(Winker+, BAMS'10)





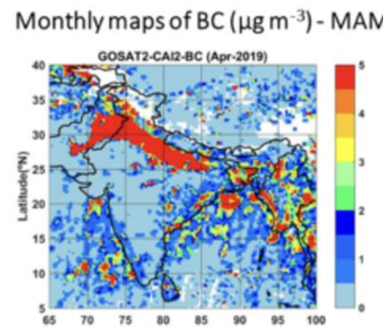
Sulfate, Carbonaceous, Soil Dust, Sea Salt
SeaWiFS(412, 443, 670, 865nm)

4ch-method:
Higurashi&Nakajima (GRL'02)

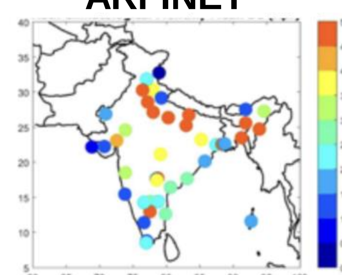


Fine (blue) and coarse aerosols (red) from NOAA11/AVHRR (2 ch-method with 670, 865nm; *Higurashi et al., JC 2000*)

CAI-2

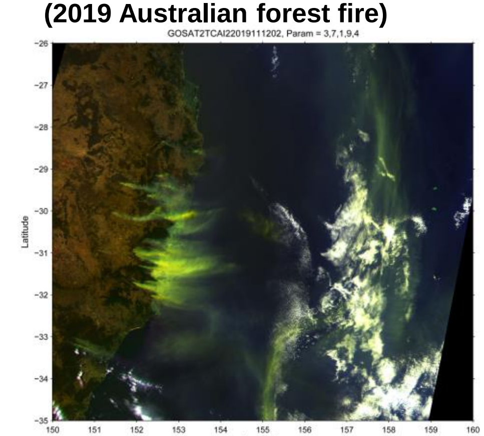


ARFINET



Validation of BC retrieval from 340nm, 380nm of G2/CAI2 (FOV500m) *Gogoi+ (ACP 2000)*

340nm signature of carbonaceous from GOSAT-2/CAI2 (2019 Australian forest fire)



Shi+ (ACP'19, IEEETGRS'20)

Aerosol-low cloud interaction

2000s: b(WLP)>0 (lifetime regime)
AVHRR ocean: +0.2 *(Nakajima+, GRL'01)*
MODIS global: +0.04 *(Sekiguchi+, JGR'03)*
POLDER: +0.2 (*Quaas+, JGR'04*)
MIROC: +0.06 (*Suzuki+, JAS'04*)

2010s: b(LWP)<0 (extinction regime)
Satellite (A-Train): -0.05 *(Michibata+, ACP'16)*
GOCART: -0.2 (*Matsui+, JGR'06*)
NICAM-Chem (14km) -0.1 *(Y.Sato+, Nature-C'18)*

Land area: b(COT, b(RE)>0 (Anti-Twmey regime)
MODIS land: +0.2 *(Myhre+, ACP'07)*
POLDER land total*: +0.04, (Quaas+, ACP'04, land)*

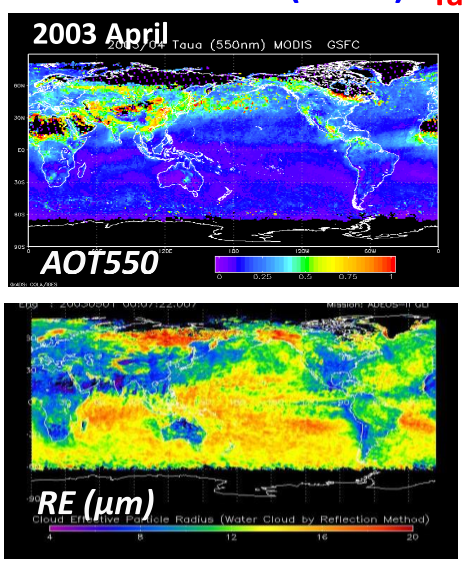
Interaction slopes:

$$W = \rho_w \frac{2r\tau}{3} \qquad N_a \sim \alpha\tau_a \text{ (AI)}$$

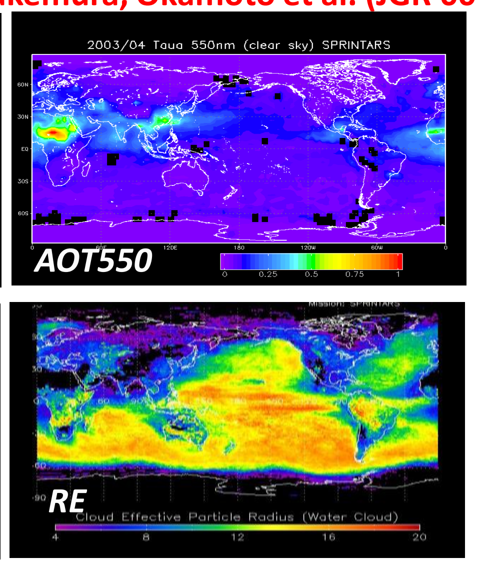
$$b(RE) = \frac{d\ln r_e}{d\ln N_a}, \quad b(COT) = \frac{d\ln \tau_c}{d\ln N_a}$$

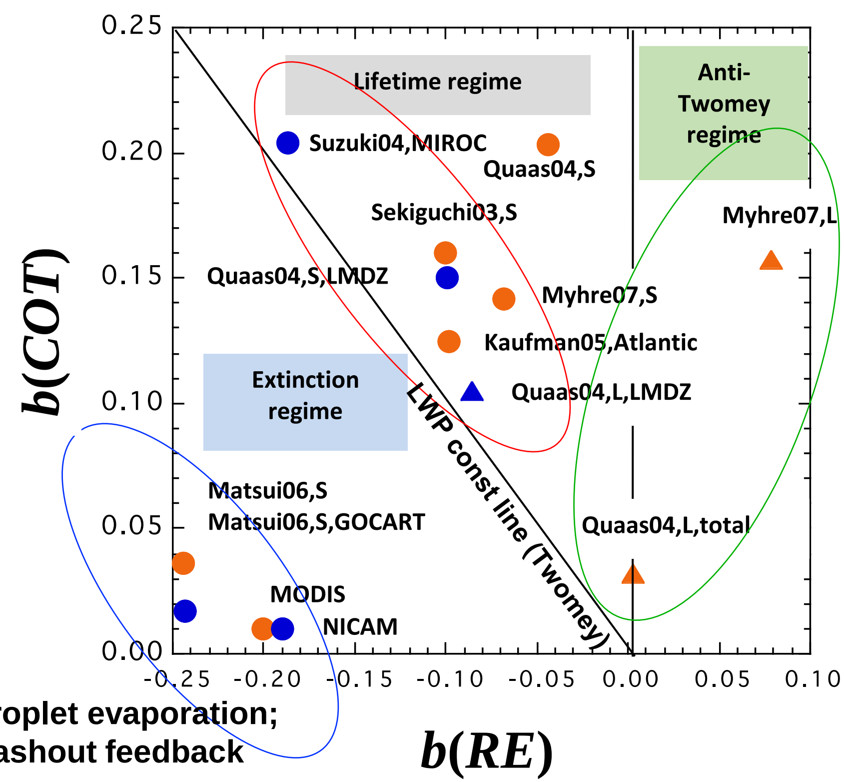
$$b(LWP) = b(COT) + b(CDR)$$

TERRA-MODIS (NASA)



MIROC-SPRINTARS
Takemura, Okamoto et al. (JGR'00)

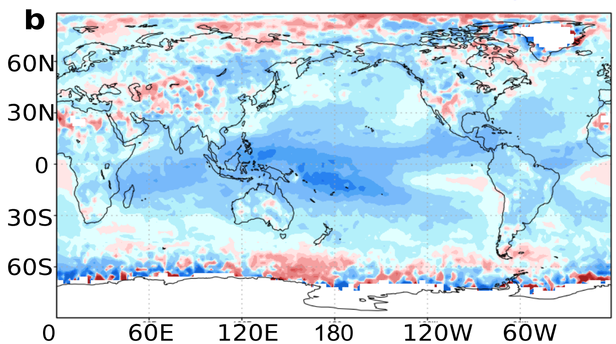




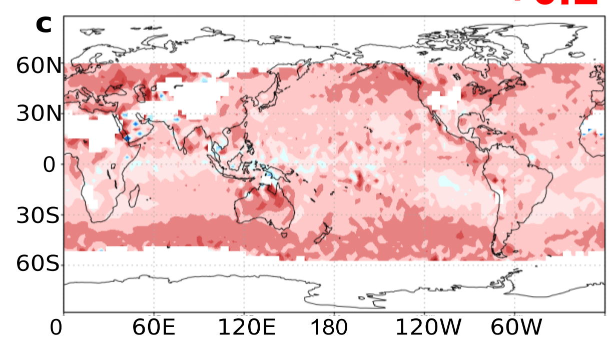
Nakajima&Schulz, (Heintzenberg, Charlson eds, MIT Press'09)

Cloud-aerosol interaction inconsistencies???

NICAM-Chem model (14km)
(Sato+, Nature-C'18)
~-0.1



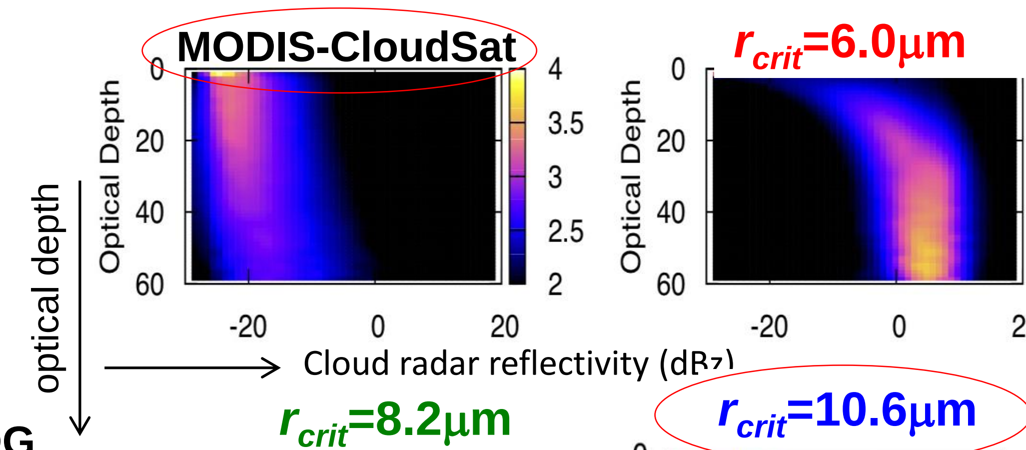
MIROC-SPRINTARS GCM (300km)
~+0.1

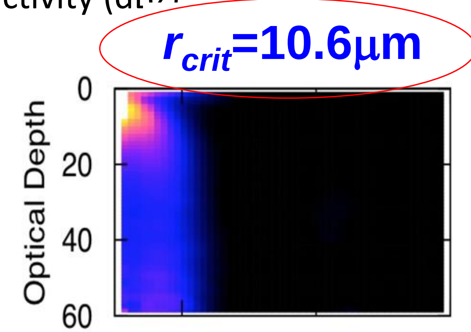


$b(LWP)$

Satellite Obs. (A-Train, active) **~-0.05**
(Michibata+, ACP'16)

CFODD (COD vs radar refl. plot)





Discussion started:
- ***Rosenfeld+ (Science'19)***
- ***Sato&Suzuki (Science'19)***

Causes???
- **Horizontal resolution?**
- **Cloud & rain scheme OK?: DIAG vs PROG**
- **Entrainment, cloud top evaporation**
- **Sampling methods (time, location)**
- **Cloud scavenging region (clear bias)**
- **Ice cloud effect?**

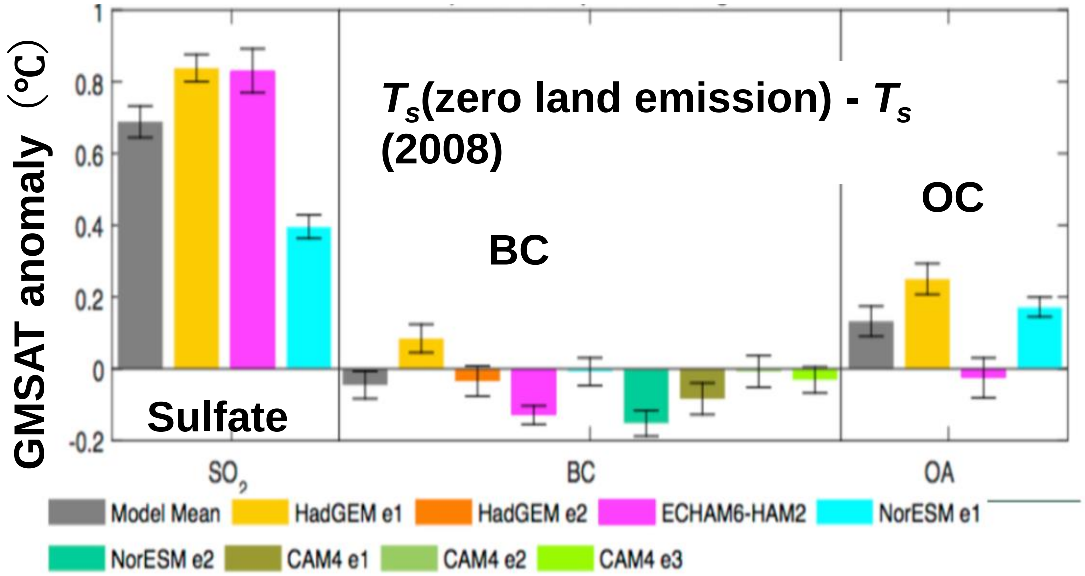
TY Nakajima+(JAS'10)
Suzuki+ (GRL'13)
Golaz+ (GRL'13)

Weak efficacy of BC direct climate effect

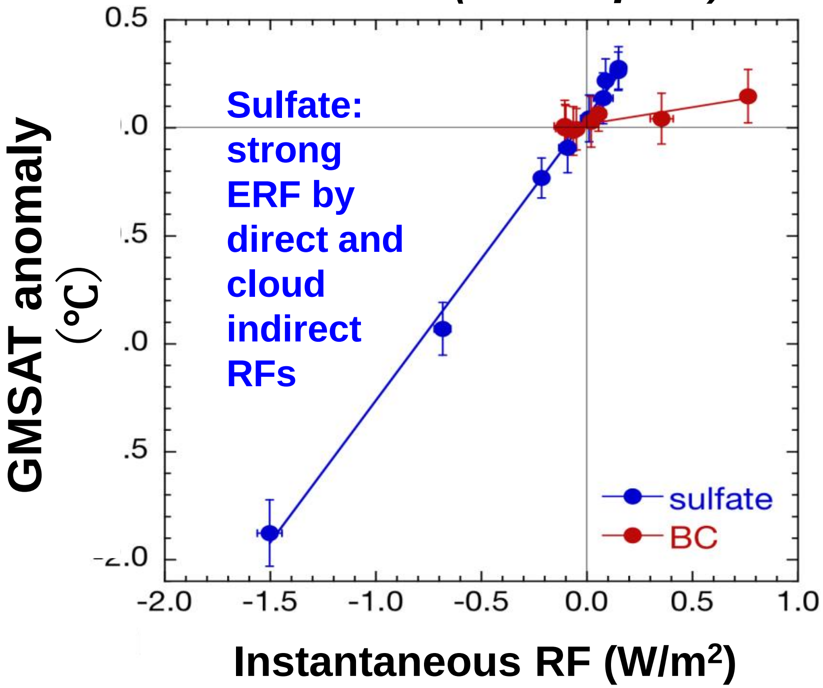
Concept of Efficacy (*Hansen+, 2005*)

$dT_s/dR_f / (dT_s/dR_f)_{CO2}$

Stohl+ (ACP'15)



Suzuki&Takemura (JGR'18)
Takemura&Suzuk (Sci Rep'19)

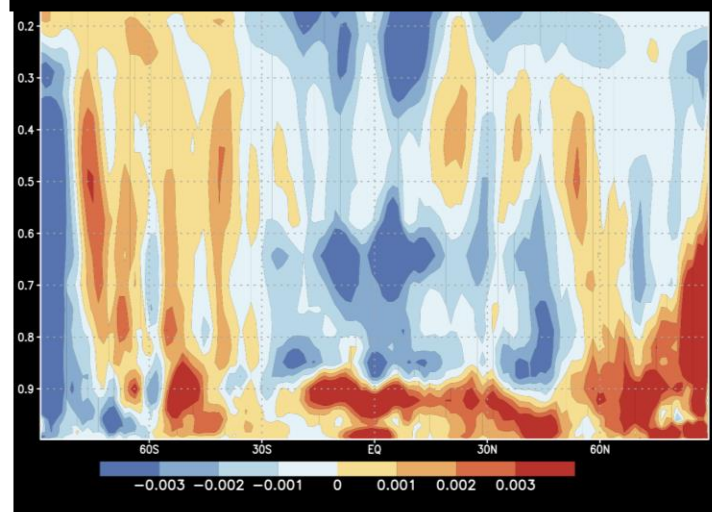


BC: weak ERF to precip???

Atmos-pheric stability change

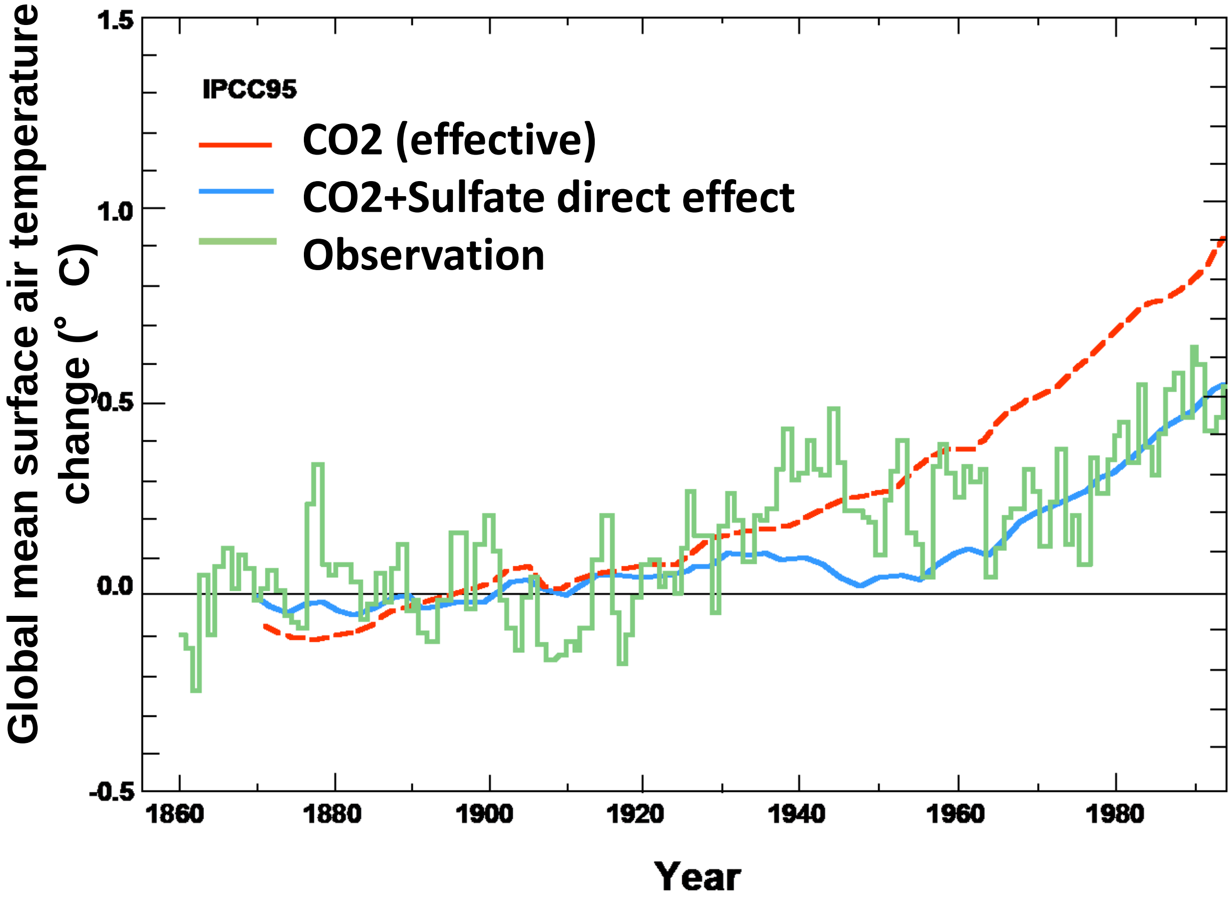
Counter negative cloud RF

Cloud amount change for 10xBC



Missing heat sink problem in global warming

Mitchell+ (Nature'95)



RF to 2005

LLGHGs: +2.7 W/m^2
well understood

2000's: Direct: -0.3
(Larger BC)
Cloud albedo：-0.6
(Various & ice response)

2010's:
BC direct: smaller
Cloud indirect: smaller

Current:

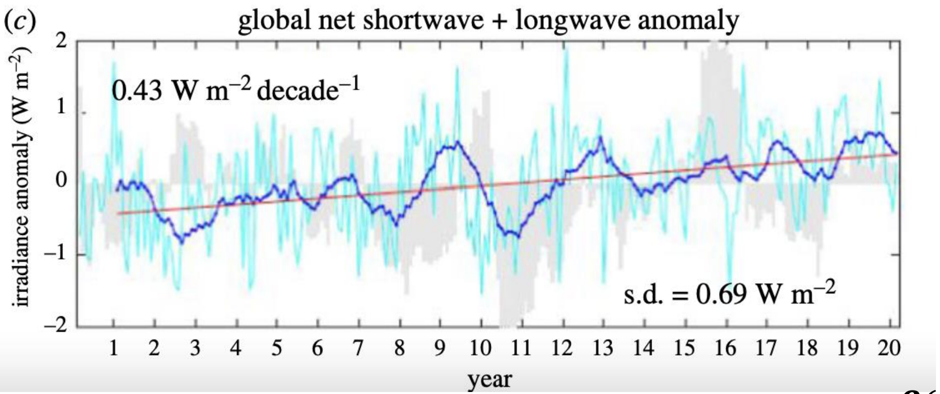
- **Missing sink again from vertical observation and GCRM???**
- **Multi-layer and ice clouds ???**

Cloud effect of aerosols

Large cloud droplet

Air pollution aerosols become many small droplets

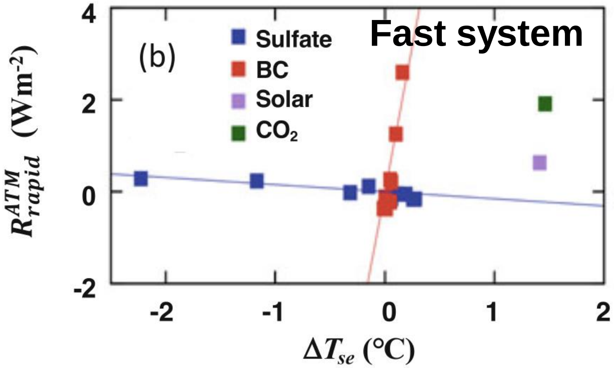
What is the doom of absorbed solar energy?



Stephens+ (Proc. R. Soc. '22)

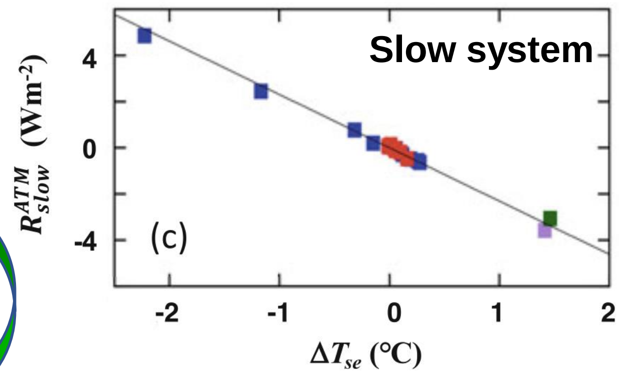
- **A decreasing trend of ERB with Earth albedo change: aerosol change**
- **There are differences in some climate model interpretation: need study**

Suzuki& Takemura (SOLA '00)



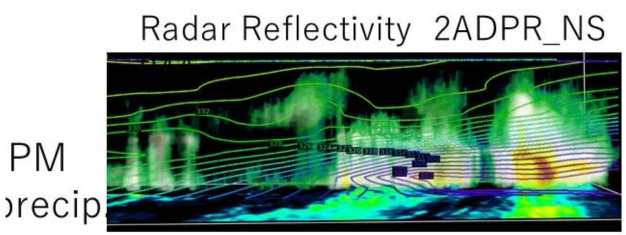
$$\beta(t) = \frac{dF_R}{dT_s} = 4\varepsilon\sigma T_s^3 + \beta_\alpha + \beta_\varepsilon + \cdots$$

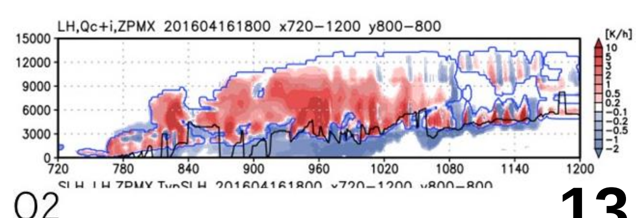
time dependence of the feedback parameters



- **A decreasing trend of AOT in ISCCP data: Mishchenko (Science'07), whereas the cloudiness is very stable**
- **Precipitation, rapid and then slow climate system, and then feedbacks?(*Sherwood+, Rev. Geophys., 2000*)**

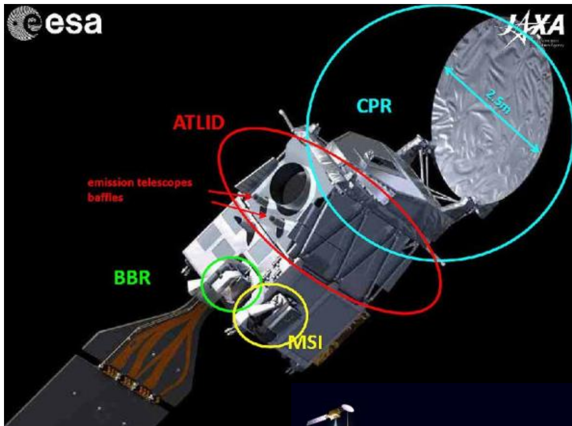
GPM observations *(provided by Prof. Takayabu, Univ. Tokyo)*





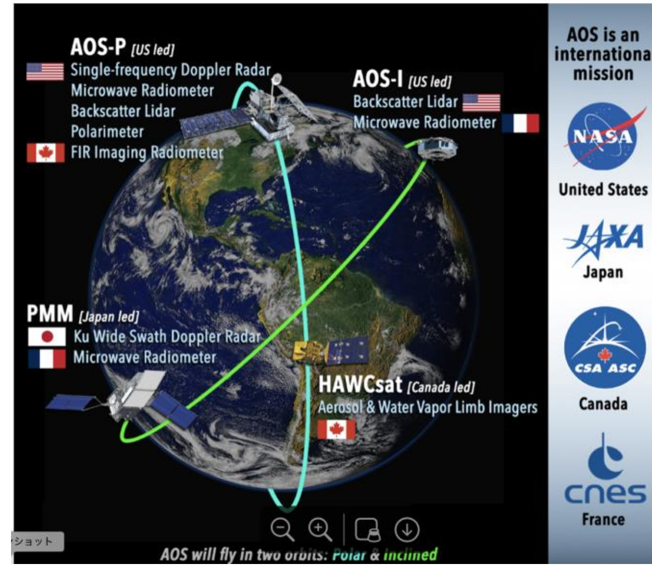
Adventures continue

Earth explorer/EarthCARE (ESA-JAXA)



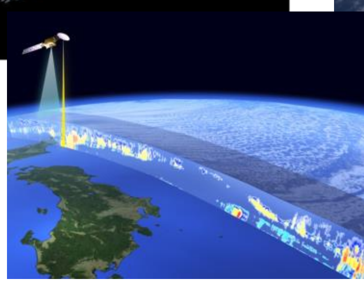
Sentinel-5/ 3 MI

NASA AOS mission



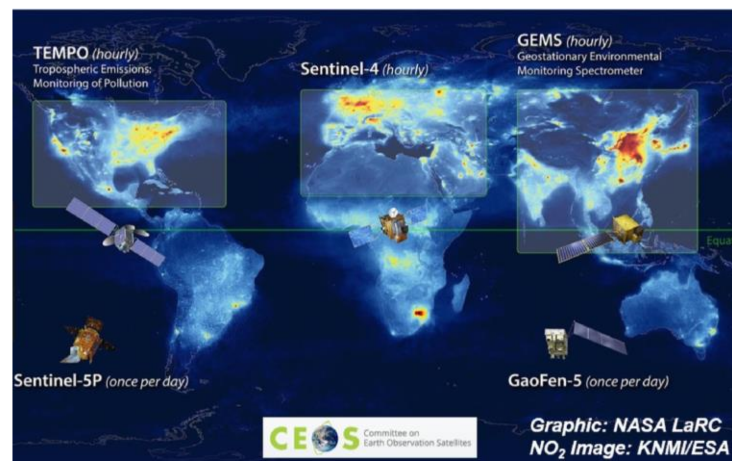
Aerosol-Cloud-Precip

Active sensing, Doppler



Multi-angle polarization

GOSAT-GW etc GHGs



Geostationary chemistry

Conclusions

- Atmospheric particulate matter impact on the earth radiation budget significant, but still needs studies for understandings and future projection
- Aerosol, cloud and precipitation being linked (EarthCARE, NASA/AOS programme)
- 3D and wide spectram data needed: EarthCARE, Sentinel-5/3MI, GOSAT-GW, Global geostational chemical satellites (GEMS, Sentinel-4, TEMPO) etc
- Validation and assimilation needed by high resolution transport models, ground-based networks, and AI technologies

- **E. Raschke**
- **R. Kandel**
- **K. Terada**
- **A. Lefevble**
- **P. Ingmann**
- **P. Baptista**
- **T. Wehr**
- **H.Kumagai**
- **T. Kimura**
- **R. Oki**
- **...**

Thanks!