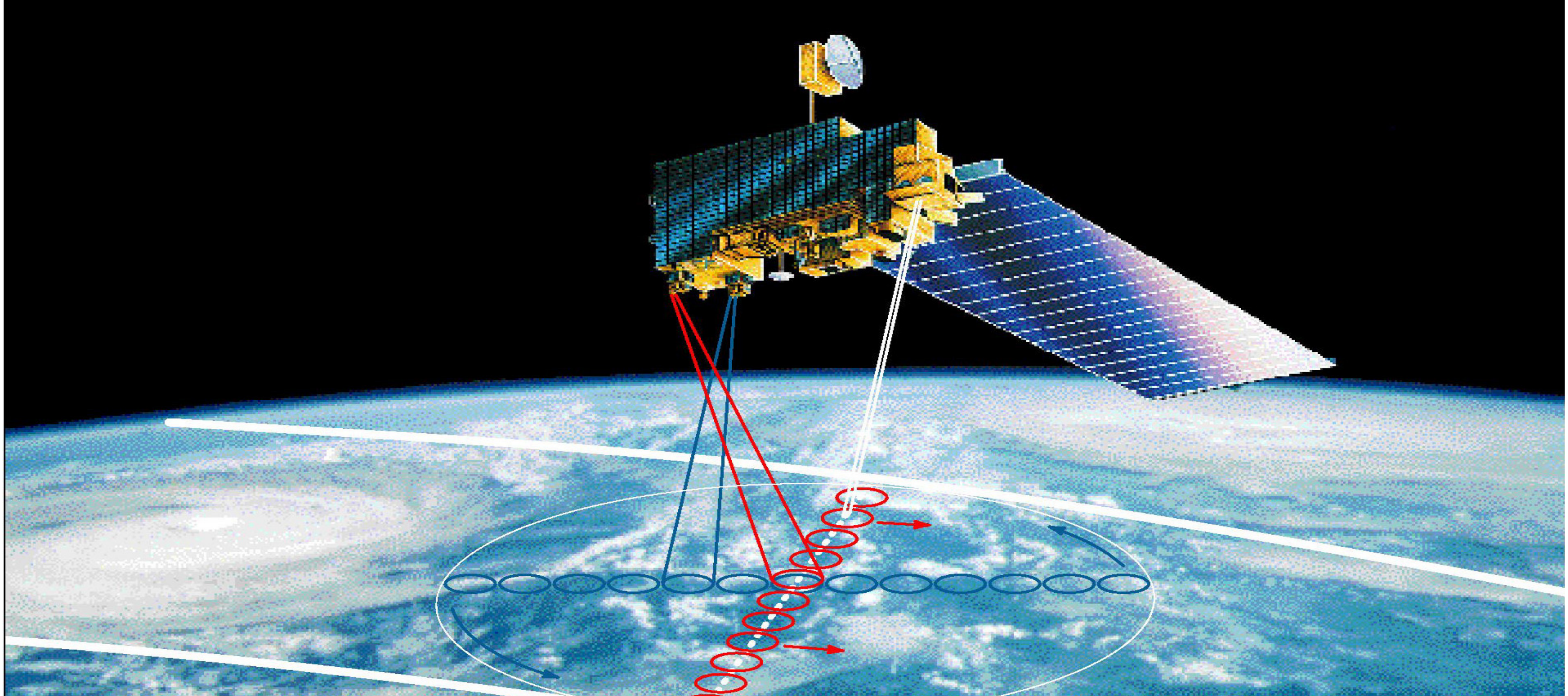
AOSC400-2015
October 29, Lecture # 16

- Global Radiation Budget
- Climate Sensitivity to Clouds
- Cloud Radiative Forcing
- Results from Radiation Budget Missions (ERBE; CERES)
- Special Programs to Better Understand Clouds (ARM)
- Angular Distribution Models (ADM) Models

*Sources of information used for this lecture are listed in updated Syllabus.

Clouds and the Earth’s Radiant Energy System



Important issue in climate research:

Is the global energy budget changing?

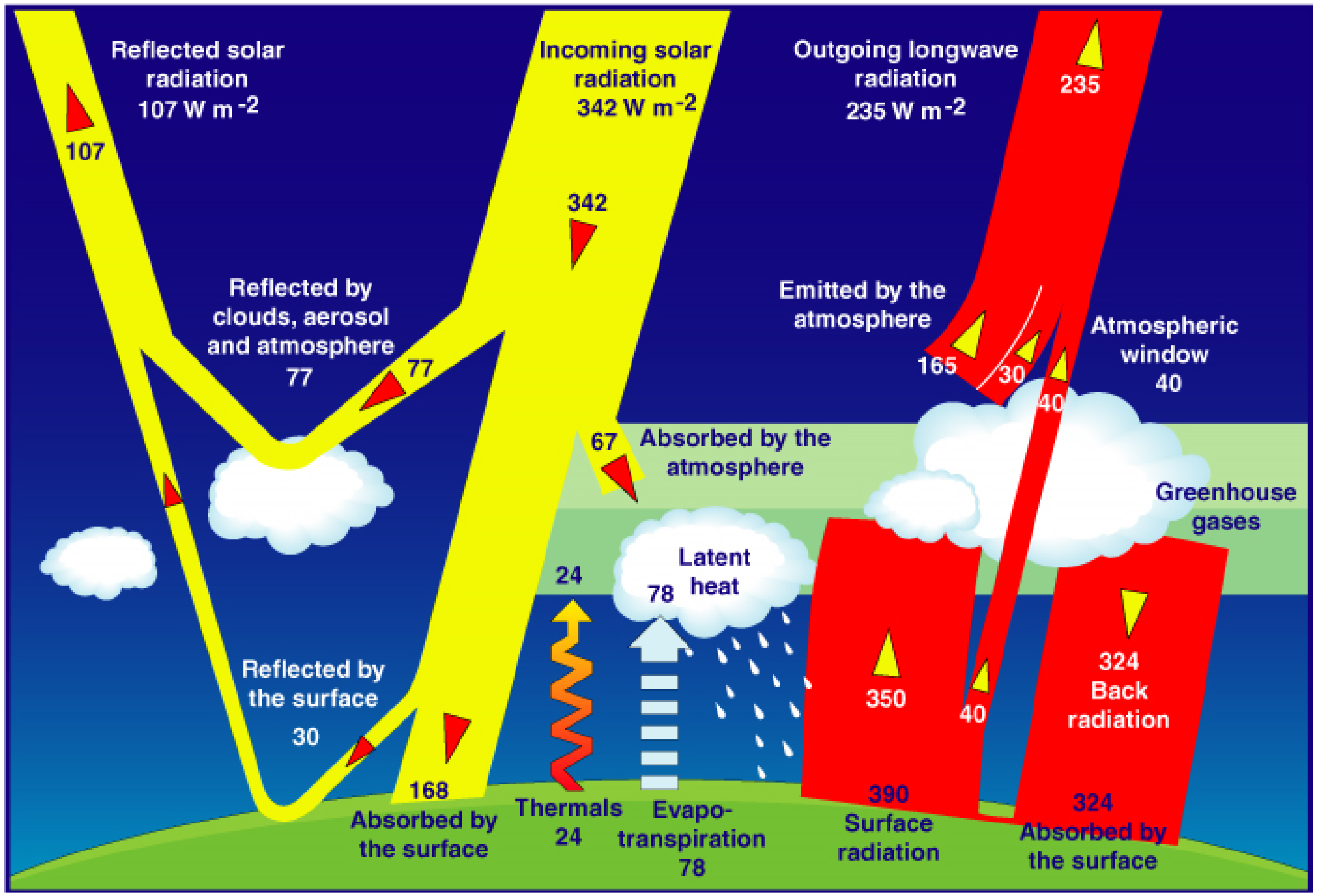
Effect of clouds on the radiation budget.

Why are Clouds So Important?

Cess et al. (1990):

"Eighteen atmospheric General Circulation Models (GCMs), using prescribed Sea Surface Temperature (SSTs), have been compared to top-of-atmosphere radiation fluxes from satellites. A small subset does a reasonable job of replicating the satellite data, but typically, the models overestimate cloud cooling. This is because their clouds are either too bright, or at too low an altitude, or both."

Satellites are source of information on the Global Energy Budget



A famous diagram in climate research That is now periodically updated)

As estimated from models (Kiehl and Trenberth, 1997)

Net radiation is defined at top of the atmosphere (TOA) as:

Net (TOA) = Solar_down (TOA) - SW_up (TOA) - LW_up (TOA)

where Solar_down (TOA) is the solar incoming flux at TOA,
SW_up (TOA) is the reflected shortwave flux at TOA, and
LW_up (TOA) is outgoing longwave flux at TOA.
The sign convention for net radiation is that positive/**negative** sign represents a net radiative energy surplus/**deficit** of the Earth system, respectively.

Effect of Clouds

Clouds interact both with solar radiation, in the shortwave region of the spectrum, and with the radiation thermally emitted by the earth and atmosphere, in the longwave region.

Clouds reduce the net absorption of solar radiation by increasing the earth albedo, and they decrease the loss of terrestrial radiation to space by decreasing the effective radiative brightness temperature of the earth.

- The solar radiation effect and the thermal emission effect are in opposite directions as far as net radiation at the top of the atmosphere is concerned.
- Each effect, by itself, is large, but the combine effect is relatively small and will depend significantly on the cloud-free profile of atmospheric temperature, humidity, and aerosols, and upon surface temperature and optical properties.
- The net effect is the difference of two large terms; led to a debate in the 70s on the role clouds play in the climate system.

The effect of cloud cover on solar radiation depends primarily on the *thickness of the cloud*, but also it depends upon particle size and phase.

The *longwave* effect depends primarily upon *cloud top temperature,* which is a function of cloud height, and, for *thin clouds,* upon *emissivity*, which is related to *optical thickness*.

The concept of Radiative Forcing

Radiative forcing is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism.

Well known examples of this concept are related to greenhouse gases or other atmospheric constituents as shown in next figure.

An example is related to direct aerosol forcing. Direct TOA Aerosol Radiative Effects are defined as:

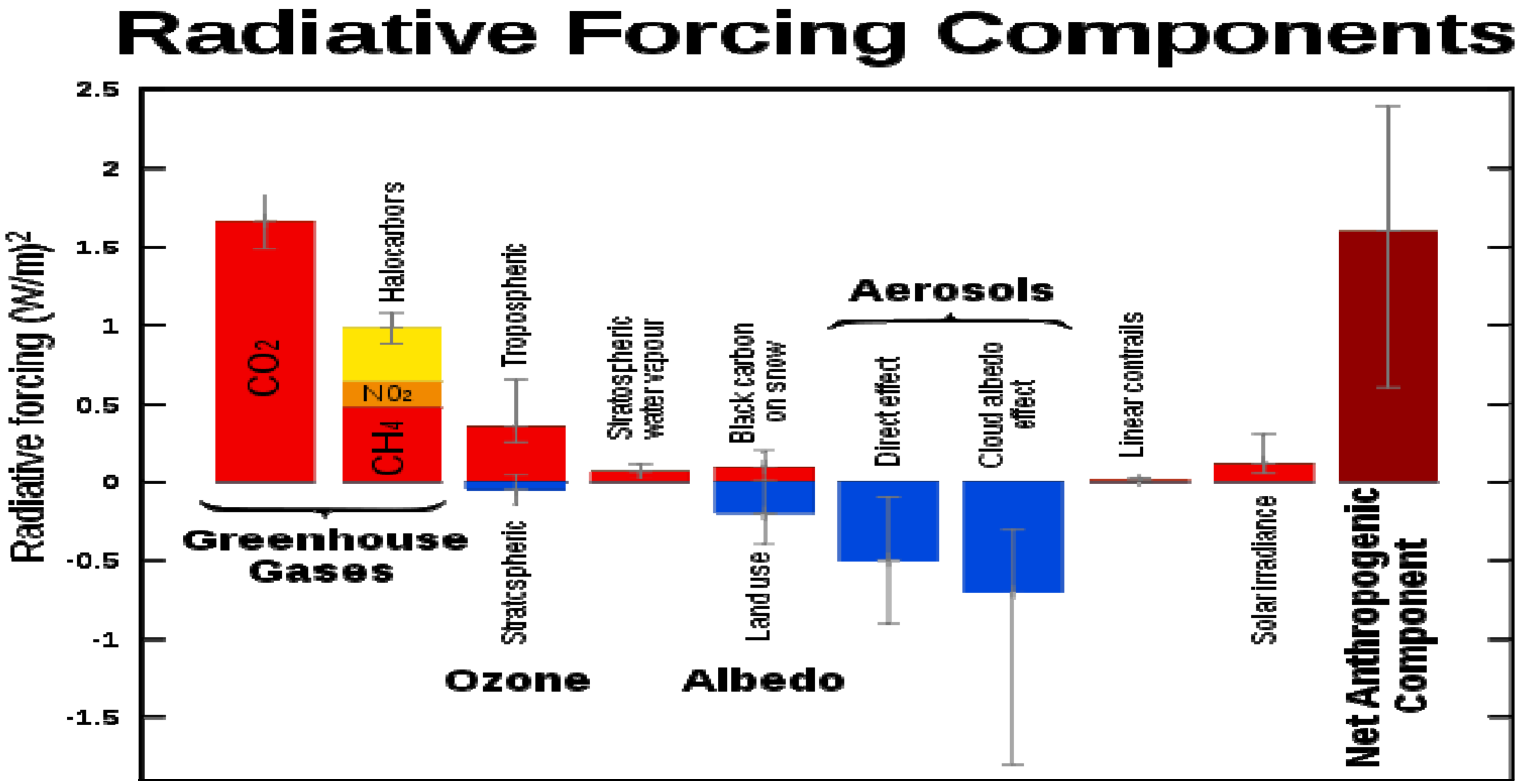
$$DF\,(AER) = F\,(\text{no AER}) - F\,(OBS)$$

Where:

F(OBS) = *SW TOA flux inferred from cloud-free SW radiances*

F(no AER) = *"No aerosol" flux approximated by the intercept of TOA flux against aerosol optical depth.* See next slide from the IPCC report.

Similar concepts apply to clouds:



Changes in radiative forcings between 1750 and 2005 as estimated by the IPCC 2007

Cloud Radiative Effects

The effect of clouds on the Earth's radiation balance is measured as the difference between clear-sky and all-sky radiation results

$$F^{X}(\text{cloud}) = F^{X}(\text{clear}) - F^{X}(\text{all-sky})$$

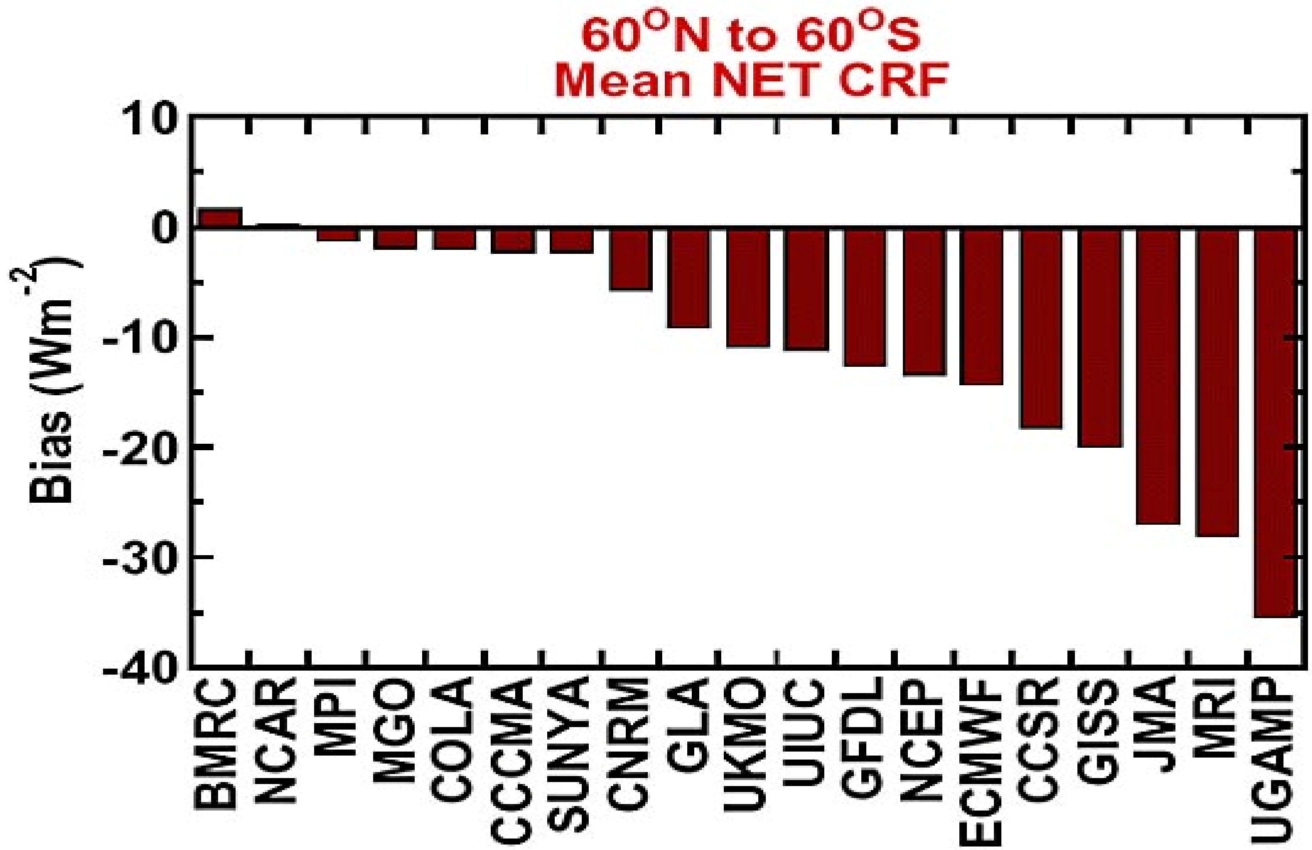
$$F^{Net}(\text{cloud}) = F^{SW}(\text{cloud}) + F^{LW}(\text{cloud})$$

where X= SW or LW

Negative $F^{Net}(\text{cloud})$ => Clouds have a cooling effect on Climate

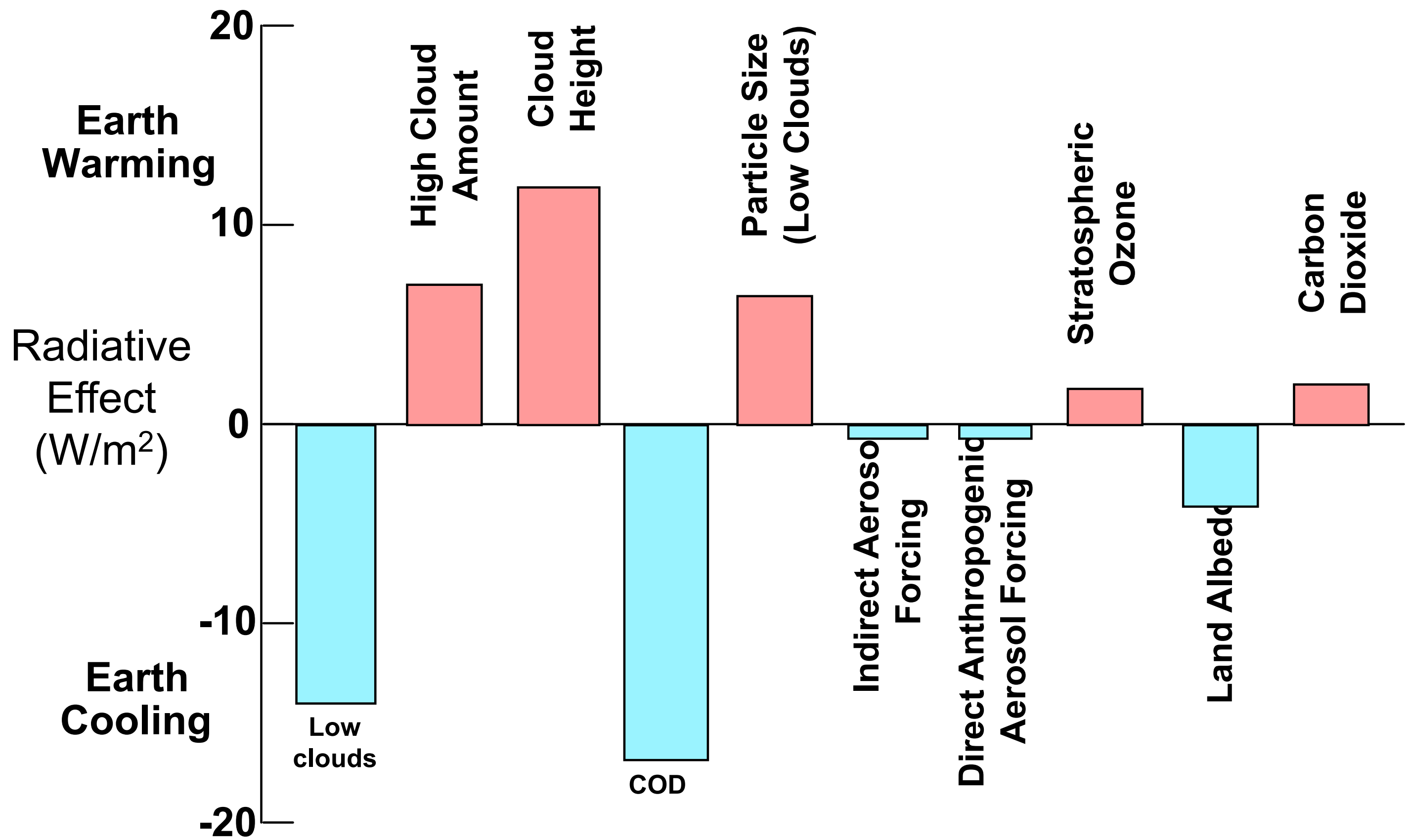
Positive $F^{Net}(\text{cloud})$ => Clouds have a warming effect on Climate

Net Cloud Radiative Forcing from 19 GCMs



Climate Sensitivity

Radiative Effect at the Top of the Atmosphere
For a 50% Increase in Climate Parameter



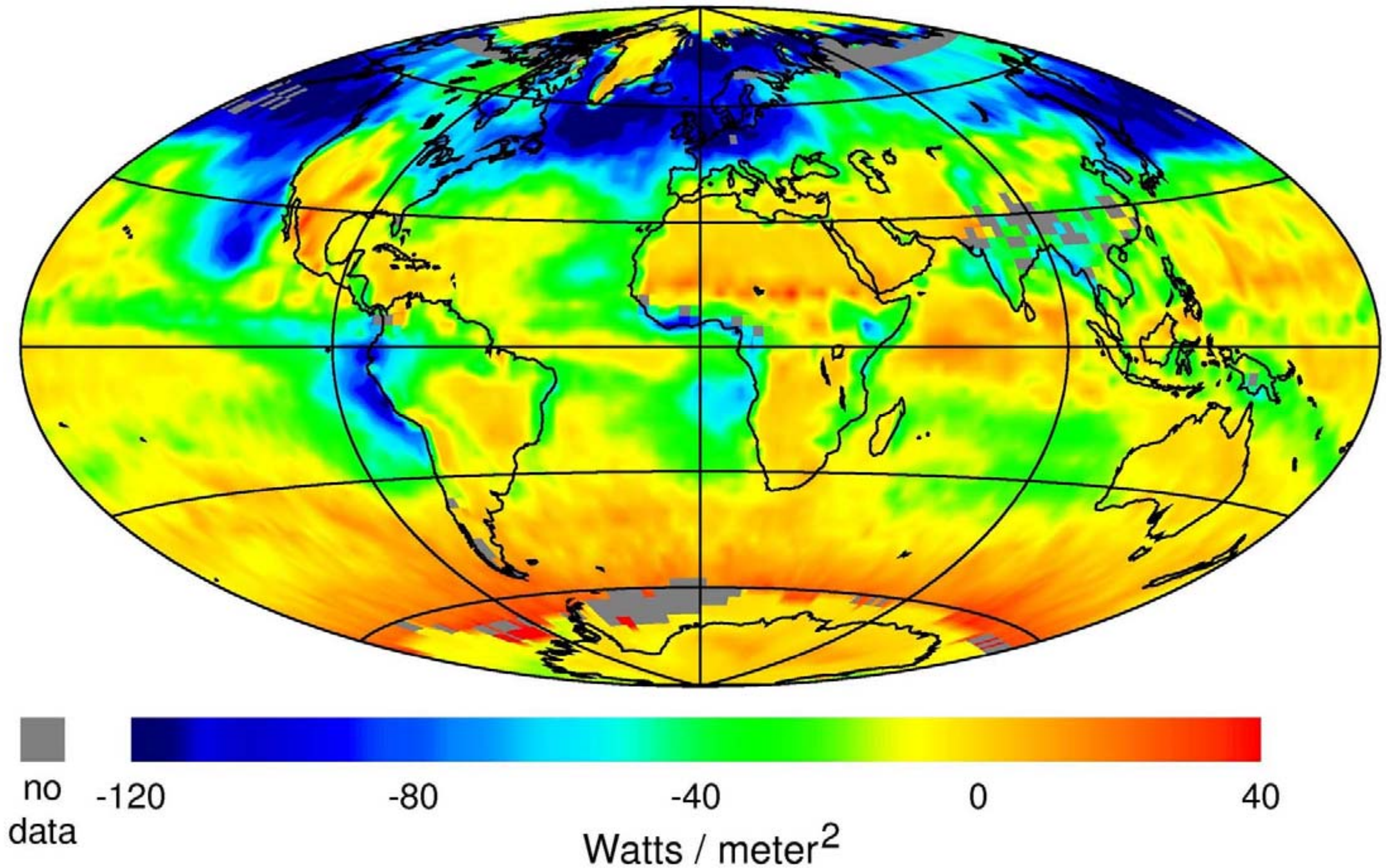
Cloud Forcing for Different Cloud Types

- Optically thick low-level clouds: Reflect more SW radiation back to space than the darker surface would in their absence. Thus, less solar energy is available.
  => cooling effect

- High thin cirrus clouds: Transmit most of the incoming solar radiation while, simultaneously, they absorb some of the Earth's infrared radiation and radiate it back to the surface
  => warming effect

- Deep convective clouds: Have neither a warming nor a cooling effect because their cloud greenhouse effect, although large, is nearly balanced by the reflected SW radiation due to their high albedo

Net Cloud Forcing (July, 2000) from Clouds and Earth's Radiant Energy System (CERES)

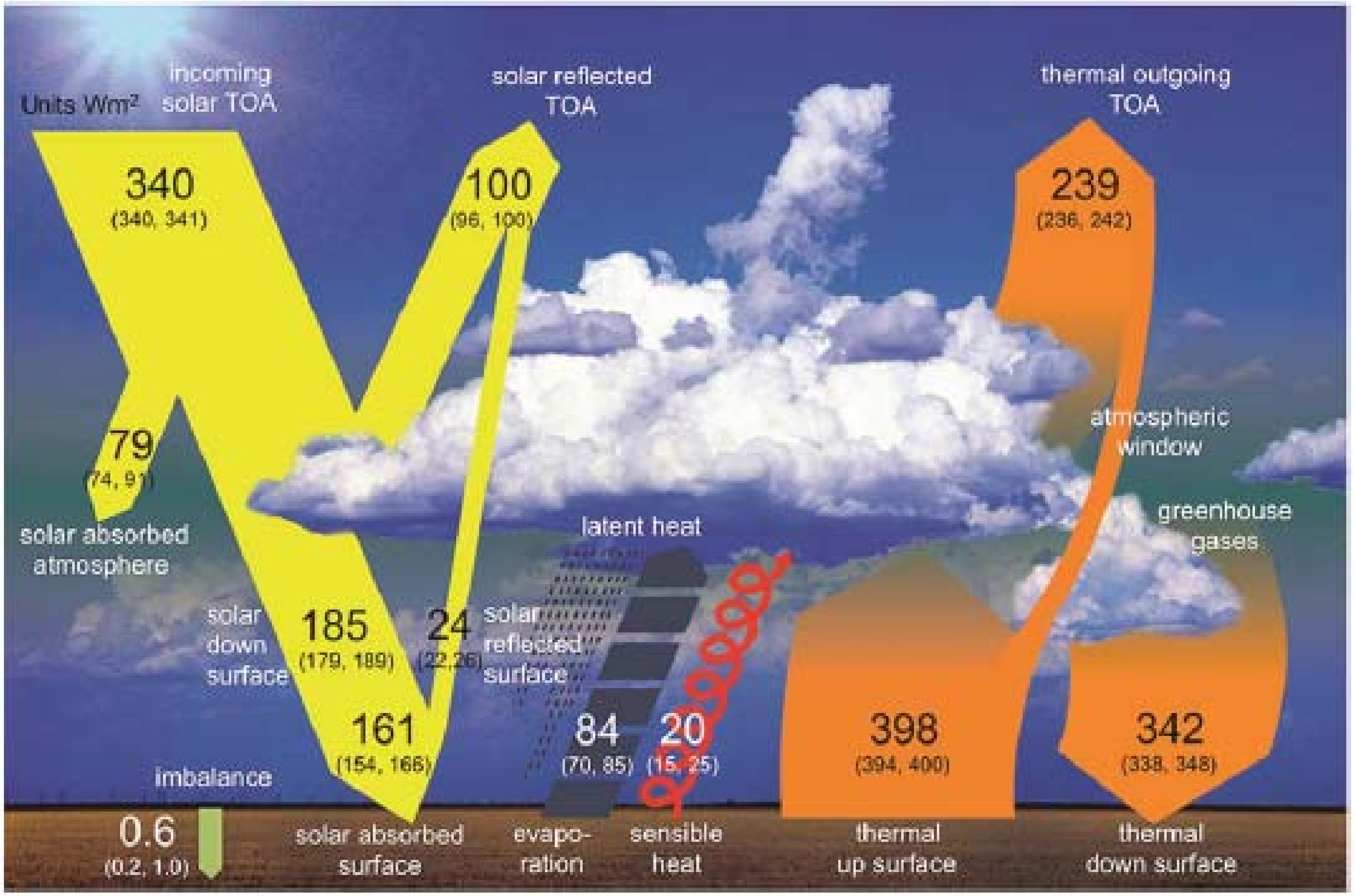


What is currently known on the Radiation Budget *(from IPCC 2013)*

- The radiation budget at the Top Of Atmosphere (TOA) includes the absorption of solar radiation by Earth, determined as the difference between the incident and reflected solar radiation at the TOA, as well as the thermal outgoing radiation emitted to space.

- The surface radiation budget takes into account the solar fluxes absorbed at Earth's surface, as well as the upward and downward thermal radiative fluxes emitted by the surface and atmosphere.

Global mean energy budget under present day climate conditions (from IPCC 2013)



Global Mean Radiation Budget

- Observed from space-borne platforms such as the Solar Radiation and Climate Experiment (SORCE) (Kopp and Lawrence, 2005) for radiation from the sun, and from the Clouds and the Earth's Radiant Energy System (CERES, Wielicki et al., 1996) for the reflected SW and outgoing LW.

- The total solar irradiance (TSI) incident at the TOA is now much better known, with the SORCE Total Irradiance Monitor (TIM) instrument reporting uncertainties as low as 0.035%, compared to 0.1% for other TSI instruments (Kopp et al., 2005).

- Kopp and Lean (2011)* conclude that the SORCE/TIM value of TSI is the most credible value because it is validated by a National Institute of Standards and Technology calibrated cryogenic radiometer.

- This revised TSI estimate corresponds to a solar irradiance close to 340 W/m^2 globally averaged over Earth’s sphere.

- ***Kopp and Lean was required reading**.

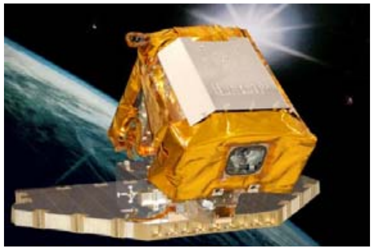
Continuity of 34+year TSI Record

- Loss of Glory-TIM at launch on March 4, 2011
- Delay of TSIS Flight Opportunity to 2015+

SORCE/TIM

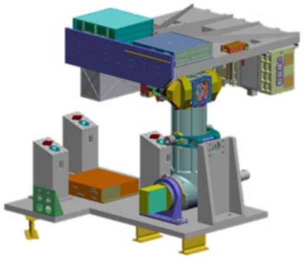
SORCE : 2003 – 2015
??

Glory/TIM



2011 - 2014 (failed)

JPSS Free Flyer/TSIS



TSIS : July, 2016

TSI record continued since 1978
TCTE : 2013-2016 (expected)

Mission to study the Earth Radiation Budget: Clouds and Earth's Radiant Energy System (CERES)

The first CERES instrument was launched in December of 1997 aboard NASA's Tropical Rainfall Measurement Mission (TRMM). CERES instruments are now collecting observations on three separate satellite missions, including the EOS Terra and Aqua observatories and now also on the NPOESS Preparatory Project (NPP) observatory *(more on this in next lecture)*

CERES products include both solar-reflected and Earth-emitted radiation from the top of the atmosphere to the Earth's surface. Cloud properties are determined using simultaneous measurements by other EOS and NPP instruments such as the (MODIS) and the Visible and Infrared Sounder (VIRS). Analyses build on previous experience such as the Earth Radiation Budget Experiment (ERBE), leading to a better understanding of the role of clouds and the energy cycle in global climate change.

CERES Measurements

- 5 Instruments on 3 Satellites (TRMM, Terra, Aqua) for diurnal and angular sampling
- 3 Channels per instrument:
  - Shortwave (0.2-4.0 mm) – Reflected solar radiation
  - Total (0.2-100 mm) – Earth emitted radiation by subtracting SW
  - Window (8-12 mm) – Thermal infrared emission
- Coincident Cloud and Aerosol Properties from MODIS/VIRS

After N. Loeb et al., 2009)

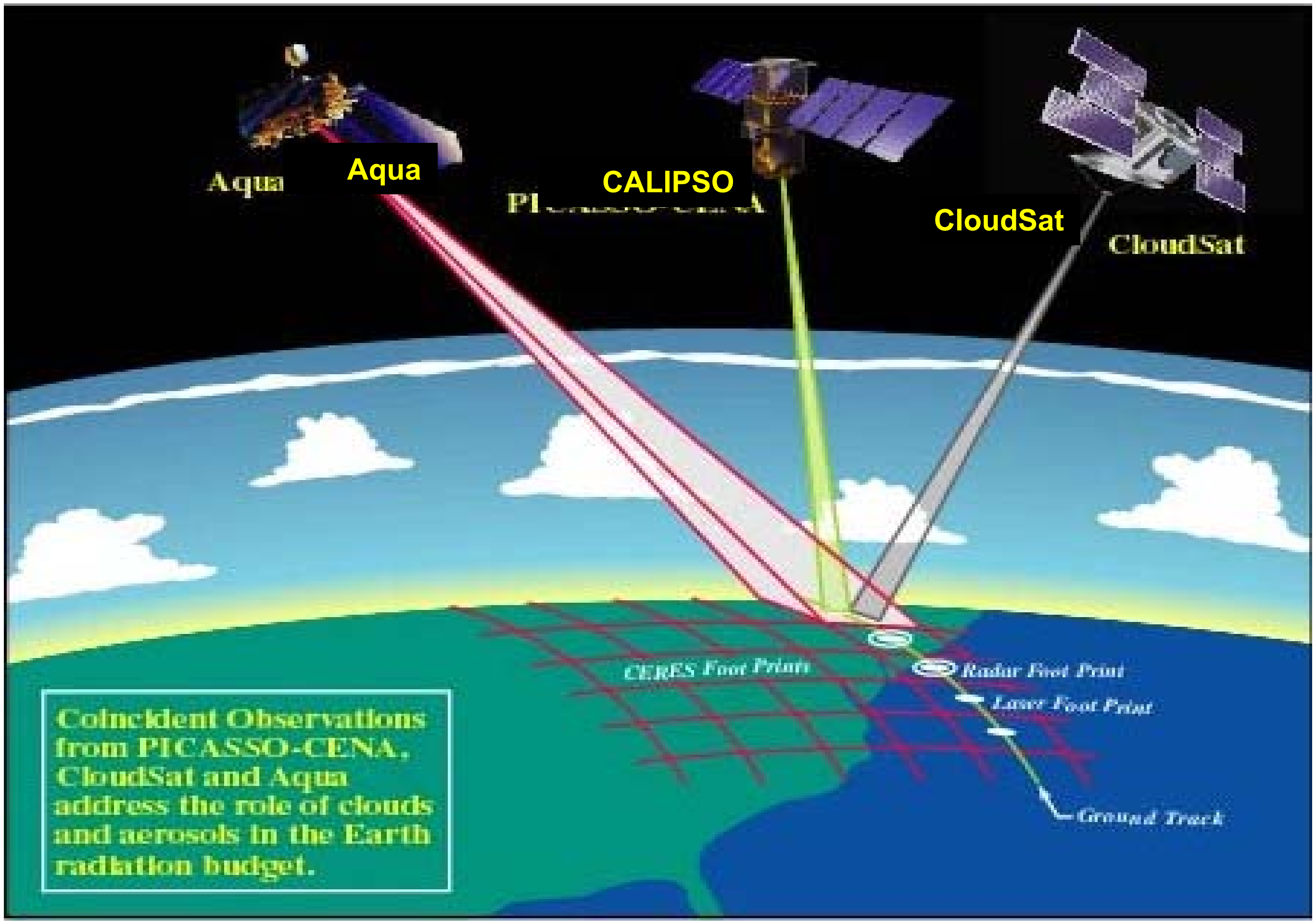
- Flies in Formation with CALIPSO and CloudSat

The stated uncertainty in the solar reflected TOA fluxes from CERES due to uncertainty in absolute calibration alone is ~2% (2-sigma), or equivalently 2 W/m^2 *(Loeb et al., 2009).*

The uncertainty of the outgoing thermal flux at the TOA as measured by CERES due to calibration is ~3.7 W/m^2 (2σ).

In addition to this, there is uncertainty in removing the influence of instrument spectral response on measured radiance, in radiance-to-flux conversion, and in time-space averaging, which adds up to another 1 W/m^2 *(Loeb et al., 2009).*

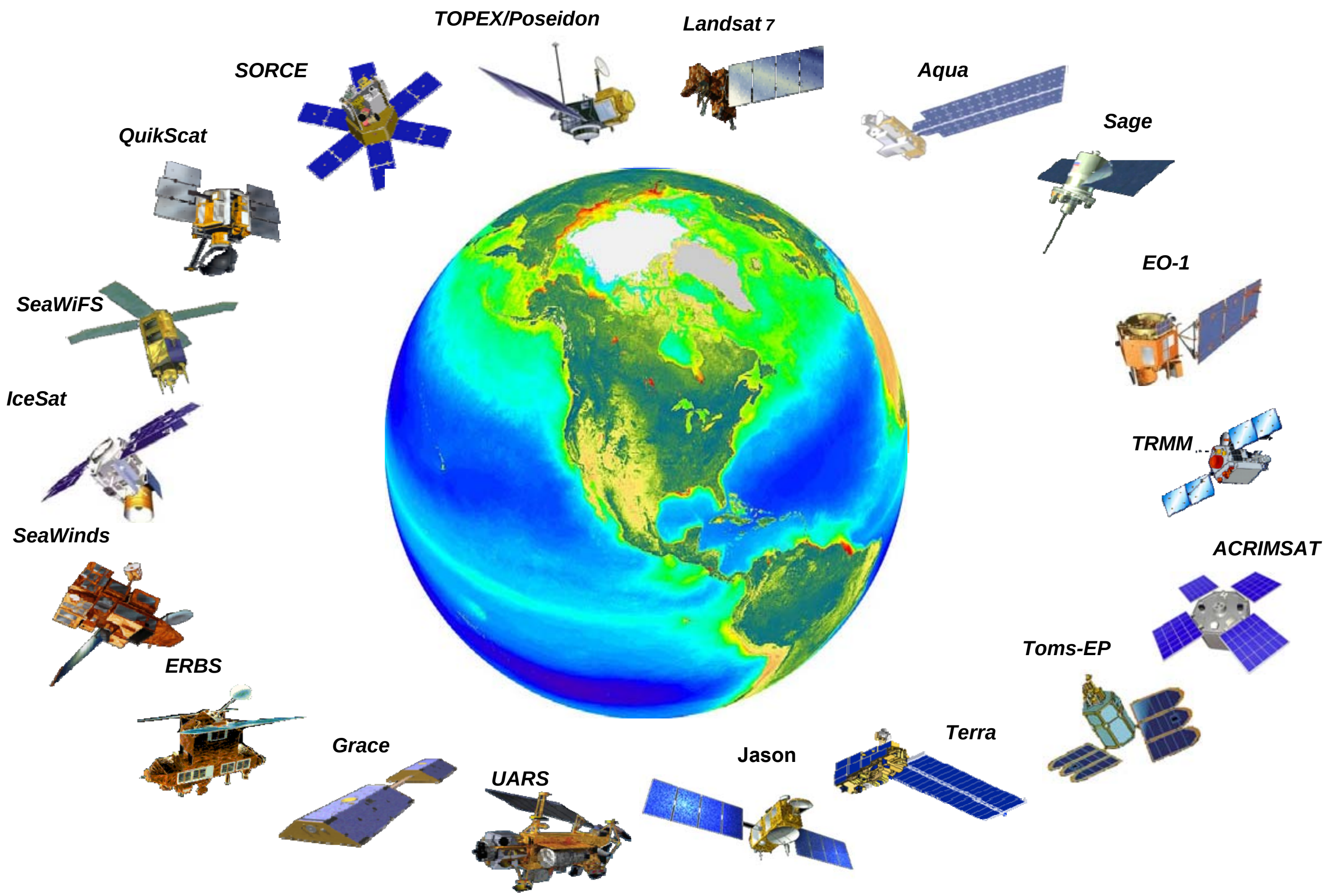
A configuration of several satellites with complimentary capabilities is considered as ideal for cloud research. In particular, the newer systems with active capabilities.



Over the last dozen years, NASA has launched a series of satellites – known collectively as the Earth Observing System (EOS) – that has provided critical insights into the dynamics of the entire Earth system: clouds, oceans, vegetation, ice, solid Earth and atmosphere (see next slide).

Now NASA is helping to create a new generation of satellites to extend and improve upon the Earth system data records established by EOS.

Space-borne Earth Observation Systems



- The components of the radiation budget at the surface are more uncertain than their counterparts at the TOA because they cannot be directly measured by passive satellite sensors.

- Decadal changes in observational records of surface shortwave radiation (SSR) reported - a decline from the beginning of widespread measurements in the 1950s until the mid-1980s (known as *'global dimming',* and a partial recovery from the 1980s onward ('brightening').

- Estimates of absorbed solar radiation at Earth's surface (SSR) include considerable uncertainty. Published global mean values inferred from satellite retrievals, re-analyses and climate models range from below 160 W/m^2 to above 170 W/m^2.

- Recent studies favor values towards the lower bound of this range, near 160 W/m^2, atmospheric solar absorption around 80 W/m^2 and a downward thermal flux slightly above 340 W/m^2.

- Globally complete satellite estimates are available since the early 1980s. Since satellites do not directly measure the surface fluxes, they have to be inferred from measurable top-of-atmosphere signals using models to remove atmospheric perturbations.

- Available satellite-derived products qualitatively agree on a brightening from the mid-1980s to 2000 averaged globally as well as over oceans, on the order of 2–3 W/m^2 per decade *(Hatzianastassiou et al., 2005; Pinker et al., 2005; Hinkelman et al., 2009).*

Knowledge of the decadal variation of aerosol burdens and optical properties, required in satellite retrievals of SSR and considered relevant for dimming/brightening particularly over land, is very limited.

Extensions of satellite-derived SSR beyond 2000 indicate tendencies towards a renewed dimming at the beginning of the new millennium .