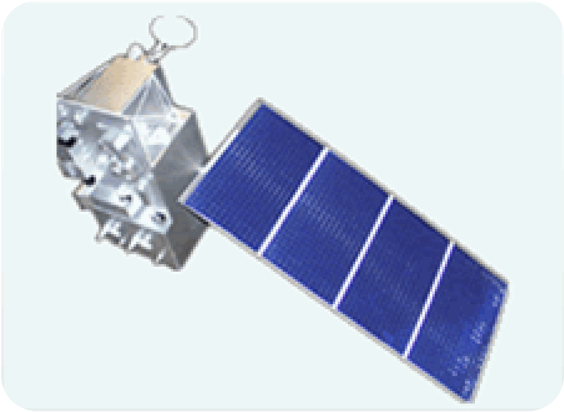
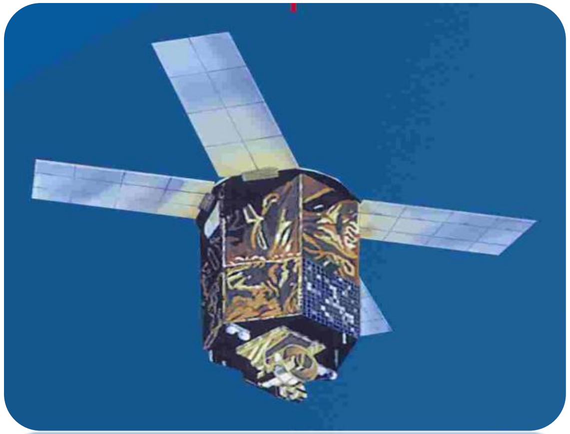
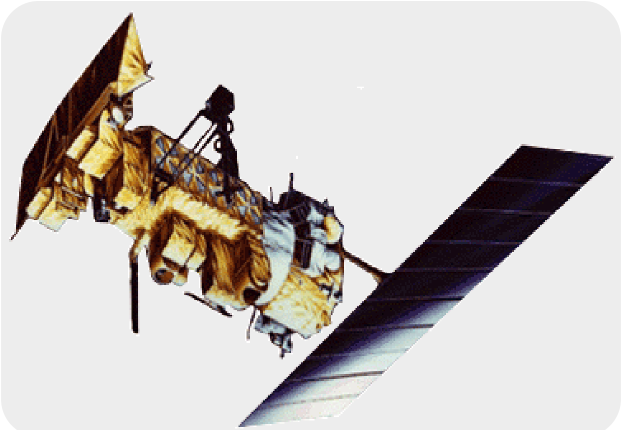
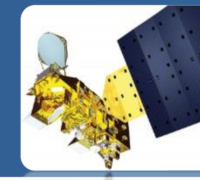
Frontier of Earth System Science Seminar No.8
Spring 2013

The Role of Satellite Remote Sensing in Climate Change Studies

Jun Yang
Center for Earth System Science
Tsinghua University

Outline



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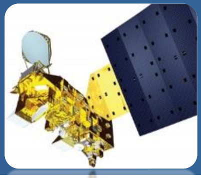
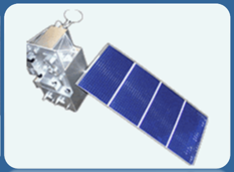
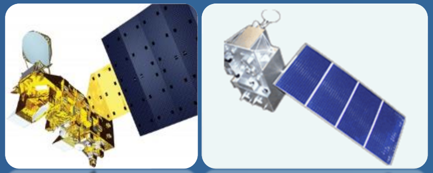
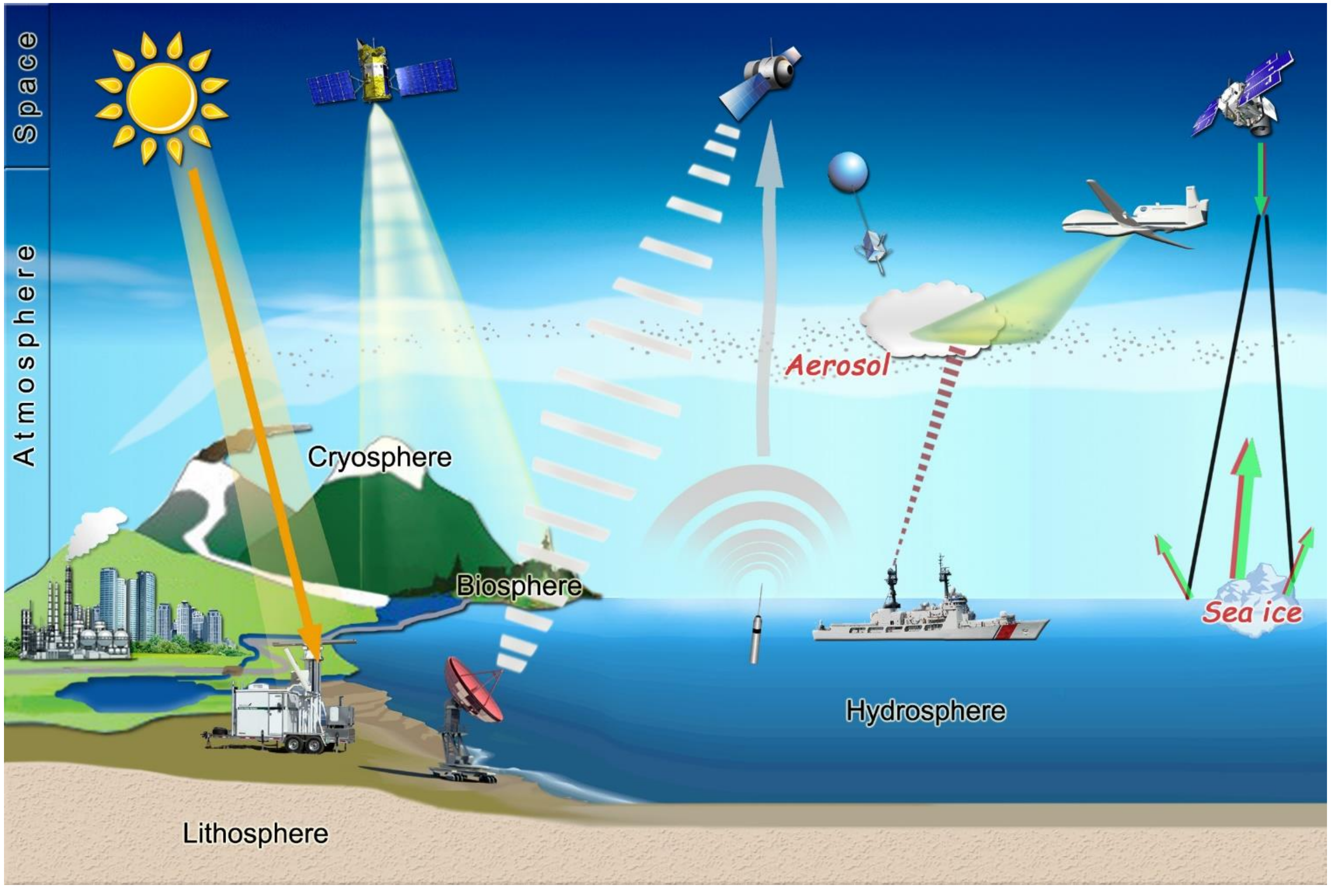




1. INTRODUCTION

1. Introduction





(Source: Yang et al. under review)

Climate observation

-the foundation of our understanding of the climate system (*Overpeck*, 2011, *Science*)

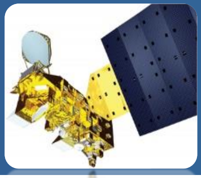
1. Introduction

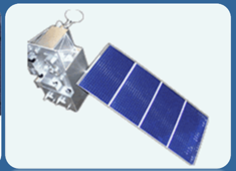
(Source: NASA 2011)

What is satellite remote sensing?

-acquires information about the Earth's surface and its atmosphere remotely from sensors onboard satellites.

1. Introduction

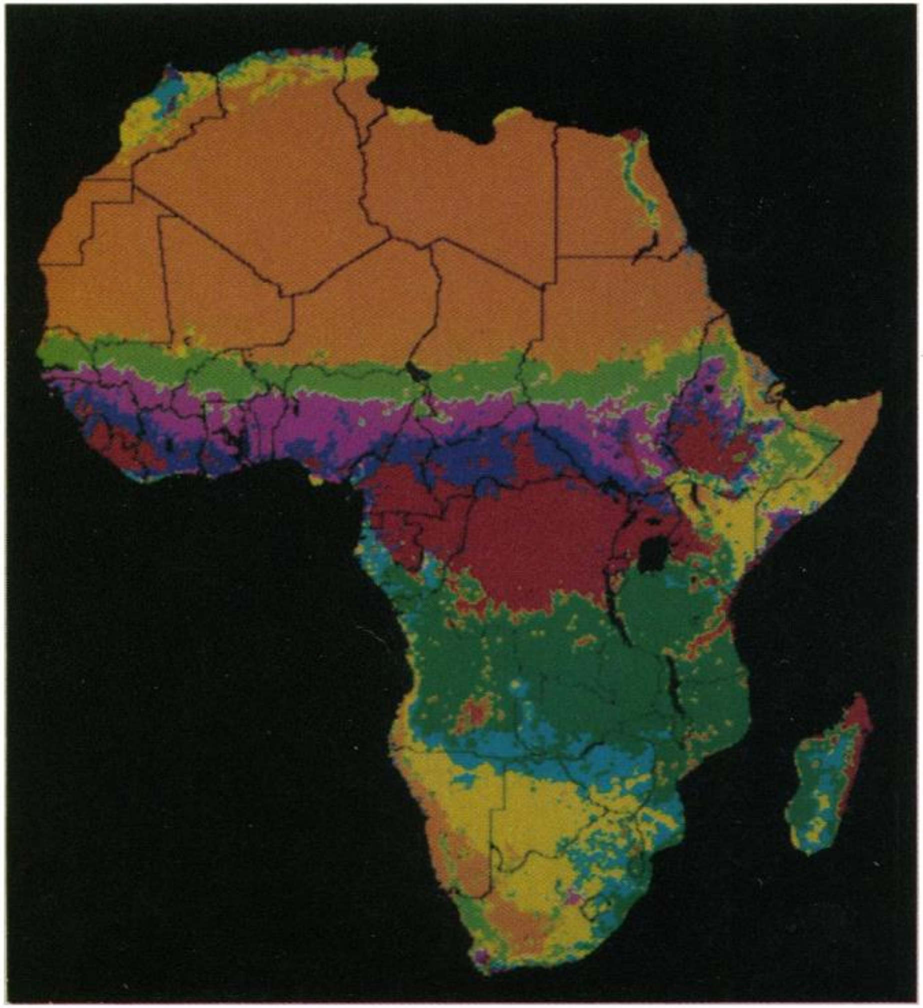




Why satellite remote sensing?

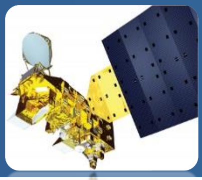
- **Observing the climate system at multiple spatio-temporal scales**
- **E.g.**

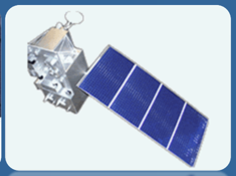
  The most efficient approaches to monitor land cover and its changes in time over a variety of spatial scales. (*Bontemps et al*., 2011, *Biogeosciences Discuss*; *Gong et al*., 2012, *Int. J. Remote Sens.*)



Tucker et al., 1985, *Science*

1. Introduction

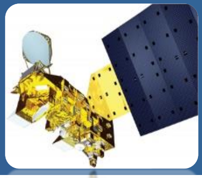


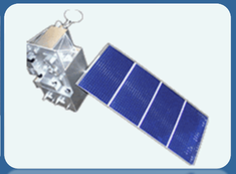


Why satellite remote sensing?

- Improvement of meteorological reanalysis data
  - E.g.
    - – National Center for Environmental Prediction (NCEP) reanalysis
    - – European Center for Medium Range Weather Forecasts (ECMWF)

1. Introduction

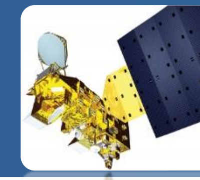




❖ Why satellite remote sensing?

- The Global Climate Observing System (GCOS) declared **26** out of **50** essential climate variables (ECVs) as significantly dependent upon satellite observations.
  (*GCOS*, 2010)

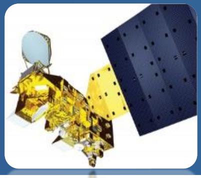
1. Introduction

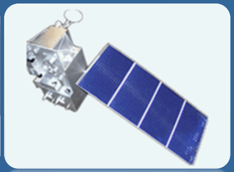


❖ Why satellite remote sensing?

- SRS are used for developing prevention, mitigation and adaptation measures to cope with the impacts of climate change.(*Joyce et al*., 2009, *Prog. Phys.Geog.*)

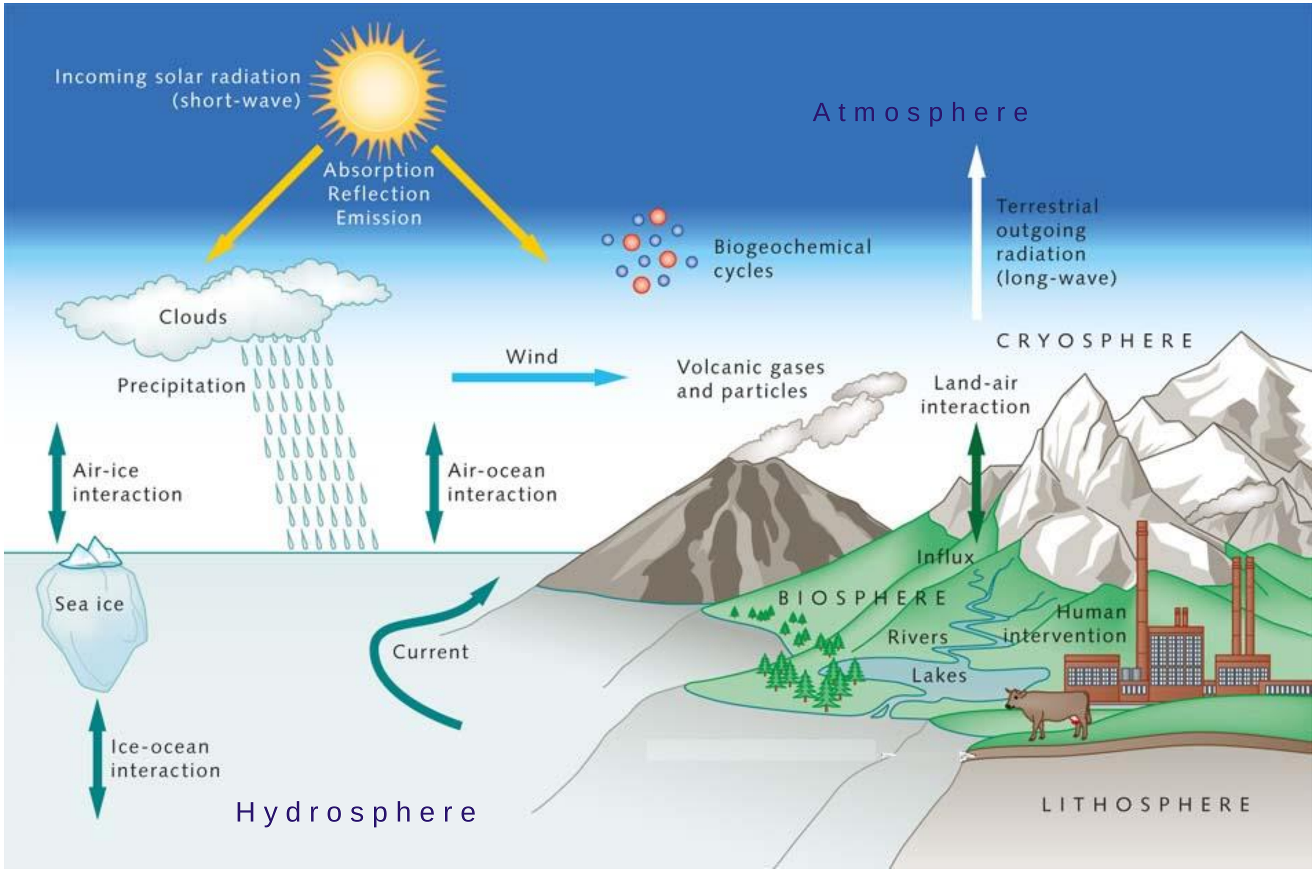
Country Operator	Designation	Type	Imager	Launch
Nigeria NASRDA	Nigeriasat-NX	SSTL-100i	22m MS	2011
Nigeria NASRDA	Nigeriasat-2	SSTL-300	2.5m Pan 5m MS 32m MS	2011
UK DMCii	UK-DMC2	SSTL-100i	22m MS	2008
Spain Deimos	Deimos-1	SSTL-100i	22m MS	2008
China BLMIT	Beijing-1	SSTL-150i	32m MS 4m Pan	2005





2. Observation of the climate system

1. Observation of the climate system

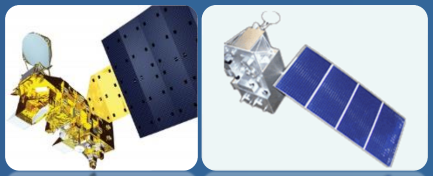


(Source: www.worldoceanreview.com)

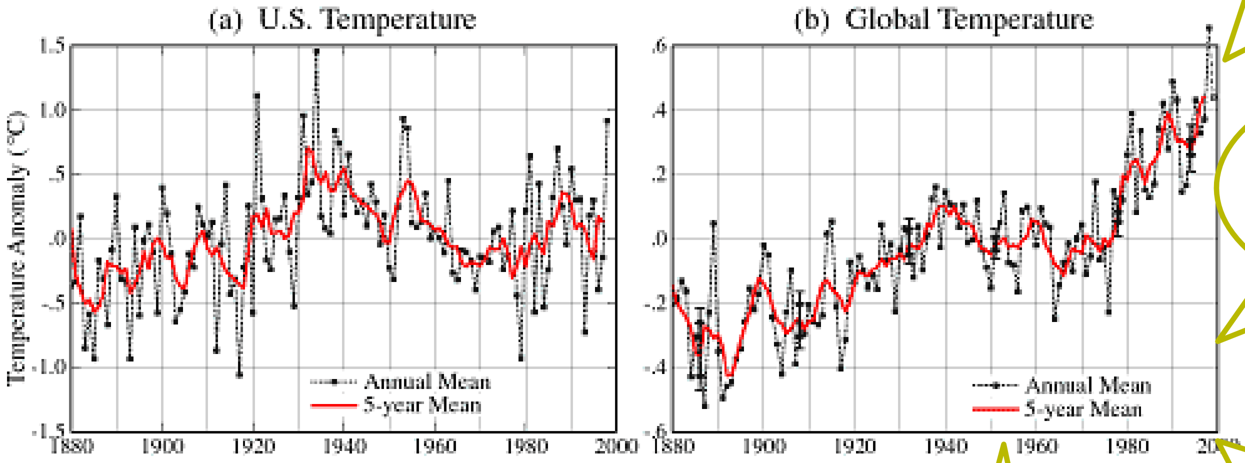
Climate system

-observe the spatio-temporal states and processes of the climate system

2. Observation of the climate system



Global Warming



Uneven distribution of stations

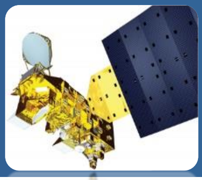
Instrument change

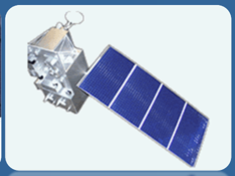
Urban contamination

Missing data and metadata

Hansen et al., 1999, *J. Geophys. Res.*

2. Observation of the climate system





❖ Global Warming

- Atmospheric temperature

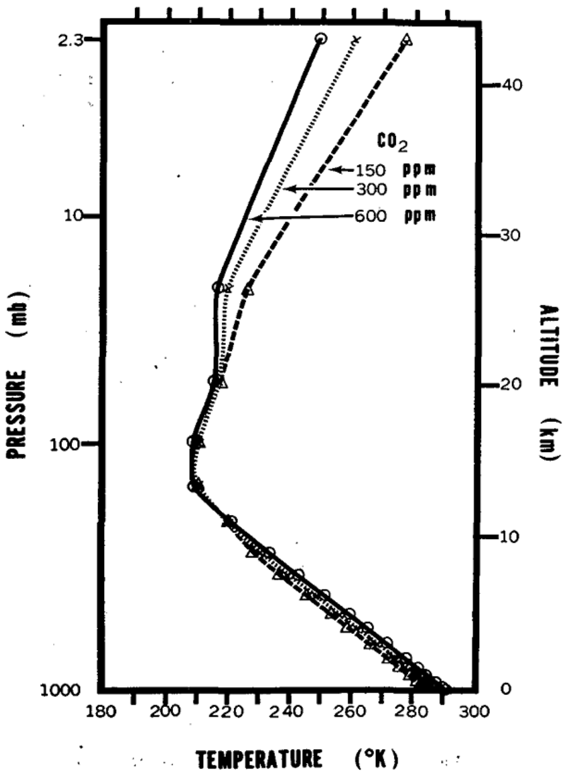


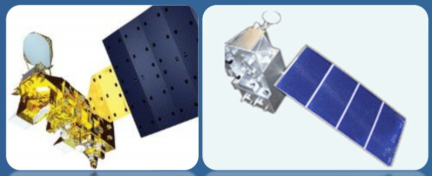
FIG. 16. Vertical distributions of temperature in radiative convective equilibrium for various values of CO_2 content.

-Increase of CO_2 will increase the atmospheric temperature

-Enhanced maximum warming in the tropical upper troposphere

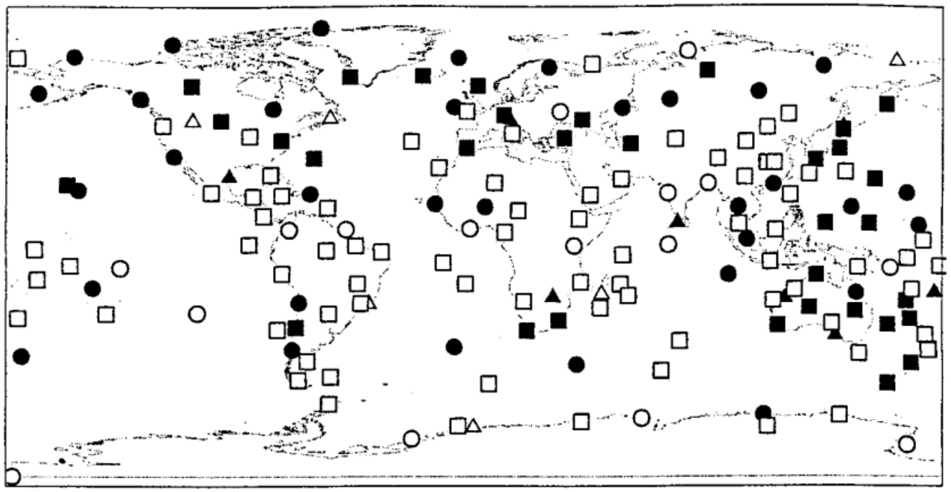
Manabe and Wetherald, 1967, 1975, *J. Atmos. Sci*

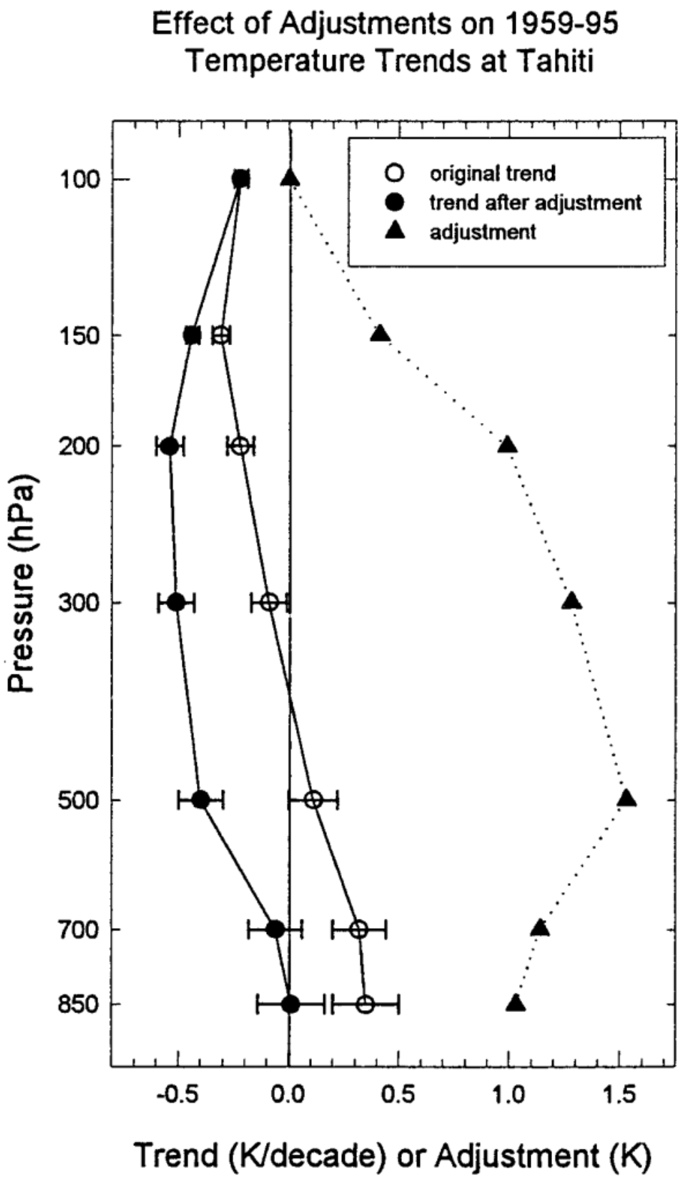
2. Observation of the climate system



❖ Global Warming

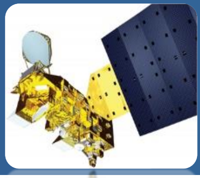
- Atmospheric temperature

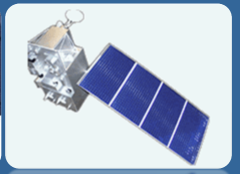




Radiosone data
Pro: since 1940
Con: distribution, inhomogeneous data
(*Gaffen et al*., 2000, *J. Climate*)

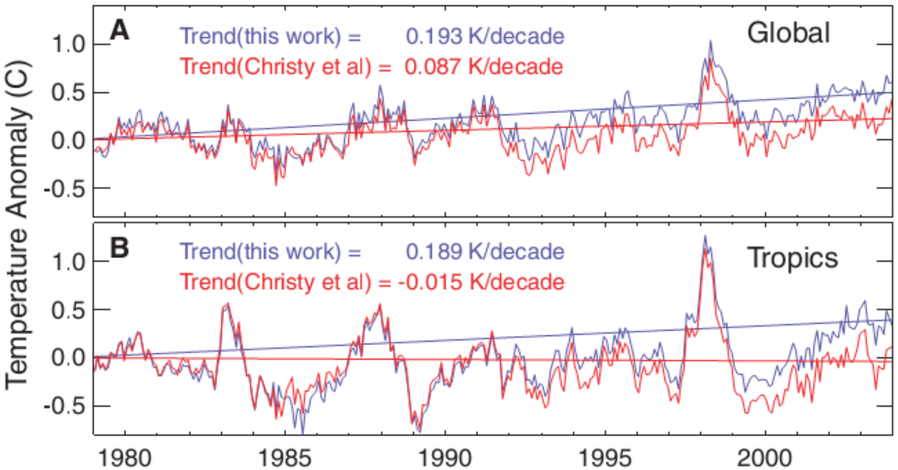
2. Observation of the climate system



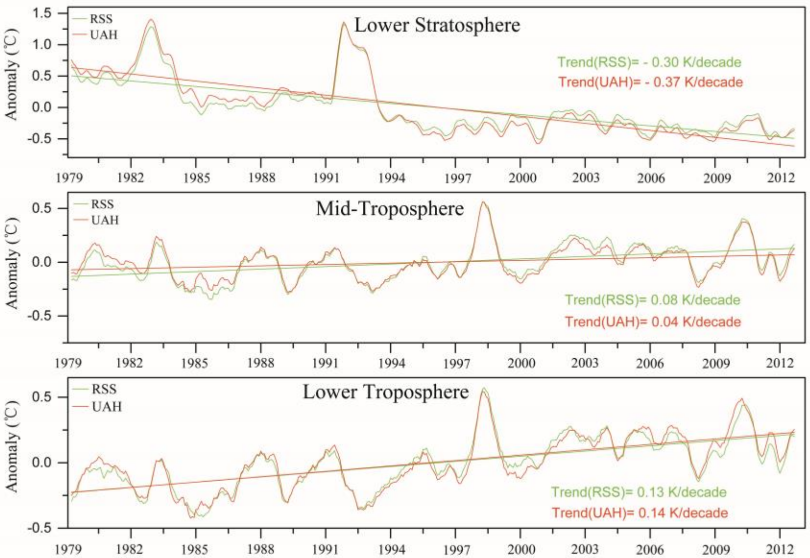


❖ Global Warming

- Atmospheric temperature
  - Microwave Sounding Unit (MSU)



Mears and Wentz, 2005, *Science*



Yang et al. 2013, *under review*

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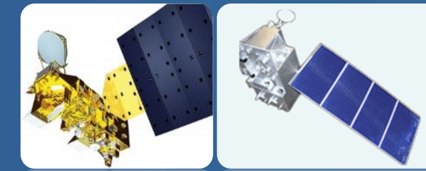


Global Warming

- Sea surface temperature (SST)

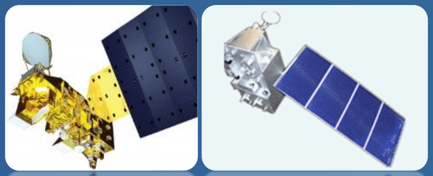
VOS

1850s

1970

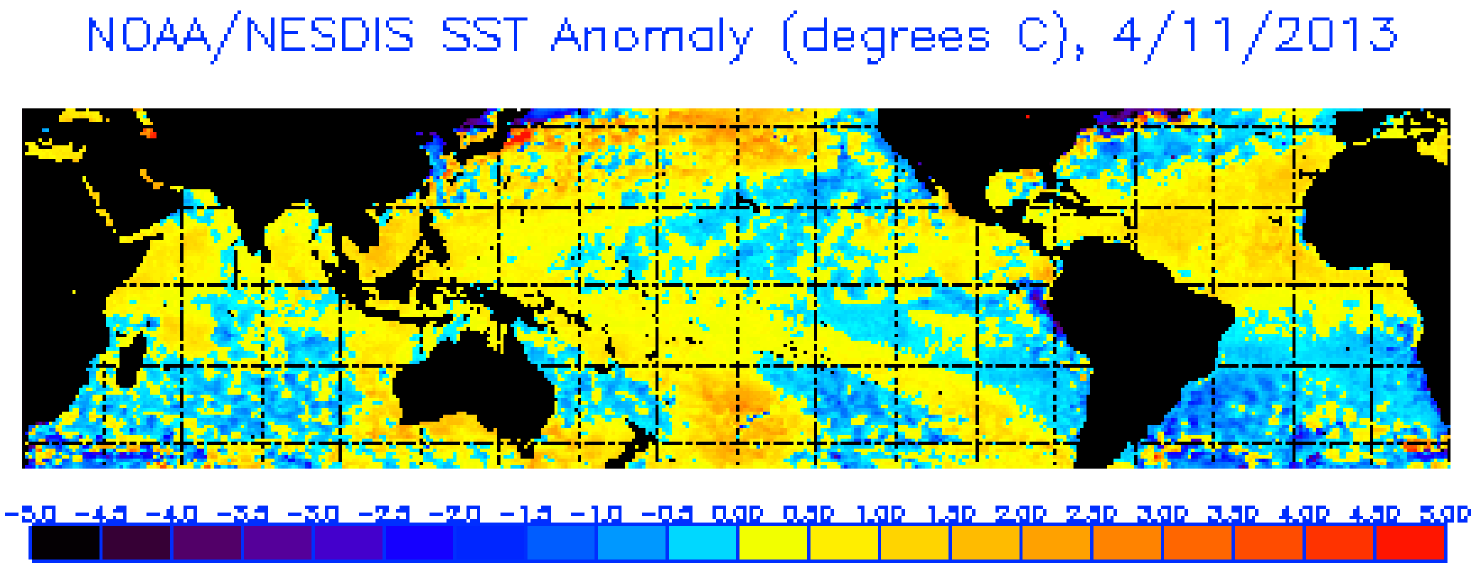
1981

2. Observation of the climate system

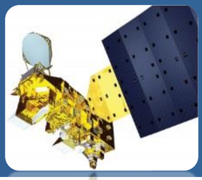


❖ Global Warming

- SST

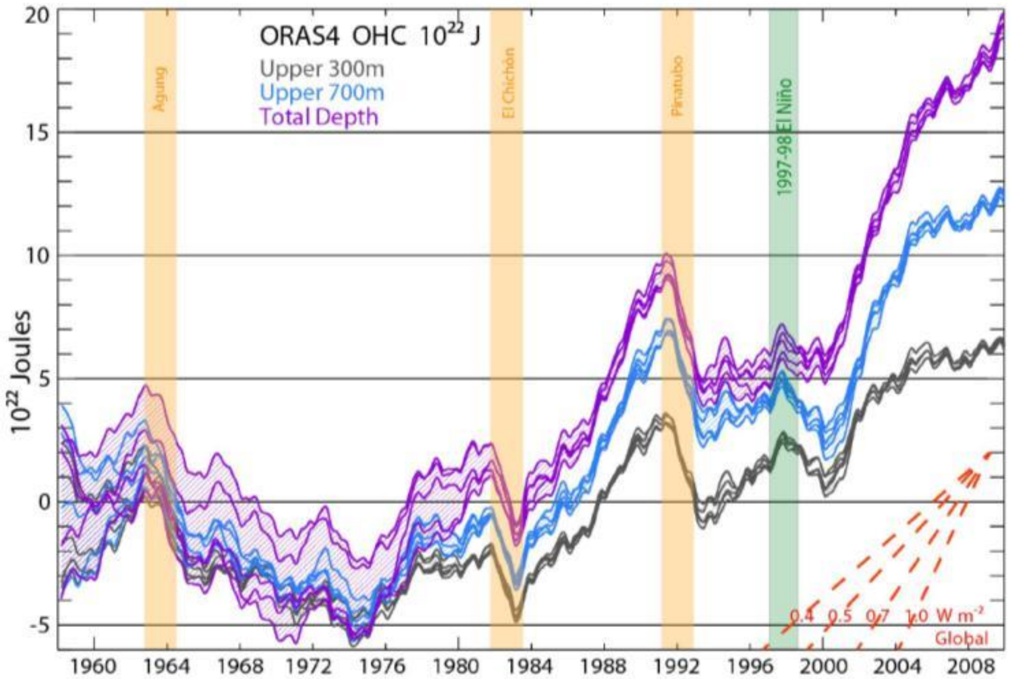


SST Anomaly Chart (NOAA-OSPO)



❖ Global Warming

- SST
  - Slow down of sea surface warming in the last decade
  - “Missing heat”



- *Balmaseda et al*., 2013, *Geophys. Res. Lett*.

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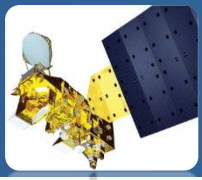
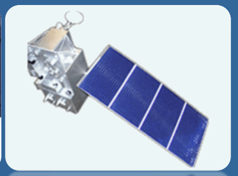
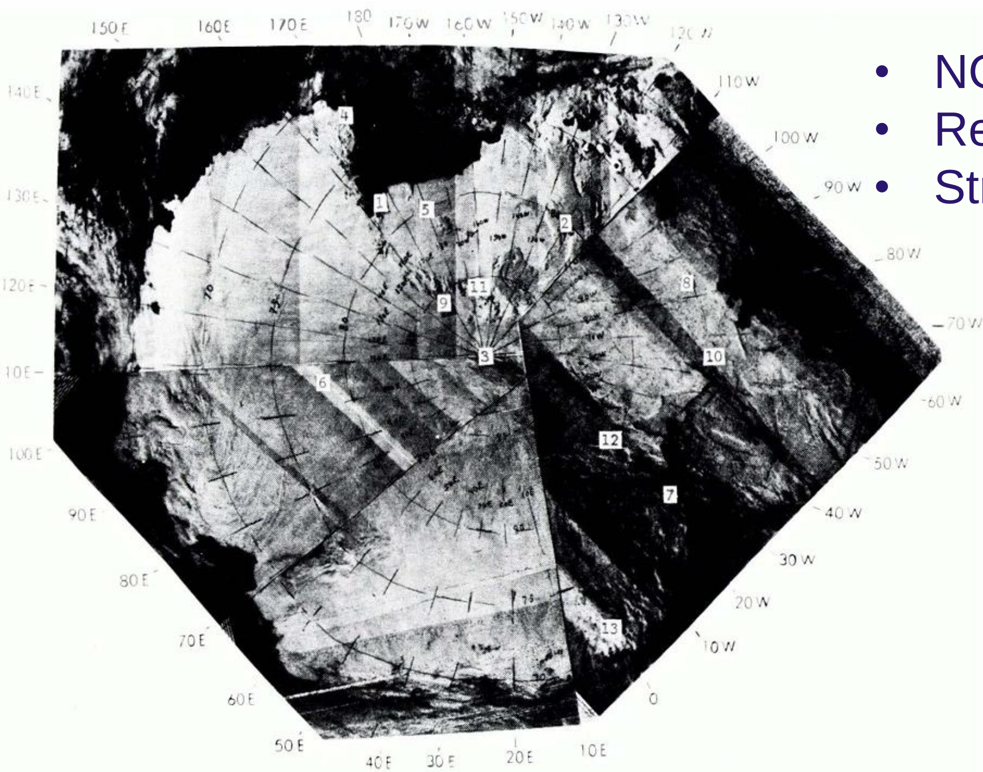




Snow and Ice

- Snow cover extent

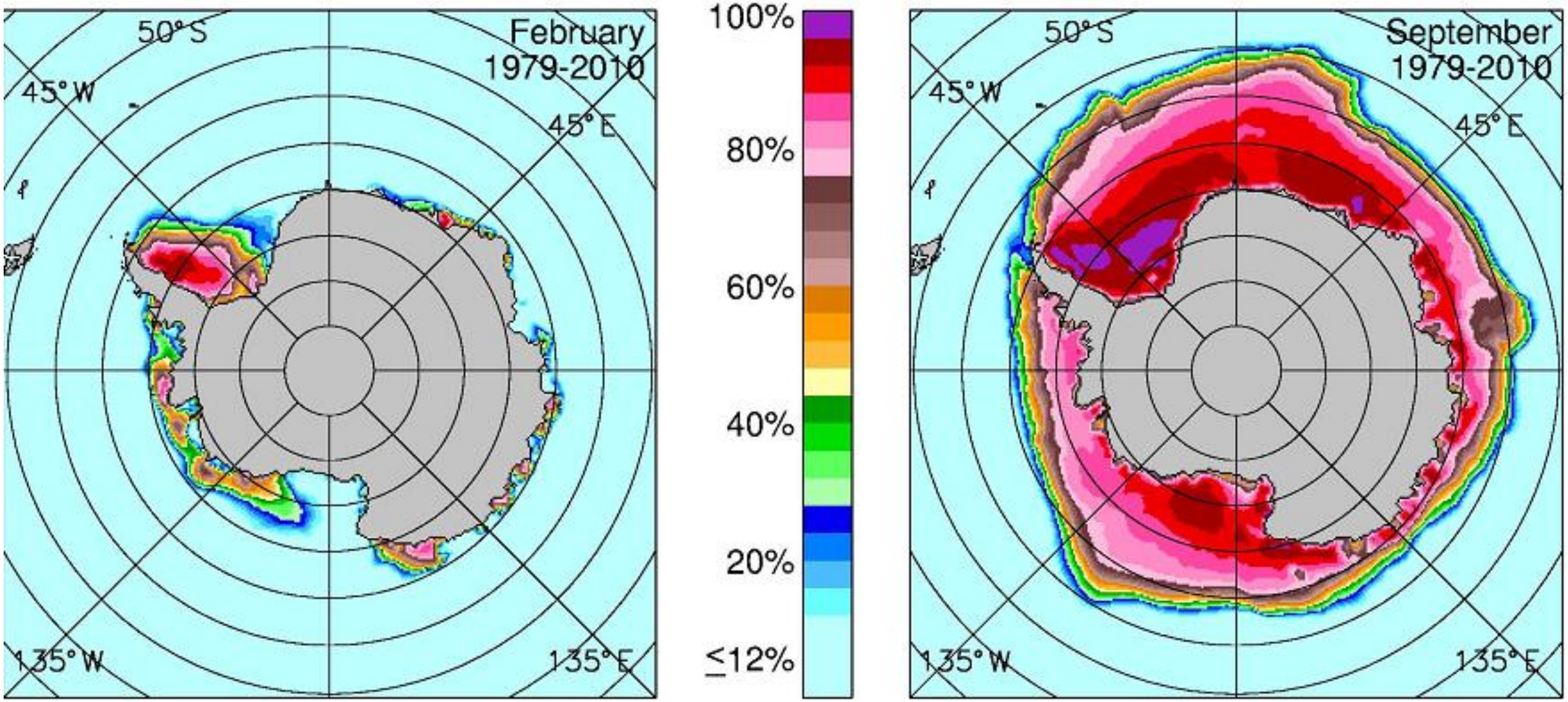


- NOAA SCE data since 1967
- Reduced SCE in Northern Hemisphere
- Strong regional variations

Antarctica in 1972, Nimbus 4 images
(*Gloersen and Salomonson*, 1973, *J. Glaci*)

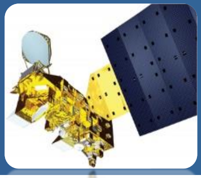
❖ Snow and Ice

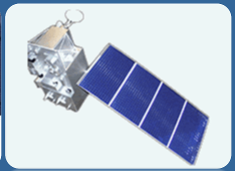
- Sea ice extent (SMMR, SSMI, SSMIS)



Map of sea ice extent in Southern Hemisphere (1979-2010)

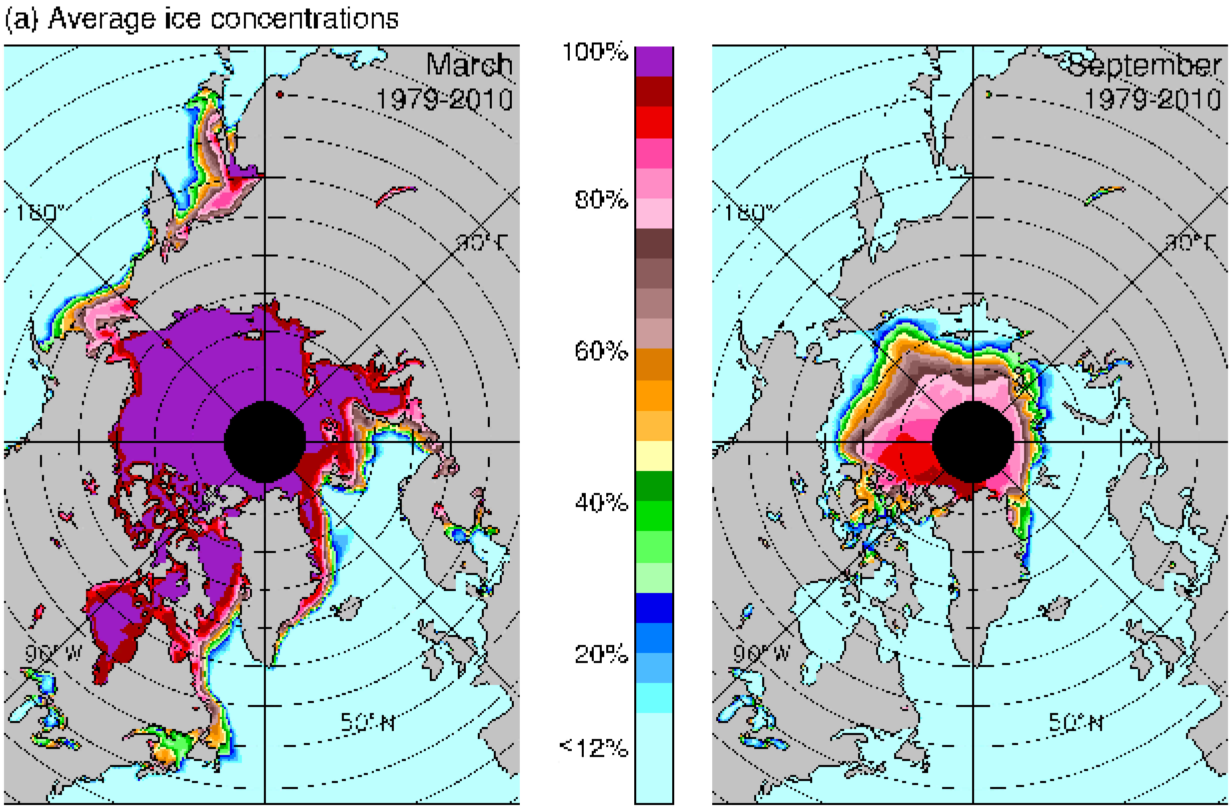
Parkinson and Cavalieri. 2012, *Cryosphere*





Snow and Ice

- Sea ice extent

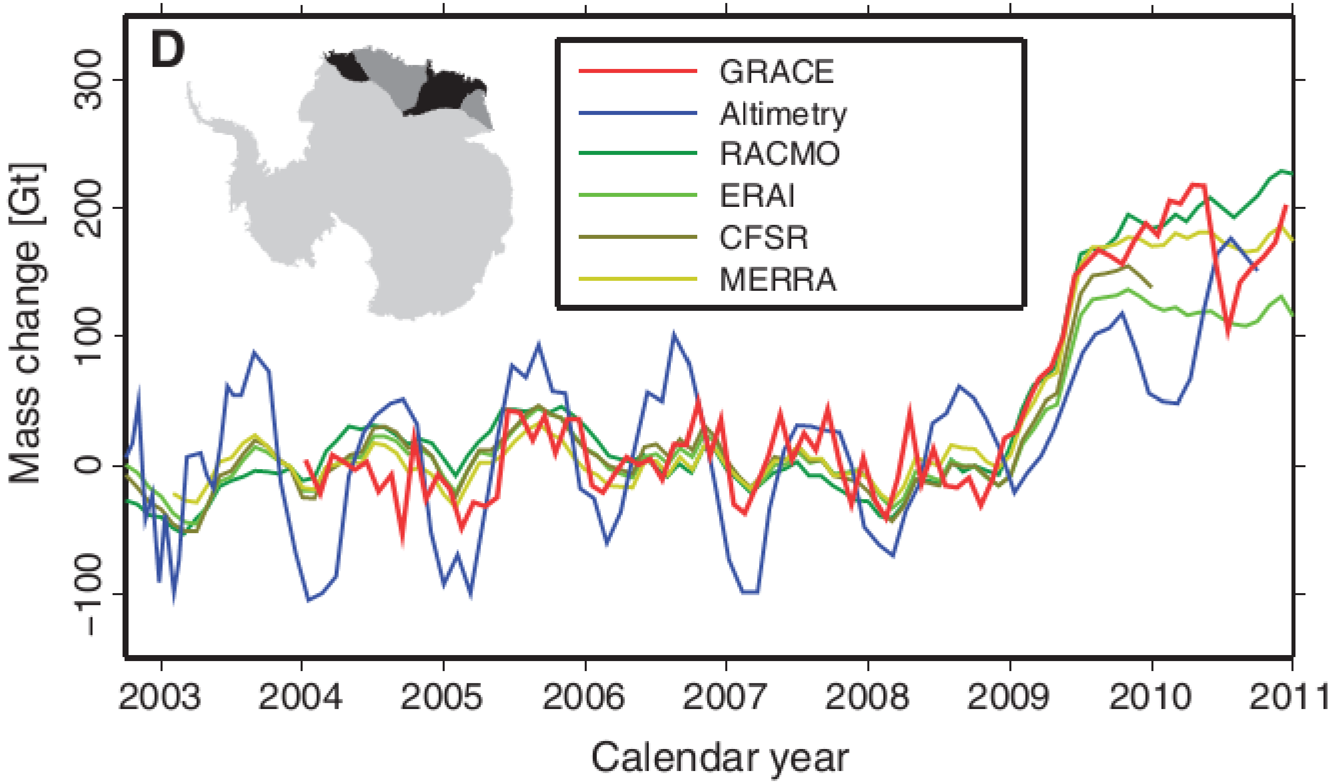


Map of sea ice extent in Northern Hemisphere (1979-2010)
Cavalieri and Parkinson, 2012, *Cryosphere*

2. Observation of the climate system

❖ Snow and Ice

- Mass of Ice sheets and glaciers



Mass change in East Antarctica (2003-2011)
Shepherd et al., 2012, *Science*

Region	Data type	Period	Mass loss rate (Gt yr^{-1})	References
Antarctica	ICEsat	2003-2007	171±4	[1]
	GRACE	4/2002-1/2009	190±77	[2]
	GRACE	4/2002-2/2009	143±73	[3]
	GRACE	8/2002-6/2010	80	[4]
	GRACE	5/2002-4/2011	104±48	[5]
	GRACE	1/2003-12/2010	165±72	[6]
	MBM[a]	1/2003-12/2008	161±150	[7]
Greenland	ICEsat	10/2003-3/2008	191±23 - 240±28	[8]
	ICEsat	2003-2008	205.4±10.6	[9]
	GRACE	4/2002-12/2008	104±23	[10]
	GRACE	4/2002-2/2009	230±33	[3]
	GRACE	2/2003-12/2008	165±15	[11]
	GRACE	8/2003-6/2009	191.2±20.9	[9]
	GRACE	8/2003-8/2009	195±30	[12]
	GRACE	3/2003-2/2010	201±20	[13]
	MBM	1/2003-12/2008	237±20	[14]

a Estimates made using the mass balance model (MBM), listed here as comparison.

Glacial-isostatic adjustment (GIA)

Short time span

Density of ice

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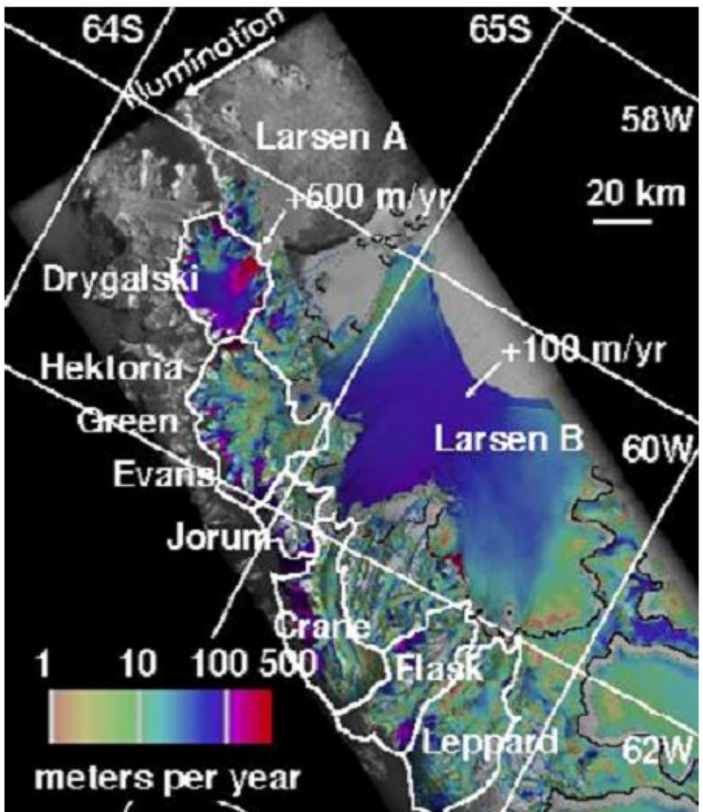
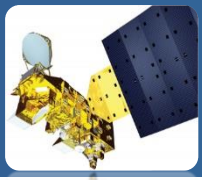
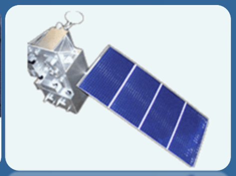
Snow and Ice

- Mass of Ice sheets and glaciers



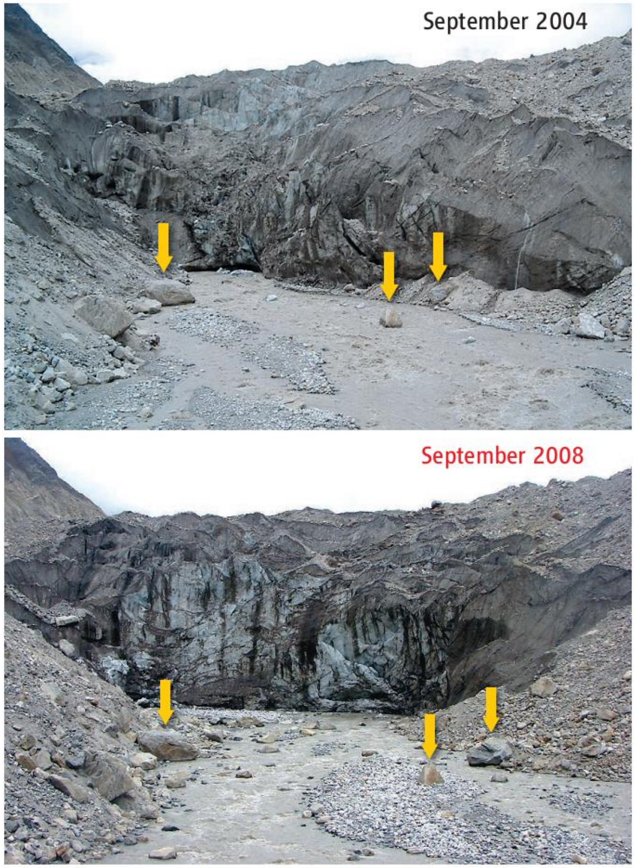
Ice-ocean interaction drives much of the recent increase in mass loss from Antarctic and Greenland ice sheets -*Joughin et al*., 2012, *Science*

Changes in ice velocity measured by ERS-1/2 (*Rignot et al*., 2004, *GRL*),

Snow and ice

- Mass of ice sheets and glaciers



Hanging tough. Gangotri glacier, source of the Ganges River, retreated a few dozen meters from 2004 to 2008—"hardly an abnormal retreat" that would have been expected from rising temperatures, states a provocative new report.

- Glaciers in Himalaya remain stable
- Global estimates were 30% less than mass
- Less contribution to SLR
- Shrinkage decrease from the Himalayas to the eastern Pamir

(*Scherler, et al*., 2011, *Nat Geosci*; *Jacob et al*., 2012, *Nature*; *Yao et al*., 2012, *Nat. Clim. Change*)

Bagla, 2009, *Science*

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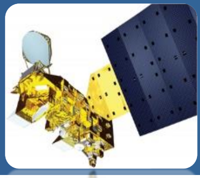
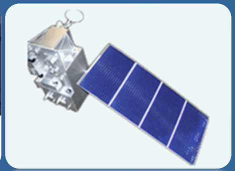
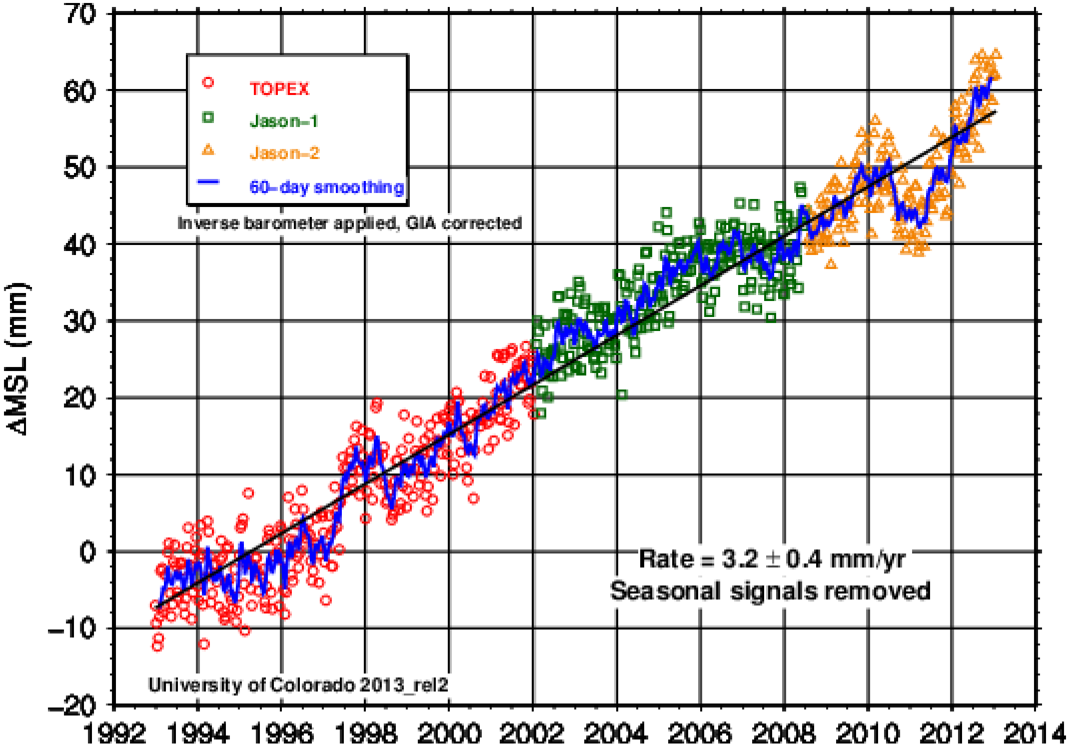
2. Observation of the climate system



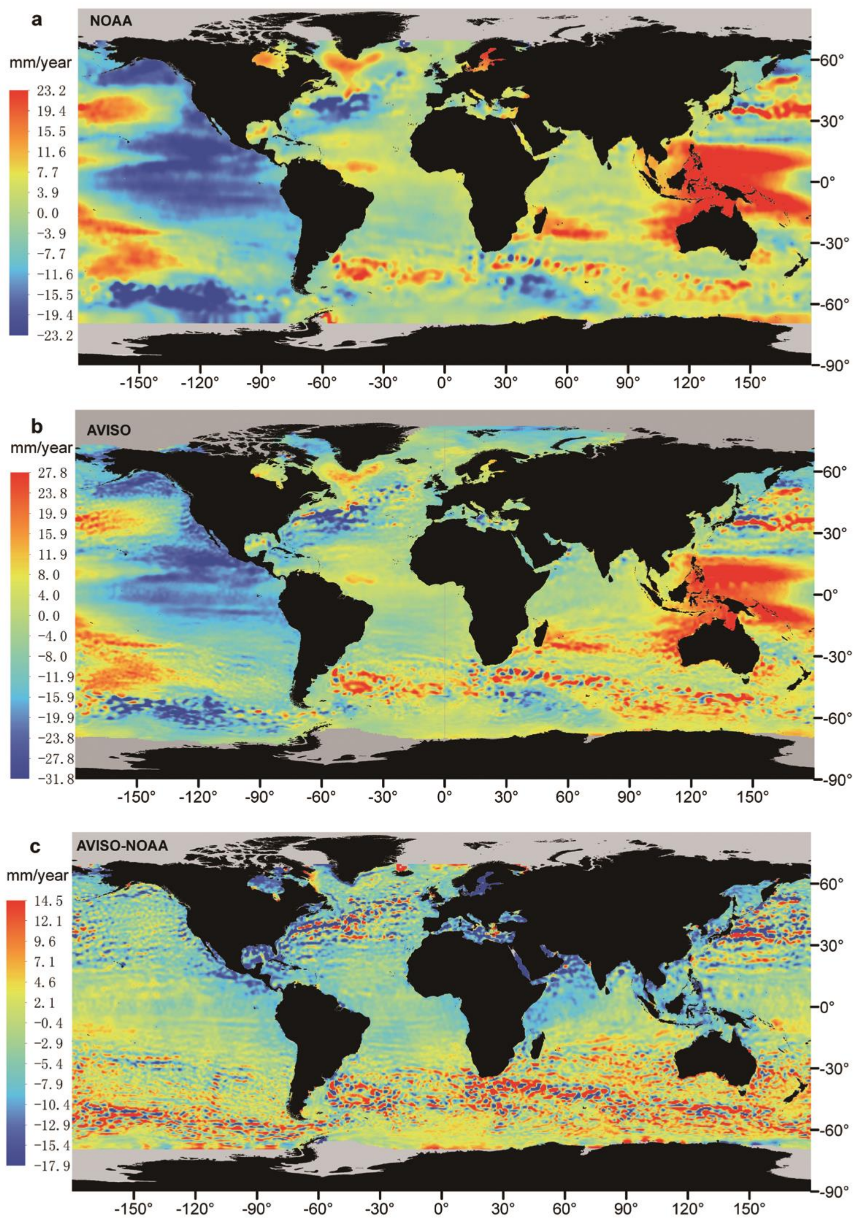


❖ Sea Level Change

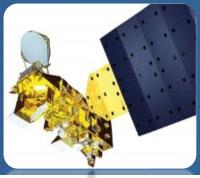


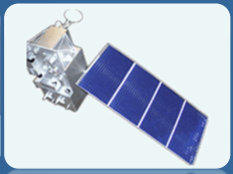
Global mean sea level time series (1992-2012)
CU Sea Level Research Group

2. Observation of the climate system



- Strong regional differences: AVIOS, NOAA, CU
- Close the Sea level rise budget: steric expansion + mass gain
- GRACE, ARGO, Altimetry



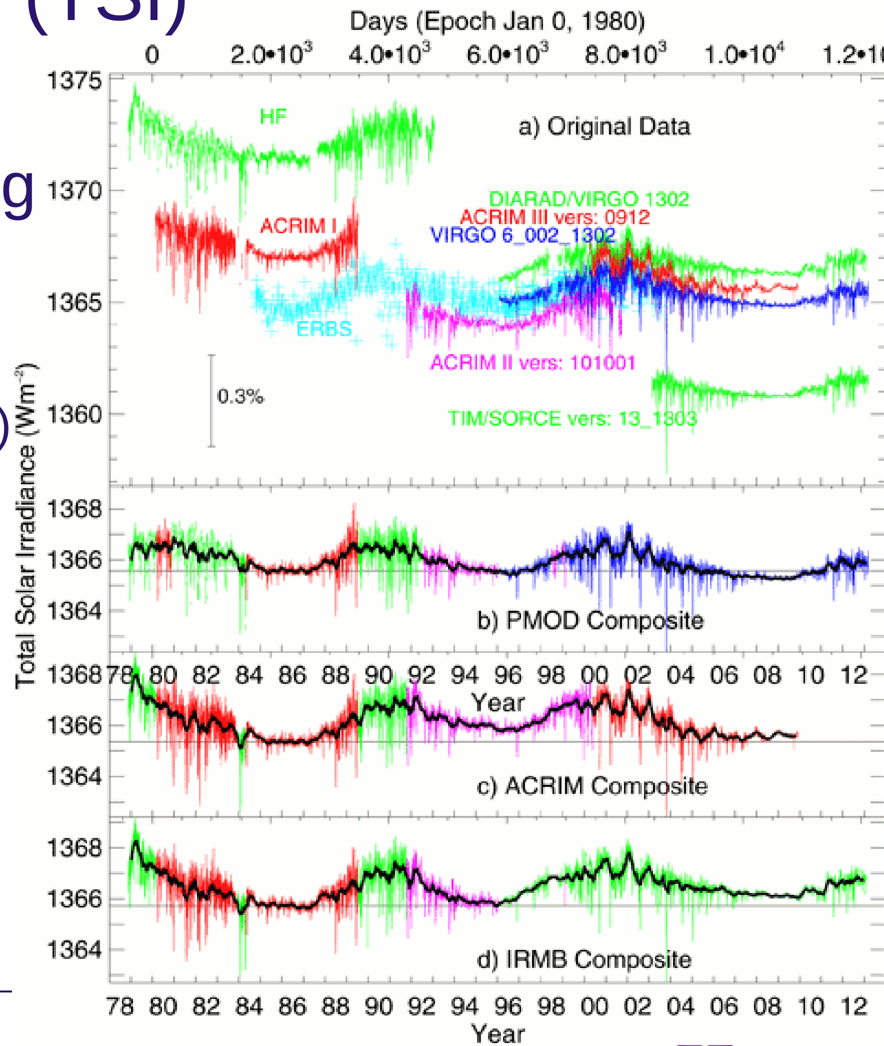


2. Observation of the climate system

Solar Radiation

- Total solar irradiance (TSI)
  - PMOD vs. ACRIM
  - 35% of global warming vs. negligible influence

(*Scafetta and West*, 2006, *GRL*; *Benestad and Schmidt*, 2009, *JGR*)



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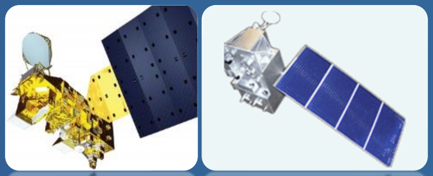
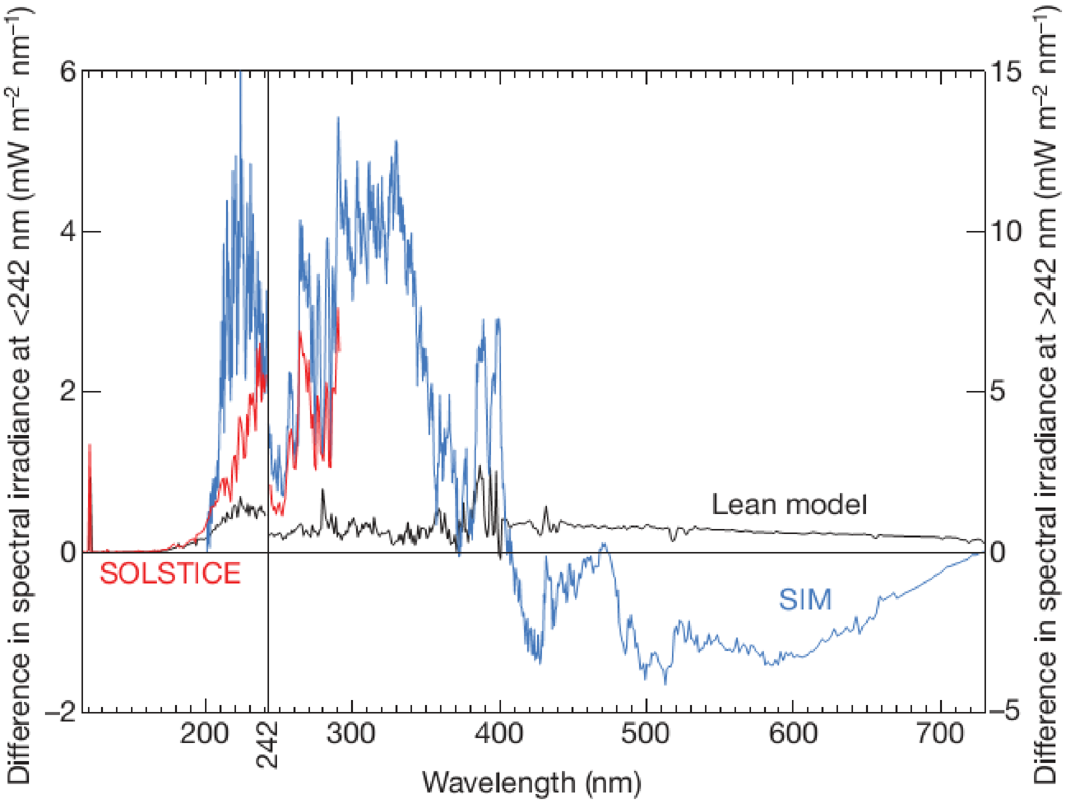


❖ Solar Radiation

- Spectrum variance

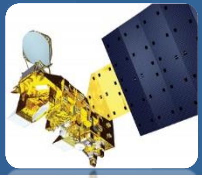


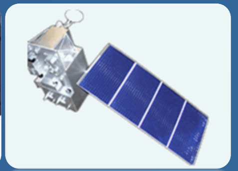
- Decline in ultraviolet was 4-6 times more than predicted, compensated by visible wavelengths in 2004-2007 （*Haigh et al*., 2010, *Nature*)

- Led to cold winters in northern Europe and the US (*Ineson et al*., 2011, *Nat. Geosci*)

- Errors in calibrations of sensors (*Lean and DeLand*, 2012, *J. Clim*)

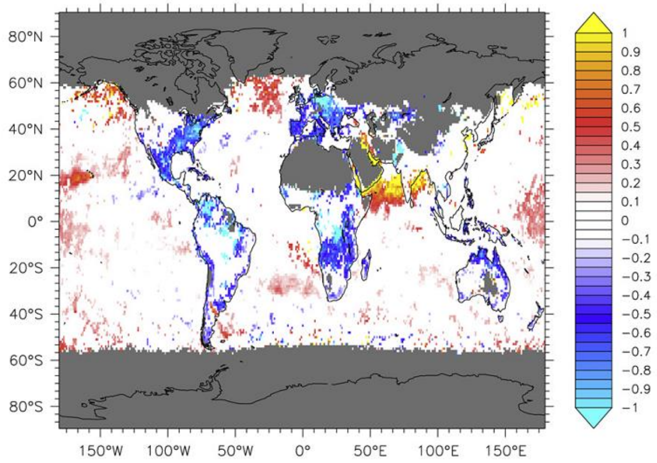
2. Observation of the climate system



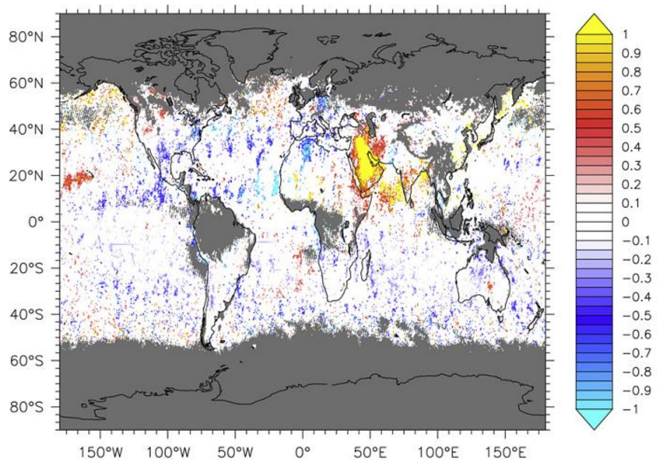


❖ Aerosols

a MODIS AOD slope trend between 2001–2009 (10^{-2}/yr)



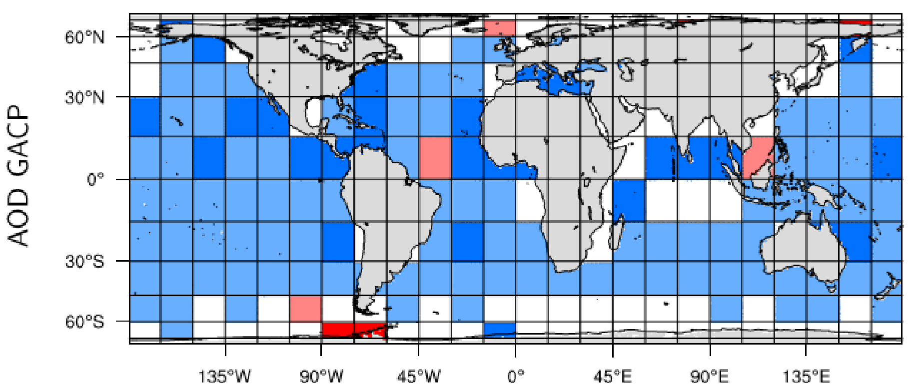
b MISR AOD slope trend between 2001–2009 (10^{-2}/yr)



Aerosol optical depth (AOD)

- Reduction over Europe and North America (2001-2009)
- Increase over South and East Asia

(*de Meij et al*., 2012, *Atmos. Environ*)



General decline trend, 1982-2000

(*Cermak et al*., 2010, *GRL*)

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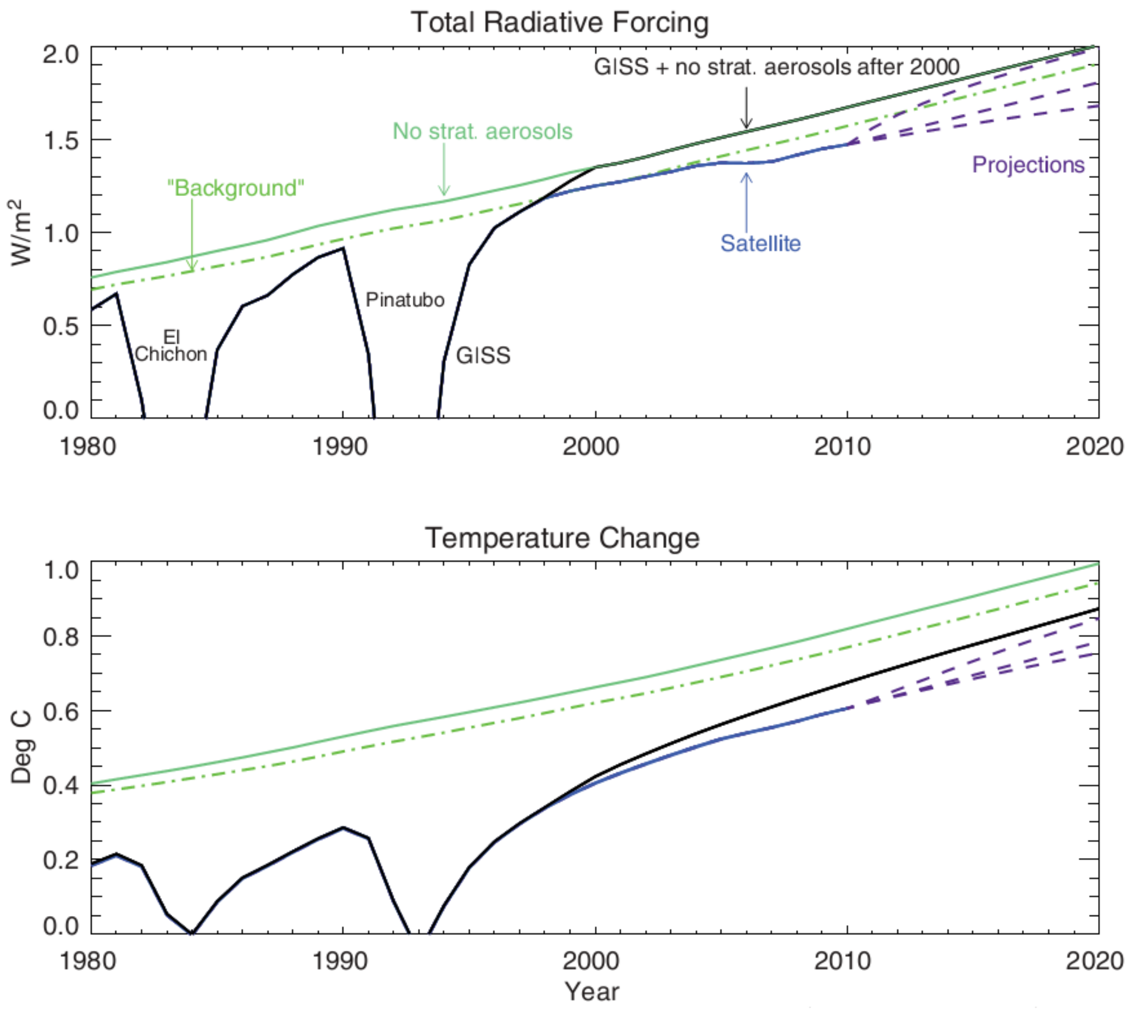
2. Observation of the climate system

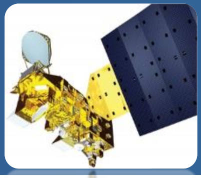
Aerosols

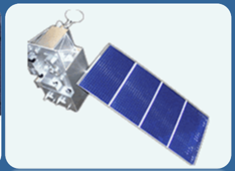


Stratospheric aerosols

- Increased by 10% in 2000-2010
- A negative radiative Forcing of -0.1 W m^{-2}
- A global cooling of -0.07^{o}C
- 10% less of SLR (*Solomon et al*., 2011, *Science*)
- Driven by small scale volcanic eruptions (*Vernier et al*., 2011, *GRL*)

2. Observation of the climate system



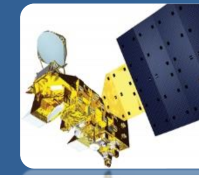


❖ Aerosols

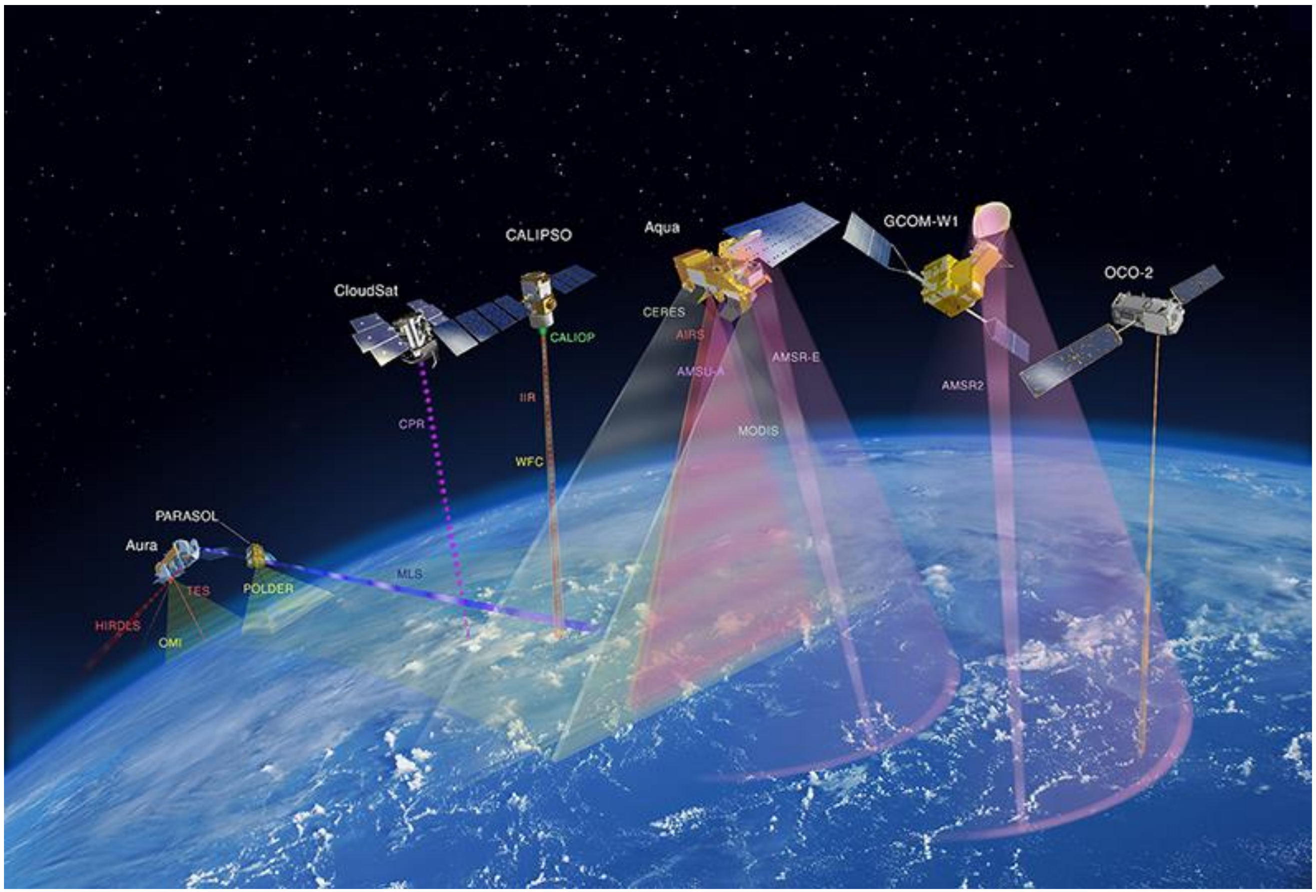
Type of forcing	Satellite	Model
Direct radiative forcing	-0.65 to -1.0 W m^{-2}	-0.5±0.4 W m^{-2}
Indirect radiative forcing	-0.2 to -0.5 W m^{-2}	-0.5 to -2.03 W m^{-2}

(*Zhao et al*. 2011, *Int. J. Remote Sens*; *Penner, et al*., 2011, *PNAS*)

2. Observation of the climate system



❖ Aerosols



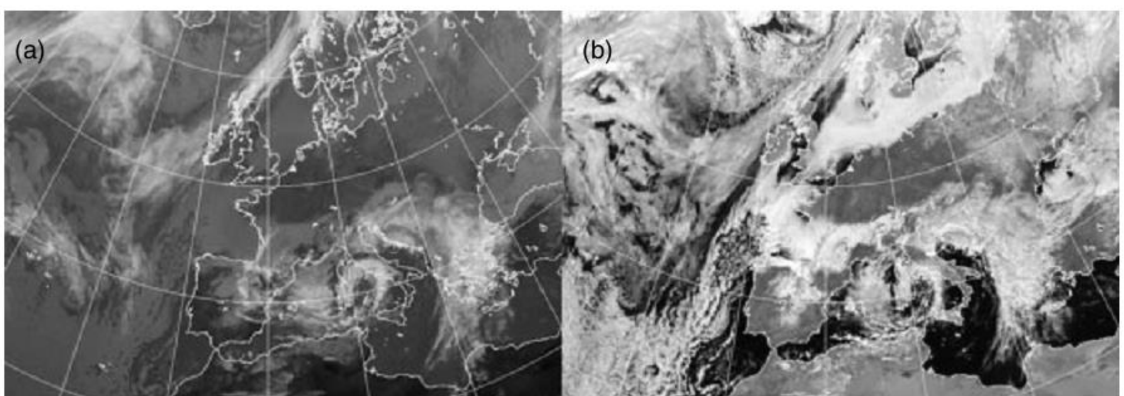
GCOM-W1
Aqua
Aura
CALIPSO
CloudSat
PARSOL
OCO-2

A-train formation (NASA 2012)

2. Observation of the climate system

Clouds

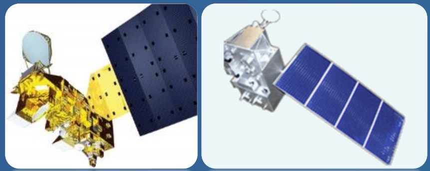
- Net cloud forcing (NCF)
  - $-21\ W\ m^{-2}$
  - Reduction in the solar radiation absorbed at the surface
  - Heating the moist tropical atmosphere
  - Daytime vs. night time (*Allan*, 2011, *Meteorol. Appl*)



SEVIRI/Metosat-9

Infrared channel Visible channel

2. Observation of the climate system

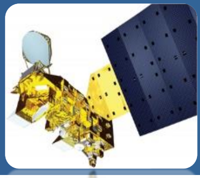
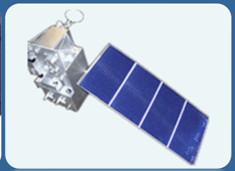


Clouds

- Cloud feedback
  - Short-term climate variations : 0.54±0.74 W m^{-2} K^{-1}
  - Long-term climate variations: unknown

(*Dessler*, 2010, *Science*; *Taylor*, 2012, *Surv. Geophys*)

2. Observation of the climate system

❖ Water vapor and precipitation

- Water vapor
  - Model prediction: climate warming→increase atmospheric specific humidity→amplify the warming
  - Satellite observation:
    - an increase of 0.4±0.09 mm decade-1 of precipitable water over the ocean
    - Average increase of water vapor content in the upper troposphere
    - Strong inter-annual correlation between water vapor content and surface temperature over the ocean-land

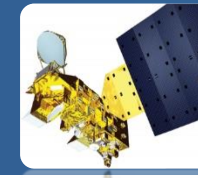
(Dessler and Davis, 2010, JGR; Trenberth et al.,2005, Clim. Dyn.; Gu et al., In. J. Climatol
Shi and Bates, 2011, JGR-A)

Water vapor and precipitation

- Water vapor
  - Stratosphere
    - 10% increase of water vapor in 2000-2009
    - Contribute to the flattening of the global warming trend
    - Not simulated by climate model

Solomon et al., 2010, *Science*

2. Observation of the climate system



❖ Water vapor and precipitation

- Precipitation
  - Is there a global mean trend?
    - 7% K^{-1} of surface warming vs. 1-3% K^{-1} by models

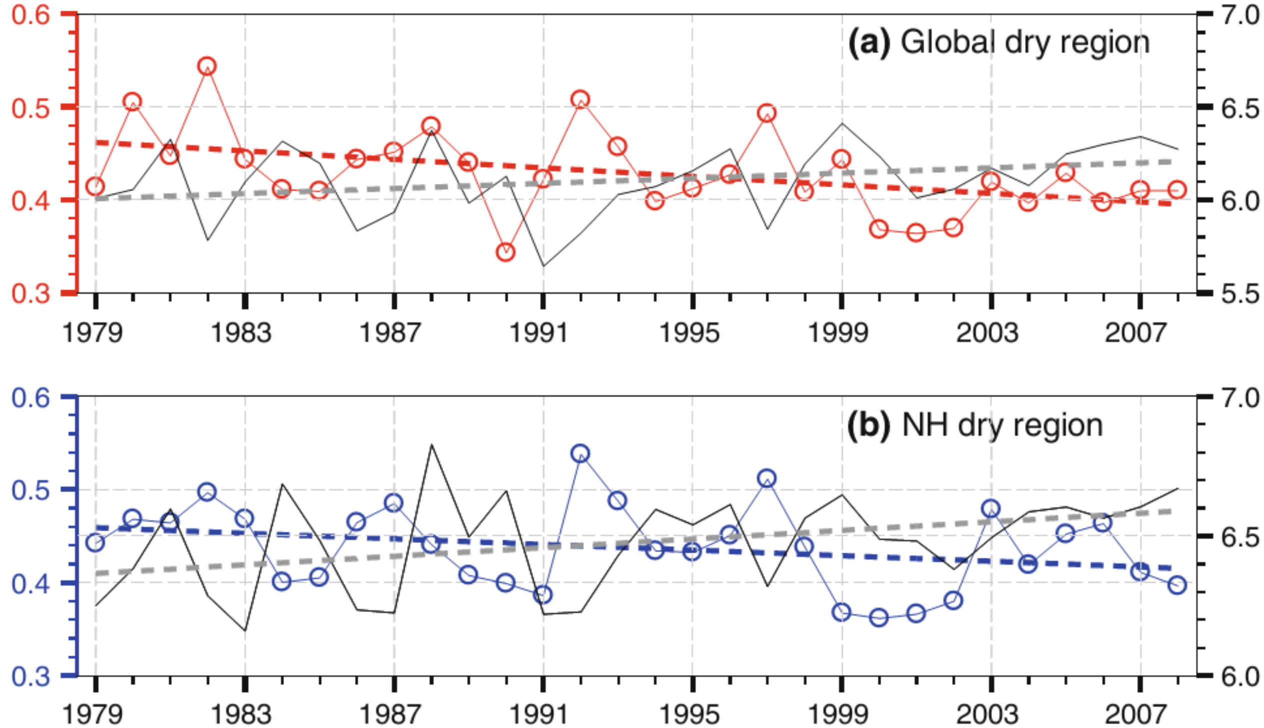
      (*Wentz et al*., 2007, *Science*)
    - Weak correlation between precipitation and surface temperature anomalies

      (*Gu et al*., 2012, *Int. J. Climato*)
    - No trend in global precipitation

      (*Gruber and Levizzani*, 2008, *WCRP report*)

Water vapor and precipitation

- Precipitation
  - Regional patterns: “wet-gets-wetter”



Wang et al., 2012, Clim. Dynam

3. Integration with climate models

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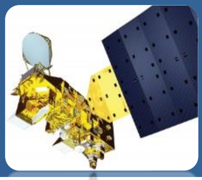
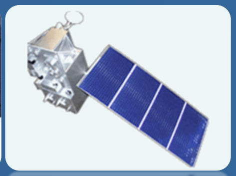


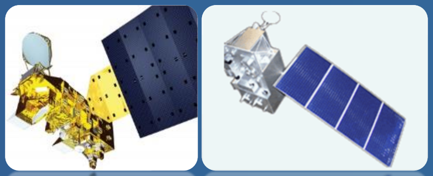


❖ Input of climate models

- Provide boundary conditions
- Reinitialize models
- Update the state variables
- Provide constrains
  - Net cloud forcing
  - Short-term cloud feedback

❖ Validate/calibrate climate models

3. Integration with climate models



Improve climate models

- Revise model parameters
- Improve representation

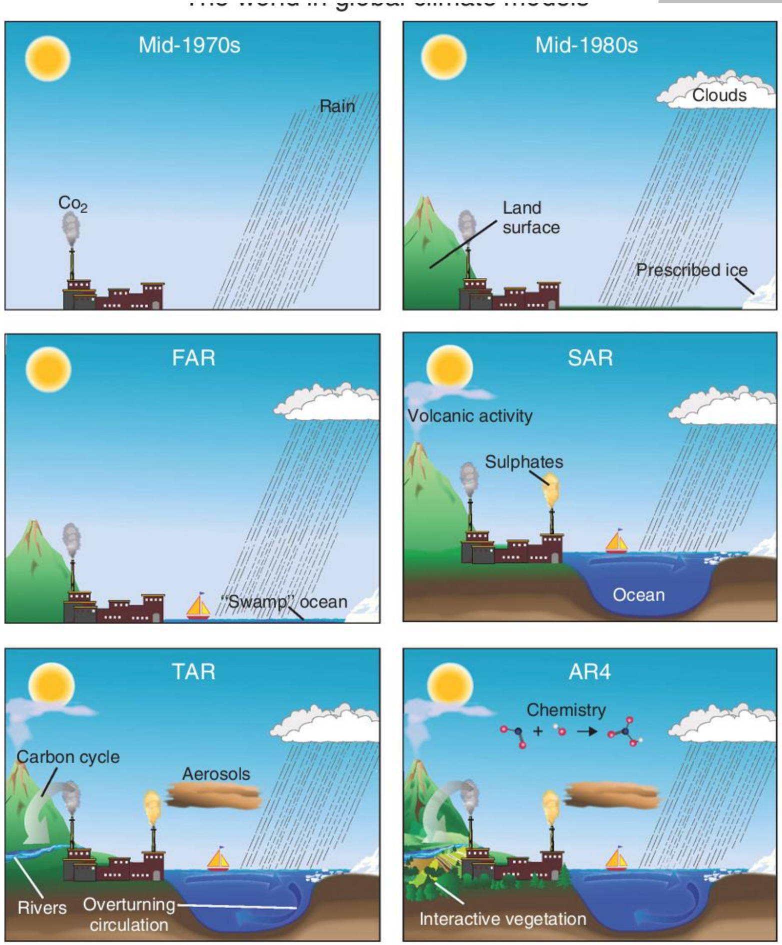
Homogeneous land cover

↓

Dynamic vegetation model

↓

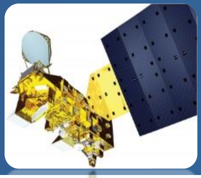
Dynamic vegetation model with disturbances

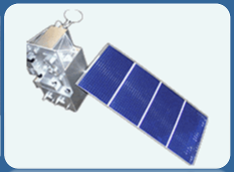


3. Integration with climate models

Problems

- Spatio-temporal mismatching
- Lack of interfaces in climate models





4. Limitations

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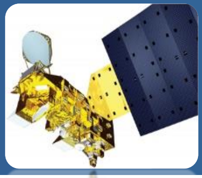
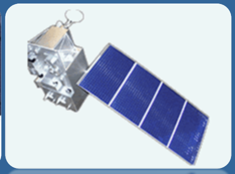
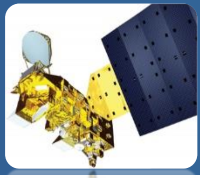
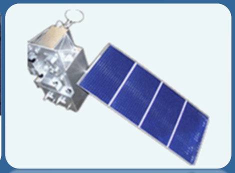




- Short data spans of satellite data
- Biases associated with instrument
- Uncertainties in retrieval algorithms

4. Limitations



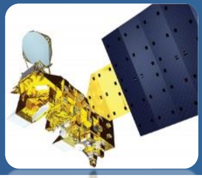
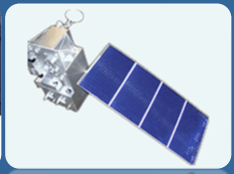


Short data spans of satellite data

- Suggested data length

Climate variable	Suggested length	Source
Sea level rise	60 years	*Douglas*, 1997, *Surv. Geophys*
Sea surface temperature	50 years	*Gornitz*, 1995, *Climatic Change*
Ocean color	40 years	*Henson et al.*, 2010, *Biogeosciences*
General	30 years	GCOS, ESA

4. Limitations

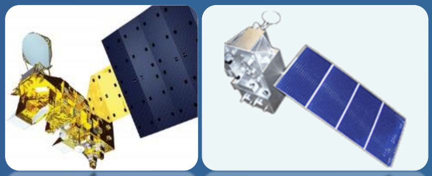
❖ Short data spans of satellite data

Time length of available observations

Time length (year)	Atmospheric ECV	Oceanic ECV	Terrestrial ECV
0~9		Ocean salinity	Biomass, Glacier and ice caps
10~19	Wind speed and direction(Upper air), Carbon dioxide, Ozone	Ocean color, Sea state	Land cover, Albedo, fAPAR, Fire disturbance
20~29	Radiation budget, Wind speed and direction(surface), Water vapor, Cloud properties, Aerosol properties	Sea level	Lakes, LAI
30~39	Precipitation, Upper air temperature	Sea surface temperature, Sea ice	Soil moisture
40~49			Snow cover

Yang et al. 2013, under review

4. Limitations

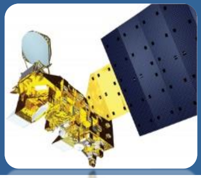


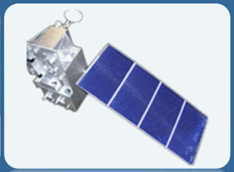
- **Biases associated with instrument**
  - Inadequate spatial resolution and temporal frequency
  - Poor calibrations
  - Merging data from different systems

4. Limitations

Uncertainties in retrieval algorithms

- Radiative transfer models
- Uncertainties in common inputs





5. Prospects

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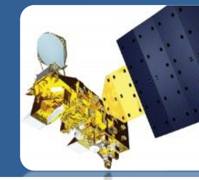


❖ Improvements in

- Future works
  - Intercomparison of data sets
  - Innovative use of existing data
  - Rigorous reanalysis
- Future systems
  - Dedicated satellite missions
  - Combine passive and active remote sensing
  - High-quality validation networks