Guide to the Science of Climate Change in the 21st Century

Chapter 14
Modern Instrumental Period

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Table of Contents

List of Figures

Figure 14.12 GOES-8, a United States weather satellite of the meteorological-satellite service. https://en.wikipedia.org/wiki/Weather_satellite

Figure 14.13 Global precipitation measurement from NASA GES DISC satellite https://www.nasa.gov/mission_pages/GPM/overview/index.html

Figure 14.14 Infrared Sounder on NASA's Aqua Satellite. https://airs.jpl.nasa.gov/#:~:text=AIRS%2C%20the%20Atmospheric%20Infrared%20Sounder,gases%2C%20surface%20and%20cloud%20properties.

Figure 14.15 Ice thickness. https://icesat-2.gsfc.nasa.gov/

Figure 14.16 Landsat 9 taken from https://landsat.gsfc.nasa.gov/landsat-9/landsat-9-overview

Figure 14.17 Data is collected from sensor mounted on the ISS and provided to earth system models https://earth.jpl.nasa.gov/emit/mission/about/ and https://earth.jpl.nasa.gov/emit/documents/3/ .

Figure 14.18 Illustration of the Surface Water and Ocean Topography (SWOT) satellite, https://climate.nasa.gov/news/3084/international-cutting-edge-swot-satellite-to-survey-the-worlds-water/ .

Figure 14.19. Illustration of MethaneSAT, https://www.methanesat.org/ .

Figure 14.20. GOES-16 First of the GOES-R series of Geostationary Operational Environmental Satellite (GOES) https://www.spaceweatherlive.com/en/news/view/399/20191209-welcome-goes-16.html .

Figure 14.21 NASA Terra satellite https://terra.nasa.gov/about . Carries five instruments, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Clouds and Earth's Radiant Energy System (CERES), Multi-angle Imagine Spectroradiometer (MISR), Measurements of Pollution in the Troposphere (MOPITT) and Moderate Resolution Imaging Spectroradiometer (MODIS).

List of Tables

Table 14.1 Data products available from NASA, Moderate Resolution Imaging Spectroradiometer, MODIS. https://modis.gsfc.nasa.gov/data/dataprod/index.php

Chapter 14.0 Modern Instrumental Period

14.1 Introduction

The instrumental period refers to the time when weather observations, meteorological observations, were performed using equipment that directly measured temperature and precipitation. The instrumental period of climate history began in the 19th century with the commencement of routine weather observations at fixed sites. Data collected from 1900 to the present is used to calibrate and evaluate global circulation models (GCM's) that would ultimately be used to predict future climate changes.

The type and frequency of meteorological observations has steadily grown to include temperature (actual, minimum and maximum), precipitation (type and rate), dew point, humidity, wind speed and direction, radiation (incoming and reflected short wave, incoming long wave and outgoing long wave, hours of bright sunshine), barometric (air) pressure and visibility. The observations are made at a variety of elevations above the Earth's surface. Observations acquired using equipment and techniques endorsed by the World Meteorological Organization (WMO) are collected and archived by the WMO and made available to the public.

Advances in data collection over recent decades have enabled high quality computer modelling of the global climate system. This is evident in the complexity of the atmosphere ocean global climate models or AOGCM's. It was argued that there was insufficient theory and data to support such modelling initiatives. These criticisms are not valid, particularly with the availability of global scale information made available from recently launched satellite platforms and the inevitable fine tuning and development of theoretical considerations themselves. Modelling initiatives can only evolve if they have the data they need. Computational capacity has improved to the point where it has disappeared as a major constraint. The IPCC AR5 clearly reflected this trend.

14.2 Instrumental temperature record

The instrumental temperature record, considered the most reliable record for estimating global average temperature, is considered to start in the mid 19th century (1880) when in situ global coverage started to become available. The global average temperature change from 1850 to present is shown in Figure 14.1
https://en.wikipedia.org/wiki/Instrumental_temperature_record . The most striking observation about the graph is how well the results from different contributors agree. Equally striking is the steady climb in temperature from 1975 on. The data sets used in Figure 14.1 are available from the various contributors.

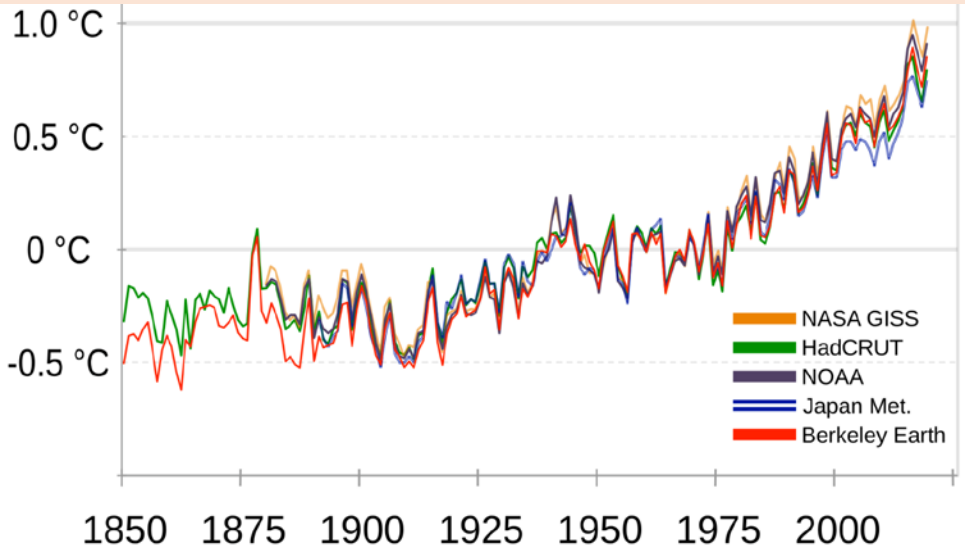

Figure 14.1 Global average temperature change – 1850 to present
https://en.wikipedia.org/wiki/Instrumental_temperature_record .

14.3 Modern instrumentation

The instrumentation and platforms used to make the meteorological observations have evolved dramatically in recent years to take advantage of advances in electronics, communication, data collection and management, computational capabilities and satellite technology. Many agencies, universities, research organizations and countries have contributed to the advances, in particular the United States National Aeronautics and Space Administration (NASA), https://climate.nasa.gov/blog/3071/the-raw-truth-on-global-temperature-records/ and the United States National Oceanographic and Atmospheric Administration (NOAA). The European Union, Japan, Canada, Australia and several other countries have several satellite programs as well.

The Global Observation System managed by the World Meteorological Organization, WMO, (187 member states and 6 member territories https://public.wmo.int/en/about-us/members) is shown in Figure 14.2. The observation system includes a variety of land based, ocean based, airborne, and satellite platforms that monitor continuously or intermittently as required https://en.wikipedia.org/wiki/Weather_station . There are a variety of other information gathering systems presently active (including weather balloons and pilot balloons) which are also able to observe air chemistry (greenhouse gases) including ozone. Most types of aerosols can be detected and monitored. Much of the data managed by the WMO is available to users directly or through the bureaucracy of the member state. WMO maintains quality control over the data collected by providing guidelines for the type of technology used and how it must be

employed. These guidelines must be followed before data collected can be accepted and published. See WMO-No. 8, Guide to Meteorological Instruments and Methods of Observation https://www.weather.gov/media/epz/mesonet/CWOP-WMO8.pdf.

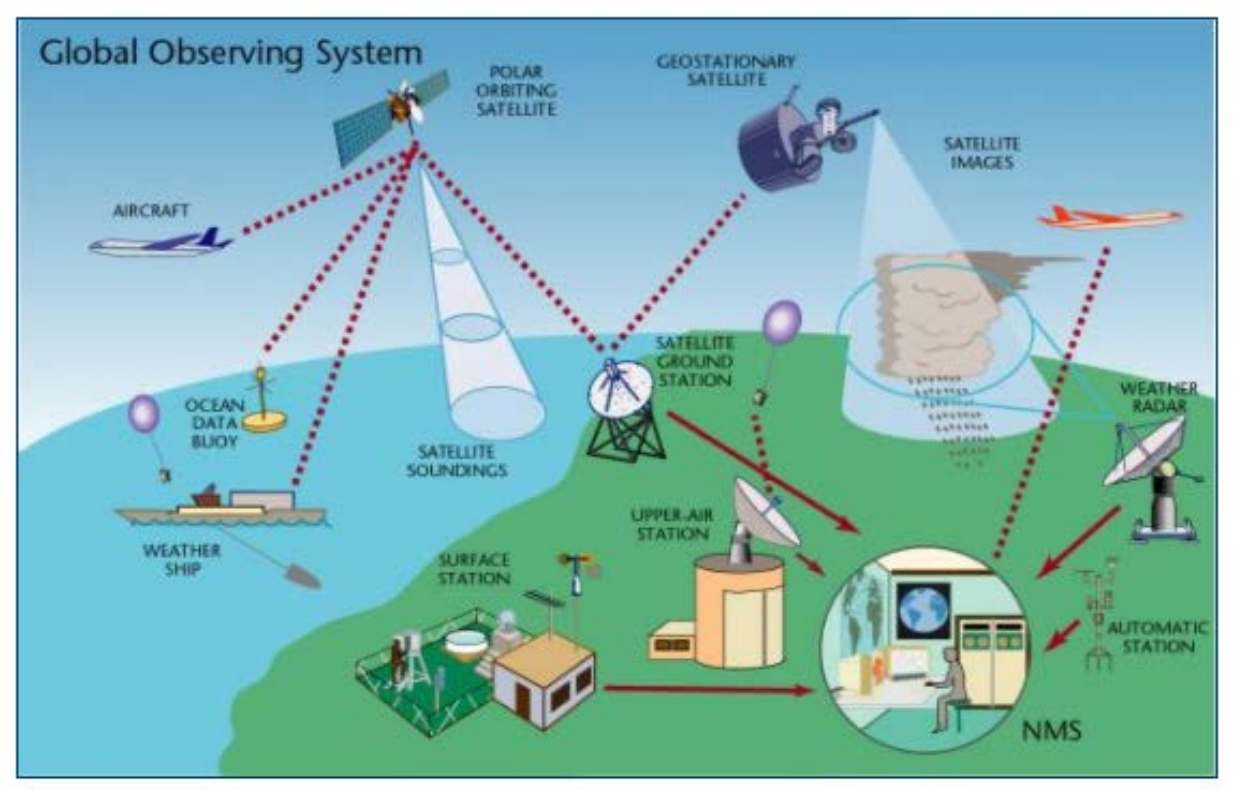

Figure 14.2 Global Observing System – WMO https://public.wmo.int/en/programmes/global-observing-system

Images of the various observation platforms are shown in Figures 14.3 to 14.9, land based, ship and buoy. Figure 14.10 illustrates use of weather balloons.

Climate data is generally available online – typically managed by country centred agency. For example, in the United States this function is performed by NOAA, https://www.ncdc.noaa.gov/cdo-web/ and https://www.ncei.noaa.gov/ .

Figure 14.3 Modern surface weather station, U.S. Climate Reference Network Station, Ithaca, New York.

Figure 14.4 Weather ship MS Polarfront at sea – decommissioned in 2009. Note that weatherships are no longer used.

Figure 14.5 Weather buoy operated by the NOAA National Buoy Center.

Figure 14.6 Weather Station – remote land based.

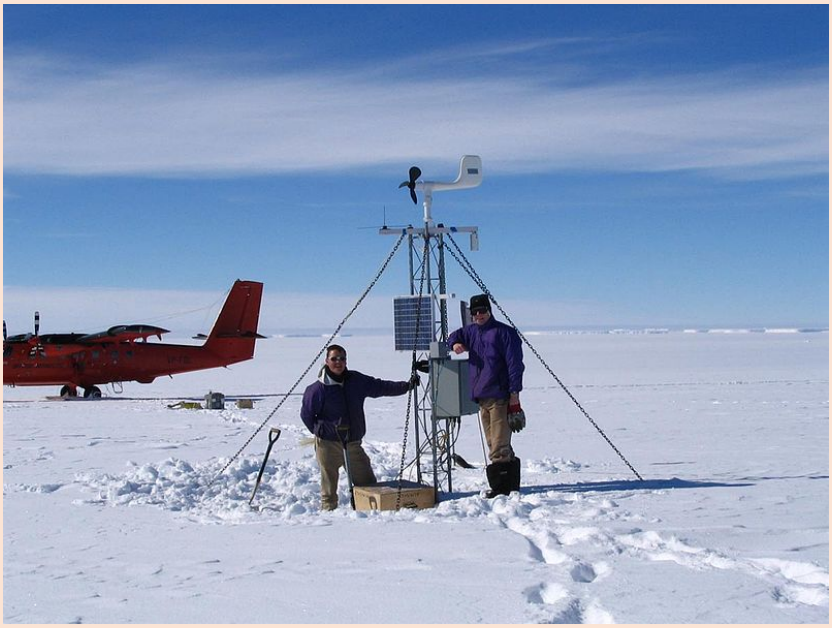

Figure 14.7 Antarctic automatic weather station – part of the automatic weather stations project AWS in Antarctica https://en.wikipedia.org/wiki/Automatic_weather_station .

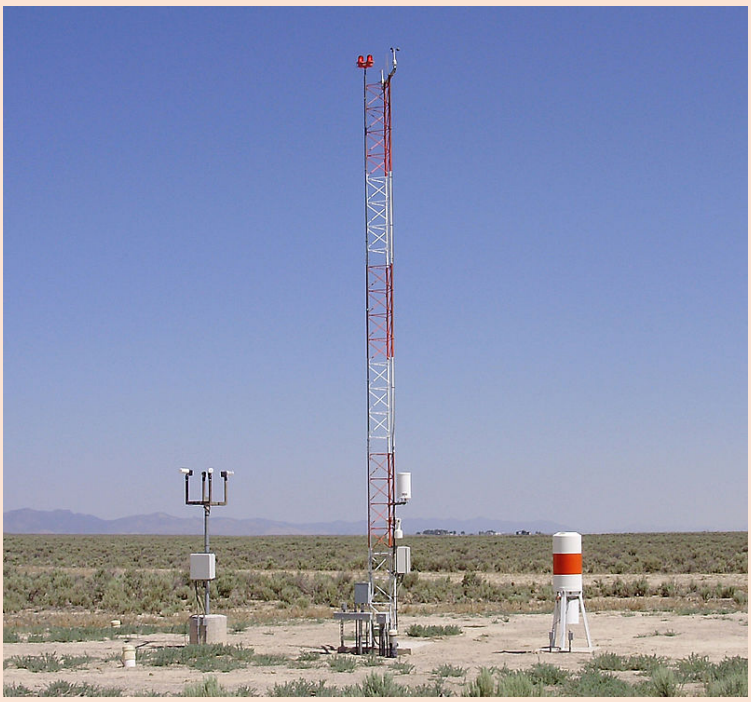

Figure 14.8 Commercial automatic weather observation station AWOS.

Figure 14.9 Remote manned weather stations.

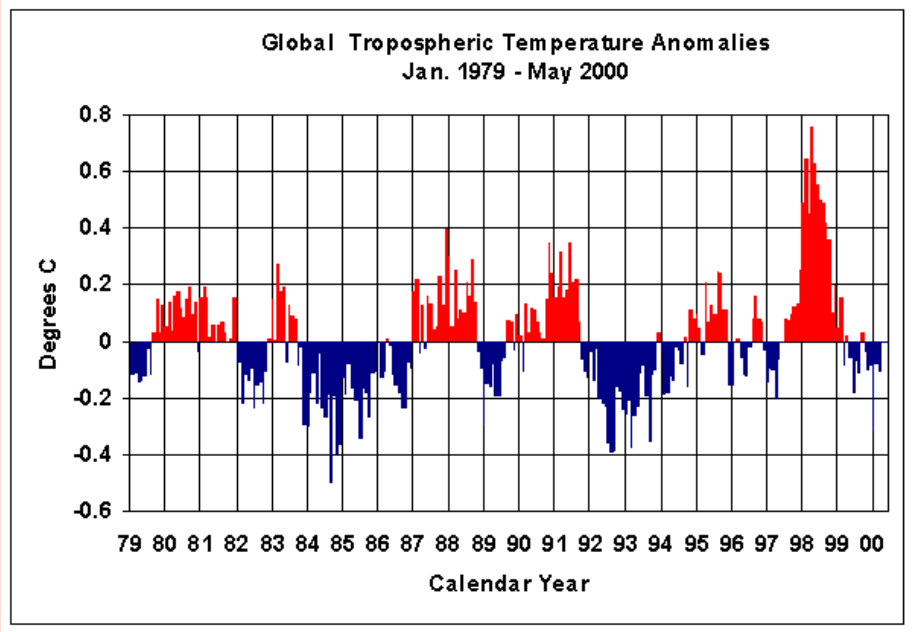

Figure 14.10 Weather balloons with radiosonde.

14.4 Satellites

Satellites are able to collect many meteorological observations on a global scale https://climate.nasa.gov/nasa_science/history/ . The NASA Earth fleet is illustrated in Figure 14.11. Satellites are now providing most of the data required for climate modelling. A list of some of the data available is shown in Table 14.1 taken from https://modis.gsfc.nasa.gov/data/dataprod/index.php . Examples of the types of satellites are shown in Figures 14.12 to Figure 14.17. Internet searches will identify which satellites are available to collect the information of interest. Most of the data is available from NASA.

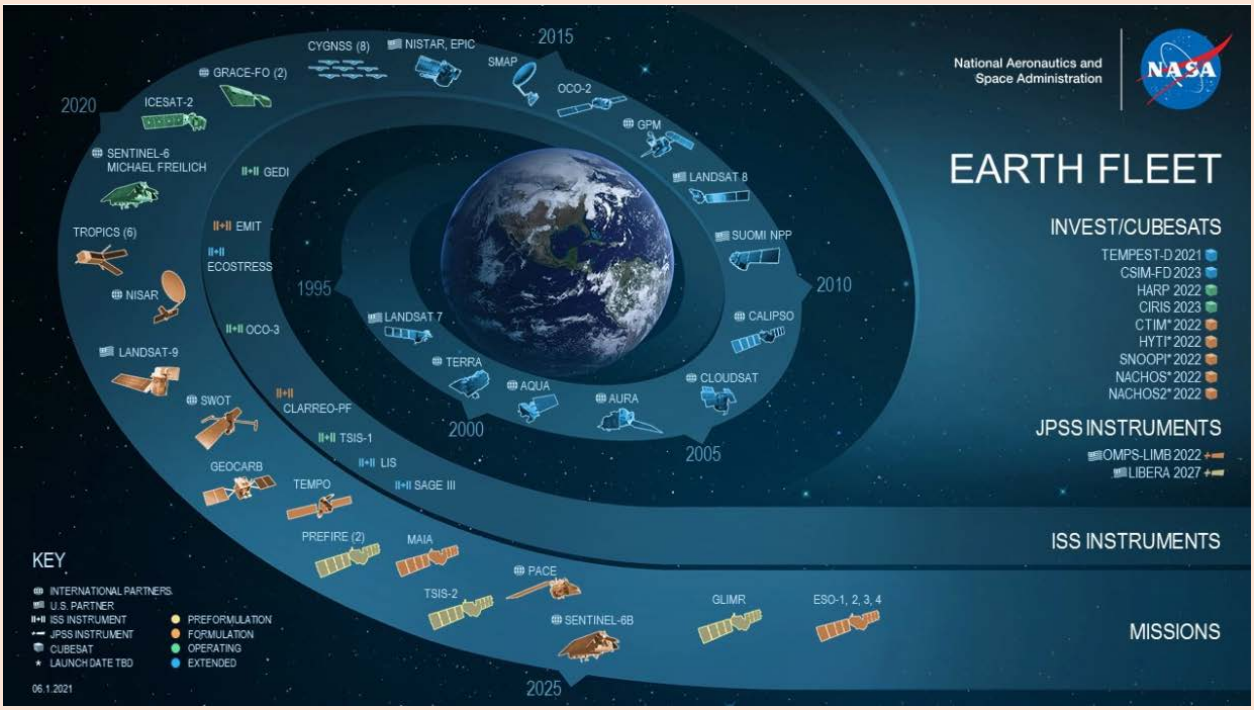

Figure 14.11 NASA Earth science spacecraft and instruments in orbit https://climate.nasa.gov/nasa_science/history/ .

Level 1
MODIS Raw Radiances
MODIS Calibrated Radiances
MODIS Geolocation Fields

MODIS Atmosphere Products
MODIS Aerosol Product
MODIS Total Precipitable Water
MODIS Cloud Product
MODIS Atmospheric Profiles
MODIS Atmosphere Joint Product
MODIS Atmosphere Gridded Product
MODIS Cloud Mask

MODIS Land Products
MODIS Surface Reflectance
MODIS Land Surface Temperature and Emissivity (MOD11)
MODIS Land Surface Temperature and Emissivity (MOD21)
MODIS Land Cover Products
MODIS Vegetation Index Products (NDVI and EVI)
MODIS Thermal Anomalies - Active Fires
MODIS Fraction of Photosynthetically Active Radiation (FPAR) / Leaf Area Index (LAI)
MODIS Evapotranspiration
MODIS Gross Primary Productivity (GPP) / Net Primary Productivity (NPP)
MODIS Bidirectional Reflectance Distribution Function (BRDF) / Albedo Parameter
MODIS Vegetation Continuous Fields
MODIS Water Mask
MODIS Burned Area Product

MODIS Cryosphere Products
MODIS Snow Cover
MODIS Sea Ice and Ice Surface Temperature

MODIS Ocean Products
MODIS Sea Surface Temperature
MODIS Remote Sensing Reflectance
MODIS Chlorophyll-a Concentration
MODIS Diffuse Attenuation at 490 nm
MODIS Particulate Organic Carbon
MODIS Particulate Inorganic Carbon
MODIS Normalized Fluorescence Line Height (FLH)
MODIS Instantaneous Photosynthetically Available Radiation
MODIS Daily Mean Photosynthetically Available Radiation

Table 14.1 Data products available from NASA, Moderate Resolution Imaging Spectroradiometer, MODIS. https://modis.gsfc.nasa.gov/data/dataprod/index.php

Figure 14.12 GOES-8, a United States weather satellite of the meteorological-satellite service. https://en.wikipedia.org/wiki/Weather_satellite

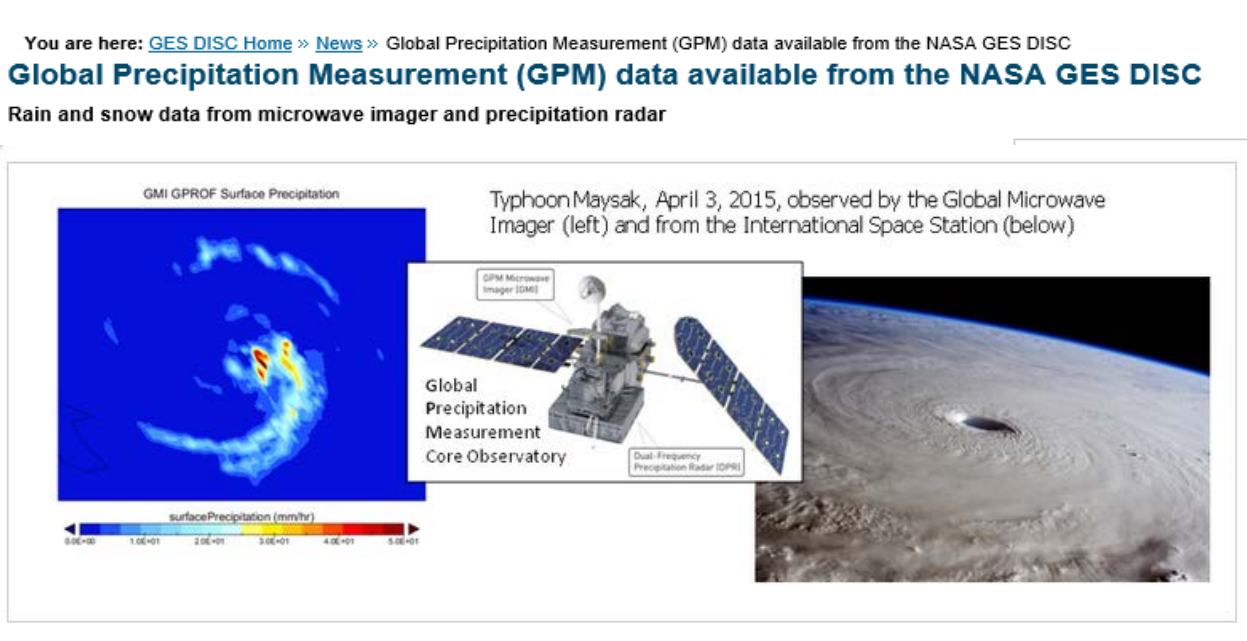

Figure 14.13 Global precipitation measurement from NASA GES DISC satellite https://www.nasa.gov/mission_pages/GPM/overview/index.html

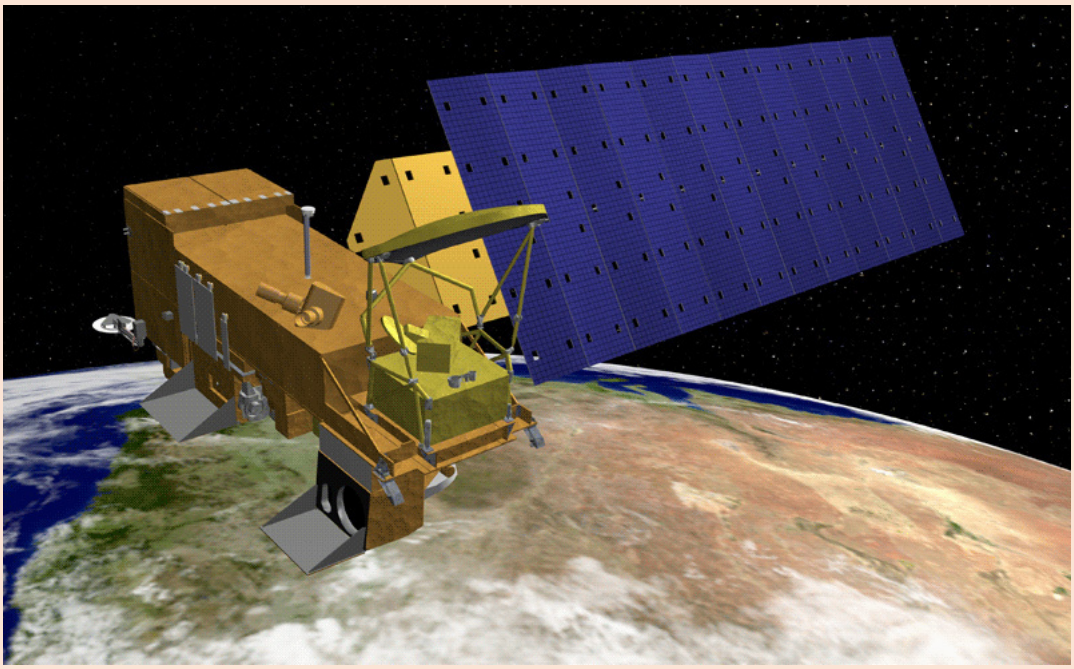

Figure 14.14 Infrared Sounder on NASA's Aqua Satellite
https://airs.jpl.nasa.gov/mission/overview/ ,
https://airs.jpl.nasa.gov/#:~:text=AIRS%2C%20the%20Atmospheric%20Infrared%20Sounder,gases%2C%20surface%20and%20cloud%20properties.

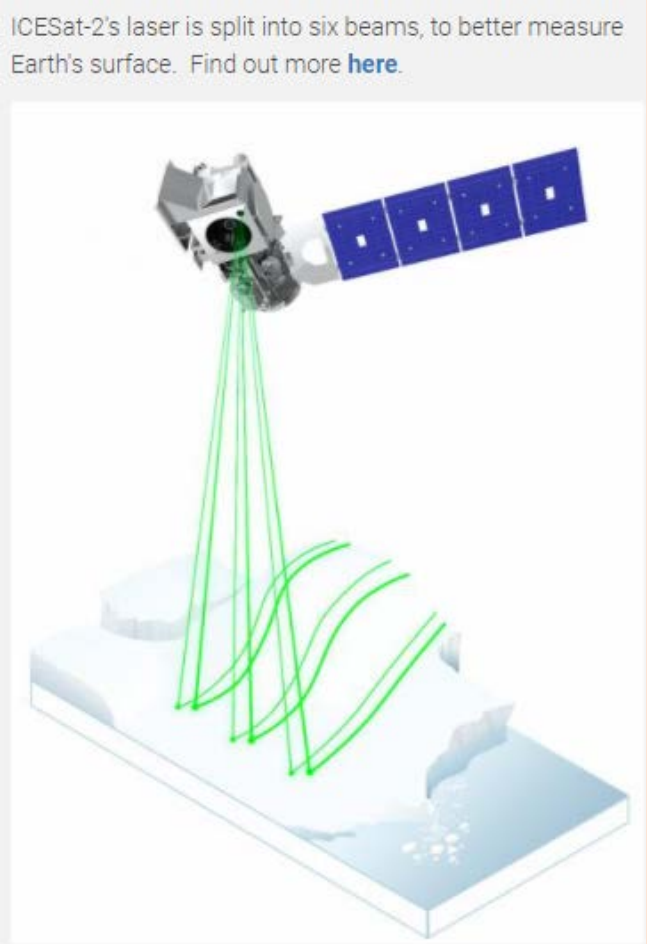

Figure 14.15 Ice thickness. https://icesat-2.gsfc.nasa.gov/

The mass of the Greenland and Antarctic ice sheets are monitored using the GRACE satellites, GRACE and GRACE-FO which are capable of measuring very small gravitational changes, https://en.wikipedia.org/wiki/GRACE_and_GRACE-FO, https://gracefo.jpl.nasa.gov/resources/33/greenland-ice-loss-2002-2016/, and https://grace.jpl.nasa.gov/resources/31/antarctic-ice-loss-2002-2020/.

Recent studies using the NASA Terra satellite have been able to assess 97% of the world's glacierized regions that established that melting glaciers drove 21% of sea level rise over the past two decades https://www.carbonbrief.org/melting-glaciers-drove-21-of-sea-level-rise-over-past-two-decades?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20210429&utm_medium=email&utm_source=Revue%20Daily and https://www.theguardian.com/environment/2021/apr/28/speed-at-which-worlds-glaciers-are-

melting-has-doubled-in-20-years?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20210429&utm_medium=email&utm_source=Revue%20Daily.

Between the Grace satellites and innovative use of the Terra satellite ice masses that are able to contribute to sea level rise are capable of being monitored.

A satellite named the Sentinel-6 Michael Freilich is now providing real-time measurements of sea surface height and other important ocean features. It is the result of U.S.-European collaboration. See https://climate.nasa.gov/news/3091/major-ocean-observing-satellite-starts-providing-science-data/ and https://www.nasa.gov/sentinel-6.

NASA has launched Landsat 9 (September 2021) joining Landsat 8 monitoring Earth's land surface. Details can be found in the following web site, https://landsat.gsfc.nasa.gov/landsat-9/landsat-9-overview. An image of the satellite is shown in Figure 14.16. Satellites such as Landsat 9 provide the opportunity to monitor type and extent of vegetative cover that might be part of natural carbon removal facilities (forests for example) that would be used as part of carbon off-sets.

Figure 14.16 Landsat 9 taken from https://landsat.gsfc.nasa.gov/landsat-9/landsat-9-overview

July 14, 2022 NASA launched a sensor that was attached to the International Space Station as part of a project named the Earth Surface Mineral Dust Source Investigation (EMIT) https://earth.jpl.nasa.gov/emit/instrument/overview/ and https://earth.jpl.nasa.gov/emit/mission/about/). A fact sheet was published which describes the specifics of the project, https://earth.jpl.nasa.gov/emit/documents/3/ . The science goals and objectives are:

1. To acquire remote-sensing measurements of the abundance of surface minerals — namely,

hematite, goethite, illite, vermiculite, calcite, dolomite, montmorillonite, kaolinite, chlorite, and gypsum — in arid regions between 50-degree south and north latitudes in Africa, Asia, North America, South America, and Australia

2. To deliver an improved assessment of the heating and cooling effects of mineral dust in Earth's atmosphere

3. To improve predictions of how future climate scenarios might change the amount and type of mineral dust emitted into Earth's atmosphere

Figure 14.17 illustrates how the information from EMIT is used in earth system models.

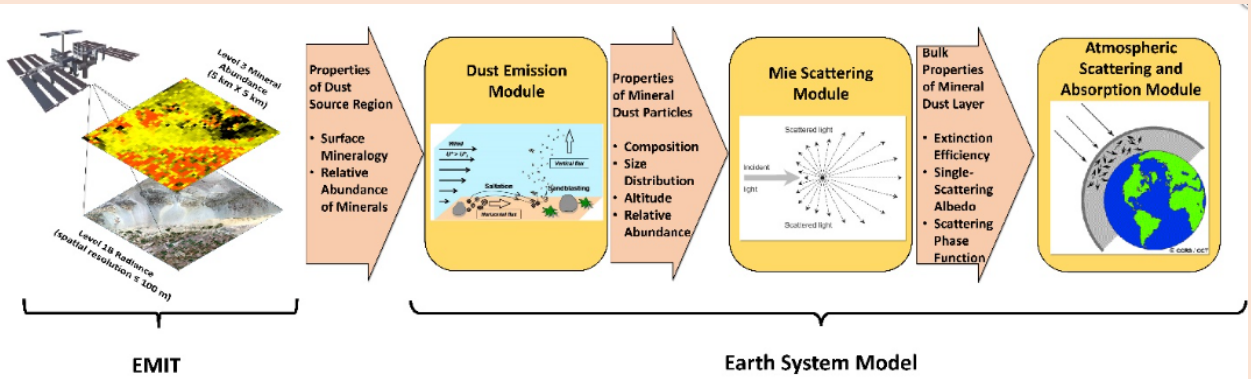

Figure 14.17 Data is collected from sensor mounted on the ISS and provided to earth system models https://earth.jpl.nasa.gov/emit/mission/about/ and https://earth.jpl.nasa.gov/emit/documents/3/ .

EMIT has also proved very successful in pinpointing emissions of methane from oil and natural gas operations and landfills: https://www.nasa.gov/feature/jpl/methane-super-emitters-mapped-by-nasa-s-new-earth-space-mission and https://www.nasa.gov/feature/jpl/nasa-sensors-to-help-detect-methane-emitted-by-landfills .

On December 16, 2022 the Surface Water and Ocean Topography (SWOT) satellite as part of a joint mission between NASA and the French space agency CNES, https://scitechdaily.com/nasa-successfully-launches-game-changing-swot-mission-to-survey-earths-water/ , https://climate.nasa.gov/news/3084/international-cutting-edge-swot-satellite-to-survey-the-worlds-water/ and https://www.nasa.gov/feature/jpl/latest-international-water-satellite-packs-an-engineering-punch . See Figure 14.18.

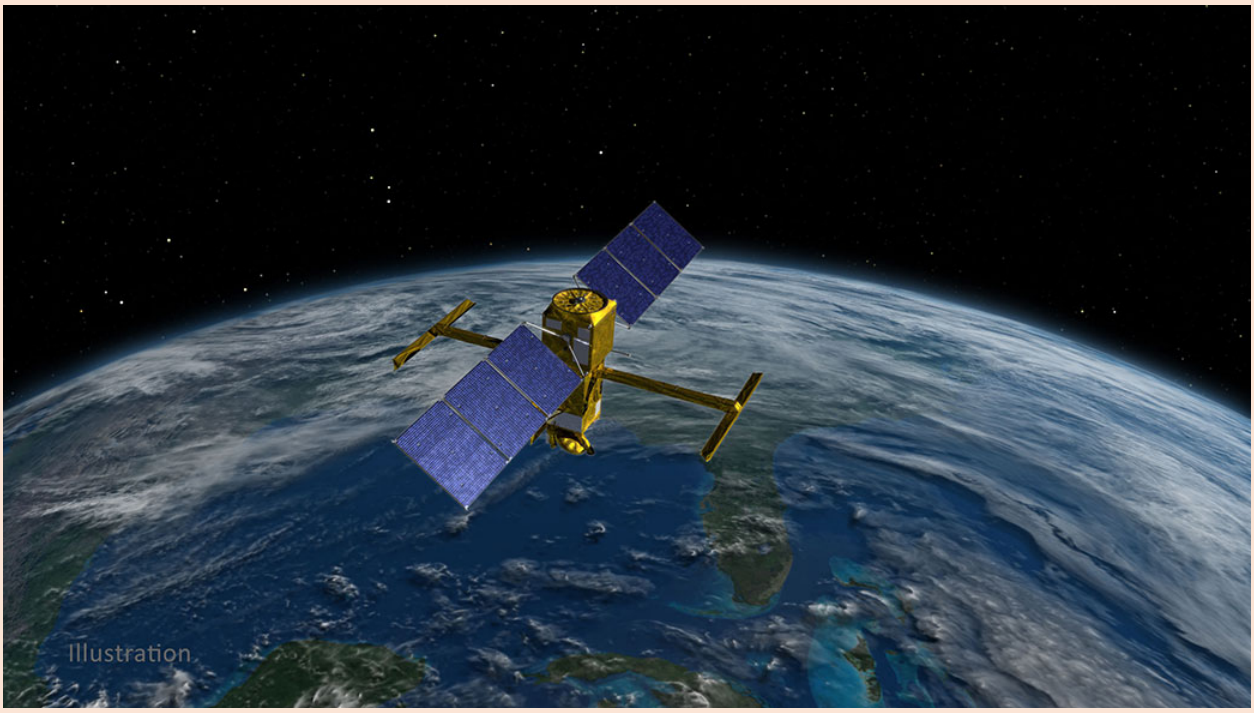

Figure 14.18 Illustration of the Surface Water and Ocean Topography (SWOT) satellite, https://climate.nasa.gov/news/3084/international-cutting-edge-swot-satellite-to-survey-the-worlds-water/ .

Soon to be launched is a satellite named MethaneSAT which will be able to accurately pinpoint methane emissions with the hope that the information will facilitate management of methane emissions, https://www.methanesat.org/ . The satellite is owned by the Environmental Defense Fund. Data collected will be publicly available. MethaneSAT will be able to precisely detect and track methane emissions from very small sources which other methane detecting satellites might miss.

An illustration of MethaneSAT is shown in Figure 14.19.

GOES-16 First of the GOES-R series of Geostationary Operational Environmental Satellite (GOES) https://www.spaceweatherlive.com/en/news/view/399/20191209-welcome-goes-16.html , Figure 14.20.

NASA Terra satellite https://terra.nasa.gov/about was launched December 1999, Figure 14.21. It carries five instruments, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Clouds and Earth's Radiant Energy System (CERES), Multi-angle Imagine

Spectroradiometer (MISR), Measurements of Pollution in the Troposphere (MOPITT) and Moderate Resolution Imaging Spectroradiometer (MODIS).

Figure 14.19. Illustration of MethaneSAT, https://www.methanesat.org/ .

Figure 14.20. GOES-16 First of the GOES-R series of Geostationary Operational Environmental Satellite (GOES) https://www.spaceweatherlive.com/en/news/view/399/20191209-welcome-goes-16.html .

Figure 14.21 NASA Terra satellite https://terra.nasa.gov/about . Carries five instruments, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Clouds and Earth's Radiant Energy System (CERES), Multi-angle Imagine Spectroradiometer (MISR), Measurements of Pollution in the Troposphere (MOPITT) and Moderate Resolution Imaging Spectroradiometer (MODIS).

14.5 Information support

Key web sites:

1. Instrumental temperature record. https://en.wikipedia.org/wiki/Instrumental_temperature_record

2. Observed climate variations and change. https://www.ipcc.ch/site/assets/uploads/2018/03/ipcc_far_wg_I_chapter_07-1.pdf

3. Global observing system. https://public.wmo.int/en/programmes/global-observing-system

4. WMO member states and territories. https://public.wmo.int/en/about-us/members

5. Guide to meteorological instruments and methods of observation. https://www.weather.gov/media/epz/mesonet/CWOP-WMO8.pdf

6. Global temperature records and climate observation, NASA. https://climate.nasa.gov/blog/3071/the-raw-truth-on-global-temperature-records/

7. Climate data online. https://www.ncdc.noaa.gov/cdo-web/

8. National Centers for Environmental Information. https://www.ncdc.noaa.gov/

9. Weather station. https://en.wikipedia.org/wiki/Weather_station

10. Automatic weather station. https://en.wikipedia.org/wiki/Automatic_weather_station

11. NASA Earth science spacecraft and instruments in orbit https://modis.gsfc.nasa.gov/data/dataprod/index.php .

12. GOES-16 Space weather station. https://www.spaceweatherlive.com/en/news/view/399/20191209-welcome-goes-16.html

13. Weather satellite. https://en.wikipedia.org/wiki/Weather_satellite

14. Global precipitation measurement. https://www.nasa.gov/mission_pages/GPM/overview/index.html

16. Atmospheric Infrared Sounder on NASA's Aqua Satellite. https://airs.jpl.nasa.gov/mission/overview/ , https://airs.jpl.nasa.gov/#:~:text=AIRS%2C%20the%20Atmospheric%20Infrared%20Sounder,gases%2C%20surface%20and%20cloud%20properties .

17. NASA taking a global perspective on Earth's climate. https://climate.nasa.gov/nasa_science/history/

18. ICESat-2. https://icesat-2.gsfc.nasa.gov/

19. GRACE satellite monitoring, https://en.wikipedia.org/wiki/GRACE_and_GRACE-FO, https://gracefo.jpl.nasa.gov/resources/33/greenland-ice-loss-2002-2016/ and https://grace.jpl.nasa.gov/resources/31/antarctic-ice-loss-2002-2020/.

20. Terra satellite, NASA. https://terra.nasa.gov/about

21. Melting glaciers, Carbon Brief, Ayesha Tandon. https://www.carbonbrief.org/melting-glaciers-drove-21-of-sea-level-rise-over-past-two-decades?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20210429&utm_medium=email&utm_source=Revue%20Daily

22. Melting glaciers, The Guardian. https://www.theguardian.com/environment/2021/apr/28/speed-at-which-worlds-glaciers-are-melting-has-doubled-in-20-years?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20210429&utm_medium=email&utm_source=Revue%20Daily

23. Sea surface measurements using the Sentinel-6 Michael Freilich Satellite. https://climate.nasa.gov/news/3091/major-ocean-observing-satellite-starts-providing-science-data/ and https://www.nasa.gov/sentinel-6 .

24. Landsat 9, https://landsat.gsfc.nasa.gov/landsat-9/landsat-9-overview

25. EMIT Earth Surface Mineral Dust Source Investigation, NASA. https://earth.jpl.nasa.gov/emit/instrument/overview/ , https://earth.jpl.nasa.gov/emit/mission/about/ , https://earth.jpl.nasa.gov/emit/documents/3/ , https://www.nasa.gov/feature/jpl/methane-super-emitters-mapped-by-nasa-s-new-

earth-space-mission , and https://www.nasa.gov/feature/jpl/nasa-sensors-to-help-detect-methane-emitted-by-landfills .

26. SWOT, Surface Water and Ocean Topography mission, https://www.nasa.gov/feature/jpl/latest-international-water-satellite-packs-an-engineering-punch, https://climate.nasa.gov/news/3084/international-cutting-edge-swot-satellite-to-survey-the-worlds-water/ , and https://www.nasa.gov/feature/jpl/latest-international-water-satellite-packs-an-engineering-punch .

27. MethaneSAT, Environmental Defense Fund, https://www.methanesat.org/ .

Videos:

Measuring ice thickness with ICESAT-2.
https://www.youtube.com/watch?v=S1_-3uu1VIw&feature=emb_rel_end