MET 4410 Remote Sensing: Radar and Satellite Meteorology
MET 5412 Remote Sensing in Meteorology

Lecture 2: Brief history of radar and satellite meteorology

History of Radar Meteorology

- Will cover the period from just before World War II through about 2013
- Will cover both the hardware development, meteorological applications of radar, and US radar networks

Pre-World War II

- 1904: German Engineer Hulsmeyer's patent: A device to detect radio waves reflected by ships
- U.S. Navy (among others) tried using radio waves to detect ships.
- 1920's-1930's: Meteorologist Robert Walson-Watt in Britain is regarded as the inventor of radar (Father of radar)

Robert Walson-Watt

Pre-World War II

- Memo (“Detection of Aircraft by Radio Methods”) drafted by Watson-Watt on February 12, 1935:
  - – Memo earned Watson-Watt the title of “the father of radar”
  - – In the memo, “radar” was called “Radio Direction Finding (RDF)”!

World War II (1939-1945)

- 1940: The term RADAR (Radio Detection And Ranging) was first used:
  - Term “RADAR” officially coined as an acronym by U.S. Navy Lt. Cmdr. Samuel M. Tucker and F. R. Furth in November 1940

Radar Hardware Advances during World War II (1939-1945)

- Big development: cavity magnetron
  - – Capable of increasing power output tenfold plus, generate high frequencies in microwave band
  - – Invented by John Randall and Henry Boot at the University of Birmingham (in Britain) on February 21, 1940
  - – Opened the door wide for significant development
- The radiation Lab in MIT, USA manufactured the radar magnetron transmitter tube developed in Britain.

CAVITY MAGNETRON (IEEE)

Radar and the Atmosphere

- Meteorological effects found by military users of radar:
  - -- stimulated the theoretical work on the scattering, absorption, and propagation of microwaves in the lower atmosphere
- In Britain:
  - 1) 1940: the first observation of precipitation likely was made.
  - 2) 1945: the first account of radar observation of a tropical cyclone was published
  - 3) 1946: the first major post-war symposium on radar meteorology was held in London.
  - 4) 1951: the book "***Propagation of short radio waves***" by Kerr.

Radar and the Atmosphere

- In the US:
  - 1) 1941: First detection at Rad Lab, MIT: 7 February 1941
  - 2) 1943: First U.S. publication regarding meteorological weather echoes: “Radar echoes from atmospheric phenomena” (Bent, 1943)
  - 3) 1946: Weather Radar Research Project at MIT
    - – Initial project director: Alan Bemis
  - 4) 1945: U.S. Air Force All Weather Flying Division: project AW-MET-8
    - – David Atlas among the first to lead

Early Equipment

- Innovative uses of military radar by meteorologists:
  - 1) Tracking balloons to determine upper-level winds
  - 2) Detection of precipitating cloud systems
- First radar for meteorological use:
  - -- AN/CPS-9, 3-cm radar produced in U.S. in 1949
- First meteorological observation with Doppler radar:
  - -- was made in Britain in 1953.

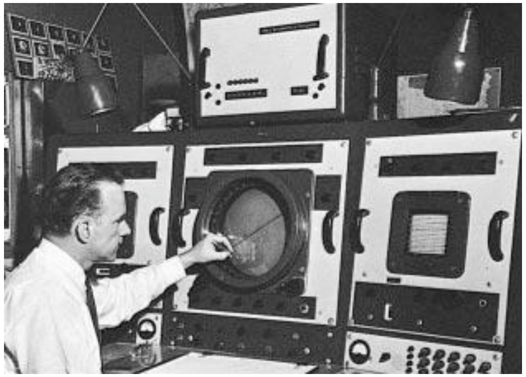
More in U. S.

- 1946-1947: Thunderstorm Project (Florida and Ohio)
  - – First multiagency field experiment for thunder storm study and that relied so heavily on radar for research
- 14 March 1947: first Weather Radar Conference held at MIT
  - – Over 90 attendees from various agencies
- 1950s: Operational radar meteorology forming
  - –Weather Bureau obtained 25 AN/APS-2 radars, modified them, and renamed them WSR-1s, 1As, 3s, and 4s.

First U.S. Operational Radar Network: WSR-57

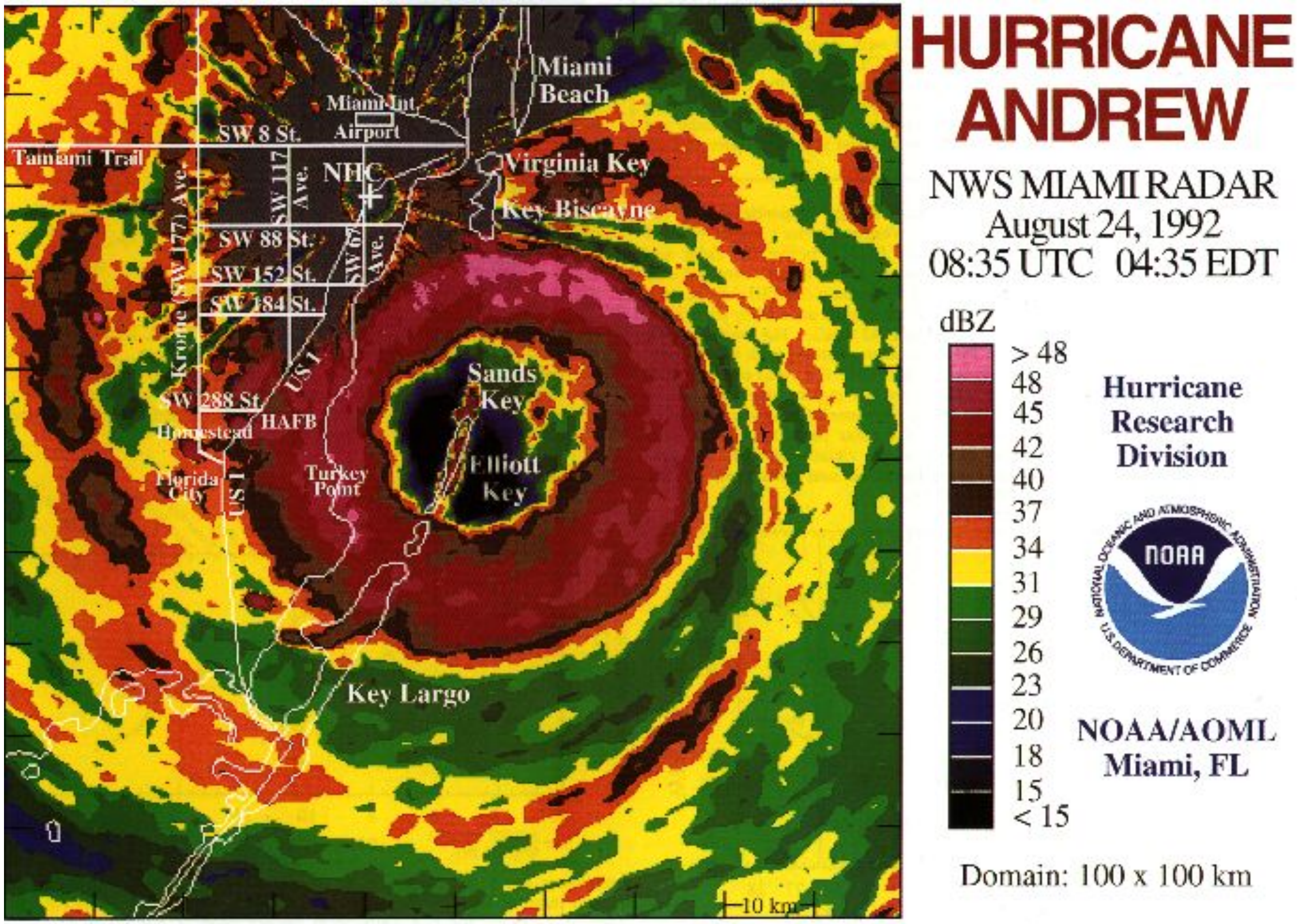
- 1954 & 1955: several hurricanes struck the U.S. Atlantic coast
  - No radar to detect them
- 1956: U.S. Weather Bureau appeals to Congress and gets funded in 1956, buys 31 radars which become WSR-57s
  - 14 placed ~200 nmi apart along the coast
  - First operational WSR-57 installed in Miami in June 1959
  - 11 placed in the Midwest for storm detection
  - Network will continue to expand through the 1960s

→WSR-57 console



WSR-57 Radars

- **WSR-57** radars were the USA's main weather surveillance radar for over 35 years for severe weather.
- The WSR-57 network was very spread out, with 66 radars to cover the entire country.
- The last WSR-57 radar in the United States was decommissioned on December 2, 1996
- WSR-57 radar properties:
  - S-band 10.3 cm wavelength (frequency of 2890 MHz)
  - Dish diameter: 12 feet (3.7 m)
  - Power output: 410,000 watts
  - Maximum range: 915 km (494 nm)



Last image of the Miami's WSR-57 blown off by Hurricane Andrew on August 24, 1992

Addition of WSR-57 Network: WSR-74 radars

- **WSR-74 radars** were **W**eather **S**urveillance **R**adars (WSR) designed in 1974 for the NWS.
- WSR-74 were added to the existing network of the WSR-57 model to fill in the gaps. (Some have been sold to other countries like Australia, Greece, and Pakistan.)
- WSR-74 radar properties:
  - WSR-74S: S-band, same as WSR-57 radars
  - WSR-74C (used for local warnings) : C-band, wavelength of 5.4 cm; dish diameter of 8 feet; a maximum range of 579 km (313 nm) as it was used only for reflectivities

Circles showing the coverage of the WSR-57 and WSR-74 radars. Note the large gap over the western United States.

Advent of Doppler radar

- – Ian Browne and Peter Barratt (Cambridge) first to demonstrate the use of Doppler techniques to calculate motion
  - 27 May 1953: vertical motion measured in a rain shower
    - – Doppler spectrum consistent with 2 m/s downdraft
    - – Paper reporting this (Barrat and Browne, 1953) not published or publicized at conferences for a few years
- – James Brantley and Barczys got that work published and presented
  - Brantley and Barczys (1957): CW Doppler measurements of weather echoes
- – Brantley convinced Vaughn Rockney that this could be used for tornado detection; applied for grant
  - 92 m/s winds measured by radar in tornado in El Dorado, KS on 10 June 1958
- – Thus began the Doppler era

US Next-Generation Radar (NEXRAD) Network: WSR-88D

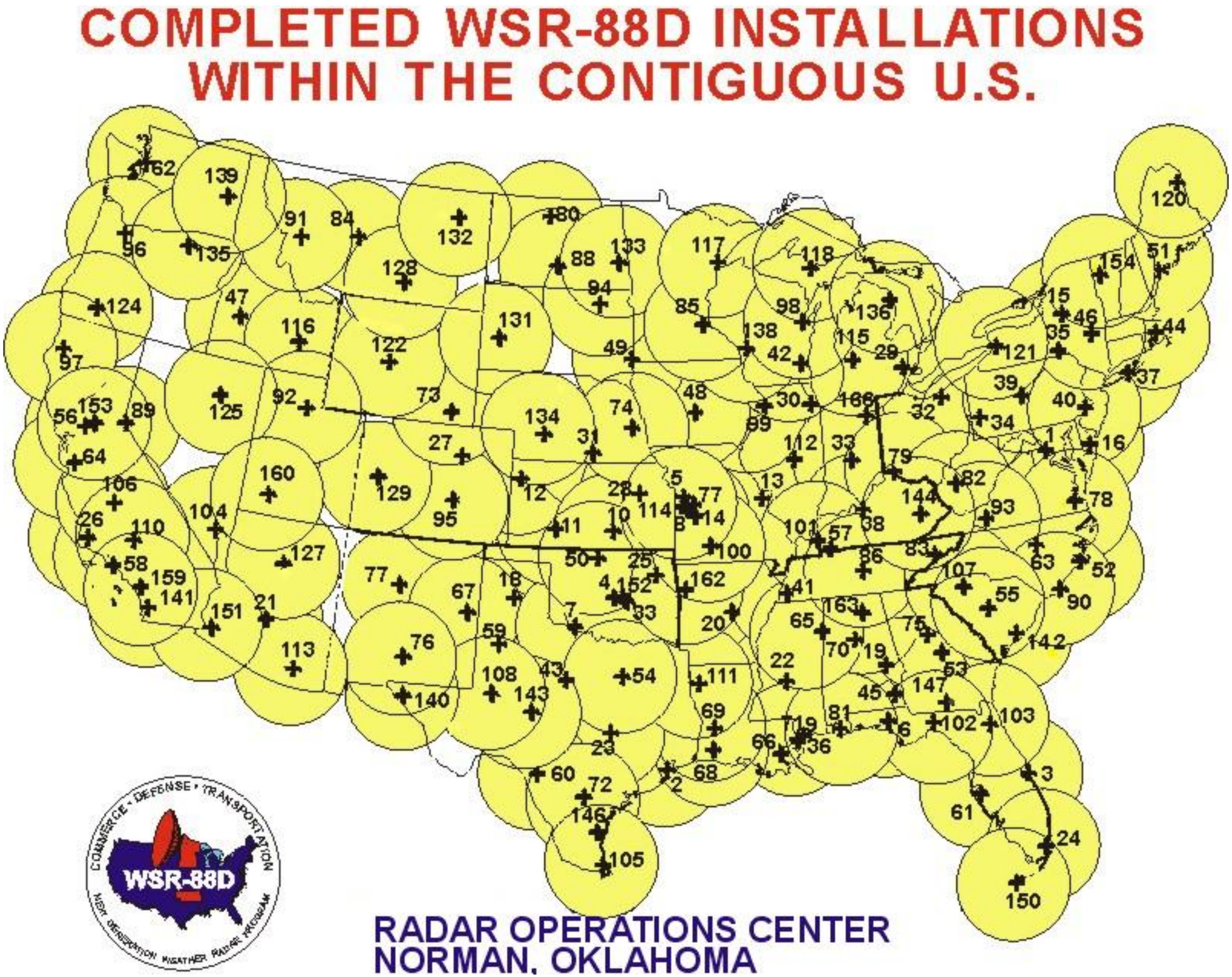
- **NEXRAD** is a network of 159 high-resolution S-band Doppler weather radars operated by the National Weather Service (NWS). Its technical name is **WSR-88D**, which stands for Weather Surveillance Radar, 1988, Doppler.
- WSR-88D replaces the WSR-57 and WSR-74 national radar network, which did not utilize Doppler technology.
- NEXRAD detects precipitation and wind.
- WSR-88D development, maintenance, and training are coordinated by the NEXRAD Radar Operations Center (ROC) located at the National Weather Center (NWC) in Norman, Oklahoma.

NEXRAD/WSR-88D Radar Properties and Scan Strategies

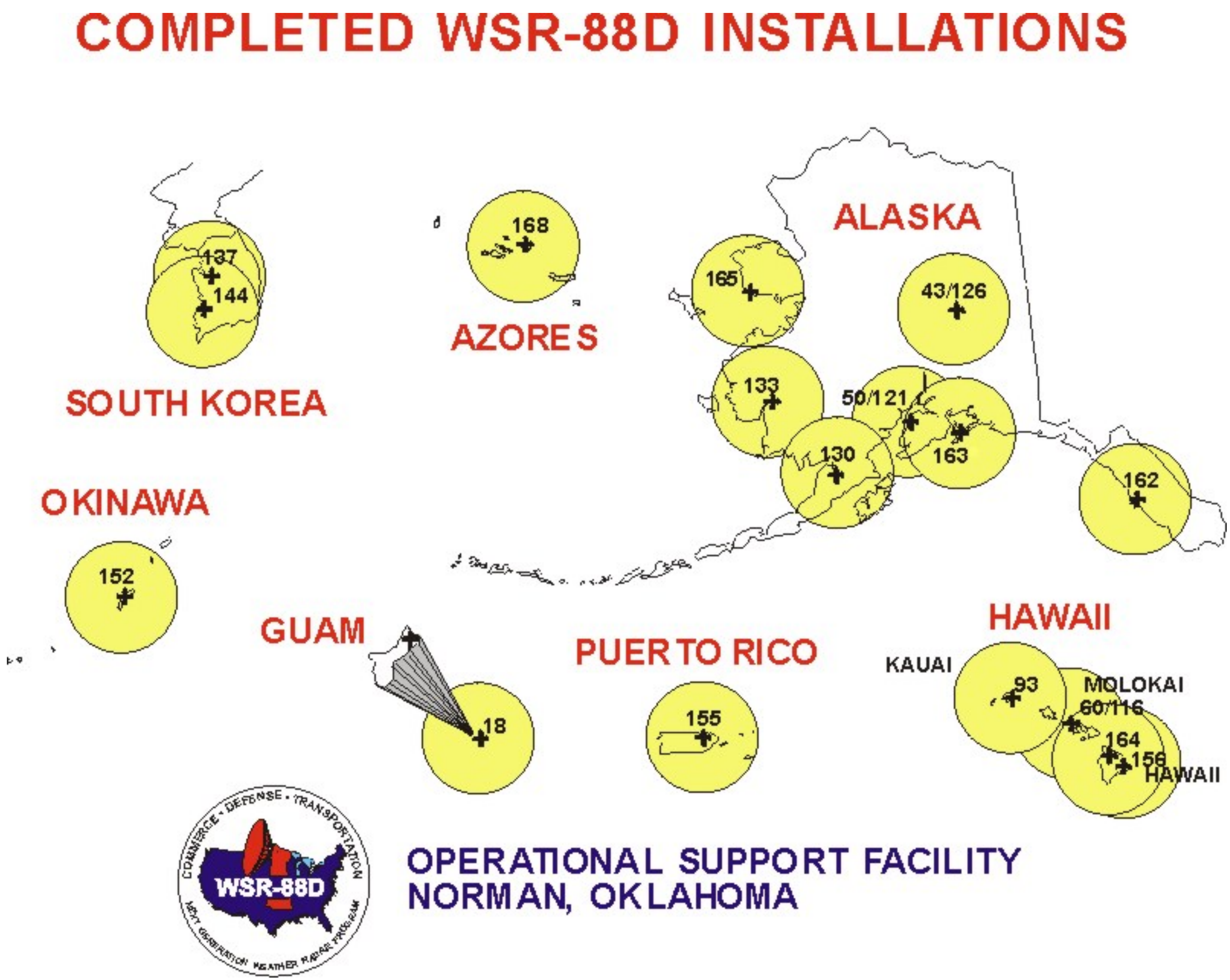
- S-band
- **Dish diameter of 9.1m (30ft); Antenna diameter of 8.5m (28ft).**
- **Spatial resolution varies with data type and scan angle - level III data has a resolution of 1km x 1 degree in azimuth, while super-res level II, (implemented in 2008 nationwide), has a resolution of 250m by 0.5 degrees in azimuth below 2.4 degrees in elevation.**
- **9 Volume Coverage Pattern (VCPs) available. Each VCP is a predefined set of instructions that control antenna rotation speed, elevation angle, transmitter pulse repetition frequency and pulse width.**
  - Clear Air or Light Precipitation: VCP 31 and 32
  - Shallow Precipitation: VCP 21
  - Convection: VCP 11, 12, 121, 211, 212, and 221
- **Traditional elevation minimum and maximum ranging from 0.1 to 19.5 degrees, although the non-operational minimum and maximum spans from -1 to +45 degrees.**

Dual Polarization Upgrade of NEXRAD Network

- The deployment of the dual polarization capability (Build 12) to NEXRAD sites began in 2010 and was completed by the summer of 2013.
- The radar at Vance Air Force Base in Enid, Oklahoma is the first operational WSR-88D to be modified to utilize dual polarization technology; the modified radar went into operation on March 3, 2011.
- Dual-pol radar adds vertical polarization to the horizontal radar waves, in order to more accurately distinguish between rain, hail, and snow, therefore improving warning s of winter storms and thunderstorms.



NEXRAD sites within the Contiguous U.S.



NEXRAD sites in Alaska, Hawaii, U.S. territories, and military bases.

Works in Other Countries

- In Canada: Project Stormy Weather, 1943
  - –AKA the “Stormy Weather Group” after 1950 at McGill University
  - –First led by J. Stewart Marshall
  - –Pioneer work on precipitation and cloud microphysics:
    - Marshall-Palmer raindrop size distribution
    - The definition of radar reflectivity factor
    - Melting band studies
    - CAPPI (Constant Altitude Plan Position Indicator)

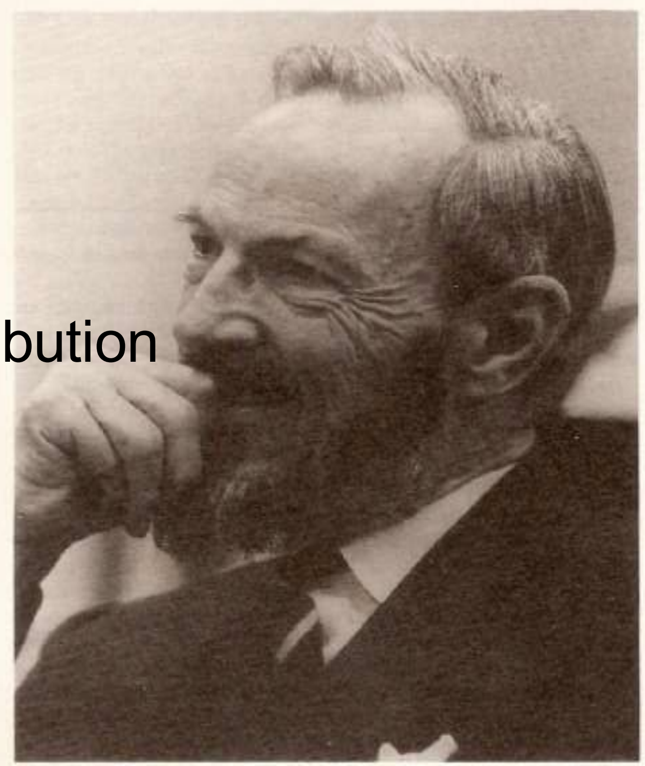
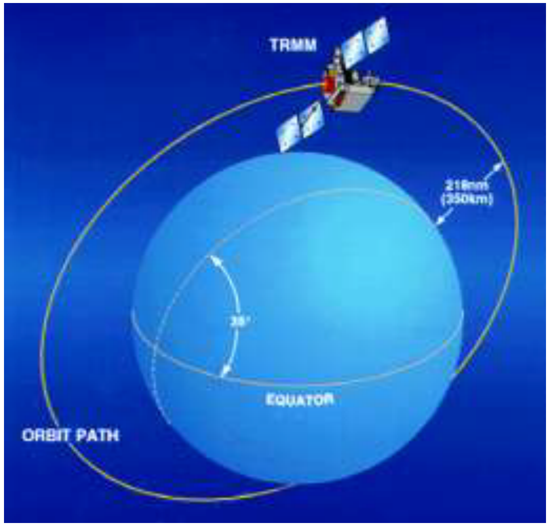


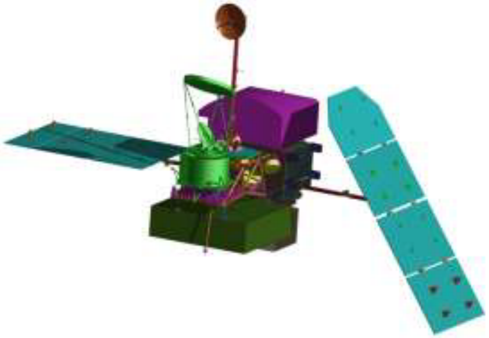
Fig. 1 J. Stewart Marshall (in 1979), founder and Director of

Works in Other Countries

- In Japan:
  - – 1954: First 3-cm radar made.
  - – 1965: A remote controlled weather radar was set up on Mt. Fuji (3776 m above sea level) to detect typhoons
  - --1997: TRMM precipitation radar (PR, the first weather radar on satellite) was launched. The radar was made by Japan.
  - --2014: GPM satellite dual frequency precipitation radar (DPR) was made by Japan too.



TRMM Satellite


GPM radar (DPR)

History of Satellite Meteorology

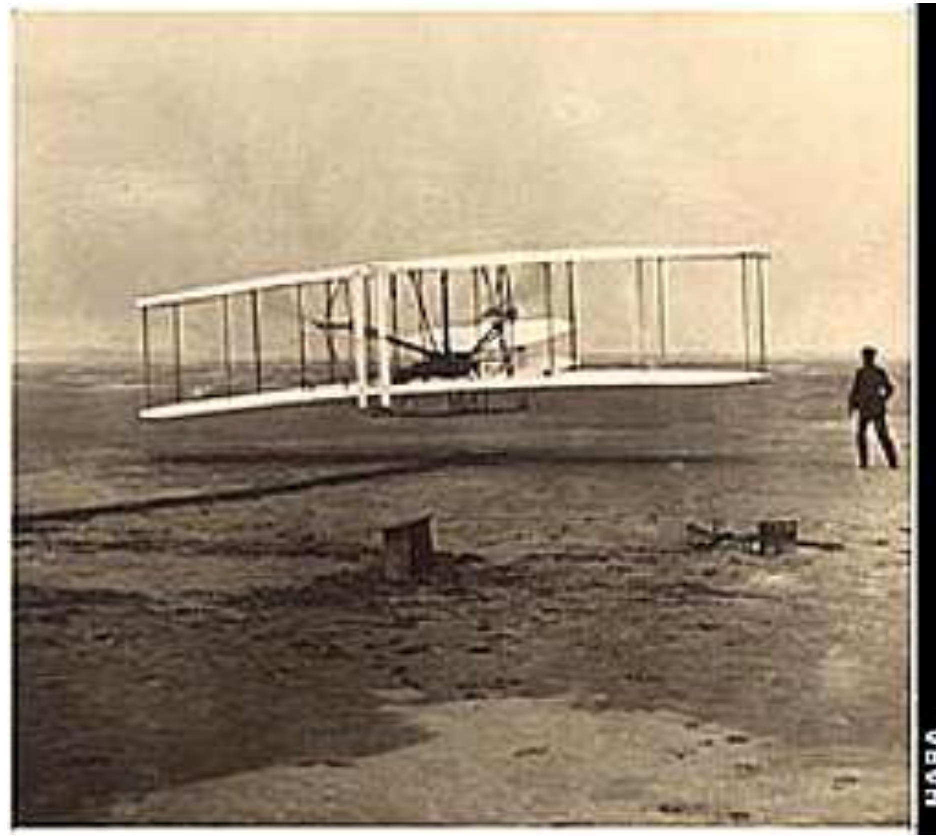
Aerial Photography


Boston City, 1860

- The invention of photography in 1839 made remote sensing (eventually) possible.
- Remote sensing began in the 1860s as balloonists took pictures of the Earth's surface.
  - Pigeon fleets were another form of remote sensing at the beginning of the 20th century.

Early Aeronautics

Robert Goddard's first rocket, 1926



Wright brothers and the earliest airplane

First Images from space (1940s): V2 Rocket

Early Meteorological Satellites (Metsat)

- **The first satellite with a meteorological instrument:Vanguard 2**, launched in Feb 1959.

--Supposed to get a visible Earth image. But the data were unusable because the satellite wobbled on its axis.

- **Explorer 6: the satellite with meteorological instruments** launched in Aug. 1959, carried an imaging system and a Suomi radiometer.The data were unusable too.
- **The first successful meteorological instrument** on an orbiting satellite was the **Suomi radiometer**, which flew on **Explorer 7**, launched Oct 1959. The Suomi radiometer was developed by Verner Suomi and colleagues at the Univ. of Wisconsin, and designed for measuring solar and infrared radiation.

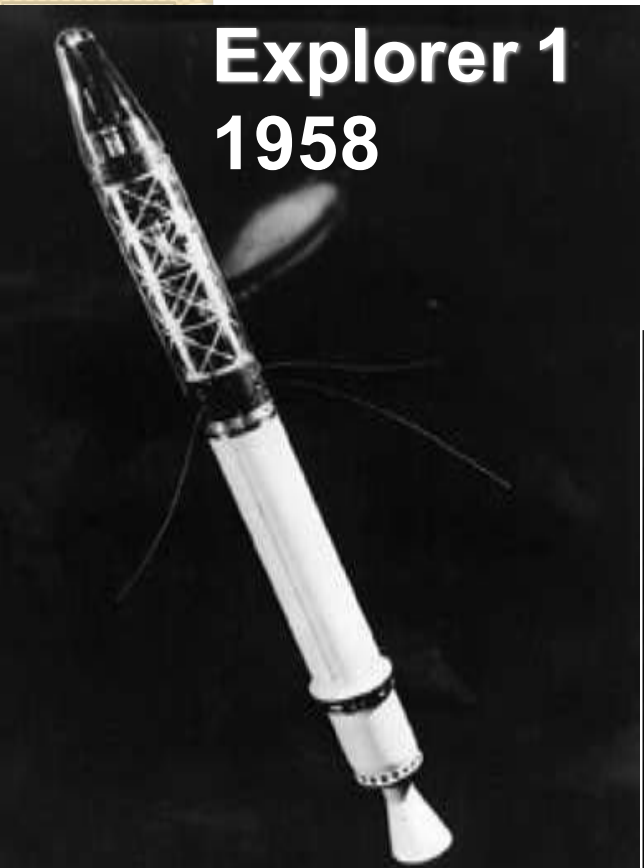
- **The first satellite completedly dedicated to satellite meteorology was**

TIROS 1 (Television and Infrared Observational Satellite), launched in April 1960.

-- Image-making instrument: a vidicon camera

- **TIROS series:** TIROS 1-10 (1960-1965) -- with improved meteorological instruments.
- **Nimbus series:** Nimbus 1-7 (1964-1978) – An extremely important series of experimental metsats. Nimbus 1 was the first sunsynchronous satellite (passed over any point on Earth at approximately the same local time).

First Satellites

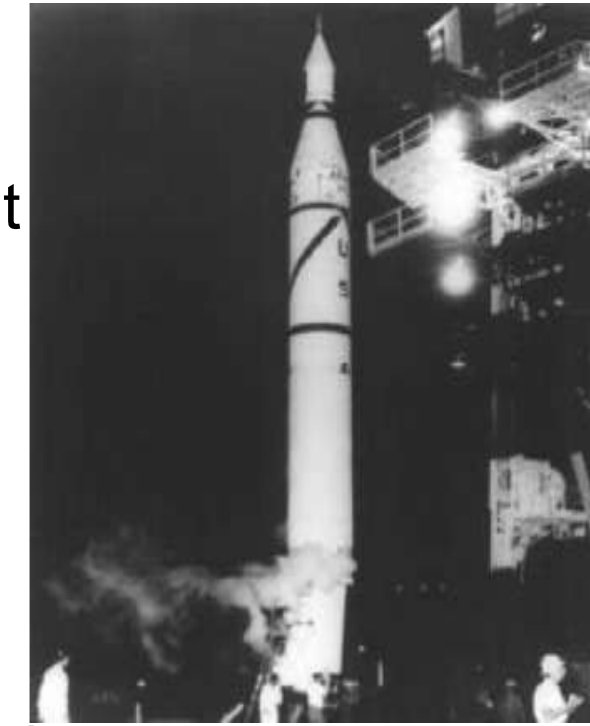


NASA was founded in 1958 to advance American interests in space.

National Aeronautics
and Space Administration

Explorer 7

Jupiter C launch rocket

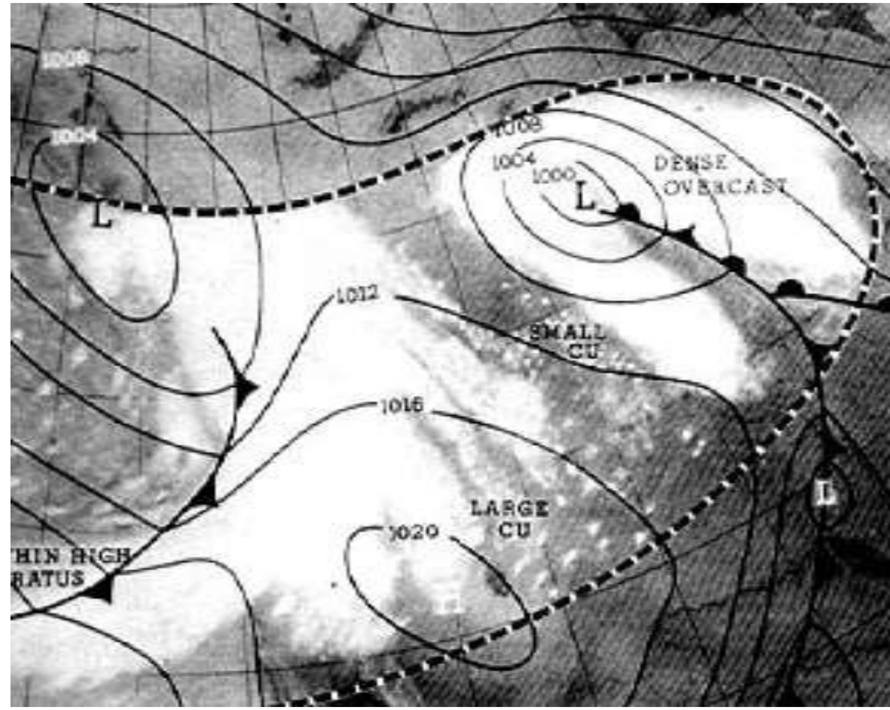


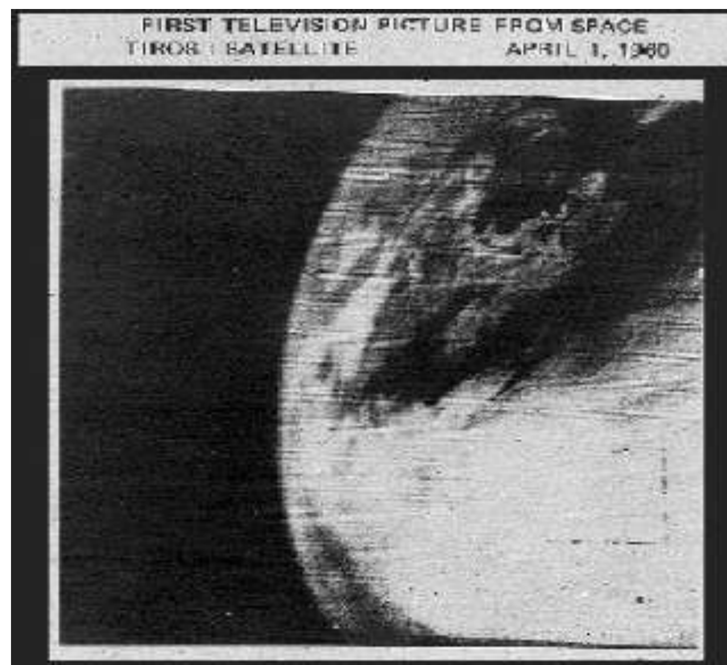
E7 (1959): First satellite with a successful instrument for meteorological remote sensing.

Designed by Verner Suomi, U Wisconsin

Postcards (US and Brazil) celebrating E7

The TIROS I Series (1960)



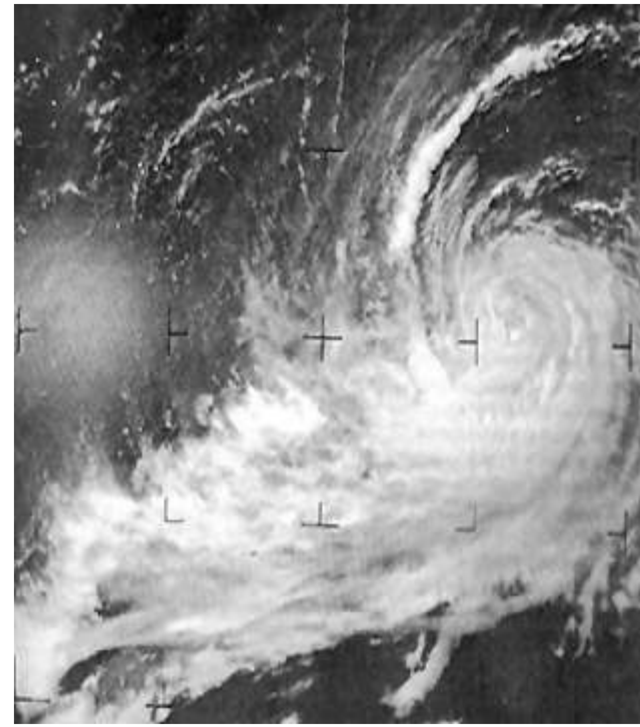


The Nimbus Series 1963

NIMBUS III HRIR DAYTIME ORBIT 711 6 JUNE 1969
ASIA MINOR

ESSA Satellites

- The Environmental Science Services Administration (ESSA) satellite program was designed to provide operational cloud-cover monitoring.
- ESSA 1 was launched in February 1966.
- The last ESSA (9) was launched in 1969.
- ESSA was absorbed into what is now NOAA (National Oceanographic and Atmospheric Administration).

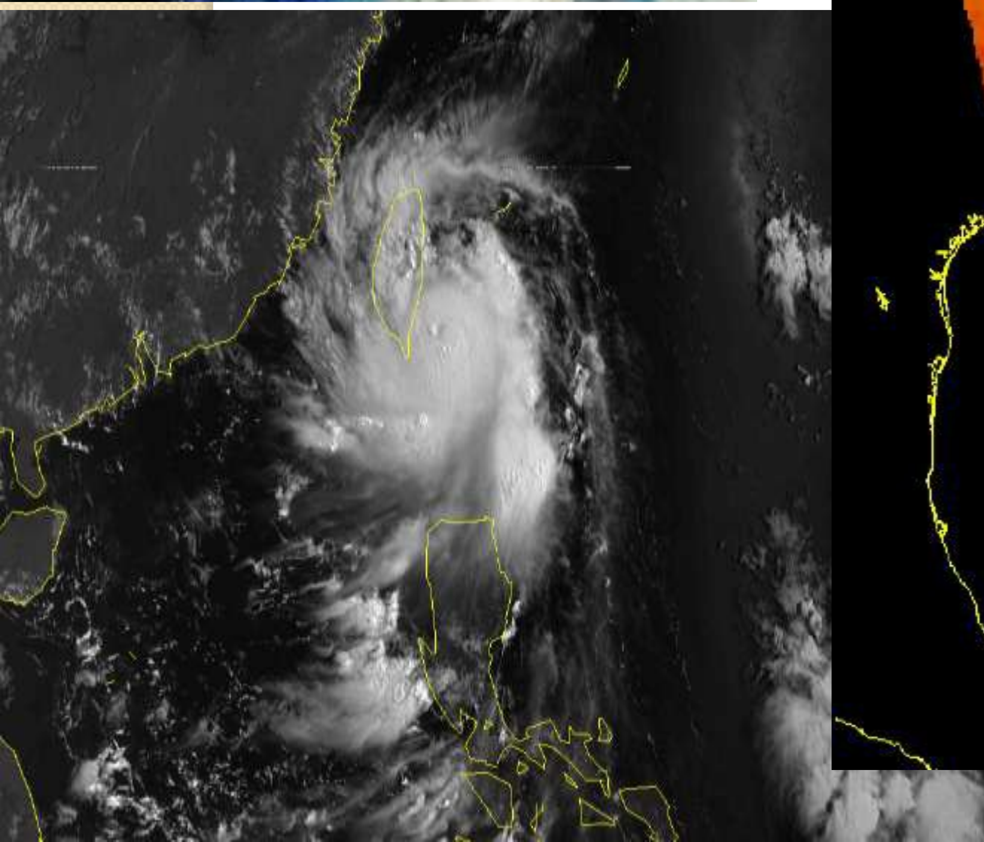


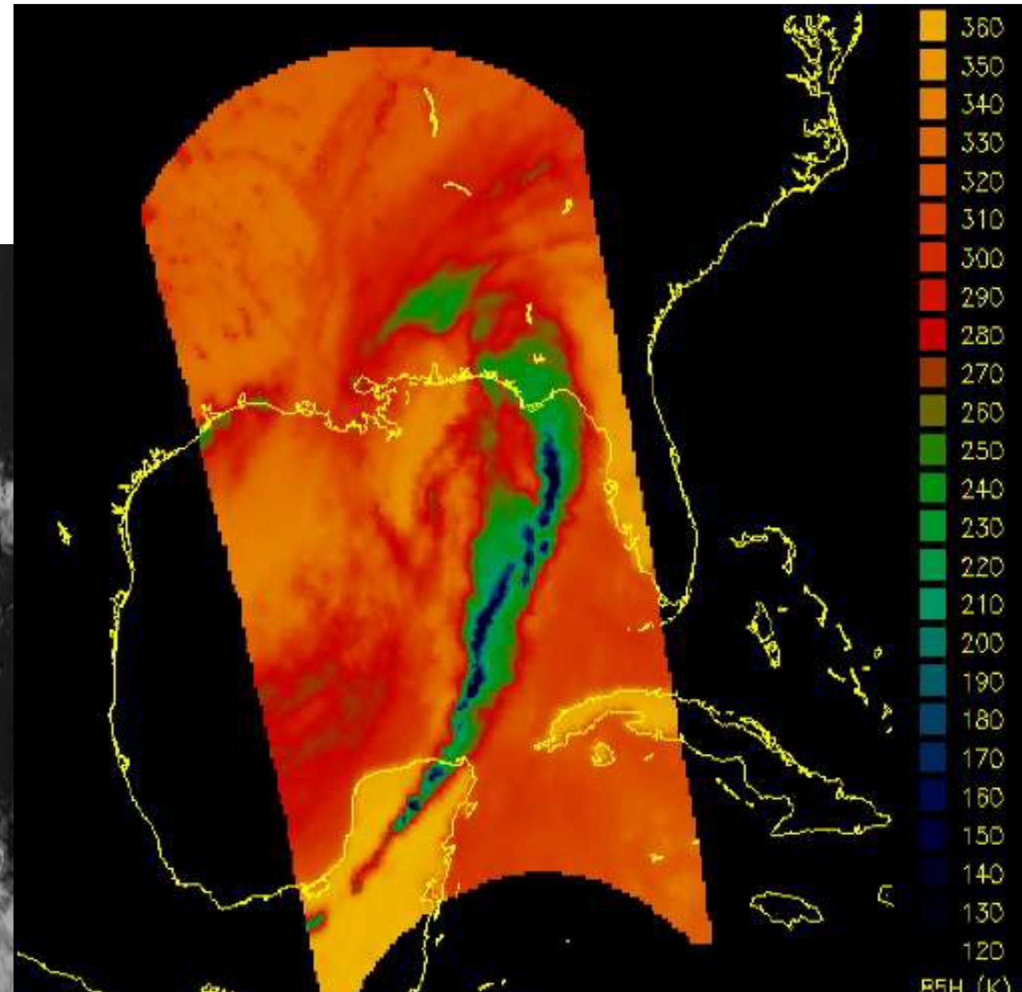
Hurricane Faith (1966) as it moves towards Cape

Recent Decades

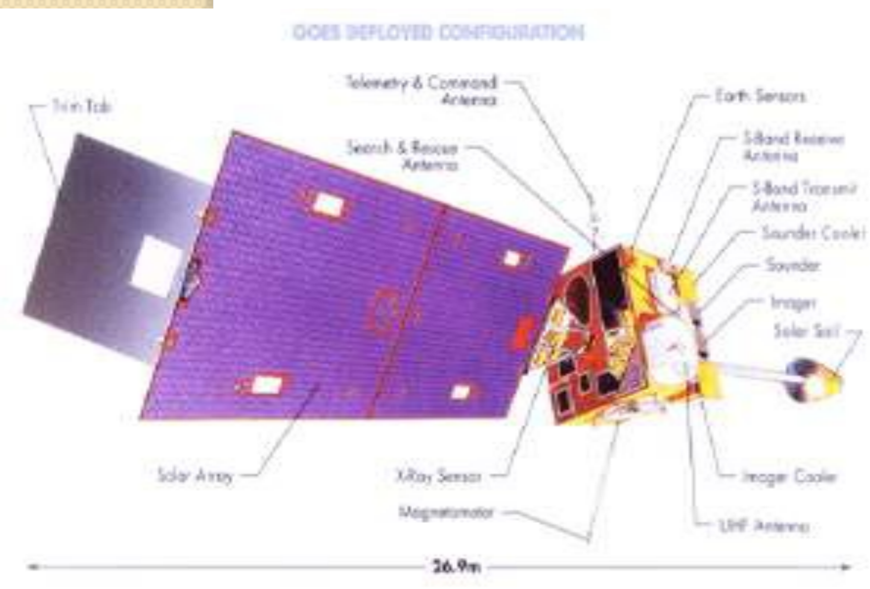
- Since the mid-1960s, no undetected TCs anywhere on Earth.
- GOES 1: The first truly operational geo stationary metsat was launched in Oct. 1975.
- **Defense Meteorological Satellite Program** (**DMSP**) satellites (SSM/I, SSMIS on DMSP):
    - Initiated by US Department of Defense (DOD) in 1973
    - Provides cloud cover imagery from polar orbits that are sun-synchronous at nominal altitude of 450 nautical miles (830 km)
    - On June 1, 1998 the control and maintenance of the satellites were transferred to National Oceanic and Atmospheric Administration (NOAA) in order to reduce costs..

Defense Meteorological Satellite Program (DMSP)

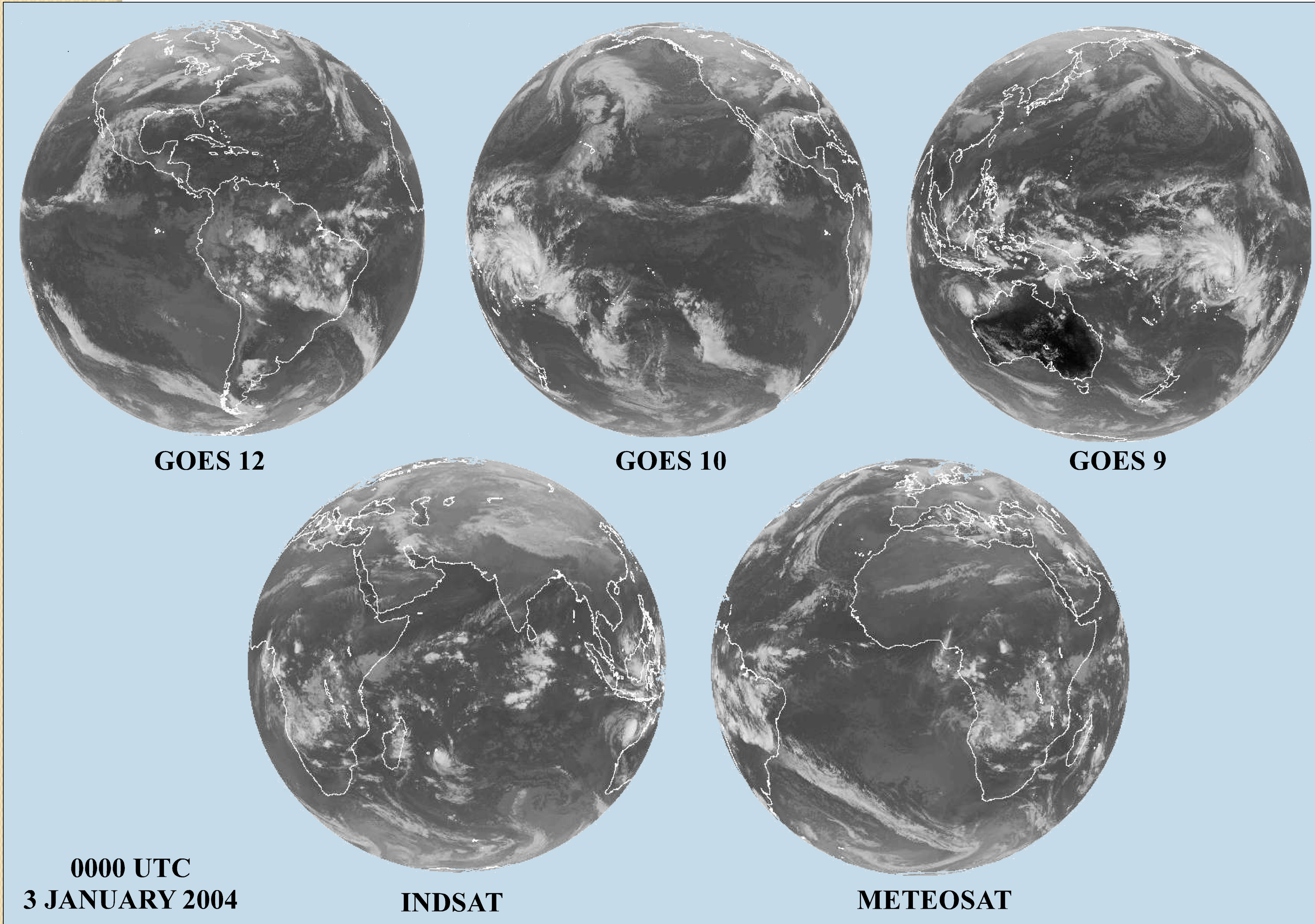




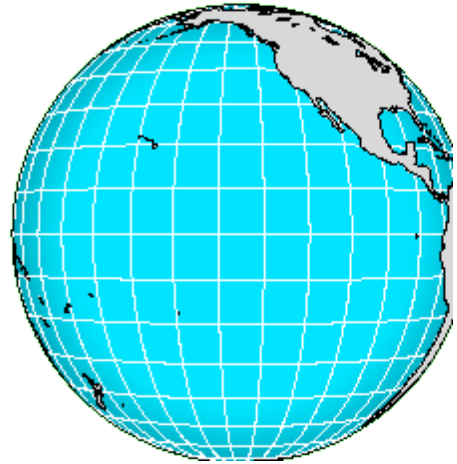
GOES: Geostationary Operational Environmental Satellite



Previous Geostationary satellite coverage (2004)



Current Geostationary satellite coverage (2015)

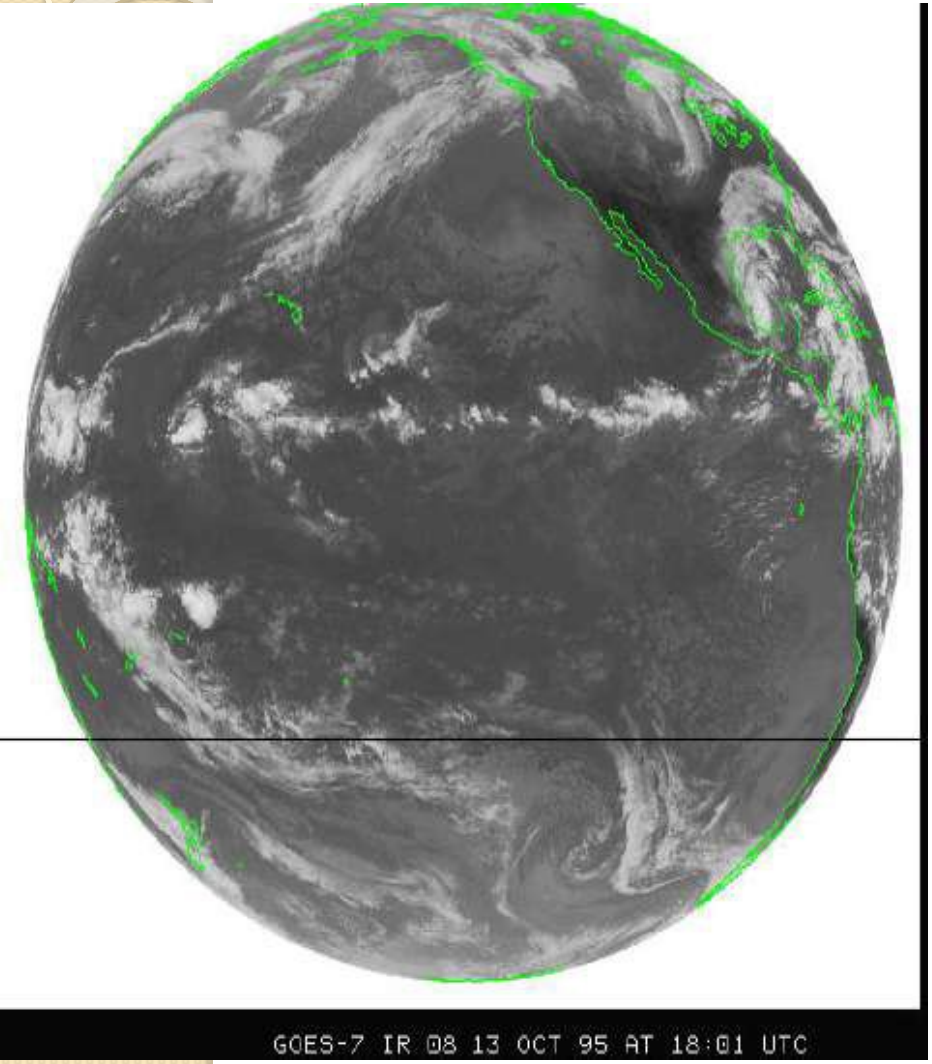


GOES-EAST: U.S. satellite, GOES-13 now at 75 deg west (launched in 2010)

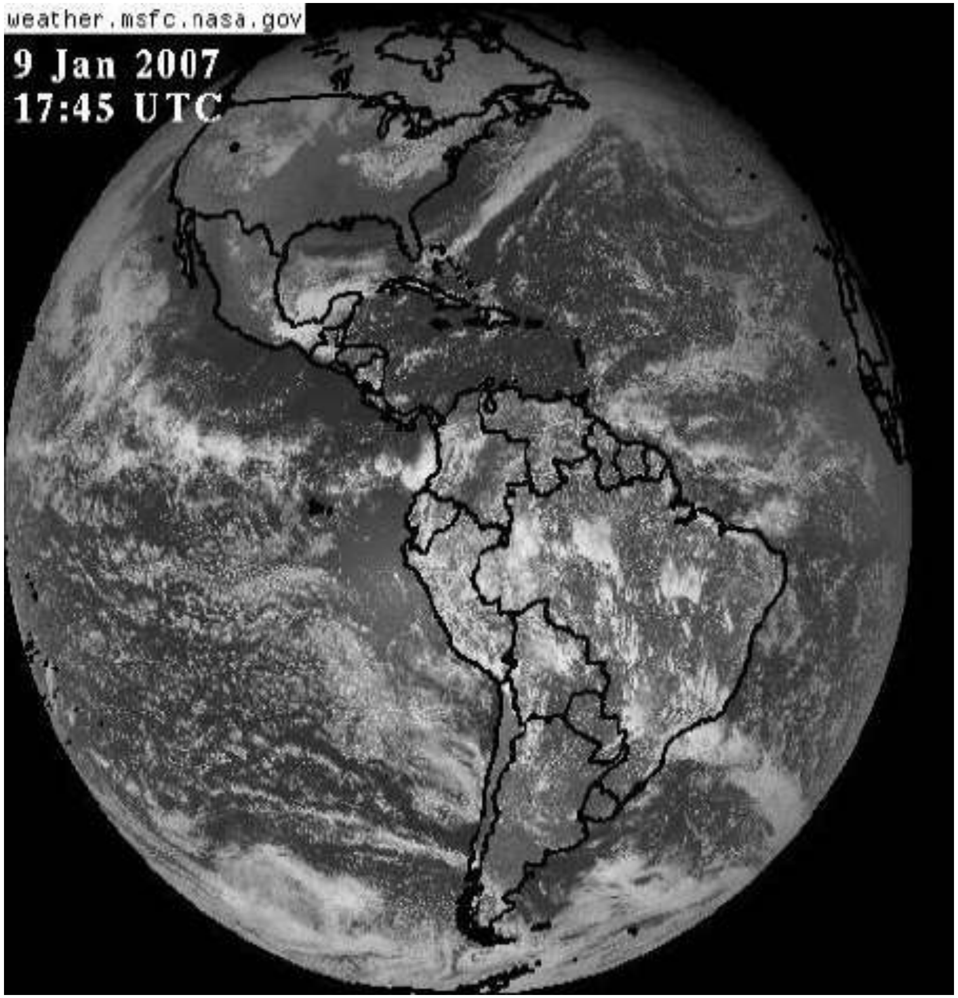
GOES-WEST: U.S. satellite, GOES-15 (launched in 2011) now at 135 degrees west

- Russia's new-generation weather satellite Elektro-L 1 operates at 76°E over the Indian Ocean.
- The Japanese have the MTSAT-2 located over the mid Pacific at 145°E and the Himawari 8 at 140°E.
- The Europeans have Meteosat-8 (3.5°W) and Meteosat-9 (0°) over the Atlantic Ocean and have Meteosat-6 (63°E) and Meteosat-7 (57.5°E) over the Indian Ocean.
- India also operates geostationary satellites called INSAT which carry instruments for meteorological purposes.
- China operated the Fengyun (风云) geostationary satellites FY-2D at 86.5°E and FY-2E at 123.5°E, which are no longer in use.

Hemispheric Views from GOES

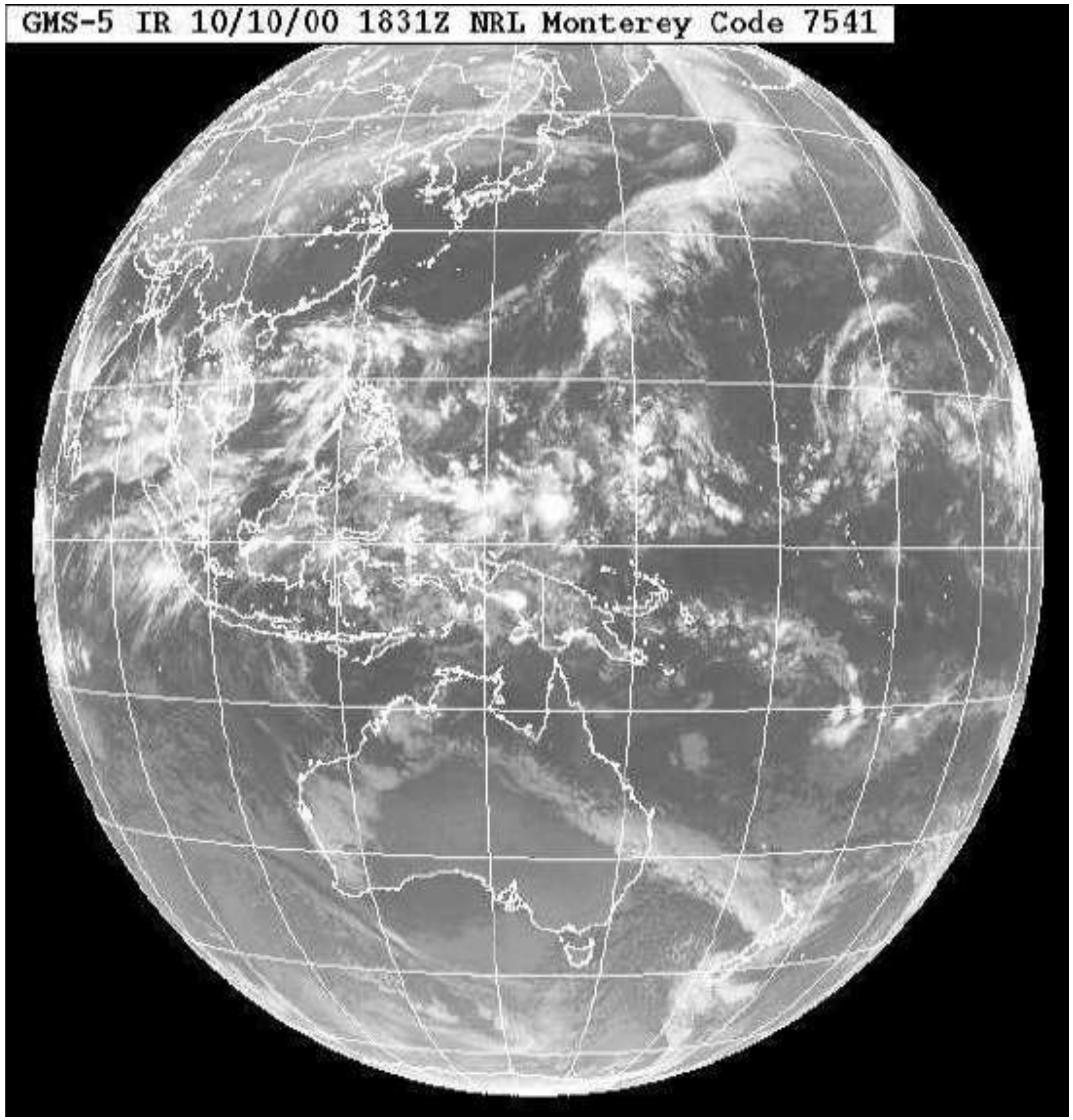


GOES West IR

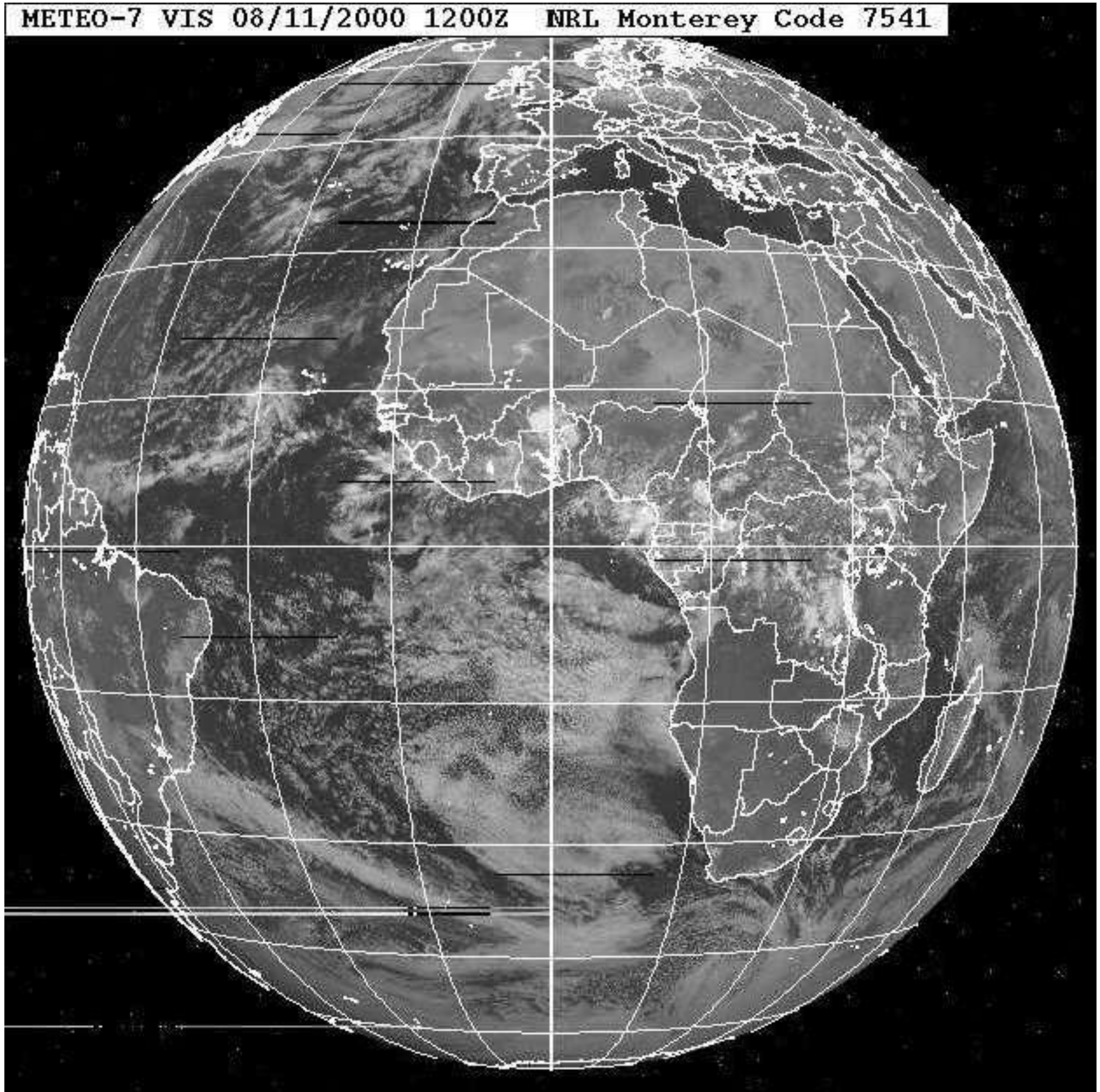


GOES East VIS

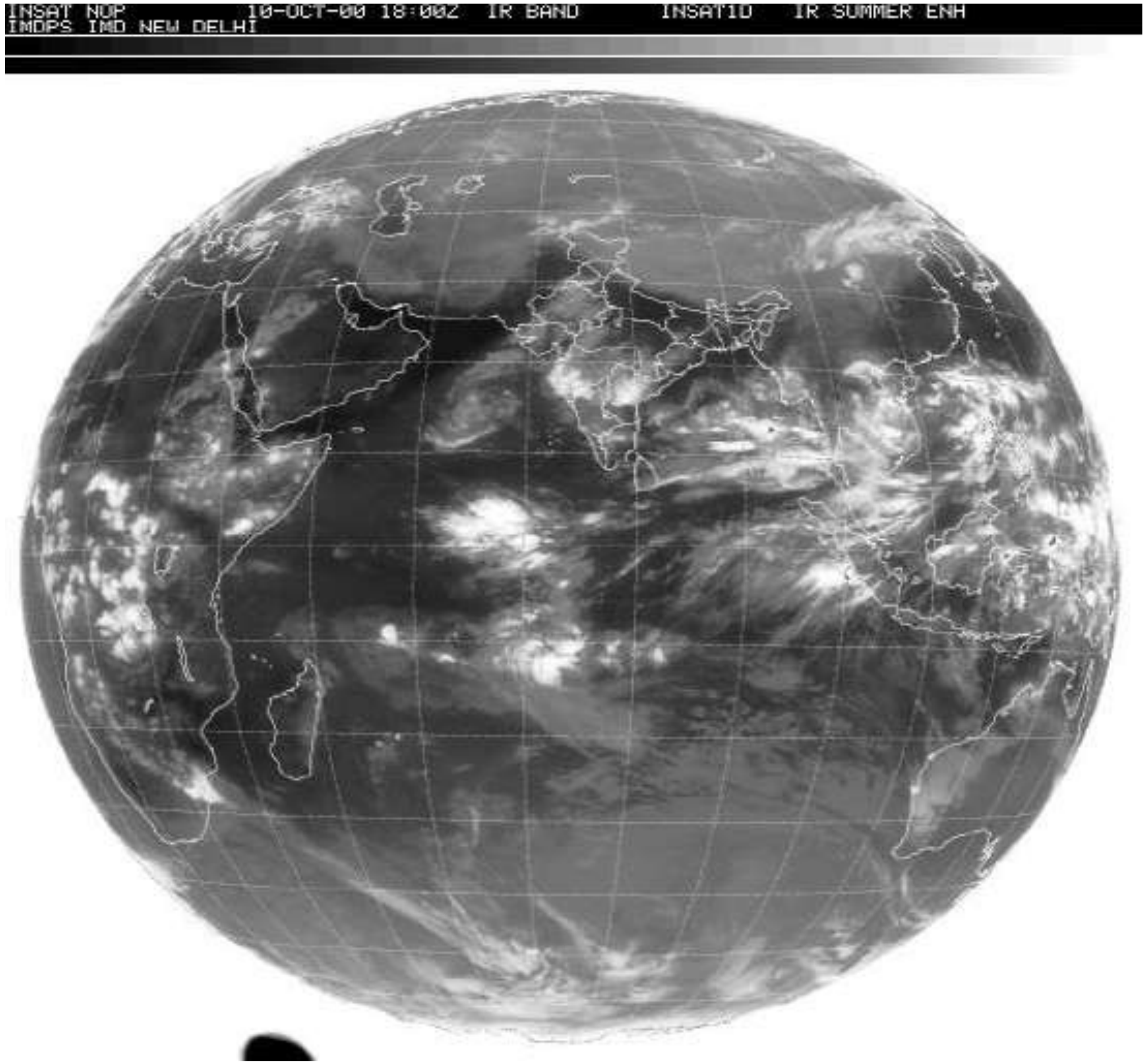
GMS: Geostationary Meteorological Satellite (Japan)



Meteosat: the European geostationary metsat

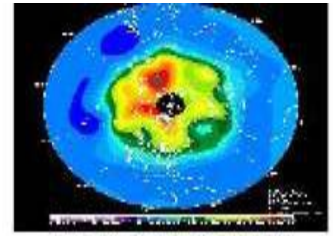


INSAT: the Indian geostationary metsat



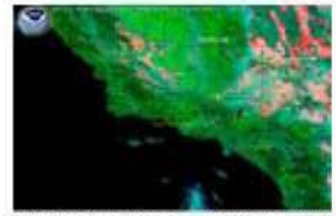
POES: **Polar Orbiting Operational Environmental Satellite**

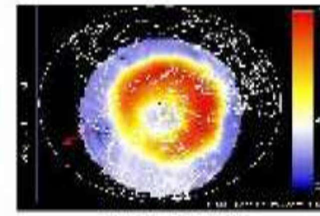

Hurricane Isabel
NOAA-15, AVHRR

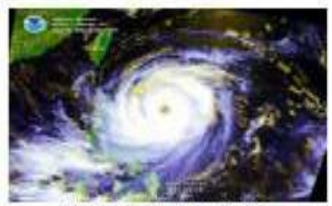

Total Ozone Product
NOAA-16, SBUV

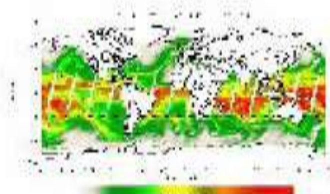

Icebergs in Antarctica
NOAA-16, AVHRR

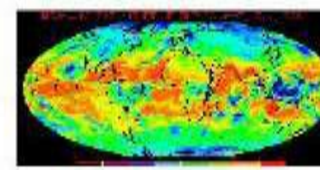

Snow and Sea Ice Product
AVHRR and AMSUs

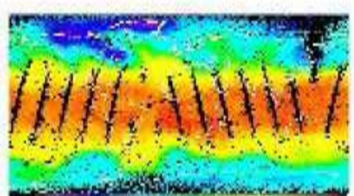

Heat signatures and smoke from
Pine, Foothill, and Crown Fires
Los Angeles County, CA
NOAA-16, AVHRR


Auroral Oval
Northern Hemisphere
NOAA-17, SEM-2

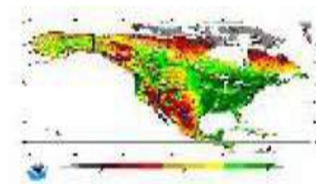

Typhoon Mindulle
NOAA-17, AVHRR


Total Precipitable Water
NOAA-16, AMSU-A

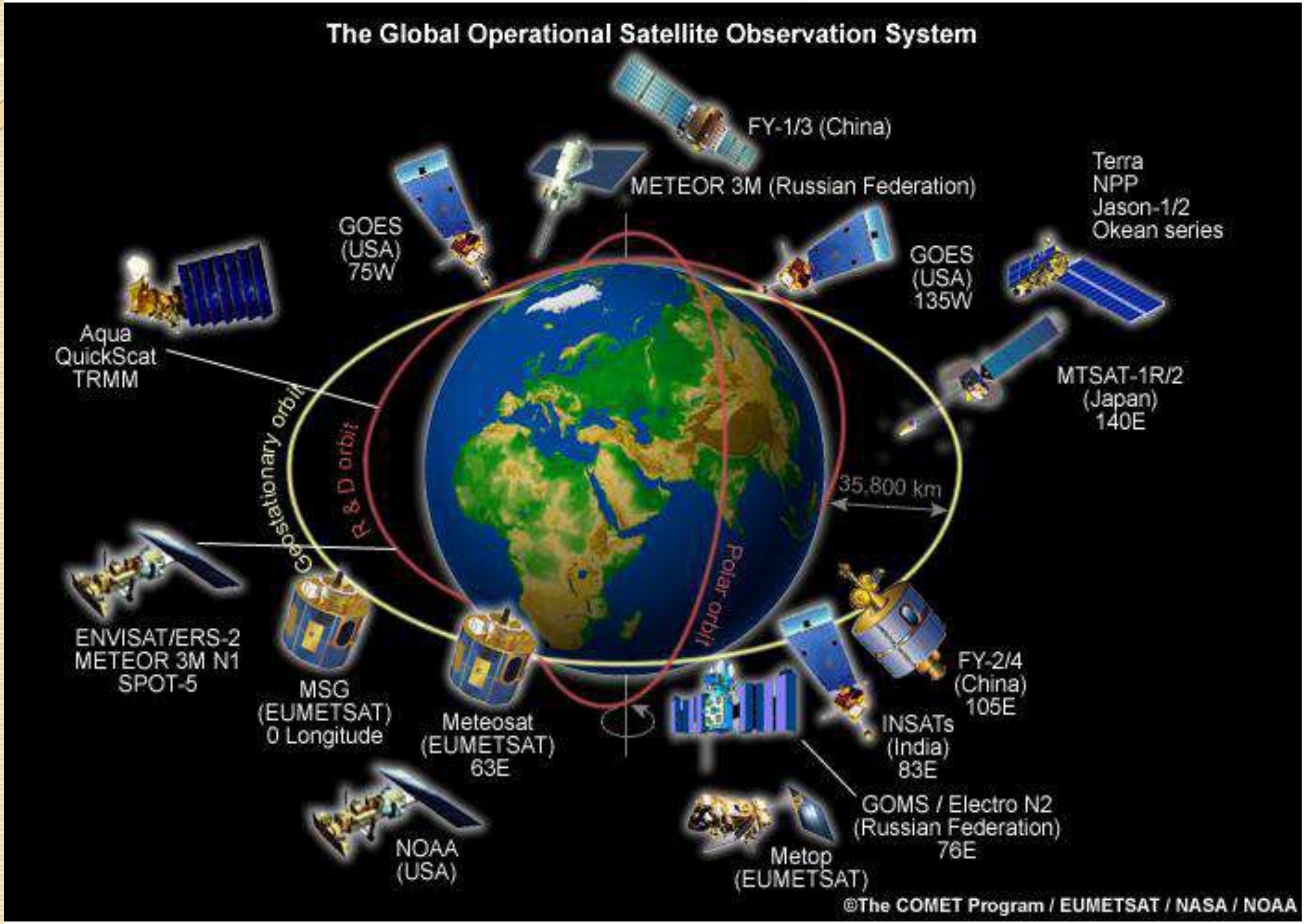

NESDIS AVHRR Outgoing
Longwave Radiative (OLR)
NOAA-16, AVHRR


Global Atmospheric
Temperature Profiles
NOAA-16, AMSU-A, HIRS, and


Snow Cover
Plains and Midwest
NOAA-16, AVHRR (HRPT)


Green Vegetation Fraction
for North America
AVHRR

Worldwide Network of Meteorological Satellites (till 2014)



Status of Current and Future Satellites Contributing to the WMO Integrated Global Observing System (WIGOS)

Core Meteorological Satellite Programmes Contributing to WIGOS		
Geostationary orbit	Current GEO Satellites	Future GEO Satellites
Sun-synchronous	Current Sun-sync. Satellites	Future Sun-sync. Satellites

Sustained or R&D Satellite Programmes Contributing to WIGOS		
Highly elliptical or geosynchronous orbit	Current HEO Satellites	Future HEO Satellites
Low Earth orbit	Current LEO Satellites	Future LEO Satellites
Specific orbits (for space weather)	Current other Satellites	Future other Satellites

http://www.wmo.int/pages/prog/sat/satellitestatus.php

Summary 1 (Radar)

- The history of radar is very closely linked to the history of radio.
- World War II stimulated the development of
radar, and radar meteorology.
- The invention of cavity magnetron opened the door for real radar development.
- Radar meteorology is closely related to precipitation and cloud microphysics.

Summary 2 (satellite)

- Satellite remote sensing science started with the
development of cameras in the mid 19th century.
- The development of aircraft and rockets, particularly during WWII, made meteorological remote sensing possible.
- Low earth orbiting satellites (TIROS, DMSP) operational became operational in the 60's.
- High earth orbiting (geostationary) satellites such as GOES became operational in the 70's.
- Both are used for a wide range of geophysical applications in addition to meteorology.