Outline of 4 Lectures

1. Sept. 17, 2008: **TC best track definition and datasets, global distribution of TCs; Review of history of meteorological satellites, introducing different orbits, scanning patterns, and space-time samplings. Also introduce the differences between the satellites and the instruments.**

2. Sept. 19, 2008: Introduction of space borne instruments including visible, IR and microwave. Will briefly talk about radiative transfer theories in different channels and rainfall retrieval algorithms from IR and microwave.

Problem set: Due on the 3rd lecture day

3. Oct. or Nov. ?: Current status of TC intensity and rainfall forecasts. Introduction of satellite-based TC intensity and rainfall prediction techniques, including DVORAK, SHIPs, and R-CLIPER.

4. Oct. or Nov. ?: Convective properties of tropical cyclones. An introduction of TRMM-based TCPF database. Climatology of tropical cyclone rainfall and its contribution to global precipitation.

Outline for Today (Sept. 17, 2008)

1. Best Track

2. Global Distribution of TCs

3. History of meteorological satellites

4. Different orbits, scanning patterns, and space-time samplings.

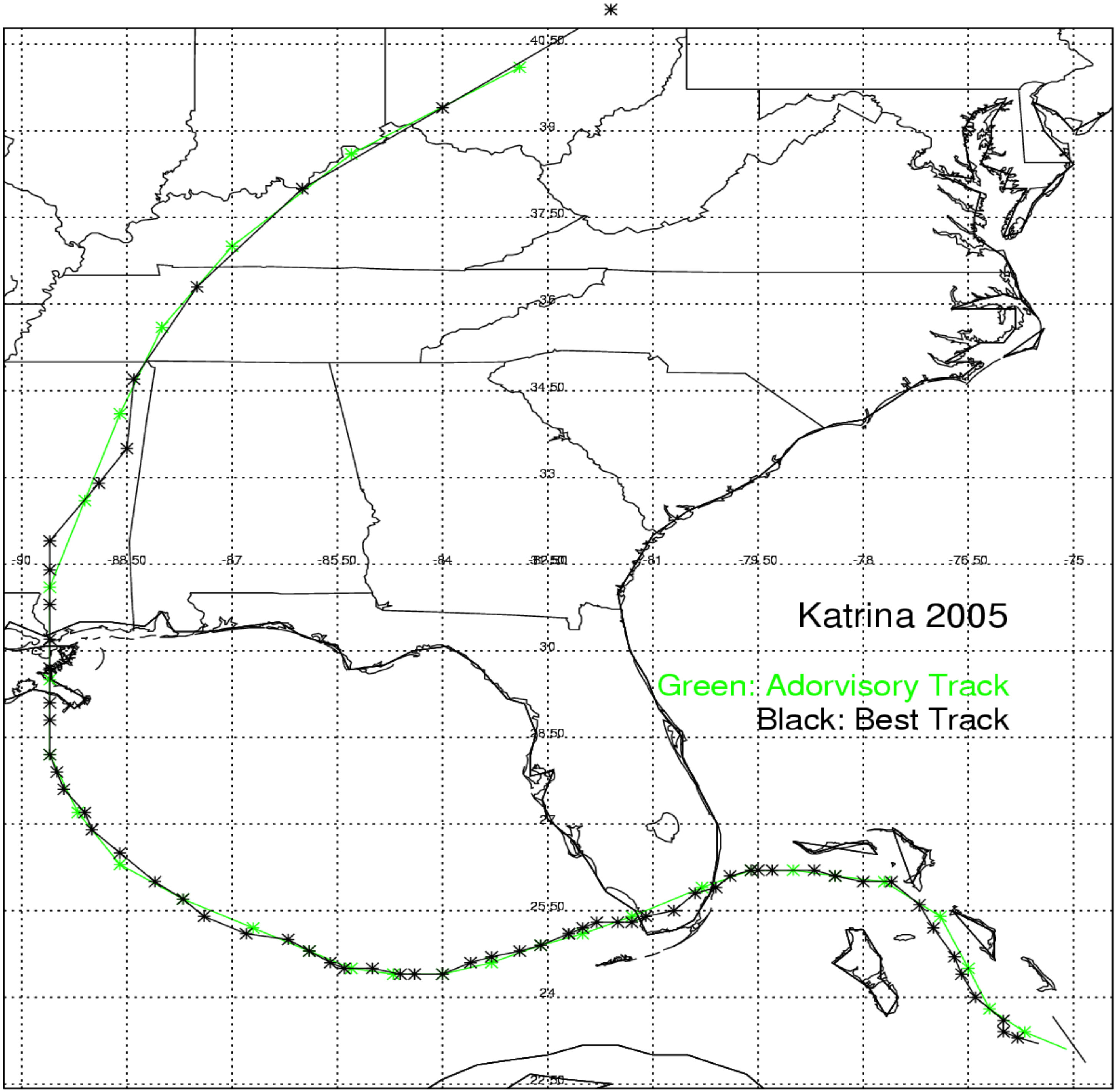
5. Differences between the satellites and the instruments.

What is “best track”?

Best Track:

A subjectively-smoothed representation of a tropical cyclone's location and intensity over its lifetime. The best track contains the cyclone's latitude, longitude, maximum sustained surface winds, and minimum sea-level pressure at 6-hourly intervals. Best track positions and intensities, which are based on a post-storm assessment of all available data, may differ from values contained in storm advisories.

ID	Name	YYYYMMDDHH				lat	Lon	MaxV	MinP					
199102	BOB	1991	8	16	0	25.6	74.3	25	1014	*	14	1	2	HR
199102	BOB	1991	8	16	6	25.7	74.9	25	1012	*	14	1	2	HR
199102	BOB	1991	8	16	12	25.9	75.4	30	1010	*	14	1	2	HR
199102	BOB	1991	8	16	18	26.4	75.8	35	1005	*	14	1	2	HR
199102	BOB	1991	8	17	0	27.1	76.2	40	1003	*	14	1	2	HR
199102	BOB	1991	8	17	6	27.8	76.5	45	998	*	14	1	2	HR
199102	BOB	1991	8	17	12	28.4	76.9	55	996	*	14	1	2	HR
199102	BOB	1991	8	17	18	29.0	77.1	65	986	*	14	1	2	HR
199102	BOB	1991	8	18	0	29.7	77.0	70	980	*	14	1	2	HR
199102	BOB	1991	8	18	6	30.5	76.9	75	979	*	14	1	2	HR
199102	BOB	1991	8	18	12	31.5	76.6	80	974	*	14	1	2	HR
199102	BOB	1991	8	18	18	33.0	76.1	85	965	*	14	1	2	HR
....														
....														
199102	BOB	1991	8	29	0	40.0	9.9	10	1015	E	14	1	2	HR


Katrina 2005
Green: Adorvisory Track
Black: Best Track
40.50
39
37.50
36
34.50
33
30
28.50
27
25.50
24
22.50
-90
-88.50
-87
-85.50
-84
-81
-79.50
-78
-76.50
-75

NHC and JTWC Best Tracks

http://www.nhc.noaa.gov/pastall.shtml

--Hurricane Best Track Files (HURDAT)

North Atlantic (1851-2007)

East pacific (1949-2007)

--Images of Past Tracks

https://metocph.nmci.navy.mil/jtwc/best_tracks/

-- Southern Hemisphere (1945-2007)

-- Northern Indian Ocean (1945-2007)

-- Western North Pacific Ocean (1945-2007)

-- Data only

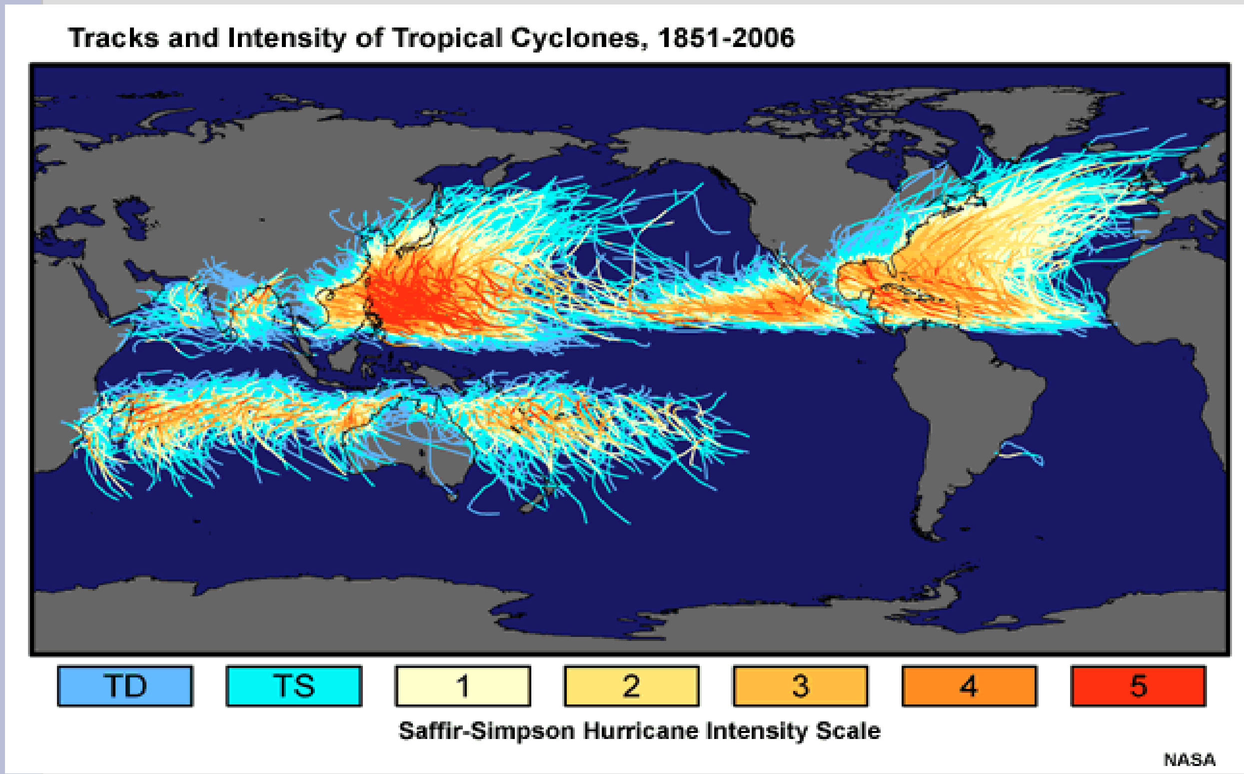
http://weather.unisys.com/hurricane/index.html

-- Sorted by year and 6 basins

-- Include advisory tracks as well as best track for recent years

-- Include both images and data

Global Distribution of Tropical Cyclones



Courtesy of the COMET program online text book "Introduction of tropical meteorology"

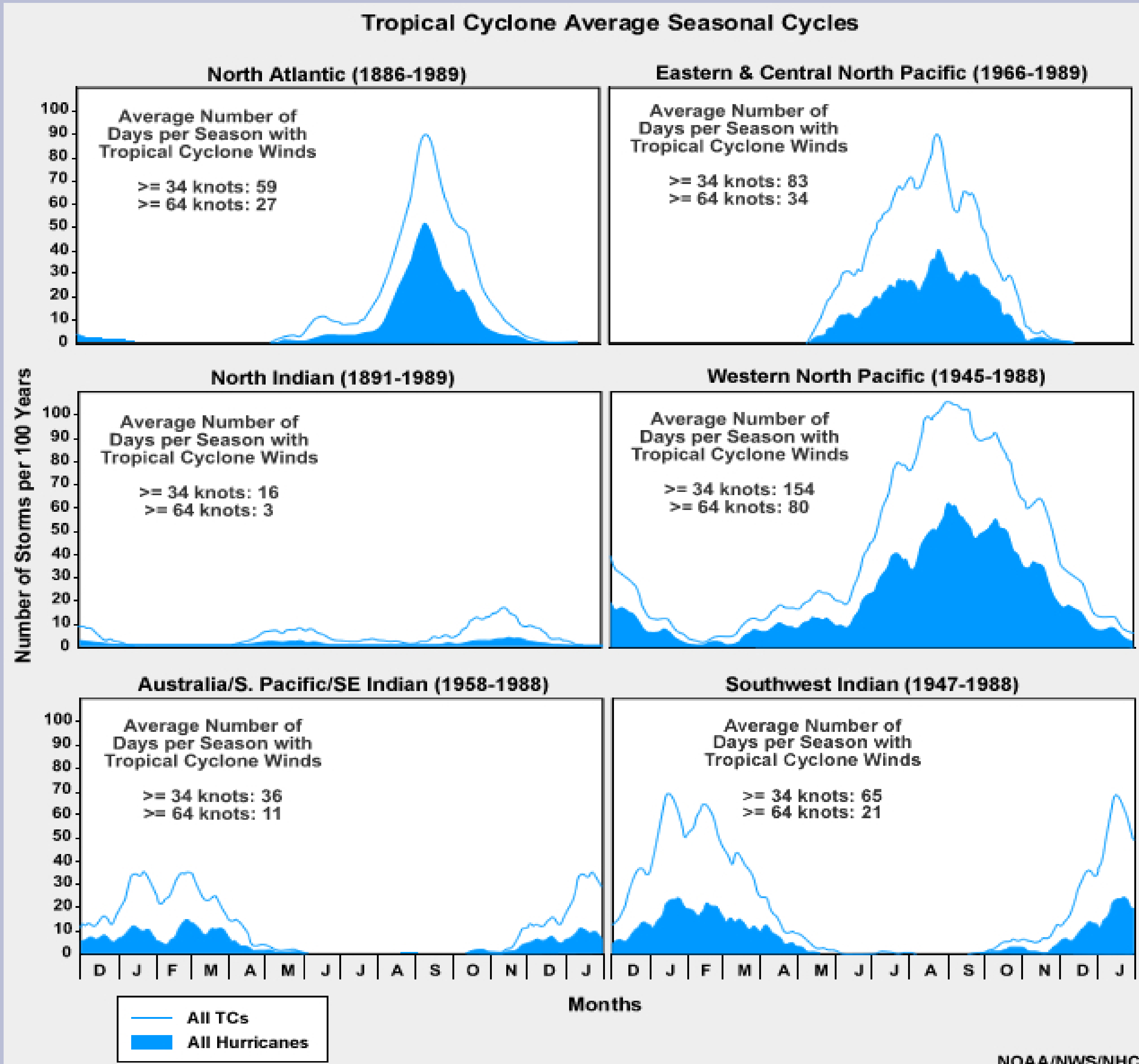
<u>TCs do not form very close to the equator and do not ever cross the equator;</u>

<u>Northern Hemisphere:</u>

- **The western North Pacific is the most active tropical cyclone region. It is also the region with the largest number of intense TCs;**
- **TCs in the western North Pacific and the North Atlantic can have tracks that extend to very high latitudes. Storms following these long tracks generally undergo extratropical transition;**
- **The North Indian Ocean (Bay of Bengal and Arabian Sea) is bounded by land to the north and the eastern North Pacific is bounded by cold water to the north. These environmental features limit the lifetimes of storms in these regions.**
- **The Bay of Bengal has about five times as many TCs as the Arabian Sea. The high mountain ranges and low-lying coastal plains and river deltas of the Bay of Bengal combine to make this region extremely vulnerable to TCs. Indeed, the two most devastating TCs on record occurred in this region.**

<u>Southern Hemisphere:</u>

- Southern Hemisphere (SH) tropical cyclones are generally weaker than storms in the North Pacific and Atlantic basins;
- The extension of the subtropical jet into tropical latitudes in the SH acts to constrain the tracks of tropical cyclones. Even so, a few SH tropical cyclones undergo extratropical transition;
- Although rare, systems resembling tropical cyclones can occur in the South Atlantic Ocean and off the subtropical east coasts of Australia and southern Africa.



TC season:

ATL: 1 Jun - 30 Nov

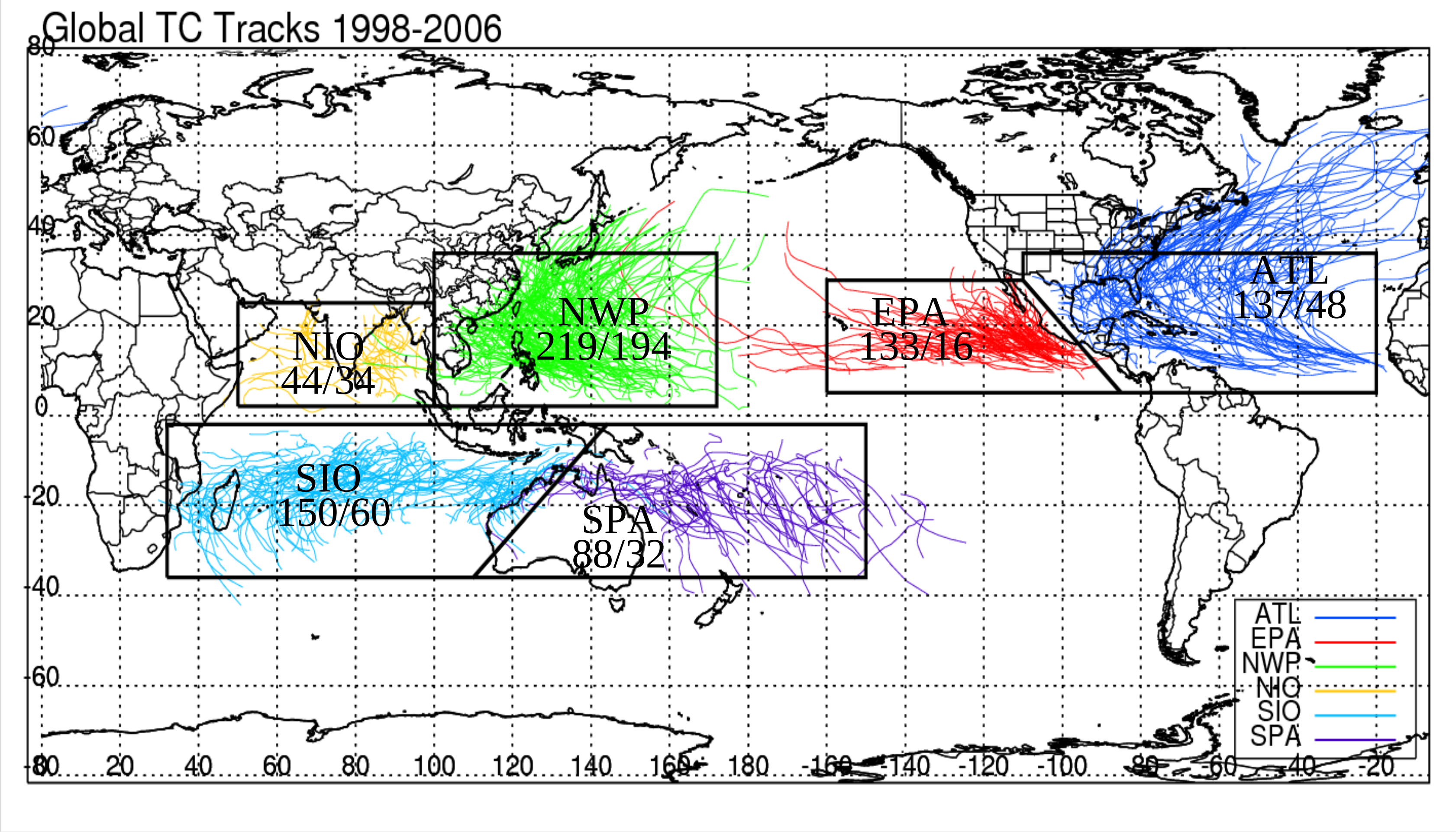
EPA: 15 May - 30 Nov

NIO: TCs tend to occur in the monsoon transition months of early (May-June) and late in the wet season (October-November).

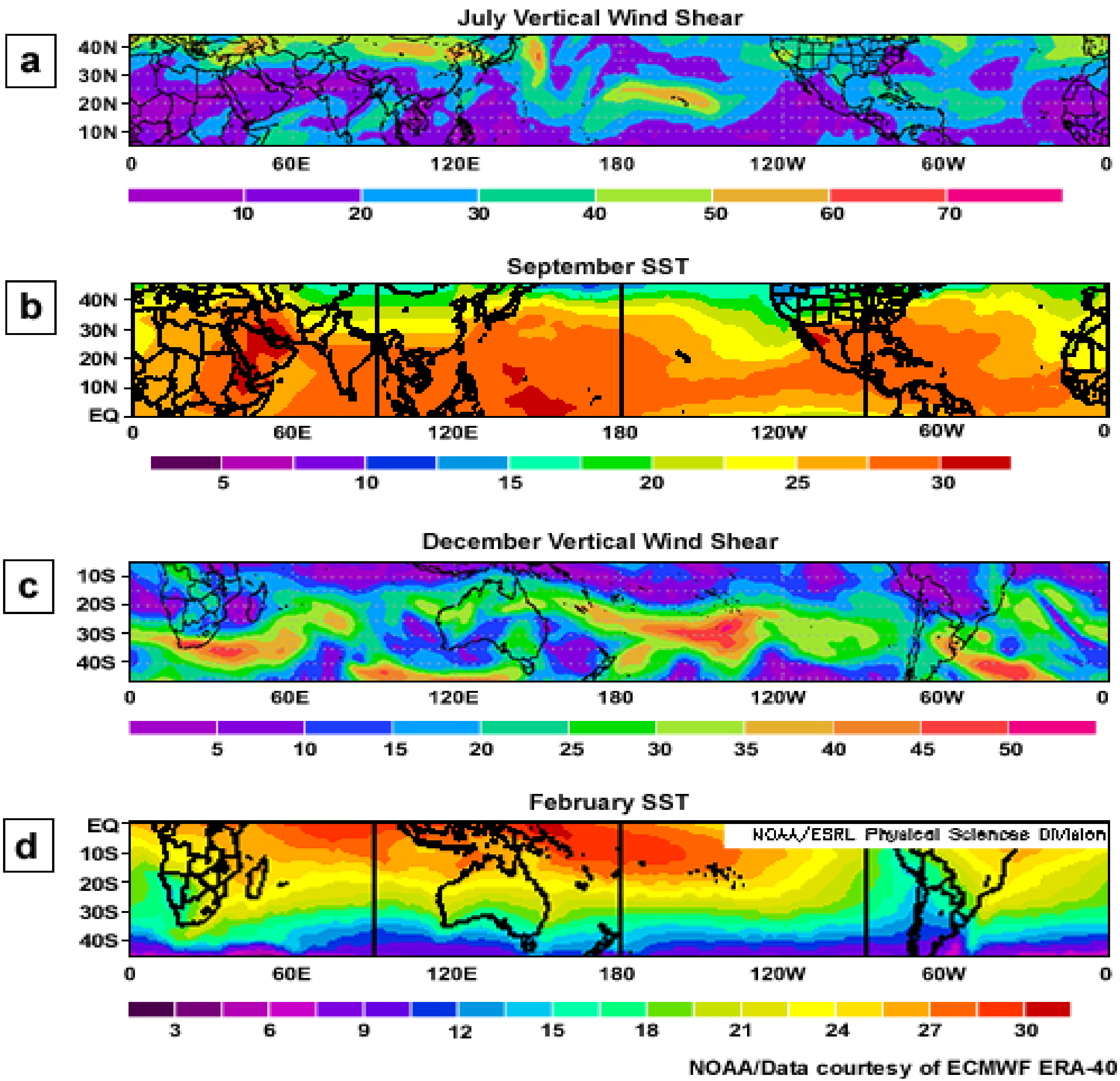
NWP: TC could occur every month, but mainly during Jun. through Nov.

SPA & SIO: Nov. - Apr.

1998-2006 TC/lanfalling TC Numbers in Each Basin

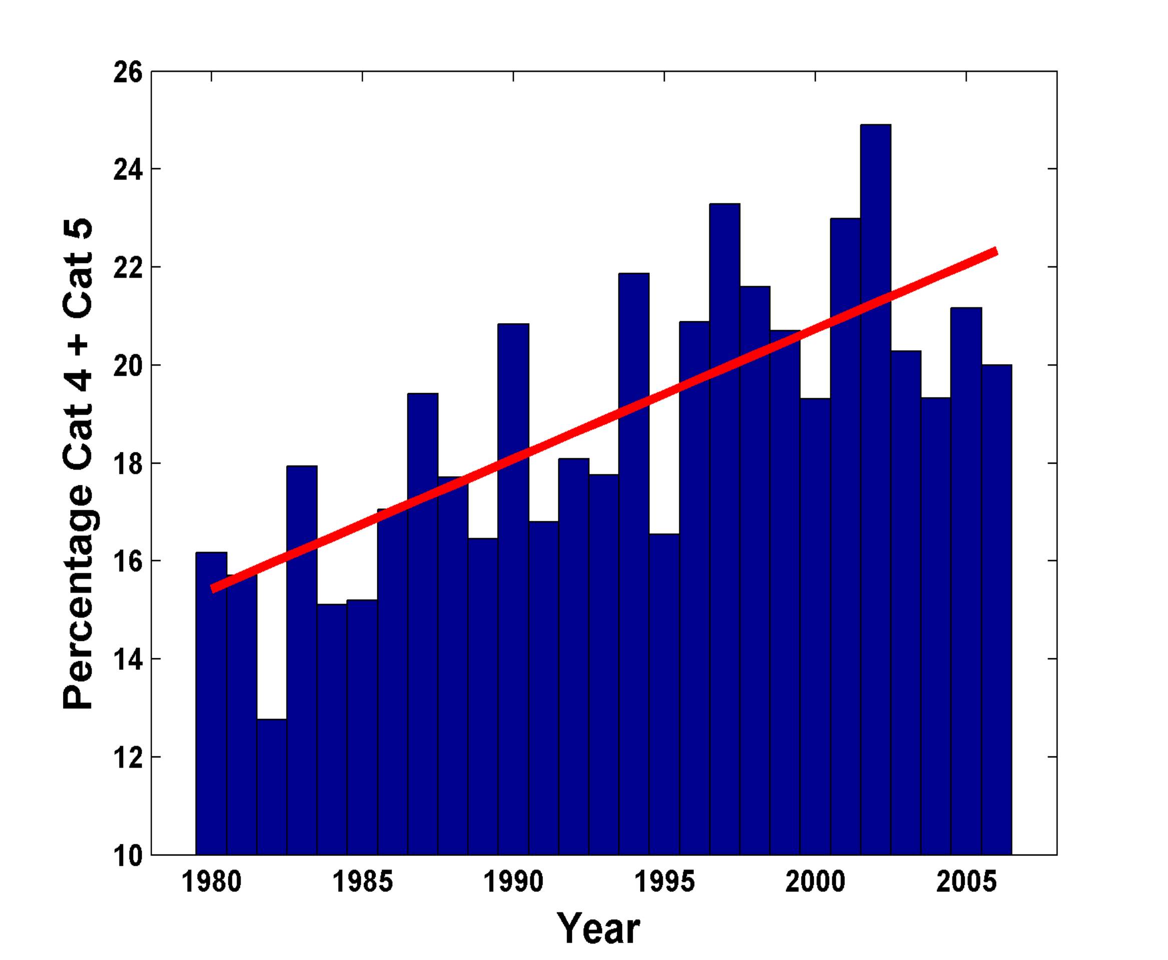


Monthly diagnostics of 850-200 hPa vertical wind shear (1958-2002 in m s^{-1}) and sea surface temperature (1977-2006 in °C)



Change in Numbers of Intense TC:Global Warming or Multi-Decadal Variability?

Judy Curry-----
"So for the studies that have actually examined changes in major or cat 4+5 TCs, here is a summary of what we have:
1) Webster et al. (2005): doubling of % of cat 4+5 TCs (1970-2005).
2) Kuleshev et al. (2008): tripling of SH TCs less than 949 mb (1980-2005)
3) Emanuel (personal communication): 50% increase of % Cat 4+5 TCs (1980-2007)
4) Elsner et al. (2008): 31% increase in % cat 3+ TCs per 1oC SST increase"



Elsber et al. (2008)

History of Meteorological Satellites (metsats)

1. **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.

2. **Explorer 6: the satellite with meteorological instruments** launched in Aug. 1959, carried an imaging system and a Suomi radiometer. The data were unusable too.

3.**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.

4. **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

5. **TIROS series:** TIROS 1-10 (1960-1965) -- with improved meteorological instruments.

6. **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).

Current Global Metsat Observation System

7. Since the mid-1960s, no undetected TCs anywhere on Earth.

8. GOES 1: The first truly operational geo stationary metsat was launched in Oct. 1975.

Different orbits, scanning patterns, and space-time samplings.

Satellite Orbits: 1

1. Geostationary orbits:

Geostationary satellites orbit in the earth's equatorial plane at a height of 38,500 km. At this height, the satellite's orbital period matches the rotation of the Earth, so the satellite seems to stay stationary over the same point on the equator.

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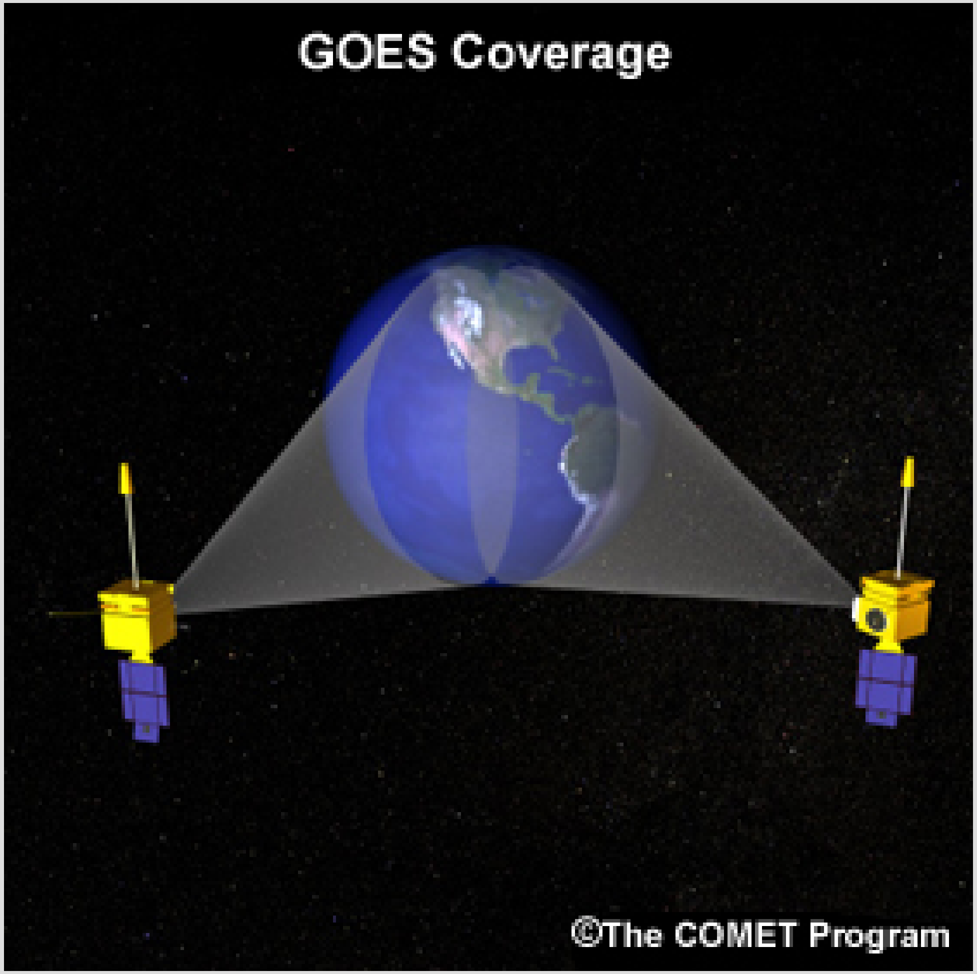
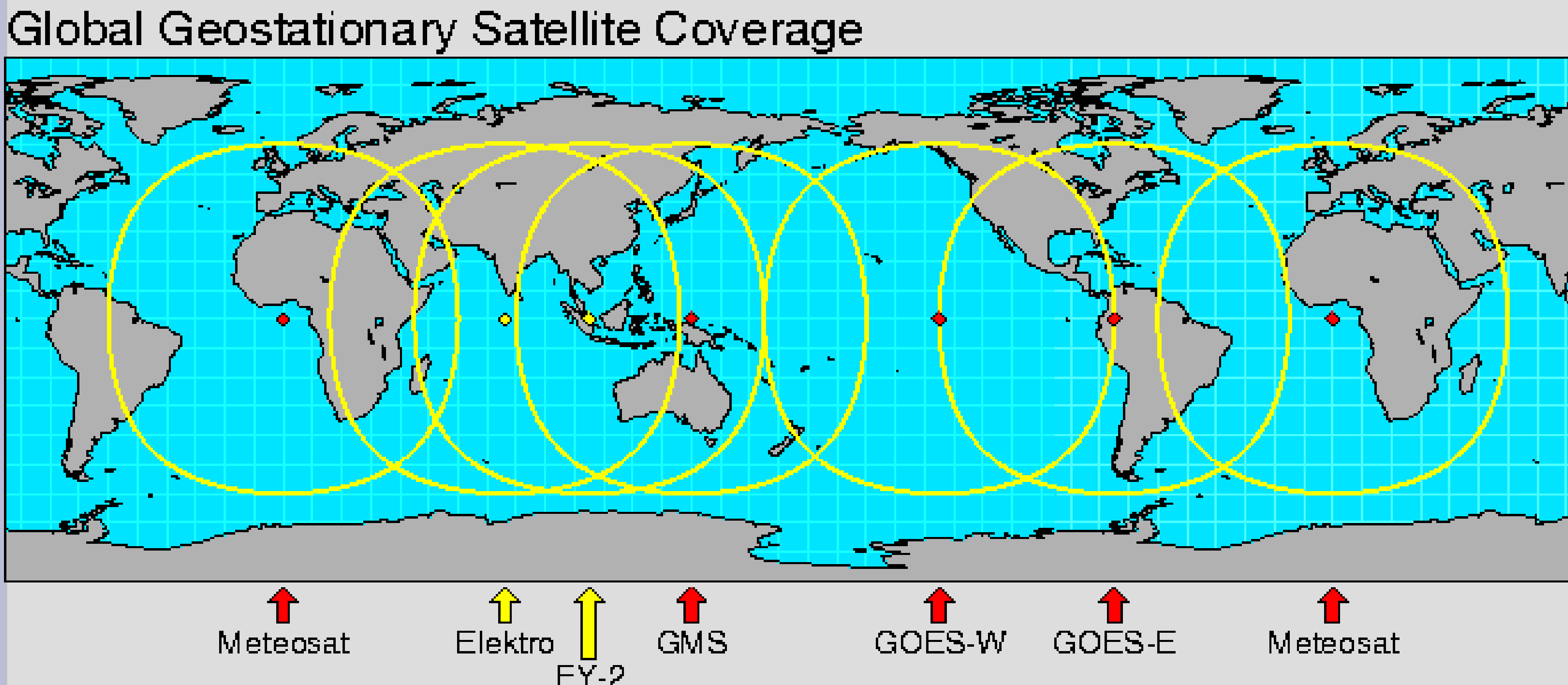
GOES US coverage



Geostationary Satellite Coverages



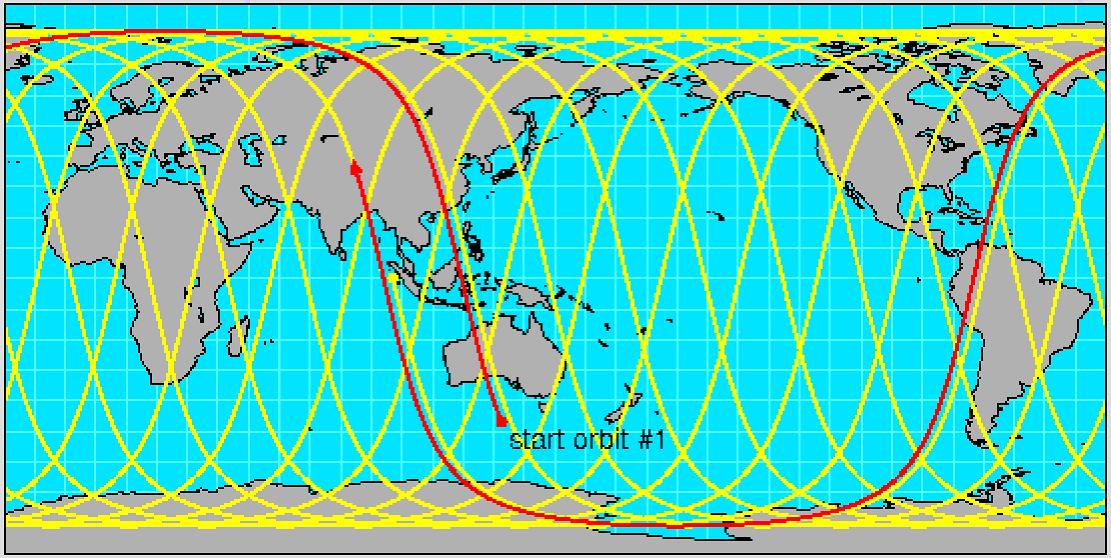
Facts for Geostationary Orbits

1. **Continuous observation and high temporal resolution**: Since the field of view of a satellite in geostationary orbit is fixed, it always views the same geographical area, day or night. This is ideal for making regular sequential observations of cloud patterns over a region with visible and infrared radiometers. High temporal resolution and constant viewing angles are the defining features of geostationary imagery. Good for diurnal variation studies.

2. **Spatial resolution**: Geostationary satellites sensors are most useful for tracking atmospheric features over great distances because of their high temporal resolution (15 – 30 minute intervals) and hemispheric field of view . However, the orbital distance of the satellites means that their spatial resolution is less than optimal for the identification of features smaller than 1km.

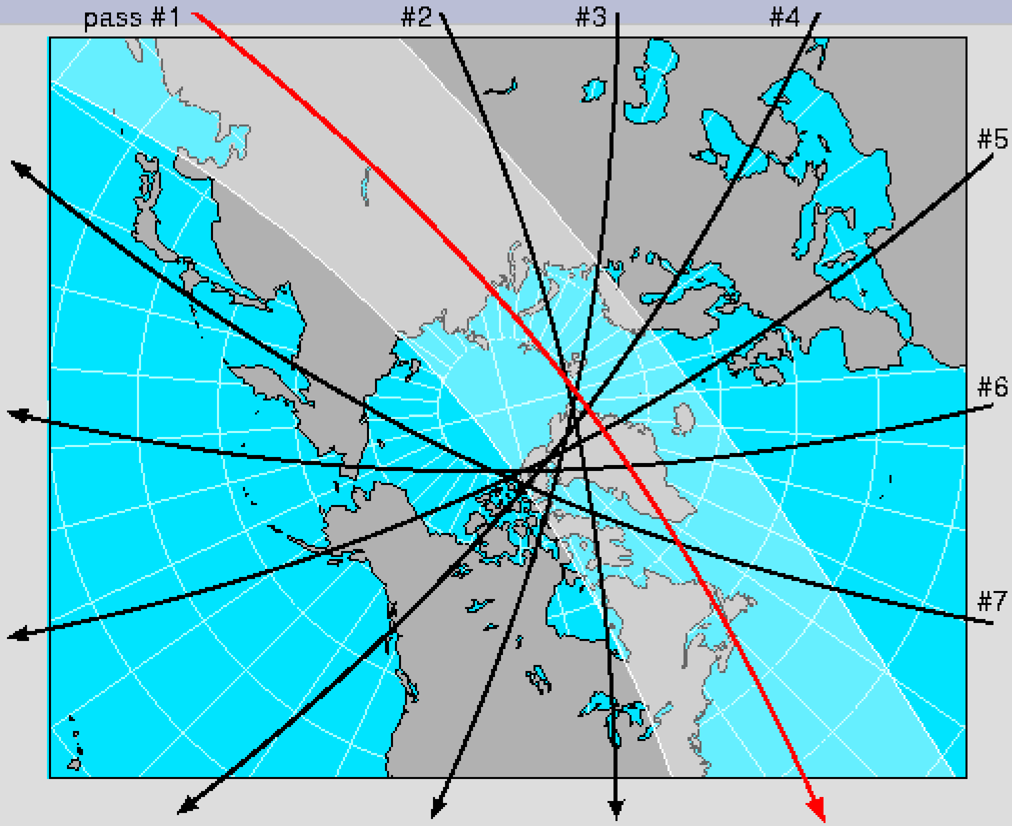
Satellite Orbits: 2

2. **Sun-synchronous near-polar orbits, also referred as polar orbits:**
On this orbit the Metsat passes over any given point on the Earth's surface at the same local solar time. Polar-orbiting satellites are around the poles at approximately **850 km** above the surface. Satellites in this category include the NOAA Polar-orbiting Operational Environmental Satellites (POES), satellites of the Defense Meteorological Satellite Program (DMSP) , the European Space Agency's MetOp, National Polar-orbiting Environmental Satellite System (NPOESS), A-Train constellation, QuikScat, and Global Precipitation Mission (GPM).
-- Inclination angle: the highest latitude reached by the subsatellite point. About 98.7 degree for sun-synchronous orbits.
-- Animation: http://www.meted.ucar.edu/EUMETSAT/eps/leo_ani.htm

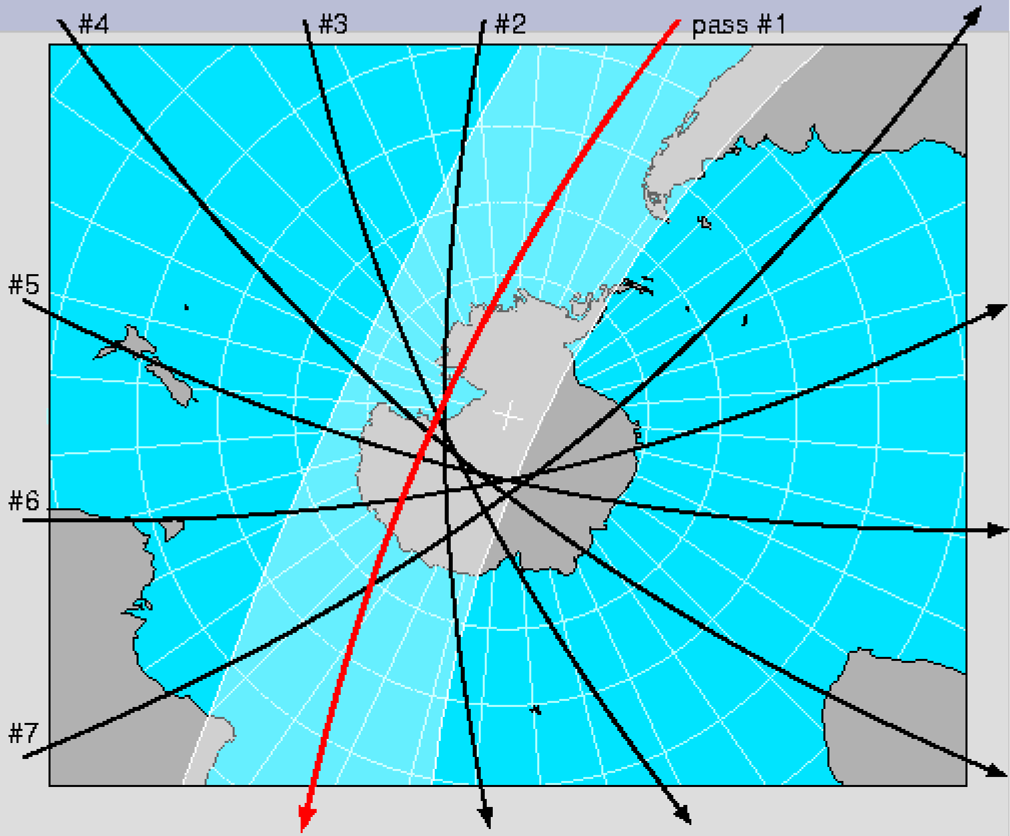


14 orbital tracks for a sun-synchronous satellite in near-polar orbit.: Daily coverage.

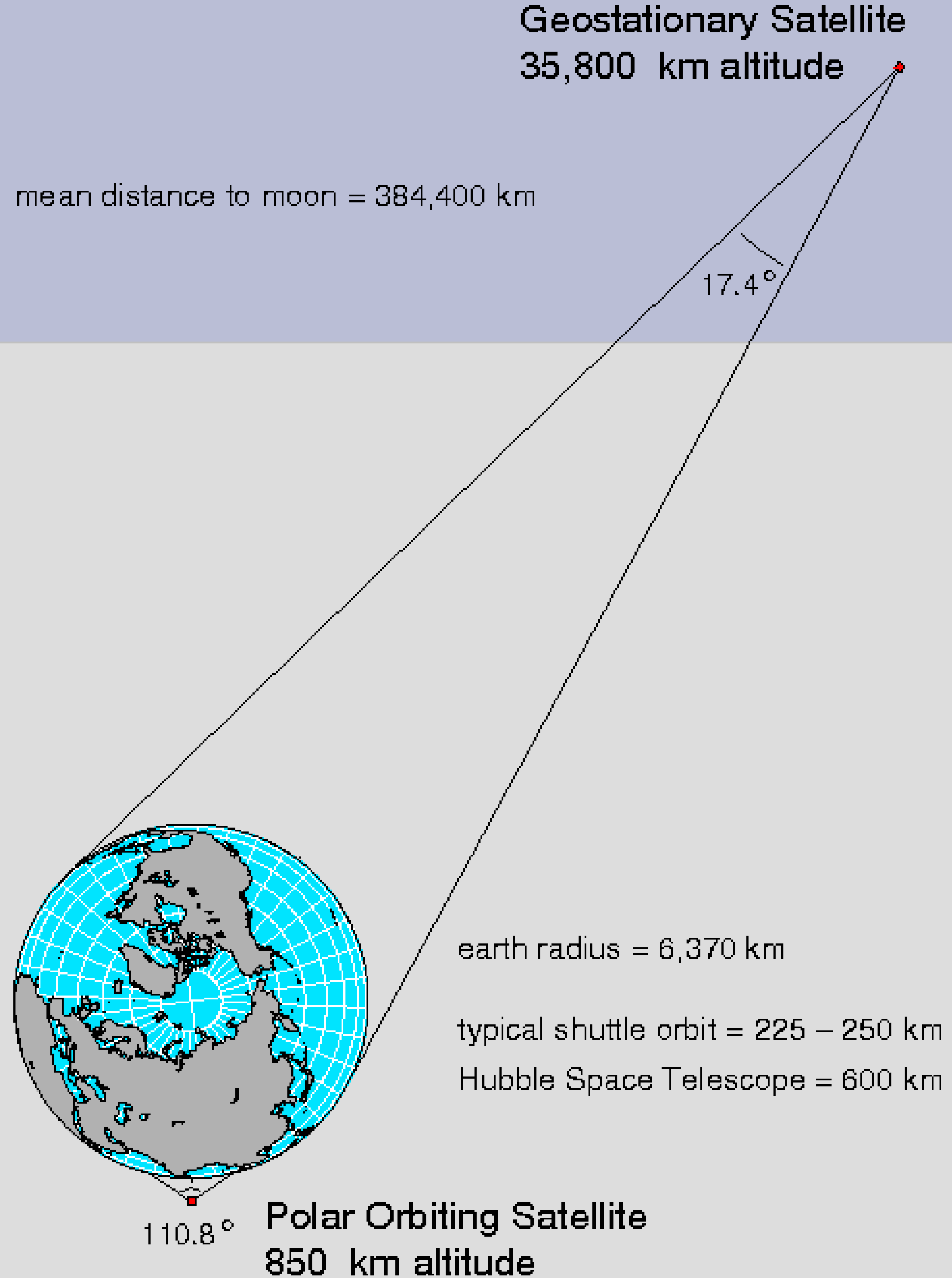
http://www.rap.ucar.edu/~djohnson/satellite/coverage.html



POES coverage of north polar regions
in a half day



POES coverage of south polar regions
in a half day


Geostationary Satellite
35,800 km altitude
mean distance to moon = 384,400 km
17.4°
earth radius = 6,370 km
typical shuttle orbit = 225 – 250 km
Hubble Space Telescope = 600 km
110.8°
Polar Orbiting Satellite
850 km altitude

Facts for Polar Orbits

1. Due to its shorter distance to the Earth, a polar orbiting satellite provides **superior spatial resolution** over a small field of view (on the order of 100 to 1000km).

2. **Global coverage from a single satellite.**

3. Polar orbiting satellites pass the equator **at most twice a day** at same local times: one is descending, the other is ascending.

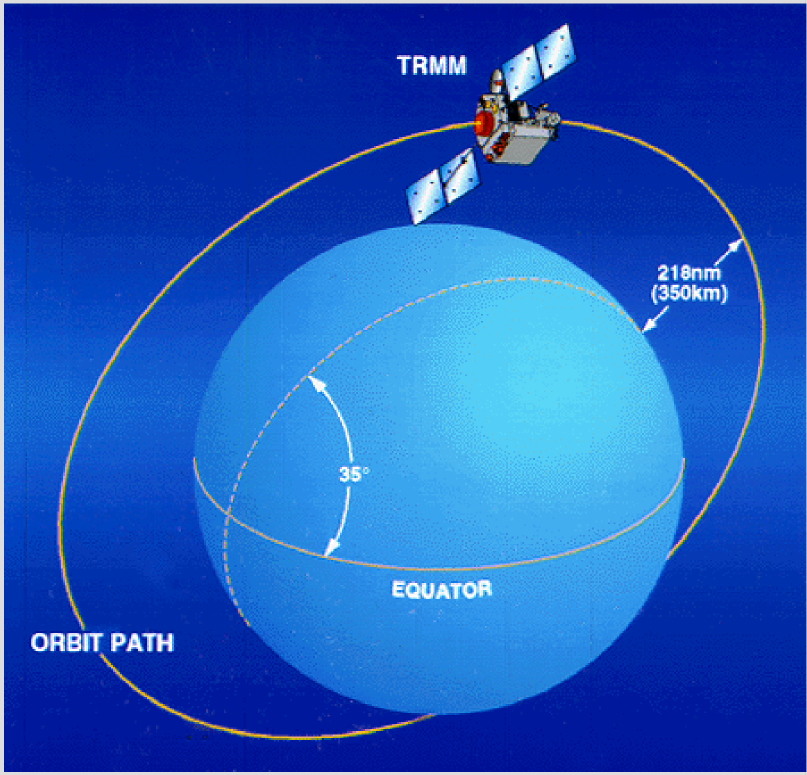
4. For studies of diurnal variation, a point must be observed at local times throughout the day. Since polar orbiting satellites view a point at nearly the same two local times everyday, they are **not useful for diurnal variation studies**.

Satellite Orbits: 3

2. Other orbits: research and development which orbit between certain latitudes a few hundred km above the surface (lower Earth orbits)

-- Example: The TRMM orbit is circular and is at an altitude of 350 km and an inclination of 35 degrees to the Equator. TRMM flies over each position on the Earth's surface at a different local time each day. So it is good for diurnal variation studies.

-- Animation of TRMM orbit
http://earthobservatory.nasa.gov/Library/TRMM/



Satellite Instruments

Instruments are sensors on board satellites. Meteorological observations are taken by instruments.

For example,

Instrument	**Satellite**
PR	TRMM
TMI	TRMM
SSM/I	DMSP F14
SSM/I	DMSP F15
CPR	CloudSat
MODIS	Terra
MODIS	Aqua
SeaWinds	QuikSCAT
SeaWinds	NSCAT

Before you use any data from an instrument, you should know...

1. Frequencies/Channels: visible, IR, microwave, or other...
2. Footprints on each channel: spatial resolution
3. Scanning geometry: conical or cross-track or along track
4. Measured/retrieved physical parameters
5. Data dimensions

Satellite Instrument Scanning Geometry

Animation of Satellite Instrument Scanning Geometry:
1. Conical (SSM/I, TMI, etc)
http://www.meted.ucar.edu/npoess/microwave_topics/res

2. Cross-track (TRMM PR)
http://www.meted.ucar.edu/npoess/microwave_topics/resourc

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How to calculate the altitude of a GEOS satellite

Balance between centripital force (mv^2/r) and gravity force (GMm/r^2):

Angular velocity of earth: 7.3×10^{-5} rad/s (=2xPI/T)

Orbital constant: $GM = 3.986 \times 10^{14}\ m^3/s^2$