Outline of 5 Lectures

(A Satellite-based Tropical Cyclone Module)

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 Oct. 6, 2008

3. Oct . 10, 2008: Homework presentation. Climatology of tropical cyclone rainfall and its contribution to global precipitation.

4. Nov. 19, 2008: **SeaWinds & SFMR sea surface wind retrieval; Current status of TC intensity and rainfall forecasts. Introduction of satellite-based TC intensity and rainfall prediction techniques, including DVORAK, SHIPS, and R-CLIPER.**

5. Nov. 21, 2008: Convective properties of tropical cyclones. An introduction of TRMM-base TCPF database.

Problem set: Due on the Dec. 5, 2008

Outline for Today
(Nov. 19, 2008)

1. SeaWinds (on QuickSCAT satellite) sea surface wind retrieval

2. SFMR (on NOAA P-3 aircraft) sea surface wind retrieval

3. TC intensity forecast techniques: DVORAK and SHIPS

4. TC rainfall forecast technique: R-CLIPER

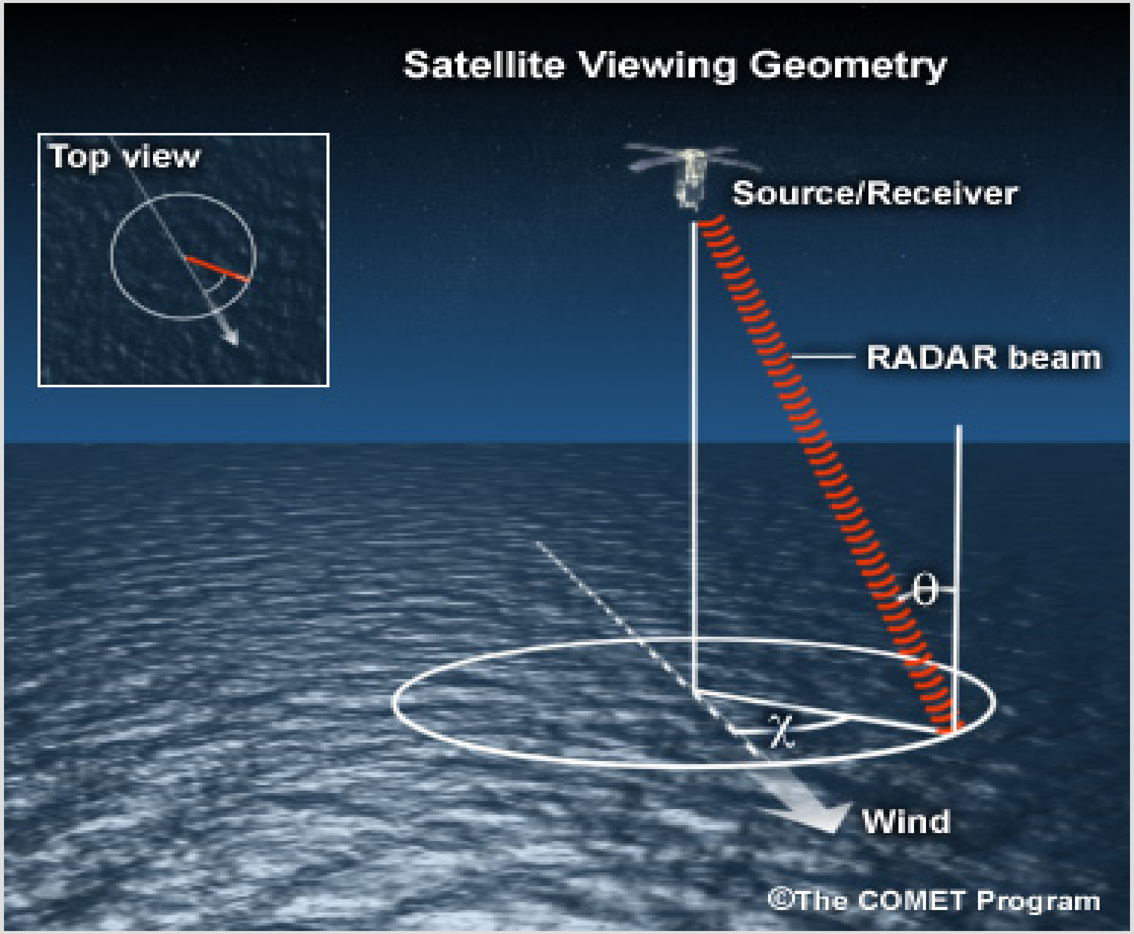
SeaWinds

The SeaWinds scatterometer on the QuikSCAT satellite, launched by NASA in 1999, provides high-resolution ocean surface wind vectors.

The SeaWinds observation on QuikSCAT has offered near-continuous daily coverage of over 90% of the tropical oceans.

How Does SeaWinds Work?

The SeaWinds scatterometer is a microwave radar. Radar frequency: 13.4 GHZ (3 cm)



How does it work?

The antenna transmits the signal to the Earth's surface as energy pulses. When the pulses hit the surface of the ocean it causes a scattering affect referred to as backscatter. A rough ocean surface returns a stronger signal because the waves reflect more of the radar energy back toward the scatterometer antenna. A smooth ocean surface returns a weaker signal because less of the energy is reflected.

Ambiguities of Wind Retrieval from SeaWinds

Radar backscattering cross section → wind speed & direction

Because more than one combination of wind speed and direction is possible, the process ‘ranks’ the most likely solutions.

Information of location, neighboring wind, and a comparison with a NWP model analysis are used in the selection.

Rain contamination: Unfortunately, there is no rain or water vapor measurement sensor onboard QuikSCAT.

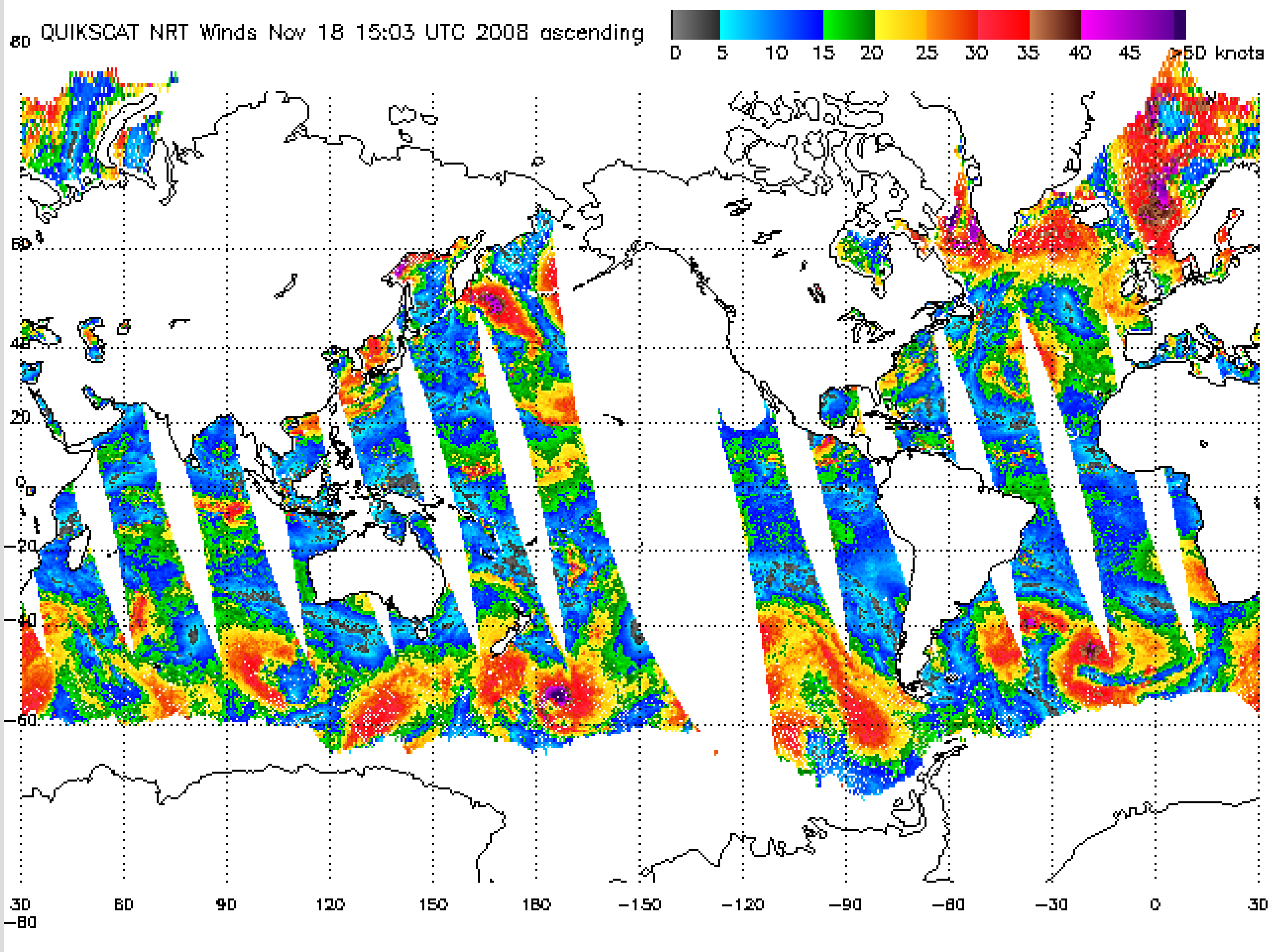
QuikSCAT

Polar-orbiting, sun-synchronous satellite with an equator-ascending time of approximately 0600 local (+/- 30 minutes).

Swath: 1800km.

A given location is viewed at most twice per day.

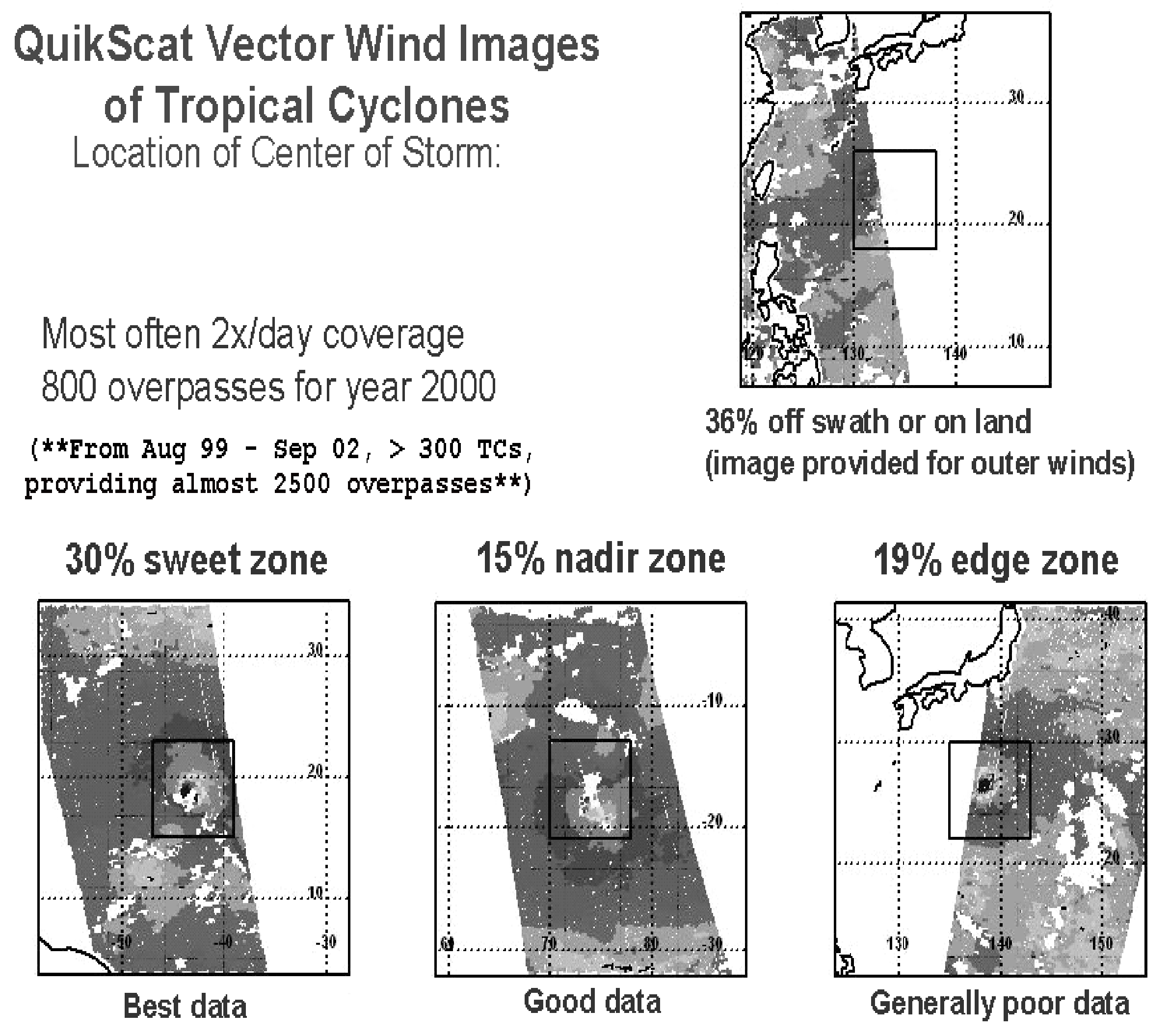
Spatial scale of wind measurements: 25km x 25km.



QuikSCAT Coverage Over TCs

Over 800 passes each year at least partially view a TC.

In this figure, one can visualize the type of coverage to be expected for varying direct hits and near-misses.



QuikScat Vector Wind Images of Tropical Cyclones

Location of Center of Storm:

Most often 2x/day coverage

800 overpasses for year 2000

(**From Aug 99 - Sep 02, > 300 TCs, providing almost 2500 overpasses**)

36% off swath or on land (image provided for outer winds)

30% sweet zone

Best data

15% nadir zone

Good data

19% edge zone

Generally poor data

Adapted from D. Smith (2001).

Working with QuikSCAT data and TC Analysis

*“Current research shows that QuikSCAT wind speeds are found to be extremely accurate, especially for the interpretation of the radius of gale-force winds and positioning requirements. However in many cases, the data are difficult to directly analyze without using various interpretation procedures**. In extensive rain regions, light winds are often greatly overestimated. In high winds, the current empirical algorithm generally underestimates the speeds above 30 to 40 m/s and is not tuned to the tight gradients and curvatures that are typical in TCs. The greatest interpretation issues are the correct wind direction selection procedure and the effect of rain on the wind retrieval process**.*” --
--Edson et al. 2002 (WMO Report).

Problem areas:

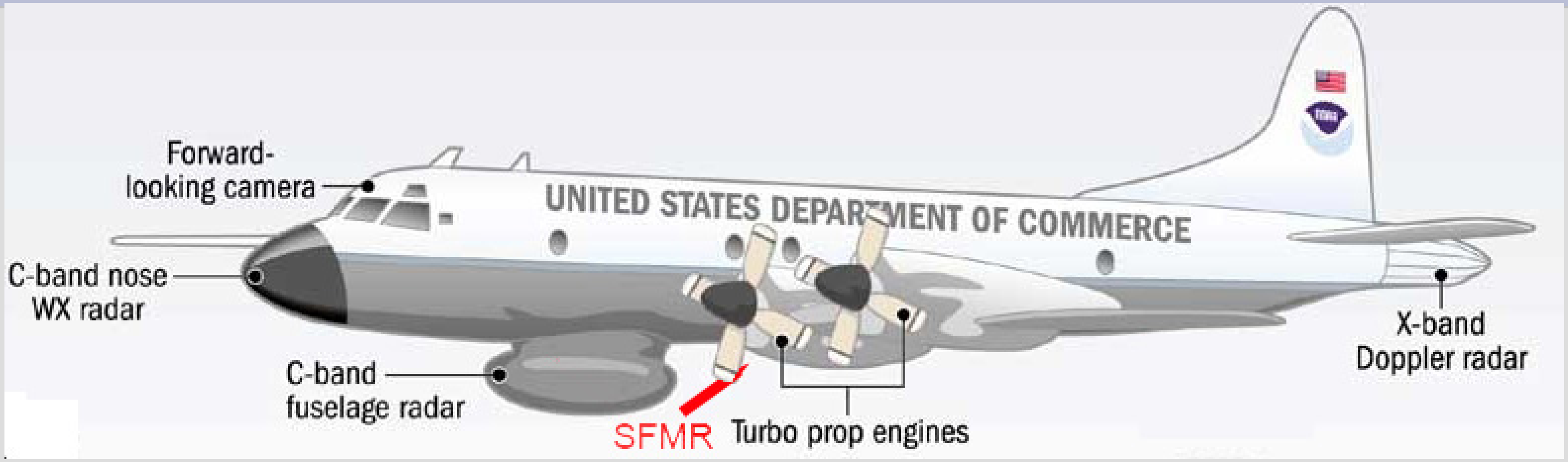
1. **Edge of swath and along sub-track (nadir; lack of view angle difference).**
2. **Sensitivity to heavy rain.**
3. **Wind selection sensitivity to errors in NWP model in low skill locations.**
4. **“Practical” wind regime between 5 and 30 m/s (especially in TC core).**
5. **Resolution of 25 km by 37 km footprint (beamfilling in TC core).**
6. **Ambiguity selection process and how rain flags are used.**

Explore QuikSCAT and SeaWinds Webpages

QuikSCAT webpage:
http://manati.orbit.nesdis.noaa.gov/quikscat/

SeaWinds webpage:
http://winds.jpl.nasa.gov/index.cfm

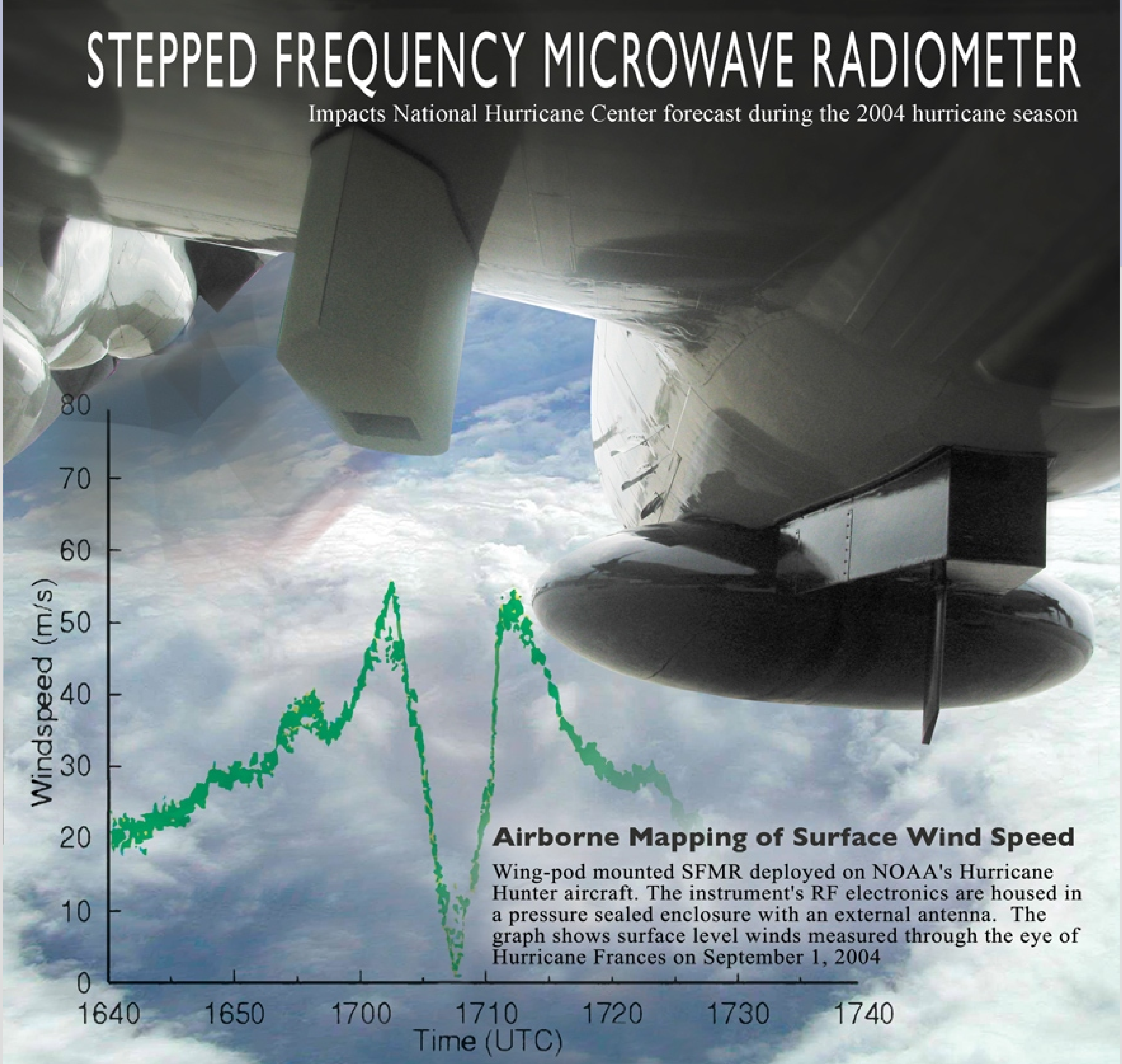
SFMR (Stepped Frequency Microwave Radiometer) on NOAA WP-3D Aircraft



Stepped Frequency Microwave Radiometer (SFMR):

--6 frequencies (4.55, 5.06, 5.64, 6.34, 6.96, 7.22 GHz), 600-800 m footprints at flight altitude of 1.5 km

--Could retrieve along-track sea surface **rain rate & wind speed** at 10-s resolution from six Tb measurements by using a microwave radiative transfer model.

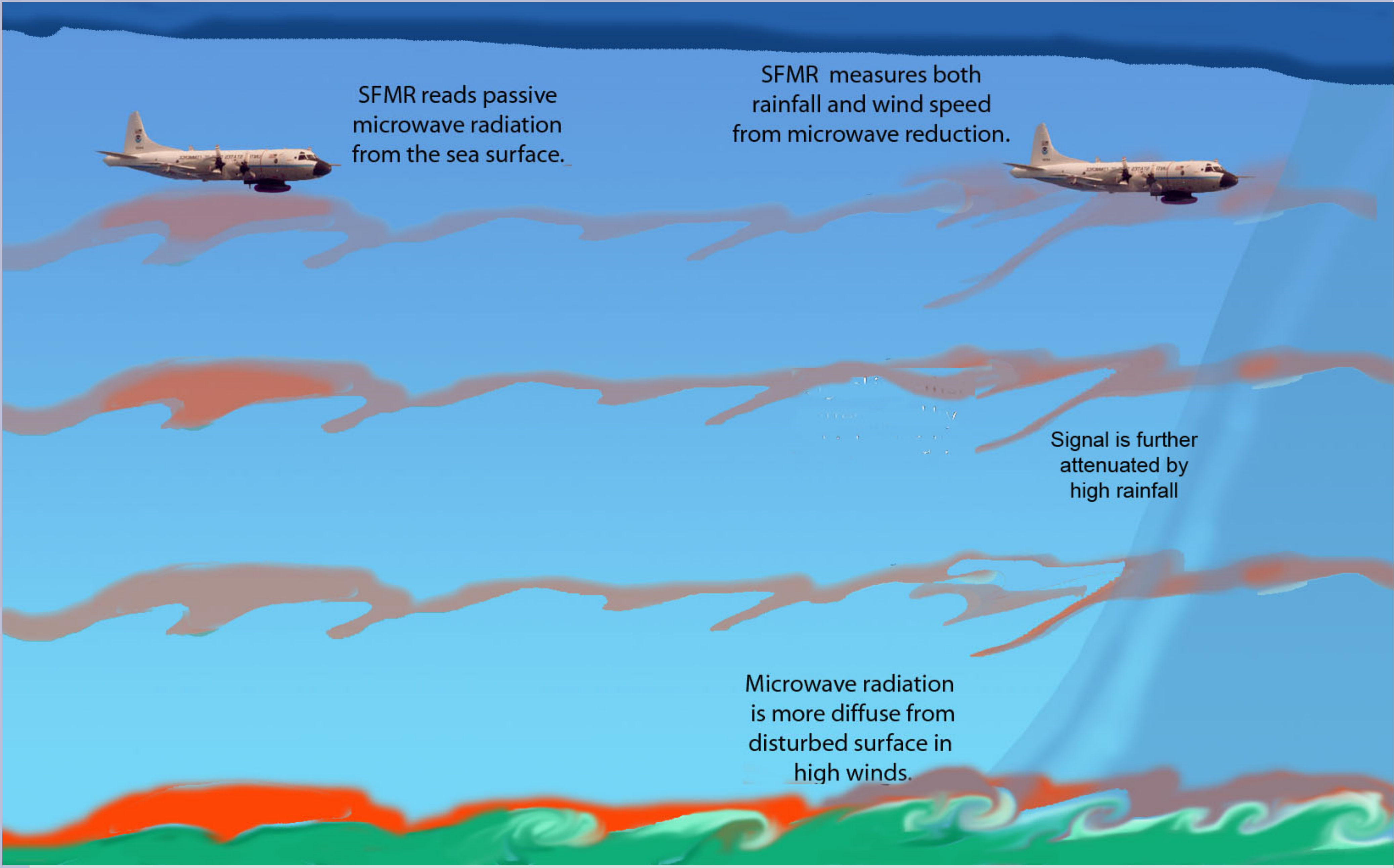


STEPPED FREQUENCY MICROWAVE RADIOMETER

Impacts National Hurricane Center forecast during the 2004 hurricane season

Airborne Mapping of Surface Wind Speed

Wing-pod mounted SFMR deployed on NOAA's Hurricane Hunter aircraft. The instrument's RF electronics are housed in a pressure sealed enclosure with an external antenna. The graph shows surface level winds measured through the eye of Hurricane Frances on September 1, 2004

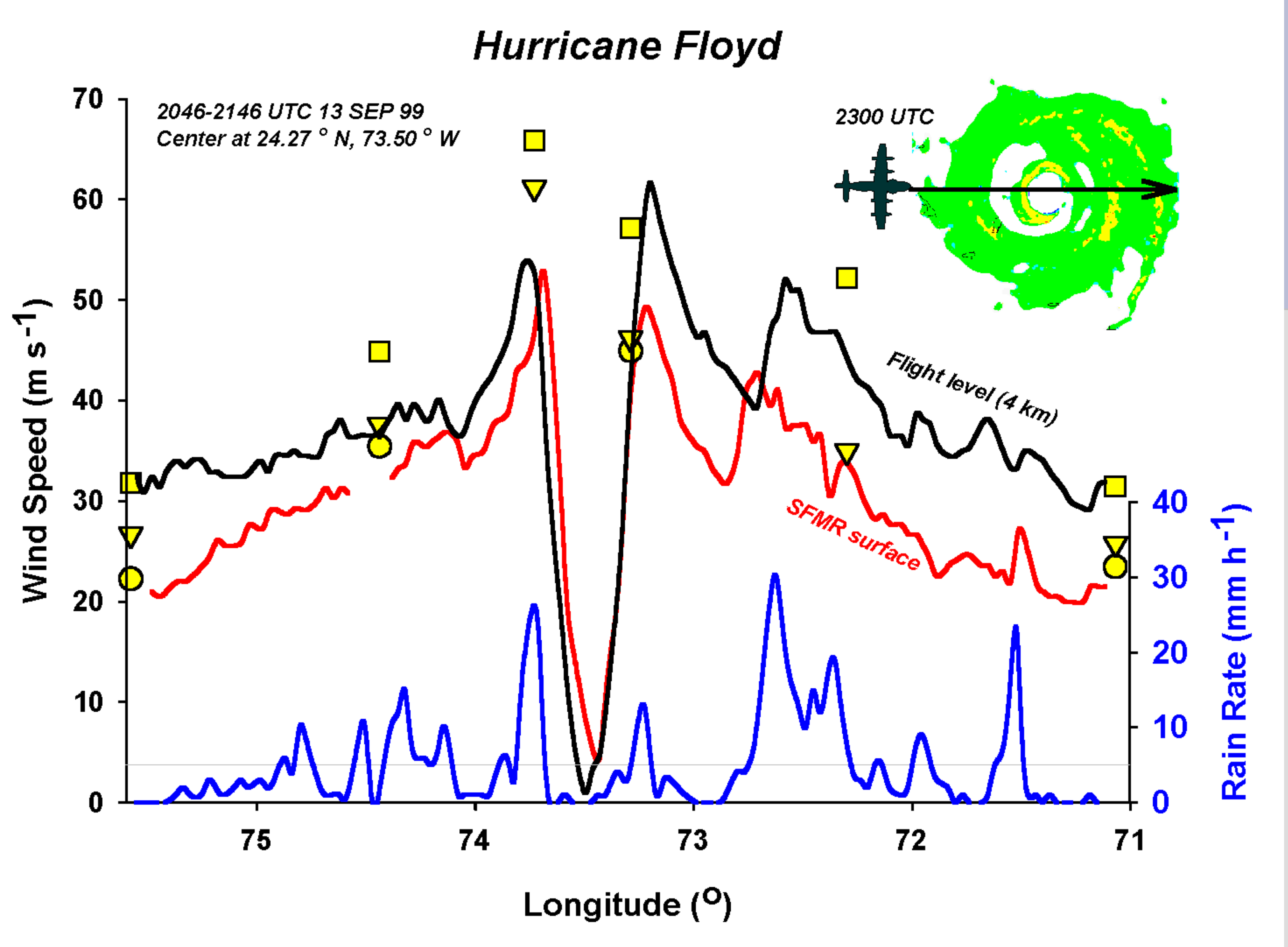


SFMR reads passive microwave radiation from the sea surface.

SFMR measures both rainfall and wind speed from microwave reduction.

Signal is further attenuated by high rainfall

Microwave radiation is more diffuse from disturbed surface in high winds.



As shown by the green, horizontal radar plot in the upper right this is data from a west-to-east aircraft pass across Hurricane Floyd (1999) when it was a Category 4 hurricane due east of Miami. The graph compares wind measured at 6 km altitude (black curve) with that sensed remotely at the surface by the SFMR (red curve) and measured by dropsondes (yellow emblems). The SFMR rain rate esitmate is shown by the blue curve.

Why SFMR is more accurate than QuikSCAT SeaWinds?

-- SFMR has six frequencies. Use 6 known to retrieve two unknown.

-- Rain can be retrieved together with wind speed, so the rain contamination problem is solved.

-- Some other instruments on board the same aircraft (such as radar and IR radiometer) help solving the radiative transfer model.

But SFMR can only measure along-track wind speed, while SeaWinds can measure both wind speed and direction in horizontal dimensions.

The DVORAK TC Intensity Estimation Technique – A Satellite-based Method (Veldon et al. 2006 BAMS)

-- Has been used for TC monitoring for three decades and has saved tens of thousands of lives.

-- Dvorak technique is an empirical method relating TC cloud structures as seen from satellite images to storm intensity using a simple numerical index [the current intensity (CI)], corresponding to an estimate of the maximum sustained (surface) wind (MSW).

Vernon Dvorak (1970s)

Basics Behind the Method

-- Relying on 4 properties that relate organized cloud pattern to TC intensity: two are dynamic, vorticity and vertical wind shear; two are thermodynamic, convection and core temperature.

-- Strength and distribution of circular wind (vorticity) are related to MSW

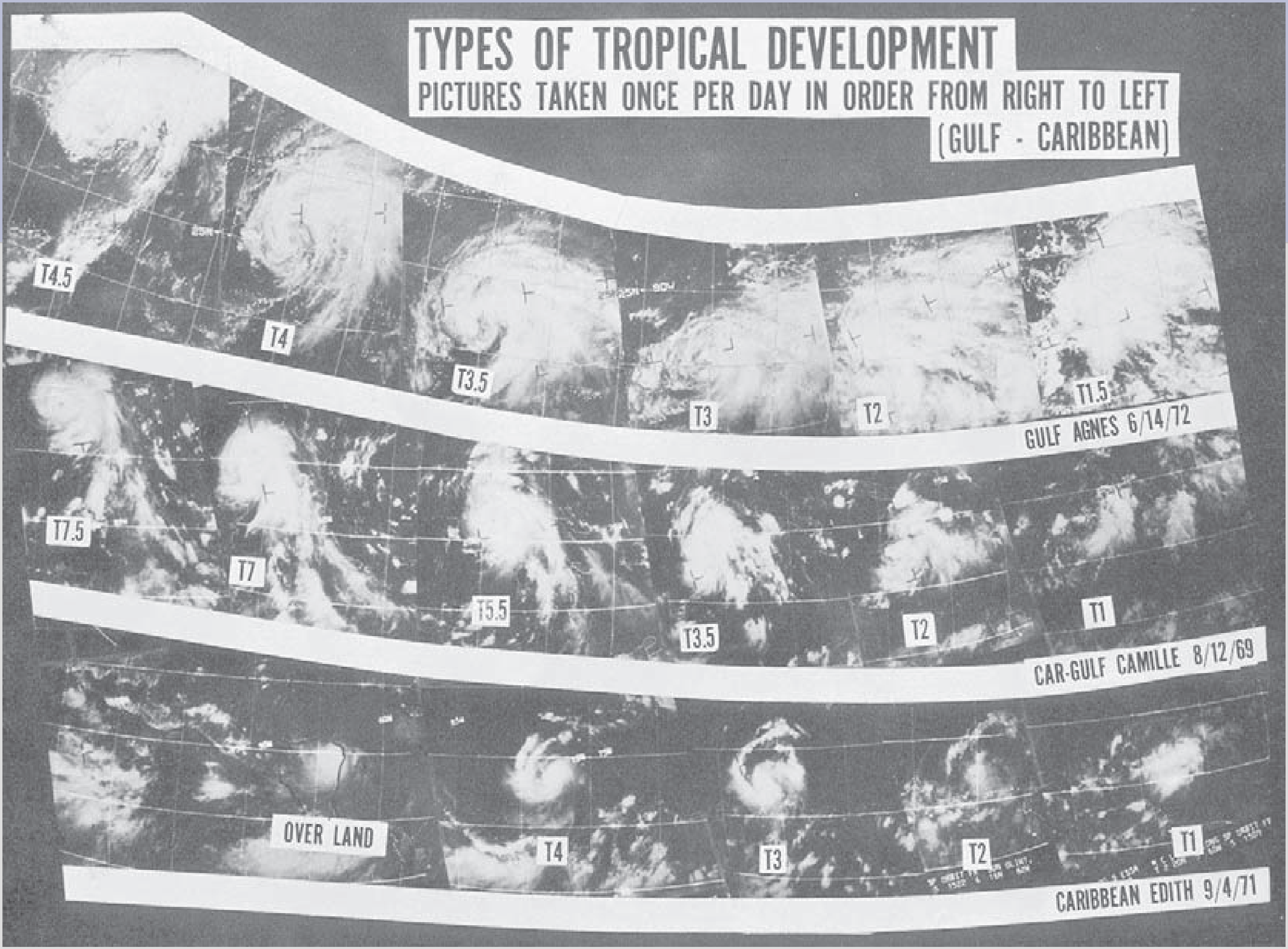
-- Degree of distortion (shear) is related to MSW too.

-- Using satellite-measured IR cloud-top temperatures in the TC inner core, the technique relates convective vigor to intensity.

-- In cases of TCs with eyes, the technique determines the temperatures of the eye and surrounding clouds (eyewall) using IR data and relates them to Intensity.

TABLE Summary of the Dvorak (1984) Atlantic and WestPac wind–pressure relationships.

CI	MSW (kt)	Atlantic MSLP(hPa)	WestPac MSLP(hPa)
1.0	25		
1.5	25		
2.0	30	1009	1000
2.5	35	1005	997
3.0	45	1000	991
3.5	55	994	984
4.0	65	987	976
4.5	77	979	966
5.0	90	970	954
5.5	102	960	941
6.0	115	948	927
6.5	127	935	914
7.0	140	921	898
7.5	155	906	879
8.0	170	890	858



Examples of characteristic cloud patterns of developing TCs (from Dvorak 1973).

Statistical Hurricane Intensity Prediction Scheme (SHIPS)

-- The model was developed using a standard multiple regression technique with climatological, persistence, and synoptic predictors by DeMaria and Kaplan (1994 and 1997) and DeMaria et al. (2005) for Atlantic and North East Pacific basins.

-- DeMaria and Kaplan (1994): model development sample includes Atlantic TCs from 1989-1992.

-- An updated version (DeMaria and Kaplan 1997): change from a “statistical-synoptic” model to “statistical-dynamic” model, add 1993-1996 TCs from both Atlantic and North East Pacific basins.

-- DeMaria et al. (2005): modifications for 1997-2003.

Predictors Used in SHIPS

1) Absolute value of (Julian day peak season value)
2) Gaussian function of (Julian day peak value)
3) Initial maximum winds
4) Max wind change during the past 12 h
5) Initial max winds times previous 12-h change
6) Zonal component of storm motion
7) Pressure level of storm steering
8) 200-hPa divergence
9) 200-hPa eddy momentum flux convergence
10) 200-hPa eddy momentum flux convergence
11) Max potential intensity current intensity
12) 850–200-hPa vertical shear
13) 200-hPa zonal wind
14) 200-hPa temperature
15) 850–700-hPa relative humidity
16) 500–300-hPa relative humidity
17) 850-hPa relative vorticity
18) Surface 200-hPa Theta-e deviation of lifted parcel
19) Vertical shear times sine of storm latitude
20) Square of potential current intensity
21) Initial intensity time shear

Statistical Typhoon Intensity Prediction Scheme (STIPS)

-- Similar to SHIPS, but for North Western Pacific by Knaff (et al. 2005).

-- Static predictors: those related to climatology, persistence, and trends of intensity.

Initial Intensity; Initial Intensity Squared; 12-h Change in Intensity; Absolute Value of Yearday Minus 248; Storm Translational Speed

-- Time dependent predictors: those related to current and future environmental and SST conditions

Time Dependent (synoptic) Predictors for STIPS

1) MPI: Maximum potential intensity
2) MPI2: MPI squared
3) MPI * VMAX: MPI times the initial intensity
4) RHLO: Area-averaged (200–800 km) relative humidity at 850–700 hPa
5) RHHI: Area-averaged (200–800 km) relative humidity at 500–300 hPa
6) U200: Area-averaged (200–800 km) zonal wind at 200 hPa
7)T200: Area-averaged (200–800 km) temperature at 200 hPa
8) Sigma200: Area-averaged (0–1000 km) 200-hPa divergence
9) REFC: Relative eddy flux convergence within 600 km
10) SHRG: Generalized 200–850-hPa vertical wind shear
11) SHRS: Area-averaged (200–800 km) 500–850-hPa wind shear
12) SHRD: Area-averaged (200–800 km) 200–850-hPa wind shear
13) USHRS: Area-averaged (200–800 km) 500–850-hPa zonal wind shear
14) USHRD: Area-averaged (200–800 km) 200–850-hPa zonal wind shear
15) SHRD * SIN(LAT): 200–850-hPa wind shear times the sine of the latitude
16) SHRG * SIN(LAT): Generalized wind shear times the sine of the latitude
17) Vort850: Area-averaged (0–1000 km) 850-hPa relative vorticity

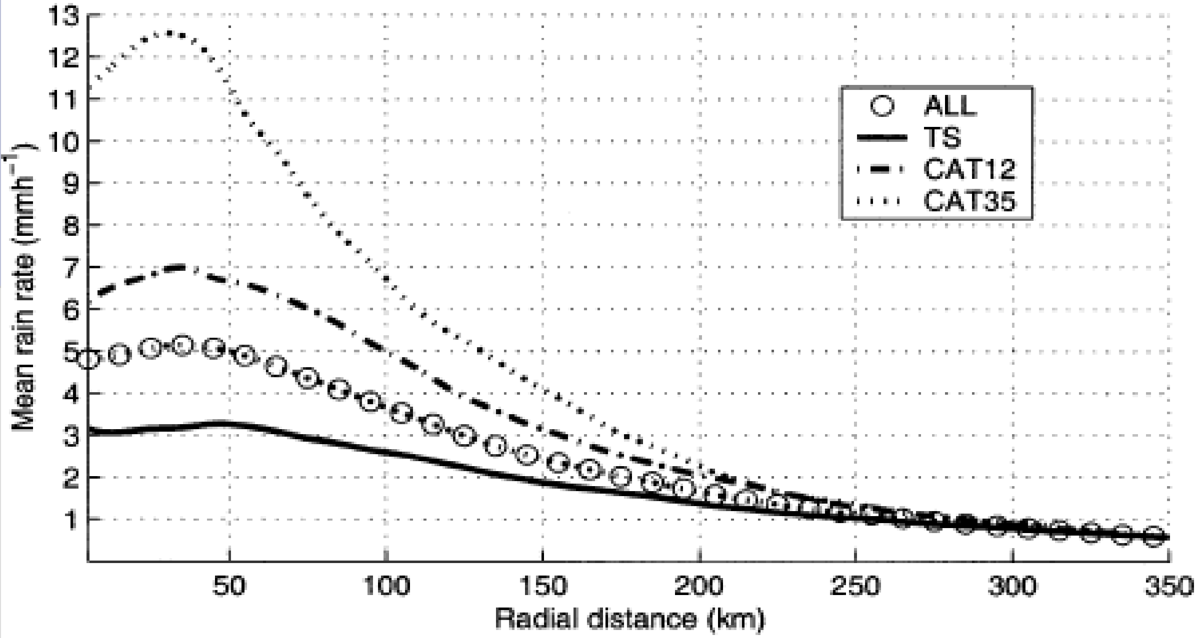
TC Rainfall Prediction Technique: R-CLIPER

-- R-CLIPER is a TC rainfall climatology and persistence model.

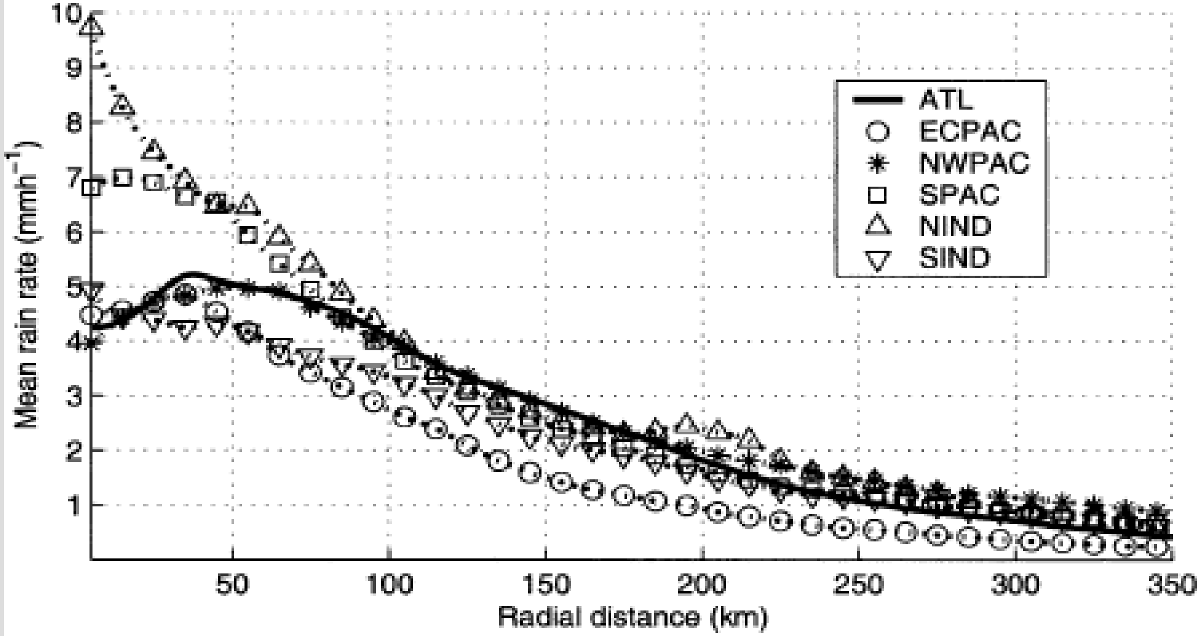
-- Lonfat et al. (2004): use 3-years of TRMM TMI rainfall observation to derive the distribution of TC rainfall as a function of radial distance, TC intensity, and geographical location.

-- R-CLIPER uses radial distributions of azimuthally averaged rainfall derived by Lonfat et al. 2004 to construct an instantaneous rainfall footprint that depends on storm intensity.

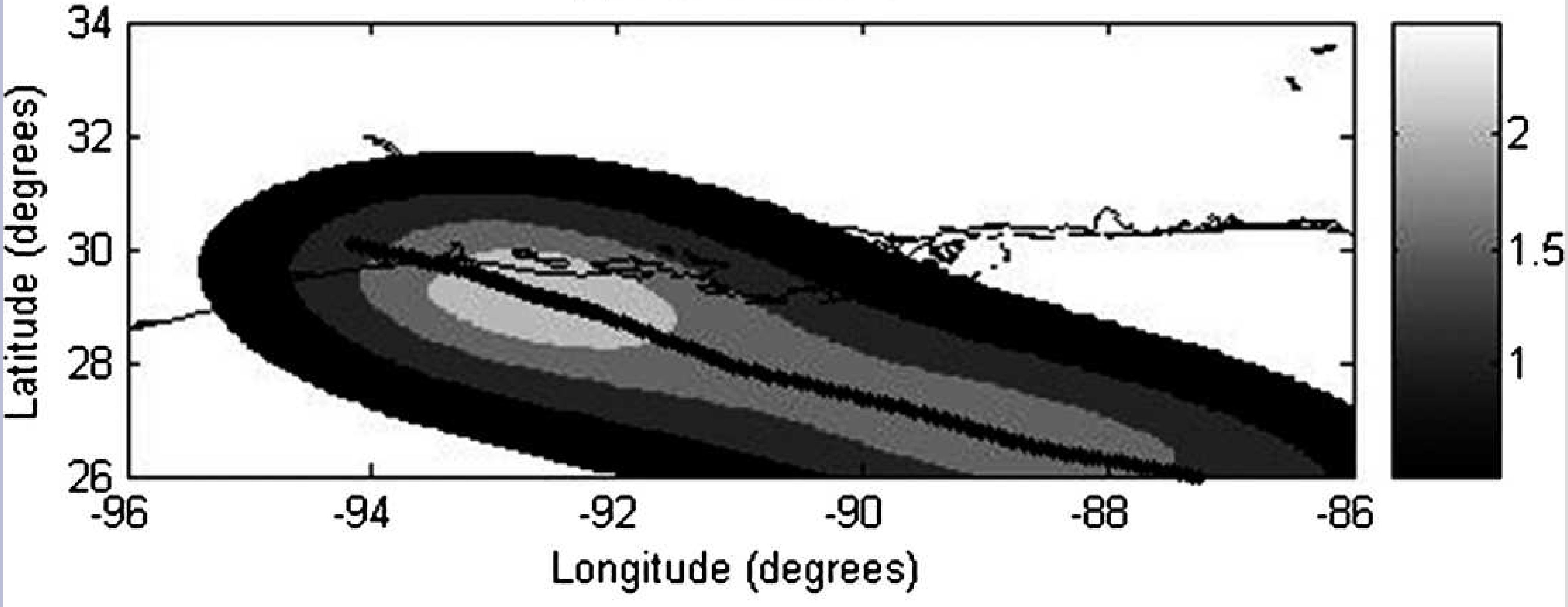
(a) Intensity



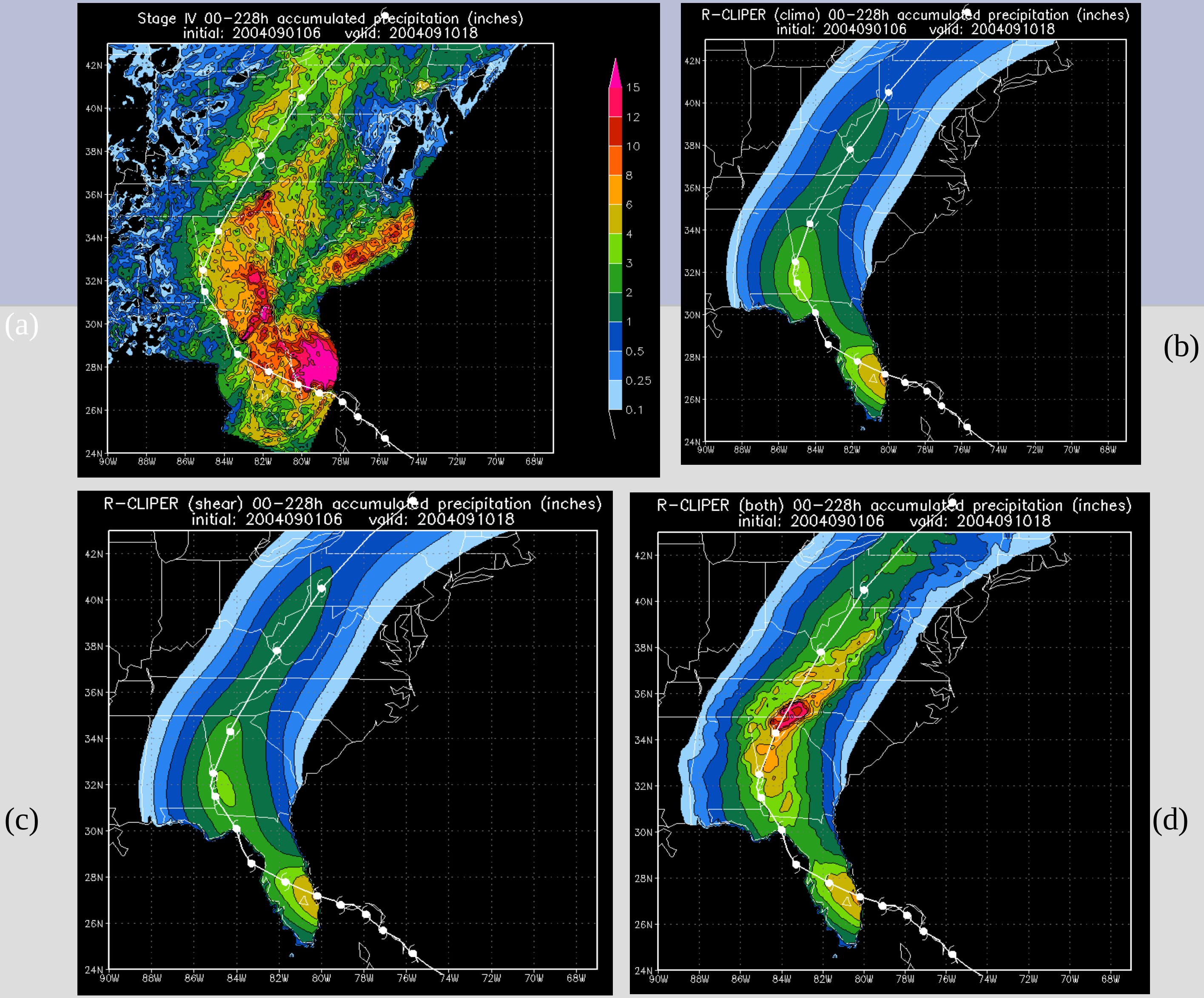
(b) Geographic location



An Example of R-CLIPER derived Accumulated Rainfall Distribution



Hurricane Ivan (2004) during the second Gulf of Mexico landfall. (from Lonfat et al. 2007)



Storm-total rainfall accumulations (inches) for Hurricane Frances beginning 06 UTC 01 Sep 2004 and ending 18 UTC 10 Sep 2004 for: a) Stage IV observations, b) R-CLIPER, c) R-CLIPER with shear, and d) R-CLIPER with shear and topography. Solid line indicates the best track for Frances. The scale is in inches.

Review of Lecture 1

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.

Review of Lecture 2 & 3

1. Basic Radiative Transfer

2. Image Interpretation for visible, IR, and microwave channels; Introduce microwave instruments including TRMM TMI, SSM/I, AMSR-E, AMSU-B, PR and CPR

3. Rainfall retrieval from IR

4. Rainfall retrieval from microwave

5. Climatology of tropical cyclone rainfall and its contribution to global precipitation.