UMassAmherst

Remote Sensing of Ocean Winds

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Dept. of Electrical and Computer Engineering

Offshore Wind Energy IGERT Seminar

3/5/2015

Remote Sensing of Wind

- For wind energy applications: Wind Profilers
  - Radar: UHF frequency
  - Sodar: audible
  - Lidar: IR

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  - Platform required: buoy, mooring
  - Data retrieval, power constraints
  - motion compensation, maintenance (salt)

Motivation

- Why measure global ocean winds?
  - Input to global circulation models (GCMS)
  - Numerical weather prediction (NWP)
  - Wind and wave forecasting (shipping)
  - Wind energy forecasting/climatology

Motivation

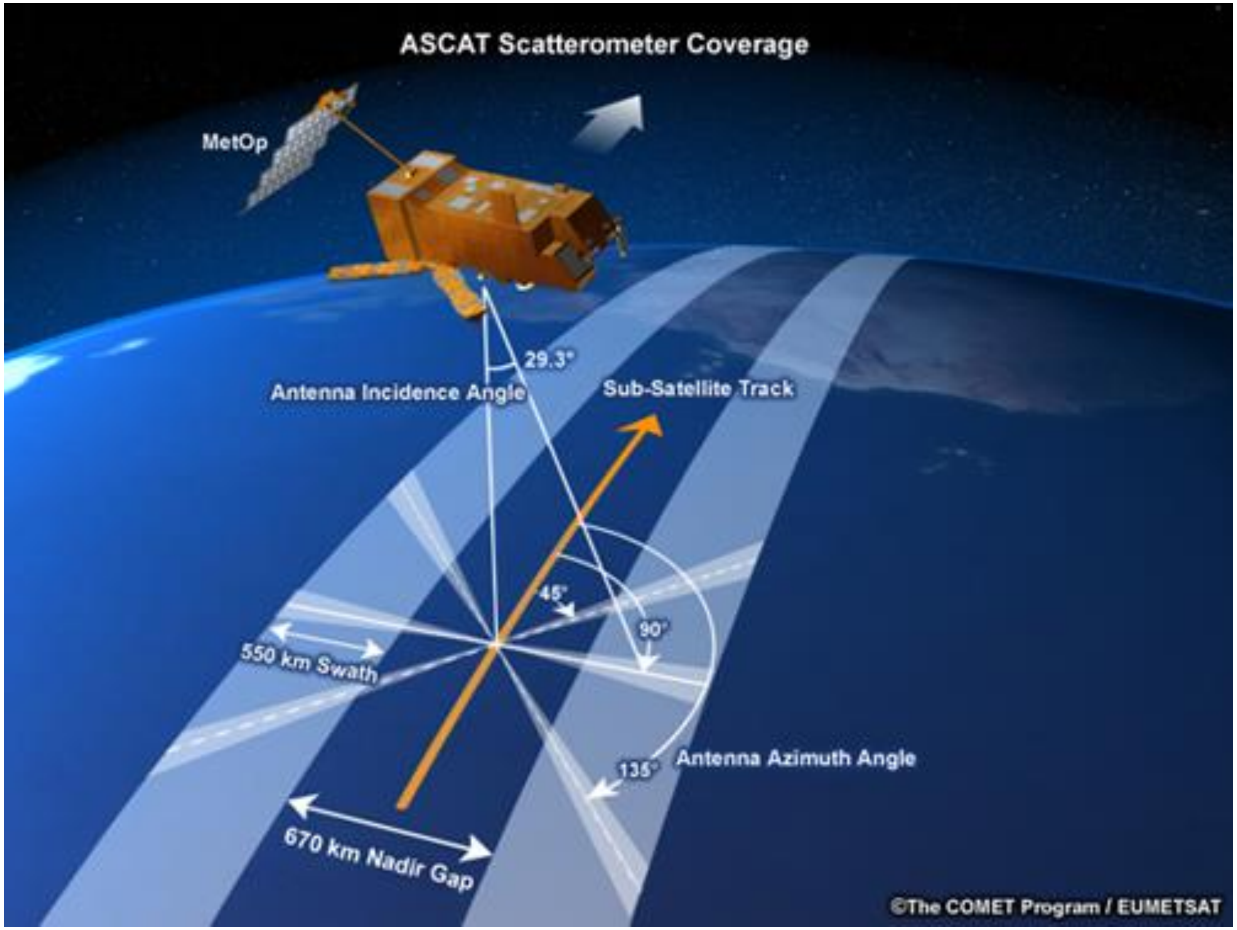
How do we measure from space or aircraft?

- Radar "scatterometers" (active)
- Radiometers (passive)
- Measure sea-surface signature of wind
- Day/Night/All-weather operation

ISS Rapidscat Mission

NASA's latest wind scatterometer deployed on the international space station (9/2014)

EU's Advanced Scatterometer



A Brief History

- NASA missions

– RadScat onSkylab (1973)	demonstration
– SASS on SeaSAT-A (1978)	failed at 100 days
– NSCAT on ADEOS-1 (1996-1997)	solar panel failure
– SeaWinds on QuikSCAT (1999-2010)	“rescue” mission
– SeaWinds on ADEOS-2 (2002-2003)	solar panel failure
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- ESA missions
  - ERS-1 (1991-2000), ERS-2 (1995-2011)
  - Envisat (2002-2012)
- EUMetSat operational satellites
  - ASCAT on METOP-A (2006-), METOP-B (2013-)
  - OSCAT (2009-2014): India

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- Other agency missions
  - OSCAT (2009-2014): India
  - HY-2A (2011-): China

Radar echo from surface roughness

Bragg Scattering

Incident microwave radiation in resonance with short waves (dominant for 30° < θ < 70°)

$$\lambda_B = \lambda/(2\sin(\theta))$$

λ ~ 2cm (Ku-band) ; λ ~ 5cm (C-band)

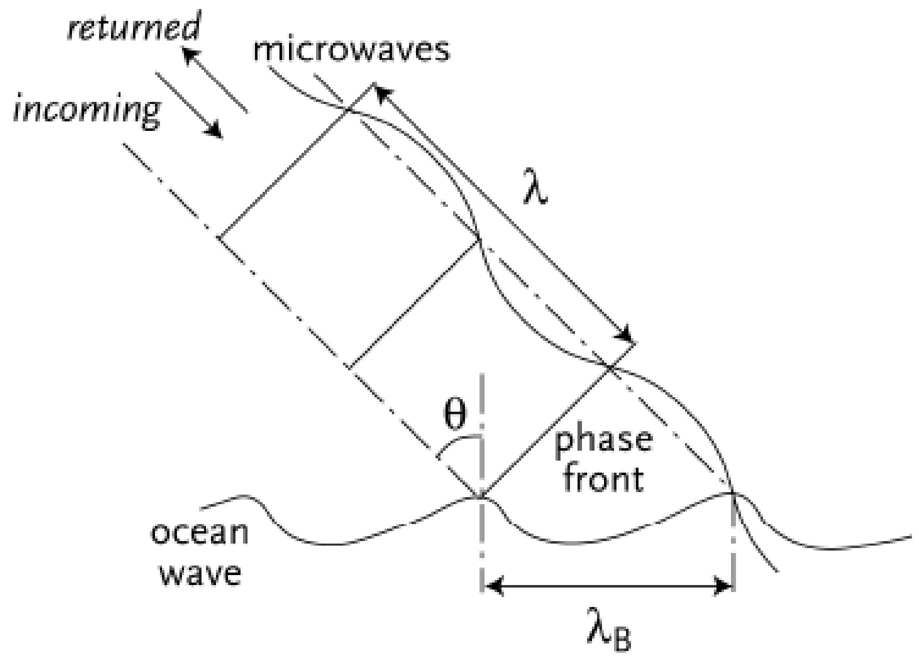
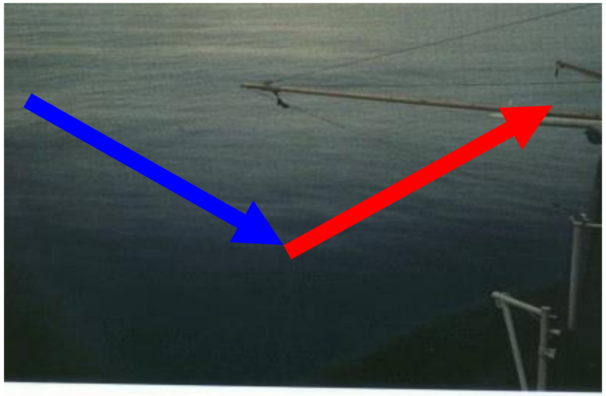


Figure 11. Bragg scattering: A plan-parallel radar beam with wavelength λ hits the rough ocean surface at incidence angle θ, where capillary gravity waves with Bragg wavelength λ_B will cause microwave resonance.

Radar echo from surface roughness

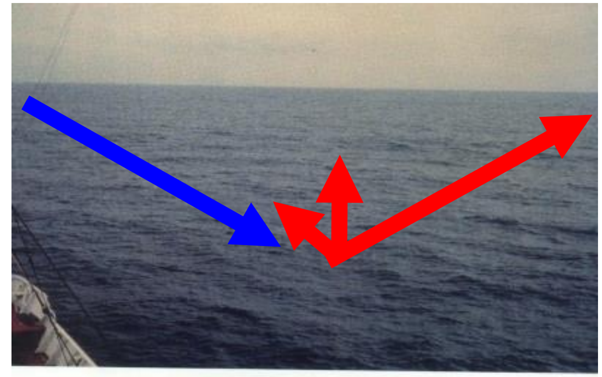
Courtesy Z.Jelenak

Radar echo from surface roughness



BEAUFORT FORCE 0
WIND SPEED: LESS THAN 1 KNOT

SEA: SEA LIKE A MIRROR

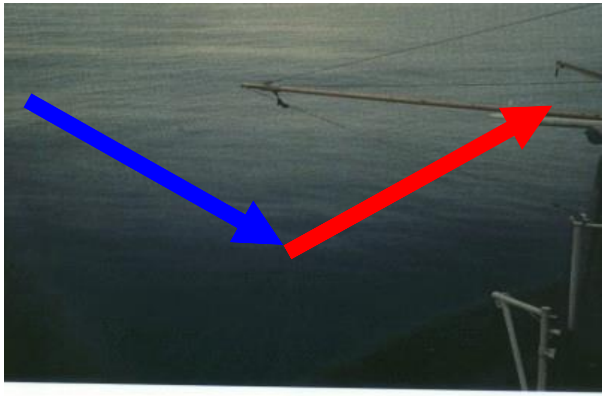


BEAUFORT FORCE 3
WIND SPEED: 7-10 KNOTS

SEA: WAVE HEIGHT .6-1M (2-3FT), LARGE WAVELETS, CRESTS BEGIN TO BREAK, ANY FOAM HAS GLASSY APPEARANCE, SCATTERED WHITECAPS

Courtesy Z.Jelenak

Radar echo from surface roughness



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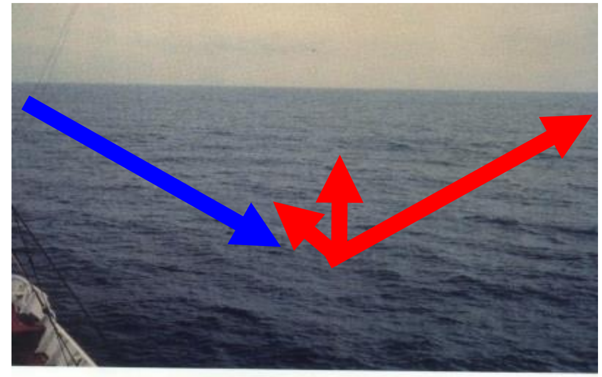

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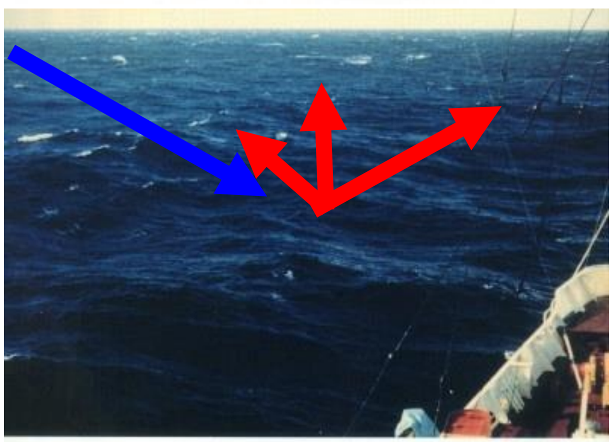
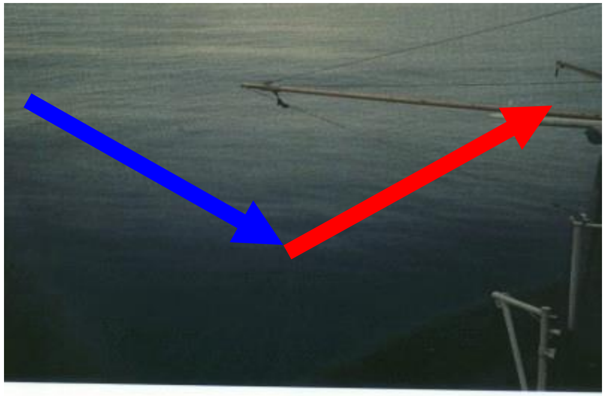


BEAUFORT FORCE 6
WIND SPEED: 22-27 KNOTS

SEA: WAVE HEIGHT 3-4M (9.5-13 FT), LARGER WAVES BEGIN TO FORM, SPRAY IS PRESENT, WHITE FOAM CRESTS ARE EVERYWHERE

Radar echo from surface roughness



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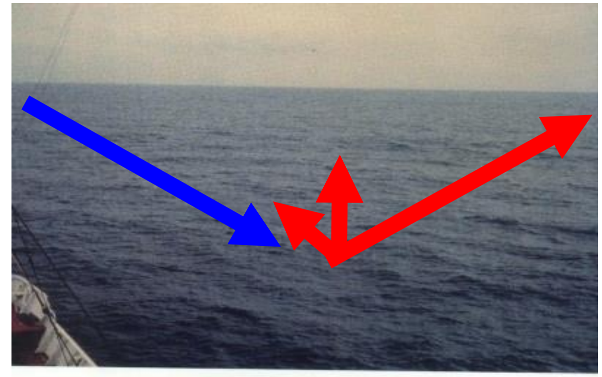

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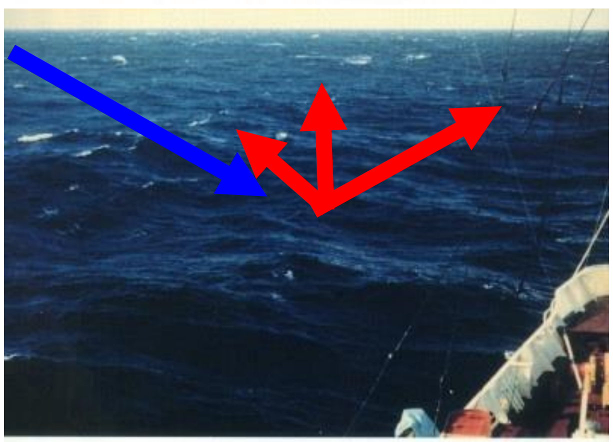

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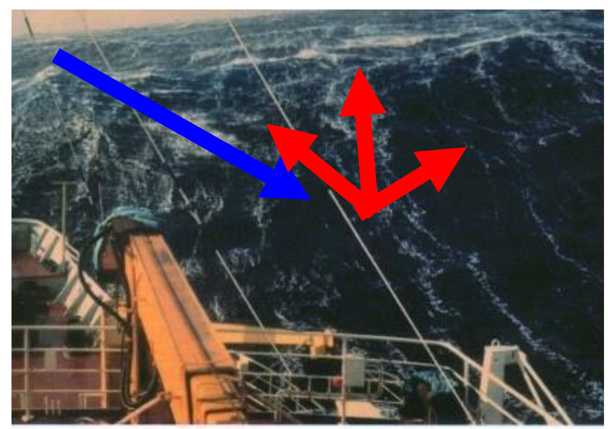
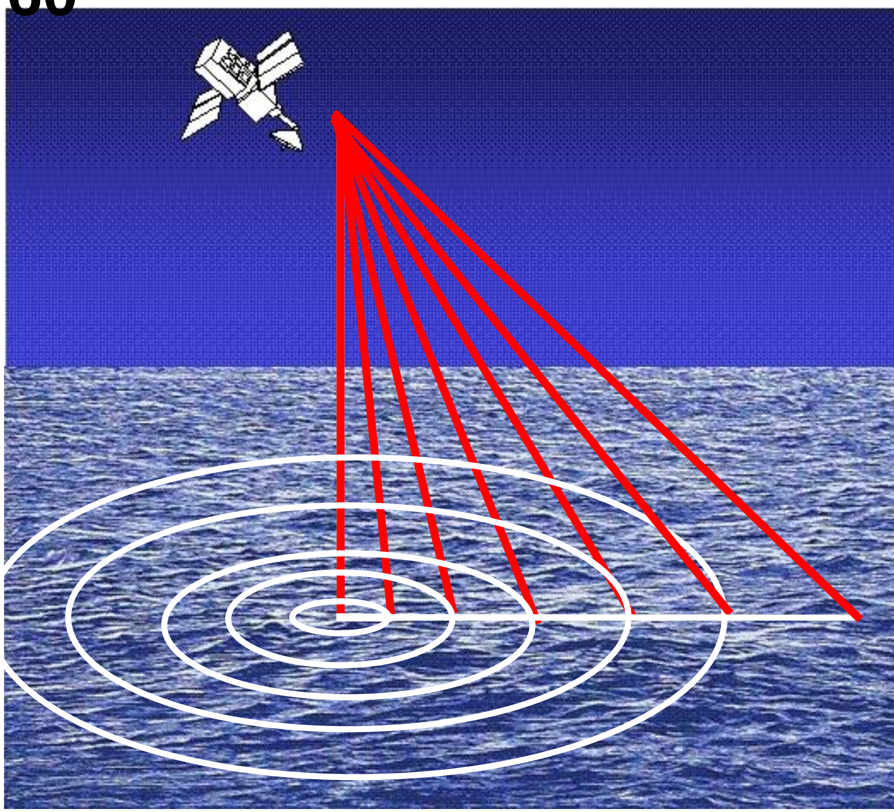


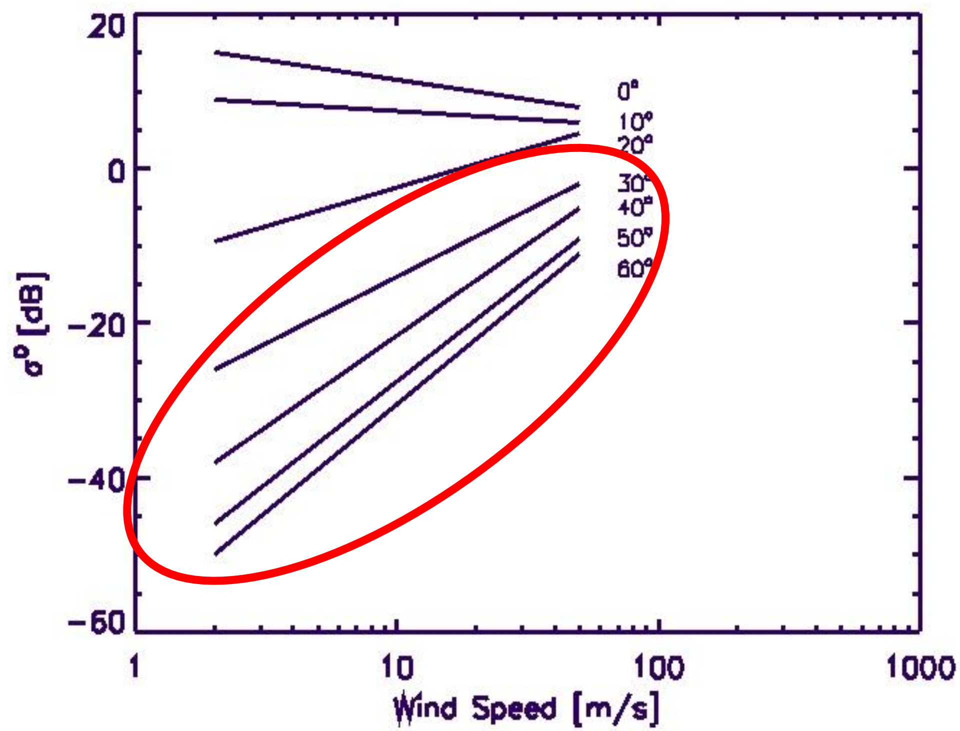
BEAUFORT FORCE 9
WIND SPEED: 41-47 KNOTS

SEA: WAVE HEIGHT 7-10M (23-32FT), HIGH WAVES, DENSE STREAKS OF FOAM ALONG DIRECTION OF THE WIND, WAVE CRESTS BEGIN TO TOPPLE, TUMBLE, AND ROLL OVER. SPRAY MAY AFFECT VISIBILITY.

Dependence on Wind and Incidence Angle

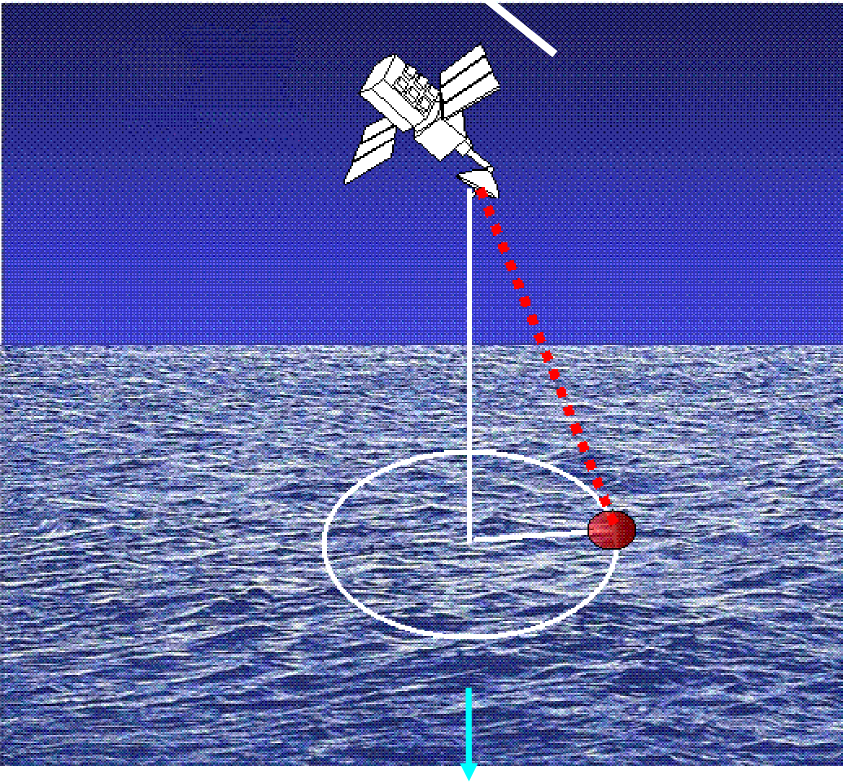
Most sensitivity to wind at moderate incidence angles 30° - 60°

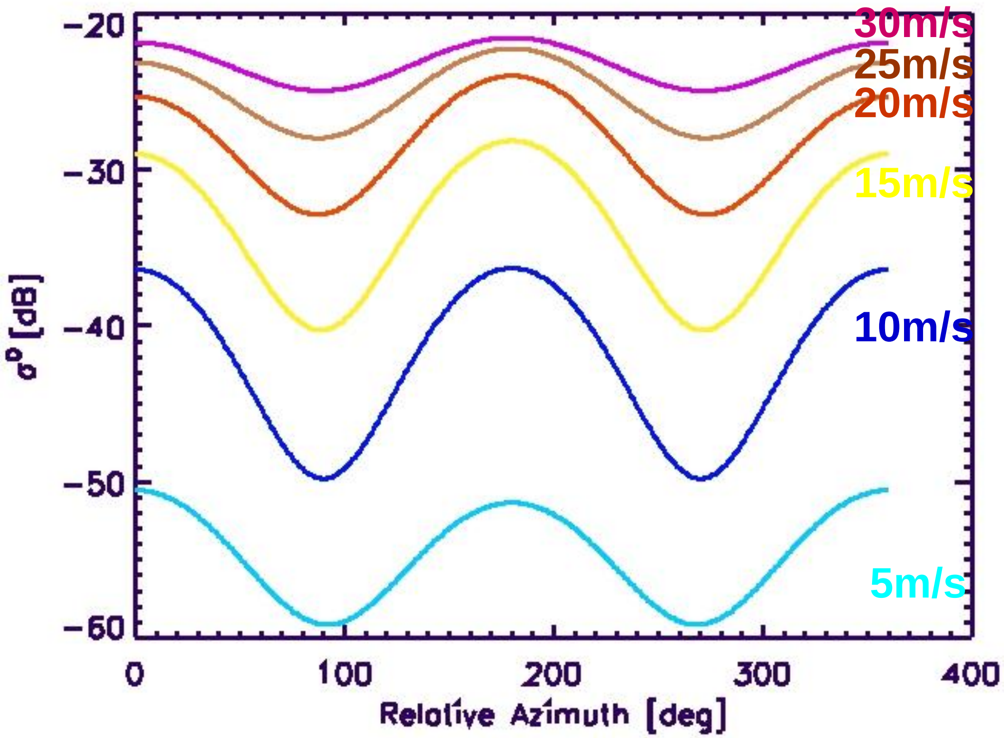




Dependence on Wind and Azimuth Angle

Most sensitivity to wind dir. at moderate wind speeds

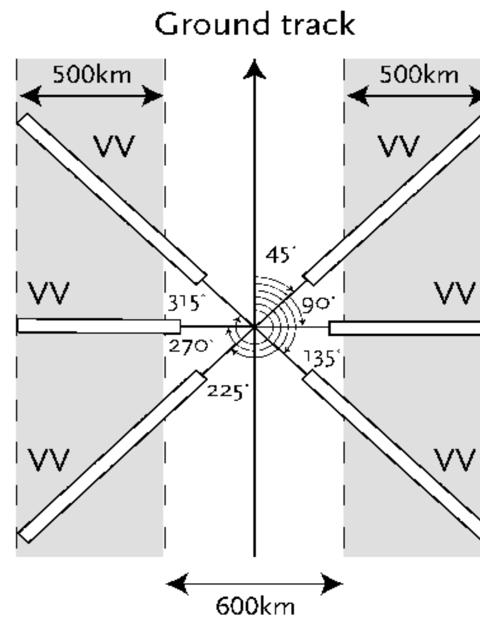




Current Scatterometer Designs

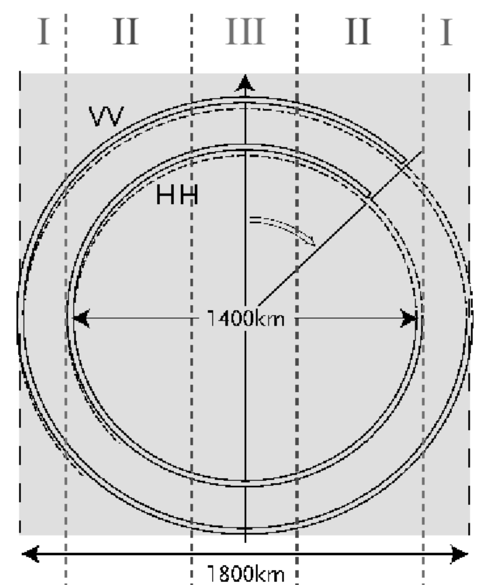
Fixed fan beam

- C-band (5 cm)
- VV-pol
- Sampling 12.5-25 km
- Static antenna
- ASCAT, double swath



Rotating pencil beam

- Ku-band (2 cm)
- Dual polarization
- Sampling 25-50 km
- Rotating antenna
- Seawinds

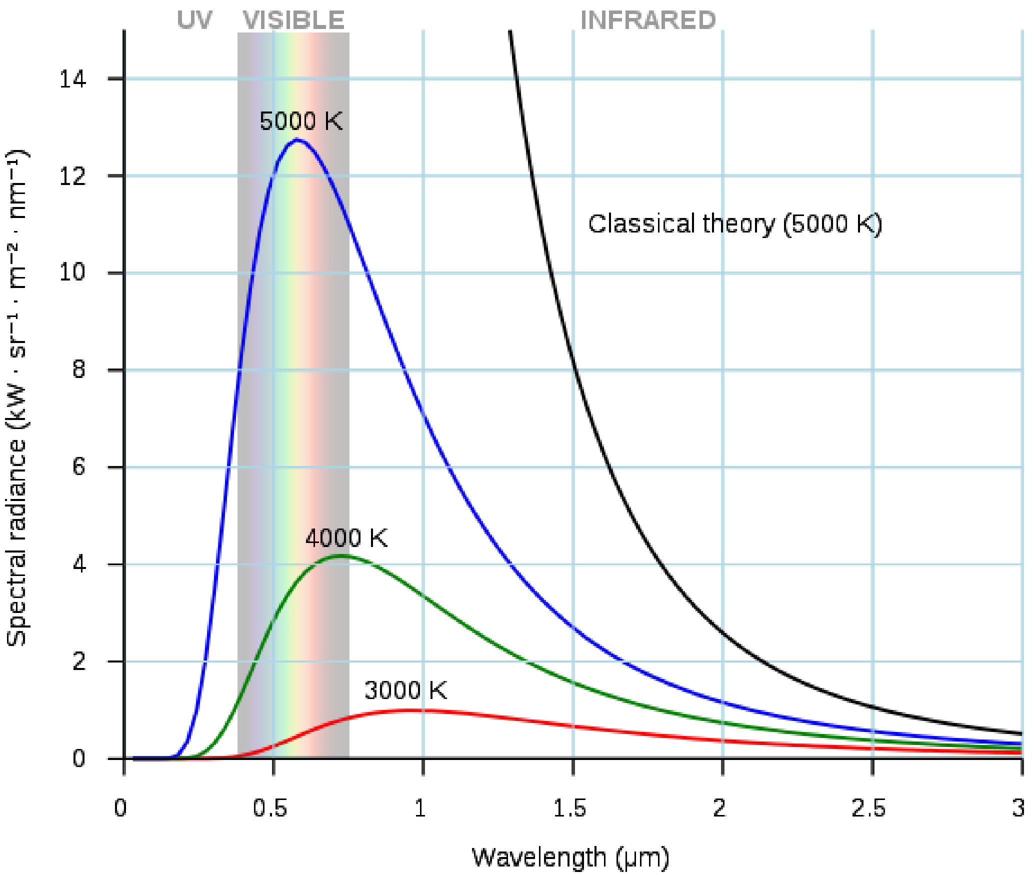


Near Real-Time Products

http://manati.star.nesdis.noaa.gov/datasets/ASCATData.php

Microwave Radiometry

Blackbody Radiation



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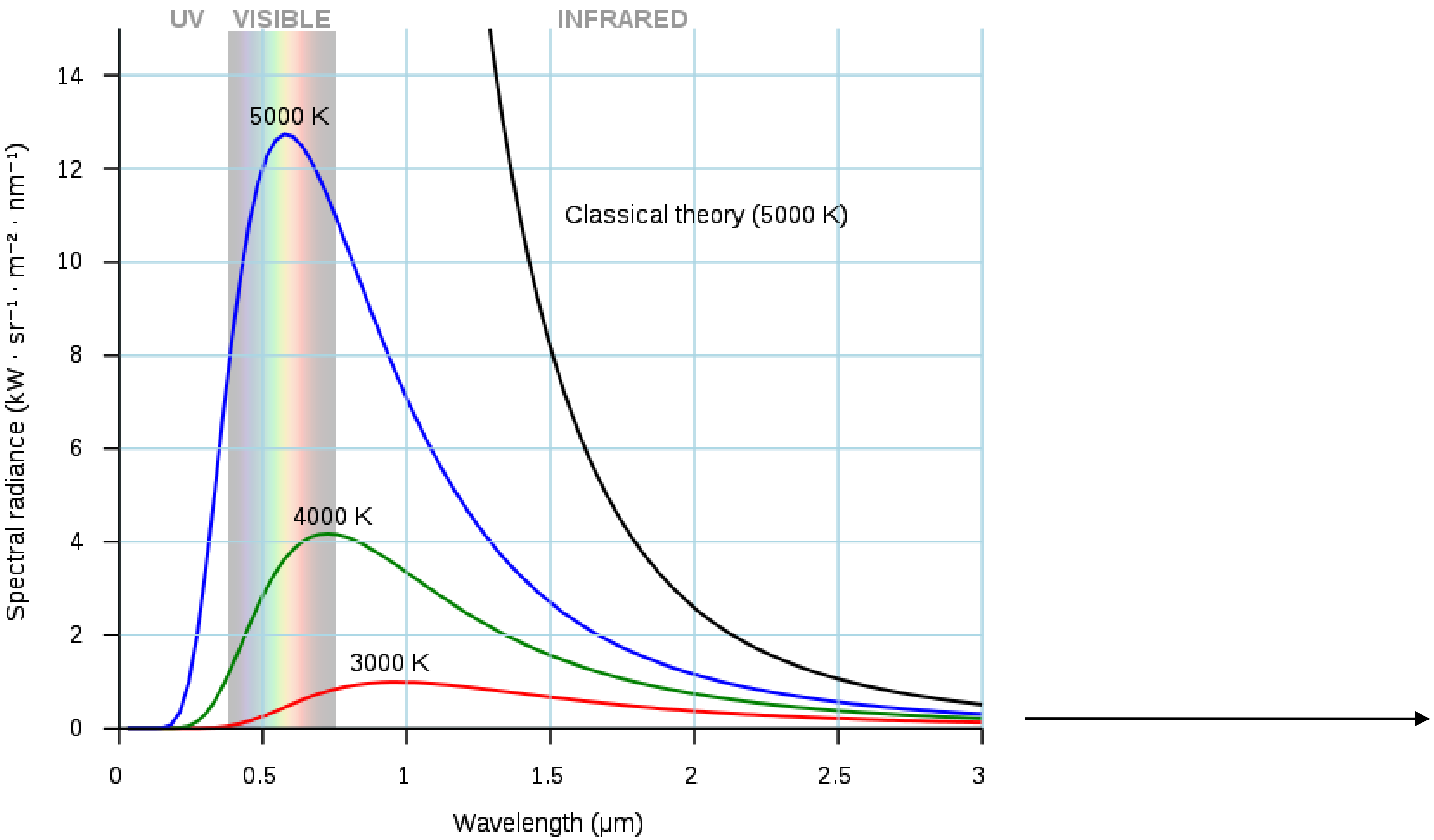

Microwaves over here

Microwave Radiometry

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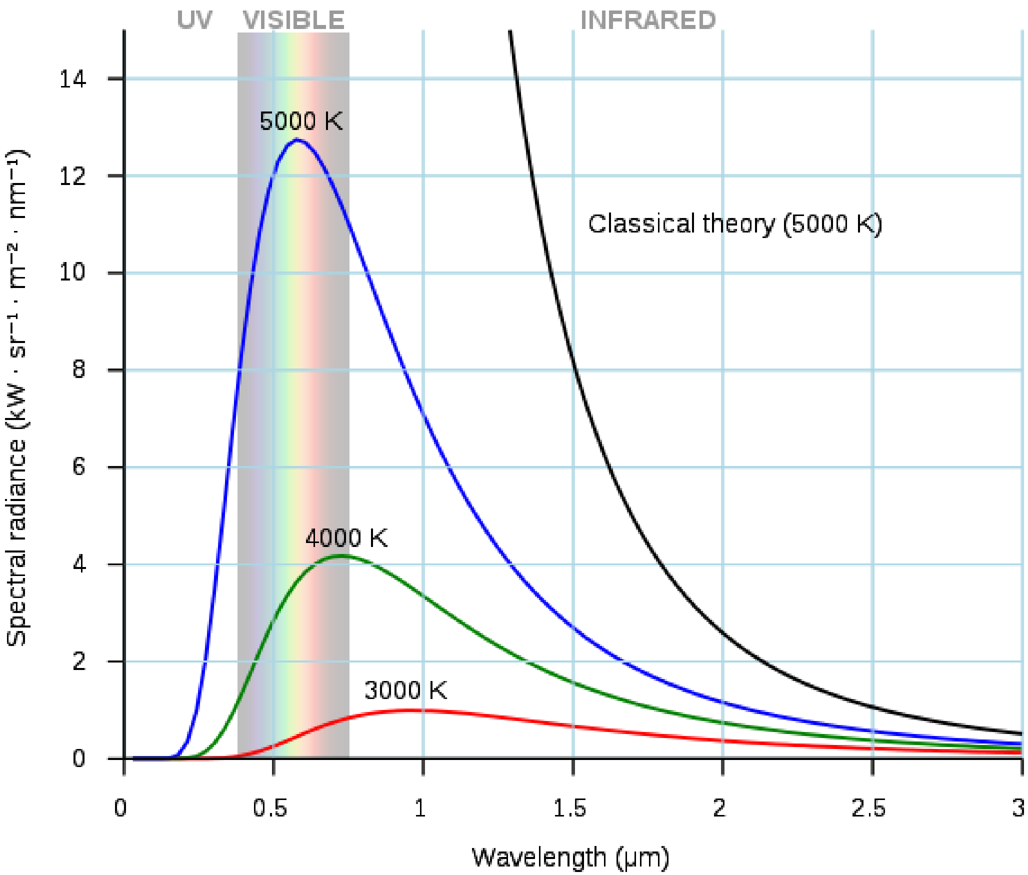


"Greybody Radiation"

$$P = k(eT)B$$

e = emissivity
T = Temperature

$eT = T_B$ Brightness Temperature

→ Microwaves over here

Microwave Radiative Transfer

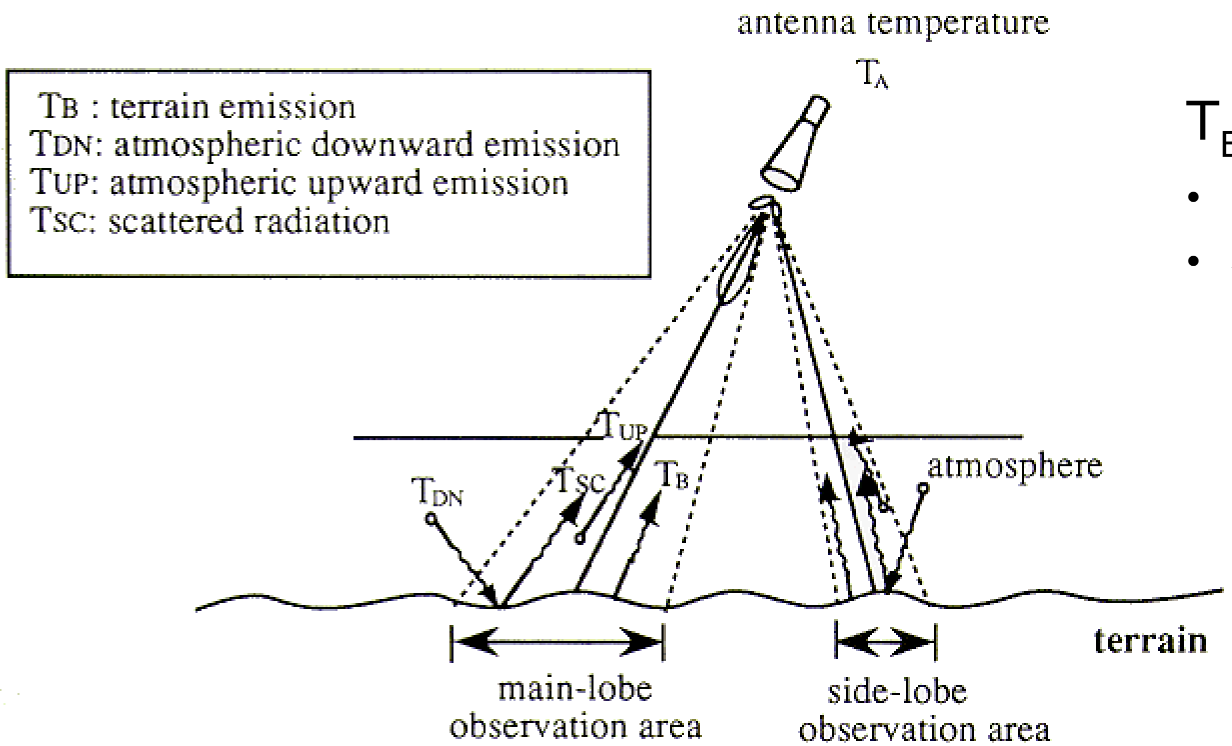
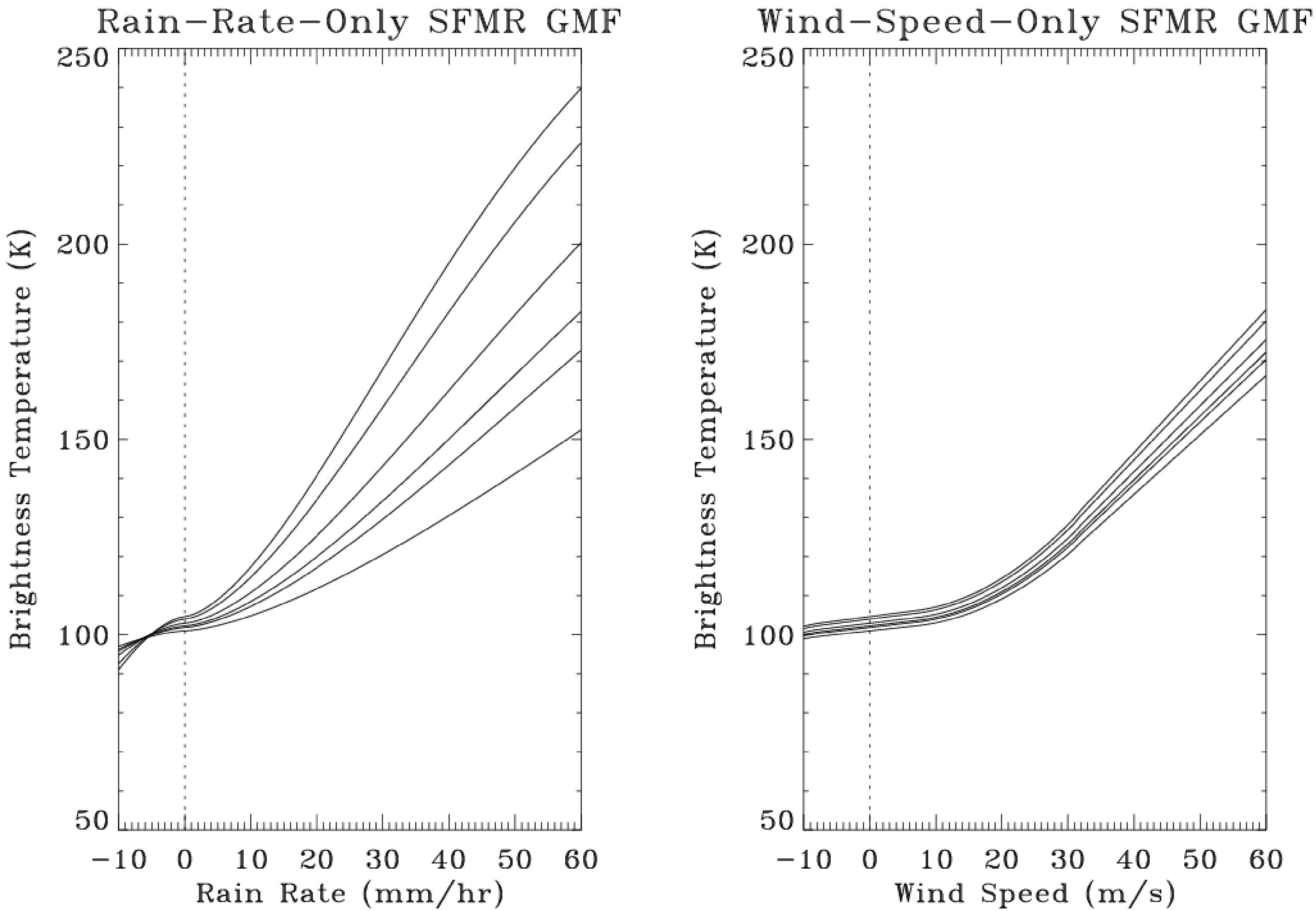


Fig.3.1.2 Principle of passive microwave sensor. The apparent temperature represents the energy incident upon the antenna.

T_B Observations:

- Surface properties
- Atmospheric properties

Dependence on Wind Speed and Rain



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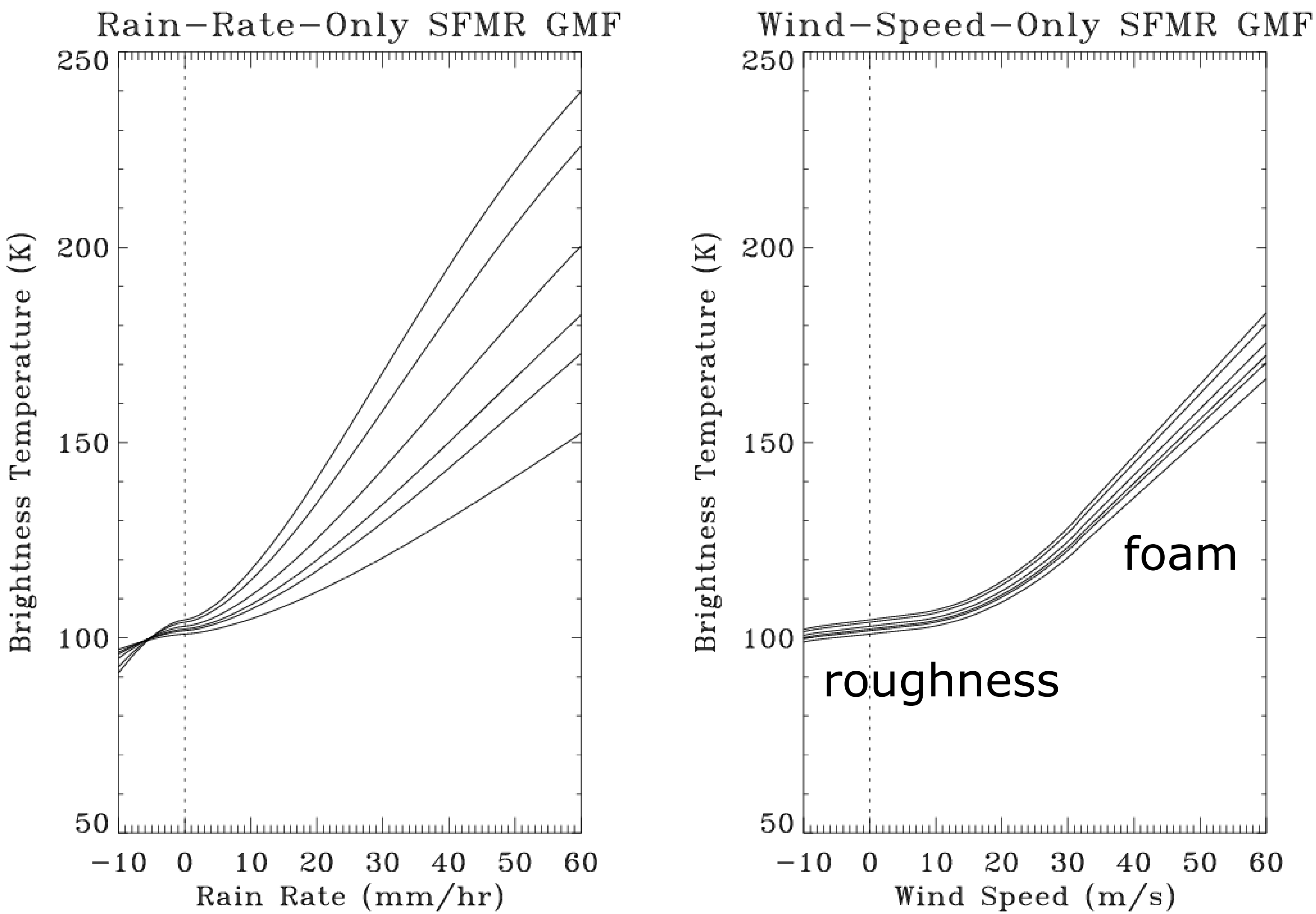

Ocean Wind Climatology from Satellite

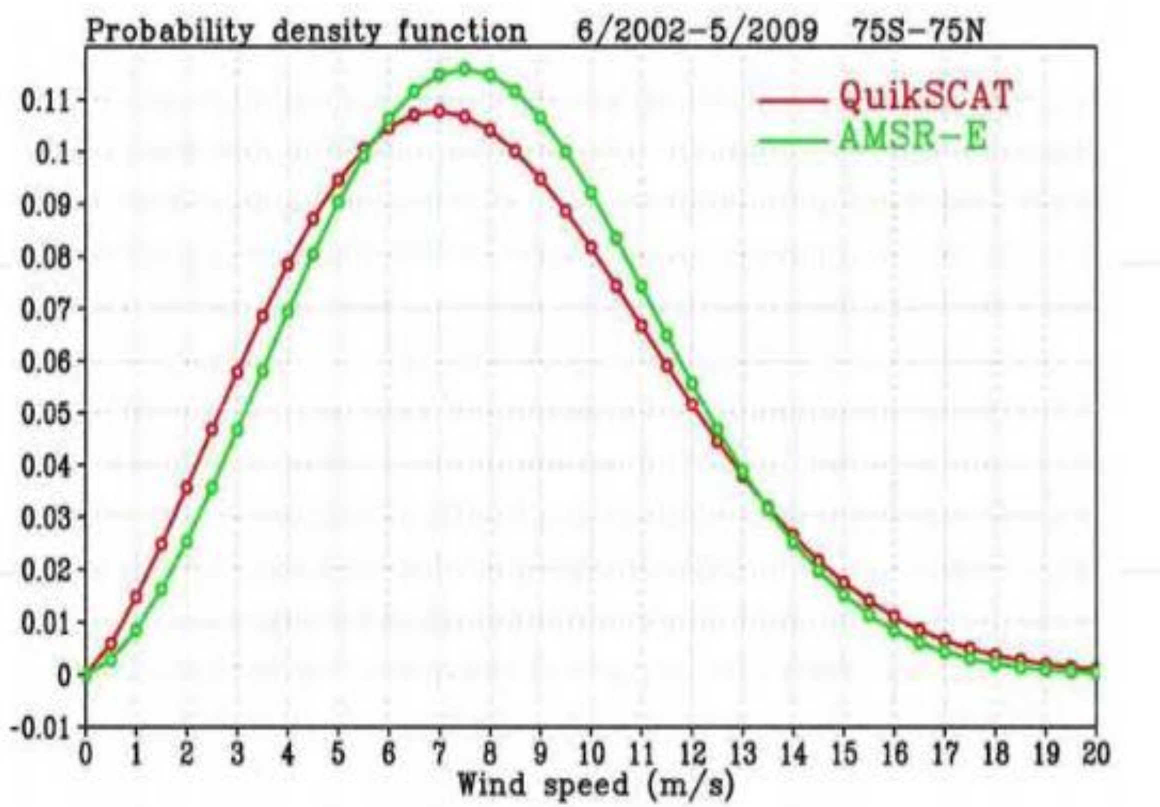

Fig. 1. Comparision of the probability density function of ocean surface wind speed from 7 years of QuikSCAT and AMSR-E measurements.

Liu et al., "Wind power at sea as observed from space," ch 14 in Muyeen, S.M. (ed.), Wind Power, Intech, Vienna, 2010.

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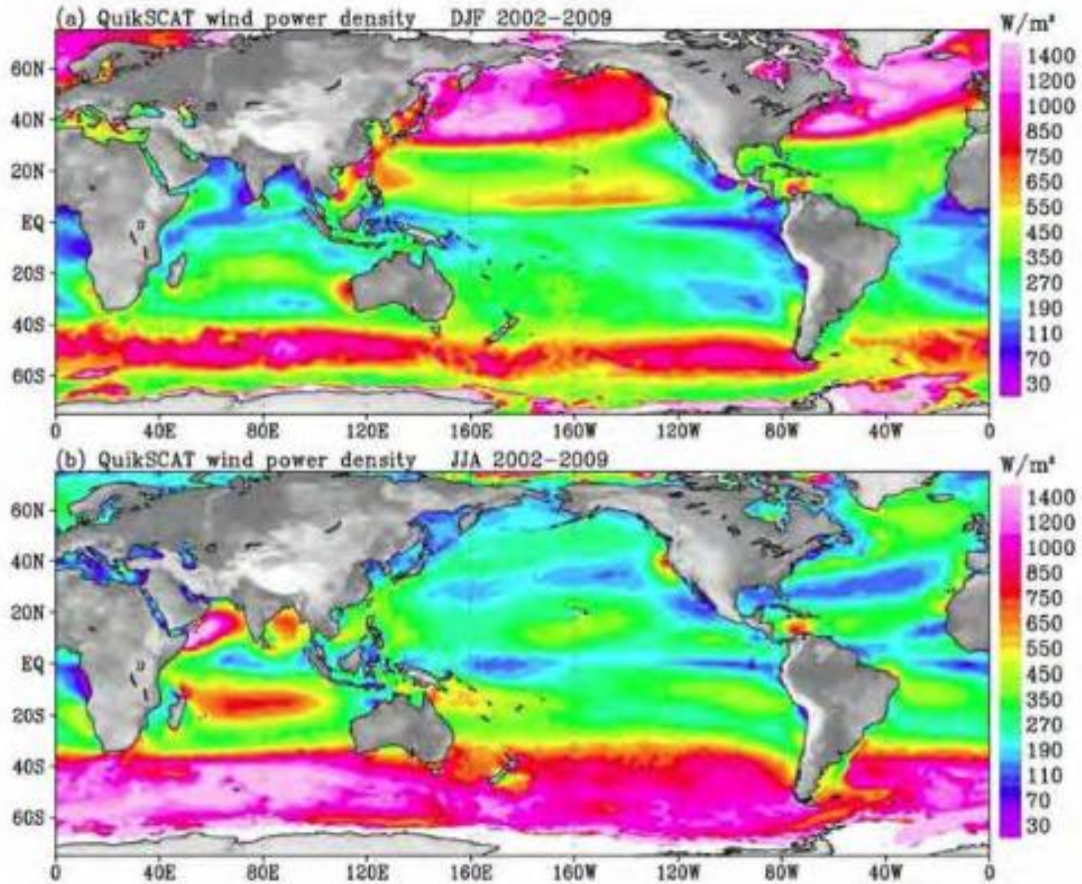
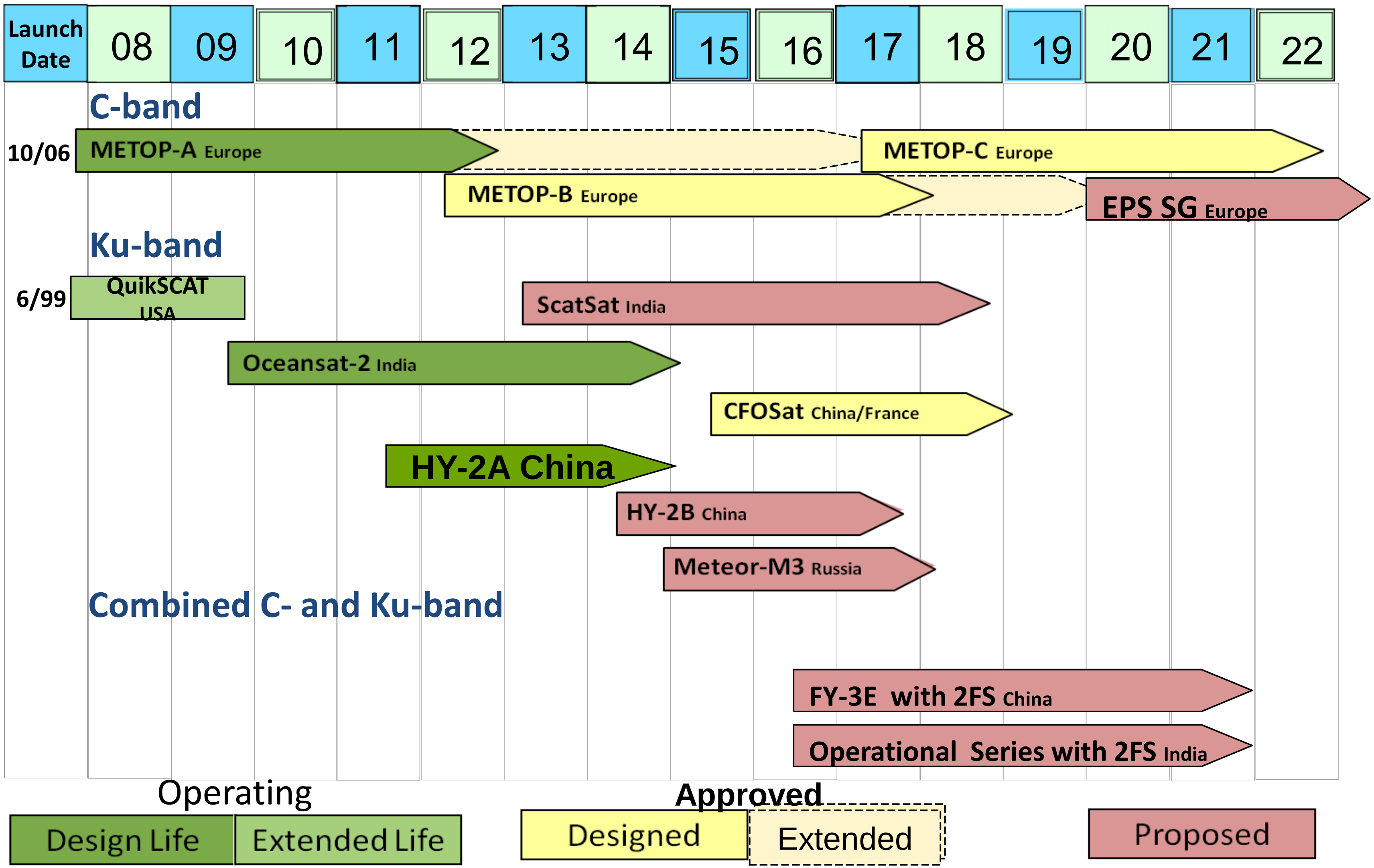


Fig. 2. Distribution of power density of ocean surface wind (10 m) from QuikSCAT for (a) boreal winter (December, January, and February) and (b) boreal summer (June, July, and August).

Global Scatterometer Missions



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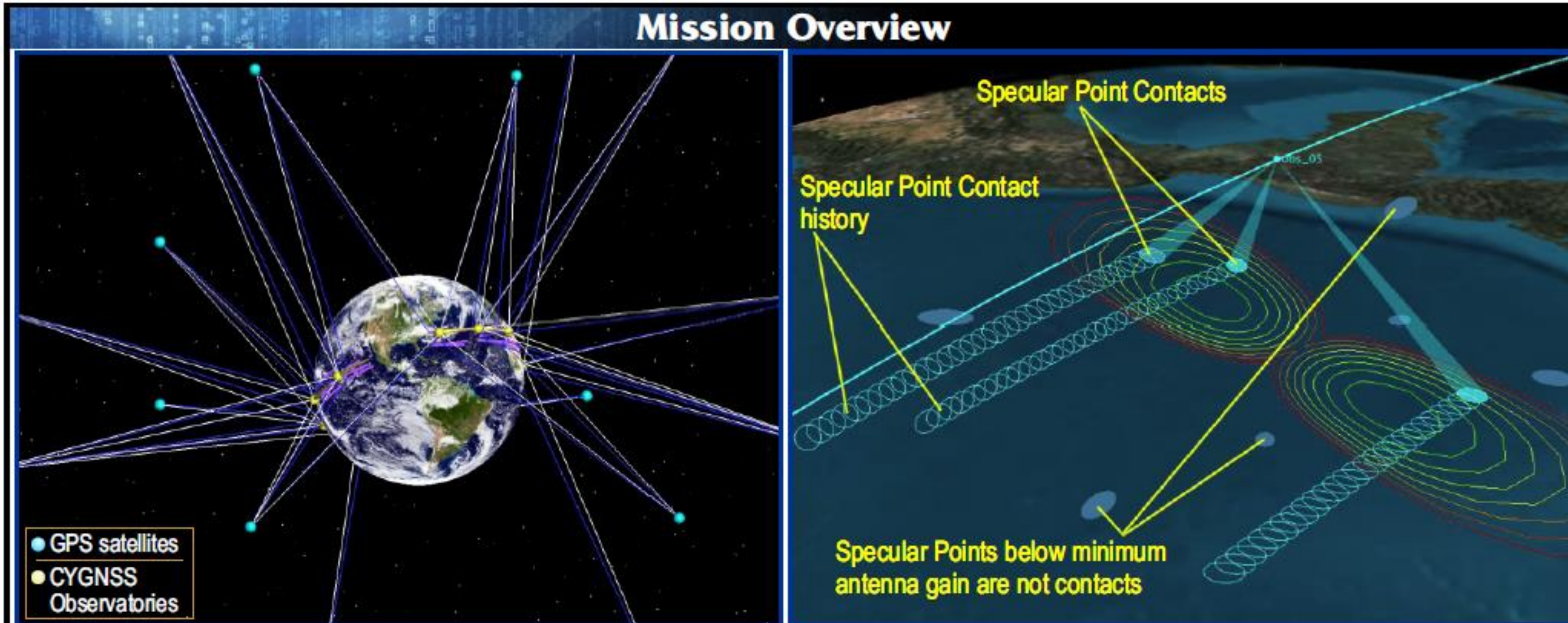
A Future Scatterometer Design

Cyclone Global Navigation Satellite System (CYGNSS)

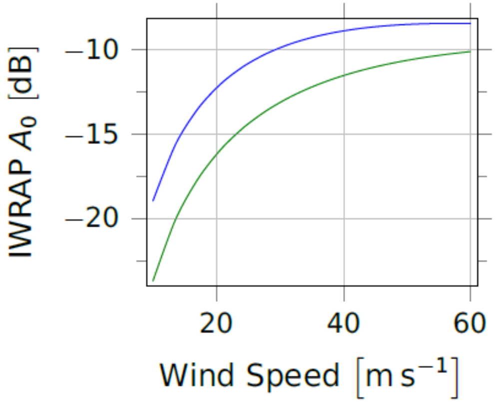


The CYGNSS mission is comprised of 8 Low Earth Orbiting (LEO) spacecraft (S/C) that receive both direct (white lines) and reflected (blue lines) signals from GPS satellites. The direct signals pinpoint LEO S/C positions, while the reflected signals respond to ocean surface roughness, from which wind speed is retrieved. GPS bi-static scatterometry measures ocean surface winds at all speeds and under all levels of precipitation, including TC conditions. In the right figure, instantaneous wind samples are indicated by individual blue circles. Five minutes of wind samples are shown.

Scatterometry "Issues"

Poor sensitivity in high winds

- Investigation polarizations



Contamination by rain

- Attenuation through atm.
- Add'l surface roughening by drops and/or downdrafts

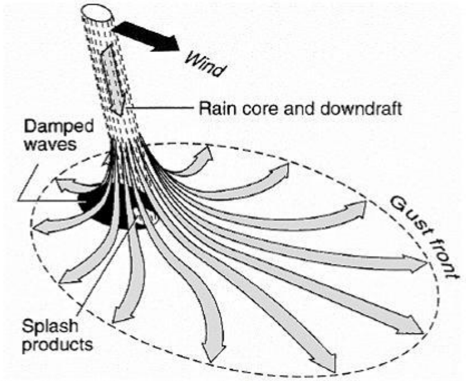


Figure 17.1. Schematic sketch of the downdraft associated with a rain cell. The downdraft spreads over the sea surface, causing and enhanced roughening of the sea surface and, thus, an increase in the backscattered radar power [After *Atlas*, 1994b].

Spatial smoothing

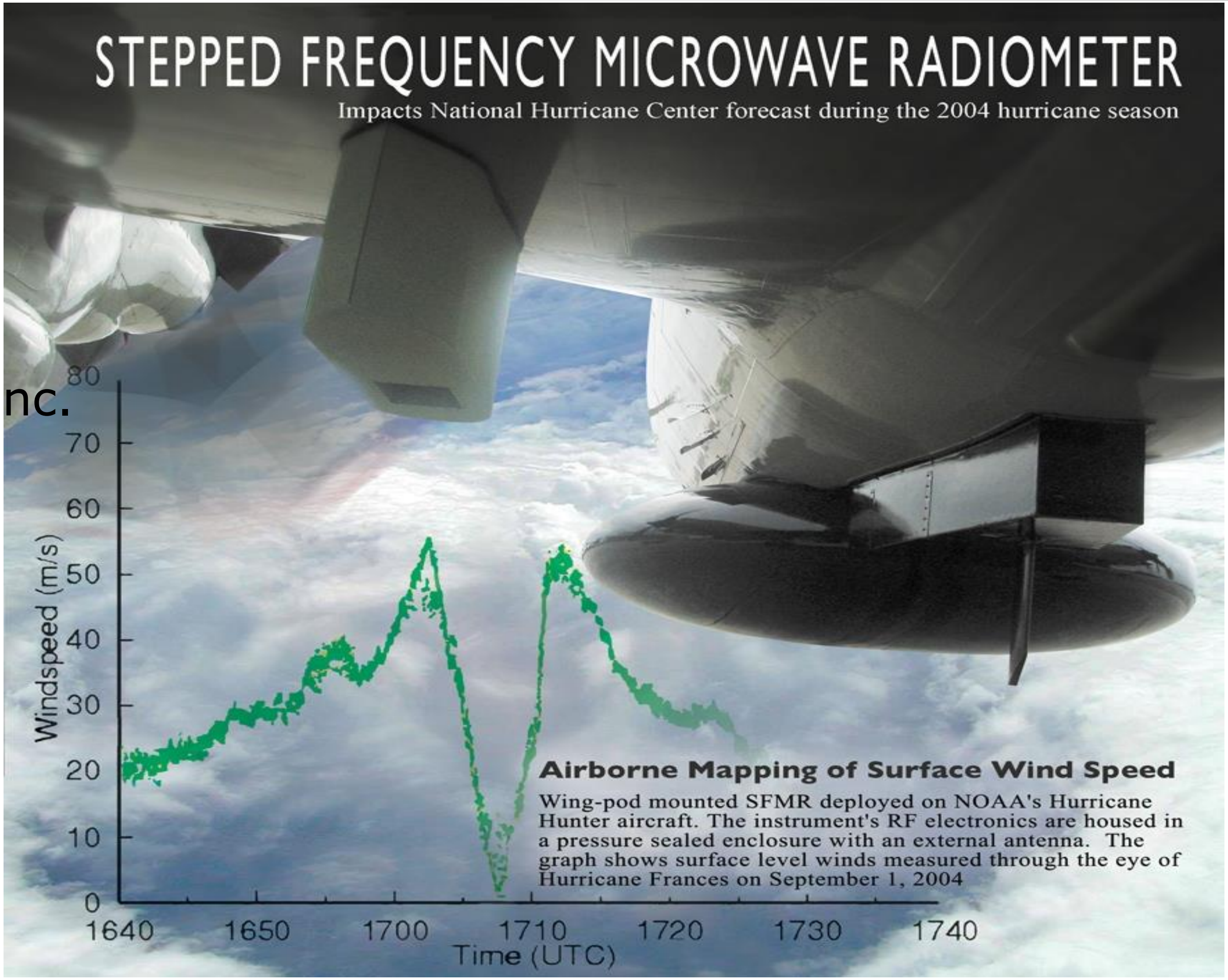
- Extreme events smaller than resolution

What do we do?

- Obtain scatterometer measurements in high-wind (and rain) regimes
  - Hurricanes (typ. Aug-Oct)
    - Based from Tampa, St. Croix, or Barbados
  - High-latitude winter storms (Jan-Feb)
    - Based from Anchorage, St. Johns, Halifax

- How does it work?

- Developed at NASA/UMass (C.T. Swift)
- Sold/maintained by Prosensing, Inc.
- Nicknamed "the Smurf"



Hurricane Reconnaisance

- 53rd Weather Reconnaisance Squadron
  - Based at Keesler AFB in Biloxi, Mississippi
  - Provide **operational** reconnaisance for National Hurricane Center (NHC) in Miami, FL.
  - Fly specialized (W)C-130 aircraft
  - *These are the guys on the TV show "Hurricane Hunters"*

- NOAA Aircraft Operations Center
  - Based at McDill AFB in Tampa, FL
  - Do **research** reconnaisance for developing new observing techniques or studying storm structure.
  - Fly specialized (W)P-3 aircraft.
  - Periodically tasked by NHC for operational storm fixes.

Research Aircraft: Lockheed WP-3D

Research Aircraft: Lockheed WP-3D

NOAA has 2 WP-3Ds:

N43RF “Miss Piggy”

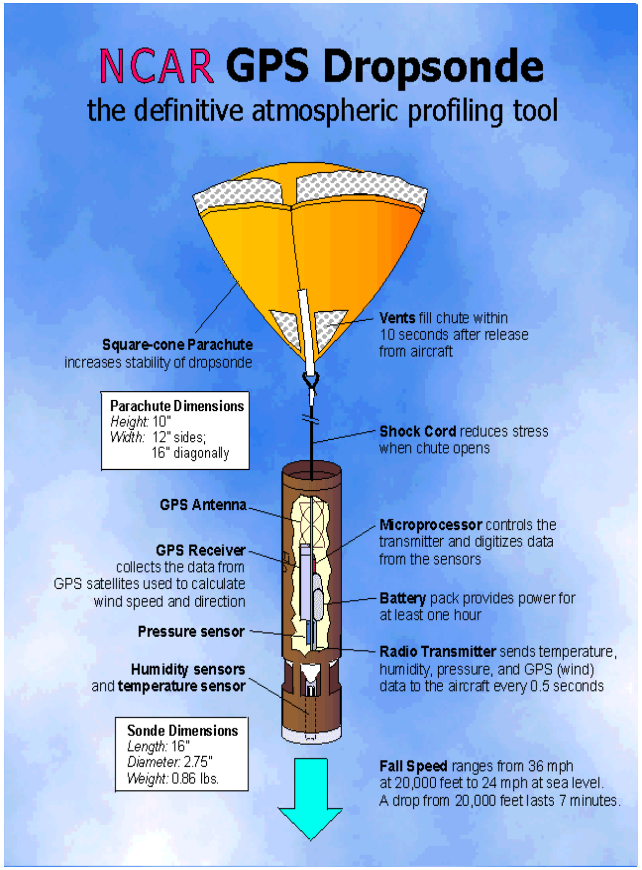
In the cockpit...

In the cockpit…

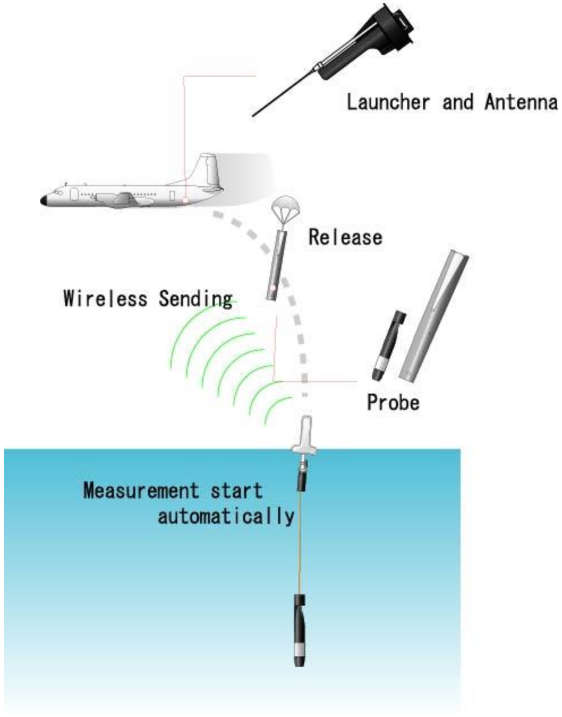
Aircraft Measurements

- Flight-level winds pressure
- Wind, temperature, humidity profiles
  - via GPS dropsonde
- Winds & precipitation aloft
  - via tail Doppler radar
- Surface-level winds
  - via microwave radiometer & dropsonde
- Sea surface temperature
  - Expendable bathythermographs
- **Our measurements:**
  - Radar signature of sea-surface
  - Precipitation between aircraft and sea-surface

Expendables

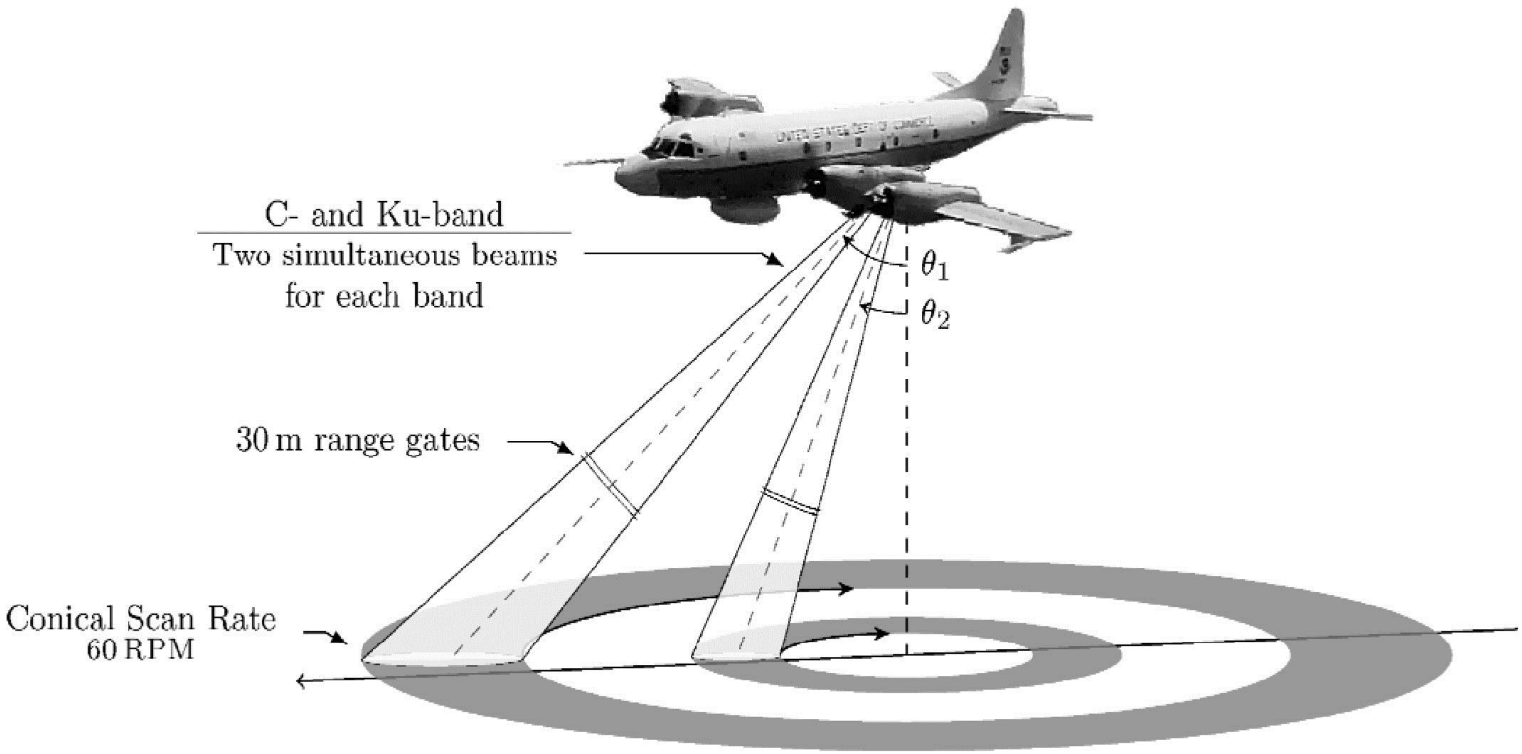


XBT: expendable bathythermograph



Our Radar

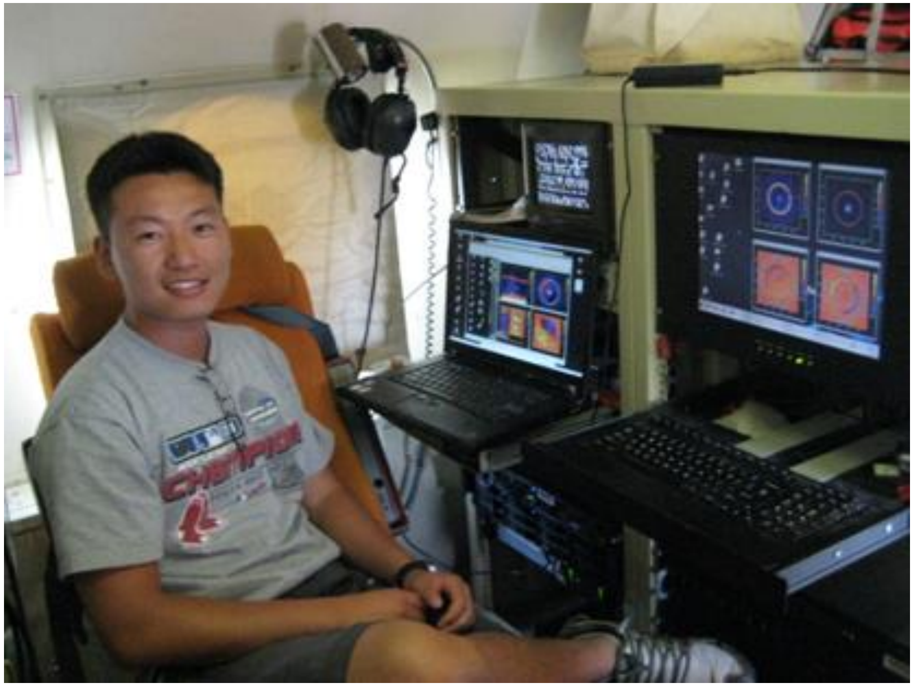
Imaging Wind & Rain Airborne Profiler



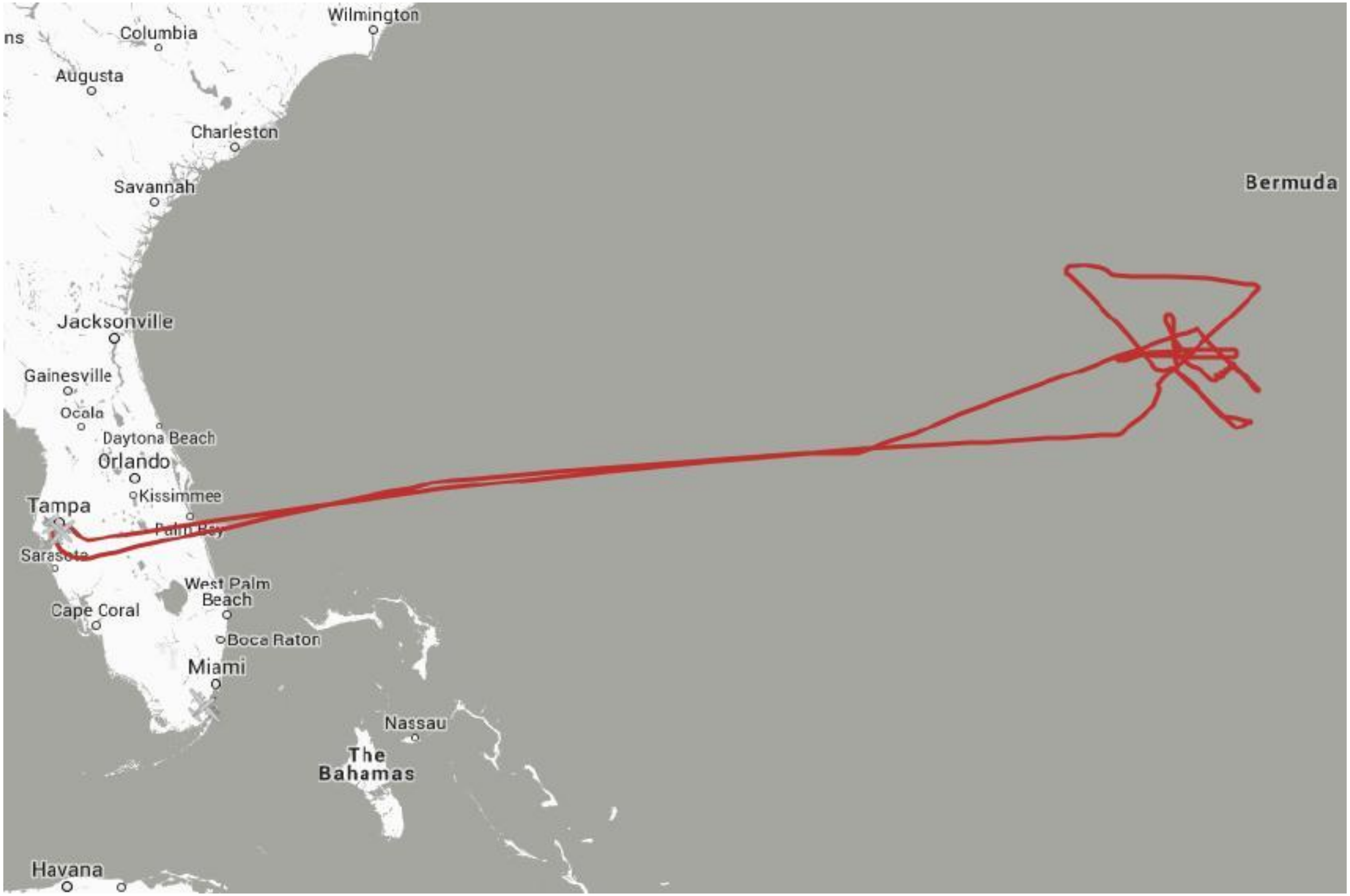
Our digs on the P-3

Radar electronics in the back

Data recording up front



Tasked Mission on 10/17/2014



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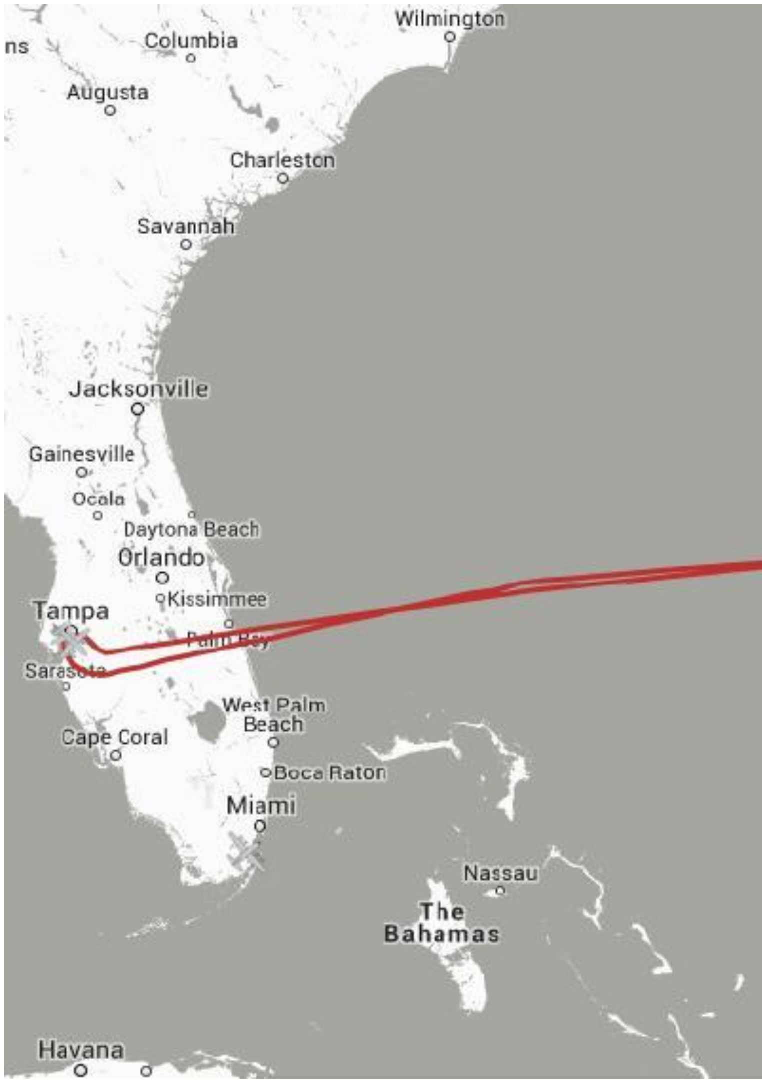

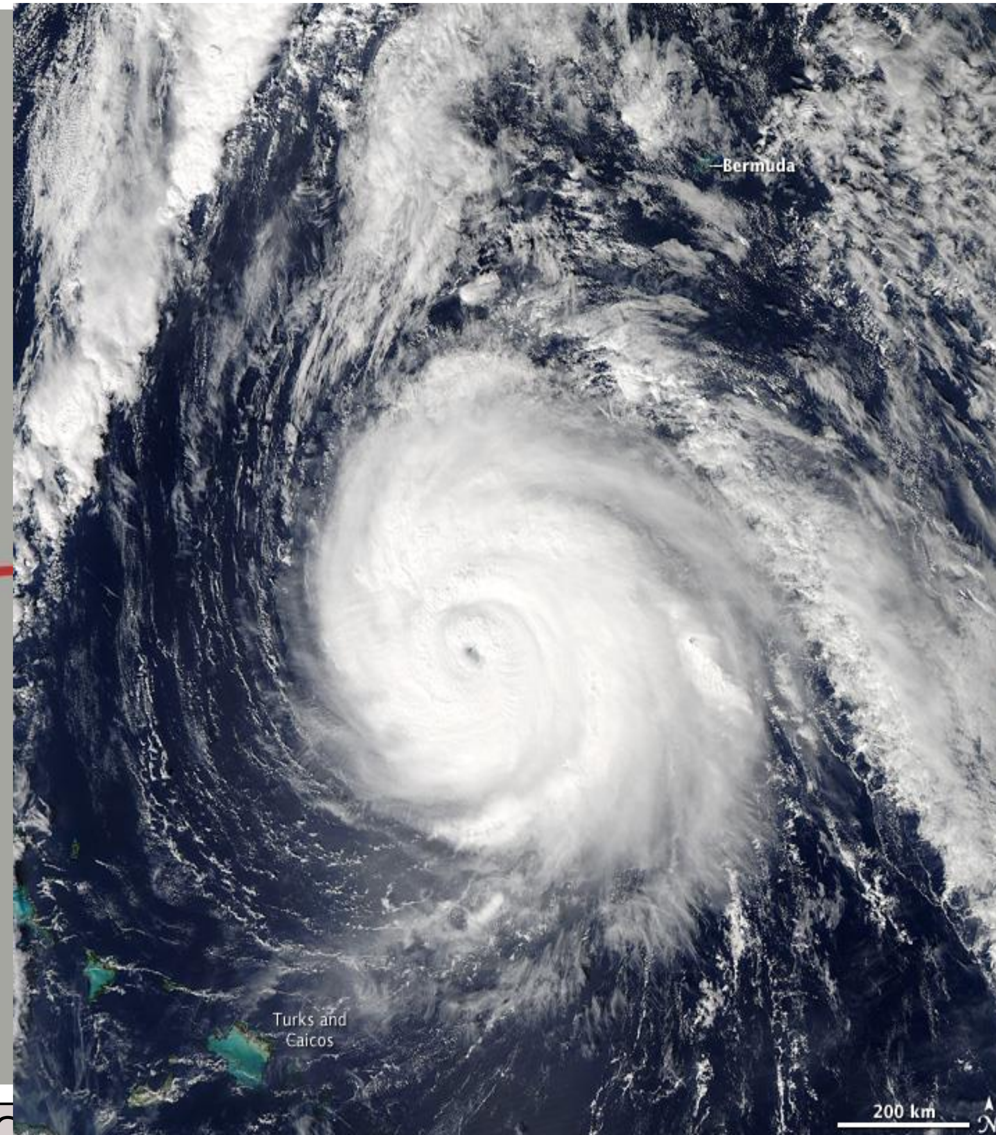

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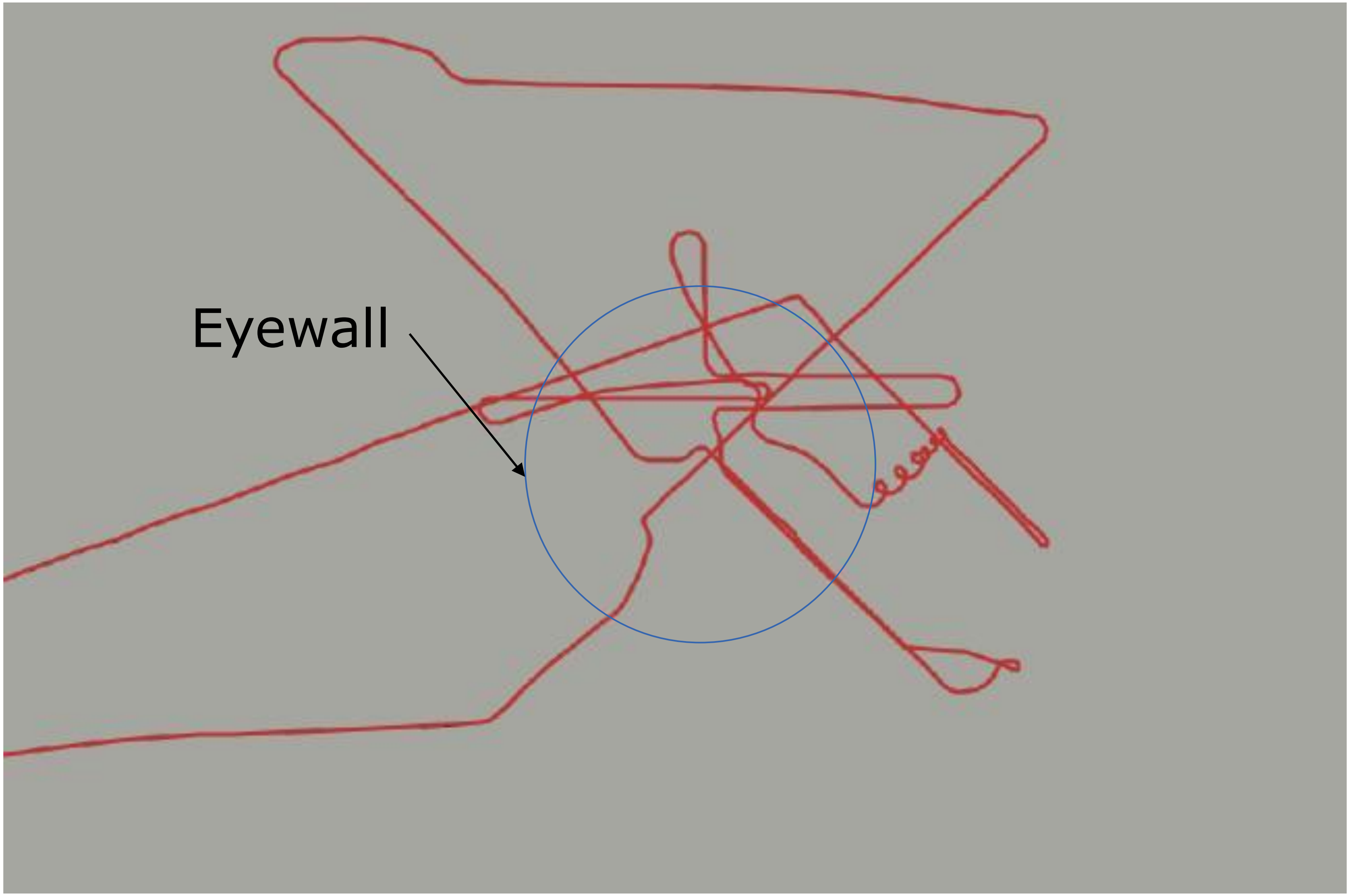

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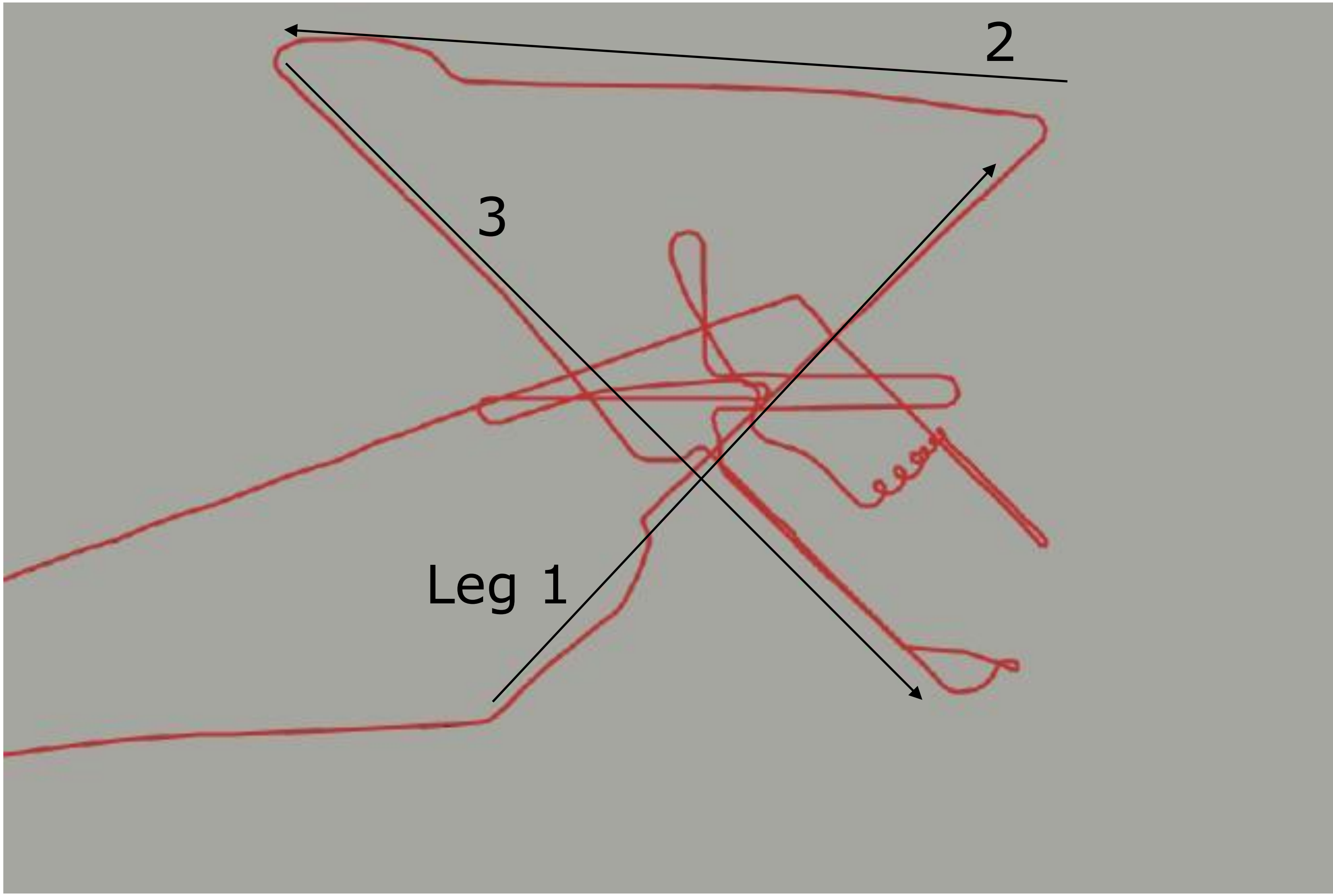
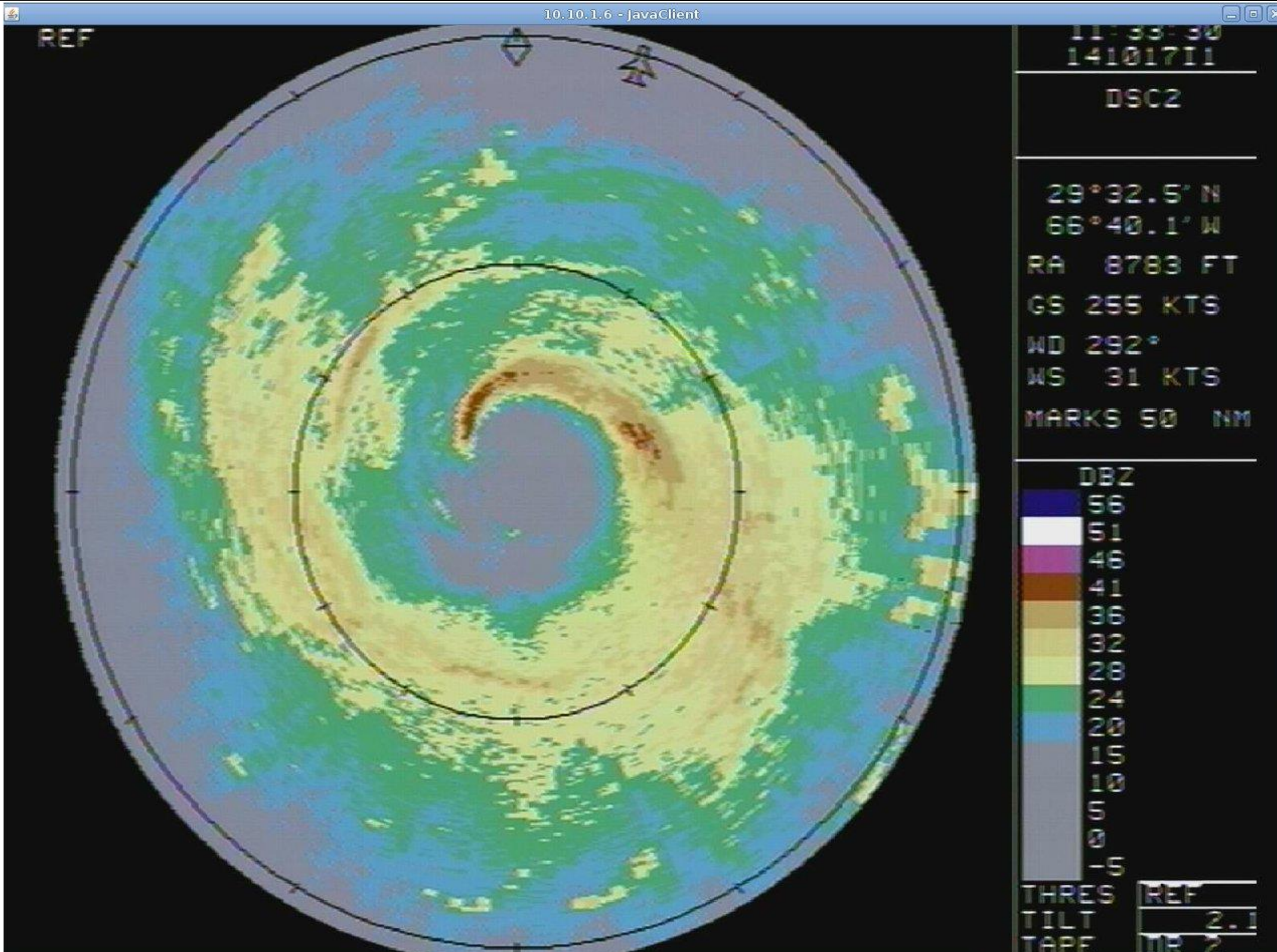
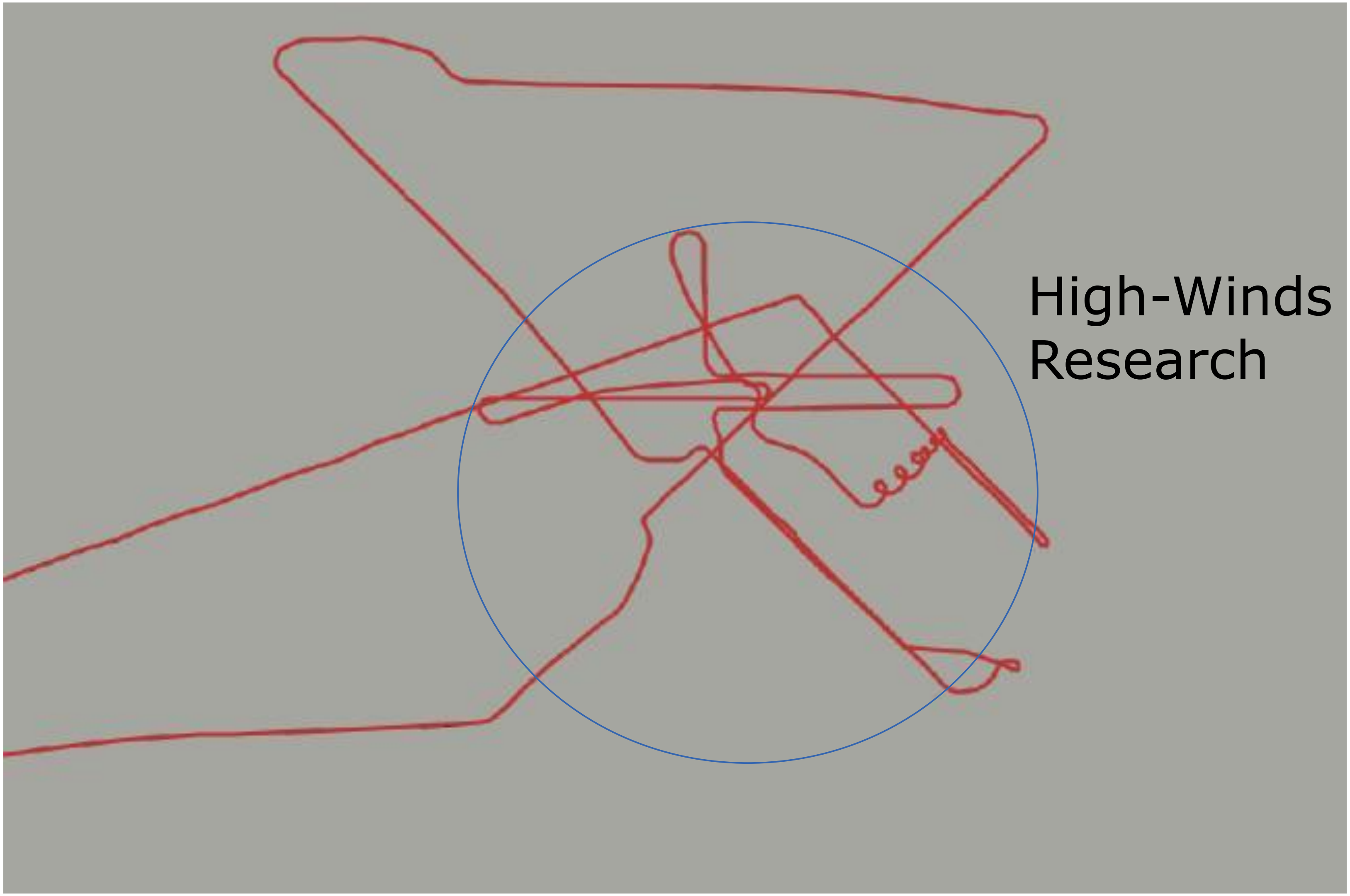


Radar view from the eye…



View from 8 kft just inside the eye…

Tasked Mission on 10/17/2014



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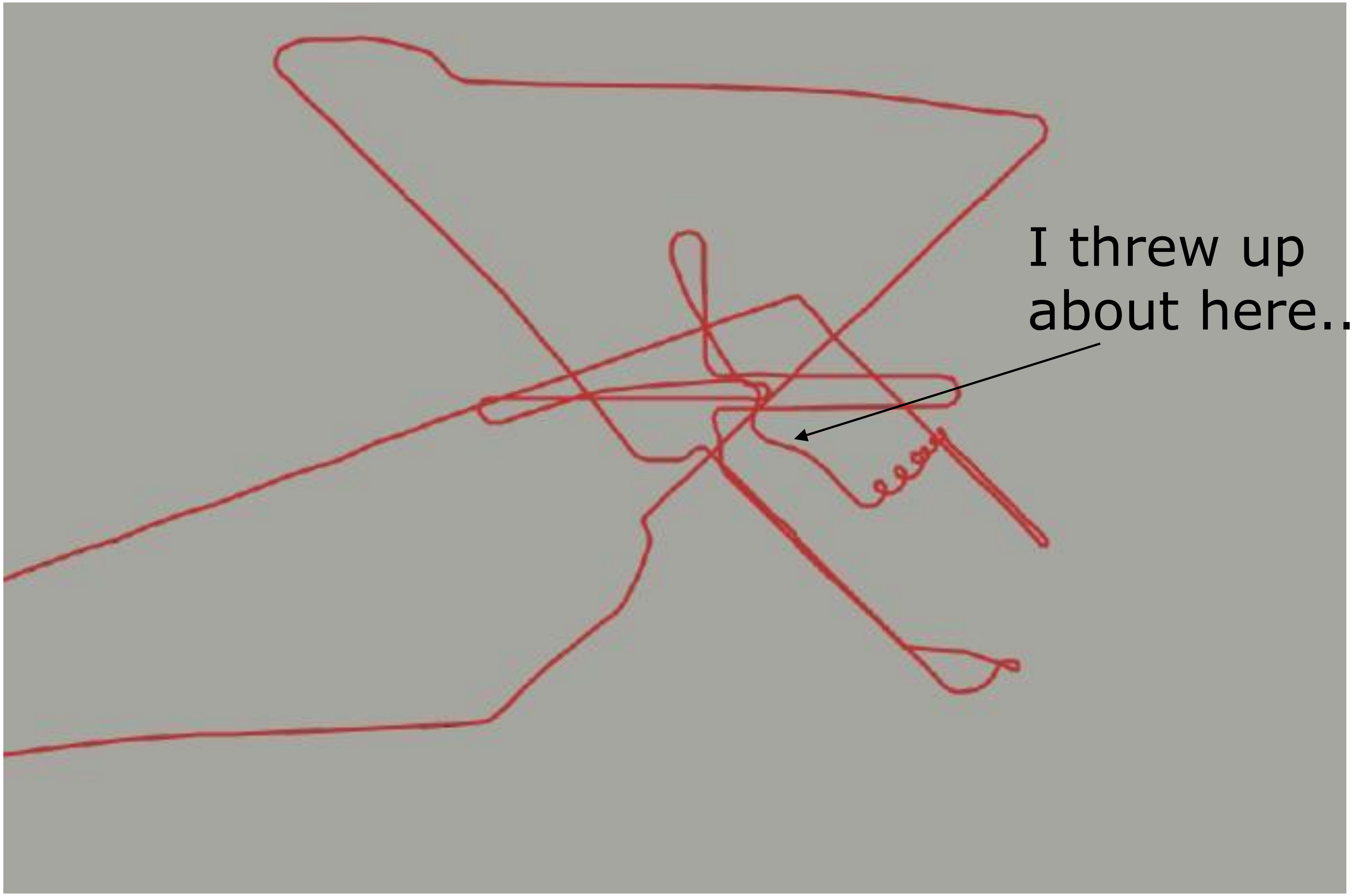
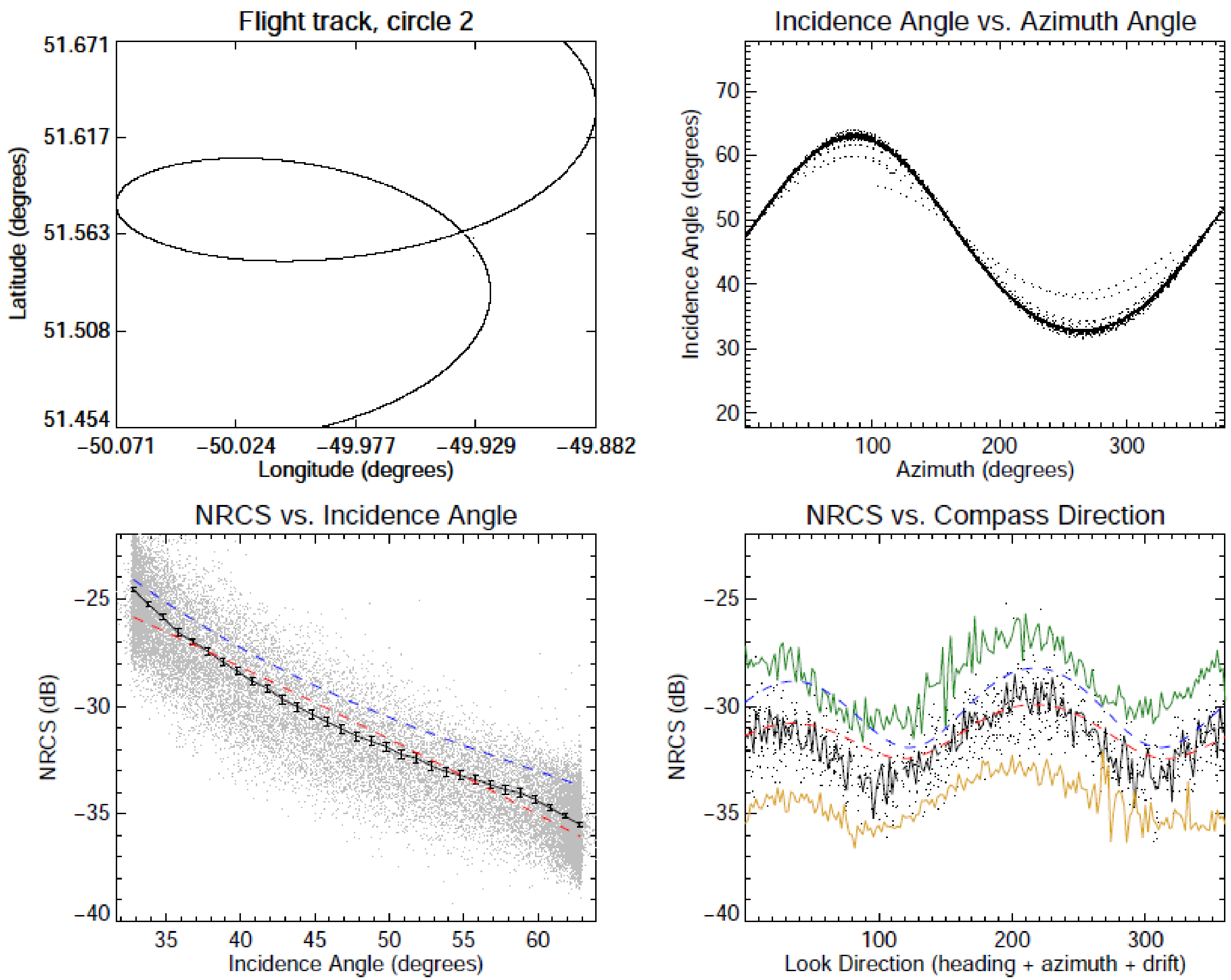


I threw up
about here…

Sample NRCS Observations



The End

Eye Transect of Hurricane Rita (Cat 5)