Introduction to the Spaceborne Scatterometry

Presentation to

Science & Technology Space Master
Tor Vergata University, Rome, Italy

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  - Ice
  - Land

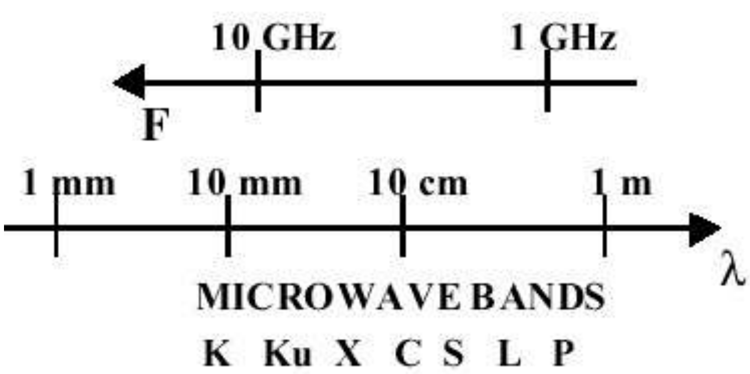
The Scatterometry

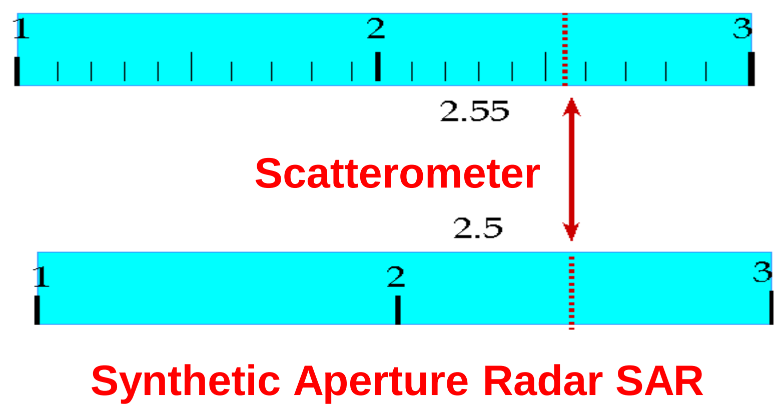
What is spaceborne Scatterometry ?

- Mature technique for observing Earth Phenomena (about >50 Km^2) from the Space in the areas of interest for:
  - Meteorology
  - Oceanography
  - Sea Ice Climatology
  - Glaciology
  - Land surface states & vegetation

The Scatterometry

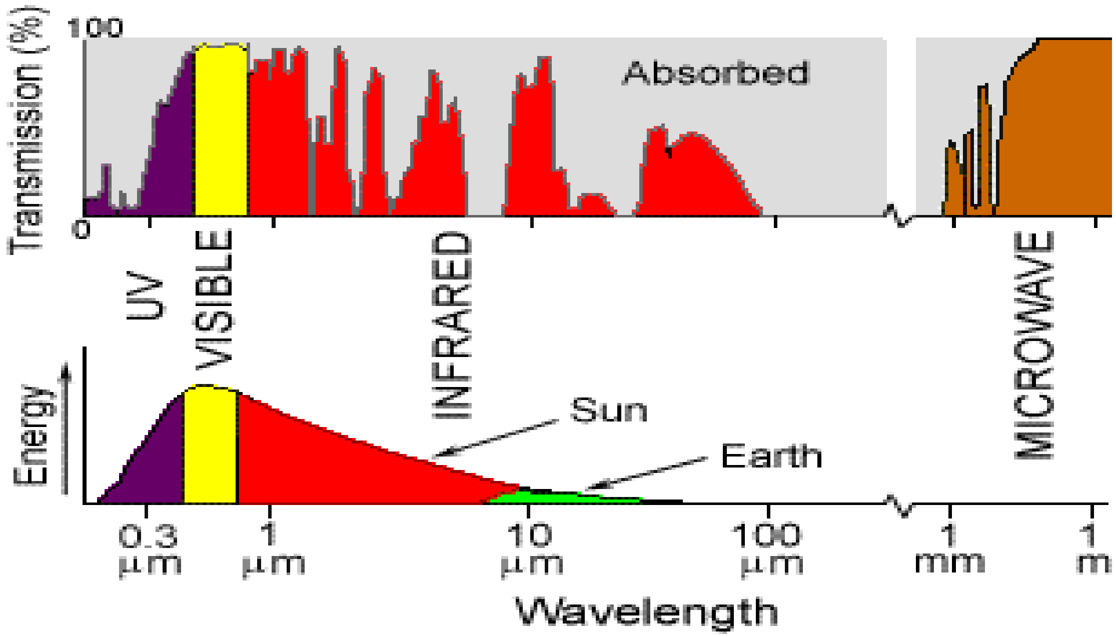
- Spaceborne Scatterometry consists in:
  - **measuring** the backscatter signal when scanning the Earth's surface from a satellite with an active sensor (@ microwave, accuracy within 1-2%) called Scatterometer.
  - **retrieve** "potential" geophysical information carried by the electromagnetic waves after interactions with Earth surface





The Scatterometry

- Active microwave remote sensing allows data collection whatever the weather (atmosphere) or the sunlight conditions
  - Polar regions being in total darkness six months a year
  - tropical region very cloudy

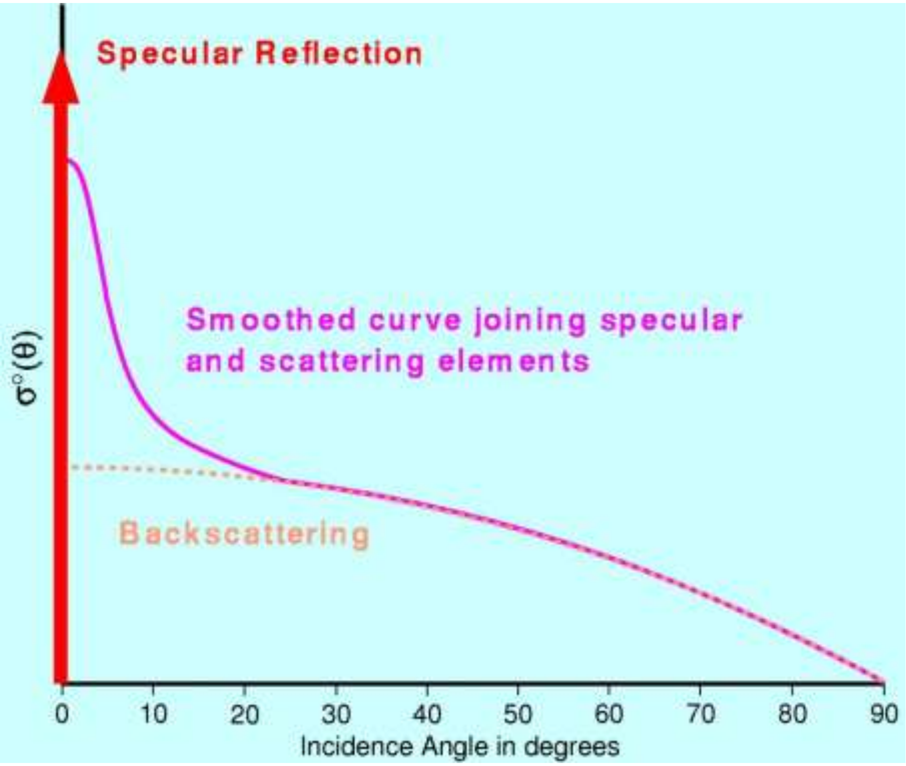


The Scatterometry

- It measures the "Normalized Radar Cross Section" that is function of:
  - **Geometry**: distance, azimuth & elevation
  - **Instrument**: carrier frequency, resolution, polarization, Antenna pattern, receiver attenuation
  - **Target**: nature of surface, roughness, dielectric properties

$$\sigma_0(\theta,\phi,p,\lambda,\varepsilon,\mu)=\frac{(4\pi)^3 R^4}{\lambda^2 G(\theta,\phi)A}\frac{P_R}{P_T}$$

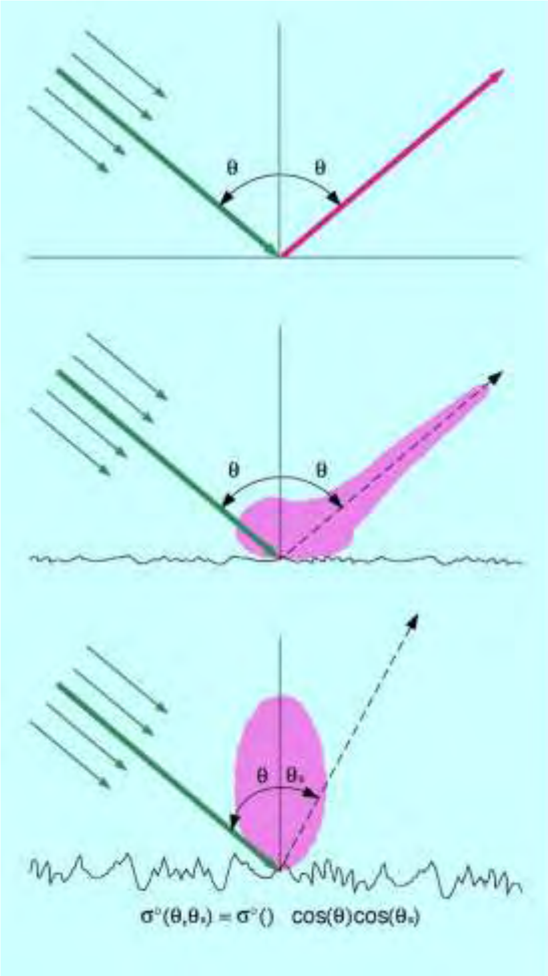
The Scatterometry



- In the real life, we have:
  - at low incidence angles (<25°) a combination of specular reflection and backscattering.
  - At high incidence angle (>25°) only backscattering.

The Scatterometry

- Reflection over a very smooth surface
  - All the energy is reflected away from the radar. Typically water surfaces with no wind.
  - Over a slightly rough surface, most of the energy is reflected away. A small part is backscattered.
  - Ice shelves and ocean with calm wind (< 3 m/s)
  - Backscattering over a very rough surface. For a given direction, the energy varies with the cosine of the look angle.

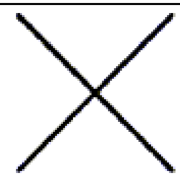
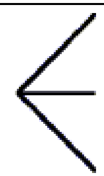
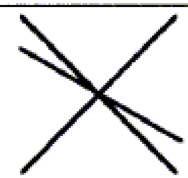
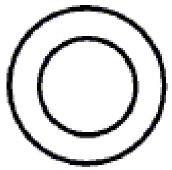
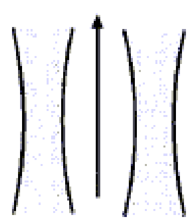
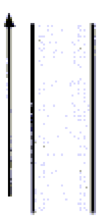
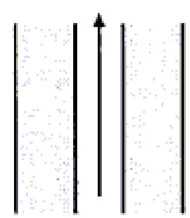
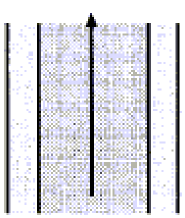


The Scatterometry

- From the measured “Normalized Radar Cross Section” it is possible to retrieve:
  - Winds vector over Ocean (primary application)
  - Sea Ice presence
  - Ice age
  - Soil moisture / soil status
  - Vegetation index
  - Land crop

The Scatterometry

- **Summary of basic Scatterometer characteristics to measure backscattering**

	SASS	ERS-1/2	NSCAT	SeaWinds
FREQUENCY	14.6 GHz	5.3 GHz	13.995 GHz	13.6 GHz
AZIMUTHS				
POLARIZATION	V-H, V-H	V ONLY	V, V-H, V	V-OUTER/H-INNER
BEAM RESOLUTION	FIXED DOPPLER	RANGE GATE	VARIABLE DOPPLER	PENCIL-BEAM
SCIENCE MODES	MANY	SAR, WIND	WIND ONLY	WIND/HI-RES
RESOLUTION	50/100 km	25/50 km	25/50 km	25 km/6x25km
SWATH		 500	 600 600	 1400,1800

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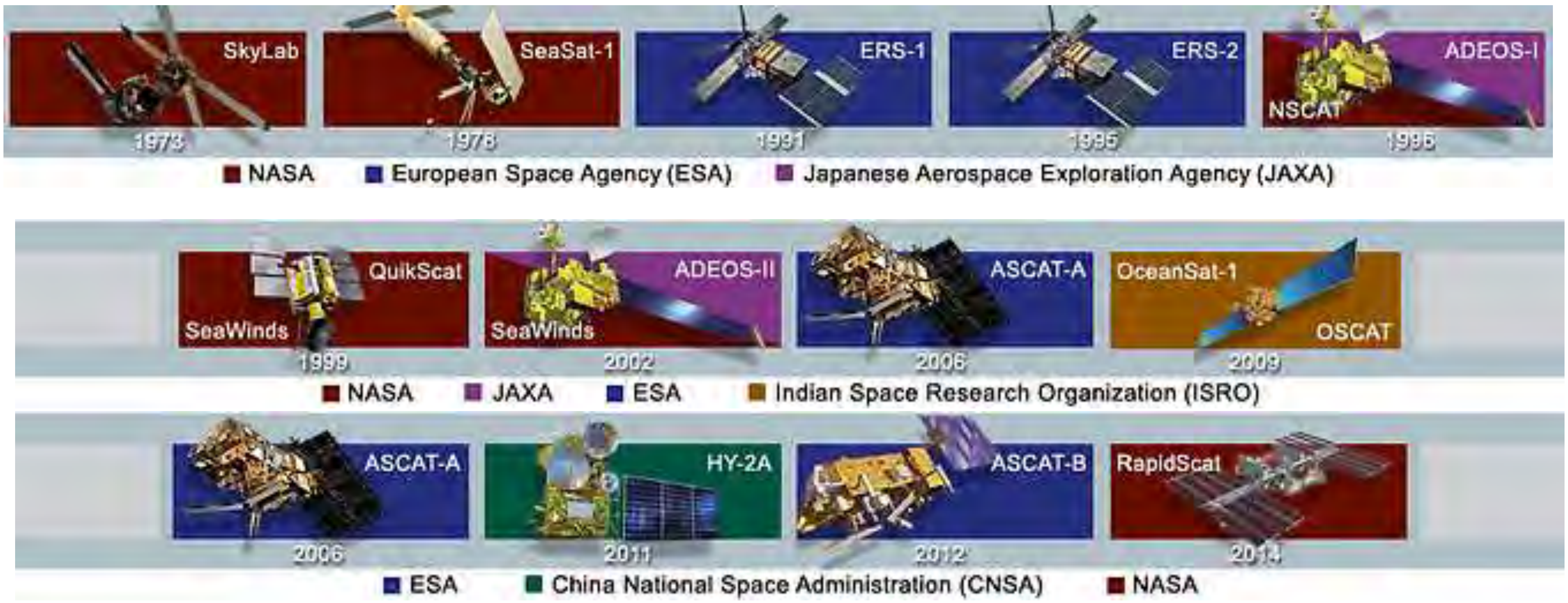
Watching the Winds: Where Sea Meets Sky

More than 40 years of continuous observation of Sea winds from space …



http://www.nasa.gov/jpl/rapidscat/sea-meets-sky-20140813/

serco ECMWF TU WIEN GEO

… and the successfully story will continue beyond 2020 !

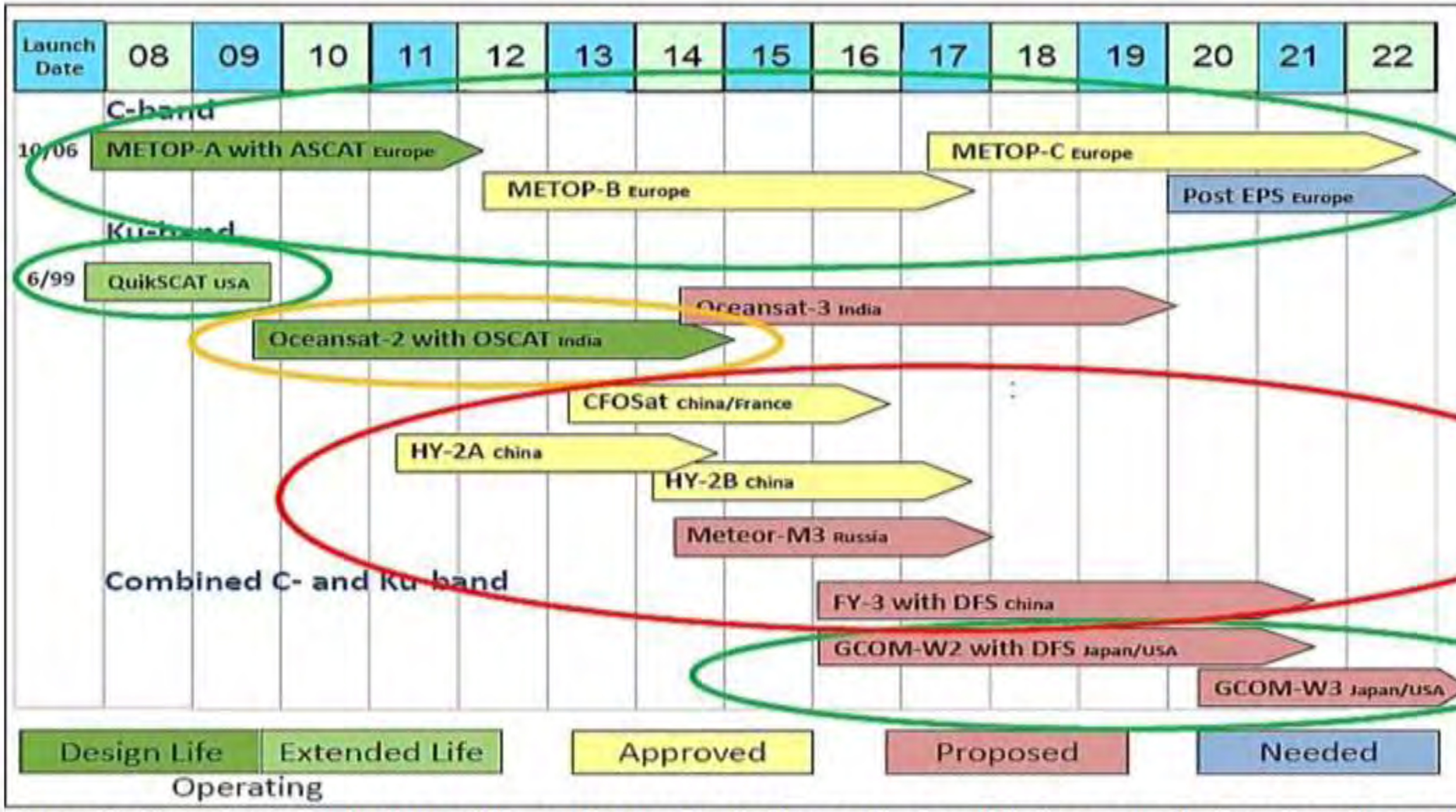


Figure 5: Overview of missions with scatterometer instruments for global ocean wind vector observations (image credit: CEOS) [16]

https://directory.eoportal.org/web/eoportal/satellite-missions/q/quikscat/

Scatterometer Missions

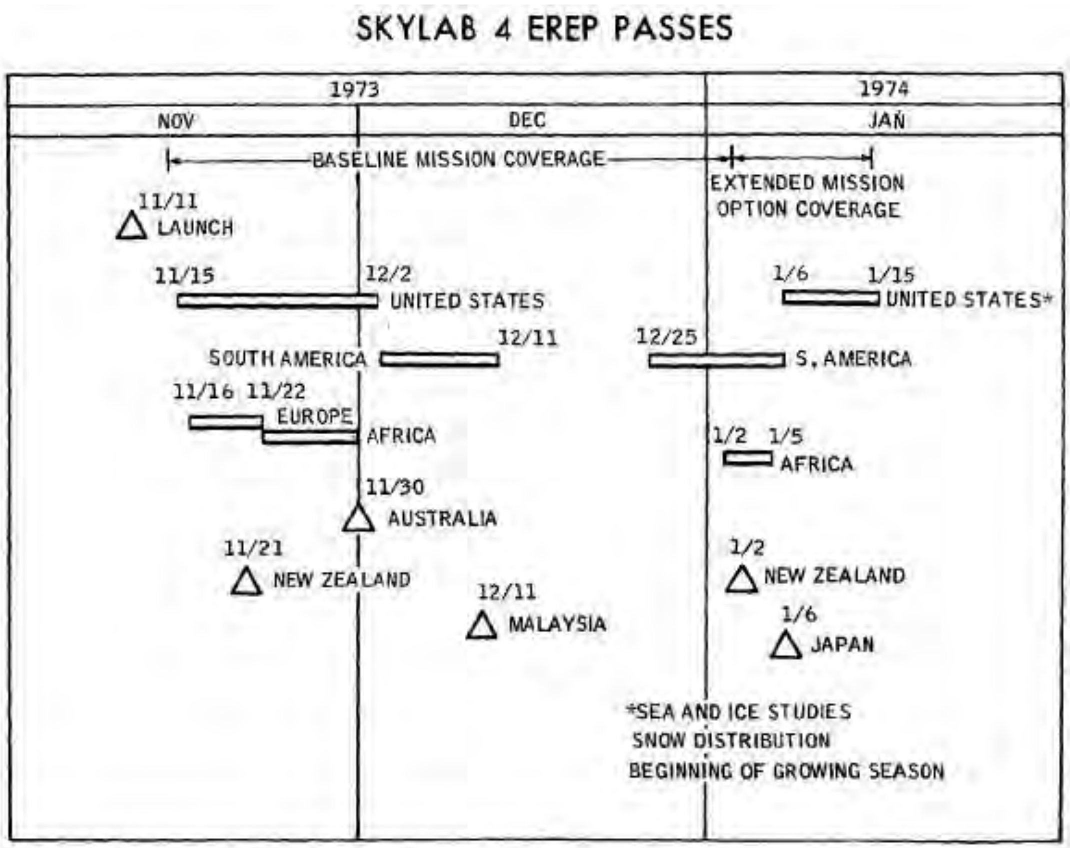
- Scatterometers have been flow on space missions since the early '70s
- From NASA Skylab (1973) press Kit
  - Earth resources experiments (EREP) employ six devices to advance remote-sensing technology and at the same time gather data applicable to research in agriculture, forestry, ecology, geology, geography, meteorology, hydrology, hydrography and oceanography through surveys of site/task combinations such as mapping snow cover and water runoff potentials; mapping water pollution; assessing crop conditions; determining sea state; classifying land use; and determining land surface and structure.

Scatterometer Missions

- EREP 1973 – 1974 (NASA)
  - S190A Multispectral Photographic Cameras
  - S190B Earth Terrain Camera
  - S191 Infrared Spectrometer
  - S192 Multispectral Scanner
  - **S193 Microwave Radiometer/Scatterometer and Altimeter**
  - S194 L-Band Radiometer

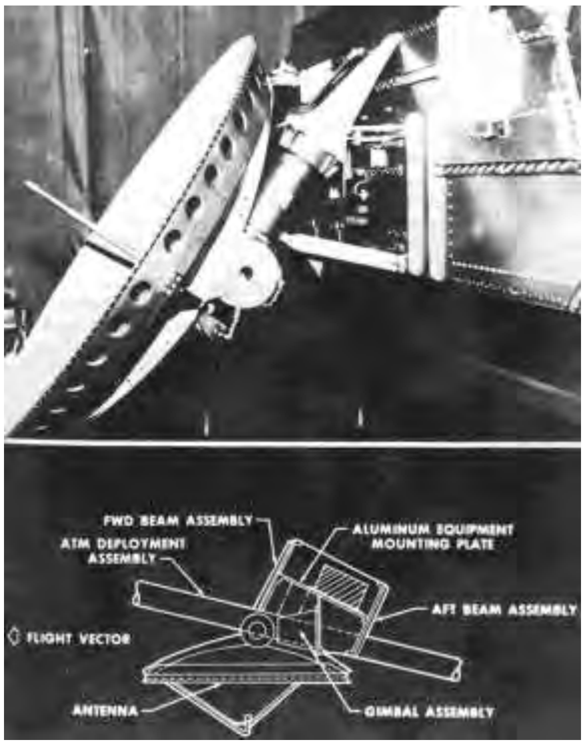
Scatterometer Missions

- EREP Scheduled passes



Scatterometer Missions

- S193 Microwave Radiometer/Scatterometer and Altimeter



– 13.9 GHz
– HH, VV, HV, VH pol.
– 1.5° circular beam
– 1°,17°,32°,43°,50° inc.
– 100 - 750 Km2 res.
– Max forward 48°

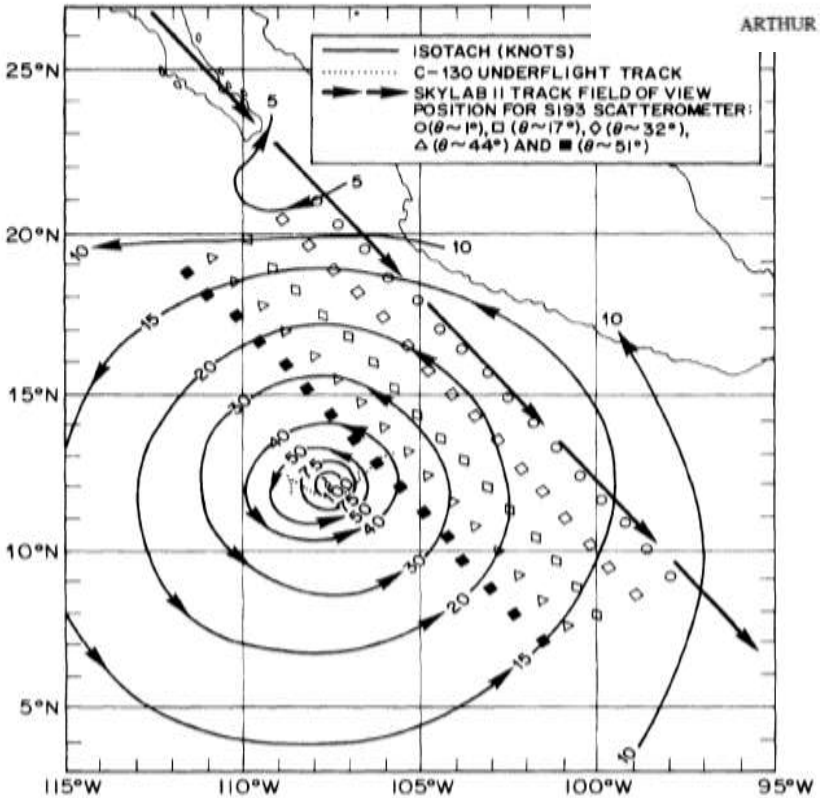
Scatterometer Missions

- S193 Results

IEEE TRANSACTIONS ON GEOSCIENCE ELECTRONICS, VOL. GE-14, NO. 2, APRIL 1976

An Analysis of Skylab II S193 Scatterometer Data

ARTHUR K. JORDAN, SENIOR MEMBER, IEEE, CHARLES G. PURVES, AND JAMES F. DIGGS



'ig. 2. Field of view positions (CTNC Mode) of the S193 scatterometer, *VV* polarization for the SKYLAB II pass of June 6, 1973, with isotach analysis.

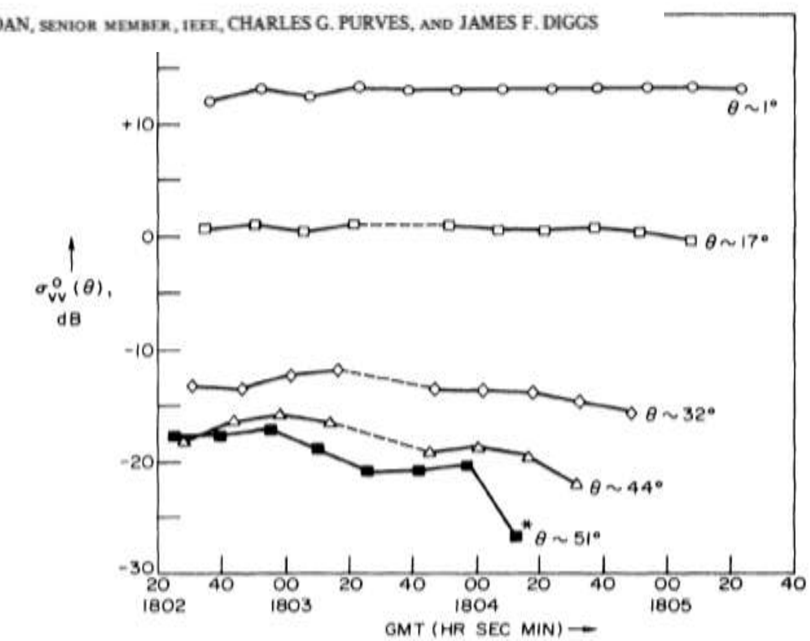
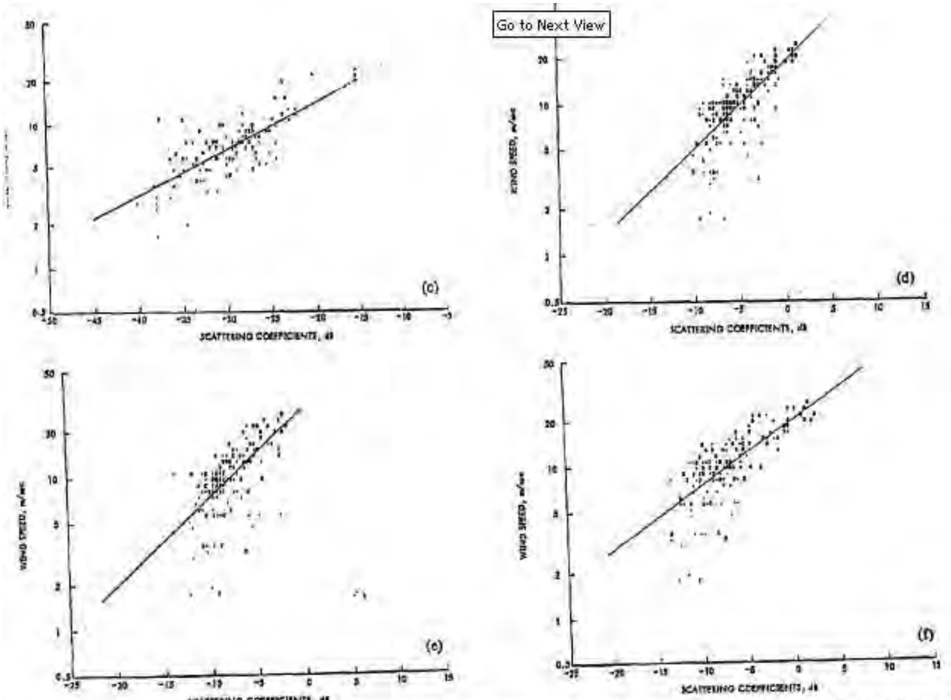


Fig. 3. Normalized cross-section, $\sigma^{\circ}{}_{VV}(\theta)$, as a function of time from S193 data for June 5, 1973 (missing data points are interpolated with dashed line).

can be ascribed to the frequency difference of 5.0 GHz. Within the limits of validity of the theory, the NRL slightly rough surface model gave good agreement with S193 data that were taken when a relatively uniform field was present. For

Scatterometer Missions

- **S193 Results** (J.D. Young R.K. Moore Active Microwave Measurement from Space of Sea-Surface Winds IEEE Journal of Oceanic Engineering Oct 1977)



g. 8. Scattergram of surface-truth wind speed versus σ^0 at 43°-incident angle using logarithmic scales. The scattering coefficients are adjusted to upwind. Note that wind data below 3 m/s are suspect, and their effect is somewhat overemphasized by the logarithmic scale. (a) VV polarization, SL 2 and 3 data. (b) HH polarization, SL 2 and 3 data. (c) VH polarization, SL 2 and 3 data. (d) VV polarization SL 4 data. (e) HH polarization, SL 4 data. (f) VH polarization, SL 4 data.

Symbol	Surface Truth	
A	weather ship	within one-objective grid distance
B	anem. know height	
C	anem. unknown height	
D	visual observation	
+	no ship report	
M	hurricane model	

TABLE III
RMS RESIDUALS ABOUT THE REGRESSION FITS OF LOG SURFACE-TRUTH WIND SPEED AS A FUNCTION OF THE ADJUSTED BACKSCATTER MEASUREMENTS FROM SL 2 AND 3 TAKEN at 43°- INCIDENT ANGLE

Interval of regression estimates of surface-truth wind speed (m/s)	Data Category	Polarization	r.m.s residual (log wind speed)	Number of Observations
3 - 10	B, C, D†	VV	0.132	40
		HH	0.135	36
		VH	0.147	36
3 - 10	E	VV	0.159	43
		HH	0.148	48
		VH	0.136	51
10 - 30	B, C, D	VV	0.213	3
		HH	0.186	4
		VH	0.037	1
10 - 30	E	VV	0.130	14
		HH	0.122	12
		VH	0.110	7

†Residuals from categories B, C, and D were pooled.

Scatterometer Missions

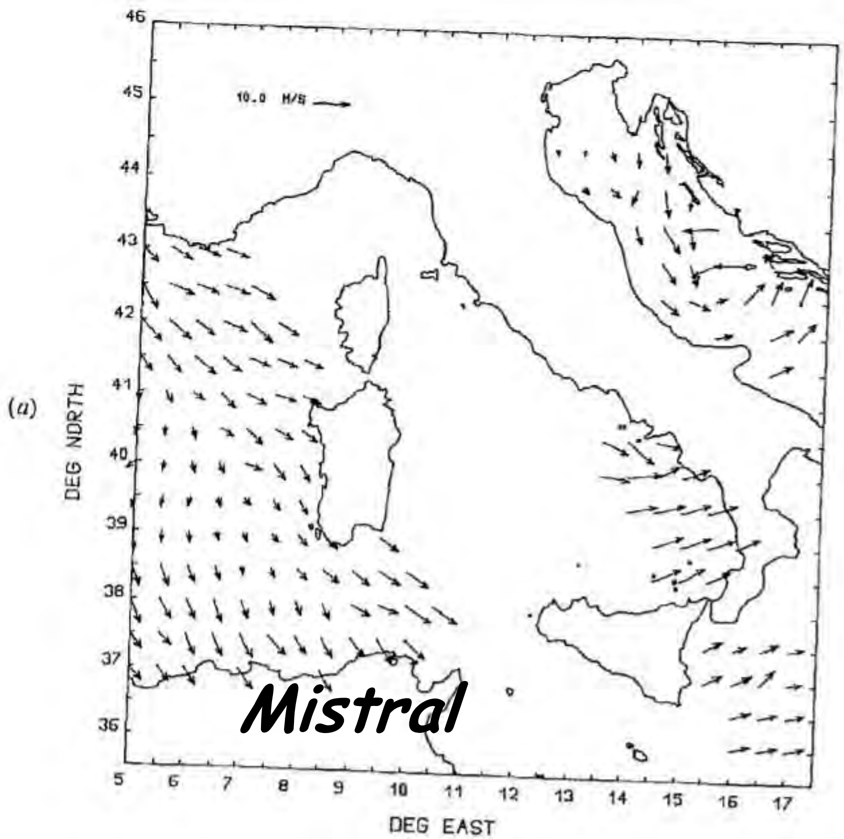
- **Seasat Jun - Oct 1978 (NASA)**

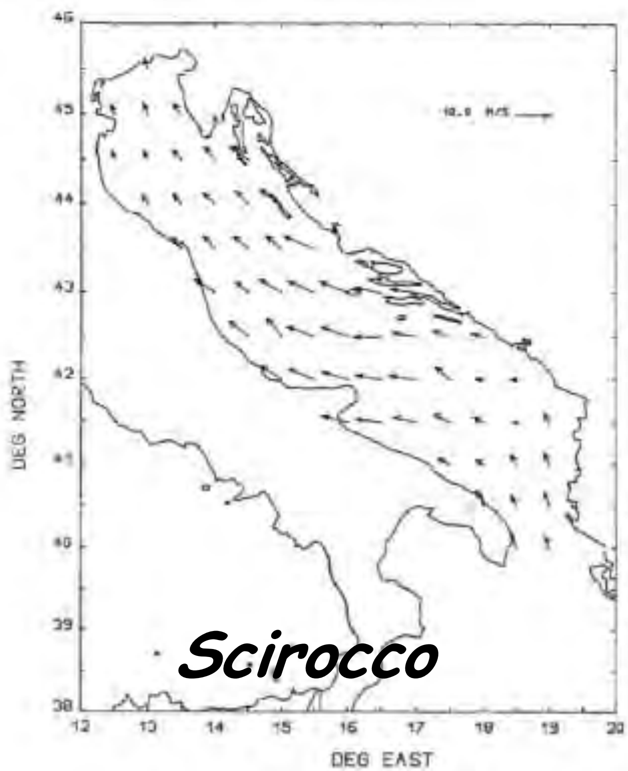
  - Scatterometer (SASS) operated at 14.6 GHz
  - 4 fan-beamed antennas
  - Fore 45° & Aft 135° beam
  - Swath 370 Km
  - Resolution 50 Km
  - First satellite with SAR
  - The mission ended on October 10th , 1978

Scatterometer Missions

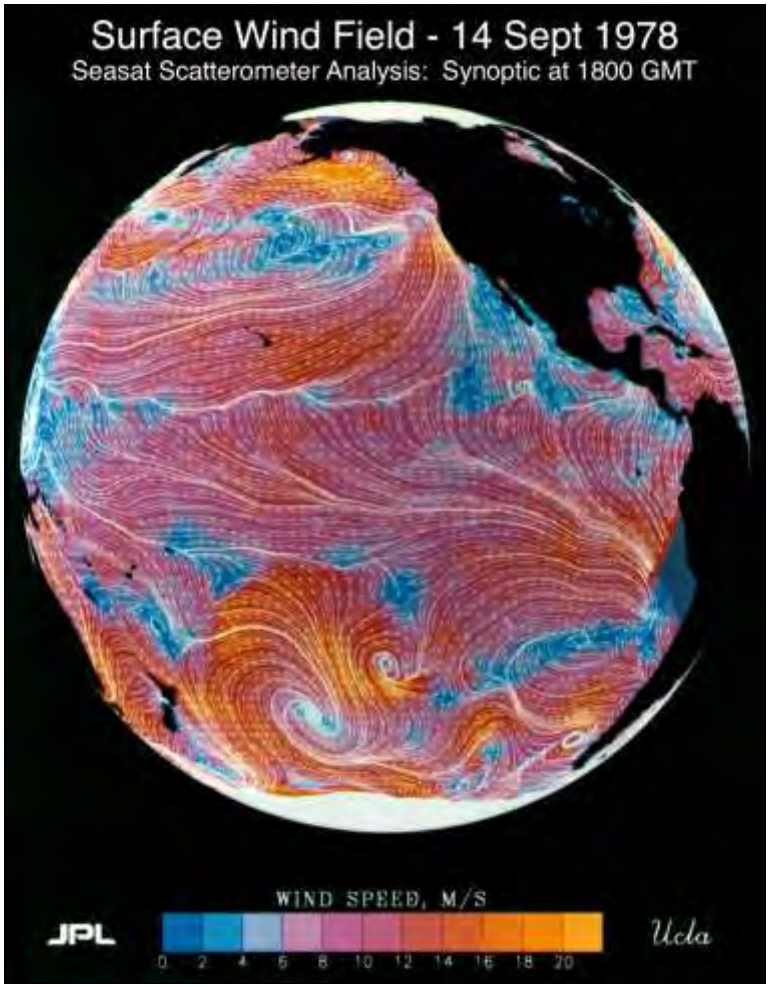
- ## Seasat Results on Mediterranean Sea

T.H. Guymer S. Zecchetto Wind derived from Seasat microwave suite J. of remote Sensing 1991





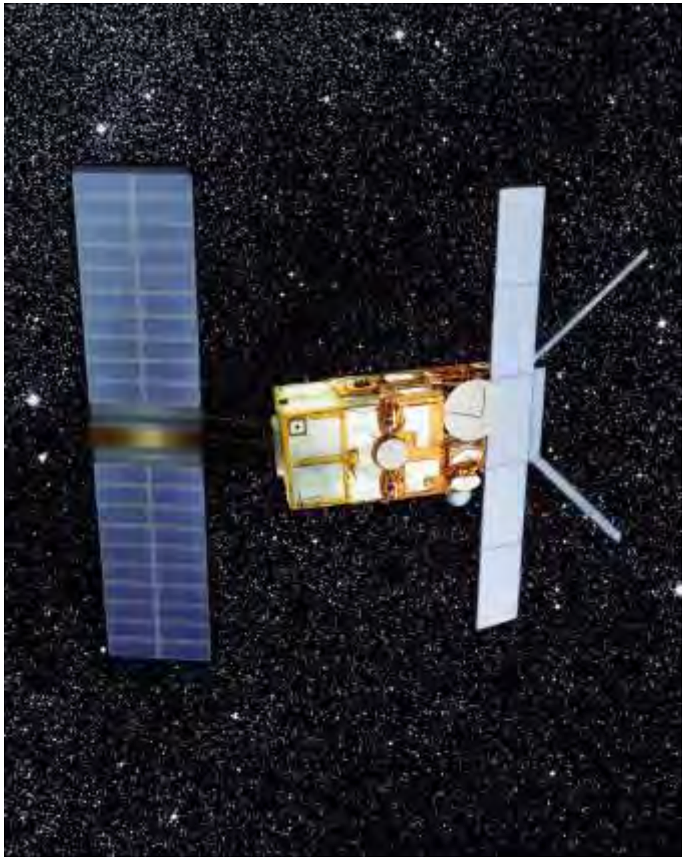
Scatterometer Missions



- Seasat Global Winds

Scatterometer Missions

- ERS-1/2 1991 - 2011 (ESA)



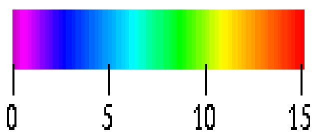
- Active Microwave Instrument (AMI) 5.3 GHz
- 3 Operational modes
- SAR
- Scat
- Scat + wave
- 3 fan-beamed antennas
- Fore 45° Mid 90° & Aft 135°
- Swath 500 Km
- Resolution 50 Km

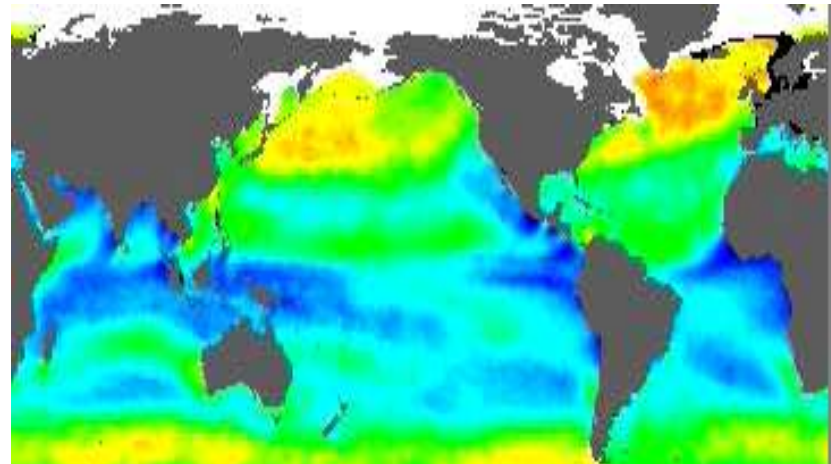
Scatterometer Missions

- ERS-1/2 milestones:
  - ERS-1 Launched on 17th July 1991
  - ERS-2 Launched on 21st April 1995
  - ERS-2 Scat mission suspended on 17th January 2001 due to degraded satellite attitude
  - June 2003 recovery Scat mission with new on-ground processor
  - Feb 2011 repeat cycle changed from 35 days to 3 days
  - July 2011 mission decommissioned
  - **Scat has operated continuously for 20 years providing the longest record of global Scatterometer high quality data yet obtained.**
  - Exploitation of this unique data set still continue (i.e. SCIRoCCo project)

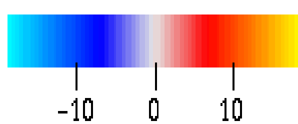
Scatterometer Missions

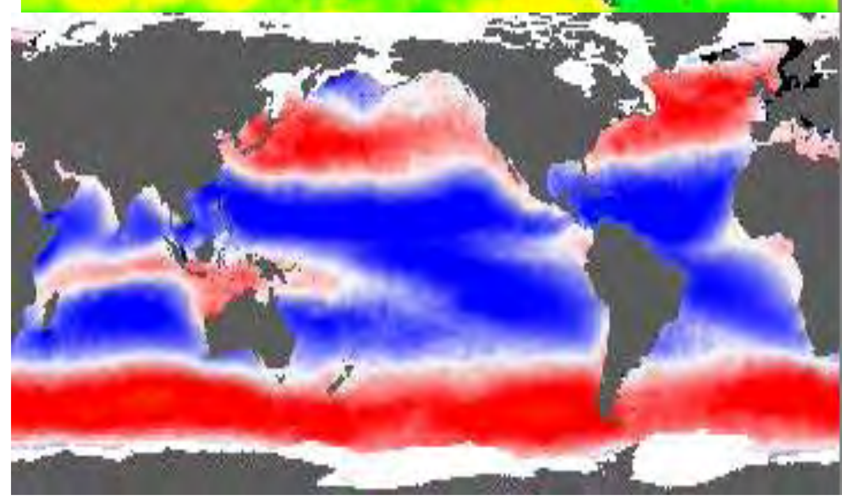
- ERS-1/2 Ocean Results
  - Mean Wind speed 1991 -2000





  - Mean West wind 1991 - 2000

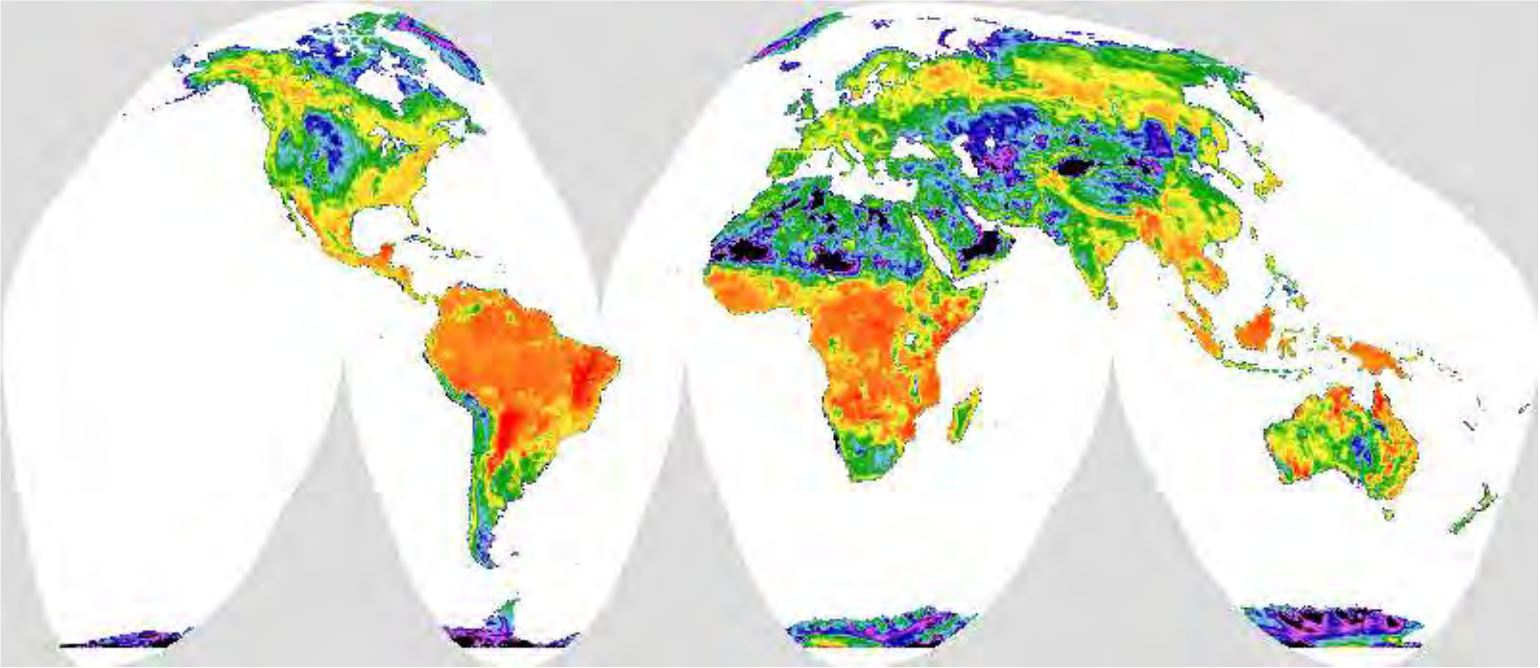




Scatterometer Missions

- ERS-1/2 Land Results
  - Multi year Sigma Nought

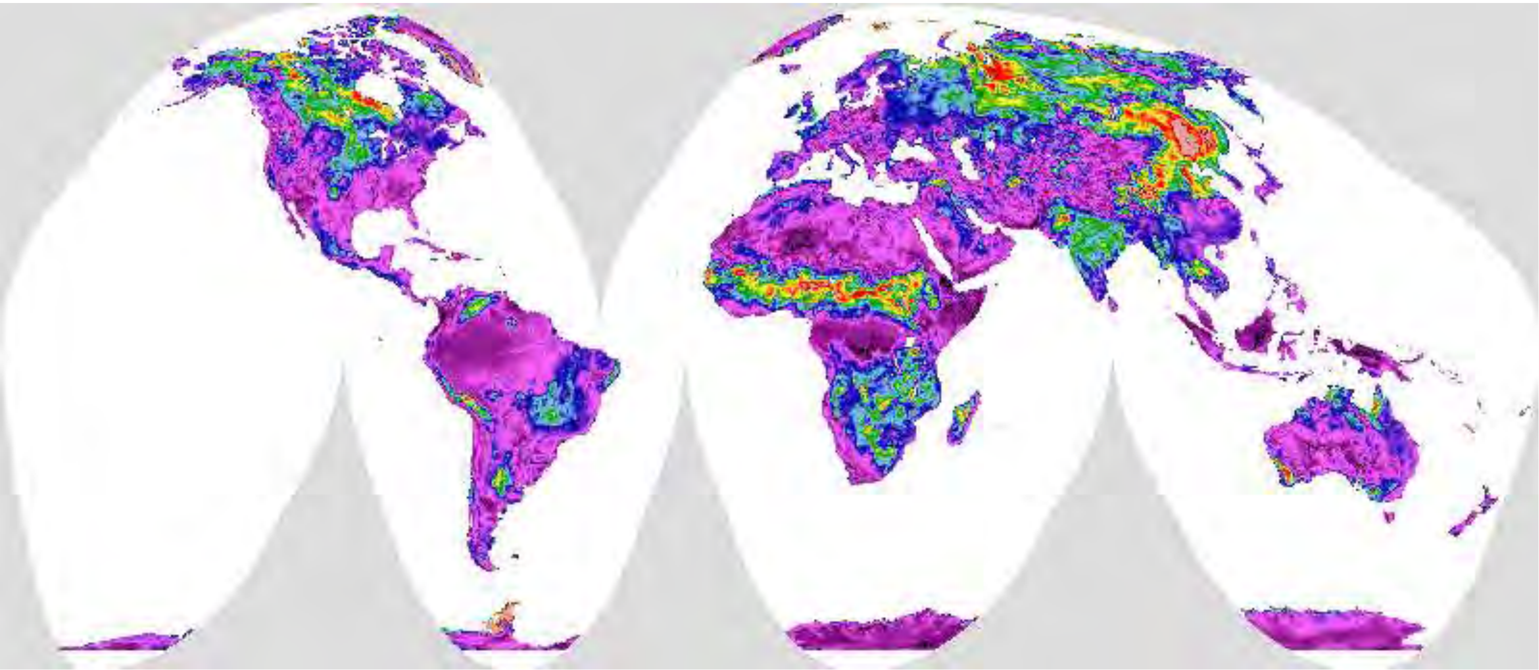
Database of global C-Band Radar backscattering



Scatterometer Missions

- ERS-1/2 Land Results
  - Sigma Nought Seasonal variation

Database of global C-Band Radar backscattering



Scatterometer Missions

- NSCAT on ADEOS 1 (NASA)

  - Launched on August 17th 1996
  - Spacecraft failed on June 30th 1997
  - Ku Band, Dual polarization (only mid beam)
  - 6 fan-beamed antennas
  - Fore 45° Mid 115° & Aft 135°
  - Swath 2x600 Km
  - Resolution 50 Km

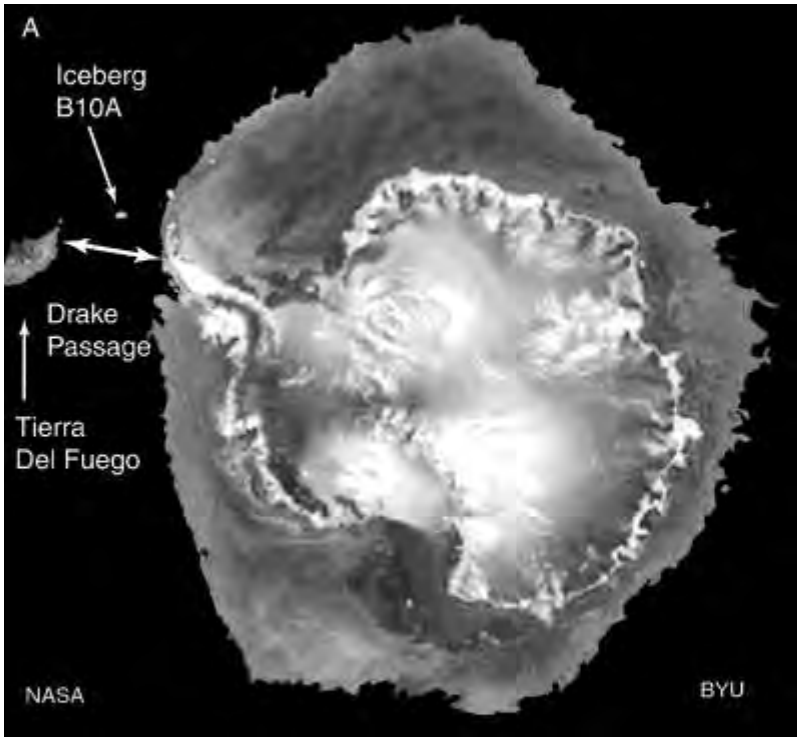
Scatterometer Missions

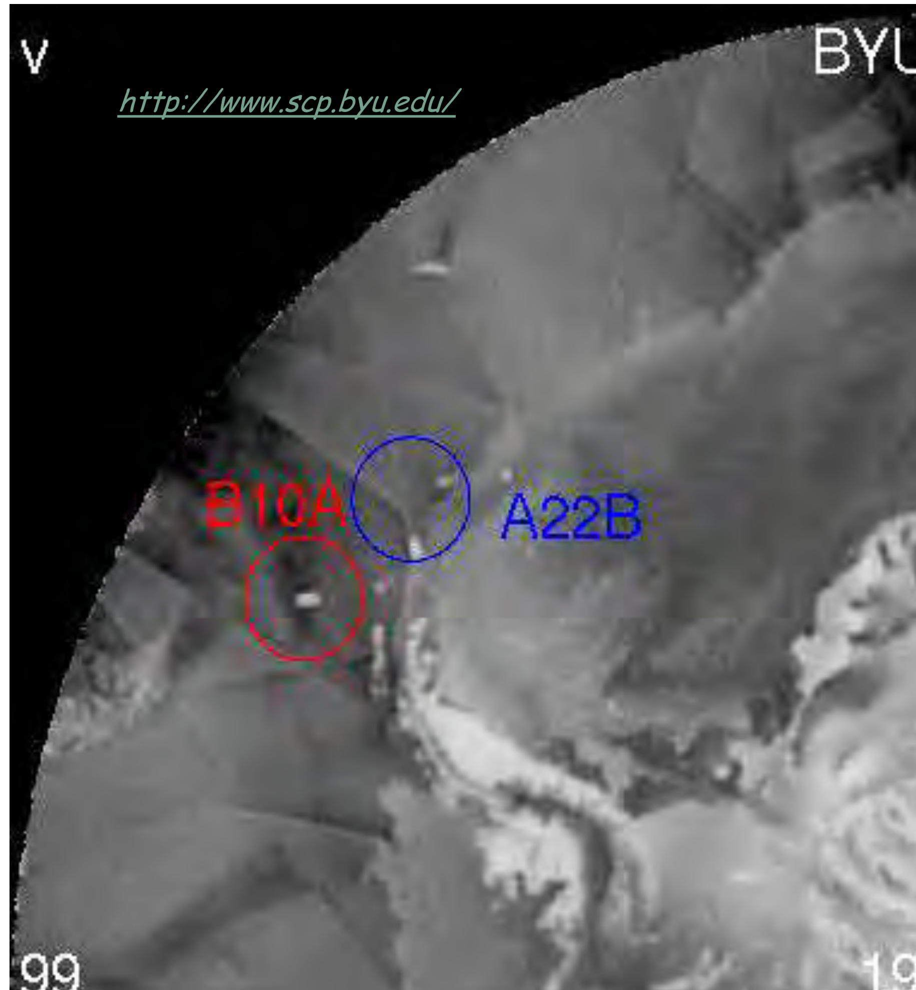
- QuickSCAT 1999 - 2009 (NASA)

- – Quick recovery of NASA Scat mission
- – Launched on June 19th 1999
- – 13.4 GHz Ku Band
- – Dual polarization
- – Inner swath HH inc 40°
- – Outer swath VV inc 46°
- – Rotating dish antenna (stopped on 23/11/2009
- – Swath 1800 Km
- – Resolution 25 Km

Scatterometer Missions

- QuickSCAT



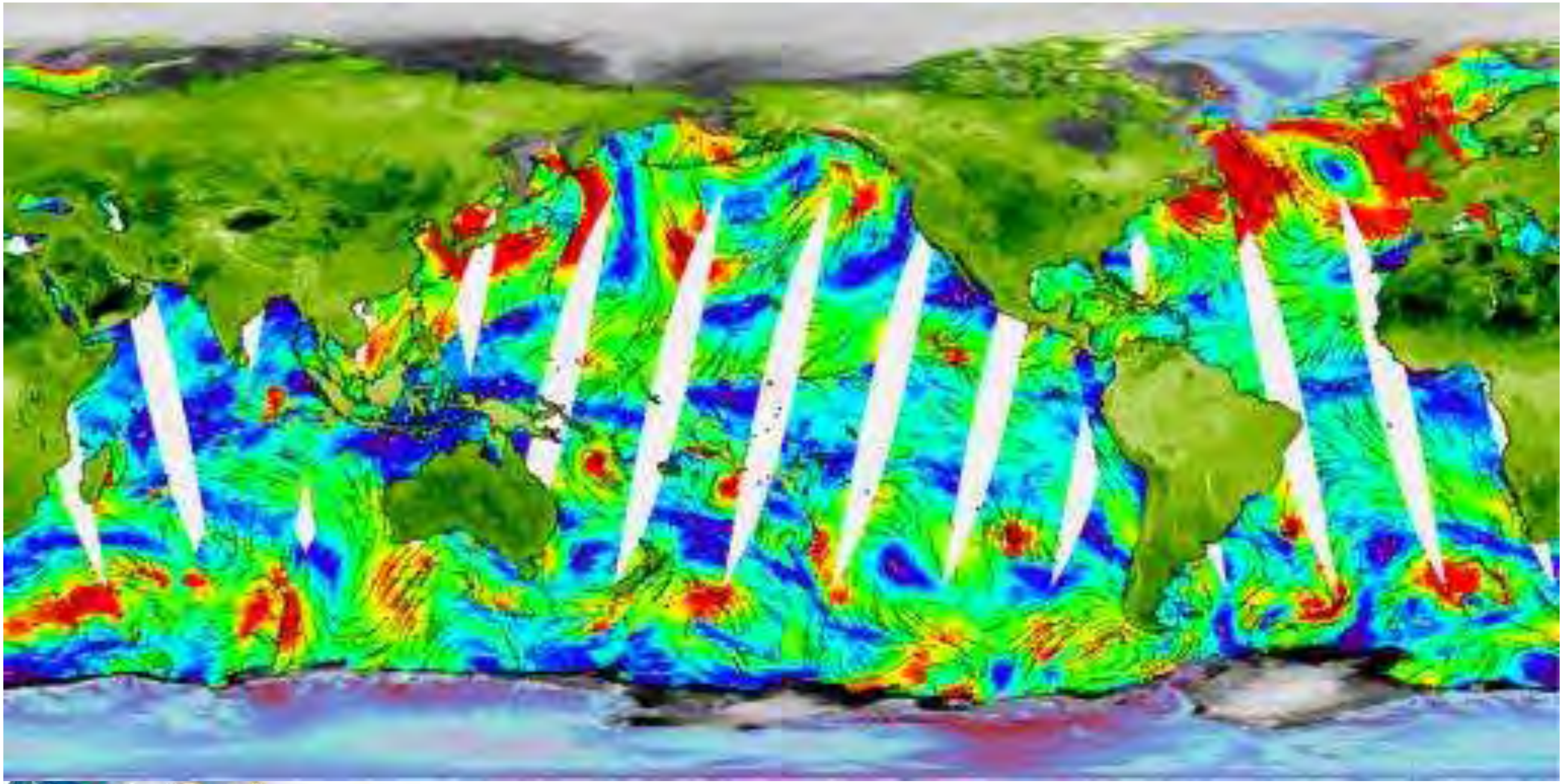


Scatterometer Missions

- SeaWinds 2002 – 24/10/2003 (NASA/Jaxa)

- Launched on December 14th 2002
- ADEOS-2 (now Midori-2)
- 13.4 GHz Ku Band
- Dual polarization
- Inner swath HH inc 40°
- Outer swath VV inc 46°
- Rotating dish antenna
- Swath 1800 Km
- Resolution 25 Km

Scatterometer Missions

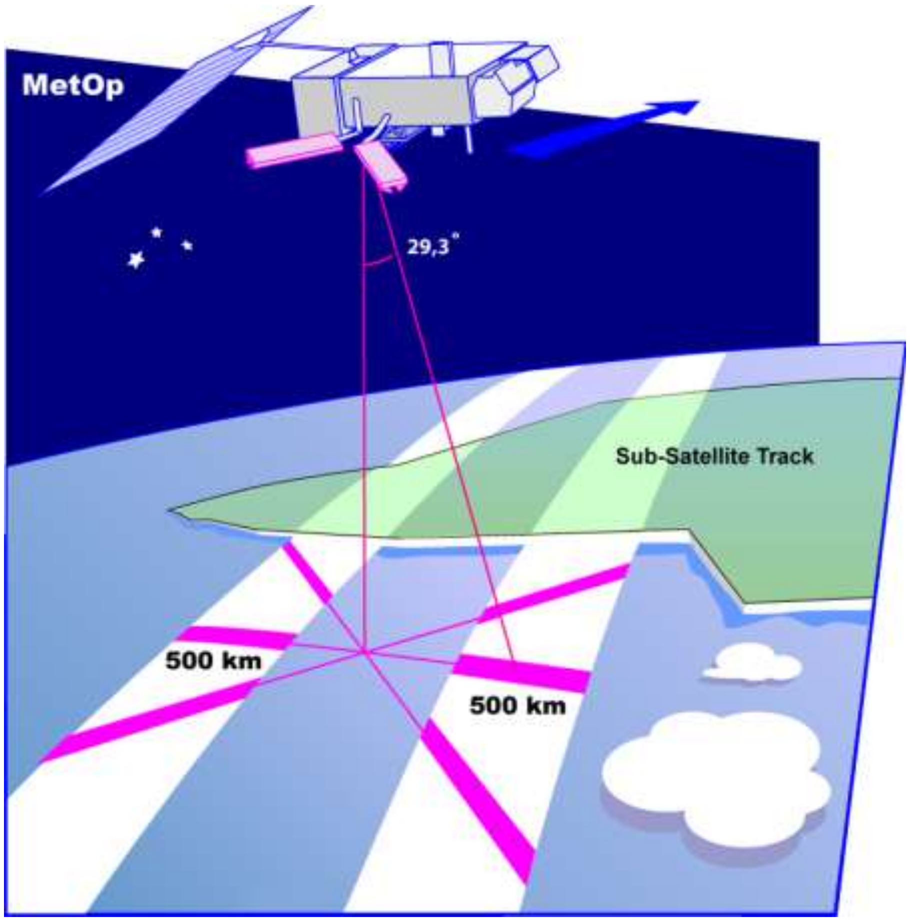


SeaWinds: First Image January 28th – 29th 2003

Scatterometer Missions

- ASCAT on MetOp
  - –MetOp is a series of three satellites to be launched sequentially over 14 years, starting in 2006 (metOp-A), 2012 (MetOp-B) 2017 tbc (MetOp-C), and forms the space segment of EUMETSAT's Polar System (EPS).
  - –MetOp is the Europe's first polar-orbiting satellite dedicated to operational meteorology.

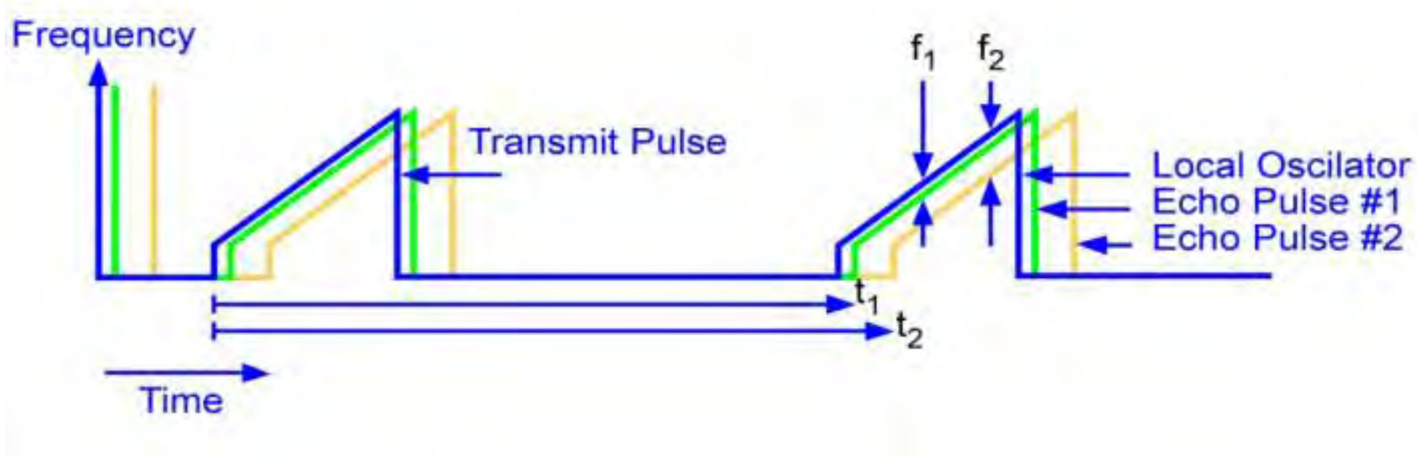
Scatterometer Missions



- ASCAT on MetOp
  - Frequency 5.255 GHz
  - V pol
  - 6 fan-beamed antennas
  - Fore 45° Mid 90° & Aft 135°
  - Swath 2x500 Km
  - Resolution 50/25 Km

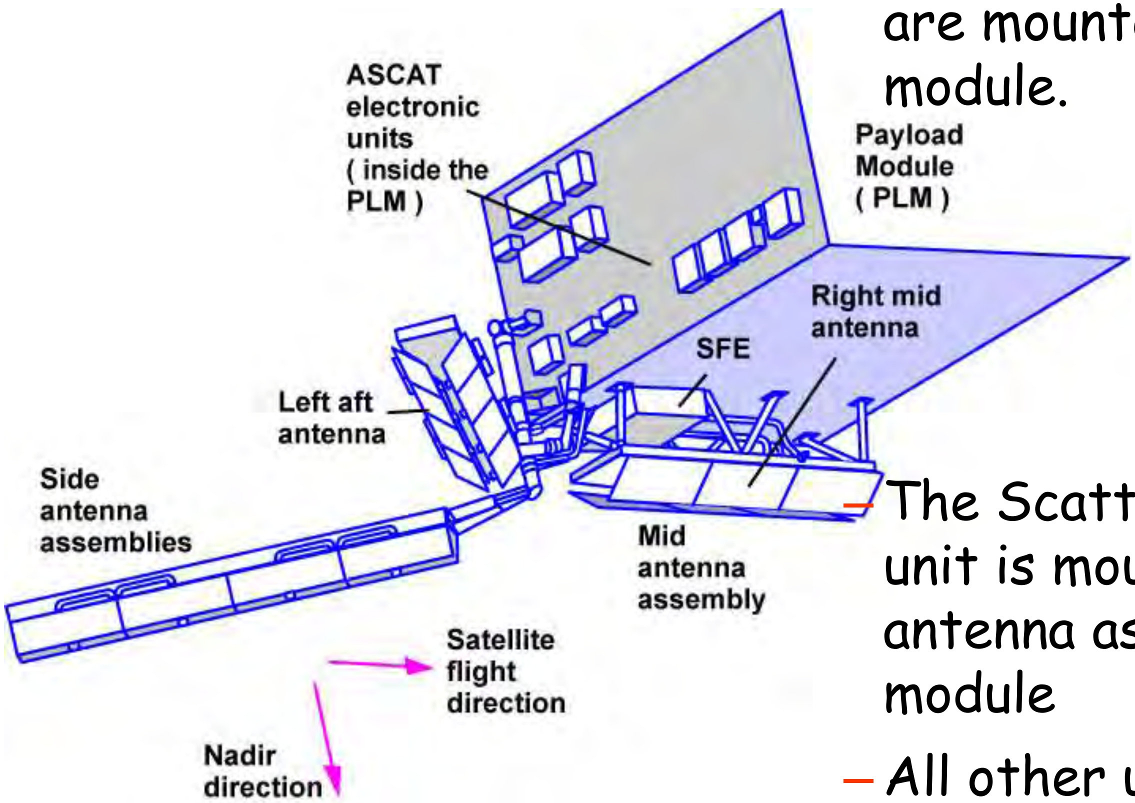
Scatterometer Missions

- ASCAT on MetOp
  - Along Track resolution: controlled primarily by design of the antenna azimuth footprint
  - Across track resolution: uses a frequency modulation technique in conjunction with relatively long, medium power transmit pulses



Scatterometer Missions

- ASCAT on MetOp



– The three pairs of antenna assemblies are mounted outside the payload module.

– The Scatterometer Front End (SFE) unit is mounted between the mid antenna assembly and the payload module

– All other units of ASCAT are mounted inside the Payload Module.

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Scatterometer Missions

The MetOp-SG program is being implemented in collaboration with EUMETSAT. ESA develops the prototype MetOp-SG satellites (including associated instruments) and procures, on behalf of EUMETSAT, the recurrent satellites (and associated instruments). EUMETSAT is responsible for the overall mission, funds the recurrent satellites, develops the ground segment, procures the launch and LEOP services and performs the satellites operations. The corresponding EUMETSAT Program is termed EPS-SG (EUMETSAT Polar System – Second Generation).

On October 16, 2014, contracts were signed to build three pairs of MetOp Second Generation satellites, ensuring the continuity of essential information for global weather forecasting and climate monitoring for decades to come. Airbus Defence and Space of France now takes up the role as prime contractor for the A satellites and Airbus Defence and Space of Germany for the B series. Although the different satellites will be developed and built in Toulouse, France and Friedrichshafen, Germany, respectively, a large industrial consortium of many European companies will be involved under the leadership of Airbus Defence and Space. [8]

New instruments observing extended spectral and frequency ranges will allow new environmental measurements to be collected. In addition, the A series will carry the Copernicus Sentinel-5 instrument on behalf of the European Commission. Sentinel-5 includes five 'spectrometers' from the ultraviolet to the shortwave infrared, to monitor atmospheric composition and support the forecasting of air quality.

https://directory.eoportal.org/web/eoportal/satellite-missions/m/metop-sg/

Scatterometer Missions

ASCAT. The major improvements to be brought by SCA with respect to ASCAT are the spatial resolution of 25 km x 25 km, the radiometric stability of ≤ 0.1 dB and the addition of VH polarization measurements on the mid beams.

Parameter	ASCAT	MetOp-SG SCA
Frequency	5.3 GHz	
Polarization	VV for all beams	VV for all beams + VH for Mid-beams
Azimuth views	45°, 90° and 135° w.r.t. satellite track	
Minimum incidence angle	25°	20°
Horizontal resolution	Nominal: $(50\ km)^2$ High resolution: $(25 - 35\ km)^2$	Nominal: $(25\ km)^2$ High resolution: $(17 - 22\ km)^2$
Horizontal sampling	Nominal: $(25\ km)^2$ High resolution: $(12.5\ km)^2$	Nominal: $(12.5\ km)^2$ High resolution: $(6.25\ km)^2$
Radiometric resolution	≤ 3 % for $\theta_i \leq 25°$ at 4 m/s cross-wind (VV) $(0.175 \times \theta_i - 1.375)$ % for $\theta_i > 25°$ at 4 m/s cross-wind (VV) ≤ 3 % at 25 m/s up-wind	
Radiometric stability	≤ 0.2 dB	≤ 0.1 dB
Coverage	97 % in 48 hrs	99 % in 48 hrs

Table 7: Main technical requirements of SCA versus ASCAT

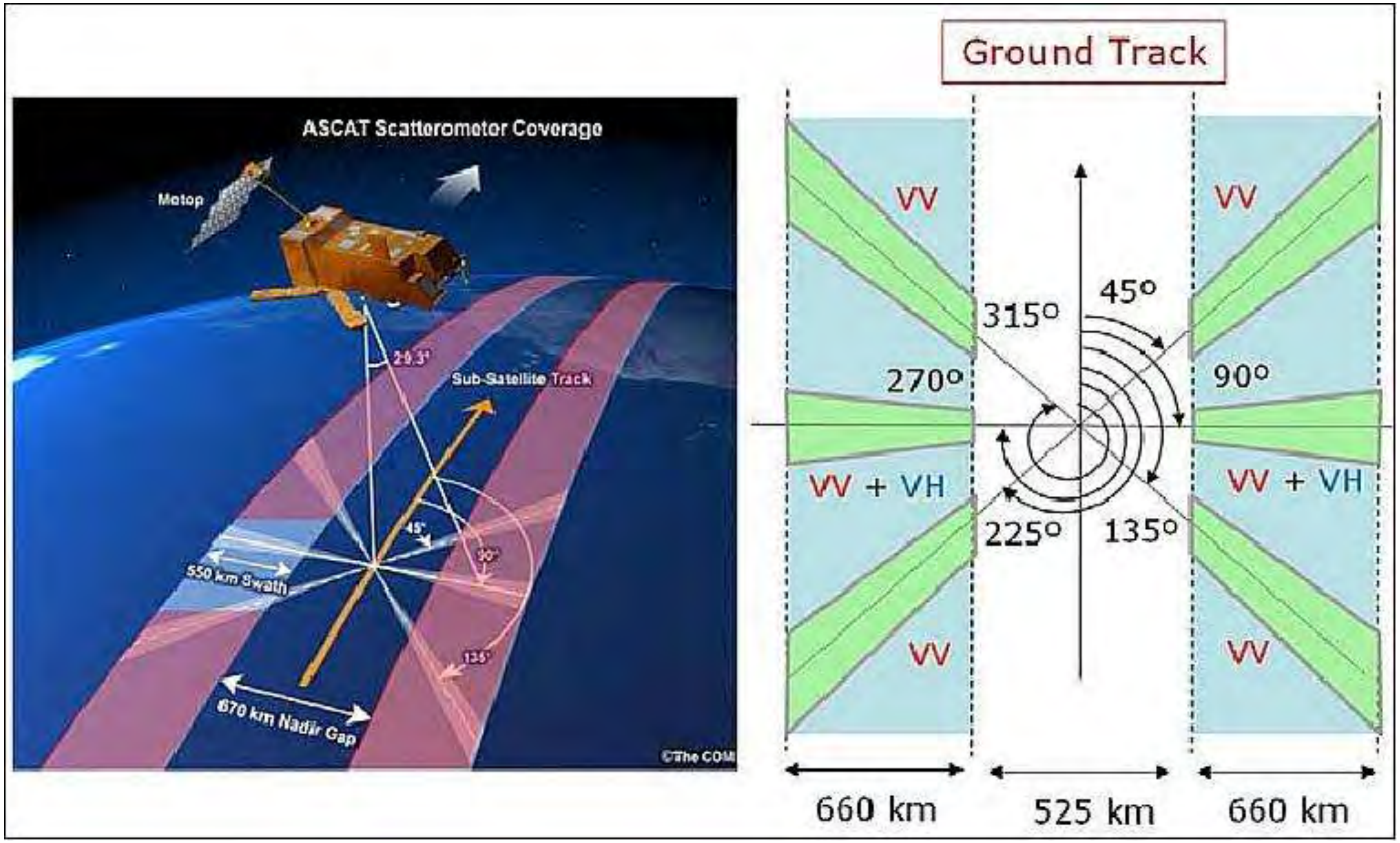
https://directory.eoportal.org/web/eoportal/satellite-missions/m/metop-sg/

EPS-SG

Scatterometer Missions

ASCAT vs SCA acquisition geometry

EPS-SG



https://directory.eoportal.org/web/eoportal/satellite-missions/m/metop-sg/

The ERS Scatterometer

- The ERS Satellite
  - The Active Microwave Instrument AMI
  - The ERS Attitude Onboard Control System
  - The ERS Data Record & Download

ERS-1 Launch

The ERS Scatterometer

- Mass

Total Payload mass Kg 1085

Total platform mass Kg 1296

- Orbit

Near-circular,polar, sun-syn

Altitude 780 Km

Inclination 98.5

Orbits per day 14.3

- Communications

Telemetry S-Band

Data X-band

105 MBit/s HR and 15MBit/s LR

The ERS Satellite

The ERS Scatterometer

- Active Microwave Instrument

    SAR Image and wave mode

    Scatterometer

    - **Radar Altimeter**

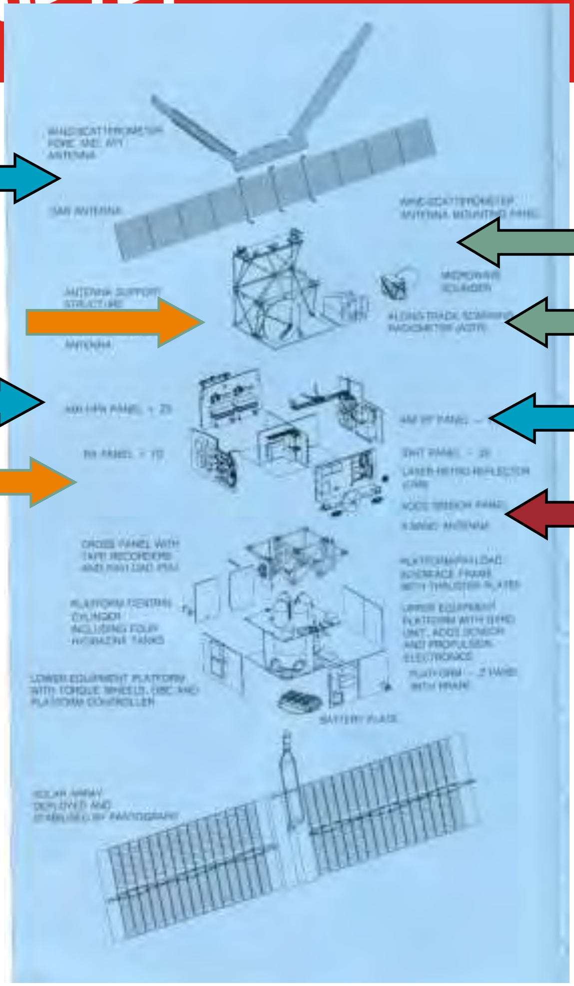
    - **ATSR**

      IRR 4 + 3 (vis) channel (ATSR-2)

      MWR 23.8 GHz & 36.5 GHz

    - **PRARE & LRR**

    - **GOME**



ERS exploded view

The ERS Scatterometer

The Scatterometer Geometry

Antenna size

- Mid 2.5 m
- Fore/Aft 3.6 m

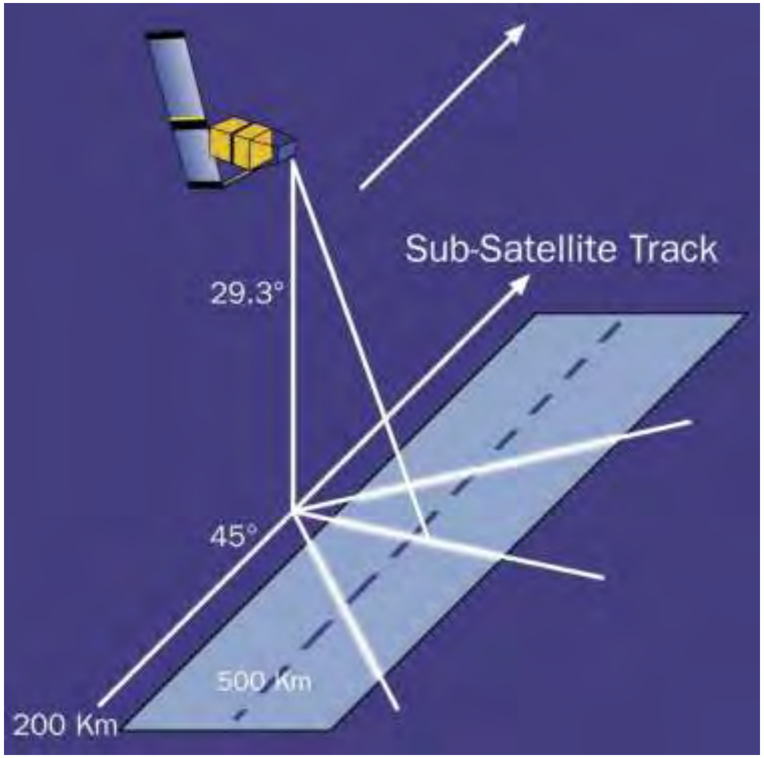
Incidence angles

- Mid 18 - 47
- Fore/Aft 25 - 59

Swath 500 Km

200 Km to right satellite track

Spatial resolution 50 Km



The ERS Scatterometer

- ## The Local Normal Pointing

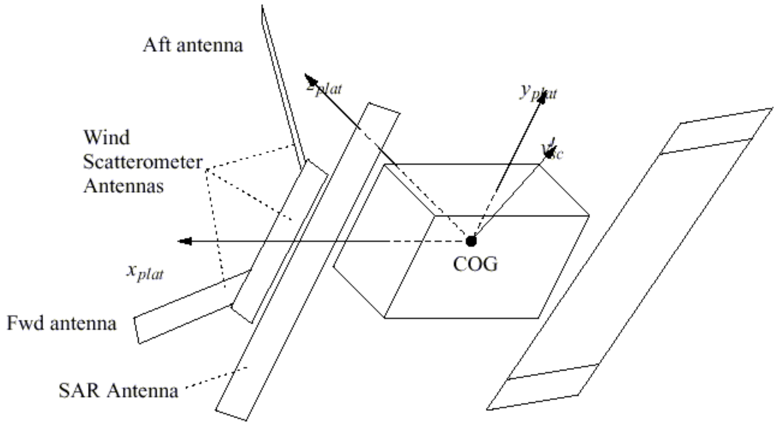
  Small changes in the roll and pitch axes are continually required to ensure RA points on Earth surface (GEM6)

- ## The Yaw Steering Mode

  To compensate for the Earth rotation.

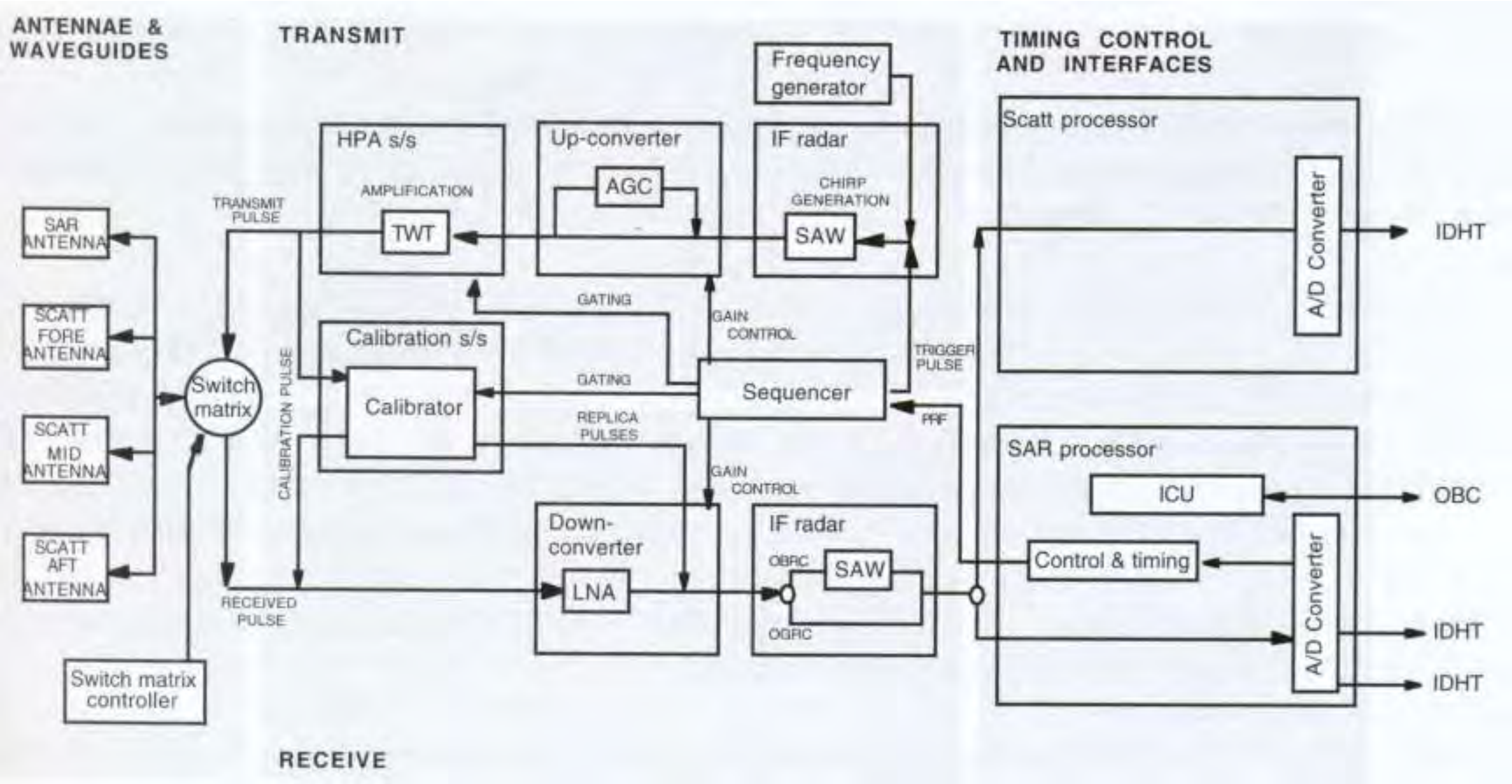
  Satellite is yaw steered up to +/- 4 deg.

  Improve Scatt coverage and minimize the Doppler effect



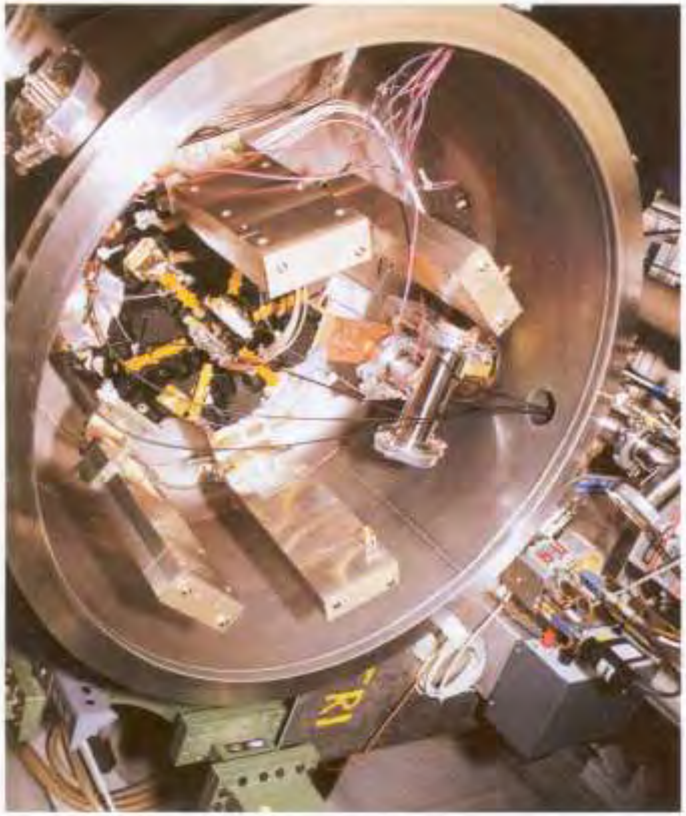
The ERS Scatterometer

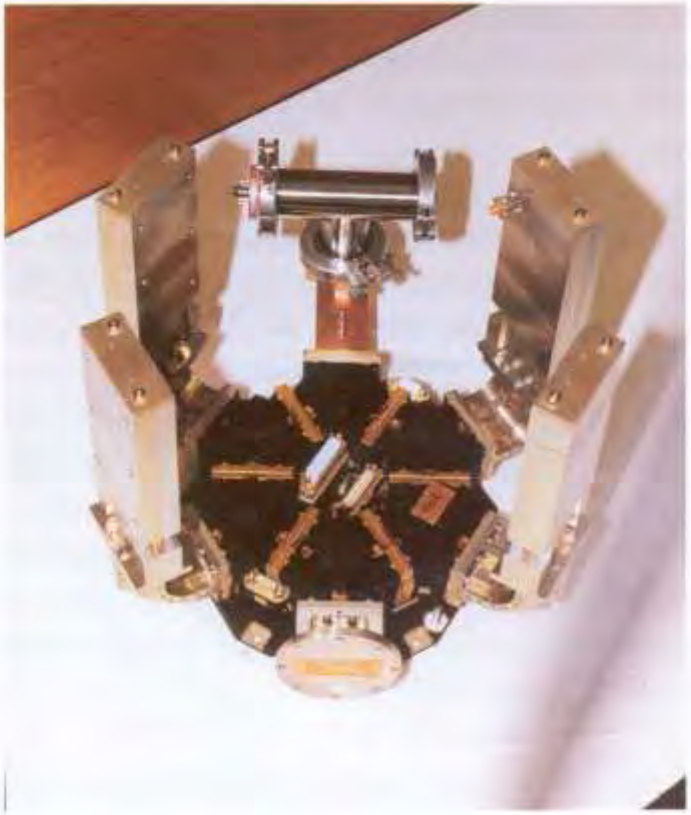
- **The AMI block diagram**



The ERS Scatterometer

- The AMI Circulator





The ERS Scatterometer

scirocco scatterometer instrument competence centre

The Scat Transmitter

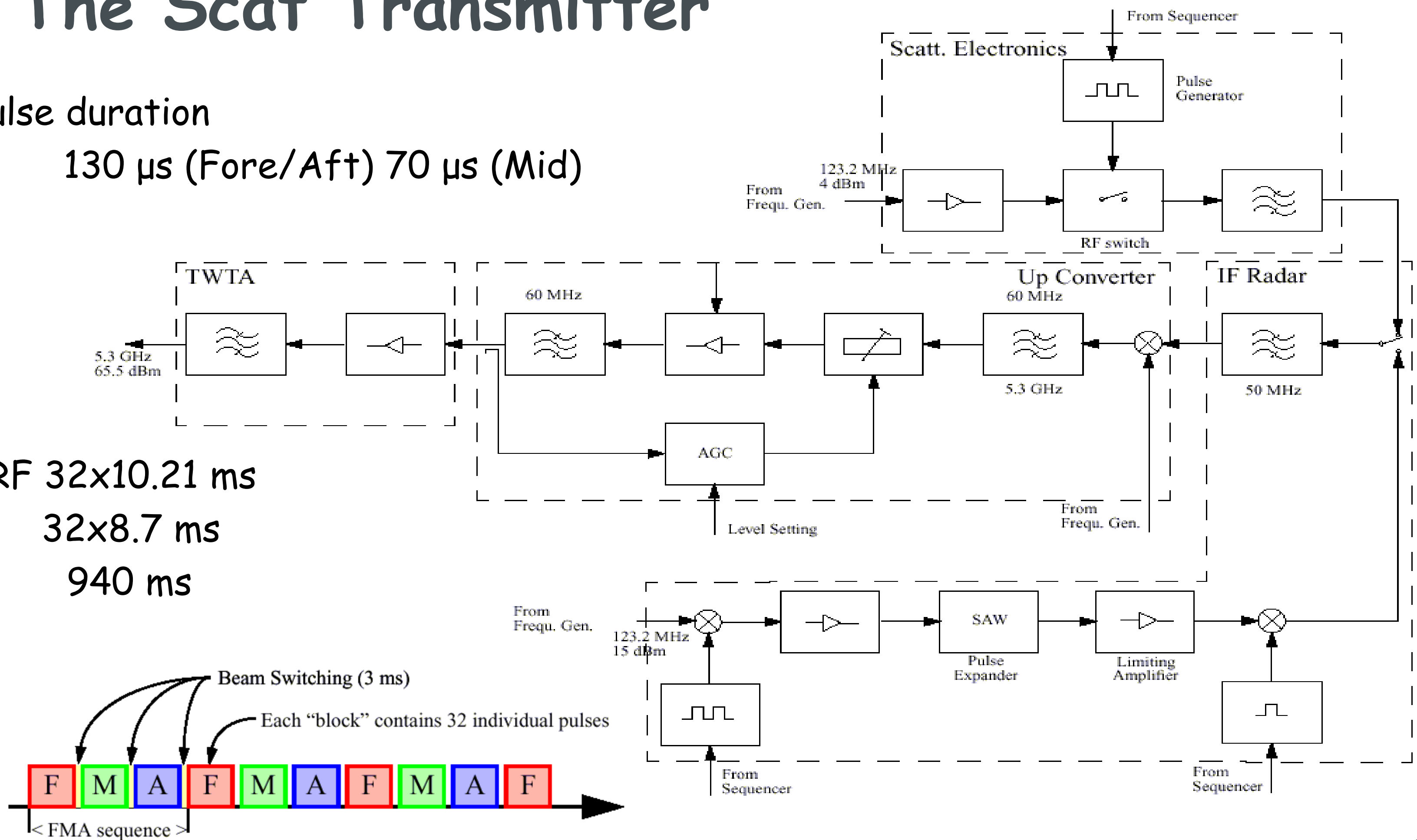
Pulse duration

130 µs (Fore/Aft) 70 µs (Mid)

PRF 32x10.21 ms

32x8.7 ms

940 ms



The ERS Scatterometer

The AMI Calibration Subsystem

Highly stable attenuating network to inject in the receiver a replica of the transmitted pulse. The pulse replica (1 pulse every 8 tx pulses) is used to calibrate the instrument

Calibartion S/S components:

C downconverter

E upconverter

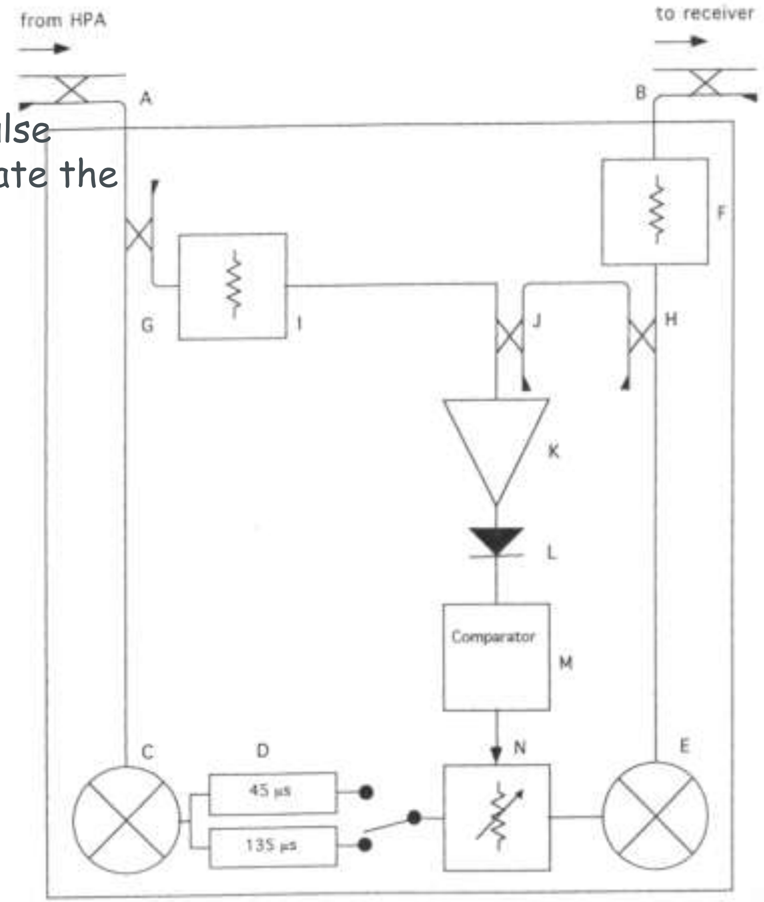
Couplers

Attenuators

Amplifier

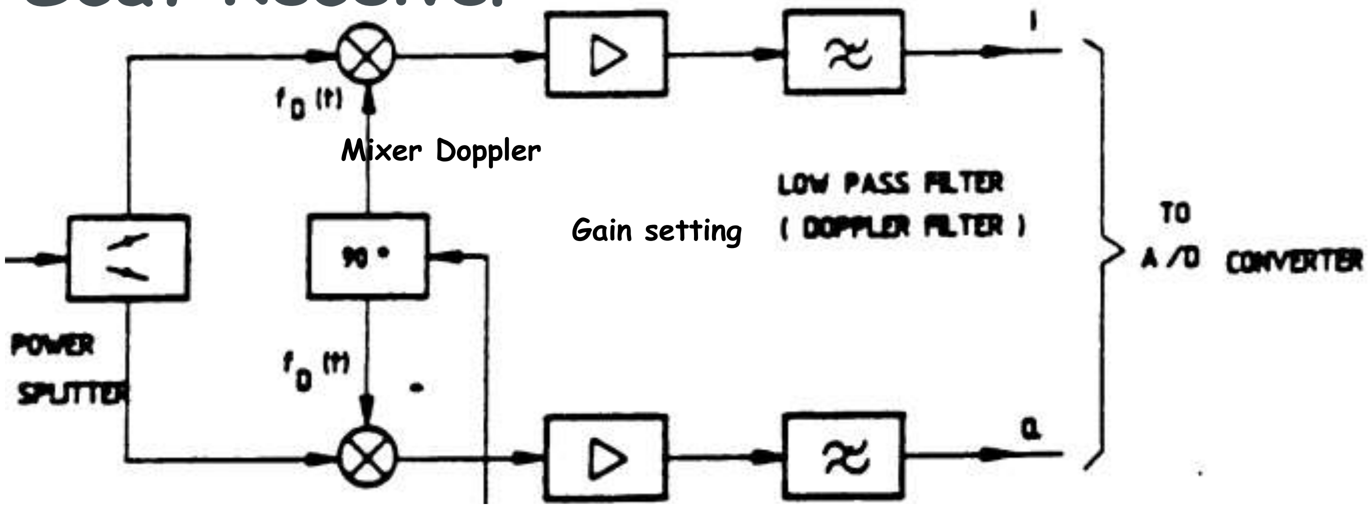
Detector

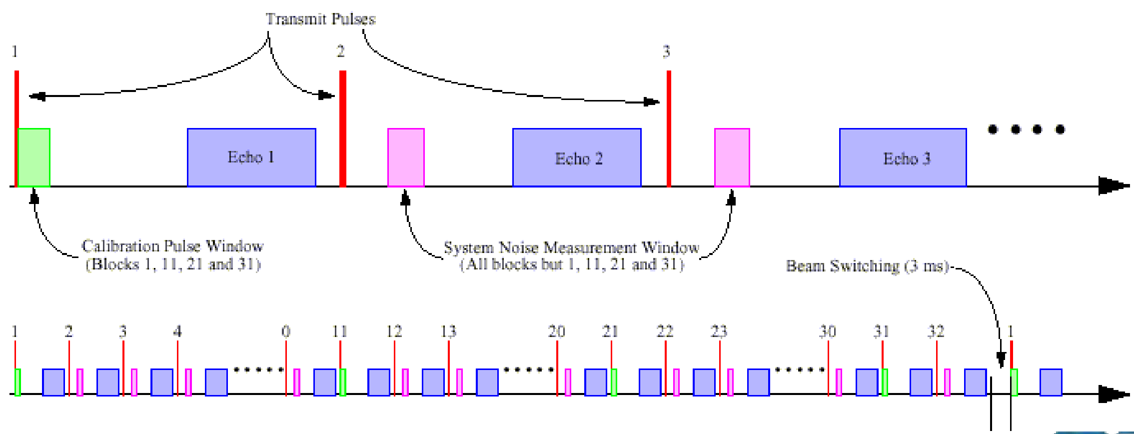
Different delay for SAR and SCATT



The ERS Scatterometer

The Scat Receiver





The ERS Scatterometer

The Doppler Compensation Mixer

The frequency shift of the received signal, depends on satellite attitude, antenna look angle, Earth and target relative motion

The frequency shift shall be compensated in the demodulator in order to keep the signal within the receiver bandwidth

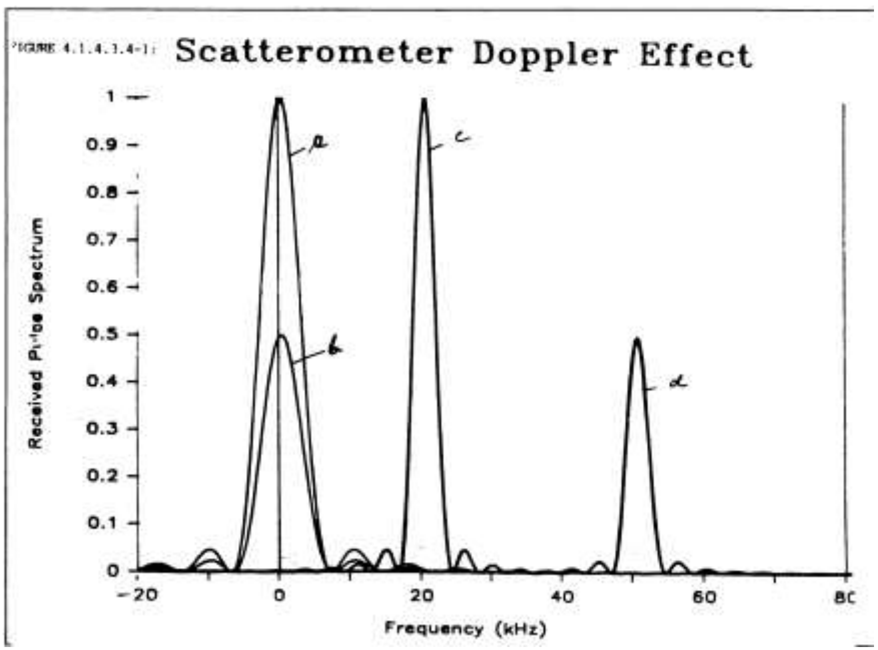
$$\omega_D = \frac{2\omega_0}{C} \vec{V}_{rel} \cdot \vec{R}_{rel}$$

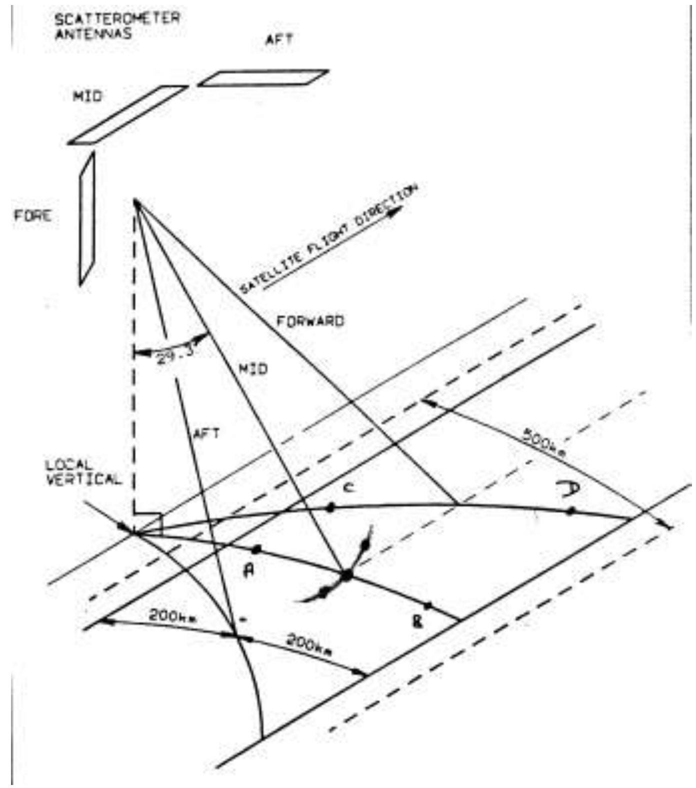
$$\vec{V}_{rel} = \vec{V}_{Satellite} - \vec{V}_{Earth\,pos}$$

$$\vec{R}_{rel} = \frac{\vec{R}_{Satellite} - \vec{R}_{Earth\,pos}}{\left|\vec{R}_{Satellite} - \vec{R}_{Earth\,pos}\right|}$$

The ERS Scatterometer

- The Doppler Compensation Mixer





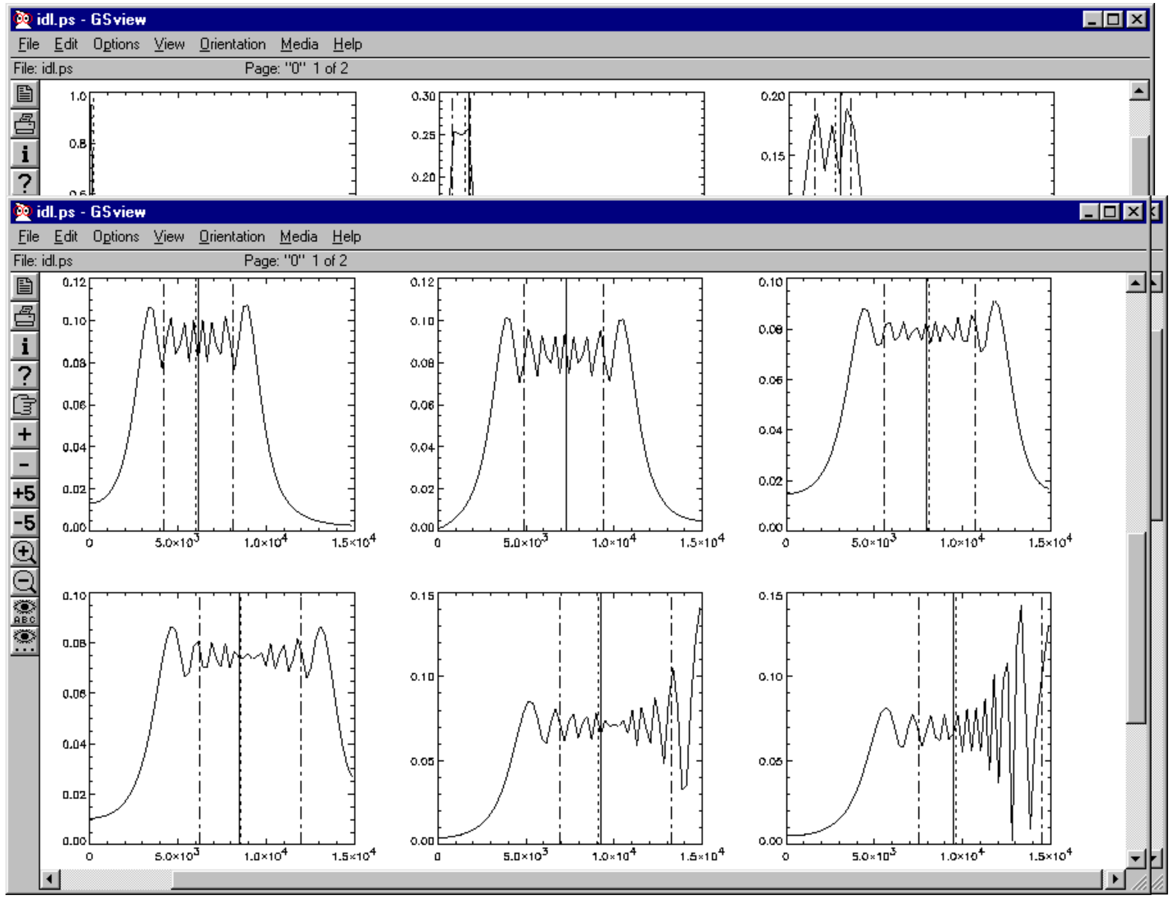
The ERS Scatterometer

- The Doppler Compensation Mixer: convolution kernel

Mid beam
Simulated yaw
between
[0°,2.5°].

Fore beam
Simulated yaw
between
[0°,2.5°].

Fore beam
Simulated yaw
between
[3°,5.5°].



The ERS Scatterometer

The Doppler Compensation Mixer

- The range of the Doppler shift is 50-150 KHz for the Fore and Aft beam and 0-10 KHz for the Mid beam
- Yaw steering minimize only Mid beam shift
- A continuous frequency tuning is required to keep the echo within 25Khz of receiver bandwidth
- The required tuning signal is synthesized on-board by the Scatterometer electronic module, using a time dependent algorithm (both in orbit time and echo time) with coefficient provided to the instrument by macrocomand from the on-ground satellite control centre

The ERS Scatterometer

The Doppler Compensation Mixer

It acts as a linear frequency demodulator in the time domain Fore & Aft Doppler compensation law

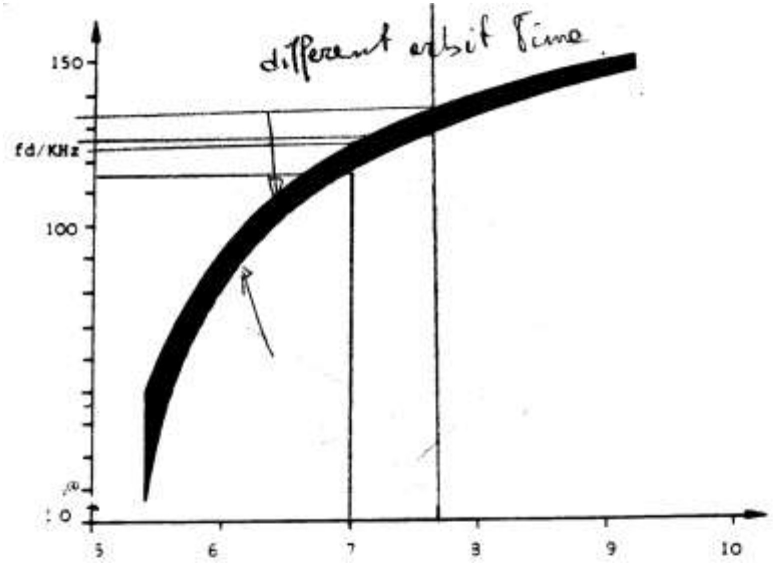
$$F_d(\tau,T) = F_{ref}(\tau,T) + c_0\delta(\tau)$$

$$F_{ref}(\tau,T) = a_0 + a_1\{\tau+\tau'(T)\} + a_2\{\tau+\tau'(T)\}^2 + a_3\{\tau+\tau'(T)\}^3 + a_4\{\tau+\tau'(T)\}^4$$

$$\tau'(T) = b_1 cos\{\frac{\pi(T-b_2)}{b_3}\} - \frac{T_p}{2}$$

$$\delta(\tau) = \frac{\tau-5.7}{2.9} - \frac{T_p}{2}$$

$$T_p = Duration\ of\ transmitted\ pulse\ (0.13msec)$$



Tau received echo time

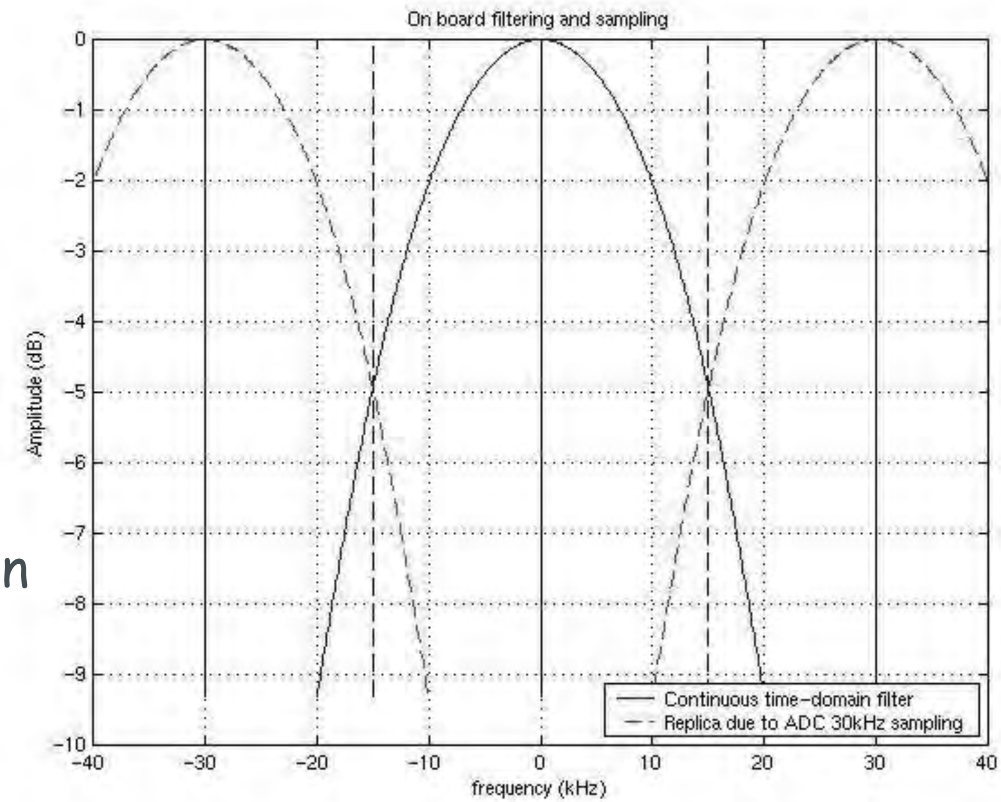
The ERS Scatterometer

The Low Pass Filter & Sampling

Bandwidth 25KHz

Bessel Filter

30 KHz sampling interval



Samples on ground resolution

- 5.2 Km Mid beam near
- 13.3 Km Fore beam far

The ERS Scatterometer

The Scat Receiver Numbers

Parameter		Fore and Aft beams	Mid Beam
Pulse Shape		Rectangular	Rectangular
Pulse width		130 s	70 s
Pulse Repetition Interval		10.210 ms	8.700 ms
Sampling rate		30 kHz	30 kHz
Number of bits for I & Q		8 bits	8 bits
Number of samples	Echo Signal	118	74
	Cal. Pulse	30	30
	Noise	32	32
Calibration Window start		100 s	100 s
Calibration Pulse Delay		135 s	135 s
Length of Cal. Window		1.000 ms	1.000 ms
Noise Window start		1.500 ms	1.500 ms
Length of Noise Window		1.030 ms	1.030 ms
Echo Window start		5.400 ms	5.200 ms
Length of Echo Window		3.910 ms	2.440 ms

The ERS Scatterometer

The AOCS

ERS is a 3-axis stabilized, Earth pointing satellite

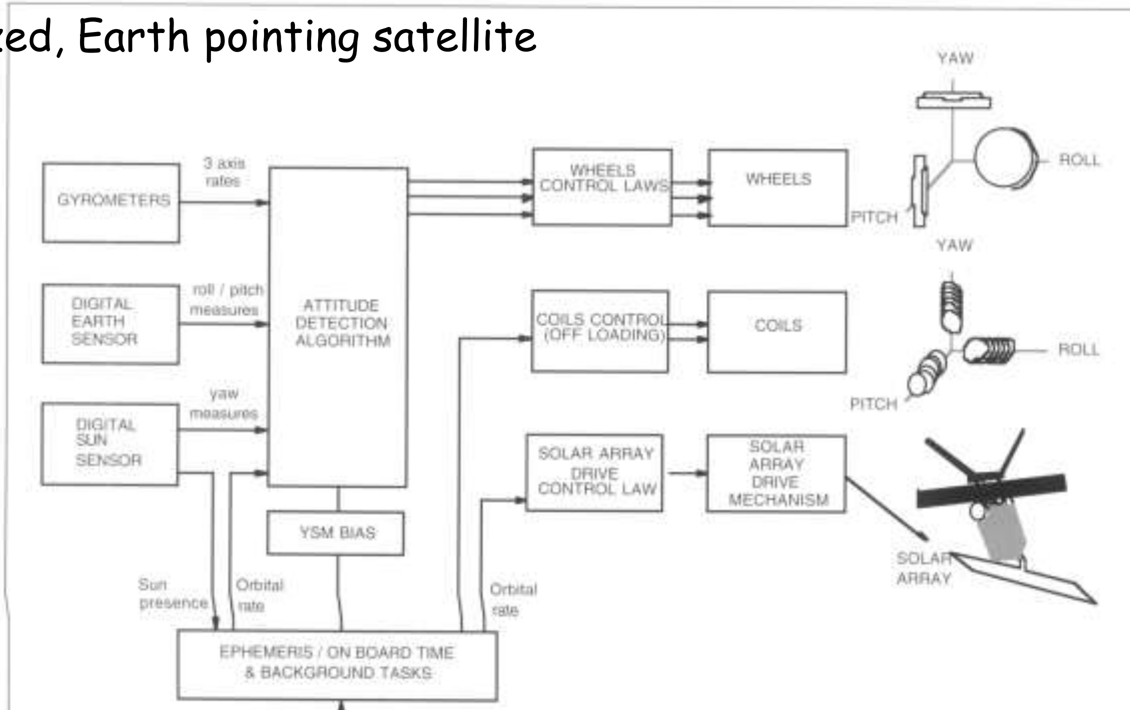
- 2 DES
- 2 DSS
- 2 Digital Sun acq.
- 6 gyroscopes

Max error bias:

- 0.11° roll/pitch
- 0.21° yaw

Harmonic and random

- 0.03° pitch/roll
- 0.07° yaw



ERS AOCS

The ERS Scatterometer

- The IDHT

One Scatt packet (EWIC) contains:

32 Echo

I & Q

74 (mid) /118 (fore/aft) samples

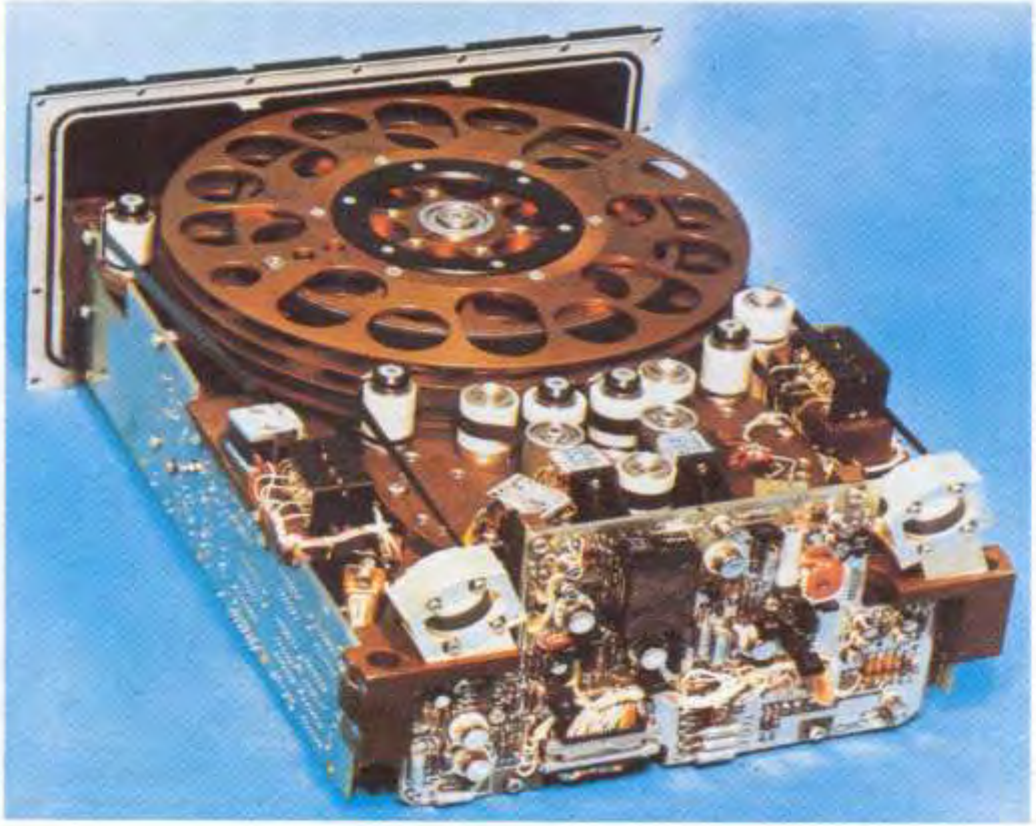
Noise power

Cal samples

Gain setting

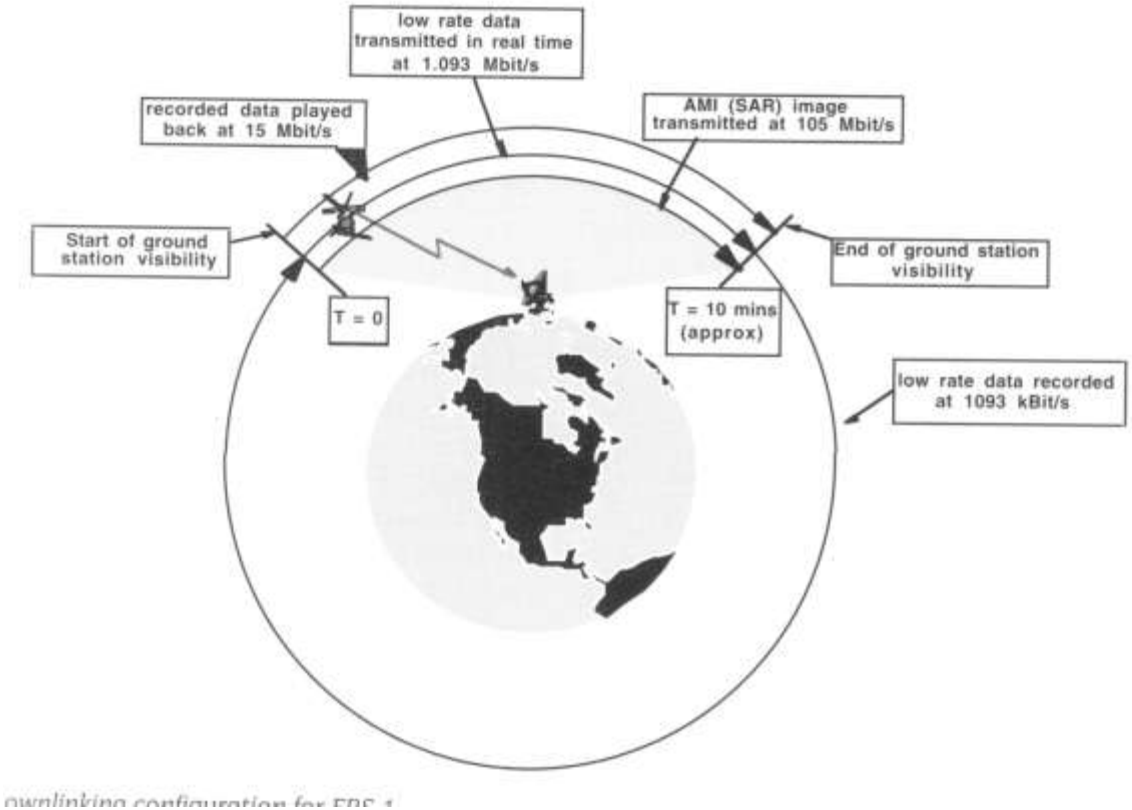
Doppler coeff

Sat Time



The ERS Scatterometer

- ## Data Dump Strategy



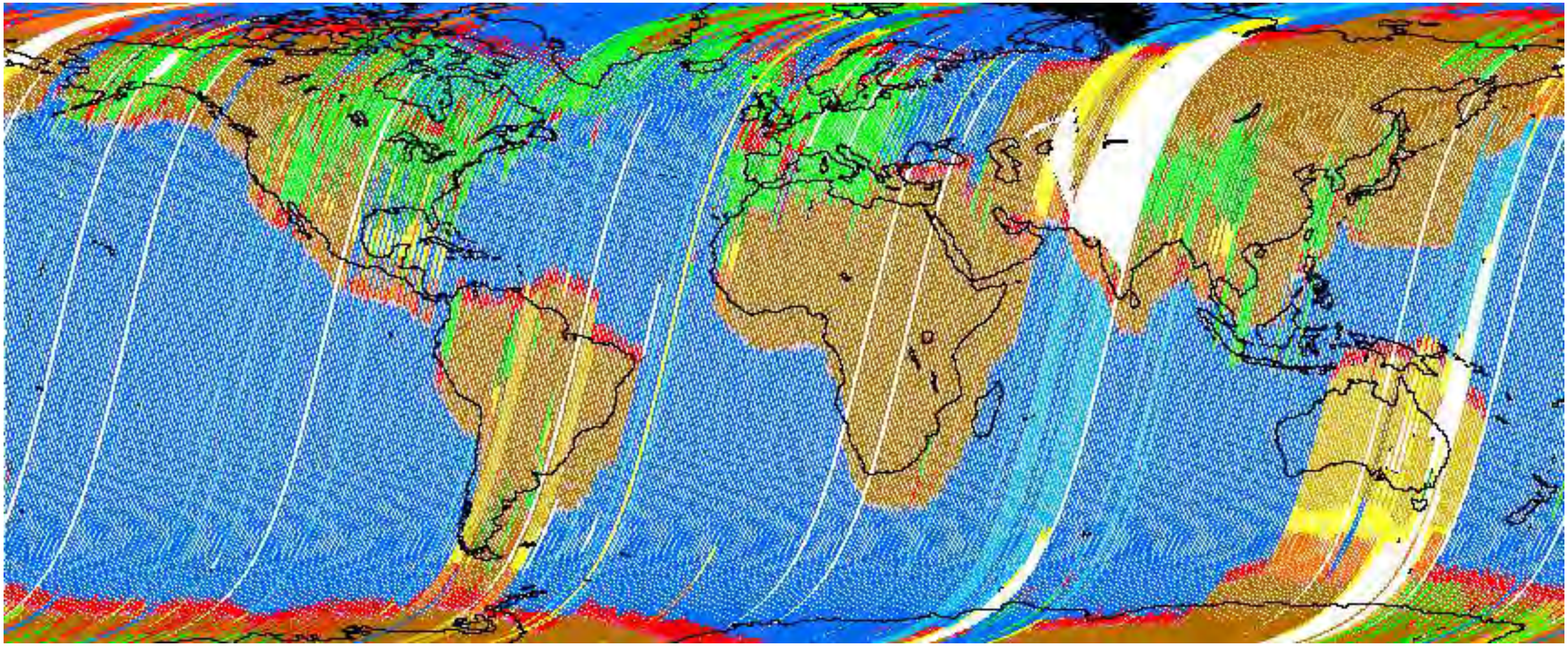
The ERS Scatterometer

- Ground Stations

The ERS Scatterometer

The AMI Operation modes

Wind Only (brown) Wind/Wave (blue) Image (green)



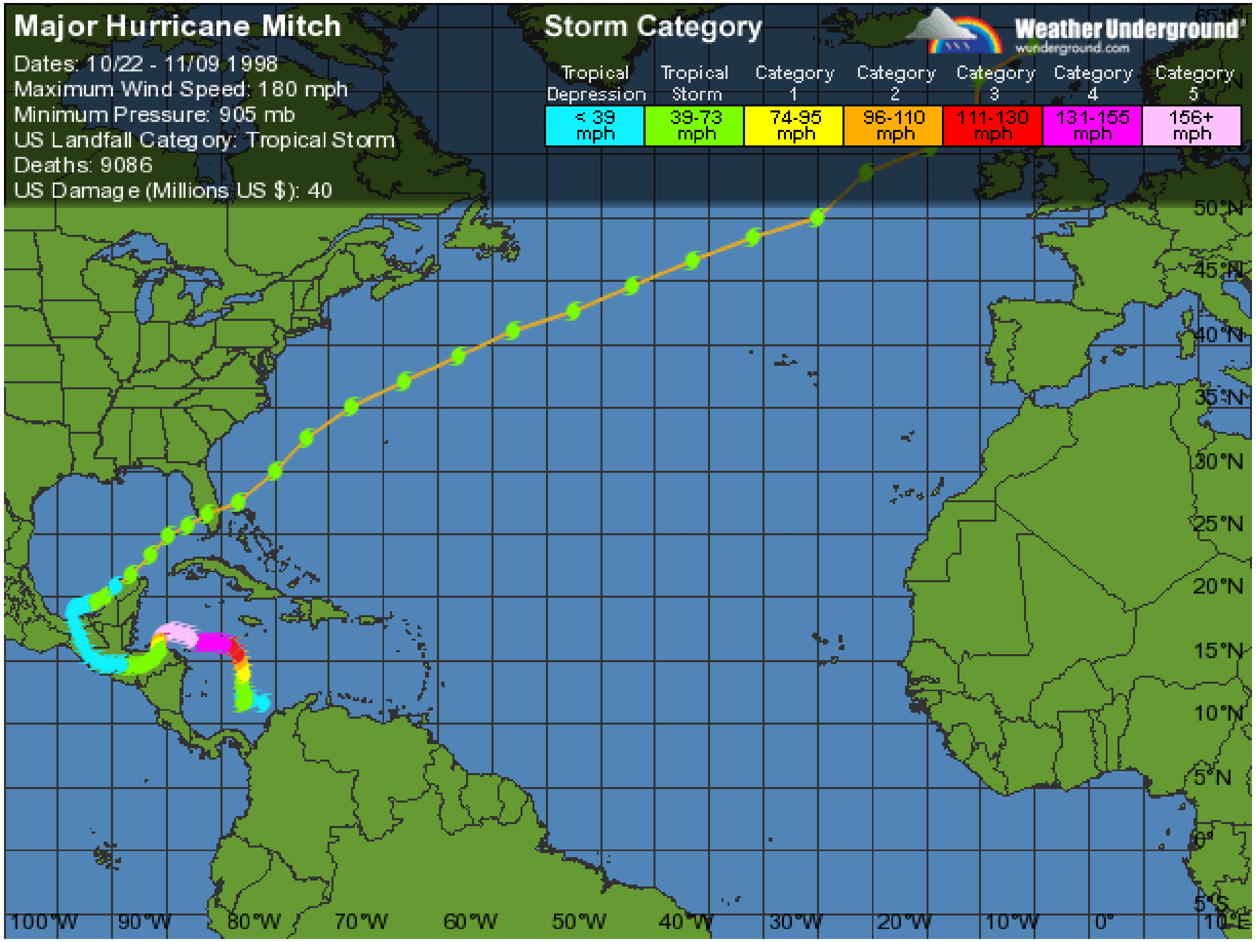
The TC Mitch October 1998

MITCH miles south of Kingston, Jamaica late on the 21st.october. On the 24th it turned West and became a hurricane.

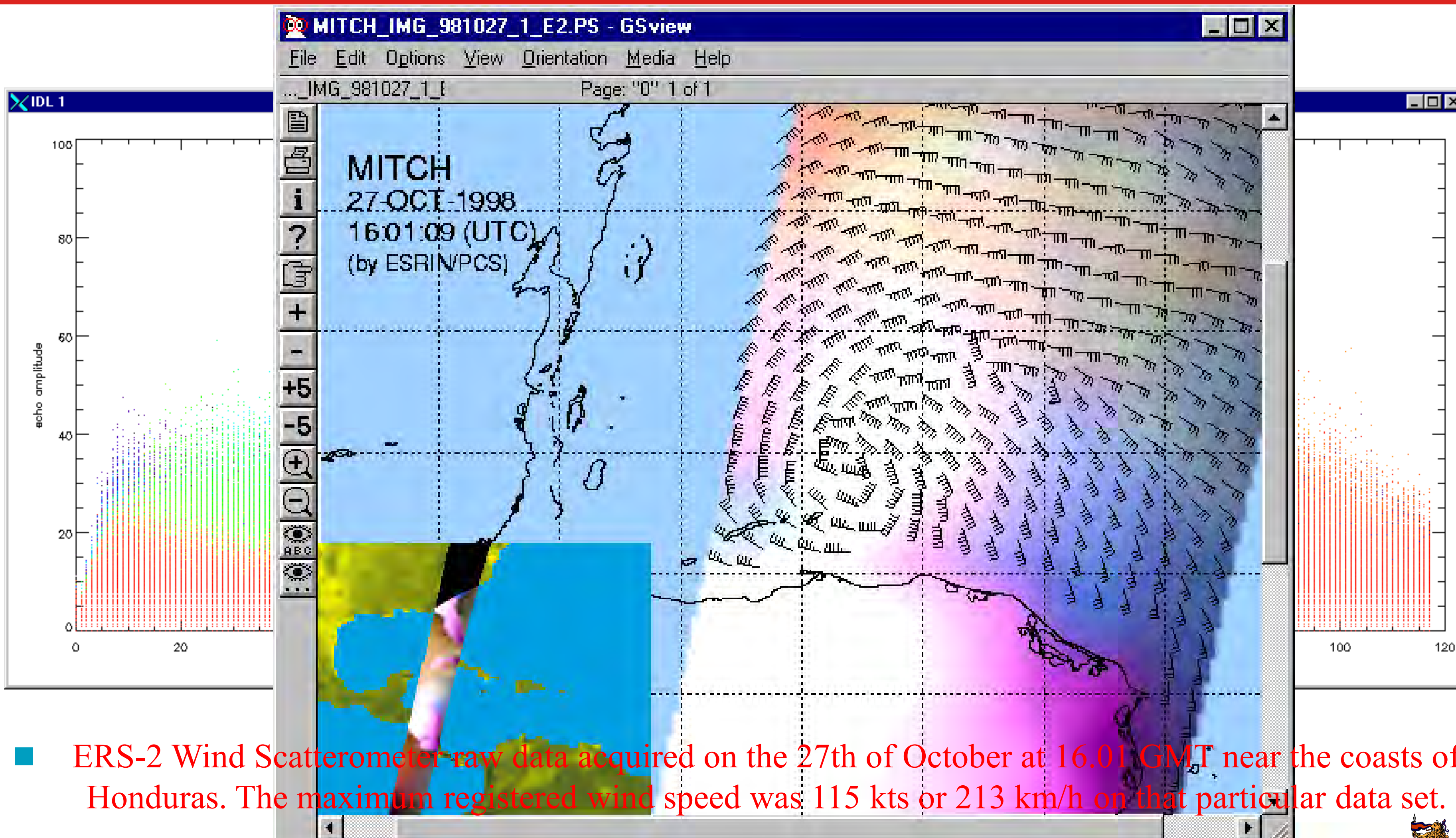
The central pressure reached a minimum of 905 millibar about 40 miles Southeast of Swan island on the afternoon of the 26th. This pressure is the fourth lowest ever recorded in an Atlantic hurricane this century.

At its peak intensity, Mitch's maximum 1-minute sustained surface winds were estimated to be 320 km/h. After passing over Swan island Mitch began to gradually weaken (on the 27th) while moving slowly toward the bay islands off the coast of Honduras. The cyclone center passed very near the island of Guanaja and then, up to the 29th near the north coast of Honduras. After it moved Southward and inland over Honduras and Guatemala (30th and 31st) weakening to a tropical storm.

The 5th November, Mitch became extratropical and its dissipated on the North Atlantic Ocean.



The TC Mitch October 27th 1998



- ERS-2 Wind Scatterometer raw data acquired on the 27th of October at 16.01 GMT near the coasts of Honduras. The maximum registered wind speed was 115 kts or 213 km/h on that particular data set.

Ocean Winds

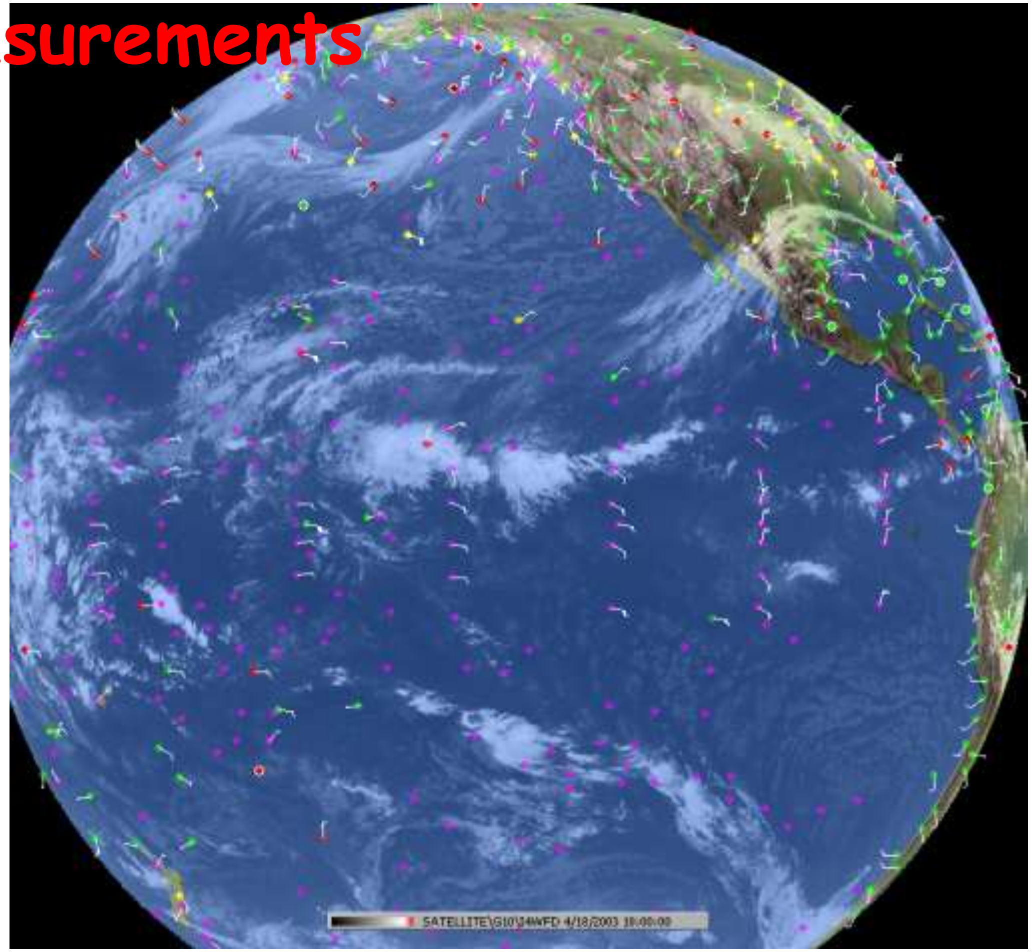
Sea Surface waves in a Storm

Ocean Winds

■ Why a Scatterometer ?

- Variability of ERS Scatterometer data
- Thirty day mean sensor density effect the forecast models ran by metoffice

Typical wind measurements



GOES-10 Western Hemisphere satellite imagery with:

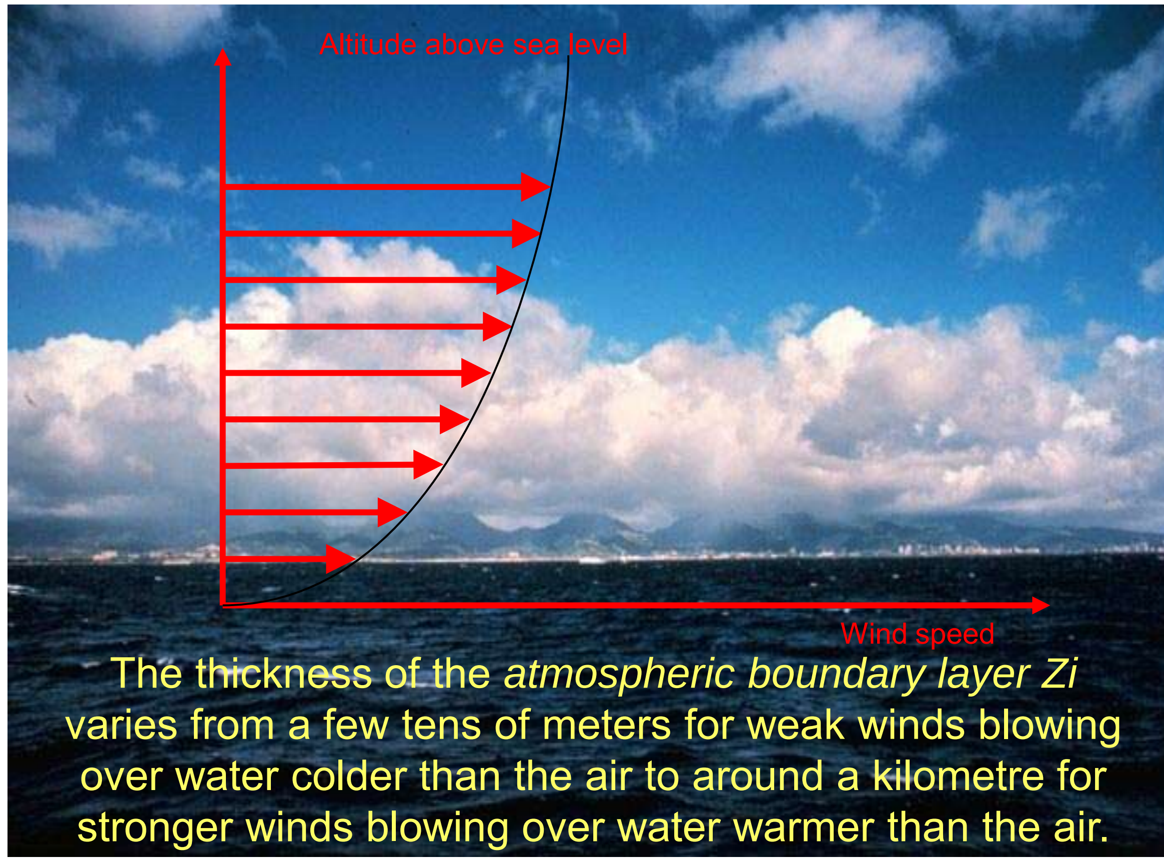
buoys, ships, and ground stations represented with wind barbs.

April 18th, 2003

18:00 UTC

Ocean Winds

- Quality of the wind (fisherman or instrument)
- Altitude of the anemometer
- Boundary layer & atmosphere stability
- 10 m neutral winds



Ocean Winds

Ship Measurements

- Oceanography vessel

Ship Measurements

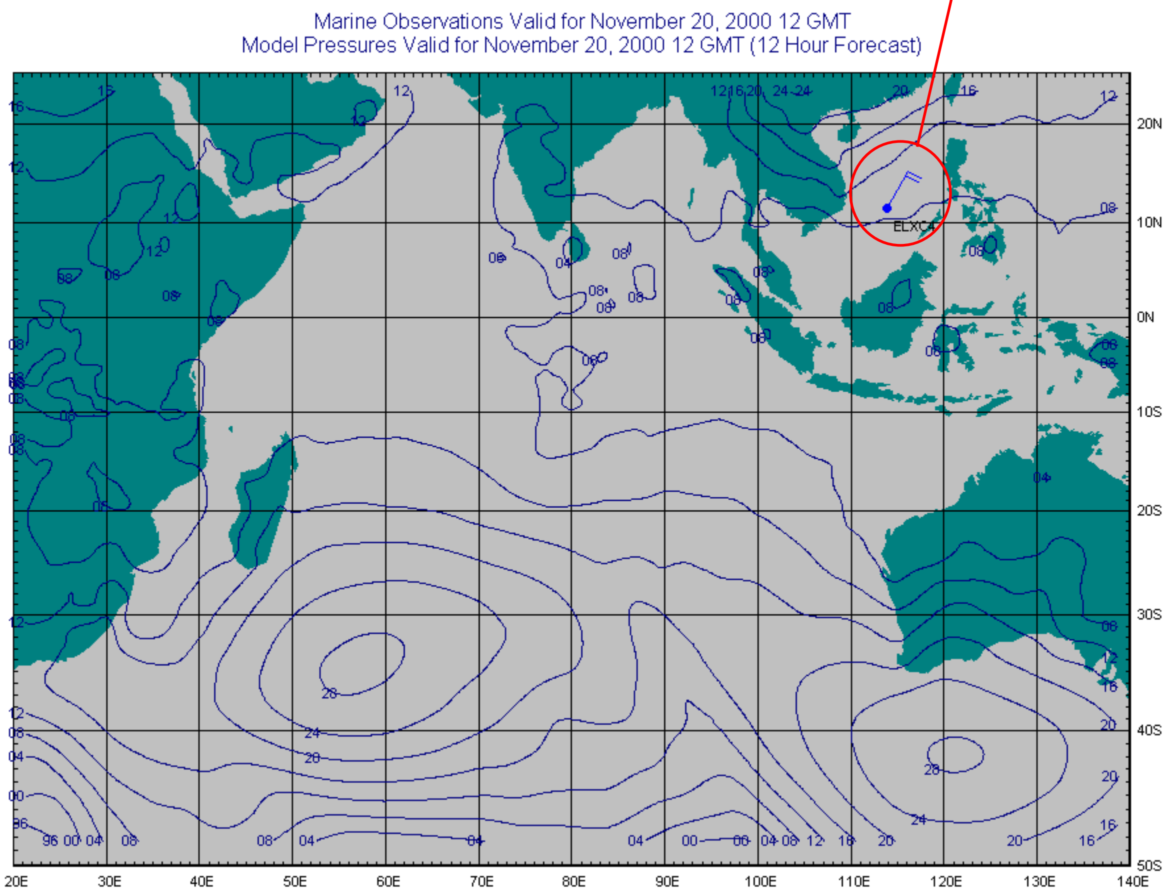
Oceanographical vessel PolarStern

Fishing ship

Container and Passenger Vessel

Ocean Winds

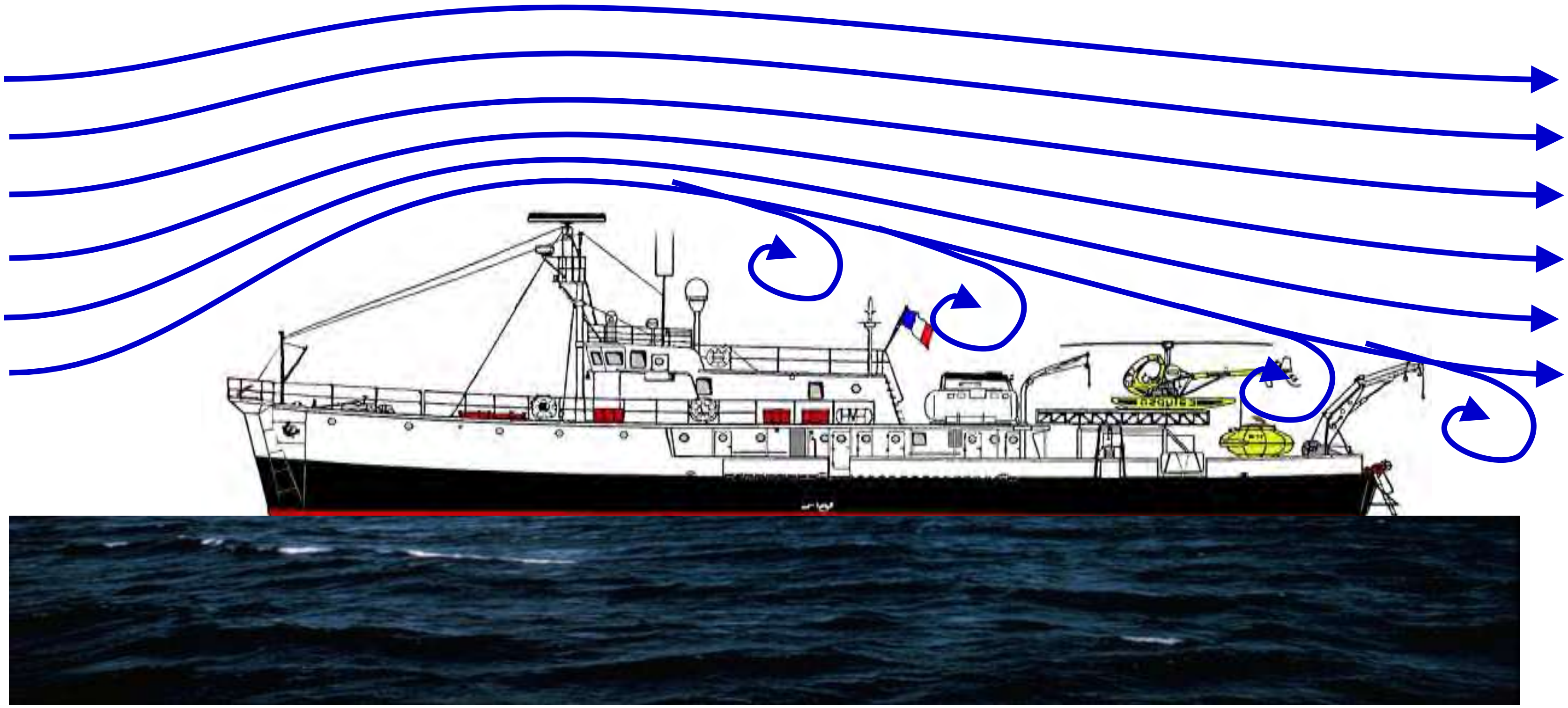
Only one measurement that particular day !



oceanweather inc.

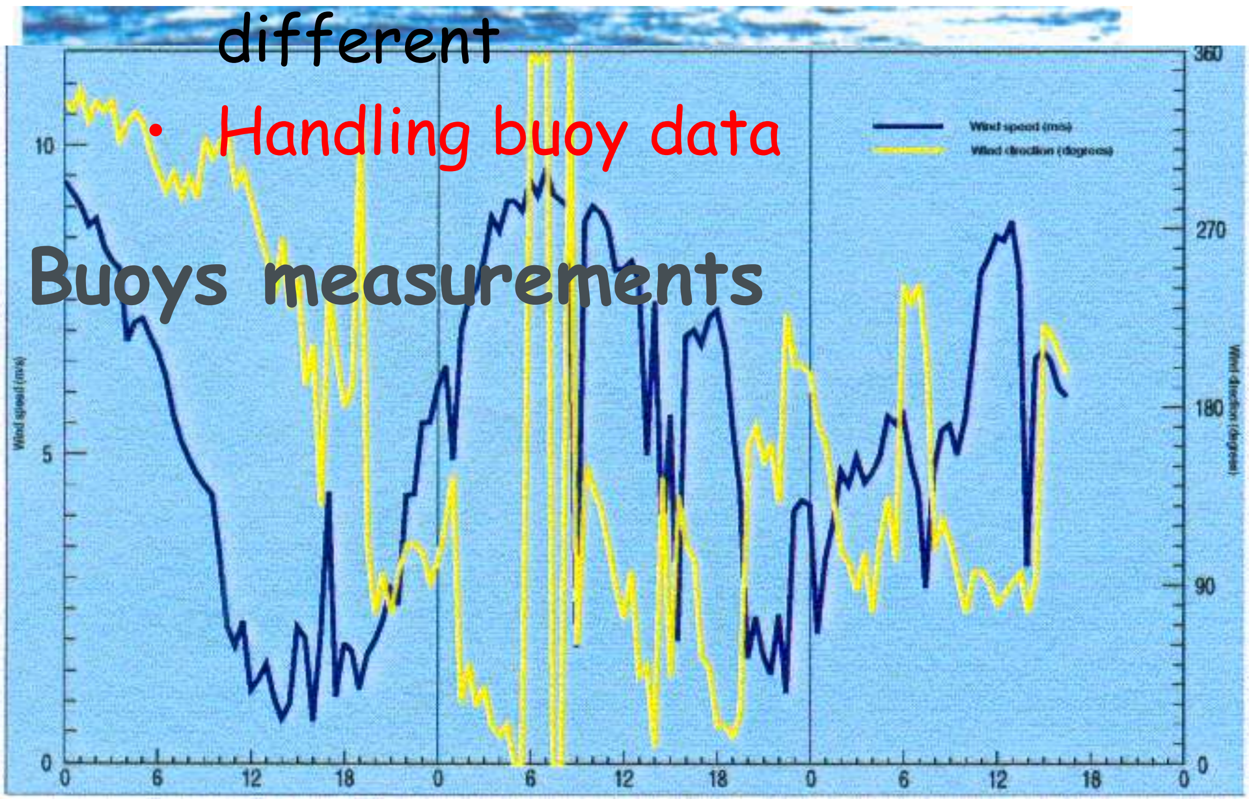
Ocean Winds

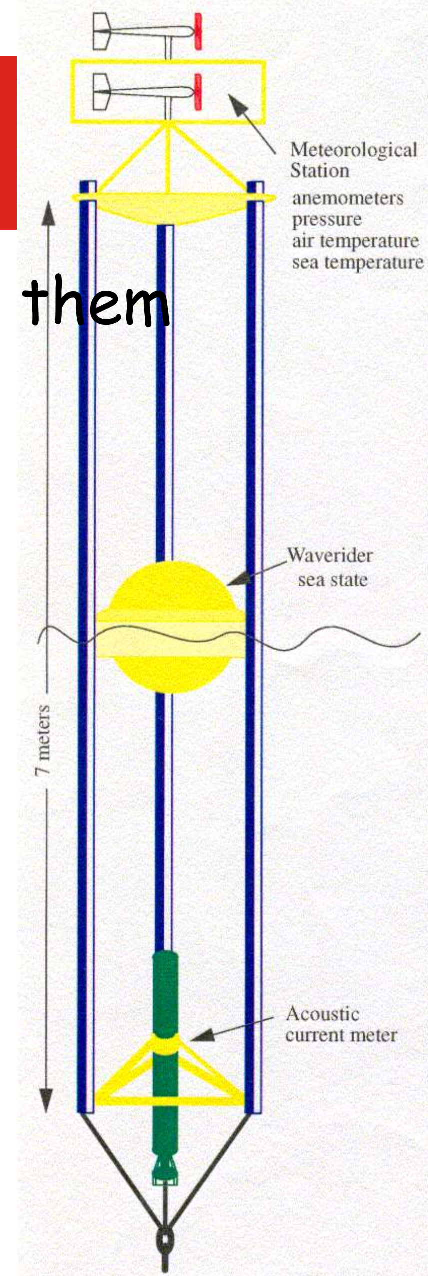
The wind blockage effect due to the ship structure modify locally the wind field by introducing acceleration and deviation of the wind.



Ocean Winds

- Buoys measurements
  - Difficulties to operate and to maintain them
  - Altitude of measurements can be very different
  - Handling buoy data



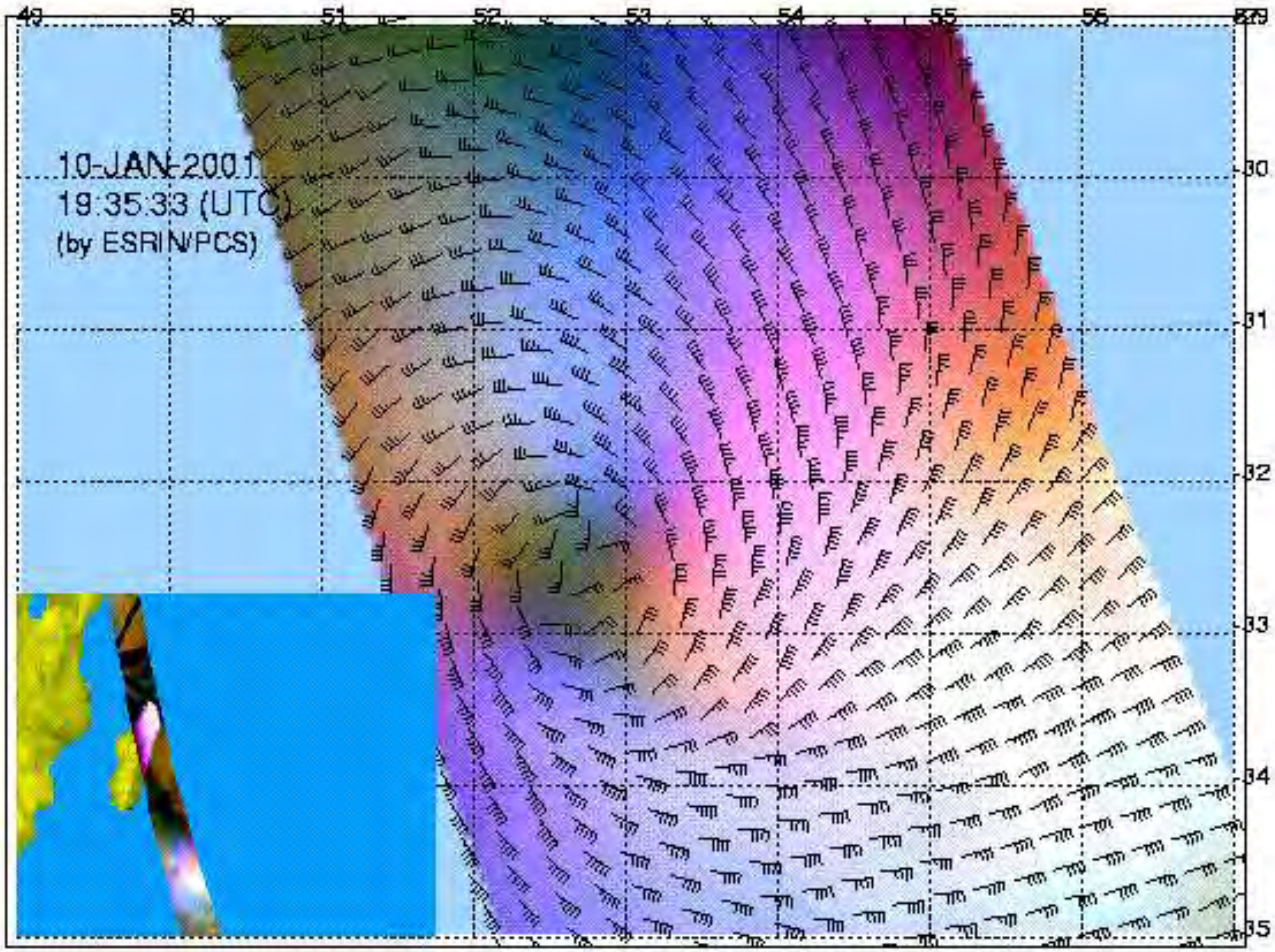


Measuring wind at sea - Buoys

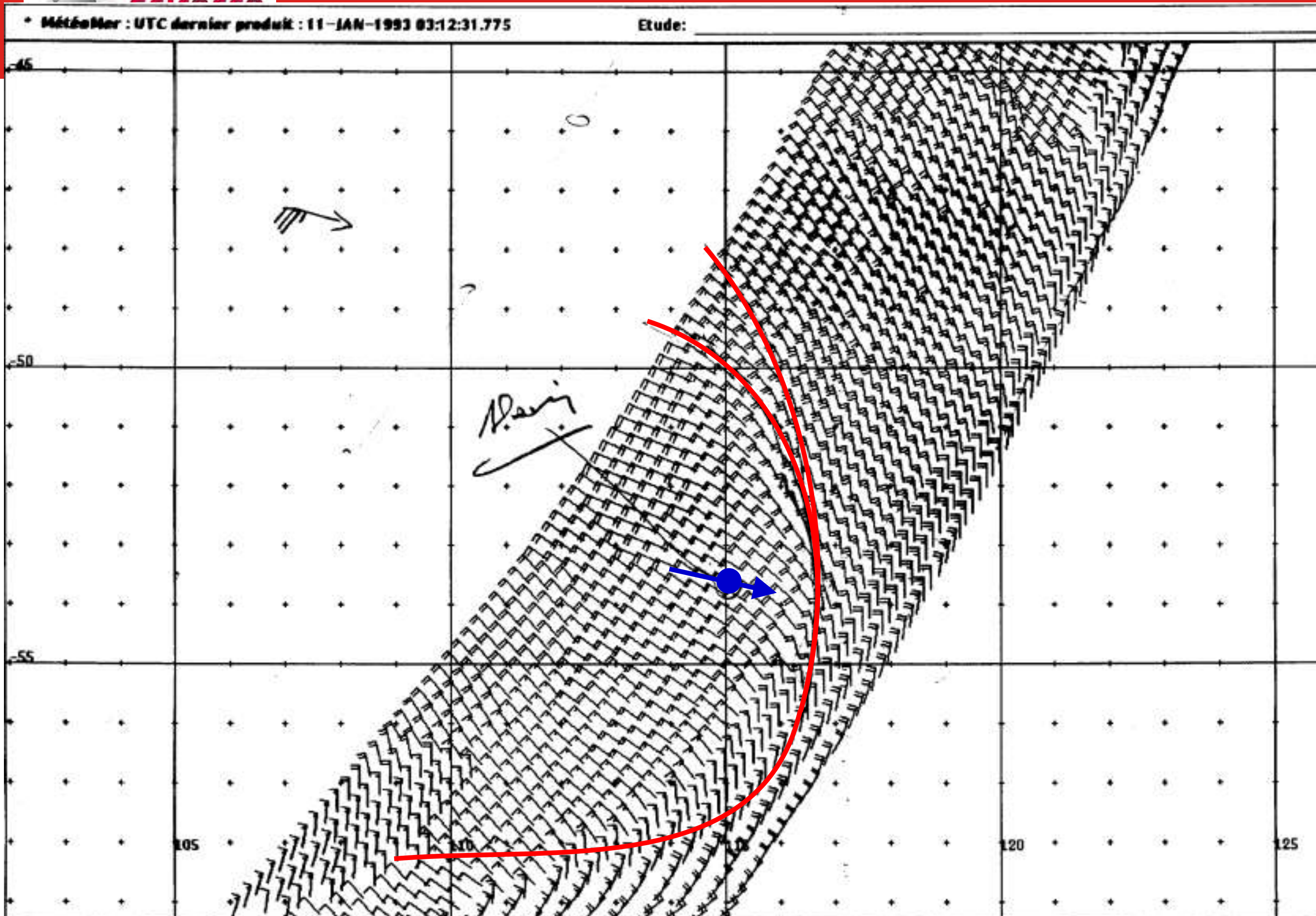
Typical wind sensor accuracy: 0.3 m/s   3.0º

Ocean Winds

- Scatterometer measurements 25 x 25 Km wind field over a swath of 500 Km



Cold Front

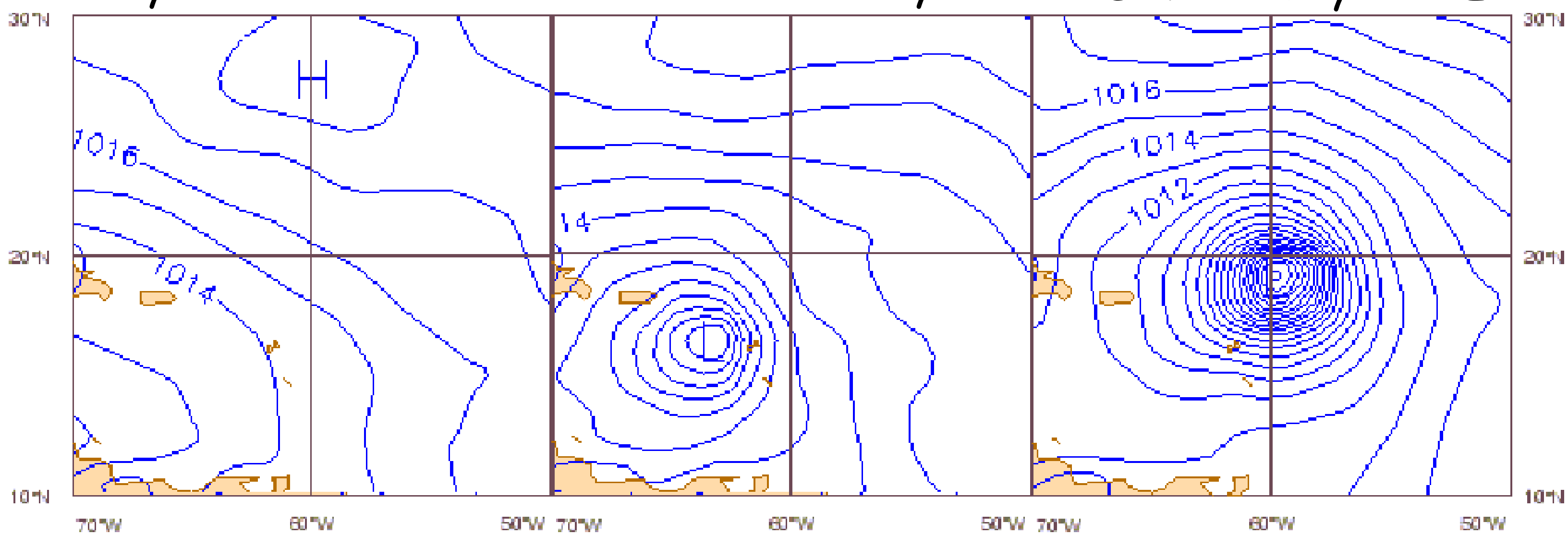


MétéoMer : UTC dernier produit : 11-JAN-1993 03:12:31.775
Etude:
-45
-50
-55
105
110
120
125

Ocean Winds

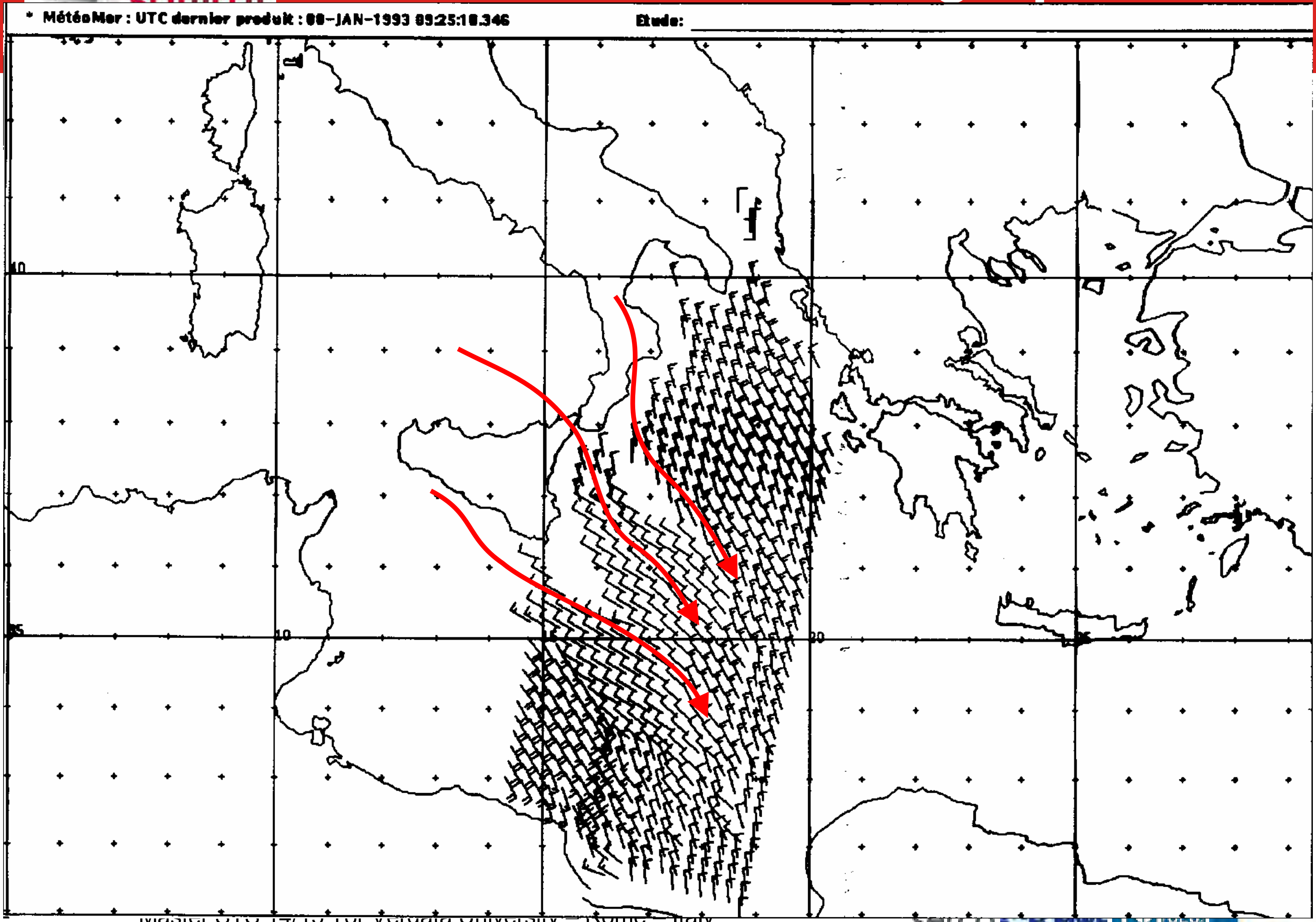
- Scatterometer measurements
- New powerful tool for meteorological forecast
- Data are immediately assimilated in NWP model

5 days forecast TC Luis | 4D-Var analysis | 4D-Var analysis + ERS



From Ad Stofflen A generic approach for assimilating Scatterometer Observations

Orographic effect



Ocean Winds

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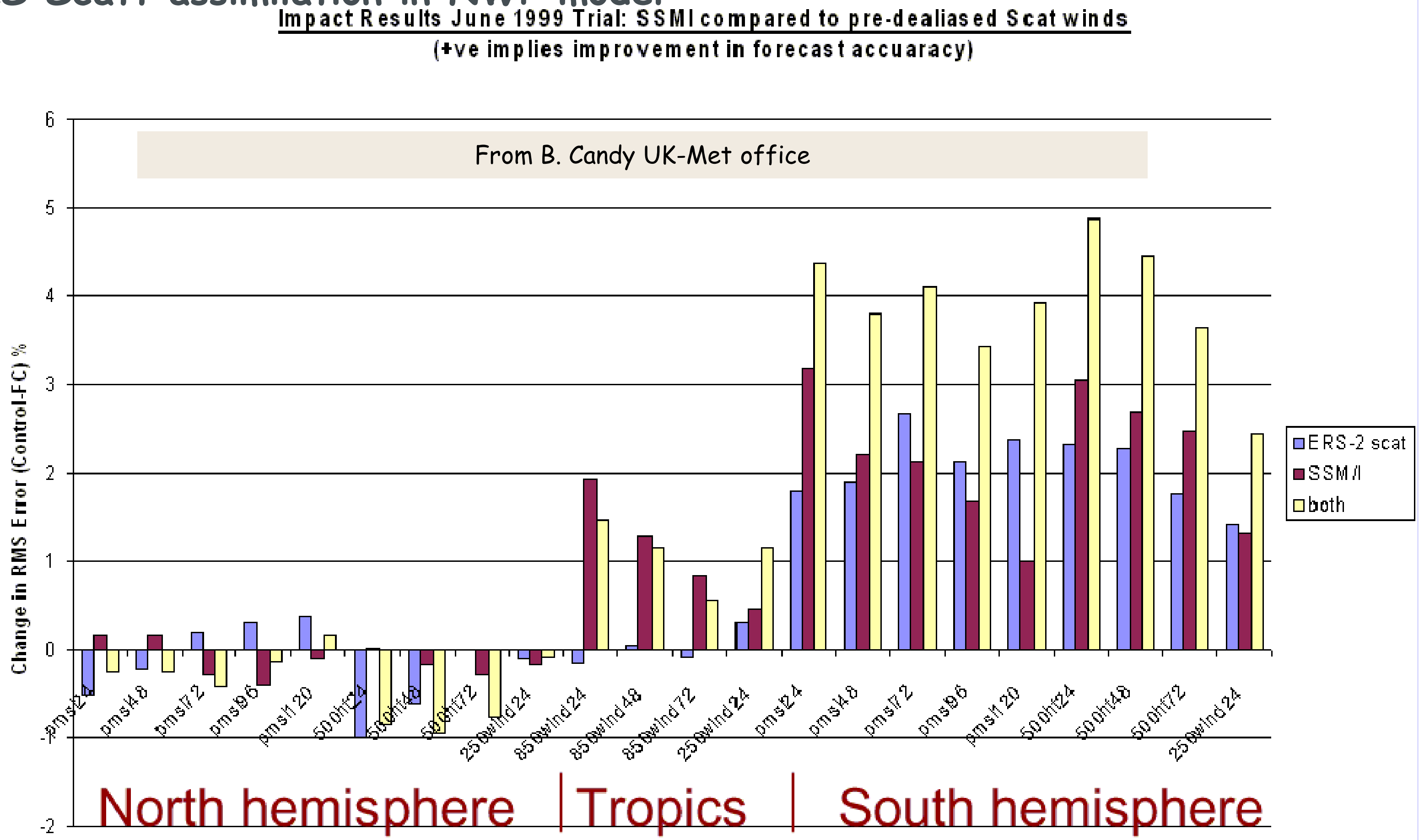
- ERS Scatt assimilation in NWP model



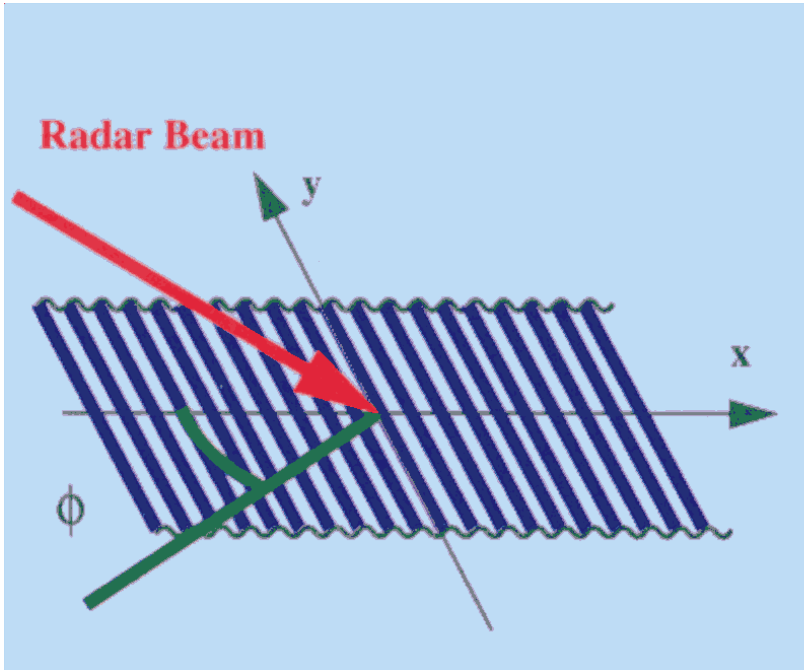
serco ECMWF TU WIEN GEO

Ocean Winds

Ocean backscattering

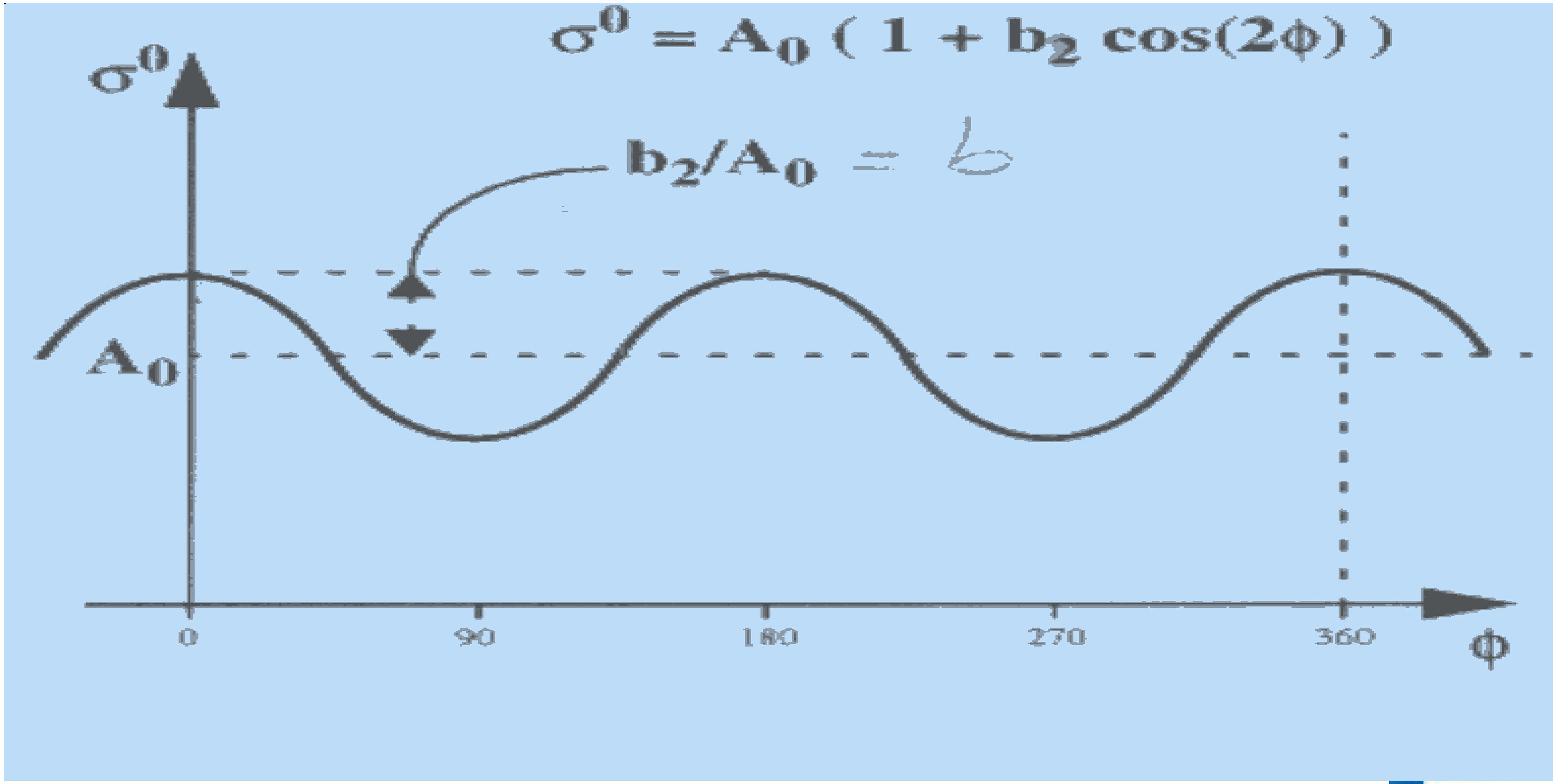
- The Ocean surface is not isotropic
- The roughness seen is related to small ripples which have only few centimeters wavelength

- Water surface is:
- smooth parallel to wave crests
- rough perpendicular to wave crests



- Ocean backscattering

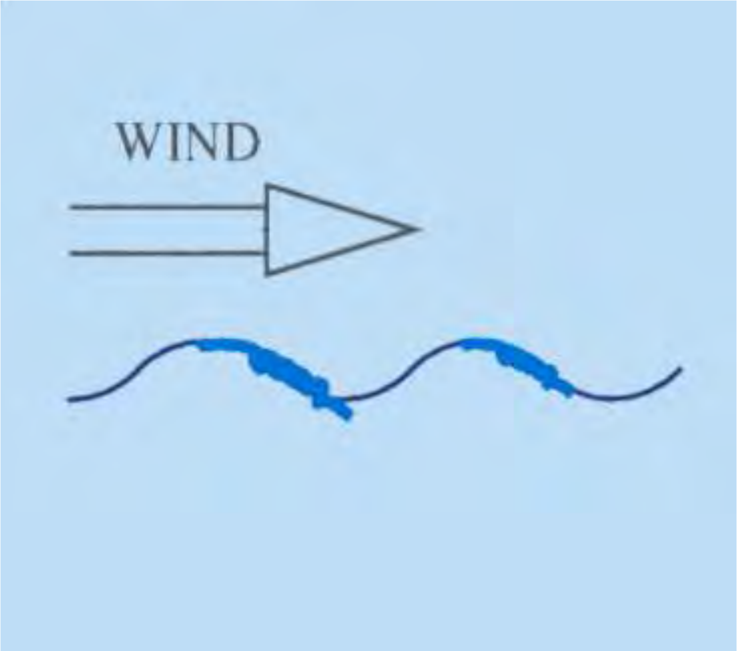
- Two elements model



Ocean Winds

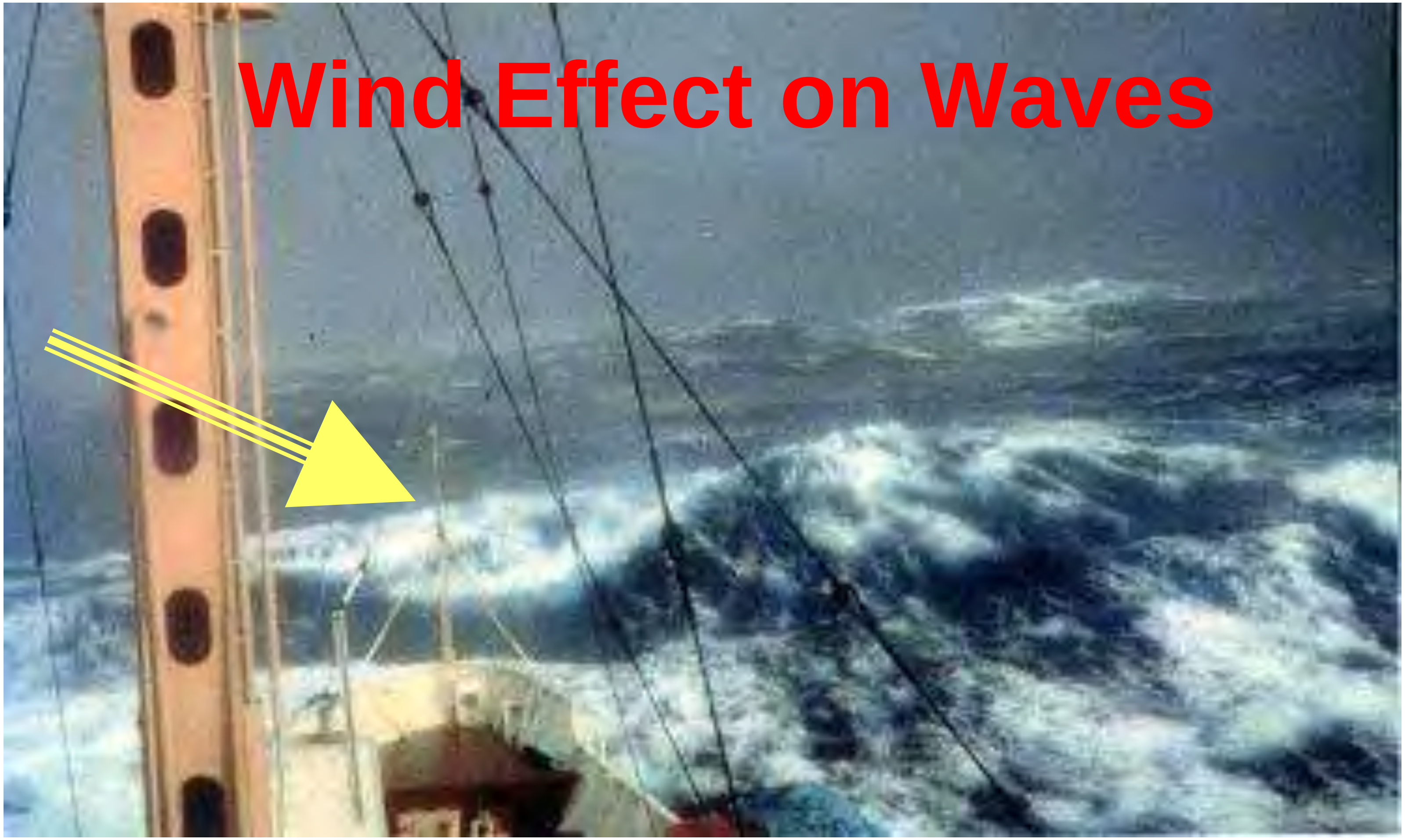
■ Ocean backscattering

- The two sides of the waves are not identical
- Upwind
- Downwind



Ocean Winds

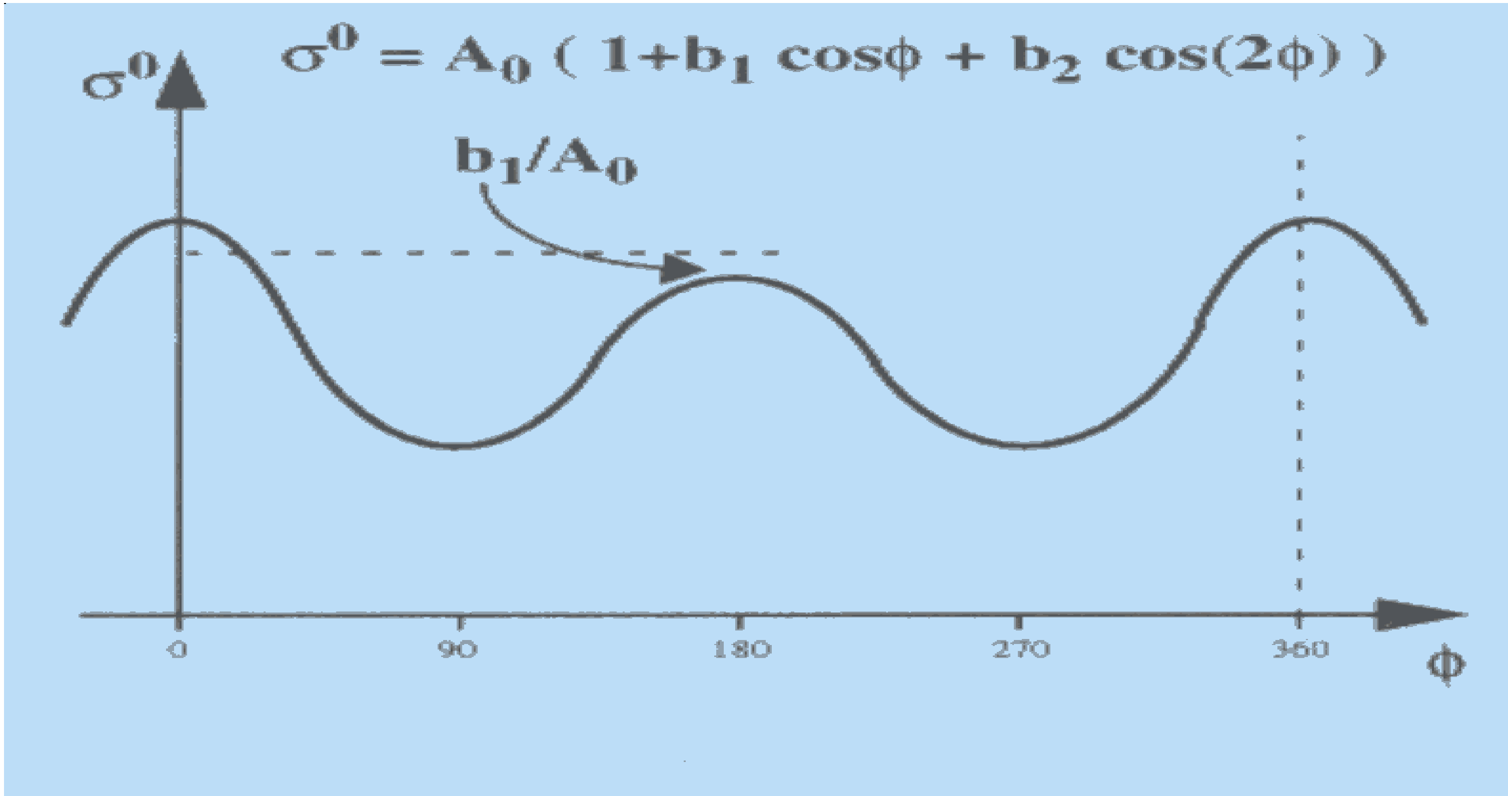
Ocean Winds



Ocean Winds

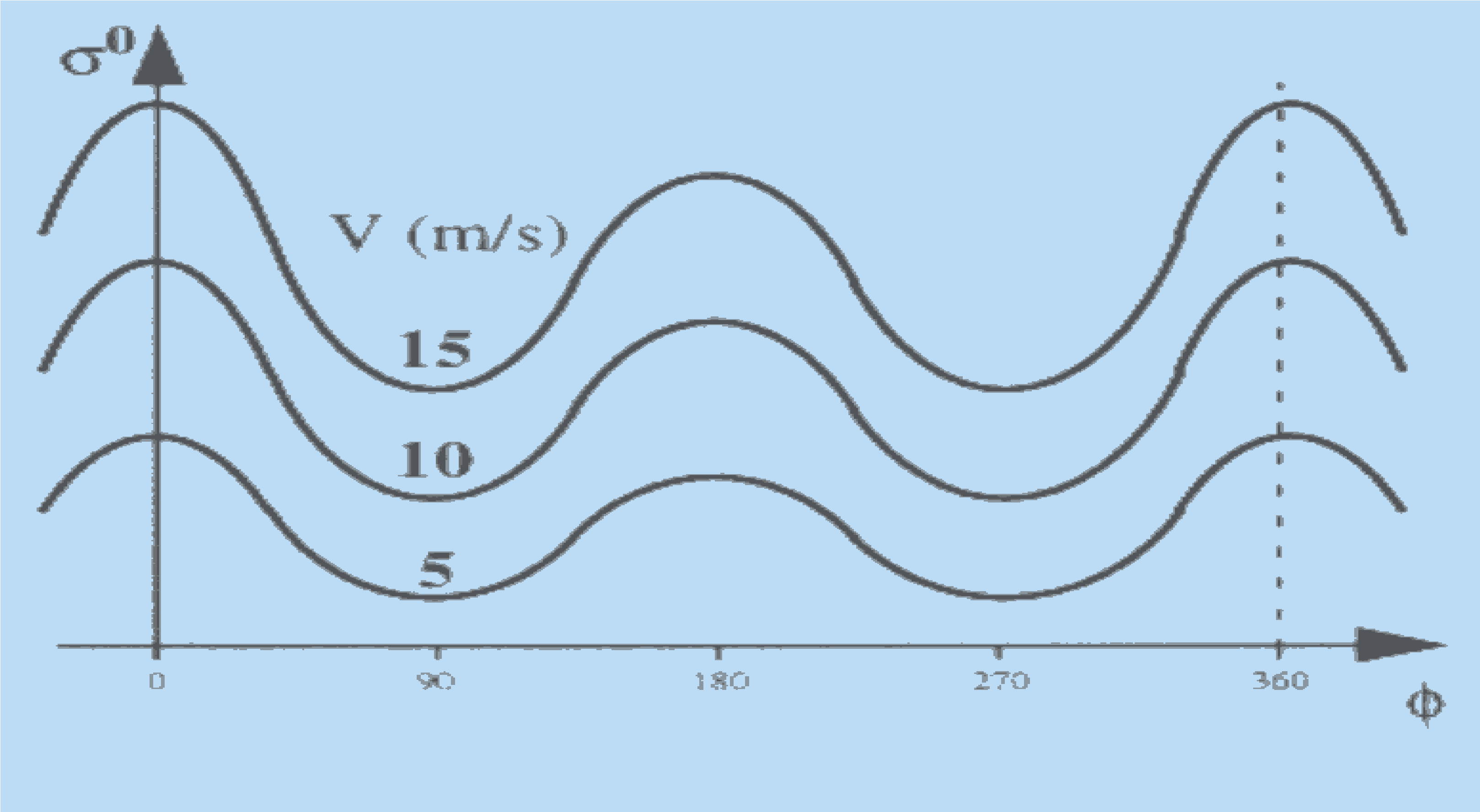
- Ocean backscattering

• Three elements model



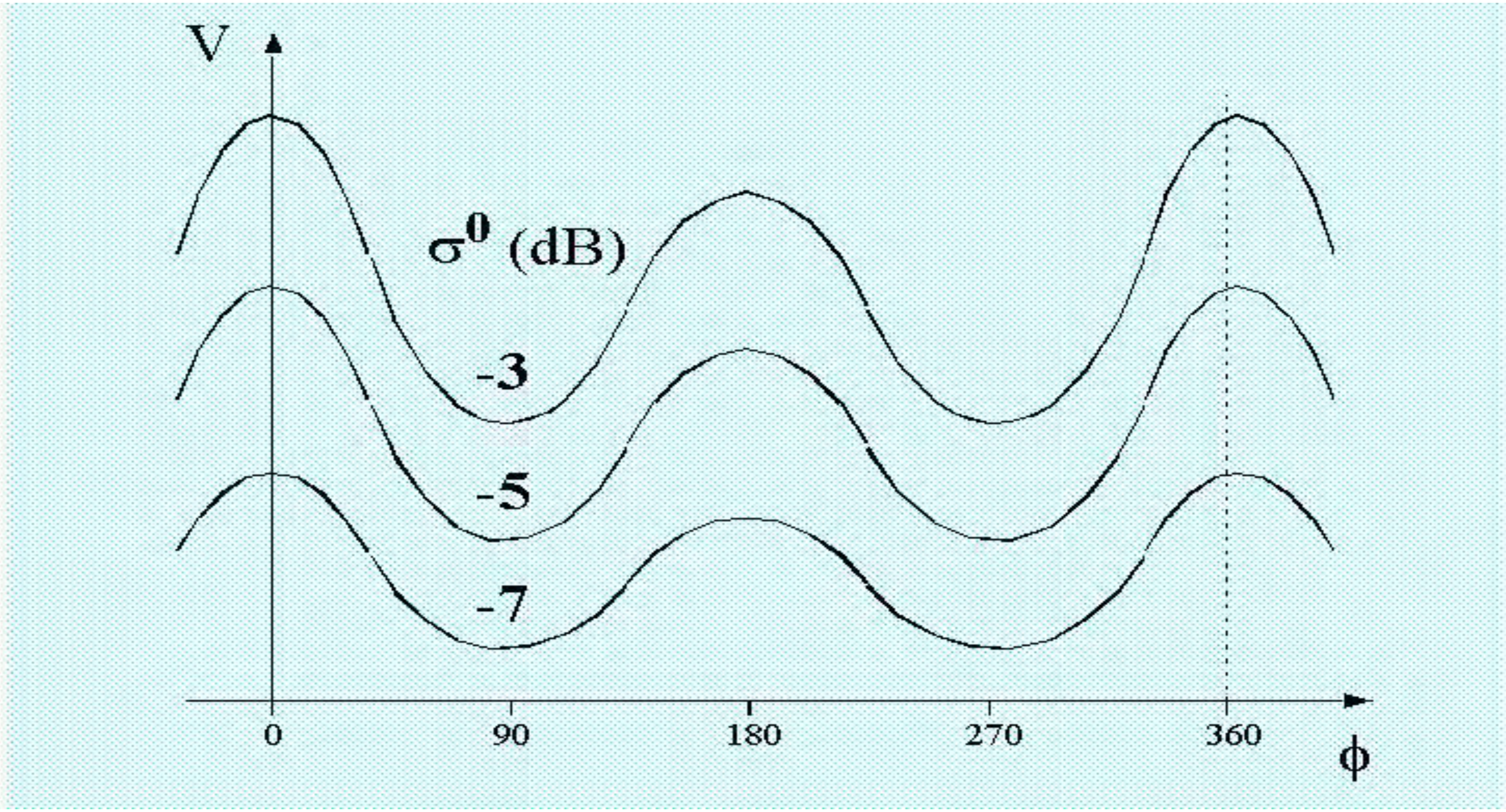
Ocean Winds

- Ocean backscattering: sigma nought w.r.t. wind speed



Ocean Winds

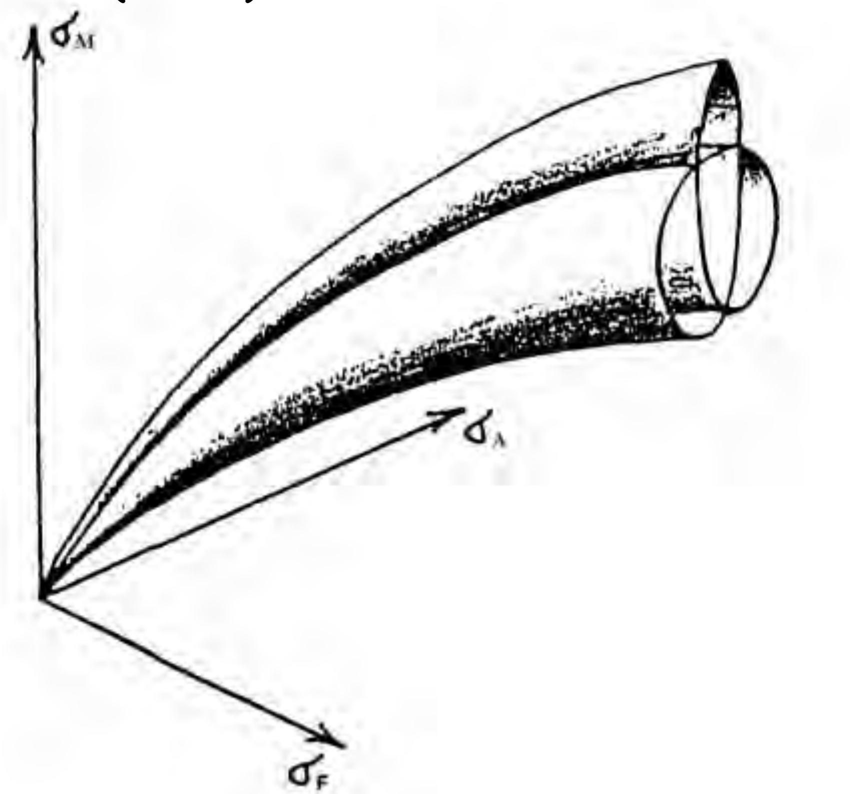
- Ocean backscattering: Wind speed w.r.t. Sigma 0



Ocean backscattering: CMOD4

- Empirical Geophysical model function (GMF)
- Based on ground truth data
- 18 coefficients
- The cone

$$\sigma^0 = b_0\left(1 + b_1 \cos\phi + b_3 \tanh(b_2) \cos 2\phi\right)^{1.6}$$



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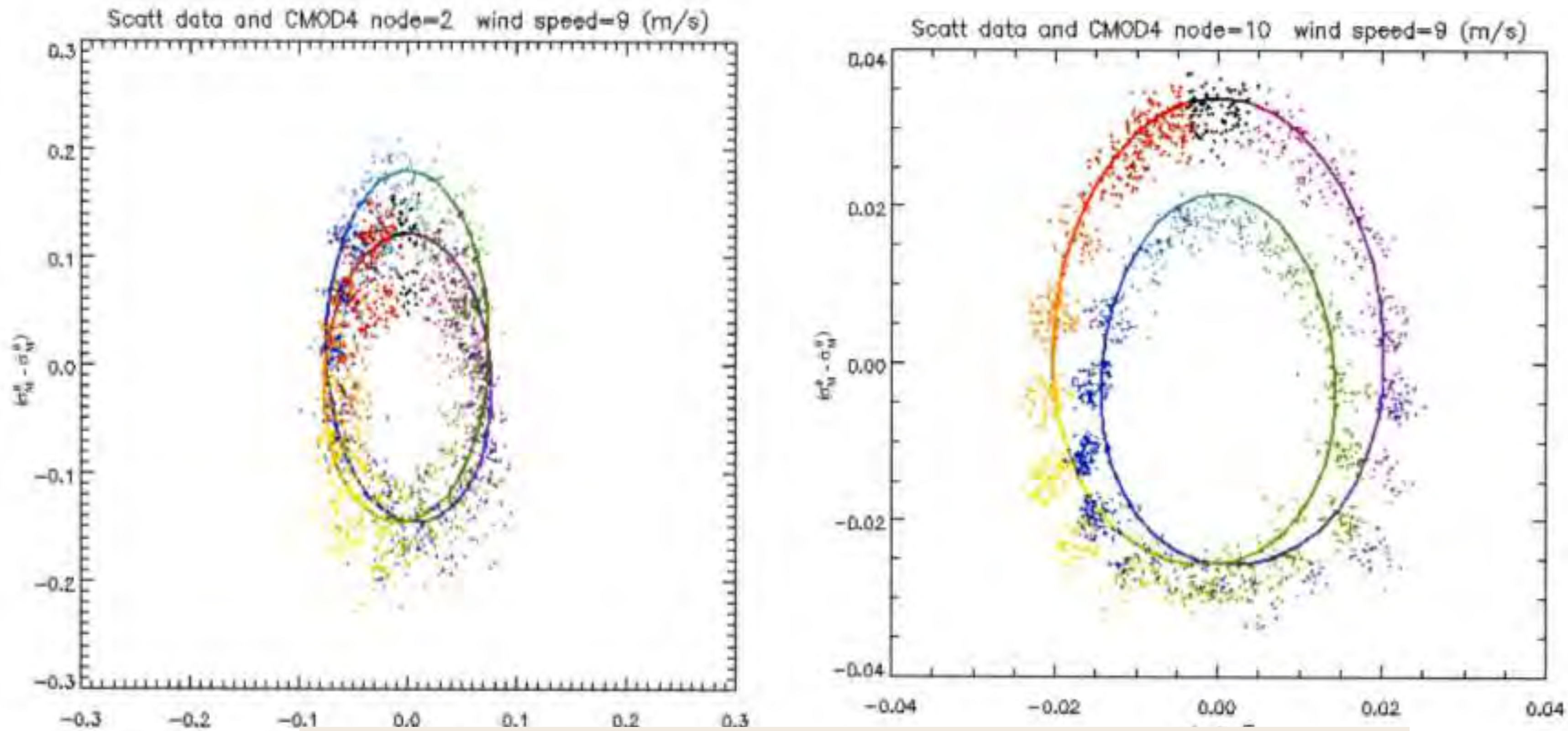
scatterometer instrument competence centre

Ocean Winds

Ocean backscattering: CMOD4

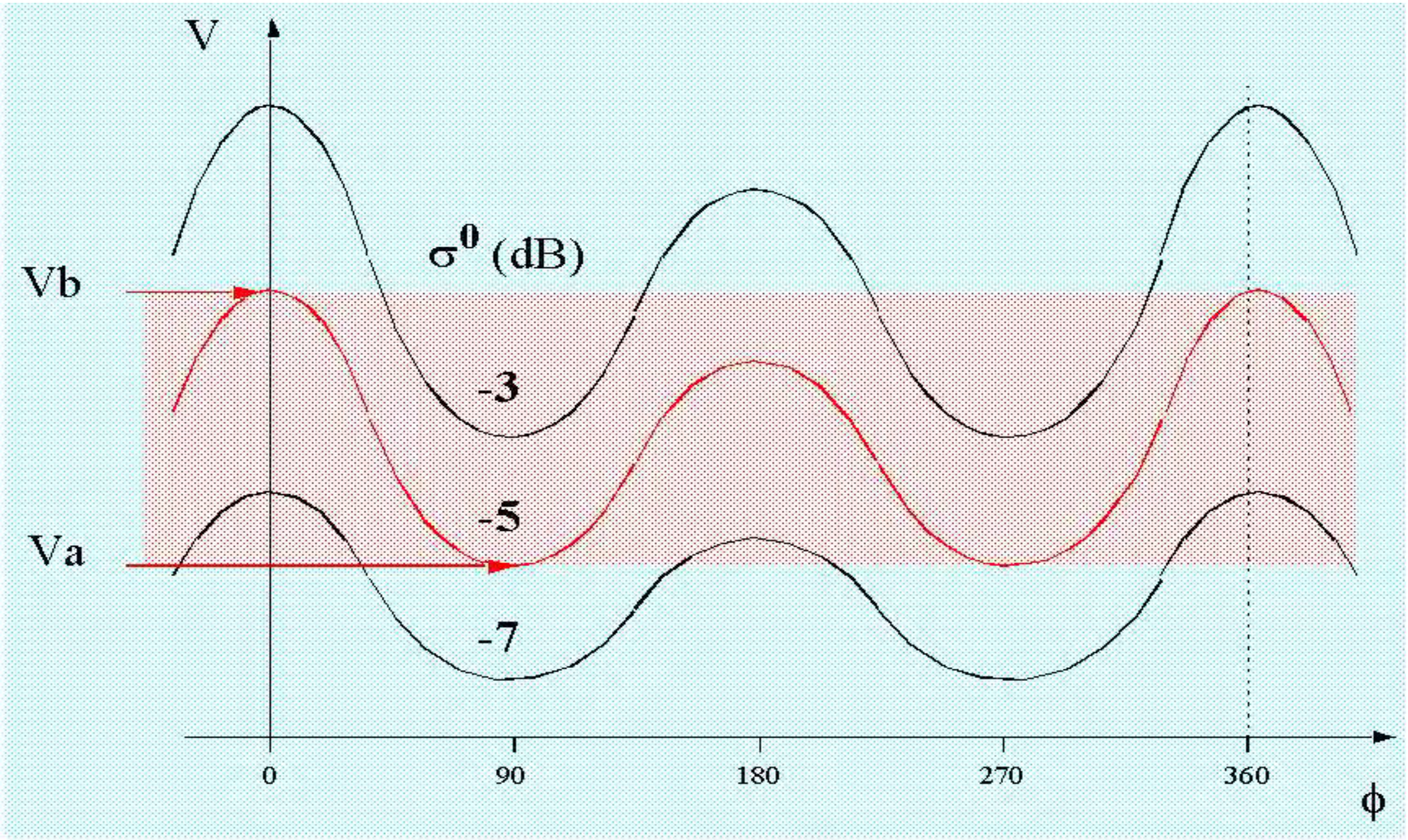
- Comparison with real sigma nought



From G. De Chiara Tracking a Tropical Cyclone with ERS-SCAT a CMOD4 model review

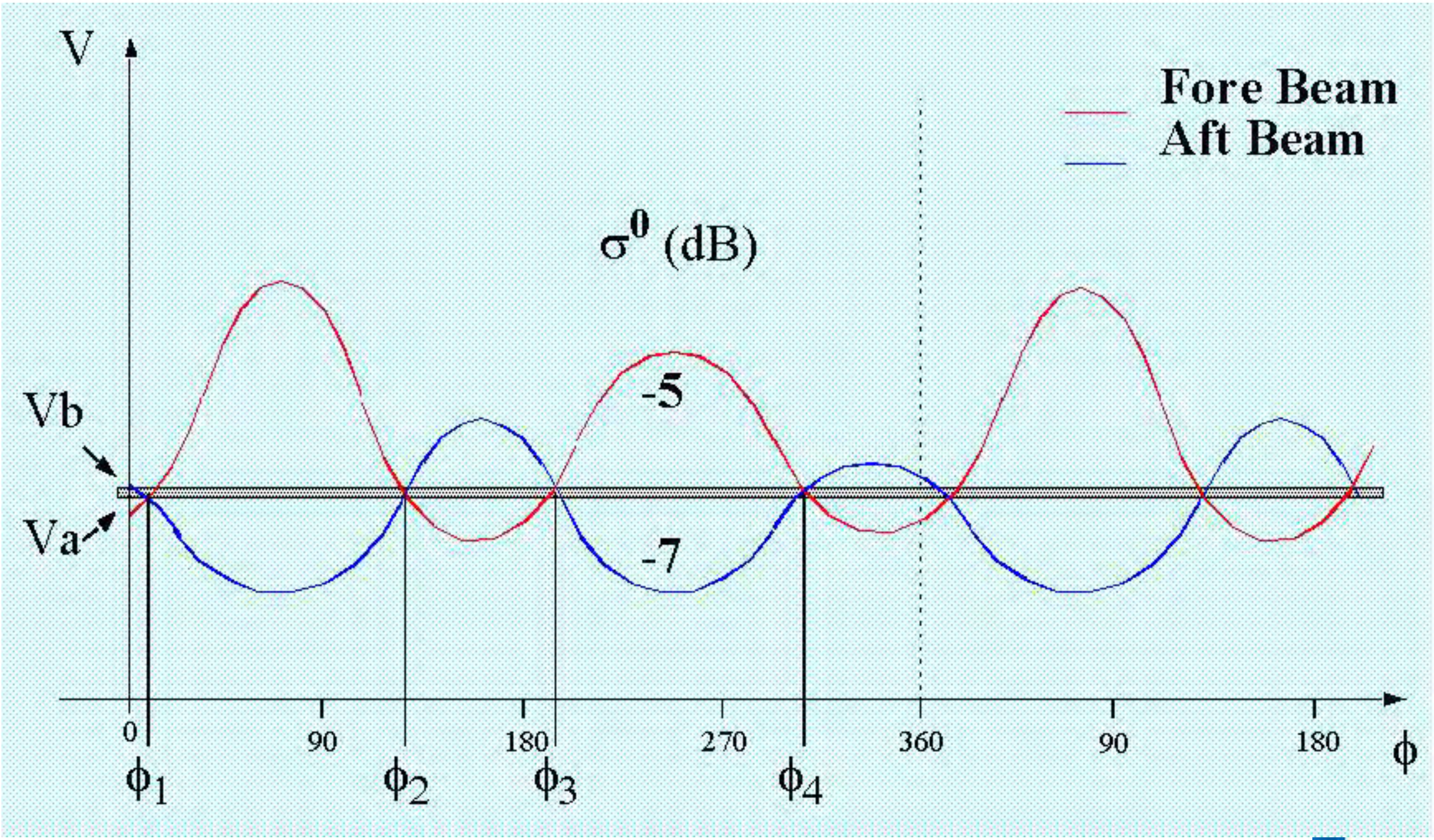
Ocean Winds

- Scatterometer with 1 antenna - SAR



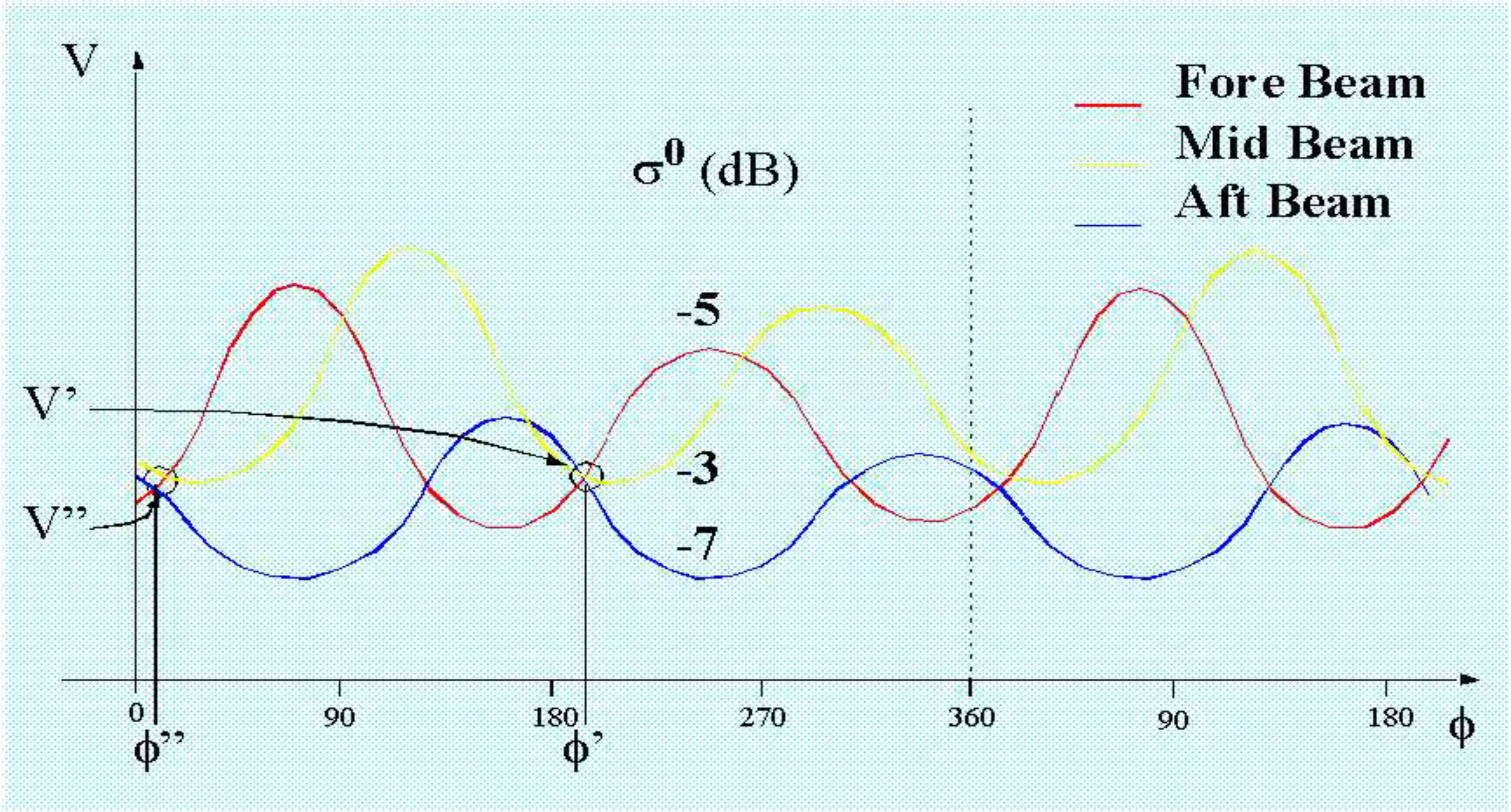
Ocean Winds

- Scatterometer with 2 antenna for / aft 45 deg.



Ocean Winds

- Scatterometer with 3 antennae for/aft/mid



Ocean Winds

Wind retrieval

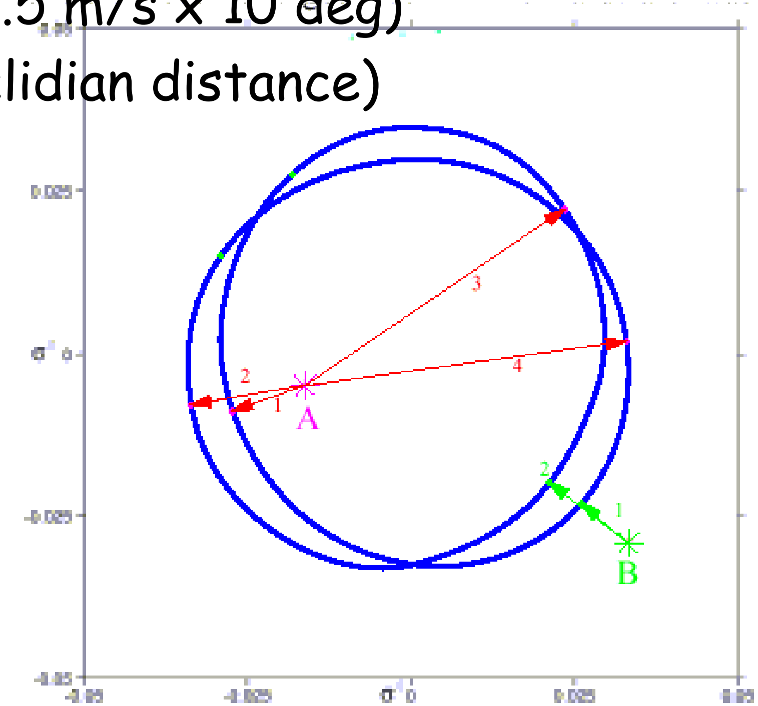
- Three sigma nought (Fore, Mid, Aft) measurement space. In this space the C-Band model looks like a double cone
- It consists in finding the minima, in the sigma nought space, of the distance between the triplet measured and the cone
- Historically two definitions of the distance where used
- The first one correspond to the maximum likelihood distance. The second is simply the Euclidian distance

$$D_L = \sum_{i=1}^{3} \frac{(\hat{\sigma}_i - \sigma_i)^2}{K_{p_i}} \qquad D_E = \sum_{i=1}^{3} (\hat{\sigma}_i - \sigma_i)^2$$

Ocean Winds

Wind retrieval Algorithm description

- Realistic wind speed as starting point
- Minimization with variable wind speed and fixed direction using Newton-Raphson (0.5 m/s x 10 deg)
- Retrieve of the 4 minima (with Euclidian distance)
- Ranking the minima



- A has up to 4 solutions
- B has only 2 solutions

Ocean Winds

Ambiguity Removal

- It consists in choosing the right solution within the up to 4 wind available from the wind retrieval
- Based on the first two solution (usually 180 deg apart) two coherent wind fields are constructed
- Best field is chosen by:
  - Counting the number of Rank-1 winds (autonomous)
  - Comparing the average wind field with meteorological forecast (with background info)

Ocean Winds

Ambiguity Removal 2-D var

- The optimal estimation of the wind field is the most probable (statistical sense) given the available observations (rank-1 and rank-2)
- Most probable wind field is then compared with rank-1 and rank-2. The closest Scatt solution is selected
- Assumptions:
  - No divergent wind field inside the Scatt swath
  - Background wind field available (forecast)

Ambiguity Removal 2-D var

- Minimization of the cost function, x is the wind vector at Scatterometer observation points

- The cost functions has two error component background and observations:

$$J(x) = J_b(x) + J_o(x)$$

- B is derived by assuming that all the errors in the background field are in the non-divergent part

$$J_b = \frac{1}{2}(x - x_b)^T B^{-1}(x - x_b)$$

Ocean Winds

Ambiguity Removal 2-D var

- The cost function for the observation is

$$J_{o(scatt)K} = -\ln\left(\frac{1}{2}e^{J_{K1}} + \frac{1}{2}e^{J_{K2}}\right)$$

$$J_{Km} = \frac{1}{2}\frac{\left(u_{o_{Km}} - u_k\right)^2 + \left(v_{o_{Km}} - v_k\right)^2}{\varepsilon_s^2}$$

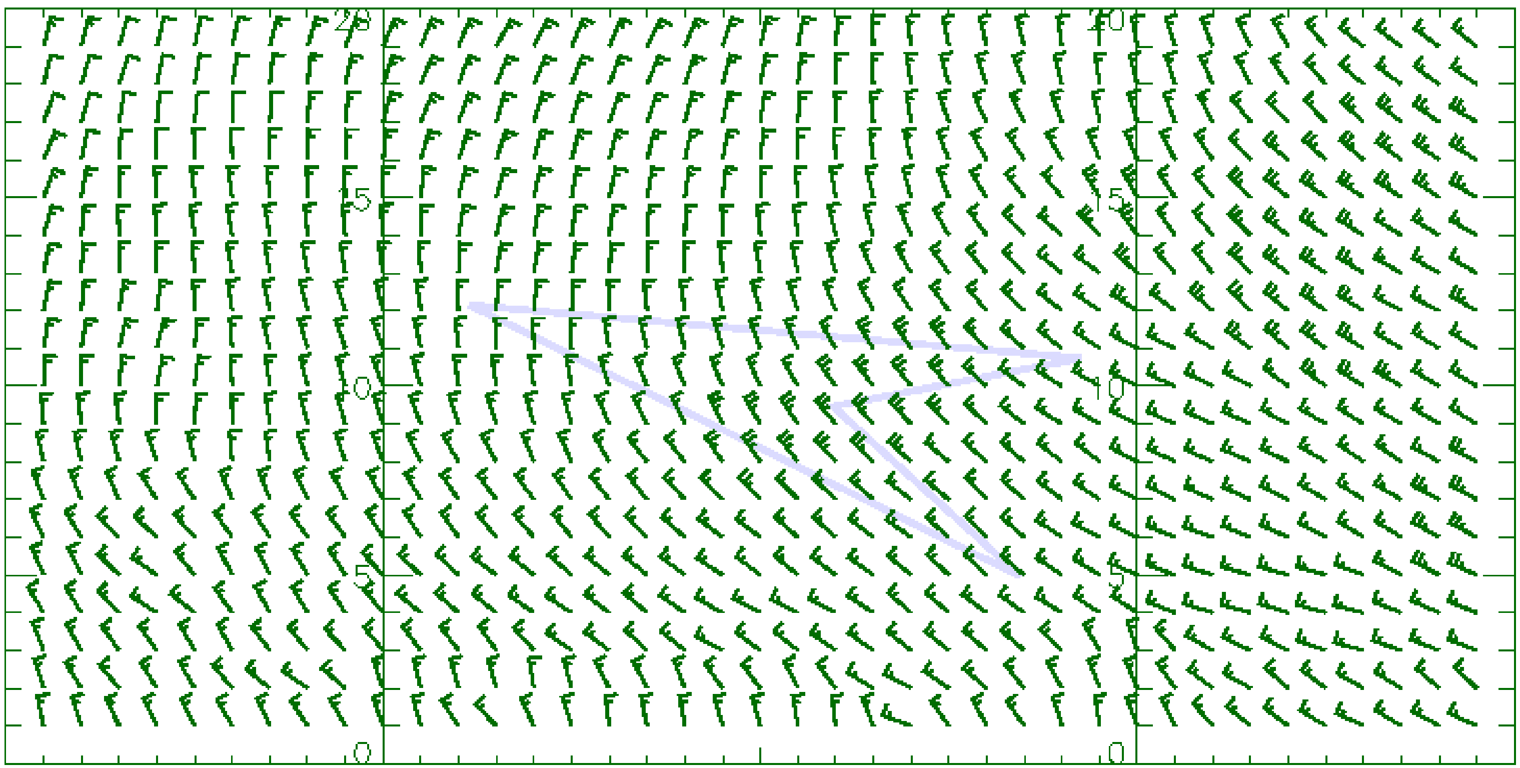
- m = Rank-1 and Rank-2 same probability
- Gaussian distribution with same standard deviation in wind components observation error u and v

Ocean Winds

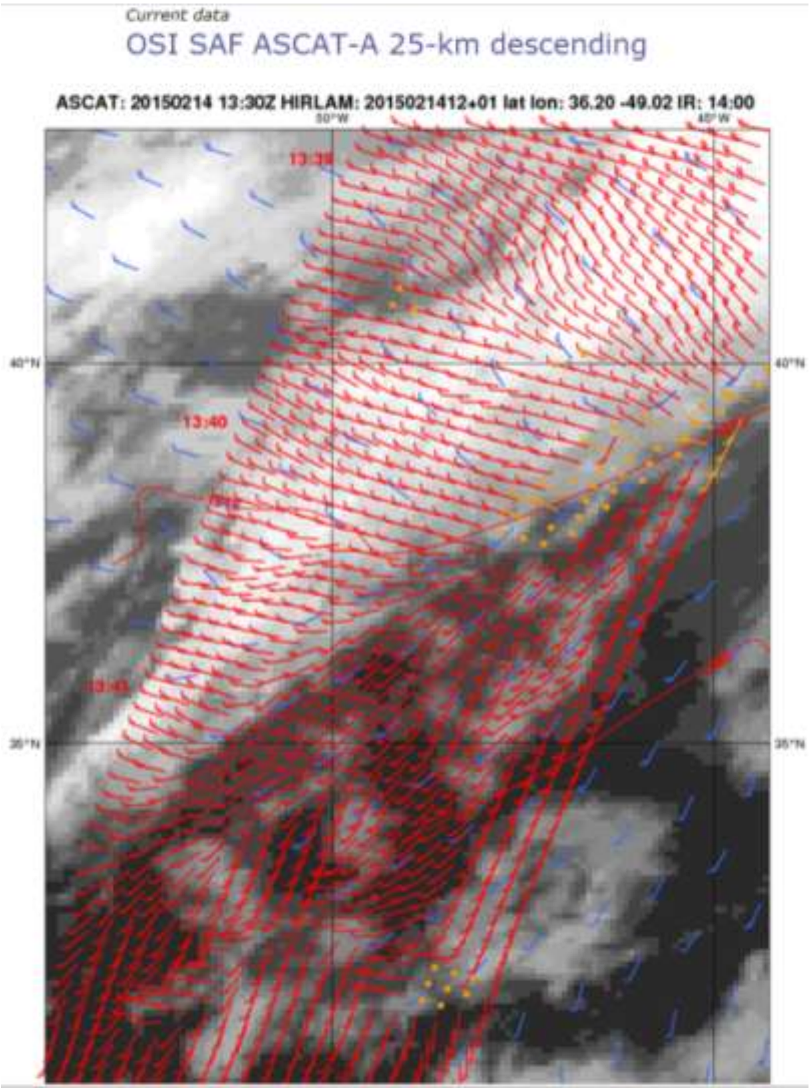
- **Ambiguity Removal 2-D var**

24th July 2001 15:14 utct

De-aliased by ESRIN/PCS



Thanks !



- North Atlantic wind front 14/02/15