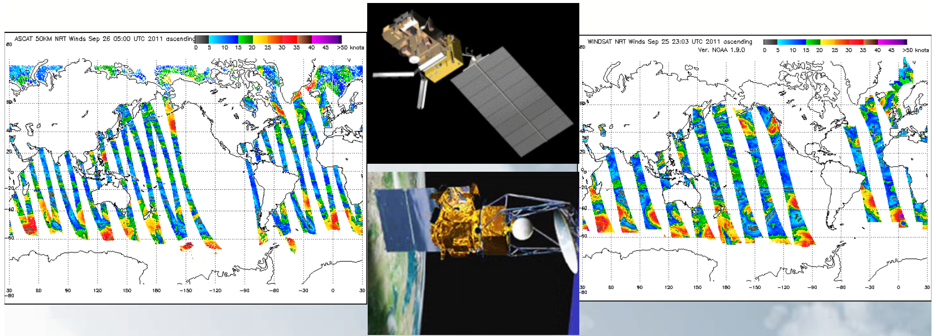
Advanced Satellite Meteorology

Australian Government
Bureau of Meteorology



Session 3: Training in the use of Microwave Scatterometer / Radiometer data

Bodo Zeschke
Bureau of Meteorology Training Centre
Australian VLab Centre of Excellence

Advanced Satellite Meteorology Course

Session 1 8th May	Advanced training in the use of visible and infrared satellite imagery.
Session 2 9th May	Advanced training in the use of water vapour satellite imagery.
Session 3 15th May	Training in the use of microwave scatterometer data
Session 4 15th May	Training in the use of cloud drift wind data
Session 5 17th May	Training in the use of rapid scan data.
Session 6 19th May	Training in the use of RGB products
Practical sessions (17th and 19th May)	Practical sessions focus upon Rapid Scan and RGB Product data
2 hour exam (26th May)	**Open book exam with resources on latitude**

Feedback from Operational Forecasters regarding the use of Scatterometer / Radiometer data (1)

Rebecca Patrick (Northern Territory Regional Forecasting Centre)

- Scatterometer data (ASCAT, Rapidscat, Windsat (the latter 2 not always available)) is used extensively in Darwin RFC/RSMC/TCWC for analysing position of systems (H, L, TC) and troughs/ridges. It is also used to groundtruth wind speed/direction for marine forecasts as we have very few maritime obs. Personal preference whether to use this in VWx or via website. VWx data is available slightly earlier. In VWx we overlay the last 10 hours of scat data over satellite imagery, so it is important to check the time of the pass as this may not correspond to the satellite picture you are looking at. This is particularly important for faster moving systems & fronts. For info, WA also put together a microwave viewer for TCWC operations http://wa-aifs-local.bom.gov.au/tc/microwave/viewer1.2/ which is another option for viewing scat data, but not particularly relevant for junior mets.

REFERENCE

Feedback from Operational Forecasters regarding the use of Scatterometer / Radiometer data (2)

Chris Davies (South Australian Regional Forecasting Centre)

- In SA we have scatterometers integrated into all our situational awareness displays and maps. They are particularly useful for verifying positions of fronts (see attached examples from the last couple of days) and the strength of the change behind them.

Dean Stewart (Victorian Regional Forecasting Centre)

- MSLP analysis chart construction, especially over the oceans to the south and east of Victoria
- Monitoring the location of fronts approaching Victoria from the west

John Turnbull (BNOC)

- Can be used for High Seas Forecast analysis though the sparse coverage is an issue

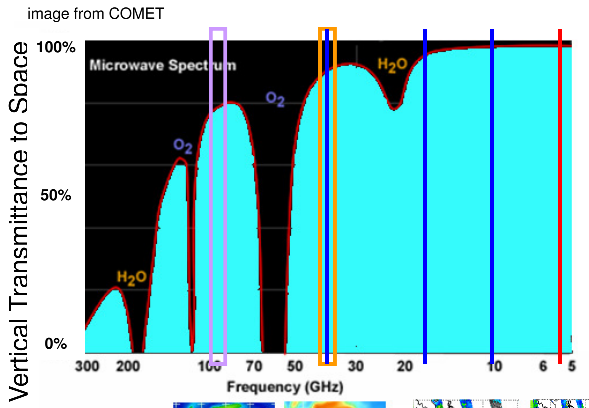
REFERENCE

Contents

- Introducing ASCAT and WINDSAT microwave channels.
- Microwave scanning by METOP (ASCAT) and Coriolis (WindSAT) satellites.
- Derivation of wind data from WINDSAT and ASCAT microwave data
- Forecaster use of microwave derived wind data
- Sources of ambiguity and errors in the imagery
- An exercise: Question from a past exam paper

Microwave channels

image from COMET

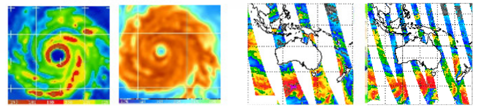


QUIZ – which channel is a Window Channel ?

A: 5.3 GHz
B: 13.4 GHz
C: 37 GHz
D: 65 GHz

Which channels are absorption channels ?

Image Product



(GHz)	85	37	10.7, 18.7, 37	5.3
			WindSAT	ASCAT

Microwave Scatterometers/Imagers compared to RADAR

Electromagnetic radiation having wavelengths between approximately 1 mm and 1 m (corresponding to 0.3- and 300-GHz frequency) bounded on the short-wavelength side by far infrared (< 1 mm) and on the long-wavelength side by very high frequency radio waves (> 1 m). AMS Glossary

ASCAT (METOP) 5.255GHz	**Windsat (Coriolis)** 10.7, 18.7, 37GHz (also 6.8, 23.8GHz)
RAPIDSCAT (ISS) 13.4GHz	**SSM/I (DMSP)** 19.35, 22.235, 37, 85.5 GHz

from https://www.wmo-sat.info/oscar/instruments

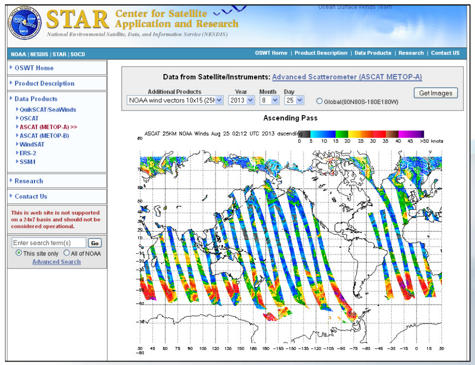
RADAR frequencies

- S band radars 2.7-2.9 GHz, 10cm wavelength (as used by VICRO). S band radars are not easily attenuated.
- C band radars 5.6-5.65 GHz, 5cm wavelength (as used by VICRO). Signal is more easily attenuated, so best for short range weather observations
- X band radars operate on a wavelength of 2.5-4 cm and a frequency of 8-12 GHz. ONLY 1 X-BAND RADAR IN SYDNEY – TOO HEAVILY ATTENUATED BY PRECIPITATION

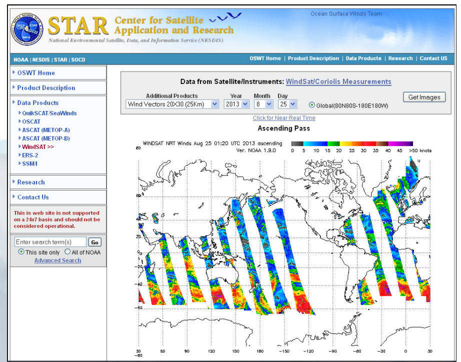
REFERENCE

Scatterometer / Radiometer data

ASCAT (currently available), WINDSAT (for reference)



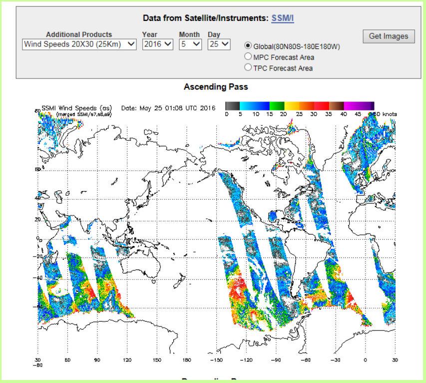
METOP-A and METOP-B satellites



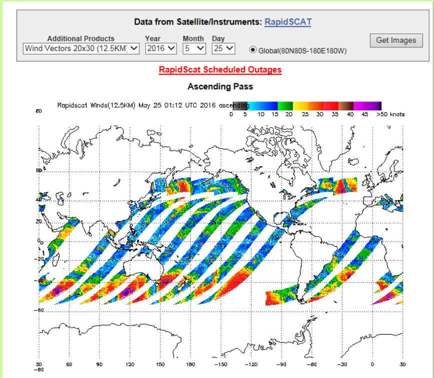
Coriolis satellite

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

Other microwave satellite data occasionally available



SSM/I (DMSP)

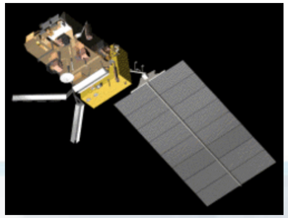


RapidSCAT (ISS)

images from NOAA / STAR

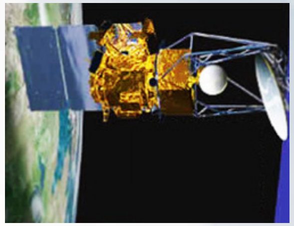
REFERENCE

ASCAT/METOP-A, -B (active) and WindSat/Coriolis (passive) microwave satellites



ASCAT – on the MetOp A and B satellites

- Uses 5.255GHz (C-band) – insensitive to rain.
- Two swath per pass, each 550 km wide
- Has 25 km and 50 km resolution.



WindSat – on the Coriolis satellite

- Uses 10.7, 18.7, 37GHz – more sensitive to rain.
- Swath width is 1025 km
- Has 25 km resolution (frequency dependent).

MetOp satellite image courtesy Wikipedia, Coriolis image courtesy NASA

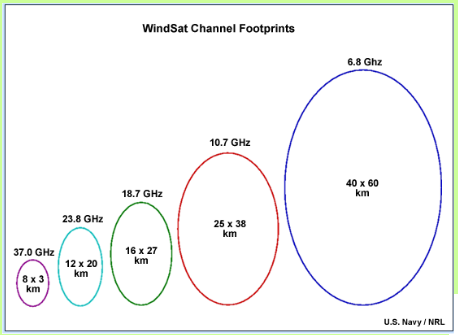
Active scatterometer vs. passive radiometers (1)

- Active microwave radiometers (scatterometers) have an onboard power supply used to send periodic energy pulses towards the earth and measure the return signal
- A passive instrument, by sensing existing microwave radiation, has the advantage of requiring much less power than an active system. The strategy is relatively inexpensive approach to collecting large amounts of information across the globe. (COMET module – Topics in Remote Microwave Sensing)

REFERENCE

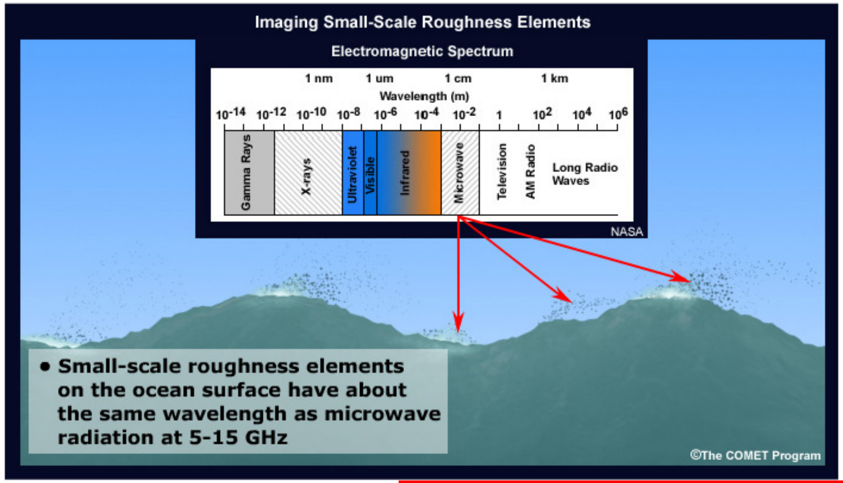
Active scatterometer vs. passive radiometers (2)

The relatively small amount of emitted microwave energy available for passive satellite sensors requires large fields of view to collect sufficient energy for measurement. Passive microwave sensors require larger fields of view on the scale of 10 km or more. (COMET module – Topics in Remote Microwave Sensing)



REFERENCE

Microwave remote sensing of wind speed and direction



• The atmosphere is transparent to microwave radiation in the 2-5 cm wavelength range

Image courtesy COMET

Microwave sensing of sea surface windspeed and direction

Gravity-capillary waves respond to the wind almost instantaneously, align themselves at right angles to the wind.

For an active (scatterometer) such as the ASCAT, the backscatter from the Bragg-resonance of the small capillary waves is measured.

For a passive (radiometer) such as WindSAT the change in emissivity of wind roughened sea surface is measured (as the winds increase, the seas become rougher and the microwave emission increases).

REFERENCE

ASCAT scanning

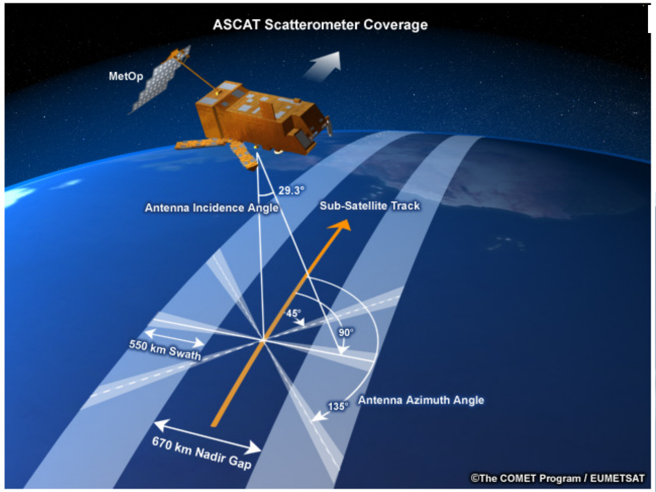


image from COMET

"Push-broom" scanning – active microwave. Incidence angle varies along swath, so wind vector derivation more complicated.

ASCAT scanning

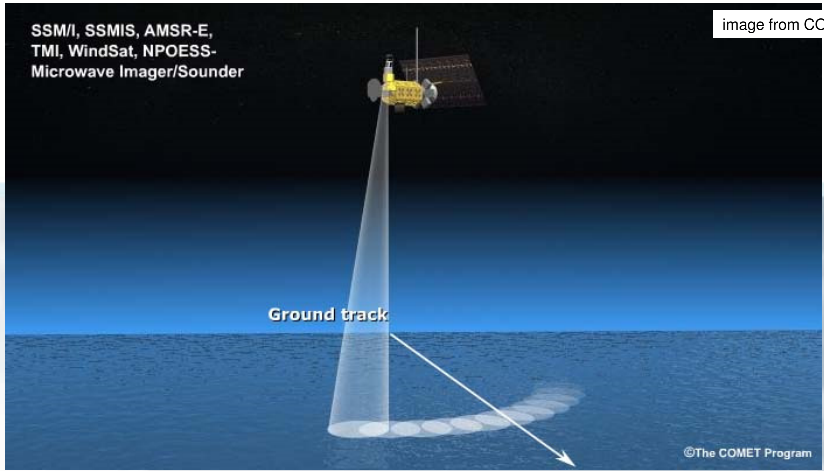
Fan beam scatterometers (ASCAT) use fixed antennas that have the same look angle
The fan beam antenna's send out long narrow radar beams.
A value is calculated for each location on the long axis of the beam.
The same point is then imaged by another antenna on the satellite.

Advantage: Removes variation in look angle from calculations.

Disadvantage: Incident angle is different for each measurement on the sea surface.
Disadvantage: Fan beam scatterometer have a nadir gap because backscatter cross section is relatively insensitive to wind speed at low incidence angles

REFERENCE

WindSAT scanning



Conical scanning – passive microwave.
WindSAT uses both forward and aft view to collect data.

WindSAT scanning

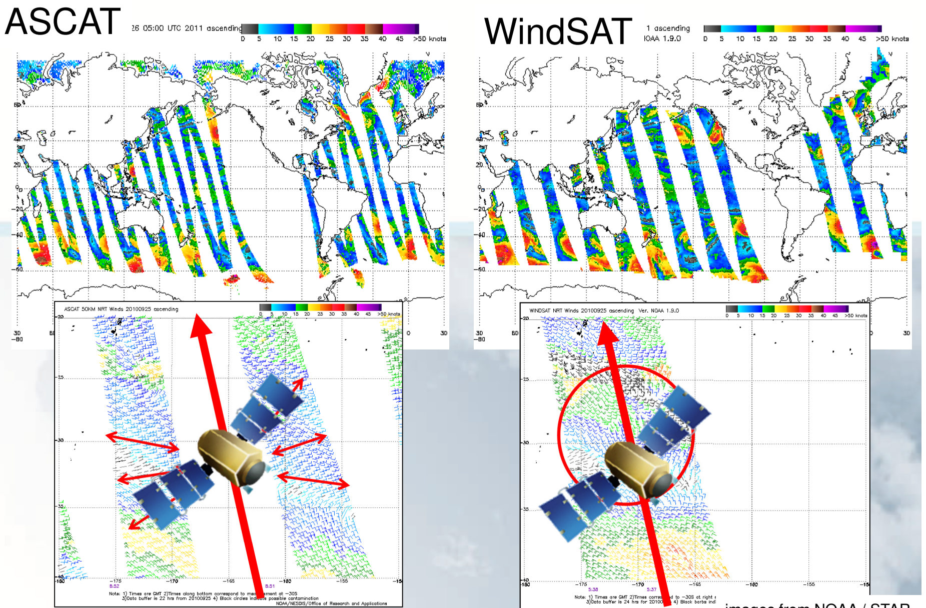
Conical radiometers (WindSAT) use a dual beam conical scanner approach to get multiple looks at the same location on the sea surface.

Advantage: incidence angle is constant across the swath
Advantage: no nadir gap because the antenna is always looking to the side of the satellite

Disadvantage: look angle is different for each measurement
Disadvantage: at the edge of the scan only two or three looks are possible instead of four
Disadvantage: Azimuth angles are not ideal for calculating wind speed and direction near the nadir track and near the edge of the swath.

REFERENCE

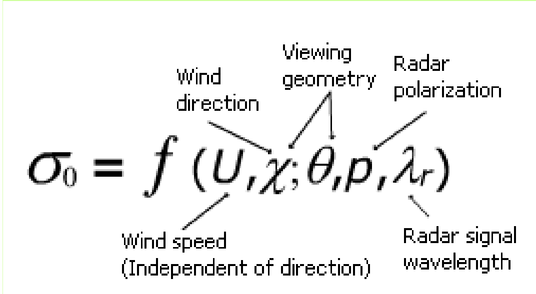
ASCAT vs WINDSAT tracks and scanning



images from NOAA / STAR

ASCAT scatterometer wind retrieval

Normalised backscatter cross section



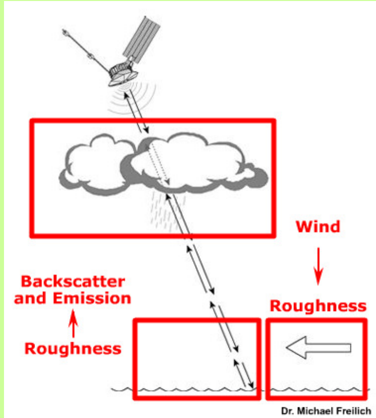
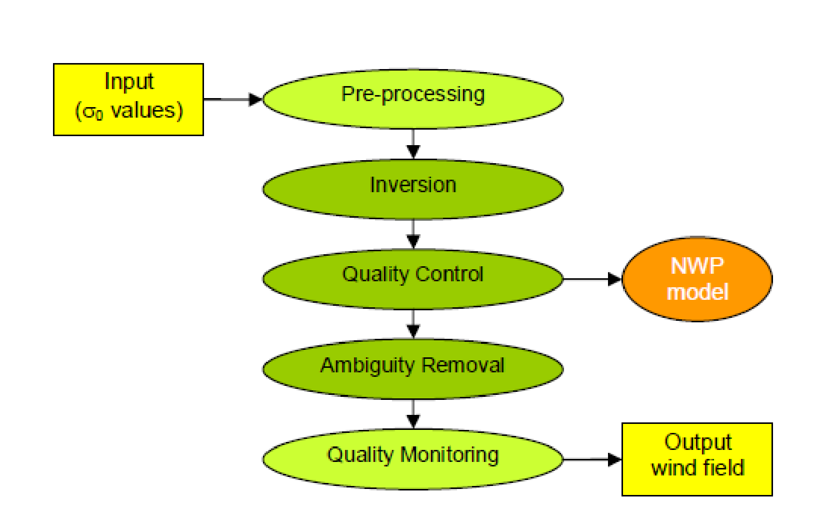


Image from COMET

REFERENCE

General scheme of scatterometer processing

from "The Quality of the ASCAT 12.5km Wind Product" Vogelzang et al. KNMI



REFERENCE

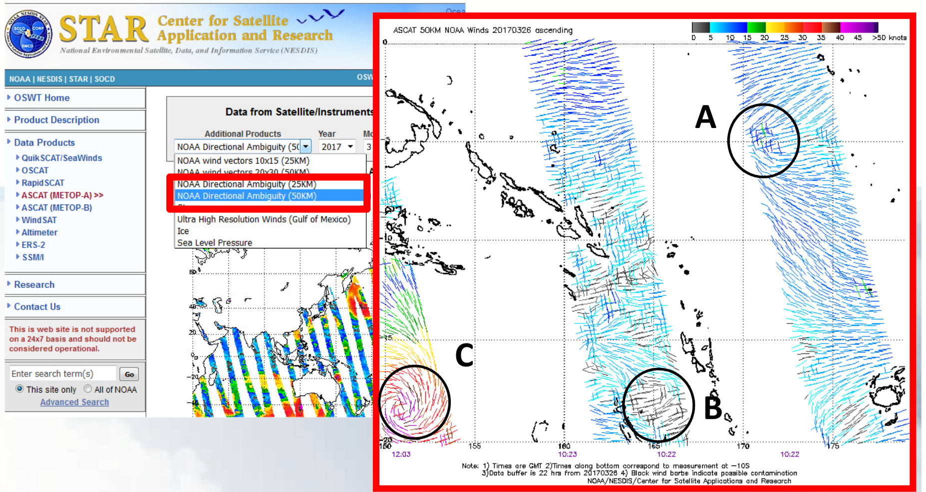
Processing scatterometer data (ASCAT).

1. Measure radar backscatter at different polarizations and 'look-angles'
2. Invert the signal from each 'look' using an empirically derived (statistical) function (Geophysical Model Function) to create a set of possible solutions ('ambiguities'). These solutions are ranked according to skill level = probability of being the correct solution.
3. Flag rain affected areas based on noisiness of the signal
4. Ambiguity removal step (Two Dimensional Variational Ambiguity Removal, 2DVAR). This makes an analysis of the scatterometer observations and a model background wind field (ECMWF). The ambiguity closest to the analysis is selected as solution.
5. Display the resultant wind vectors

REFERENCE

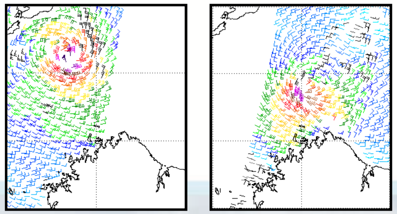
http://www.knmi.nl/scatterometer/publications/pdf/ASCAT_Product_Manual.pdf

ASCAT "Chicken Scratch Diagrams"

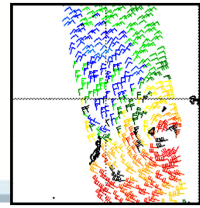


QUIZ - Find areas of great ambiguity, areas of little ambiguity

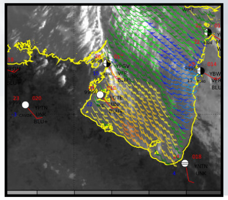
Use of scatterometer / radiometer data for analysis and prognosis



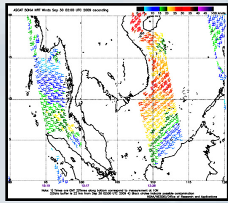
Monitoring Developing Lows / TC's



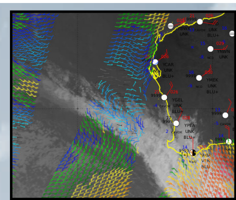
Monitoring / tracking Tropical Cyclones



Monitoring Trade Wind surges



Monitoring winds associated with ex-TC's



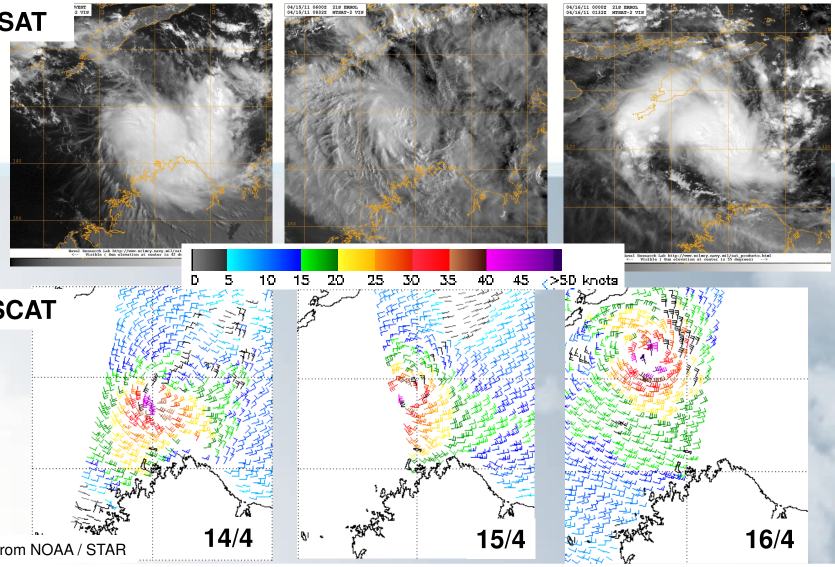
Determining the location of fronts

images from NOAA / STAR

images sourced from NRL Monterey Marine Meteorology Division web site http://www.nrlmry.navy.mil/TC.html

Tracking and analysing Tropical Cyclones – TC Errol

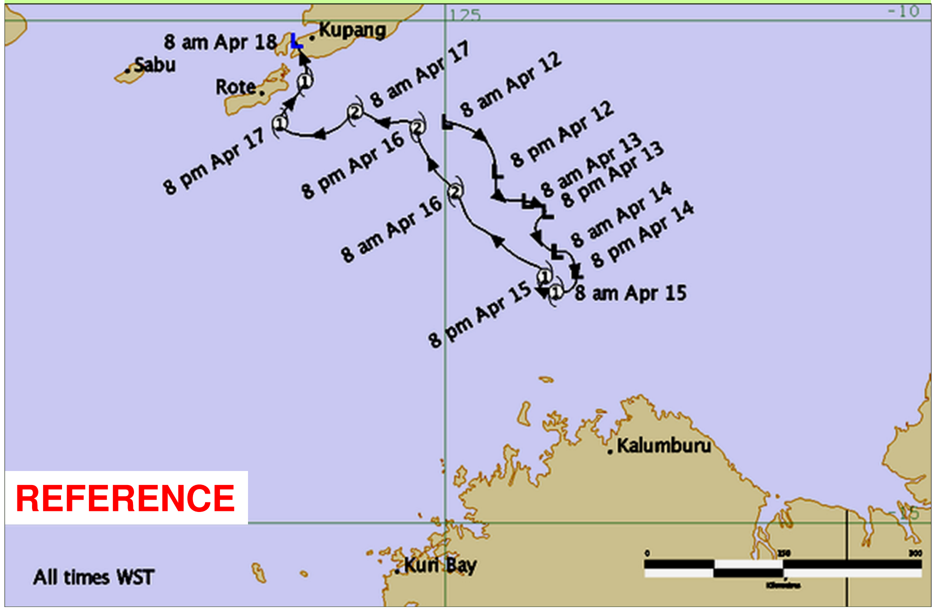
Small system could be followed for 3 days (14-16 April 2011)



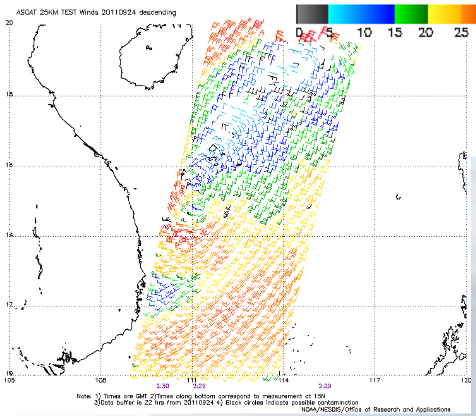
images from NOAA / STAR

image courtesy BOM

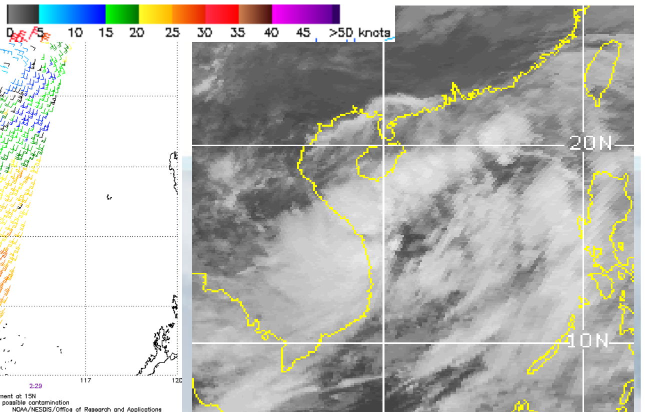
Tropical Cyclone Errol



Detecting strong / gale force winds around developing tropical lows – ASCAT example



ASCAT 24 September 2011 0230UTC

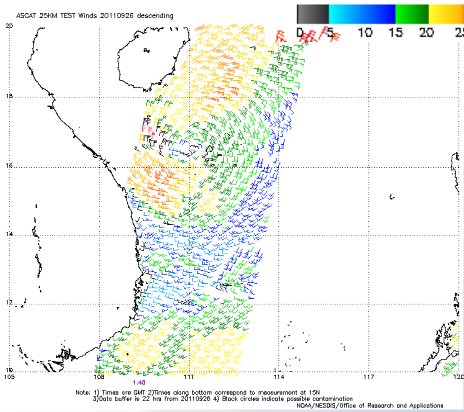


24 September 2011 00UTC

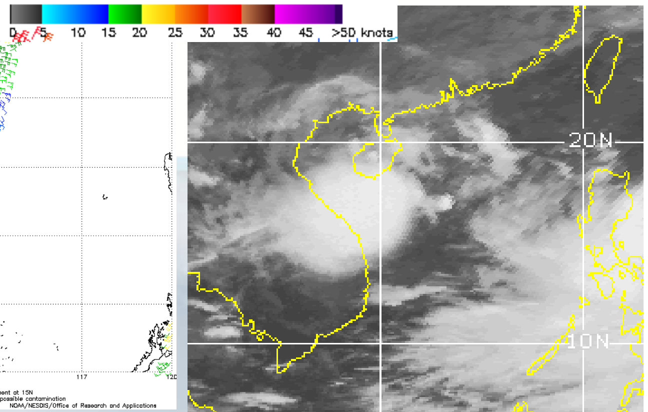
image from NOAA / STAR

image from CIMSS

Detecting strong / gale force winds around developing tropical lows – ASCAT example



ASCAT 26 September 2011 0146UTC



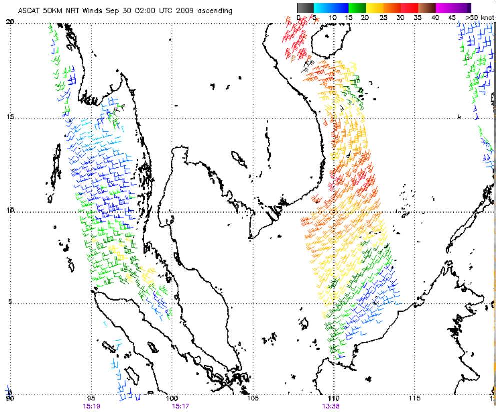
26 September 2011 00UTC

image from NOAA / STAR

image from CIMSS

Detecting gale force winds associated with ex-TC's

image from NOAA / STAR



ASCAT 29th September 2009 1338Z
Ex-TC Ketsana over IndoChina

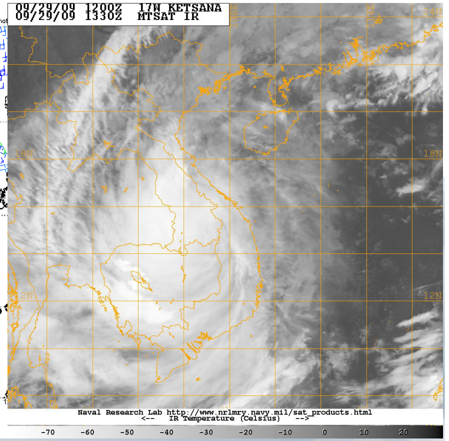
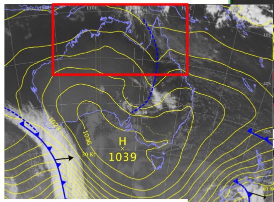


image sourced from NRL Monterey Marine Meteorology Division web site http://www.nrlmry.navy.mil/TC.html

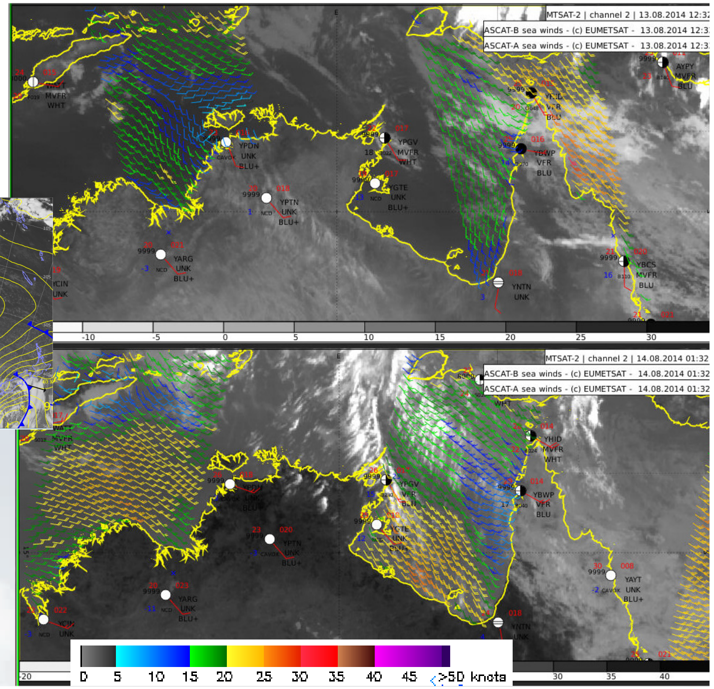
Radius of gale force winds can actually increase in ex-TC's, especially after making landfall.

images courtesy BOM/JMA

Monitoring Trade Wind Surges



14August, 00UTC

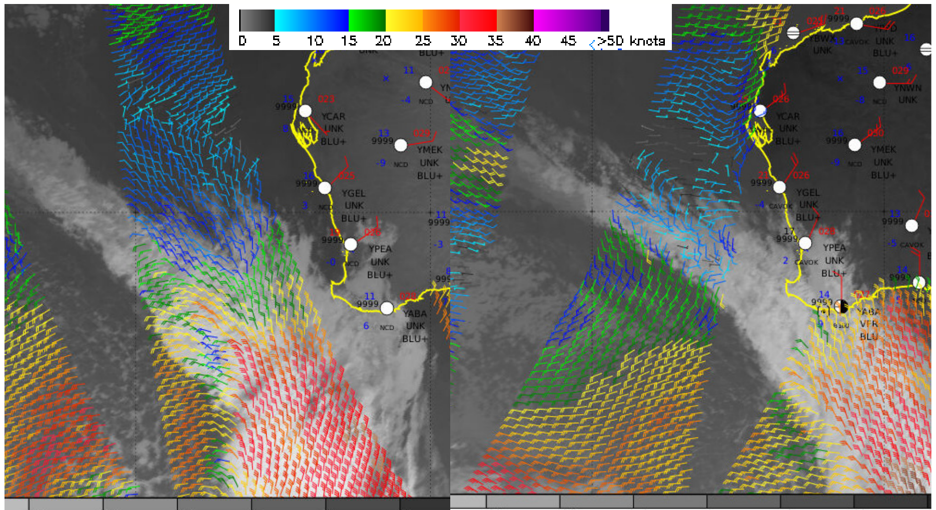


METOP A and B ASCAT data

13 August 12UTC (top) 14 August 01UTC (bottom)

image courtesy BOM/JMA

Location of Fronts

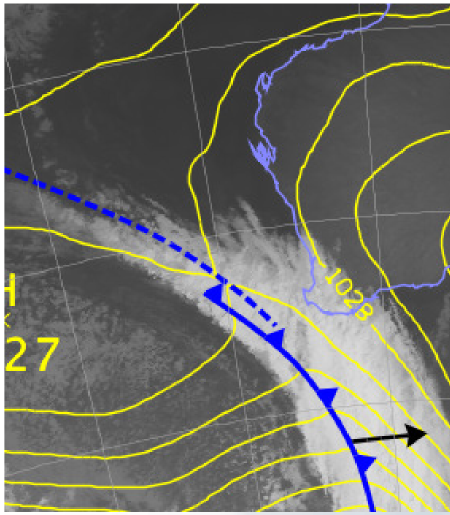


13th August, 15UTC

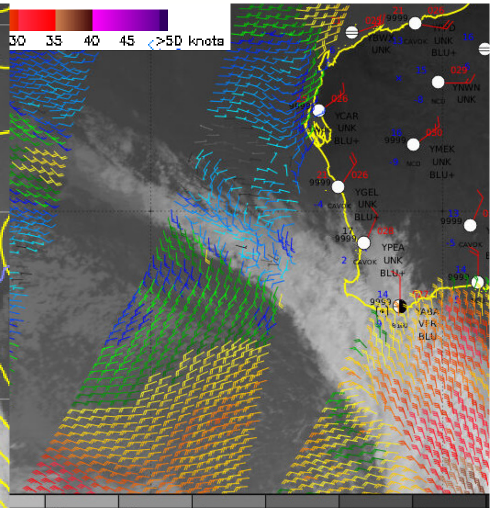
14th August 02UTC

image courtesy BOM/JMA

Location of Fronts



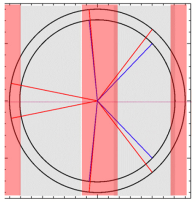
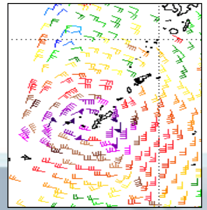
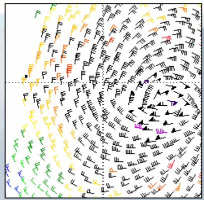
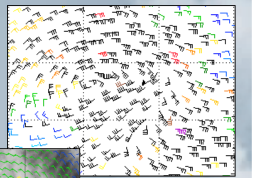
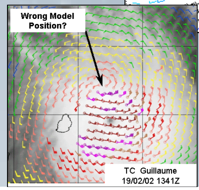
14th August, 00UTC



14th August 02UTC

Sources of error in ASCAT / WindSAT data

- Wind vector uncertainty areas
- High / low wind speed errors
- Rain contamination
- Across track rain contagion effect
- Sensitive to errors in NWP

ASCAT vs WindSAT scanning geometry and errors

ASCAT

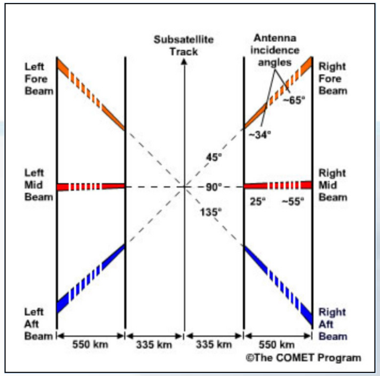


image from COMET

WindSAT

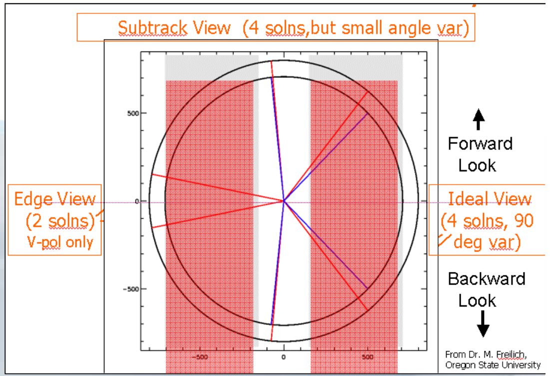
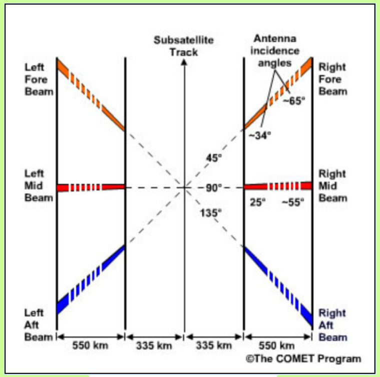


image from "QuikSCAT winds. An Operational Perspective" A. Burton BOM

ASCAT scanning geometry and errors

ASCAT



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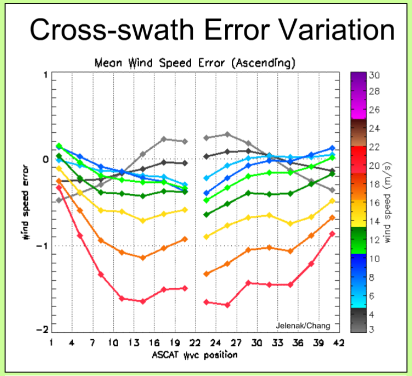


From RAMMB: VISIT Training Sessions – ASCAT Winds Ross Van Til

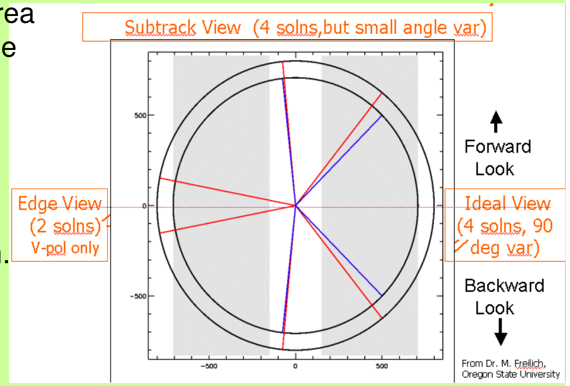
REFERENCE

WindSAT Conical scanning

Grey area:
The best solutions. This area can be caught at 90 degree differences (forward and backward scan).

Edge views:
Only the outer beam (V polarised) sees this region. Lacks data for wind evaluation.

Under the subtrack:
Small difference in spacecraft / surface wave orientation. Not good.

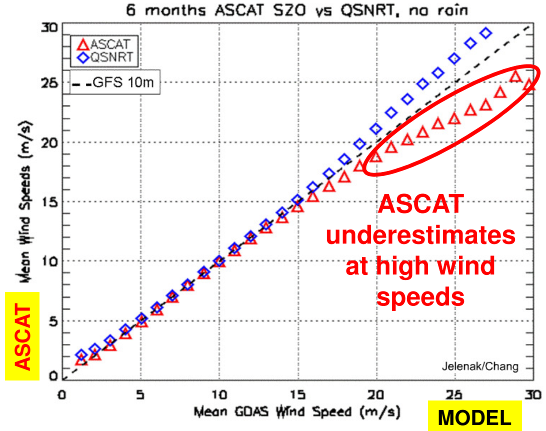


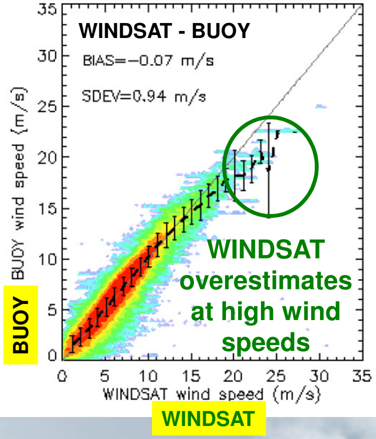
ASCAT overcomes this problem by scanning only in the grey areas

image from "QuikSCAT winds. An Operational Perspective" A. Burton BOM

REFERENCE

ASCAT data comparison to GFS model winds, WINDSAT data compared to buoy measurements





ASCAT, QuikSCAT and GFS global data assimilation system 10 m winds in areas without rain

From RAMMB: VISIT Training Sessions – ASCAT Winds Ross Van Til

WINDSAT – BUOY comparison

Meissner et al. 2010

LIMITATIONS - Too light or too strong winds. Strong gradients in wind speed

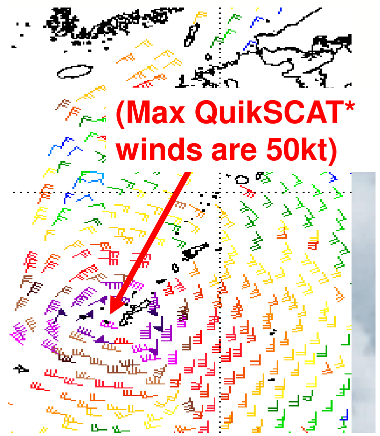
Rain Flag alarms increase with wind speed (esp. if there are tight gradients (TC's) due to the coarse resolution of scatterometers).

Light winds (< 6 knots) – signal to noise problems.

ASCAT exhibits a wind speed low bias for wind speeds above 30 knots.

*note QuikSCAT is similar to WindSAT

Edson lecture, APSATS 2006

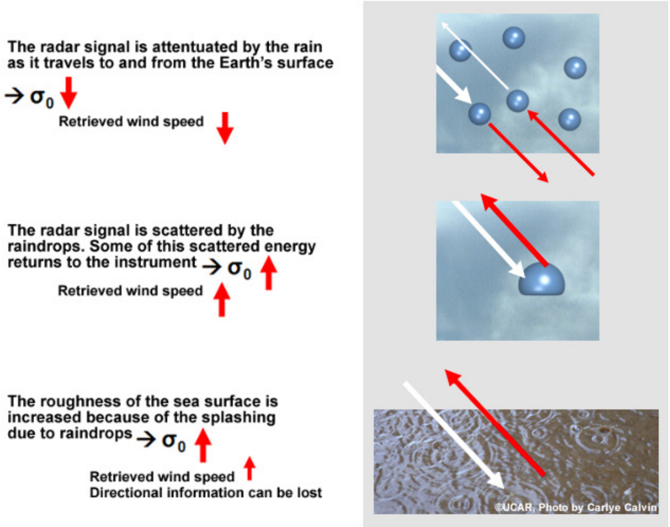


SUPER TYPHOON BART (24W)
Best Track Intensity is 140 kt

image from NOAA / STAR

Limitations – Rain effects

Rain Effects on Wind Speed and Direction



Zorana Jelenak, UCAR, NOAA / The COMET Program

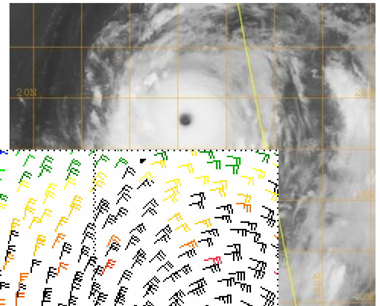
image from COMET

LIMITATIONS - Rain effects

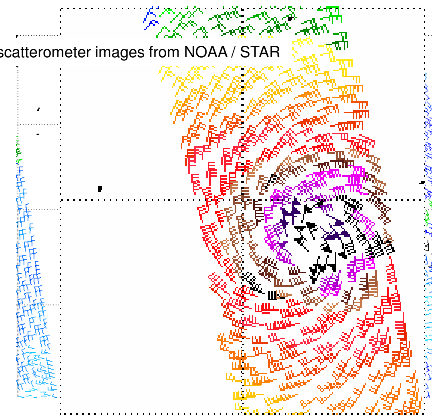
Typhoon Choi-Wan

(13.4GHz more sensitive to rain effects than 5.2 GHz)

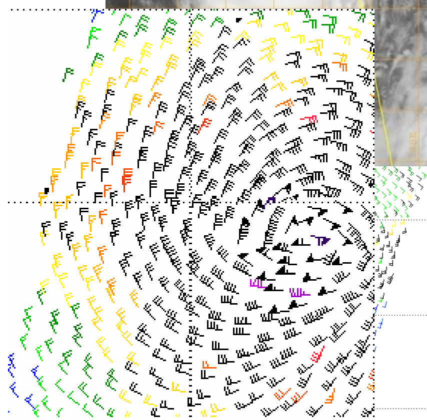
Image sourced from NRL Monterey Marine Meteorology Division web site http://www.nrlmry.navy.mil/TC.html



scatterometer images from NOAA / STAR



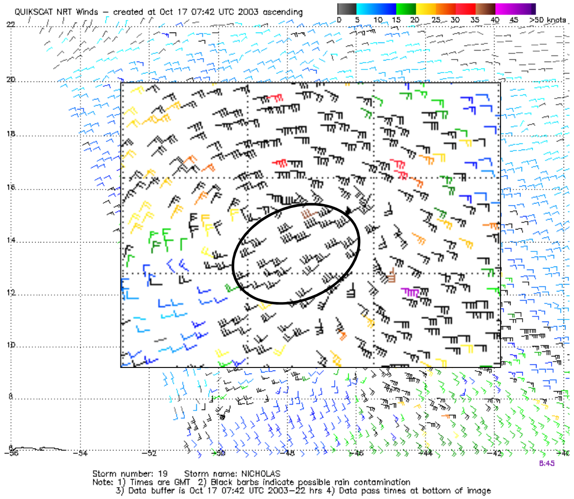
ASCAT 1125Z 16Sep 2009 (5.2GHz)



QuikSCAT 0844Z 16Sep (13.4GHz) WINDSAT is similar

LIMITATIONS - Across-track “Rain Contagion” effect

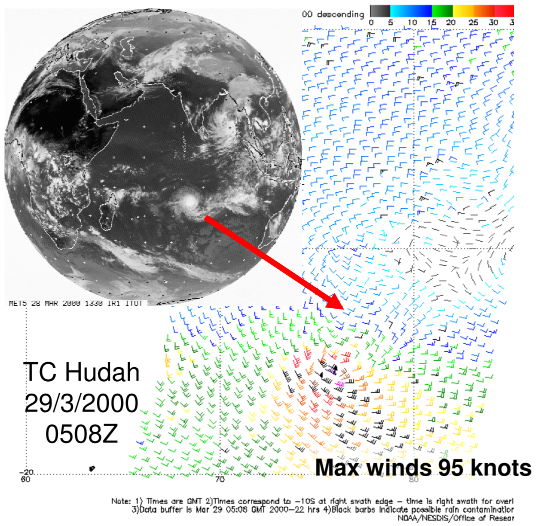
One or two bad wind solutions may affect neighboring wind vector cells through buddy-checking during ambiguity removal causing a ‘rain contagion’ effect.



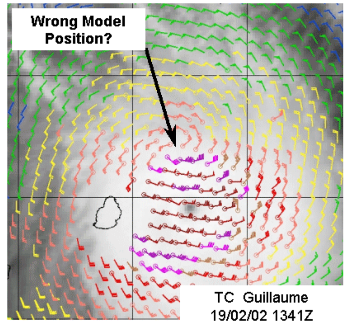
QuikSCAT example
17th October 2003

image from NOAA / STAR

LIMITATIONS - Sensitive to errors in NWP



images from APSATS 2006

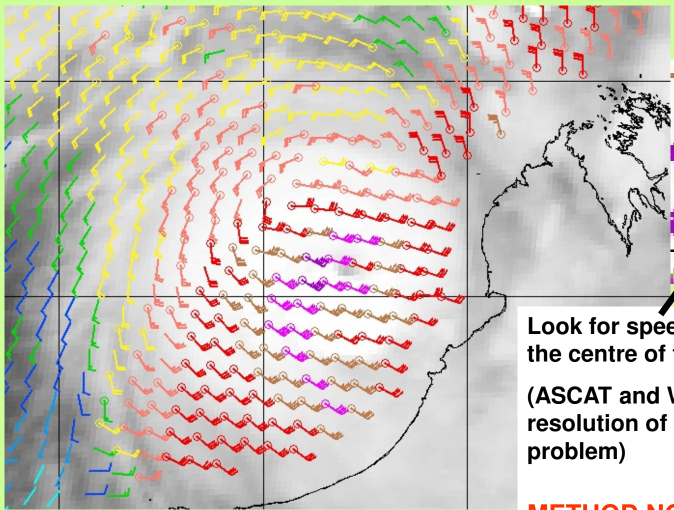


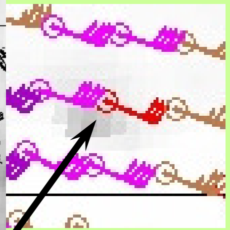
Poor model initialisation results in displaced centres (below), or no centres identified (left).

The example on the left may also have a problem because the TC centre is located right below the satellites pass.

“FIXITS” – The Isotach Method

TC Chris
04/02/02 1002Z





Look for speed minimums near the centre of the system.

(ASCAT and WINDSAT coarse resolution of 25-30 km can be a problem)

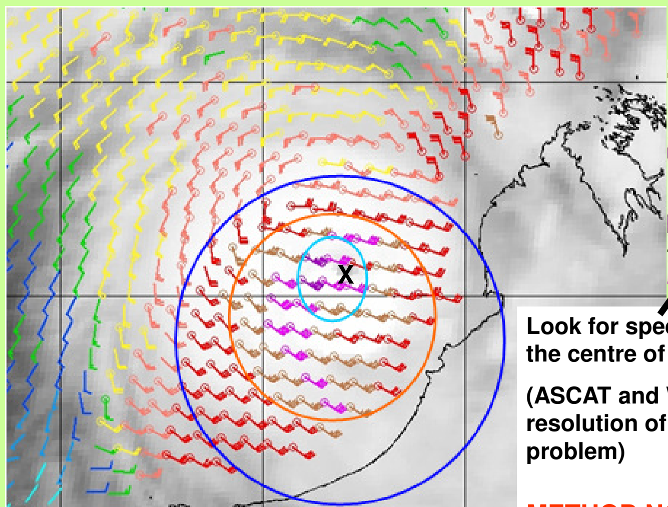
REFERENCE

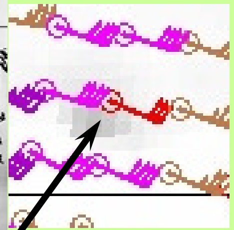
METHOD NOT SUITABLE FOR SHEARED SYSTEMS

image from APSATS 2006

“FIXITS” – The Isotach Method

TC Chris
04/02/02 1002Z





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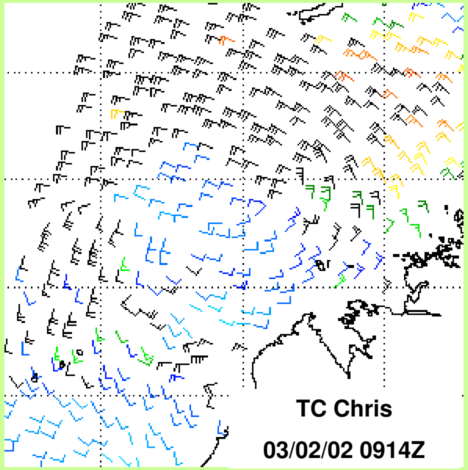
“FIXITS” – The Streamline Method



Look for non-rain flagged winds

Beware of winds perpendicular to the swath (E-W orientation), even when they are not flagged. Can be ambiguous.

High confidence (2-way) solutions primarily away from the center

image from APSATS 2006

REFERENCE

“FIXITS” – The Streamline Method

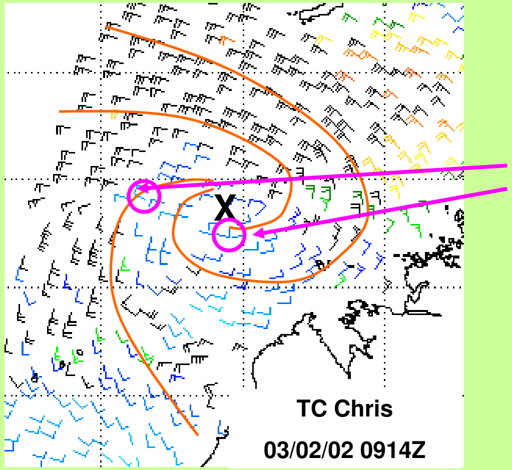


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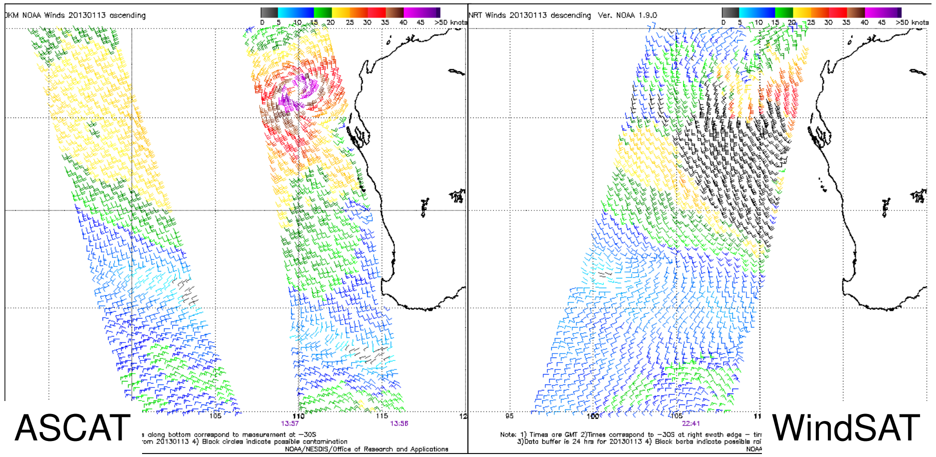
image from APSATS 2006

REFERENCE

Exercise 1 – comparing ASCAT and WindSAT data



ASCAT pass (1358UTC) and WindSAT pass (2241 UTC) of the 13 January 2013, covering the eastern Indian Ocean / Western Australia.
Note that Severe Tropical Cyclone Narelle was moving in a SSW direction.

images from NOAA / STAR

Exercise 1 questions

Inspect the ASCAT pass (1358UTC) and WindSAT pass (2241 UTC) of the 13 January 2013, as shown in the previous slide.

Note that Severe Tropical Cyclone Narelle was moving in a SSW direction during that day

- List or annotate regions of potential error in surface wind determination and explain the cause of these errors.

- What do you think the maximum winds near the centre of the Severe Tropical Cyclone are ?

Summary

Have given an outline of satellites and satellite instruments operating in the microwave region of the spectrum, focussing in particular on the METOP-A and –B (ASCAT) and Coriolis (WindSAT).

Have shown where to find the data on the Internet.

Have discussed the use and limitations of ASCAT scatterometer and WindSAT radiometer products over maritime regions and how to overcome the limitations.

- Developing tropical lows, Tropical Cyclones, ex-Tropical Cyclones
- Trade wind surges, fronts.

Sources of ambiguity and errors in the imagery have been discussed with an exercise to consolidate the learning.