RADARSAT Synthetic Aperture Radar Measurements of some 1998 Hurricanes

Paris W. Vachon
Canada Centre for Remote Sensing
588 Booth Street, Ottawa, ON K1A 0Y7 Canada
Telephone: 613 995-1575 Facsimile: 613 947-1385 E-mail: paris.vachon@ccrs.nrcan.gc.ca

Kristina Katsaros, Peter Black, and Peter Dodge
Atlantic Oceanographic and Meteorological Laboratories, National Oceanic and Atmospheric Administration
4301 Rickenbacker Causeway, Miami, FL 33149 USA
Telephone: 305 361-4300 Facsimile: 305 361-4449 E-mail: katsaros@aoml.noaa.gov

The RADARSAT synthetic aperture radar (SAR) acquired C-band HH polarization images over four 1998 hurricanes: Bonnie, Danielle, Georges, and Mitch. We present the SAR images and discuss their quantitative use in understanding hurricane morphology. The SAR provides a complimentary "view from below" that is most beneficial when considered in the context of more conventional hurricane observations.

INTRODUCTION

Synthetic aperture radar (SAR) images of the ocean surface are a mapping of the surface roughness distribution, which is a function of the surface wind speed. SAR provides the opportunity to measure the surface wind field associated with extreme weather events with high spatial resolution. The C-band HH polarization RADARSAT SAR with its 500km swath ScanSAR Wide (SCW) mode can provide a near synoptic scale overview with a resolution of 100m, while the Wide beam modes (e.g. W1) offer smaller swath coverage, but with higher spatial resolution.

Hurricanes are strong non-frontal synoptic scale low-pressure systems that occur over tropical or sub-tropical waters; they usually contain organized convection and have surface winds with sustained speeds of at least $33 ms^{-1}$ (64knots, 74mph). Hurricanes represent interesting wind retrieval validation opportunities for SAR.

THE 1998 HURRICANES

We obtained RADARSAT SAR images from four 1998 hurricanes (see Table 1 and Fig. 1). The SCW images show Bonnie at landfall and the relatively calm 40km diameter eye of Danielle, both off the East Coast of the USA. Note the wind direction effect as the wind varies from range-ward to cross-range and back around the eye of Danielle. The W1 images show Georges and Mitch to the east of their eyes in the Gulf of Mexico. Note the atmospheric gravity waves of

Table 1: RADARSAT SAR hurricane images.

Hurricane	*Date/Time*	*Mode*	*Scale*
Bonnie	27-08/11:07	SCWB desc	457km X 943km
Danielle	31-08/10:48	SCWB desc	430km X 900km
Georges	26-09/11:35	W1 desc	182km X 330km
Mitch	27-10/11:33	W1 desc	184km X 322km

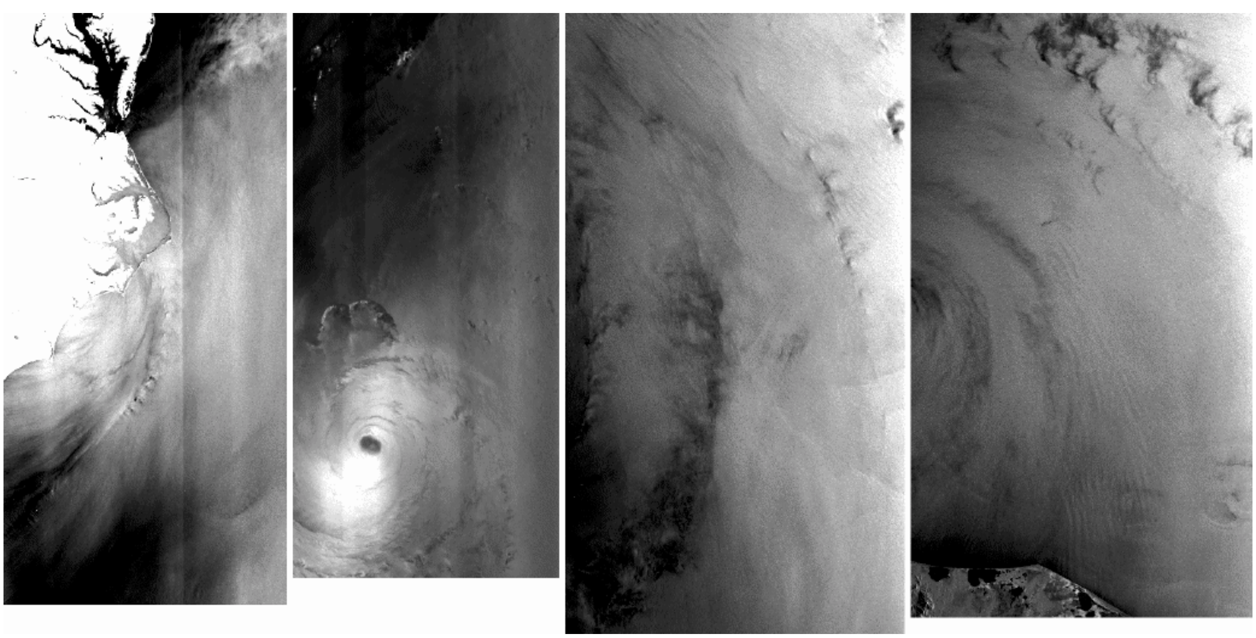


Figure 1: RADARSAT SAR hurricane images (Bonnie, Danielle, Georges, and Mitch) from 1998 (©CSA 1998).

Presented at the IEEE 1999 International Geoscience and Remote Sensing Symposium (IGARSS'99), 28 June to 3 July, Hamburg, Germany

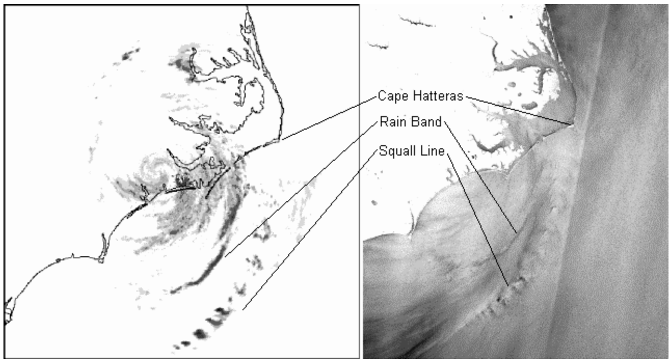


Figure 2: WSR-88D (>34dBZ) and RADARSAT for Bonnie.

10km scale in the Mitch image that appear to be radiating away from the storm disturbance. At this stage, we are primarily interested in radiometric calibration and wind speed retrieval from the radar cross section. However, we have also tied the SAR images to more traditional hurricane measurements.

In Fig. 2, we show the rainfall from a WSR-88D precipitation radar [1] for Bonnie. We see that dark regions in the SAR image, presumably associated with lower wind speed, are associated with the heaviest rainfall including an intense rain band and a squall line. In Fig. 3 we have plotted the relative radar cross section along an azimuth transect through the rain band and one of the cells in the squall line along with model C-band HH cross sections [6], normalized to the observed profile. We see a reduction of 0.5 to 1dB in the rain band and up to 6dB in the cell. If a wind speed effect alone, the latter could represent a reduction in local wind speed by > 5ms^{-1}.

In Fig. 4 we show the surface wind field for Georges that was derived by interpolating between successive wind fields acquired using NOAA P-3 flights into the hurricane [3]. The structure in the SAR image (see Fig. 1) is well correlated with the appearance of the wind field.

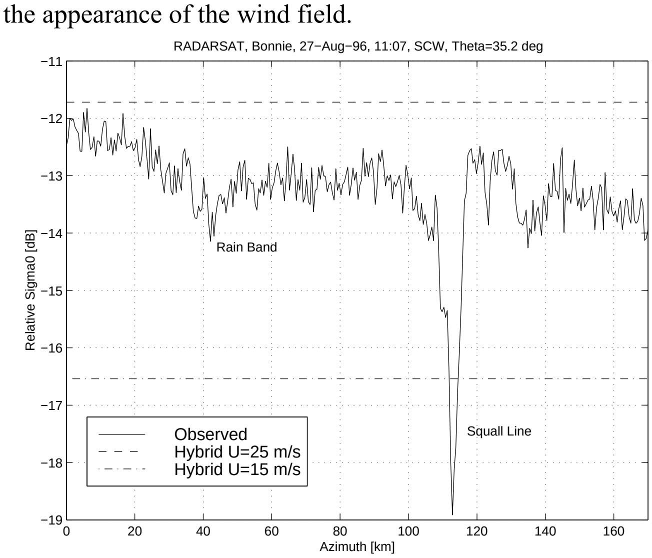


Figure 3: Azimuth radar cross section transect for Bonnie.

RADARSAT CALIBRATION ISSUES

There are still some RADARSAT calibration issues that impact observations of large cross section distributed targets such as hurricanes. The first concerns the implementation of the automatic gain control circuit. Usually it is disabled in favour of a fixed gain acquisition. If the fixed gain is not suitably chosen, the analogue-to-digital converter (ADC) could saturate, one effect of which is a reduction in image power [5]. Each of the hurricane images considered suffers from this effect. We have compensated for this by analyzing the raw SAR signal data and applying a spatially varying scaling factor to recover the lost power. This procedure has been used previously for calibration of ERS SAR data [4].

The second concerns the calibration status of RADARSAT ScanSAR images. For data processed at the Canadian Data Processing Facility (CDPF), there are still image quality issues to be overcome. Scalloping, the rangeward bands that originate from Doppler estimation errors, may be present and ScanSAR data are not properly calibrated since the platform attitude is not well known. So far, we have not treated the ScanSAR cases quantitatively in an absolute sense.

SAR DERIVED WIND SPEEDS

We have calibrated and carried out wind retrieval for the W1 cases. The result for Georges, based on an automated analysis using the Ocean Monitoring Workstation [2], is shown in Fig. 5. The OMW derives the wind direction from the orientation of the low wavenumber image energy and the wind speed from the radar cross section and the geometry. The wind field uses opposing vectors if a good direction is found since there is no *a priori* way to resolve the 180^{o} ambiguity. If a good direction is not found, the wind field includes the lower (range) and upper (azimuth) speeds.

To compare the surface wind field with the SAR observation, in Fig. 6 we show a transect of normalized radar cross section, both with and without the ADC saturation correction (note that the difference is as large as 3dB), for Georges along the transect shown in Fig. 4. We have included profiles from a hybrid C-band HH wind retrieval model [6] run at 15 and 25ms^{-1}, along with a conversion of the surface wind field to radar cross section. Although the hybrid model begins to fail above 25ms^{-1}, evidently, the wind speed has exceeded 30ms^{-1} towards the eye of the storm and the SAR-derived wind speed is always larger than that of the wind field. The rain bands in the Georges image could also contain wind speeds reduced by up to 5ms^{-1}.

CONCLUSIONS

These RADARSAT SAR images provide a unique, high-resolution view from below of hurricane morphology. When used together with cloud images and precipitation information, we can start to develop a 3-D high-resolution perspective of the storm morphology. The dark bands in the RADARSAT images appear to be associated with heavy rainfall and reductions in local wind speed of $5ms^{-1}$ or more. We will attempt to better co-ordinating the P-3 flights with the RADARSAT acquisition opportunities in 1999.

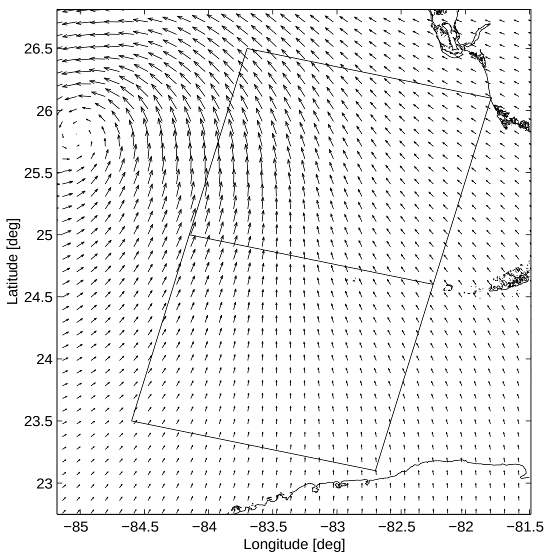
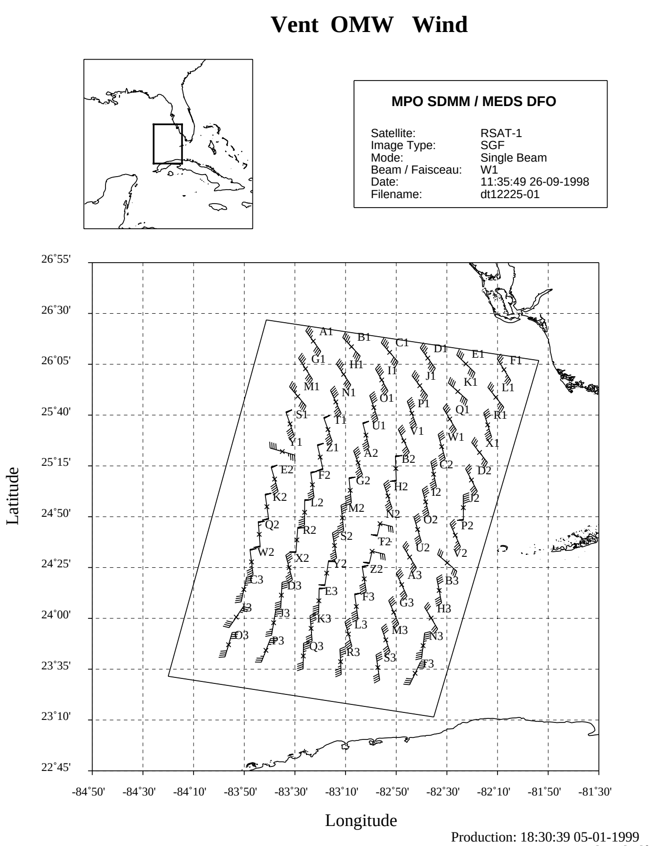


Figure 4: Georges wind field.



Satlantic

Figure 5: OMW product for Georges.

ACKNOWLEDGMENTS

Julie Cranton and John Wolfe (CCRS) contributed to the acquisition and processing of the RADARSAT data; the WSR-88D radar data for Bonnie were collected by the Morehead City, NC Weather Service Forecast Office and were supplied by the National Climatic Data Center in Asheville, NC; George Soukup (AOML) supplied the interpolated wind field for Georges. We thank Mark Powell (AOML) and Bob Beal (APL) for helpful discussion.

REFERENCES

[1] Crum, T.D., and R.L. Alberty, "The WSR-88D and the WSR-88D Operational Support Facility", Bull. Amer. Meteor. Soc., 74, 1669-1687, 1993.

[2] Henschel, M.D., P.A. Hoyt, J.H. Stockhausen, P.W. Vachon, M.T. Rey, J.W.M. Campbell, and H.R. Edel "Vessel Detection with Wide Area Remote Sensing", Sea Technology, 39(9), 63-68, 1998.

[3] Powell, M.D., S.H. Houston, L.R. Amat, N. Morisseau-Leroy, "The HRD real-time hurricane wind analysis system", Journal of Wind Engineering and Industrial Dynamics, 77 & 78, 53-64, 1998.

[4] Vachon, P.W., and F.W. Dobson, "Validation of wind vector retrieval from ERS-1 SAR images over the ocean", The Global Atmosphere and Ocean System, 5, 177-187, 1996.

[5] Vachon, P.W., A.L. Gray, C.E. Livingstone, and A.P. Luscombe, "Adaptive compensation of RADARSAT SAR analogue-to-digital converter saturation power loss", Geomatics in the ERA of RADARSAT (GER'97), CD-ROM Proceedings, 27-30 May 1997, Ottawa, Ont., Canada.

[6] Vachon, P.W. and F.W. Dobson, "Validation of Wind and Wave Retrieval from ERS and RADARSAT SAR Images", to appear, Proc. ADRO Final Symposium, 13-15 October 1998, Montréal, Canada.

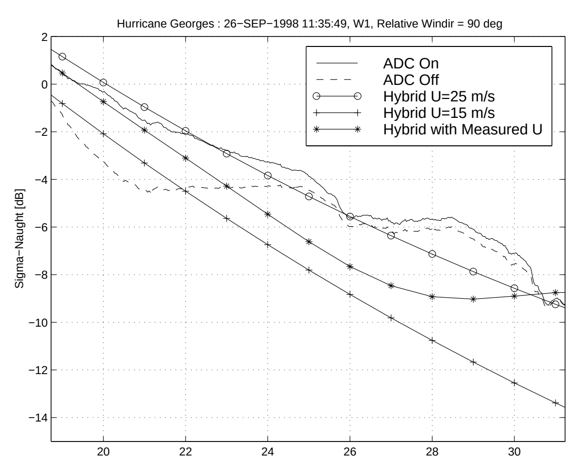


Figure 6: Rangeward radar cross section transect for Georges.