RADARSAT-1 Hurricane Watch

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Abstract – **RADARSAT-1 ScanSAR Wide mode images of Atlantic basin hurricanes have been acquired over the past two hurricane seasons through the Canadian Space Agency's Disaster Watch program. These images provide a high-resolution view of these intense storms and new insights into their morphology. A new result is recognition of the widespread presence of boundary layer rolls in these storms. In 2001, "Hurricane Watch" will focus on obtaining contemporaneous aircraft-based turbulence measurements at RADARSAT-1 pass times.**

I. Introduction

RADARSAT-1's ScanSAR Wide (SCW) modes, with swath widths of 450 or 500 km and a spatial resolution of 100 m, can provide both synoptic scale and small-scale views of the imprint of mesoscale meteorological processes on the ocean surface's roughness. A striking example is the case of hurricanes, for which the images show wind speed and direction effects around the eye, convection, rainfall, boundary layer rolls, and storm-generated waves [1,2,3,4]. In this paper, we present the "Hurricane Watch" project and discuss some implications of these unique observations.

II. Hurricane Watch

Although initial RADARSAT-1 observations were largely serendipitous, "Hurricane Watch", a collaboration between CCRS, CSA, and NOAA, routinely acquired SCW imagery of hurricanes during the 1999 and 2000 Atlantic Basin hurricane seasons (usually August through October). The CSA's Disaster Watch and Background Mission Programs submitted SCW imagery requests in support of this project. Mission planners made manual submissions for Disaster Watch as late as 29 hours in advance of the pass time. These submissions were fewer in number but more accurate than those of the Background Mission.

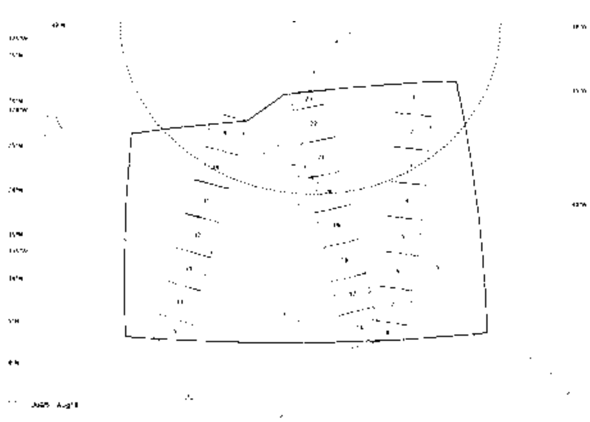

Fig. 1. One day RADARSAT-1 ScanSAR wide mode coverage for the Hurricane Watch area of interest. The semicircular dashed line shows the coverage mask for the Gatineau Satellite Station near Ottawa.

We focussed on use of the SCW mode since it provides the most complete coverage over the area of interest. However, that coverage is still rather sparse (Fig. 1) and so SAR images of hurricane eyes over the ocean are still rather rare (Table I). The acquisition planning is based upon hurricane track forecasts that are routinely available from the web (*e.g.* http://www.nhc.noaa.gov/).

III. Implications

A. *Boundary Layer Rolls*

The presence of boundary layer rolls in hurricanes is known from coastal weather radar observation [5]. However, their large spatial extent in hurricanes was first revealed by RADARSAT-1 images (*e.g.* Fig. 2). Boundary layer rolls may modulate the air-sea fluxes. Hence, a better understanding of these rolls as hurricanes develop could result in more precise predictions of intensity change.

B. *Precipitation*

Coastal Doppler radar has permitted the correlation of dark bands in SAR ocean images of hurricanes with heavy rainfall [1,2,3,4]. Although the imaging mechanism is not well understood, other SAR studies suggest that turbulence generated in the upper few centimetres of water by the droplet impacts tends to damp the small scale roughness [6]. The droplet impacts can also produce roughness, depending on the duration of the rainfall. Also, under high rain rate conditions, rain volume attenuation can be a factor in

TABLE I
Hurricane Watch Results

Year	Hurricane Watch Submissions	Eye Hits Over Ocean
1998	0	1
1999	33	4
2000	19	2

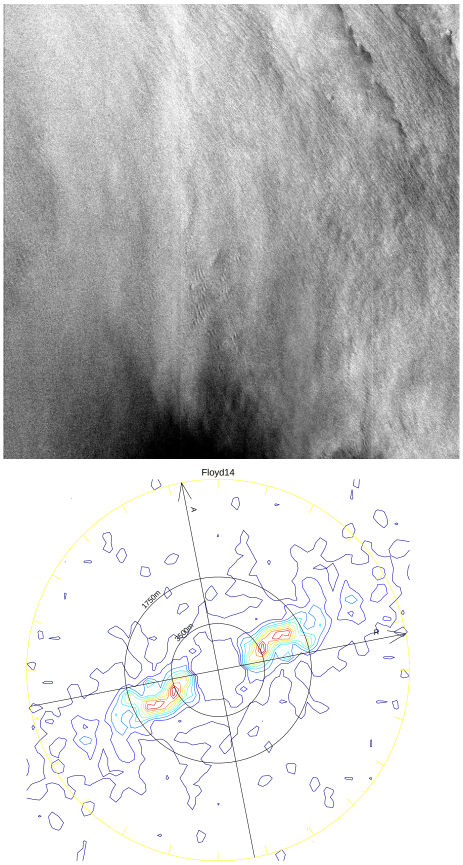

Fig. 2. RADARSAT-1 SCW image of Hurricane *Floyd* on 14 Sept. 1999 covering 500 km from left-to-right (top). (© CSA 1999). Note the striations across the image corresponding to boundary layer rolls. The corresponding image spectrum (bottom) indicates that the striations have a scale of 3.5 km.

lowering the observed radar backscatter. SAR images provide the potential for offshore precipitation observation (*e.g.* when hurricanes are beyond the range of coastal Doppler radar).

C. *Eyewall Features*

SAR images of hurricane eyes show interesting eyewall mesovortex features (see Fig. 3). For example, the image of Hurricane *Dennis* on 27 August 1999 (Fig. 3, row 1, column 2) shows a protrusion of higher backscatter curling into the eye from the north-east. This feature corresponds to a “super cell” that developed within the eyewall, which was also observed by a NOAA P3 research aircraft that circled upwind along the eyewall for about 1 hour shortly after the SAR pass. Analysis of the P3 Doppler radar and stepped-frequency microwave radiometer data [7] will help to define the wind field associated with this feature and will help to describe the processes causing the enhanced SAR return from well within the radius of maximum winds. Similar features were observed in Hurricane *Dennis* on other days and in other hurricanes; they may signal changes in storm structure and perhaps provide clues to intensity change, which is still one of the most difficult things to forecast for a tropical cyclone.

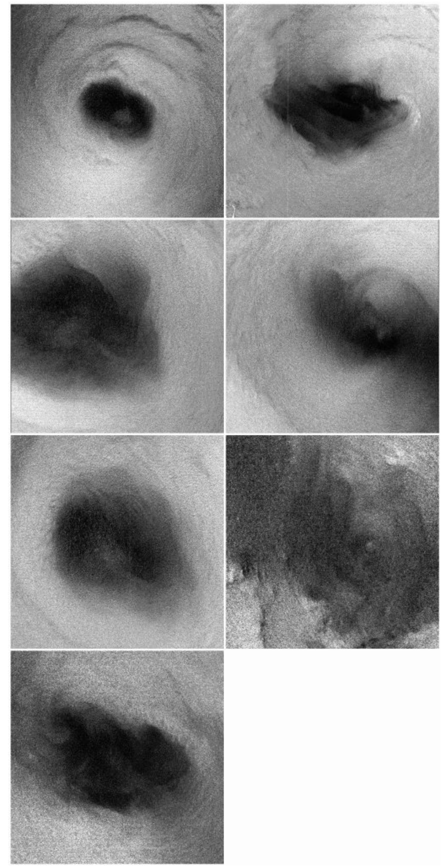

Fig. 3. RADARSAT-1 ScanSAR Wide mode images of hurricane eyes: *Danielle* (upper-left, 31 Aug. 98); *Dennis* (upper-right, 27 Aug. 99); *Dennis* (29 Aug. 99); *Dennis* (31 Aug. 99); *Floyd* (15 Sept. 99); TS *Alberto* (17 Aug. 00); *Florence* (lower-left, 13 Sept. 00). Each subscene spans 100 km from left-to-right. (© CSA 1998, 1999, 2000)

D. *Hurricane Wind Fields*

In principle, it is possible to estimate the surface wind field from the radar brightness distribution in SAR images of the ocean surface. This usually proceeds by estimating the wind direction (with a 180° direction ambiguity) from the orientation of the boundary layer rolls, and the wind speed from a scatterometry wind retrieval model. However, most models have problems with the high wind speeds associated with hurricanes. We have used a model with a modified high wind speed behaviour [8] that tends to saturate for higher wind speeds. An example wind field for Hurricane *Danielle* is shown in Fig. 4. Validation of this type of wind field is the subject of ongoing research.

E. *Ocean Waves*

The ability of SAR to image surface wave fields is dependent on the spatial resolution of the SAR, the height and length of the surface waves, and the platform range-to-velocity ratio, which is large for RADARSAT-1 and not particularly favourable for ocean wave observation. Nevertheless, long waves generated by hurricane winds are

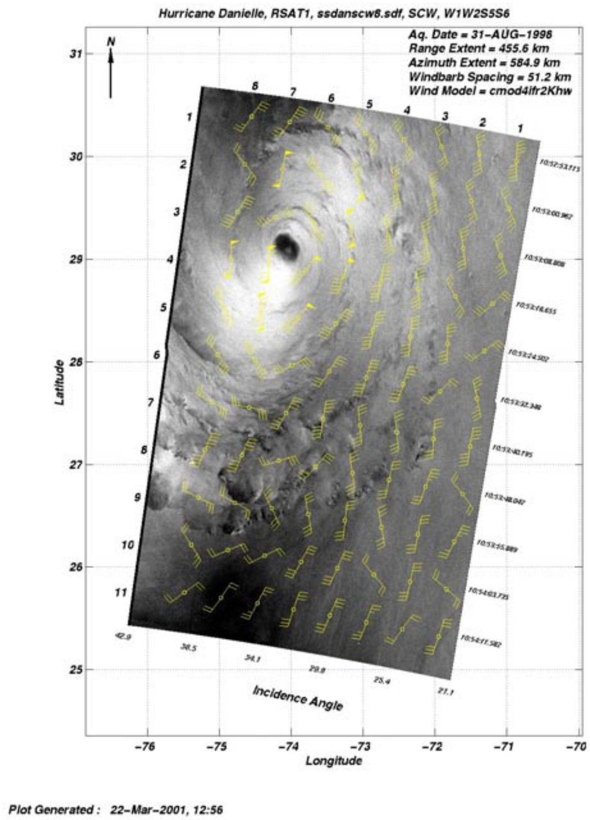

Fig. 4. RADARSAT-1 ScanSAR Wide mode image of Hurricane *Danielle* overlain with a SAR-derived wind field with ambiguous wind direction solutions retained. (the image is © CSA 1998)

often observed in the available RADARSAT-1 imagery. Although they are not imaged with high fidelity, they do provide evidence of wave field in-homogeneity within these storms.

IV. PLANS

RADARSAT-1 ScanSAR wide mode images of hurricanes are providing new insights into storm morphology. Although repeat coverage is a problem, their "high" resolution provides kilometre scale observations of winds and wind shear, while their 500-km swath is nearly synoptic in scale. These images provide a sea surface view that is complementary to conventional cloud top observations. They provide the locations of the storm centre, the state of boundary layer evolution, zones of precipitation, the surface wind field, regions of precipitation and strong convection, and information on storm-generated waves.

Our research efforts in 2001 will focus on acquiring more supporting observations to further study the boundary layer rolls noted in the RADARSAT-1 data. We will attempt to acquire NOAA P3 aircraft measurements, including, GPS dropsondes, stepped frequency microwave radiometer, scanning radar altimeter, and gust probe data to measure surface fluxes near the times of RADARSAT-1 hurricane acquisitions.

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