Ocean Remote Sensing Data Predicts Trajectory of Oil Spill
An Analytical Model for SAR Polarimetric Scattering Matrix

Bo Wang[1], Bertrand Chapron[2] and René Garello[3]
[1]*Department of Computing and Communication, China University of Petroleum (Huadong), Qingdao, China*
[2]*LOS, IFREMER, Plouzané, France*
[3]*Department ITI, Telecom Bretagne, Brest, France*

Keywords: Ocean Remote Sensing, Polarimetric SAR, Oil Trajectory.

Abstract: The ocean surface is part of the upper ocean which directly interacts with the overlying atmosphere and sea ice. Once oil spill happened due to an accident such as the oil rig pipe leaking and exploring, it would be unimaginable disaster to the oceanic environment, especially in the coastal area. If we can predict the direction along which the oil films floats over the marginal sea surface, the damage would be controlled within a pre-knowledge level. Under these knowledge, we analysed the polarimetric SAR (Synthetic Aperture Radar) data with an analytical model to separate backscattered contributions by different sea surface scatterers. Furthermore, it provides a possible prediction of the local wind direction by using the separated backscattered signal. With this direction, it is ready to predict the direction of oil film's floating.

1 INTRODUCTION

The ocean environment plays an important role in the global climate change. Ocean remote sensing offers satellite observations as a data collection which could be assimilated into ocean models. Such assimilations as SAR acquisition used in a flood model (García-Pintado et al., 2013), the ozone analyses based on Envisat data (Geer et al., 2006; Lahoz et al., 2007), the cloud and precipitation observations effort in a numerical weather prediction model (Ohring et al., 2005), have all achived benefits from the satellite data. The ocean surface is part of the upper ocean which directly interacts with the overlying atmosphere and sea ice. Surface films isolate the air from the ocean surface, they also damp the surface wave vibration (Gade et al., 2006), leaving a dark area or dark textures in the SAR imagery. Based on the above understandings, we analysed multi-polarization data by SAR onboard of the Radarsat-2 satellite, with the first result of wind wave direction estimated by a Bragg wave component. This estimation of local wind direction can help to predict the trajectory of the surrounding oil films, by applying this parameter into an ocean wave prediction model, such as the numerical model Wavewatch III (Feng et al., 2006).

2 SAR POLARIMETRY

SAR measurements or derivatives have recently been assimilated into models, including hydraulic (Giustarini et al., 2011), snowpack (Phan et al., 2013). The efforts to ocean wave modelling trace back to the 1990s when a large number of researches focused on the wave retrieval from the SAR imagery (De las Heras et al., 1995; Olsen et al., 1995; Hasselmann et al., 1997; Breivik et al., 1998), which have seldom updates recently. Polarimetric SAR refocused the researches on ocean wave retrieval, however, it had rarely been considered that the sea surface is composed by different scattering mechanisms. A theoretical model concern different polarization properties in the radar backscattering coefficient expressed the NRCS (Normalized Radar Cross-Section) as the sum of polarization dependent Bragg and polarization independent Scalar contributions (Quilfen et al., 1999). Following this theoretical model, we proposed an analytical model for polarimetric SAR scattering matrix. In our model, the Bragg contribution was expressed in scattering matrix by the tilt Bragg model, while the Scalar contribution concerned the Rayleigh scattering from foams introduced by sea surface wave breaking, the specular reflection by the steep wave, and double-bounced metallic sea surface

wang B., Chapron B. and Garello R..
Ocean Remote Sensing Data Predicts Trajectory of Oil Spill - An Analytical Model for SAR Polarimetric Scattering Matrix.
DOI: 10.5220/0005125308220827
In *Proceedings of the 4th International Conference on Simulation and Modeling Methodologies, Technologies and Applications* (MSCCEC-2014), pages 822-827
ISBN: 978-989-758-038-3

target. The interaction between i.i.d. (independent and identically distributed) scatterers has been considered within each pixel area using the random walk model, with the assumption that the Bragg contribution is the vector sum of the random walk by all the Bragg scatterings. This analytical model was iteratively resolved by a former estimate (WANG et al., 2011). In this iteration algorithm, a Bragg related polarization ratio, β, was determined iteratively to separate the Bragg contribution from the non-Bragg contribution. This model is indeed the theoretical model of Quilfen et al. when the cross product of Bragg and Scalar contributions is zero. But in real case, the latter could not be ignored. Thus the sea surface depolarization and polarization can be separated better by complex scattering matrix than by NRCS. Wind seas were also retained from separated scattering contributions, indicating a finer resolution than traditional retrieval method.

3 WIND DIRECTION

3.1 Polarization Wind Wave Parameters

Since 1990s, global measurements of the two-dimensional wave spectrum by space-borne SAR sensors on-board of satellites such as ERS-1/2, Radarsat-1/2 has been investigated. Missions of ocean wave investigated mapping of ocean wave spectrum from the SAR image spectrum (Hasselmann and Hasselmann, 1991), the unification of the directional spectrum (Elfouhaily et al., 1997), and the effect of the longer wave and swell (Chen et al., 2000; Plant, 2003; Ardhuin et al., 2007). Furthermore, the bound wave / free wave model (Plant et al., 2010) consists with sea surface slope spectrum measured in 1950s (Cox, 1958). However, all the algorithms were limited within the range of wavelength longer than a cut-off wavelength, till the full polarization radar imagery being available. At a specially selected orientation angle, the modulation of the wave slope on radar measured intensity could be enhanced, better than any of that from the standard linear polarization HH, VV, HV or VH (Boerner et al., 1992; Schuler et al., 1995). It is possible to find this special orientation angle to solve optimal polarization problems. This principle is called polarization modulation transfer function (MTF) (Schuler et al., 1995). A combined polarization MTF with an eigenvector α angle modulation (Cloude and Pottier, 1996) could also enhance the wave slope in the azimuth direction (Schuler et al., 2004). However, Schuler's method was questioned for applying to the sea surface by not considering the non-linear velocity bunching effect (Alpers, 1983).

The α parameter of the entropy-anisotropy-α decomposition theorem (Cloude and Pottier, 1996) is roll-invariant in the azimuth direction. It has high sensitivity to wave-induced change of local incidence angle. Decomposition theorems consider polarimetric radar backscattered signal matrices as the summation of different scattering mechanisms coherently or incoherently. According to Cloude-Pottier's theorem, the mean scattering matrix has an eigenvector

$$\mathrm{k} = \sqrt{\lambda}\mathrm{e}^{j\varphi}\begin{bmatrix} cos\alpha \\ sin\alpha cos\beta \mathrm{e}^{j\delta} \\ sin\alpha sin\beta \mathrm{e}^{j\gamma} \end{bmatrix} \tag{1}$$

in which λ, α is the mean target power (span) and roll-invariant mean scattering respectively, the rest three parameters β, δ, γ are orientation angle related, and rotation variant, could be used to define the target polarization orientation angle. The five parameters are connected with the radar measurements by

$$T_3 = k_p \cdot {k_p}^{*T} = k \cdot k^{*T} \tag{2}$$

in which T_3 is the covariance matrix, and

$$k_p = \begin{bmatrix} S_{VV} + S_{HH} \\ S_{VV} - S_{HH} \\ S_{HV} + S_{VH} \end{bmatrix} \tag{3}$$

is the '3-D Pauli feature vector' (Lee and Pottier, 2009), where $\mathrm{S}_{PQ}, \mathrm{P}, \mathrm{Q} \in \{\mathrm{H}, \mathrm{V}\}$ is the components of Sinclair scattering matrix.

From Eq. (1) and Eq. (3), the approximation of the α parameter from polarimetric SAR measurements should be as

$$\tan\alpha \approx \frac{S_{VV} - S_{HH}}{S_{VV} + S_{HH}} \tag{4}$$

On the other hand, the relationship between α angle and incidence angle θ_i could be find as Eq. (5),

$$\tan\alpha = sin^2\theta_i \tag{5}$$

using the SMP model and considering only incidence angle, for the water dielectric constant $\epsilon \to \infty$.

So far, the range slope can be derived from the local incidence angle corresponding to α angle subtracted by the incidence angle according to the radar geometry as

$$\gamma = \theta_i - \theta \tag{6}$$

3.2 Wind Wave Direction Retrieval

Based on the above analysis, the local incidence angle is reasonable to be iteratively estimated by the polarimetric SAR measurements, hence possible to assign each scattering contribution due to different polarization characteristics (Wang, 2013). The Bragg scattering of wind seas is considered to be sensitive to the radar polarization, and the other scattering mechanisms introduced by steep waves or breakers are insensitive to the polarization, being scalar contributions. Separated scattering contributions correspond to different range of the ocean wave spectra. As the primary results, we showed the capability of wind wave direction retrieval from the Bragg scattering component.

3.3 First Results

In-situ platforms collocated with Radarsat-2 satellite data set are offered by the Observing System Monitoring Center (OSMC) programme funded by NOAA/OCO, providing both the near real and historical status of meteorological and oceanographic data collection systems. These platforms include both buoys and voluntary ships, returning one record per hour, generally. Records in the nearest distance were interpolated in time for satellite acquisitions in August and September. Other records following up are supplied by meteorological moored buoys located exactly inside of the satellite image scene. The result does not always support our assumption that a special part of the wave spectra could be assigned for the Bragg scattering and scalar contribution separately. To the contrary, scalar contribution retains a wind wave direction much more consist with the in-situ data than the Bragg contribution. We are not ready to give an explanation in this paper, however, the reginal currents should be considered more carefully since all the contradiction data located in the Mediterranean Sea, where the swell is not so significant to domain in the scalar component as the polarization insensitive contribution, both in summer and in winter. Nevertheless, the results from the data located in the North Sea and North West Atlantic Ocean indicates consisted wind derived short wave direction on the Bragg scattering contributions.

3.3.1 Case Study

We showed in Fig. 1 the location of the SAR imagery acquired on 2011 December 5th, to the south west of Scotland and northwest of Bretagne, with the satellite LOS of 45.11 deg. in the center of image. The local wind speed is 10.29m/s, blowing to the direction of 290 deg. departing from the North, as shown in Table 1.

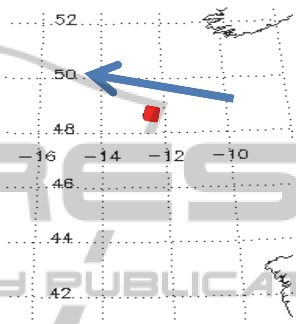

Figure 1: The location of the SAR imagery 20111205 (red square) and the local wind direction (blue arrow).

Table 1: The in-situ measurements to be counterpart with the SAR imagery of 20111205.

Wind speed (m/s)	Wind direction (degree)	Wave height (m)
10.29	290	4.5

3.3.2 The Direction

The cross spectrum of Bragg component in VV polarization indicated a peak direction consist with the in-situ 290 deg. from the North, shown in Fig. 2.

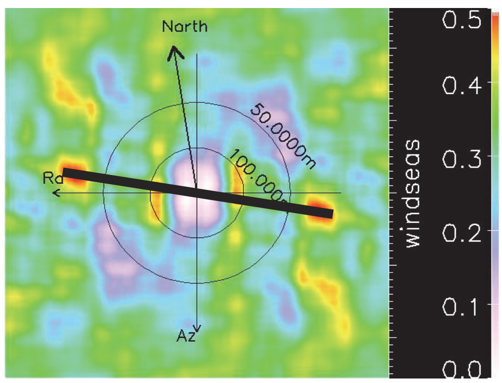

Figure 2: Cross spectrum of Bragg component in VV polarization. The peak direction (thick line in black) retains the local wind direction of 290 deg. from the North.

It is clear from the comparison of Figure 2 to 3 that the separation of scattering mechanisms such as Bragg contribution helped to tell the local wind direction, which was impossible by using the single polarization data. The direct SAR measurement is definitely a combination of different scattering contributions. This study supported the theoretical model of NRCS concerning the polarization (Quilfen et al., 1999).

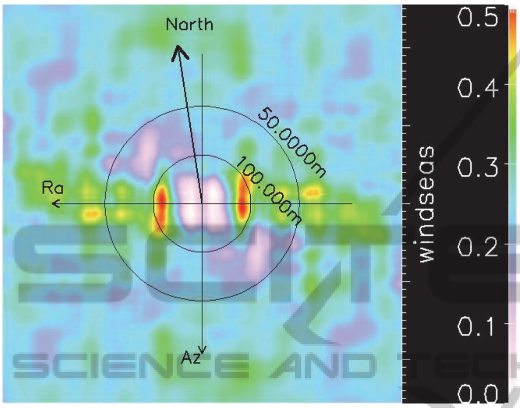

Figure 3: Cross spectrum of SAR imagery in VV polarization. There is hard to find the local wind direction.

4 OIL FILMS

Surface films could not only be a natural sea slick generated by plankton, but also the floating oil introduced by an oil spill. Oil spill is easily to accompany with an accident such as the oil rig pipe leaking and exploring. Oil spill ruins the local sea, depresses the air/sea interaction, and is even worse to the environment than the natural plankton films.

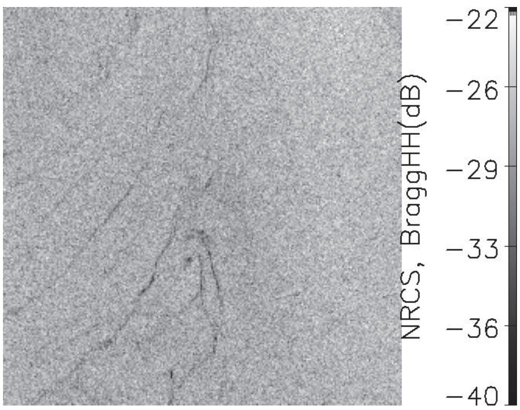

Figure 4: Bragg scattering component in HH polarization.

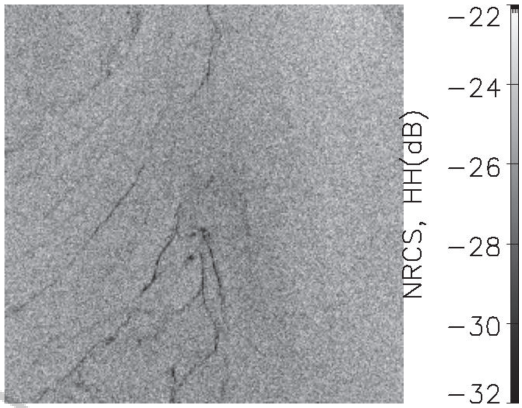

Figure 5: Direct SAR measurement in HH polarization.

In Fig. 4 and 5 is the Bragg scattering component and the direct SAR measurement, both in HH polarization. The improvement from original measurement to the separated single scattering mechanism could be indicated by the expansion of the range of data value from [-32dB, 22dB] to [-40dB, -22dB], although the image quality has not been much improved. On the other hand, the slick texture domains the minimum values, i.e. around -40dB for Bragg component. It helped the accuracy of local wind direction estimated from the cross spectrum of Bragg contributions.

5 CONCLUSIONS

The polarimetric SAR data have been analysed in this paper, introducing an estimation of short wave directions, for the wind seas with a wavelength less than 50 meters. This kind of short wave is considered to be the wind wave, the propagation direction of which accords to the local wind. The local wind direction is critical to predict the trajectory of oil spills. However, the oil films float over the sea surface not only along the local wind, but also tracing the longer wave and current. This is the same problem that encountered by the contradiction data of Mediterranean Sea in section 3. For example, the predictions for significant wave height by the numerical model such as NCEP Wavewatch III have been identified to have substantial differences when include and exclude ocean surface currents.

ACKNOWLEDGEMENTS

This work was partially supported by a grant from the European Union, the Brittany Region and the

Brest Metropole Oceane to the VIGISAT project, in the framework of a FEDER grant Presage # 32635, and by “the Fundamental Research Funds for the Central Universities” No. 14CX02135A. The Radarsat-2 data was supported by CLS under the contracts #08 GET 13M and 09 GET 11M.

REFERENCES

García-Pintado, J., Neal, J. C., Mason, D. C., Dance, S. L., Bates, P. D., Scheduling satellite-based SAR acquisition for sequential assimilation of water level observations into flood modelling, *Journal of Hydrology 495* (2013) 252-266.

Geer, A. J., Lahoz, W. A., Bekki, S., Bormann, N., Errera, Q., Eskes, H. J., Fonteyn, D., Jackson, D. R., Juckes, M. N., Massart, S., Peuch, V. H., Rharmili, S., Segers, A., The ASSET intercomparison of ozone analyses: method and first results, *Atmos. Chem. Phys., 6*, 5445-5474, 2006.

Lahoz, W., Geer, A., Bekki, S., Bormann, N., Errera, Q., Eskes, H. J., Fonteyn, D., Jackson, D. R., Juckes, M. N., Massart, S., Peuch, V. H., Rharmili, S., Segers, A., Evaluation of MIPAS and SCIAMACHY data using data assimilation, *In Proceedings of the Third Workshop on the Atmospheric Chemistry Validation of Envisat (ACVE-3),* 4-7 December 2006, ESA SP-642, February 2007.

Ohring, G., Weng, F., Errico, R., Mahfouf, J. Turk, J., Bauer, P., Campana, K, Ferrier, B., Assimilation of satellite cloud and precipitation observations in NWP models: Report of a workshop, *In Proceedings of ITSC-14*, Beijing, May 25-31, 2005.

Gade, M., Hühnerfuss, H., Korenowski, G., 2006, *Marine Surface Films*, Springer-Verlag Berline Heidelberg, The Netherlands.

Feng, H., Vandemark, D., Quilfen, Y., Chapron, B., Beckley, B., “Assessment of wind-forcing impact on a global wind-wave model using the TOPEX altimeter”, *Ocean Engineering*, Vol. 33, Issues 11-12, August 2006, P. 1431-1461

Giustarini, L., Matgen, P., Hostache, R., Montanari, M., Plaza, D., Pauwels, V. R. N., De Lannoy, G. J. M., De Keyser, R., Pfister, L., Hoffmann, L., Savenije, H. H. G., Assimilating SAR-derived water level data into a hydraulic model: a case study, *Hydrol. Earth Syst. Sci. Discuss., 8,* 2103-2144, 2011)

Phan, X. V., Ferro-Famil, L., Gay, M., Durand, Y., Dumont, M., Morin, S., Allain, S., D’Urso, G., Girard, A., 3D-VAR multilayer assimilation of X-band SAR data into a detailed snowpack model, *The Cryosphere Discuss., 7*, 4881-4912, 2013

De las Heras, M. M., Burgers, G., Janssen, P. A. E. M., Wave data assimilation in the WAM wave model, *Journal of Marine Systems 6* (1995) 77-85

Olsen, R. B., Dunlap, E. M., De Margerie, S., Wilson, L. J., Assimilation of SAR image spectra in a spectral ocean wave model, *In Proceeding of Geoscience and Remote Sensing Symposium*, 1995

Hasselmann, S., Lionello, P., Hasselmann, K., An optimal interpolation scheme for the assimilation of spectral wave data, *Journal of Geophysical Research, Vol. 102, No. C7*, Pages 15823-15836, 1997

Breivik, L. A., Reistad, M., Schyberg, H., Sunde, J., Krogstad, H. E., Johnsen, H., Assimilation of ERS SAR wave spectra in an operational wave model, *Journal of Geophysical Research, Vol. 103, No. C4*, Pages 7887-7900, 1998

Quilfen, Y., Chapron, B., Bentamy, A., Gourrion, J., Elfouhaily, T., Vandemark, D., Global ERS 1 and 2 and NSCAT observations: Upwind / crosswind and upwind / downwind measurements, *J. Geophys. Res., vol. 104, C5*, no. 11,459-11,469, May 15, 1999.

Wang, B., Chapron, B., Mouche, A., Mercier, G., Garello, R., He, M., Depolarization model - a polarimetry approach, presented at the CFOSAT meeting, 2011.

Hasselmann, K., Hasselmann, S., On the nonlinear mapping of an ocean wave spectrum into a synthetic aperture radar image spectrum and its inversion, *J. Geophysical Research, vol. VOL. 96, No. C6,* no. P.10713-10729, June 15, 1991.

Elfouhaily, T., Chapron, B., Katsaros, K., Vandemark, D., A unified directional spectrum for long and short wind-driven waves, *J. Geophys. Res., vol. Vol. 1O2 (C7)*, no. P.15781-15796, July 15, 1997.

Chen, G., Belcher, S. E., Effects of long waves on wind-generated waves, *Journal of Physical Oceanography, Vol.30*, September 2000.

Plant, W. J., Bound waves and sea-surface slope, *In Proceedings of OCEANS2003*.San Diego, CA, USA, vol. Vol.4, no. 1825-1828, 22-26 Sept. 2003.

Ardhuin, F., Herbers, T. H. C., Vledder, G. P., Watts, K. P., Jensen, R., Graber, H. C., Swell and slanting-fetch effects on wind wave growth, *Journal of Physical Oceanography, Vol.37*, no. pp.908-931, April 2007.

Plant, W., Keller, W. C., Hayes, K., Chatham, G., Normalized radar cross section of the sea for backscatter: 1. mean levels, *J. Geophys. Res., vol. 115*, C09032, 2010.

Cox, C. Measurements of slopes of high frequency waves, *J. Mar. Res., vol. 16*, no. 199-225, 1958.

Boerner, W. M., Liu, C. L., Zhang, X., Comparison of optimization procedures for 2x2 sinclair, 2x2 graves, 3x3 covariance and 4x4 mueller (symmetric) matrices in coherent radar polarimetry and its application to target versus background discrimination in microwave remote sensing and imaging, *International Journal of Advances in Remote Sensing (IJARS), Vol. 2*, No.1-1, no. pp. 55-82, January 1993.

Schuler, D. L., Lee, J. S., A microwave technique to improve the measurement of directional ocean wave spectra, *Int. J. Remote Sensing, Vol. 16*, No. 2, no. 199-215, 1995.

Cloude, S. R., Pottier, E., A review of target decomposition theorems in radar polarimetry, *IEEE Transacctions on Geoscience and Remote Sensing, VOL.34,* NO. 2, MARCH 1996.

Schuler, D. L., Lee, J. S., Kasilingam, D., Pottier, E., Measurement of ocean surface slopes and wave spectra using polarimetric sar image data, *Remote Sensing of Environment, vol. 91*, no. 198 - 211, 2004.

Alpers, W., Monte carlo simulations for studying the relationship between ocean wave and synthetic aperture radar image spectra, *J. Geophys. Res., vol. Vol. 88,* NO. C3, no. p.1745-1759, February 28, 1983.

Wang, B., *Synthetic aperture radar multi-polarization ocean surface characteristics and ship detection*, Ph.D. dissertation, Télécom Bretagne, Brest, December 2013.