ANALYSIS AND INTERPRETATION OF ERS-1 SAR DETECTED WIND ROWS
RELATIVE TO OBSERVED AIR-SEA INTERACTION PROCESSES

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Abstract
SAR images obtained during an ERS-1 calibration/validation campaign conducted off the west coast of Norway, NORCSEX'91, are examined. The examination is based on in situ data including shipboard measured surface layer vector wind, thermal stability, and rawinsonde derived atmospheric boundary layer profiles. FFT analyses on the SAR images provided vector information on low-wavenumber structure. For two overpasses, derived direction and spatial separation for coherent structures were compared with model prediction for features of organized large planetary boundary layer eddies. The feature are related to the mixed-layer vector wind and depth. Predicted wind directions were in agreement with observed and mixed layer depths in relative agreement.

I. INTRODUCTION
SAR images have revealed high resolution coherent backscatter manifestation of wind rows caused by variations of the vector wind across organized large eddies, i.e. "roll vortices", in the planetary boundary layer, PBL. Gerling [1] successfully used SEASAT SAR spectra to extract wind direction from such signatures. Previous to detection by surface remote sensing, natural occurrences of rolls have usually been described on the basis of coherent cloud patterns with clouds aligned along the wind in the ascending portions of the vortices. The wind-induced low-wavenumber structure relation to boundary layer features are described by existing physical models [2,3]. The angle between the roll's major axis and the mixed layer wind is usually parallel with some dependence on the stratification within the surface layer. Because the longitudinal velocity perturbation -- and hence frictional stress -- varies across the rolls, and there is convergence/divergence in the windfield across the rolls, very high resolution backscatter measurements can detect the orientation and separation of the resulting wind rows.

II. APPROACH
Shipboard measurements and satellite sensor interpretations were made for a month-long (November 1991) ERS-1 SAR calibration/validation experiment (NORCSEX'91) conducted off the Norwegian west coast, Fig. 1. The shipboard measurements characterized surface layer wind and stratification, atmospheric boundary layer profile properties including vector wind, and ocean surface temperature and currents as well as normalized radar backscatter at L-, C-, and X-band [4]. The approach is based on relating features in SAR sensed high resolution backscatter to wind phenomena controlled by boundary layer features using physical model predictions, i.e. [2,3].
Low-wavenumber structures are very discernable in processed NORCSEX91 ERS-1 SAR images within both high and low background backscatter regions of the same pass. Those considered in this paper are shown in Figs. 2 and 3, passes late on 10 and on 16 November, respectively. We are examining the relationships between SAR detected features and properties of the overlying atmospheric features as well as to the surface layer vector wind.

III. RESULTS

A. SAR Images

Visual comparisons of structures, with horizontal resolution of meters, in Figs. 2 and 3 reveal more evidence of horizontal rows in the former. Two-dimensional pattern recognition (FFT spectral) processing enable quite accurate quantification of the existence of and the orientation, and separation scales of the wind rows. Low-wavenumber spectra for images in Figs. 2 and 3 are shown in Figs. 4 and 5. The spectra represent ensemble averages over four regions of the image. As expected on the basis of the visual examination, the spectrum in Fig. 4, corresponding to the image in Fig. 2, contains a sharp, well-defined dominant peak aligned along a south-southwest to north-northeast direction. The axis of the role would be perpendicular to this alignment and, as described above, along the general direction of the wind.
The dominant wave number on the 10 November image (Fig. 4) had coherent structure separations, read from the inner concentric circles, near 3000 meters. The lower peak (3 versus 3.5 km) is selected for discussion because, as will be shown for the 16th, structures with 3.5 km or larger separations seem to occur with no connection to boundary layer properties.

Since the increased backscatter would correspond to downdrafts on opposite side of adjacent roles, this separation would be associated with 1500 meter depth roles if the role "pair" had 2:1 aspect ratio. The depth of the rolls equals the mixed-layer depth and the ratio, "aspect ratio", of lateral to vertical dimensions for a roll "pair" can vary [3]. The aspect ratio has nominal values from 3 to 5:1, i.e. the vortices are flattened circles distorted by mean wind shear. The aspect ratio depends on the boundary layer stratification [3] and can become very large [4]. Physical scaling studies have also related the aspect ratio to the virtual temperature difference at the top of the mixed-layer.

The 16 November image (Fig. 2), visually clearly different with non-row coherent structures, has spectrum (Fig. 5) that doesn't have a distinct dominant wave number. Instead it has two marginally distinct wave numbers with southwest to northeast alignments. Further, the separations are greater than for those on 10 November.

B. Atmospheric boundary layer properties and SAR images

Questions arise as to whether properties of the overlying PBL would suggest the more likely occurrence of distinct roles with the 10 November rather than the 16 November pass and if inferred alignment and spatial scales are due to boundary layer properties. Brown [2] describes general conditions associated with the formation of horizontal roll vortices in the boundary layer. These conditions include, at least, an unstable surface stratification.
with moderate to strong winds. Regional surface weather patterns for the November 10th and 16th indicate that no significant weather systems were transiting the NORCESEX'91 region during either day. However, the west Norwegian coast was under a ridge line on the 10th and was under the influence of a troughline extending from a closed low over north Norway on the 16th.

1) Atmospheric Surface layer properties:
Time series of surface layer pressure, vector wind, and air and sea temperatures for these two days appear in Figs. 6 and 7. Vector wind information from these time series are added to Figs. 4 and 5 spectra.

![Figure 6](image1)

Figure 6. Time series (from 11/10/12 UT to 11/11/08 UT) of Pressure, vector wind, and air and sea temperature measured on R/V Haakon Mosby.

![Figure 7](image2)

Figure 7. Time series (from 11/16/12 UT to 11/17/08 UT) of Pressure, vector wind, and air and sea temperature measured on R/V Haakon Mosby.

The time series don't have readily discernible features explaining the visually and spectrally established differences in the coherent structure, distinct or non-distinct roles. On the 10th, the vector winds, persistent before and after the overpass time, assigned to the spectra are certainly in agreement with model predictions for the wind being generally parallel to the rows, i.e. perpendicular to the detected wave alignment. There is agreement between the wind and the alignment with one of the wavenumbers on the 16th but not with the other. Hence, we believe these demonstrate that SAR sensed coherent structures could be applied to wind direction determinations. Shuchman et al. [5] have described an approach for backscatter determination of wind speed and direction.

Similarities exist for two days relative to stability and wind speed conditions associated with roll vortices. For both days the sea is 4-5 C warmer than the air so that the both had the unstable conditions and the surface wind was moderate to strong being above 10 ms\(^{-1}\) for at least an hour preceding and for several hours following SAR image times. Differences that could suggest dissimilar forcing of the boundary layer are decreasing pressure trend on the 10th reflects the area being on the backside of a passing ridge during the period while the increasing trend on the 16th reflects the area being under the backside of a passing troughline. Ridge/trough influences on the region would correlate with divergence/convergence establishment of an inversion capped boundary layer.

2) Profile properties: R/V Haakon Mosby launched rawinsonde vertical profiles (up to 3 km) near the times of overpasses of the ERS-1 on the 10th and 16th are shown in Figs. 8 and 9. On both days the R/V Haakon Mosby was within the image.
On the 10th when the role separation was estimated to be approximately 3 km, the rawinsonde profile near the overpass time has a possible mixed-layer depth of either .3 or .9 km, Fig. 8. The lower level had a moderate to strong capping inversion due to offshore flow. The winds were uniform in direction and speed, 10-12 m/s, throughout either mixed-layer. These mixed layer would yield an aspect ratio near 5 or between 1 and 2, within the range or on the low side of those normally reported. Further studies with model predictions, that depend on the inversion strengths, will be required to investigate what a representative ratio should have been in these atmospheric conditions. However, we believe the comparisons show the surface coherent structures to have spacing compatible with an unstable .9 km mixed layer depth, and with moderate wind speeds.

The R/V Haakon Mosby rawinsonde profile near the ERS-1 overpass time on the 16th is shown in Fig 9. There is no temperature inversion below 3 km but a mixed layer depth of near 2.5 km is exhibited in the humidity (dew point temperature) profile. We believe that the trough influenced convergence is responsible for the temperature profile being well mixed to levels above 3 km. The image for this time, Fig. 3, did not exhibit distinct rows and the spectrum, Fig. 5, was ambiguous on orientation of any coherent structure. The wave number predicted to be aligned with the observed wind had a separation of 3 to 4 km.

The roll "pair" aspect ratio for the 16th is
less than 1 if the humidity profile is used as an indication of mixed layer depth. This is less than expected particularly in view of the wind shear, i.e. 20 ms\(^{-1}\) increase across the 2.5 km deep boundary layer, Fig. 9. We believe the suggested convergence pattern and the deep well-mixed temperature profile vertical is indicative of significant convection in the region.

The deep convection could explain the coherent structures having "cellular" versus "row" surface patterns. Hence, the SAR detected low-wavenumber structure is related to properties of the overlying boundary layer in this case even if they were not determined by "roll vortices".

CONCLUSIONS

A very limited sample of processed high resolution SAR imagery of low-wavenumber structures were interpreted definitely for surface wind direction information and to lesser extend for information on boundary properties. The latter include thermal stratification and if an inversion capped mixed-layer exists. Further, the absence of an inversion due to convergence was related to the fact that the coherent structures did not have features associated with "roll vortices".

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