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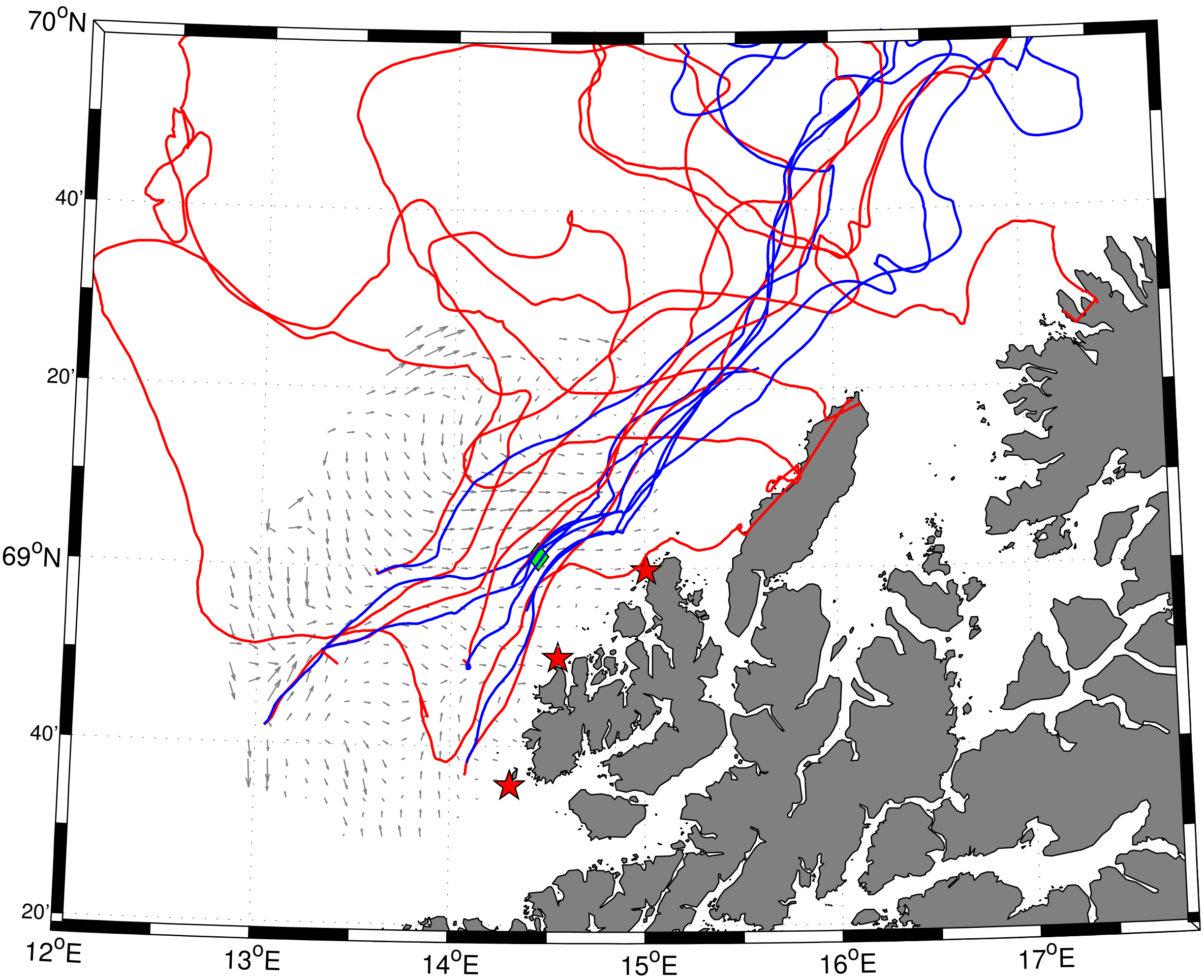
Oceanography

The spring 2013 field experiment of the ENI/NOFO HF radar project

Kai H. Christensen, Ann Kristin Sperrevik & Johannes Röhrs



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Abstract This report summarizes the 2013 field experiment that was part of the ENI/NOFO HF radar project (task 2). It contains a short description of the various observation systems and instruments, as well as an overview of their spatial and temporal coverage. Some comments are made on the quality of the upper ocean current observations. In particular, we conclude that

- the HF radar currents agree well with independent drifter observations,
- the HF radar currents are essentially representative of the Eulerian part of the upper ocean currents (i.e., do not contain the Stokes drift),
- the effective depth of the HF radar observations is 0.8 meters, which is consistent with theory.

Keywords

Oceanography, cruise, surface drifters, ADCP, HF radar, CTD

Lars-Anders Breivik

Disciplinary signature

ØH

Responsible signature

Meteorologisk institutt
Meteorological Institute
Org.no 971274042
post@met.no

Oslo
P.O. Box 43 Blindern
0313 Oslo, Norway
T. +47 22 96 30 00

Bergen
Allégaten 70
5007 Bergen, Norway
T. +47 55 23 66 00

Tromsø
P.O. Box 6314
9293 Tromsø, Norway
T. +47 77 62 13 00

www.met.no
www.yr.no

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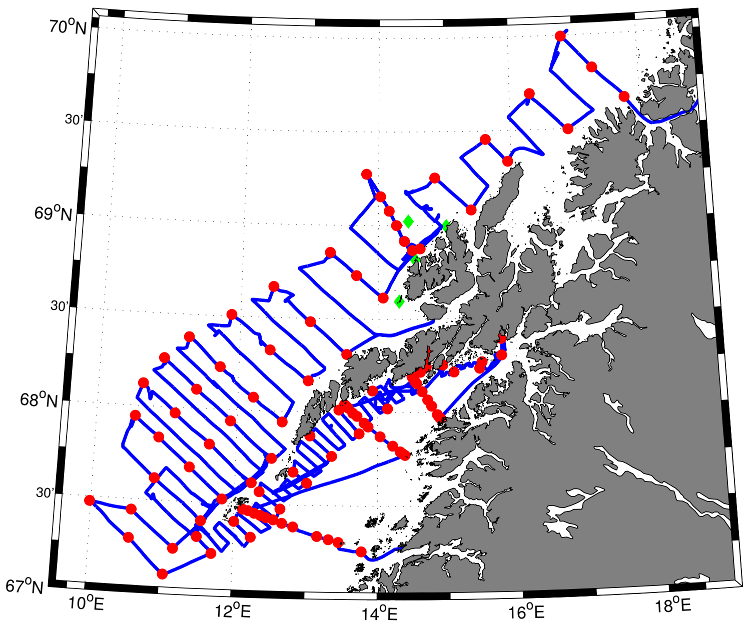

Figure 1: The ship track of R/V Johan Hjort during the cod stock assessment cruise in March 2013. The cruise started in Tromsø and ended in Bodø. The red dots indicate stations where CTD profiles where taken. The positions of the three HF radars and the ADCP rig are shown as green diamonds.

1 Introduction

The three mobile HF radar stations acquired by ENI/NOFO in 2012 were deployed along the coast of Vesterålen in the period March-May 2013 as part of an extensive field campaign. The main motivation for deploying the radars here was the co-location with the annual cod stock assessment cruise of the Institute of Marine Research (IMR) (see Fig. 1). Hydrographic and acoustic data are routinely collected during these cruises, and, by being onboard the IMR research vessel, we had the opportunity to release drifters in the area covered by the HF radars. A further motivation for focusing on this region was the presence of the so-called LoVe cabled observatory. Prior to the IMR research cruise we were able to deploy a rig containing three separate acoustic Doppler current profilers (ADCPs). This rig was also equipped with a pressure sensor collecting data on the surface gravity wave field. Remote sensing data from satellite (SAR) and surveillance aircraft (LN-KYV, SLAR and images) were also collected.

2 Observation systems

2.1 Current measurements

2.1.1 HF radars

Three SeaSonde HF radars from CODAR Ocean Sensors were deployed in Vesterålen in the first week of March 2013 (see Fig 2). The operating frequency of the radars were 13.525 MHz. The radars were named after their geographical positions as LITLØY, HOVDEN and NYKSUND (see Table 1). All three stations were demobilised in the beginning of June 2013.

Name	Latitude	Longitude
LITLØY	68.5933 N	14.3075 E
HOVDEN	68.8165 N	14.5449 E
NYKSUND	68.9955 N	15.0084 E

Table 1: Positions of HF radar stations.

2.1.2 Drifters

A total of 14 surface drifters from MetOcean, Canada, were used in the field experiment. Seven of these were “iSphere” type drifters, which are spherical floats designed to stay at the very surface, and the other seven were “iSLDMB” drifters with a drogue centered at 65 cm below the surface. Previous studies have shown that the behaviour of these types of surface drifters can be markedly different, mainly depending on the wave conditions [Röhrs et al., 2012]. All the drifters were deployed from the IMR vessel “R/V Johan Hjort” between March 16 and 17. All drifters produced useful data within the coverage area of the HF radars (see Fig. 2) except one of the iSpheres, which failed directly after deployement, most likely due to age. The iSLDMBs are expendable, hence no attempt has been made to recover these. All the iSpheres except the one that failed have been recovered.

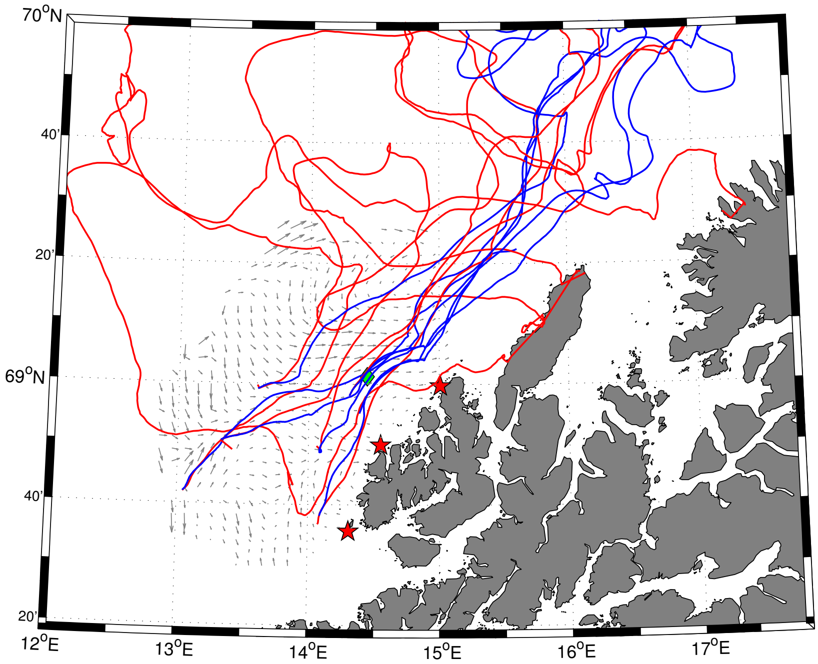

Figure 2: HF radar stations, drifter trajectories, and ADCP rig. Starting from the south the HF radar stations are LITLØY, HOVDEN, and NYKSUND. The grey arrows are total vector currents from the HF radar system, indicative of the coverage when all three stations were operational. The iSphere trajectories are red, while the iSLDMB trajectories are blue. The position of the ADCP rig is marked by a green diamond.

2.1.3 ADCP measurements

The ADCP rig was designed and assembled at the IMR. The instrumentation consisted of two Anderaa RDCP 600 (IMR), both mounted approximately at middle depth, one upward looking and one downward looking, in addition to an upward looking Nortek Aquadopp Profiler (on loan from the navy) at approximately 10 m depth. The rig was deployed from the Coastal Administration's "NSO Crusader" on March 1 at 69.021N/14.446E (see Fig. 2). The depth was 84 m. It was recovered by the IMR vessel "R/V Haakon Mosby" on April 14.

2.2 Hydrographic observations

2.2.1 CTD profiles

R/V Johan Hjort is equipped with a standard CTD profiler which is operated by the crew. During the part of the cruise when the ship was on the continental shelf, hydrographic profiles were collected at the start and end points of each leg out from the coast (see Fig. 1). A total of 107 profiles were collected during the entire cruise period from March 14 to March 26. The CTD data set has gone through a post cruise quality control at the IMR oceanographic data center, which includes calibration of salinity values.

2.2.2 Sea surface temperature

Both the iSphere and iSLDMB drifters are equipped with temperature sensors. The iSLDMB sensors gave spurious results, however, hence these data should not be used. The iSphere data appear to be of good quality, but comparison with independent data (e.g. satellite SST) has not yet been made.

2.3 Other observations

2.3.1 Pressure sensor

The ADCP rig was equipped with a pressure sensor TWR-2050P from RBR (on loan from the Univ. of Bergen), which was used to sample waves and sea surface elevation. The TWR-2050P is shaped as a small tube and usually moored at a fixed distance from the bottom, but was here attached to the uppermost floating element of the ADCP rig. Wave measurements are facilitated by configuring the instrument in so called burst mode. High frequency (2 Hz) sampling are made every 20 minutes and a sea surface height/pressure transfer function is used to estimate wave parameters such as significant wave height and peak period. The pressure sensor recorded data from March 1 until April 14 when the rig was recovered.

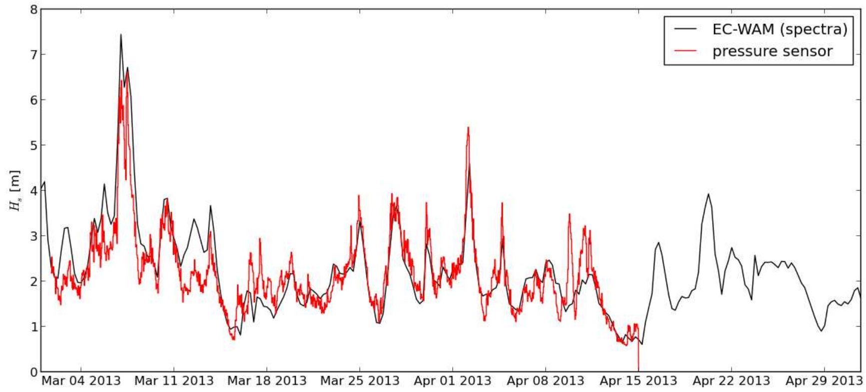

Figure 3: Comparison between measured (red) and modeled (black) significant wave height.

A pressure sensor only provides 1D spectra, that is, no information about propagation direction. Wave directionality is needed to estimate the wave-induced drift, and we have therefore obtained data from the European Centre for Medium Range Weather Forecasts (ECMWF) wave model used in the ERA Interim Reanalysis[Dee et al., 2011]. A comparison between sensor and model significant wave height demonstrates good agreement during the period of interest (see Fig. 3), indicating that model data may be used as a partial substitute for full directional wave measurements.

2.3.2 SAR and SLAR data

Remote sensing data from Radarsat were collected on March 17 and 18 (Standard Scenes, see example in Fig. 4), as well as on March 20 (ScanSAR Narrow). In addition, the surveillance aircraft LN-KYV made several passages on March 18 and 19 in the area collecting data using SLAR (see Fig. 5). On March 19 the aircraft also collected images of the sea surface that may possibly be used to estimate surface wave whitecapping. Such estimates can for example be useful for model studies on the drift and dispersion of oil spills.

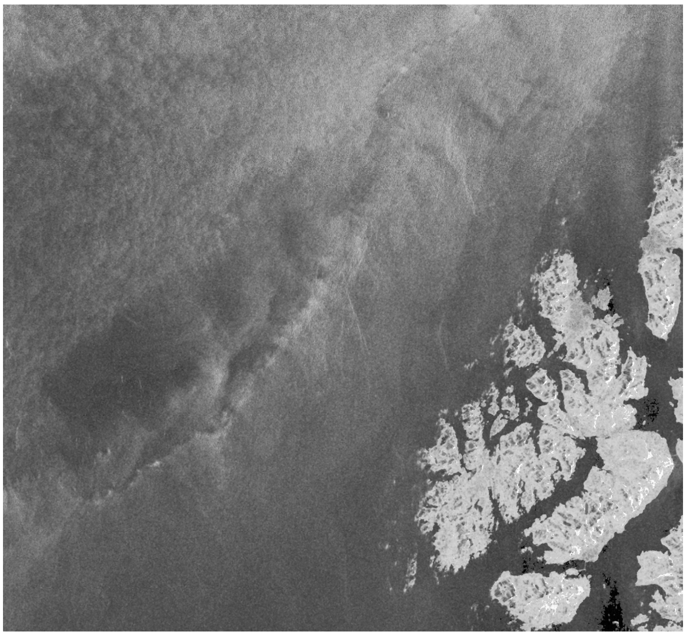

Figure 4: Radarsat SAR image (Standard Scene) from March 18, here in HH polarization. The image has been de-speckled and the contrast increased to more clearly show the oceanic features.

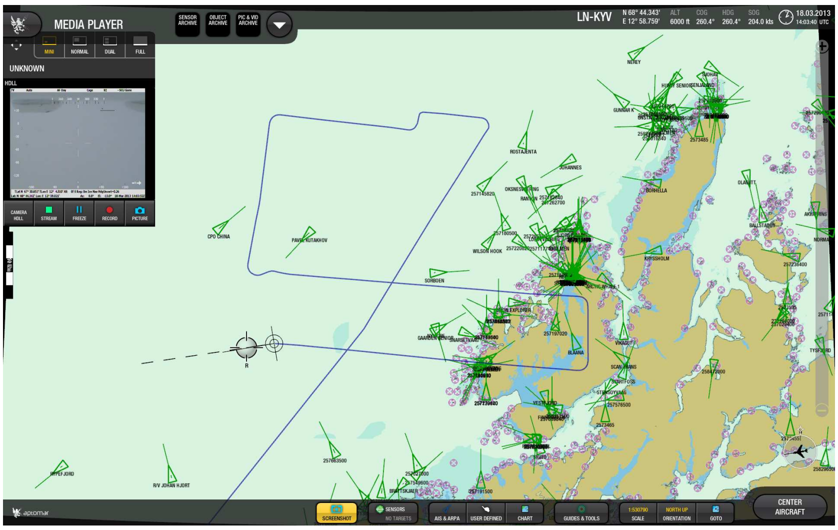

Figure 5: Flight track of the surveillance aircraft LN-KYV on March 18. R/V Johan Hjort is seen in the lower left part.

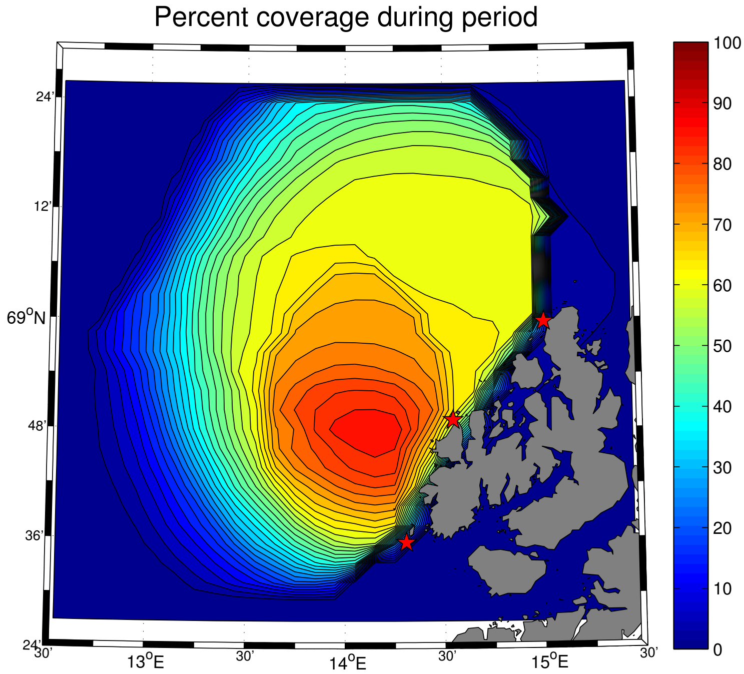

Figure 6: Availability of data from total vector files as a percentage of the entire deployment period.

2.3.3 Other ship-borne instruments

R/V Johan Hjort has several onboard instruments that may be useful for subsequent data analysis. Most important of these are the weather station and the shipborne ADCP. Near surface temperature data may also be of interest.

3 Data coverage

The density of observations varied significantly in space and time during the field experiment. The HF radars were not always operational, and in the case of loss of one station, the amount of data for total vectors (which requires two or more antennaes) would be substantially reduced. The drifters deployed from R/V Johan Hjort either stranded or drifted out of the area of interest within a week, which was expected from previous experience with drifters in this area.

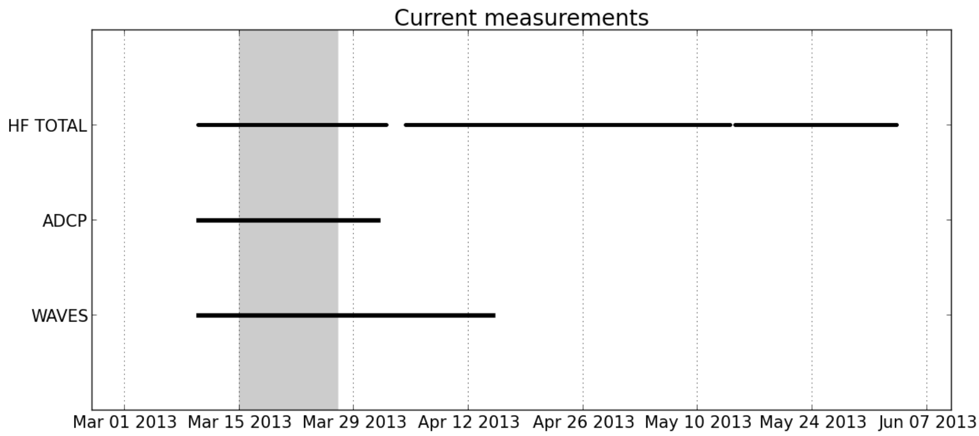

Figure 7: Availability of total vector files from the HF radar stations and data from the ADCP rig as a function of time. The shaded area indicates the full cruise period of R/V Johan Hjort.

3.1 Spatial distribution

The spatial distribution of HF radar data (total vectors) is shown in Fig. 6. The northernmost station NYKSUND had the lowest uptime of all three stations. At all stations the data would be logged locally, hence although the near real-time availability would decrease once a station went offline, we still obtained data when it came back online.

All the drifters passed through the area covered by the HF radars (see Fig. 2). Several drifters continued northwards for some time, the last remaining iSLDMB reached 72.29N/45.96E in the eastern part of the Barents Sea before the batteries finally gave out on Oct. 6—more than 200 days after deployment.

3.2 Temporal distribution

An overview of the temporal availability of HF radar data (total vectors), ADCP currents, and wave measurements is shown in Fig. 7. The data content of a total vector file depends on the number of stations that were operational, as discussed in the previous section. The number of point observations within each total vector file is shown in Fig. 8. As can be seen, the numbers are low in the beginning of the cruise period, but increased rapidly within a few days.

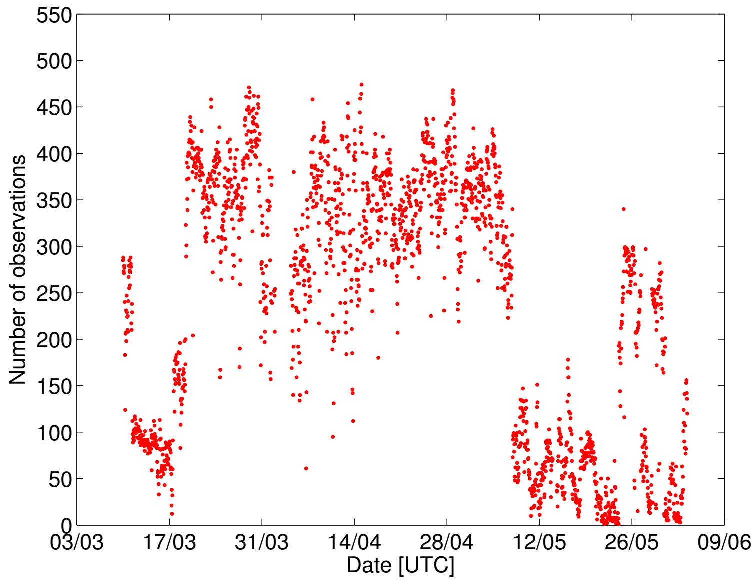

Figure 8: Number of point observations within each total vector file from the HF radar system. Hourly total vector files were produced provided radial current observations from two or more stations were available.

3.3 Evaluation of HF radar measurements

The HF radar total currents have been evaluated using independent data from drifters, ADCP currents, and wave data. In particular we have been interested in the impact of the wave-induced drift and how the HF radar radial currents correlate with drifter velocities. We have also compared ADCP and HF radar data to assess the effective depth the HF radar currents.

3.3.1 Wave impact and drifter/HF current comparisons

Previous studies have shown that in particular the iSphere drifters are influenced by the wave-induced drift, that is, the so-called Stokes drift [Stokes, 1847]. During a field experiment in Vestfjorden in 2011, we measured both the ocean current (by ADCP) and the Stokes drift (by waverider) and found that the iSphere trajectories were well represented by their sum [Röhrs et al., 2012]. This sum is hereafter referred to as the *Lagrangian* current. This analysis has been repeated here to investigate the importance of the Stokes drift (Figs. 9 and 10). The main difference between the 2011 and 2013 field studies is that the ocean currents were

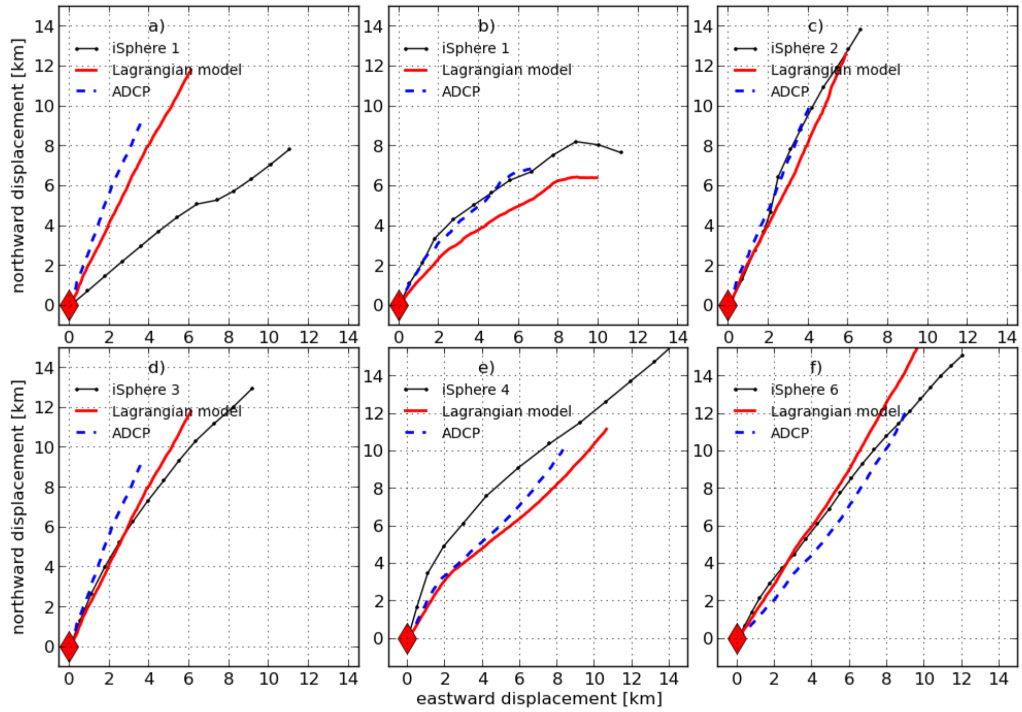

Figure 9: Observed drift trajectories of the iSpheres, as well as progressive vector diagrams based on ocean current only (dashed blue line) and the sum of the Stokes drift and the ocean current (solid red line).

much stronger in the latter case. Hence the relative importance of the Stokes drift is smaller, although the waves were comparable or higher in 2013.

The Stokes drift decays rapidly with depth, and while the Stokes drift appears to play a role for the iSphere drift (Fig. 9), the influence on the iSLDMB drifters is smaller (Fig. 10). The strong currents in the region implies that comparison between vector diagrams and drifter trajectories should be treated with some caution. In order for such a comparison to be meaningful, the observations in the point where the ADCP is located must be representative over the whole area covered by the drifter for the period in question.

According to theory, the HF radar currents include parts of the Stokes drift, namely the components induced by waves longer than the Bragg wave [e.g. Ardhuin et al., 2009, and references therein]. It is therefore of interest to see if the radar currents correlate better with the drifter velocities when the Stokes drift is included

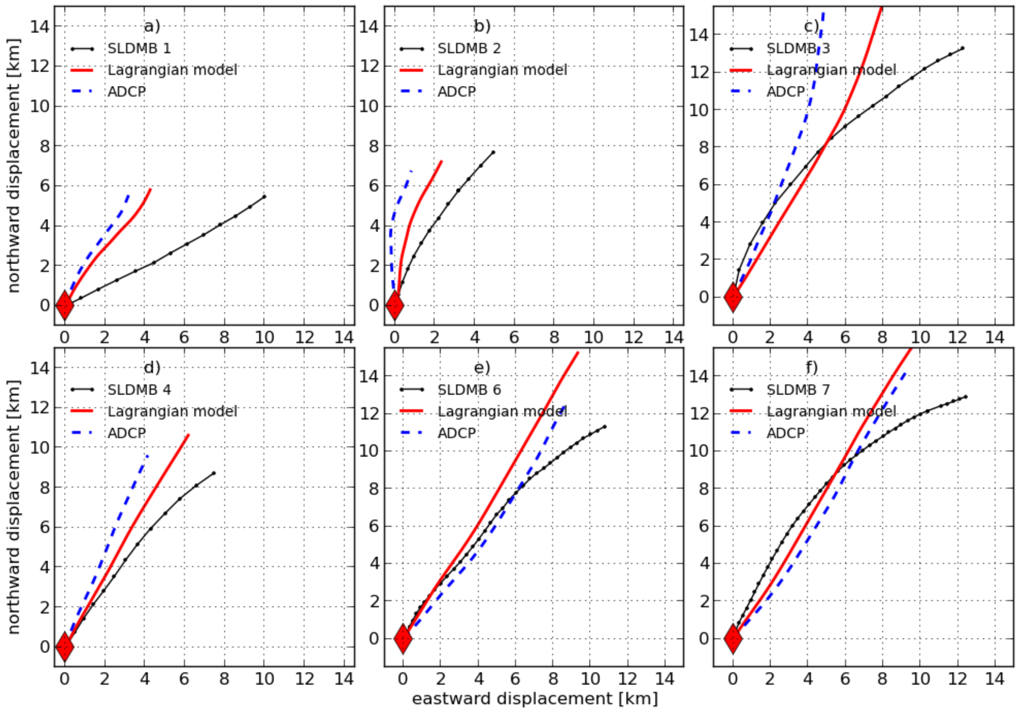

Figure 10: Observed drift trajectories of the iSLDMBs, as well as progressive vector diagrams based on ocean current only (dashed blue line) and the sum of the Stokes drift and the ocean current (solid red line).

or not. The radial currents measured by the NYKSUND radar are compared with the corresponding velocity components of both iSpheres and iSLDMBs in Fig. 11. The iSpheres drifted faster out of the area, so there are less data points. In both cases we see that the Eulerian model gives better fit between the observations, which indicates that the HF radars essentially measure the Eulerian currents.

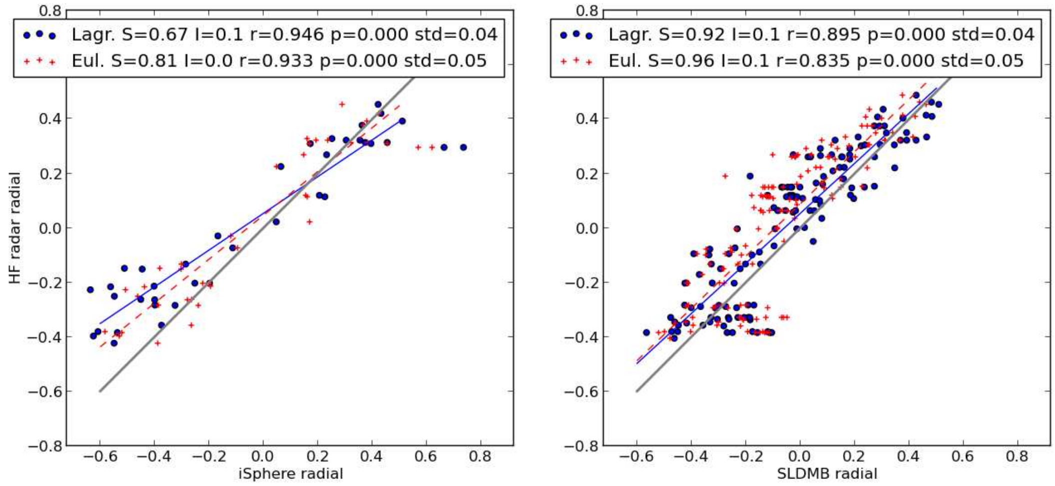

Figure 11: Scatter diagram of radial velocities from drifters and NYKSUND radar. Left panel shows iSphere data, while the right panel shows iSLDMB data.

3.3.2 Effective HF current depth

According to theory [Stewart and Joy, 1974], the HF radar observations represent surface currents filtered by a weighted averaged over the upper 1-2 meters, where the weight decays exponentially over an e-folding scale of $D = 1/(2k)$, where k is the Bragg wave number. This theory is based on an assumption about the vertical velocity shear. Figure 12 shows the so-called Pearson correlation coefficient and root-mean-square deviation between the vertically averaged ADCP current and the HF radar current for different e-folding scales D. For the actual Bragg wave number of the HF radars considered here, the e-folding scale is $D = 0.833$, which corresponds to the e-folding scale that yields maximum correleation with the ADCP. In the literature, the depth of HF radar currents is sometimes interpreted in terms of an effective depth, referring to being representative currents at fixed depth. From Figure 12, an effective depth of 0.7 m $< D_{eff} < 1.2$ m seems to fit well. In conclusion, the observations agrees with established theories on the vertical origin of HF radar measurments. We recommend to interprete the HF radar measurements as currents at an effective depth of about 0.8 meters depth.

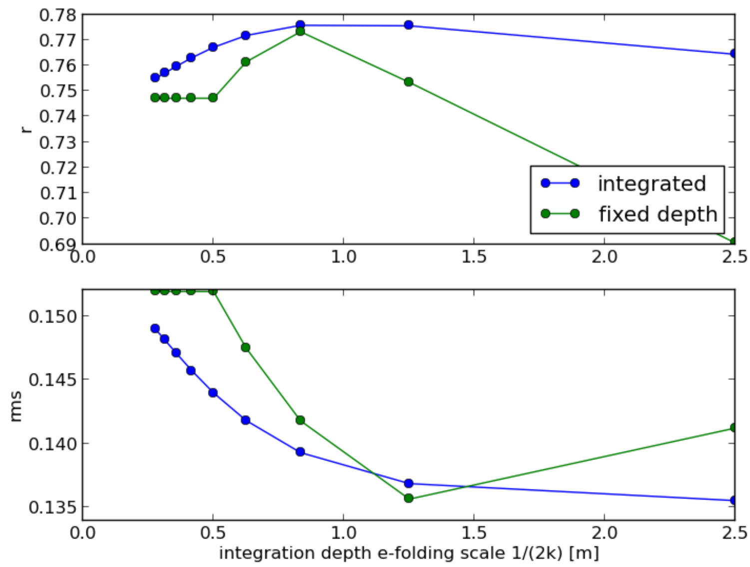

Figure 12: Pearson correlation and RMS deviation between HF radar currents and ADCP currents as function of depth of ADCP currents. For the blue line, ADCP currents were vertically filtered using a weighted average of exponentially decaying weights; the x-axis displays the e-folding scale of these weights. For the green line, ADCP currents are exptracted at fixed depth without vertical filtering.

4 Concluding remarks

During the spring 2013 ENI/NOFO field experiment we collected data from HF radar stations, shipborne CTD profiler, surface drifters, upward and downward looking ADCP, and pressure sensor. Remotely sensed data were also collected, that is, SAR, SLAR and images of the sea surface. There exists more data sets for the period, e.g. from the so-called LoVe cabled observatory and additional shipborne instruments on R/V Johan Hjort, but these are not described here as they have not yet been considered in any analysis.

The availability of HF radar total vectors is highly variable because of intermittent problems with the operation the HF radar stations. Radial currents from the stations appear to agree well with drifter data. A dedicated study of the HF radar observations show that the measurements are essentially Eulerian, that is, the Stokes drift is not contained in the data. On the other hand, analysis of drifter data reveals that the Stokes drift is relatively small compared to the Eulerian current. Finally, comparison with ADCP confirms that the effective depth of the HF currents is about 0.8 meters.

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