Accord Scientific Visit Report

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Topic: *Meteorological Radar Doppler Wind Data Assimilation in HARMONIE-AROME using the Field-Alignment Algorithm*

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SUMMARY

During the five-day visit the following activities were carried out:

- ✓ Preparation of an HDF5 interface for the FA software
- ✓ Study of the properties of the DOW radar data from two Scandinavian radars and evaluation of their suitability for processing by the FA algorithm
- ✓ Portability of the FA and VC software in Cy43 to the new Atos HPC facility in Bolognia

These activities (particularly the second) were continued during some days after the visit was over. The following lines present the main results and conclusions. The structure of the report is as follows. An "introduction" puts in context the reason for this ACCORD Scientific Visit. "Background" presents the verification results obtained with the latest implementation of the FA software in HARMONIE-AROME cycle43. These verifications were conducted on the new HPC AEMET facility "Cirrus" and using ODIM-BUFR AEMET radar data. It is this FA software that is used in the exercises with HDF5 data that follow. The main part of the report "FA tests with ODIM-HDF5 data" describes the characteristics of the data used for this visit and discusses different aspects of it from the point of view of their usability by FA. A series of "cold runs" have been performed to illustrate the conclusions (Tables#3 and #4).

1. INTRODUCTION

Following the ideas by Ravela et al. (2007) a method to assimilate DOW weather radar data was implemented at AEMET (2011) which derives corrections to the FG wind field by matching or aligning FG radial wind fields with radar DOW images. This implementation has been tested quite comprehensively in the last years on different occasions (2013a, 2013b, 2015, 2019), but always with AEMET DOW data and/or simulated data. The last exercise of this kind has just been carried out during an intense rainy episode in March 2022 in the south of the Spain. The main aspects and results of this work are summarized in section ("background"). They are used to put into

perspective the planning and goals of this ACCORD scientific visit whose main results and conclusions are presented thereafter ("tests with ODIM-HDF5 data").

Most of the different members in the ACCORD Consortium operate meteorological radar networks. The EUMETNET Programme OPERA aims at establishing common standards and procedures that facilitate the exchange of weather radar information. In an attempt to spread the use of the Field-Alignment (FA) algorithm and to show its potential benefits for other radar data sources beyond AEMET, an ACCORD scientific visit was approved to extend the FA interface to OPERA ODIM-HDF5 DOW data. This was necessary because the tests that had been done so far were with ODIM-BUFR data (https://www.eumetnet.eu/wp-content/uploads/2017/03/OPERA_2008_14_BUFR_Guidelines.pdf)

2. BACKGROUND

The implementation of the Field-Alignment (FA) and Variational Constraints (VC) software in Cycle43 has been verified with data from the AEMET radar network and also observations from anemometers and rain-gauges of the AEMET network of automatic stations collected during a rainy episode in the South of Spain that took place on the 23rd and 24th of March 2022. It is this implementation the one used in the exercises carried out with Scandinavian radars in the framework of this scientific visit.

The areas covered by two radars, Málaga (wmoid=08475) and Sevilla (08386) (Figure#1, left), were swept by heavy rainy weather, especially in the case of Málaga, during the late evening of the 23rd and early hours of 24th March 2022. Figure#1 (right) displays the time series of the "overlap parameter" (i.e. fraction of radar Doppler images covered by meaningful echoes) for the two elevations used for alignment in this verification (1.4 and 0.5 degrees). The setup of the verification experiment consists of a run without radar assimilation (reference) plus four experiments exp1, exp2, exp3 and exp4, where DOW radar data are assimilated (FA + VC). The names of each one of these experiments reflects the number of hourly assimilation cycles previous to the start time of +9H forecasts used to wind-up the model. This setup is designed to study possible spin-up effects in DA cycles one hour apart from each other.

ETS (Equitable Thread Score) tables are computed from the data gained by the automatic stations which report hourly rain intensities and maximum wind gust. The number of stations with valid data in an area about 120 Km around (08475) varies between 33 and 37 and around (08386) between 39 and 43, depending on the particular case of the 26 +9H forecast runs from 23rd at 09UTC until 24th at 10UTC. Figure#2 shows the results of these ETS computations. There is a clear positive impact for these experiments on the accumulated rain intensities, while it is neutral for the wind gusts (not shown).

Figure#3 illustrates a result of these experiments which is worth to mention. It displays the statistical distribution of maximum accumulated rain for 1, 3, 6 and 9 hours around the radar sites. 26 +9H forecast by 2 radars make a sample size of 52 for each accumulation time interval. The plots vividly show that the assimilation of DOW data has corrected the deficit in maximum precipitation forecasted by the reference. Also the "build-up effect" (positive contributions from successive cycles adding up coherently) is clear here as well. Although the precise location of the maximum is not correctly predicted (note that there is no clear improvement for the highest thresholds in the ETS curves), at least, within an area of 120 Km around the radar, the peak of accumulated precipitation is.

In the light of these results, it is fair to conclude that the implementation is done correctly. We now proceed to describe the work specifically carried out during the visit, and during some days after the end of it.

3. FA TESTS WITH ODIM-HDF5 DATA

In order to carry out the tasks of this visit, SMHI provided to the visiting scientist with ODIM-HDF5 data from two Scandinavian radars integrated in the OPERA Programme: Angelholm (WMO code 02606) and Virring (06103). The time period selected is 24 May 2022, when a rain band moving from west to east over Kattegatt Strait provided radar images with enough echoes. Figure#4 (left) gives the location of both radars and the range reach corresponding to the lowest elevations used in this work (120 Km for Virring and 148 Km for Angelholm, see tables#1 and #2 below). Figure#4(right) shows the time series at hour resolution for 24 May for the "coverage parameter", i.e. the fraction of the radar image with meaningful echoes. The rain band moved uniformly in about 4 hours across the sea.

3.1 Data Decoder

The first task of the visit consisted in writing decoding software for ODIM-HDF5 radar data files. The work was done on the cca facility at ECMWF, using the cray-hdf5/1.8.16 libraries. It is to be expected that it will not have impact on the correct functioning of the code when other compilations of that version of the hdf5 libraries, or higher, are used. The programming took as starting point some routines to be found in "bator_decodhdf5_mod.F90" and "bator_decodhdf5_balt.F90" modules, cycle43 in Harmonie-Arome.

The HDF5 data files used in this work belong to ODIM_H5/V2.2. Comprehensive information on the content of these files can be found in: (https://www.eumetnet.eu/wp-content/uploads/2017/01/OPERA_hdf_description_2014.pdf)

3.2 Data Selection

A first difficulty immediately arises: the two radars are operated by SMHI and DMI respectively, and the volume acquisition schedules and scanning parameters are different.

1. **Virring** One volume is generated every 5 minutes. Those gained at 0, 10, 20, 30, 40 and 50 minutes in the hour do not contain DOW winds with high enough Nyquist folding speeds. Therefore they are not considered further. Those gained at 5, 15, 25, 35, 45 and 55 minutes in the hour do contain DOW winds with Nyquist at 47.20 m/s and they are selected for the tests. Table#1 summarizes the characteristics of the scans included in these files. As we will discuss later in the report, the FA algorithm is very sensitive to the geometry of the scans selected for processing, with lower elevations more advantageous because the beam footprint intersects wider areas on model levels. The scans selected are indicated by bold characters.

Dataset#-scan#	Elev (º)	BeamW (º)	Bins (#)	Rays (#)	BinSize (m)	StartRange (Km)	Nyquist (m/s)
8	88.98	0.9	240	360	500	0.5	47.2
7	12.99	0.9	240	360	500	0.5	47.2
6	8.49	0.9	240	360	500	0.5	47.2
5	4.49	0.9	240	360	500	0.5	47.2
4 – 1	**2.41**	**0.9**	**240**	**360**	**500**	**0.5**	**47.2**
3 – 2	**1.50**	**0.9**	**240**	**360**	**500**	**0.5**	**47.2**
2 – 3	**1.00**	**0.9**	**240**	**360**	**500**	**0.5**	**47.2**
1 - 4	**0.69**	**0.9**	**240**	**360**	**500**	**0.5**	**47.2**

Table#1. DOW (VRADH) data content for radar Virring (DMI) in the files selected for the tests. Scan number in the first column as used by FA

The parameters displayed in Table#1 are nearly optimal for application of the FA algorithm. Unfortunately, the actual content of the files shows many missing lines and, even worse, a strange removal of values close to 0 m/s (Figure#5). These latter values are coded as “undetect”. It is not straightforward to recover these values because also pixels with no radar echoes (clear sky) are classified as “undetect”. It is unfortunate that these two very different situations: no wind along the line-of-sight, and no echo, are treated as equivalent in these files. It must be pointed out straight away that this situation has not been found neither in the AEMET nor in the SMHI data (see later).

The data displayed in Figure#5 requires some sort of correction. The FA algorithm works at model resolution (2.5Km) while the radar data has finer resolution. A superobbing must then be applied to the radar data. One can use this fact to go around the problem of the missing values. This

solution is of course not optimal but the result still shows a considerable amount of information and structure in the DOW wind field (Figure#6). These images are the ones that will finally be processed by the FA algorithm in the tests below.

2. **Angelholm** Volumes are also generated every 5 minutes, but now the content of all the files is the same. This increase in time resolution trades-off with small Nyquist speeds in the lower scans. However, higher elevations still come with adequate Nyquist folding speeds (40.11 m/s). As a compromise between both parameters, elevation and ambiguous velocity, two scans are selected (in bold in Table#2)

Dataset#-scan#	Elev (º)	BeamW (º)	Gates (#)	Rays (#)	GateSize (m)	StopRange (Km)	Nyquist (m/s)
10	40.0	1.0	480	360	250.0	0.0	40.11
9	24.0	1.0	480	360	250.0	0.0	40.11
8	14.0	1.0	592	360	250.0	0.0	40.11
7	8.0	1.0	592	360	250.0	0.0	40.11
6 – 1	**4.0**	**1.0**	**592**	**360**	**250.0**	**0.0**	**40.11**
5 - 2	**2.5**	**1.0**	**592**	**360**	**250.0**	**0.0**	**40.11**
4	2.0	1.0	480	360	500.0	0.0	24.07
3	1.5	1.0	480	360	500.0	0.0	24.07
2	1.0	1.0	480	360	500.0	0.0	24.07
1	0.5	1.0	480	360	500.0	0.0	24.07

Table#2. DOW (VRADH) data content for radar Angelholm (SMHI) in the files selected for the tests. Scan number in first column as used in FA.

The set of data acquisition parameters for Angelholm is not optimal for FA. The four lower scans have now twice as much longer range (240 Km) but at the cost of half wind speed range. Also the increase in reach range but with the same angular resolution generates separations among the rays in the outer parts of the scan disk with detrimental effects on FA performance. Although this second drawback can be effectively handled by a suitable remaping of the image, it is decided for this work to select out elevations at 4.0 and 2.5 degrees (in bold). This choice is also motivated as a good way to illustrate the importance of selection of elevations.

Figure#7 displays footprints of the radar beams on the levels used for alignment. On the right, Virring shows a smooth continuous coverage of the area swept by the different elevations. On the left, Angelholm lacks this continuity because the angular distance between scan 1 (4.0 degrees) and scan 2 (2.5 degrees) is too wide to avoid the occurrence of areas in

the shadow for alignment level 26 (4792 m a.m.s.l). This situation is also reproduced for many other alignment levels.

3.3 Running FA software on the ODIM-HDF5 data

The final task consists in running the FA application on the DOW data presented above. The exercise comprises 12 runs, from 01 UTC to 12 UTC on May 24th. The following tables summarize the results. The "overlapping threshold" which usually is introduced to avoid running the app on empty or nearly empty images is here lifted in order to illustrate the behavior of the algorithm in these cases.

Date	Overlap (%) sc1/sc2/sc3/sc4	Iterations to Convergence (#)	Winds (#) Raw / after th+QC
20220524:01	17 / 21 / 22 / 21	70	5792 / 230
20220524:02	32 / 40 / 40 / 39	89	11177 / 587
20220524:03	43 / 53 / 53 / 48	83	14567 / 727
20220524:04	46 / 56 / 55 / 47	80	15092 / 671
20220524:05	39 / 52 / 51 / 47	65	13973 / 569
20220524:06	26 / 37 / 38 / 35	77	10048 / 304
20220524:07	10 / 22 / 25 / 23	100 (max)	5874 / 184
20220524:08	1 / 6 / 8 / 8	0	0 / 0
20220524:09	0.5/ 0.5/ 0.9 / 2	0	0 / 0
20220524:10	0.4/ 0.5/ 0.8 / 2	0	0 / 0
20220524:11	3 / 2 / 2 / 3	0	0 / 0
20220524:12	5 / 3 / 2 / 3	0	0 / 0

Table#3 Summary of the results obtained with FA algorithm applied on Virring DOW data.

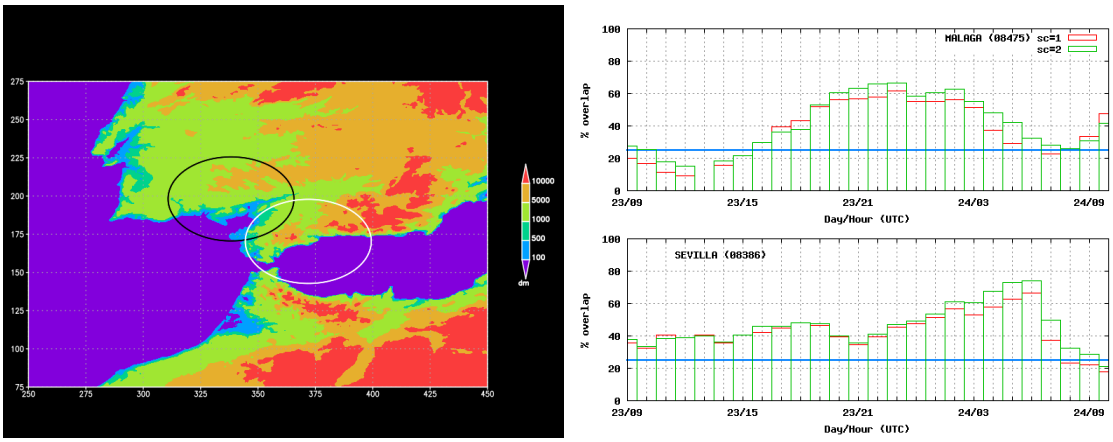
Date	Overlap (%) sc1 / sc2	Iterations to Convergence (#)	Winds (#) Raw / after th+QC
20220524:01	0.2 / 0	0	0 / 0
20220524:02	0.3 / 0.1	0	0 / 0
20220524:03	0.5 / 0.5	0	0 / 0
20220524:04	0.9 / 1.8	0	0 / 0
20220524:05	5 / 12	100 (max)	1203 / 1
20220524:06	13 / 25	100 (max)	2737 / 17
20220524:07	20 / 30	100 (max)	3626 / 20
20220524:08	23 / 37	100 (max)	4353 / 16
20220524:09	22 / 33	100 (max)	4036 / 17
20220524:10	19 / 29	100 (max)	3429 / 36
20220524:11	14 / 21	100 (max)	2509 / 17
20220524:12	8 / 19	100 (max)	1912 / 19

Table#4 Summary of the results obtained with FA algorithm applied on Angelholm DOW data.

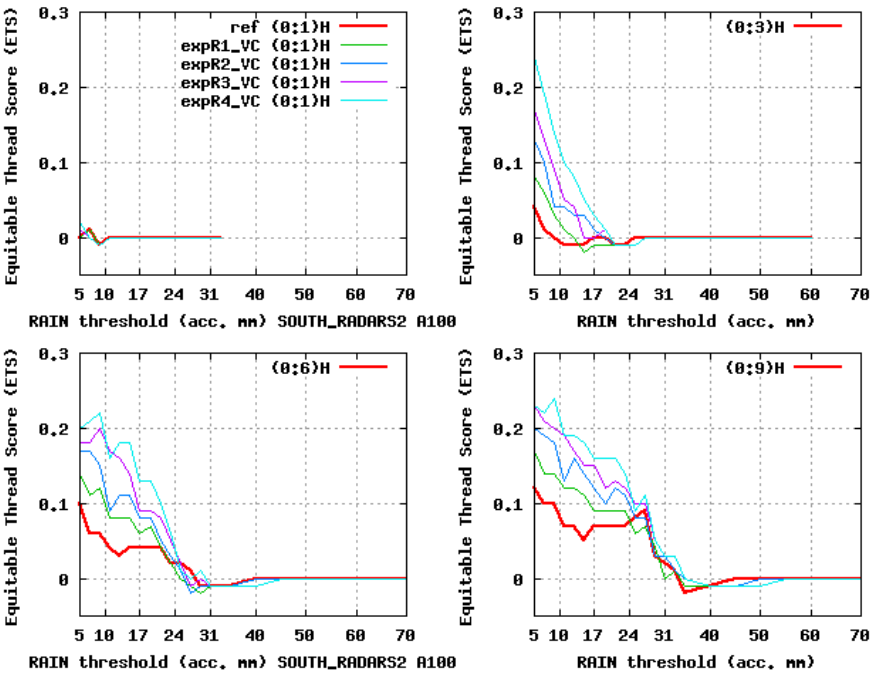
For Virring (Table#3) the FA performs well as expected. The cases with good coverage produce a high number of winds and convergence criteria are reached before the maximum allowed number of iterations (100). The process for selection of winds (QC+Th) depends on several parameters that can be adjusted. The values used here correspond with those used in the experiments carried out with AEMET data. The last two figures of this report illustrate the results of the FA processing on the DOW image corresponding to Figure#6. The first one (#8) displays the initial difference between radial wind model field and DOW radar image (left) and final difference (right). The last figure (#9) displays the field of wind corrections on one of the 30 alignment levels that compose together to give the four scans from Virring on the 24th at 04UTC. The left part of the figure displays the wind corrections on the mask used to work out the areas suitable for correction (color scale 0-1, with 0 displacement constrained to 0 and 1 displacement not constrained). The right part displays the same wind corrections with color scale for speeds in m/s. In both cases a 3x3 thinning has been applied on the image to improve clarity of the figures.

For Angelholm (Table#4) the FA does not perform well. The number of winds left after QC+Th is too low. Although this situation can be improved by adjusting some parameters, the important point here is that the selection of scans is crucial for the successful processing by FA. As already explained in the text above, the situation in this case is controlled by the non-optimal selection of scans.

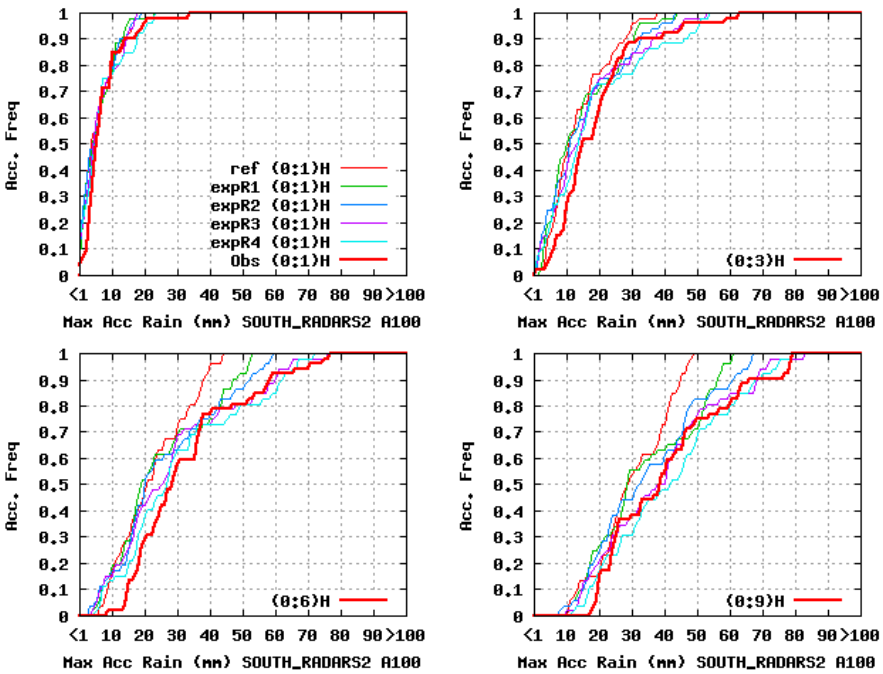
4 FIGURES



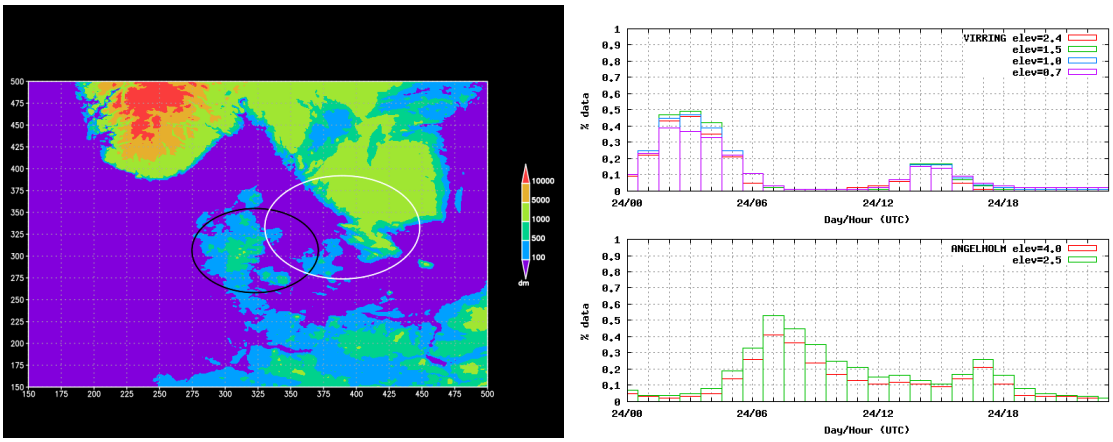
Figure#1 Location and DOW max range of the two AEMET radars used in the exercise to verify the implementation of FA in Cy43 (left). On the right the time series of the "overlap parameter" showing the % of the DOW radar image with meaningful echoes for the time period from March 23rd 09UTC until 24th 11UTC. The horizontal line marks the minimum value required to process the images with the FA algorithm.



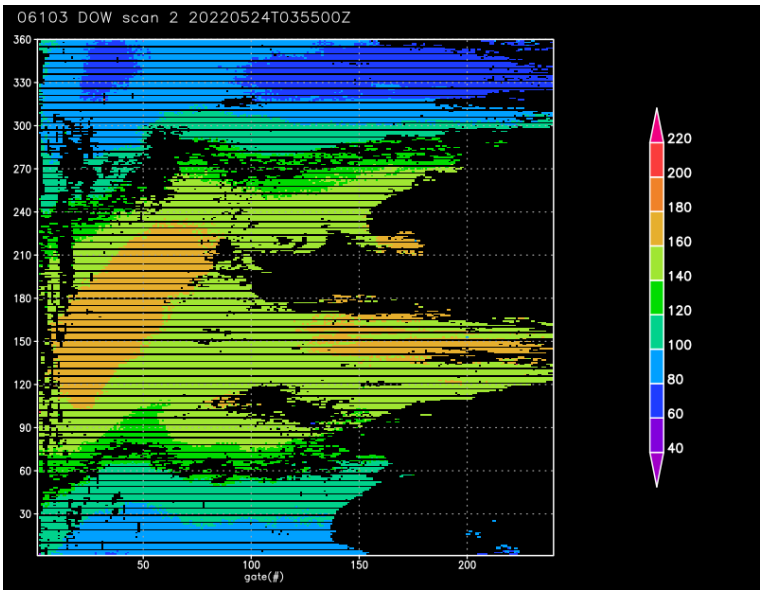
Figure#2 Equitable Thread Score (ETS) curves for precipitation accumulated in 1 hour (top left), 3 hours (top right), 6 hours (bottom left) and 9 hours (bottom right). The verification data comes from the AEMET network of automatic stations reporting hourly rain intensities. The stations used to compute these curves are located within an area of about 120 Km around the two radar sites (Figure#1). The curve colors correspond to the different experiments (see text). For moderate precipitation amounts there is a clear improvement with DOW FA and also with increasing number of DA cycles.



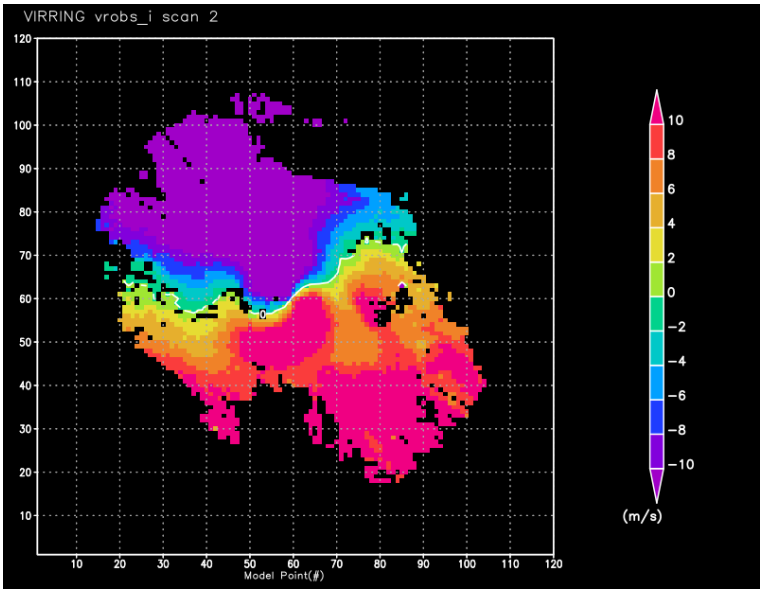
Figure#3 Accumulated histogram for the parameter maximum accumulated precipitation (m.a.p) in 1, 3, 6 and 9 hours. The sample is constructed by picking up the m.a.p. values from the 26 +9H forecasts between 23rd 09UTC and 24th 10UTC for the two areas around the radars of Málaga (08475) and Sevilla (08386). The red thick line corresponds to the observed values.



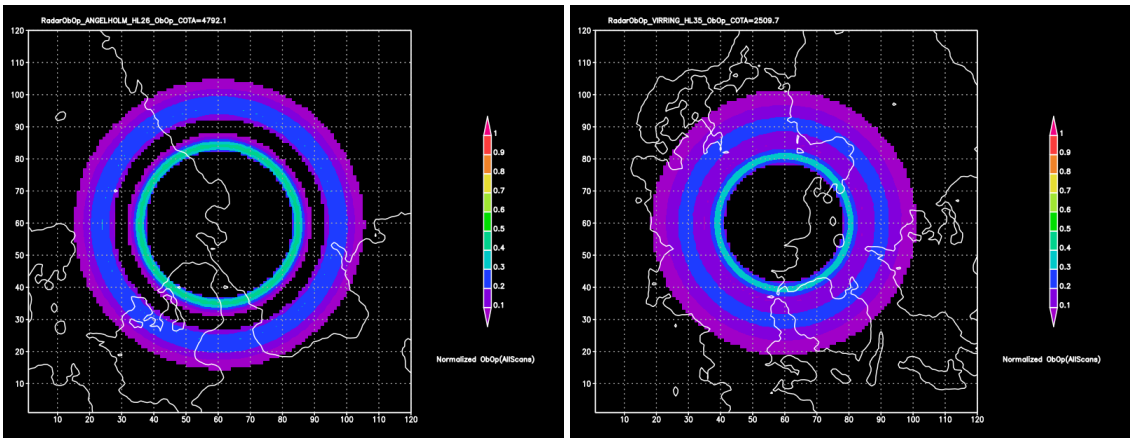
Figure#4 Location of the two Scandinavian radars used in this study and the max range reached for the elevations selected (see text). On the right, time series of fraction of DOW image covered by meaningful echoes at hourly resolution for the two radars (Virring top, Angelholm bottom). The data are actually available every 10 min (Virring) or 5 minutes (Angelholm).



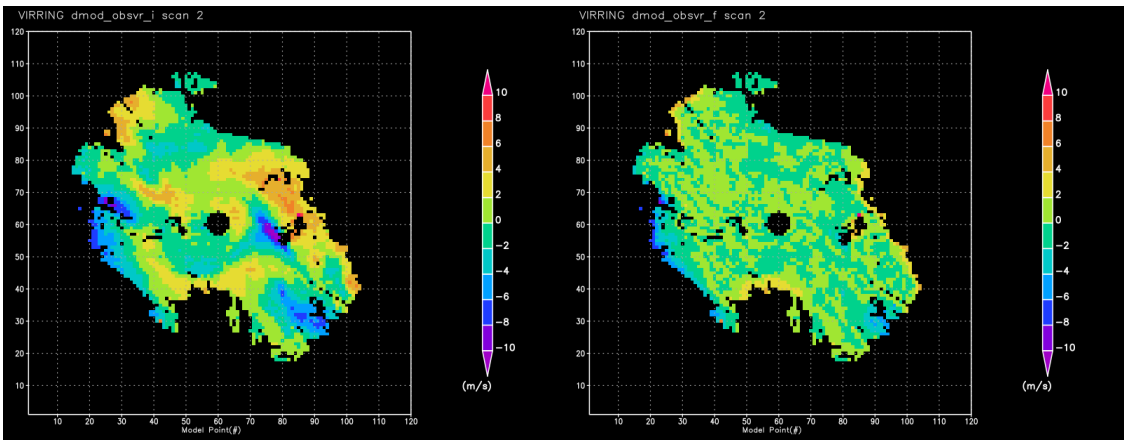
Figure#5. Data content of one DOW (VRADH) image corresponding to the VIRRING radar. The color scale is for 1-byte counts (calibration parameters are gain=0.36852, offset=-47.17). The missing rays are (correctly) encoded as “no-data” (255) but the pixels with no echoes (more frequent on the right of the image) and those with DOW values close to 0 m/s (wind perpendicular to the line-of-sight, 128 on the color scale), are all encoded as “undetect” (0). These files display also the “(-) out (+) in” convection for radial wind at difference with most other radars.



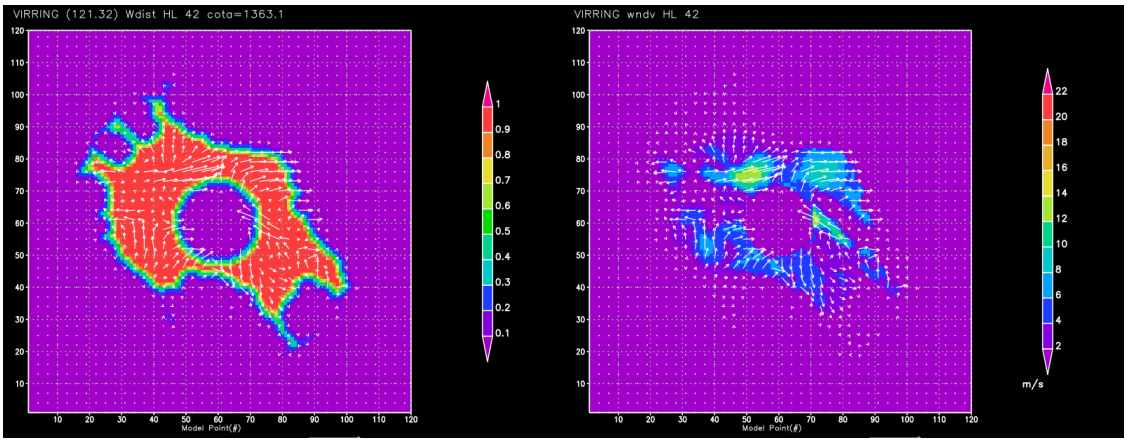
Figure#6. Data in Figure#5 after reduction to model resolution by superobbing. The data is now also translated to physical units (m/s) using the calibration coefficients in the HDF5 file. These are the images inputted to the FA algorithm.



Figure#7 Footprint of the radar beams on the model alignment levels for the cases of Angelholm (left) and Virring (right). The elevations selection is that described in the text. The annular areas in the shadow for the case of Angelholm have a clear detrimental impact on the FA algorithm performance as discussed in the section 3.3 “FA tests with ODIM-HDF5 radar data” of this report.



Figure#8 Differences between model radial winds and DOW radar image (that of figure#6) (i.e. VRmod-VRobs) before the FA process (left) and after the alignment (right). The case corresponds to 04UTC on the 24th from Virring, elevation 1.5 degrees. The color scale is in m/s. The other elevations (up to 4 in Virring) display similar features.



Figure#9 Corrections to the wind field extracted by the FA processing on the case illustrated also with figures #6 and #8 (Virring on May 24th at 04UTC). On the left the wind corrections (thinned 3x3) are displayed on top of the mask used to deal with data void areas. The color scale goes from 0 (displacement solution constrained to 0) to 1 (displacement solution unconstrained). On the right the same wind field corrections but now plotted on a color scale that represents wind speeds in m/s.

5 REFERENCES

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