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Detecting weather radar clutter using satellite-based nowcasting products

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Abstract. This contribution presents some initial results from investigations into detection of weather radar clutter by data fusion with satellite-based nowcasting products.

Weather radar data from three C-band Doppler weather radars of the Danish Meteorological Institute has been extracted for cases of sea and land clutter caused by anomalous propagation as well as cases of clutter free data. In addition, an operational nowcasting product developed by the *Nowcasting Satellite Application Facility* of EUMETSAT is used. The *Precipitating Clouds* product, which is based on Meteosat-8 data and auxiliary information from numerical weather predictions, provides probabilities of precipitation for every pixel in a Meteosat-8 scene. Via pixel-level image fusion of the radar data and the *Precipitating Clouds* product, supervised classification of the radar echoes into clutter and precipitation classes is performed.

Results from classification of three typical events are shown and discussed. Cases of moderate and severe ground clutter caused by anomalous propagation is detected with high accuracies. However, misclassification of radar echoes is observed both during no-clutter precipitation events and when precipitation areas are close to areas of clutter.

1 Introduction

Weather radar clutter is a major contributor to degraded radar data quality and is an obstacle for the many applications of weather radar data: For its traditional uses in forecasting and decision making and in particular for the use in automated procedures and models incorporating radar data, e.g. hydrological, nowcasting and numerical weather prediction models.

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Various methods for detection, mitigation, and removal of clutter has been proposed (Steiner and Smith (2002) gives a good overview) ranging from low-level signal processing methods over higher level pattern recognition to data fusion methods and the use of new advances in radar technology (e.g. dual polarimetric radars). Traditional clutter detection methods using Doppler velocity filtering are capable of removing stationary land clutter, however, sea clutter and other clutter originating from moving targets is difficult to detect using single-polarized radar data alone.

This contribution thus takes a data fusion approach, more specifically image fusion of a new nowcasting product based on mainly Meteosat-8 multispectral data. Previous studies using information fusion of weather radar data and first generation Meteosat multispectral imagery have shown promising results for the detecting and removal of clutter (Michelson and Sunhede, 2004). Naturally, the improved spatio-temporal resolution of the Meteosat Second Generation sensors, coupled with its increased number of spectral bands, is expected to yield even better estimation of precipitation (Levizzani et al., 2001) and therefore potentially improved clutter detection.

2 Data

2.1 Radar data

Radar volume data were retrieved for three of the four weather radars of the Danish Meteorological Institute (DMI) located at Sindal, Rømø, and Stevns. All three radars are C-Band Doppler radars. The individual radar volumes where preprocessed into 2D images using an in-house DMI algorithm and then projected into a common mosaic for full coverage of all three radars (See Fig. 1, top row). The spatial resolution of the final radar mosaic is 1 km and the temporal resolution is 10 min.

2.2 Nowcasting SAF products

Measuring and mapping of precipitation from space-borne platforms (in low-earth and geostationary orbits) can be performed using passive sensing of the visible and infrared parts of the electromagnetic spectrum as well as passive and active sensing in the microwave region (See Levizzani et al. (2001) for an overview of the techniques).

For this study a new product developed by EUMETSATs 'Nowcasting Satellite Application Facility' (Nowcasting SAF) is used. A wide range of products are developed within the Nowcasting SAF, of which some are more or less related to precipitation: Cloud masks, types, and height products, and several precipitation products. Of the latter, the *Precipitating Clouds* (PC) product is particularly interesting in relation to quality control of weather radar data. The *Precipitating Clouds* product provides probability values for three precipitation classes for each pixel in the Meteosat-8 scene: heavy, light to moderate and no precipitation. The algorithm behind the PC product uses a linear combination of the spectral information of the Meteosat-8 bands together with surface temperatures from a numerical weather prediction model (NWCSAF/PGE04, 2005). The PC data have a 3 km spatial resolution at nadir (5 km at latitudes of Scandinavia) and 15 minute temporal resolution.

3 Method

The data sets are combined by pixel-level image fusion (Pohl and van Genderen, 1998) followed by supervised classification using a scale-space ensemble classifier as described by Bøvith et al. (2006).

3.1 Pixel level image fusion

Pixel-level image fusion involves geocoding and interpolation of the images to a common grid. Here a stereographic map with a grid spacing of 1 km is chosen to match the resolution of the radar data.

The difference in temporal resolution of the data sets is dealt with in this simple way: For each radar image the closest matching nowcasting image in time is chosen. The maximum temporal mismatch between the data sets is thus 5 min which at a velocity of clouds of e.g., 10 ms^{-1} will result in a 3 km mismatch of the observed features. This corresponds to three pixels in the final grid and could give rise to increased misclassification errors.

The effects of the difference in temporal resolution was inspected visually by superimposition of the fused images and some disagreements between features were observed. The reason for the mismatch, however is not only the temporal misalignment but also the fact that the two datasets observe different phenomena; The radar measures backscatter from the precipitation itself whereas the satellite product is derived from the reflected and emitted energy from cloud top.

3.2 Scale-space ensemble method

Supervised classification is performed by extraction of manually selected training samples for precipitation and clutter classes in the radar images. The training data are divided into two groups, one for building the classifiers and one for evaluation of the classification results by computation of the classification error.

Classification is done using a *scale-space ensemble classification method*: Firstly, a scale-space representation of the input features is created by convolution of the input features with a Gaussian kernel of a given window size corresponding to the scale. This blurs the input features which was shown in Bøvith et al. (2006) to mitigate the influence of the misalignment between the fused images. Secondly, an ensemble classification method (also called a multiple classifier method) is used in which several models for classification are combined into an improved classifier with better performance than classification by use of each model individually.

4 Example cases

Three typical cases were processed using the method described above. Case I is a case of severe sea clutter and moderate land clutter without precipitation. Case II is a case of sea clutter with precipitation and finally, Case III is a case of no clutter during the passage of convective precipitation (See Fig. 1).

Case I. Clutter, no precipitation. 2006-05-05 20:10 UTC
In the months of spring, summer and fall in Denmark, anomalous propagation (AP) conditions are quite frequent, giving rise to weather radar clutter due to superrefraction and ducting of the radar beams. Especially the radar at Stevns experiences AP due to its location very close to the coast line of the Baltic Sea where temperature inversions occur frequently due the flow of hot and moist air masses over the colder ocean surface.

For more than a week starting around May 5, 2006, the weather in Denmark was characterized by clear air and high pressure with little precipitation. Pronounced sea clutter is seen over a large part of the Baltic Sea and moderate sea clutter is seen in the North Sea (See Fig. 1, column 1). On all radars, close range land clutter is seen, especially on the northern most radar at Sindal. From the Meteosat-8 infrared band 4 and the *Precipitating Clouds* probability map it is seen that only a little precipitation was present (in the middle of the North Sea).

The bottom image in column one in Fig. 1, shows the result of classification of the radar echoes by image fusion with the PC image. Perfect classification, i.e. a classification error of zero, was obtained for this case. The classification error (reported in Tab. 1) was computed from the confusion matrix between training samples and validation samples.

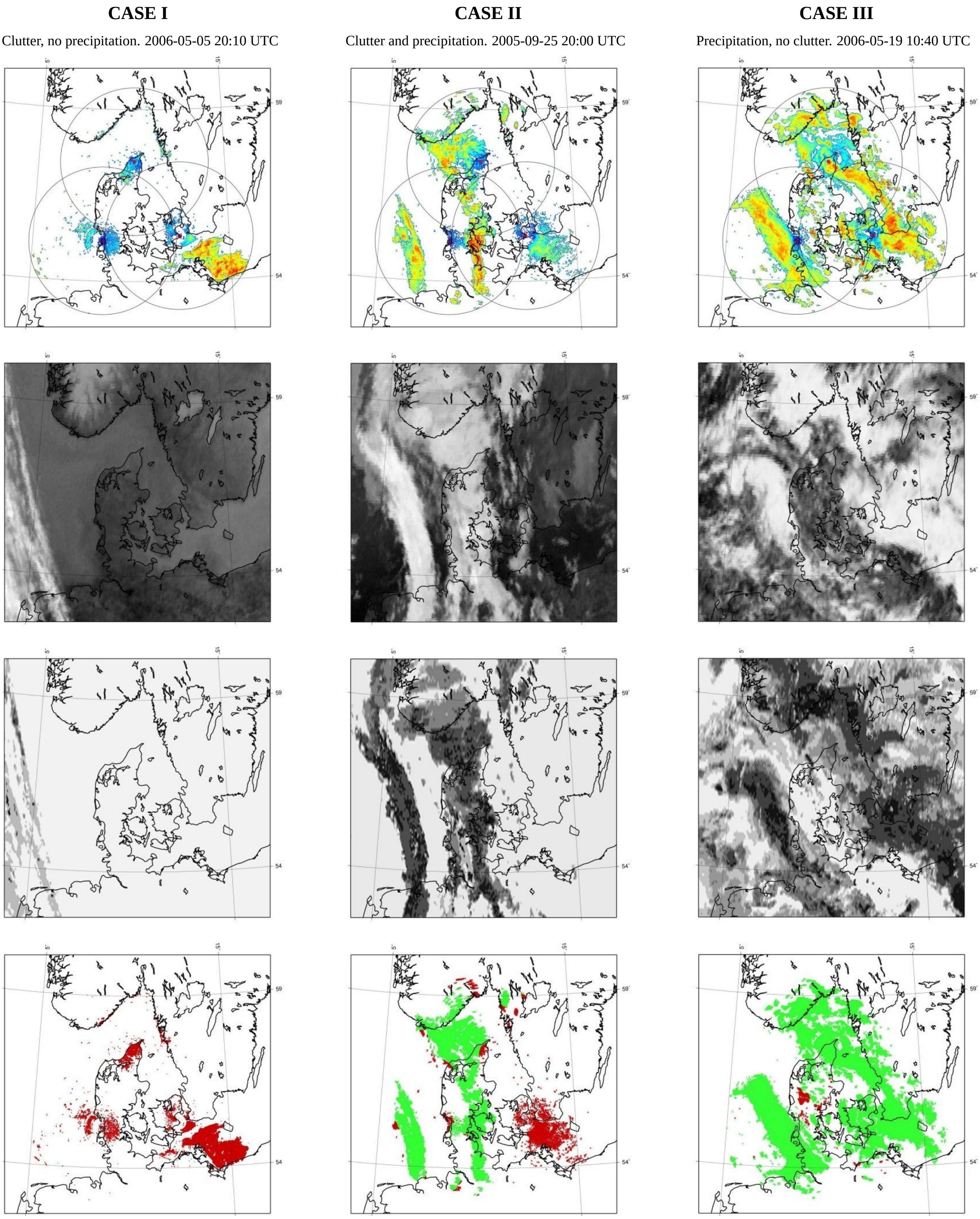

Fig. 1. Case I–III. Rows (top down): **1)** *Radar reflectivity factor* (blues are low reflectivities, greens and yellows are medium, orange and red hues are high reflectivities). Northern-most radar is Sindal, western is Rømø, eastern is Stevns **2)** *Meteosat-8 IR 3.9 μm* (bright hues are low brightness temperatures (clouds)) **3)** *Nowcasting SAF Precipitating Clouds* (dark colors are higher probabilities of precipitating clouds, bright or white are lower probabilities) 4) *Classification result* (red are radar echoes classified as clutter, green are precipitation).

Table 1. Classification error (validation samples misclassified) and the Total Error (all pixels taken into consideration).

Case	Classification error rate	Total error
I	0.00 %	0.00 %
II	1.37 %	8.01 %
III	0.94 %	3.26 %

Case II. Clutter and precipitation. 2005-09-25 20:00 UTC This case exemplifies the case of AP clutter echoes near precipitation areas. Two precipitation areas stretching north-south coming in from south-west are noticed as well as a large area of sea clutter in the Baltic Sea. The reason for the AP conditions was a strong temperature inversion which lasted throughout the day into the night. Severe AP clutter mixed with precipitation is not as common as AP clutter alone due to the meteorological conditions causing AP, however the cases of mixed clutter and precipitation are more complex to detect.

The classification result is not as good as in Case I; the classification error is 1.37 % and the total error is 8.01 %. The total error is computed on the basis of all of the pixels in the scene and not only the training/validation samples which are selected in areas where there is no doubt upon the alignment of the two data sets (i.e. not on the edges of precipitation and clutter areas). Clutter is seen to be classified very well, however some precipitation on the edges of the precipitation fronts is misclassified as clutter and close range land clutter on the radars at Sindal and Rømø is misclassified as precipitation.

From Case II it is also noticed how the *Precipitating Clouds* product contains accurate information on which clouds are precipitating and which are not. For example, the clouds near the sea clutter area are not given very high probability of precipitation and hence the clutter echoes off the coast of Stevns are classified correctly as clutter. It can also be seen how the PC product has a tendency to overestimate the amount of precipitating clouds which leads to misclassification in areas of mixed precipitation and clutter.

Case III. Precipitation, no clutter. 2006-05-19 10:40 UTC Case III shows an event of convective showers moving north-east extending over most of the radar coverage. No clutter was observed during this event except for minor areas of close range ground clutter and some mid to far range land clutter on the coasts of Norway and Sweden on the northern most radar at Sindal. This case was included for checking the detection method on clutter free data which is relevant for the evaluation of the method in relation to its operational use. Ideally, all radar echoes in this case should be classified as precipitation. As seen in the classification result this is not the case. The precipitation areas of the convective system are classified as precipitation with a classification error of 0.94 % and a total error of 3.26 %. Areas of precipitation in the central part of Jutland are misclassified as clutter which is due to low PC probabilities here. The problems of misclassification at the edges of precipitation is not seen in this case.

5 Conclusions

The initial results of detecting weather radar clutter by pixel-level image fusion with *Precipitating Clouds*, an operational nowcasting product based on satellite data, is presented.

The method uses supervised classification and the results from three typical cases is shown. Classification error rates from 0.00 to 1.37 % (0.00 to 8.01 % total error) are achieved depending on the complexity of the scene. Cases of sea and land clutter caused by anomalous propagation are detected with high accuracies, especially for the case of no precipitation in the vicinity of the clutter. Misclassification occurs when precipitation is near areas of clutter and in the case of precipitation and no clutter.

The satellite-based dataset overestimates precipitation which results in clutter being misclassified as precipitation. Other sources of errors stems from the different nature of the multi-source data. The method is generally capable of detecting clutter with a high accuracy at the expense of some misclassification of precipitation.

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