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Synergetic use of METEOSAT 8 data and Radar products

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Abstract

Satellite and radar products are important data sources for operational meteorology. They provide information to monitor numerical weather model behaviour. In many cases comparing them to each other validates their products. In the comparison, however, one of them is accepted as providing the 'truth', despite known deficiencies.

This paper proposes a synergetic use of both different remote sensing techniques. The synergy provides a method to compensate the deficiency of one technique by using information from the other technique.

The paper illustrates the benefit of synergy for the precipitation and echo top heights products of radar and cloud top heights from satellite. The synergy leads to suppression of spurious signals and facilitate the product interpretation both by forecasters and the general public. It also facilitates the removal of errors in automated processing of data.

INTRODUCTION

Radar and Satellite observations are well embedded and appreciated in the operational meteorological community. Both methods provide a large aerial and regular distributed coverage in comparison to synops stations, radiosondes and other meteorological observations. Radar and geo-stationary satellite imagery provide a high temporal sample frequency much appreciated in now-casting and forecasting. The prevailing use of this information is dominated by the direct interpretation of the observed signals, of which the signals directly relating to significant weather phenomena are preferred by forecasters, e.g. cloud coverage and precipitation.

Improvements in radar technology and the SEVIRI instrument on board of METEOSAT 8 led to an increase in available products for end users. The EUMETSAT initiative of the Satellite Application Facility on Nowcasting and short range forecasting (SAFNWC) resulted in a number of added value products intended to support the forecaster. The product list from radar increased due to the introduction of the Doppler radar, next to the already well appreciated precipitation product.

The acceptance of new products in forecasting encounters lower thresholds when the products are validated, and the accuracy and error characteristics are known. Independent validation of remote sensing observations, active; radar or passive; satellite imager, is not a straightforward activity. It may involve expensive in-situ observations. Cost effective validation methods are welcomed.

Fortunately the synergy between radar and satellite facilitates the opportunity to validate part of the products of both remote sensing instruments. The synergy does not always provide a direct validation, but provides information to correct for erroneous interpretations in both techniques. This valuable information intends to lead to an increase in product use as the forecasters have a better understanding of the observation characteristics and uncertainties.

In most studies one of the two methods radar or satellite observation is accepted as the truth. Here a cross fertilization is proposed where the deficiencies of one method can be partial or even completely corrected by the other method.

This paper describes the start of synergetic use of radar and satellite observations in the following sections covering: radar products, satellite products, method, results, conclusions and applications.

INTRODUCTION TO (KNMI) WEATHER RADARS

A weather radar employs scattering of radio-frequency waves (5.6 GHz/5 cm for C-band) to measure precipitation and other particles in the atmosphere (See Doviak and Zrnić (1993) for more details). The intensity of the atmospheric echoes is converted to the so-called radar reflectivity *Z* using the equations for Rayleigh scattering. The Rayleigh equations are valid when the wavelength of the radar is much larger than the diameter of the scatterers (maximum 6 mm for rain). In that case, the radar reflectivity depends strongly (sixth power) on the diameter of the rain droplets. The radar reflectivity is a good measure for the strength of the convection (updrafts) and the amount of moisture in the atmosphere.

KNMI operates two identical C-band Doppler weather radars from Gematronik GmbH. One radar is located in De Bilt (52.10N, 5.18E) and the other one in Den Helder (52.96N,4.79E). The received signal is digested by a RVP6 radar processor (Sigmet Inc, www.sigmet.com) and the generation of radar products is done with the Rainbow package (www.gematronik.com). The operational reflectivity scans currently consist of a four-elevation scan (0.3 – 3 deg) every five minutes and a 14-elevation scan (0.3 – 12 deg) every 15 minutes. In addition, a five-elevation Doppler scan (2 – 25 deg) is performed every 15 minutes. The following products are produced operationally from the weather radar scans:

Reflectivity composites at low altitude (800 meter above msl). This main radar product showing the precipitation patterns is generated from the four-elevation scan. A European composite is generated every 15 minutes from the national composites of UK, Germany, France, Belgium, and the Netherlands.

Accumulated precipitation over 3-hour and 24-hour periods. The accumulations are based on the reflectivity composites and are adjusted with rain gauge observations.

Echotop height composites (ETH). This product showing the maximum height of the radar echoes is generated from the 14-elevation scan.

Hail warning product. Large hail is detected using the height difference between the 45 dBZ echotops and the freezing level from a Numerical Weather Prediction model (Holleman 2001).

Weather radar wind profiles extracted from the Doppler scans. A study focused on the optimisation and verification of these wind profiles has been performed at KNMI (Holleman 2005).

All weather radar products are available in the HDF5 format (hdf.ncsa.uiuc.edu/HDF5). The HDF5 data model used by KNMI is described in Roozekrans and Holleman (2003).

SPURIOUS ECHOES IN WEATHER RADAR IMAGERY

Within weather radar imagery spurious echoes can sometimes be seen which are not related to hydrometeors/precipitation. These echoes are referred to as “clutter” and can have many different causes. Echoes due to the antenna side lobes, from mountains, buildings, and due to anomalous propagation of the radar beam are the most common kind of clutter. Most operational weather radars have effective systems to reject or filter this kind of clutter. At KNMI a statistical filtering is used to reject (anomalous propagation) clutter, see for details Holleman and Beekhuis (2005). Occasionally other kinds of clutter can be seen in weather radar imagery originating from (Asmus, 2005):

Kerosene. An aircraft sometimes releases large amounts of kerosene (droplets) which can be detected by radar.

Birds and insects. Especially during large migration events echoes due to birds and insects around convergence lines can be seen in radar.

Ionised gases. Smoke from industry containing ionised gases can give spurious echoes.
Refraction gradients. Atmospheric turbulence and gradients can give rise to Bragg scattering.
Artificial objects (chaff). Aluminium flakes are sometimes distributed by military aircrafts to distract enemy radar.
Nowadays, the most direct way to reject spurious echoes is by using a so-called dual-polarization radar. This type of radar can make a direct distinction between the hydrometeors and other non-meteorological target using phase and intensity information from horizontal and vertical polarizations (Bringhi and Chandrasekar, 2001). Unfortunately, the vast majority of the operational weather radars in Europe still uses single polarization (about 150 radars), and so far only a few dual-polarization radars have been installed. In the meantime satellite information can provide additional information for the rejection of spurious echoes.

This study starts with the evaluation of the ETH product. This product is selected as the synergy with satellite is expected to have the largest added value in this stage of the project. Next to this the European precipitation composite, and the hail probability are studied.

SAFNWC PRODUCTS: CLOUD MASK, CTTH, RDT, HRV WINDS.

The synergetic use of radar and satellite data is here focussed on nowcasting purposes. Nowcasting is served by a high observation frequency as is provided by radar.

The observation frequency of the radar has to be matched by the satellite information when satellite information is used to improve the radar signal. The update cycle of the ETH product is 15 minutes, corresponding to the METEOSAT 8 cycle. This renders the obvious choice to start the study with the METEOSAT 8 products.

METEOSAT 8 corresponding products to radar products can be delivered by the SAFNWC. (nwcsaf.inm.es). The SAFNWC software provides products within the required timeliness. Still the SAFNWC products have a time delay of approximately 10 minutes. For the proof of concept presented here the time delay is not relevant. In a future operation phase of this project the time delay issue can be addressed by using forecasted METEOSAT 8 imagery, e.g. based on the CINESAT software (www.gepard.at). As only a limited forecast time of 15 or at the most 30 minutes is required for this application, the forecasted images are expected to differ marginally from the observed images.

A number of SAFNWC products can be used to improve or compare to the various radar products: Cloud mask, Cloud type, Cloud top temperature, pressure, height (CTH), Rapid developing Thunderstorms (RDT), Convective rainfall rate, precipitating clouds, and High resolution winds (HRV).

The SAFNWC software version 1.2 is installed and products are available at KNMI. The end users however have some reluctance towards the use of some products as they lack information about the product validity and error characteristics. Here comparison to radar products is introduced to improve SAFNWC product use.

METHODOLOGY

The applied method to improve products from one of the two observation methods is a straightforward approach, depicted schematically in figure 1. One of the two observations is compared or evaluated and when applicable filtered on base on the results of the other method. The filter is not a predefined function here. It depends on the application what the function will do with the observations.

Radar product → Filter → Improved product

SAFNWC ↑ product

***Figure 1*: Scheme to improve either one of remote sensing methods. The Filter can use SAFNWC products or Radar products to improve the products from the other sensor.**

The method is kept straightforward to ensure that the end-users can interpret the end product easily, and also the associated error characteristics.

RESULTS

The Echo top heights product at KNMI is presently not filtered for clutter at KNMI. Here the SAFNWC cloud information leads to an improved product as is shown in figure 2. Here an ETH product is heavily affected by clutter, indicated in red in the figure. Displaying only radar signals where the SAFNWC cloud mask identifies a cloud, resulted in a radar product more appreciated by the end-users.

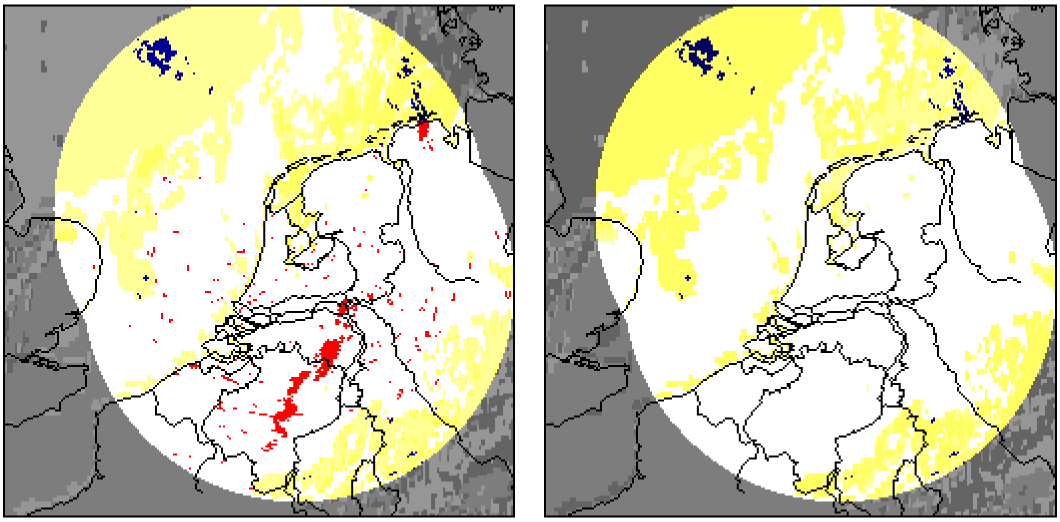

Figure 2. **June 8, 2006, 12:00 hr GMT. Composite of the KNMI radar ETH product in red (clutter) and blue merged with the SAFNWC cloud mask, represented in white as cloud free and yellow as cloudy. The coloured area within the grey area indicates the radar coverage. Left is the original image and right is the filtered radar product.**

The applied method is only applicable in clear cases as shown in figure 3 for a case with nearly complete coverage. Here the filter function has only a marginal impact on the radar observations.

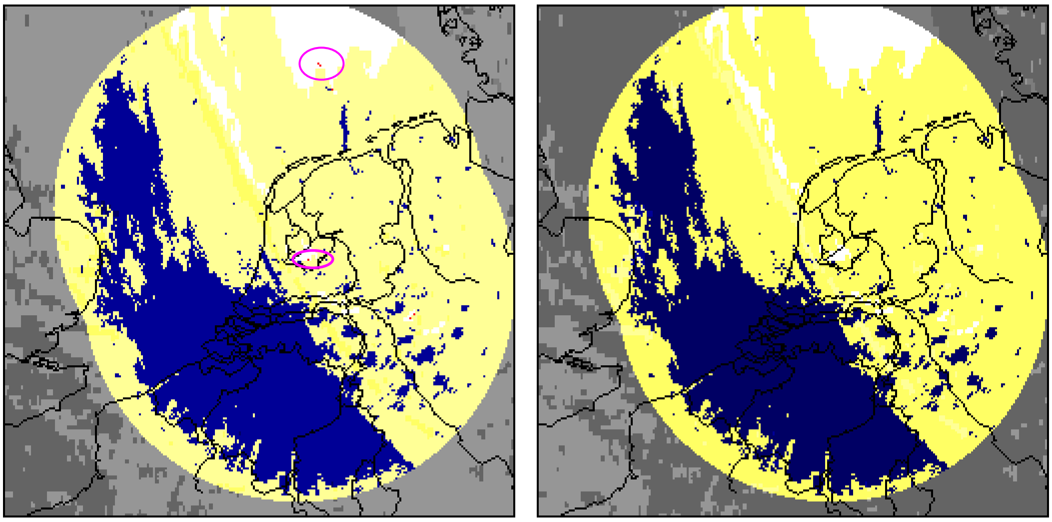

Figure 3. **Caption as in Figure 2 but for June 1, 2006, 12:00 hr. Only two clutter cases could be identified indicated by the purple ellipses. Please note the attenuation at the South West of the radar product.**

The filter method based on satellite information has the advantage that it will not remove any correct radar echoes. The statistical based clutter removal algorithms can remove some of the correct radar echoes.

The filter method enables a more homogeneous presentation of the European composite available at KNMI. An example is given in Figure 4 for the precipitation product.

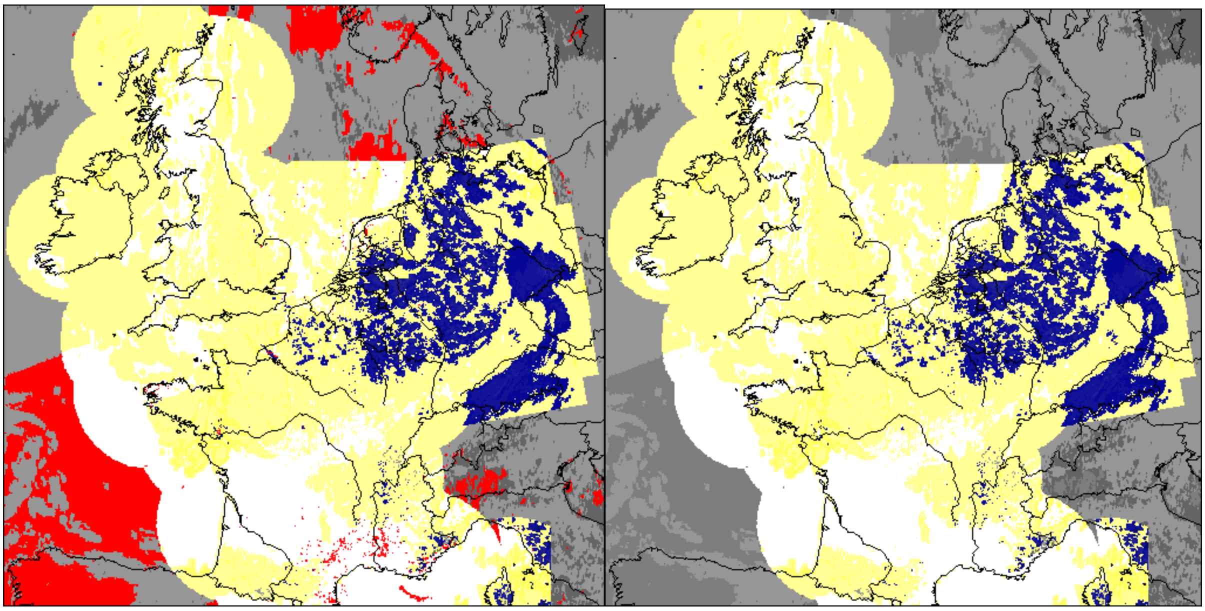

***Figure 4*: June 1,2006, 12:00 hr GMT. Precipitation product based on radar observations from the United Kingdom France, Germany, Belgium, and the Netherlands. Notice the clutter removal in the left image over southern France and in the northern part of the Netherlands. The cloud free areas outside the radar coverage also appear in red in the left image.**

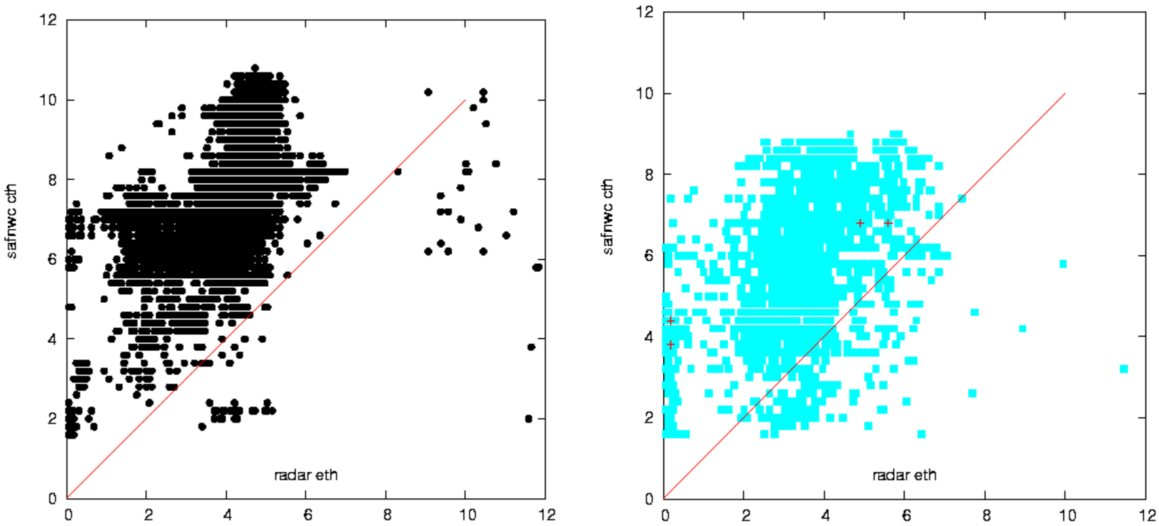

***Figure 5*. Comparison of radar echo top heights (ETH) with the SAFNWC cloud top heights (CTH) in kilometers for June 1, 2006 stratiform rain in black (left) and April 29, 2006 at 12:00 hr, convective rain in cyan (right). The red line indicates the one to one ratio. Only for 0.7 percent of the total number the ETH is higher than the CTH for the stratiform case and 10 percent for the convective case. The hail probability radar product is indicated in red in the right figure. Four cases could be identified for this specific moment, two with a low probability, close to the ordinate, and two with high probability, close to the one to one ratio red line.**

The ETH radar product is also directly compared to the SAFNWC CTH for two cases, a stratiform rain and a convective rain case. As both observation methods observe essential different phenomena;

radiation by satellite and signal reflection by radar, differences are expected with CTH derived from satellite observations being higher than ETH. This is in agreement with the stratiform case as shown in Figure 5. Only in 0.7 percent of the cases ETH is higher than CTH.

In convective cases the stronger updrafts enable the hydrometeors to come closer to the cloud top. This is apparent in figure 5 where for the convective day the results are closer to the one to one ratio line. There are more cases where ETH is larger than CTH, 10 percent of the cases. This can be attributed partially to resolution differences between the radar and the satellite. The radar can observe smaller scale features. The satellite products are derived from satellite pixels that are larger than the radar pixels. This difference could cause cases where ETH is larger than the CTH.

From the studied cases it is apparent that up to a height of 8 km the CTH and ETH can be compared. Above 8 km the chances increase that satellite and radar do not observe the same cloud. The occurrence of semi transparent or multi-layer clouds results in differences in determined cloud top heights. The radar is not able to observe non-precipitating clouds, where the satellite can observe (over laying) cirrus clouds.

The comparison of radar derived wind profiles versus the high resolution wind products of the SAFNWC was hampered by the apparent differences between the ETH and CTH. As CTH is in most cases higher than ETH, the wind vectors derived from both methods are not expected to have a good correlation.

A first study was made on the improvement of the hail product. In figure 5 the hail probability for four cases occurring on June 1 2006, 12:00 hr are indicated. The cases with higher probability are close to the one to one ration line and the cases with a low probability are close to the ordinate. This is in accordance with the expected results. Unfortunately the data archive was too small to have a significant number of cases, which could serve as a solid base to improve the hail probability product. Information about the cloud top temperature and/or cloud top phase from satellite is expected to have added value for the hail probability product.

CONCLUSIONS

Radar observations and geostationary satellite observations are both remote sensing techniques having a significant aerial coverage and high frequency in temporal sampling. Hitherto both techniques are used to validate each other. It is however beneficial to make use of the synergy of both techniques, where one of the observation methods can compensate deficiencies of the other technique.

In this study two radar products, echo top heights and European precipitation product can be improved by using information from geostationary satellite observations. The cloud information of the SAFNWC software is used as it is rapidly available after the METEOSAT 8 observation.

The radar products can be contaminated with echo’s originating from non-hydrometeors, also referred to as spurious echo’s. When this occurs in areas where the satellite does not observe clouds the information of the satellite can be used to remove the clutter. This filtering method is only applicable in clear areas.

The proposed clutter removal is a secure and prudent method that will not remove correct hydrometeor echo’s, where statistical removal techniques could remove correct signals. The removal results in a filtered radar image. The improved image increases the confidence of the professional end user and the general public in the radar products.

The SAFNWC Cloud top height can be used to improve the radar Echo Top Height. Too high values can be filtered when compared to the corresponding CTH.

It is known that the SAFNWC cloud mask may miss certain clouds, e.g low clouds. However for this application it is expected that the SAFNWC will correctly determine the thick clouds that produce rain. Low shallow clouds producing drizzle can be missed by the satellite. But these clouds are most likely also missed by the radar. So no erroneous filtering will occur in those drizzle cases.

APPLICATIONS

In daily practice the skilled forecaster hardly has problems distinguishing clutter from precipitation echo's. A filtered radar image, however, facilitates the interpretation by the forecaster and the general public when the radar images are shown on television or via internet.

For automated processing of the radar precipitation products for determining accumulated rain products, the presented filtering technique decreases the errors in the summation. Also other automated, non-manual supervised interpretations of radar observations will benefit from this filtering.

Comparison of SAFNWC CTH versus the radar ETH enables a filtering on the ETH product. Again resulting in a cleaner image, which will increase the confidence of the end user in the product.

Future applications

The ETH product can be used to validate the aerial coverage of the SAFNWC Rapid Developing Thunderstorm product. In this study a sufficient amount of data was lacking to perform this comparison.

The radar derived hail probability can be improved using the cloud top temperatures from the SAFNWC. Also here the stored data archive was too small to obtain any significant statistical correlation. This study is planned in the summer of 2006.

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