From Pulse to Product,
Highlights of the upgrade project of the Dutch national weather radar network

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Extended Abstract to Poster 408

1 Introduction

In 2015 KNMI has successfully finished the upgrade of the Dutch weather radar network. The main results of this upgrade are replacement of the two weather radar sensors of the KNMI Weather Radar Network and enhancements in the subsequent product processing in order to fully deploy capabilities found in the modern weather radar equipment.

During the European tender carried out in this project SELEX SI (formerly known as Gematronik) was awarded a contract to perform the replacement of both KNMI weather radars. Part of this contract is the integral maintenance of the radars, including all repairs and spares on a flat fee basis. KNMI itself however is taking care of the monitoring and configuration of the radars. KNMI in this way stays in control over its radar production.

Figure 1: The radar site Herwijnen at 5.1379E 51.8370N Low 25 meter tower, but far better radar horizon.

Figure 2: The retired radar on the 45meter tower at the KNMI premises in De Bilt .

In the course of his project KNMI took the opportunity to relocate the radar that for historical reasons was situated on the main premises of KNMI in De Bilt to a new location near the village of Herwijnen. Main reason for this relocation stems from the detoriation of the radar horizon of De Bilt, due to the vertical expansion of the city of Utrecht. KNMI acquired access to the tower of the former ATC radar situated in Herwijnen.

The radar product processing, in our central computer facilities, was updated as well. The Rainbow based Radar Product Processor is offering 'off the shelf' data processing, but is extended with KNMI maintained input and output filters, in order to create flexibility in the conversion to and from formats used by KNMI.

Some of the main design considerations are stated in this abstract, for the purpose of sharing this information

1.1 Workhorse approach

KNMI strived to deploy a rugged design with a strong focus on cost effectiveness and reliable operational use. This is reflected by KNMI's choice to stick on the classical receiver under elevation design. By placing the receiver in a well acclimatized room and providing hard wired connections to the signal processor, problems related with reliability often found in Receiver over Elevation (ROEL) setups are avoided. By restricting dual polarization operation modes to Simultaneous Transmit and Receive (STAR) mode only, problems that can occur with the switching elements in the waveguide are absent too. To keep the price of the radar low KNMI choose to install magnetron driven radars. Although klystron based transmitters show better performance characteristics when it comes to phase and power stability, much of the shortcomings of a magnetron driven transmitter can be corrected for by a capable signal processor.

1.2 Constant duty scan

Modern modulator equipment design does not rely on a pulse forming network to deliver power to its magnetron. In the classic pulse forming modulator design one could only chose from few discrete pulse lengths, but the modulators in the KNMI radars allow for choosing any pulse length between 0.5 and 3.5 microseconds. By carefully choosing pulse repetition rates and pulse lengths for each elevation it is possible to operate the magnetron close to its maximum power for each individual elevation in the volume scan. In this way the volume is probed with the maximum available energy, which thus optimizes the amount of information that can be derived from the atmosphere. As an extra the operating frequency of the magnetron is more frequency stable, because of the continuous load reduces temperature variations in the operating temperature of the magnetron.

1.3 Calibration on the fly

The (receive) path calibration of the radar is monitored by performing a single point calibration during every volume scan. For this purpose two high power wide ban noise sources are mounted in the receive path, one for each polarization. The noise sources are activated by the volume scan scheduler such that data sampled is not of meteorological interest as it will be beyond the atmosphere. In a similar way zero checks are performed several times during a volume scan. The results obtained are monitored on stability and trends. KNMI does not let the installations automatically adjust the calibration, but is warned by the radar monitor software when deviations in the calibration are detected by the built in test equipment.

1.4 Maintenance by the manufacturer

KNMI has decided not to perform maintenance of the radars itself, but to outsource it to the manufacturer. In former days KNMI employed its own radar technicians, but when they grew into retirement, their functions were not replaced. The main driver for this is that the maintenance of radar equipment is greatly reduced from radar generation to radar generation. Early nineties KNMI still scheduled yearly some 60 workdays on checks and maintenance of the two radars, while the current setup is serviced with an ample 6 days yearly. This made it more and more difficult for KNMI staff to keep up their skills on the desired level of operationality. On the other hand these skills are necessarily available by a manufacturer that designs and builds the radar equipment. So the KNMI management decided that the integral maintenance should be part of the tender, and that this should be acquired against fixed yearly costs. In this way the trust of the manufacturer in its own equipment is translated in yearly costs and covered by a service level agreement. As a result the total cost of ownership for the radars has not risen during this tender, whilst the risks on costly repairs are not put on the KNMI administration. It is mentioned here that radome maintenance is part of this settlement as well, as it is foreseen that the radome coating shall be renewed each five years.

1.5 Monitoring and configuration by KNMI

Knowledge on radar hardware and software configuration is important for KNMI in order to make an optimal use of the equipment. KNMI decided that this function should stay with KNMI. New young staff has been trained during the upgrade project and is now responsible for the configuration of the radar. Skilled staff is also important as interface to the manufacturer, reporting and commenting on errors and specifying enhancements needed by KNMI. Also monitoring of the equipment is a duty that KNMI performs. By automating procedures the level of monitoring is brought both to a higher level and a less time consuming task.

2 Radar Sensor Layout and Characteristics

KNMI operates two identical Meteor METEOR 735CDP10 Magnetron based C-band Dual polarization weather radars from SELEX, located in Herwijnen (5.1379E 51.8370N, WSG-84) and at a naval base in Den Helder (4.78997E 52.9533N, WSG-84). A brief overview of the main components in the radar processing chain is detailed below:

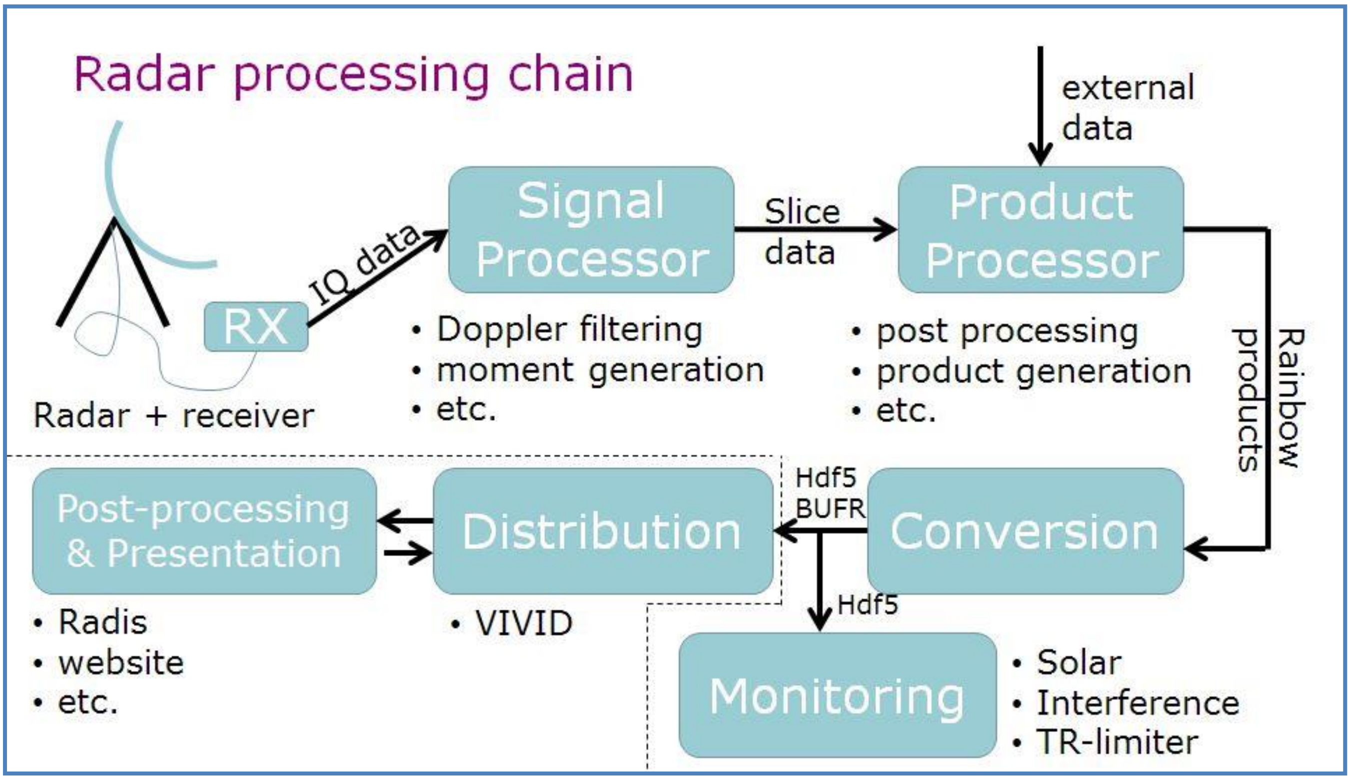

Figure 3: The radar processing chain..

2.1 Antenna and Mover

The 4.3 meter antenna is offering a one degree beam width and a 45 dB gain. The brushless drives and built in servos allow for a compact design of the radar cabinets as the servo racks are now integrated in the pedestal. The mover positions the antenna with high accuracy and can move 180 degrees over its horizontal axis.

2.2 Transmitter

The KNMI radars use magnetron based C-band transmitters offering a nominal peak power of 500 kW/peak. As setups require nowadays that spurious out of band emissions are greatly reduced a harmonic filter is placed in the waveguide. This filter is filled with SF6 gas to avoid arcing, which could occur in the filter due to the complex geometrical shapes needed to perform the filtering. The RF pulse is split in an horizontal and vertical channel after it passed the filter of equal power. As already stated the modulator setup can accommodate pulse lengths anywhere between 0.5 and 3.5 microseconds. The transmitter allows for Pulse Repetition Frequencies up to 2400 Hz.

2.3 Receiver

The returned echo signals in H and V are captured by two analog frontends that allows for a 120 dB dynamical range, and a 2 dB noise figure. Each frontend uses two separate receivers that have a gain offset of 20 dB. The most sensitive receiver is used to process low and intermediate signals but before the receiver reaches the nonlinear region of is sensitivity curve the less sensitive receiver takes over to handle the higher signal levels. By combining these signals a 120 dB dynamical range is reached. The receiver downmixes the received signals to an Intermediate Frequency (IF) of 60 MHz. The analog IF signals are digitized in the GDRX digital receiver directly, using 80 MHz ADCs. The GDRX receiver takes in the attenuated HF pulse generated by the magnetron too. This TX-sample is used to generate In-phase and Quadrature-phase (I & Q) signals, and to monitor the transmitted power.

2.4 Signal Processor

The signal processor is a capable industrial linux machine. Processing power and storage make it possible to retrieve and process all the moments in at the same time. KNMI retrieves the moments Zh, Zv, uZh, uZV, Vh Vv, W Wv, ZDR , cCor cCorv SQI SQIV CPA CPAv uPhiDp PhiDp, KdP, RhoHv. The signal processor is capable of processing all moments simultaneously. From the Signal Processor data are sent to the central Product Processor on a per PPI basis thus minimizing lag times due to transmission. The signal processor has a 3 terabyte storage buffer that can be used as a ring buffer to record continuously IQ data on the fly, thus allowing for replay and analysis of recorded events.

2.5 Control Processor

The radar control processor runs on standard industrial hardware, and is responsible for controlling all the radar hardware. Of course the antenna is the most “active” element to be controlled. But the control processer handles all bite messages and health and safety checks of the radar equipment too. It is the control processor too that controls the various interlock circuitry and software so to safeguard human exposure to dangerous voltages, radiation and physical risks.

2.6 Product Processor

The Linux based Radar Product Processor is using Rainbow5 application software for the product generation and configuration control of the radars. All single radar products are generated on this platform. In addition it performs compositing of local and European radar data. The Product Processor is extended with user maintainable input and output converters. As a result it is able to process BUFR data delivered by the GTS, as well as the sensor data coming in from the radar sensors. Output of the system is fed into the central KNMI distribution systems.

2.7 Distribution and display

KNMI uses an open (HDF5 based) data model for distributing radar data. This model is used for internal and external users alike. Applications within KNMI use this format to post-process radar data. One of these postprocessors is the web based display called RADIS available for all computers within KNMI, which has been developed in house using java.

New in house developments are underway in the form of a web based meteorological workstation called GEOWEB is now running for test.

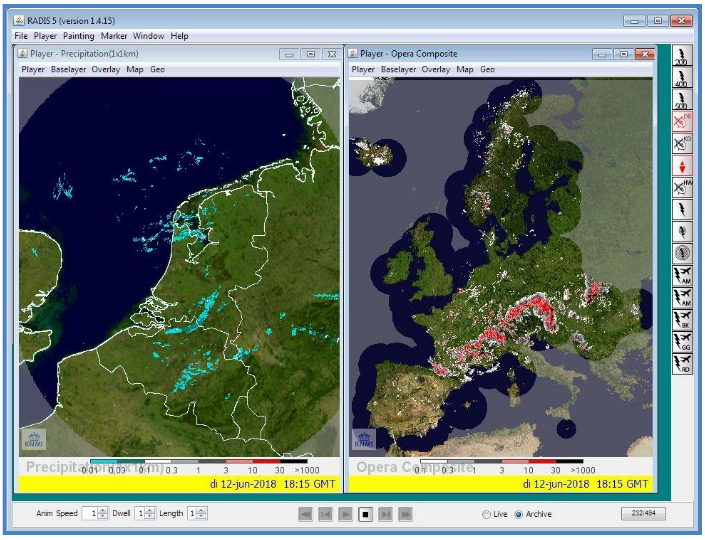

Figure 4: KNMI Radis display showing NL and ODC composite

3 Radar in operation: Scan schedule

The operational scanning of the KNMI weather radars generates a 16-elevation volume every 5 minutes. For all elevations in this volume scan, parameters can be chosen independently.

no.	elevation [deg]	high PRF [Hz]	low PRF [Hz]	pulsewidth [µs]	Time start	Time end
1	90	2400	-	0.5	0:00	0:12
2	12	2000	1200	0.6	0:12	0:27
3	8.0	2000	1200	0.6	0:27	0:39
4	4.5	1200	800	1	0:39	0:54
5	2.0	800	600	1.5	0:54	1:10
6	0.8	800	600	1.5	1:10	1:27
7	0.3	450	-	2.67	1:27	1:59
8	25	2000	1200	0.6	1:59	2:12
9	20	2000	1200	0.6	2:12	2:24
10	15	2000	1200	0.6	2:24	2:36
11	10	2000	1200	0.6	2:36	2:48
12	6.0	1200	800	1	2:48	3:03
13	2.8	800	600	1.5	3:03	3:19
14	1.2	800	600	1.5	3:19	3:36
15	0.3	800	600	1.5	3:36	3:59
16	0.3	450	-	2.67	3:59	4:30

Table 1: The main parameters of the volume scan.

The KNMI volume scan is semi interlaced, and allows for generating two pseudo cappi products from the same volume that are using nearly the same elevations but are time separated by 2.5 minutes. This intermediate pseudo cappi is currently running under test. By top down scanning the lowest elevation that is covering most of the area in pseudo cappi products is captured just before the production starts, so most of the visual content of the products distributed is scanned just a minute before. The lowest elevation is repeated a total of 3 times: twice at single PRF for the generation of the pseudo cappi and another time using dual PRF to obtain unambiguous velocity data.Also a 90degree elevation scan (birdbath) is part of the schedule. This scan is added for the purpose of monitoring Zdr stability. What is new here is that monitoring parameters (noise level, single point calibration and Zdr stability are integral part of the volume scan, so these parameters can be acquired with a minimal overhead, and are available in every volume scan.

4 Corrections applied on Volume Data

4.1 Clutter Processing

The KNMI ground clutter processing scheme based upon statistical filtering has been abandoned. This method has been used from 1992 to 2016, with a last update introduced in 2007. Research by Iwan Holleman shows that dualpol radars offer far better opportunities to reduce clutter in addition to the DFT-filtering with spectral reconstruction which is now applied on all elevations. Aart Overeem is currently working on the operational implementation of these clutter filters.

4.2 Occultation correction

Even in a country as flat as the Netherlands the radar beam can be obstructed, be it mostly by man made objects that mostly block only small sectors. The applied occultation correction reconstructs blocked sectors on a per elevation basis by performing a linear weighted averaging of data found close to the edges of the blockage.

5 Quality Monitoring, Looking at the sun and more

The sun emitting in its spectrum weak radar signals offers the possibility to check the radar sensors against an external source. By offline processing of received volume sets KNMI is monitoring the sun passages during sunrise and sunset. The output of this tool offers a day to day record of the sun power compared to the DRAO standard. It shows that our installations follow DROA observations in good agreement thus offering a valuable monitoring tool for the sustained low power sensitivity of our receivers. In a similar way deviations in the pointing of the antenna as small as 0.05 degree are easily detected. Although these procedures were first developed around 2005, this suite of solar monitoring procedures has shown gradual growth in the products that can be monitored, as well as in the number of radars it is applied to. Latest innovations are application of this type of monitoring on the Opera Odyssey volume data hub providing a cross European monitoring, and work in progress to have similar procedures applied on the Nextrad network.

Other parameters will be added to the monitoring suite. Lately TR-limiter failure that can be seen in the range dependant degradation of return close to the radar is implemented. As an example of its output see figure 4 below, in which indeed no deviations are seen. For more examples see the extended abstract by Tiemo Mathijssen on operational monitoring of TR-limiter degradation. (This ERAD2018 conference ID 407)

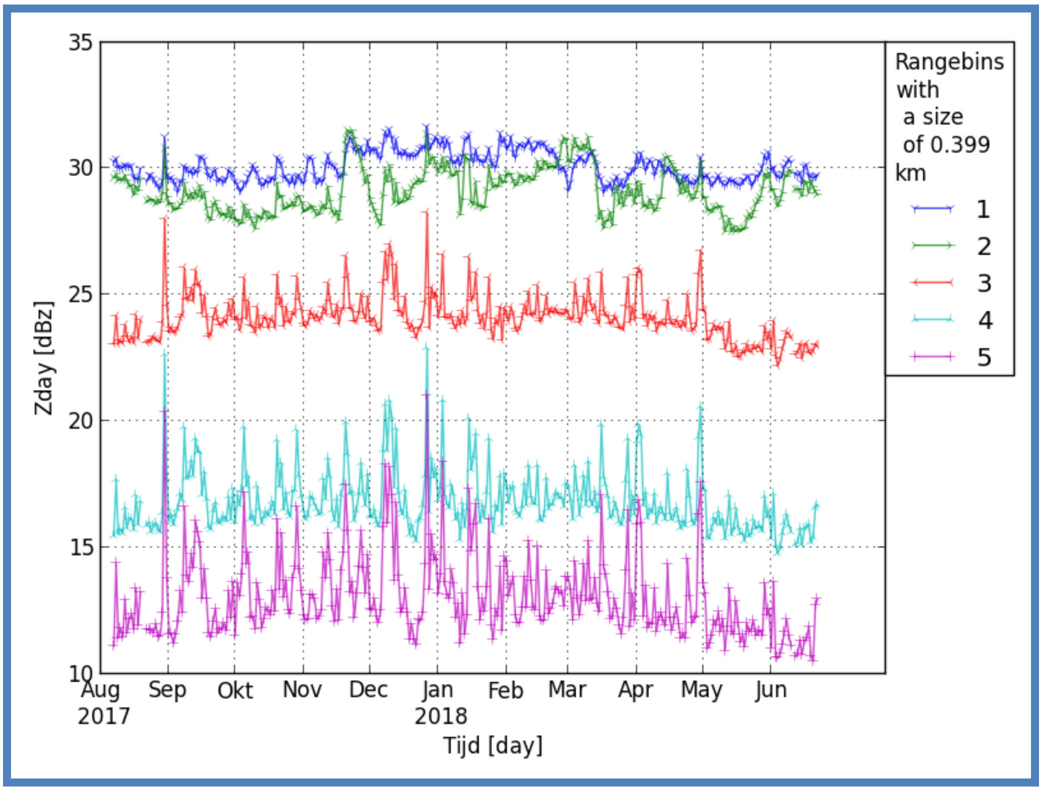

Figure 5: Monitoring Tr-limiter degradation, nothing to worry here.

Other offline monitors are currently under development. These include Zdr stability statistics (WLAN) interference alerting and monitoring of the total transmitted power by analyzing nearby ground echo return.

6 Data Model

The KNMI internal standard for operational radar products and volume data is based on HDF5. KNMI uses a proprietary (although freely available) data model. One of the advantages of the hierarchical structure of HDF5 is the way metadata can be stored along with the data.

The KNMI data model and the Opera data model are close, as they evolved from shared ideas originally promoted by Baltrad. KNMI is now experimenting with a hybrid form of HDF based volume data. In the volumes two meta data sets are available, being in the form prescribed by ODIM as well as in the form the KNMI model requests. So software expecting ODIM or KNMI style metadata will be able to read these volumes. As KNMI uses an open data policy all radar data is distributed freely, which can be read from the KNMI Data Center (KDC). Professional end-users are offered enhanced delivery services against additional costs.

7 Product generation

In order to be able to fulfill high availability KNMI distributes preferably products based upon multiple radar inputs, E.g. composites, to its professional external users:

7.1 Reflectivity Composites

Reflectivity composites at low altitude (1500 meter above msl) for Netherlands and Western Europe. These main radar products are showing the temporal and spatial evolution of precipitation patterns. KNMI uses an adopted form of range weighted compositing that suppresses close to the radar echo return (and thus ground echo's).

7.2 Accumulated Precipitation

Precipitation is accumulated over 3 hour and 24 hour periods. The accumulations are based on the reflectivity composite and are adjusted with rain gauge observations.

7.3 Echotop Height Composites

The echotop height composites show the observed maximum height of the radar echoes. They are of special interest for aviation purposes.

7.4 Hail Warning Product

Large hail is detected using the height difference between the 45 dBZ echotops and a fixed height of 2500m, which is assumed the average freezing level over the Netherlands in summer conditions. model.

7.5 Single radar products

But when requested KNMI distributes single radar products to other post processing institutions, such as the opera data centre Odyssey, the E-profile data hub, or bilateral exchange partners as IRM, or the DWD. Preferable these products are ODIM based volumes, but other products are available as well.

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