by Urs Germann, Marco Boscacci, Marco Gabella and Maurizio Sartori

PEAK PERFORMANCE

Radar design for prediction in the Swiss Alps

The latest fourth-generation MeteoSwiss weather radar network is called Rad4Alp

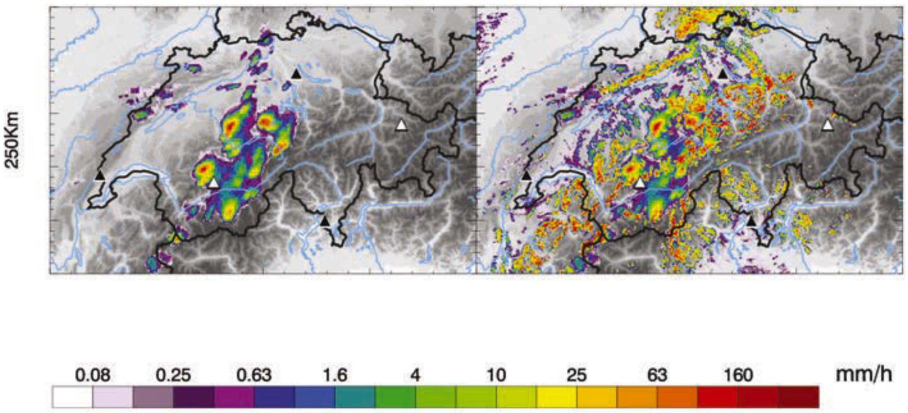
It was back in 1959 that the first weather radar was deployed in Switzerland. It was a one-parameter-one-customer solution with analog technology. Five decades later, in June 2011, the first system of the fourth-generation MeteoSwiss radar network was commissioned. It combines dual-polarization Doppler receiver-over-elevation technology. It takes less than 60 seconds after the completion of a 'scan' to deliver various meteorological products to a large number of customers.

In an Alpine region like Switzerland, there is no perfect technological solution for weather radar. Siting is a trade-off between having good visibility over a large area from a high location versus observing weather close to the ground from a lower site. One has to select a site as high as necessary to cover the desired area, but as low as possible to get accurate measurements of precipitation at ground level.

The first-generation Swiss weather radar on La Dôle, 1,682m above sea level (1959)

A radar operator has to cope with complex shielding by mountains, strong ground clutter over large parts of the radar umbrella, the need to extrapolate radar measurements from aloft down to the unseen floors of the valleys, and harsh climatic conditions to install and operate

The radar on Pointe de la Plaine Morte, 2,937m above sea level after commissioning in November 2013. This is one of the two additional radar sites built to improve radar coverage in the Alps



Radar precipitation analysis with (left) and without (right) clutter suppression. The dual-polarization capability improved substantially the distinction between weather and clutter signals. Radar sites are indicated as triangles in black (existing) and white (new)

a radar at remote locations at high altitudes. On mountainous sites, wind load on the radome, space and costs of infrastructure are limiting factors. For the sites in Switzerland, antennas of 4.2m diameter are a reasonable choice. For a given antenna diameter, a short wavelength offers a narrower beam and lower sidelobes compared with a longer wavelength. As a result, C-band and X-band wavelengths give better spatial resolution and better clutter isolation than S-band. Also, the smaller the wavelength, the better the weather-to-ground-clutter signal ratio for hydrometeors in the Rayleigh region. In a mountainous region, a narrow beam, low sidelobes and a high weather-to-clutter signal ratio are crucial to obtain useful observations of precipitation and thunderstorms. Therefore, Switzerland opted for X-band (first generation) and C-band technology (second, third and fourth generations). However, X-band, and to some extent C-band, waves suffer from attenuation in areas with strong echoes. Signal attenuation is mitigated by intelligent compositing thanks to large overlapping and by exploiting the information from the dual-polarization capability.

Scan program

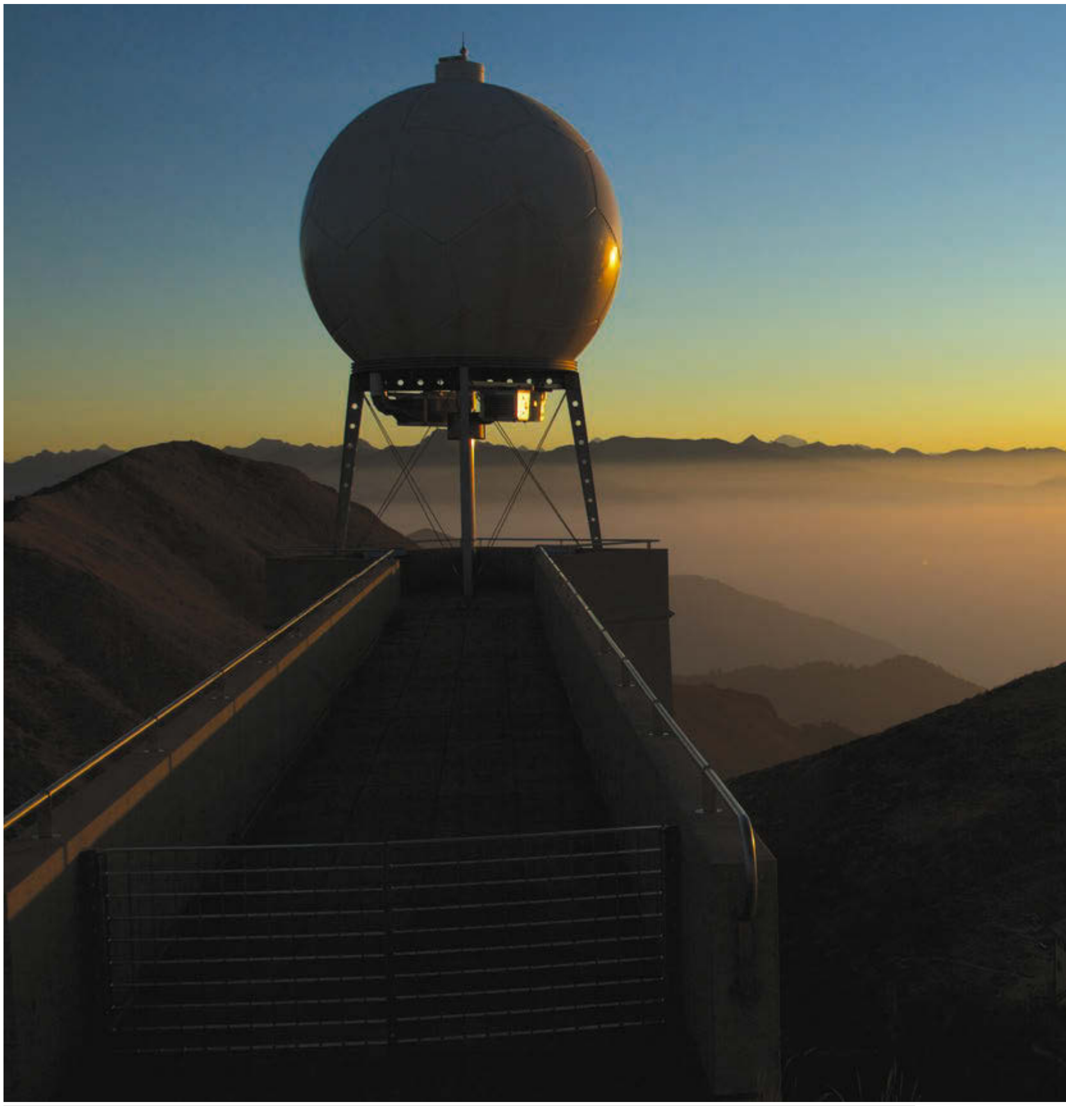
A crucial element in the design of a radar network to be operated in a mountainous region is the scan program. MeteoSwiss has run a scan program with 20 elevation sweeps repeated every five minutes since the early 1990s. The products are updated every 2.5 minutes, taking advantage of an interleaved sweep pattern. The high temporal resolution is mandatory to sample the rapid evolution of convective storms.

At the same time, one needs high resolution in space to cope with complex shielding and ground clutter contamination in the Alps and to get a picture of the vertical structure for storm severity diagnostics.

Besides this, there are many other aspects that need to be considered carefully when designing a radar network for unsupervised 24/7 operation on remote mountain sites, including remote control, automatic calibration and system monitoring, lightning protection and solutions to cope with the complex space-time error structure.

Rad4Alp – the Swiss radar network

As part of the Rad4Alp project, MeteoSwiss completely renewed and extended the Swiss operational weather radar network. The project was carried out in collaboration with several partners including: Selex ES for the radar hardware; ELDES for the software; and the Federal Office for Buildings and Logistics for civil construction works. The design and configuration are a combination of proven solutions from the past, new technologies from the industry and results from research projects, and were driven by the need for availability, stability and



The Monte Lema radar, 1,626m above sea level, after commissioning of the fourth-generation radar system in 2011. (Photo: S Müller)

accuracy. In order to improve coverage in the Alpine regions, the government decided to install two additional radars, one in southwestern and one in eastern Switzerland. The selected sites on Pointe de la Plaine Morte, 2,937m above sea level and Weissfluhgipfel, 2,840m above sea level, offer good visibility and accessibility by cable car. In addition to better coverage in the Alps, the new radars have large overlapping areas with the existing three radars and hence serve as back-up in the event of malfunction of one of the other radars. All five radars have identical hardware and software.

The fourth-generation system has a number of innovations, one of which is its dual-polarization capability. The technology itself is not new, but long-term performance and robustness for automatic quantitative applications in an operational context have yet to be proved, in particular in a mountainous region. If the horizontal and vertical channels are calibrated and monitored properly, dual-polarization measurements allow users to better distinguish between weather and non-weather signals, know more about the type and size distribution of hydrometeors in the pulse volume, diagnose hardware anomalies, correct reflectivity for signal attenuation, and improve estimates of precipitation rates.

A prime example is clutter cancellation. Adding dual-polarization in the clutter algorithm resulted in a substantial reduction in the level of residual clutter and also fewer erroneously canceled weather signals.

One of the innovative elements is the receiver-over-elevation (ROEL) design developed by Vollbracht, which works with Selex ES. In the ROEL design, the receiver is mounted on the back of the reflector. This has several advantages over the standard design. The wave guide paths of the two polarizations are symmetrical and the receive path is much shorter. Also, the dual-polarization rotary joint, an expensive component that is prone to failures is not needed. As a result, there is a gain in sensitivity and data quality.

On the Albis radar, MeteoSwiss gained 9dB in sensitivity, half of which is attributed to the new receiver design and the other half to the reduction of the wave guide path on transmission by moving the transmitter to the top of the 40m tower.

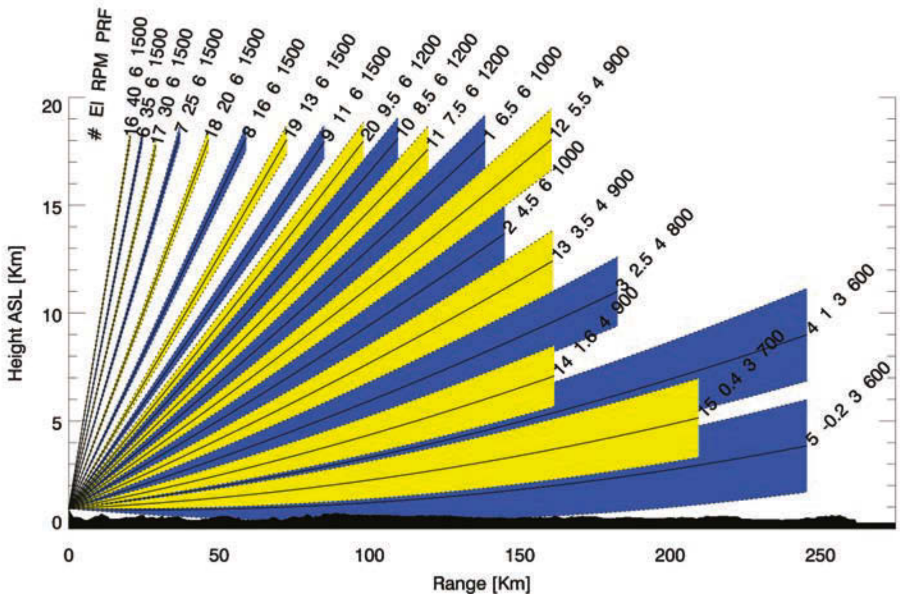
Measurements are transmitted from the radar sites to the central server in Zurich at a radial resolution of 83m. All further processing is done centrally, opening the way for sophisticated data compositing, an opportunity already put into practice in the algorithm for quantitative precipitation estimation.

There are two parallel data-processing chains at the level of the signal processor, and four on the central server, one of which is for operational product generation; the others are for research and testing. All the chains are processing data in real time.

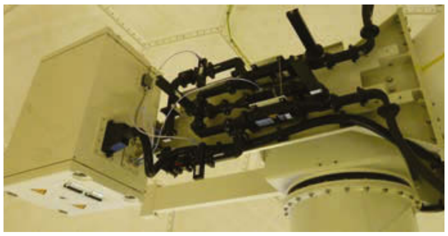
The radar trilogy: acceptance testing, calibration and monitoring

For quantitative radar use, high stability and accurate calibration within a few tenths of a decibel are mandatory. This is only achievable by a combination of rigorous acceptance testing, robust procedures for automatic calibration, and comprehensive monitoring of the hardware and site infrastructure.

In preparation for the factory acceptance test (FAT), each radar system was installed on the roof of the Selex ES factory in Germany, and run for a couple of weeks in operational mode to test stability and



The antenna scans 20 elevation sweeps every five minutes. The products are updated every 2.5 minutes, taking advantage of an interleaved sweep pattern



Receiver-over-elevation (ROEL) design improving sensitivity and data quality

performance with a focus on calibration, sensitivity, sun measurements and antenna mechanics. After installation in Switzerland, performance and stability were tested in four steps: one week of offline testing (ISAT-offline); three weeks of online testing (ISAT-online); a six-month period in operational mode (SEAT); and a final network test of four months.

A guiding principle of the acceptance testing, monitoring and calibration was to combine as many independent sources of information as possible. This includes various types of weather echoes; ground clutter signals; signals from the sun; signals transmitted by the radar and measured by an external receiver; signals received by an external transponder and transmitted back to the radar with a shift in time, intensity, frequency and polarization; signals reflected by nearby towers at the factory and on site; signals from a noise source; and test signals inserted at various locations by laboratory test equipment.

In order to obtain reliable polarimetric measurements, one needs an antenna radiation pattern with low sidelobes and matched radiation for both polarizations, at least in the main lobe. Performing measurements of antenna patterns and characterizing the whole radar chain with the radome in the real environment is a key quality factor. However, these kinds of measurements are difficult.

Two methodologies have been adopted in collaboration with Armasuisse, a federal agency of the Swiss Confederation. The first is based on a one-way passive calibrator used for checking the scan strategy, the transmitted power and the antenna radiation patterns beyond the radome. The second is based on a two-way active calibrator that is able to detect radar pulses and send them back coherently with user-defined radar cross-section, time delay, Doppler shift and polarization. The ability to delay the re-transmitted signal enables moving out of the region of strong ground clutter, which is a major advantage over corner reflectors.

Calibration of the hardware is performed automatically using a noise source and an integrated test signal generator, offline during the acceptance tests and from time to time during preventive maintenance. The noise source signal is inserted every 2.5 minutes in both polarization channels of the receive path.

Another crucial element is automatic monitoring of the radar hardware and site infrastructure. More than 350 parameters are monitored and submitted from each radar site to the central server after completion of every single sweep – that is, 20 times in five minutes. The parameters are automatically checked for anomalies and archived for diagnostic analyses. ▮

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