Urs Germann, Jordi Figueras, Marco Gabella, Alessandro Hering, Ioannis Sideris and Bertrand Calpini, MeteoSwiss

TRIGGERING INNOVATION

The latest MeteoSwiss Alpine weather radar network, Rad4Alp, has already shown a wealth of research and innovation improvements

Weather radar on Plaine Morte, 2937 m.a.s.l., southwestern Switzerland. It has been operational since May 2014

B Petroni

Alpine weather radar

The design of the fourth-generation polarimetric Doppler C-band weather radar network of MeteoSwiss was driven by contradicting needs. On one hand, radar services for air traffic control and civil protection in situations with heavy rain, severe convection and hail require high stability, availability and accuracy. On the other hand, the complex terrain in the Swiss Alps and the increasing demands for new and customized products require adapted data processing and potential for innovation. Furthermore, two weather radar stations are located on mountain peaks close to 3,000m above sea level, a challenge for installation, operation and data interpretation.

The requirements for stability, availability and accuracy had to be met from the very beginning. Innovation on the other hand is a long-term task. Still, even before its completion, the new Swiss radar generation has already triggered an avalanche of research and innovation, ranging from spectral signal processing and polarimetric ground clutter suppression, to semi-supervised hydrometeor classification, automatic hail alerts and the study of chaos through exploration of big data.

DATA QUALITY

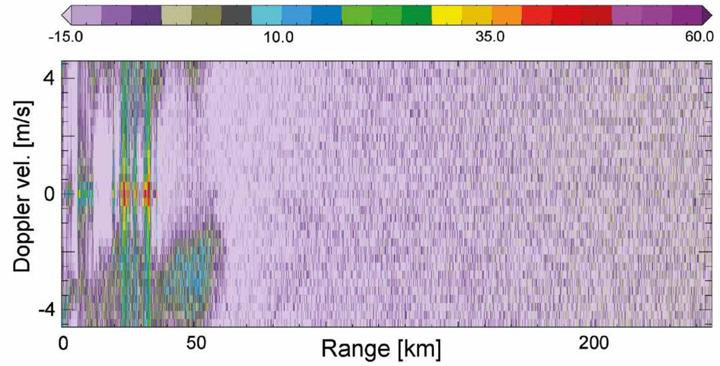
The increase in data quality was immediate and can be attributed to the inclusion of dual-polarization capability, the employment of the latest digital receiver technology and receiver over elevation design, rigorous acceptance testing, and automatic hardware monitoring and calibration (see *Peak Performance*, April 2015 issue, p42).

In Switzerland about 14% of the radar volume of the five stations are contaminated by false echoes, mainly returns from mountains. If projected to the ground, the false echoes, or 'clutter', cover almost 50% of the country! Suppression of clutter has always been a top priority in radar operations in the Alps. Since the early 1990s, cluttered pixels have effectively been suppressed by means of a multiparameter decision tree applied to raw data at a resolution of 80m. But the introduction of dual-polarization capability resulted in another major improvement in clutter suppression that surpassed expectations. Presently the group is experimenting with spectral processing of polarimetric signals. The aim is to estimate the noise level and calculate the polarimetric moments after cancellation of noise and clutter in the spectral domain.

Dual-polarization measurements also helps improve system diagnostics and data quality assurance because of their sensitivity to hardware instabilities. Through careful monitoring of polarimetric moments, one can detect and repair hardware problems at an early stage. The development of polarimetric algorithms for the operational C-band network takes large profit from the experience gained with a mobile polarimetric X-band radar.

HYDROMETEORS AND HAIL

The identification of different types of hydrometeors is important for various reasons, ranging from improved quantitative precipitation estimation and better understanding and modeling of microphysical processes, to customized products for air and road traffic. MeteoSwiss and Alexis Berne's research group at École Polytechnique Fédérale de Lausanne (EPFL) are currently developing a novel semi-supervised classification method. As opposed to supervised fuzzy-logic schemes, this method decreases the sensitivity on



Spectral processing of I/Q raw data allows calculation of polarimetric moments after cancellation of noise and clutter in the spectral domain. The figure shows reflectivity at horizontal polarization in dBZ of Albis radar at -0.2° elevation

presumed electromagnetic behavior of different hydrometeor types. Furthermore, EPFL, the German Weather Service and MeteoSwiss are working on the development of a forward operator that enables the simulation of radar measurements from fields of the COSMO model of the Consortium for Small-Scale Modelling. This opens the door to replace the latent heat nudging scheme used for assimilation of radar data in COSMO since 2008 with a local ensemble transform Kalman filter.

As part of a collaboration with Olivia Martius and the Mobiliar Lab for Natural Risks at University of Berne, MeteoSwiss is analyzing the frequency of hail and its dependence on a variety of parameters using past radar data archives. At present, the study is based on 14 years of radar data comprising 30,000 hail cells over Switzerland and border regions. Triggered by the introduction of dual polarization, the analysis is extended to polarimetric hail identification.

In order to get measurements of hail on the ground, a pilot network of seven automatic hail sensors has been deployed in a hail-prone region in central Switzerland. To complement the network of sensors, a feedback functionality has been incorporated in the MeteoSwiss app that enables smartphone users to report observations of hail including information on size, time and location. The app was released in spring 2015, shortly before the start of the hail season, and triggered more than 14,000 observations of hail from the public in 2015. Both the high-quality data of the automatic sensors and the crowdsourcing data of the app users help to verify and refine the radar hail algorithms.

In a recent project, the radar hail signatures have been combined with the radar thunderstorm tracking algorithm to develop a system for customized automatic hail alerts on a kilometer grid. It was tested with 520 test users in 2015, and is now being implemented for operational use.

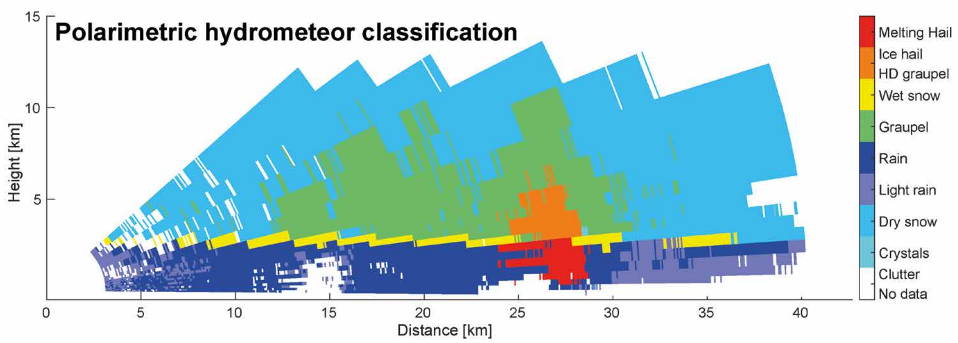
RAINFALL AND THUNDERSTORM NOWCASTING

Quantitative estimation of precipitation is one of the main applications of radar in the Alps. The full volumetric radar information is used to obtain estimates of precipitation at ground, taking into account shielding of the radar beam by mountains. The radar rainfall maps are then combined in real time with measurements of the automatic rain gauge network by means of a space-time co-Kriging with external drift technique, that has specifically been designed for automatic processing in a mountainous region. The resulting precipitation field is input to a climatological study of return periods and a newly developed system for automatic heavy precipitation alerts. An alert is issued whenever the sum of rainfall of the immediate past and future as reported by radar, rain gauges and model forecasts over a given region exceeds a pre-defined threshold. The system is used both at national level to issue alerts for the 159 official warning regions, and locally for specific customers.

Ongoing research aims to further improve radar precipitation estimation using dual-polarization measurements for the correction of signal attenuation and effects related to microphysics. When incorporating polarimetric data in the operational processing, attention is paid to the fact that the accuracy of polarimetry is sensitive to subtle changes in the hardware. The algorithms are designed so that, in the event of quality issues with polarimetry, the performance relaxes toward that of single polarization.

For short-term forecasts up to a few hours, Lagrangian extrapolation of radar precipitation fields is a common approach. But in the Alps, the influence of the mountain ranges on precipitation makes things more complex. Depending on the state of the atmosphere, the orography can act both as a forcing term and a barrier, altering in a significant way the motion and evolution of precipitation. An ongoing research project aims to develop a nowcasting system that combines Lagrangian extrapolation of the latest radar field with orographic forcing derived from radar archives using machine-learning techniques. In a second step, the radar nowcast will be blended with COSMO forecasts to generate a seamless ensemble of precipitation scenarios.

A particular case is that of thunderstorms. Here, the strengths of the radar – that is, detailed volumetric scanning of the atmosphere and timeliness of data below 60 seconds – are most obvious. Radar thunderstorm tracking, severity ranking and extrapolation with the operational C-band network has been used for many years and is continuously being updated. Recently the mobile X-band radar has been configured so that it automatically starts adaptive high-resolution scanning whenever a thunderstorm detected by the C-band network happens to be close to the X-band radar. Present research has three focuses: wind gusts, the generation of automatic alerts, and usage of satellite imagery. Visible and infrared imagery of the Meteosat second-generation geostationary satellite is combined with volumetric radar, lightning and COSMO data aiming at an early identification of severe thunderstorms. The method builds on temporal signatures in satellite imagery and a statistical multisensor fingerprint of the lifetime of severe thunderstorms as derived from past archives.



Semi-supervised hydrometeor classification using dual-polarization data from Albis radar near Zurich looking south on June 12, 2014. The data is from the operational volume scan with 20 elevation sweeps repeated every five minutes (Figure: N Besic)

Alpine weather radar

"In Switzerland about 14% of the radar volume of the five stations are contaminated by false echoes, mainly returns from mountains"

To complement the pilot network of hail sensors, a feedback functionality has been incorporated in the MeteoSwiss app that allows smartphone users to report observations of hail, including information on size, time and location

ATTRACTORS AND PREDICTABILITY

The most out-of-the-ordinary project currently being done is on attractors and predictability. The concept of strange attractors and analogs builds a powerful framework to investigate the intrinsic predictability of chaotic systems such as the atmosphere. This goes back to the work of Edward Lorenz, who used dynamic equations and naturally occurring analogs in past observations to study the growth of uncertainty in predictions of a non-linear process.

Starting from any arbitrary initial condition, a chaotic system relaxes toward a limited sub-domain of the phase space called 'strange attractor', which, in the case of the Lorenz model, takes the well-known shape of a butterfly. For the real atmosphere, the situation is much more complex. But, the rapidly growing archives of radar and satellite data are a unique opportunity to go back to the concept of analogs and construct an attractor from observational data.

The temporal evolution of precipitating clouds as described by radar and satellite data forms a trajectory in the phase space of the attractor. By superimposing data from large archives, we can calculate the density of trajectories in the phase space and thus get a picture of the attractor. The rate at which trajectories that are nearby at some point on the attractor diverge in time is a measure of predictability. The goal is to better understand the limits of predictability and build the basis for a new generation of techniques for seamless nowcasting. ∎