2.2 Concatenating Weather Monitoring and Forecast: the WxFUSION Concept

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The meteorological network of observation and prediction continuously delivers an enormous amount of various atmospheric parameters. In particular in the area of an aerodrome the observation density is typically higher than on average. In the project we spawned the idea to smartly concatenate the variety of available data which are relevant for aviation and develop new products which use the information contained in the data but describe the phenomenon of interest in a simple and unambiguous way for direct use for the aviation stakeholders. We developed this idea in a concept and related system named WxFUSION, meaning "weather forecast user-oriented system including object nowcasting".

The Concept of Combining Weather Observation and Prediction Data

Several integrated systems, which automatically combine different data sources and provide weather hazard information specially tailored to the needs of decision makers at airports, have been developed and successfully tested in the USA. Examples are the Integrated Terminal Weather System (ITWS) by the Massachusetts Institute of Technology (Evans and Ducot, 1994) and the Auto-Nowcast System developed at the NCAR (Mueller et al., 2003). In 2010 the Commission for Aeronautical Meteorology of the World Meteorological Organisation established an expert team on meteorological services for the terminal area (ET/MSTA) and a task team on the user needs (http://www.ntf.weather.gov.hk/). The German Meteorological Service, DWD, installs an ITWS together with a low-level wind shear alert system (LLWAS) at the airports of Frankfurt and Munich (http://www.dwd.de/itws). The LLWAS basically augments the standard observation means at the airports by a cloud RADAR and a Doppler LIDAR in order to detect wind shear layers and aircraft wake vortices along the glide paths of aircraft under rainy as well as dry weather conditions.

The WxFUSION concept (Figure 1) aimes at the combination of data from observation systems, nowcasting tools, and numerical models in order to detect, track, nowcast (up to about 6 hours), and forecast (beyond 6 hours) hazardous weather phenomena for aviation purposes as precisely and as consistent as possible [Forster and Tafferner, 2009a]. The combination within one integrated system can be expected to provide a greatly enhanced benefit in monitoring and nowcasting capability, i.e. an integrated system can process and contrast the assertions of the individual tools, e.g. as regards to the exact location of a particular weather system, its intensity and movement, and thus provide a more reliable assertion of the future state of a weather system as when only one data source or nowcasting tool were used (Tafferner et al., 2008).

Certainly, in order to be useful an integrated system for nowcasting and short term forecasting must be constructed in a way that it can process large data amounts within a very short time. The prime aim of such a system is to reduce the complexity of weather to a description of the event that supports users in decision making. This requirement is quite obvious in extreme weather situations where individual weather parameters change quickly and not much time is available to analyze a complex and large data set visually or by hand. Therefore, there is a need for automation in order to fulfill this requirement. The system is currently under development; several components, however, exist already and are described in the following. Examples of individual components are also presented in the following.

Figure 1 illustrates the system, various data sources and system components are represented by symbols. The elements in the top row are the cloud tracker Cb-TRAM, the radar tracker Rad-TRAM and the VERA analysis (see below). In addition polarimetric radar and lightning observations are available. Together these elements compose the observation and nowcasting part of WxFUSION. The bottom row of elements comprises numerical model forecasts and forecast validation components. Forecast data are available from the COSMO-DE (Baldauf et al., 2011) ensemble and from the high-resolution time-lagged ensemble COSMO*MUC* (Dengler et al., 2011, see Section 2.5). From these model outputs synthetic satellite ('SYNSAT') and radar images ('SYNRAD') are generated which are used as input to Cb-TRAM and Rad-TRAM. Synthetic objects are thus obtained which can be compared to the observed counterparts ('object comparison'). The best match will determine which members from the ensemble will be used for the fusion with nowcast data (Köhler, 2012).

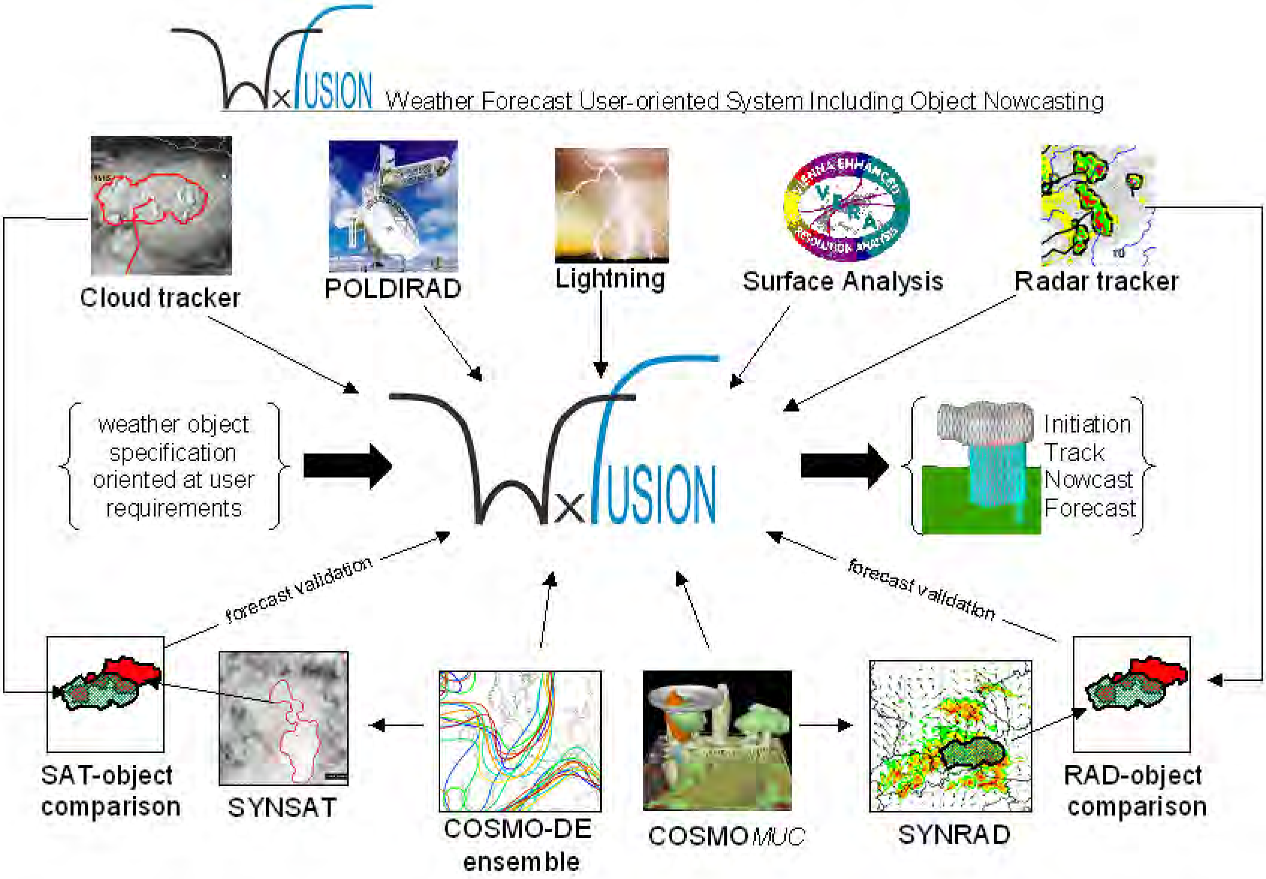

Figure 1. The concept of WxFUSION. The initiation, track, nowcast, and forecast of user specified weather objects are characterized by appropriate information through fusion of selected nowcast information (upper half) and forecast products (lower half) (adapted from Tafferner et al., 2008; Forster and Tafferner, 2009b).

Data Fusion to Get Simple Products

The central part comprises the fusion component. A weather object specification oriented at user requirements has to be provided as further input to WxFUSION. As already mentioned above, users of weather forecasts need this information in a form that can be used for decision making. Users do not want, and often do not have the background knowledge, to interpret a multitude of complex meteorological data. Instead, as noted above, users need this information in a reduced form, easy to understand, free of interpretation and tailored to their needs. Figure 2 makes this reduction of complexity visible. On the left side two photographs of two different thunderstorms are composited in order to make visible typical weather features in one image. In the upper part there is a fully developed cloud anvil typical of mature thunderstorms together with a new convective cloud developing in front of it. In the lower part the typical cloud wall in front indicates the forced ingest of moist air into the storm, in the rear heavy precipitation with corresponding downburst can be seen. Correspondingly, by use of Cb-TRAM which detects the upper part, and by use of Rad-TRAM which detects the bottom part, a composite thunderstorm object can be constructed as shown on the right hand side (see also Section 2.3). Also indicated is a surface object which shall describe the squall line generated from the thunderstorm outflow (Westermayer, 2012). Therefore, the information about the thunderstorm given to users is a top and a bottom part, each of which consisting of a polygon with bottom and top, and some descriptive parameters, as e.g. intensity, trend, rain rate, etc. which are deduced from other observation data.

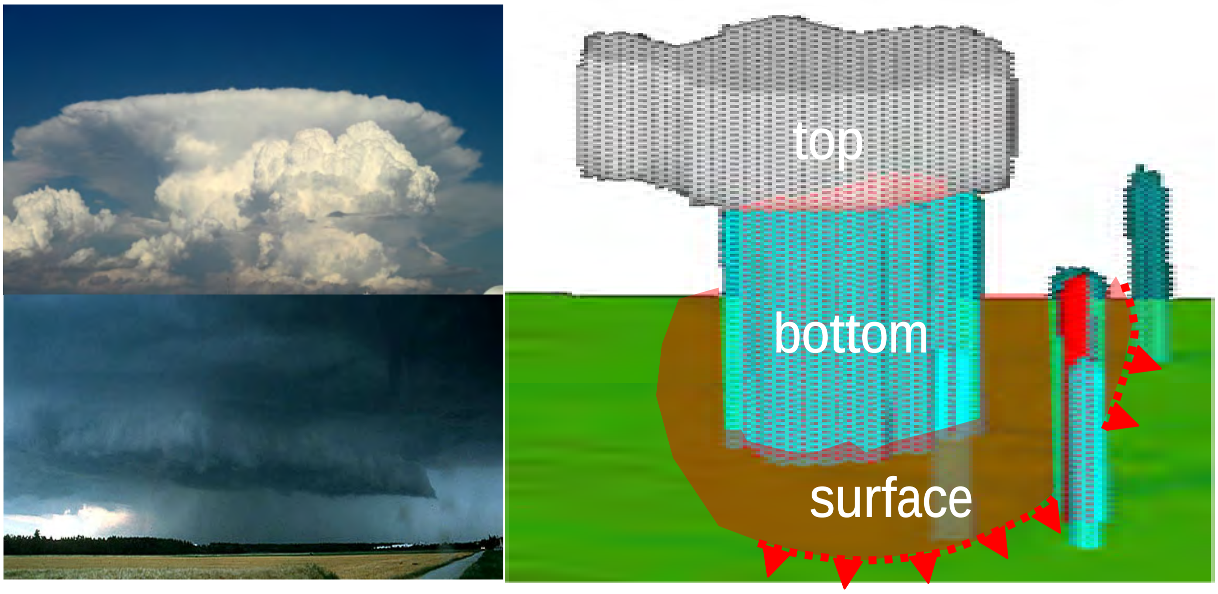

Figure 2: Real thunderstorm as seen by an observer (upper photograph by M. Köhler) and thunderstorm weather objects constructed from nowcasting tools. Explanation see text.

The heart of WxFUSION is the fusion module (centre of Figure 1). Its task is to retrieve from all available nowcast and forecast tools those data which are needed to calculate the required parameters of the weather object on output. E.g. a thunderstorm weather object on output (symbolized on the right in Figure 1) should contain information on initiation, actual state, nowcast up to one hour and forecast for later hours based on model forecasts.

The Fuzzy Logic Approach

The data fusion itself is undertaken employing fuzzy logic. The fuzzy logic procedure mimics the data analysis of an experienced forecaster. By evaluating and combining the outputs of nowcasting procedures and numerical prediction together with his knowledge about thunderstorm development (conceptual model) he composes a picture in his mind of what is going to happen. In contrast to decision trees which build on true/false branches when information contents are evaluated, fuzzy logic is a decision finding technique that allows a gradual transition between true and false, i.e. it deals with parameter ranges instead of fixed thresholds. Every contribution can be weighted with regard to its importance for the weather phenomenon by using so-called fuzzy functions. A final decision is then determined through an adequate combination of all weighted contributions. As an example let us consider the task to estimate the intensity of a thunderstorm. As contributing elements cloud top temperature, radar reflectivity and lightning density are chosen. Figures 3 and 4 show an example of the fuzzy logic evaluation. The influence (weight) of every data is taken into account by appropriately chosen fuzzy functions for low, middle or high membership grade. An observed value, e.g. a cloud top temperature of 228 K as shown by the dashed line in the top diagram (Figure 3), belongs with a membership grade of 0.8 to “cold” and with a grade of 0.2 to “middle”. The other parameters are evaluated similarly. After having collected and evaluated all possible data combinations a thunderstorm intensity value of 6.4 on a scale from 0 to 10 is found from the output fuzzy sets which are composed of 5 different thunderstorm intensity classes from very light to very strong (Figure 4).

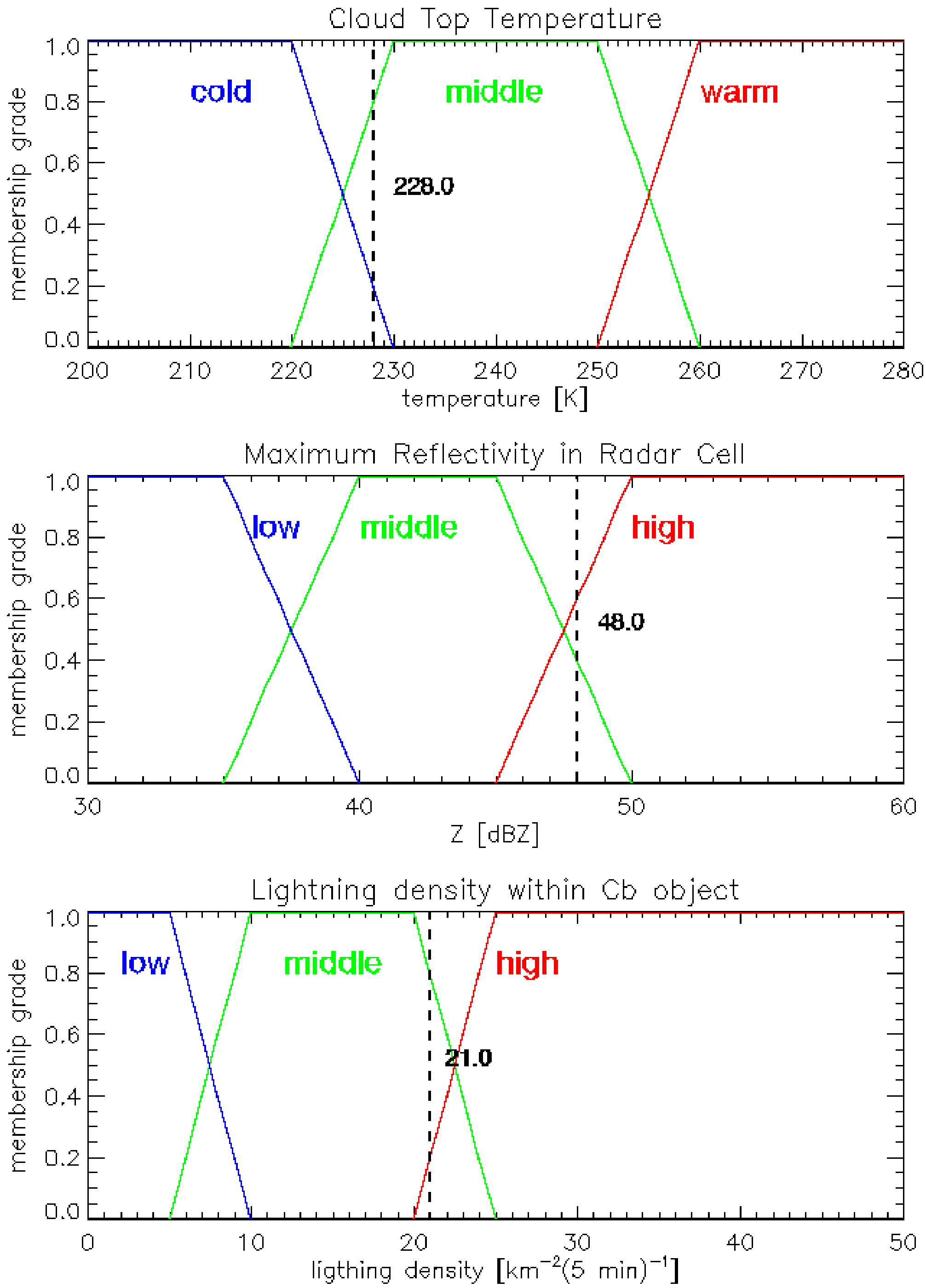

Figure 3. Fuzzy logic: input fuzzy sets with observed values of 228 K, 48 dBZ and 21 flashes km^{-2} (5 min) $^{-1}$ for cloud top temperature, radar reflectivity and lightning density; explanation see text.

The so calculated intensity is included as a descriptive parameter in the weather object together with output from the already mentioned nowcasting tools. Further detail, i.e. trend and lightning density will be included in the fuzzy logic procedure by taking into account the results of the research work of Bretl (2010) and Meyer (2010).

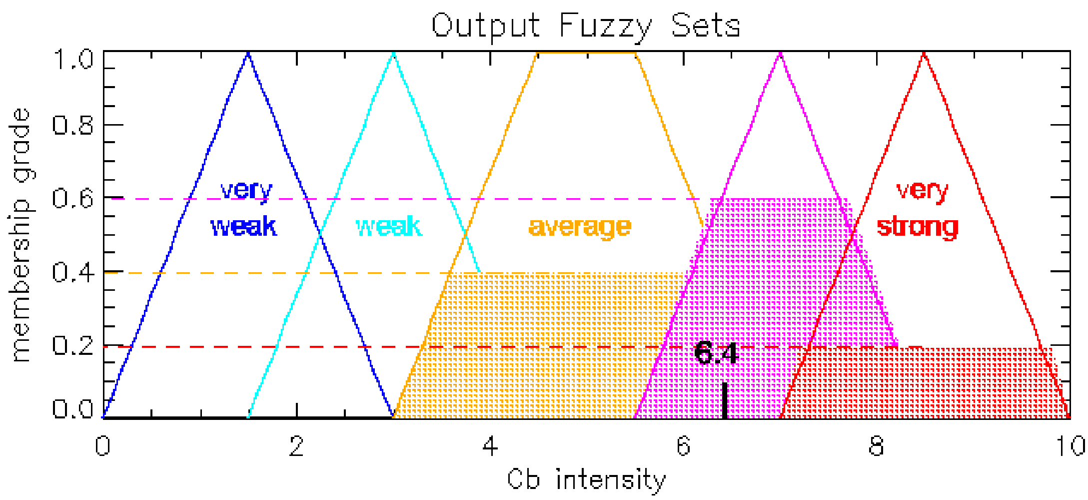

Figure 4. Fuzzy logic: Output fuzzy sets for 5 different thunderstorm intensity classes; explanation see text.

For the estimation of the future development only output from the nowcasting tools and numerical model output is available. It therefore makes sense to relax the detailed description of a weather phenomenon based on observation data to a more probabilistic estimate of how the event will evolve. This is rendered schematically in Figure 5. Whereas a 3-dimensional description of a thunderstorm is possible at analysis time together with small scale additional features, like e.g. the position of a gust front, after 30 minutes only the location of the thunderstorm is nowcast. Beyond one hour this is relaxed to a probability of occurrence.

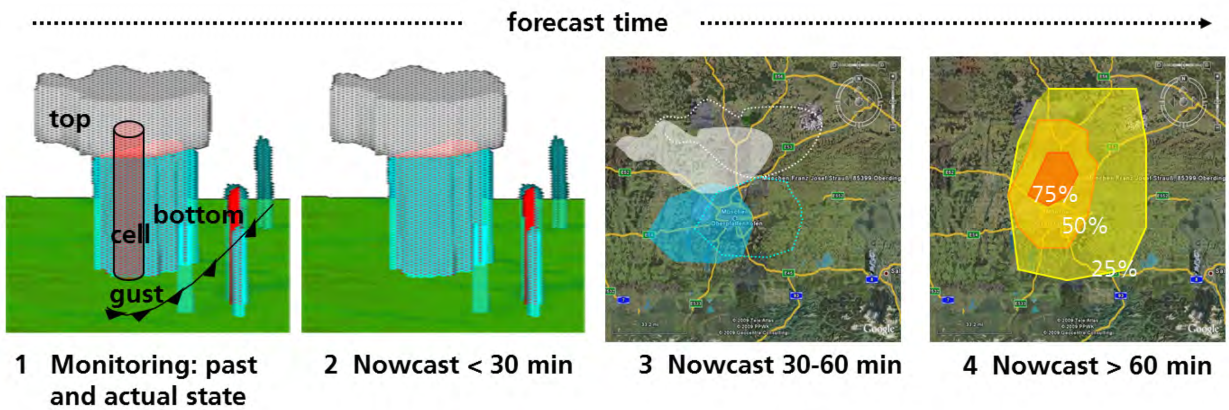

Figure 5: Nowcasting: decrease of descriptive detail over forecast time.

Considering the typical life time of thunderstorms, the uncertainties in numerical forecasting and the experience gained it would not make sense to forecast thunderstorms deterministically beyond one hour. Work is underway (Köhler, 2012) to combine output of nowcasting tools with numerical forecasts in order increase forecast accuracy. Thereby forecast evaluation plays an important role, first promising results have been achieved.

Graphical User Interface (GUI)

Figure 6 shows the graphical user interface of WxFUSION. Output data from the individual nowcasting tools, from the forecast models as well as fuzzy logic output, are ingested and processed. The GUI serves various purposes: an overlay of all data provides a synopsis of the weather event in one figure, it enables a quick evaluation of nowcasting quality, the best member out of the forecast ensemble is determined automatically, fuzzy logic procedures can be triggered by mouse over. In addition, the WxFUSION GUI can be run in real time as has been demonstrated already during the summer campaigns (see Section 2.3).

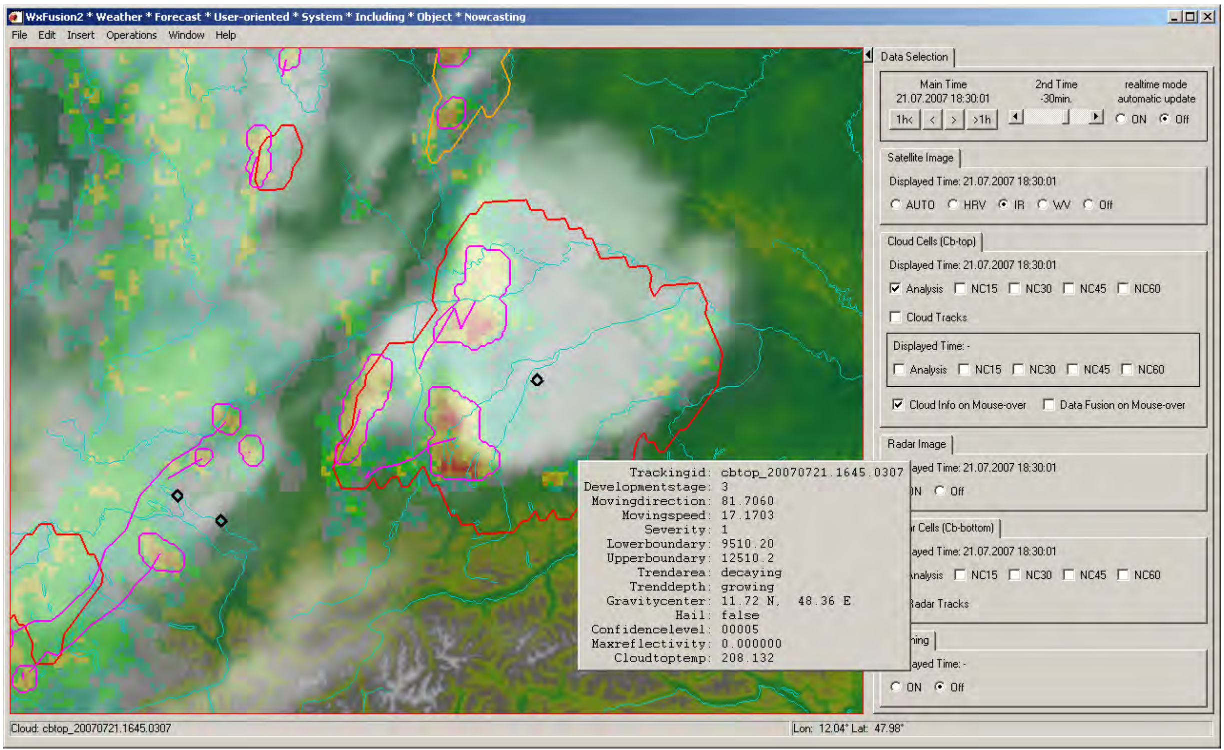

Figure 6: WxFUSION GUI: data overlay composed of satellite and radar image on geographic background together with Rad-TRAM (pink) and Cb-TRAM objects (red). Also shown tracks of cell centres and mouse over information on chosen weather object

Outlook

WxFUSION will further be developed, for both thunderstorm and wintry weather events, and finally demonstrated and validated in close cooperation with the decision makers at the ground and in the air. The aim is to bring the system to an international standard that makes it possible to apply the system European wide as a MET tool serving aviation needs in a Single European Sky. Once the LLWAS of DWD at the airports of Frankfurt and Munich is functioning, WxFUSION will also include these data into the fusion process and, eventualy, WxFUSION may become a part of DWD's Integrated Terminal Weather System (ITWS).

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