

CARPE DIEM: EU project

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Abstract. Flooding is a major worldwide problem that seems to have increased in severity within the last decade. The crucial role-played by rainfall accumulation and the accuracy of extreme precipitation forecasts and consequent floods forecasts is of extreme importance in preventing loss of life, health and psychological damage and infrastructure and property loss or damage. In this respect CARPE DIEM (that is a shared-cost project founded by the European Commission under the 5th Framework Programme) seek to identify how conventional raingauges, Doppler radar data, together with other remote sensing data, may be best linked to NWP models. The overall objectives are how the prediction and the estimation of severe rainfall can be qualitatively and quantitatively improved. The scientific strategy would be to convert Doppler data into atmospheric parameters suitable for linking to NWP algorithms. Another innovative aspect of the proposed work is to exploit NWP results to improve the interpretation of radar measurements. Finally, a major component will be the hydrological assessment of the benefits in terms of reduced uncertainty obtainable with the improved rainfall field, forecasted and estimated, coupled with an assessment of the sensitivity of hydrological models to different errors in their input. The joint use of all the information available will increase the overall quality of the actual flood forecasting. This article discusses the CARPE DIEM project, its structure and objectives as well as the radar estimation/correction techniques and the assimilation methodologies that will be used.

1 Introduction

Flooding is a major world-wide problem whose severity seems to have increased over the last decade (NOAA, 1994; NRC, 1996; Rodda, 1995; DHA, 1994). Many studies have focused on the “major” recent floods and on methods for forecasting and managing floods at such large scales (Jacob et al., 1998). On the contrary, more efforts should be addressed to the smaller-scale “localized” severe flood events, called flash floods, which can be very damaging and often require much more complex forecasting techniques than the larger scale floods.

The accuracy of extreme precipitation forecasts and consequently flood forecasts is extremely important in preventing loss of life, health and psychological damage, and infrastructure and property loss or damage. Extreme rainfall events also generate landslides. Therefore benefits in terms of risk assessment will follow from the increased understanding of the generating mechanisms and the spatial distribution of heavy rainfalls.

The crucial role played by rainfall accumulation needs to be examined to understand the flood forecasting uncertainty associated with the state of the art rainfall estimation and forecasting techniques (e.g. Obled et al., 1994).

The US Weather Research Program – Prospectus Development Team on Hydrological Aspects of Weather Prediction and Flood Warnings (PDT 9) has recently pointed out that precipitation is the main forcing variable of surface hydrological process, but it is still poorly predicted by meteorological models and the quantitative radar estimation of rain patterns suffers from an uncertainty that needs to be better specified (Droegemeier et al., 2000).

CARPE DIEM addresses the problem of the best possible use of data from raingauges, Doppler radar data, and other remote sensing data, in numerical weather prediction (NWP) models. The overall objectives concentrate on how the prediction and the estimation of severe rainfall can be qualitatively and quantitatively improved. Hence the principal objective will be to assimilate information obtained from Doppler moments and reflectivity along with other remote sensing data in the currently available NWP methods. The scientific strategy would be to convert Doppler data into atmospheric parameters suitable for direct assimilation into NWP algorithms. Another innovative aspect is the exploitation of NWP results to improve the interpretation of radar measurements. This exercise, which complements the previous one, not only enables a general improvement in extracting information from radar but also represents a reduction in inherent radar errors, thus allowing to quality control radar measurements.

Recent research has demonstrated the importance of NWP models, especially high resolution limited area models (LAM), in forecasting extreme precipitation at catchment scales. However, one of the key limitations to their use is the availability of real-time data whose scale and coverage is suitable to initialize and verify the NWP model output.

The link between radar and NWP models is yet an under-developed and at the same time potentially very useful field of research (Casale and Samuels, 1998; Collier, 2000). A two-way synergistic strategy is conceivable, i.e. radar inputs into NWP models and NWP model dynamics used in interpreting radar fields. The importance of these aspects has been demonstrated and emphasized by several authors, such as Rossa (2000) and Macpherson (2000).

Finally, a major component of the project is the hydrological assessment of the benefits in terms of reduced uncertainty in the determination of forecasted and estimated rainfall field. The same emphasis is given to the assessment of the sensitivity of hydrological models to different input errors. The joint use of all the available information will increase the overall quality of the actual flood forecasting.

CARPE DIEM seeks an improvement of the quality of flood forecasting for small and medium size catchments developing an innovative methodology to exploit radar data (Doppler moment, reflectivity and polarization information) to enhance rainfall estimation and prediction. The main objectives are:

- The processing of the retrieved atmospheric parameters so that they can be ported into NWP algorithms. The information injected into the NWP will be processed in order to be compatible with the atmospheric state.
- Improve the techniques for the assimilation of radar data in NWP models, with emphasis on the forecasting of flooding events and nowcasting.
- Improve the quality of radar products using NWP results.
- Improve the quality of radar rain retrieving techniques.

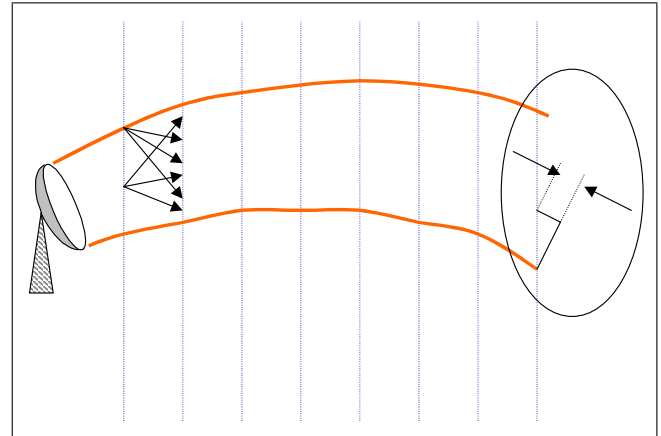


Fig. 1. Parabolic Equation Method.

- Establish a quality control procedure for filtering raw data.
- Improve the quality of rainfall field inputs to hydrological models.
- Assess the sensitivity of hydrological models to input data.
- Improve the useful lead-time and reliability of forecasted floods.

The project is structured in three areas of work: “Improve radar products by using NWP results”, “Data assimilation and NWP improvements” and “Flood forecasting”. In the following each area will be briefly presented.

1.1 Improve radar products by using NWP results

One of the most significant problems of using radar data in flood forecasting procedure and of integrating radar data with NWP techniques is to make sure that parameters derived from radar data are free of contamination to which radar data are generally prone. This is also relevant in reducing the impact of unknown biases on the accuracy of parameter extraction from radar data only. The mutual interaction between radar parameters and NWP methods allows a positive feedback to radar products itself. An integrated use of all available information could decrease the interpretational errors due to atmospheric inhomogeneity.

Anomalous propagation (ANAPROP) is a common source of strong non-atmospheric reflectivity in radar measurements. Many techniques were used in the past to identify and remove such echoes (Alberoni et al., 2001) with different rate of success. In order to eliminate such spurious effects before the radar data can be used for assimilation in NWP or for “real-time” precipitation estimation it is important to predict the behavior of the propagation condition during the day. In such way a quality flag could be associated with the

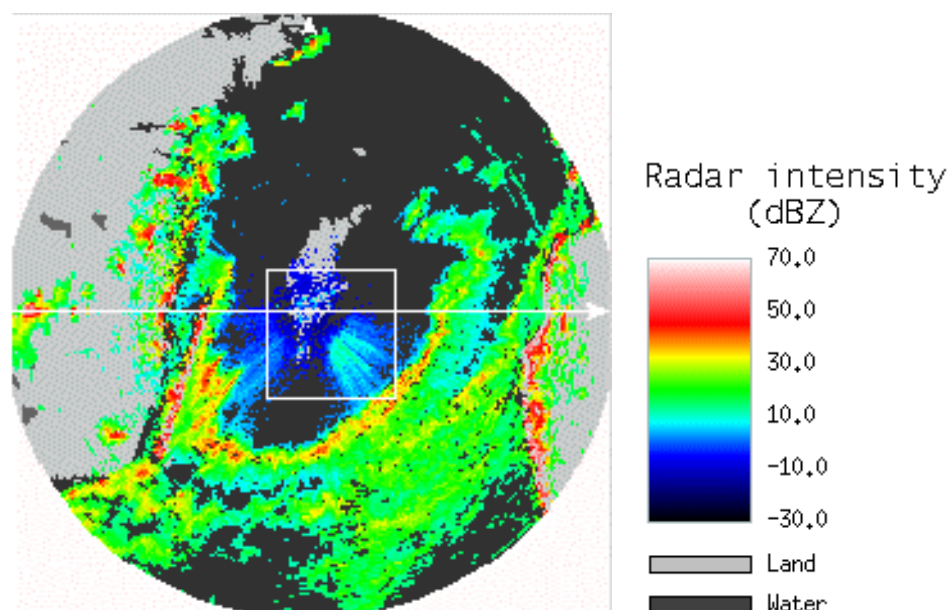


Fig. 2. 25 August 1997. Reflectivity data from the SMHI Gottland Radar.

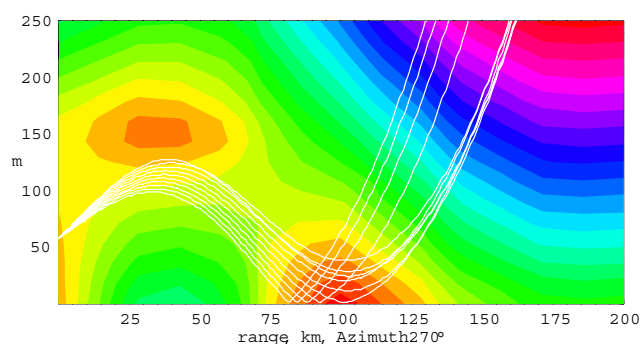


Fig. 3. Raytrace from SMHI Gottland Radar. Contours of RRI at intervals of 1N-unit.

radar data. The key tool will be a microwave propagation model, which will be used to diagnose and predict the incidence of ANAPROP, see Fig. 1 for a pictorial description of the method.

The atmospheric conditions required as input for the propagation model will be taken from standard TEMP products and from NWP mesoscale data. The outputs from this model would be fed into algorithms and products capable of improving ANAPROP recognition and cancellation in real-time. NWP models provide temperature and humidity fields as a basis for the prediction of the radio refractive index field. Experience gained in the DARTH project (EU project N° ENV4-CT96-0261) showed that, although the spatial sampling is relatively coarse for the purpose, it is possible to predict the occurrence and, to some extent, the location of ANAPROP. Fig. 2 shows the PPI data from the SMHI Gottland radar, on 25 August 1997 which shows a strong sea clutter echo due to ANAPROP. The results of a modeled

ray-trace over the Baltic sea calculated from NWP output is shown in Fig. 3. In CARPE DIEM, ANAPROP prediction will be refined by the use of a parabolic equation model for predicting the field and surface backscatter to construct predicted ANAPROP images. Ultimately, it may be possible to use the mismatch in location of the actual anomalous echoes to refine the atmospheric parameterization.

In the current practice of operational radar, it is customary to obtain volumetric reflectivity information under the assumption that the thermodynamic phase of hydrometeors is homogeneous (usually liquid water) over the whole measured volume. In the European climate, such a simplification leads to large biases in radar data as the thermodynamic phase in reality varies within the 3-D volume. This spatial variation strongly affects the magnitude of attenuation along the beam and it also distorts the relationship between the radar reflectivity factor and the precipitation intensity. The novel approach in CARPE DIEM will use 3-D atmospheric fields from a NWP model to diagnose the 3-D distribution of hydrometeor phase. This latter, in turn, would enable reliable calculations of the attenuation along the beam and a better estimation of precipitation intensity and water content. The direct result of this exercise will be better reflectivity data both for assimilation and nowcasting purposes.

A crucial problem in quantitative application of radar measurements at long ranges is the sampling difference between the actual precipitation reaching the ground and the radar estimate well above the ground level. The radar simply cannot detect the actual reflectivity profile below the lowest elevation beam. This feature of radar observation often introduces strong underestimation of surface precipitation at longer ranges. On the other extreme, intensive frontal precipitation at the radar beam level often evaporates completely

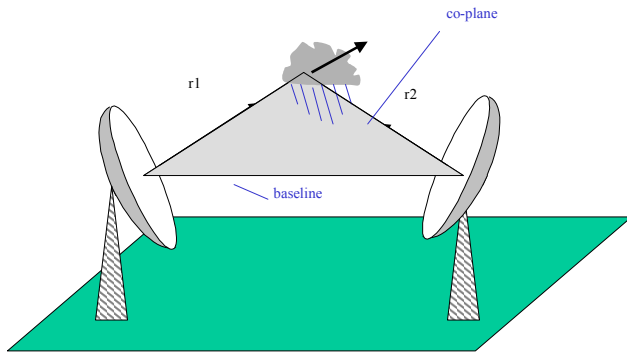


Fig. 4. Dual Doppler wind geometry.

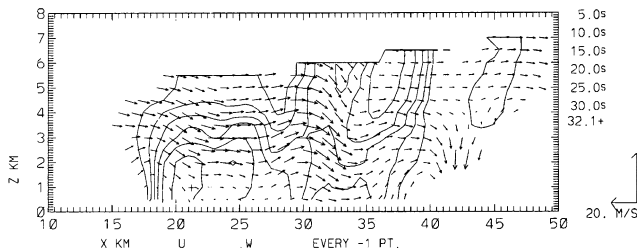


Fig. 5. 23 June 1992. Dual-Doppler synthesis of data from the SMR-ARPA and the CSIM radars in a plane perpendicular to baseline, 42.5 km North of SMR-ARPA radar. Contours of SMR-ARPA radar reflectivity at intervals of 5 dBZ (Watson, 1996, Appendix C).

before it reaches the ground. To correct for such effects, the measured vertical radar reflectivity profile and the 3-D reflectivity distributions parameterized from the 3-D NWP model fields will be used. The methods and algorithms will improve considerably the radar estimates of surface precipitation at long ranges. The main advantage of this technique is that it widens the quantitatively reliable coverage area of a radar network.

Radar rainfall retrieval procedures are mainly based on spatially and temporally averaged drop size distributions, which lead to a fixed Z-R relationship. A more physical based approach, which takes full advance of polarimetric radar data, is proposed in order to evaluate errors and uncertainty related with a single Z-R approach.

1.2 Data assimilation and NWP improvements

The current situation of weather forecasting sees high resolution forecast models entering the praxis of operational forecasting, and weather radar systems as a well established tool for real time monitoring of weather developments and for nowcasting in particular severe weather. In synthesis, weather radar data are potentially relevant for providing input to the forecast models when the required forecasting lead-time is within the responding time of the catchment. This potential has been only very marginally exploited up to the present and this is not the place to examine the reasons that are manifold. Recent developments in processing and qual-

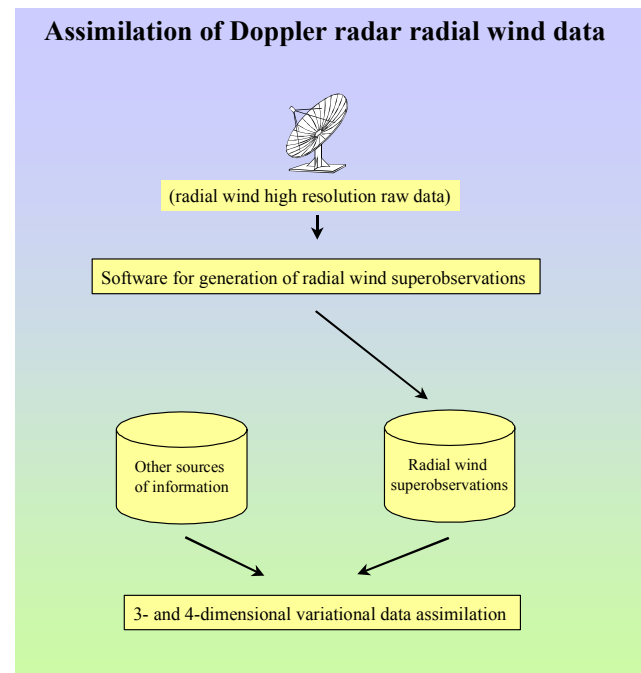


Fig. 6. Schematic description of data processing.

ity control of radar information as well as in data assimilation techniques have considerably raised the level of data provision and use. The field is in very rapid evolution and, at the present stage is rather premature to suggest that the present project will contribute a major breakthrough in the quantitative utilization of weather radar information for numerical weather prediction.

For high resolution model integration, it has generally been demonstrated and also indicated by the geostrophic adjustment theory, that it is most vital to accurately determine the 3-dimensional wind fields. The standard wind observing system is the radiosonde network whose horizontal resolution (500 km mean distance over Europe) is very poor, especially when the grid resolution of NWP models is of the order of 10 km. Generally, the potential data sources for atmospheric winds are automated aircraft reports, radars and satellites. Radar winds are quite problematic since only the velocity component along the radar beam is measured at full resolution. Other problems with radar winds are the inconsistencies between the vertical components of the radar radial winds and modeled vertical velocities, and a Doppler velocity folding. An impressive early demonstration of the potential of assimilation of radar radial winds is given by Kapitza (1991).

In order to correctly link radar data and NWP methods, the pre-processing phase will be explored. The main task will be the extraction of parameters suitable for data assimilation procedures. Doppler radar data will be processed to extract wind field information suitable for ingestion in NWP procedure or to be used in forecast validation. The quality control of radar information prior to their ingestion in NWP algo-

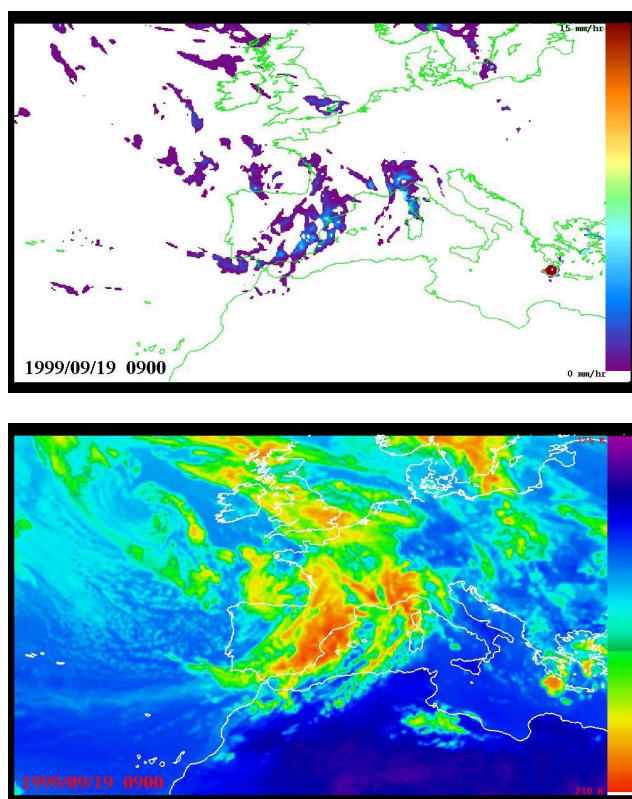


Fig. 7. 19 September 1999, 09:00 UTC. Precipitation estimation (left), and METEOSAT IR brightness temperature (K) (right).

gorithms is therefore a critical aspect of the operational application. Activities will be addressed to increase the reliability of Doppler information.

With two Doppler radars it is possible in principle to determine the three-dimensional wind field in the area of beam overlap, except near the baseline through the two radars (Fig. 4). Figure 5 (Watson, 1996) shows a vertical section recovered from the Doppler data from the ARPA-Servizio Meteorologico Regionale (Emilia-Romagna) radar at San Pietro Capofiume near Bologna, and the CSIM (Veneto) radar located near Teolo.

One more important data-set that needs to be exploited is the clear air echo to obtain wind profiles and boundary layer characteristics. This might happen through the use of pre-processing techniques such as the velocity-azimuth display (VAD) or the volume velocity processing (VVP), or through the direct assimilation of measured quantities. Knowledge of scattering properties employed in conjunction with modified signal handling may serve to improve the frequency and accuracy of retrieved information.

The development of techniques for the assimilation of radar data, among other remote sensing data, will be addressed to improve the quality of the description of the atmospheric state used as initial conditions in NWP methods. The impact of radar data on the forecast quality will be studied through Observing System Experiments (OSE). Bearing in mind the constraints of the different numerical methods to

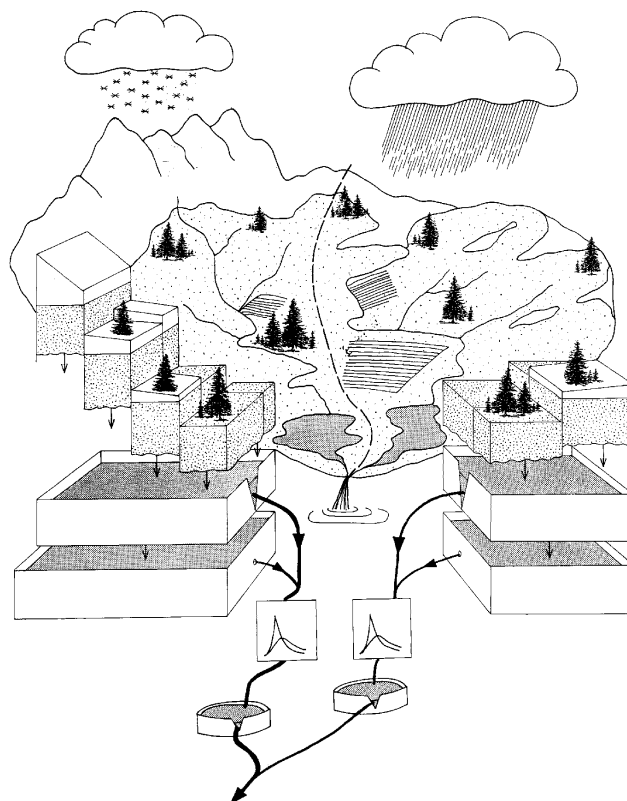


Fig. 8. Schematics of the semi-distributed HBV-model, that will be used at SMHI to investigate the spatial pattern and temporal variability of errors in different sources of areal precipitation estimates.

be used by the project (i.e. nowcasting and very short-range forecasting over sub-national scale and short range forecasting over national scale), a spread of assimilation techniques will be investigated, ranging from laborious 3- and 4-dimensional variational assimilation (3D- and 4D-Var) to simpler interpolation techniques and nudging applied in continuous assimilation. Doppler radar data in super-observation form, will be used as input to the variational data assimilation. The general strategy is illustrated in Fig. 6, which shows schematically how software will be developed and refined to generate Doppler radar radial wind superobservations. 3D- and 4D-Var data assimilation systems will then be extended to manage the assimilation of radar radial wind superobservations.

1.3 Remote sensing data and hydrological models – Flood forecasting

The objective of the area 3 is to develop and assess procedures for combining radar information into NWP models and radar and rain gauge rainfall measurements within discharge forecast models in urban and rural catchments.

Full exploitation of the areal precipitation estimates produced from stochastic models, rain gauges, radar, satellite and NWP models is subjected to the better understanding of their spatial statistical and physical characteristics. An

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