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Using SAR Imagery for Flood Modelling

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Abstract

Airborne radar technology has long been exclusively devoted to military applications. In the recent years, applications in telecommunications, oil exploration and agriculture have proved that radar technology can also be used commercially. This paper focuses on an application in the insurance industry and describes the development of a large-scale flood risk assessment model for the River Thames. The model is based upon airborne Synthetic Aperture Radar (SAR) data and was built using commonly used Geographic Information Systems (GIS) and image processing tools. From the Ortho-rectified Images (ORIs) a land cover map was produced, from which surface roughness could be derived. A Digital Elevation Model (DEM) had to be processed to remove trees and other soft barriers and obtain the effective ground level. This was achieved by using the land cover information and remote sensing processes. This methodology is applicable to any organisation exposed to flood risk.

Key words: DEM, flood, GIS, insurance, ORI, remote sensing, SAR.

As highlighted by recent events in the UK (e.g. Easter 1998) and elsewhere (e.g. Eastern Europe), riverine flood is a major natural hazard in Europe. Flood is the costliest natural hazard in the world and accounts for 31% of the economic losses resulting from natural catastrophes (Munich Re, 1997).

The insurance industry is becoming increasingly concerned that the financial cost of flooding is quantified accurately. This concern is further aggravated by the projected increase in UK households by 4 millions by 2010. The Environment Agency (EA, 1999) itself has requirements for flood risk assessment. Determination of at risk areas is needed not only for flood warning, but also for flood plain development control (Parker, 1998).

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A lot of research has been done to determine loss estimates by water depth (Black & Evans, 1999). However, adequate flood depth estimates have been difficult to acquire for large areas such as the Thames flood plain. The insurance industry, for example, has typically relied on coarse resolution flood risk assessments. It can be argued that this is due in part to the lack of terrain and land cover information with an adequate spatial and temporal resolution. New techniques for terrain collection have become available in the past two or three years (e.g. SAR and Laser scanner), which have the potential to provide very high resolution data. In conjunction with other remote sensing data sources such as CASI or airborne photography, these can be used for state-of-the-art flood modelling.

1. Introduction

1.1 Development partners

The project was conducted by the consultancy division of Willis, a world-wide risk practice. Willis uses a blend of hazard and GIS expertise allied to actuarial and financial engineering to provide risk consultancy to the insurance, reinsurance and financial markets world-wide.

The Synthetic Aperture Radar (SAR) data was supplied by Intermap Technologies, a multi-national digital mapping company. Intermap focuses on providing image data from radar satellites (e.g Radarsat), interferometric airborne radar (STAR-3i) and aerial photography. Digital Elevation Models (DEMs), Ortho-rectified images (ORIs), and Thematic Maps are the primary outputs.

Hydrological data was supplied by Hydraulic Research, Wallingford, a leading hydraulic engineering consultant, specialising in river and coastal flooding in the UK and overseas.

1.2. The River Thames

The 340 kilometres long River Thames is the UK's most important river. At Teddington lock, its regime changes from tidal (susceptible to storm surge) to non-tidal (susceptible only to rainfall induced flooding). Flood modelling has to take this dual regime into account. For the purpose of this study, the river effectively ends at the Thames barrier (Woolwich) which was completed in 1982 to prevent flooding from coastal surge with a design criteria of the 1000-year event. The river has a discharge rate of 680 cumecs for a 50 year flood event at Teddington lock.

The catchment covers an area of approximately 14,000 square kilometres. While the upper reaches are steeper, the majority of the flood plain is relatively flat. For most of its length the river can be described as semi-managed. Although the non-tidal section frequently does not feature banks or levees, management is carried out using alleviation techniques such as diversion channels and ponding reservoirs. There are 1.4 million residential and 100,000 commercial properties in the immediate vicinity of the river, with a population of approximately 3 million people.

2 Development

Three factors underpinned this study: the physical and insurance conditions that drove the project commercially, the data innovations that drove the project technically, and the tools and processes that determined the methodology.

2.1 Physical and insurance conditions

The River Thames is a flood prone river. It has suffered serious flooding at least 20 times during the last 200 years. Major events occurred in 1894 and 1947, both of which caused severe flooding, particularly in London. Minor floods occur more frequently, flooding smaller areas and areas of lower economic value. In the recent past, there has been considerable property development on the flood plains, particularly ‘out-of-town’ commercial development and new residential development in response to the UK government’s call for 4 million new homes to be built during the next 10 years. Property values have also increased greatly during the past 15 years, by 1.5 times the annual inflation rates, thereby adding to the value of property at risk.

In the UK, flood insurance is normally provided as part of buildings and contents insurance. For residential property, approximately 70% of property has buildings cover, and 85% has contents cover. Commercial flood insurance is similarly provided as part of normal cover. Flood insurance in the UK covers all types of flood.

The consequence of the increasing value of property at risk, and the insurance conditions (nearly universal cover), have resulted in very large exposures to potential flood risk for insurance companies. This exposure is also of interest to reinsurance companies and other organisations interested in risk (e.g emergency services, planning authorities). Willis had been asked to study the feasibility of providing loss estimates for Thames flood for insurance companies in the past, but due to data limitations had not been able to identify a suitable methodology which combined regional coverage, detailed property location and a feasible flood risk area delineation technique.

2.2 Innovative technologies

2.2.1 Digital Elevation Model and Surface Roughness information

The STAR-3i system is an interferometric radar system mounted on a Learjet36. The system generates DEMs and ORIs simultaneously. The system consists of two X-band radar antennae mounted on the Learjet. Data collection from the two antennae occurs simultaneously. Only the first surface elevation is measured. The set of acquired data is interfered by a digital correlation process to extract terrain height data, which is used to geometrically correct the radar image. STAR-3i uses post-processed Differential Global Positioning Systems (DGPS) data, together with on-board laser-based inertial measurement data, to attain highly accurate horizontal and vertical positioning control. Precise terrain height and positioning data are enhanced by careful calibration of the baseline (the distance between the two antennae). Due to the accuracy of the positioning information and the careful baseline calibration, no in-scene control points are required. The only restriction is that a ground-based GPS receiver must be located within 200km of the data collection site for DGPS processing. Adding ground-truthing allows the increase of the data resolution further. In the typical collection mode, the system is flown at a height of 12,000m and acquires a 10km wide swath of 2.5m resolution radar data. The system has been designed to collect <2m vertical accuracy DEMs at a rate of up to 100 km^2/min.

ORI's are images that have had all distortions caused by platform instability, radial distortion (airphoto) and terrain displacement removed. A DEM is used to remove the distortions due to terrain and elevation. Correcting for these distortions results in the imagery becoming a true scale representation of the ground, which can be used in a GIS for measurements of length, area, and azimuth.

The main data input used in flood risk assessment is the DEM. There have been a number of elevation models available in the UK, principally from the national mapping organisation, the Ordnance Survey. These have been used in the past for coastal flood models, but neither their accuracy nor their resolution were considered suitable for the planned new riverine models. Other data sets are becoming available, including Laser Scanner and SAR. Satellite SAR from ERS1 & 2 and Radarsat does not have sufficient accuracy or resolution and requires data from multiple passes, leading to problems with coherence. Laser Scanner has very high collection and processing costs, has longer collection timescales and is normally collected at a much higher resolution than is required for regional models.

In planning this study, airborne SAR has proved to be the ideal source for regional flood modelling. The DEM has a resolution of 5 or 10 metres, with a vertical accuracy from 3m to 0.5m. The ORIs have a 2.5 metre resolution. The combination of DEMs and ORIs provides a data set that can be handled with reasonable ease (due to its reasonable file size), and can provide sufficient vertical and horizontal detail for most regional risk assessment requirements. Further advantages include cloud penetration and day/night acquisition. The use of airborne SAR for a commercial, large area flood risk assessment has not previously been carried out in the UK. This project is based completely on commercial requirements and was funded by Willis.

The specifications of the SAR products are detailed in Table 1.

Table 1 : Specifications of airborne derived SAR products

Data	***Digital Elevation Model (DEM)***	***Orthorectified Image (ORI) Data:***
Horizontal resolution	posting every 5m, 10m	pixel size 2.5m horizontal RMS 2.5m
Vertical resolution	vertical RMS 0.5 to 3m	n/a
Mosaic coverage	7.5' tiles	7.5' tiles
Format	ASCII, BIL or GEOTIFF	BIL, GEOTIFF or TIFF

The accuracy of the data, which has been used on this project delivered with a vertical RMS of 2m, is likely to have been better than that quoted. SAR gives higher accuracy on flat or homogenous surfaces, such as flood plains. The Institute of Navigation, University of Stuttgart (Kleusberg A. and Klaedtke H. G, 1998) has produced an independent report on the accuracy of STAR-3i.

2.2.2 Hydrological data

The other essential data for flood risk assessment is hydrological data. Conventional hydrological modelling is both data intensive and processing intensive. The complex multiple inputs interact in a way which provides a suitable result for local area studies. However, application of full hydrological models to areas larger than a single reach is problematic. Hydrological modelling is useful for local studies with good quality, site specific data. The new flood risk assessment process outlined in this paper is suitable for regional areas with minimal data. The hydrological data used in this project included raw flood levels for events with various return periods, produced by HR Wallingford (HR Wallingford, 1999; HR Wallingford, 1997).

2.3 Tools and processes

The processes used on this study were closely linked with the tools selected. If advanced hydrological modelling had been required, tools such as Mike11 (from Danish Hydraulics Institute) or ISIS (from HR Wallingford) would have been used in addition to the GIS and image processing tools. Instead, standard GIS tools were used.

2.3.1 GIS tools

The primary data processing and editing tools for this project were ArcInfo and ERDAS Imagine. ArcInfo 7.2.1 runs on a Sun Enterprise 450 and accesses a DEC Raid5 storage works for data storage. The GRID and TIN modules were used extensively in this project.

ERDAS Imagine version 8.3.1 runs on a Compaq SP700 PC, which is networked to the UNIX equipment. The Essentials and Advantage modules were used. ArcView 3.1 was also used in the project, running alongside ERDAS. The extensions Spatial Analyst, Cad Reader, 3D Analyst and Geoprocessing were particularly useful.

2.3.2 Processes

The Thames survey flown by Intermap in August 1998 produced 120 tiles of data, each 120 square kilometres in area, consisting of approximately 600Mb of data each. Only 34 tiles were used for the purpose of this Thames study.

The project was carried out over 12 months elapsed time at the Willis offices in London. The initial processing carried out on the DEM data involved producing a physically limited and horizontally corrected DEM, which could be used for the flood processes. Image enhancement tools were used to produce a land cover map from the ORIs, from which surface roughness coefficients, or Manning's *n* values (Dingman, 1994), could then be derived for flood propagation modelling.

The generalised algorithms are detailed below:

Generalised process for producing DEM

- Reprojection from UTM to UK National Grid
- Geoidal correction from WGS84 to OSGB36[1]
- Conversion of ASCII DEM to GRID Lattice
- Data size management: an approximate flood plain was defined using the river elevation as a baseline, and an arbitrary 10m contour

ARC/INFO

- Use of image processing tools to provide 'ground level' elevation,

ERDAS Imagine

Process for producing landuse map from ORI

- Registration of ORIs using ArcInfo
- Conversion to GRID
- Reprojection from UTM to UK National Grid
- Data size management: DEM grid used to mask ORI grid

ARC/INFO

- Noise reduction and image enhancement of ORIs
- Unsupervised classification of multispectral images to provide landuse/roughness map

ERDAS Imagine

[1] The geoidal correction of the DEM was found to be beyond the capabilities of the GIS software used in-house. This process was outsourced to the Geomatics Department, University College London in order for specialist software and expertise to be applied.

The next stage in the process was to take the raw flood levels provided by HR Wallingford, and produce a flood surface for a number of return periods corresponding to the 50, 100, 200, 500 and 1000 year events. The points were located upstream of weirs and locks, to produce a representation of the flood that was relatively unaffected by the structures. There were 55 points used in the tidal and non-tidal Thames. The flood height at each point was extended along a line perpendicular to the river, which takes into account the orientation of the flood plain at each cross-section. These points were used as inputs to build a TIN: the subsequent water surface was used as an estimate of the slope of the stream channel and the flood.

Two processes were compared for the creation of flood maps:

a) Intersecting the flood surface with the DEM:

A key feature in the algorithm removed polygons non-adjacent to the river, i.e. areas which the terrain model indicates are not logically flooded at a given water depth. This process produces a logically correct flood risk envelope.

b) Using a basic propagation model:

Existing propagation models were examined (Consuguera et al., 1993; Giammarco et al., 1994a, 1994b) and an appropriate methodology was developed, whereby the water is propagated out from the river across the DEM surface in a series of iterations until the limit of the surface likely to be flooded is reached. As with the previous method (a) this takes into account embankments and solid features (trees and other 'non-solid' features have been previously removed with a filter). Both processes were carried out using ArcInfo GRID tools and processes. A visual comparison of techniques a) and b) showed that both methods provided similar flood extents.

3. Application: risk analysis and loss estimation

Flood modelling allows the delineation of areas at risk, as well as the estimation of indicative flood depths expected at any location within the area affected. This data is then used to assess risk to property. Using a suitable interpolation algorithm, property locations at a unit postcode level, are intersected with flood depth data. This results in a measure of flood intensity (water depth) for each location.

Potential loss to an insurance company portfolio of properties can then be estimated for flood events of various return periods. The process is carried out using a proprietary data warehouse system, built using an Oracle Relational Database Management System (RDBMS), and called the Integrated Catastrophe Modelling Platform (ICMP™). This process takes the inputs of flood intensity, client portfolios, and suitable loss curves, and outputs an estimated loss, for each location, and/or for the whole portfolio. The initial use of the outputs from the system is to allow insurance companies to accurately calculate their reinsurance purchase requirements. The data can also be used by insurers as a rating tool for properties and to provide hazard intensity for potential development sites. A user interface was also developed, which can be used to interrogate the data and visualise the areas at risk.

4. Discussion and conclusion

The airborne SAR data proved ideal for regional flood risk assessment. The combination of resolution and accuracy delivered a final product that is far superior to anything else currently available. Initial problems with data sizes, particularly with the DEM data, were overcome by 'trimming' the area of interest to the floodplain only and careful disk space management. The SAR data provides a unique combination of elevation models and ORI image, which allows land use to be included in the estimation of flood propagation. This is a major advantage over other data sets and allows a great refinement of the flood estimation process, with little additional processing. GIS tools also proved adequate for regional risk assessment, as opposed to single-site analysis.

This approach can give planners as well as insurers a valuable tool for assessing the required flood risk. The flood risk assessment system developed by Willis is now available to UK insurance companies, and enables them to estimate their exposure to flood risk on the Thames from a number of different return period events, both at a portfolio level and at a geocode level. The methodology developed for this study is currently being assessed by local and national authorities in the UK and elsewhere, and is being proposed for use by the insurance industry in Europe and the Far East.

The Bye report (Bye, 1998) for example, is using 100 year (river) and 200 year (coastal) as planning return periods. However, it is belived that both planners and insurers will need an assessment of risk for more than one scenario. Therefore, a multi-scenario approach was adopted.

There are a number of potential refinements, which will further increase the value of the flood risk assessment model. The propagation of the flood can be enhanced by the addition of improved volumetrics for historic floods. This may prove problematic for the Thames, but will prove more successful for other rivers which have defined defences (levees) and for which a realistic limit can be set for available floodwater volume.

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Integrated Catastrophe Modelling Platform is a registered trademark.

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