THE USE OF SATELLITE RADAR FOR MONITORING FLUVIAL AND COASTAL FLOODING

Ken Blyth

Natural Environment Research Council
Institute of Hydrology, Wallingford, OX10 8BB, UK

Abstract

In the past, satellite observations of floods have been hampered by the presence of clouds and high resolution satellite data have not been available in near real-time. Initial tests in the UK have shown the ERS-1 SAR to be a suitable sensor for flood mapping and fast delivery products can be obtained within hours of satellite acquisition. Suitable data acquisition, processing and dissemination methodologies are required to facilitate worldwide practical applications. An EC-European Space Agency funded pilot project for flood hazard assessment and mapping using ERS-1 in the Philippines has recently begun.

1. Introduction

Each year, river and coastal flooding, worldwide, results in major loss of life and property. For major floods, especially where ground communications may be severed, there is a requirement for overview information on floodwater extent to enable relief efforts to be directed to areas of greatest need in the short term and for flood hazard assessment and mitigation in the longer term. In the past, satellite observation of floods have been hampered by the presence of clouds and high resolution data have not been available in near real-time. Satellite radar imaging systems which can penetrate cloud are now becoming widely available and methods for the rapid dissemination of such data are steadily improving.

After placing flooding in context with other natural hazards, some of the main uses of satellite remote sensing for flood hazard assessment are outlined. The synthetic aperture radar (SAR) on the European ERS-1 satellite has been evaluated by the Institute of Hydrology for flood mapping and the results of this evaluation together with the main advantages and shortcomings of the system are summarised. Examples of the use of the ERS-1 SAR for temporal studies of flooding both of rivers and wetlands are given. For any satellite flood monitoring systems to be used to full effect, it is essential that a good communication system with the user community be established and that adequate training in the use of the data be given. An EC-European Space Agency sponsored project has recently been established for flood monitoring in the Philippines and this is outlined.

2. Flooding in relation to other natural hazards

Flooding is a natural hazard which can occur in almost any part of the world and with which most people can directly associate, often as a result of their own experiences. Because the effects and severity of flooding can be directly influenced by human intervention to a much greater degree than with many other natural hazards, the possible benefits of monitoring and mapping by remote sensing are potentially greater.

In terms of the numbers of people killed in disasters declared by the U S. Office of Foreign Disaster Assistance during 1980-89, flooding is ranked 6th of the naturally occurring disasters. However, in terms of the numbers directly affected by declared disasters, flooding is ranked 1st with almost 280 million people affected The difference in the two rankings for flooding may be due in part to the success of current flood warning systems to reduce loss of life whilst being ineffective against loss of property. By comparison, earthquakes, which generally occur with little forewarning, have similar ranking both for numbers killed and numbers affected.

3. Requirements for remote sensing of flooding

Two degrees of flood extent monitoring can be identified The first is a broad-brush approach which looks at the general flood situation within a river catchment or coastal belt with the aim of identifying areas at greatest risk and in need of immediate assistance, the second is a more detailed mapping approach which is required for the production of hazard assessment maps and for input to various types of hydrological and land use models. Both approaches require the timely acquisition of satellite data and this can only be achieved on a regular basis with the use of cloud-penetrating radar

The need for overview information is most apparent when large areas are inundated and communications are severed, the most extreme example being found in Bangladesh. A rapid measure of floodwater extent is required to prioritise :

- rescue/evacuation of residents
- supply of food/medical aid
- strengthening/repair to flood defences
- repair of communications
- repair of water supply, power and other infrastructure

In the longer term, an assessment of the flood damage to the agriculture of a region is often of prime importance to the local economy and to future planning. Satellite data with ground resolution up to 100m would be of value for the above rapid response requirements. A more precise measure of floodwater extent (<30m resolution) is required for the production of hazard assessment maps, for hydrological modelling applications and for the assessment of land use change such as urbanisation or deforestation on hydrological response. The former can only be achieved with satellite radar because of the critical timing requirement, whilst the latter can make use of both satellite radar and non-microwave sensors which may be able to acquire data during cloud-free periods Accurate floodplain maps are required for the successful management of floodplains through such measures as agricultural and urban development control, the building of flood alleviation structures and the control of drainage, erosion and sediment deposition This type of information can be most successfully assessed if it is first digitised then incorporated with accurate topographic information in a GIS

4. The ERS-1 Synthetic Aperture Radar

Table 1 lists those satellites which carry radars suitable for flood monitoring In 1978, the Seasat satellite first demonstrated the potential of cloud-penetrating radar, but further satellite systems were not available until the 1990s. The main satellite currently in use is the European ERS-1 and this will be followed by 4 other satellites which will ensure the availability of radar data well into the next century.

Table 1. Satellites with radar sensors suitable for flood monitoring

Satellite	Origin	Launch Date	Operational Life
SEASAT	USA	June 1978	3.5 months
Almaz	Russia	March 1991	2.5 years
ERS-1	EC	July 1991	4 years
J-ERS-1	Japan	February 1992	3 years
ERS-2	EC	early 1995	3-5 years
Radarsat	Canada	early 1995	5 years
Envisat	EC	1998	3-5 years

Advantages

The European Space Agency ERS-1 satellite carries a C-band Synthetic Aperture Radar (SAR) which is capable of observation both at night and through cloud to maximise the possibility of capturing flood events. Each SAR image covers an area 100 x 100 km which enables large river basins to be covered within a single frame at a nominal spatial resolution of 30 m. The radar system is particularly well suited to the detection of temporal change (such as floodwater extent) as a result of its good radiometric and geometric stability which allows time-series images to be easily co-located and compared. Smooth water surfaces appear black on radar images because they reflect most of the radar energy away form the sensor. This is in contrast to surrounding land features which generally appear much lighter. An additional advantage of using radar lies in the possibility of detecting floodwater beneath some vegetation canopies. Whilst the ERS-1 radar cannot penetrate dense vegetation directly, gaps in the canopy may allow reflectance from the water/vegetation interface, often producing a bright radar return signal (Hess et al., 1990). The sensitivity of radar to changes in surface roughness should provide a good basis for the detection of flood related erosion and deposition features and for the delineation of crop damage, but neither have been tested so far. Two levels of data products are relevant to flood monitoring. The SAR 'Fast Delivery' (FD) product can be disseminated to primary user centres within 3 hours of acquisition and thus would be the preferred medium for rapid assessment of a major flooding event. The SAR 'Precision Image' is better suited to temporal studies as the data are fully calibrated but data dissemination takes about 2 weeks.

Disadvantages

The design of the ERS-1 microwave instruments was determined by the requirement to measure ocean roughness and hence the selected frequency and

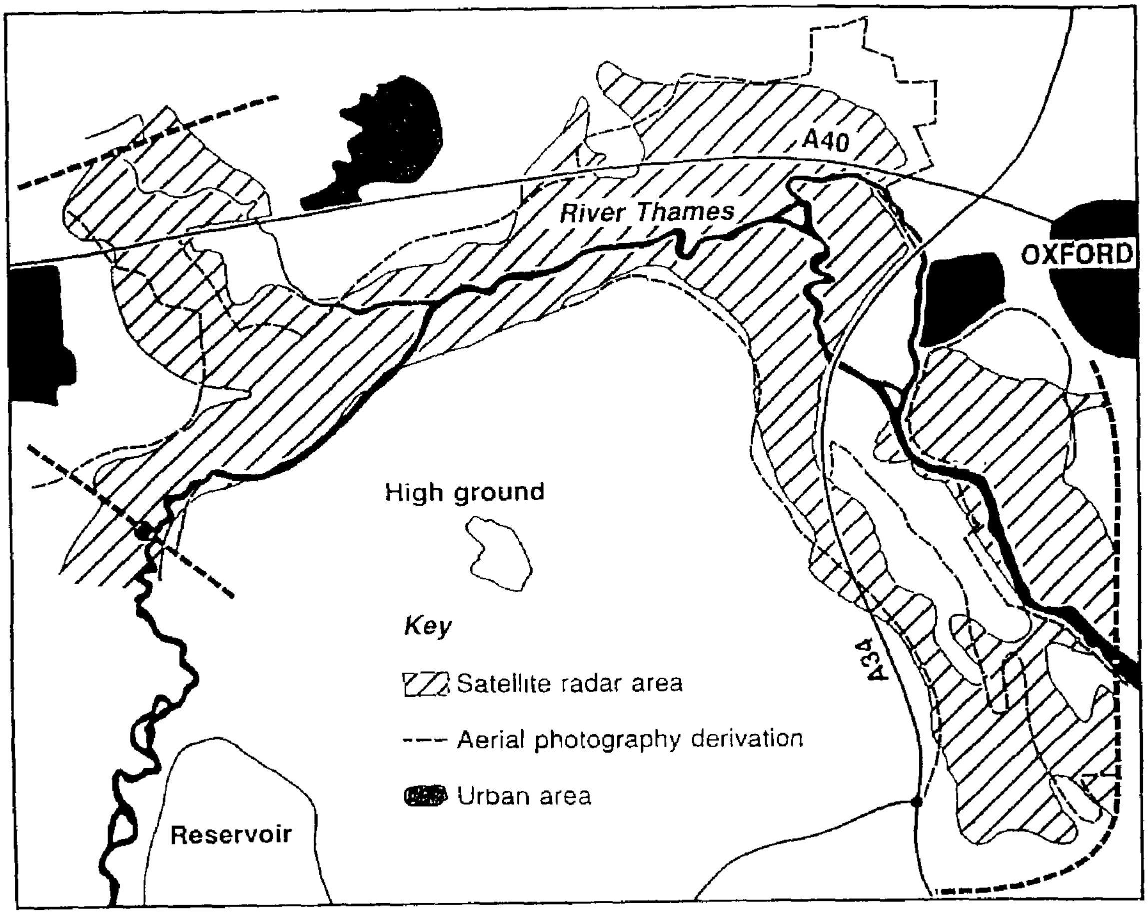


Figure 1. Comparison of floodwater extent derived from ERS-1 SAR and aerial photography, River Thames, 4 December 1992.

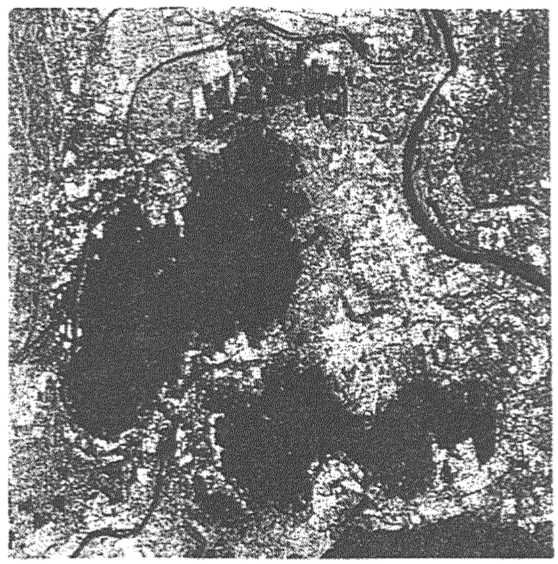
polarisation of the SAR make it inherently sensitive to wind-induced roughening of the water surface. For inland floodwater situations this can reduce the land/water contrast during windy conditions and the possibility of this occurring should be kept in mind during interpretation of radar data. ERS-1 was designed as a research satellite and a number of orbit changes have been undertaken to satisfy different user requirements. Whilst a satellite return period of 3 days has been available for 2 periods of 3 months duration, in general the return period has been too infrequent for operational flood monitoring purposes. To acquire SAR data over a particular area, it is normally necessary to make a request 2 weeks in advance of the acquisition time and clearly this is not possible for unforeseen events such as floods. Any last minute changes to the satellite acquisition timetable is made at the discretion of the ERS-1 Mission Management and to date, every effort has been made to accommodate requests for the coverage of major flood events. However, the capability to acquire data at short notice is an area which requires serious consideration in the planning of future operational satellite flood monitoring systems.

5. Flood mapping with ERS-1 SAR

The ability of the ERS-1 SAR to record floodwater extent was first tested over the River Thames, U.K. in December 1992 when an ERS-1 overpass corresponded closely to the maximum flood level throughout much of the upper Thames river network. Within a single ERS-1 image, flooding was observed along 400 km of mainstream and tributaries. As a means of testing the ability of the SAR to differentiate floodwater from surrounding saturated land, aerial photographs were taken along most of the mainstream. A light aircraft was used by the Institute of Hydrology to acquire a detailed photographic record of the extent of floodwater within 2 hours of the ERS-1 overpass. Interpretation of the SAR data was carried out before that of the aerial photographs and Figure 1 compares the flood boundaries extracted from the two sources for an area to the west of Oxford. Generally there is good correspondence between the two lines, the main differences occurring where the floodwater is very shallow and emerging vegetation is present. Interpretation of the ERS-1 data was made easier by the combination of images depicting the flood and the no-flood situation By applying different colours to each image it was possible to differentiate permanent water features such as reservoirs and flooded gravel pits from the transient flood water

Extensive flooding on the Mississippi River in July 1993 was first captured during a persistent cloudy period by the ERS-1 SAR. Radarsat International, the distributors of ERS-1 data in the USA and Canada provided a number of government organisations with processed SAR images within 24 hours of acquisition. These data enabled the floodwater extent of this important 1 in 500 year flood and its associated damage to be assessed and appropriate action to be taken. In addition, it was found that, by combining the radar images with optical images obtained by the Landsat and SPOT satellites, more detailed land use information and the effects of flooding could be extracted (Radarsat International, 1993)

(a)



(b)

Figure 2 a). ERS-1 SAR pre-flood image of Camargue wetland, S. France, 3 January 1994 b). Flooding on Camargue wetland, S. France, 12 January 1994.

As part of our ERS-1 Principal Investigator studies, the Institute of Hydrology received ERS-1 SAR images from the European Space Agency of the extensive River Rhine floods of December 1993 and of the closely following inundation of the Camargue wetlands in January 1994. The usefulness of time-series SAR data was evident in both of these cases. Figure 2 shows part of the Camargue a) before flooding on 3 January 1994 and b) near the maximum flood extent on 12 January 1994. The Grand Rhone is clearly seen top right, the narrower Petit Rhone to the left and the Etang de Vaccares, bottom right. The black, field-shaped features in the pre-flooding image are marshes and abandoned rice paddy fields Extensive flooding to the right of the Petit Rhone appears black as a result of the low radar backscatter from the smooth water surface, whilst some evidence of wind roughening is seen in the lighter tones of the Etang de Vaccares. ERS-1 SAR images were also acquired on 15 and 21 January 1994 and these show the gradual recession of the flood water. Time series combinations of the SAR images have been produced and vividly show in colour the change in floodwater extent at time intervals of 3-9 days (see front cover of this volume) This type of information could not be acquired with conventional visible/infrared sensors and demonstrates the powerful capability of satellite radar for this application.

6. Philippine ERS-1 Flood Monitoring Project

The capability of satellite SAR for flood monitoring has been demonstrated above, but to achieve success it is imperative that timely information reaches the right people on the ground who are capable of taking remedial action. This can only be accomplished through the development of a suitable flood warning and mitigation infrastructure within each country at risk. The EC-ASEAN ERS-1 Project has been set up as an EC/ European Space Agency collaborative project with Indonesia, Malaysia, Thailand and The Philippines to develop applications of ERS-1 radar data through 8 pilot projects, one of the Philippine projects covering flood hazard assessment. Training is a major element in the projects, beginning with Decision Makers Seminars where government officials are informed of the project aims to ensure that appropriate communications links are established to disseminate the remotely sensed data. Training in handling and data extraction techniques for satellite SAR images ensure that local organisations can incorporate this information into their existing severe weather warning systems. Technology transfer of this kind is essential if the full potential of remotely sensed data for hazard assessment and mitigation is to be realised.

7. Future prospects

It can be seen in Table 1 that a number of satellites carrying synthetic aperture radars will be available from the present to the turn of the century. Depending on their final launch dates and operational lifetime, it is conceivable that there could be up to 3 systems in operation at any one time. This would considerably increase the likelihood of acquiring timely satellite coverage of flood events, but the need in the long term is for the coordinated planning of future satellites to provide worldwide coverage at a time interval of 3-7 days Both Radarsat and Envisat will have steerable beam SAR's which will improve their site revisit capabilities and the associated change in radar incidence angle should not pose difficulties for flood mapping, although this may be a problem for other applications. The real challenge now lies in our ability to make full use of these satellite data sets through the development of near real time distribution and analysis systems

8. References

Hess, L.L., Melack, J.M. and Simonett, D.S. (1990) Radar detection of flooding beneath forest canopy: a review. *Int. J. Rem. Sens.*, **11**, 1313-1325.

Radarsat International (1993) Radar satellite tracks Mississippi River flood. *Reflections*. A Radarsat International Inc. Newsletter. Richmond, Canada. 2/ 2, 2-4.

Discussion

Dr. Walter (NASA) asked about the level of inter-space agency collaboration to ensure multiple use of satellite radars. Dr Blyth did not know how closely ESA and Radarsat were collaborating, but suspected little coordinated work had been done on designing applications