A Review of Remote Sensing in Flood Assessment

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***Abstract*—Flood is defined as water that temporarily submerges land. In the United States, flood is being considered as an event only if it last over 72 hours, but the time frame is much longer in the Europe. The information of water bodies is an important source when examining floods. However, this data is not always available or accurate by traditional survey since water surface changes frequently. Remote Sensing provides an alternative method to traditional survey with lower cost and much frequent revisit cycles. Some sensors have very fine spatial resolution but relative long revisit circle; while some fine temporal resolution satellites are not able to provide spatial information in detail. This paper provides a brief review and comparison of major optical and Radar satellite sensors which are currently adopted in flood assessment. Result indicated that both optical sensors and Radar systems play important roles in flood assessment. Although many agencies use Radar or optical data independently when ding flood assessment, the potential of combining data from both systems is huge.**

Keywords—Remote Sensing; flood assessment; optical sensor; Radar; flood monitoring

I. INTRODUCTION

Flood is defined as water that temporarily submerges land [1]. Flood could come from various sources. For example, tsunami and typhoon could cause flood while intensive precipitation and glacier melting could be source of flood as well. One of the most significant figures of floods is duration. Duration of floods may vary from several days to months. For example, according to the historical records of Tana River Delta (Kenya) during 2002 - 2011, the mean flood duration is 41 days while some floods were less than 15 days; on the other hand, a few floods could last more than two months [2]. It is popular to define floods base on the duration of floods. Different countries have different rules to define floods. In the United States, a flood is being considered as an event only if it last over 72 hours, but the time frame is much longer in the Europe.

II. OPTICAL REMOTE SENSING IN FLOOD

The information of water bodies is an important source when examining floods [3]. However, data are not always available or accurate by traditional survey since water surface changes frequently [4]. Remote Sensing provides an alternative method to traditional survey with lower cost and much frequent revisit cycles. Several satellites will be discussed in this paper based on their ability of water recognition. Satellite sensors could be grouped into two main categories: optical sensors and Radar systems. The capability of wavelengths is one of the major difference between optical sensors and Radar systems. Optical sensors use lower wavelengths than Radar systems. Optical sensors are commonly used for collecting post-flood information due to the poor cloud penetration compared with Radar systems [5]. Many studies which use optical sensors are only able to do post-flood analysis but not monitoring floods due to cloud cover during flood event; more importantly, the revisit cycle is too long for many sensors. As a result, these sensors are most used to generate flood extent. For example, flood extent has been generated in research from various data source in 2005 acquired from Landsat (TM and MSS), IRS and SPOT with using different calculation methods [4]. However, some optical sensors become valuable in flood study due to their fine temporal resolution. The six-hour revisit capability of NOAA satellites has a potential use of disaster monitoring [5]. AVHRR, which is available at both low price and less technical requirements, is good for developing countries [5].

A. Landsat

Landsat is one of the most popular Remote Sensing data sources since it provides decades of non-gap free data at globe coverage. The advantages of Landsat data have been discussed in research [4], [6], [7]. Three different methodologies were used to calculate flood areas using data collected from sensors: Landsat TM and IRS LISS III [4]. Results from several approaches have been compared with each other [4]. Normalized Difference Water Index (NDWI) is the best method in terms of mapping flood area among these methods [4]. Similar to NDVI, NDWI is an index describes the “water-ness” by calculating the ratio of green band and near infrared band [8]. A cut-off value is needed for NDWI to determine the boundary of water and non-water features. This number various depending on the scale factors used and different local situations.

Direct loss is not the only damage caused by floods, floods bring problems such as species invasion and disease spread. For example, habitats of water species could expand when there is a significant flood [9], [10]. Floods brings species to downstream ecosystems [7]. This kind of movement may benefit the diversity of ecosystems, but most time it is not good [7]. The research demonstrated the significant expansion of snail habits after the flood in late 1990s [7]. The amount of snails increased dramatically since there was no enemy in other marshlands [7]. Prediction of flood could help people to control disease and minimize the loss leaded by floods [7]. The potential location may emerge schistosomiasis (a common disease after floods) could be estimated from the predicted flood map using satellite information [7]. The Landsat TM data provide a way to watch flood related disease and provide early warning to public [7].

There are many ways to prevent floods. Floodplains are the product of floods; on the other hand, floodplain is one of major ways to prevent floods [6]. Floodplains provide not only buffer zones for flood storage, but also habitats for wild-animals. Inundated extents over time were extracted to see the changes of water levels [6]. Research indicated that flood durations and frequencies are associated with elevations and surrounding vegetation [6]. A Water Line DEM (WL-DEM) was generated form the combination of DEM and Landsat TM/ETM+ images [6]. Flood frequency for the study area was calculated with using statistical methods and historical records [6]. The paper pointed out that the poor accuracy of the DEMs and satellite images may lead to incorrect results [6]. Since contour-based DEM has better spatial resolution than Shuttle Radar Topography Mission DEM (SRTM-DEM), the contour-based DEM provides better inundation extents [6]. WL-DEM method they generated could provide more detail information about flood extents than both SRTM-DEM and contour-based DEM methods [6].

B. IRS

Fine spatial resolution data are required for urban planning since it needs precise mapping. Inaccurate data could lead to a waste of useful spaces or inefficient planning. IRS-D provides relative fine spatial resolution data compared with other satellite. Reference [1] developed a method which using IRS-D and DEM data to evaluate safe and unsafe regions for Tapi Basin and Surat District. The study area in the research has lost thousands of life during past five floods [1]. Flood map was generated from IRS-D data and historical records. By combining flood data, DEM data and historical flood depth, safe regions were extracted from a 3D analysis [1]. The safe regions mean that these places will be safe if the city is going to experiencing same or less than the scale of flood in the future given the same conditions. Reference [1] pointed out that the urbanization may decrease the number of safe regions because the width of streams has been decreasing rapidly. On the other hand, they also mentioned that protection facilities such as reservoirs will be needed for preventing floods. The high resolution images are very useful for decision makers in flood forecasting and quick response system.

C. NOAA/AVHRR

Most satellites are not suitable for capturing changes of floods due to their long revisit cycles. NOAA/AVHRR becomes useful on monitoring floods due to its extremely fine temporal resolutions and large spatial extents. Advanced Very High Resolution Radiometer AVHRR (AVHRR) is a sensor carried by National Oceanic and Atmospheric Administration (NOAA). Because of the satellite group (NOAA 15, 18, 19), scientists could get couple images per day for each location. One drawback of the high frequency revisit is sensors are not able to acquire fine spatial resolution images, but the moderate temporal resolution is sufficient for sensors to capture floods since floods are usually large scale events [5].

A dynamic flood monitoring study was conducted to examine the usability of AVHRR data for flood [5]. The flood extents were clearly showed based on the multiple AVHRR images. They claimed that the stages of flood could be understood better and the damage analysis could be more accurate with the continuous flood data over time. Although Radar systems are very useful for flood study, the usage of NOAA AVHRR could be significantly useful when monitoring flood because the convenience of spatial extensibility and data accessibility.

D. MODIS

Another system which is similar to NOAA AVHRR is called Moderate Resolution Imaging Spectroradiometer (MODIS). MODIS has many bands but scientists frequently use band 1 and 2 for research in floods. MODIS band one and two have 250-meter spatial resolution and up to daily revisit cycle. The fine temporal resolution of MODIS is suitable for flood change analysis; at the same time the moderate spatial resolution will not affect the result very much since flood is large scale events. As a result, although MODIS does not provide long term data like Landsat, there are a lot of ongoing research on flood using data from MODIS.

The major sources of lake-flood are coming from either upstream or local precipitation [11]. Inundation area of lakes could vary dramatically between raining and dry seasons [12], [13], [14], [15], [16]. Research has been done to measure the dynamic variation of lakes for both short and long terms [11]. Reference [11] discussed one way to display the difference of inundation areas over time is by showing the minimum and maximum flood extents in certain time frames. Based on daily data from MODIS, the research group was able to draw the minimum and maximum inundation area for each month. From the result, water extents for each month have been compared to see if there are significant differences [11]. One interesting result pointed out by the paper is the differences of water extents are significant different within a year and the maximum/minimum ratio could be as high as 4 which means the maximum extent of inundation area is four times larger than the minimum extent [11]. Moreover, the correlation between the difference of the flood areas and the precipitation are statistically significant when excluding summer time [11].

Similar techniques have been applied in several research [2], [11], [17]. Reference [17] used MODIS data to generate flood maps during 2000- 2010 to see the trend pattern for three lakes. One step further from the work, another group did a damage assessment for floods [17]. It is hard to do damage assessment using image independently, but the research provides a way to quantify the loss by measuring acreage loss of different land covers that was affected by floods.

MODIS provides a way for scientists to monitor floods at a fine temporal resolution; however, MODIS data also brings some inconvenience. MODIS sensors could not penetrate cloud while most floods happing with a heavy cloud coverage. For example, the Dartmouth Flood Observatory (DFO) provides daily flood data based on MODIS, and the daily data were smoothed by three day composition to remove cloud cover images. The short history of MODIS is another shortage for scientists who want to do long term analysis. Although 15 years is not short, but it is certainly not as longer as other sensors such as Landsat.

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TABLE I. SPATIAL AND TEMPORAL RESOLUTION COMPARISON BETWEEN OPTICAL SENSORS

Sensors	**Spatial resolution**	**Temporal resolution**
Landsat	Fine	Moderate
IRS	Moderate	Relative Fine
AVHRR	Coarse	Fine
MODIS	Coarse	Fine

III. RADAR SYSTEMS IN FLOOD

Optical sensors are not dominating Remote Sensing world for mapping floods. On the other hand, some people believe that Radar works better than optical sensors for floods [18], [19], [20], [21], [22]. One of the significant advantages of Radar system is the ability of cloud penetration. The long wavelength of radar systems helps Radar to penetrate cloud and some ground objects such as trees. The classification result from Radar systems help to extract some features that could not display clearly from optical sensors [19], [23]. Due to the unique wavelength of Radar system. Although many scientists knew that Radar is significantly useful for navigation and geology, many scientists have been working with flood using Radar for decades. This chapter will discuss some Radar systems that have been used for monitoring floods.

A. *Radarsat-1*

Sensors of Radarsat-1 ScanSAR work in C band (5.6 cm), and HH polarization. It has near range incidence angle of 20° and 49.42° for far range incidence angle. The resolution of the system is 50 meter. Reference [20] used SAR data to measure the flood extent after hurricane, and the result was pretty neat when combining data from Radar and ground stations. Three images which representing before, during and after floods were acquired to be compared to see if average backscatter values change over time [20]. Result shows that the average DN values drop significantly when there is a hurricane related flood happening [20]. Reference [20] discussed that the Radarsat-1 ScanSAR data is suitable for mapping coastal floods. Moreover, knowledge of local topography and ground data are required when understanding pattern on Radar images [20].

B. *SIR-C*

SIR-C SAR is a joint project from NASA and other agencies. Data of SIR-C provides images with some ground data input which help people understanding images. Reference [19] discussed that floods mixing with vegetation is usually hard to measure. However, this kind of floods is able to be detected from Radar. For example, floods with herbaceous vegetation could be seen from CHH, and floods in forest could be detected from LHH [19]. Reference [19] compared two SIR-C images for Amazon floodplain in April and October to see the differences. A successful supervised classification was implemented to detect floods that are mixing with vegetation such as herbaceous and forests [19].

C. *AMSR-E*

Advanced Microwave Scanning Radiometer Earth Observing System (AMSR-E) which is a Radar system under Earth Observing system (EOS) was developed by National Space Development Agency of Japan (NASDA). AMSR-E provides data with various spatial resolutions (5km to 60 km) and very fine temporal resolutions (2 day or less). Reference [22] worked on different bands of AMSR-E data to study floods at Brahmaputra basin. The research group discovered that the X band provides a good balance of spatial resolution and noise sensitivity [22]. Other bands could not produce result as good as X band. For example, they argued that high frequency bands such as Ka band brings noticeable noise from raindrop [22].

D. *ASAR*

Water are usually dark toned on Radar images due to its specular reflectance property; however, floods are hard to be identified since they are disturbed and not flat [18]. Different signatures could be detected from different polarizations and thus using property polarization is important to object identifications [18]. Reference [18] compared different polarizations for land use mapping and they argued that HV is best for mapping forest and field, HH is good at identifying urban and water.

With comparing different polarizations and cross-polarization, it is believed that combining different polarizations will perform a better result than use polarizations separately [18]. A time series analysis has been done on hurricane Rita at western coastal Louisiana with using Envisat Advanced Synthetic Aperture Radar [21]. Spatial resolutions for different images various from 30 meter to 150 meter. Eight Radar images were acquired between July 23 and December 29 in 2005 to measure the water extents [21]. The research group also compared different polarizations' images and they concluded that the signatures of water are different between polarizations [21].

IV. CONCLUSION

Both optical sensors and Radar systems play important roles in flood assessment. As paper pointed out, optical data is not only widely available, but also having long historical data. Moreover, it is easy to access the data with a low rate of cost. For instance, one of the most popular data sources is Landsat which provides continuous data for decades at no cost. One of the biggest limitations for optical sensors is the absence of cloud penetration. Due to the design of optical sensor system, it is hard to get data when the study area is covered by cloud. This shortage brings difficulties for flood assessment since most floods are associated with heavy cloud.

Radar is a system that could ignore cloud since it uses microwaves. Radar works well on distinguishing water and other features due to the unique specular reflectance of water. However, Radar is not a popular source for scientific research due to the economic cost. Moreover, it is not easy to understand data from Radar without enough knowledge of study area. Although there are some false color Radar images, signature interpretation is still much easier on optical data than Radar.

Flood is one of the major sources of disaster on the Earth. Good understanding of flood is useful to increase agricultural productivity, reduce property and life loss, and help make better decisions. Many studies on flood monitoring, assessment, and prediction have been conducted using Remote Sensing techniques these years.

This paper discussed the feasibility of Remote Sensing in flood assessment. Some major types of sensor including optical sensors and Radar systems have been compared by their roles in flood assessment research. In additional, combining data from Radar and optical systems may help outstanding some features on images. Although many agencies use Radar and optical data independently when doing flood assessment, the potential of combining data from both systems is huge.

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