USE OF NOAA/AVHRR DATA FOR FLOOD DISASTER MONITORING IN THE MEKONG RIVER DELTA

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ABSTRACT

The Mekong River Delta is one of the most important agricultural lands in Viet Nam. Every year, it faces floods and water-logging, causing many problems and damage. The NOAA/AVHRR data have been used to monitor floods in this area. The method of Sheng Yongwei (1996) has been modified, using information from different channels of NOAA/AVHRR data, including visible and infrared split window channels, to remove cloud influences, including cloud shadows, when cloud contamination is not very serious. The quantitative split window channel threshold value has been given for the identification of water bodies and land surfaces under semi-transparent clouds. In this way, much wider ground areas for any weather conditions and any kind of cloud systems can be analyzed and detected. Techniques have been developed for objectively defining the threshold values and automatically running the program for flood monitoring. A technique has also been developed for identifying the image's pixels with different rates of mixing between water and land. The case study for flood monitoring in the Mekong River Delta was conducted in late 1997, and the results of flood monitoring on November 15, 1997 are given in the paper as a demonstration.

1. INTRODUCTION

The NOAA/AVHRR data has a high use and potential for use in flood disaster monitoring in plains areas. The success of flood monitoring with the meteorological satellite data mainly depends on the availability of cloud-free images during the flood process. The recognition of ground cover in remotely-sensed images is mainly based on its spectral characteristics. In the near-infrared waveband, water has low albedo, while the vegetation and other objects on land have absolutely high values. In comparing visible channel 1 to near-infrared channel 2 according to spectral characteristics, we see that in near-infrared 0.9μm channel 2, the water has lower albedo, while the vegetation and other ground cover on land have a higher value. But in visible 0.6μm channel 1, just the opposite occurs: the water has higher albedo, while land lower. Therefore, the ratio band of CH2/CH1 can be used to enhance the water and land information. In the ratio image, the water has extremely low value, and the land has relatively high value. There are several models to identify a water body using AVHRR data. In our work, we use a ratio of channel 2 to channel 1 (CH2/CH1). It is water if CH2/CH1 =< Ro (Ro is a threshold value), and it is land if CH2/CH1 > Ro. It is a big problem that during floods, cloud-free images are quite rare. Cloud influence is one of the main obstacles to flood monitoring using AVHRR data. When cloud contamination is not very serious (thin clouds), some of the cloud influence (including cloud shadows) can be removed using the ratio method (Sheng Yongwei, 1996). The histogram of the ratio image presents a remarkable bi-peak distribution. The threshold value Ro, which is located between the two peaks in the histogram, can be determined interactively.

2. DEFINING THE THRESHOLD VALUES FOR FLOOD MONITORING

Testing both with normalized and origin visible data, received in September and October 1997, we find that the value of Ro is not the same for different images, which are received at different times of day, for different weather systems, for different geographical areas, and possibly for different season of the year. The interactive determination of Ro on the histogram of the ratio (CH2/CH1)*100 has some disadvantages:

- It is not precise, and the wrong selection of Ro with some units, even with only one unit value, can causes great error in an estimation of the flooded areas;
- It is difficult to determine the image pixels, which are mixed between water and land; and,
- The interactive determination of Ro on the histogram of the ratio is not favourable for a fully automatic process of flood monitoring.

It is not difficult to prove that when an object is under cloud shadow, or when the cloud is not thick, the ratio of CH2/CH1 for land has a greater value than for water (Sheng Yongwei, 1996). In the area covered by semi-transparent clouds, the reflective value obtained by the satellite sensors contains information both from the cloud and the under-cloud ground. That is:

$$Vsi = Vci + Vgi \qquad (1)$$

where, Vsi is the value obtained by satellite sensor in channel I, Vci is the cloud component, and Vgi is the ground component.

Therefore, the Ratio of CH2/CH1: $R21 = (Vc2+Vg2)/(Vc1+Vg1)$
for Water, $R21(w) = (Vc2 + Vg2(w))/(Vc1 + Vg1(w))$
for Land, $R21(l) = (Vc2 + Vg2(l)) / (Vc1 + Vg1(l))$

According to the spectral characteristics of land and water, $Vg1(l)<Vg1(w)$ and $Vg2(w)<Vg2(l)$, thus, $R21(i)>R21(w)$.

This means that water and land covered by semi-transparent clouds or in cloud shadow can be distinguished. In the area covered by cloud shadow:

$$Vsi = Vgi = A*Ei + Ep \qquad (2)$$

where, Ai is an albedo of channel I, Ei is a received radiance in channel I, and Epi is a part of radiance in channel i.

Therefore, the ratio band:

$$R21 = (A2*E2+Ep2)/(A1*E1 + Ep1) \qquad (3)$$

for water, $R21(w) = (A2(w)*E2 + Ep2)/(A1(w)*E1 + Ep1)$
for land, $R21(l) = (A2(l)*E2 + Ep2)/(A1(l)*E1 + Ep1)$
while, $A2(w) < A2(l)$ and $A1(w) > A1(i)$, thus $R21(i) > R21(w)$, so the water and land in cloud shadow can be distinguished.

It is important to recognize exactly through which kinds of semi-transparent clouds we can still distinguish water and land. If we look for an albedo threshold value to identify water and land, we will face many problems. Images received from NOAA satellites are not from the same time of day. Images received in the early morning or in the late afternoon have much lower albedo than images received at noon. In these cases, it is difficult to identify the albedo threshold value. Beyond that, we know that the satellite scanning time for different pixels in the same images are not the same, so that the pixels are received at different sun zenith angles. So for a precise albedo threshold value, we must do a sun zenith angle normalization for every visible image and for all pixels of that image. It is well known that a normalization of visible images is a difficult and complicated process (Binder, 1989).

We have made some investigations and improvements to this method by giving an infrared split window threshold value for the identification of water under semi-transparent clouds. As we know, with differences in infrared split window channels 11 micrometer and 12μm, we can recognize the thickness of cloud (Schejwach, 1982). We take differences of temperature between, first, 11 μm infrared channel and, second, 12μm infrared channel:

$$Dt = TBb11 - TBb12 \qquad (4)$$

where TBb11 is a black body temperature of 11μm infrared channel 4 and TBb12 respectively of 12μm infrared channel 5.

The results from (our) research show that, with increasing thickness of clouds, the value of Dt decreases. From primary testing with AVHRR data in September and October, 1997, flood monitoring in the Mekong River Delta of Southern Viet Nam, we recognized that the Dt could be used as a good parameter for the threshold limit. On the basis of these findings, we have developed new software, which we call INVEST. We have created a geographical image file (named AREA.BMP) of an area of interest for detecting floods. In our case, for AREA.BMP we have selected the area from latitude 7.7^{o}N to 13.7^{o}N and from longitude 109.8^{o}E to 102.5^{o}E, in the center of which lies the Mekong River Delta of Southern Viet Nam. The total area is 455,792 km^2. The total number of pixels in an AREA.BMP image is 211,071. The main functions of INVEST are as follows:

- *Cutting of images from an area of interest to be the area of AREA.BMP;*
- *Calibration of images;*
- *Projection of images with the same projection of the AREA.BMP;*
- *Geometric correction of images;*
- *Normalization of visible images;*
- *Change of the values of Dt with a step = 1, and use of the Dt as a first threshold for detecting thickness of clouds in the process of identifying water and land;*
- *Change of the values of Ro with a step = 1, and use of Ro as a second threshold for checking the ratio CH2/CH1. If Ratio=<Ro, it will be coded as a water pixel, while if Ratio>Ro, it will be coded as a land pixel, where Ratio = integer part of [100*(CH2/CH1)];*
- *Identification of water body, land surface, and unknown surface pixels under thick clouds by given threshold values for Ro and Dt. Creation of a composite image with the assignment of different colors to the three kinds of pixels;*
- *After a double looping of calculation with changing values of Dt and Ro, automatically analysis of all created composite images by statistical methods. Saving of the values of Dt and Ro that give the best results for detection of water and land; and,*

- *Calculation for other images and saving of all the best threshold values of Dt and Ro in the archive file.*

We have applied INVEST for calculation of all NOAA images that were received in September and October, 1997. Analyzing the results from the calculation of all the above-mentioned images, we find that:

- *Dt has the best meaning for identifying water and land with values from -1 to 3;*
- *For Dt > 3, the total number of identified pixels is very small and has no meaning for flood monitoring;*
- *For Dt < -1, detection of water and land is not better than for the case of Dt = -1;*
- *For Dt = -1, 0, 1, 2 and 3, Ro has the respective values R1, R2, R3, R4 and R5 and R1 < R2 < R3 < R4 < R5. This means that with a decrease in Dt, the value of Ro also decreases. As we know, channel 2 is near infrared and more sensitive to temperature. In comparison with land surface, when the cloud is thicker, the contribution of radiance from water under cloud cover in channel 2 decreases faster than in channel 1, so that when Dt decreases, the ratio CH2/CH1 will decreases and the threshold value of Ro will decreases also (as shown in the results above).*

3. PROCESS OF FLOOD MONITORING

In late 1997, we made some tests to define flooded areas in the Mekong River Delta. We created a second masked image file, named MEKONG.BMP, with the same projection as the AREA.BMP image file, to mark all pixels of interest belonging to the Mekong River Delta of Southern Viet Nam. In the AREA.BMP file, we have coded all the pixels belonging to the Mekong River Delta with a value = 1 and all other pixels in MEKONG.BMP with a value = 0. The total area of pixels in our area of interest in the Mekong River Delta of Southern Viet Nam, is 30,484 km^2 (14,247 pixels). We use the MEKONG.BMP file to calculate the number of flooded pixels and to estimate the total flooded area only for the Mekong River Delta of Southern Viet Nam.

Procedure No. 1: Flood Monitoring.

1. After a normalization of visible images, create 5 images files as follow:

Image C1 for Dt = -1 and Ro = R1
Image C2 for Dt = 0 and Ro = R2
Image C3 for Dt = 1 and Ro = R3
Image C4 for Dt = 2 and Ro = R4
Image C5 for Dt = 3 and Ro = R5

where R1, R2, R3, R4, R5 are values received from applying INVEST.

In these images, the water body, land surface, surface unidentified due to cloud contamination pixels are coded with different values.

2. Create a new composite image, named COMPOSITE.BMP, from the 5 images created in step 1, using the following principles:

If the pixels from the same position in all 5 images are identified as water, then we will code this pixel in the COMPOSITE.BMP image as a water body; if all of them are identified as land, we will code as a land surface pixel; if all of them are unidentified, we will code it as a cloud pixel with brightness value as near infrared channel 2;

Calculate the total number, Nw, of water body coded pixels, the total number, Nl, of land surface coded pixels, and the total number, Nc, of cloud coded pixels;
If Nw > 0 and Nl = 0, then code pixel with the value of a water body; if Nl > 0 and Nw = 0, then code pixel with the value of a land surface. In all other cases, which have a combination of water body and land surface, we will code them with different values (for mixed pixels) following the principles in Procedure No. 2 below.

From this procedure, we will have a COMPOSITE.BMP image file with flooded, land surface, cloud and mixed surface (different proportions of land and water) pixels.

3. Using the COMPOSITE.BMP and MEKONG.BMP files, calculate the pixels of interest of the Mekong River Delta by the formula of Sheng (1996) as follows:

*S = 2R2 * Dl * p * [A * sin(Dm/2) * cos(M) –B * sin(3Dm/2) * cos(3M) + C * sin(5Dm/2) * cos(5M) - D * sin(7Dm/2) * cos(7M)]*

where, Dm is the latitude of the different pixels; M is the latitude of the center pixel; Dl is the longitude of different pixels; R is the short semi–axis of the Earth (R = 6356.863); p = 57.295; A = 1.0033636075; B= 0.0011240273; C = 0.0000016989; and, D = 0.00000027.

Based on these procedures, we have developed a program, FLOOD.EXE, which runs automatically on microcomputer, to monitor the flood process. Water bodies have been identified in each image. Water body maps of time series derived from the images can show us how the flood changes in space. During a flood, what we care most about is the area of the flooded region. Based on the accuracy of the area estimation in each image, we can demonstrate graphically the changes in this area.

3.1 Identifying the mixed pixels

If the area of interest has many pixels that are mixed between water and land at different rates, how can we calculate their areas? In the Mekong River Delta of Southern Viet Nam, there are many areas comprised of mangrove, aquacultural land, inter-tidal land, mudflat or wetland. After investigation from the composite image files we created and checked with a topography map of the Mekong River Delta, we recognized that all of the mixed pixels are located at the boundaries between flooded and non-flooded areas, sea and land, lake and land, or river and land. After many logistical checks of mixed pixels with a topographical map and inter-tidal pixels, we have classified the mixed pixels into 6 different classes. The procedure below was used to classify the mixed pixels with different rates of mixing between water and land.

Procedure No. 2: Classifying mixed pixels

Read coded values of the pixel from 5 image files C1, C2, C3, C4 and C5.
Calculate the total number, Nw, of water body coded pixels.
Calculate the total number, Nl, of land surface coded pixels.
Calculate the total number, Nc, of cloud coded pixels.
If Nw = 1 and Nl = 4, then code pixel with value of class A.
If Nw = 2 and Nl = 3, then code pixel with value of class B.
If Nc > 0 and Nw = Nl, then code pixel with value of class C.
If Nw = 3 and Nl = 2, then code pixel with value of class D.
If Nw = 4 and N1 = 1, then code pixel with value of class E.
If Nc > 0 and Nw <> Nl, then code pixel with value of class F.

Write the value to the same position in COMPOSITE.BMP image file with new class code.

The meanings of the classes are as follows:

Class A is for pixels where approximately 20% of the area is water.
Class B is for pixels where approximately 40% of the area is water.
Class C is for pixels where approximately 50% of the area is water.
Class D is for pixels where approximately 60% of the area is water.
Class E is for pixels where approximately 80% of the area is water.
Class F is for pixels where the rate of mixing water and land is unknown.

We do not yet have the possibility to check all the estimated mixed pixels with the measurements from the field, but for now we can accept this classification from logistical deduction and checks with the topographical map and inter-tidal pixels. We have assigned different colors to the mixed pixels from different classes. Displaying these images, we show that a distribution of the pixels with a lower proportion of water always is directed toward land, while the same goes for the pixels with a higher proportion of water toward sea or lake. The results, obtained by proceeding with INVEST, show that the threshold value Dt can receive only 5 different values, -1, 0, 1, 2 and 3, while smaller or larger values have no meaning for flood monitoring. If we make calculations through INVEST by a smaller step for Dt, for example with the step = 0.5, we can increase a number of threshold values for Dt, and we can classify mixed pixels into more classes. With measurements from the field, we can check those mixed pixels to have a better understanding and better means of classifying them.

4. CASE STUDY: FLOOD MONITORING IN MEKONG RIVER DELTA ON NOVEMBER 15, 1997.

The Mekong River Delta (in the Southern region of Viet Nam) is a very important agricultural land for Vietnam. The total area of the Mekong River Delta is about 39,000 km^2. In general, the Mekong River Delta is a lowland area with many depressed places. The slope of the Mekong River Delta is very small, so that it is very sensitive and dynamic with regard to flooding, and floods cause a number of human problems and economic damage. Every year the flood season in the Mekong River Delta lasts from 3 to 5 months (from August to November or December), and sometimes serious floods have lasted continuously longer than

2 months. As a demonstration, below we show the results of calculations following the two above-mentioned procedures for the NOAA/AVHRR data received at 08h GMT (local time was 15h), on November 15, 1997, for the Mekong River Delta of Southern Viet Nam.

Table 1. Results of calculations following Procedures No. 1 and No. 2

Number of water body pixels:	3255
Total flooded area:	6951 km^2
Total flooded area as a %:	22.8%
Number of land surface pixels:	10461
Total land surface area:	22391 km^2
Total land surface area as a %:	73.45 %
Number of mixed pixels:	531
Total mixed area:	1142 km^2
Total mixed area as a %:	3.75 %
Number of unidentified pixels:	0
Total of unidentified area:	0 km^2
Total of unidentified as a %:	0 %

Table 2. Results of calculation following Procedure No. 2 for the mixed area

Class	Rate of Water/Land	Number of Pixels	Total area (km^2)	Total area (%)
A	20%	190	409	1.340
B	40%	153	328	1.079
C	50%	71	153	0.501
D	60%	59	127	0.416
E	80%	47	101	0.332
F	Unknown	11	24	0.078
All classes		531	1142	3.75%

In this case, at 8h GMT November 15, 1997, the cloud cover over the Mekong River Delta of Southern Viet Nam was not thick. Therefore, as we can see from results of the calculations, we have removed all cloud contamination and have identified the whole area of the Mekong River Delta. But results of the calculations show that around the Mekong River Delta, in the area of AREA.BMP, there are 788 unidentified pixels. Those pixels take only 0.37% of whole area in AREA.BMP.

5. CONCLUSION AND REMARKS

We can use the above-mentioned method, techniques and programs for flood monitoring for different NOAA/AVHRR images, which are received at different times of day, at different times of year, for different weather systems, and for different geographical areas. Through this method, we can detect much wider areas under cloud cover, and we can fully automate the process of flood monitoring.

If we increase the level of quantization of Ratio, for example Ratio= INT [200*(CH2/CH1)], we may obtain more precise threshold values of Ro. With a decrease in the step for Dt, we may produce better classification for mixed pixels, too. And in these cases, we can increase the accuracy of flood monitoring. But calculation and analysis with INVEST will take much more computer time.

The good geometric correction of images is very important for high accuracy in flood monitoring. With a good quality and high-resolution topographical map of an area of interest, we can increase the accuracy of flood monitoring and the estimation of flooded areas.

With measurements from the field, we can check our estimations from NOAA/AVHRR data mixed pixels so that we will have a better definition and classification of those pixels.

Knowledge of the rainfall situation over a flooded area is very important to flood monitoring and flood warning. When we have the images from two different geostationary satellites, with double look techniques, we can improve normalization of visible images and improve methods and techniques for flood monitoring.

6. REFERENCES

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