PANTANAL INUNDATION AREA PREDICTION FROM SPACE

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Abstract. In this study, a combined use of monthly Precipitation (PCP) and monthly maximum value composite Normalized Difference Vegetation Index (NDVI) data is proposed to predict monthly River Water Level (RWL) at Ladário station, which monitors the Upper Paraguay River Basin (UPRB) flood conditions. Inundation area estimation method presented by Hamilton et al. (1996) was used to predict Pantanal inundation area extension. Averaged monthly PCP data were obtained from six rainfall stations and averaged NDVI data were obtained from the watershed monitored at Ladário. The data of May 1981 to April 1994 were used for RWL model construction while the data of November 1994 to September 2000 were used for RWL model validation. The results showed that the RWL model had R^2 of 0.7903 and MSE of 0.3612 and SD of 0.601. An averaged absolute error of 14.45% was obtained from the model validation. An averaged absolute error of 23.65% was obtained from the comparison of the inundation area calculated from observed and predicted RWL for the period of 1981 to 2000. It is concluded that by the combined use of RWL model and inundation area estimate, the Pantanal inundation area extension can be predicted one month in advance with reasonable accuracy.

Keywords: remote sensing, Pantanal, Inundation, NDVI, river water level.

1. Introduction

The Pantanal wetland located at the center of the South America Continent covers an area of 137,000 km^2. The shaded area of Figure 1 shows the location of the area, including western part of Brazil, eastern part of Bolivia and Paraguay. The Pantanal holds one of the most diversified human patrimony, housing innumerous floras and faunas. The distinct annual cycle of inundation provides rich natural resources for economically important fishes and wildlife, as well as more recently ecological truism. Fish yields may vary from the alteration of their life cycle caused by seasonal and annual variation of inundation pattern (Welcomme, 1985). Animals may have difficulty to find out dry refuges during unpredicted high flood years (Mittermeier et al. 1990). Therefore the occasional unpredicted high floods and severe drought affect fishes and wildlife as well as important cattle production in the region. In the past thirty years, agricultural activities, especially, cattle production in the catchments area have been increased considerably. The combination of improper land management on sandy soils in the upper basin causes serious erosion and acceleration of sediment load in the flood plain over this past thirty years. Besides the gradual loss of ranchlands, unpredicted floods often result serious cattle loss. Also, due to recent increase of river transportation, riverbanks erosion in low water level period becomes more seriously each year.

The UPRB has a very distinct hydrological feature, which makes the traditional hydrological routing more complicated. That is the river may change its course from year to year due to the combination of a rapid river water current acting on a fragile and curved sandy riverbank, a shallow riverbed and a very flat flood land. Galdino and Clarke (1997) used the correlation of RWL to rainfall monitored at Ladário to probability of floods occurrence. Hamilton et al (1996) estimated Pantanal inundation area estimation using passive microwave remote sensing data. They have observed that the maximum inundation occurred as early as February in the northern sub basin and as late as June in the south, reflecting the gradually delayed drainage time in responding to rainfall from upper to lower part of the UPRB. They also proposed the use of RWL to estimate monthly inundation area with two months after inundation. The SMMS data were used only for the inundation area estimation not for the river water level prediction. Also the inundation area estimation using RWL data of two months after the inundation is not quite practical in predicting inundation area extension for mitigation purposes. Therefore, in this study, we are seeking an alternative method to predict Pantanal inundation extension before the event.

Recent advances in satellite data application have shown that NDVI infers quite well vegetation greenness conditions which indicates ample soil moisture status but shows up with a certain time lag after a certain rainfall event (Liu et al., 1994). NDVI value is calculated by taking the ratio of reflectance values of AVHRR channel 1 (Ch1: 0.58-0.68 μm) and channel 2 (Ch2: 0.725 -1.10 μm) and divided by the sum of them, which is expressed by the following equation:

$$NDVI=(Ch2-Ch1)/(Ch2+Ch1). \qquad (1)$$

Some green surfaces inferred by NDVI always exist as long as the river does not dry out in a certain river basin. But NDVI will reach its maximum value around 0.7 while the surface greenness reaches its maximum. On the other hand, a high rainfall amount may infer quite well the RWL in wet season but a close to zero rainfall may fail to infer RWL in dry season. Therefore the purpose of this study is to develop a river water level forecast model using both rainfall and NDVI (Liu et al. 2002) and to apply the inundation area estimation method proposed by Hamilton et al (1996) to predict flood area extension in advance for flood management and for erosion as well as river transportation traffic control.

2. Methods

2.1. Study Area

The UPRB has a catchment's area of 484,970 km^2, which is located at the central part of South America, covering parts of western Brazil (372,501 km^2), Eastern Bolivia (80,843 km^2) and northeastern Paraguay (31,626 km^2). **Figure 1** shows the basin boundary which extends from Latitude: 14°S to 23°S and longitude: 52°W to 61°W. The annual rainfall ranges from 1100 mm to 1900 mm with a distinct wet season occurred during the period of October to April and a dry season during the period of May to September. Most part of the flood plain is very flat with the RWL dropping at a rate of 2.5cm/km, which forms the world largest continental wetland called Pantanal.

2.2. Data Used

RWL data recorded at the Ladário hydrological station (Latitude: 19°05´S; Longitude: 57°30´W) for the period of January of 1981 to December of 2000 provided by the Brazilian Marine Corp at Corumbá, Mato Grosso do Sul State were used in this study. For the same period, monthly PCP data of six rainfall stations, including Arenapólis (14.51°S, 56.1°W), Quebo (14.65°S, 56.11°W), Porto Estrela (15.31°S, 56.23°W), Ponte Cabaçal (15.47°S, 57.9°W), N. S. Livramento (15.77°S, 56.35°W) and Barão de Melgaco (16.19°S, 55.95°W), provided by the Brazilian National Water Agency (Agencia Nacional de Aqua, ANA) were used. The locations of RWL and PCP measurement stations were shown in the **Figure 1**.

Averaged values of six station rainfall data were used to represent the rainfall amount received in the upper part of the UPRB. RWL represents the river water level of the drainage area indicated by the area above the dash line **Figure 1**.

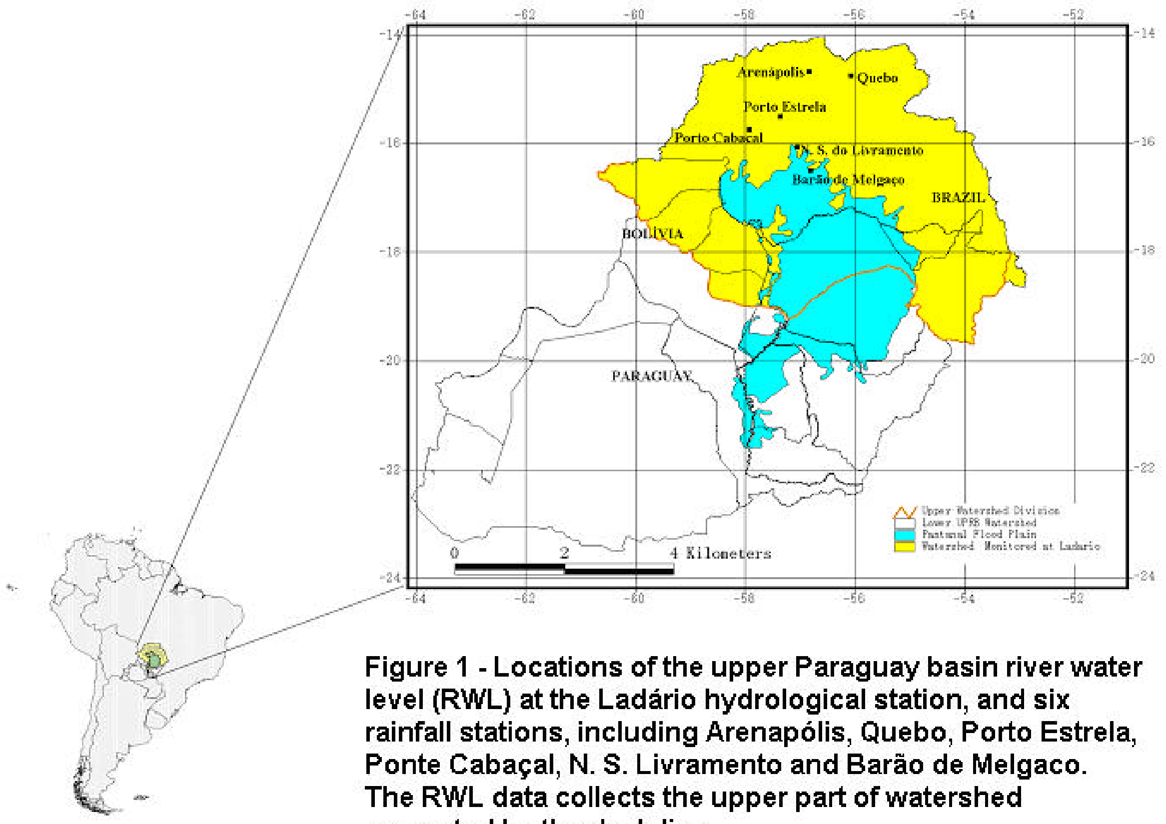


Figure 1 - Locations of the upper Paraguay basin river water level (RWL) at the Ladário hydrological station, and six rainfall stations, including Arenapólis, Quebo, Porto Estrela, Ponte Cabaçal, N. S. Livramento and Barão de Melgaco. The RWL data collects the upper part of watershed separated by the dash line.

NDVI monthly maximum value composite data (Holben, 1986) with a resolution of 8 km by 8km for the period of July 1981 to December 2000, provided by the GSFC/NASA were used in this study. According to Eidenshink *et al*. (1997), these data have already been processed with radiometric calibration using the NOAA standard method (Rao and Chen, 1995) and atmospheric corrections including Raleigh scattering using method of Gordon *et al*. (1988) and ozone absorption using method presented by Eidenshink and Faundeen (1997). Averaged NDVI data of the northern part of the UPRB watershed were used in this study. **Figure 1** shows the watershed area above the dash line was used.

2.3. RWL Prediction Model Construction and Validation

Correlations of RWL to PCP and RWL to NDVI were carried out to investigate the time lag of RWL in responding to PCP and NDVI in order to select candidate independent variables for model construction. A stepwise multiple linear regression technique was applied to construct the model. The data of June 1981 to February 1993 were used for model construction while the data of November 1994 to September, 2000 were used for model validation.

2.4. Inundation Area Estimation

An inundation area estimation equation presented by Hamilton et al. (1996) was used to estimate the inundation area for the period of 1981 to 2000. Equation 2 shows the monthly inundation, as a function of an averaged RWL of the following two-month's RWL, which is expressed as following:

$$A1 = 18.52\ (RWL2 + RWL3)/2 - 17.309 \qquad (2)$$
$$R^2 = 0.9025\ (P < 0.001, N=102)$$

Where: A1 = Inundation area (km^2) of month 1
RWL2 and RWL 3 = River water level (m) of month 2 and 3, respectively

3. Results and Discussions

3.1. RWL Model Construction

Table 1 shows the correlation coefficient (r) of RWL to PCP and RWL to NDVI with a time lag of RWL from zero to the month with a highest r-value. The results showed that a highest r-value of 0.809 was obtained for RWL in responding to PCP after 6 months and a highest r-value of 0.624 was obtained for RWL in responding to NDVI after 4 months. **Table 1** also shows that a highest r-value of 0.579 was obtained for NDVI in responding to PCP with a time lag of 2 months.

Table 1 – Correlation Coefficients (r) of PCP x RWL; NDVI x RWL and PCP x NDVI with 1 month time lag of either RWL or NDVI for each step of correlation.

Correlation Coefficient (r)			
Time Lag (month)	RWL x NDVI	RWL x PCP	NDVI x PCP
Parameter	RWL	RWL	NDVI
0	**0,083**	**-0,553**	**0,277**
1	**0,364**	**-0,200**	**0,494**
2	**0,572**	**0,189**	**0,579**
3	**0,624**	**0,543**	**0,531**
4	**0,500**	**0,769**	**-**
5	**-**	**0,807**	**-**
6	**-**	**0,652**	**-**

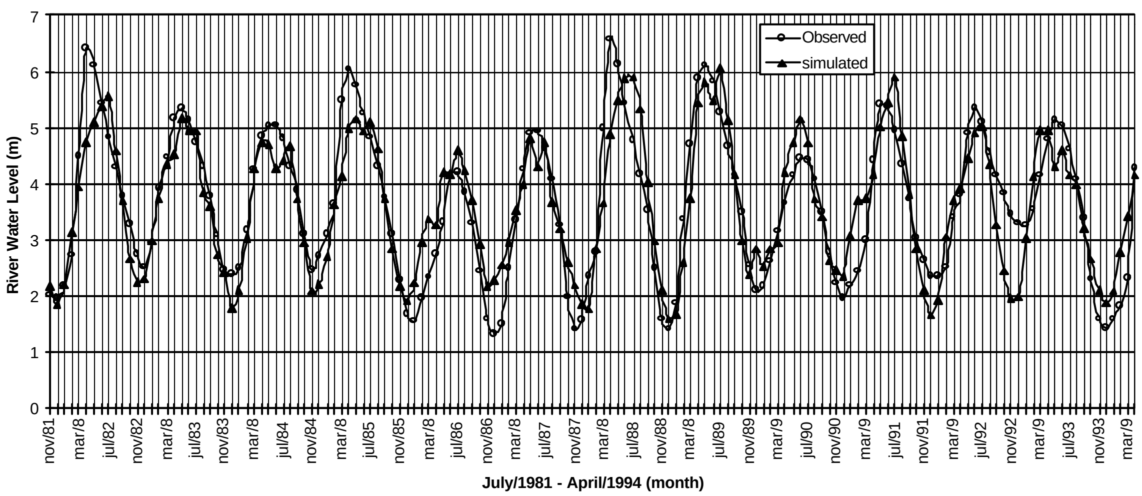
By examining the correlation coefficients presented in the **Table 1**, nine parameters, including PCP1, PCP2, PCP3 SPCP12, SPCP23, SPCP123, NDVI3, NDVI4 and SNDVI34 were used as independent variables and RWL7 as dependent variable for RWL model construction. Number 1, 2, 3, 4 and 7 represent month 1, 2, 3, 4 and 7 respectively. The letter S of SPCP and SNDVI represents the sum of months indicated by the numbers. For example, taking PCP1 as PCP of May, NDVI3 is NDVI of July and RWL7 is RWL of November. SPCP12 represents sum of PCP1 and PCP2 whiles SNDVI34 presents sum of NDVI3 and NDVI4. By applying the Stepwise Multiple Linear Regression Technique, a RWL model was obtained and presented by the following equation:

$$RWL7=0.94578+1.02594SNDVI34+0.00275PCP3+0.00309SPCP123 \qquad (3)$$

The model had a R^2 value of 0.7903 with MSE of 0.3612 and SD of 0.6010 (P < 0.008). The averaged absolute error of 15.22% was obtained for the simulated RWL. **Figure 2** shows the comparison of observed and simulated RWL for the period of November 1981 to April

1994. It was observed that the model simulated mostly quite well the occurrences and magnitudes of maximum and minimum RWL. But failed to simulate the occurrence of peak RWL in 3 years including: 1982, 1985 and 1988. The peak RWL were all occurred in April instead of the simulated in July. From checking the RWL data, it was observed that all these 3 years had maximum RWL over 6 meters. It may indicate that a larger volume of surface runoff water caused by intensive summer rainstorm may contribute significantly to anticipate the RWL to reach its peak value 1 to 3 months before normal rainfall years. The model also failed to simulate peak RWL in years of 1984, 1989 and 1993. Instead of rising to a peak RWL occurred in July, the simulated RWL dropped and then rose again in the following month. A lower NDVI caused by a larger flood area may contribute to this error. Therefore further study on the rainfall behaviors should be made in order to detect the anticipation of peak RWL in high rainfall years and correct the abnormal drop of RWL caused by a low NDVI in the peak of rainy season.

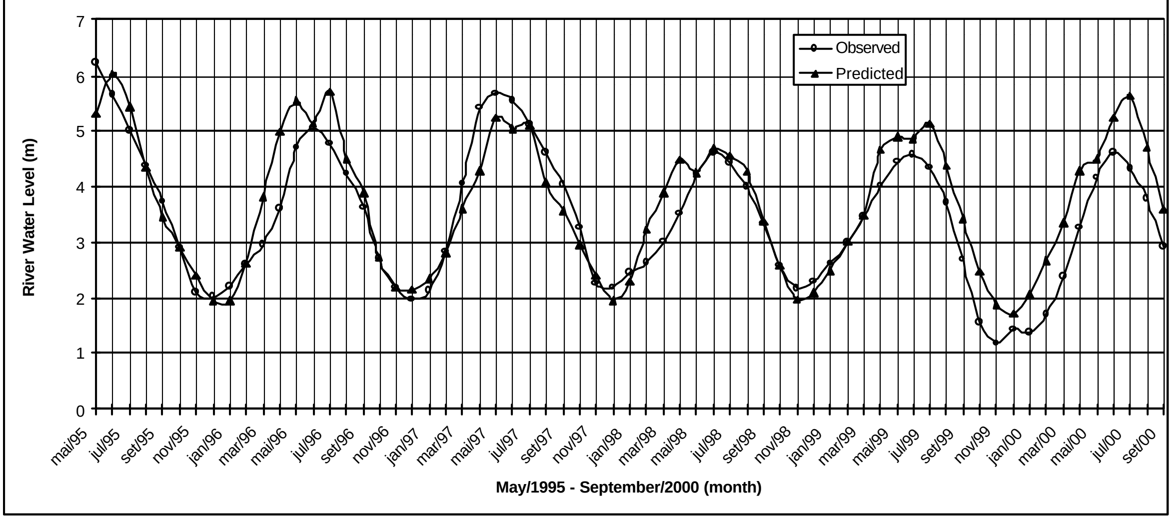
Figure 2 - Comparison of observed and simulated river water level for the period of July, 1981 to April, 1994 at Ladário Station (19.1°S;57.5°W), MS, Brazil



3.2. RWL Model Validation

The results of model validation showed that an averaged absolute error of 14.45% was obtained. It indicates that the RWL model was quite stable since this value was within the simulated error (15.22%). **Figure 3** shows the comparison of observed and predicted RWL for the period of May 1995 to September 2000. It was observed that there were 39 out of 65 months had absolute error within 10% and 19 months had absolute error between 10 to 30%. The rest of 7 months had error higher than 30%. Within these 7 cases, 6 cases were occurred in 1999. It was observed that in this particular year, a lowest RWL of 1.17m was recorded. From checking the rainfall data of year 1999, it was observed that there were almost no rainfall from May to August and a lower rainfall amount recorded in September (40 mm) and October (80 mm). It demonstrated that the model did not predict this extreme drought event. Except the year 1999, the RWL prediction model works quite well.

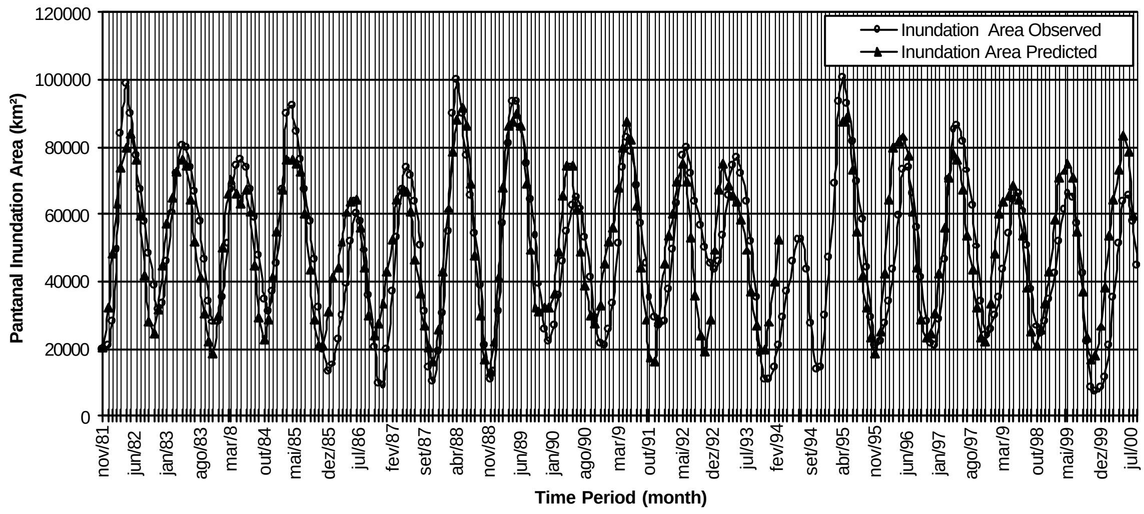
Figure 3 - Comparison of observed and predicted river water level for the period of May, 1995 to September, 2000 at Ladário Station (19.1°S;57.5°W), MS, Brazil



3.3. Inundation Area Prediction

Inundation area estimation equation (2) presented by Hamilton et al. (1996) was used to predict Pantanal inundation area extension for the studied period. **Figure 4** shows the comparison of the inundation area calculated from observed and predicted RWL for the period of 1981 to 2000. An averaged absolute error of 23.65% was obtained. The error was acceptable since the error was a sum of two estimation errors including the error from the RWL prediction model (14.45%) and the other from the inundation area estimation equation. It is worthwhile to mention that the RWL prediction model can be used to predict RWL four months before and the inundation area estimation equation can be used to estimate inundation area two months after. Therefore the combined use of these two models, the inundation area can be predicted one month before it occurs. The advantage of applying this approach is that the inundation area extension can be predicted in one month before the inundation occurs.

Figure 4 - Comparison of Pantanal Inundation Area Estimation by Hamilton Method Using Observed and Predicted RWL at Ladário Station



4. Conclusion and Suggestions

This study has demonstrated that the inundation area extension can be predicted one month before it occurs by a combined use of RWL prediction model and inundation area estimation method proposed by Hamilton et al. (1996). For further study, it is suggested that several sub basins models should be constructed to evaluate the consistency of the method as well as to improve the prediction accuracy. Also a high resolution Digital Elevation Model is needed to better understanding the detailed interflows between sub basins caused by spatial variation of rainfall. It is concluded that the statistical approach presented in this study may provide us a useful tool to predict RWL and hence to prevent floods damage in high RWL period as well as to control river transportation traffic in order to prevent riverbank erosion during low RWL period.

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5. References

Eidenshink J.C. and J.L. Faundeen, 1997. The 1-km AVHRR global land data set: first stages in implementation. *International Journal of Remote Sensing*. 51:39-56.

Galdino Sergio and Clarke Robin T. Probabilidade de ocorrência de cheia no Rio Paraguai, em Ladário. MS – Pantanal. 1997. *Circulação Técnica N° 23*, EMBRAPA-CPAP, Corumbá, MS. 58p, 1997.

Gordon H.R., Brown J.W. and Evans R.H.. Exact Rayleigh scattering calculations for use with the Nimbus-7 coastal zone colour scanner. *Applied Optics*, 27:2111-2122, 1988.

Hamilton S.K., Sippel S. J. and Melack J. M. Inundation patterns in the Pantanal wetland of South America determined from passive microwave remote sensing. *Arch. Hydrobiology*. 137: 1-23, 1996.

Kidwell, K. B. NOAA Polar Orbiter Data Users Guide. *Satellite Data Service Division, NESDIS/NOAA, Washington D.C., USA.* 435p, 1995.

Liu W.T.H., Massambani O. and Nobre C.. Satellite Vegetation response to drought in Brazil. *International Journal Climatology,* 14:343-354, 1994.

Liu W.T.H. Ayres F.M., Salles A.T. and Padovani C.. Upper Paraguay river water level prediction using NOAA AVHRR NDVI. *Proceeding of the 1º International Symposium "Recent Advances in Quantitative Remote Sensing*", Valencia, Spain, 2002. (in press).

Mittermeier R.A., Camara I.G., Padua M.T.J., and Blanck J.. Conservation in the Pantanal of Brazil. *Oryx* 24: 103-112, 1990.

Rao, C.R.N., and Chen J. Inter-satellite calibration linkages for the visible and near-infrared channels of the Advanced Very High Resolution Radiometer on the NOAA-7, -9, and -11 spacecrafts. *International Journal of Remote Sensing.* 16, 1931-1942**, 1995.**

Welcomme R.L. River fisheries.-Food and Agriculture Organization of the United Nations, Rome, Italy: *FAO Fisheries Technical Paper N° 262,* 1995.