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MAXIMIZING THE BENEFITS FROM WATER AND ENVIRONMENTAL SANITATION

Preliminary investigation of Lake Victoria groundwater situation from AVHRR data

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This study uses the findings that lake temperatures from processed thermal infrared data can be used to identify inflow zones of groundwater into a lake. Spatial and temporal temperature anomalies are indicative of groundwater flow into a lake. NOAA AVHRR scenes of Lake Victoria catchment for different seasons of 2004 were acquired, processed and analyzed. The surface temperature maps of the lake produced from this data indicated two major seasonal patterns of lake surface temperature distribution. These warm and cold season patterns are indicative of groundwater inflow. This preliminary assessment of groundwater discharge of Lake Victoria, probably the first of its type in the history of the lake's water balance studies is a good starting point for further studies including investigation of possible subsurface outflow.

Introduction

Lake Victoria is the second largest fresh water lake in the world with an average depth of 40 m and a surface area of about 69,000 km2 in a catchment of 263,000 km2. In spite of decades of studies about its water balance, consideration of its groundwater situation had never featured. This paper reports on the preliminary findings of the groundwater phenomena deduced from consideration and analysis of National Oceanic and Atmospheric Administration Advanced Very High Resolution Radiometer (NOAA AVHRR) images.

Background

Remote sensing methods have been applied to delineate groundwater flow systems in the Western Sandhills, Nebraska, Evgueni, (2002). This study hypothesized that the spatial and temporal temperature anomalies could be used to indicate groundwater flow into Crescent, Blue, Island and Hackleberry lakes in Western Sandhills. Landsat images of the lakes acquired for different weather conditions from 1989 to 2002 were processed and analyzed. Distribution of uncorrected surface temperatures of the resulting Landsat infrared data indicated that each lake exhibited one or several zones with warm season patterns. Warm season patterns occur when some cooler zones are detected during the warm season and cold season patterns are recognized by the existence over the lake of warmer zones during the cool season. These findings were found not only to be consistent with Thermal Infrared Multispectral Scanner data, Rundquist et al.,(1985) but were also consistent with the Crescent lake reconnaissance of January 2002 when the first ice melt was found in the warmer zones associated with warmer temperatures near the groundwater inflow zones.

Detailed understanding of the lake hydrological system and mechanisms of groundwater-surface water interactions requires knowledge of location, spatial and temporal distribution of zones of active groundwater discharge zones. These include zones of significant flux of groundwater across the lakebed which could be identified using the conventional hydrological techniques of wells and piezometers which are time-, labour-intensive and prohibitively expensive. Several analytical and numerical modeling studies have demonstrated that groundwater mostly seeps into a lake through the littoral zones and lake water is discharged out of the lake across the lakebed to the groundwater system through the deep parts of the lake (John and Lock 1977, Lee 1977, Winter and Pfannkuch 1984). It is also generally accepted that the seepage flux from the groundwater system to a shallow lake decreases as the distance from the shore increases, Evgueni et al.,2003. One of the methodologies which allows studying groundwater discharge zones for the lake involves the use of thermal infrared imagery, Banks et al.,(1996) in combination with measured surface water temperatures for the lake. The identification of groundwater discharge zones is based on the fact that there is a contrast between ground and surface water.

Methodology

NOAA AVHRR images of the lake for 2004 were collected and processed to produce surface temperature maps using the Split Window Technique (SWT). This is one of the methods used to estimate surface characteristics from satellite data. In this study, using the SWT, the difference in corrected brightness temperatures between two nearby infrared channels 4 and 5 of AVHRR sensor are used to estimate the effective surface temperature. The greater the difference between channels 4 and 5 brightness temperatures, the higher the surface temperatures of the pixels in question.

NOAA AVHRR data were imported into Winchips software. This is the Copenhagen Information Processing System for Windows with modules to process AVHRR images. During import the following processing was performed independently of the file format.

- Image line synchronization is checked. Noisy and missing lines are identified and removed or blank lines inserted into the data stream.
- Image data is unpacked and converted into a set of Chips images in 8- or 16-bits.
- Calibration coefficients are determined using the in-flight calibration data embedded in the data stream for thermal and non-thermal bands.
- A calibration lookup table which expresses the conversion of Digital Numbers into physical units is created.
- If the input file format contains embedded orbital elements they are extracted and stored in the Chips Orbit file that is created.

At the end of the import process you have a text file containing a calibration table of in-flight calibration data combined with stored database information, orbit file and 1 to 5 channel images. The imported images are optionally navigated, a sort of georeferencing of the images to improve the precision of geocoding.

Sun and satellite angles representing the sun and satellite view angles for each pixel necessary for atmospheric corrections of the data were created and concurrently rectified with the five channel images to preserve the angular information for later use. The rectification process facilitates the creation of new geocoded images by resampling the existing images. The rectified images for channels 4 and 5 were calibrated and corrected to produce brightness temperature maps. Calibration converts raw AVHRR pixel values into reflectance and temperatures using the calibration tables created during data import. Various corrections of the AVHRR signal for atmospheric distortion to account for the sun and satellite geometry for each pixel in the input image were executed during this process. The corrected brightness temperature maps were combined using the SWT to produce the lake surface temperature maps from which warm and cold season patterns were identified.

Reference Lake temperature

The reference Lake Victoria surface temperature were those of Tallings (1969) as given by Yin (1998) and the corresponding air temperatures were from FAO (1984) and are given in Table 1.

To identify warm and cool season patterns the lake surface temperatures were compared with the reference lake temperatures tw. A simple examination of the lake temperature data in Table 1 reveals that the periods October to May and June to September correspond to warm and cool seasons respectively over the lake although the temperature differences are quite small. Average air temperatures from lakeshore stations would similarly characterize lake seasons. The surface temperature maps were therefore analysed for cool or warm season patterns according to this classification. The distribution of warm season and cold season patterns are then identified from the resulting surface temperature maps.

Table 1. Lake Victoria surface and air temperatures

Month	Lake temperature t_w(^{0}C)	Air temperature t_a(^{0}C)
Jan	25.5	22.6
Feb	26.3	22.8
Mar	26.3	22.9
Apr	25.8	22.5
May	25.4	22.2
Jun	25.3	21.8
July	24.7	21.3
Aug	24.8	21.6
Sep	24.7	22.1
Oct	24.9	22.7
Nov	25.4	22.7
Dec	25.7	22.4

Surface temperature maps

Surface temperature maps and other products may be created from the calibrated images. Surface temperature maps were retrieved from the two thermal channels using the SWT standard procedure. This technique has been designed to account for the absorption effects that atmospheric water vapor has on radiometric surface temperatures. The more the water vapor the greater the difference between channels 4 and 5 brightness temperatures. The SWT is based on similar emissivity values in the 10.3 to 12.4 µm spectral range and derived according to the algorithm given in equation 1 below, a default method due to Coll and Caselles, (1997).

$$t = .39c^2 + 2.34c - 0.78cc' - 1.34c' + .39c'^2 + .56 \quad 1$$

where t is the lake surface temperature in Kelvin c and c' are brightness temperatures in Kelvin of channels 4 and 5 brightness temperature maps respectively.

Calibration of the Split Window Technique coefficients is done using real data. This Default method of surface temperature retrieval is strictly accurate in case of Sea Surface Temperature (SST) retrieval. But it was considered a good approximation for Lake Victoria surface temperature, due to the lake's large surface area. The surface temperature maps were then analyzed for warm and cold season patterns in order to infer groundwater inflow into Lake Victoria.

Warm season patterns

Groundwater is cooler than surface water during the warm season and warmer during the cool season. Therefore inflow of cooler groundwater into a warmer lake during the warm season results in plumes of cooler water and temperatures lower than the water surface temperatures of the lake (warm season patterns). These signatures of groundwater discharge can be detected from surface water temperature maps retrieved from NOAA AVHRR channels 4 and 5 using the SWT algorithm.

Cold season patterns

During the cool season groundwater is warmer than the lake surface water and inflow of warmer water into a cool lake results in warmer water in the discharge zones (cold season patterns).

Monthly Lake Victoria temperature distribution

Data of the surface temperature maps for the lake for the whole year is summarized beginning with the warm season.

- October
  Most of the lake surface are at 299-302 K (26-29 ^{0}C)but some littoral zones in the South exhibit temperature patterns of 297 and 298 K (24-25 ^{0}C).
- November
  Most of the lake area shows temperatures in the range 299-304 K (26-31 ^{0}C). A number of zones in the Western and South Western areas of the lake show cooler temperatures of 296-298 K (23-25 ^{0}C).
- December
  The Central part of the lake is characterized by temperatures between 298 and 303 K, (25-30 ^{0}C) littoral areas in the Western and Eastern parts of the lake predominantly have temperatures of about 297 K.(24 ^{0}C)
- January
  Although the temperatures for most of the lake are predominantly in the range 298-304 K (25-31 ^{0}C) a few littoral areas in the Western and Eastern parts show temperatures of 293-297 K (20-24 ^{0}C).
- February
  One of the hottest months shows temperatures between 300 and 309 K (27-36 ^{0}C) (for most of the lake area), the Western littoral area exhibits temperatures between 285 and 298 K (12-25 ^{0}C).
- March
  With the same surface temperature as February, most areas of its surface temperature map shows temperatures between 297 and 305 K (24-31 ^{0}C)while some Western and South Western littoral areas lie between 292 and 296 K (19-23 ^{0}C).
- April
  Most of the lake surface is between 298 and 303 K (25-30 ^{0}C). The Western part of the lake is covered with what seem to be clouds making it difficult to identify the warm season pattern conclusively.
- May
  The best warm season pattern is exhibited by this month. Most of the lake surface is covered by temperatures between 299 and 305 K (26-32 ^{0}C). But there are distinct warm season patterns (black) in the Western, Eastern and Southern littoral areas at 298 K (25 ^{0}C).
- June
  Most of the lake has temperatures in the range 298 to 300 K (25-27 ^{0}C), Western, South Western and Eastern littoral zones exhibit temperatures of 302-303 K (29-30 ^{0}C) signifying cold season patterns.
- July
  Most lake surface temperatures lie between 296 and 299 K (23-26 ^{0}C). However North Western, Western and Eastern littoral zones show much higher temperatures of 301-302 K (28-29 ^{0}C).
- August
  Most of the lake is at temperatures between 297 and 299 K (24-26 ^{0}C). A few North Western, Western and North Eastern littoral parts show temperatures of between 301 and 303 K (28-30 ^{0}C).
- September
  Most of the lake temperatures lie between 294 and 299 K (21-26 ^{0}C), North Eastern and South Eastern littoral zones show temperatures higher than 300 K (27 ^{0}C).

Fig. 1 and 2 represent the warm and cold season patterns, respectively. The dark areas within the lake are some of the seasonal zones.

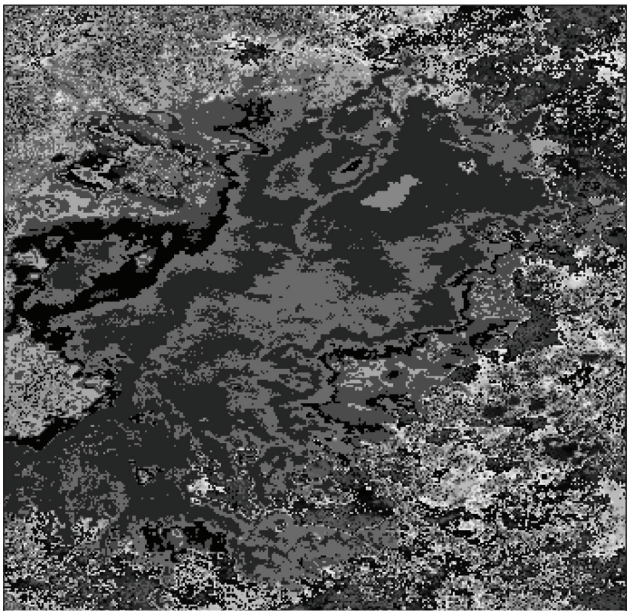

Figure 1. May 5, 04 Lake Victoria Surface temperature map

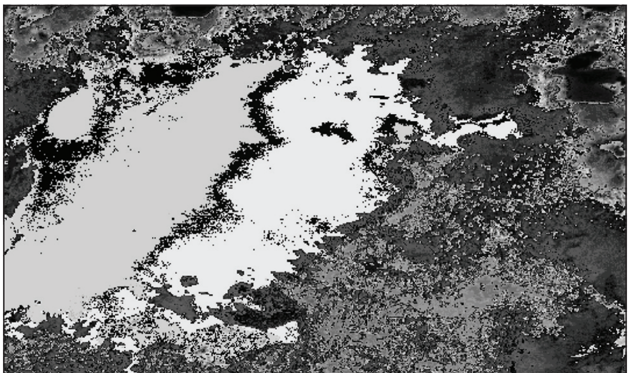

Figure 2. Lake Victoria Aug 5,04 surface temp map

Conclusions and Recommendations

According to the seasonal patterns theory and surface temperature maps from AVHRR data,

- There exist warm season patterns (black over the lake in Figure 1).
- Similarly the black patterns over the lake area in Figures 2 signify cold season patterns.
- Both warm and cold season patterns occur predominantly in the Western and Eastern littoral zones with some rare occurrence in the Southern part.
- This preliminary study therefore provides enough evidence indicative of the existence of groundwater inflow into Lake Victoria especially in the Western and Eastern parts although this term has been neglected in all Lake Victoria water balance studies.
- More investigation about Lake Victoria groundwater situation involving ground based studies using labour-, time- intensive and expensive conventional hydrological techniques of observation wells and piezometer measurements should be carried out especially in the Western and Eastern littoral zones.
- In addition, geophysical explorations including modern techniques such as Helicopter Electromagnetic (HEM) surveys should be carried out to finally quantify the lake groundwater situation.
- Thorough knowledge of all the components of Lake Victoria water balance is required for its critical evaluation.

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