The physical limnology of Winam Gulf and Rusinga Channel of Lake Victoria during April-May and August of 2005

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Abstract

Winam Gulf is a large (surface area ~ 1400 km^2) and shallow (<20 m) bay of northeastern Lake Victoria with only one connection to the open lake through Rusinga Channel. To understand the exchange dynamics between Winam Gulf and the offshore waters of Lake Victoria and the hydrodynamics of the region, field studies were carried out from Apr. 22-May 4 and Aug. 5-16 of 2005. A meteorological station (shortwave, total radiation, air temperature, relative humidity, wind speed and direction), thermistor chain (0.75 m vertical resolution) and ADCP (40 cm vertical resolution) were deployed in Rusinga Channel in a depth of 20 m. Similarly, at an offshore station in northeastern Lake Victoria another thermistor chain was deployed in a water depth of 40 m along with wind speed and direction sensors.

Over both field campaigns the exchange dynamics through Rusinga Channel behaved similar to a tidally-driven system with surface level fluctuations of between 5-15 cm at the ADCP location, and much larger excursions at the eastern end of Winam Gulf. In general, these surface level movements led to barotropically driven flows into the Gulf during rising surface levels and currents towards the open lake during falling lake level. The frequency of these currents was found to vary between 6 and 12 hours and current speeds ranged from 10-50 cm s^{-1}. Field data and ELCOM simulations indicate that despite the high current velocities in the channel the net exchange is low due to the oscillatory nature of the forcing. This implies that the Gulf is relatively decoupled from the main lake.

Key words: Lake Victoria, Exchange flow, Flushing times

Introduction

The Winam Gulf region of Lake Victoria is an important regional resource to Kenya (Figure 1). In recent years, particular problems have appeared in the Gulf due to the presence of water hyacinth, which has had the impact of reducing fish catches and potentially impacting directly on human health (Opande et al 2004, Williams et al 2005). The nutrient status of the Gulf and the main lake was investigated by Gikuma-Njuru and Hecky (2005), who found the Gulf to be well-oxygenated but potentially light limited for phytoplankton. They also found the Gulf likely to act as a source of nitrogen to the main lake, but were unable to determine whether the Gulf was a source or sink of phosphorus for the main lake. The role of Winam Gulf in the management of the greater Lake Victoria, and the impact of Lake Victoria on the Gulf, remains somewhat unknown.

To help in the understanding of these problems, a study was commissioned by the Kenya Agricultural Research Institute (KARI) and the Lake Victoria Environmental Management Project (LVEMP) titled "Pilot Study of the Hydraulic Conditions over Rusinga Channel and Winam Gulf of Lake Victoria". The study was conducted by the Centre for Water Research (University of Western Australia) in conjunction with scientists and staff of KARI, LVEMP and the Kenya Marine and Fisheries Research Institute (KMFRI).

The study objectives were:

- To establish the major patterns of water circulation over the Rusinga Channel and the factors controlling these patterns
- To assess the influence of the Rusinga Channel on the mixing between Winam Gulf and the main lake
- To determine whether other 'bays' constitute comparatively 'dead' zones
- To improve on existing estimates of the mean hydraulic retention period of the lake

We discuss the methods used to achieve these objectives and the preliminary findings of this investigation in this paper.

Materials and methods

In order to address these objectives, two major field campaigns were conducted. The first was carried out between April 22 – May 4 and the second between August 5 – 16 2005. The timing of the first experiment was set to coincide with the wet season, whereas the second experiment was timed to coincide with the dry season.

Each experiment required significant logistics planning and organization. A substantial amount of time and effort was spent on ensuring the participation of the local riparian communities of the study region. This involved meetings conducted between local experts in community participation and the scientists conducting the study. The experimental work was based in Mbita at the ICIPE research station.

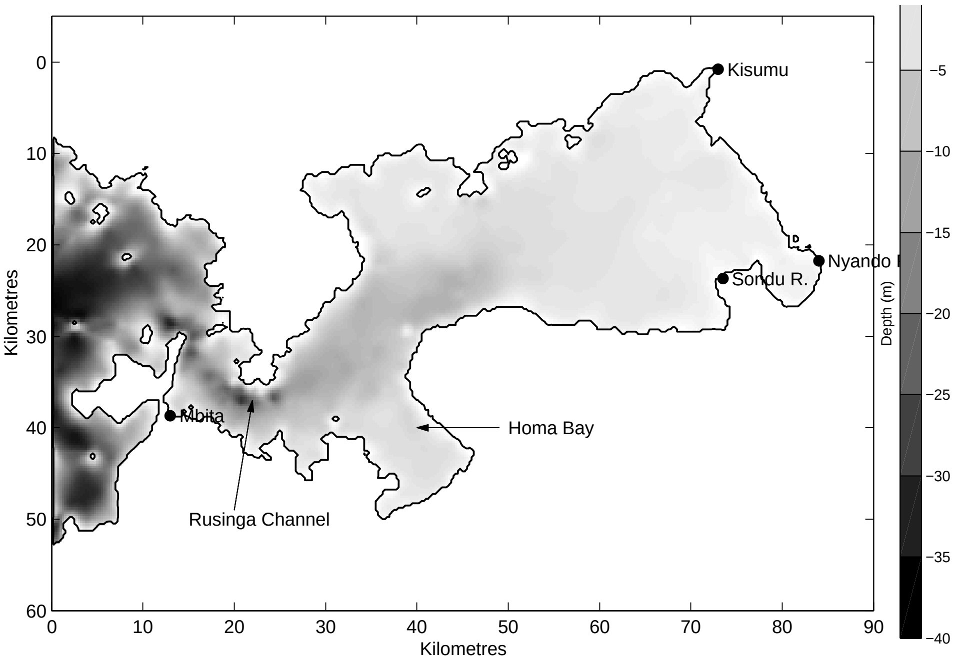

Figure 1: Bathymetric map of Winam Gulf showing the locations of Kisumu city, the Mbita township, the Rusinga channel, the Homa Bay region, and the locations of the Sondu and Nyando Rivers.

For each experiment, three moorings were deployed. At an offshore station (T1), a thermistor chain measuring the vertical temperature profile every 1 minute was deployed along with a wind speed and direction sensor. For the second experiment, this station was also fitted with a pressure sensor to determine the water level. In the channel, a second thermistor chain (T2) was deployed that included a full meteorological station measuring shortwave radiation, net radiation, air temperature, relative humidity, wind speed and direction (Figure 2a). At the same location an acoustic Doppler current profiler (ADCP) was deployed to determine the vertical structure of the currents flowing through the channel (Figure 2c). During the second experiment, a pressure sensor was also installed in Kisumu Bay to measure the water level.

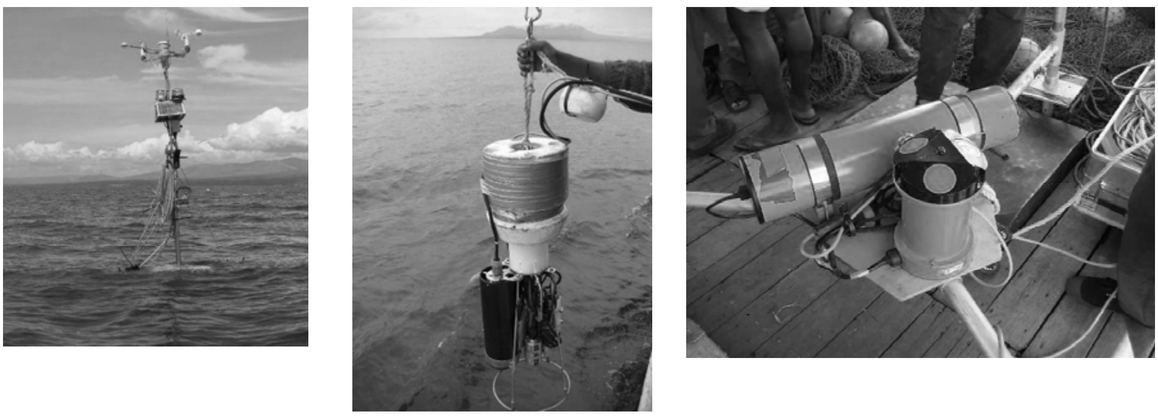

Figure 2 Instrumentation deployed in Winam Gulf during the experiments. From left to right: Lake Diagnostic System consisting of 20 high frequency thermistors, solar radiation, net radiation, air temperature, relative humidity, wind speed and wind direction; F-probe profiler consisting of conductivity, temperature, depth, pH, turbidity, dissolved oxygen, chlorophyll a and coupled with a BBE Fluoroprobe measuring 4 response regions of phytoplankton; ADCP measuring horizontal velocities and variation in water height. These fixed point measurements were complemented by profiling conducted on the RV Utafiti.

The main instrument used was the F-probe profiler (Figure 2b), which measures conductivity, temperature, depth, pH, dissolved oxygen, turbidity and chlorophyll a at approximately 2cm intervals in the vertical. This instrument was deployed in a free-falling mode at numerous stations in the channel and Gulf (Figure 3). Also incorporated into this probe was a BBE Fluoroprobe (http://www.bbe-moldaenke.de/english/fluoroprobe_e.html) , which measures chlorophyll fluorescence in four different algae classes and can be used to differentiate between algal groups in-situ. A microstructure profiler was also used, consisting of high vertical resolution (1mm) measurements of temperature, conductivity and depth. This was used to determine turbulence and mixing characteristics in the Gulf.

Results

The pattern of stratification due to temperature at moorings T1 and T2 is shown in Figure 4 and Figure 5 for the two field experiments. During the April/May experiment (Figure 4), the offshore waters of Lake Victoria demonstrate a strong daily heating pattern with surface temperatures reaching in excess of 28°C before cooling to approximately 27°C during the night. There was persistent stratification, with the water at 40 metres depth typically 1-2°C cooler than the surface waters. From April 27 onwards, however, this pattern changed markedly in the offshore station (T1), with a large volume of cold water (< 25.5°C) upwelling from the deeper parts of the lake into the waters offshore of Winam Gulf. The surface temperatures also cooled to approximately 26.5°C. In the shallower channel region, the water was characterized by heating at the surface during the day and mixing to the bottom at night. During this period the upper 15 metres of the water column in the Gulf was approximately 0.5°C cooler than the main lake, though this temperature differential was eliminated as the system cooled towards the end of the experiment.

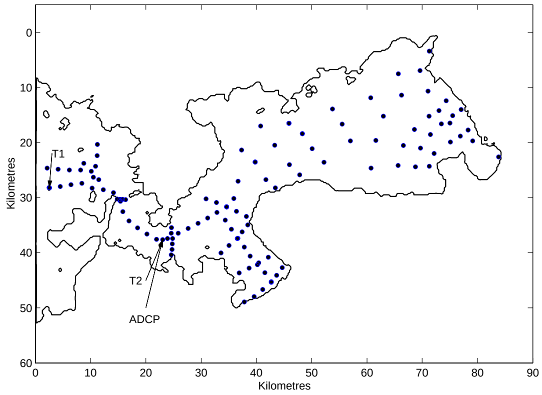

Figure 3. Sampling locations within the study area.

The location of the T1, T2 and ADCP station are shown. Samples were taken using the F-probe profiler at each location arranged in transect formations in order to capture the dominant spatial and temporal patterns in physical, chemical and biological parameters. During the second experiment (Figure 5), the lake was up to 2°C cooler than during April (note the change in scale between Figure 4 and Figure 5). The surface layer in both the offshore (T1) and channel (T2) regions showed similar characteristics to during April 2005, where the persistence of stratification was more evident in the offshore regions than in the channel. As with the first experiment, during this period the upper 15 metres of the water column in the Gulf was approximately 0.5°C cooler than the main lake, though this temperature differential decreased towards then end of the experiment to less than 0.2°C.

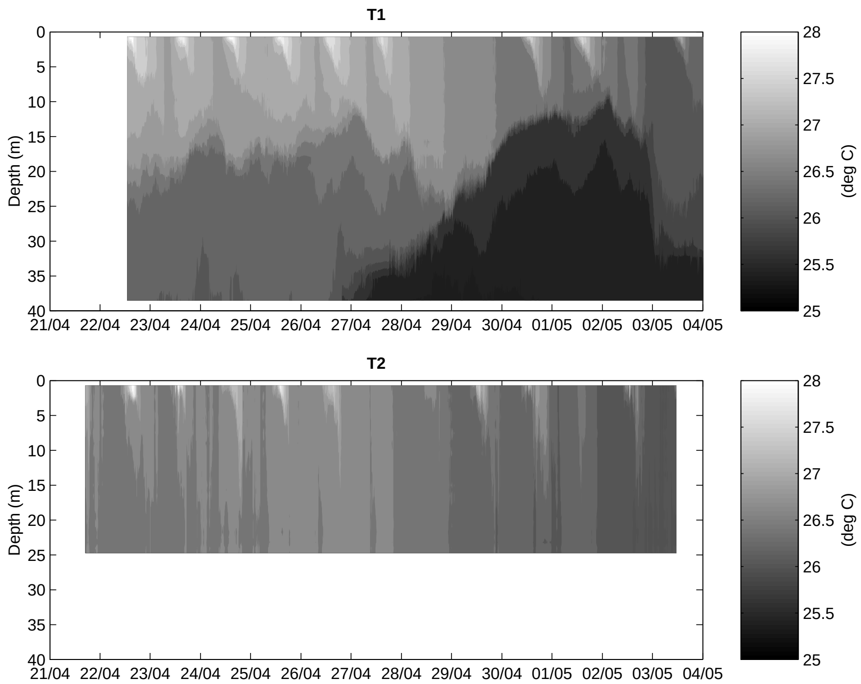

Figure 4. Temperature profiles collected in the offshore (T1) and channel (T2) locations during the April experiment. Depth is the vertical axis, time is the horizontal axis, and the shading represents temperature.

Measurements of currents are presented in Figure 6 along with the water level difference between station T1 and T2. The depth averaged velocity in the channel is highly oscillatory in nature, varying between zero and 15-30 cm/s over approximately a 6 hour cycle. The direction of flow is either into the Gulf (a direction of 90°) or out of the Gulf (a direction of 250°). The flow in and out of the gulf is dominated by the water level difference between the gulf and the main lake. We highlight one period on day 226 (14 August 2005) where the current increases rapidly from near zero to 35 cm/s and is flowing into the gulf from the main lake. The water level difference between T1 and T2 shows a strong gradient with the water level higher at T1 than at T2. This pressure gradient drives the flow into the Gulf from the main basin. The next cycle immediately after this shows a flow reversal with flow out of the Gulf into the main lake associated with a water level pressure gradient from the gulf into the main lake. It appears this is the dominant transport mechanism for flushing water into and out of the gulf from the main lake.

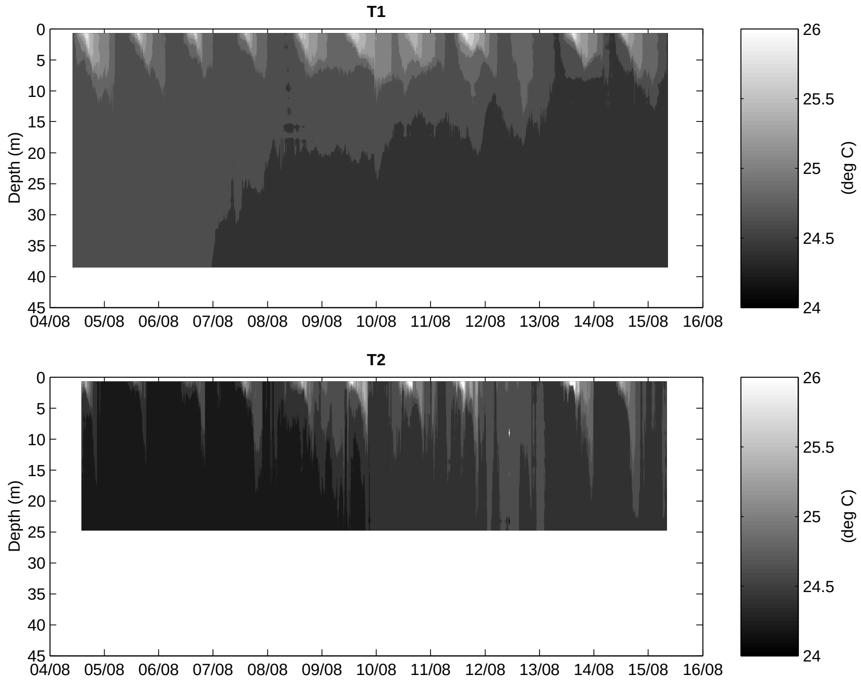

Figure 5. Temperature profiles collected in the offshore (T1) and channel (T2) locations during the August experiment. Depth is the vertical axis, time is the horizontal axis, and the shading represents temperature.

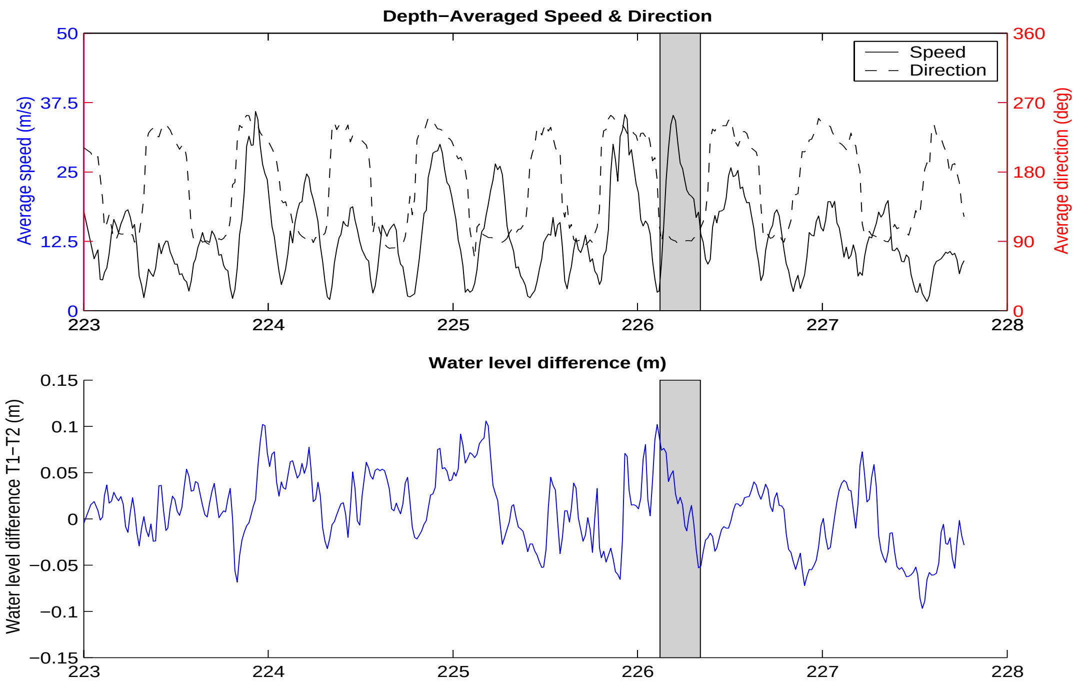

Figure 6. Depth-averaged speed and direction (upper panel) and water level difference between T1 and T2 (lower panel). The shaded area is discussed in the text.

We also present data for the full record available (Figure 7). These data demonstrate the variability in the flow regimes in the Rusinga Channel. Up until day 222 (August 10), the flow shows a 24 hour cycle of one period of water flowing into the Gulf, followed by flow out of the gulf. This changes dramatically on day 222 (August 10), where the flow now changes direction twice in each day, with two peak periods of flow into the gulf and two peak periods of flow out of the gulf. There is one day earlier in the record (day 219) where this pattern also occurs. These data demonstrate that even over a relatively short period (10 days in total), the nature of the flow regime into and out of the gulf can change dramatically. The factors causing the water level changes in the main lake and the reason for the change in the frequency of the currents in Rusinga Channel on August 10 remain subjects of further investigation.

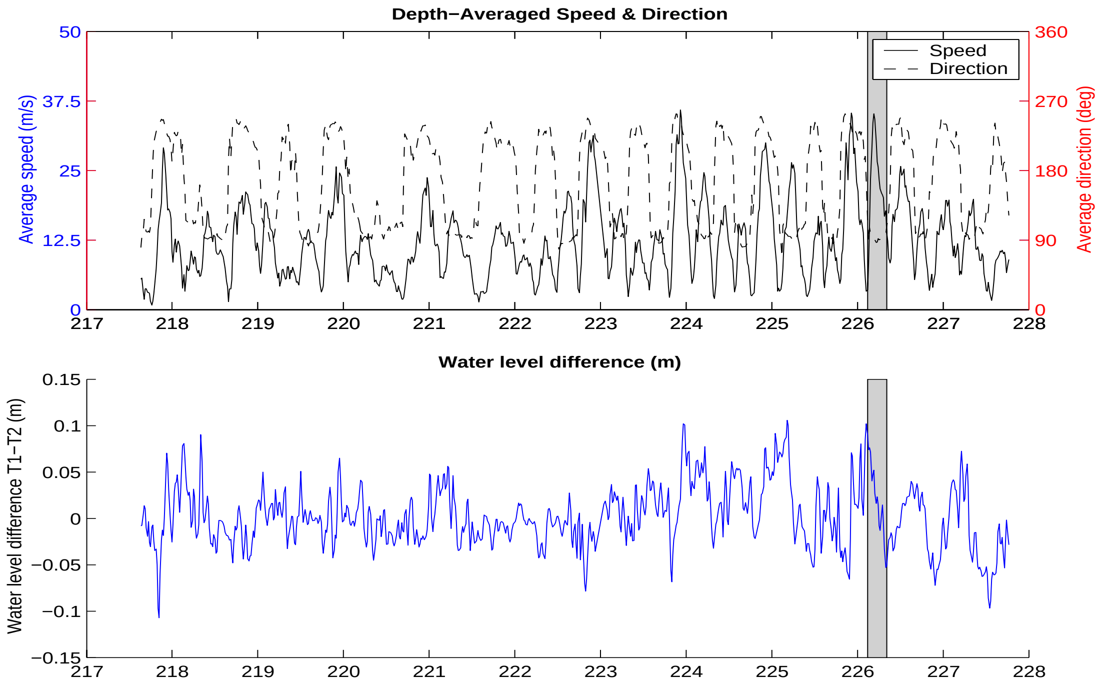

Figure 7. As for Figure 6, but for the entire record during the August 2005 experiment.

In order to estimate the flushing rates of the Gulf, three-dimensional simulations were conducted using the model ELCOM (see companion paper by Romero et al 2005.). As shown in Figure 6, the transport into and out of the gulf was dominated by a tidal-like signal driven by water level gradients. The absolute instantaneous transport into and out of the gulf ranged from -10000 (out of the gulf) to 10000 m^3 s^{-1} (into the gulf), equivalent to an average maximum velocity of approximately -10 to 10 cm s^{-1}, which corresponds to approximately 0.15 km^3 of water passing through the cross-section for each cycle. As the volume of Winam Gulf is 6.3 km^3, 2-5% of the volume of Winam Gulf passed across the cross-section on a daily basis over the course of the simulation during westerly currents and again upon the return flow during easterly currents. A more quantitative understanding of the flushing time of the Gulf was developed using tracer simulations whereby the concentration in the gulf was initialized with a known mass. Simulations were then run, and the flushing time was determined from computing the rate at which the tracer was removed from the Gulf. During the April 2005 experiment, the flushing time of the Gulf was computed to be approximately 300 days.

Summary

Two extensive field experiments were conducted in the Rusinga Channel and Winam Gulf of Lake Victoria in order to understand the exchange dynamics of the Gulf with the main lake. During both experiments, there were periods when the gulf was relatively cooler than the main lake, and periods when it was of similar temperature. The main finding of the experiments was that the flushing was driven by differences in water level between the main lake and the gulf. These water level changes resulted in periodic flow direction changes of between 6 and 12 hours, and resulted in currents in the channel of up to 35 cm/s. Despite these large flows, the amount of exchange between the gulf and the main lake was relatively small as the flows were oscillatory.

Further work is to be completed on understanding more about the processes resulting in water level changes in the gulf, and the currents driven by the water level changes compare to those driven by wind forcing and inflow events. The impact of these processes on water quality is also being investigated using a coupled hydrodynamic and water quality model.

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