The monitoring of volcanic lakes in Indonesia: from ground to space measurements.

A. Bernard[1], A. Mazot[1], B. Barbier[1] and K. Huda[2].
1: Université Libre de Bruxelles, Belgium.
2: DVGHM, Indonesia.

Indonesia has a chain of 129 active volcanoes extending nearly 7000 km from the Northern end of Sumatra through Java, Sulawesi and Halmahera. Several eruptions of these volcanoes have been catastrophic in the past both in terms of the loss of human life and the partial or total destruction of infrastructure and economy. Millions of Indonesians are currently living on volcanoes and civil infrastructures are progressively developing on their slopes. Due to the economic and demographic pressures that exist in Indonesia today, it is clearly not possible to prohibit settlement of population around these active volcanoes. One of the challenges for Indonesia during the 21st century will be to use and manage this land resource as well as to minimize the risk to humans and long-term economic effects of future eruptions.

15 active Indonesian volcanoes have their crater filled with an aqueous lake. These lakes present a hazardous situation because they contain large volume of waters like Dempo in Sumatra with 8.5 millions m^3 or Ijen in Java with 35 millions m^3. None of these lakes is equipped with a monitoring instrumentation and their geochemistry or internal physical structure is generally poorly known.
Many of these lakes are located in remote areas with difficult accessibility and it is obvious that the use of spaceborne platforms is an advantageous and cost effective solution for the monitoring of these remote lakes. The recent developments of new sensors like ASTER with an enhanced resolution and multispectral capabilities offer a new way to monitor changes in the thermal activity of these lakes. We have developed a new algorithm based on the classical Split-Window method for the retrieval of accurate surface temperatures from volcanic lakes (Figure 1).

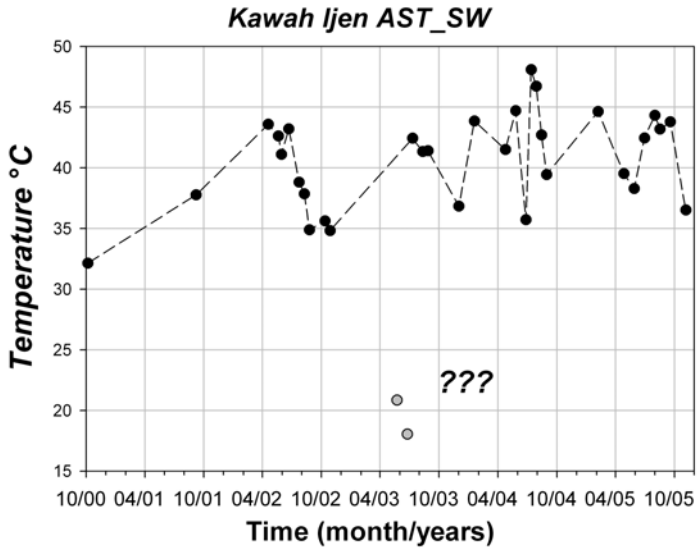

Figure 1: temperature data for Ijen lake recorded by ASTER during 2000-2005**.** Lake temperatures peaked at 48.1°C on July 13, 2004. During the same period, signs of increasing activity were reported by local observers. See Bulletin of the Global Volcanism Network, 11/04.

A large majority of volcanic lakes have acid-sulfate-chloride (ASC) waters which reflect the direct absorption of magmatic gases into a sub-surface hydrothermal system.
In Indonesia, two lakes have a contrasting composition where neutral Na/K chloride waters dominate the chemistry: Kelud in Java and Segara Anak (Rinjani) in Lombok. Neutral Na/K chloride fluids are usually typical of aged hydrothermal systems where the emission of acid magmatic gases has stopped and the acidity has been completely neutralized by fluid-rock hydrolysis reactions. The discharge of neutral-chloride fluids at the top of volcanic edifices which have experienced significant magmatic eruptions in the recent past is a relatively rare situation.
For Kelud lake, we have data collected during the past 12 years (1993-2005). These data show a continuous evolution of both temperature and composition of the lake. The initial lake chemistry (1993-1997) was dominated by Na-K chloride waters. Today, Ca-Mg sulfate waters are the main component in the lake. This evolution suggests that two independent hydrothermal systems with distinct compositions are present within the volcanic edifice and contribute to the chemistry of the lake waters.
Two notable events were observed in 1996 and 2001 when a sudden increase in lake temperatures occurred. In both events, the lake temperature peaked at 50°C and a strong increase in the intensity of the degassing from subaqueous fumaroles was observed. The two heating episodes lasted about 18 months and were not followed by any eruptive activity.
Heating episodes, sometimes cyclic, are relatively frequent in some crater lakes and reflect changes in the flow rate or in the enthalpy of hot fluids entering the lake. However, these heating episodes always represent an alarming situation because an increasing lake temperature can be a precursory signal for the renewal of magmatic activity as was observed 3 months before the 1990 eruption (Badrudin, 1994; Vandemeulebrouck et al. 2000).

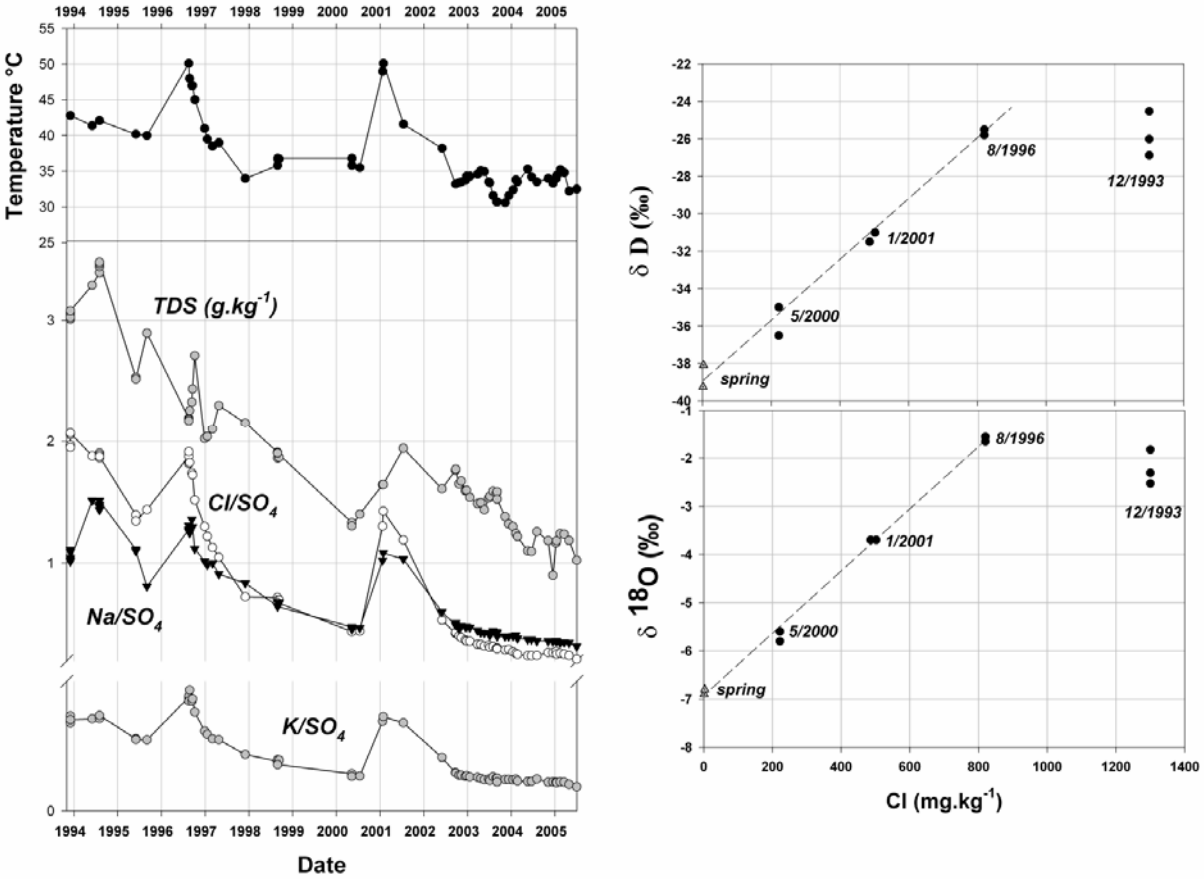

Figure 2: temporal evolution of the chemical and isotopic compositions of Kelud volcanic lake during 1993-2005.