

# The technical concept within the Integrative Landslide Early Warning System (ILEWS)

R. Bell, B. Thiebes & T. Glade

*Department of Geography and Regional Research, University of Vienna, Austria*

R. Becker

*IMKO Micromodeultechnik GmbH, Ettlingen, Germany*

H. Kuhlmann, W. Schauerte & S. Burghaus

*Department of Geodesy and Geoinformation, University of Bonn, Germany*

H. Krummel, M. Janik

*GeoFact GmbH, Bonn, Germany*

H. Paulsen

*Terrestris GmbH & Co KG, Bonn, Germany*

**ABSTRACT:** This paper describes the technical instrumentation used by the ILEWS Project to build up a landslide early warning system. Measurements of landslide movement and soil-water-status are conducted and integrated into a physically-based slope stability model for continuous calculation of slope stability and into surface-analysis early warning model. Beside the technical early warning system the ILEWS Project follows an integrative approach, also including social scientists, spatial planners and historians. The overall goal is to provide a complete warning chain, including in-situ measurements described in this contribution, data handling, automated but supervised analysis, warning and consequent communication and decision making.

## 1 INTRODUCTION

Landslides cause fatalities and economic damage all over the world. Installing early warning systems is one option to reduce severe consequences. However, early warning of landslides is a challenging topic because the possibilities of prediction vary significantly. A distinction is not only limited to different types of landslides it also comprises the differentiation between reactivated and new movements. Due to their already moved landslide body, reactivated landslides are more easily to identify and if required, appropriate monitoring instruments can be installed. The locality of new landslides is by contrast rather difficult to predict.

The aim of the project is to design and implement a prototype of an integrative early warning system for known and reactivated landslides, so that information on possible future, possibly catastrophic failures can be collected in advance. The methodical configuration of the early warning system is developed to be transferable and modular, i.e. it can be adapted to local structures of different countries, and it can be customized to other natural processes (e.g. rockfalls, debris flows).

The project ILEWS is funded by the German Ministry for Education and Research for a period of three years.

## 2 INTEGRATIVE EARLY WARNING SYSTEM (ILEWS)

Recent natural disasters (amongst others: tsunami in December 2004; hurricanes in 2005) clearly demonstrate that effective early warning must not end with providing a warning, but has to integrate social science, humanities and decision making as well.

These current demands on integrative early warning systems were stated by some of the founders of hazard research in the 70s: „It is necessary to know how technological advances in development of detection and warning systems for hurricanes, floods, earthquakes and other hazards can be more effectively translated into official and public actions to protect life and property.“ (White & Haas 1975). The ILEWS project addresses these issues.

Within this project the early warning concept is based on three parts: Monitoring (measurement, data transmission), Modelling (historical and current frequency-magnitude-determination, continuous slope stability modelling, threshold determination, early warning modeling) and Implementation (information management, cooperative risk communication, coordination of early warning with other elements of an integrated risk management).

The concept of the research project requires an interdisciplinary approach. Therefore, social scientists, spatial planners and historians participate in the

project. The paper presented here focuses on the technical part of the project.

infrastructure are frequently affected by these processes (Terhorst 1997, Bibus 1999, Bell 2007). Large

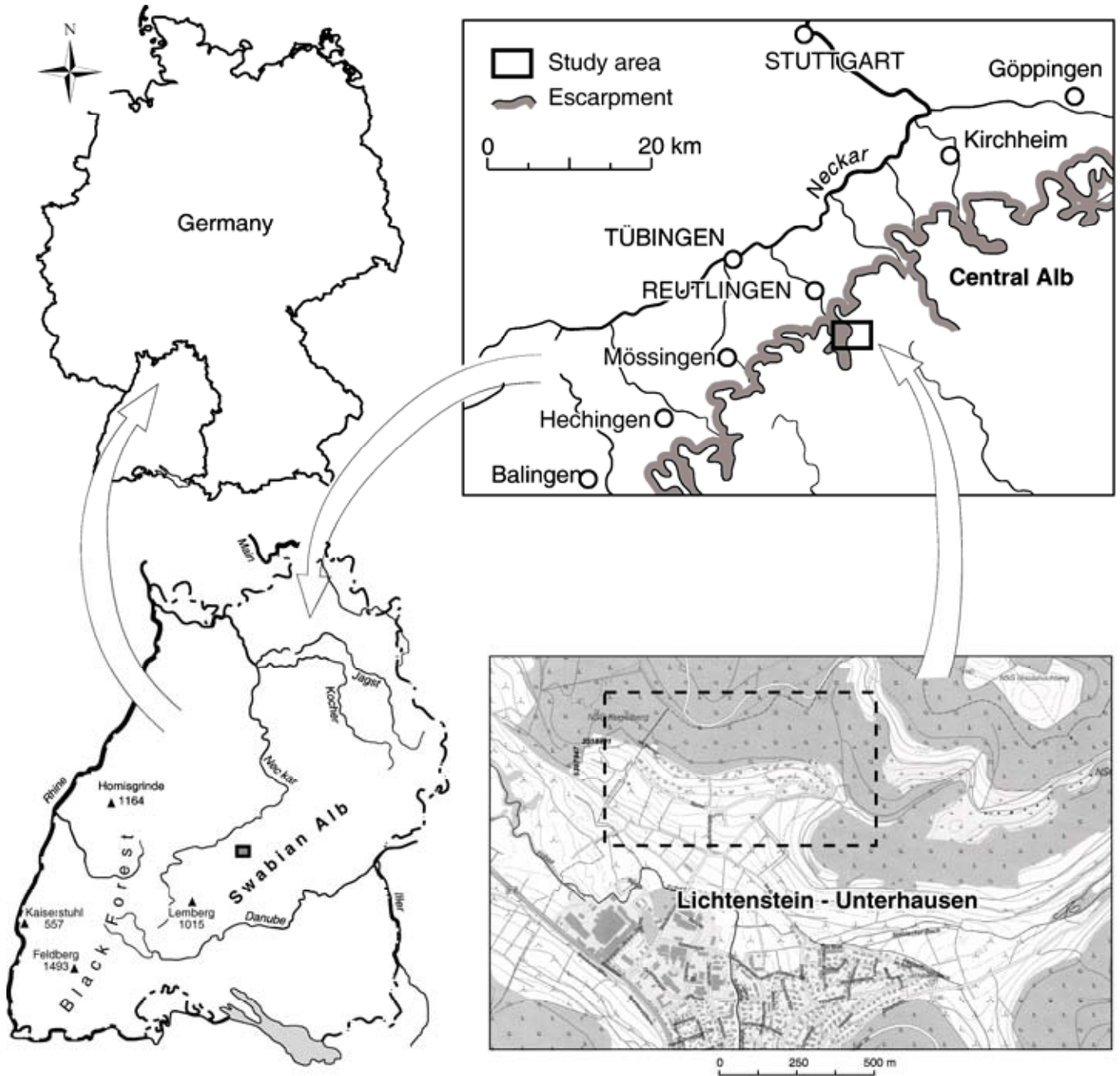


Figure 1. Location of the study area.

### 3 STUDY AREA

#### 3.1 *The Swabian Alb*

The study area is located in the Swabian Alb, SW-Germany and is part of the southern German cuesta landscape (Figure 1).

It consists of Jurassic sediments of limestone overlying marls and clays. The region shows significant landslide activity comprising deep-seated rotational and shallow translational landslides as well as creeping and flowing processes. Human settlements and

events that occurred in historic times include e.g. the landslide at the Bronner Mühle (1960, 3 fatalities) and the Mössingen landslide (1983) in which 6 million m<sup>3</sup> of material was moved (Bell 2007, Bibus 1986).

#### 3.2 *Lichtenstein-Unterhausen*

The study area is a settlement area on a historically active complex rotational slide. The landslide body had already been under investigation within the pre-

ceding research project InterRISK which documented an extremely slow movement of 0.8 mm in 2.5 years by inclinometer measurements (Bell 2007). The landslide under investigation shows a flowing movement after strong summer rainfalls down to depths of 8.5 m. Sliding is initiated in spring after snow melting and reaches down to depths of 15 m. While the flowing movement provides considerable stress on at least one house in the study area which suffers cracking during these times, the deeper sliding movement does not cause any damage.

#### 4 TECHNICAL EARLY WARNING SYSTEM OF ILEWS

The time variant soil water dynamics is the key factor ruling current geomechanical stability of the landslide body. This issue is reflected in the kind of early warning system to be set up.

The early warning modelling concept uses a physically based "Near Real-Time" Early Warning Model as well as a Surface Movement Analysis Early Warning Model. The system includes sensors for determining the load (meteorological data), the inner status of the vadose zone (water content, soil suction head, and pore water pressure) and the system response (assessed by monitoring kinematics using inclinometers and high precision geodetic methods like tacheometry and GPS) for the landslide body. Conventional sensors as well as novel measurement procedures will be used. The monitoring system includes particular measuring procedures and integrated data recording mechanisms, which will be specifically adapted to the early warning of rotational slides.

The concept and the installations are explained in detail in the following. An overview on the planned installations is given in figure 2.

##### 4.1 *Inclinometer and inclinometer chains*

Subsurface landslide movements are monitored continuously with two permanent installed inclinometer chains, each consisting of two to three inclinometer probes. Thus, movements can only be continuously monitored in two to three depths per inclinometer.

In addition, periodical measurements are carried out using a mobile inclinometer device to improve the resolution in depth (measurements are taken in 0.5 m increments). Periodic measurements started in 2004 and were performed at a more or less monthly basis.

Three inclinometers (produced by Glötzl GmbH) are used and installed at depths between 8.5 m and 15.5 m.

##### 4.2 *Continuous geoelectric measurements*

A geoelectrical soil moisture monitoring system running on a monthly basis showed that monitoring

of soil moisture is possible using geoelectrics. However, deep insights into the moisture variation were hindered by effects caused by the high portion of clay in the landslide material and due to vegetation effects. New studies of the Geological Survey of Austria show that even temperature variations have an influence on resistivity measurements and must be investigated. Using the old monitoring set up, all these effects could not be quantified since the time resolution was too poor. Thus, a new continuously running geoelectrical monitoring system is developed.

The intention is to permanently install a 2D/3D geoelectrical survey system on the landslide. An automatic procedure will be developed for data collection and for transferring the data via modem to a central processing unit. The calibration of the geoelectrical data will be done by singular in situ soil moisture measurements using TDR-Probes and Tensiometers (see subchapter 4.3). The processed results of the survey will be implemented into a central database and evaluated and interpreted with respect to the common goal of the development of an early warning system for landslides.

Prior to the installation the landslide body was examined with geophysical methods (e.g. seismic, geoelectric) to determine the geometry of the body and critical "hot spots" for the setup of the permanent array. A device developed by the Geological Survey of Austria will be used. The survey system will automatically perform several surveys each day.

Other objectives include the optimisation of the 2D/3D-geoelectrical survey arrays (e.g. linear, star shaped or quadratic arrays, electrode separation) for continuous surveying of soil moisture/flow potential at "hot spots", e.g. sliding surface of a potential landslide and the deployment of an automatic procedure for periodic data collection and data transfer. Also an automatic procedure for analysis of geoelectrical data for interpretation of soil moisture conditions will be developed which includes an inversion procedure to create geoelectrical resistivity models from apparent resistivity data. Scale transformation for soil moisture from singular in situ measurement to spatial information by using 2D/3D-geoelectrical survey systems will be incorporated. Ultimately a prototype of an automated 2D/3D-geoelectrical survey system for monitoring the soil moisture/flow potential at potential landslide locations will be compiled.

##### 4.3 *TDR probes and tensiometers*

Determining soil moisture in clay or highly electrically conductive soils is a technological challenge due to energy dissipation during the measuring procedure. The measuring principle Time-Domain-Reflectometry (TDR) is less prone to these effects and thus especially suited for the particular application. TRIME-TDR sensors by IMKO supply

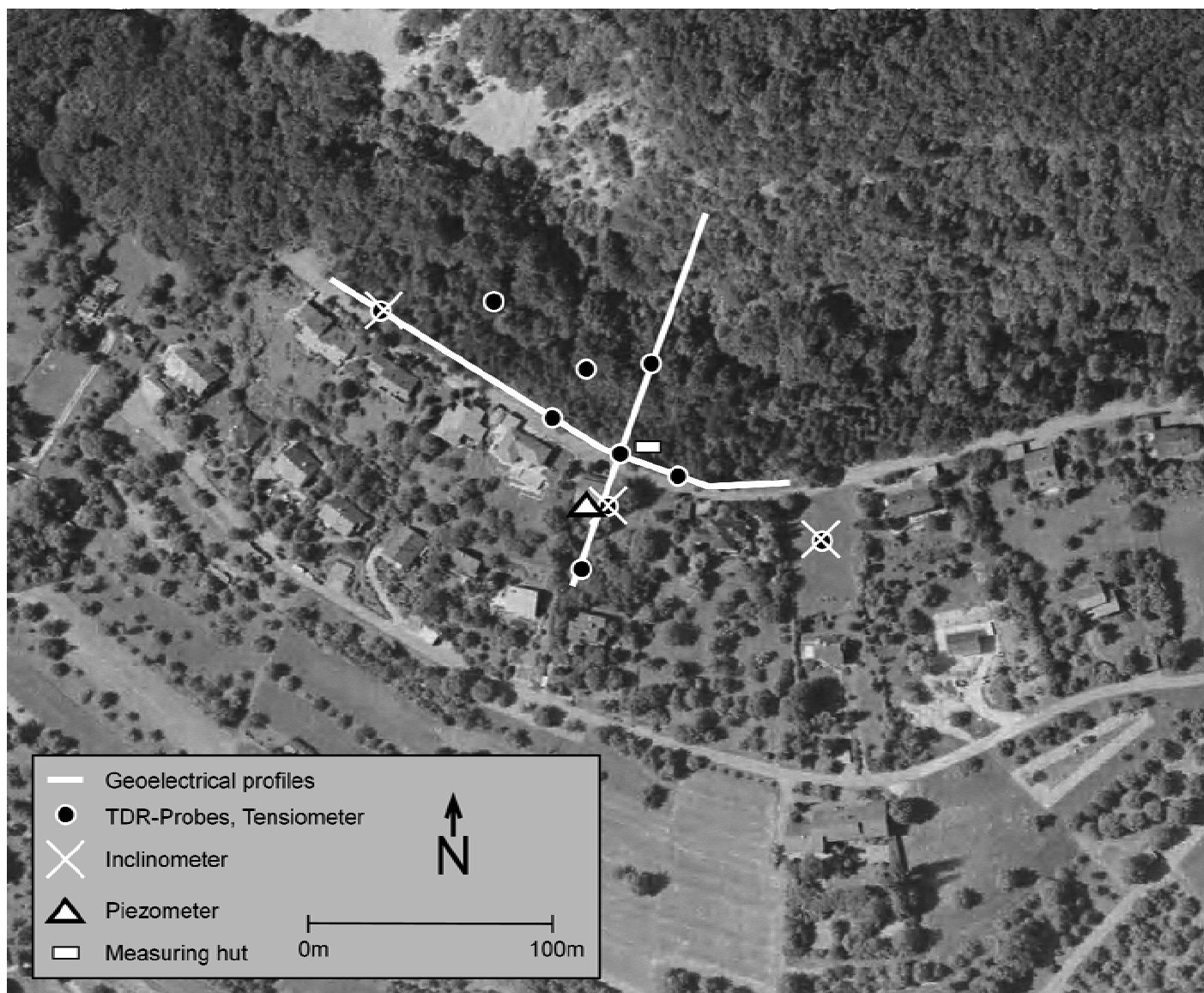


Figure 2. Location of installations

reliable measurements even in difficult soils and are therefore used as the solid back bone of ground water measurements related to landslides.

The “Spatial TDR” method currently being developed at several German universities and research institutes allows determination of water content profiles along elongated sensor cables of several meters length. However, this procedure requires a large mathematical effort to analyse signals and locally does not achieve the same accuracy as conventional TDR sensors. As part of the project it will be tested whether a combination of Spatial TDR and standard TDR sensors provides a significant information gain concerning infiltration, perched ground water tables, and hanging slippage.

Besides of the TDR probes tensiometers will be installed to measure suction capability of the soil. A piezometer will give details on pore water pressure. TDR probes and tensiometers will be mainly in-

stalled along the two profiles (indicated in figure 2) in three different depths (approximately 2 m, 5 m

and 10 m) to better understand water-movement in the soils. Some sensors will also be installed adjacent to the geoelectric profiles for testing the interpolation of soil moisture based on the point measures.

Another forward-looking aspect of the system integration is the fusion of IMKO’s well established sensor technology for recording environmental variables with novel self-organising wireless networks. A small number of the sensors for vadose zone monitoring will be taken out of the previously built cabled field bus system and will be integrated into a wireless network (together with the project partner Terrestris). The wireless network nodes from ScatterWeb have a variety of interfaces to connect the sensors. Here too, hard- and software adjustments will probably be required to match the different interfaces. Robustness, prevention of downtime, and energy supply for the planned sensor network are

important aspects of the investigations. These issues are decisive criteria for future applications of wireless sensor networks for environmental monitoring.

#### 4.4 Tacheometry

Geodetic monitoring measurements are used to get a confirmation of predictable changes (e.g. subsidence behaviour of buildings) or the proof for a non-expected or non-predictable change of an object (e.g. landslide). Information is generally being supplied through selected measuring points. The behaviour of the object can be quantified by analysing the movements over time. Closely related with the determination of movements is also the question of reasons in order to derive a causal connection.

By means of a specially created geodetic point network that spreads over stable as well as critical slope areas those areas should be identified whose movement intervals differ significantly from other areas due to certain other effects (e.g. increase of humidity, change of pore water pressure, etc.). Absolute movements of ground points in slope areas are being recorded and compared to reference points via measuring methods such as electronic precision tacheometry and GPS. The inclinometer locations must be linked to the geodetic measuring points to get best redundant but assignable measuring information on movements.

It is the intention to use both geodetic measuring methods one after another. If we assume that the movement intervals are about 0.3 mm/month, the measuring resolution of the precision tacheometer of about 0.2-0.3 mm will be sufficient to carry out episodic measurements and repeated measurements about every 2-3 months. The integrated inclinometer measurements not only deliver redundant information on areas close to each other but the automatic relative measurements can serve as indicators for beginning movements in order to possibly initiate monitoring measurements outside the scheduled measuring epochs.

As already indicated GPS measurements will be carried out with the same measuring epoch. They have advantages with continuous monitoring methods over several weeks provided they are being carried out as static measurements. The data achieved in the local network comes together in a central control and evaluation unit, by that it is possible to calculate the basic lines between the network points automatically and continuously in order to derive station movements from that.

The observation deviations with the GPS method show a certain auto-correlation in the range of a few minutes up to a few hours. Reasons for this are e.g. multipath and extension effects of the electromagnetic waves. The dimension of the deviations lies above the point movements to be expected. A reduction of those observation deviations can be achieved during long observation periods and an analysis us-

ing the post-processing method. Due to the planned early warning system a real-time process is wanted here which arranges the analysis in such a way that a separation of measurement deviations and point movements will be done in a filter approach.

To get a relative precision of tacheometric measurement clearly less than 1 ppm a regular examination of the measuring instrument will be necessary. It is also not sufficient to introduce the gained meteorological parameters of the endpoint as representative factors for the entire measuring distance. Hence the determination of the refractive index plays an important role and finally is the precision limiting factor for the distance measuring especially in mountained areas.

A successful way for high-precision distance measuring was taken in the 1990s. Based upon the light dispersion in a turbulent medium, the fluctuations due to atmospheric exchange processes are described in a model by means of statistic factors. Suitable commercial systems to measure these atmospheric fluctuations have been developed by Scintec/Tübingen in form of the scintillometer measuring systems. Regarding the chosen study areas a scintillometer will be used, which can do measurements up to 4-5 km. Its usage will lead to a significant improvement with the modelling of the refractive index and can therefore cover huge parts of the refractive components which have previously been difficult to determine.

#### 4.5 Early warning modelling

Within the physically based "Near Real-Time" Early Warning Model the continuously measured data, especially soil moisture and rainfall, will be integrated in equations to calculate slope stability. Thus, a continuous safety factor can be calculated and a respective WebGIS application will be programmed. If the safety factor gets lower than a specified threshold value, preliminary warning messages are provided in the WebGIS and SMS are sent to the scientists to check and validate the warning using sophisticated slope stability models as well as current subsurface movements.

The slope stability software will also be applied to calculate highly likely sliding circles for rotational slides and to identify the best suited slope stability equations. The results are then again input for the physically based "Near Real-Time" Early Warning Model. At the end of the optimisation period an autarkic running early warning model will be set up, which controls to some degree itself and must only be supervised by experts.

Within the Surface Movement Analysis Early Warning Model all measured movement rates (inclinometer, inclinometer chain, tacheometry, GPS) are analysed using the approach of "progressive failures" (Petley et al. 2005). Depending on the way how the movement rates change, it is assumed that

the catastrophic failure of a slope can be predicted. In a last step, it is investigated if both models can automatically support each other.

Local Early Warning Modelling will also provide information on the magnitude of potential events. To better define the endangered areas depending on the type and magnitude of the process empirical or physically based run out models are applied. Historical frequency-magnitude analyses will help to estimate the recurrence interval of landslides of various magnitudes more reliably and to better interpret local measurement results.

## 5 OUTLOOK

First field installations have been made in autumn 2007 and others will follow shortly so that the technical early-warning system will be operating soon.

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