Update on Medium-term Flood Forecasting and Warning Functionalities and Applications of the Delft-FEWS System

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ABSTRACT

The paper provides an overview of the further development of Delft-FEWS and its potential for application in the Mekong Basin. This system has been designed as a generic flood forecasting platform. Contrary to the most common approach of building a flood forecasting system around a specific model, Delft-FEWS provides a platform for data handling and is open to connect a wide range of monitored and forecasted weather inputs on the one side and of hydrological and hydraulic flood routing models on the other side. It has been equipped with generic tools providing a variety of data handling tasks, such as data validation, interpolation, aggregation and error correction in forecasts, including a variety of visualisation and forecast dissemination options. The paper concludes with a description of a number of specific advantages that the use Delft-FEWS as a platform for flood forecasting would provide to MRCS, in particular its open architecture.

INTRODUCTION

Flood forecasting and warning systems have the potential of saving lives and reducing economic loss in case of emerging flood disasters. Such systems are more effective when based upon reliable data collection systems, arrangements for sharing such data between various stakeholders, processing of data through simulation models and effective data processing to generate warnings to appropriate target organizations.

Fast developments in information and communication technology open up many possibilities for extending forecast lead times and the accuracy and reliability of such forecasts. As examples in the area of data collection in the Mekong Delta, mobile phones can be effective in point data transmission, satellite data are being processed to support the insight into spatial rainfall distributions and meteorological models are available to extend the lead time of precipitation inputs into hydrological models. The quality of hydrodynamic models is improving, both in terms of descriptive processes and accuracy of model calibrations.

With these developments in mind WL | Delft Hydraulics stimulates integration of data and models through a flexible informatics platform for flood forecasting by developing its Delft FEWS system. Delft-FEWS provides a platform for data handling and is open to connect a wide range of monitored and forecasted weather inputs on the one side and of hydrological and hydraulic flood routing models on the other side. It has been equipped with generic tools providing a variety of data handling tasks, such as data validation, interpolation, aggregation and error correction in forecasts, including a variety of visualization and forecast dissemination options. Delft FEWS has the potential to integrate the various data collection systems in place in the Mekong Delta and the various models in place, such as those based

upon SWAT, IQQM, ISIS, VRSAP, Mike11, SOBEK and the currently developed CatchmentSim and URBS models.

Besides the concepts behind Delft-FEWS, this paper briefly describes a range of recent applications, exemplifying potential use in the Mekong Basin, such as:

- National Flood Forecasting System for the Environment Agency in England and Wales;
- European Flood Alert System at the Joint Research Centre (JRC) in Italy and extension of the European pre-warning system to a world wide pre-warning system;
- Pilot applications for forecasting and reservoir management for the National Weather Service (NOAA) and the Army Corps of Engineers in the United States;
- Current development of the Mun and Chi River flood forecasting system in Thailand.

DESCRIPTION OF THE DELFT-FEWS PLATFORM

In the past, most flood forecasting systems have been built around the application of hydrological and/or hydraulic routing models. Contrary to this, Delft-FEWS has been developed as a data management platform. On the one side, this platform is open to various data sources supplying measured or forecasted weather state variables, such as precipitation and temperature. On the other side the platform enables the generic coupling of a variety of hydrological/hydraulic flood routing models (Fig. 1). The data management platform of Delft-FEWS has been equipped with generic tools providing a variety of data handling tasks, such as data validation, interpolation, aggregation and error correction in forecasts, including a variety of visualisation and forecast dissemination options. Details of requirements of such operational forecasting environment are given by Werner et al. (2004, 2005).

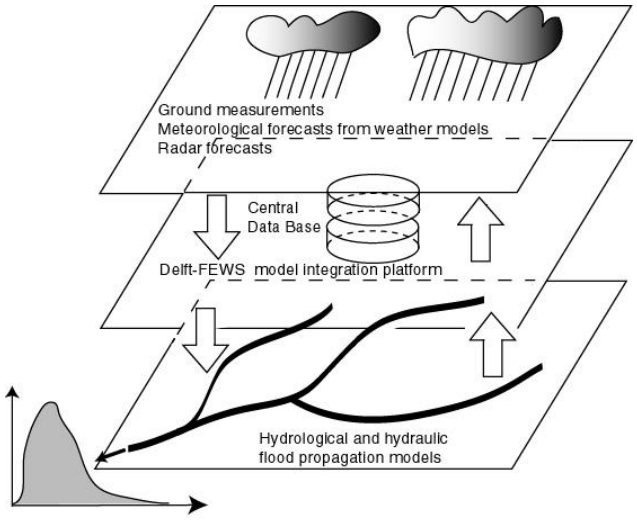

Figure 1 Delft-FEWS open flood forecasting platform

One of the most important requirements is the ability to integrate both new and existing simulation models and data streams on the basis of an open-architecture design of the system. Such design will allow for the reuse of existing hydrological and hydraulic flood routing models that form the core of already pre-existing forecasting systems or that are already in use for flood management (Verwey, 2006). In the past, extensive investments may have been made by the agencies to develop such tools. The construction and calibration of entirely new models, jointly with the development of a new forecasting platform, would increase significantly the investment costs and destroy past investments. The openness of Delft-FEWS has provided a solution to this problem, whereby only minor adaptations are required to plug existing sets of models into the novel framework.

During the past years various client organisations of Delft-FEWS have defined additional requirements to the system. One of these was the flexibility needed to realise scalable platform-independent client-server installations that would guarantee sufficient resilience of the forecasting system to potential failure of individual components. Another important requirement has been the creation of a web-based dissemination of forecasting results through configurable reports.

These recent developments have strengthened the Delft-FEWS platform (http://www.wldelft.nl/soft/fews/int/index.html) as follows:

- Further opening up of the system to process precipitation data, including weather modelling, weather radar and satellites products;
- Further opening up of the system to include a variety of existing and calibrated hydrological and hydraulic modelling systems. Currently, generic coupling has been provided to the modelling systems Sacramento, NAM, LISFLOOD, HBV, SOBEK, Mike11, ISIS, Hec-RAS and a variety of other modelling systems;
- Reprogramming parts of the system using Java™ technology to facilitate platform independent installations for a variety of operating systems;
- Facilitation of system configuration to meet the specific requirements of river basin authorities using XML formatted configuration files;
- Further development of tool kits that give access to look-up tables, correlation tools, performance indicators, generic model calibration tools, flood mapping applications and "what-if" scenario simulators;
- Facilitation of distributed and scalable client-server configurations.

The most recent version of the flood forecasting platform efficiently manages the following tasks:

- Import of external data sources, such as meteorological forecasts, including numerical weather model outputs (GRIB format), radar images, rainfall, discharge and water level time series from telemetric systems and data from external data sources. Processing also includes imports of ensemble weather predictions, such as those provided by the ECMWF-EPS;
- Data validation and serial and spatial interpolation of incoming data, using extensive data validation rules, including user-defined validation rules. Readily available interpolation methods are regression functions, Kriging, Thiessen polygons and the inverse distance method;
- Options with gap-filling and hierarchy rules allow alternative data sources to be used as a fall-back to ensure continuity in the forecasting process;
- Data transformation to prepare the required inputs for reporting and for the forecasting models, such as aggregation of precipitation from distributed point sources, from radar and from numerical weather models, as input to precipitation-runoff modelling and discharge-stage transformations;
- Execution of the hydrological and hydraulic forecasting models. These models may be provided by third parties, such as regression analysis models, lumped hydrological models, spatially distributed hydrological models and hydraulic models;
- Updating the state of the models through a feedback mechanism aimed at minimizing the gap between observed and forecasted data. Delft-FEWS provides some of the possible data assimilation models, such as the ARMA error correction method and ensemble Kalman filtering. The forecasting platform also supports the implementation of other updating techniques;
- Visualisation of results on maps that can be imported from various sources, such as GIS, aerial photo's and others, including geographic navigation, warning options and flood extent mapping;
- Dissemination of forecasts through maps and HTML-formatted reports that allow broadcasting forecasting results to relevant authorities and the public through channels such as intranet and internet.

VARIOUS RECENT APPLICATIONS

National Flood Forecasting System for England and Wales

In 2002, the Environment Agency in the UK commissioned WL | Delft Hydraulics and Tessella Scientific the development of the National Flood Forecasting System (NFFS) as a flood forecasting platform. The area covered comprises England and Wales, subdivided in 8 regional flood forecasting units (Fig. 2). The total sytem involves approximately 2500 forecasting locations and makes use of ECMWF numerical weather model ensemble simulations, radar data and approximately 2000 rainfall ground stations.

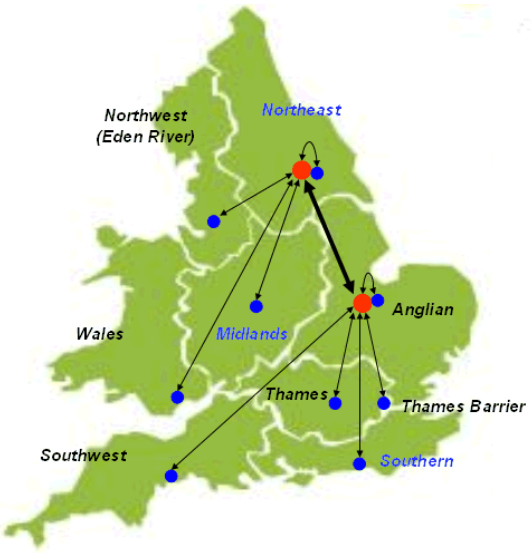

Figure 2 Forecasting centres of the NFFS, UK

A requirement given was the openness of the system to allow the continued use of various calibrated models which were already operational in flood forecasting systems for a number of river catchments in the area. So far, the calibrated models include the rainfall–runoff models based upon PDM, MRCM, TCM and NAM, the hydrologic routing models based upon DODO and KW, and the hydrodynamic modelling systems ISIS and Mike11. Currently, Delft-FEWS also has links to the rainfall–runoff software HBV, Sacramento, PRMS and VFlo, and the hydrodynamic modelling system SOBEK.

NFFS replaces, among others, the earlier FFS2 system developed for the UK Midlands region (Dobson & Davies, 1990). It comprises the MCRM lumped conceptual rainfall–runoff model and the DODO two layer Muskingum routing model, both equipped with updating techniques. These models had to be retained, as they have been extensively calibrated over the past years. The existing telemetry system was equipped with 124 meteorological gauges, 147 hydrological gauges and 272 forecasting points that may or may not coincide with gauge locations. The existing system represented a substantial asset value, of which many components were of great value in the newly installed Delft-FEWS. With the new system curently in operation, component models can be replaced by better options if and when these are acquired.

An immediate advantage of the new system is that forecast lead times increase through the link to more advanced weather forecasting, which is part of the overall platform. A longer term advantage is that gradually the hydrological and hydraulic models can be replaced by state-of-the-art products, without being bound to one single manufacturer. Similarly, with the overall platform in place, the Environment Agency can gradually increase the number of catchments where forecasting is provided.

Updated European Flood Alert System

The European Flood Alert System (EFAS) was developed in a first phase under the earlier name European Flood Forecasting System (EFFS) over the period 2000–2003 with the objective of providing a flood forecasting platform that could be applied at European scale. This first version was developed by a consortium of 19 European research institutes, universities and state agencies, with WL | Delft Hydraulics as a leading partner (Gouweleeuw et al., 2004) and installed at the Joint Research Centre (JRC) of the European Commission at

Ispra, Italy. In the period 2005-2006 the system was provided with an upgrade of Delft-FEWS to improve the European pre-warning system (Reggiani and Verwey, 2006), currently run under the name European Flood Alert System (EFAS: http://efas.jrc.it). Computations are performed for the entire area of Europe at a spatial resolution of 5 x 5 km, at hourly time-steps.

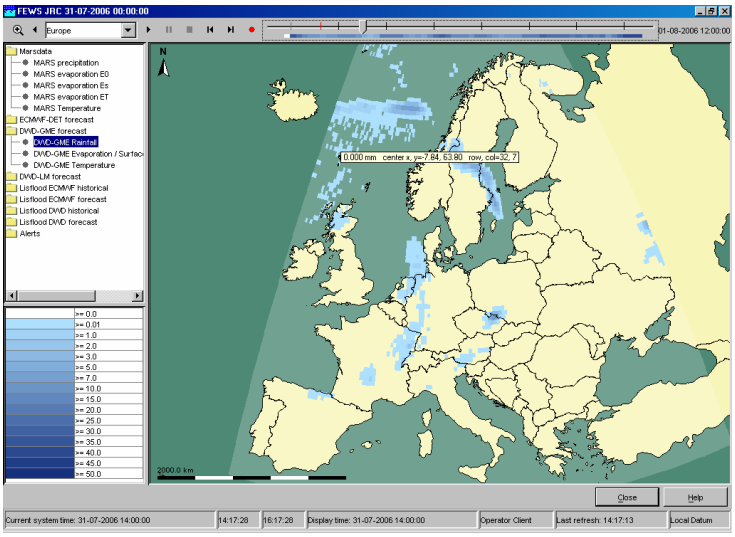

Figure 3 Rainfall forecast for EFAS

Meteorological inputs (Fig. 3) are provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) deterministic and ensemble predictions (Buizza and Hollingsworth, 2002). On the basis of 10-day forecasts provided by 50 ensemble simulations, the system is used to alert national and regional flood forecasting authorities at an early stage of possible flood risks in their basins.

Currently, WL | Delft Hydraulics, jointly with the University of Utrecht, has started a research project to extend the European approach to a system working at world scale. The resolution of that forecasting system will be limited to 0.5 to 0.5 degrees. Once completed, such system has the potential to provide flood pre-warnings for large river basins such as the Mekong Basin.

Po Basin Flood Forecasting System, Italy

Delft-FEWS forms the core of a new interregional flood forecasting system developed for the Po Basin in Italy (Fig. 4), operated by the the Environmental Protection Agency ARPA Emilia Romagna at the premises of the interregional river monitoring centre AIPO in Parma. The central server of the system is supported by dedicated “number crunchers” to run the various hydrological and hydraulic models.

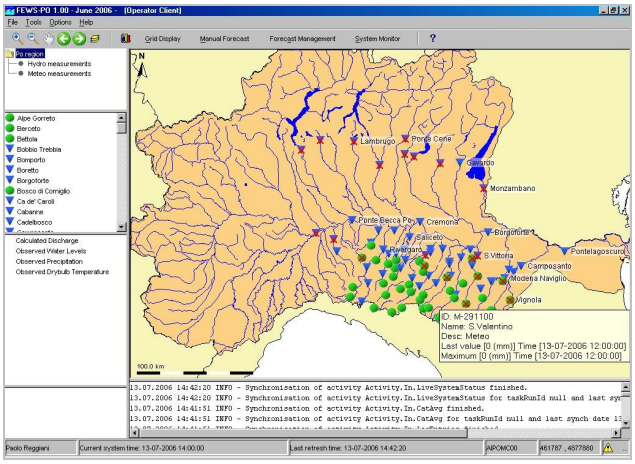

Figure 4 User interface of FEWS Po

Meteorological inputs are provided by two meteorological forecasting systems: (1) COSMO-LEPS (Limited Area Ensemble Prediction System) at a resolution of 10*10 km, providing 16 ensemble simulations (http://cosmo-model.cscs.ch) and (2) the local area model LAMI at a resolution of 7*7 km, providing one single forecast. Meteorological data are also transmitted from approximately 300 local stations.

Contrary to most applications in flood forecasting, the Po River Authority (Agenzia Interregionale

Fiume Po – AIPO) provides an additional ensemble approach by running three combinations of hydrological and hydraulic models in parellel. These combinations are: (1) HEC-HMS and HEC-RAS; (2) Topkapi and SOBEK; and (3) NAM and Mike 11. The spreading in results produced by these three combinations is taken as one of the measures of uncertainty in the forecasted water levels, monitored at approximatley 100 stations along the rivers.

Currently, ths sytem is working on the basis of Delft-FEWS, the two meteorological models and one single combination of a hydrological and hydraulic model for each of the 16 sub basins. Mid 2008 the completion of the system is expected, marking the start of an evaluation period, in particular a quality assessment of the hydrological and hydraulic models. Forecasts are disseminated through a dedicated webserver connected to ARPA's Intranet to serve the needs of various authorities with responsibilities associated to flood disasters.

Forecasting Platform for the National Weather Service, USA

Following initial discussions in 2005, the National Weather Service of NOAA in the USA is currently testing the Delft-FEWS platform for replacement of its existing National Weather Service River Forecasting System (NWSRFS). This system was developed approximately 25 years ago for application at 13 regional flood forecasting centres covering the flood forecasting needs for the whole of the USA. These days, NWSRFS lacks the flexibility to adapt itself to connecting state-of-the-art data sources and models and already for some years the need was felt to migrate to a new system. A system definition phase resulted in the design of the Community Hydrologic Prediction System (CHPS). In the early discussions between WL | Delft Hydraulics and NWS it was realized that Delft-FEWS offered most of the functionalities defined by CHPS.

After a further technical analysis of the IT structure of the Delft-FEWS platform, cooperation on its migration to the NWS appeared to be an attractive option to proceed with the development of CHPS. Following this conclusion, testing of Delft-FEWS is being performed successively in several projects:

- Implementation FEWS to run HEC ResSim for reservoir operation and flood forecasting for the Yuba & Feather Rivers in California, including the Oroville & New Bullard Bar Reservoirs;
- Application for flood forecasting on the Santiam River an upper catchment of the Columbia River as a FEWS pilot implementation for the North West Regional Forecasting Centre in Portland, Oregon
- Application for flood forecasting for a section of the Red River and the Buffalo River as a FEWS pilot for the North Central Regional Forecasting Centre in Minneapolis, Minnesota.

Parties involved in the implementation of FEWS for the Yuba & Feather forecasting and reservoir operation system are the US Army Corps of Engineers (USACE) & Hydraulic Engineering Centre (HEC), the Water Agency (CWA) & Yuba County Water Authority (YCWA) and the California Nevada Regional Forecasting Centre of NWS as clients and APEX Digital Systems (via RS Information Systems) as Delft Hydraulics' partner and main contractor in development. Core of the system is the existing HEC-ResSim model. Completion of the project is foreseen for September 2007.

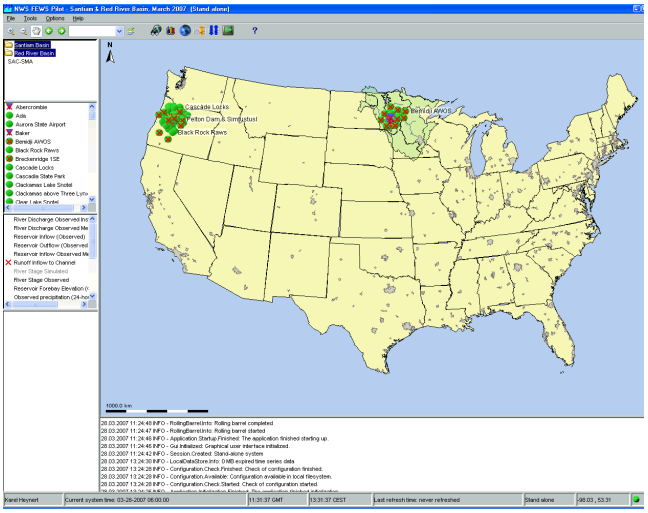

Figure 5 Pilot projects for NWS, USA

The pilot projects for the National Weather Service imply the connection of NOAA's numerical weather models and radar data. The hydrological models are based upon the SNOW-17 Snow model, NWS' Sacramento model SAC-SMA (Sacramento Soil Water Accounting Model), UNIT-HG (Unit Hydrograph), LAG/K (Lag and K Routing Model), SSARRESV (SSARR Reservoir Routing Model), the SSARROUTE (SSARR Channel Routing Model) and Delft Hydraulics' SNOWMELT as a migration of SNOW-17. In addition, for the Red River a SOBEK model has been coupled. The pilot projects are being implemented with Riverside Technology, Inc, Boulder, USA, as main contractor, and Delft Hydraulics. The pilots will be completed in November 2007.

APPLICABILITY TO THE MEKONG BASIN

Currently under development is the Delft-FEWS based flood forecasting system for the Mae Nam Mun and Chi river basin, generating most of the flows from Thailand into the Mekong River. The work is being executed for the Royal Irrigation Department of Thailand by the consulting firms ASDECON and TEAM, supported by WL | Delft Hydraulics. The rainfall runoff process from the basin will be modelled with the Sacramento model and the flood propagation along the rivers and reservoirs with an integrated 1D2D SOBEK model. Through the FEWS platform the models will be linked to information transmitted from rainfall stations in the basin. In principle, this forecasting system could be coupled to an extended flood forecasting system for the Mekong Basin to provide longer forecast lead times and higher reliability of forecasts in Laos, Cambodia and Vietnam.

MRCS and the individual member countries are making use of a number of different modelling systems to simulate hydrological and hydraulic processes. A significant investment has been made to support planning in the basin through the development of the Decision Support Framework (DSF) covering the complete area of the Mekong catchment in Thailand, Laos, Cambodia and Vietnam. This model is based upon the hydrological models SWAT and IQQM and the hydrodynamic model ISIS. In the development of a new flood forecasting system, the current DSF could provide a good starting point for the modelling of flood wave propagation along the Mekong River and its branches.

The openness of the Delft-FEWS platform allows for the coupling of these existing models. No additional investments are required on the short term for the development of new models. Also, when the existing models are recalibrated, they can immediately replace the previous calibrated versions. Connections between ISIS and Delft-FEWS have already been developed in the framework of the UK Environment Agency contract. A connection to the modelling systems SWAT and IQQM would only require a minor effort. Moreover, the structure of Delft-FEWS would allow for the replacement of part of these models by other models available, such as the earlier developed VRSAP for the Mekong Delta and existing models based upon Mike11. A longer term advantage of Delft-FEWS is that gradually the hydrological and hydraulic models can be replaced by state of the art products, without being bound to one single manufacturer.

A flood forecasting system is heavily relying on meteorological inputs. One problem in the Mekong Basin is the scarcity of rainfall stations and the difficulties in maintaining these. In general, however, there is a trend in data collection that the importance of point measurements is reducing, while the importance of spatial information is increasing. Spatial information is provided by satellite observations, processed to feed numerical weather models. With the developments in computing power and associated data storage capacity, these weather models become more refined and more accurate. This certainly also applies to the Mekong Basin.

Delft-FEWS can be made operational in various ways. For the Mekong Basin it could be configured as a client-server application with one central server at the Regional Flood Management and Mitigation Centre in Phnom Penh and web-based client applications at the local MRC offices in Vietnam, Thailand, Cambodia and Laos. These clients can also be authorized to select and run their own scenarios and other clients (read: countries) will have access to these alternative forecasts. Moreover, various authorities in the member countries can be given access to the forecast reports and to associated messaging services. This will be of great help in case of calamities by facilitating the coordination of emergency operations. The system can also be set up to provide improved resilience by duplicating the central server in one or more of the other countries.

With the overall platform in place, MRCS can gradually increase the detail with which forecasting is provided. In such detailing, the role of meteorological information based upon weather models as well as satellite image and radar data processing would become more dominant. With Delft-FEWS, extensive experience has been built up with connections to a large variety of meteorological inputs.

An example of such detailing would be the forecasting of inflows into reservoirs and the subsequent reservoir opertion, such as the Nam Ngum reservoir in Laos (Verwey, 1999).

CONCLUDING REMARKS

The present article gives a brief outline of the potential of Delft-FEWS for serving the flood forecasting needs of the Mekong River Commission. The platform facilitates the integration of meteorological forecasting systems with hydrological as well as hydraulic models within an open forecasting environment.

The principal advantage of this approach is that it enables a shift from a model-centred forecasting approach towards a data-centred system. In this approach, already existing software modules and models such as hydrological, hydraulic and inundation models can be mutually combined, re-used and encapsulated into (new) forecasting environments, whereby the data organisation remains unchanged. Examples are the SWAT, IQQM and ISIS models already in place in the Mekong Basin as part of the DSF and other already existing or newly developed models such as Mike11, SOBEK, CatchmentSim and URBS.

Adopting such a system enables a flood forecasting organisation to replace software modules freely without the need to change the entire structure of the forecasting system, as it would be necessary in case of a model-centred approach. In the latter case a change of a relevant software module would require significant retraining of the organisation in the use of the system once changes of the models take place.

These concepts have been reinforced in newer versions of Delft-FEWS, which have been developed to serve new applications, such as that of the National Flood Forecasting System for England and Wales, the Po Basin forecasting system and the updated European Flood Alert System. Currently, Delft-FEWS also finds new applications, such as drought forecasting

in the Red River catchment of Vietnam, salt intrusion forecasting for the Songkhla Lagoon in Thailand and water quality management of the Marina Reservoir in Singapore.

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