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REAL-TIME HYDROMETEOROLOGICAL OBSERVATION NETWORKS - DEVELOPMENT POSSIBILITIES FOR THE EARLY WARNING SYSTEM OF THE MEKONG RIVER BASIN

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ABSTRACT

Manual surface measurements have traditionally formed the basis for hydrometeorological observation networks. Although automation and real-time data communication has gradually increased, sufficient area coverage for minimizing uncertainties associated with spatial averaging of hydrometeorological variables is still relatively rare. The limited availability of real-time precipitation data for the Mekong River left bank (eastern) sub-basins of Lao PDR has been found to reduce the accuracy of flood forecasting. Also, the usage of surface data from Upper Mekong River Basin could be developed for better five-day water-level forecasts. During disasters like flash floods the lack of real-time hydrometeorological information for forecasting and advisory service contributes to unnecessary economic losses and human casualties. Therefore, a need to further develop hydrometeorological observation networks exists.

Longer lead times and improved input accuracy for flood forecasting can be reached by increasing observations of atmospheric water i.e. measuring water before it precipitates on a river basin. As tropical storms and typhoons arriving from the South China Sea cause the most severe flooding situations in the Mekong River Basin, enhanced observations, tracking and modelling of these storms is recommended for accurate medium-term flood forecasts.

In addition to satellite and aircraft observations, a very low frequency (VLF) long-range lightning detection network could be used to monitor convective activity and estimate rainfall associated with tropical systems over data-sparse sea areas. If suitable aircraft are available, dropsondes could enable even more detailed observations of tropical storms and their surrounding environment. Assimilation of any of these datasets into numerical weather prediction (NWP) models tends to improve both the storm track and precipitation forecasts. Weather radars play an important role in storm tracking and nowcasting over coastal and inland areas. Compared to conventional single polarization radars modern dual polarization weather radars can improve quantitative precipitation estimates (QPE) through hydrometeor classification and better data quality. Improving short term forecasts by assimilation of wind observations into NWP models such as the Fifth Generation Mesoscale Model (MM5) from weather radars is becoming evermore widespread. Finally, NWP model forecasts are used as input for medium term hydrological forecast models, while weather radar derived QPEs are combined with surface observations for improved nowcast input.

In our paper, we summarize recent findings related to operational applicability of these methods for improving hydrometeorological forecasts. Moreover, we discuss hydrometeorological observation system issues related to spatial configuration and overall performance.

INTRODUCTION

The Mekong River along with its numerous tributaries forms a significant international river basin. Its main stream stretches along for approximately 4800 km, while draining an area of around 795,000 km^2 (MRC, 2005). The Upper Mekong Basin (UMB) - represents around 1/4 of the entire river basin, draining the Chinese provinces of Qinghai, Xizang (Tibet) and Yunnan as well as parts of northern Myanmar. The Lower Mekong Basin (LMB) covers the remainder of total catchment area with over 50 million people in four riparian countries (Thailand, Lao PDR, Viet Nam and Cambodia). This region is annually affected by tropical storms of varying intensities originating from the east or southeast. Three major causes for flooding in the LMB can be broadly be identified as 1) annual monsoon precipitation resulting in large scale river fed floods, 2) intense tropical depressions, storms and typhoons creating flash floods particularly in mountainous regions, and large scale river fed floods 3) floods caused by coastal storm surges in the Mekong delta.

FOCUS OF THIS PAPER

Many geophysical phenomena like atmospheric storms do not respect artificial boundaries, such as national borders - floods in this sense make no exception. Often in context of operational hydrology however, the approach is often limited to certain natural drainage area. Although this is perfectly legitimate and justifiable, it is in our view however beneficial to expand these boundaries. Whilst considering the entire hydrological cycle as a single entity we can focus on the phenomenon that cause floods to begin with. By also focusing on the origins of these phenomenon's we can hope to provide more accurate and extended lead times for efficient flood forecasting. Therefore, we suggest that observations of the atmospheric part of the water cycle are given appropriate priority and importance in any serious attempts at improving flood forecasting accuracy and lead times. Since a large majority of tropical storms causing hazardous floods within the Mekong River Basin originate from the South China Sea (SCS), we focus our discussion on the following target areas:

- the South China Sea and the Philippines, i.e. observations along the early route of most tropical storms and typhoons.
- the coastal or otherwise tropical storm prone provinces of Viet Nam and China, located either on or in the vicinity of the storm tracks having a potential to affect the Mekong River Basin.
- those regions within the Mekong River Basin with clear observational gaps, e.g. the poorly gauged eastern sub-basins of Lao PDR

OBSERVATIONS AS PART OF THE FORECASTING SYSTEM

National hydrometeorological forecasting centres use various types of observational data, including surface observations (e.g. precipitation gauge, river gauge or weather station data), measurements of the upper atmosphere (like radiosonde or aircraft measurements) as well as various remote sensed data sets (e.g. satellite, weather radar, wind profiler data). Figure 1 shows an overview of a hydrometeorological forecasting system using such data, consisting of one or several numerical weather prediction (NWP) model(s) and hydrological model(s).

Modern assimilation techniques can accept observations performed during a system specific time frame, a so called assimilation window. As an example the global analysis performed every 6 hours (at 00, 06, 12, 18 UTC) by the Japanese Meteorological Agency (JMA) uses a 6 hour window of ± 3h (Japanese Meteorological Agency (JMA), 2007). The currently quite popular 4D-Var assimilation technique is capable of accepting both conventional observation data and many types of more advanced data e.g. radar-rain gauge analyzed precipitation sums. Furthermore, with 4D-Var it is possible to assimilate observations made at actual unsynchronized observation times.

Whereas meteorological data assimilation has a history of over 30 years, the operational data assimilation in hydrology can still be considered as being in its early infancy (e.g. Walker et al., 2003; Beven, 2007; Seo et al., 2009). Therefore, there are still many open areas of research. For example, a considerable amount of effort (e.g. Reichle et al., 2001; McLaughlin, 2002; Komma et al., 2008) have been placed on studying the possibility of utilizing space borne remote sensing products for directly assimilating near-surface soil moisture estimates to hydrological forecast models. However, as Walker et al. (2003), quite appropriately point out; applying ever more complex data assimilation techniques involving distributed surface and sub-surface data creates a trade-off, where computational feasibility needs to be weighed against perceived benefits. These kinds of approaches can not be at the moment and likely in the very near future considered as a viable option for improving the performance of operational flood forecasting models. It is therefore, in terms of hydrological forecasting in our view relevant to concentrate on utilizing more traditional approaches.

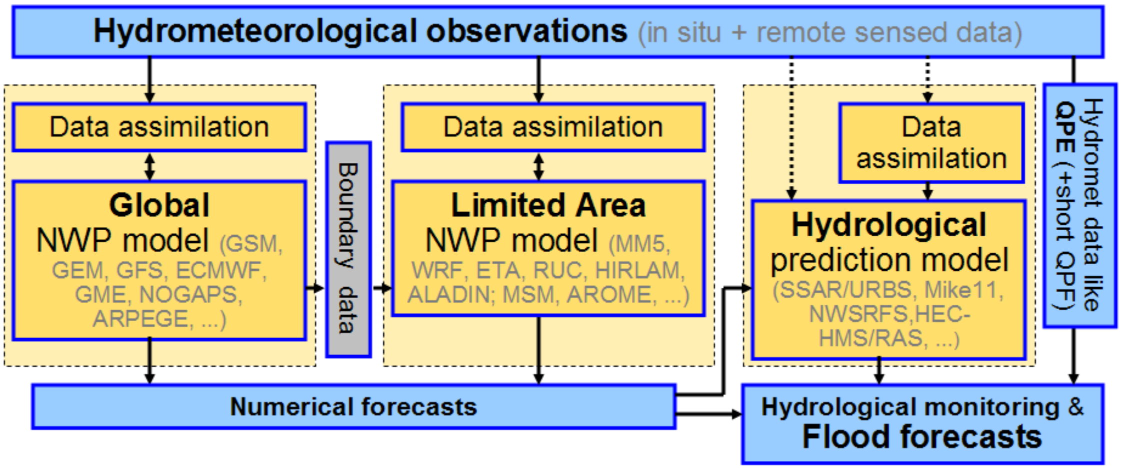

Figure 1. From hydrometeorological observations to flood forecasts.

In practice three broad categories for data assimilation can be identified; 1) error forecasting, where model output variables (generally speaking either river stage or discharge) are updated according to observed model residuals, 2) Kalman filtering or variational data assimilation, whereby all model system state variables and/or model parameters are restructured up to and prior to the time of forecast based on the relationship between observed hydrometeorological variables and discharge during an analysis window, 3) ensemble Kalman filtering whereby an ensemble of possible model states is integrated forward in time using a nonlinear forward model which replicates the noise typically caused by uncertainties in model forcing variables, system states, model structural errors and non-optimal parameterization. (Seo et al., 2003; Goswami et al., 2005; Reichle, 2008).

The combined use of Kalman filtering and error forecasting has been proven to be both very cost-effective and powerful in terms of improving hydrological forecast skill (e.g. Madsen and Skotner, 2005). Since, both of these assimilation approaches are heavily dependent on timely observations feeds, the argument for expanding and improving the real-time surface hydrometeorological observations network within the MRB can not be over emphasized. This along with a need to acquiring powerful, efficient and modern modelling systems has been acknowledged as a key limitation in current forecasting activities at RFMMC, and a priority target for improvements during previous AMF-forums (e.g. Pengel et al., 2008).

ON THE CURRENT STATUS AND DEVELOMENT POSSIBILITIES OF HYDROMETEOROLOGICAL OBSERVATION NETWORKS

Surface and upper air measurements - look downwind and within the Mekong basin

Hydrological observations and modelling have traditionally been based on manual hydro-meteorological surface measurements. In meteorological observations, surface weather stations and radiosounding networks are considered core, whereas in hydrology this is extended to include hydrometric observations. Although automation and real-time data communication has gradually increased, sufficient area coverage for minimizing uncertainties associated with spatial averaging of hydrometeorological variables is still quite rare.

In October 2008, the World Meteorological Organization (WMO) performed its Annual Global Monitoring of data availability. The traditional hydrometeorological observations from key global observation networks were collected by the main data collection centres of the world, Global Telecommunication System (GTS). Figure 2a shows the availability of 00 UTC and 12 UTC vertical soundings of atmospheric temperature, humidity, pressure and wind (Part A of TEMP) in the South-East Asia. Figure 2b depicts the availability of key surface weather reports (SYNOP) for the same area (WMO, 2009). With the exception of China and Viet Nam, the availability of radiosounding data, in particular downwind over the SCS and Philippines was found to be poor. No sounding stations are located on any of the islands of the Central SCS. Moreover, it appears likely that the forecasting community of the MRB has very limited possibilities to monitor the important lower tropospheric humidity flow of south westerly monsoons, indicated by e.g. the silent stations of Myanmar.

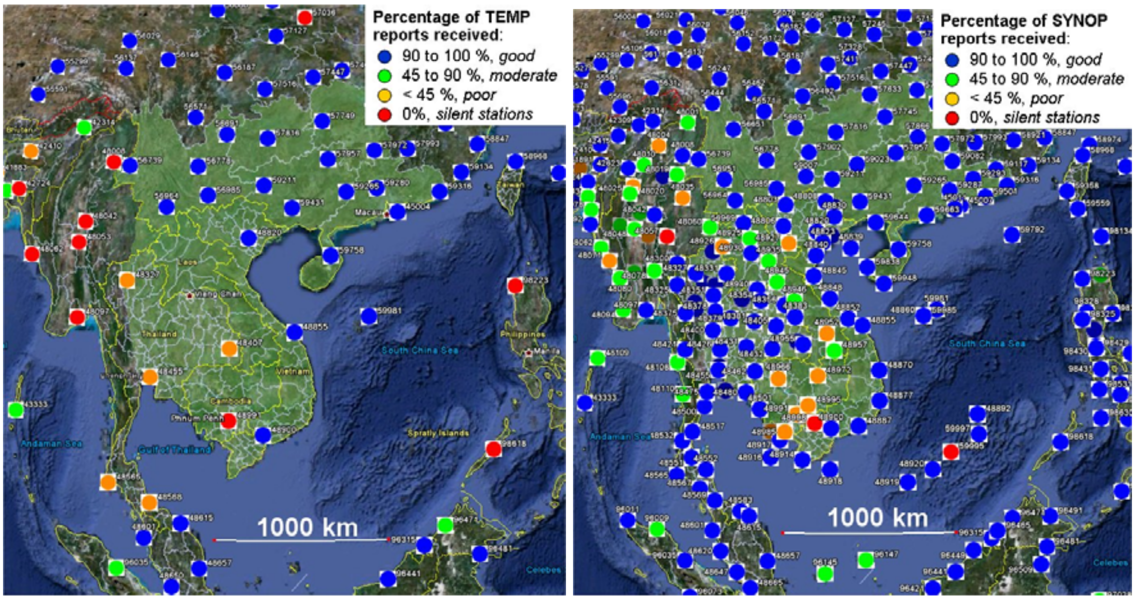

Figure 2. a) Availability of 00 and 12 UTC radio sounding reports (Part A of TEMP) from the South-East Asia during the WMO Annual Global Monitoring 1-15 Oct. 2008 (left figure). ***b)*** *Availability of 00, 06, 12 and 18 UTC surface weather reports (SYNOP) during the same monitoring period (right figure, WMO, 2009).*

The availability of surface weather reports from the key synoptic weather stations in the MRB and the surrounding countries can be seen in Figure 1b. Although regional campaigns like HYCOS-Mekong and national updates have resulted in important network developments (Solangkuon, 2008; Saravuth et al., 2008), the availability of weather reports from Cambodia, Lao PDR and Myanmar still appear to be poor or moderate. This indicates problems either at the observation sites or in data communication to GTS. It is important to acknowledge that within the MRB, this surface data is important for operational hydrological monitoring and forecasting. Moreover, this data as well as radiosounding data are used by both global and regional forecasting and monitoring centres to produce products that are used daily by the national hydrometeorological services of the MRB. The findings of the WMO thus indicate that the observations, if performed, cannot be fully utilized by international data users like global forecasting centres. This in-turn has a direct effect on regional weather forecast quality and an indirect effect on flood forecast quality for the MRB.

Lightning data in the estimation of convective rainfall

Numerous studies have looked at the relationship between lightning and rainfall on the storm-scale (Table 1, Kempf and Krider, 2003; this reference has similar comparison table for ground based precipitation gauges). These studies used both satellite-based radar reflectivity/rain gauges for rainfall estimation, and ground-based/satellite-based lightning detection networks for lightning detection. Table 1 shows that mean rain volume per CG flash is quite variable on shorter time and space scales, such as the storm-scale. However, the variability is greatly reduced when only examining isolated continental thunderstorms (Table 1) or oceanic storms (Pessi and Businger, 2009, not shown). Both rain gauge and radar reflectivity studies show values within a factor of 3-4 for isolated continental thunderstorms (Table 1).

Pessi and Businger (2009) compared convective rainfall rates obtained from the Precipitation Radar (PR) on the Tropical Rainfall Measuring Mission (TRMM) satellite with CG lightning flash rates obtained from Vaisala’s Long Range Lightning Detection Network (LLDN) and total (cloud plus CG) lightning flash rates obtained from TRMM’s Lightning Imaging Sensor (LIS). They found correlation coefficients of 0.96 and 0.92 when comparing hourly convective rainfall rates and lightning rates for central North Pacific summer and winter thunderstorms, respectively. Kuligowski and Scofield (2004) have shown that incorporating Vaisala National Lightning Detection Network (NLDN) CG lightning data into the Self-Calibrating Multivariate Precipitation Retrieval (SCaMPR) algorithm improved convective rainfall estimates. SCaMPR automatically calibrates precipitation estimates from GOES IR-based predictors to microwave rain rates from the Special Sensor Microwave/Imager (SSM/I) and Advanced Microwave Sounding Unit (AMSU) satellites.

Table 1. Mean rain volume per CG flash on the storm-scale for studies using radar reflectivity for rainfall estimation (Table 1b in Kempf and Krider, 2003).

Study using radar	Location	Mean rain volume per CG flash (m^3 per flash)	Comments
Isolated thunderstorms			
Buechler et al. (1990)	Southeastern U.S.	$3.8 * 10^4$	21 isolated storms
Tapia et al. (1998)	Florida, USA	$4.3 * 10^4$	22 isolated storms
Soula et al. (1998)	Spain	$3.1 * 10^4$	1 storm causing a flash flood
Soula and Chauzy (2001)	France	$7.2 * 10^4$	4 isolated storms
Seity et al. (2001)	France	$6.8 * 10^4$	21 isolated storms over land
MCSs and large storm systems			
Williams et al. (1992)	Darwin, Australia	$5 * 10^5$ $5 * 10^6$	Continental regime Monsoon regime
Holle et al. (1994)	Central U.S.	$7.7 * 10^5$	MCS

Possibilities of weather radar networks

The quality and usefulness of radar data is often compared to gauge data and satellite techniques; the present consensus is that they are not competitive but complementary approaches. Key application areas of weather radar systems in operational hydrology include early warning systems such as storm hazard assessment with flood forecasting, warning, and control (Cluckie and Collier, 1991). Even though aloft radar measurements do not always represent rainfall intensity at the surface, the outstanding spatial resolution makes radar data attractive.

Radar data is well suited to real-time flood forecasting applications, but they have also been used for assessing water resources and providing a basis for engineering design. This is very true in areas where rain gauge network is sparse (Meischner, 2004). In addition to QPE one of the most important applications of the weather radar is nowcasting so called quantitative precipitation forecast (QPF) up to 6 hours. Contrary to typical NWP models, which typically take about 6 hours before they show reasonably good forecast skill, nowcasting techniques typically provide the best forecast skill within the first 30-60 minutes with decreasing skill out to six hours. These extrapolation techniques are especially important for flash flood forecasting, and guidance (Collier, 2000; Collier and Krzysztofowicz, 2000).

Attenuation using shorter wave lengths has been traditionally considered as a serious limitation for C-band weather radars in climates of intense rain. With the modern operational dual polarization weather radar this traditional problem can be avoided. Dual polarization C-band weather radar provides precipitation fields at high spatial resolution (Bringi and Chandrasekhar, 2001). With the transition of dual polarization techniques from laboratory into production weather radar systems, such as the Vaisala WRM200, many weather services that traditionally used S-band systems are now reconsidering to use polarization C-band systems instead. The cost issue is often the primary motivation. Optimal siting forms the basis for ideal, cost-effective C-band radar network configuration. An installed C-band system is 1/2 to 1/3 the price of an S-band system having comparable antenna gain and transmitter power. Therefore, over complex terrain where mountains create blockages for the radar measurements, good radar coverage of flash flood prone sub-basins can be much better guaranteed by locating two or three C-band dual polarization weather radars instead of just one S-band radar. Dual polarization C Band weather radars, equipped with advanced signal processing techniques, offer new methods to mitigate attenuation, which has previously been seen as a major limitation for broader use of short wave lengths technology in climates of intense precipitation (Keränen et al., 2008).

NWP models are moving towards a super-fine resolution of a couple of kilometres. From this perspective radar data assimilation has exciting potential for improving forecasts in high resolution (Salonen et al., 2008). Therefore, new mesoscale NWP models need high resolution wind and moisture observations for initialisation, which radar networks are well placed to deliver (Meischner, 2004). Wind is one of the primary prognostic variables in NWP models. Assimilation of weather radar based radial wind observations has also shown clear improvements in mesoscale precipitation forecast skill. This can partly be attributed to better descriptions of air flow related to atmospheric convection.

DISCUSSION AND CONLUSIONS

Keeping the entire hydrological cycle in mind, we suggest that longer lead times and improved input accuracy for flood forecasting can be reached by increasing observations of atmospheric water - i.e. measuring water before it precipitates on a river basin. As tropical storms and typhoons arriving from the South China Sea cause the most severe flooding situations in the MRB, enhanced observations, tracking and modelling of these storms is recommended for accurate medium-term flood forecasts.

In conclusion, we propose the following actions to target the observational weaknesses of the Mekong River Basin EWS (Figure 3).

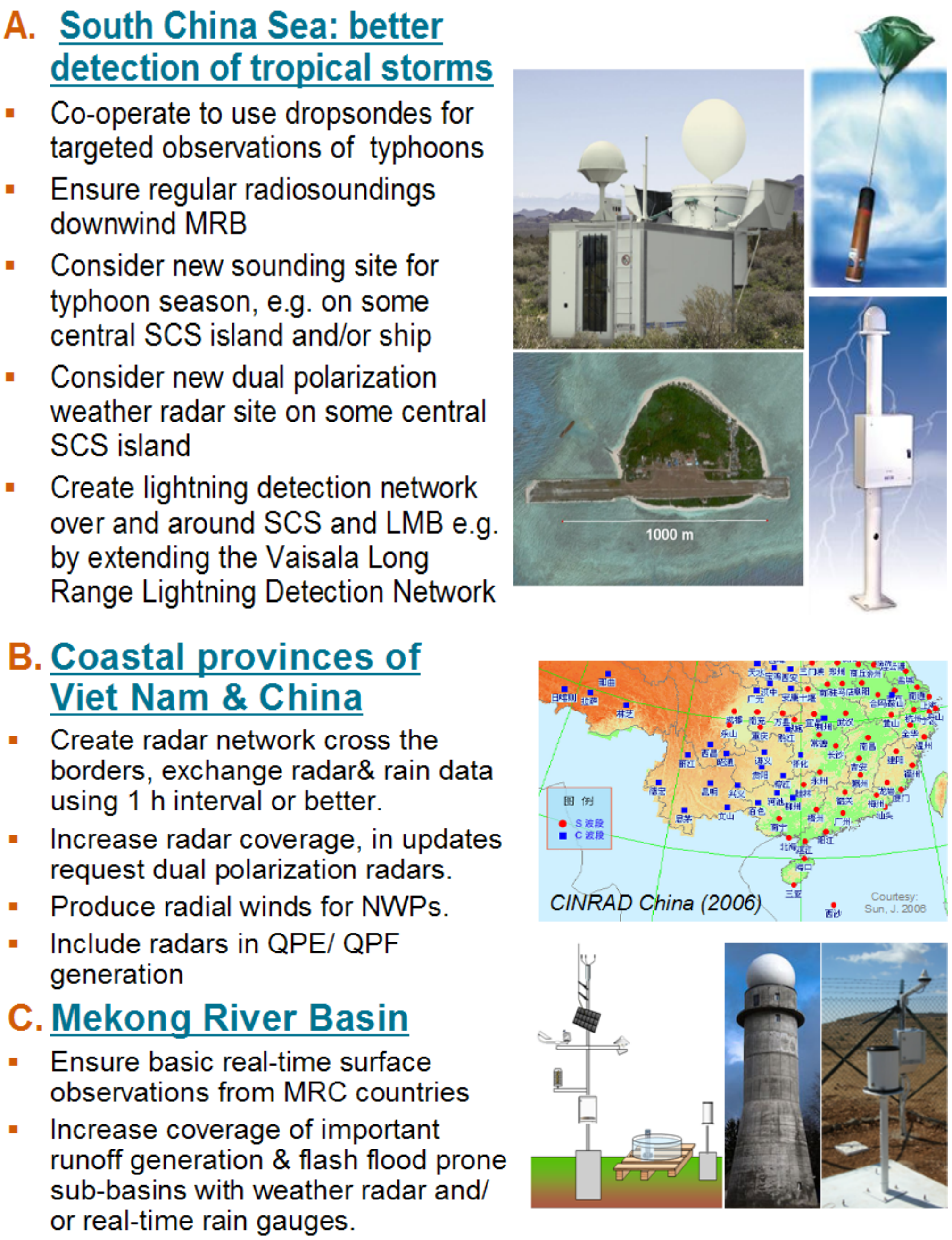

Figure 3. Key action points in targeting the observational weaknesses of the Mekong River Basin EWS.

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