A simple physically-based model for predicting sand transport dynamics in the Lower Mekong River

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Content of the presentation

- Introduction: sand transport in large rivers
- Context of the study: the Lower Mekong River
- Field measurements
- Presentation of the model for sand transport
- Results for different study sites
- Conclusion and perspectives

Introduction: sand transport

- Important issue for large rivers
  - Sand dynamics sensitive to the flow dynamics (easily trapped by dam reservoirs, river bed evolution)
  - Available stock (sand mining, sediment supply, fauna and flora habitats)
- Lack of data
  - Mainly transported in suspension during flood events (dangerous)
  - Significant spatial variability (sampling is time-consuming)
  - Assimilated to wash load (depth integrated-sampling)

→ Need of additional data

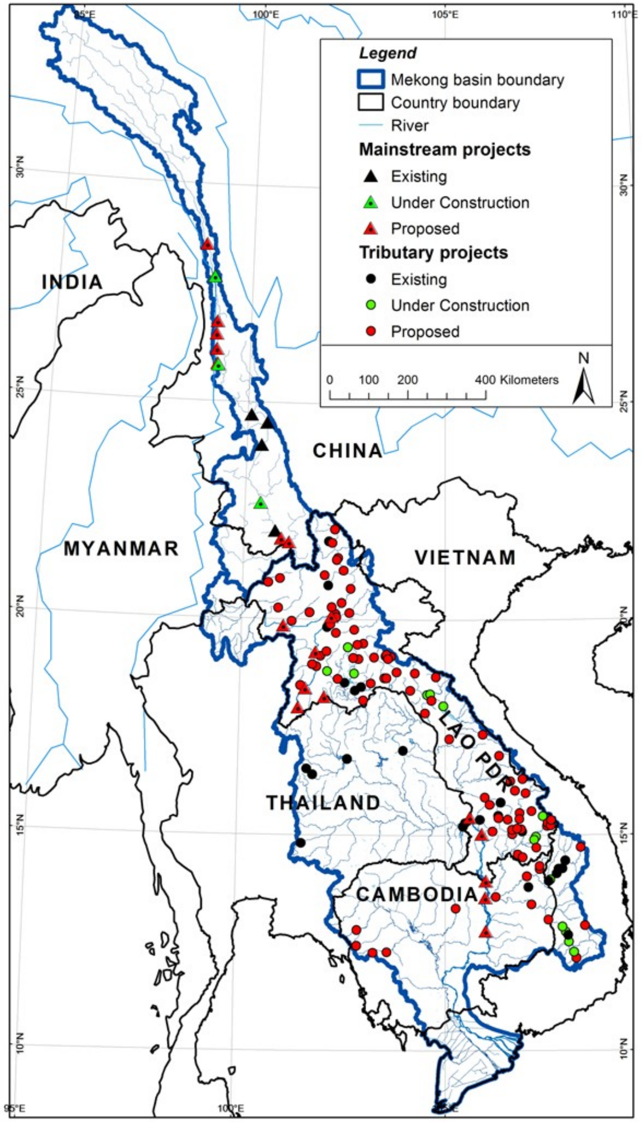
→ Need of models to extrapolate data

Context of the study: the Lower Mekong River

- Many specific issues
  - Hydropower plant projects
  - Sand mining
  - Fishing habitats

→ Sediment issues since the 1990s

- SSM data sources (since the 60's):
  - « Water quality monitoring program »: surface sampling (monthly)
  - « Sediment-sampling program »: depth-integrated sampling
- Problems
  - Quality of the data is not always perfect (methodology, frequency)
  - Incomplete or biased measurements of the sandy fraction



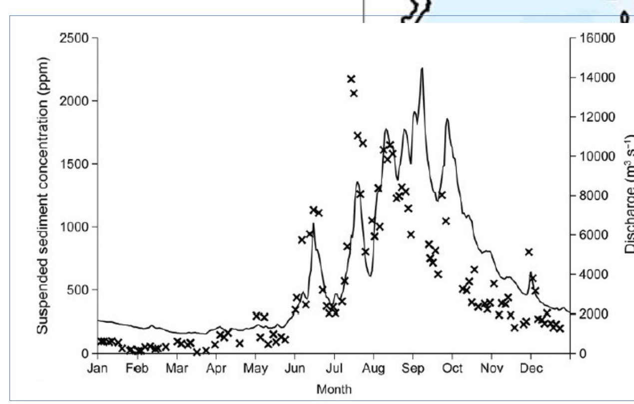
Source : data MRC, University of Canterbury

Hydrology of the Lower Mekong River

Station	Mean discharge (m^3/s)	% total	SSM fluxes (Mt/yr)	% total
Gaiju (China)	1200	9%	45	25%
Chiang Sien	2700	20%	90	55%
Luang Prabang	3900	28%	100	60%
Vientiane	4500	31%	90	60%
Mukdahan	7800	57%	120	70%
Pakse	9900	67%	150	90%
Kratie	13600	91%	90 (?)	90%

Upper Mekong River:

- ≈50% of the sediment input
- ≈20% of the water input



Discharges and Suspended Sediment Concentrations at Luang Prabang (1961)

Source : MRC
Walling (2008)

Field survey

- October 2012 with WWF, MRC : Survey in Kratie (Cambodia), Khong Chiam (Thailand) and Luang Prabang (Laos)
- August 2013 with CNR (consulting for the Laos Government) Survey in Luang Prabang and Xayaburry (Laos)

Purpose of the survey : a better estimation of the sediment transport during the monsoon season

- Sampling bedload and suspended sediment (washload + sand)
- Particle size of bed load and suspended sediment
- Spatialization of moving bed and sandy suspension using acoustic measurements (ADCP)
- Flows (flow measurement, velocity distribution)

Objective of the study : a better estimation of the sand transport

- Measurements of the sand transport
  - Bed characteristics (grain size, bedforms)
  - Bedload
  - Suspended load
  - *Use of acoustic methods in complement to classic sampling methods*
- Estimation of total sand fluxes
  - Introduction of a simple physically-based and robust model
  - Extrapolation to different discharges
  - Calculation of yearly sand flux and log term sand budget
  - *Assumption of an equilibrium with local hydraulic parameters; Validity of the model ?*

Sampling and measurement methods

ADCP-GPS coupling

Van Dorn (Niskin) water sampler

Multi-frequency hydro-acoustics : Aquascat

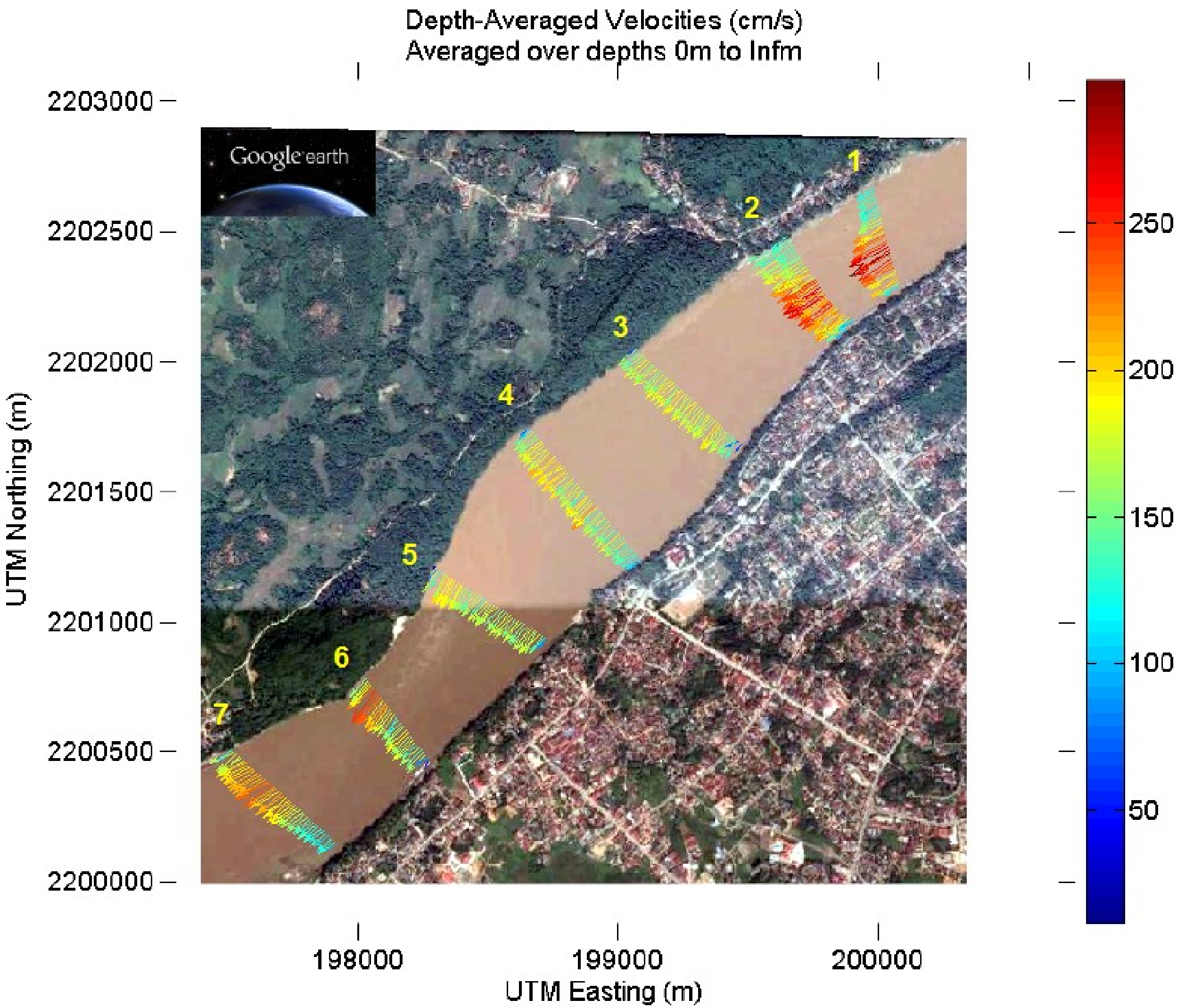
Suspended sand sampler : Delft bottle

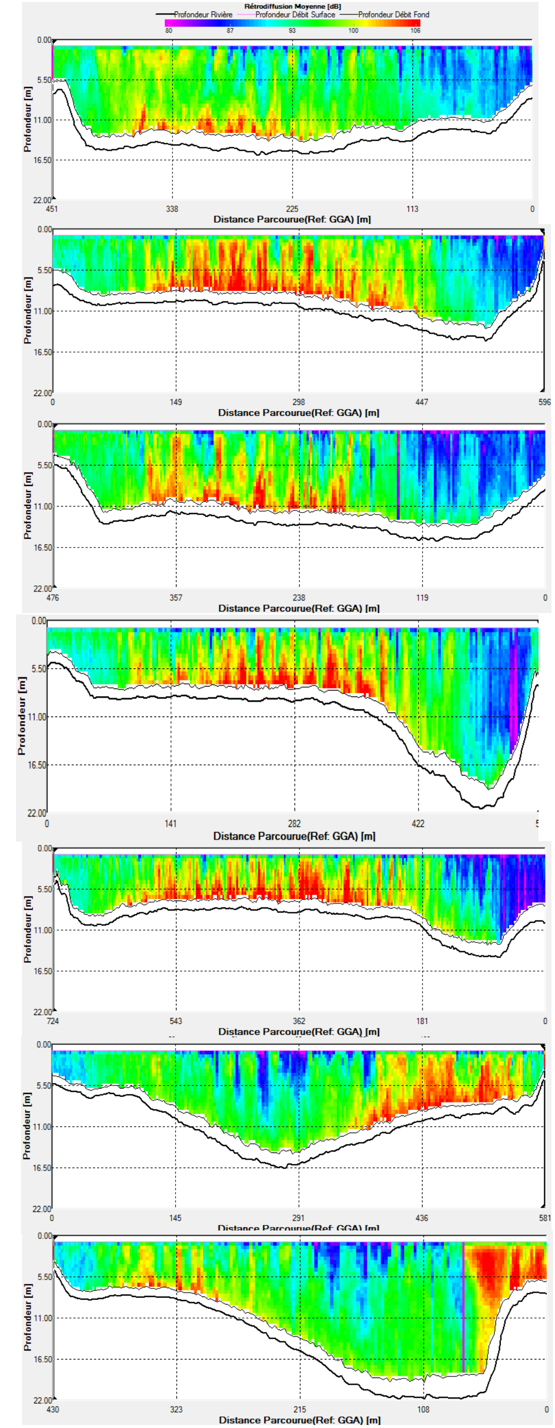
Bedload sampler : Helley-Smith

Sampling and measurement methods

- Multiple procedure for the fluxes estimation
  - Water discharge gaugings with ADCPs
  - Transect with Van Dorn (Niskin) sampling and simultaneous ADCP measurement
  - Helley smith sampling repetition on several verticals
  - Aquascat data acquisition at different depth (only 2012)
  - Delft bottle sampling repetition on several verticals (only 2013)
  - Estimation of the graded sand suspension concentration using the corrected backscatter intensity of the ADCP signal (concentration for washload assumed to be homogeneous throughout the section)
  - Dune tracking testing with ADCP and Depth sounder

Results in Luang Prabang : ADCP measurements

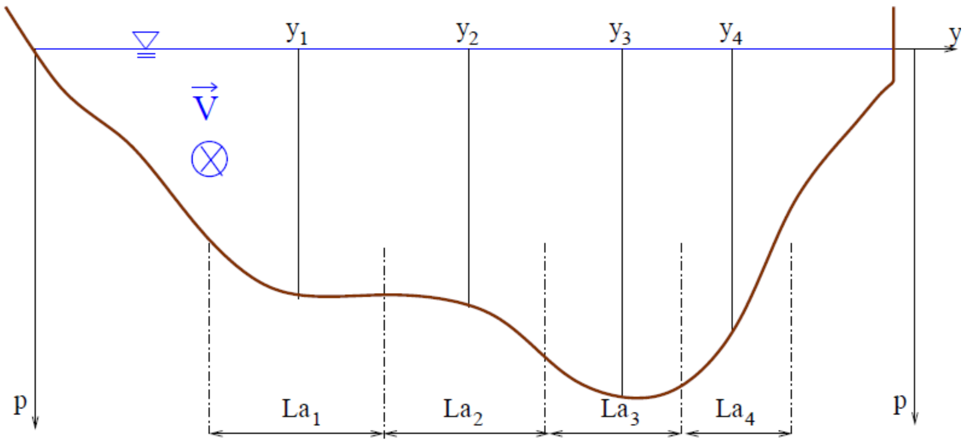




Field measurements: Methodology

- Washload
  - Concentration supposed homogeneous throughout the river section

$$Q_{s,\,fine} = C_{fine}\, Q$$



- Sand transport
  - Variability of the sand transport throughout the river section
  - Graded suspended load

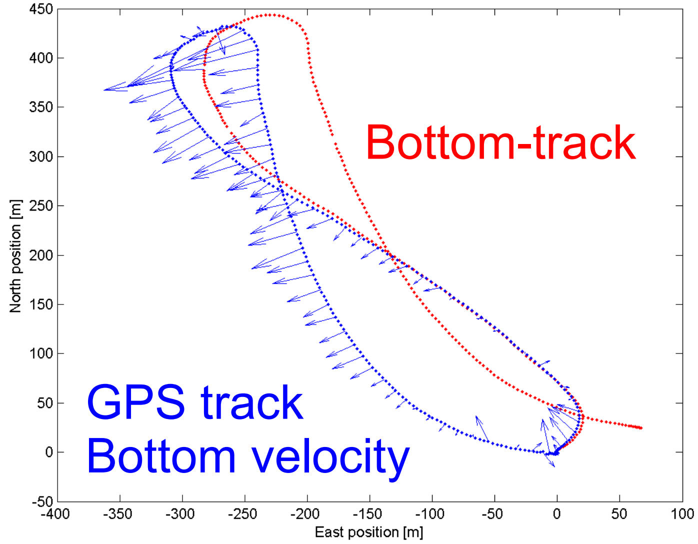
$$Q_{sb,\,sand} = \sum_{i=1}^{n} q_{sbi,\,\exp} L_{ai}$$

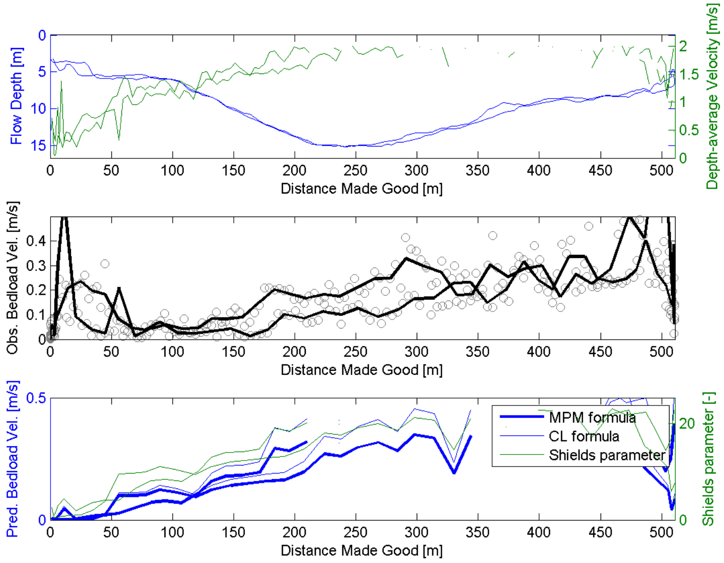
$$Q_{ss,\,sand} = \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij,\,\exp}\, u_{ij}\, \Delta z_i\, L_{ai}$$

Need to define the active width L_a

Field measurements: Bedload

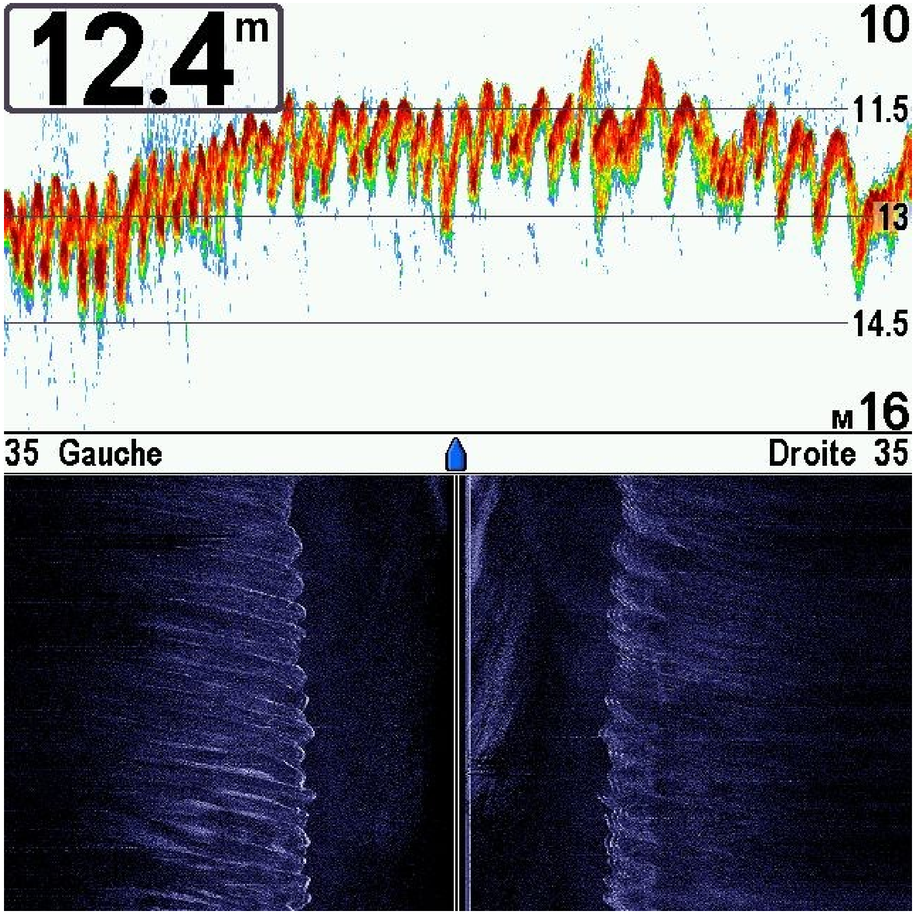
- Sampling using a Helley-Smith sampler
  - *specific focus on the stability of the sampler on the bed (no possibility to anchor, minimizing dredging, repeatability)*
- Estimation of the active width thanks to ADCP bottom tracking





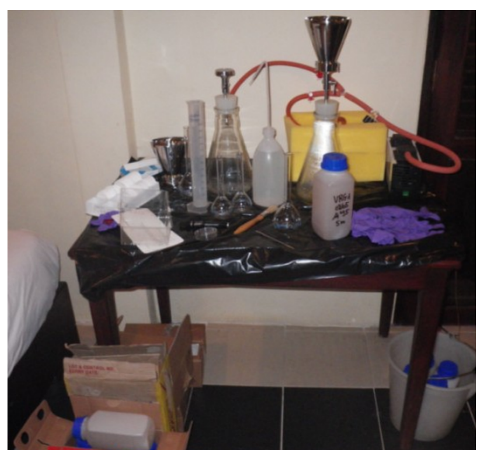
Field measurements: Dune tracking

- Observation of the dune characteristics
- Positioning of the tracks too uncertain to test the dune tracking method

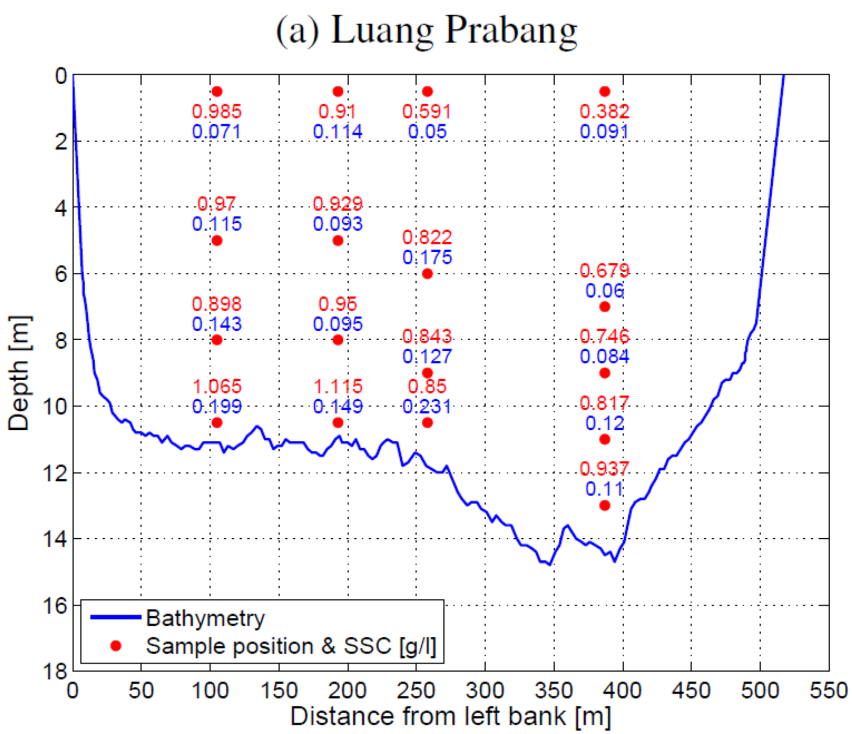


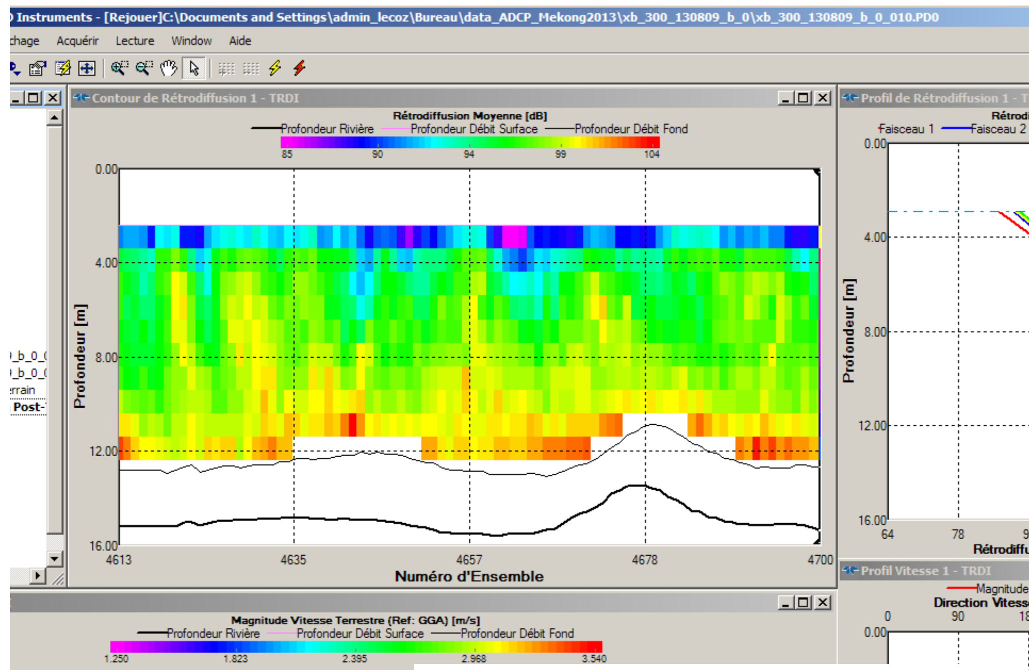
Field measurements: Suspended load

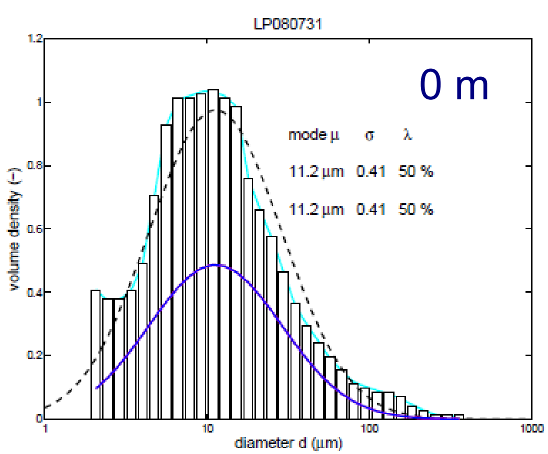
- Sampling using a Niskin-type sampler
  - Estimation of the total concentration
- Sampling using a Deflt bottle
  - Direct estimation of the sand flux
- Laboratory measurements
  - Estimation of the concentration and grain size characteristics thanks to a LISST
  - Estimation of the sand flux using ADCP measurements

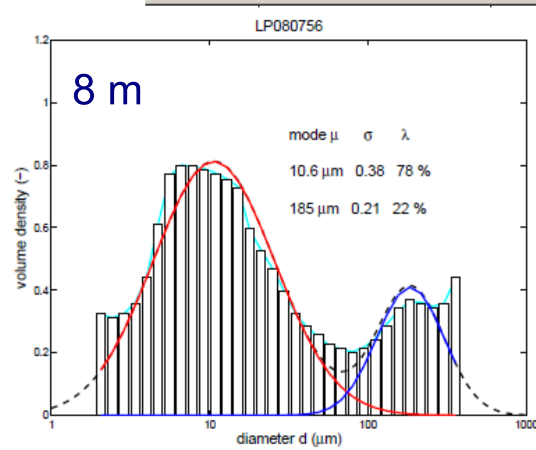


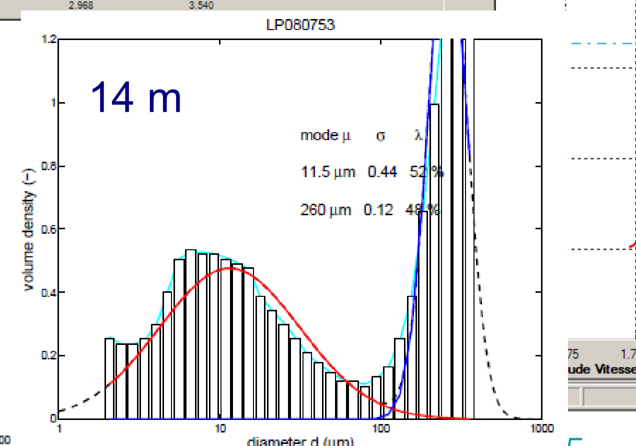
Graded sand concentration











Presentation of the model : hydraulics

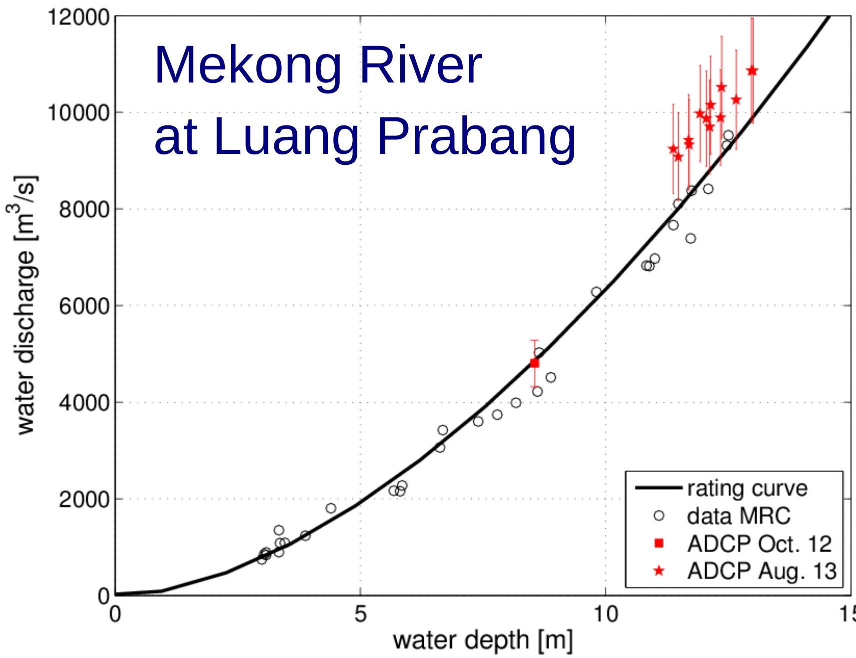
- Hydraulic parameters computed based on a stage-discharge relationship

$$Q_H = a_Q (H - H_0)^{b_Q}$$

a_Q : fitting coefficient

$b_Q \approx 5/3$ (Manning-Strickler)

H_0 : reference water depth



$$V_H = \frac{Q_H}{A_H}$$

A_H : wetted area

Shields parameter based on the log. friction law

$$\theta_H = \left(\frac{\kappa}{1 + \ln[k_s/(30 R_{hH})]} \right)^2 \frac{V_H^2}{(s-1) g d}$$

$R_{hH} = A_H / P_H$: hydraulic radius

k_s : roughness height

d : sand particle diameter

Presentation of the model : sand transport

- Bedload transport (Camenen & Larson, 2005)

$$q_{sb}=12\sqrt{(s-1)g\,d^3}\,\theta_H^{3/2}\exp\left(-4{,}5\frac{\theta_{cr}}{\theta_H}\right)$$

θ_{cr} : critical Shields parameter

- Suspended load transport (Camenen & Larson, 2008)

$$q_{sb}=V_H C_R \frac{\epsilon_v}{W_s}\left[1-\exp\left(-\frac{W_s}{\epsilon_v}R_h\right)\right]$$

Exponential vertical concentration profile

$$\epsilon_v=\frac{\sigma}{6}\kappa\, u_{*H} R_h$$

$u_{*H}=\sqrt{\tau_{Ht}/\rho}$: shear velocity

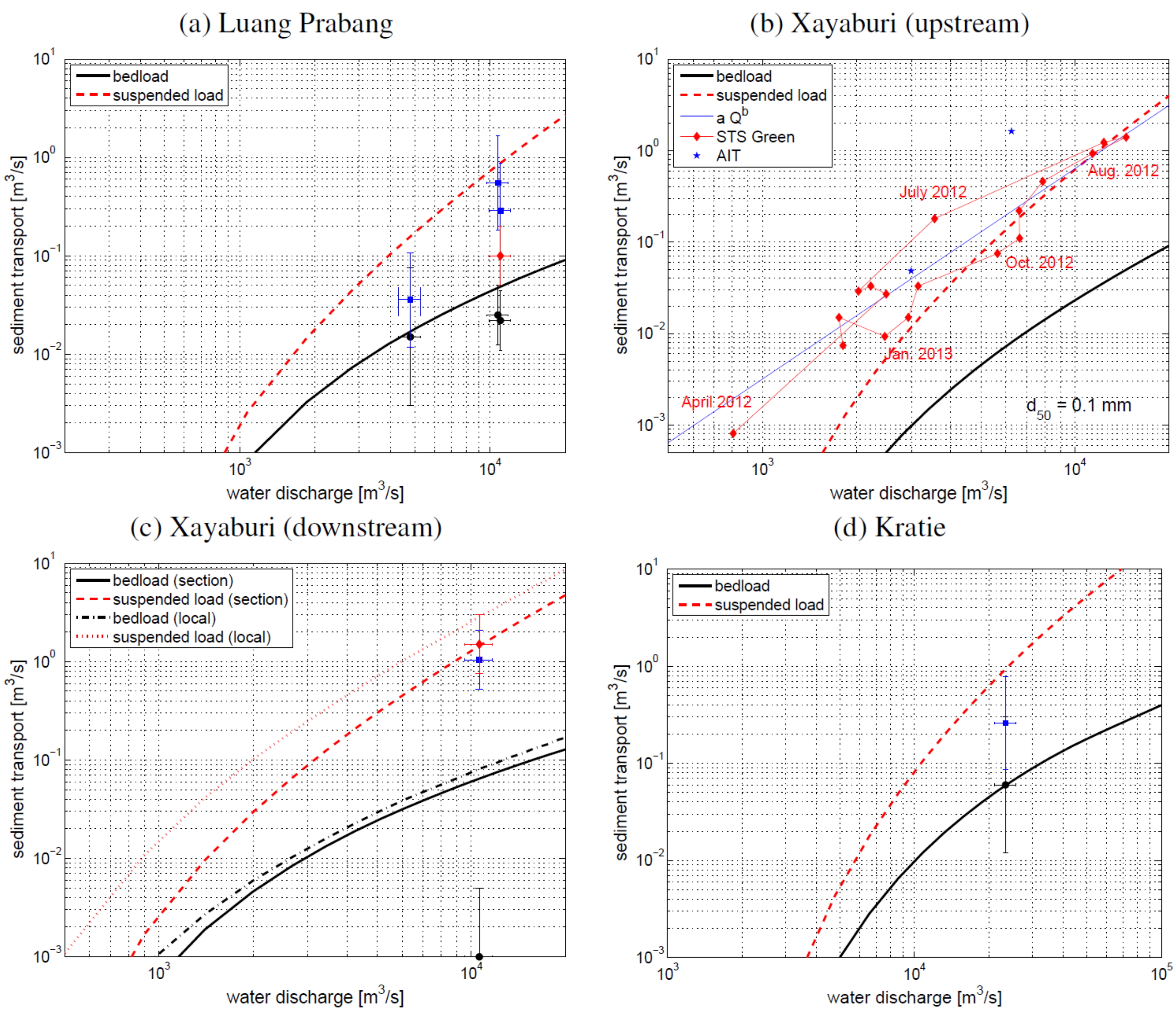
τ_{Ht} : bed shear stress including form roughness

$\sigma=1$: Schmidt number

$$C_R=1.5\times 10^{-3}\exp(-0.2\,d_*)\,\theta_H\exp\left(-4{,}5\frac{\theta_{cr}}{\theta_H}\right)$$

$$d_*=\sqrt[3]{g(s-1)/\nu^2}\,d$$

Results for 4 study sites



Conclusions on the sand transport in the Lower Mekong River

- Suspended load is prevailing to bedload transport
- Sand transport is not negligible compared to washload
- A significant hysteresis was observed at Xayabury partly due to the bed evolution during the flood
- Relatively good prediction of the model (without calibration) indicates there is an equilibrium between local hydraulics and bed sediment availability (except for the Khong Chiam station)
- What about the impact of actual and future dams, which should lead to some deficit ?

Station	Mean discharge (m^3/s)	% total	SSM fluxes (Mt/yr)	% total	Sand flux (Mt/yr)	% total
Luang Prabang	3900	28%	100	60%	16	≈ 15%
Xayaburi	4000	29%	-	-	15/28	≈ 20%
Kratie	13600	91%	90 (?)	90%	47	≈ 30% ?

Conclusions and perspectives

- Quite large uncertainties in the measurements: need of additional data (but difficult and expensive to acquire)
- Presentation of a simple model to estimate sand transport as a function of the discharge
- Validation on 4 sites of the Lower Mekong River
- Model useful to estimate yearly averaged sediment transport and sediment budget if enough sediments available in the reach (Assumption of an equilibrium with local hydraulic parameters)
- Model sensitive to the roughness heights
  - Bedload and reference concentration: skin roughness height (grain size distribution)
  - Sediment diffusivity: total roughness (presence of dunes)
  - Section-averaged parameters lead to a reduction by a factor two of the total load
- Need of spatially distributed data (ADCP) for a more accurate validation

Extraction (sand mining) issue…

Aerial picture of the Mekong River during the low flow period next to Luang Prabang (source, Google Earth)

Thanks for your attention !