MEKONG RIVER INUNDATION SIMULATION USING K-SUPER COMPUTER

Research Center for Urban Safety and Security/Civil Engineering Dept.
Associate Professor, Ken KOBAYASHI

Advantage of home

Specification of the K super computer

82944 CPUs
663552 cores

Hardware	K supercomputer	
	Node	SPARC64VIIIx (2.0 GHz), 8 cores/CPU/node
		Theoretical performance: 16 GFlops/core
	Cache	L1 command: 32 KB/core
		L1 data: 32 KB/core
		L2 (shared): 6 MB
	Memory	Main storage capacity: 16 GB
		Theoretical memory bandwidth: 64 GB/s
	Interconnect	Communication mechanism: Tofu
		Communication topology: 6D mesh/torus
		Theoretical communication bandwidth: bidirectionally 5 GB/s
Software	OS: Exclusive use OS (Linux base)	
Compiler	Fujitsu C/C++ Compiler; K-1.2.0-14 version	

Literature survey

Researcher	Neal *et al*. (2010)	Leandro *et al*. (2014)	Bates *et al*. (2010)	Bates *et al*. (2000)	Yu *et al*. (2010)	This study
CPU	Quad core Intel Harpertown E5462 processor (2.8 GHz) at the University of Bristol	AMD Opteron™ Processor 6276 (2.3 GHz) at the RUHR University of Bochum	(Not parallel)	Pentium II PC (Not parallel)	20 computational nodes with 4 × 2 cores each (i.e. 160 processors; 1.6 GHz) at Loughborough University	CPU: SPARC64 VIIIfx (2.0 GHz) of the K supercomputer
Number of processors	100 cores are used	12 cores are used			64 cores are used	8-core 8192 CPUs are used
Target area	Urban area in Glasgow, UK	Benchmark example	Urban area in Glasgow, UK	35-km stretch of the River Meuse, NL	River Wharfe, and Ouse in the UK	Osaka area, Japan
Number of cells	200 × 384	900 × 900 (max case)	500 × 200	108464	1000000	12824442 (= 3453 × 3714)
Resolution	2 m resolution	178.8 m resolution	2 m resolution	25 m resolution	8 m resolution	10 m resolution
Simulation duration	Max 7200 s	1 h	120 min	Until no water depth variation	Max 300 h	5 h
Type of time step	Adaptive time step	Fixed time step	Adaptive time step	Fixed time step	Fixed time step	Fixed time step

Hydrological Research Letters **9**(4), 61–68 (2015)
Published online in J-STAGE (www.jstage.jst.go.jp/browse/hrl). DOI: 10.3178/hrl.9.61

Parallel computing for high-resolution/large-scale flood simulation using the K supercomputer

Kenichiro Kobayashi[1], Dai Kitamura[2], Kazuto Ando[2] and Noriyuki Ohi[3]
[1]*Research Center for Urban Safety and Security, Kobe University, Japan*
[2]*Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Japan*
[3]*Fujitsu Systems East Ltd., Japan*

Abstract:

This paper reports the implementation of high-performance computing using the K supercomputer in Kobe, Japan, for large-scale/high-resolution flood simulation. Supercomputer K was developed in 2012 by RIKEN and Fujitsu and ranked first in the list of Top 500 supercomputer sites in 2011 during its development stage. A two-dimensional inundation simulation model developed based on a shallow water equation using an existing numerical scheme was parallelized with the K supercomputer. Osaka and other cities along the Yodo River were chosen as application sites and the area discretized by 12824442 (= 3453 × 3714) nodes with a resolution of 10 m. The computational time for the five-hour flood simulation was measured by changing the number of 8-core CPUs of the K supercomputer. As a result, computational time was decreased to 9.3 min by using 128 × 64 = 8192 8-core CPUs. The computational time was 1423.7 min for one 8-core CPU. Thus, the simulation speed increased by a factor of 153.2 with the use of the K supercomputer.

KEYWORDS K supercomputer; large-scale/high-resolution; flood inundation simulation; Yodo River; MPI; OpenMP

INTRODUCTION

Parallelization is a method to enhance the computational speed of flood modelling. In fact, there are several approaches to shorten the CPU time required for flood modelling, such as changing the algorithm of the numerical model, enhancing the capability of the computer hardware, and/or parallel computing. A recent trend in computer hardware development aims at increasing the number of cores in a CPU rather than the clock frequency of a CPU. Therefore, at present, there are more advantages in the development of parallel computing methodology with respect to the reduction of computational time. This study is one such attempt, i.e. a parallel computing application on a particularly large-scale/high-resolution flood simulation using the K supercomputer in Kobe, Japan. The K supercomputer is a next-generation high-performance computer developed by the Institute of Physical and Chemical Research (RIKEN) and Fujitsu as a part of the High-Performance Computing Infrastructure (HPCI) Initiative led by the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT). The shared use of the K supercomputer began in November 2012. It was ranked first in a list of the Top 500 supercomputer sites in June and November 2011 during its development stage. Since then, the computer has been considered one of the fastest computers in Japan from the perspective of LINear algebra PACKage (LINPACK). The CPU is SPARC64 VIIIfx (2.0 GHz) with 8 cores. This computer has a total of 82944 CPUs and thus, 663552 (= 82944 × 8) cores.

This paper reports the application of the K supercomputer to flood inundation simulation of Osaka and other cities in its vicinity. The simulation area was approximately 34.5 km × 37.1 km, discretized at a resolution of 10 m, resulting in 12824442 (= 3453 × 3714) computational nodes. The distributed rainfall-runoff/flood-inundation simulation model (DRR/FI, Kobayashi *et al.*, 2011, 2012, 2014a, b; Kobayashi and Takara, 2012) in the C environment with a parallel computing capability was applied. The proposed parallelization method is basically universal, and can thus be applied to any standard parallel computer. However, script code was written in order to stage-in the K supercomputer, to run the model, and to stage-out with the simulation results. Moreover, hybrid parallelization was used, i.e. 8 cores in each CPU were used exclusively for thread parallelization with Open Multi-Processing (OpenMP), while the CPUs of the K supercomputer were used for process parallelization (domain decomposition) with a Message Passing Interface (MPI). This strategy for core utilization differs from the previous works outlined below. Hybrid parallelization is recommended in the use of the K supercomputer because of the memory use and data transfer reduction. In case the core is also used for process parallelization (domain decomposition), the number of processes by MPI in each CPU increases; thus approaching limitations of both the memory and data transfer. Instructions related to the hybrid parallelization are included in the script code.

Several previous studies have investigated the application of parallel computing to flood-inundation modelling. In general, some inundation models have attempted to solve the full two-dimensional (2D) shallow water equations (Hunter *et al.*, 2008), while others have used diffusive wave simplification by neglecting the inertial terms of the momentum equation (Leandro *et al.*, 2014; Yu, 2010) or applied the so-called storage cell model based on Manning's equation for the flux calculation between cells (Bates and De Roo, 2000).

Neal *et al.* (2010) presented the application of different (i.e. OpenMP, MPI, and accelerator card) parallelization techniques on the 2D inundation model LISMIN developed

Correspondence to: Kenichiro Kobayashi, Research Center for Urban Safety and Security, Kobe University, 1-1 Rokkodai-machi, Nada-ku, Kobe 657-8501, Japan. E-mail: kkobayashi@phoenix.kobe-u.ac.jp

Received 29 June, 2015
Accepted 2 October, 2015

for Osaka

We tried up to 8192 CPUs.

A Shallow water equation

$$\frac{\partial h}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = rain$$

$$\frac{\partial M}{\partial t} + \frac{\partial uM}{\partial x} + \frac{\partial vM}{\partial y} = -gh\frac{\partial H}{\partial x} - gn^2 u\frac{\sqrt{u^2+v^2}}{h^{1/3}}$$

$$\frac{\partial N}{\partial t} + \frac{\partial uN}{\partial x} + \frac{\partial vN}{\partial y} = -gh\frac{\partial H}{\partial y} - gn^2 v\frac{\sqrt{u^2+v^2}}{h^{1/3}}$$

Mekong River simulation

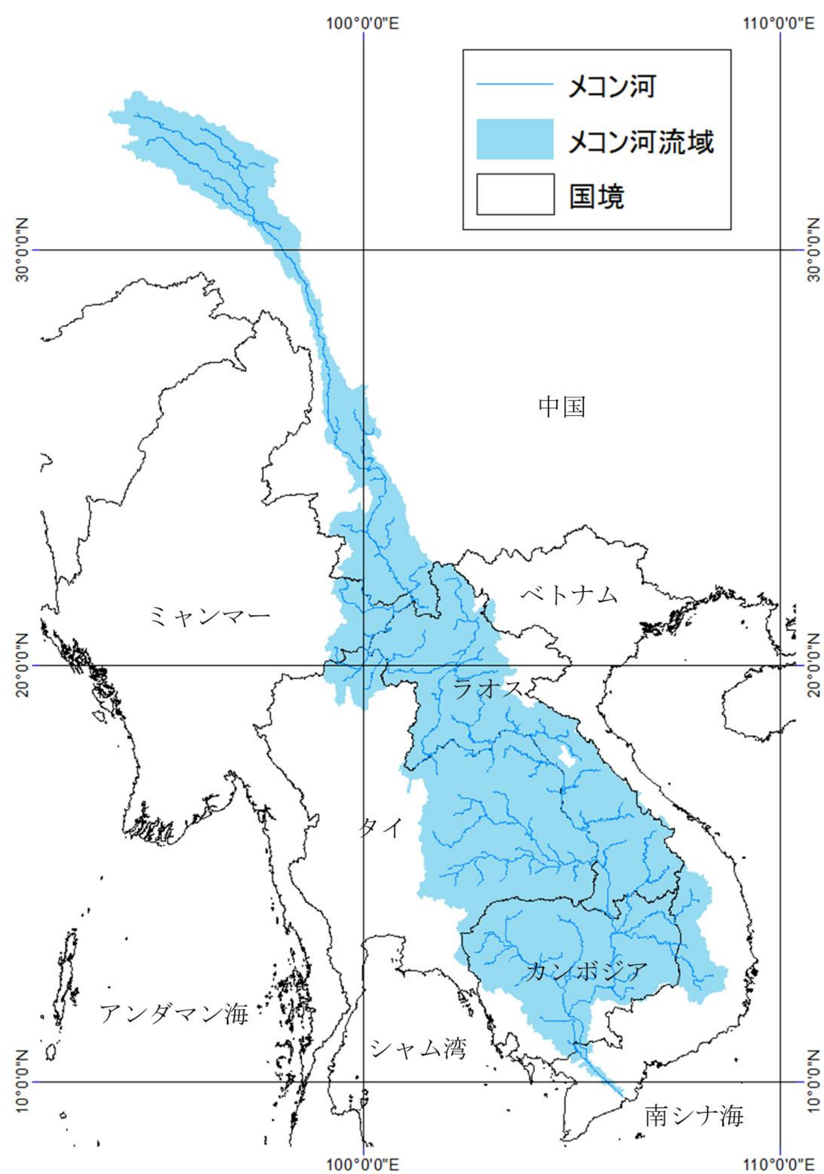
- ✓ Mekong River

  River length: 4,200km, Area:795,000km^2

  Largest river in South East Asia

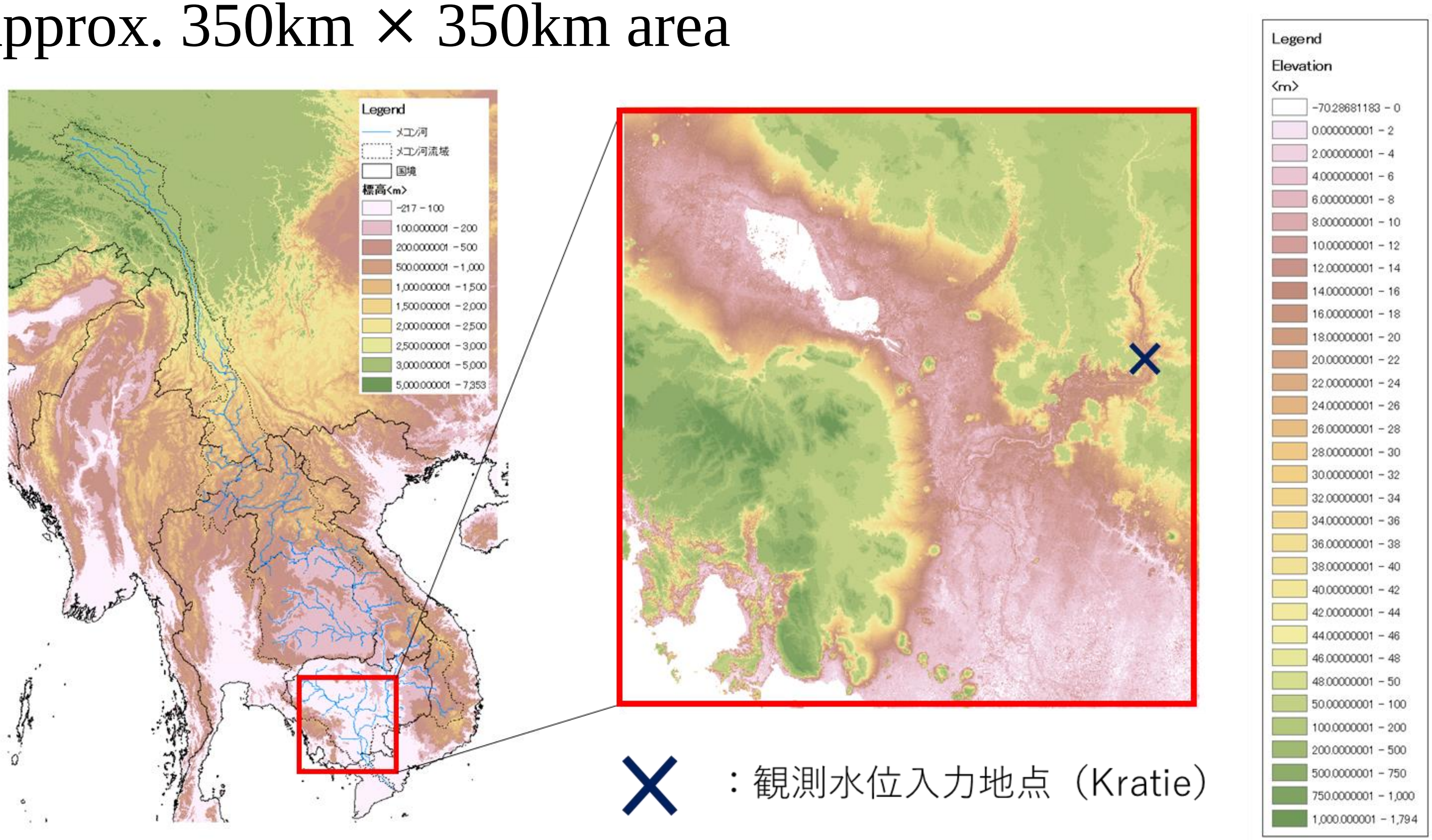
- ✓ Flooding occurs in rainy season: Huge damages in 2000 and 2011

Computational area	Cambodia, Vietnam, Mekong Delta
Cell size	200 m（Dem：JAXA ALOS World 3D - 30m）
Computational duration	UTC 2000/5/1～UTC 2000/10/31

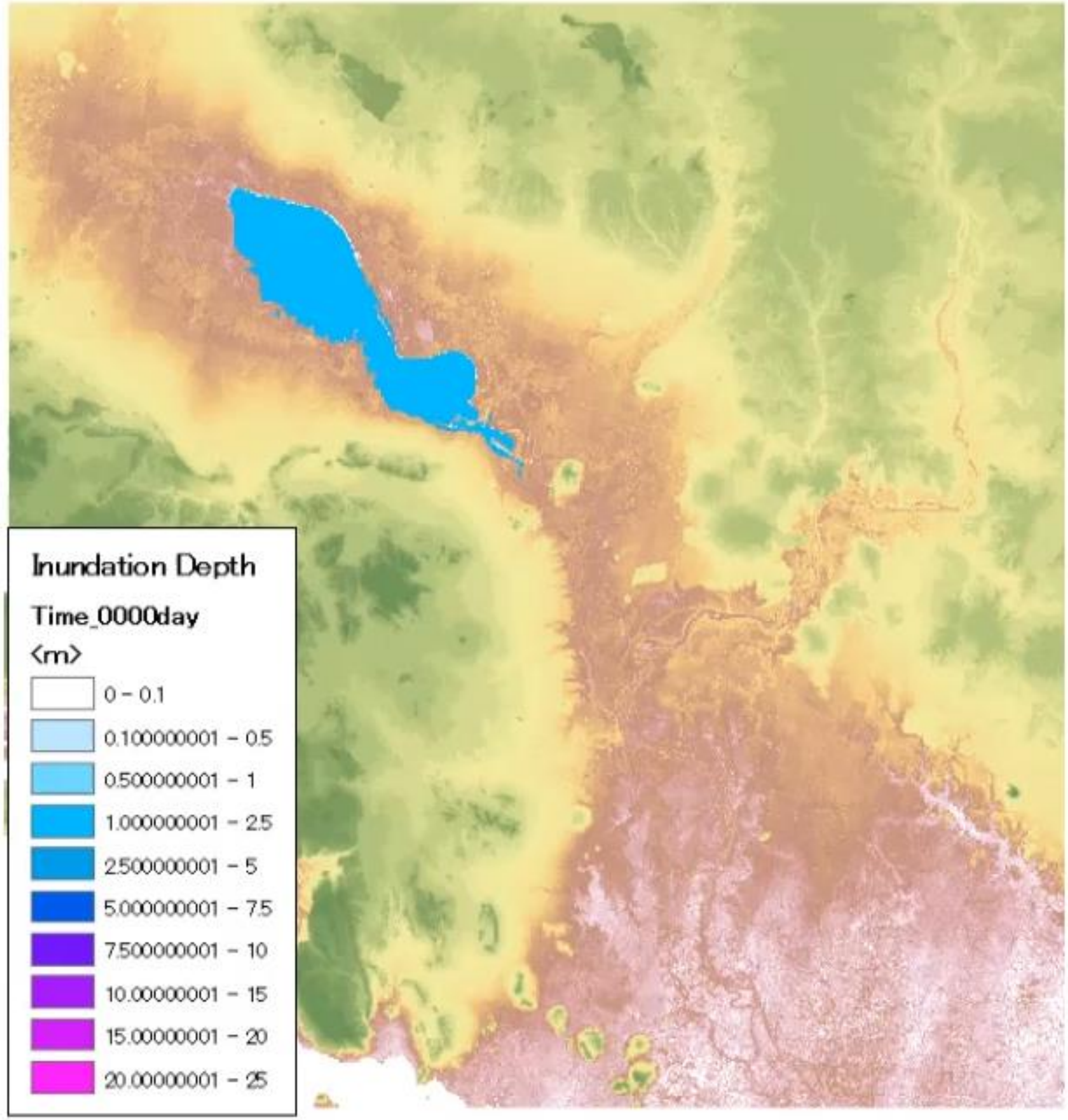


Mekong River simulation

Upper B.C. at Kratie (Observed water level)
Approx. 350km × 350km area



184 day simulation became possible within 24 hours by K supercomputer (1,891 × 1,900=3,592,900 node, 200m resol.)

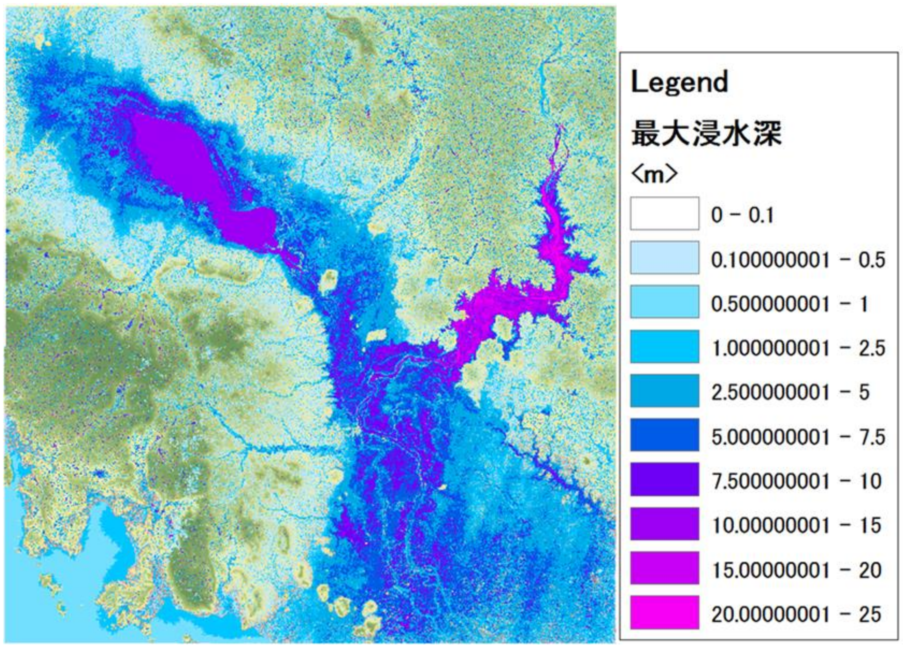


8 times larger than the Tonegawa river basin, the largest basin in Japan

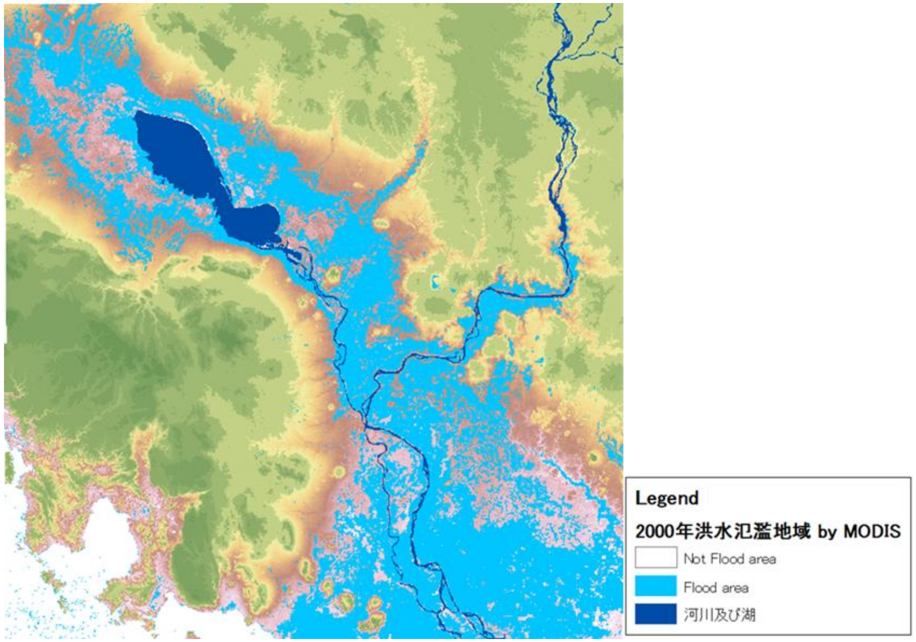
With 960CPU

Checked that the time step could be doubled though the accuracy was not checked.

Comparison with MODIS



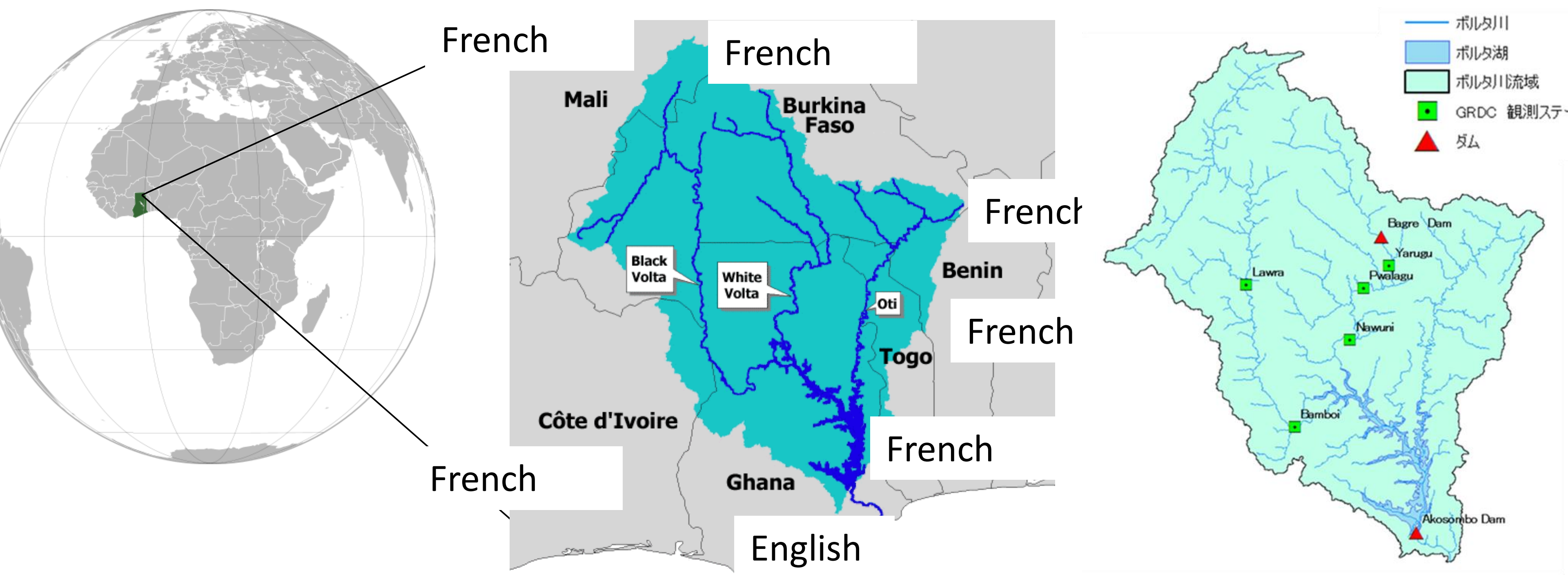
＜max. inundation depth＞



＜MODIS image＞

Volta river basin, West Africa

SATREPS 1st Phase (2012-2017): Main theme was agriculture and meteorology. It could not establish enough relationship with Water Authorities such as Water Resources Commission.



CECAR Ghana Project – Thank you very much for the opportunity

Issues needs to be solved

- We can obtain the hydrological data only within Ghana.
- Burkinafaso recently started to inform Ghana about the dam water release from Bagre dam but they do not tell Ghana how much it is.
- Language problem when developing the flood warning system (English or French?)
- The information from Burkinafaso is French.

Dam water release hypothesis

745 m^3/s as of 18 Aug. 2016 is released for 5 days.

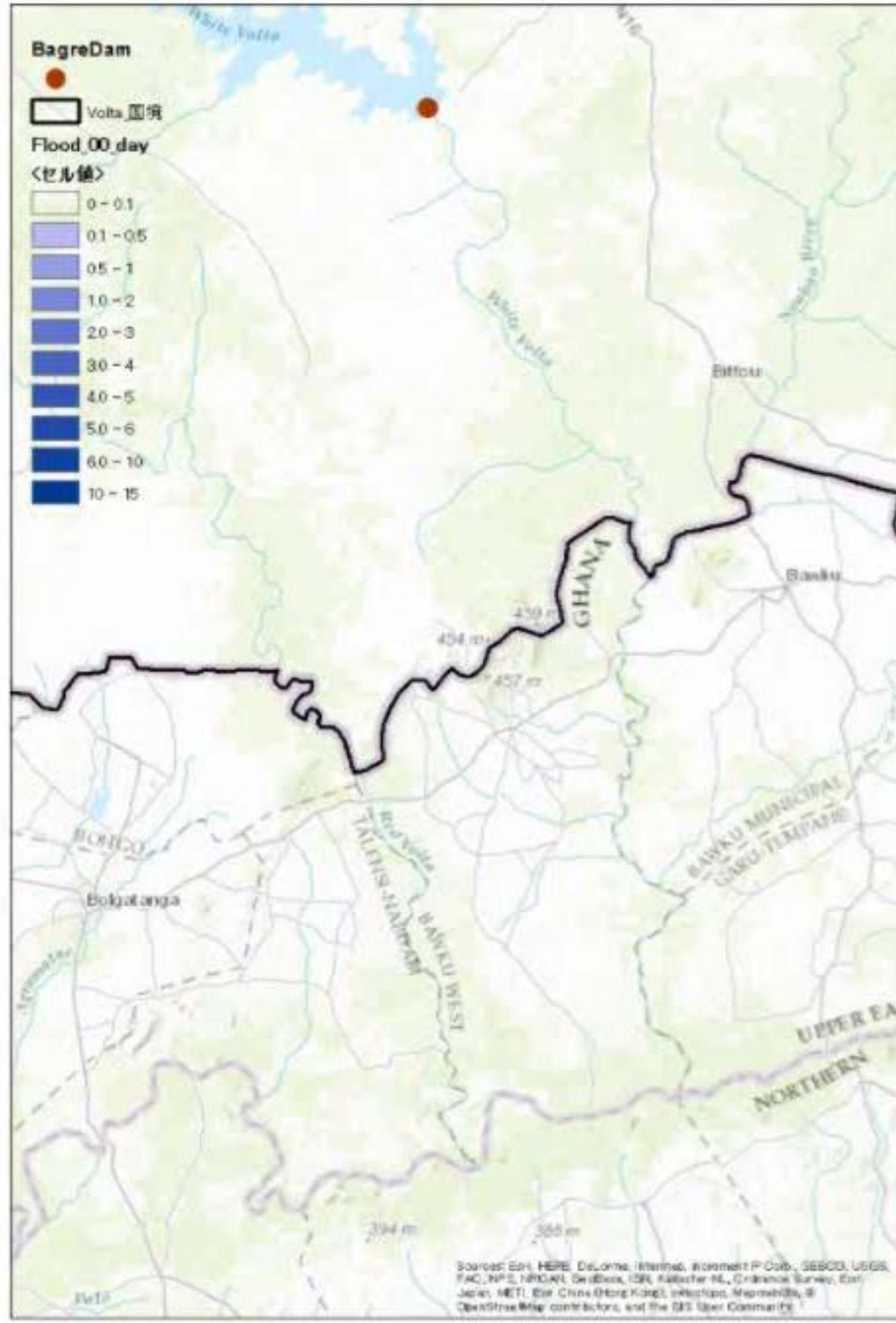
Mesh size: 2219 × 4439 (100m)

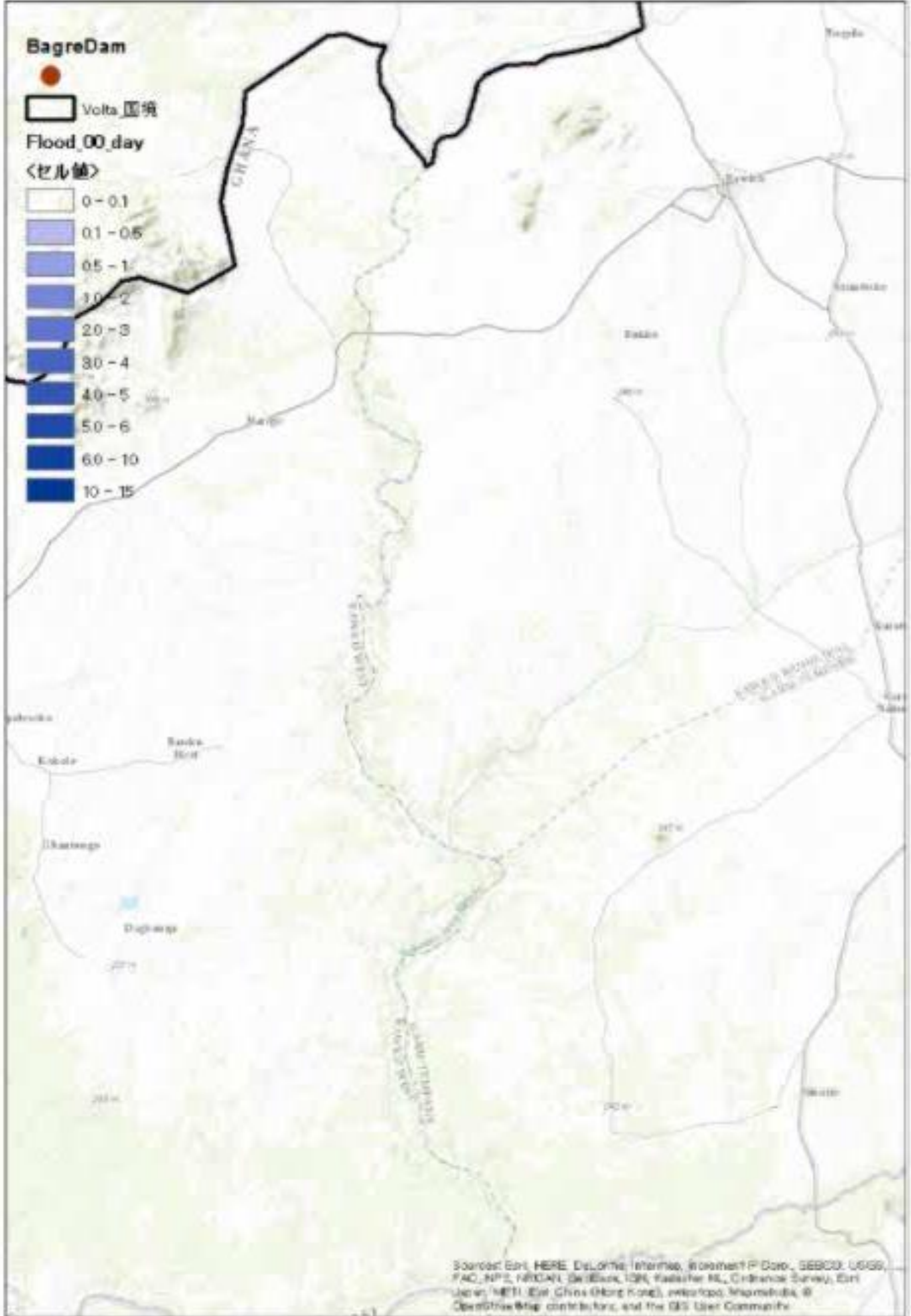
＝

221.9 km × 443.9 km

98501.41 km2

Approx. 5.8times larger than the Tone river basin



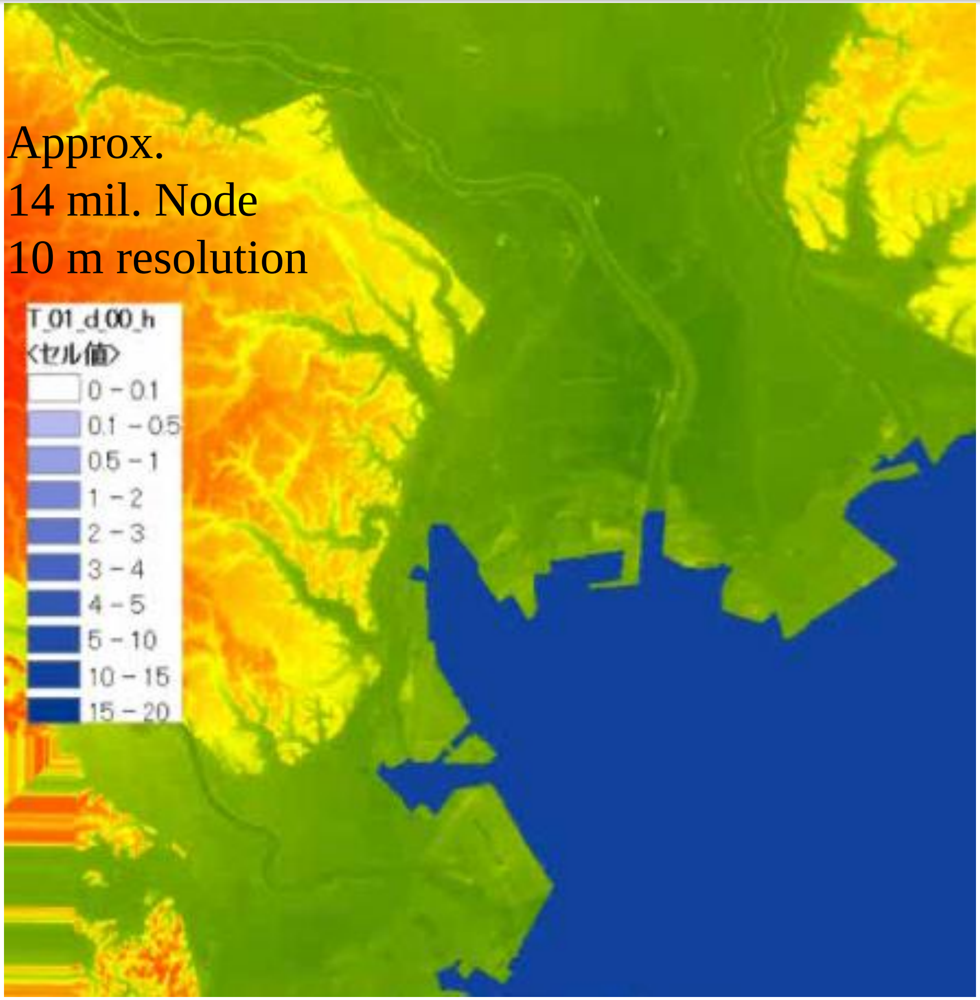

BagreDam
Volta_国境
Flood_00_day
<セル値>
0 - 0.1
0.1 - 0.5
0.5 - 1
1.0 - 2
2.0 - 3
3.0 - 4
4.0 - 5
5.0 - 6
6.0 - 10
10 - 15
GHANA
Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, Mapmyindia, © OpenStreetMap contributors, and the GIS User Community

With K supercomputer 960 CPUs (32×30 domain decompositions),
SPARC64VIIIx (2.0 GHz), 8 cores/CPU/node),
Approx. 6.3 hour（25 day simulation）

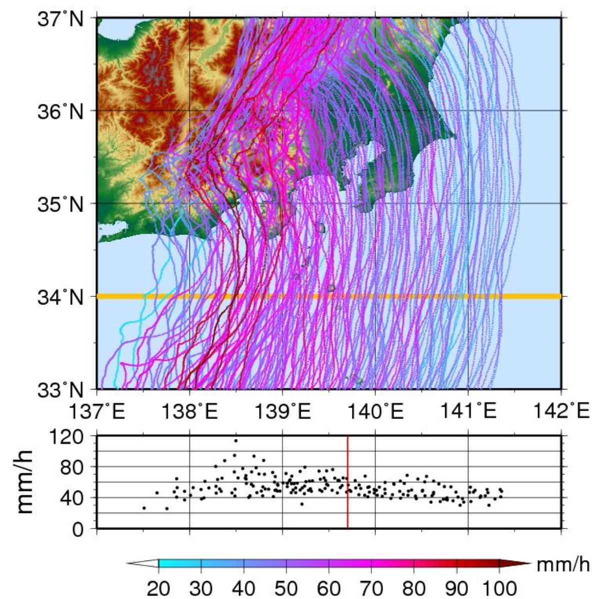
[Open MP only]
Lab. WS, 16core、Xeon CPU E5-2670 (2.6GHz)
probably approx. 46 hours (1 day simulation）?

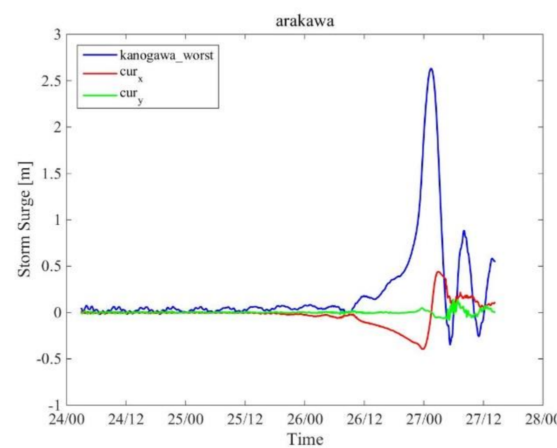
- The information of the dam water release came on Aug. 19.
- If the simulation finishes within Aug. 19, then the prediction becomes possible until Sep. 13 2016.
- It takes 3 days until the released water reaches to the border between Ghana and Burukinafaso.
- Supercomputer K was crowded so that we waited for one day.

A Combined disasters in Tokyo



Typhoon downscaling experiment
JMA GCM 2093 August Typhoon





Kanogawa Typhoon best track was moved by 50km eastward, the central pressure was lowered by 40 hPa. The initial depth was plus 83cm due to a climate change and plus 99 cm by high tide, thus totaly 1.82 m plus

Concluding remarks

- The flood inundation simulation becomes very fast using K super-computer.
- If we could show an upper limit of the simulation speed using the super computer, someone will realize it by much cheaper way as people knows the limit to break.
- Parallel efficiency is not good enough yet which needs to be improved.

Thank you very much
for your attention.