Making use of extreme events for scientific analysis

Kaoru Takara

Extreme events:

- are opportunities for knowing the unknowns,
- indicate the probable maximum capacity of the system, and
- can tell us better ways for disaster management.

Extreme events are not large noises; they are useful signals.

Why don't we make use of extreme events for scientific analysis?

Many extreme events

- Great Eastern Japan Earthquake and Tsunami in 2011 suggested the importance to consider possible largest events.
- So are other recent events:

  - Thai flood in 2011

  - Storm rain in the Kii Peninsula in 2011

  - Typhoon Storm Surge in the Philippines in 2013

  - Snow in Yamanashi in 2014

Catastrophic meteorological/hydrological extreme events in the 21st Century (Takara, 2013)

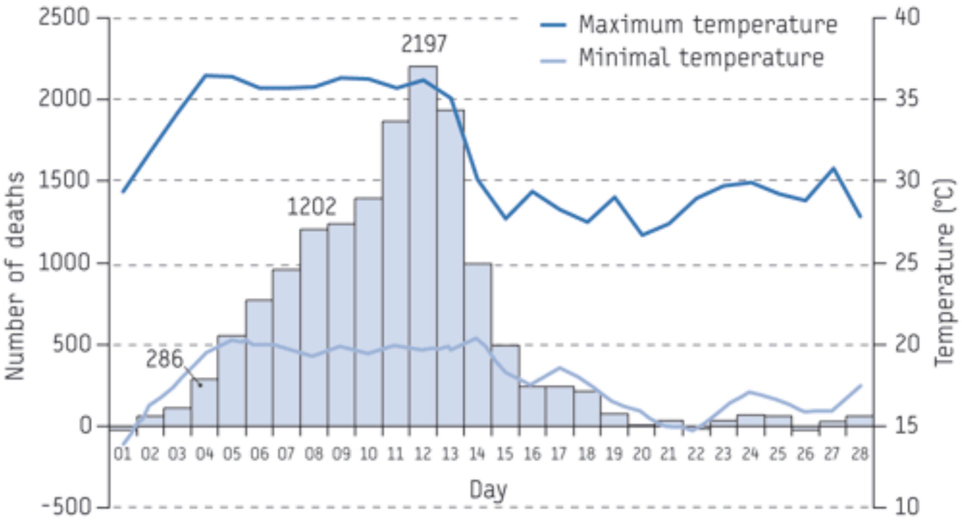
Year	Location	Hazard type	Economic Loss (Million US$)	Death toll (person)
2002	Central Europe	Flood	20,000+	69
2003	Central Europe	Heat wave	N/A	70,000+
2004	Haiti, Dominique	Flood	N/A	2,000
2004	India, Bangladesh, Nepal, etc.	Flood	N/A	1,000
2004	Indonesia + 13 countries	Indian Ocean earthquake and tsunami	14,000	230,000
2005	USA	Hurricane Katrina	14,400	1,322
2007	Bangladesh	Cyclone Sidr	1,700	3,447
2008	Myanmar	Cyclone Nargis	10,000	138,366
[illegible]	[illegible]	[illegible]	[illegible]	170
[illegible]	[illegible]	[illegible]	[illegible]	678
[illegible]	[illegible]	[illegible]	[illegible]	525+
2010	Russia	Heat Wave	15,000	55,000+
2010	Pakistan	Flood	43,000	1,781+
2011	Japan	Earthquake, tsunami	235,000	15,840
2011	Thailand	Flood	45,700	813
2013	The Philippines	Typhoon, high tide	N/A	6183+1785

Note: Many catastrophic events are taking place in the world.

Heat wave in Europe in Summer 2003

FIGURE

Daily excess of deaths during August 2003 and minimal and maximal daily temperatures, France



Source: [Ref. 1]

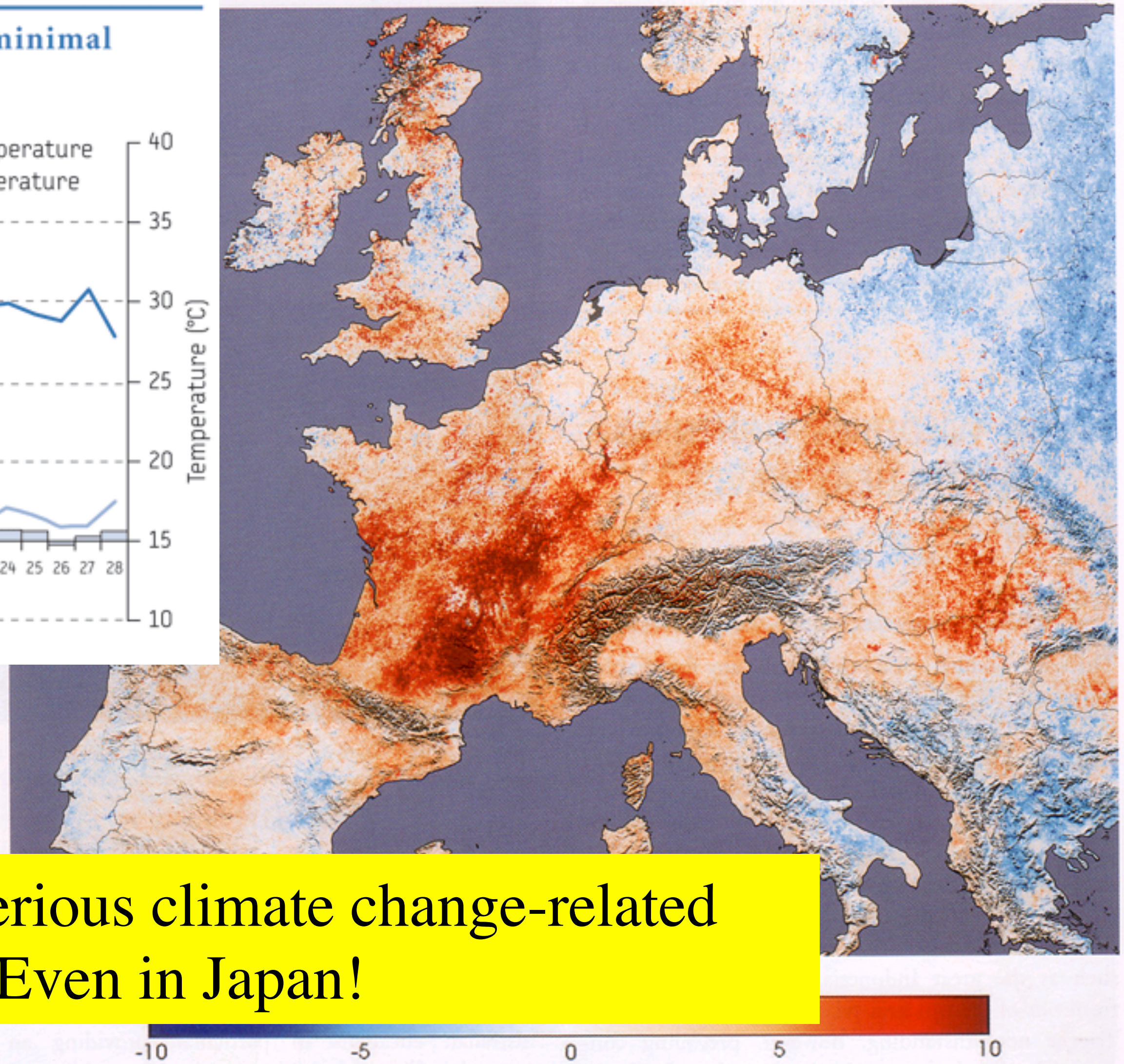
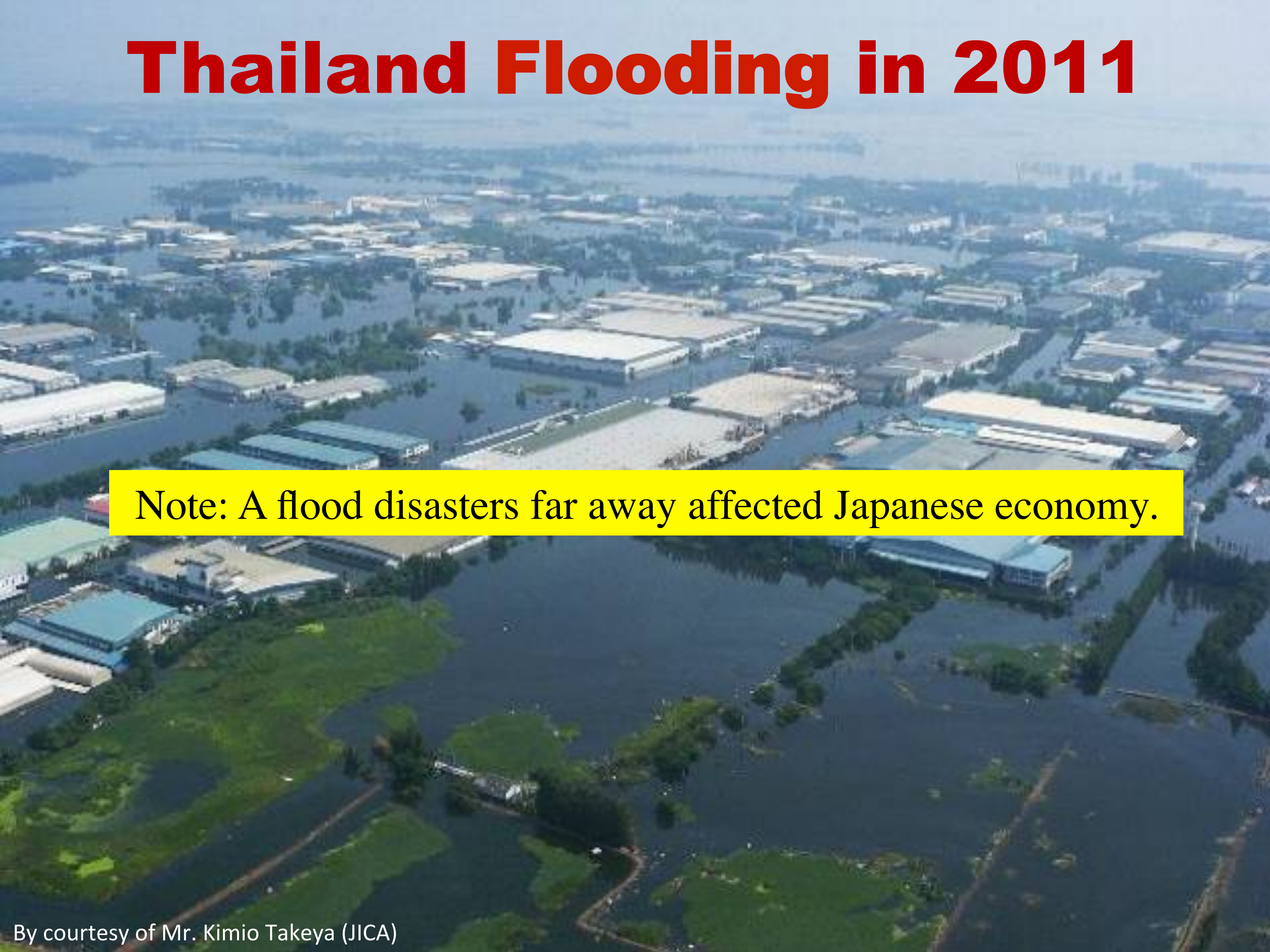


Figure 1.70 July 2003 day-time land-surface temperatures collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite are compared to temperatures for July 2001. Over large areas, particularly in France, the UK, Germany and eastern Europe are up to 10°C higher. Image credit: Reto Stockli and Robert Simmon, NASA Earth Observatory Team.

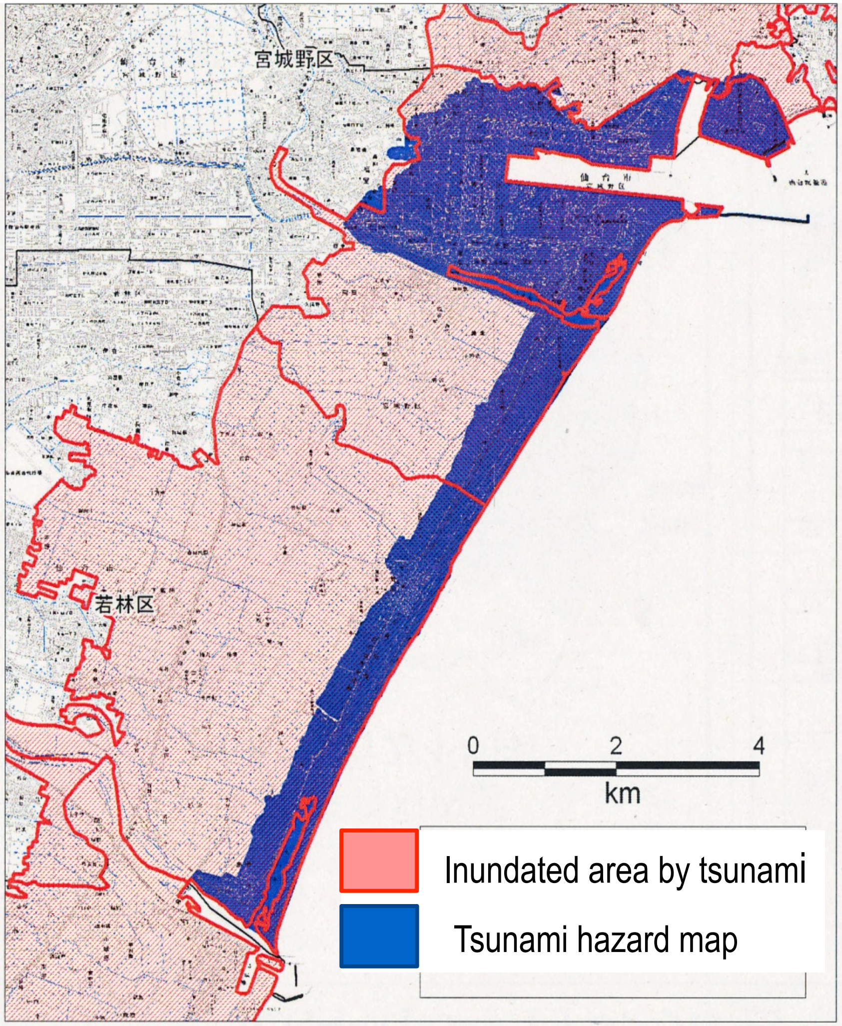
Note: Heat wave is a serious climate change-related disaster. Even in Japan!


Thailand Flooding in 2011
Note: A flood disasters far away affected Japanese economy.
By courtesy of Mr. Kimio Takeya (JICA)

Comparison of Inundated Area by Tsunami with Tsunami Hazard Map

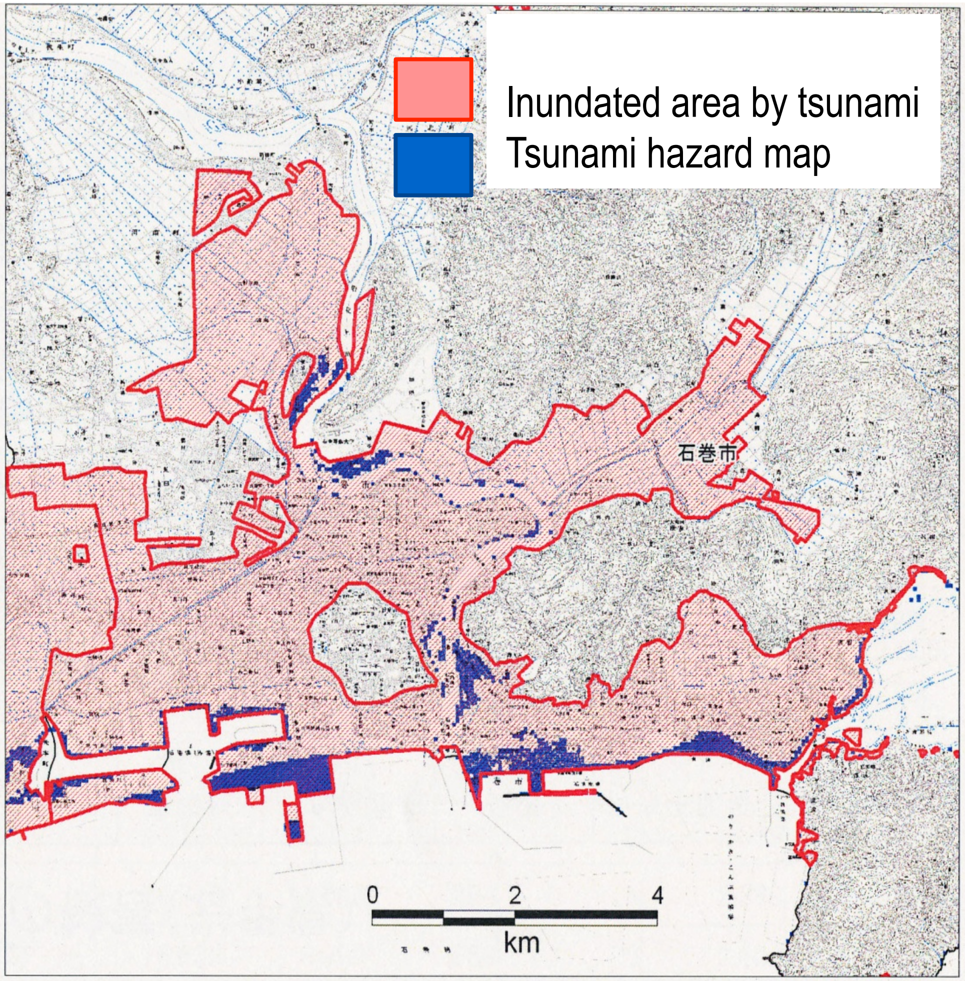
Sendai City:

Comparison of inundated area by the tsunami of the 2011 off the Pacific Coast of Tohoku Earthquake with Tsunami Hazard Map



Ishinomaki City:

Comparison of inundated area by the tsunami of the 2011 off the Pacific Coast of Tohoku Earthquake with Tsunami Hazard Map



理院資料より作図
ドマップ」, 石巻市「石巻市津波ハザードマップ」

Note: Hazard maps may give misunderstandings.

Two examples shown here

- Example-1

  Forests dam or so-called “green dam”

- Example-2

  Probable maxima and their application

Example-1
Forests dam or "green dam"

- There have been big discussions about artificial dams, which are said to:
  - destroy the environment
  - be wasting tax
  - be buried by sedimentation eventually
- Mountain forest = "green dam"
  - is sufficient for flood control
  - can store enough water resources
  - can reduce sedimentation, prevent soil erosion

Let's clarify the max- capacity of the forests dam!

Example-2
Probable maxima and their application

- Great Eastern Japan Earthquake and Tsunami suggested the importance to consider possible largest events.
- There have been record-breaking rainfall, flood and tsunami events.
- Radars have detected such extreme rains
- More than 100-year observations at many locations.

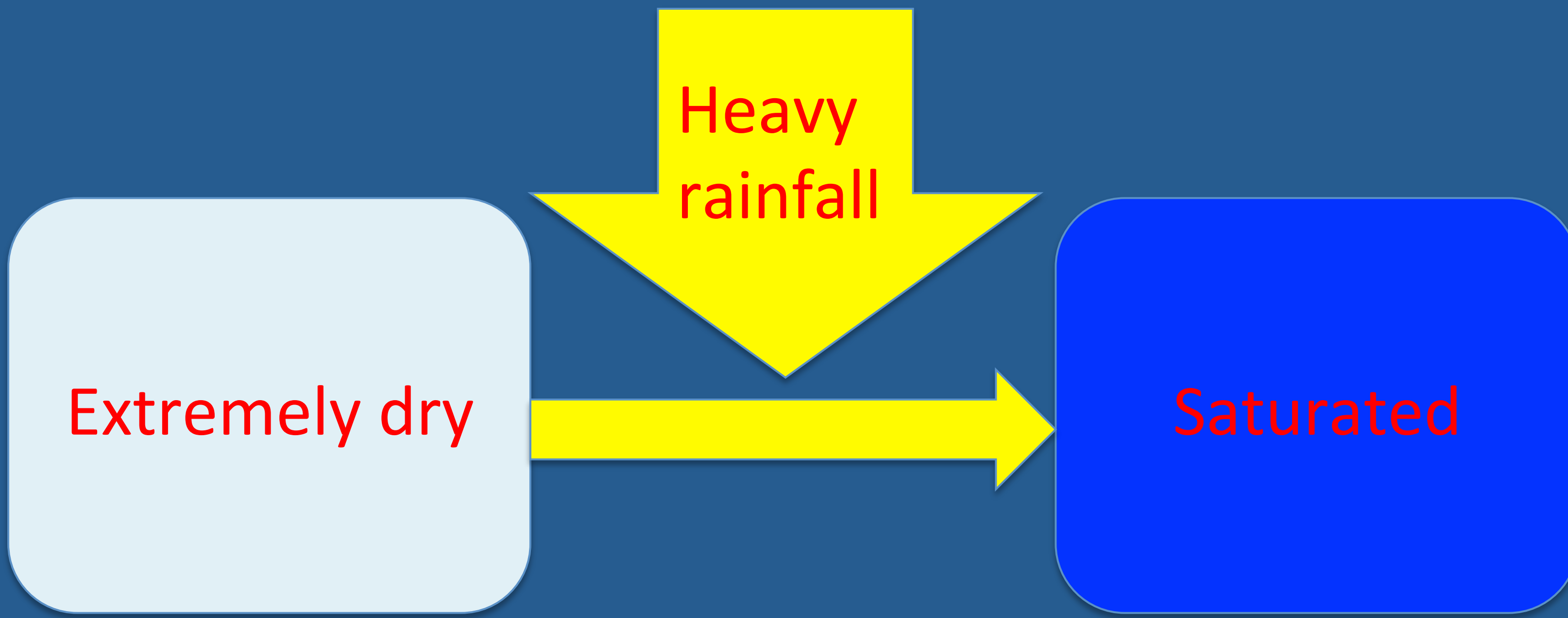
Let's use such extreme values for design practices!

Example-1

Forests dam or so-called “green dam”

Study events

Cases when the dam catchment is saturated by heavy rainfall after a severe drought.



Typhoon No. 17 in 2005 (Sep. 6)

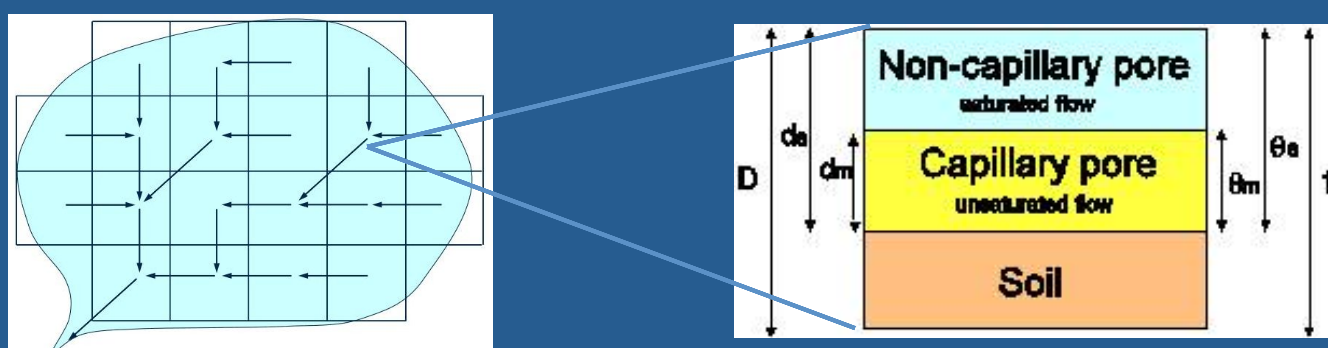
Drought and flood in 2007

Grid-cell distributed runoff model

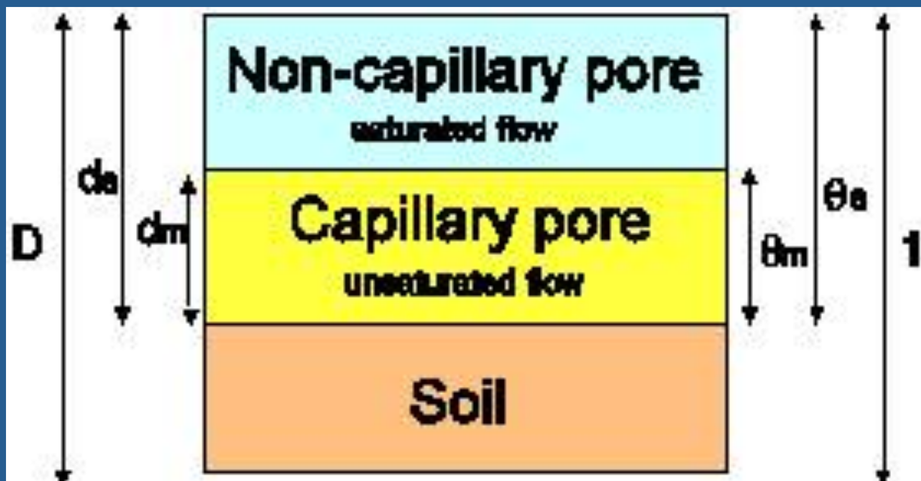
- Developed by Kojima, Takara, Oka & Chitose (1998)
- Covers the catchments with square grid and trace water to the steepest directions, which are decided by DEM (digital elevation model)
- Uses the kinematic wave model in each grid-cell for surface and subsurface runoff calculation:

 - Tachikawa, Nagatani &Takara (2004)

 cf. Ishihara & Takasao (1963)



Saturated and unsaturated subsurface flow kinematic wave model

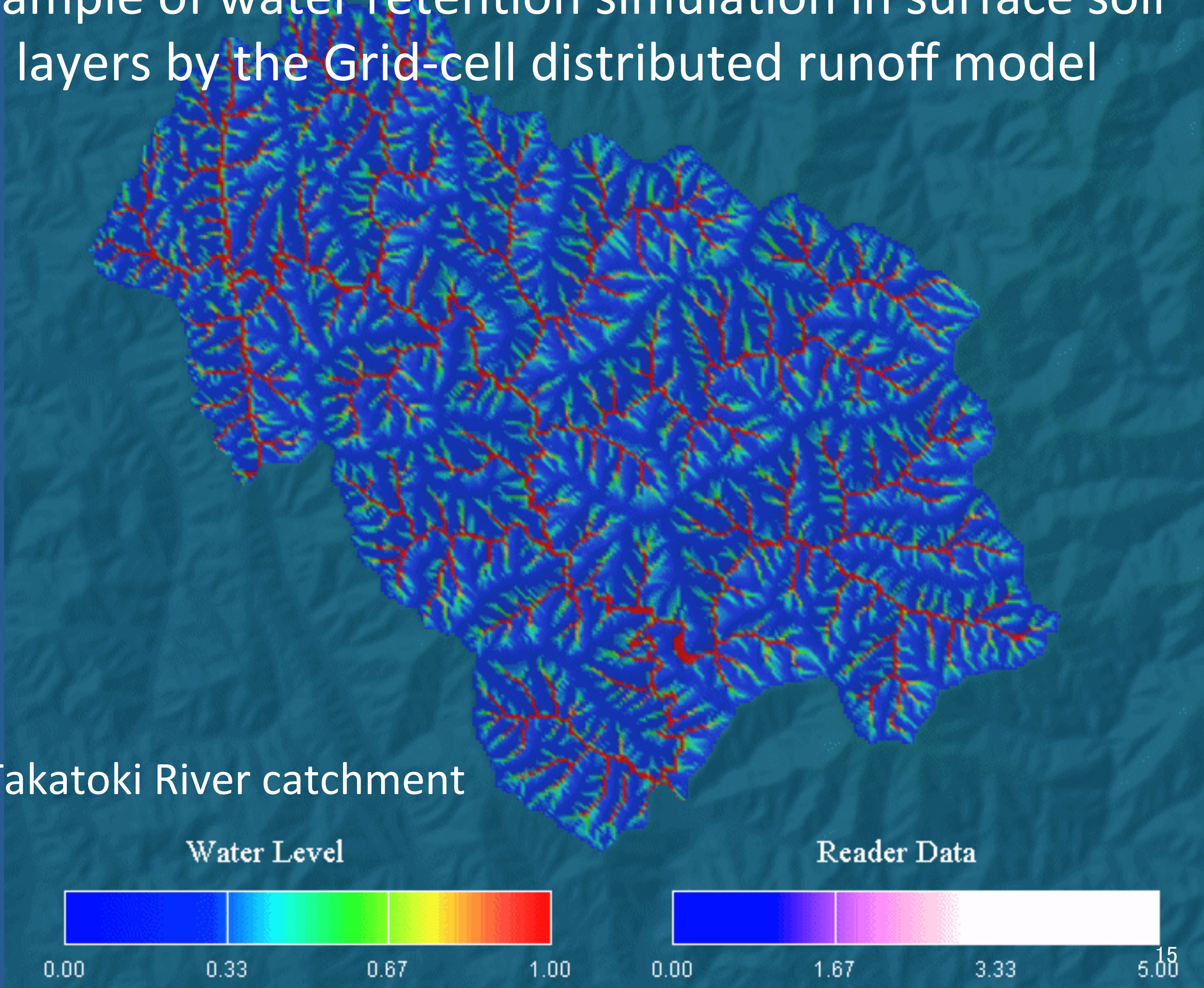


Gravity flow is dominant

Capillary flow is dominant

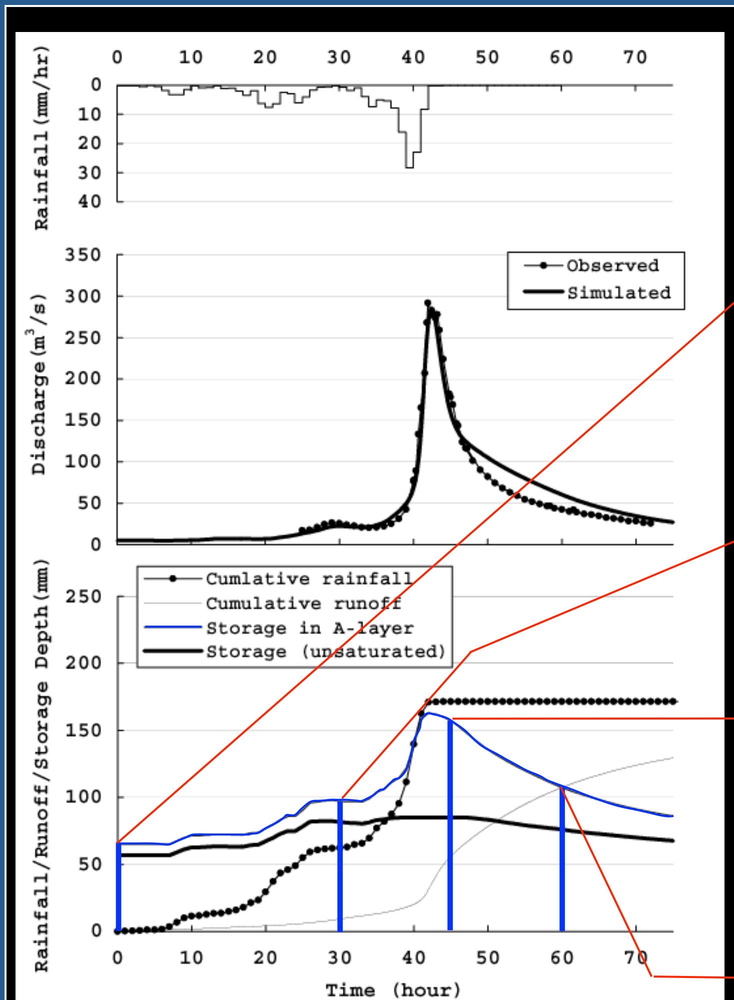
$$q(h) = \begin{cases} v_m d_m \left(\frac{h}{d_m}\right)^{\beta} & 0 \leq h < d_m \\ v_m d_m + v_a (h - d_m) & d_m \leq h < d_a \\ v_m d_m + v_a (h - d_m) + \alpha (h - d_a)^m & d_a \leq h \end{cases}$$

Example of water retention simulation in surface soil layers by the Grid-cell distributed runoff model

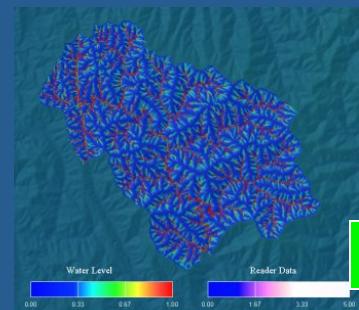


The Takatoki River catchment

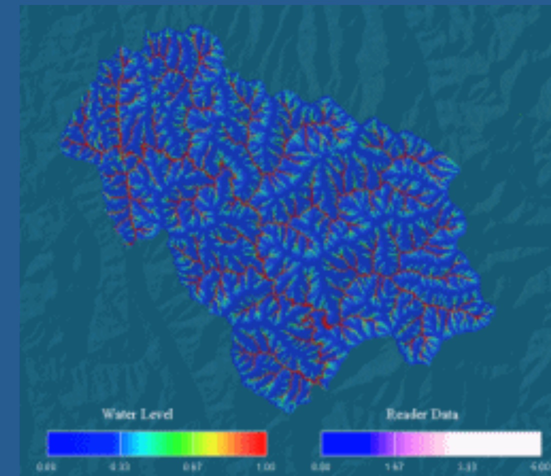
Grid-cell distributed runoff model in the Takatoki River



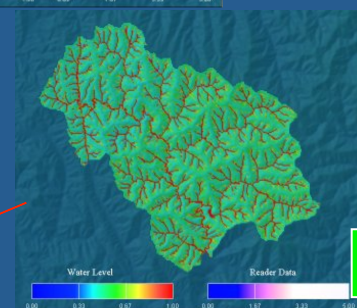
Upper: Hourly Rainfall series
Middle: Hydrographs
Lower panel:



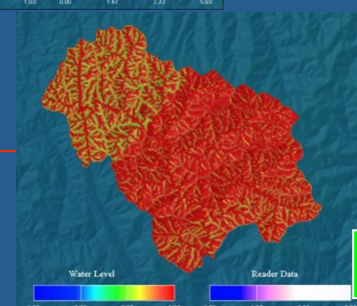
Initial



Surface soil layer water content

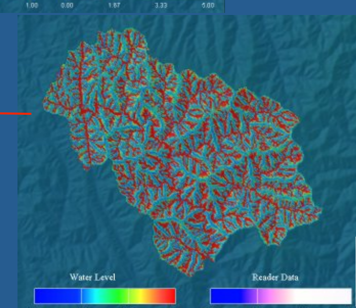


30 hrs



Almost saturated surface soil layer

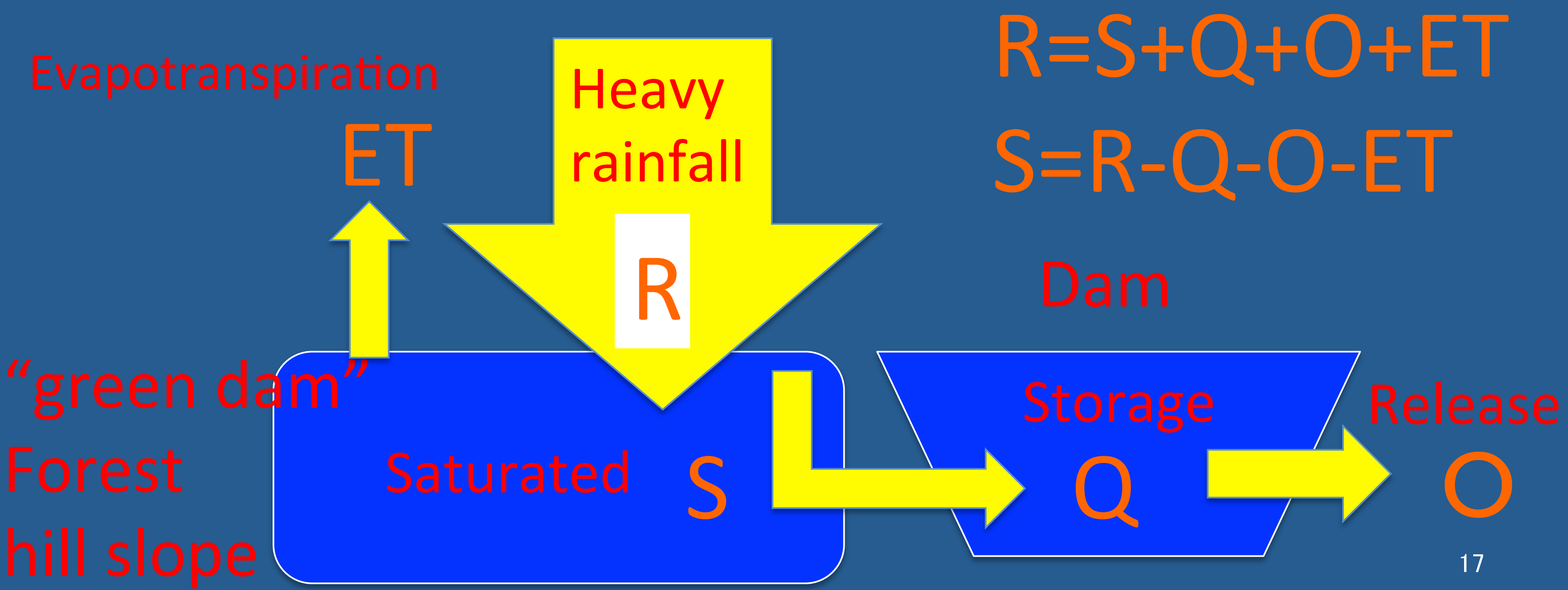
45 hrs



60 hrs

The merits of dam catchment analysis

- Upstream catchment is covered by forest
- Runoff from forest areas can be quantitatively evaluated at dam site



Sameura Dam (2005)

2005/05/19
Started reducing water intake

2005/09/04
0 %   usable water capacity

651.4 mm Rain
by Typhoon No. 14

2005/09/07
100 % usable water capacity

Oodo Dam (2005)

2005/08/11 Started to reduce water intake (more than 30%)

2005/09/06 22.7% usable water storage

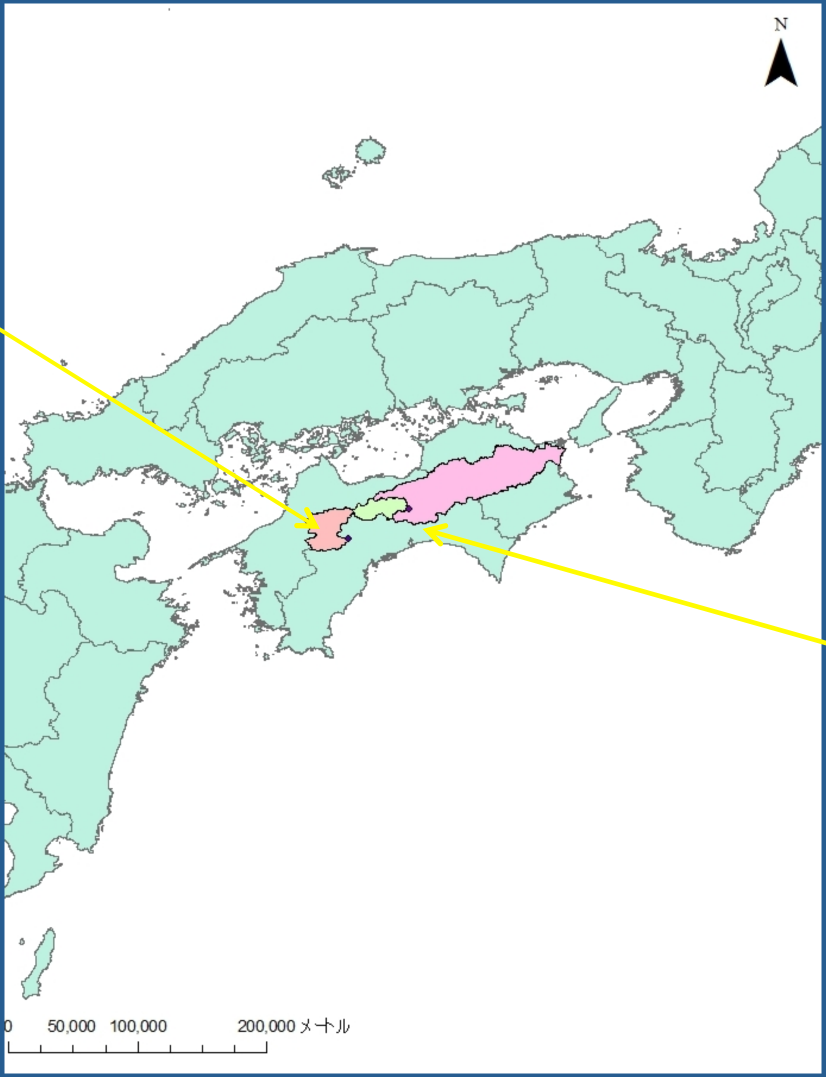
622.7 mm Rain
by Typhoon No. 14

4,655 m3/s Inflow
Historical Maximum

2005/09/06 327% usable water storage

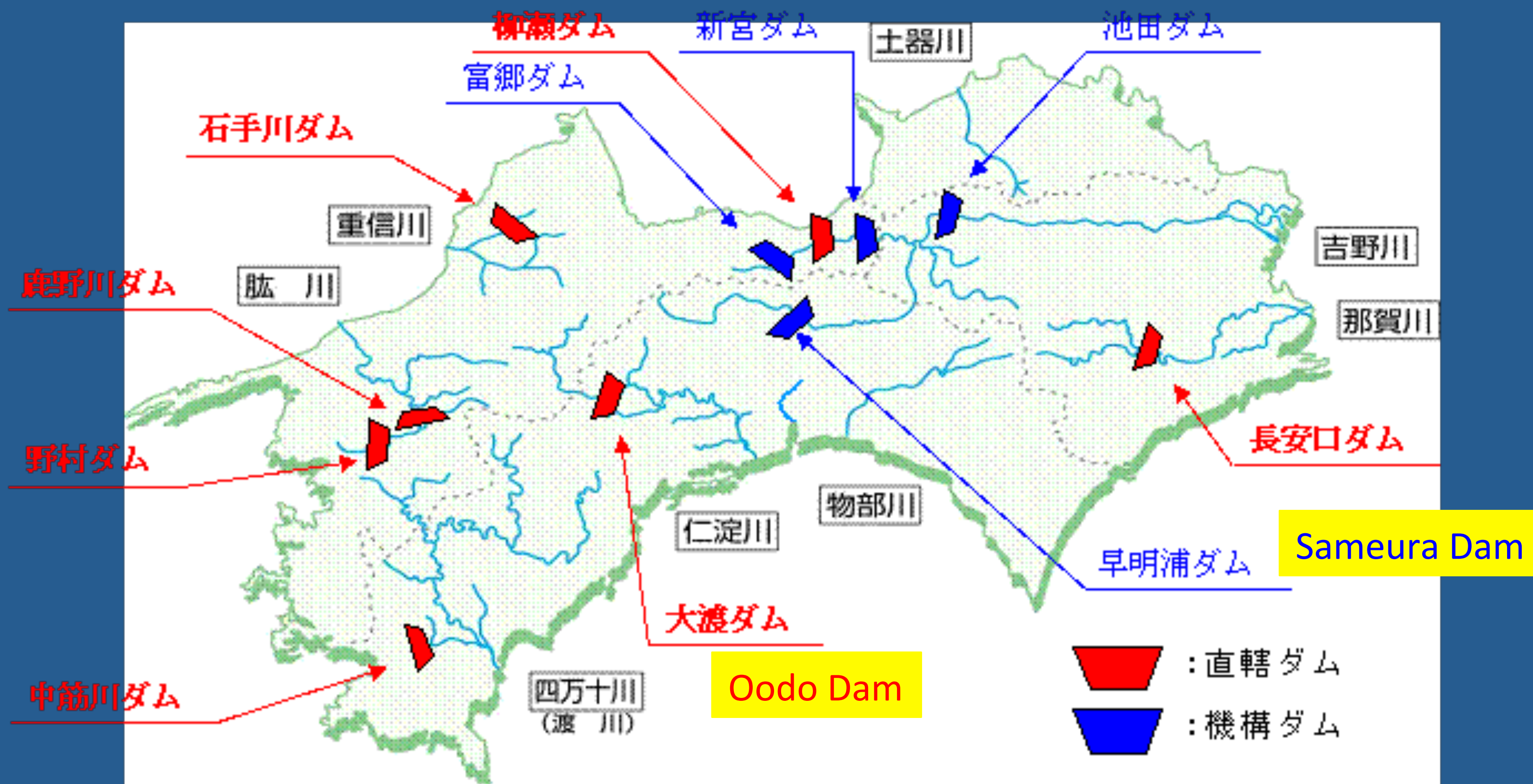
Catchments of interest

Oodo Dam
大渡ダム



Sameura Dam
早明浦ダム

Dams in Shikoku Island

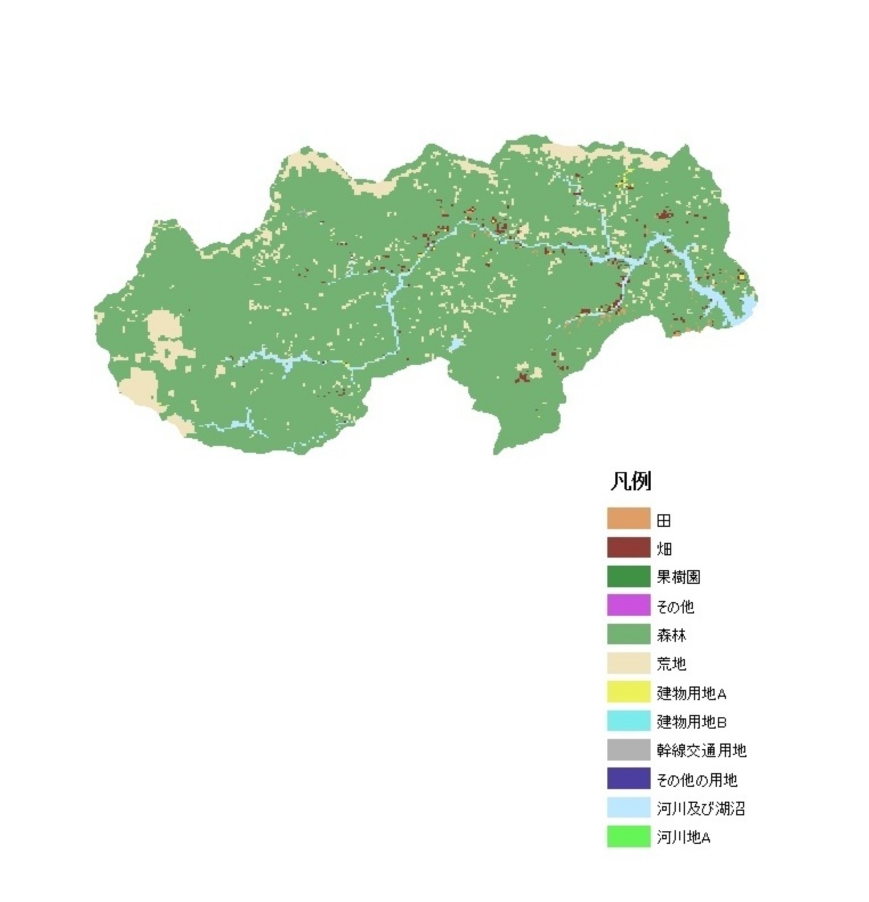


Managed by MLIT
Managed by Japan Water Agency (JWA)

Sameura Dam catchment

Sameura Dam

- Upstream of the Yoshino river
- Catchment area: 417km^2
- Total volume: 316 million m^3
- Effective capacity: 289 million m^3
- Forest: 86%
- Paddy field or waste land: 10 %

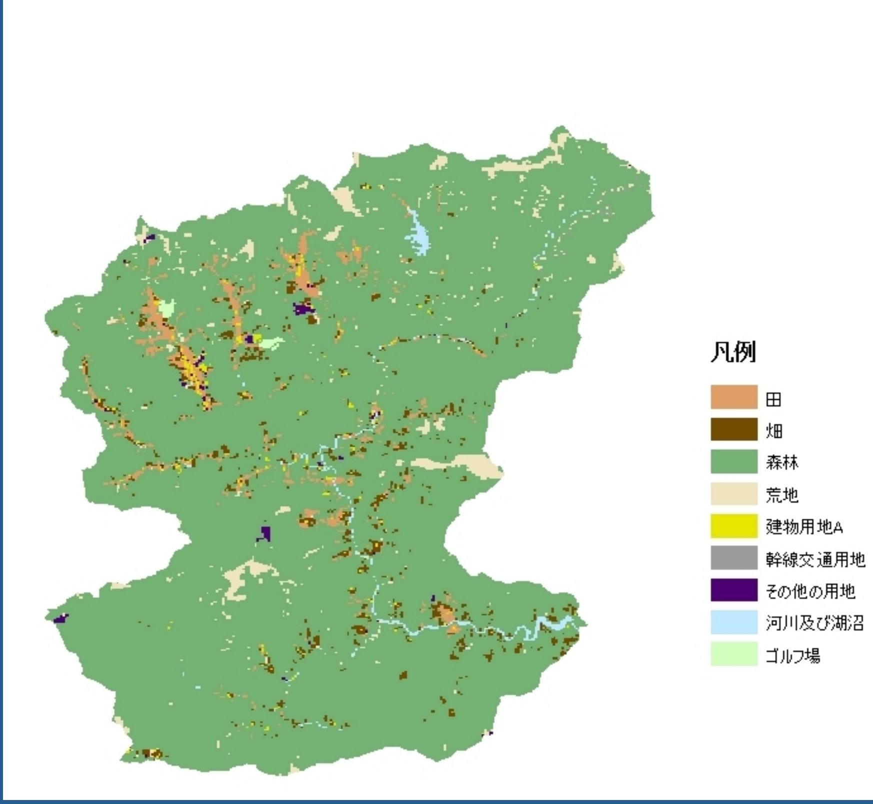


Land use of Sameura Dam catchment

Oodo Dam catchment

Oodo Dam

- Upstream of the Niyodo river
- Catchment area: 688.9km^2
- Total storage volume: 66 million m^3
- Effective capacity: 52 million m^3
- Forest: 89 %
- paddy field or wasteland: 3 %



Land use of Oodo Dam catchment

The Niyodo River and Oodo Dam (Source: MLIT)

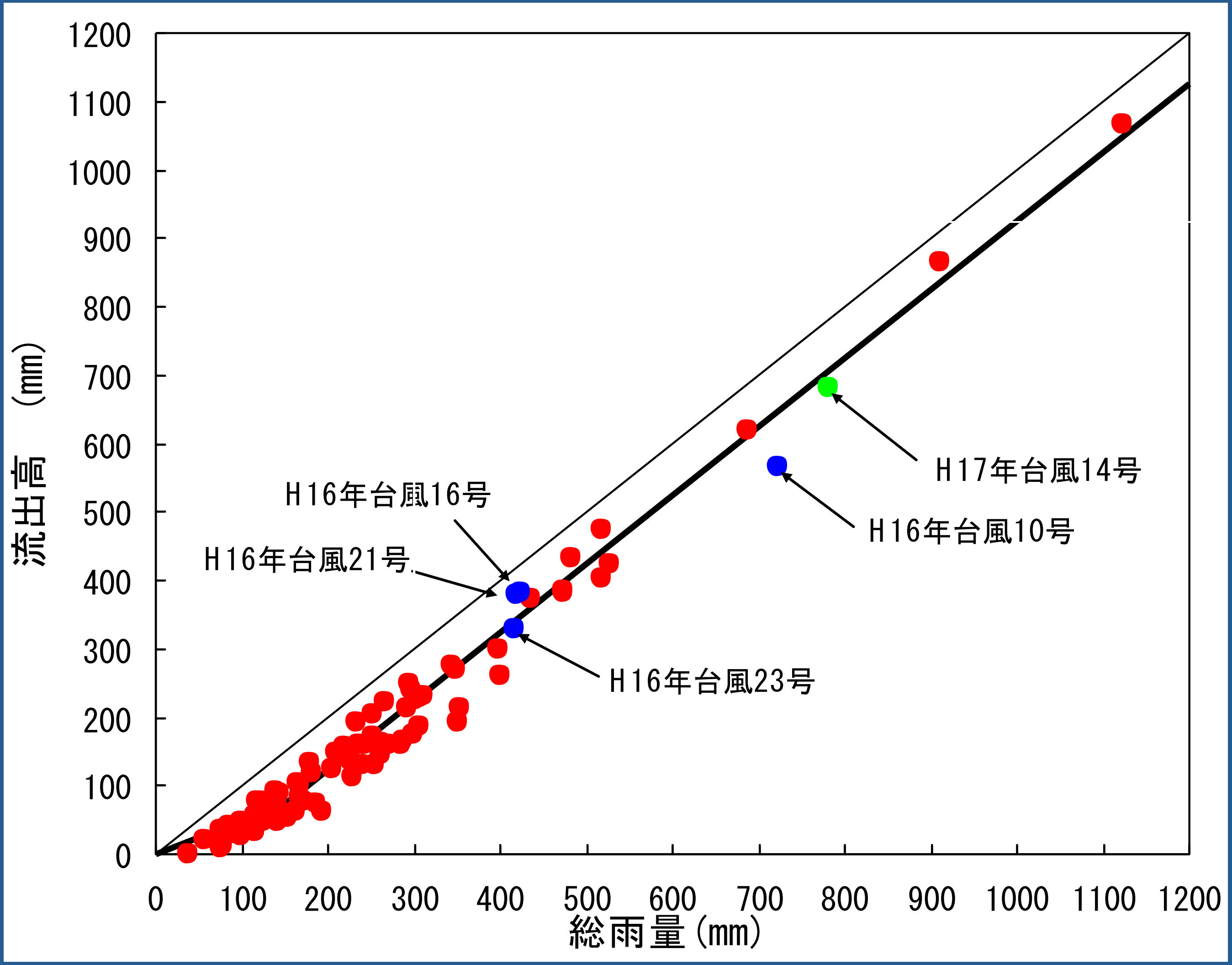
大渡ダム

1-1 仁淀川流域の概要

【仁淀川】
・流域面積：1,560km²
　森　林：約84%
　農　地：約9%
　宅　地：約1%
・流路延長：124km
・主な市町村：土佐市、いの町、仁淀川町、久万高原町等

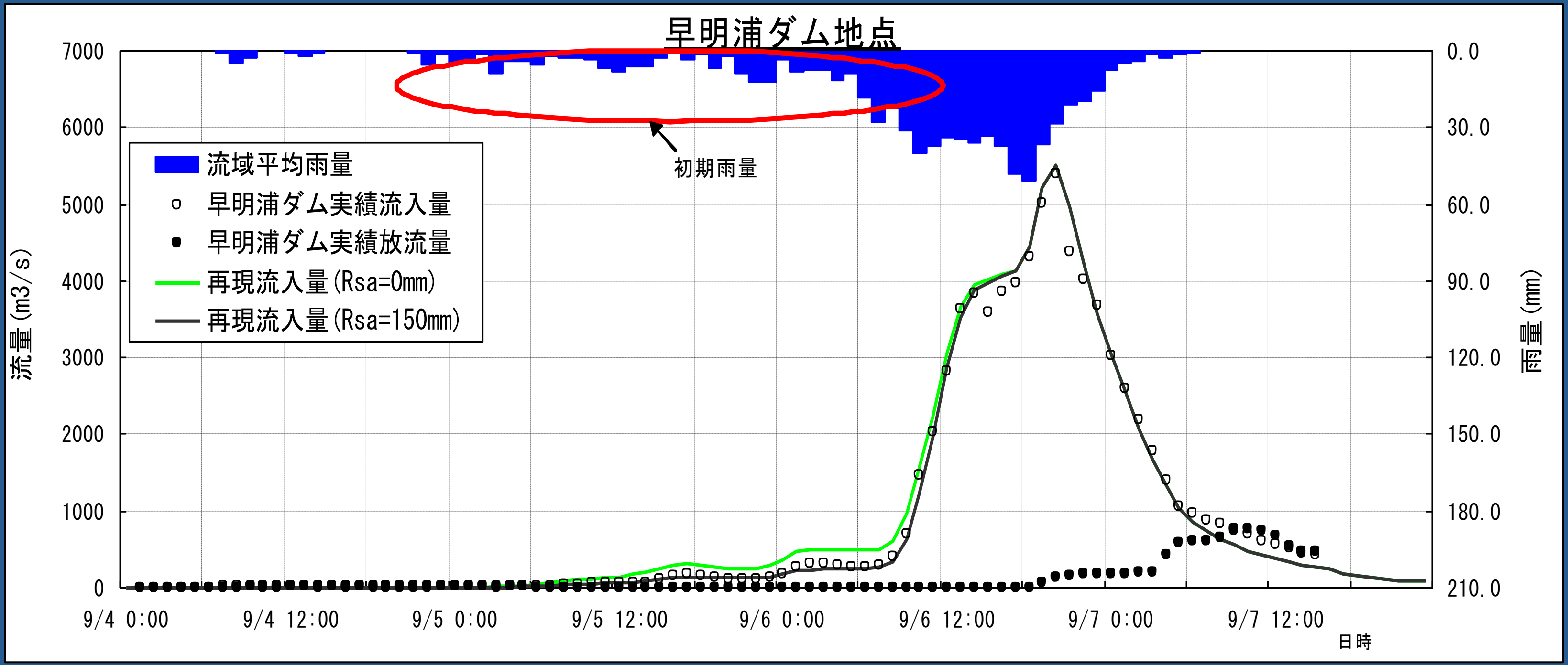
Water retention in Sameura Dam catchment is estimated as 150 mm by statistical analysis

Runoff height (mm)



Total rainfall in an event (mm)

Water retention on mountain slopes cannot reduce the peak discharge for heavier rainfall events (Sameura Dam catchment: 2005/09/04-07)



Runoff model: Storage function method

Green: Saturated initial condition assumed

Black: 150 mm initial loss is considered

Another case
Sameura Dam (2007)

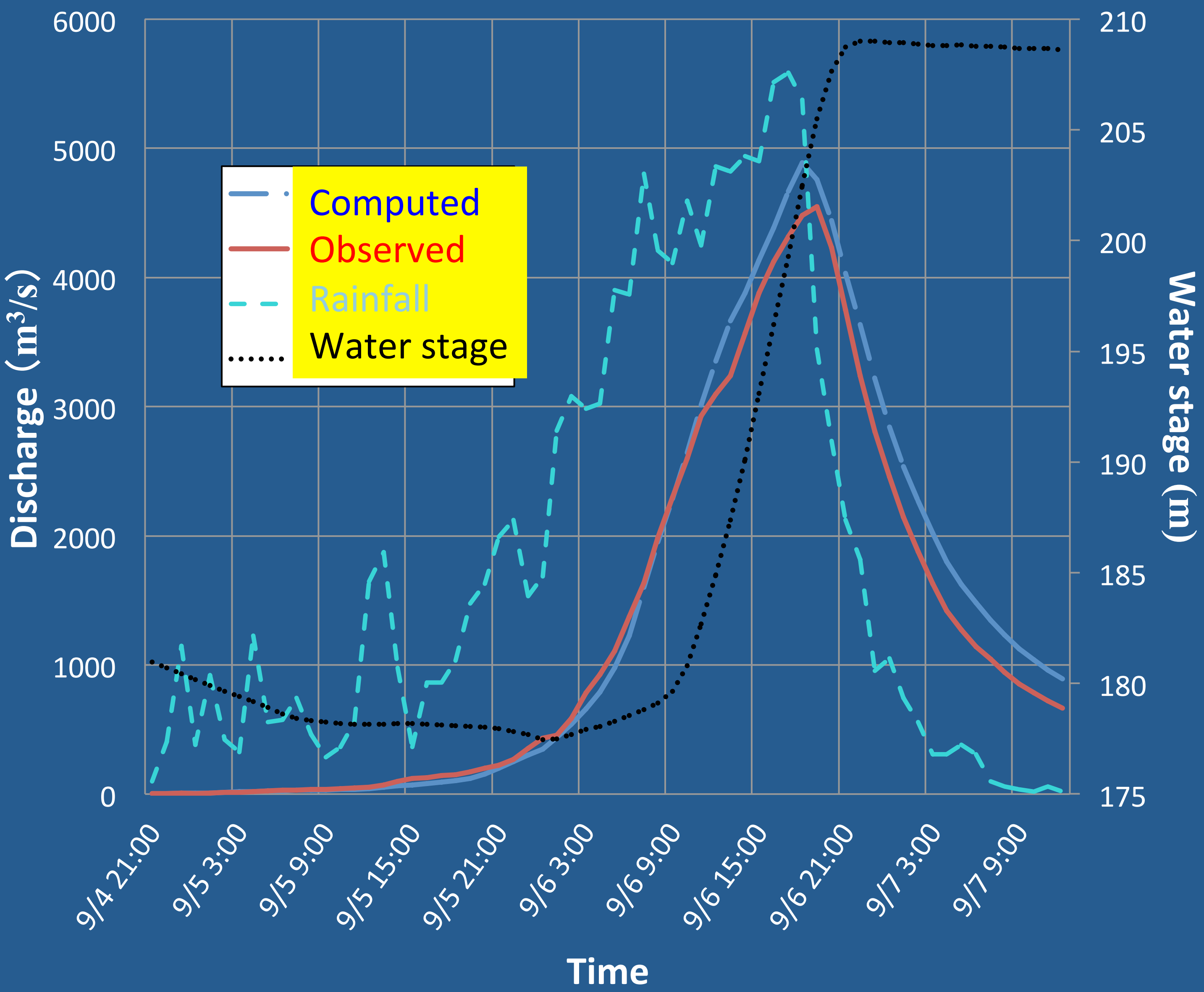
May 2007 Started reducing water intake

7/3/2007 23.5% at usable water capacity

718.8 mm Rain
During a couple of days

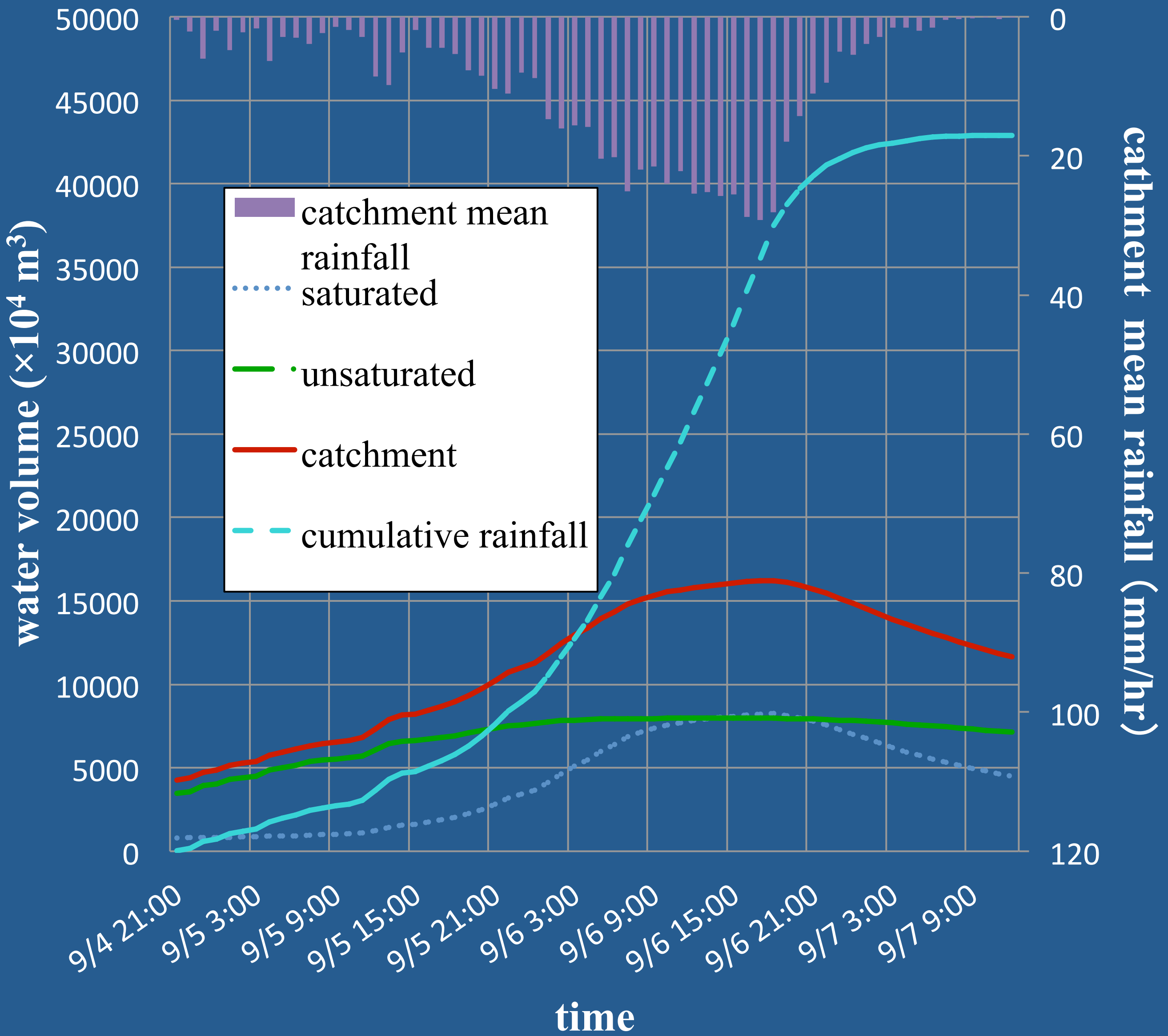
2007/07/15 100% at usable water capacity

Model calibration at Oodo Dam catchment



Runoff model parameters calibrated for Oodo Dam catchment (2005)

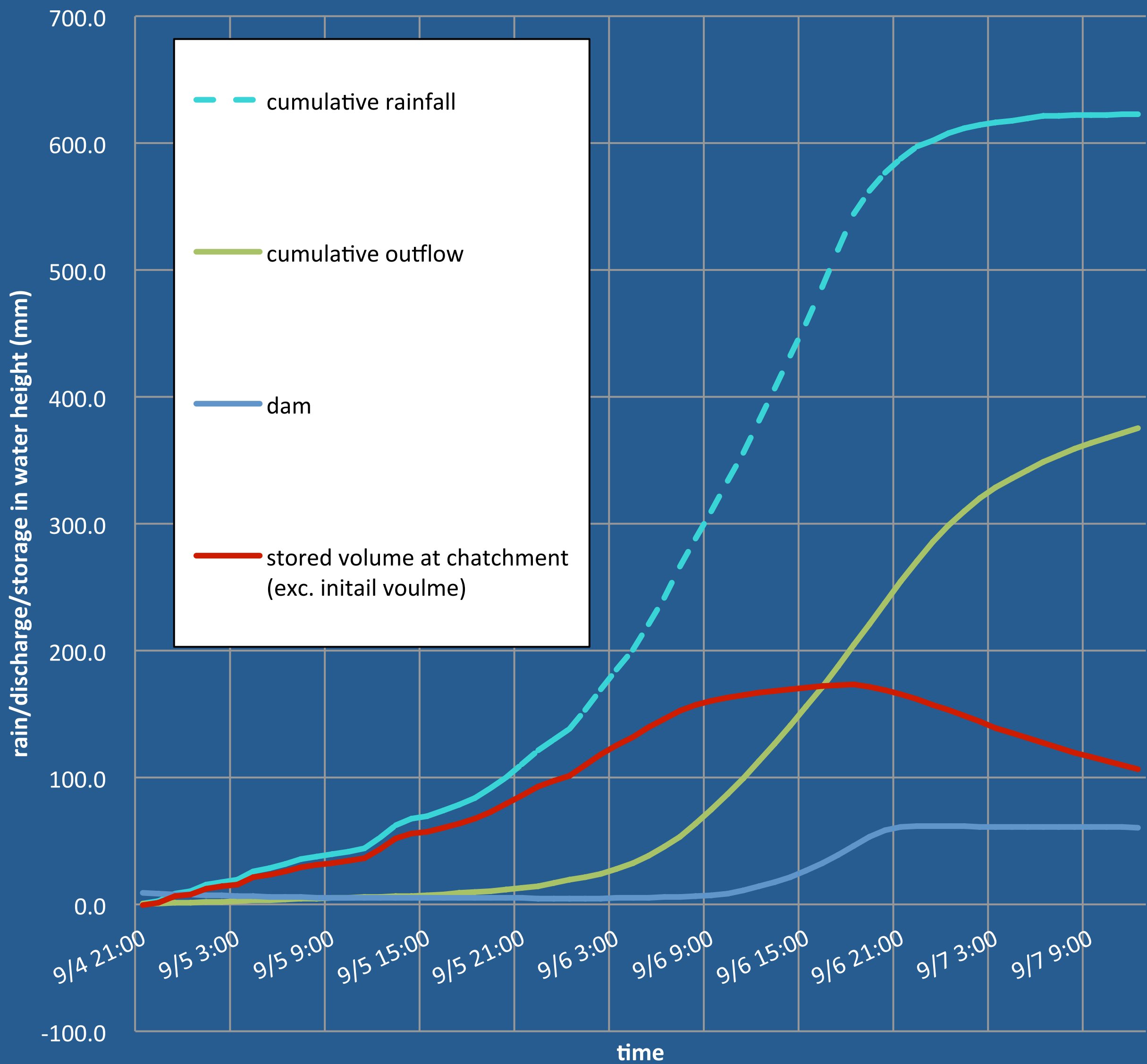
Manning coefficient	Land use types	
Np	Paddy field	0.05
Nfi	Agricultural field	0.1
No	Orchard	0.1
Nfo	Forest	0.4
Nw	Wasteland	0.3
Nu	Urban area	0.1
Nwa	Water area	0.8
NRv	River	0.01
Soil parameters		
TOUSUIMS	Ka（m/s）	0.02
ASOU	D（mm）	1000
GANMAS	θa	0.275
GANMAC	θm	0.125
BETAC	β	8



流域保水量：
9月6日18時に最大値
1億6226万m^3

Storage capacity at the catchment:
Max 162.26 MCM at 18 on 9/6/2005

Water storage at saturated zone, unsaturated zone and whole catchment at Oodo dam catchment.



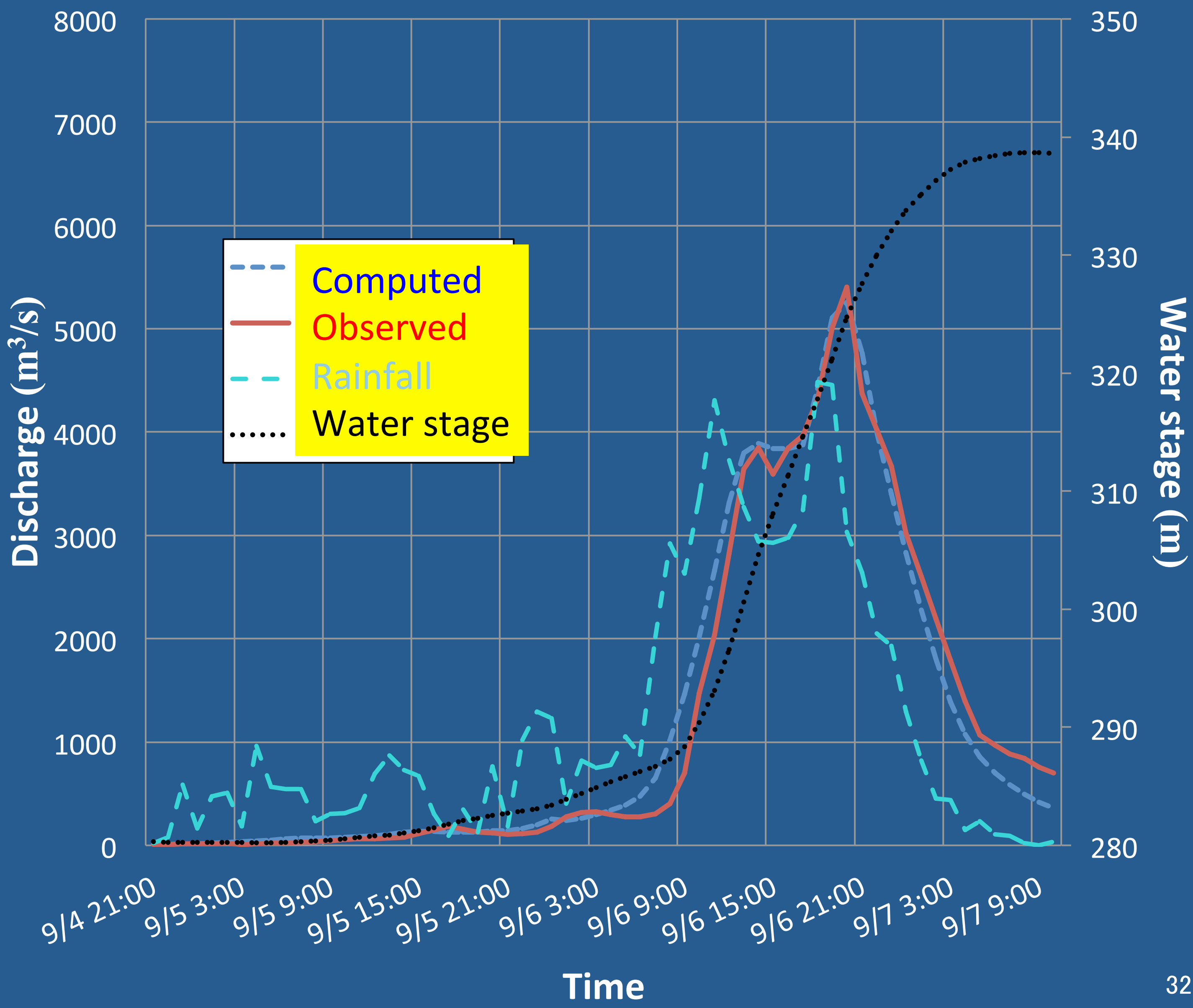
流域による最大洪水調節量（（流域保水量）-（初期保水量））/流域面積：
173mm

Flood control function at the catchment ((Storage volume at the catchment) – (Initial water volume))/catchment size:
173 mm

Stored volume at the dam and the catchment (exc. Initial volume) at Oodo dam catchment

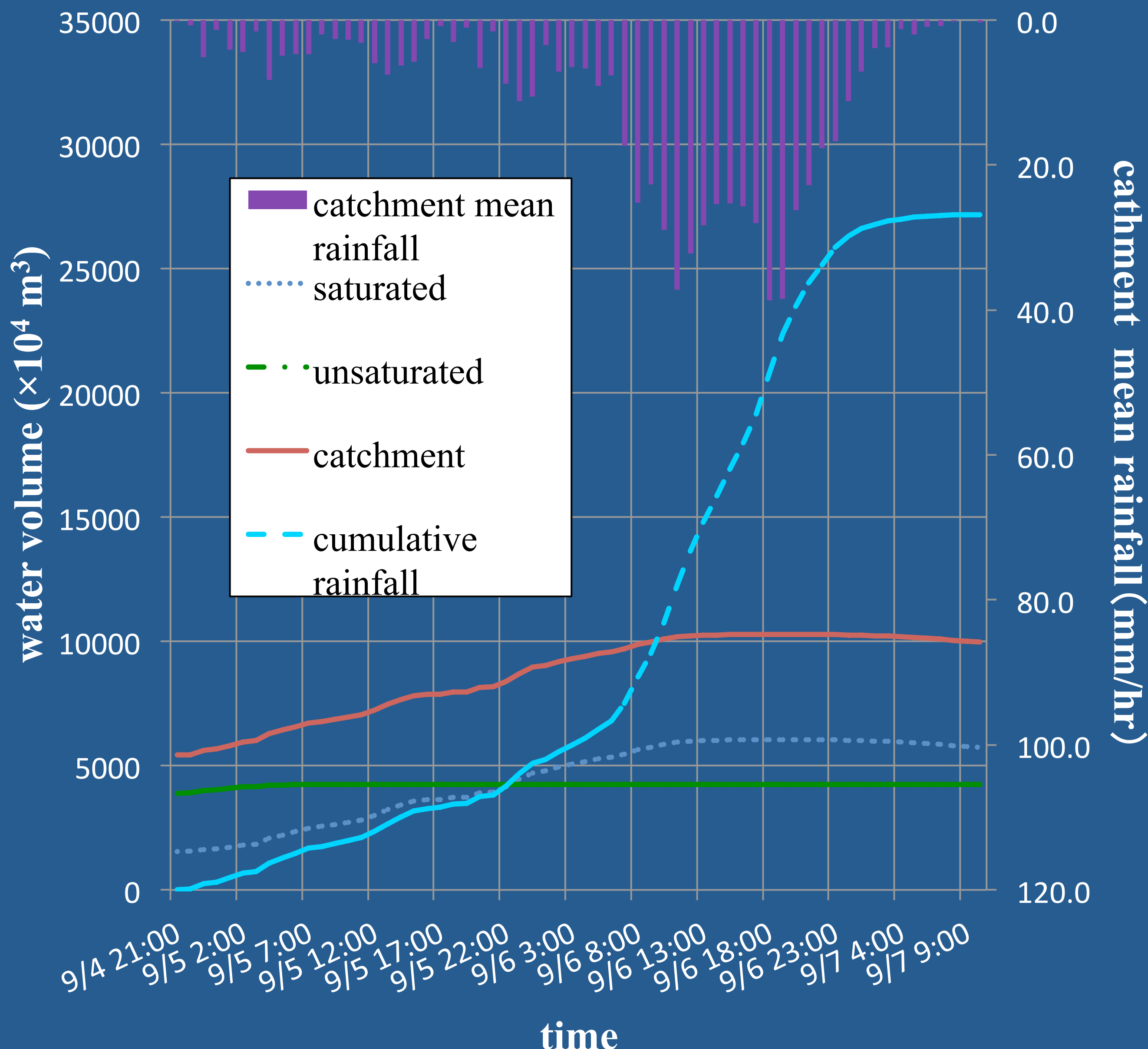
Model calibration at Sameura Dam catchment (2005)

Runoff calculation result



Runoff model parameters calibrated for Sameura Dam catchment (2005)

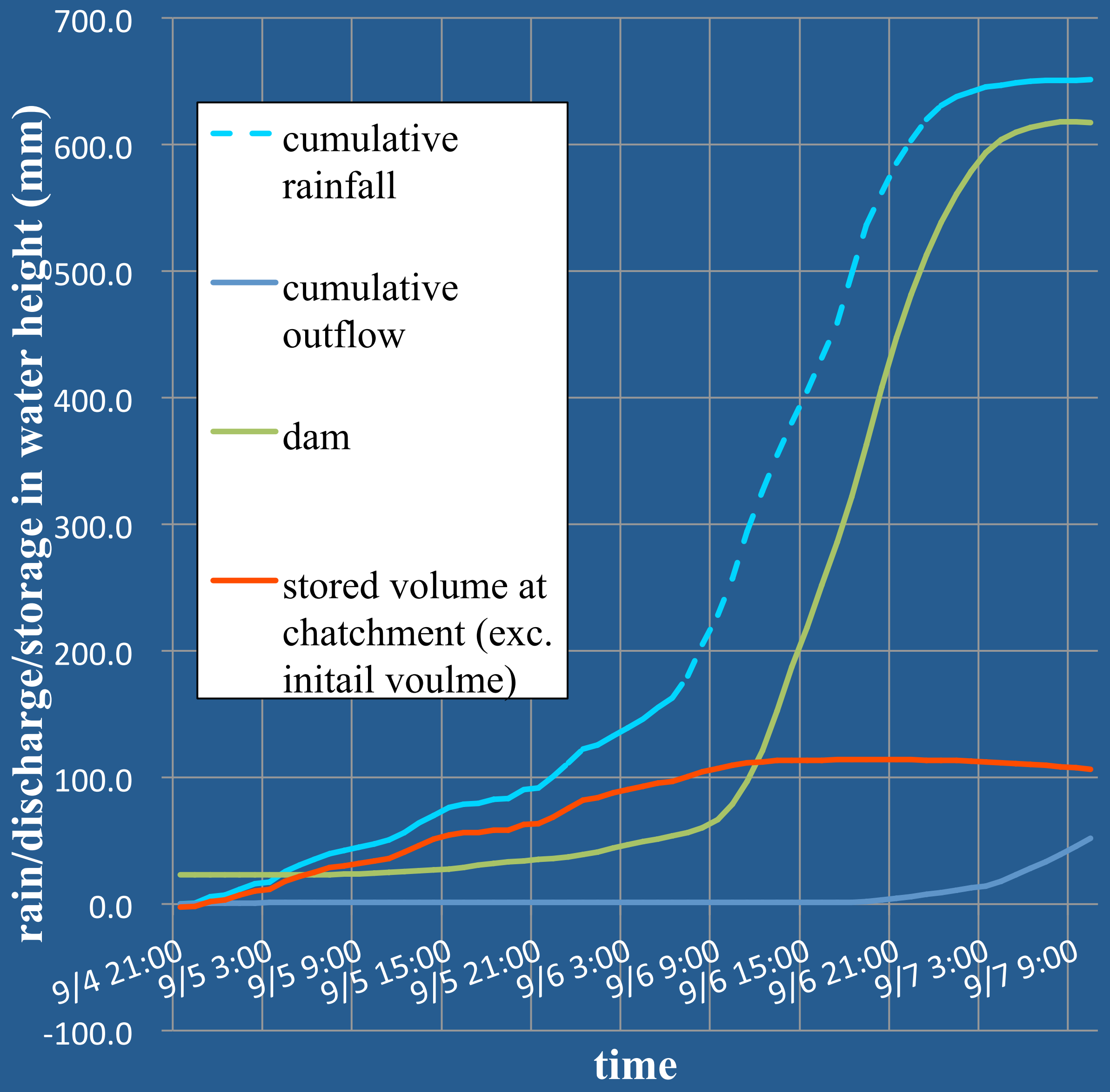
Manning coefficent	Land use types	
Np	Paddy field	0.05
Nfi	Agricultural fField	0.1
No	Orchard	0.1
Nfo	Forest	0.2
Nw	Wasteland	0.2
Nu	Urban area	0.1
Nwa	Water area	0.8
NRv	River	0.002
Soil parameters		
TOUSUIMS	Ka（m/s）	0.004
ASOU	D（mm）	1000
GANMAS	θa	0.255
GANMAC	θm	0.105
BETAC	β	8



流域保水量：
9月6日の19時に最大値1億283万m^3

Storage capacity at the catchment:
Max 102.83 MCM at 19 on 9/6/2005

Water storage at saturated zone, unsaturated zone and whole catchment at Sameura dam catchment.

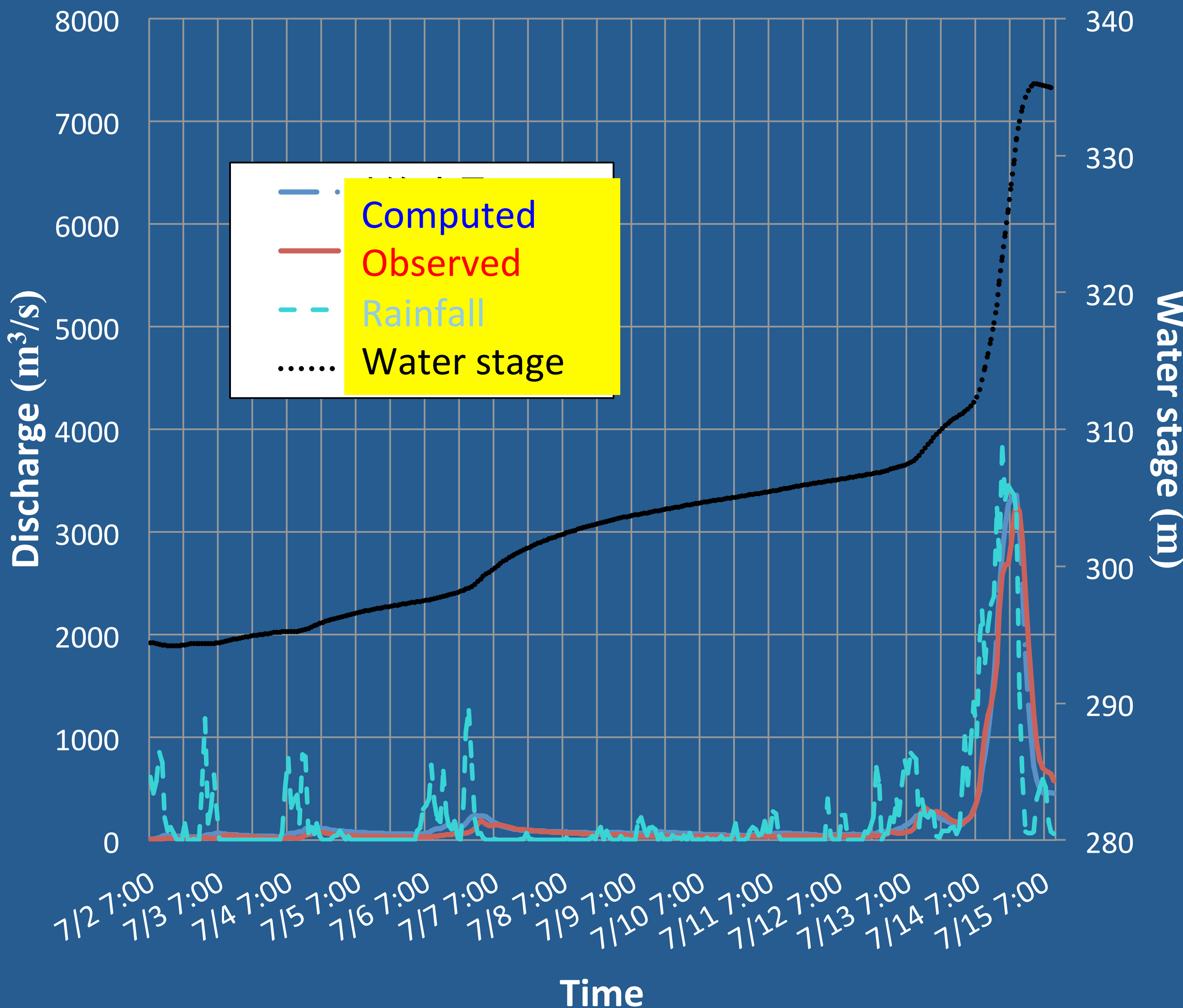


流域による洪水調節量の最大値：114mm

Flood control function at the catchment: 114 mm

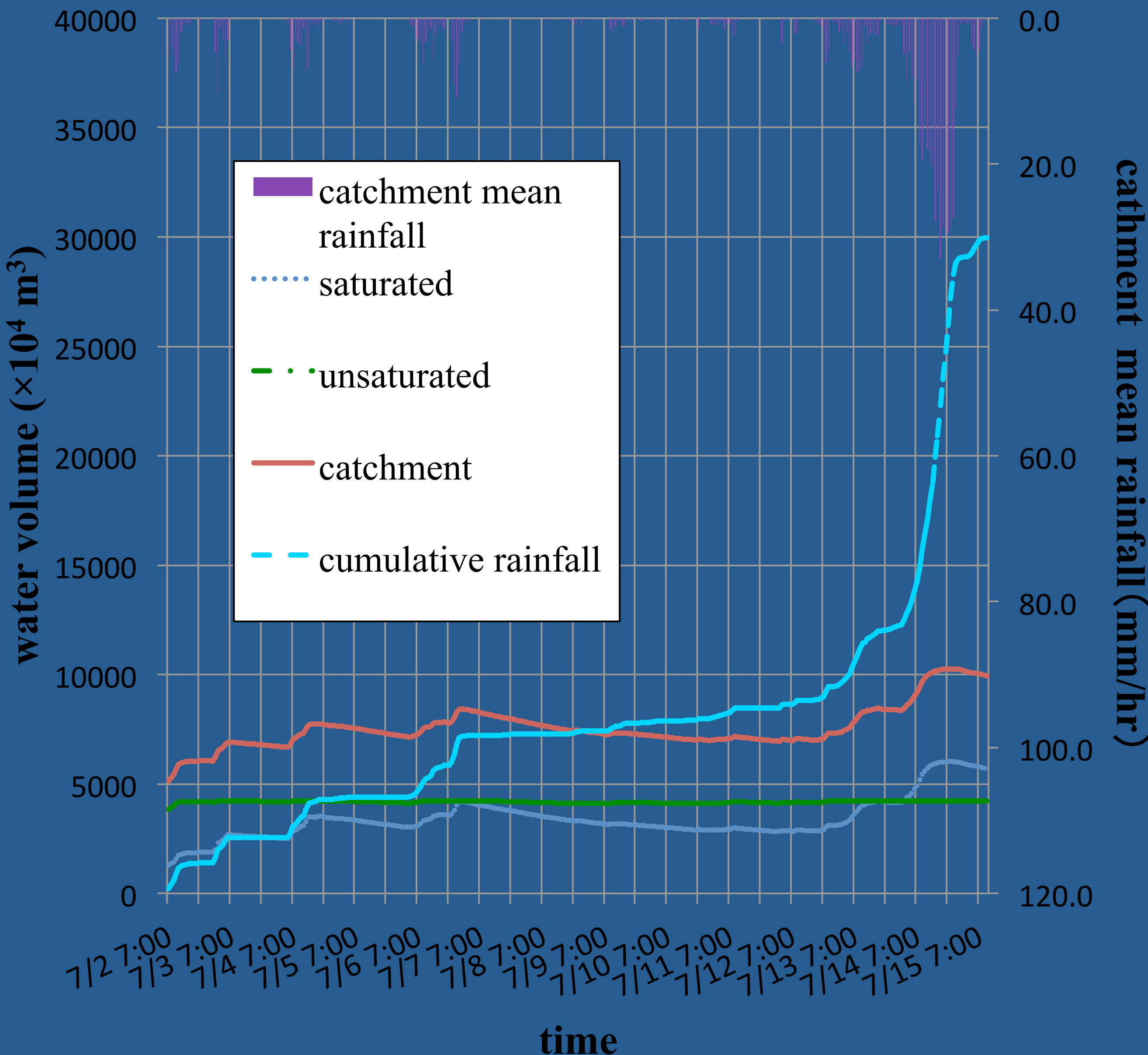
Stored volume at the dam and the catchment (exc. Initial volume) at the Oodo dam catchment

Model calibration at Sameura Dam catchment (2007)



Runoff model parameters calibarated for Sameura Dam catchment (2007)

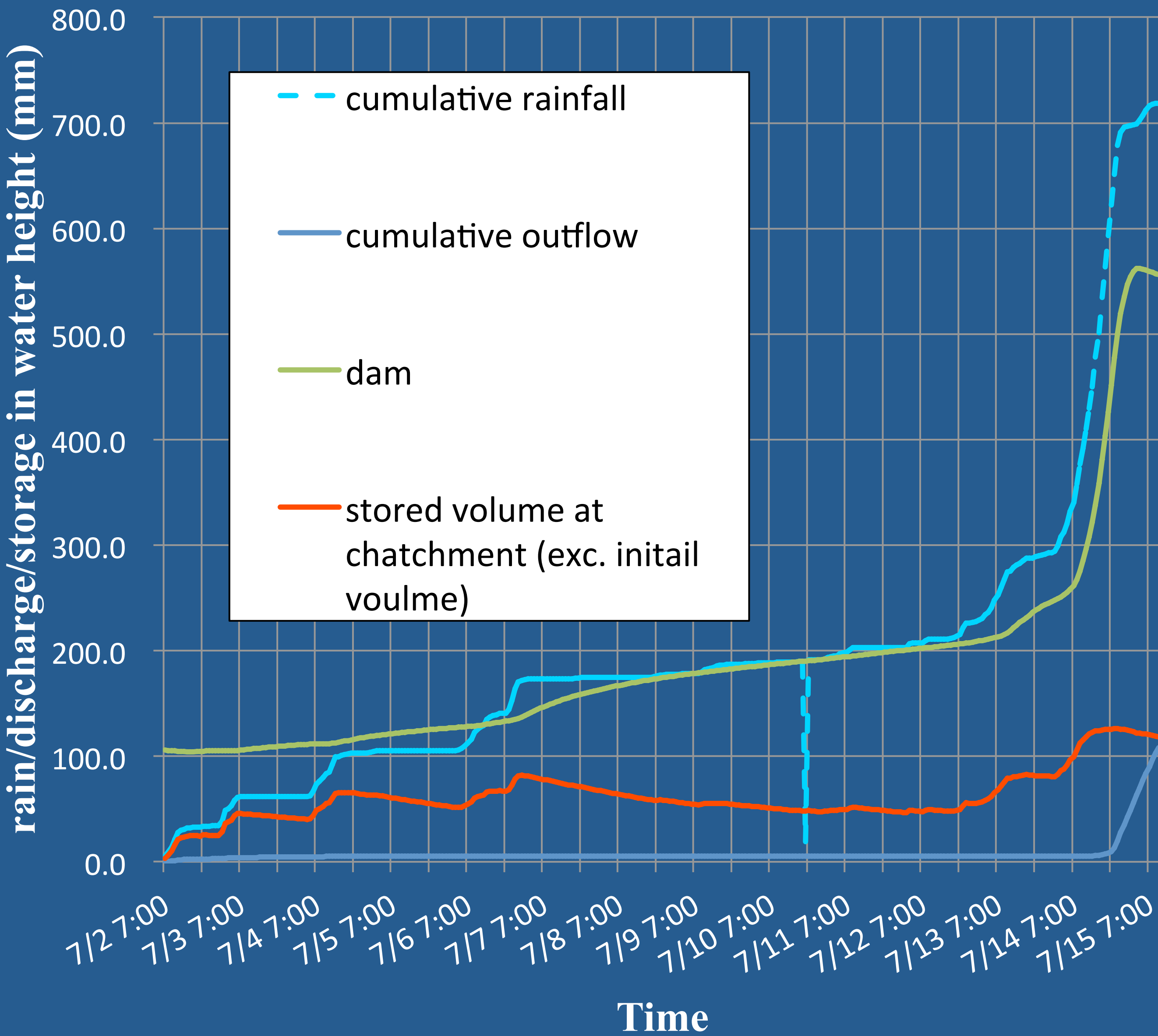
Roughness coefficient	Land use types	
Np	Paddy field	0.05
Nfi	Agricultural field	0.1
No	Orchard	0.1
Nfo	Forest	0.2
Nw	Wasteland	0.2
Nu	Urban area	0.1
Nwa	Water land	0.8
NRv	River	0.002
Soil parameters		
TOUSUIMS	Ka（m/s）	0.004
ASOU	D（mm）	1000
GANMAS	θa	0.255
GANMAC	θm	0.105
BETAC	β	8



流域保水量：
7月4日の21時に最大値1億264万m³

Storage capacity at the catchment:
Max 102.64 MCM
at 21 on 7/4/2007

Water storage at saturated zone, unsaturated zone and whole catchment at Sameura dam catchment.



流域による洪水調節量の最大値：126mm

Flood control function at the catchment: 126 mm

Stored volume at the dam and the catchment (exc. Initial volume) at Oodo dam catchment

Flood control function of “green dam” is estimated as 114-173 mm

	Oodo 2005	Sameura 2005	Sameura 2007
Total rainfall（mm)	622.7	651.4	718.8
Max of catchment mean rainfall (m^3/s)	5,588	4,483	3,823
Max dam inflow (m^3/s)	4,550	5,405	3,265
Max dam outflow (m^3/s)	3,225	776	3,823
Max of storage capacity at the catchment (10^4 m^3)	16,226	10,283	10,264
Flood control function of catchment（mm）	173	114	126
Cumulative rainfall (mm)	544.2	536.5	678.8
Dam storage volume（mm）	45.9	363.0	500.0
Cumulative outflow（mm）	204.3	2.0	19.7
Max of dam storage volume (10^4 m^3)	4,251	25,781	23,433
Effective dam storage volume (mm)	78.4	693.0	693.0

Values obtained at Oodo Dam and Sameura Dam catchments during the study events

Summary

(1) The rainfall-runoff analysis based on grid-cell distributed runoff model indicates that flood control function by forest ("green dam") is equivalent to 114 mm to 173 mm for such forest-rich catchments as Oodo and Sameura Dams.

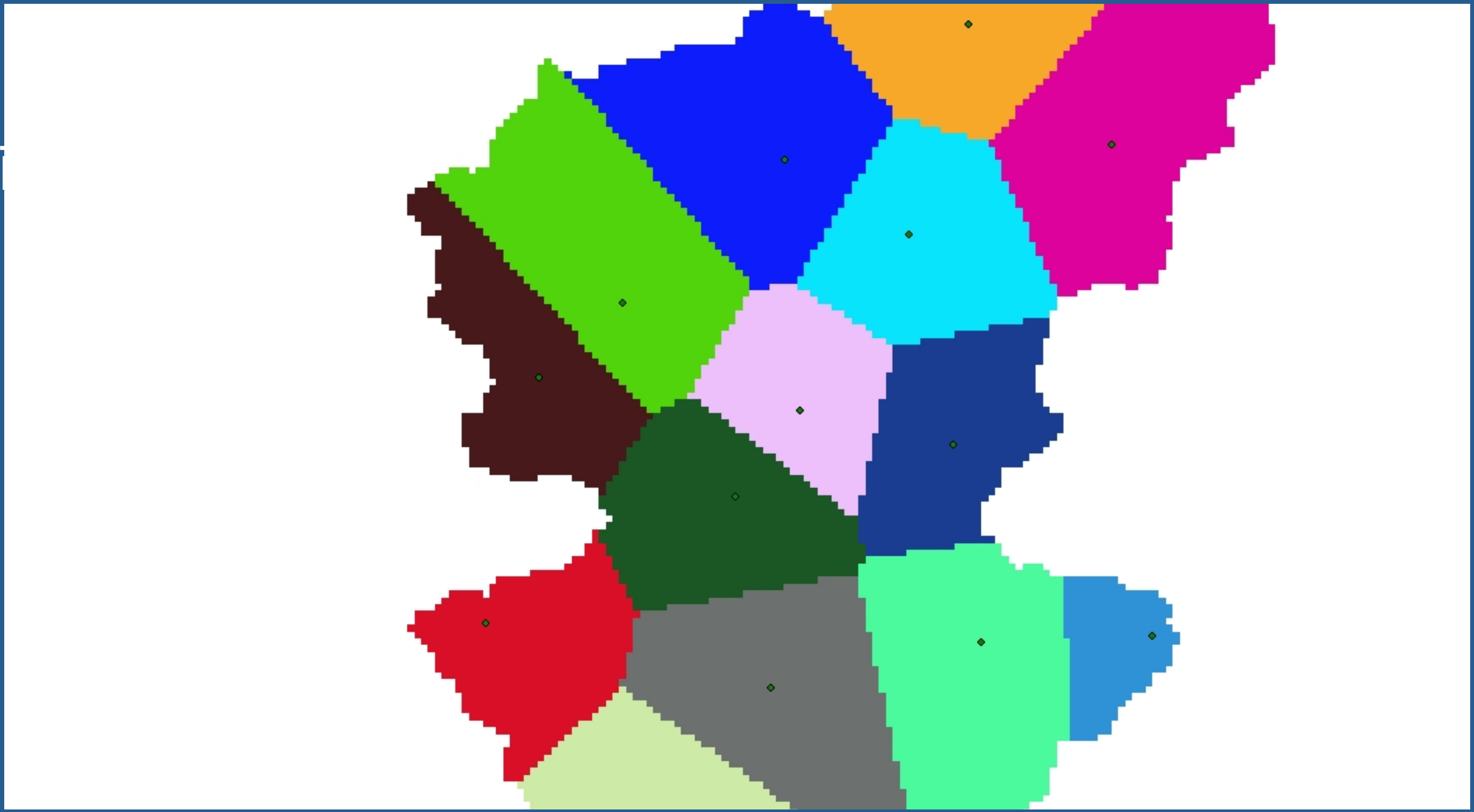
(2) Water storage capacity of forest is estimated around 100~200 mm by other research (e.g., Takara *et al.* 2004), wich is the same results.

(3) It is very important to implement flood control using combination of forest, dam and other facilities, as well as to keep enhancing the water storage capacity of forest and ground where the chance of flood is high.

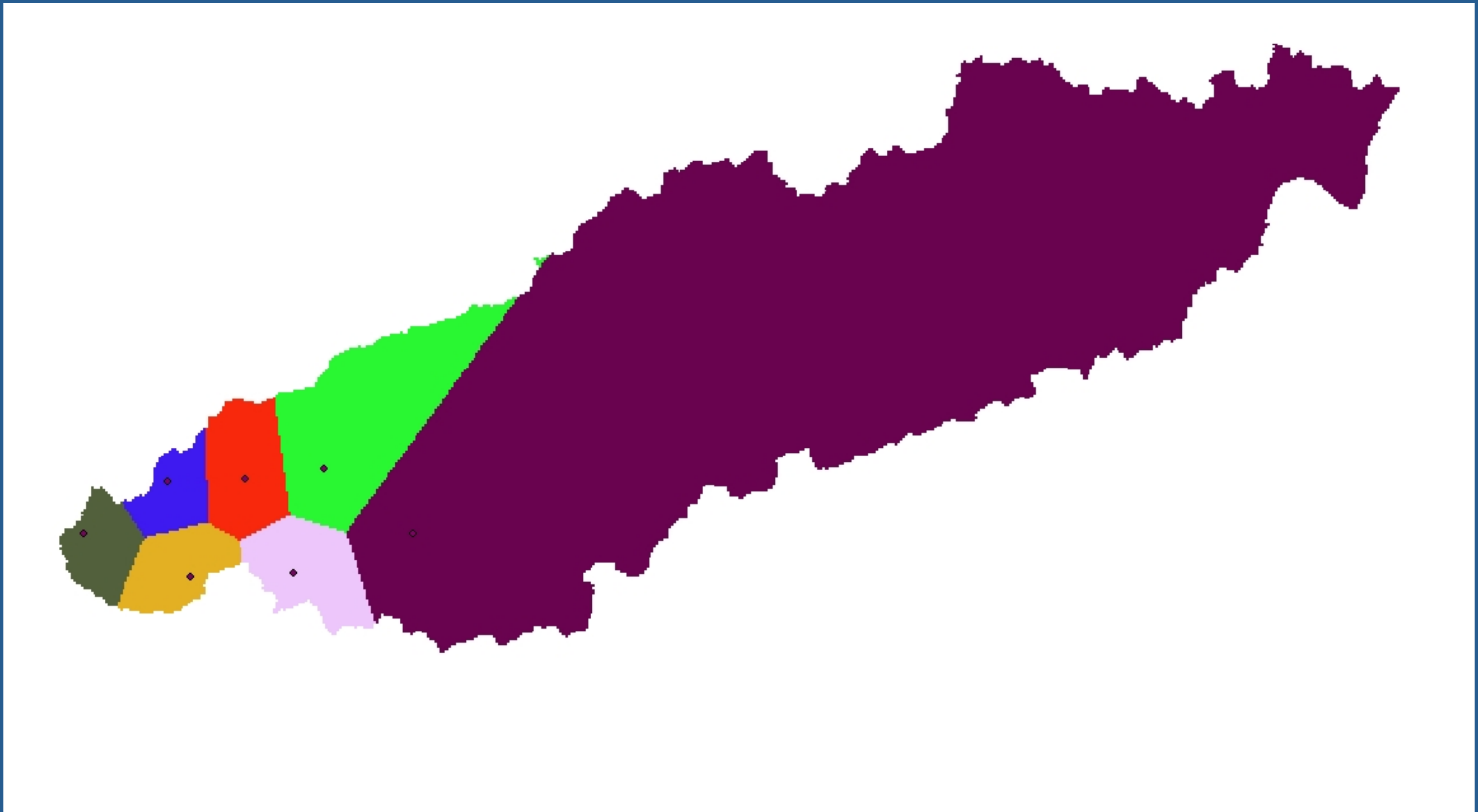
Effects of flood control by the artificial dam

- MLIT（2009）estimated that the river water stage was lowered by 1.4 m at Mori, the Niyodo River by the dam, comparing with no dam assumption case.
- Japan Dam association estimated that the river water stage was lowered by 5.2 m at Motoyamabashi.

Raingages and Thiessen polygons in Oodo Dam catchment



Raingages and Thiessen polygons in Sameura Dam catchment



Example-2

Probable maxima and their application

Study events

Cases when the record-breaking severe events took place.

Typhoon No. 10 on August 1, 2004

Tokai Rainstorm on September 11, 2000

Nasu storm and flood in August 1998

Typhoon No. 12 (Talas) in the Kii Peninsular September 2011

Old and New Issues in Hydrological Statistics

- Probable Maximum Precipitation (PMP)
- Probable Maximum Flood (PMF)
- Probable Maximum Tsunami (PMT)

which are useful for considering extreme events that exceed the design level

- Depth-Area-Duration (DAD) analysis

Recent new technologies such as AMeDAS, radars and satellites

Takara, Hashino and Nakao (2000)

2004.8 Typhoon No. 10 Landslides in Tokushima

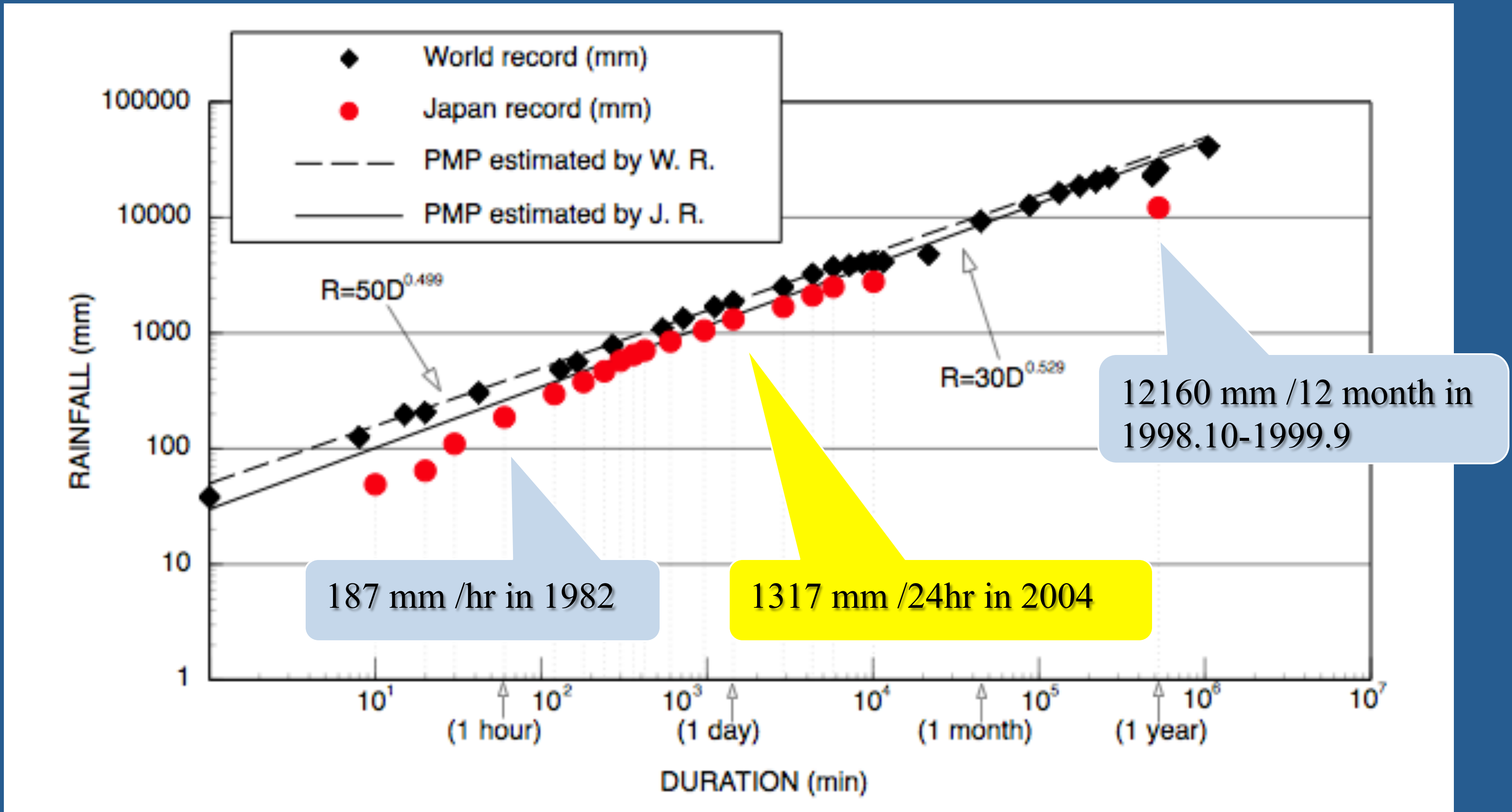
1317 mm in 24 hours !!
Japanese record at Kaikawa Raingauge on 1 August 2004

Azue, Kizawa Village

Saka, Kizawa Village, Tokushima

A bridge of Route 193 was washed away. Tunnel entrance was buried.

Precipitation records in the World and in Japan and the probable maximum precipitation (PMP)



Recent record-breaking precipitations in Japan are also indicated.

September 2000 Tokai Rainstorm

Maximum hourly rainfall 93 mm, Maximum daily rainfall 428 mm at Nagoya

Dike break at Biwajima, Aichi, September 12

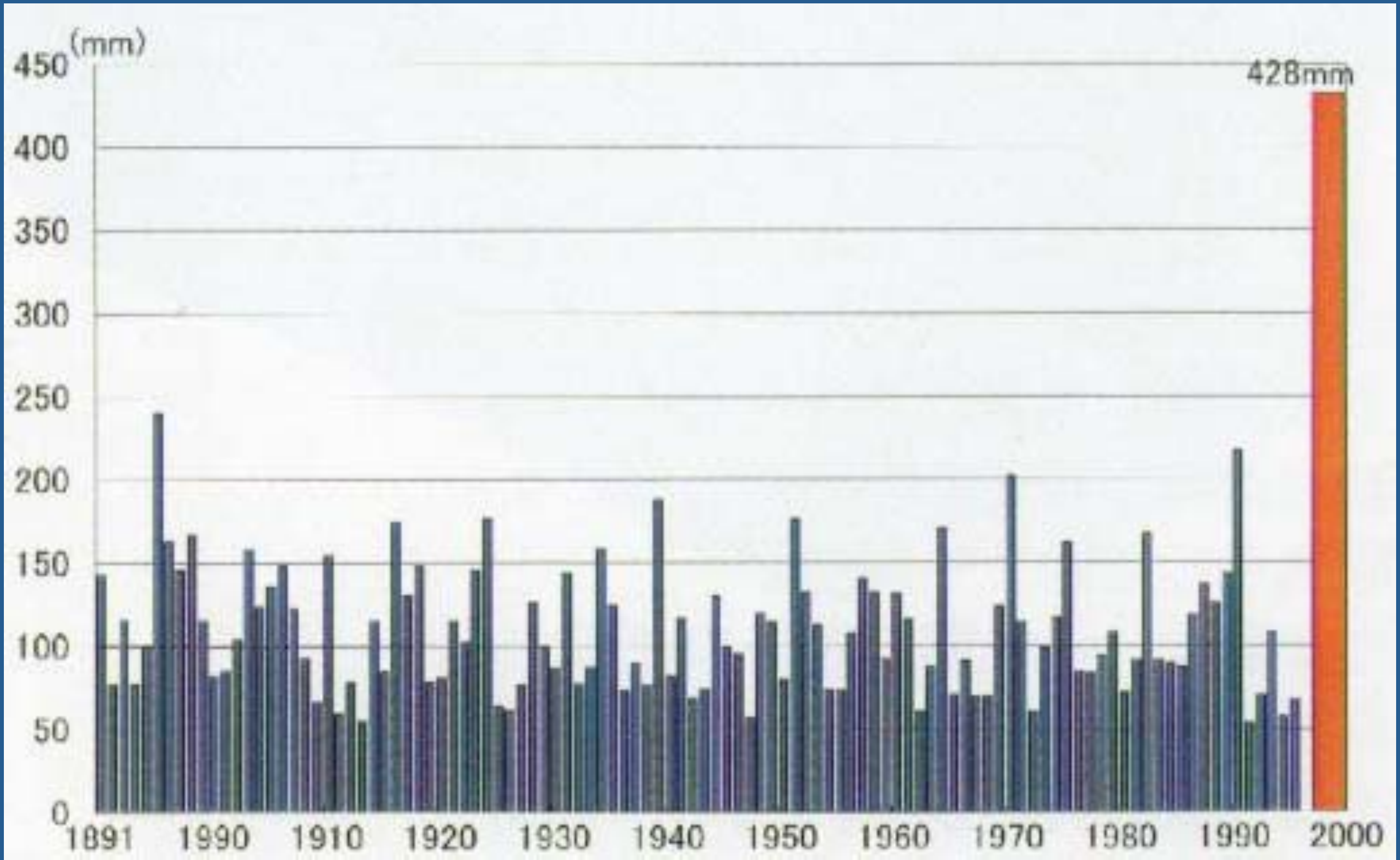
Damages

Inundated houses: about 70,000

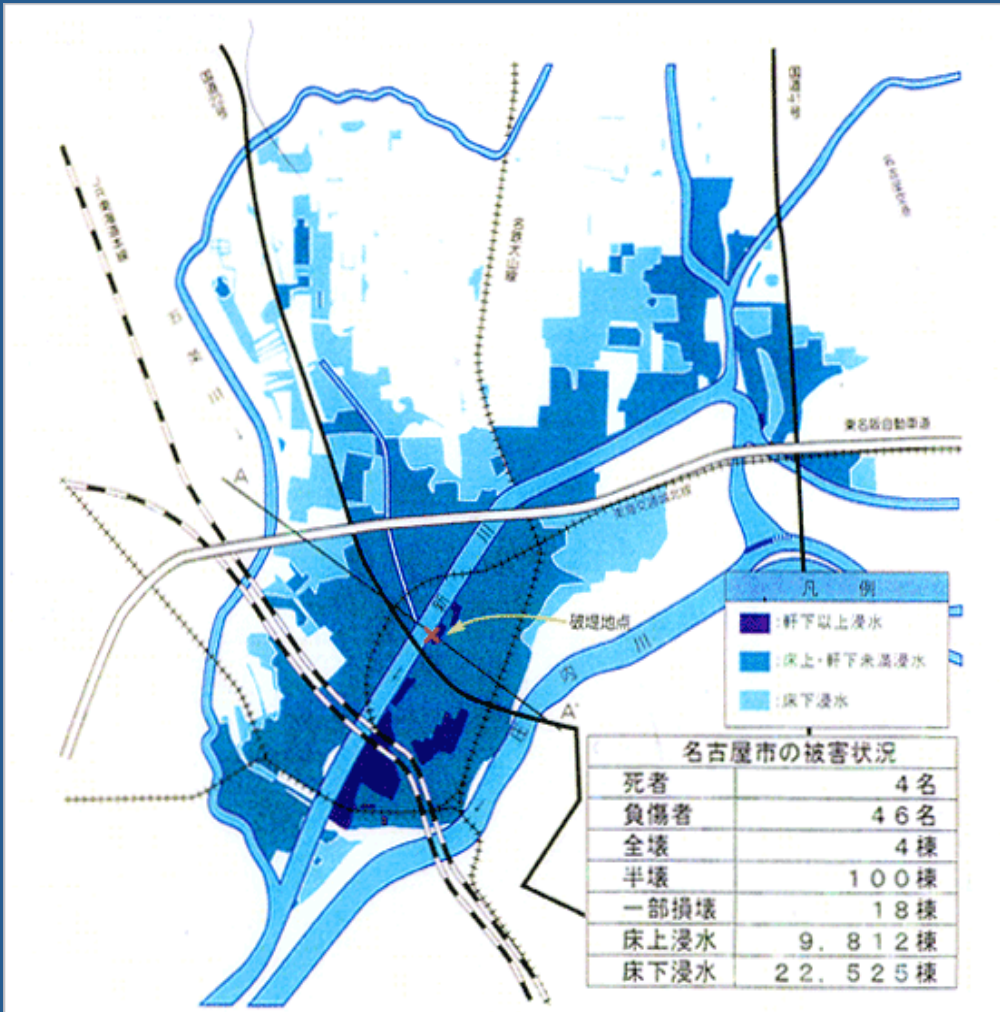
Economic damage: 6 billion USD

Tokai Rainstorm on September 11, 2000

Historical maximum daily rainfall (428 mm) at Nagoya



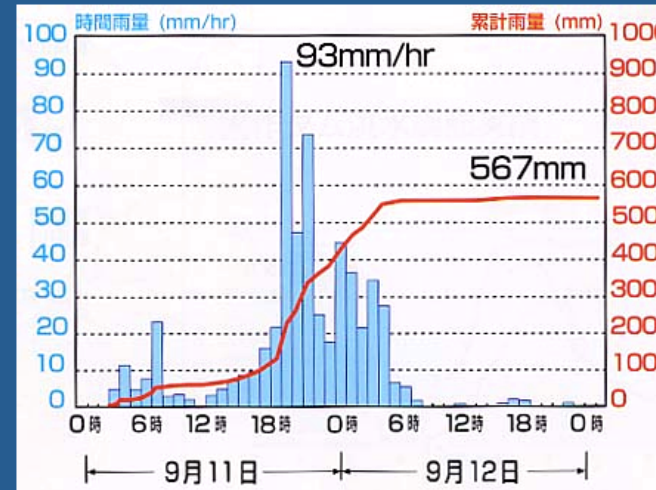
Tokai Rainstorm (September 11, 2000)

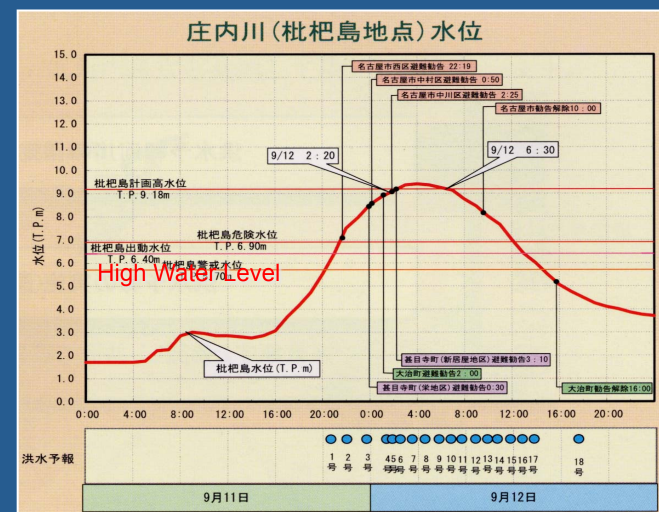


死者	4名
負傷者	46名
全壊	4棟
半壊	100棟
一部損壊	18棟
床上浸水	9，812棟
床下浸水	22，525棟

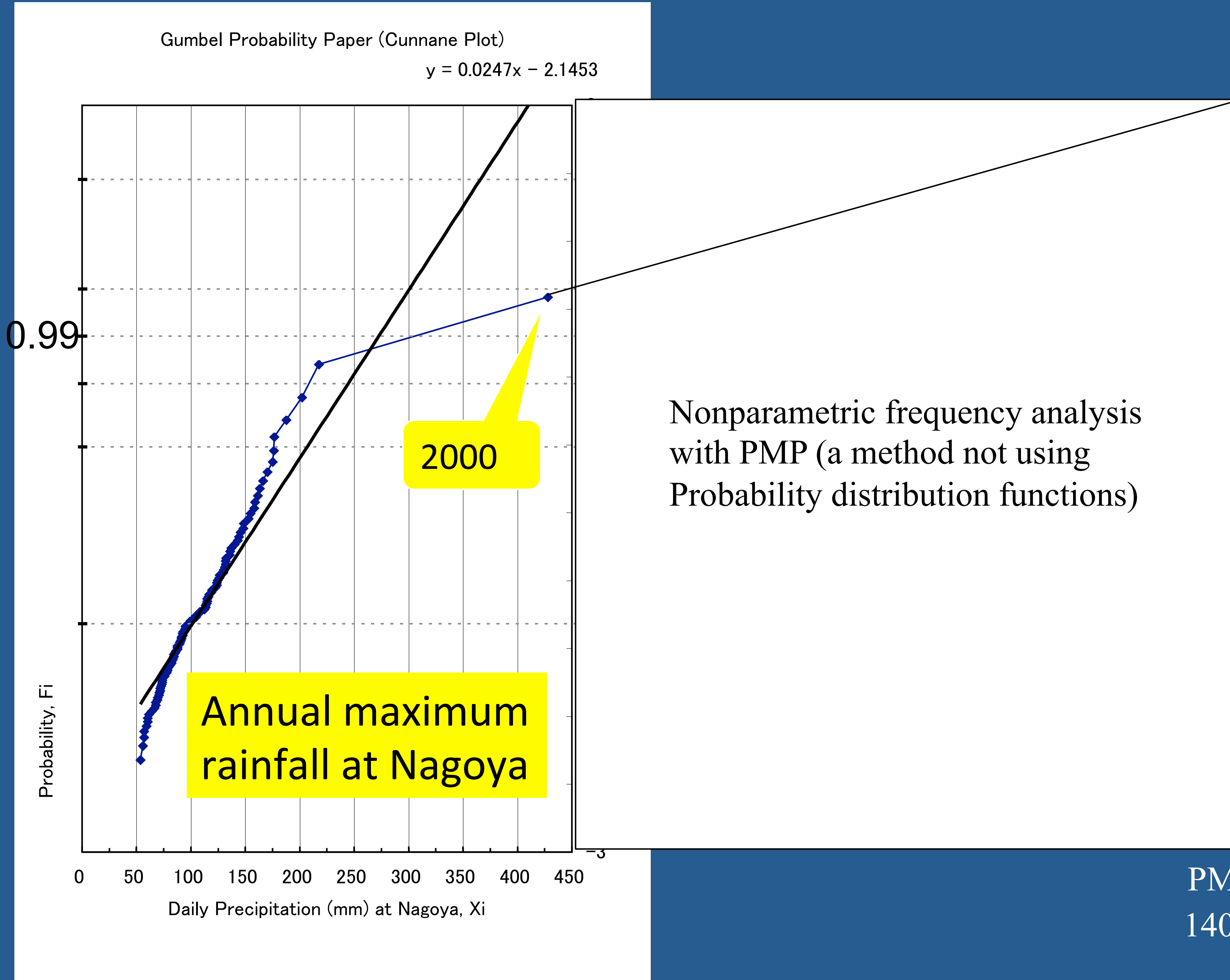
Inundation in Nagoya City area

Rainfall at Nagoya 名古屋





The Shonaigawa River
at Biwajima



Nonparametric frequency analysis with PMP (a method not using Probability distribution functions)

PMP
1400 ?

August 1998 Naka River (Nakagawa)

Max hourly rain: 90 mm, Total rainfall 1,244 mm in 5 days in Tochigi Precture

Naka River at Mito, Ibaraki Pref.

Naka River（MLIT）

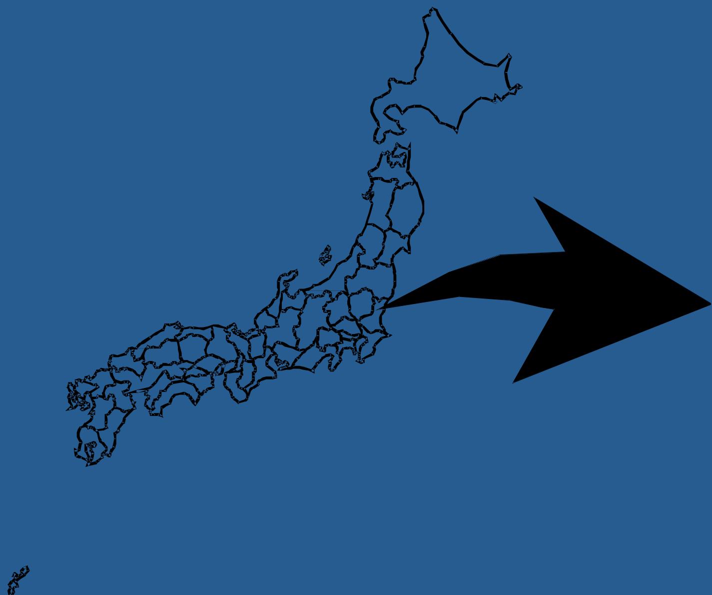
- **Inundated area: 1,726 ha**
- **Inundation above 50 cm: 575 houses**
- **Inundation below 50 cm: 436 houses**

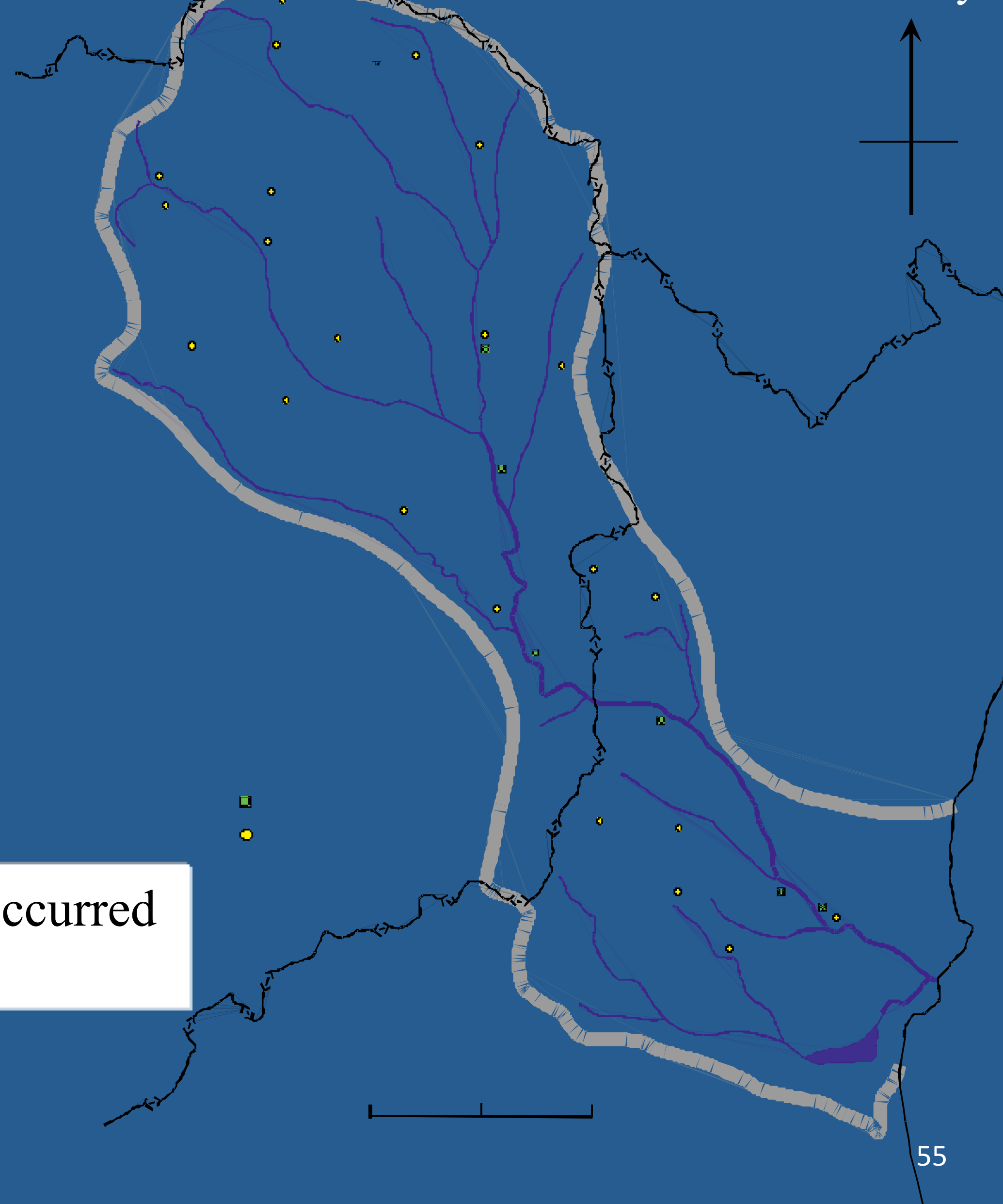
Yosasa River（Nasu, Tochigi）

The Naka river basin

Nasu storm and flood in August 1998

1200 mm rainfall in 5 days



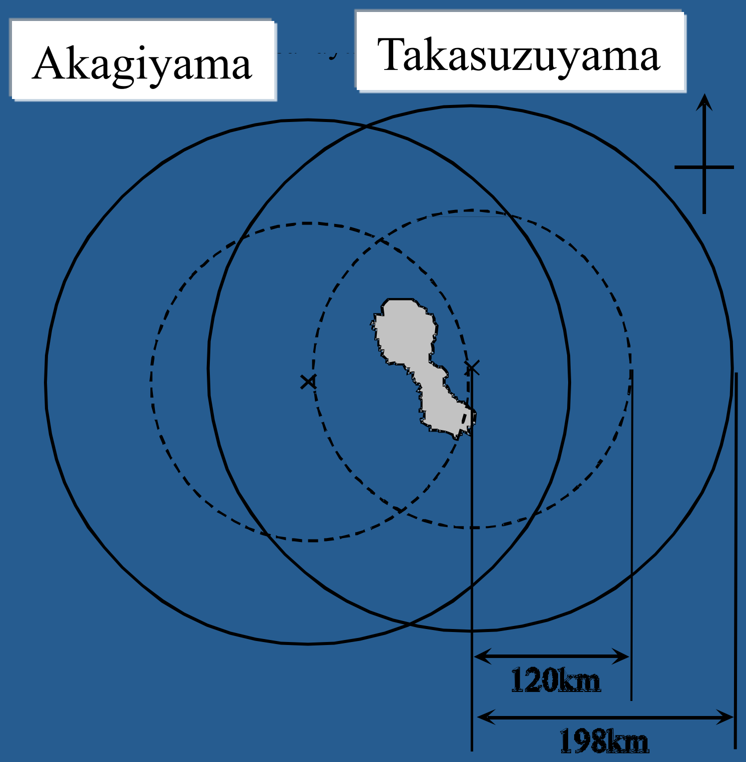


The length of the main stream : 150 km

The catchment area : 3,270 km²

Record-breaking severe storm occurred from August 26th to 31st, 1998

Two radars

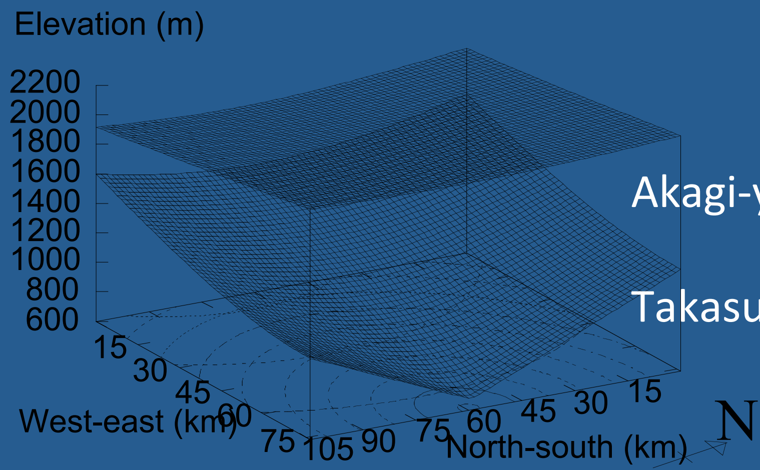


- Akagiyama radar
- Takasuzuyama radar
- 45 ground raingages (hourly rainfall)

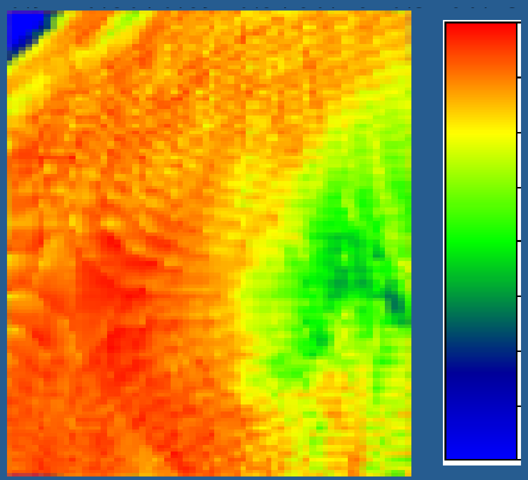
↓

Accurate Spatio-Temporal Distribution of 1998 Storm

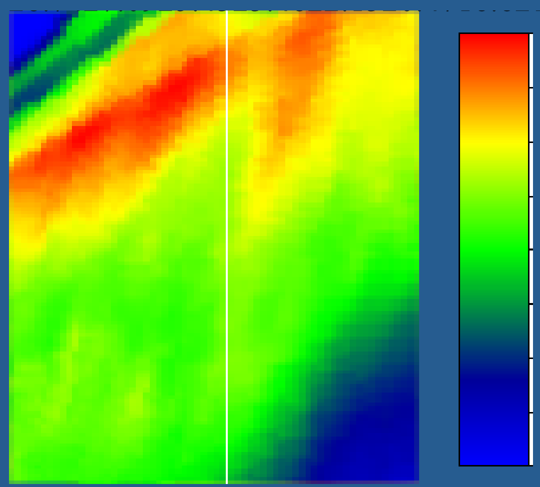
Radar reflective factors averaged every 5 minutes



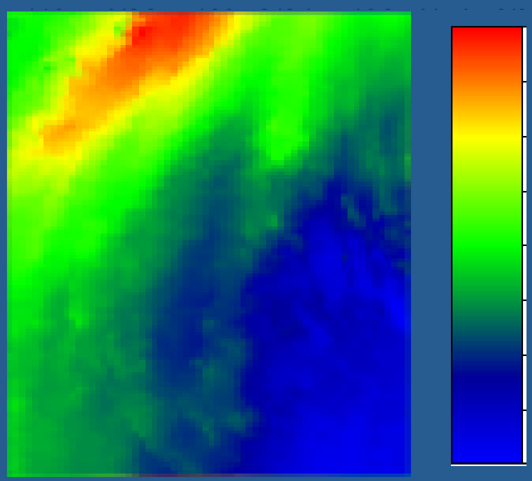
Elevation of scanning lines



Correlation coefficient of reflective factors in dBZ between Akagi-yama and Takasuzu-yama.



Mean reflective factors in dBZ at Akagi-yama.



Mean reflective factors in dBZ at Takasuzu-yama.

DAD equation (modified Horton equation)

2 radars

45 raingages

Rainfall Distribution in Time & Space

R_{mra} best estimate

DD

DA

$$\hat{P}_a(A_i, t) = a \cdot t^{1-c} \exp\left\{-u \cdot t^{-v} (A_i - A_0)^n\right\}$$

Modified Horton equation

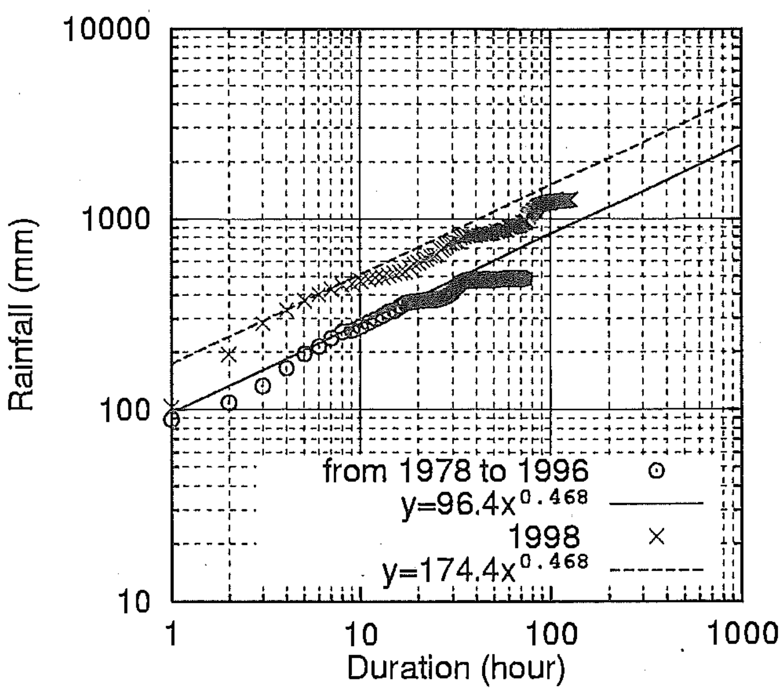
Sherman equation

- DA relationships
- Nonlinear Optimization Technique

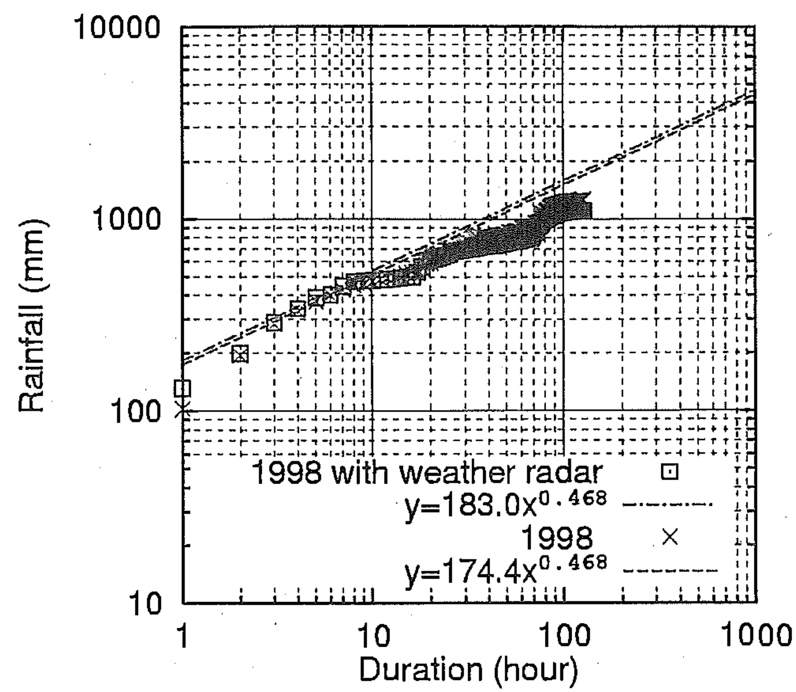
DAD analysis

PMP

Results of DD analysis

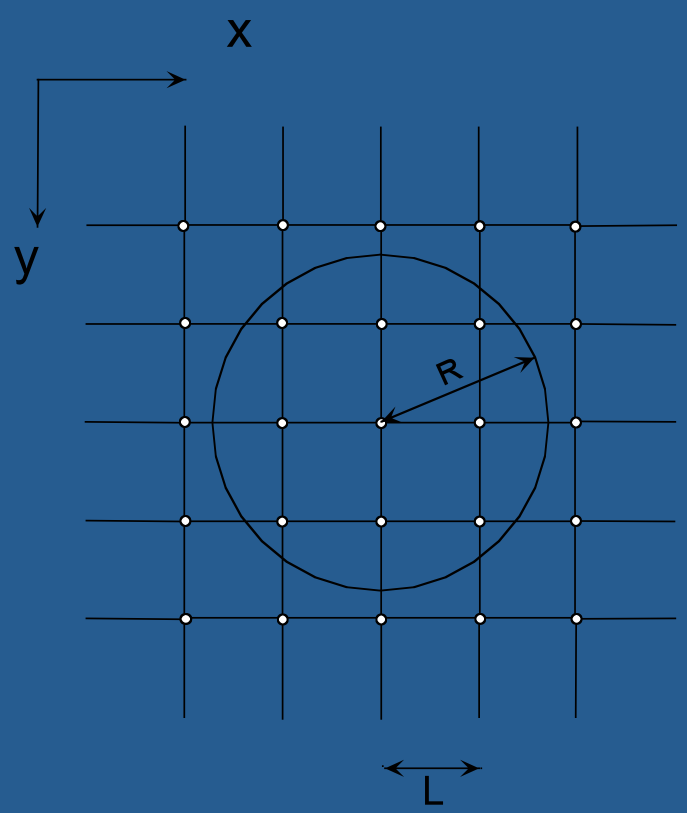


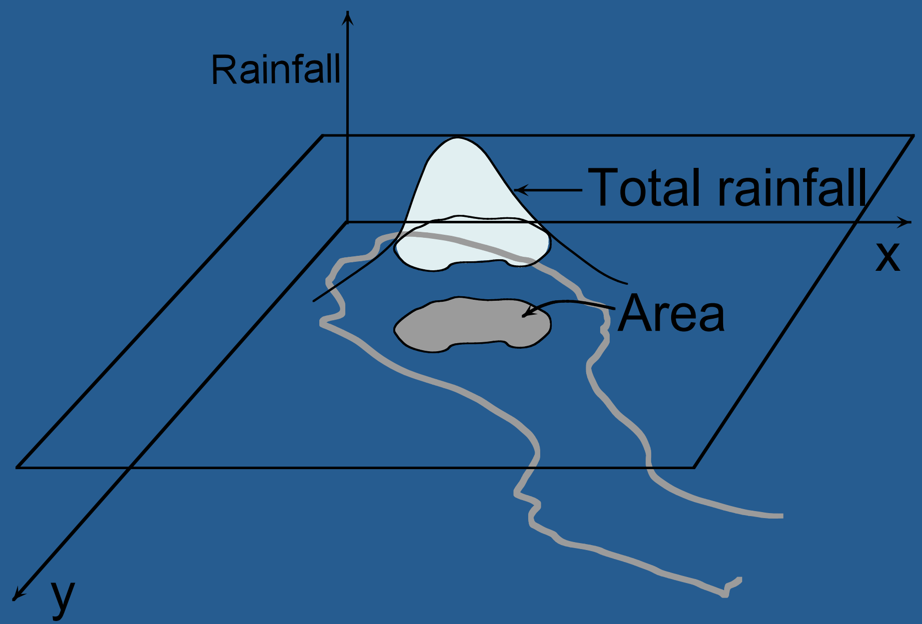
Comparison of DD relationships obtained with raingages in 1978 to 1996 and in 1998



Comparison of DD relationships with raingages and weather radar in 1998

Methods for estimating DA (Depth-Area) relationship



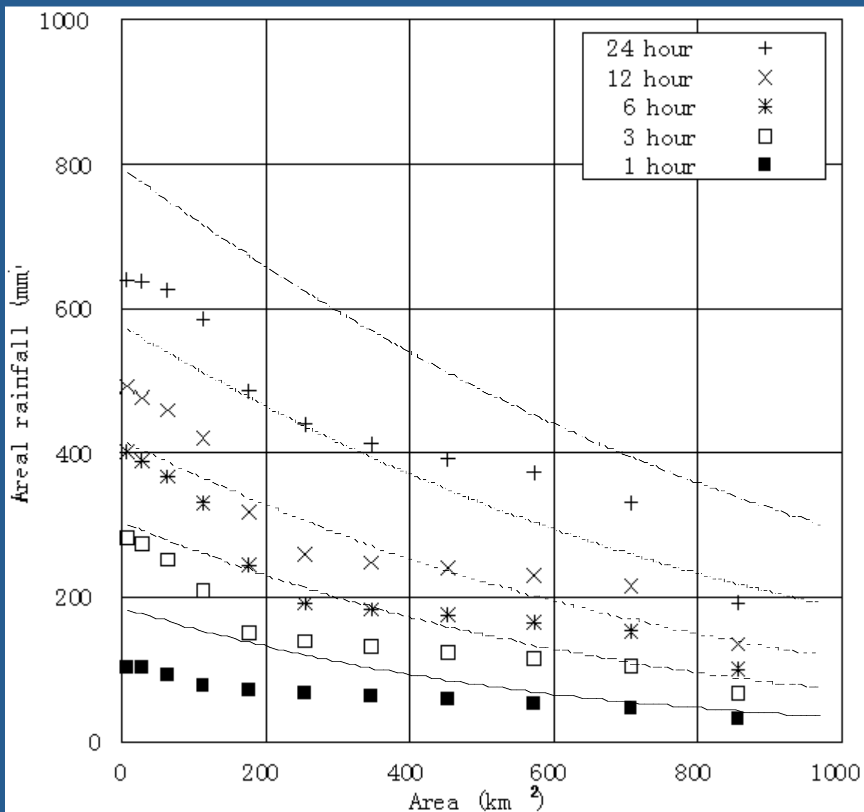


Constant Area Method (CAM)

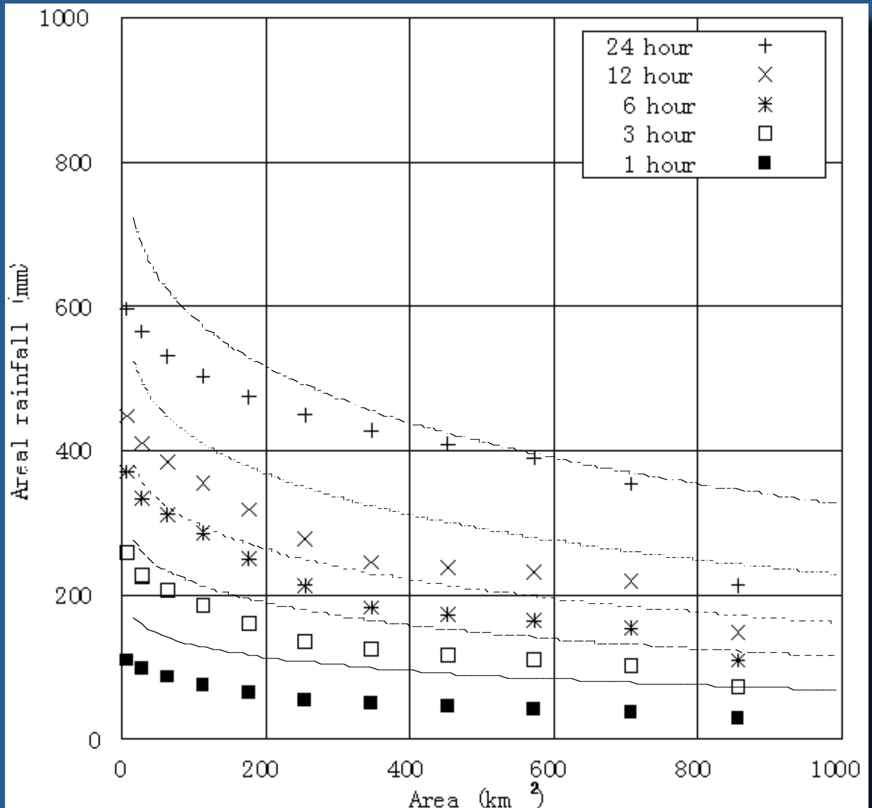
Fixed Rainfall Method (FRM)

Results of DAD analysis (1)

Nonlinear Optimization Technique



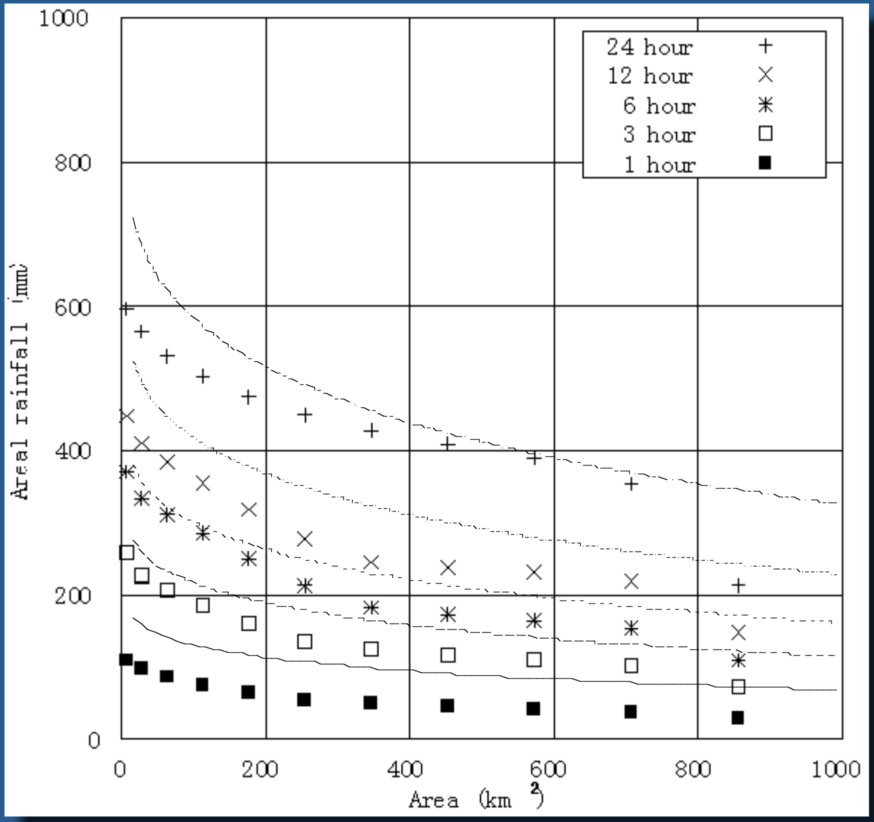
DAD analysis using CAM with ground raingages (Thiessen Method)



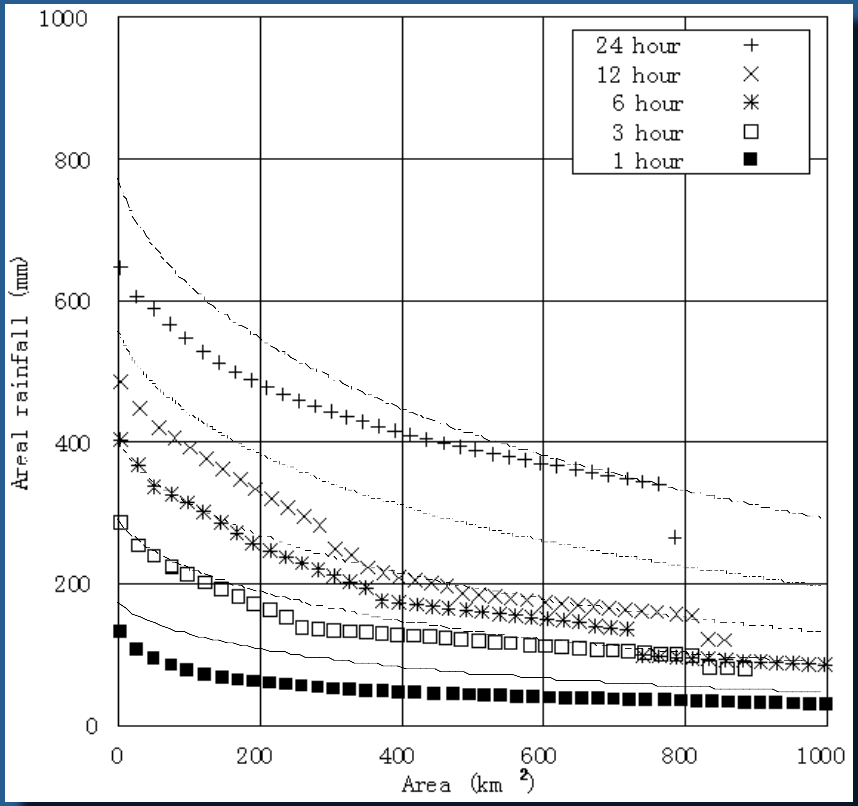
DAD analysis using CAM with weather radar (MRA)

Results of DAD analysis (2)

$$\hat{P}_a(A_i,t) = 183.0 \cdot t^{0.468} \exp\left\{-0.0239 \cdot t^{-0.108}(A_i - 2.25)^{0.595}\right\}$$

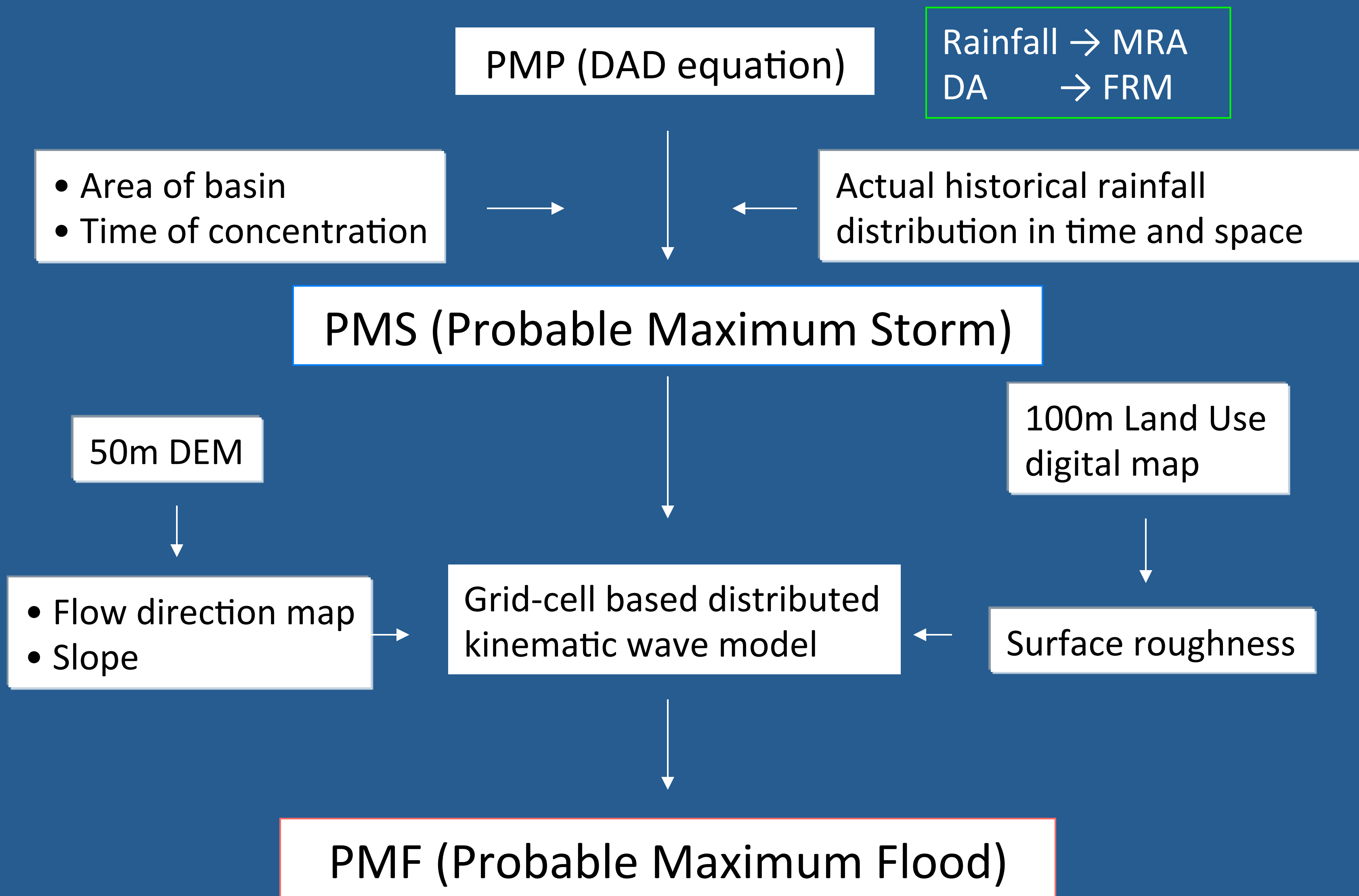


DAD analysis using CAM with weather radar (MRA)



DAD analysis using FRM with weather radar (MRA)

Grid-cell Based Rainfall-runoff Analysis

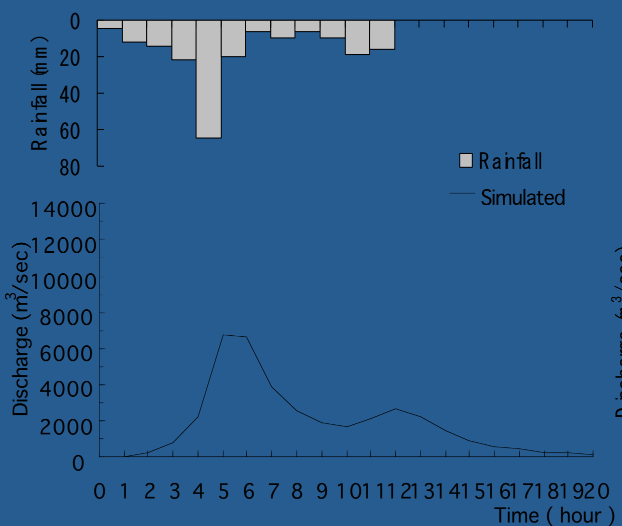


Conditions and Results of estimating PMF

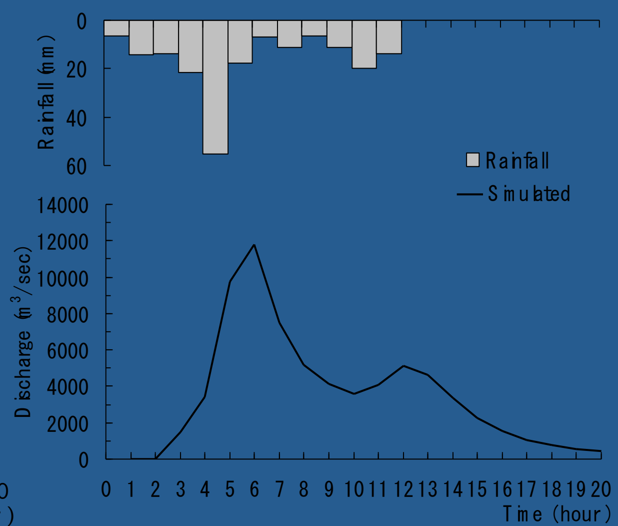
Input PMS into the grid-cell based distributed runoff model.

The parameters of the model is adjusted to reproduce the peak discharge of 1998 flood at Kawahori.

Assume that runoff ratio is 1.0 (no rainfall loss).

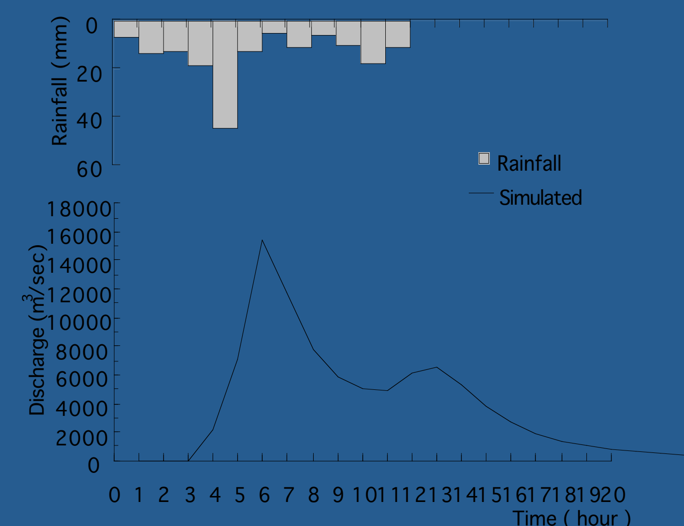


Kurobane ⟶ 6,730



Oguchi ⟶ 11,790

(1836-year discharge)



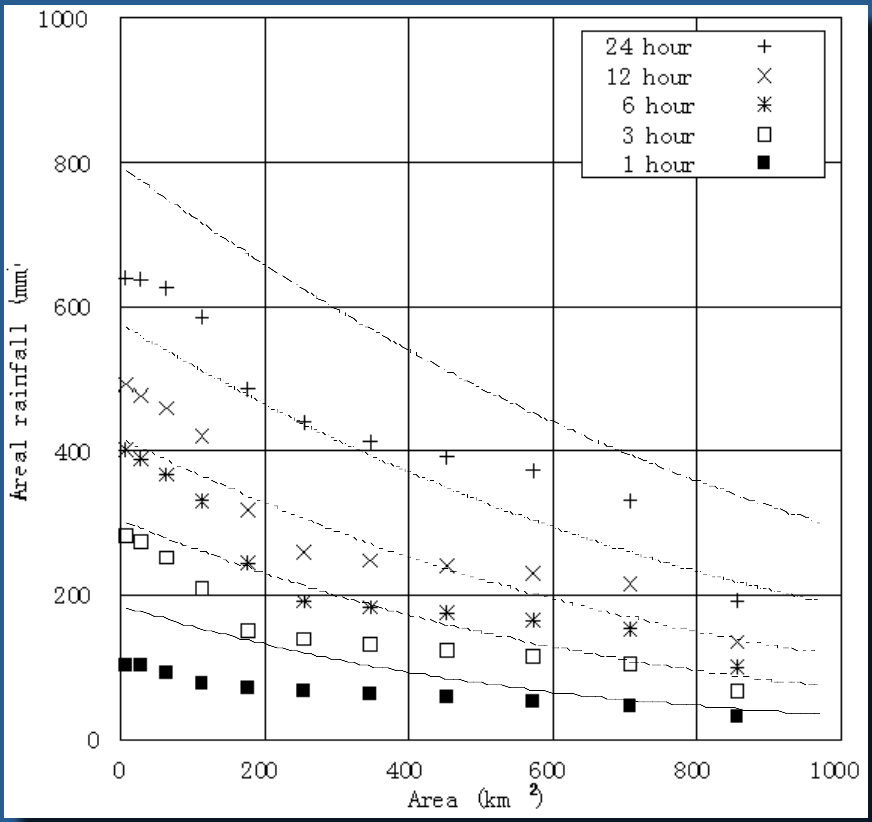
Kawahori ⟶ 15,370

(m^3/sec)

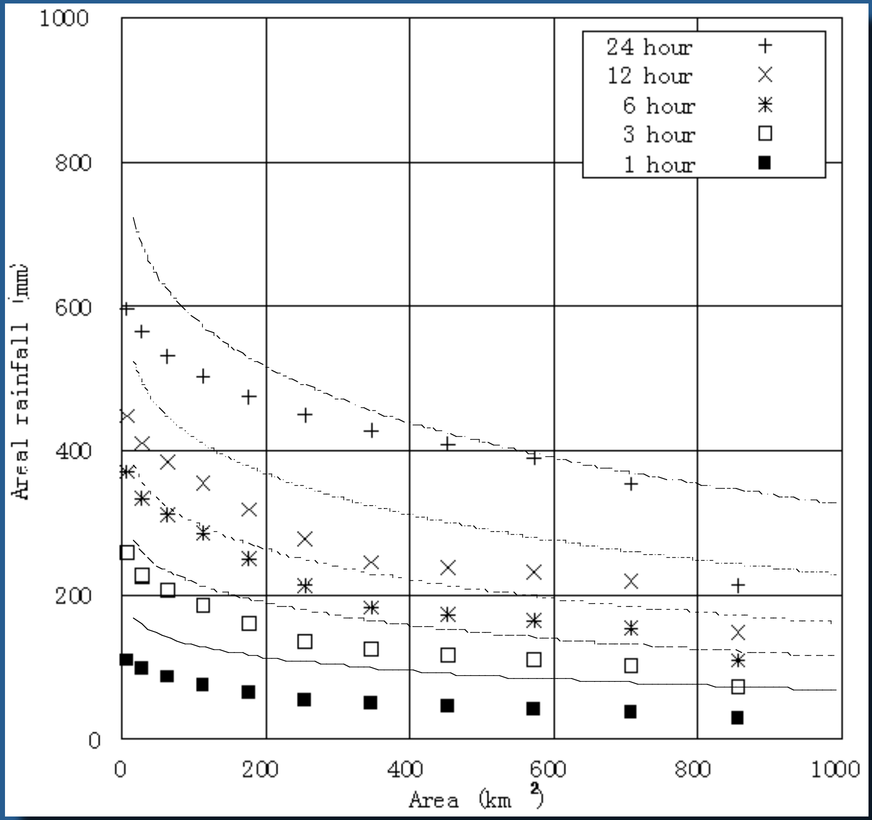
The PMF at Oguchi (11,790 m^3/s) is about two times larger than the 100-year discharge at Oguchi (5,412.1 m^3/s).

Results of DAD analysis (1)

Nonlinear Optimization Technique



DAD analysis using CAM with ground raingages (Thiessen Method)



DAD analysis using CAM with weather radar (MRA)

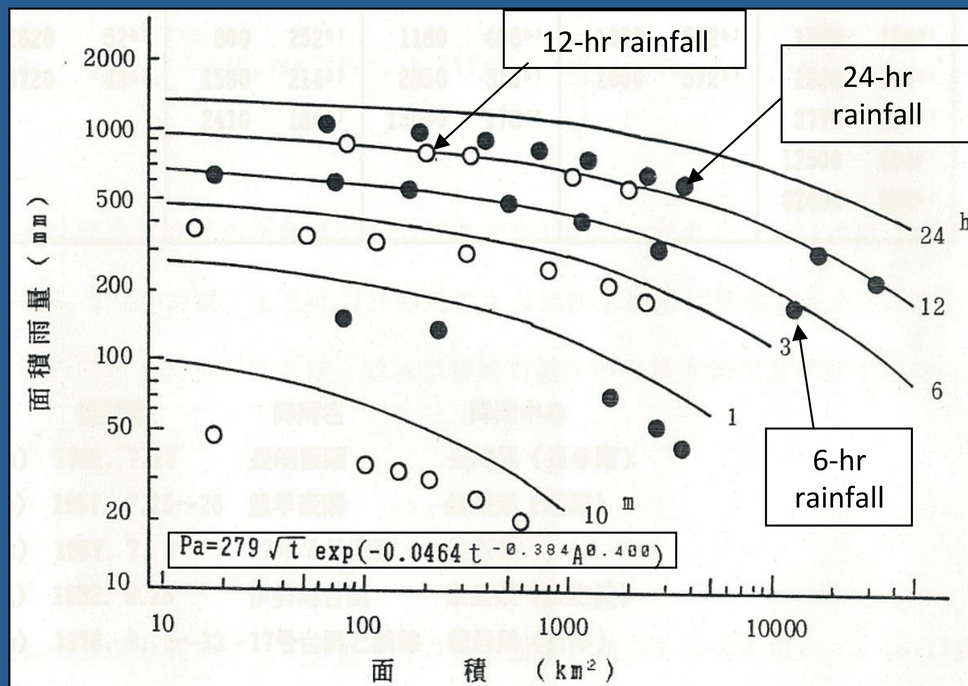
Suggestions

- Long-term records are coming: NPF (non-parametric frequency) analysis could be a best solution.
- PMP by statistical or physics-based approach can give a good guide for longer return-period events.
- Even for short-term records, combination of NPF and PMP is useful.
- DAD (depth-area-duration) analysis can be reorganized by new technologies: raingage networks, radars and satellites. PMF can be derived by using PMP and modern hydrological models for flood disaster risk management.
- Form a group on extreme events and risk research.

Typhoon No. 12 (Talas) in the Kii Peninsular September 2011

DAD analysis to evaluate maximum rainfall

D A D = Depth～Area～Duration relationship

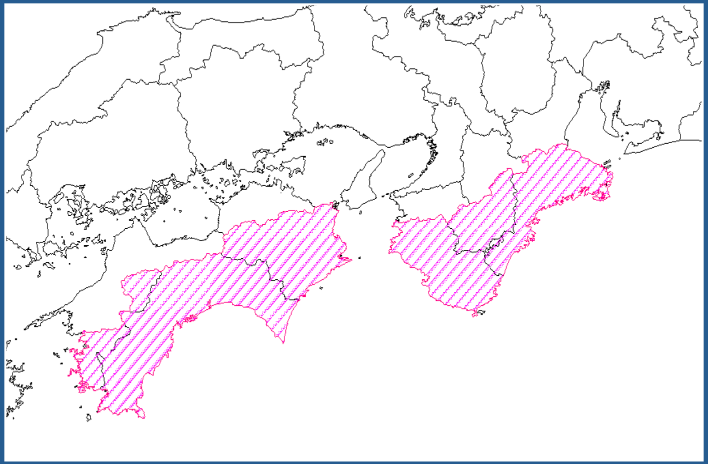


Kuwahara's DAD equation

$$P_a = 279\sqrt{t} \cdot \exp\left(-\frac{0.0248}{t^{0.414}} \cdot A^{0.5} \right)$$

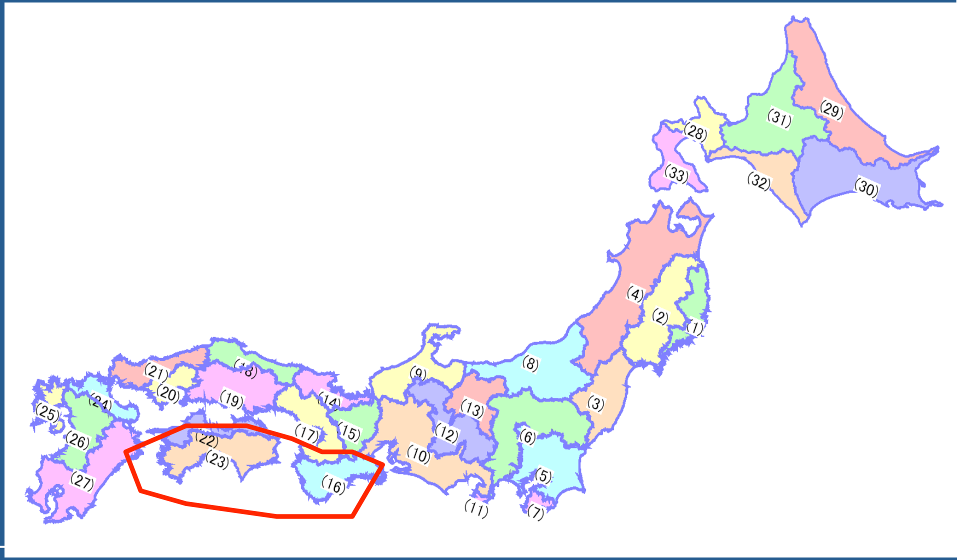
Kuwahara's DAD analysis based on raingage data

DAD study areas



Regionalization by several factors

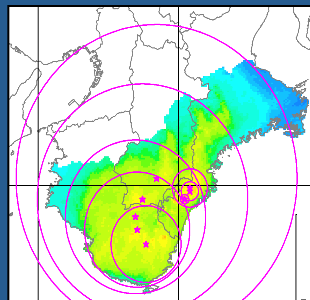
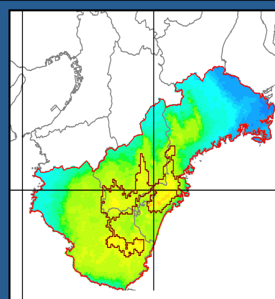
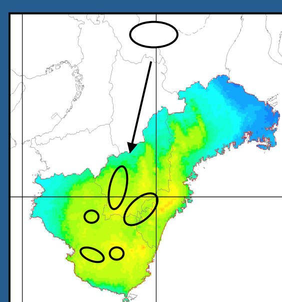
- アメダスデータ等の1時間および日雨量の既往最大値
- 日雨量100mm以上の年間発生回数の平年値（1979～2000）
- 既往最大降雨の発生要因
- 地形（脊梁山脈の配置）
- 一級河川流域界　等



Radar-AMeDAS rainfall used

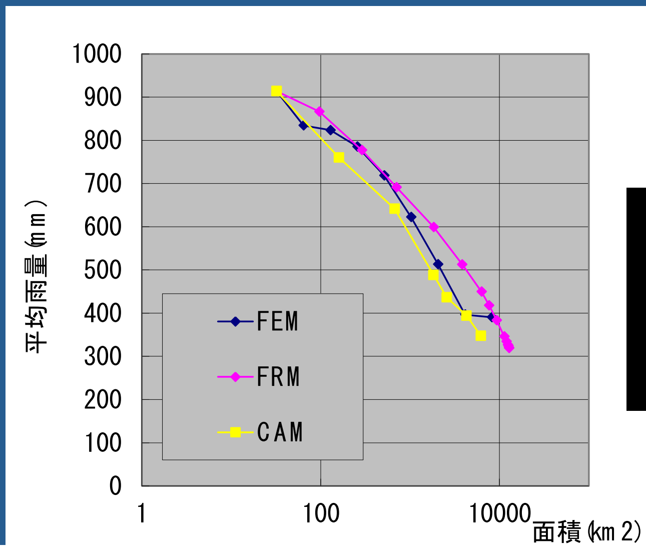
Year.month	Spatial resolution	Time interval	Geodetic reference
1988.1～2001.3	5 km Lon. 0.05° Lat. 0.0625°	1 hour	Japan
2001.4～2003.5	2.5 km Lon. 0.025° Lat. 0.03125°	1 hour	Japan
2003.6～2005.12		30 min (Prev. 1 hour)	World
2006.1～	1 km Log. 0.0083° Lat. 0.0125°	30 min (Prev. 1 hour)	World

DAD analysis methods

Method		Characteristics	Areal rainfall
面積固定法 CAM		一定形状に対する面積雨量の最大値を評価する。 当該地域の雨域空間分布を尊重した評価手法。	FEM, FRMに比べ小さい
面積固定法 （変形面積法） FEM		雨量の最大値を追跡して雨域を設定し面積雨量を算定する。	概ねCAMより大きくFRMと同程度。 雨域が分かれている場合には、FRMより小さく評価される。
雨量固定法 （計測域固定型） FRM		雨量閾値以上の雨域を集約して面積雨量を算定する。 当該地域において、ある面積に対して最大降りうる雨量ポテンシャルを評価する手法。 面積雨量の評価結果は地域区分の取り方に影響される。	概ねCAM, FEMより大きい。

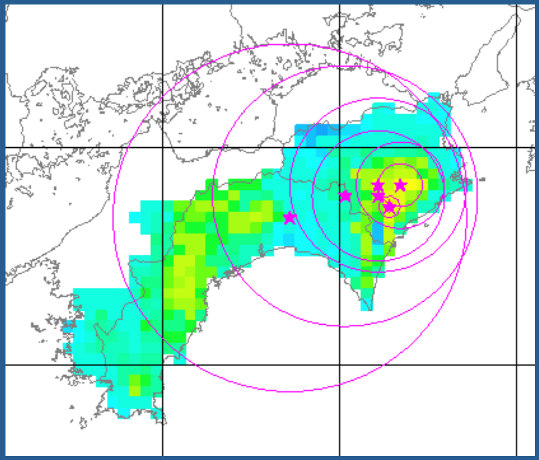
Areal rainfall depends on DAD methods

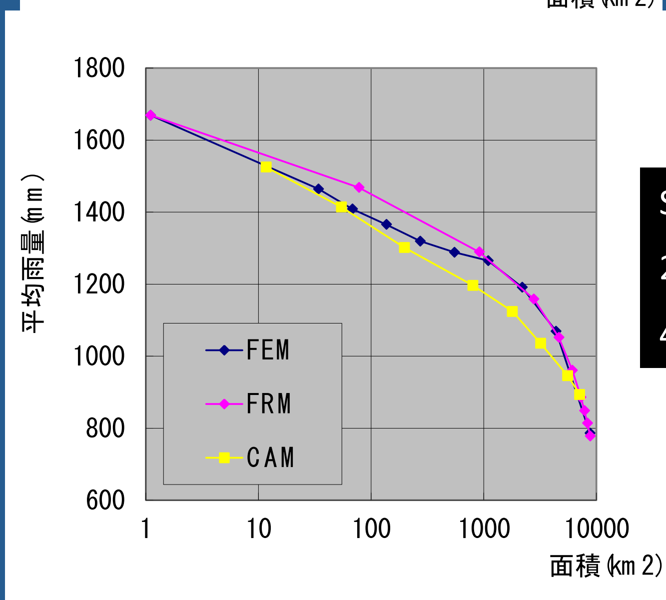
FRM ＞FEM ＞CAM



South-Shikoku1997.9.16 23:00

48-hour rain

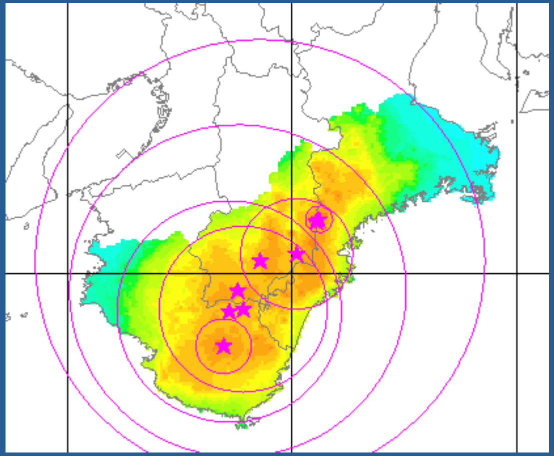




South-Kii

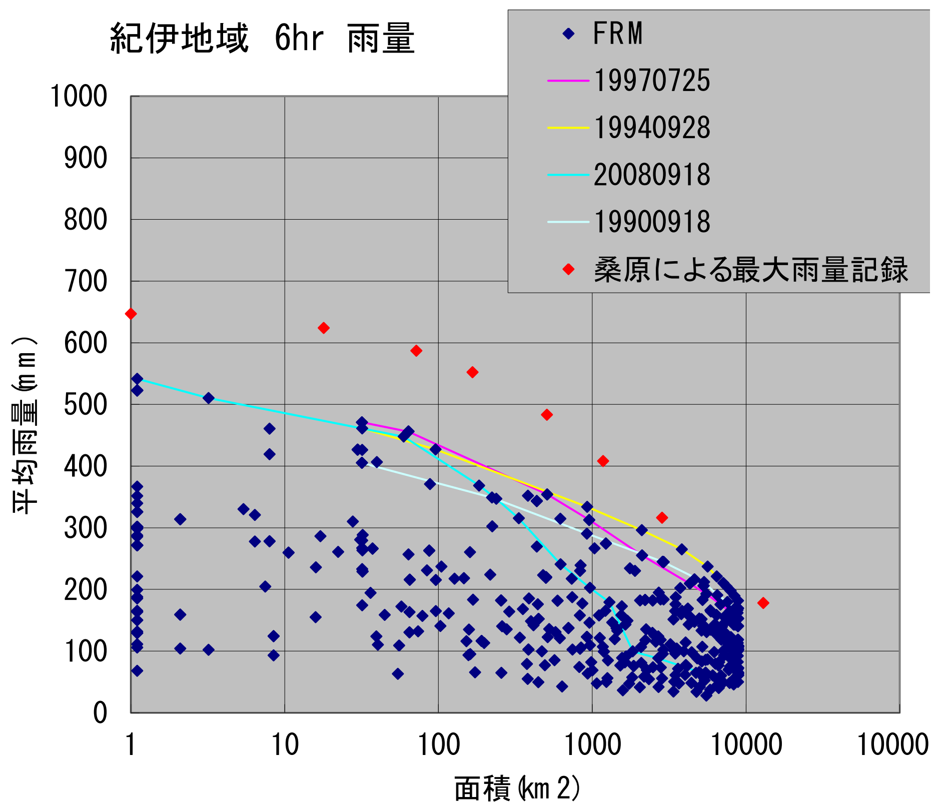
2011.9.4 10:30

48-hour rain

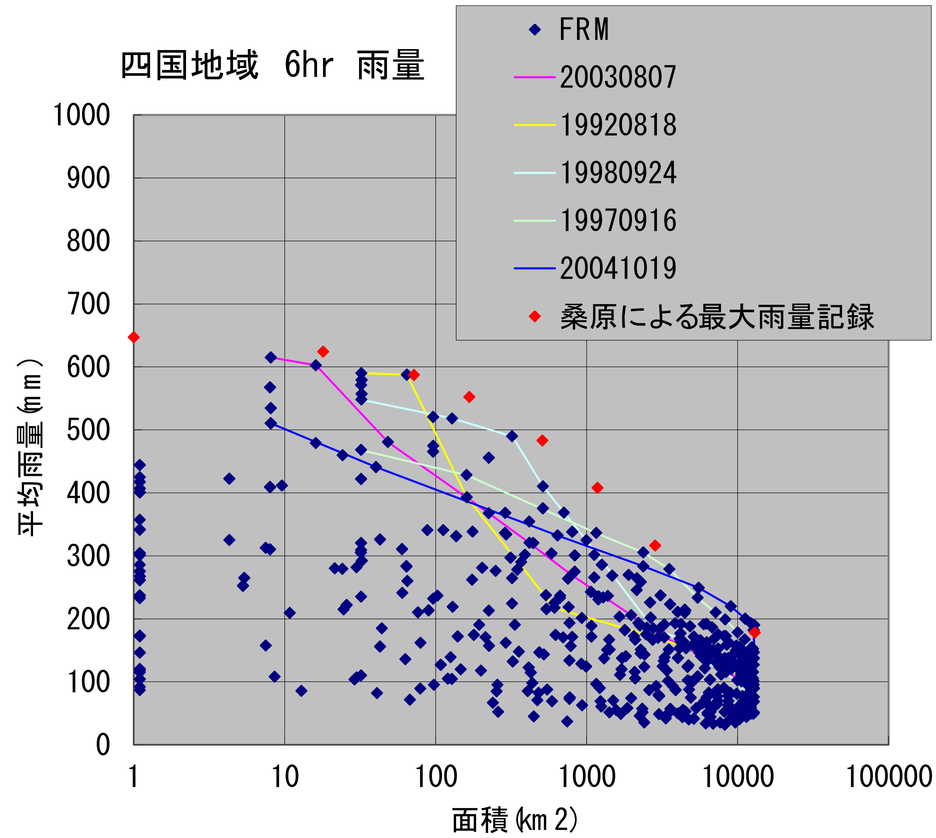


DAD analysis results fo 6-hour rainfall

Kii Peninsular



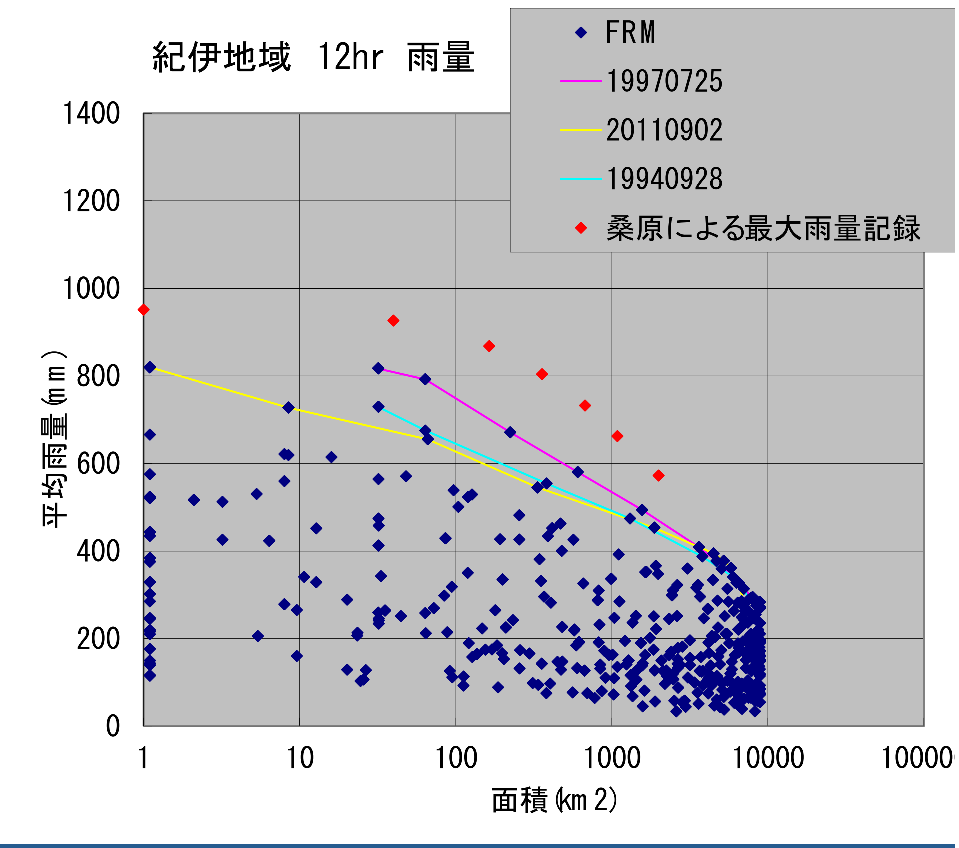
Shikoku



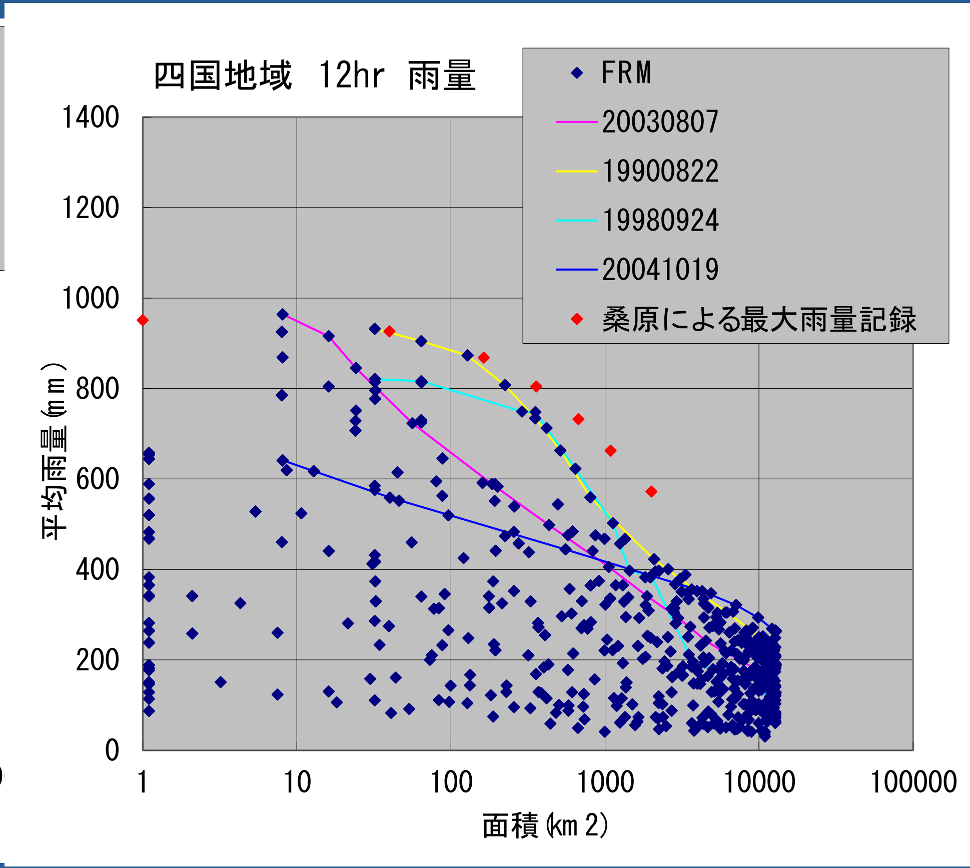
DAD analysis results（12-hour rainfall）

四国地域では、桑原による最大雨量記録と同等規模の豪雨が複数発生し，2003年8月降雨は超過している。

Kii Peninsular



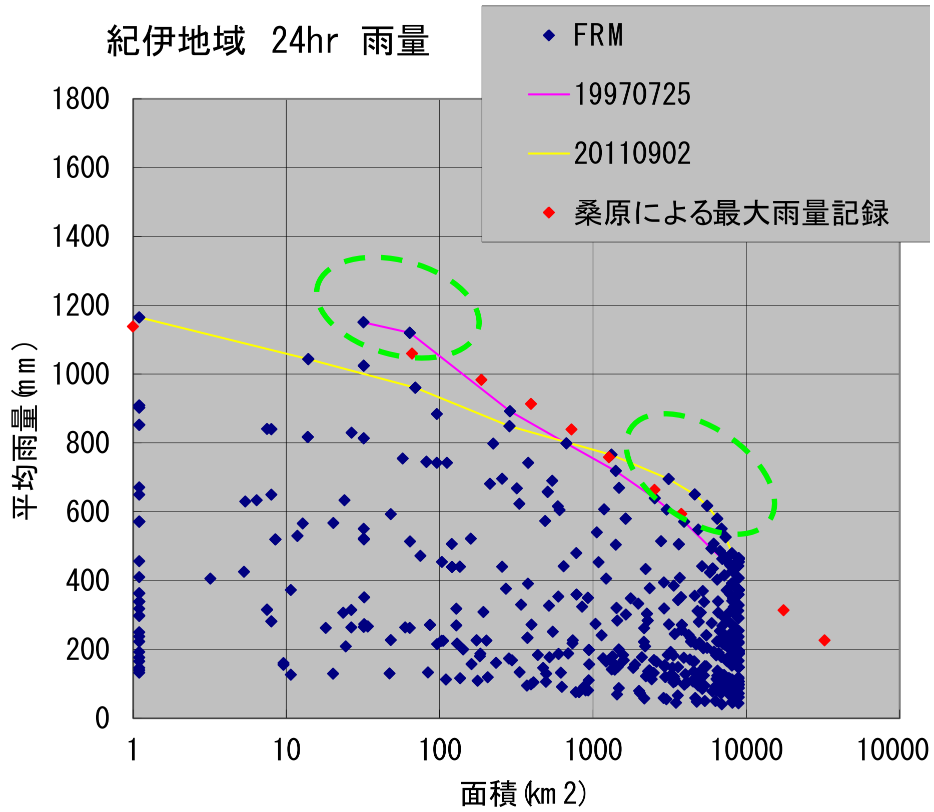
Shikoku



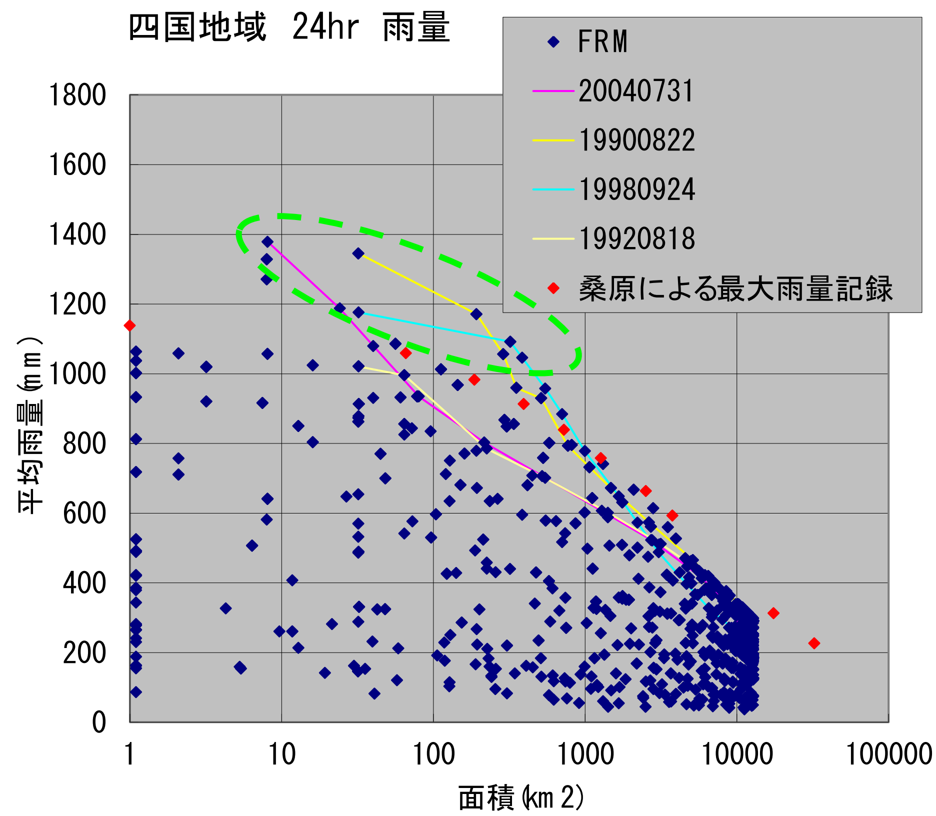
DAD analysis results（24-hour rainfall）

２地域とも、桑原による最大雨量記録と上回る規模の豪雨が複数発生している。

Kii Peninsular

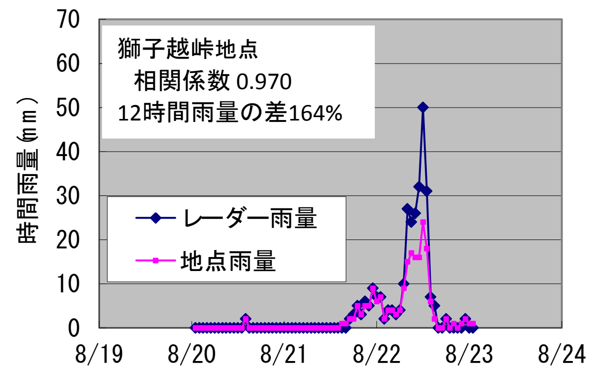


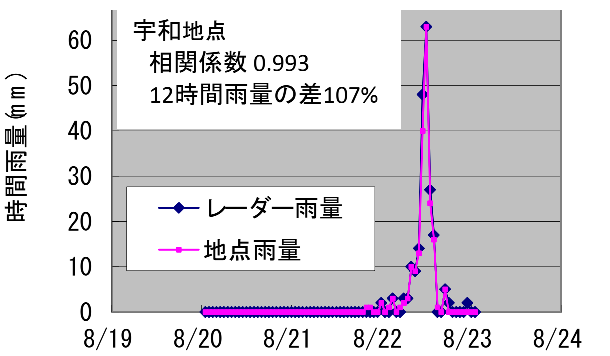
Shikoku

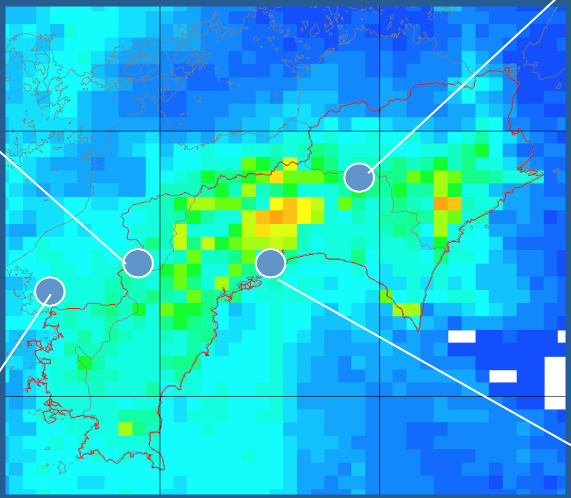


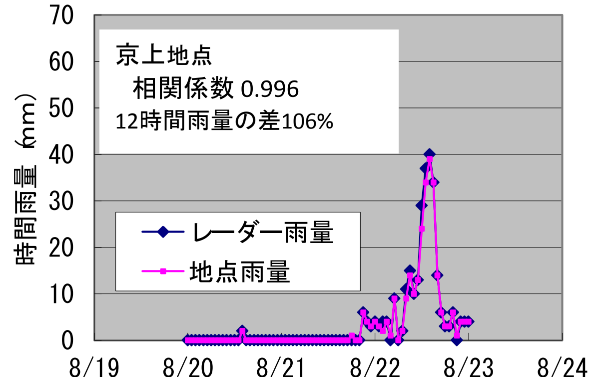
Radar rain and raingage data

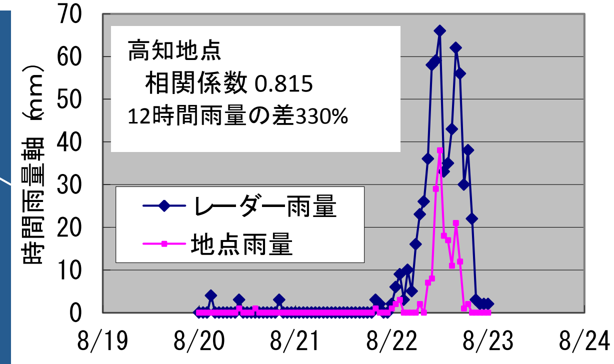
対象地域内のアメダス観測地点および国土交通省雨量観測所のうち水文水質データベースから得られる地点の毎時雨量データと，その箇所に該当するメッシュ区画のレーダー雨量データを時系列で比較した.











地域 発生日	評価地点数	相関係数 (1時間雨量の時系列データ)	12時間雨量最大値の比 (レーダー／地点)
四国1990.08.22	67	0.842	199%
四国1998.09.24	79	0.935	120%
四国2003.08.07	74	0.831	108%
四国2004.07.31	82	0.903	120%
紀伊2011.09.02	19	0.897	109%

地点雨量記録を大幅に上回るケースがある.

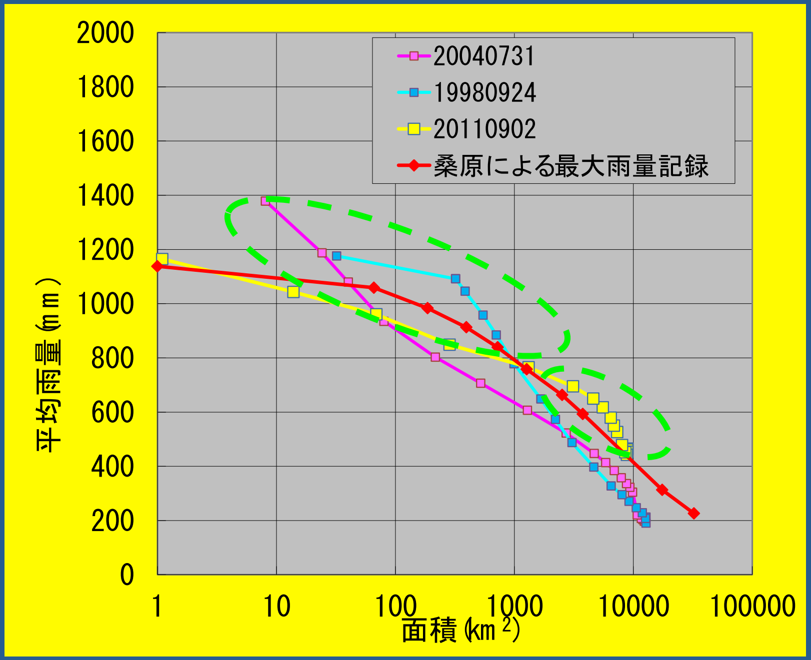
DA analysis updated the maximum rainfall

地点雨量との差異が大きい豪雨をのぞき，レーダー雨量を用いた継続時間別の面積雨量最大値により、桑原による既往の最大雨量を更新した。

既往の日本最大雨量のデータの更新状況

単位 :雨域面積［km^2］、雨量［ｍｍ ］

降雨継続時間　12hr			降雨継続時間　24hr		
雨域面積	面積雨量	生起年月	雨域面積	面積雨量	生起年月
~~0~~	~~951~~	~~1957.7~~	~~0~~	~~1138~~	~~1976.9~~
8	964	2003.8	8	1378	2004.8
40	926	1957.7	32	1176	1998.9
164	868	1957.7	~~66~~	~~1059~~	~~1957.7~~
358	804	1957.7	~~187~~	~~983~~	~~1957.7~~
675	732	1957.7	322	1092	1998.9
1090	662	1957.7	~~395~~	~~913~~	~~1957.7~~
2000	572	1957.7	547	958	1998.9
			707	884	1998.9
			725	839	1957.7
			~~1270~~	~~758~~	~~1957.7~~
			1323	765	2011.9
			~~2520~~	~~663~~	~~1957.7~~
			3115	695	2011.9
			~~3770~~	~~593~~	~~1957.7~~
			5555	617	2011.9
			8068	478	2011.9
			17500	313	1976.9
			32400	226	1976.9

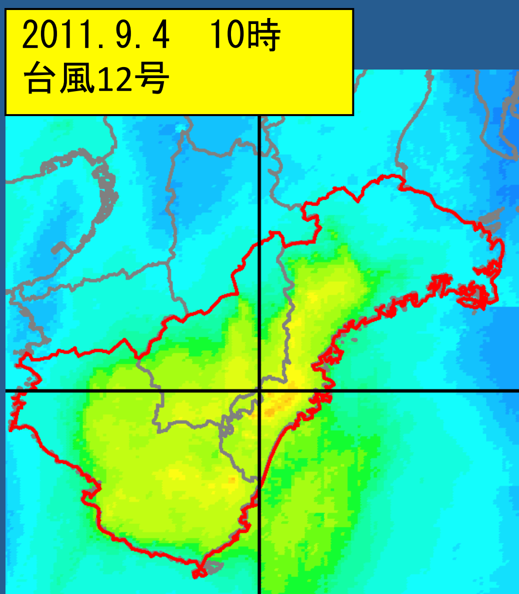


24時間雨量DA解析

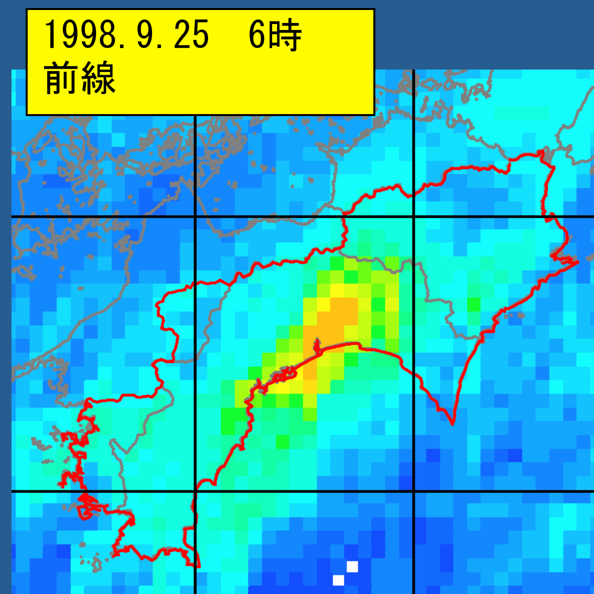
生起年月	観測日	降雨名	降雨中心
1957.7	1957.7.25-26	諫早豪雨	長崎県西郷
1959.9	1959.9.26	伊勢湾台風	奈良県入野波
1967.7	1967.7.9	昭和42年7月豪雨	佐賀県
1976.9	1976.9.8-13	台風17号と前線	徳島県日早
1982.7	1982.7.23	長崎豪雨	長崎県長与町
1998.9	1998.9.23-25	前線	高知県
2003.8	2003.8.8	台風10号	高知県
2004.8	2004.7.31-2004.8.2	台風10号	徳島県
2011.9	2011..8.30-9.6	台風12号	紀伊山地

Updating maximum rainfall by DA analysis

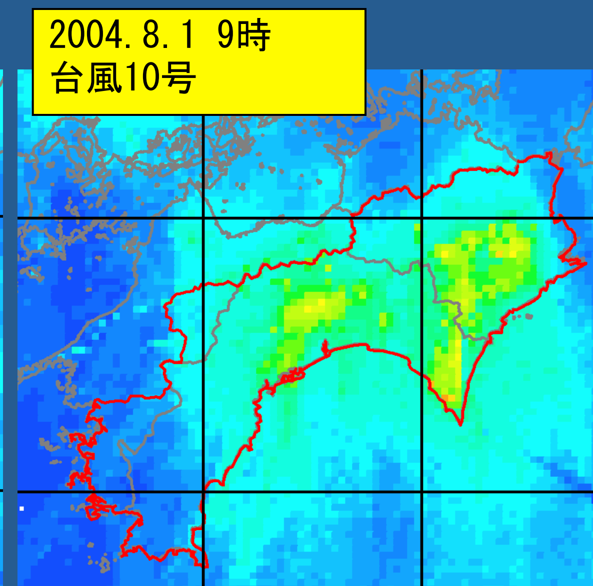
Spatial rainfall distribution when 24-hour rainfall updated



和歌山県、奈良県、三重県などで死者49 名、行方不明者55 名
（被害状況は、平成23 年9 月7 日15 時現在の消防庁の情報による）



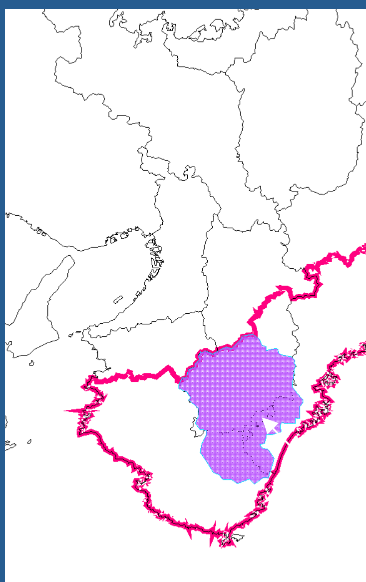
死者9名、負傷者14名
住家全壊31棟、半壊32棟、一部損壊117棟
床上浸水9,720棟、床下浸水9,973棟など
（防災白書より）



死者3名、負傷者15名
住家全壊11棟、半壊21棟、一部損壊88棟
床上浸水254棟、床下浸水2,188棟など
（消防白書より）

Simple PMF estimation in the Kii Peninsular

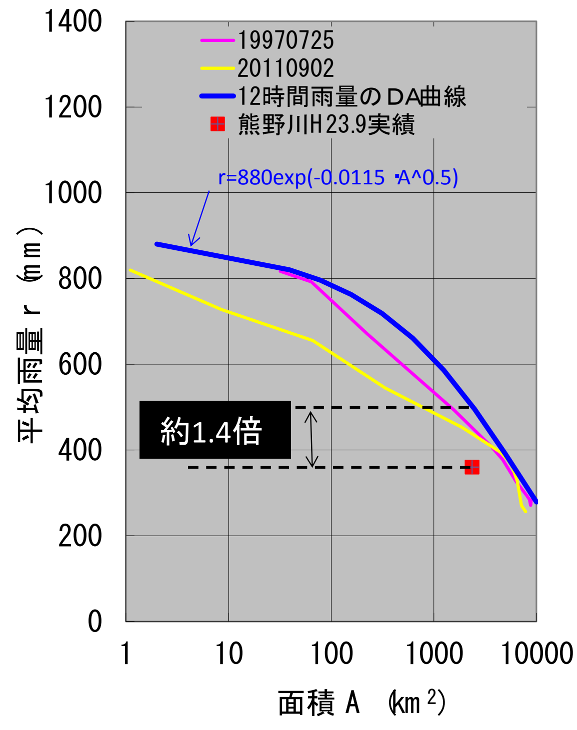
レーダー雨量から得られた紀伊半島の最大雨量を基に、平成23年9月台風12号による洪水を最大化した場合の可能最大流出量（probable maximum flood）を、概略的に試算した。

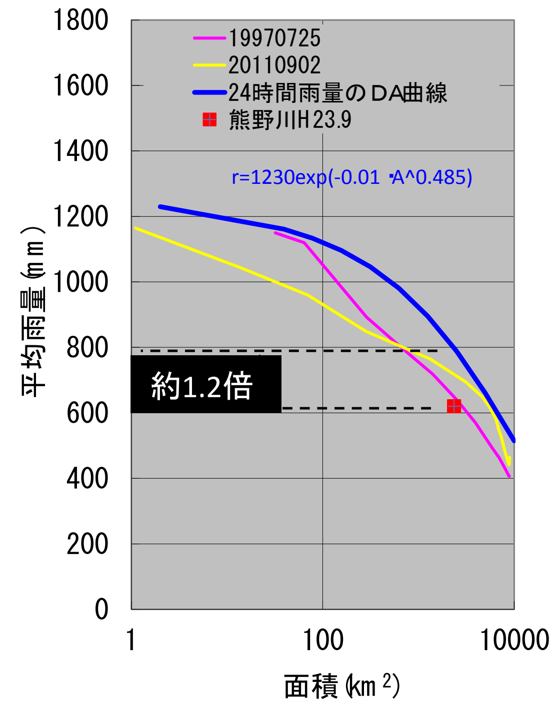


熊野川流域

流域面積2360km2

流路延長180km





熊野川の洪水到達時間は8～16時間程度(kraven式及び角屋式から推算）

紀伊半島南部のDAD解析による最大雨量は平成23年熊野川流域実績の1.2～1.4倍

平成23年熊野川最大流量（速報値）22000m^3/sの1.2～1.4倍とすると26400～30800m^3/sがPMFの概算値と推算される。

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Conclusions

- Extreme events give us new findings in hydrology, water resources and river engineering.
- When extreme events take place, intensive research is necessary from various viewpoints.