WORLD WATER RESOURCES AND DAMS IN THE 21ST CENTURY

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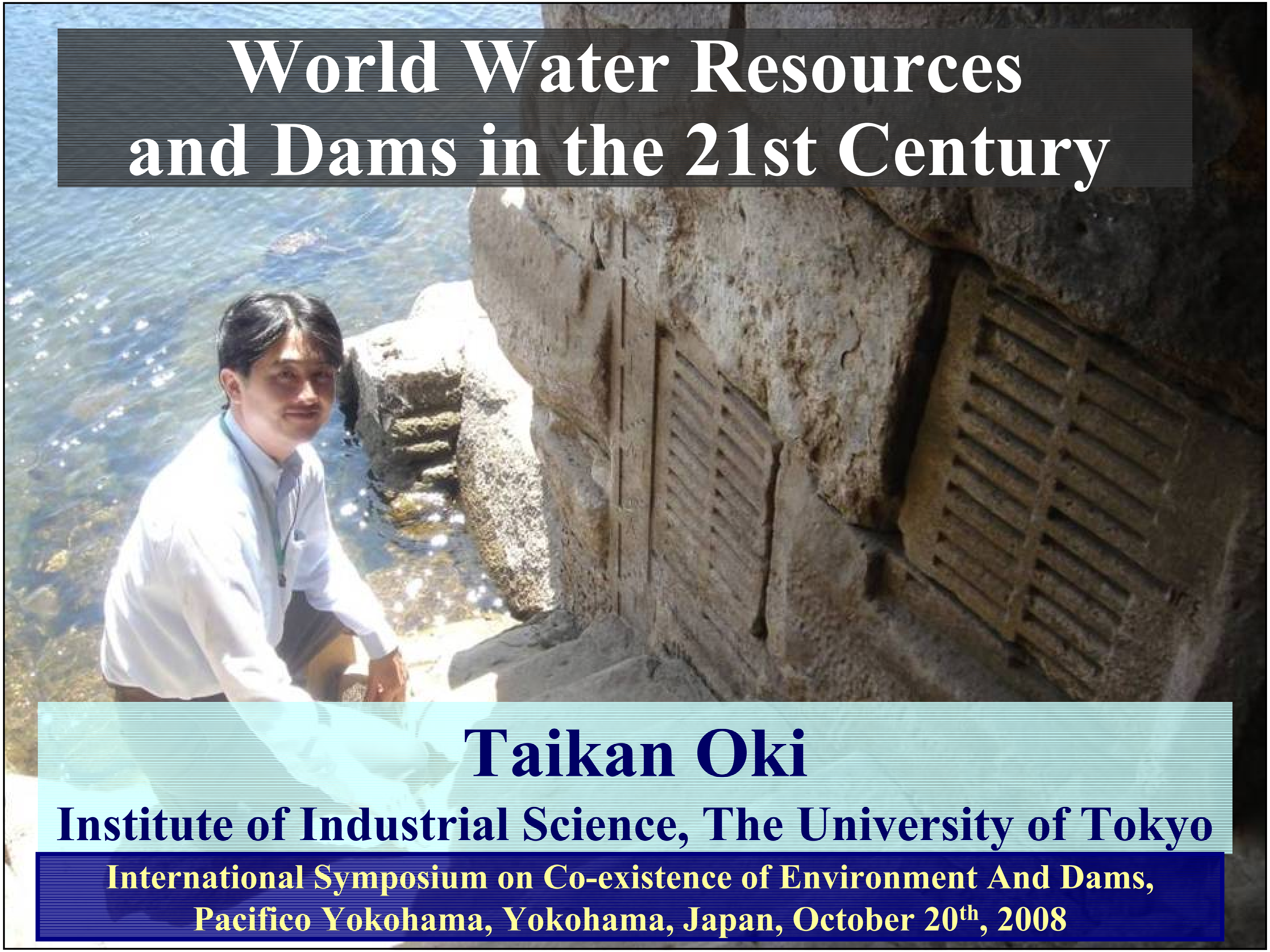
Key words: *global hydrological cycles, global warming, food and water*

Water is a naturally circulating resource that is constantly recharged. Therefore, even though the stocks of water in natural and artificial reservoirs are helpful to increase the available water resources for human society, the flow of water should be the main focus in water resources assessments. The climate system puts an upper limit on the circulation rate of available renewable freshwater resources (RFWR). Although only 10% of maximum available *blue water* and 30% of *green water* resources are used presently (Oki and Kanae, 2006) and current global withdrawals are well below the upper limit, more than two billion people live in highly water-stressed areas because of the uneven distribution of RFWR in time and space. This fact reminds that water resources development is how to stabilize the temporal variation by storing water and fill the water deficit by transporting water with reasonable cost. Climate change is expected to accelerate water cycles and thereby increase the available RFWR. This would slow down the increase of people living under water stress. However changes in seasonal patterns and increasing probability of extreme events may offset this effect, and there are places where more water stressed situation is anticipated regionally, such as Middle East, Mediterranean, and Sub-Saharan Africa. The increases of numbers of people under "water stress" are mainly due to the demographic and economical growths. Nevertheless, it is certain that there are people who are already suffering from water shortage today and that any change in the hydrological cycle will demand changes in water resource management, whether the change is caused by global warming or cooling, or by anthropogenic or natural factors. If society is not well prepared for such changes and fails to monitor variations in the hydrological cycle, large numbers of people run the risk of living under water stress or seeing their livelihoods devastated by water-related hazards such as floods. Therefore reducing current vulnerability will be the first step to prepare for such anticipated changes. The ultimate objectives of future-oriented world water resource assessments are to show the international community what will happen if we continue to manage our water resources as we do today and to indicate what actions may be needed to prevent undesirable outcomes. In that sense, studies of future world water resources are successful if their predictions based on business-as-usual are proven wrong. One of the adaptation options for the anticipated problems on water in the future is to increase storages particularly in developing countries where existing infrastructure is relatively insufficient, even though stakeholder participation is necessary for the decision making.

World Water Resources and Dams in the 21st Century



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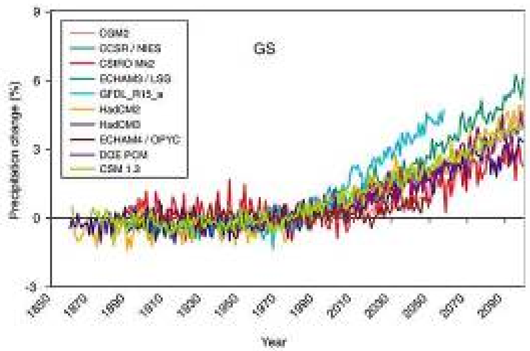
International Symposium on Co-existence of Environment And Dams,
Pacifico Yokohama, Yokohama, Japan, October 20th, 2008

World Water Issues

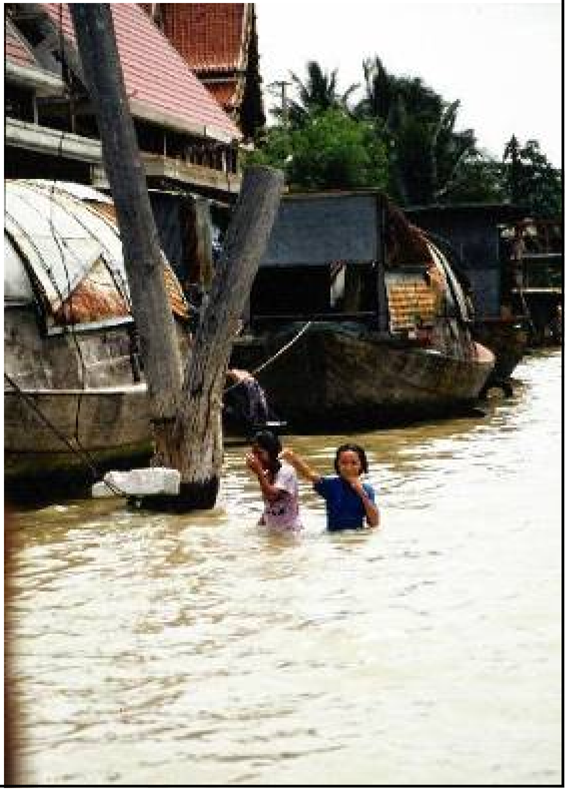


- Indisponsable water for lives
  - One in five of the world population does not have access to safe and affordable drinking water (20L/d/c within 1km).
    - Each year 3-4 million people die because of waterborne diseases
- Profitable water for agriculture and industry
  - Total withdrawals 3,800km^3(1995)→4,300-5,200km^3(2025)
- Comfortable water for human being and ecosystems
- Climate Change and Urbanization →water hazard risks
- International conflicts because of water issues?

Future Projection through the 21st Century

Changes considered include:

- **Water demand for domestic, industrial, and irrigation sectors.**
  - **Population (SRES)**
    - **Urban and rural areas separated**
  - **GDP (SRES)**
  - **Improvement of reuse (SRES)**
- **Climate change (SRES)**



Impact of human activities on freshwater resources and their management, with climate change being only one of multiple pressures

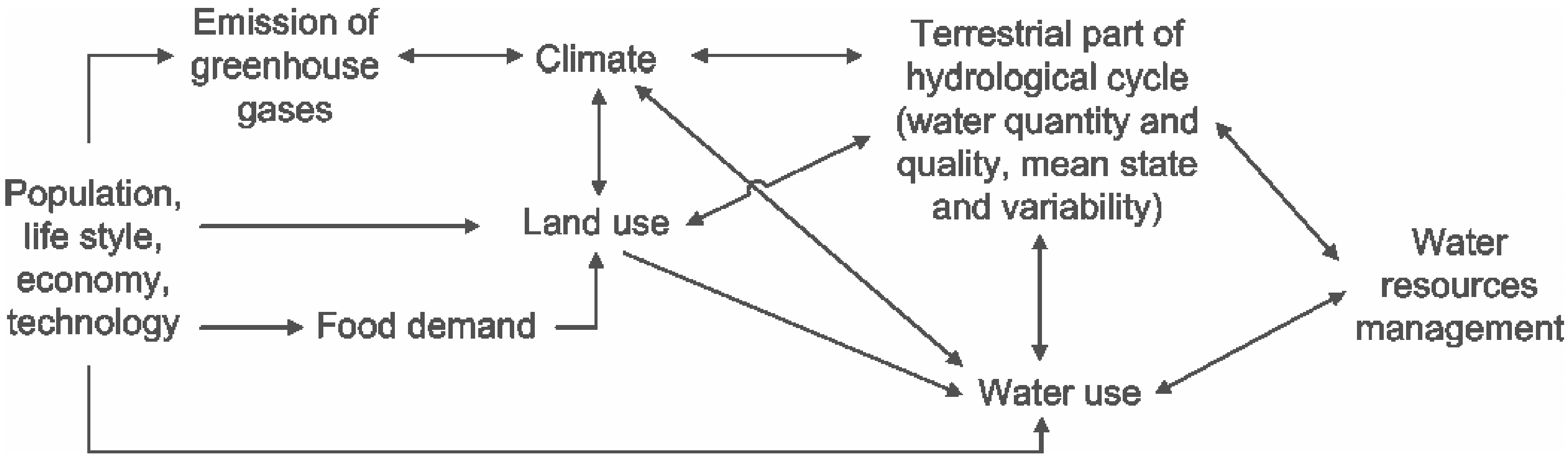
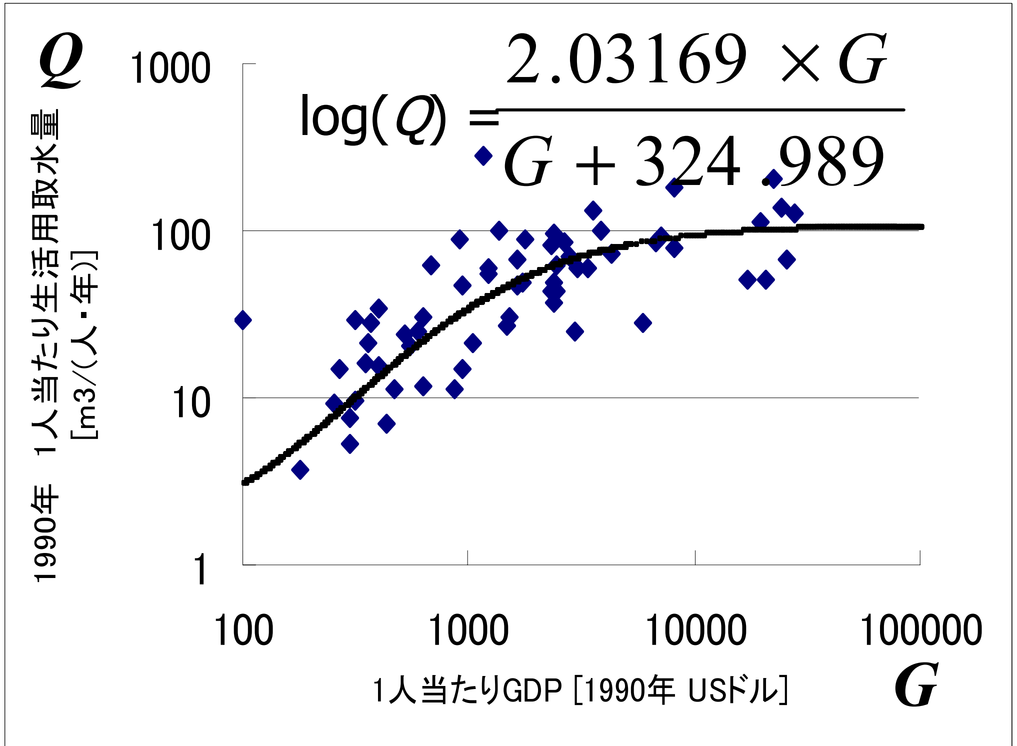


Figure 3.1: *Impact of human activities on freshwater resources and their management, with climate change being only one of multiple pressures (modified after Oki (2005)).*

(IPCC AR4, WGII, Chapter 3, "Freshwater Resources and their Management", 2006)

GDP and Domestic Water Use

GDP/capita and domestic water use



$$\log(Q) = \frac{2.03169 \times G}{G + 324.989}$$

Q **: Domestic Water Use [m3 / capita/year]**
G **: GDP per person [US$ equivalent of year 1990]**

Assumptions :

1 Domestic water use in developing countries will increase associated with the increase of GDP.

2 Life style in domestic water use is calibrated by simple manner for countries with statistics of the current domestic water use.

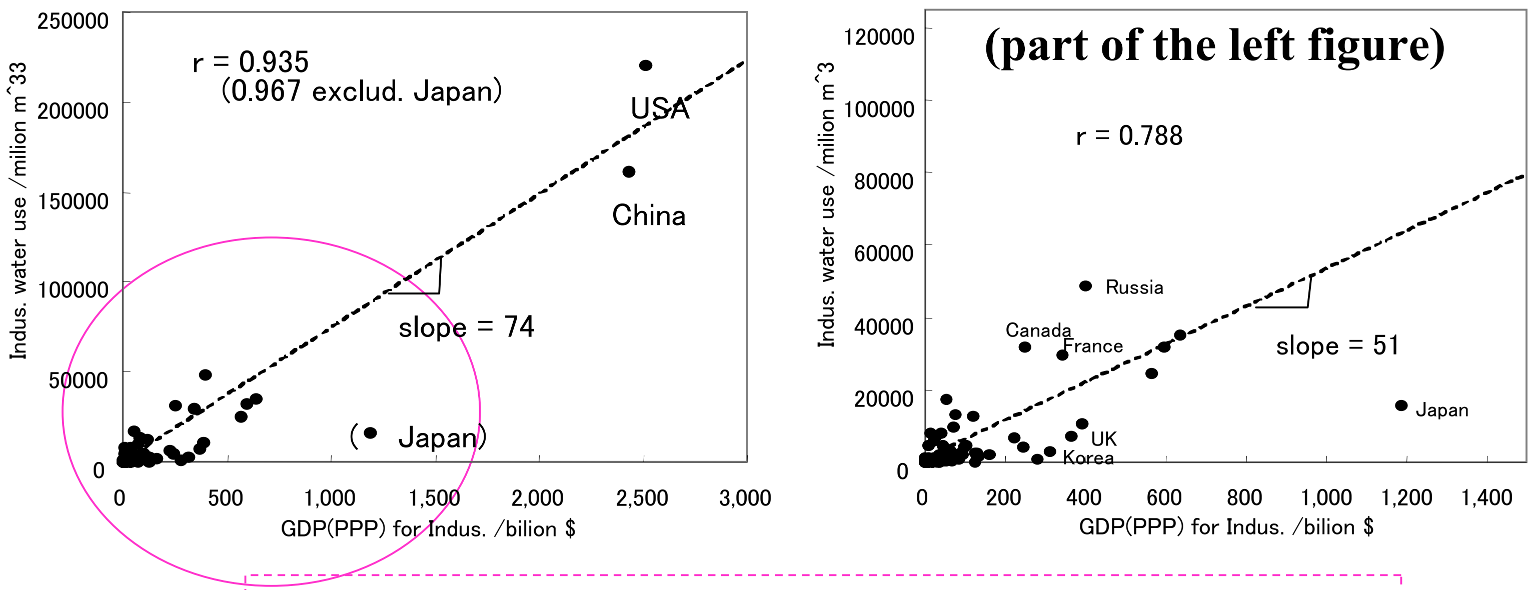
- Future Domestic Water Use= Future Estimate +D

where D is the bias error,
D=Statistics in 1900 – Estimate for 1990

*** Future GDP under SRES scenario was downscaled from GDP projection in 4 region in the world into each country by CIESIN.**

GDP and Industrial Withdrawals

Total water withdrawal and GDP for industry in each country are proportional.

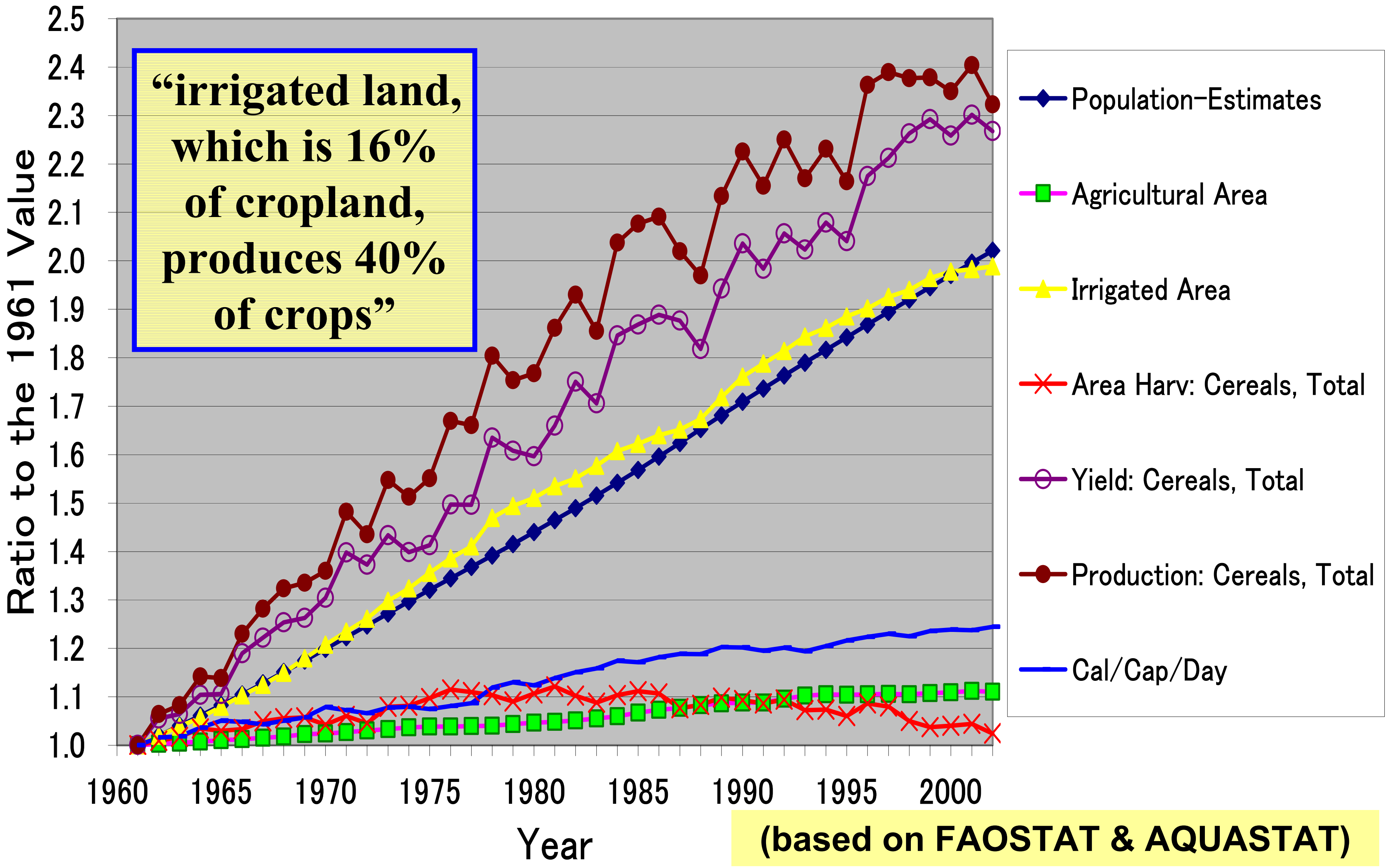


Japan is an exception with high water use efficiency.

Future Projection

Future IW＝Current IW ＊GDP Growth for Industry
＊Improvement of water use efficiency

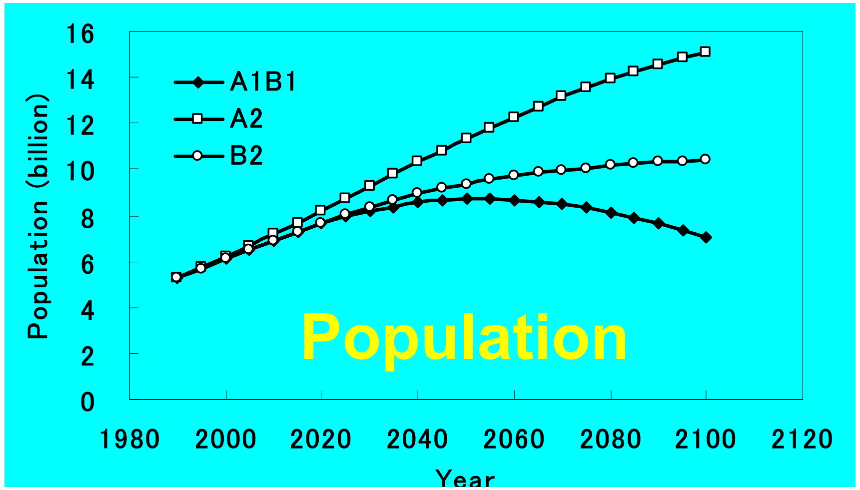
World Food Production and Supply

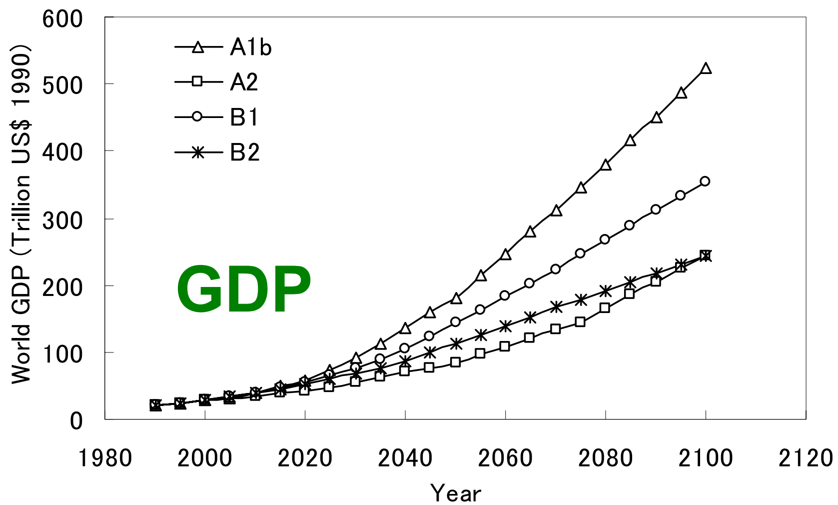


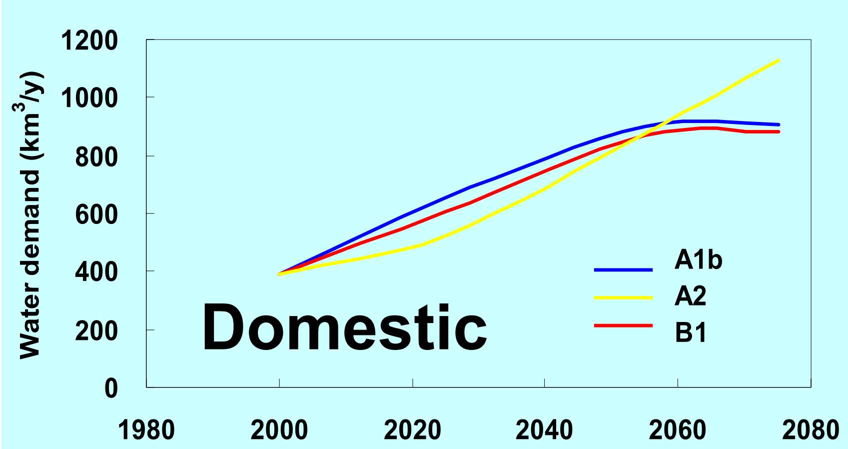
(based on FAOSTAT & AQUASTAT)

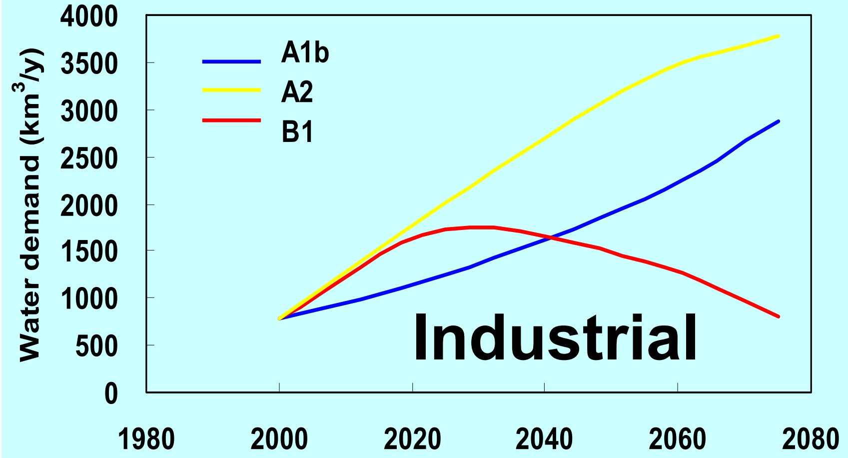
Future Projection

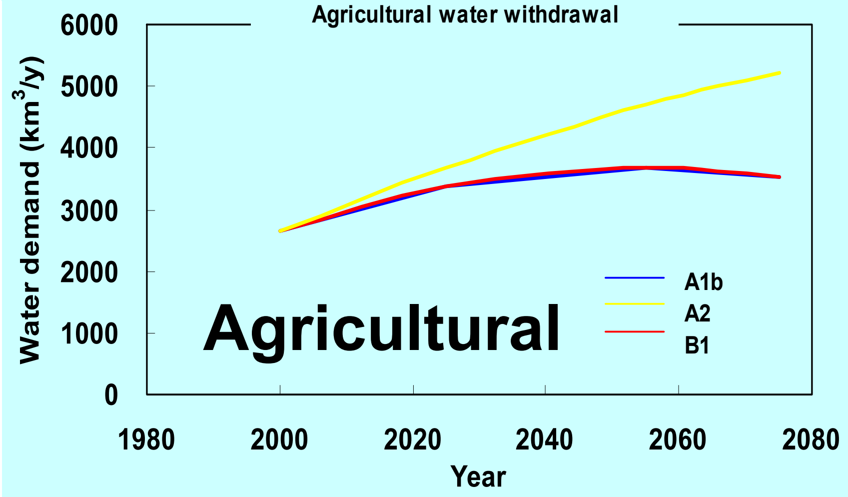
- SRES based
  - Population (urban & rural), GDP, efficiency
  - Climate change
- Global 0.5 degree grid distribution based



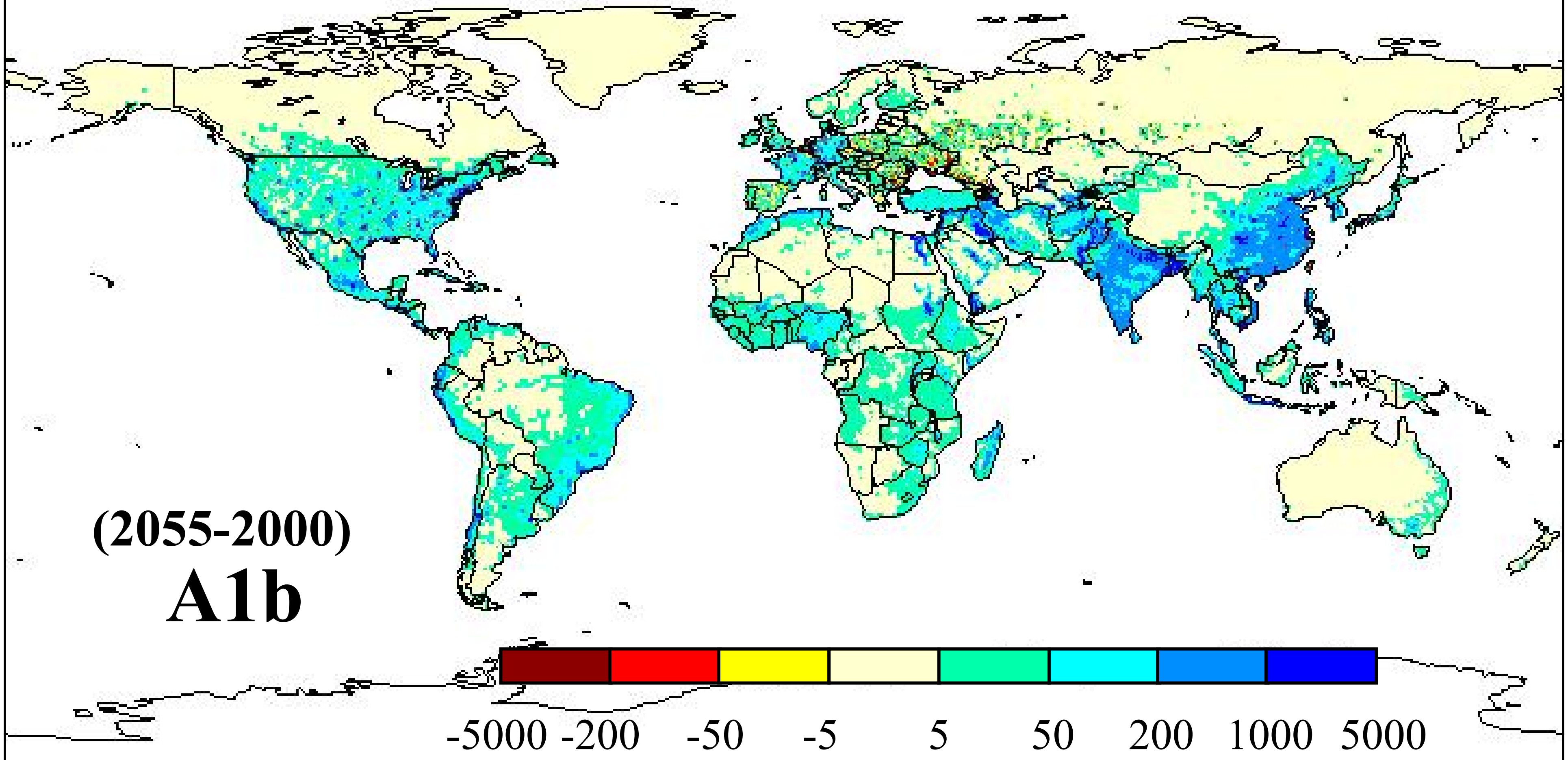




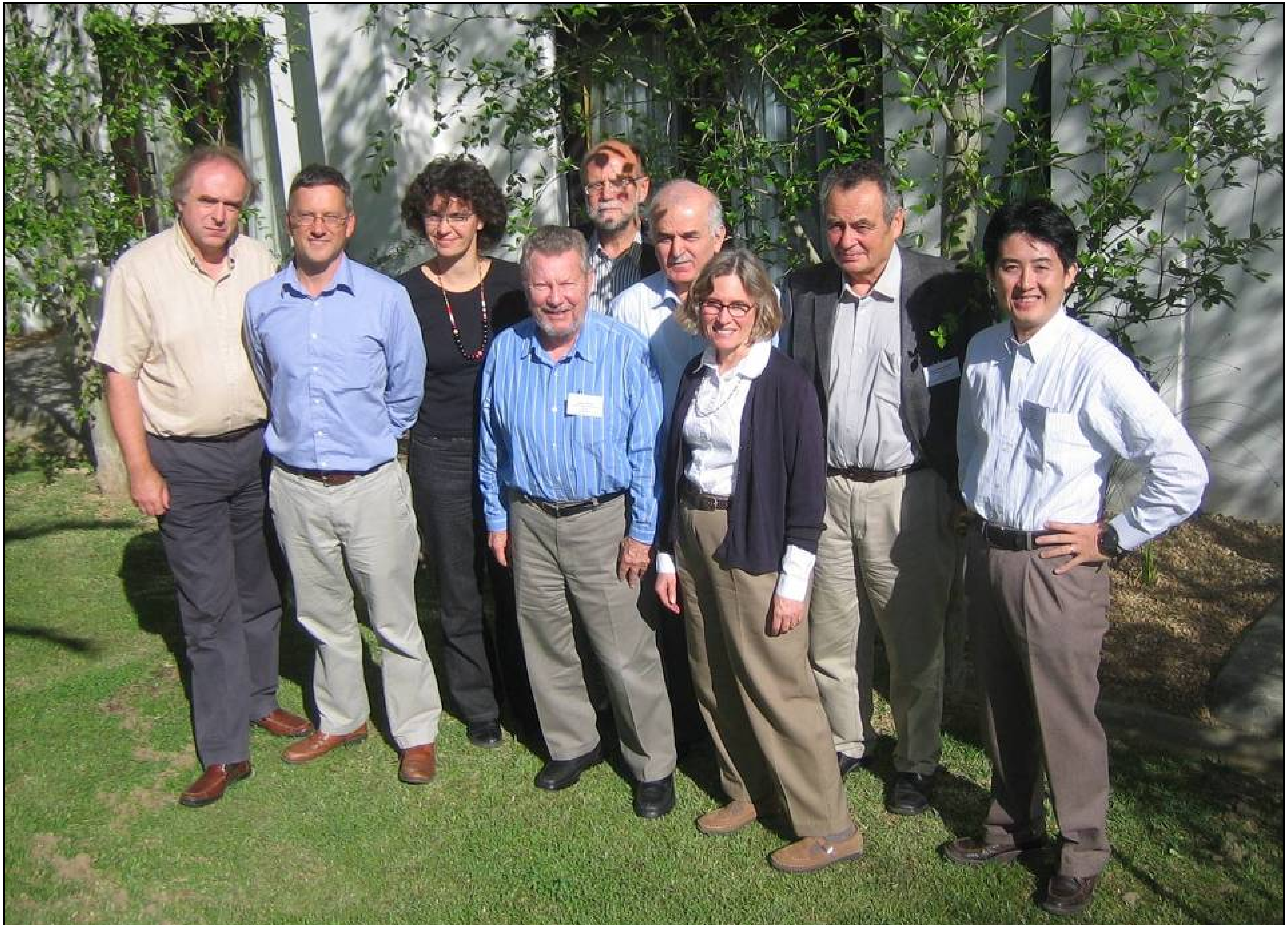




Total Water Withdrawal ($10^6 m^3/y$) in 2050 (difference to Year 2000)



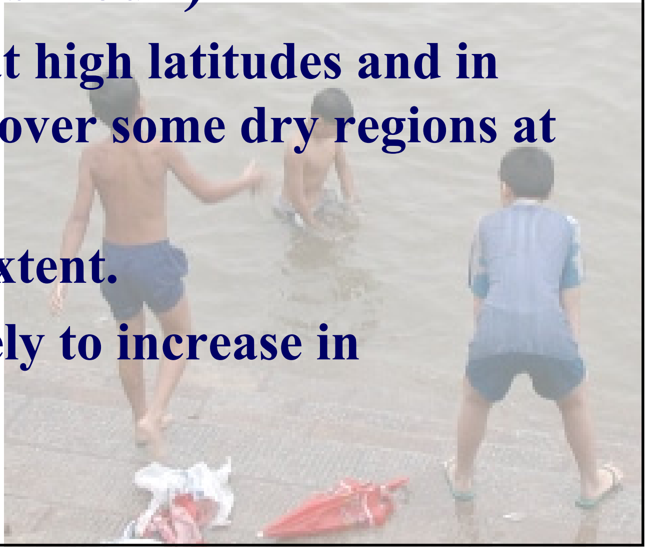
(Shen, et. al, 2008, HSJ)



(Lead Authors for the 4th Assessment Report of the IPCC, WG II, Chapter 3 “Freshwater resources and their management”)

Impacts of climate change on freshwater resources

- Temperature will increase:
  - Snow melt runoff will be changed in timing and the peak volume
  - water supplies stored in glaciers and snow cover are projected to decline
  - Water temperature will rise. Water quality and aquatic ecosystem could be deteriorated.
- Sea level will rise:
  - Sea water intrusion to ground water near coastal region
- Hydrological cycle will be changed ("intensified")
  - 10-40% increase of available water resources at high latitudes and in some wet tropical areas, and 10-30% decrease over some dry regions at mid-latitudes and in the dry tropics
  - Drought-affected areas will likely increase in extent.
  - Heavy precipitation events, which are very likely to increase in frequency, will augment flood risk.



（IPCC AR4, WGII, SPM, 2007）

Changes in Annual River Discharge

---Ensemble Mean of 15 GCM results for IPCC AR4 ---

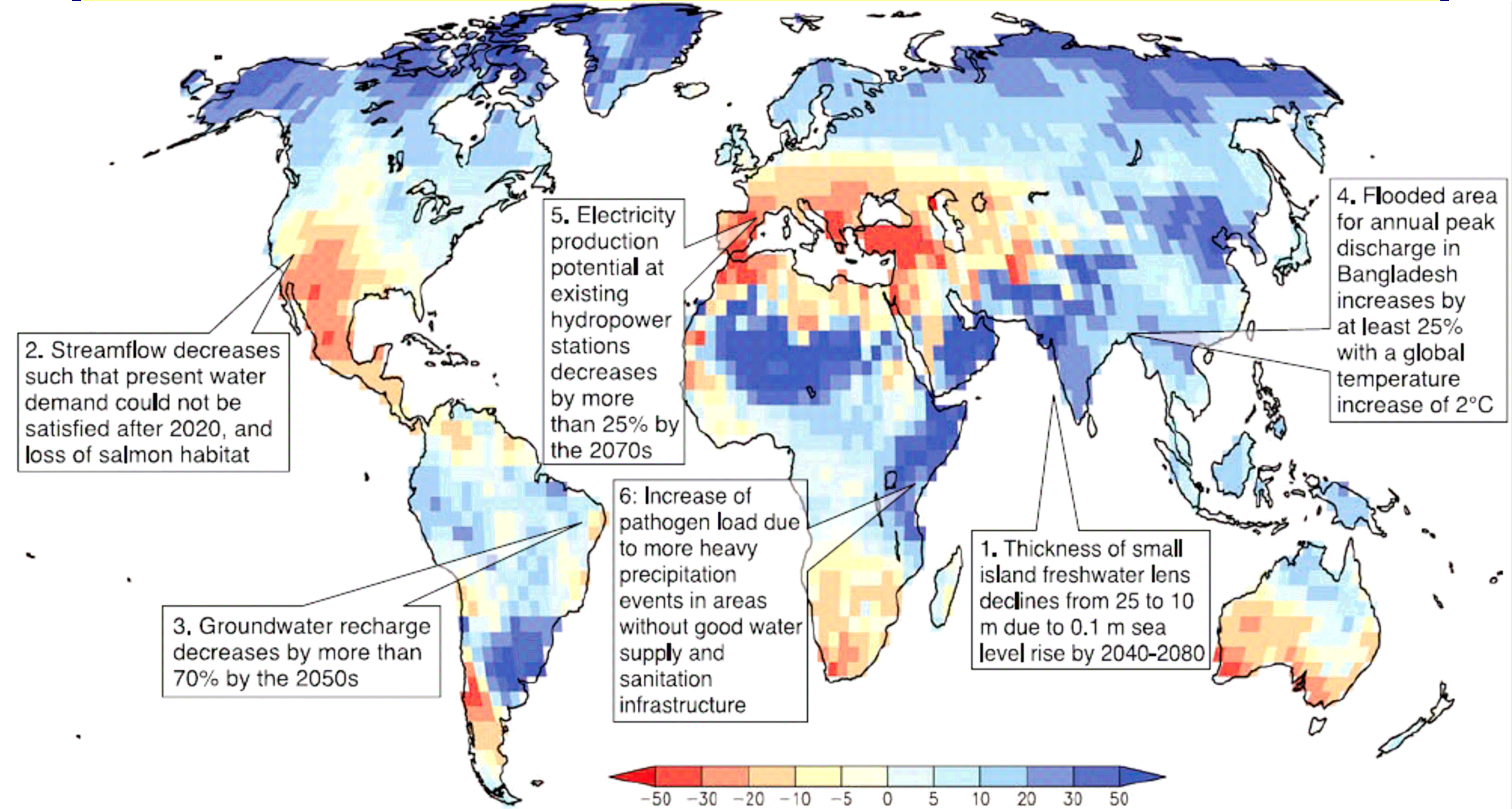
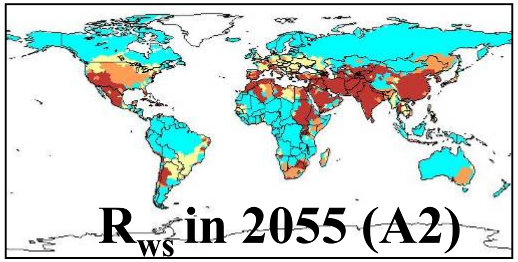
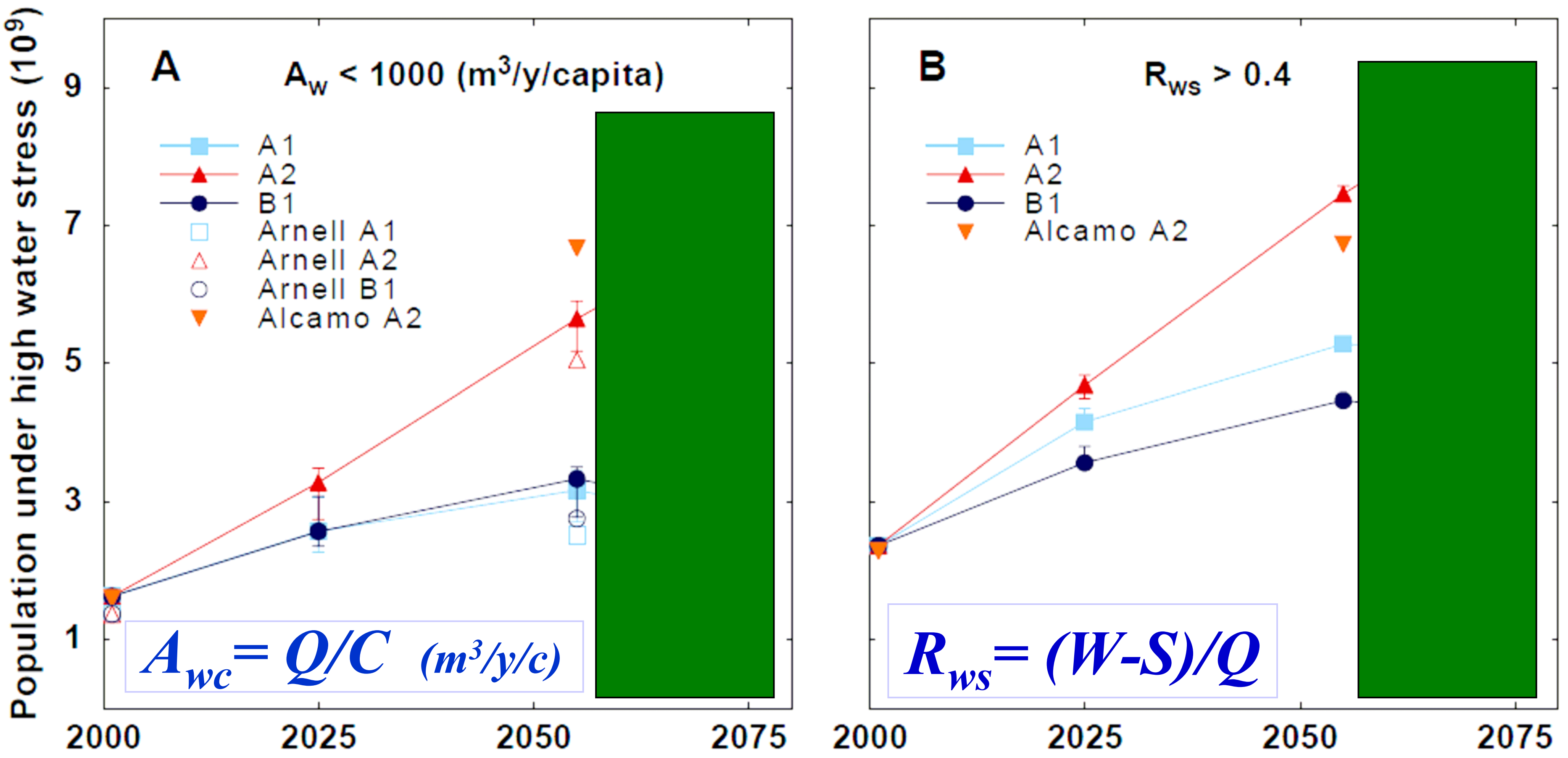


Figure 3.8. *Illustrative map of future climate change impacts on freshwater which are a threat to the sustainable development of the affected regions. 1: Bobba et al. (2000), 2: Barnett et al. (2004), 3: Döll and Flörke (2005), 4: Mirza et al. (2003) 5: Lehner et al. (2005a) 6: Kistemann et al. (2002). Background map: Ensemble mean change of annual runoff, in percent, between present (1981 to 2000) and 2081 to 2100 for the SRES A1B emissions scenario (after Nohara et al., 2006).*

Number of people under serious water stress

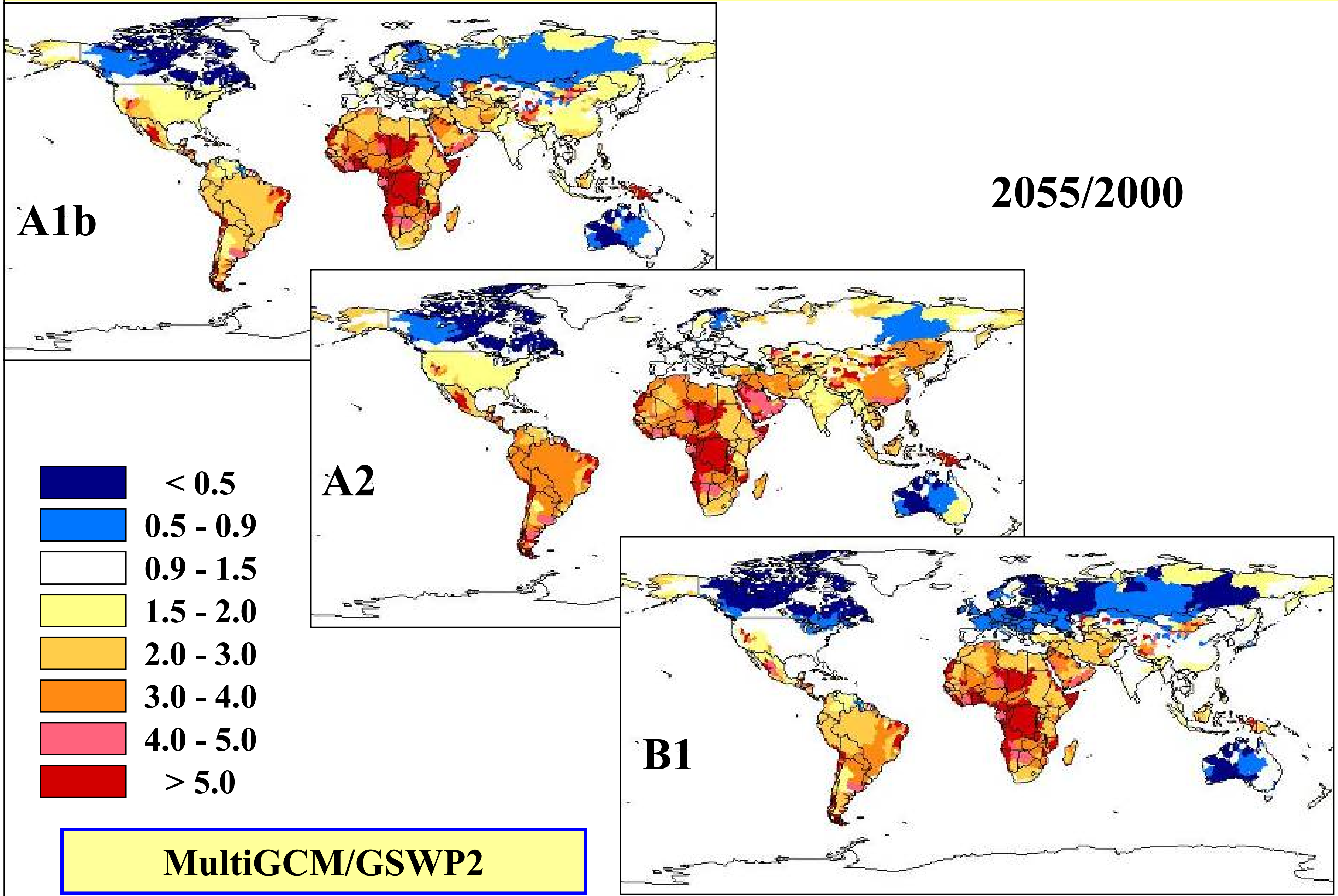




Q: How can we realize B1 society?

(Oki and Kanae, *Science*, 2006)

Change in water stress index for 2050 (ratio)




Extreme Events?

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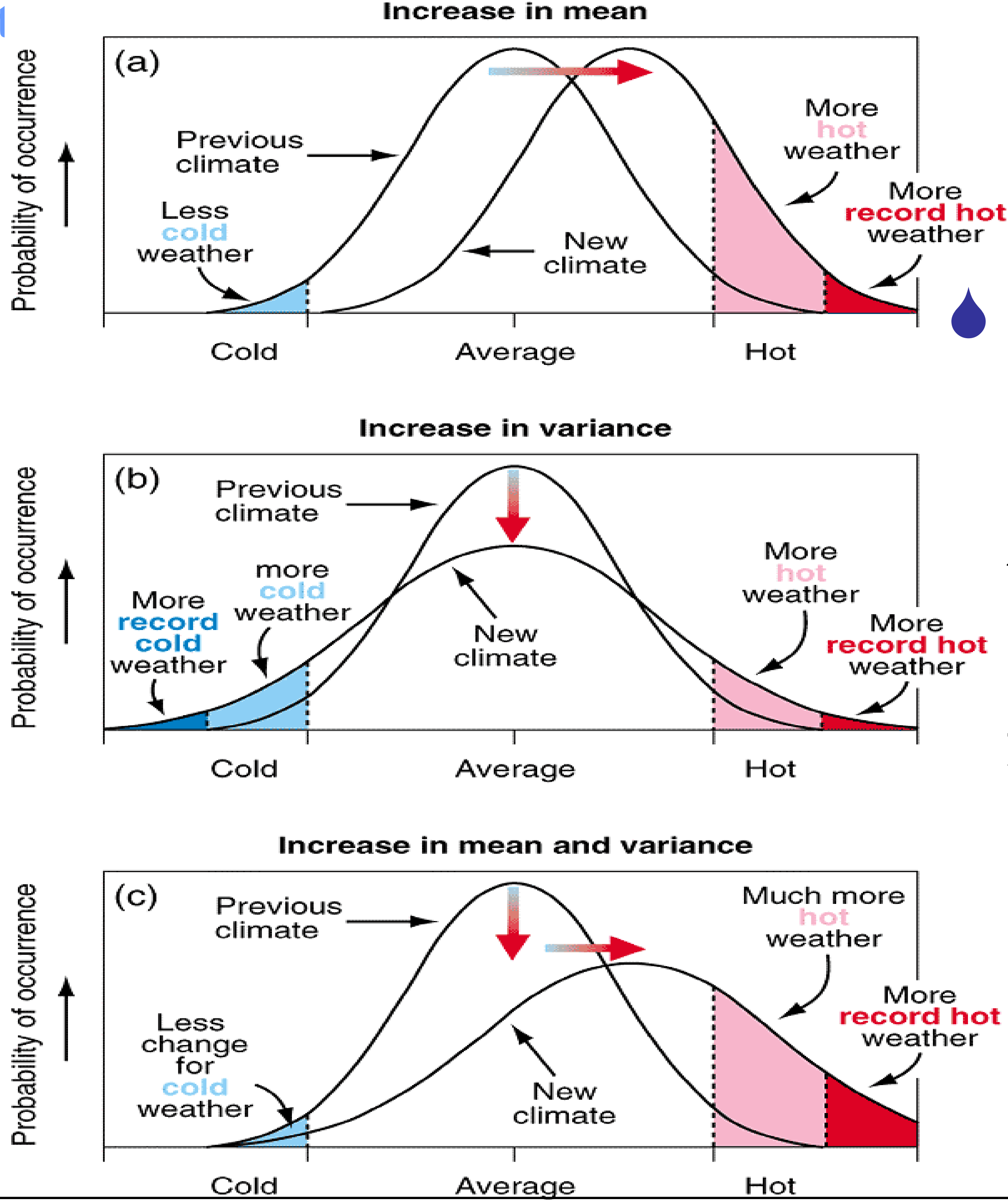


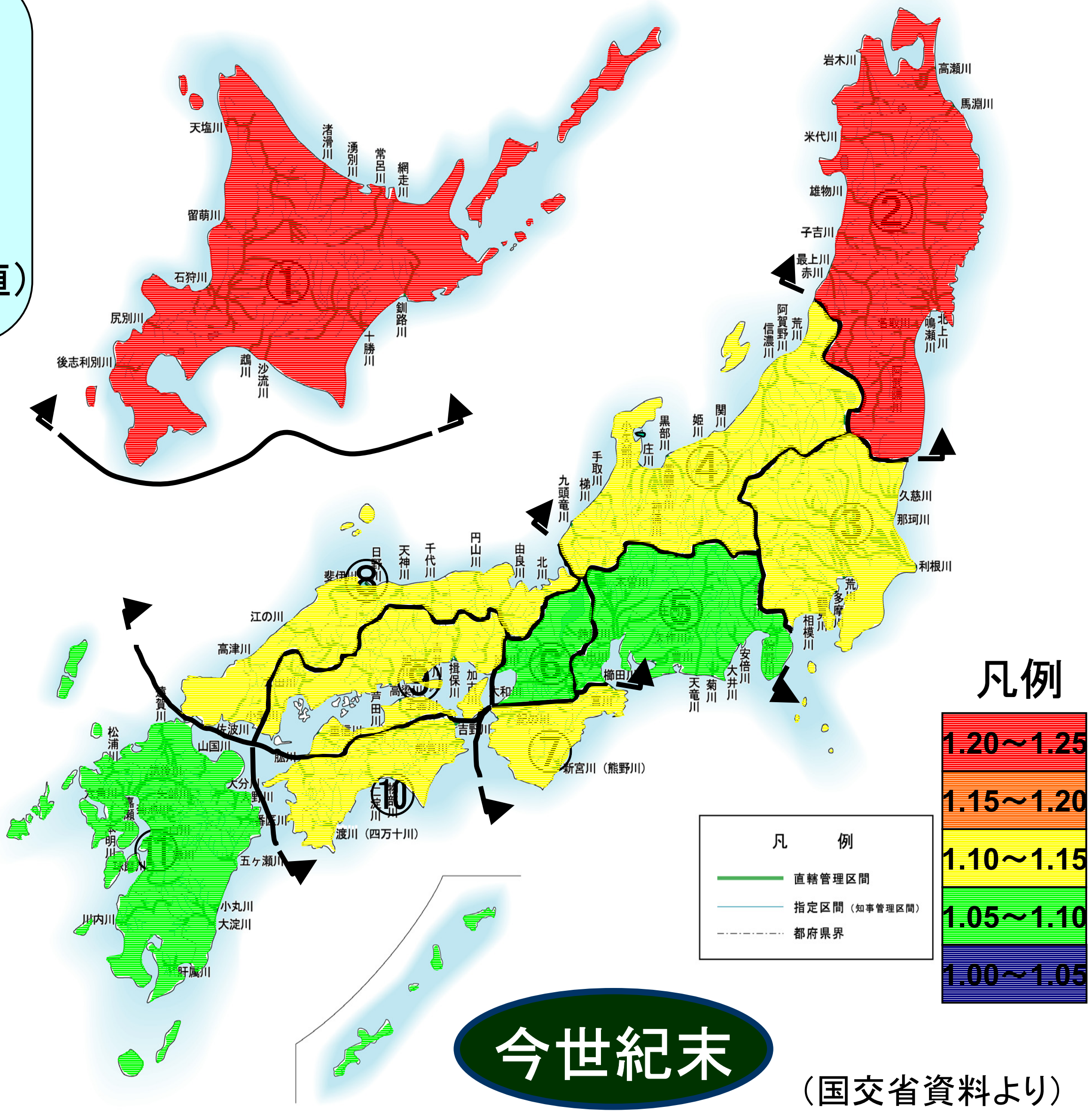
- **Signals of CC could be detected through the change of the frequency of extreme events?**

(IPCC TAR, 2001)

降雨量増加の地域分布　今世紀末でもせいぜい1.2倍程度

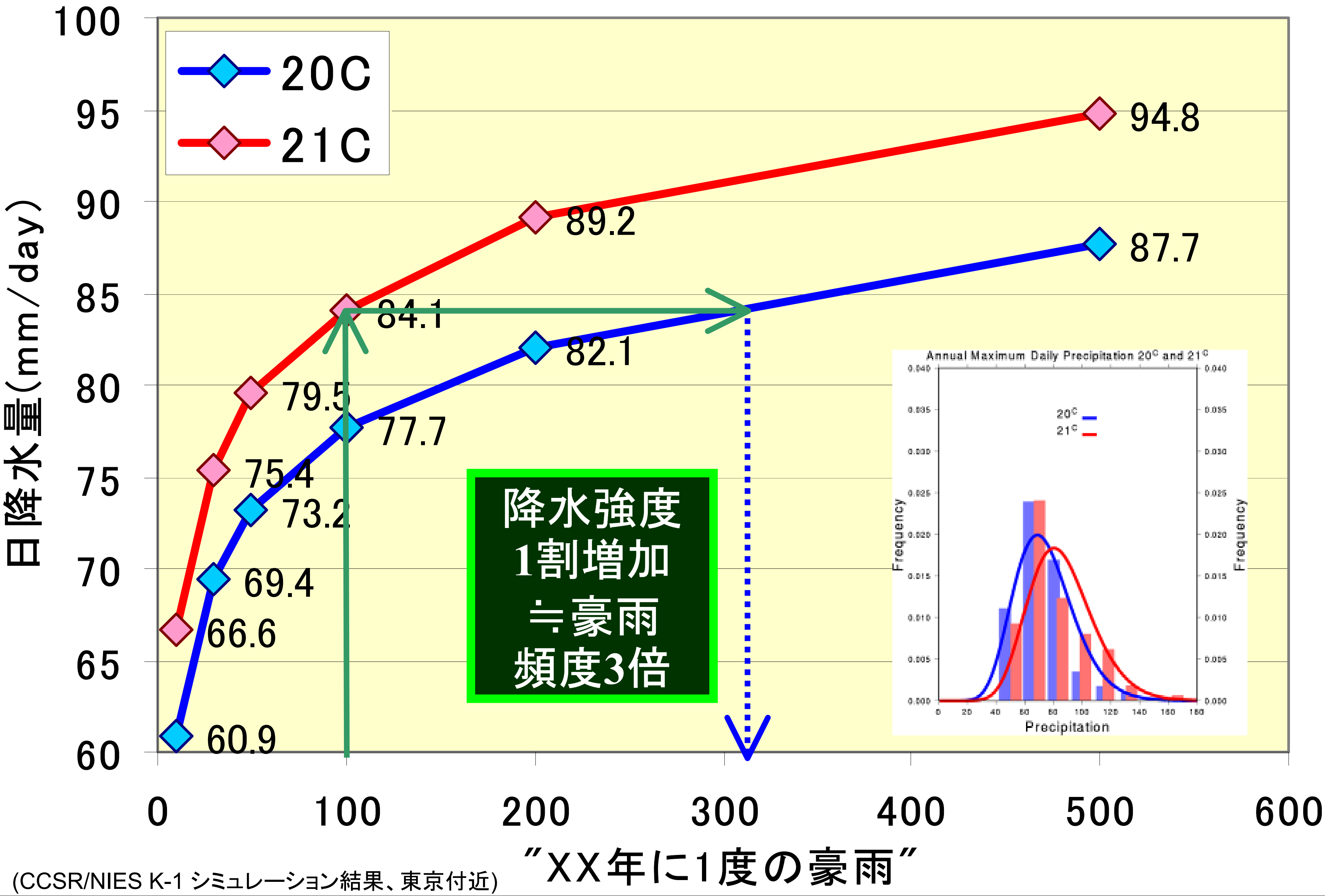
GCM20（A1Bシナリオ）で求めた
各調査地点の年最大日降水量から
（2080-2099年の平均値）／（1979-1998年の平均値）を求め
将来の降雨量を予測（上記の中位値）

①	北海道	1.24
②	東北	1.22
③	関東	1.11
④	北陸	1.14
⑤	中部	1.06
⑥	近畿	1.07
⑦	紀伊南部	1.13
⑧	山陰	1.11
⑨	瀬戸内	1.10
⑩	四国南部	1.11
⑪	九州	1.07



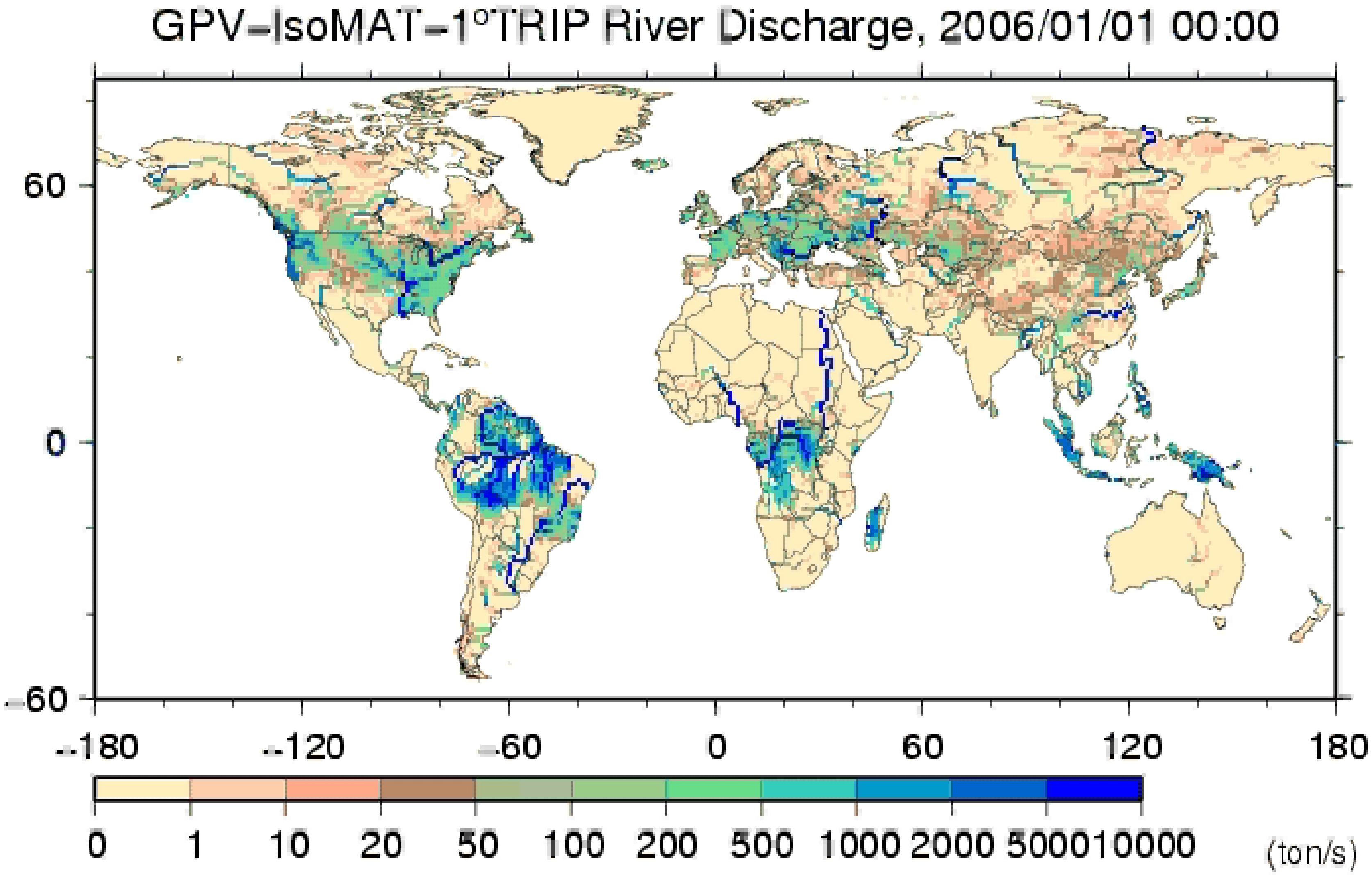
（国交省資料より）

X年確率降水量(年最大日降水量)



(CCSR/NIES K-1 シミュレーション結果、東京付近)

Simulated Daily River Discharge of the Globe

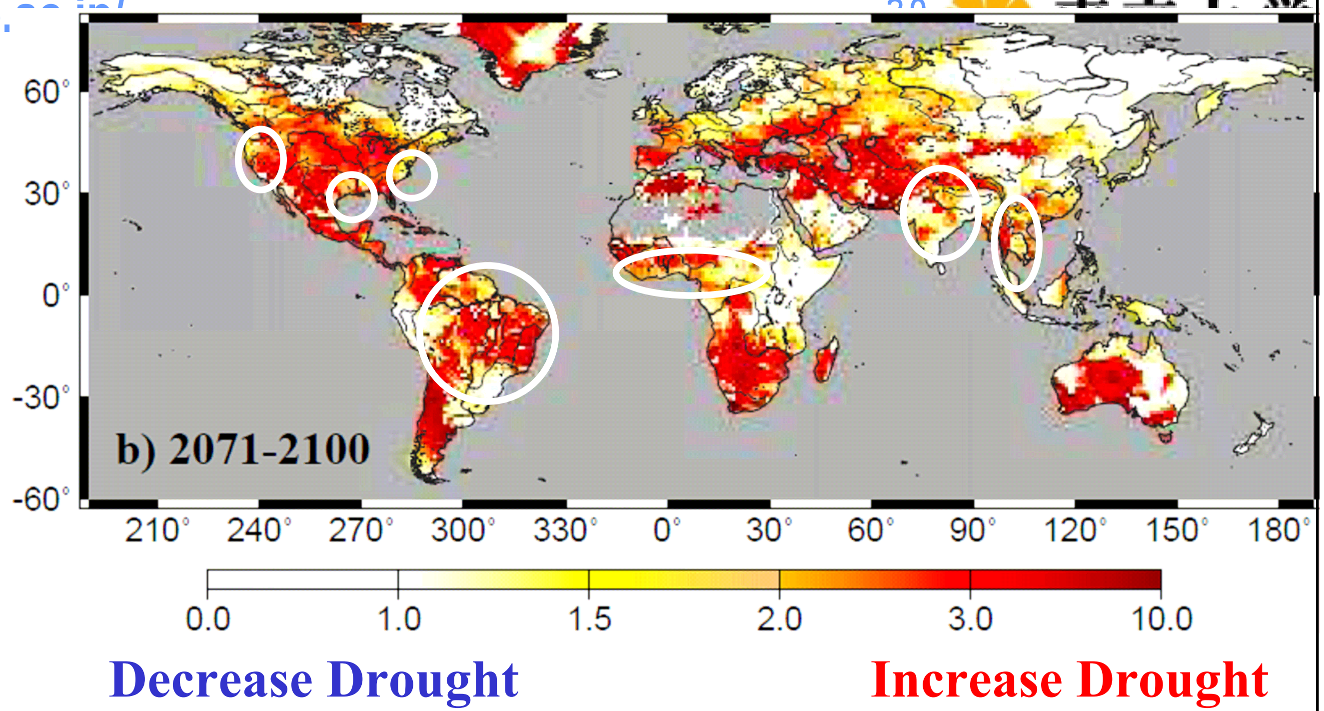


←Low River Flow High River Flow→

Change in Drought Frequency

End of 21st century compared with 20th century

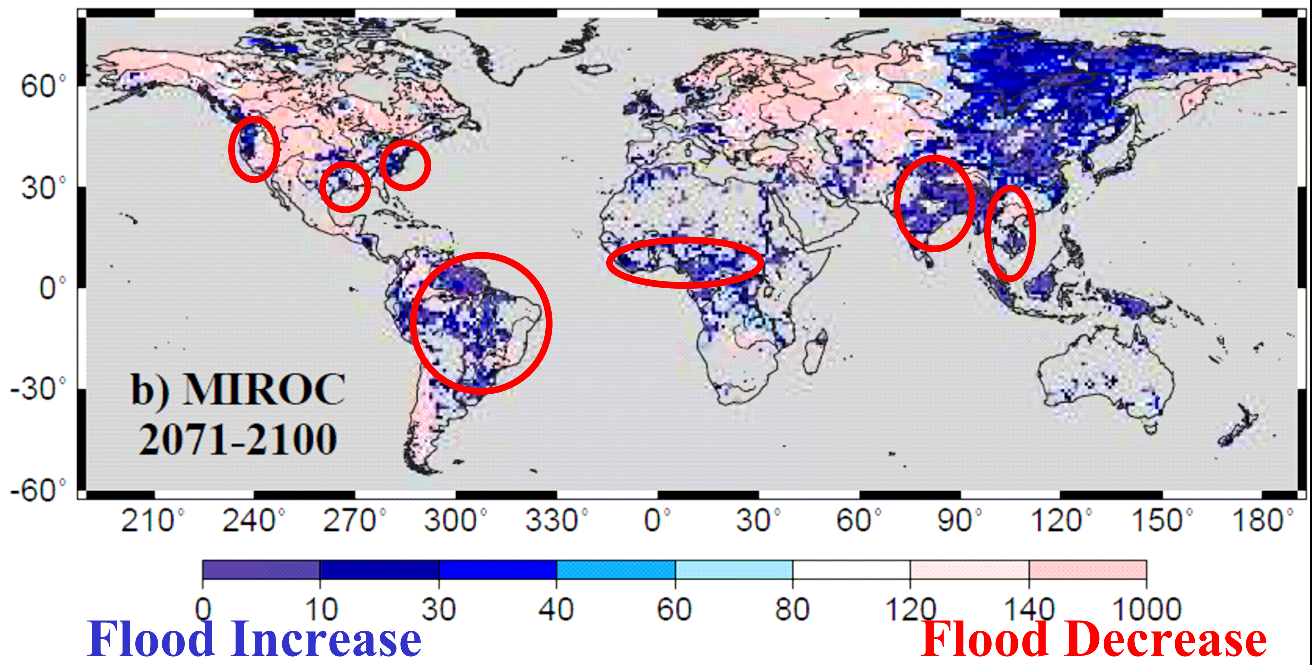
Drought: daily river discharge is below threshold of 10% percentile



Change in Flood Frequency

End of 21st century compared with 20th century

Frequency in the 21st century of 100-year flood in the 20th century



Hirabayashi et al., (*HSJ*, 2008)
Based on CCSR-NIES AOGCM

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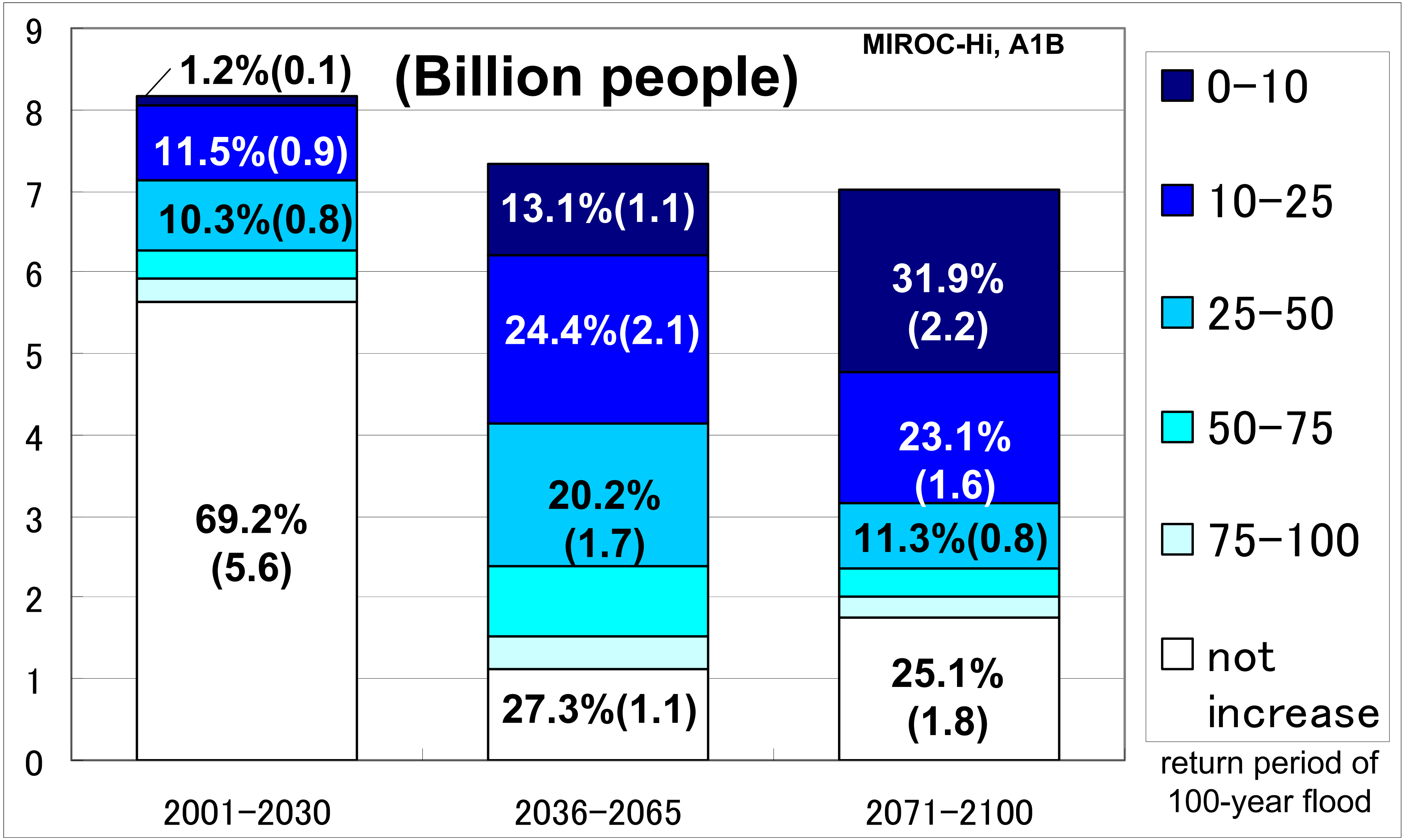
Japan Pavilion of EXPO Zaragoza (Spain)

Main Theme: Water and Sustainable Development

Animation

Changes in the Occurrence of Extreme Events in River Discharge

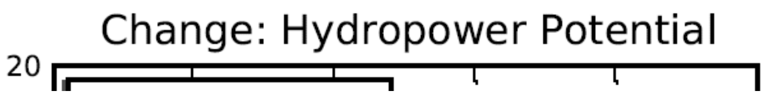
Number of people under more frequent floods



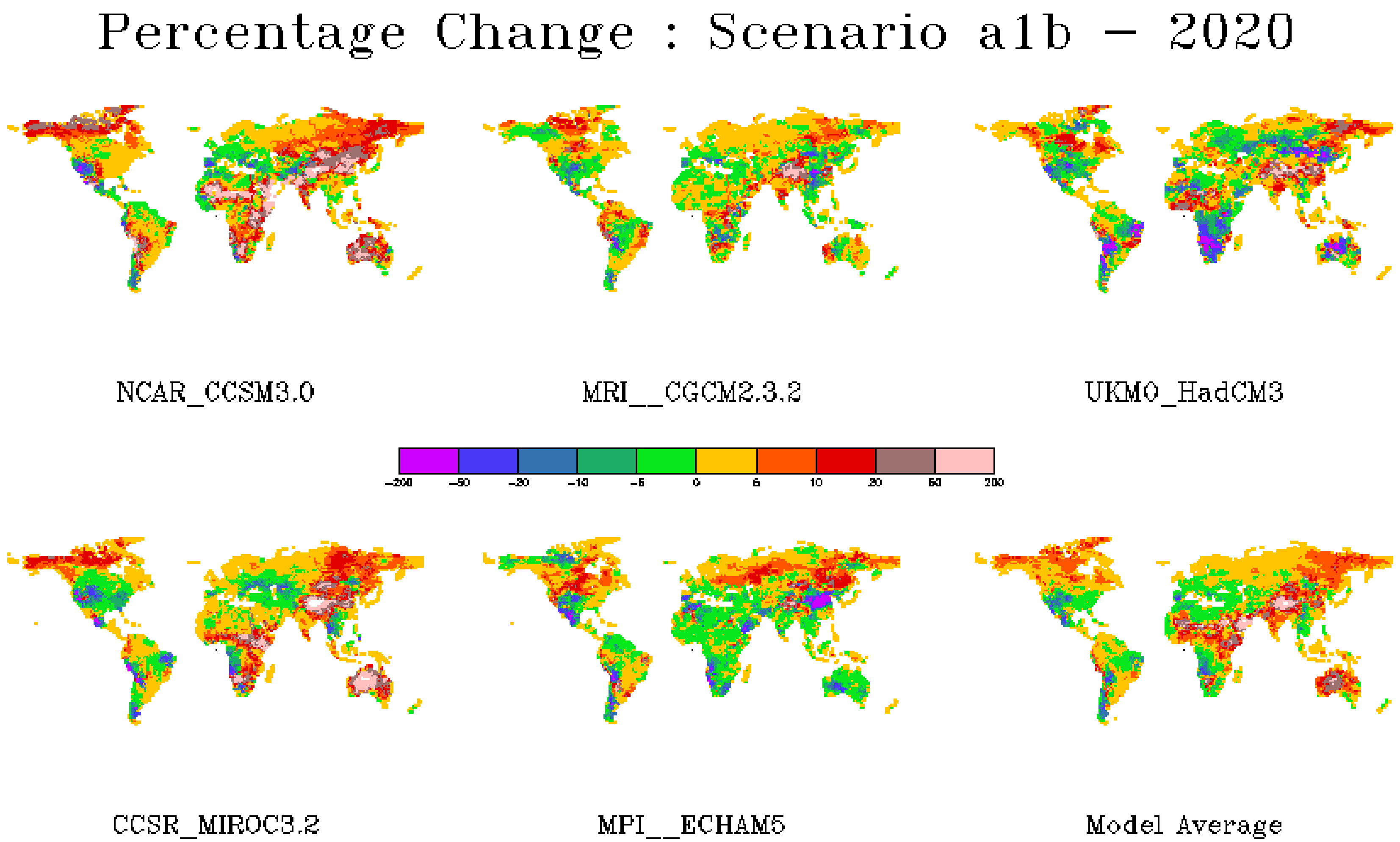
(Hirabayashi et al. 2008, HSJ)


Hydropower?

CHANGE IN HYDROPOWER POTENTIAL

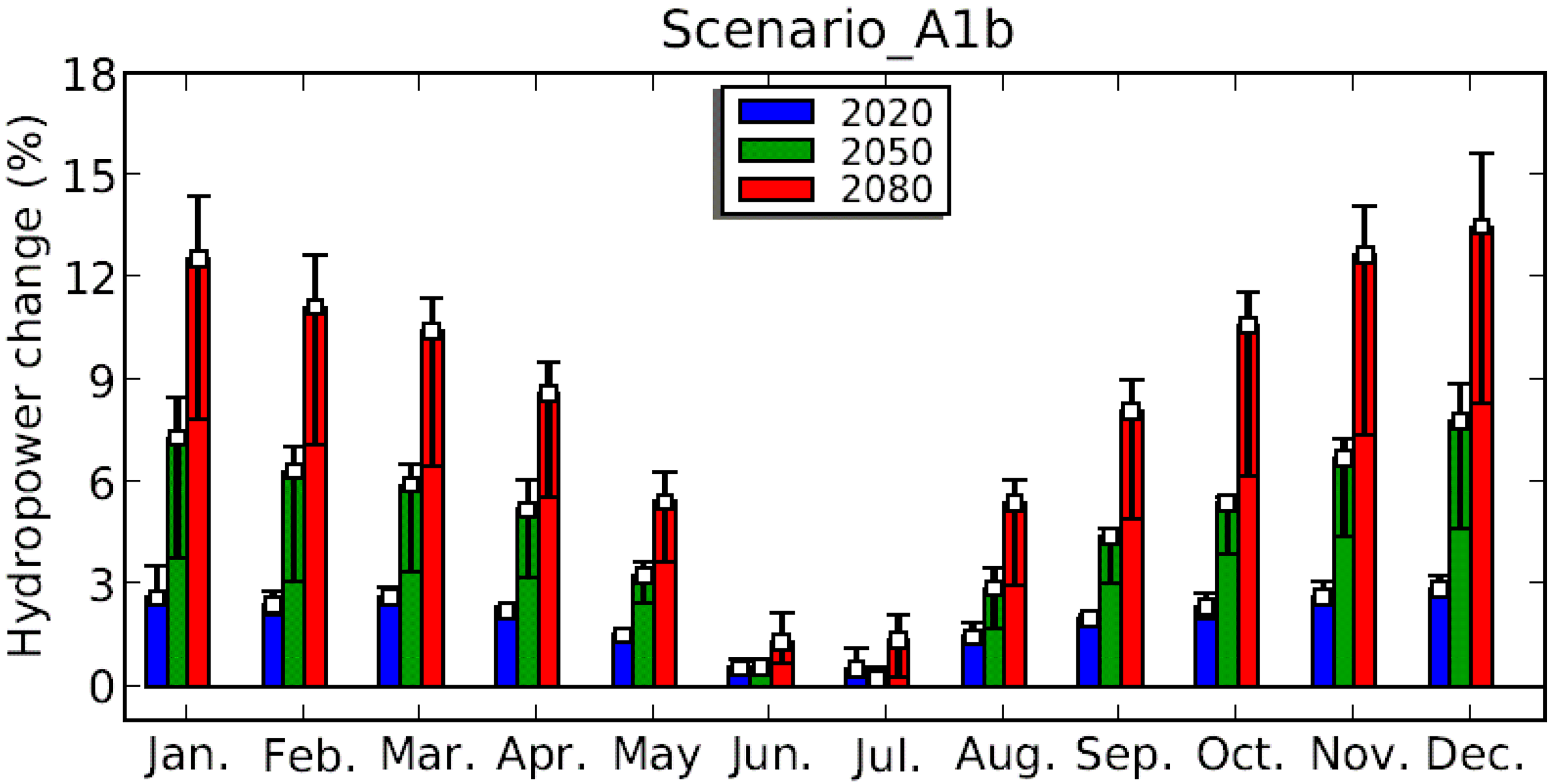


- Data from 5 different GCMs were used



(Yadu Nath Pokhrel, 2008)

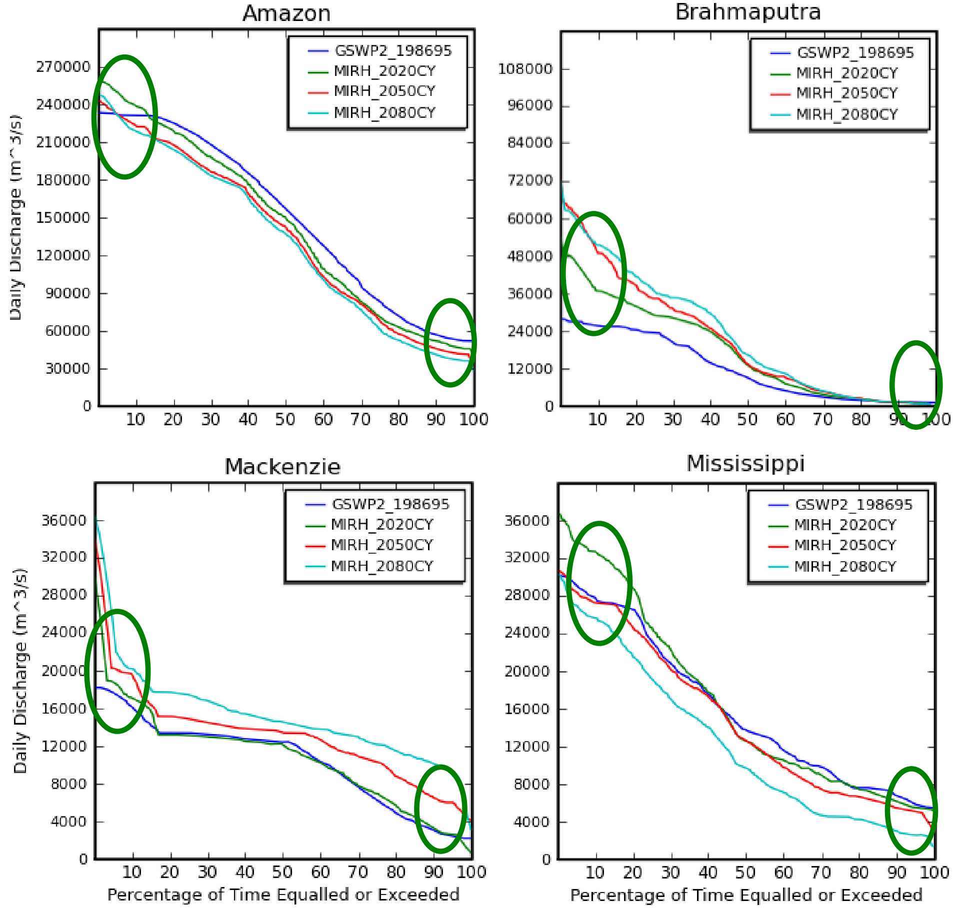
CHANGE IN HYDROPOWER POTENTIAL

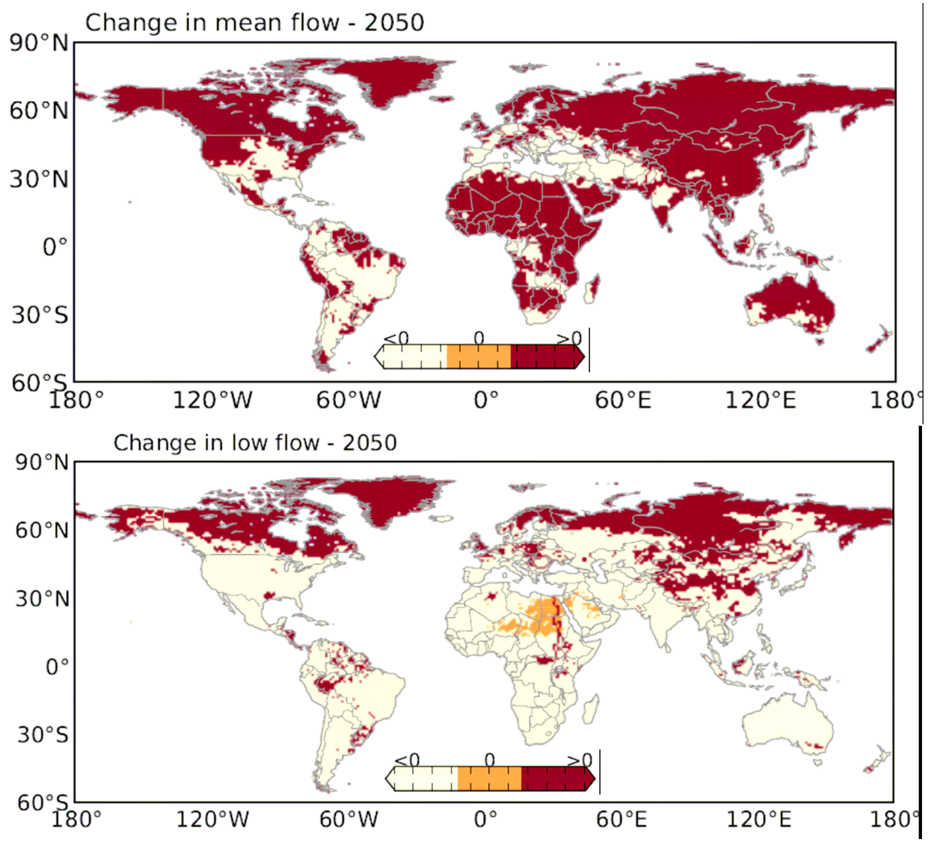


- Error bars show error bounds for other two scenarios A2 and B1
- Monthly variation in change considerably high
- Change in low and high flows ??

(Yadu Nath Pokhrel, 2008)

FDC AND CHANGE IN LOW FLOWS (Q_{95})

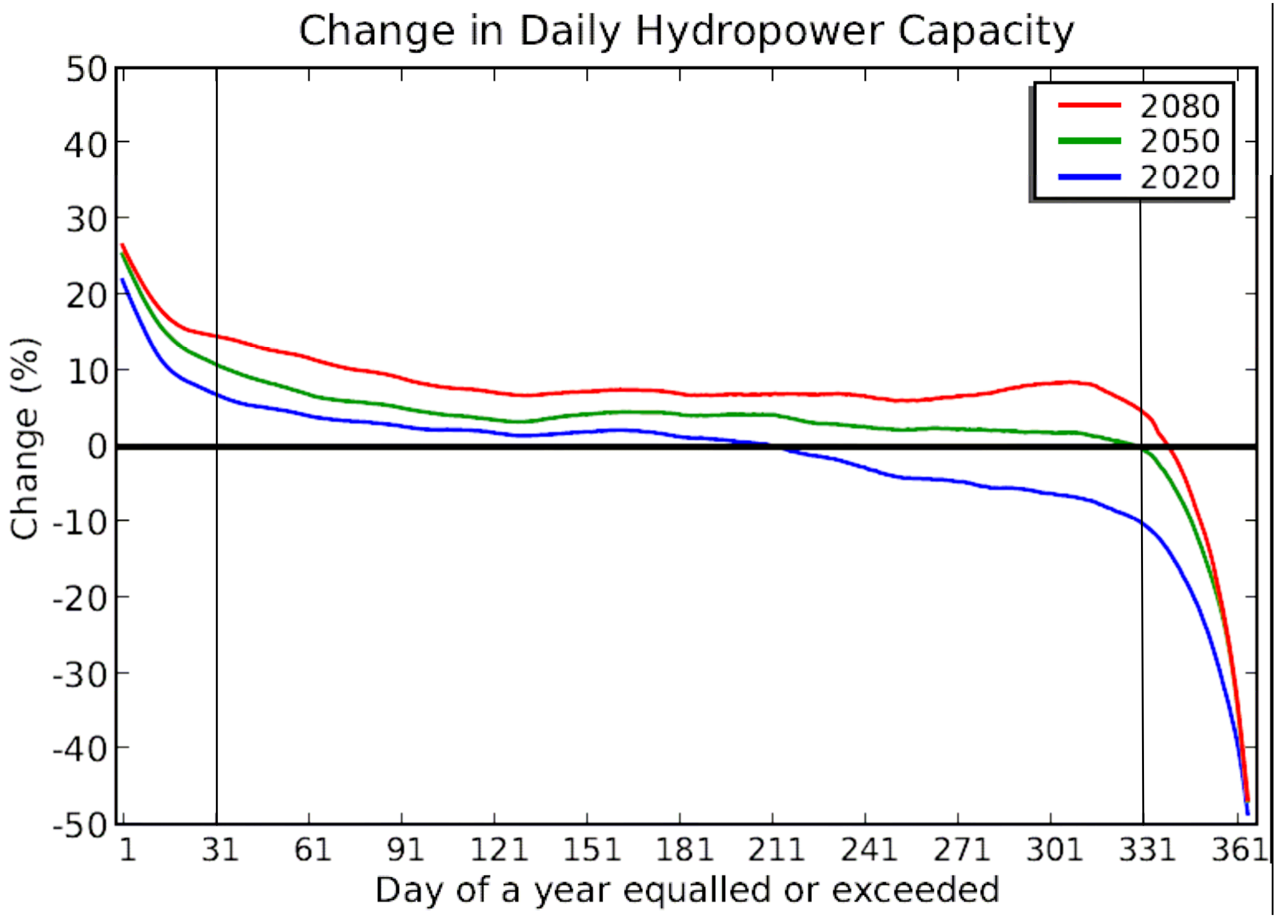




- The high flows (Q_5) and low flows (Q_{95}) will change significantly
- Mean flow may increase but low flows decrease in many regions
- Change in low flows will adversely affect the firm energy generation

(Yadu Nath Pokhrel, 2008)

CHANGE IN LOW FLOWS AND HYDROPOWER



- If projected changes occur, hydropower generation will be adversely affected
- Mainly the small hydropower plants having no storage will be affected
- Such changes should be considered in planning of future hydropower

(Yadu Nath Pokhrel, 2008)

Counter Measure against CC

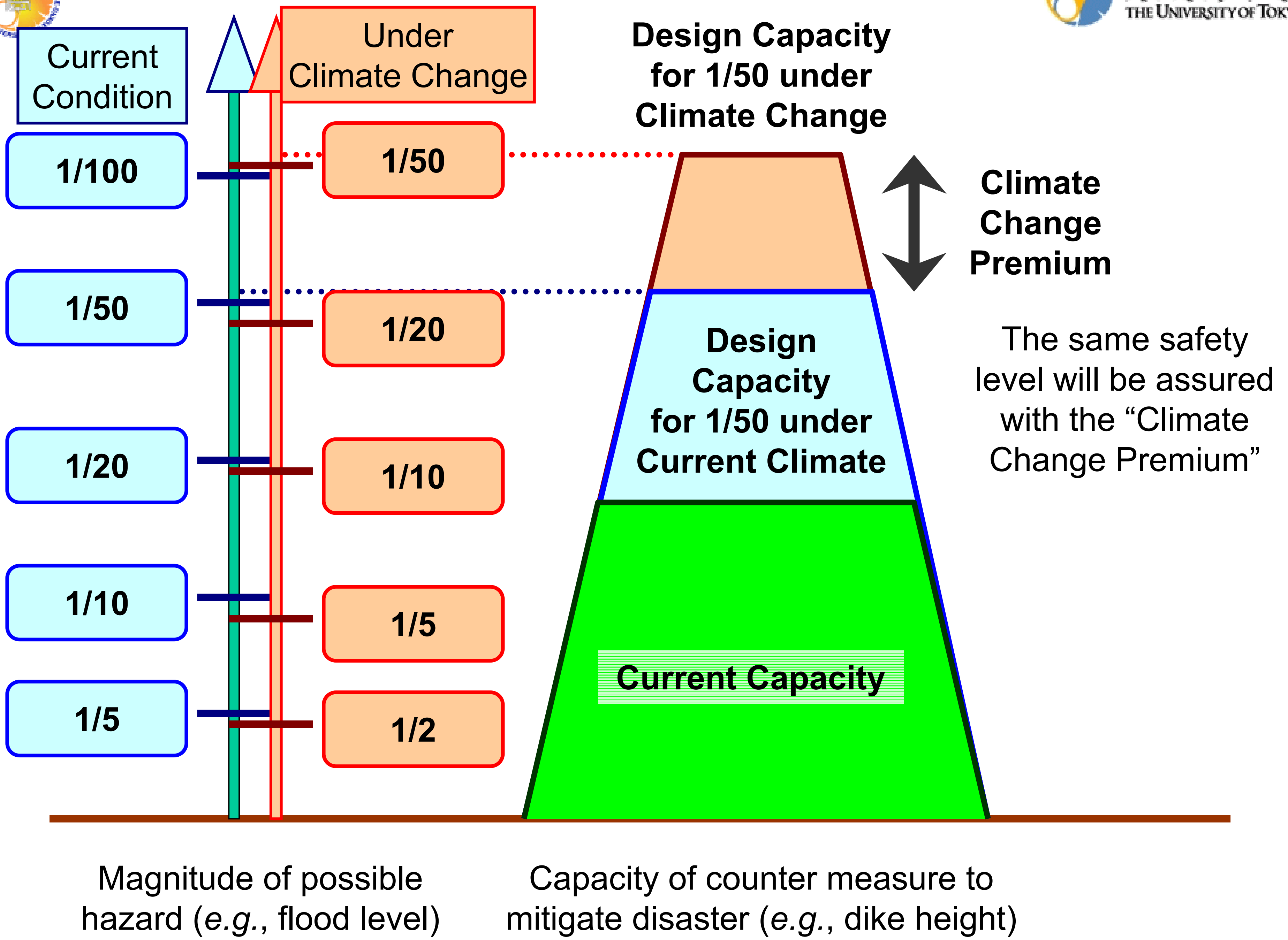
- **Mitigation**
  - **Reduce the emission of green house gases (GHGs) and slow down the speed of the climate change.**
  - **Most of the measures are also good for reducing the energy consumption and saving the fossil energy.**
- **Adaptation**
  - **Enhance the resilience of the society and reduce the disaster which is anticipated due to the climate change.**
  - **Most of the adaptation measures are also good for solving the existing social issues: poverty, vulnerabilities for natural disaster, food and agriculture, health, ecosystem, …**

What kind of adaptation measures are expected?

Adaptation Options

- **Supply-side**
  - **Prospecting and extraction of groundwater**
  - **Increasing storage capacity by building reservoirs and dams**
  - **Desalination of sea water**
  - **Expansion of rain-water storage**
  - **Water transfer**

(IPCC AR4, WGII Ch3, 2007)


Current Condition
Under Climate Change
1/100
1/50
1/20
1/10
1/5
1/50
1/20
1/10
1/5
1/2
Design Capacity for 1/50 under Climate Change
Climate Change Premium
Design Capacity for 1/50 under Current Climate
Current Capacity
The same safety level will be assured with the "Climate Change Premium"
Magnitude of possible hazard (e.g., flood level)
Capacity of counter measure to mitigate disaster (e.g., dike height)

Adaptation Options

- **Demand-side**
  - **Improvement of water-use efficiency by recycling water**
  - **Reduction in water demand for irrigation by changing the cropping calendar, crop mix, irrigation method, and area planted**
  - **Promotion of indigenous practices for sustainable water use**
  - **Expanded use of water markets to reallocate water to highly valued uses**
  - **Expanded use of economic incentives including metering and pricing to encourage water conservation**
  - **Reduction in water demand for irrigation by importing agricultural products, i.e., virtual water**

(IPCC AR4, WGII Ch3, 2007)

Summary

- Anticipated water scarce region in the future is basically where problems exist now.
  - More water stress in Mediterranean countries and Western part of NA due to climate change.
  - Social change gives more pressure in Middle East, West Asia, and South Asia.
  - Lack of social capacity in Sub-Saharan Africa and Latin America are concerned to be vulnerable.
- Serious changes in extreme events are also anticipated.
- Counter measures including "more reservoirs" should be considered especially without sufficient infrastructure to cope with intense hydrological variabilities.

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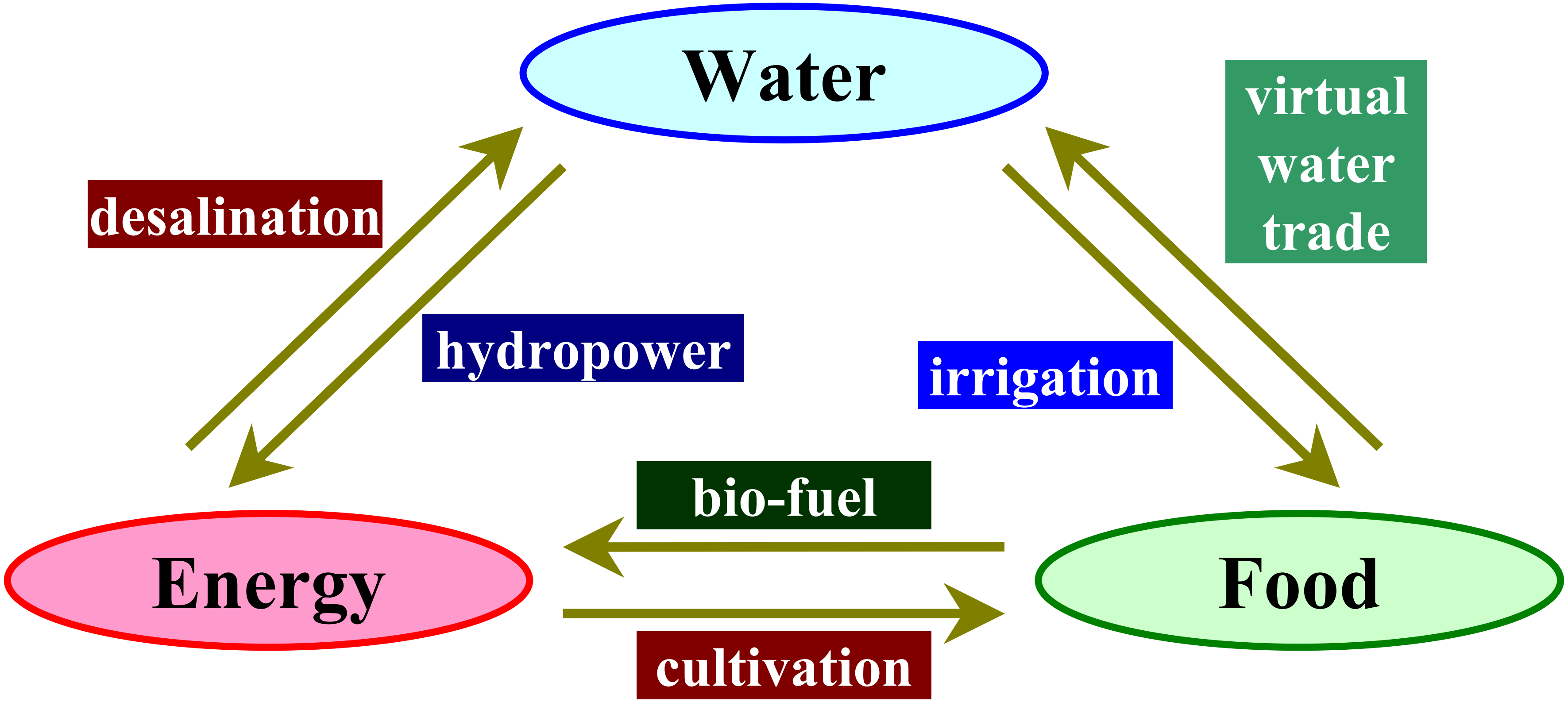
Support developing sustainability in a society

- **Water should not be dealt alone separated from food and energy. ←Limited Resources = "LAND"**



G8 Hokkaido Toyako Summit Leaders Declaration, Hokkaido Toyako, 8 July 2008

Development and Africa **Water and Sanitation**

- 47. Good water cycle management is crucial
- the issue of water has a cross-sectoral nature
- accelerate the achievement of the internationally agreed goals on water and sanitation, implement the Evian Water Action Plan
- promote integrated water resource management and the concept of 'Good Water Governance'
- strengthening of trans-boundary basin organizations
- sharing of water-related expertise and technology
- support for capacity building for water-related initiatives
- promotion of data collection and utilization
- adaptation to climate change
- ensuring adequate water supplies for human, industrial and environmental uses
- minimizing the impacts of extreme hydrological variability
- protecting human health, promoting sustainable economic growth, and ensuring peace and security.
- prioritize access to sanitation
- improve the governance of the water and sanitation sector
- ensure that monitoring and reporting are improved

Thank You!!

(Sadd el-Kafara dam, Wadi Garawi, Egypt; 2500BC?)