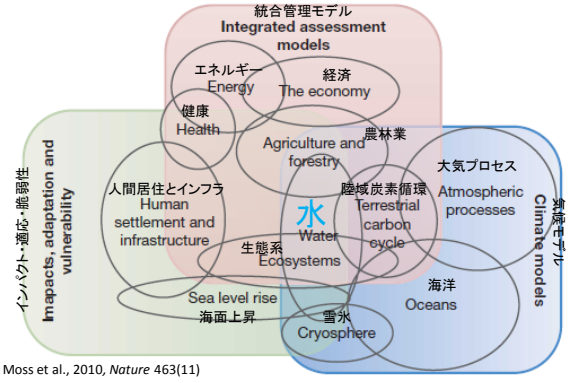
体系理解科目「地球環境変動論」2011年度
名古屋大学環境学研究科, 2011年11月15日

地球温暖化の水資源への影響

総合地球環境学研究所
谷口真人

地球環境問題のモデル化



Moss et al., 2010, *Nature* 463(11)
※出典情報１－１参照

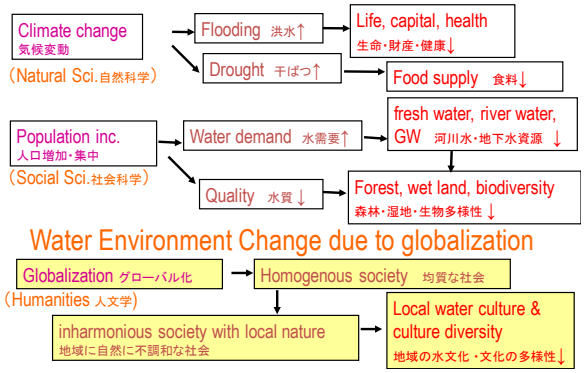
世界の水問題

世界人口の1/7が、安全な水にアクセスできない
More than 1/7 of world population cannot access safe water（=0.88 Billion, 0.48 B in Asia）
人口増加・集中と温暖化によりさらに増加

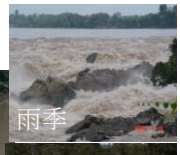
水と人のアンバランス(imbalance between water & population)
多すぎる水　too much water (to control)
少なすぎる水　too little water (to survive)

2000.9 国連ミレニアムサミット（NY）: 安全な水供給と衛生改善
2002.9　ヨハネスブルグサミット：持続可能な開発に関する首脳会議
2003.7 G8サミット(エイビアン): 水に関するG8行動計画
2005.2 第3回地球観測サミット：GEOSS 10年実施計画
2008.7 G8サミット（洞爺湖）:

水資源・水環境変化の3大要因



too much water



洪水：不適切管理
都市型洪水
地盤沈下複合
自然要因だけではない洪水被害の拡大

中国
ミャンマー
タイ
ラオス
ベトナム

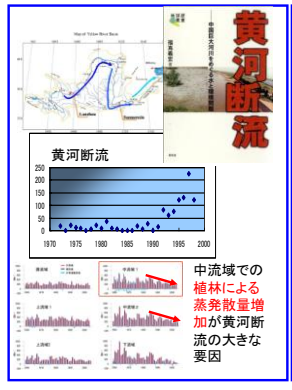
生態系の劣化と多様性の減少
グロ-バル経済による急激な変化と少数民族への負荷

現代の資源管理政策の失敗と
コミュニティーによる管理の必要性

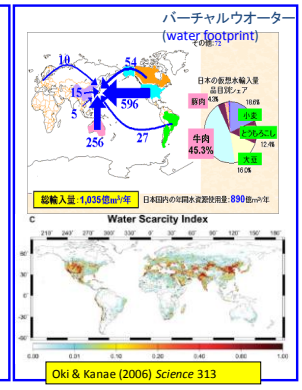
多すぎる水(too much water)は大きな被害をもたらし、今後も適応する方法が必要だが、人々は持続的ではない方法も含めて様々に対処してきた。

地球研・秋道智彌教授撮影

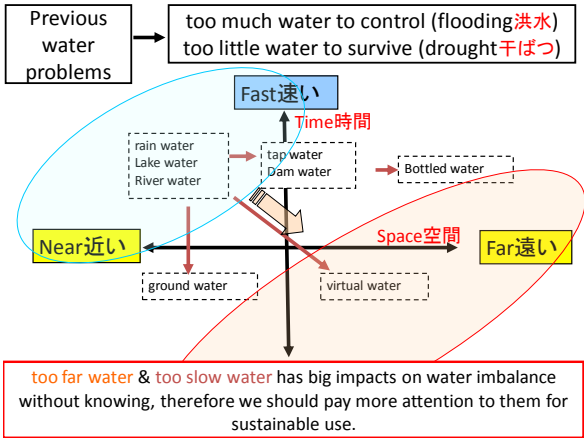
too little water

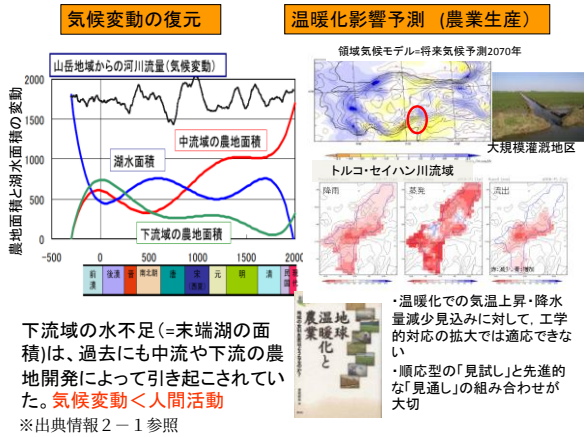


中流域での植林による蒸発散量増加が黄河断流の大きな要因



※出典情報１－６参照





地球研 渡邉紹裕 教授撮影

下流域の水不足（=末端湖の面積)は、過去にも中流や下流の農地開発によって引き起こされていた。気候変動＜人間活動

※出典情報２－１参照

21世紀は“水の世紀“

21st century is a “century of water”

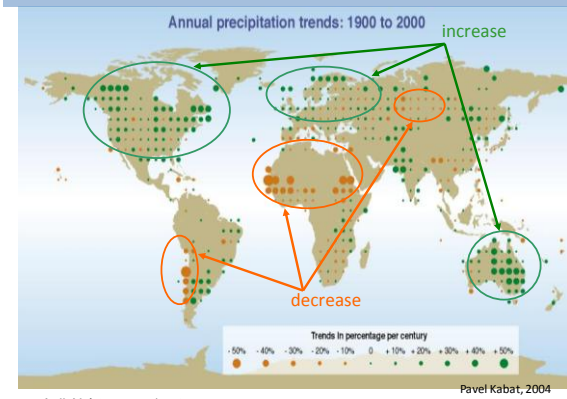
20世紀は“石油の世紀” (20th C is a “century of oil”)

vs

21世紀は“水の世紀” (21st C is “century of water”)

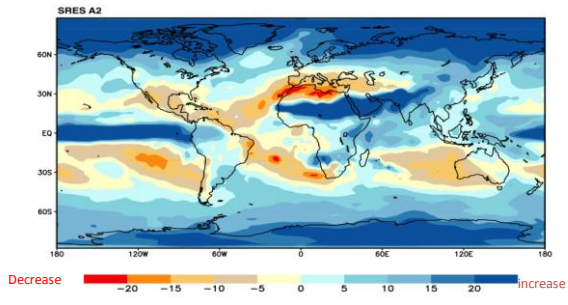
- 人口増加・温暖化・汚染→水資源減少・水紛争
  (Increase in population, global warming, contamination
  ⇒decrease WR, “war for water”)
- 枯渇型資源から循環型資源へ
  non renewal resources ⇒ renewal resources

過去の降水量変化 (1900-2000)



※出典情報２－４参照

降水量変化予測

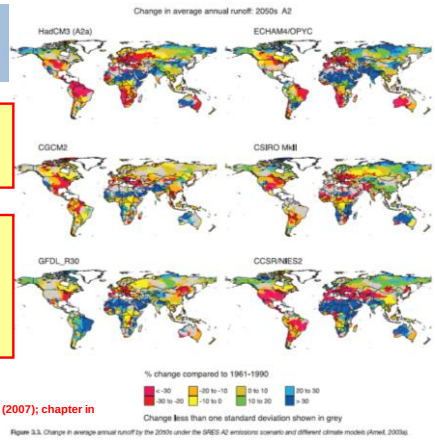


※出典情報２－５参照

気候変動モデルによる河川流量変化予測

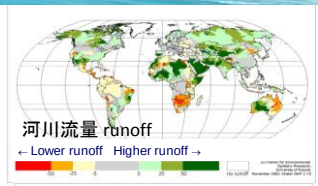
Substantial differences even in large river basins!

Hydrological model uncertainty maybe smaller than errors originating from climate change scenario modeling



Source: Kundzewicz et al. (2007); chapter in IPCC (2007)

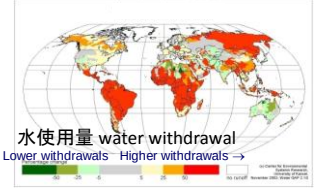
※出典情報２－６参照



Change in Annual Water 水可能量 (runoff)

(2020s, A2 Scenario, WaterGAP Model, Hadley Climate Predictions)

気候変動
climate change



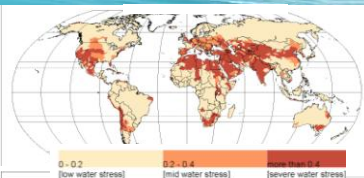
Change in Annual Water 水使用量 (withdraw)

(2020s, A2 Scenario, WaterGAP Model)

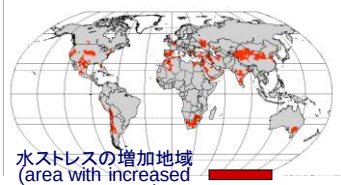
社会変化(人口増)
Social change (population increase)

Pavel Kabat, 2004

※出典情報３－１参照



Withdrawal to Availability Ratio:
水ストレス=使用量/可能量
(2020s, A2 Scenario, WaterGAP Model, Hadley Climate Predictions)



Water Scarce Areas with Increasing Water Stress (up to 2020s) because of:
- *increasing water use* (社会経済変化)
and/or
- *decreasing water availability* (気候変動)

Pavel Kabat, 2004

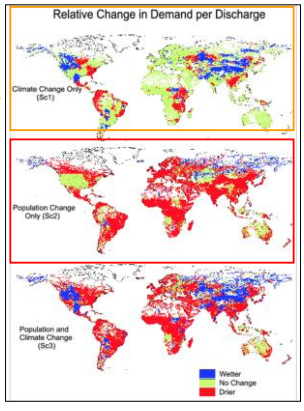
※出典情報３－２参照

Water Stress Changes to 2025

気候変動の影響
Climate change
20 %

人口増加の影響
Population change
80 %

気候変動＋人口増加の影響 (Both) 100 %



Modified from Vörösmarty et al. 2000

※出典情報３－３参照

現在の淡水資源脆弱性

(Source: Kundzewicz et al., 2007; chapter in IPCC, 2007)

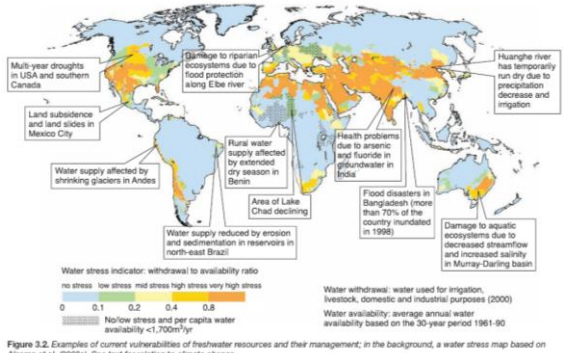


Figure 3.2. Examples of current vulnerabilities of freshwater resources and their management; in the background, a water stress map based on Alcamo et al. (2003a). See text for relation to climate change.

※出典情報３－４参照

将来の淡水資源への気候変動の影響

(Kundzewicz et al., 2007)

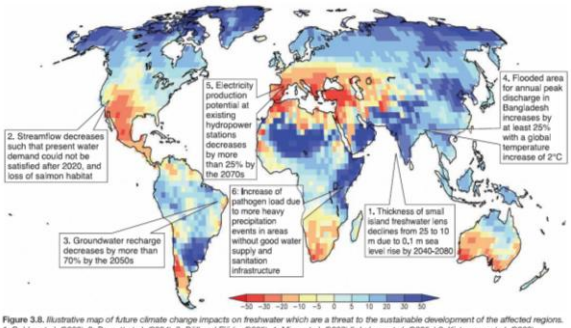
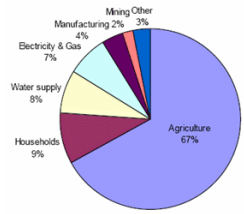


Figure 3.8. Illustrative map of future climate change impacts on freshwater which are a threat to the sustainable development of the affected regions. 1: Bobba et al. (2000), 2: Barnett et al. (2004), 3: Döll and Flörke (2005), 4: Mirza et al. (2003) 5: Lehner et al. (2005a) 6: Kistemann et al. (2002). 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).

※出典情報３－５参照

Impacts on water use sectors

- Food production
- Agriculture
- Fisheries
- Water supply
- Health
- Energy
- Transportation



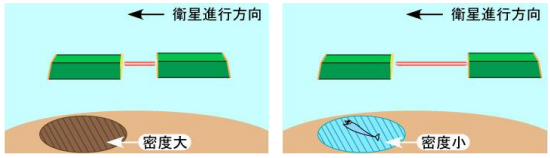
陸域淡水資源への気候変動の影響評価

Sattelite GRACE

Gravity Recovery and Climate Experiment

衛星GRACE 打ち上げ(2002年3月)
（高度450km, 距離：250km）

距離測定の精度：
250km離れた2点間で、髪毛の10分の1の差がわかる！



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http://www1.kaiho.milt.go.jp/KOHO/simosato/Japanese/articles/20020625.htm.

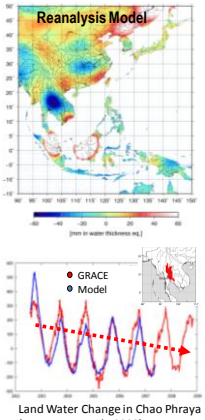
Sattelite GRACEによる陸域淡水資源評価

- Version 02 of the GRGS every 10 day gravity field solutions are used in this study (*Lemoine et al.*, 2007)
- The data from July 2002 to October 2008.
- After removing the average of the whole data period, mass variations of each time period was estimated using Eq. (1) of *Wahr et al.* (1998).

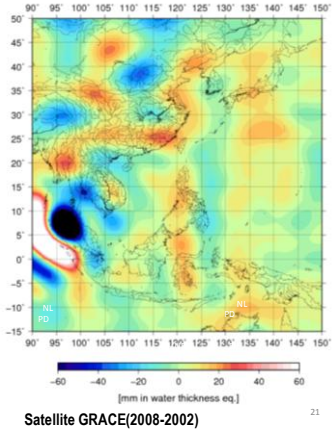
$$\Delta\sigma(\theta,\lambda) = \frac{a\rho_E(2l+1)}{3(1+k_l')}\sum_{l=0}^{50}\sum_{m=0}^{l}(\Delta\overline{C}_{lm}\cos m\lambda + \Delta\overline{S}_{lm}\sin m\lambda)\overline{P}_{lm}(\sin\theta)$$

where;

$\Delta\sigma(\theta,\lambda)$: mass change rate at the latitude θ and the longitude λ,
a : equatorial radius of the Earth,
ρ_E : the average density of the Earth,
k_l' : the load Love number of degree l,
$\Delta\overline{C}_{lm}$ and $\Delta\overline{S}_{lm}$: variable components of fully normalized GRACE harmonic coefficients of degree l and order m.



Land Water Change in Chao Phraya (Yamamoto et al., 2009)



Satellite GRACE(2008-2002)

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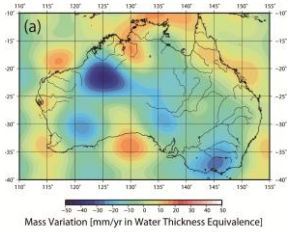
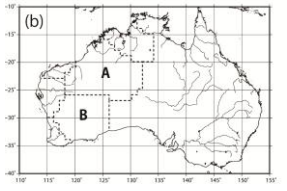
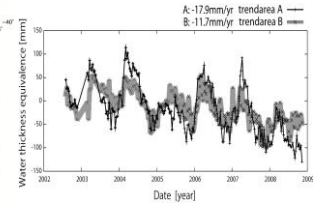
※出典情報４－３参照





Trends of land water changes during 2002 and 2008

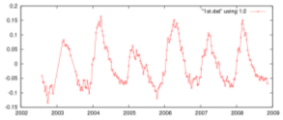


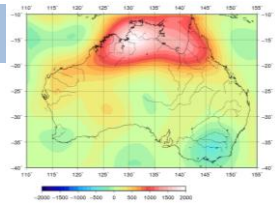
Taniguchi et al., 2011

※出典情報４－４参照

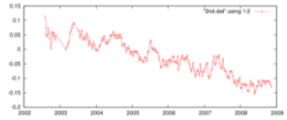
EMPIRICAL ORTHOGONAL FUNCTION (EOF) ANALYSES FOR EACH WATER COMPONENT OF THE CHANGES IN LWS

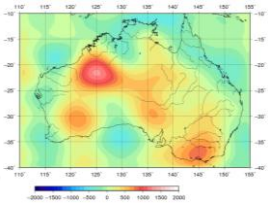
1st: 46.5 % ⇒seasonal change





2nd: 18.16 % ⇒long-term change

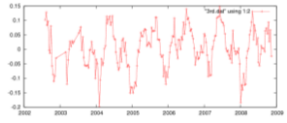


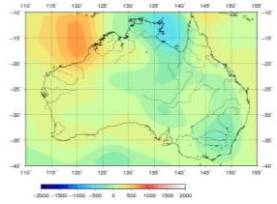


Taniguchi et al., 2011

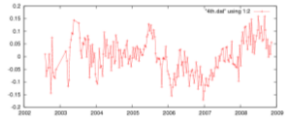
※出典情報４－５参照

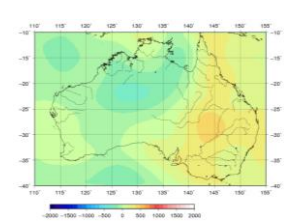
3rd: 8.37 % ⇒ bimodal change





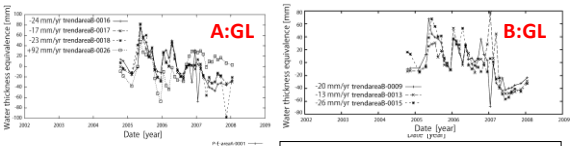
4th: 5.55 %





Taniguchi et al., 2011

※出典情報４－６参照



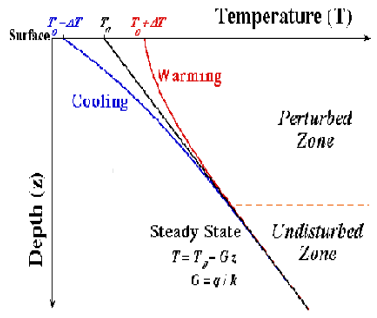
Groundwater depletion (borehole data)
0.147 m/year. (in area A) > 0.095 m/year. (in area B)
If the variable porosities of the soil are assumed to be 0.1, the depletions of groundwater are
0.015 m/year (in area A) >
0.0095 m/year (in area B)

GRACE data
0.0179 m/year in area A >
0.0117 m/year in area B .
These numbers agreed relatively well with the values observed in groundwater level change in area A and B.

Taniguchi et al., 2011

※出典情報５－１参照

温暖化の影響（水・熱環境）→地下温暖化



Reconstructions of climate change from subsurface temperature

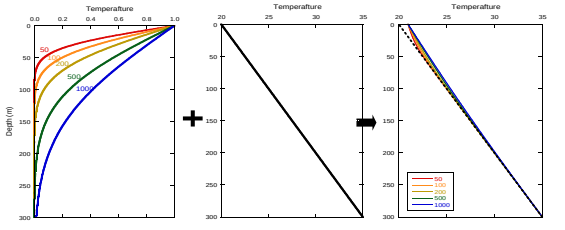
地下温度を用いた気候変動（地表面温度）復元

Surface temp.

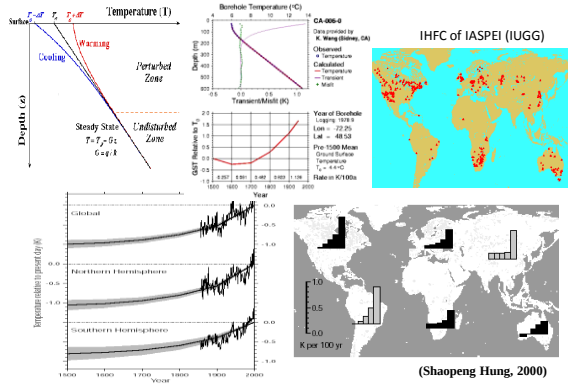
(1) Step change of surface temp. as surface condition :

$$T(z) = T_0 + G \cdot z + \sum \Delta T_i \left[erfc\left(\frac{z}{2\sqrt{\kappa t_i}} \right) - erfc\left(\frac{z}{2\sqrt{\kappa t_{i-1}}} \right) \right]$$

T(z):GW temperature, T_0:surface temperature, G:thermal gradient, κ:thermal diffusivity, t_i :time, T_i :temp. change during t_i-t_{i-1}



地下温度を用いた気候変動（地表面温度）復元

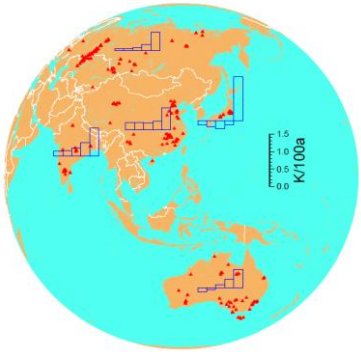


IHFC of IASPEI (IUGG)

(Shaopeng Hung, 2000)

地下温度を用いた気候変動（地表面温度）復元

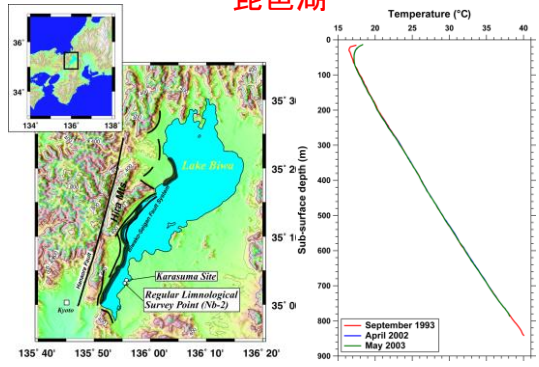
(Taniguchi et al., 2004)



※出典情報５－５参照

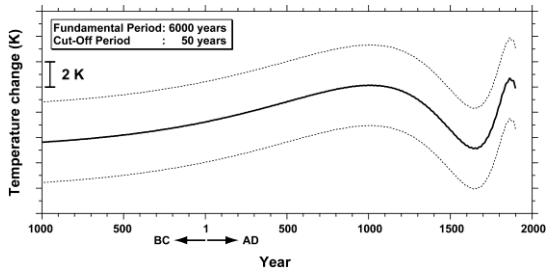
地下温度を用いた気候変動（地表面温度）復元

琵琶湖



地下温度を用いた気候変動（地表面温度）復元

琵琶湖

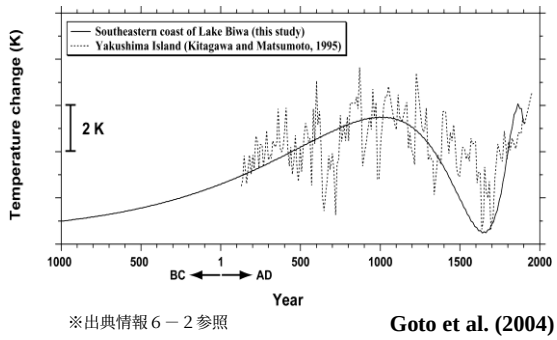


※出典情報６－１参照

Goto et al. (2004)

地下温度を用いた気候変動（地表面温度）復元

年輪解析と比較(屋久島)



※出典情報６－２参照

Goto et al. (2004)

Uncertainties（不確実性）とどう向き合うか

One thing is certain:

Nothing is certain

- Uncertainty and climate change
- How to deal with uncertainties
- Types of uncertainties
- Adaptation to climate change under uncertainty:
  - –Prediction-oriented approaches
  - –Resilience-oriented approaches

Climate change

気温と降水量変化に関する不確実性:

- **大きさ(magnitude)**
- **時期(timing)**
- **空間分布(spatial distribution)**

As well as uncertainties with respect to vulnerabilities

水管理における気候変動不確実性問題

- Uncertainty, variability and risk most important consequences of climate change
- Climate change projections inconsistent and/or inaccurate at regional/local scales
- Stationarity in weather and water systems not longer reliable basis for planning

Experience from the past is no longer a reliable guide for the future.

水管理の挑戦

- Improve predictions (temporal/spatial scales required by water managers)
- Collaboration/communication between climate and water resources management community
- Adaptive management: adaptive and flexible approaches to improve coping with uncertain developments *vs* finding optimum solutions

> *Institutional flexibility and a central role for stakeholders.*

不確実性を有する気候変動への適応

Prediction-oriented:

- Characterising, reducing, managing and communicating uncertainty
- Increasing sophistication of modelling tools and techniques

Resilience-oriented:

- Uncertainties can not be reduced
- Learning from the past

Prediction-oriented approaches

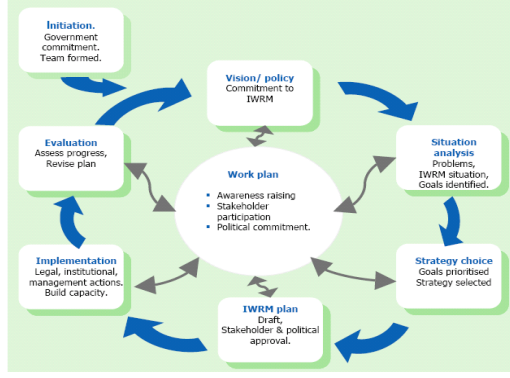
IPCC approach:

- Uncertain information by using CC scenarios as drivers for impacts from which adaptation strategies are developed

Risk approaches:

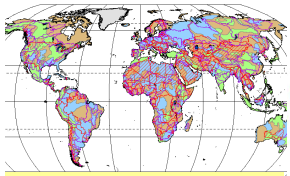
- Identify, evaluate, select and implement actions to reduce risks (probability x consequences)

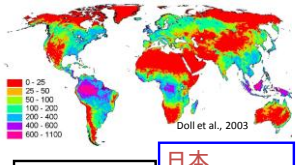
統合的水資源管理(Integrated Water Resources management)の枠組み



水資源 世界人口の1/3以上が地下水に依存

地下水涵養量（フロー）の分布 **水循環**





地下水資源の減少: 2千億t/年（貯金・ストック） ⇒1.2mm/年

アメリカ中南部・華北平原：50mm/年以下

日本 400mm/年

モンスーンアジアでは、乾燥地域とは異なる水循環・水管理法があるはず

涵養量(フロー)＜使用量 ⇒ 貯留量(ストック)減少

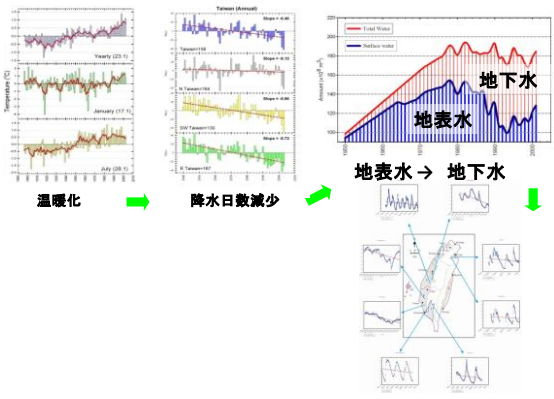
越境地下水

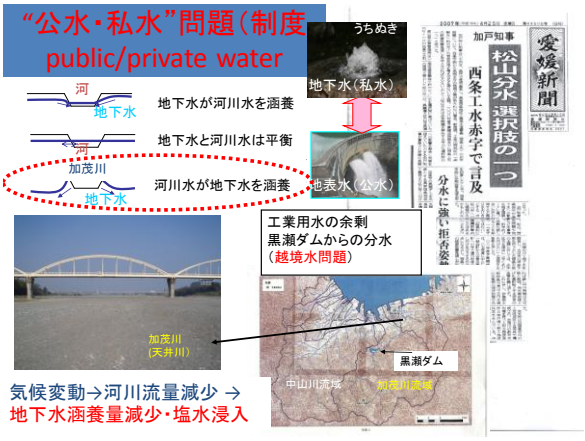
Groundwater Regions, Political boundaries, river basins & non recharged aquifers (ISRAM, 2006)

国連総会決議(2008.12.11)
2011年の秋の国連総会で越境地下水条約案の採択を検討する

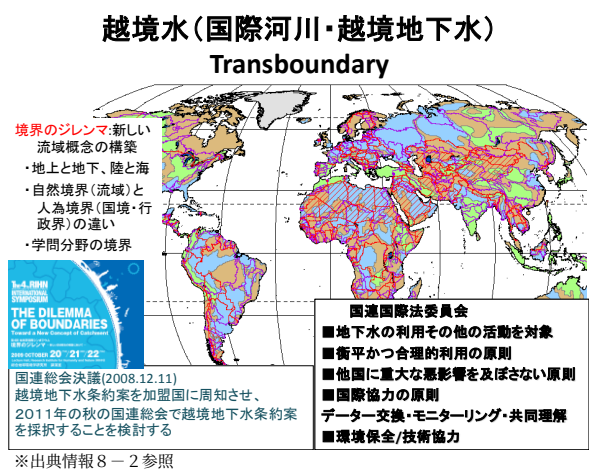
※出典情報７－５参照

気候変動と地下水：信頼できる水資源 （地表水→地下水）





筑波大・遠藤崇浩准教授よりご提供



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