

Multi-sectoral Impact Assessments of Climate Change

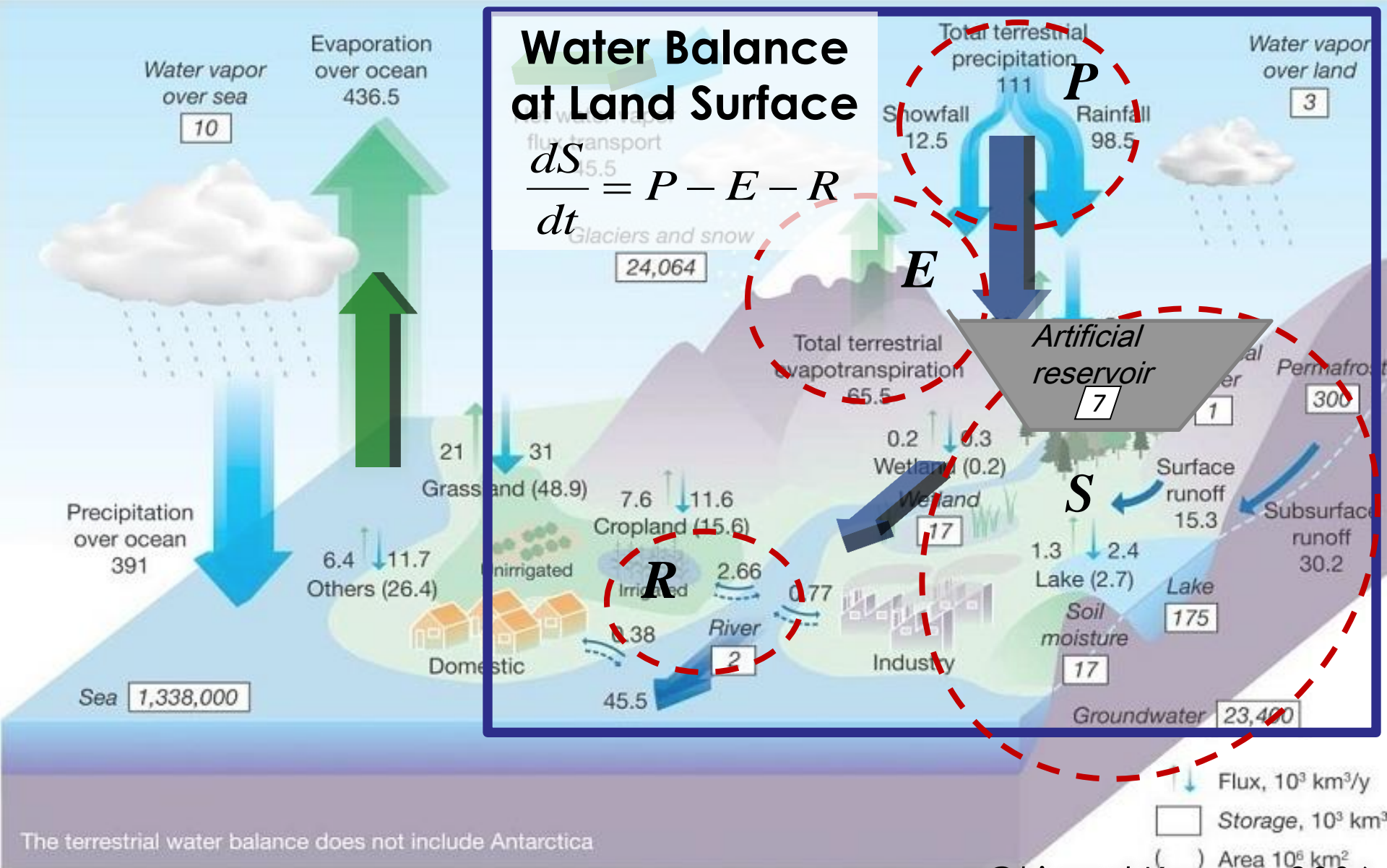
– Modeling
Human and Earth
System Interactions –

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Institute of Industrial Science, the University of Tokyo, Tokyo, Japan

& Thanks to : Yusuke Satoh, Naota Hanasaki, Yadu Pokhrel, Taikan Oki, ...

Global water flows

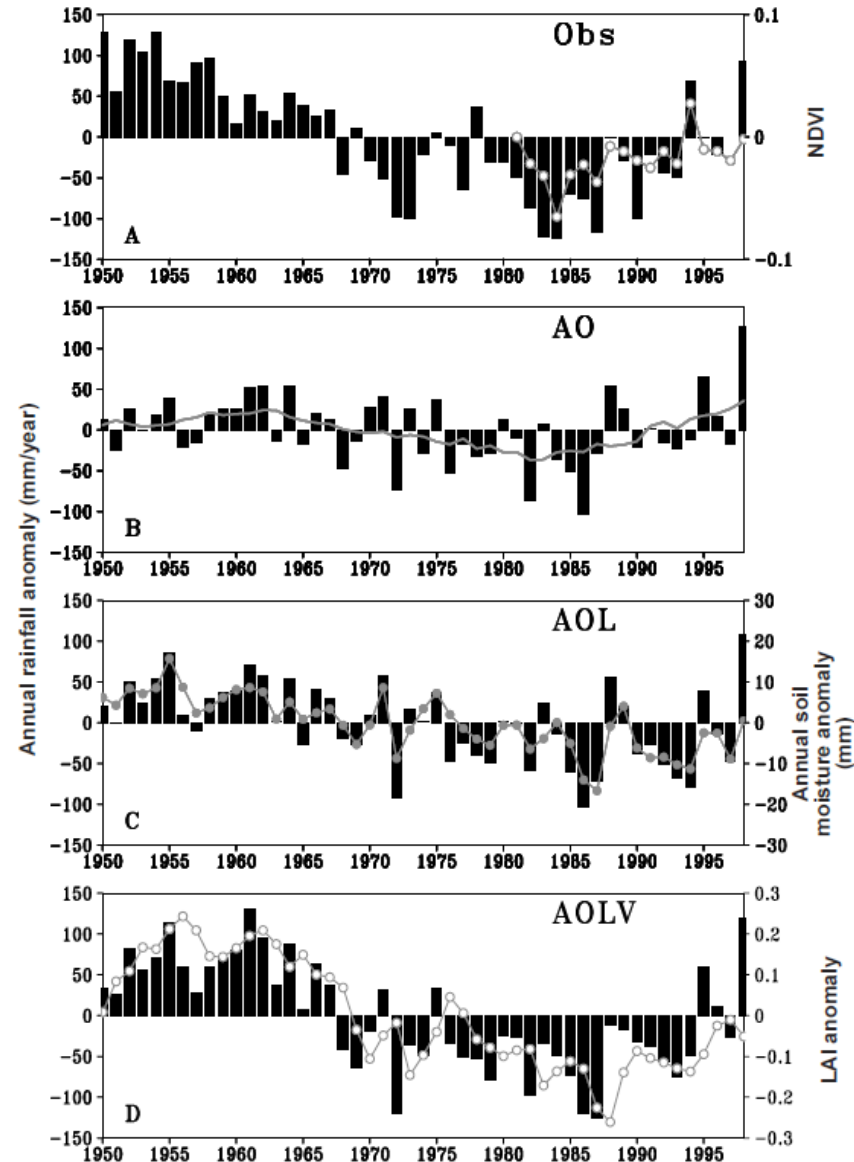


Representation of Interdecadal Climate Variability



&
Human Impacts?

Better representation of precipitation anomaly with **Atmosphere + Ocean + Soil Moisture + Vegetation Interaction**



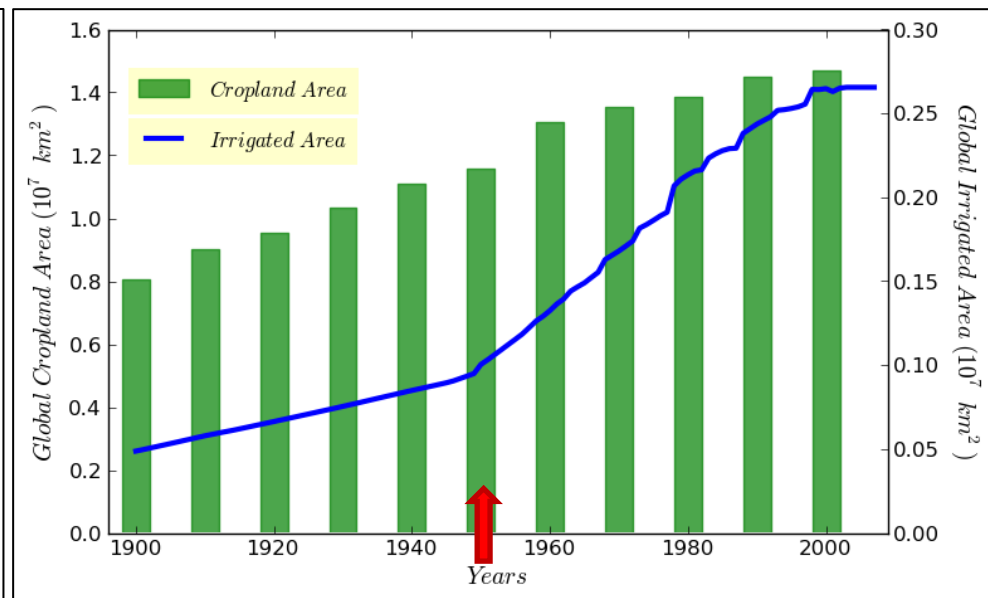
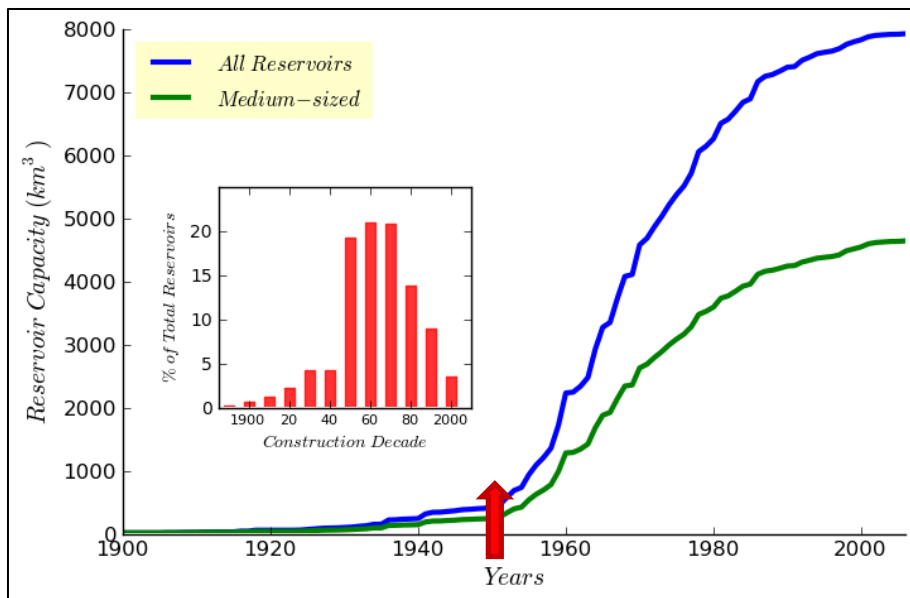
Zeng et al., 1999

Geology of Mankind: “Anthropocene*”

*Crutzen 2002

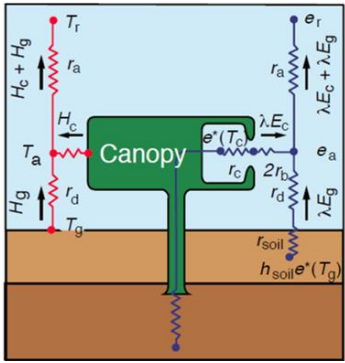
+ Human activities are the major drivers of global environmental changes

+ **Real** global water cycles are not **natural** any more...
human activities have altered water flows and storages significantly during the past century through irrigation, damming, GW extraction, ...

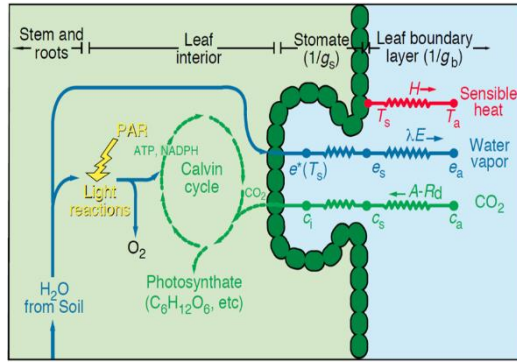


[Pokhrel et al. 2012]

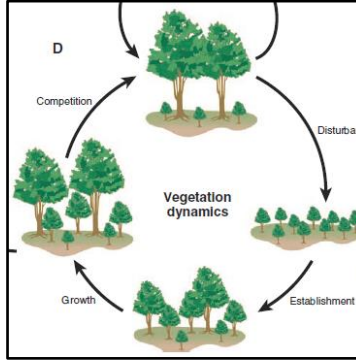
1984 Dickinson
1986 Sellers et al.



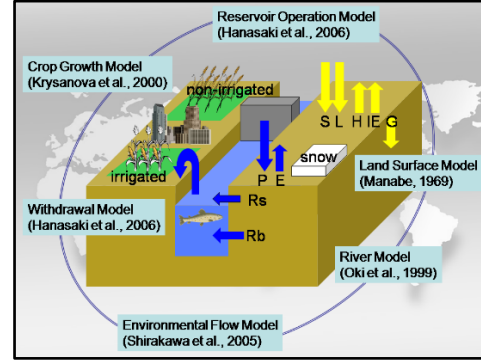
1995 Bonan
1996 Sellers et al.



1996 Foley et al.
2003 Sitch et al.
2003 Bonan et al.



2006 Hanasaki et al.
2008 Hanasaki et al.
2011 Pokhrel et al.



1st Generation

2nd Generation

3rd Generation

4th Generation

5th Generation

Bucket

Big Leaf

Physiology

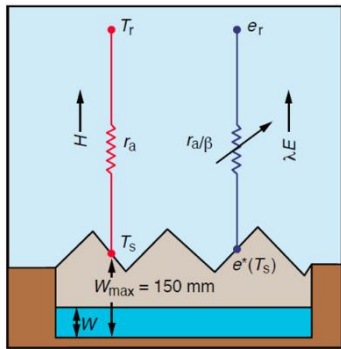
Ecosystem

Anthropocene

NEXUS

1st Integration

NEXT GEN?

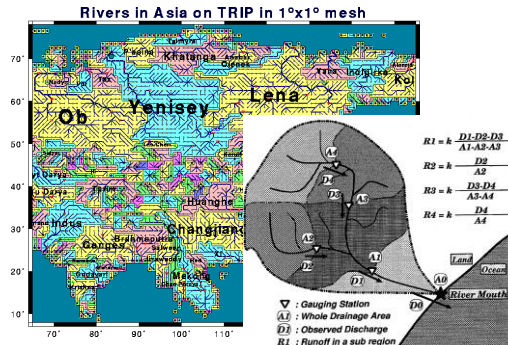


1969 Manabe

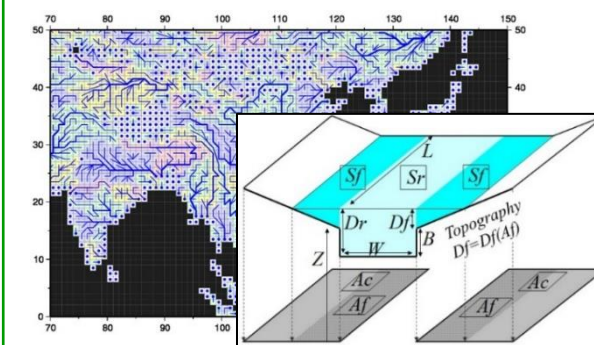
River 1st Generation

2nd Generation

Land



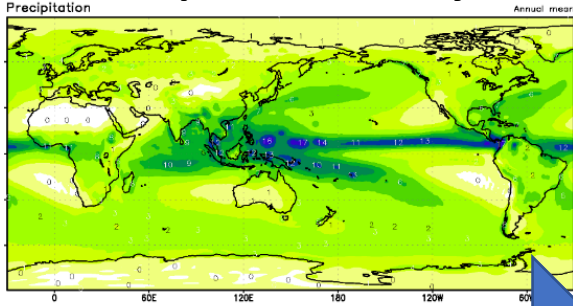
1998 Oki and Sud



2011 Yamazaki et al.

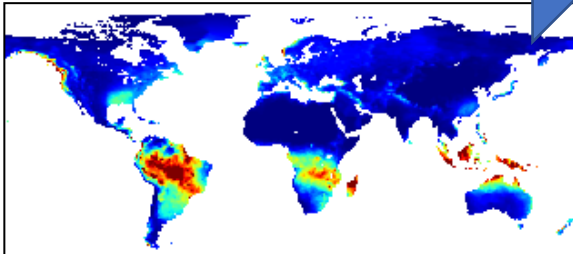
Off-line Framework for Large-scale Land Simulation

Atmospheric Reanalysis



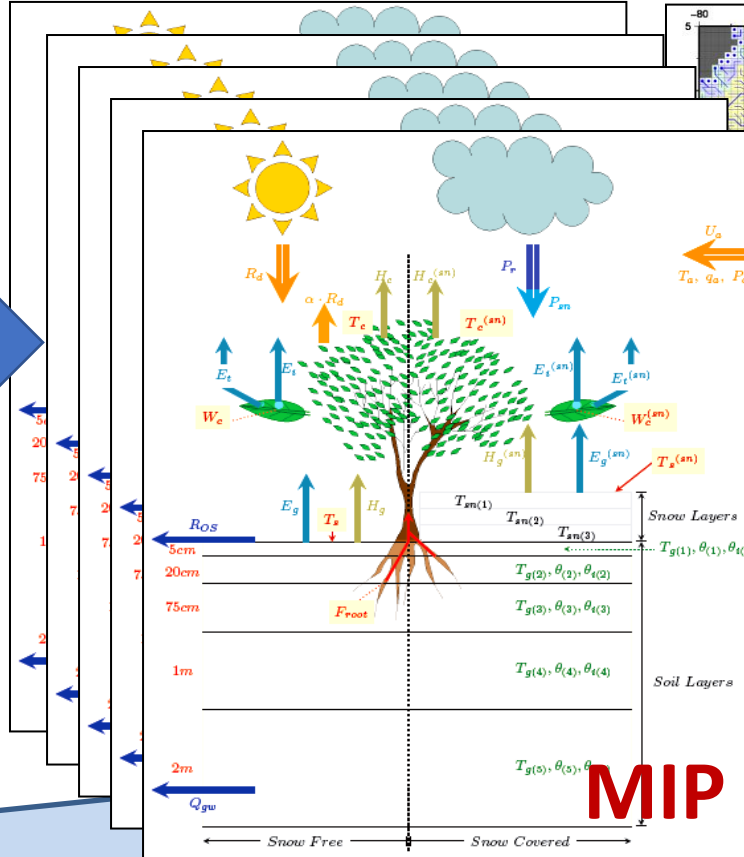
Bias Corr. +

Atmos. Forcing Data



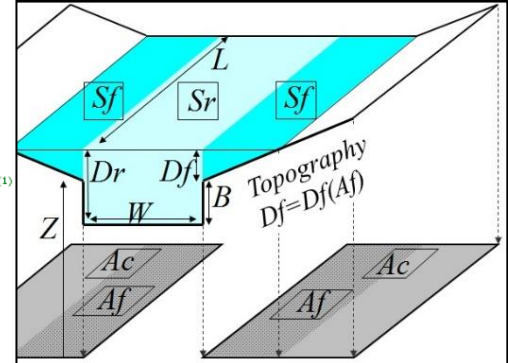
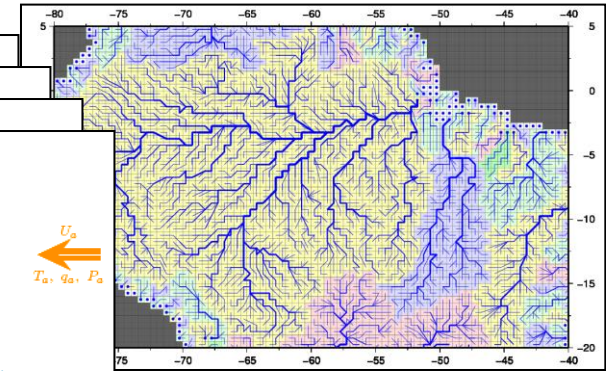
Observations

Land Surface Model



MIP

River Model

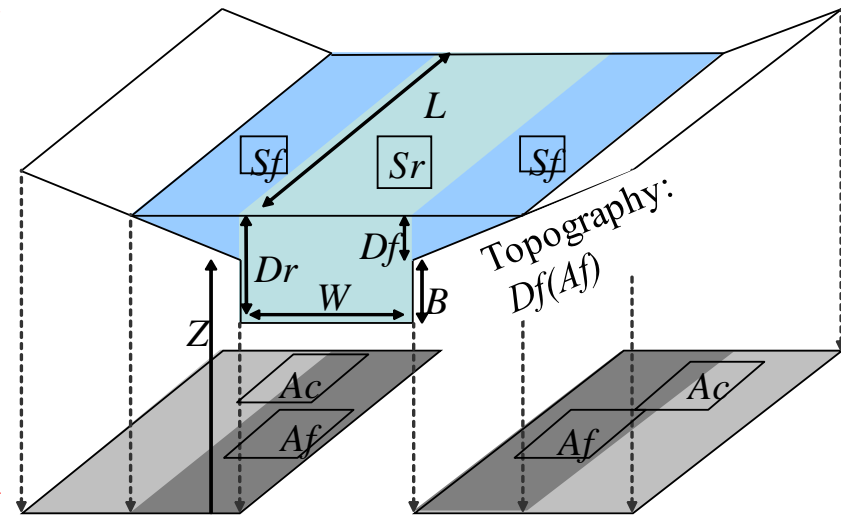
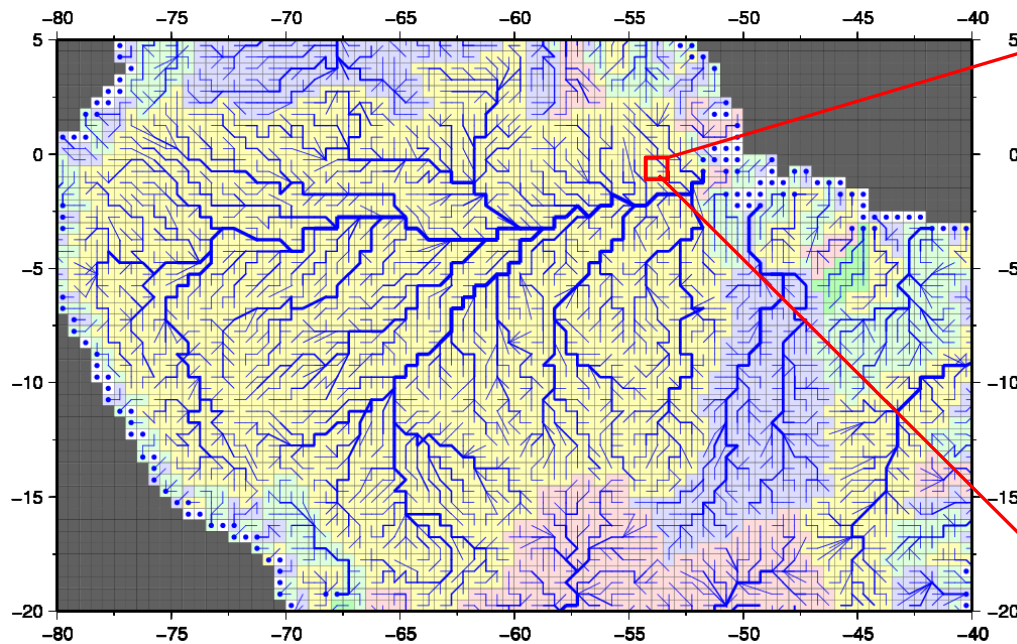


Evaluation / Benchmarking System for Model Simulations and Input Data

A physically based description of floodplain inundation dynamics in a global river routing model

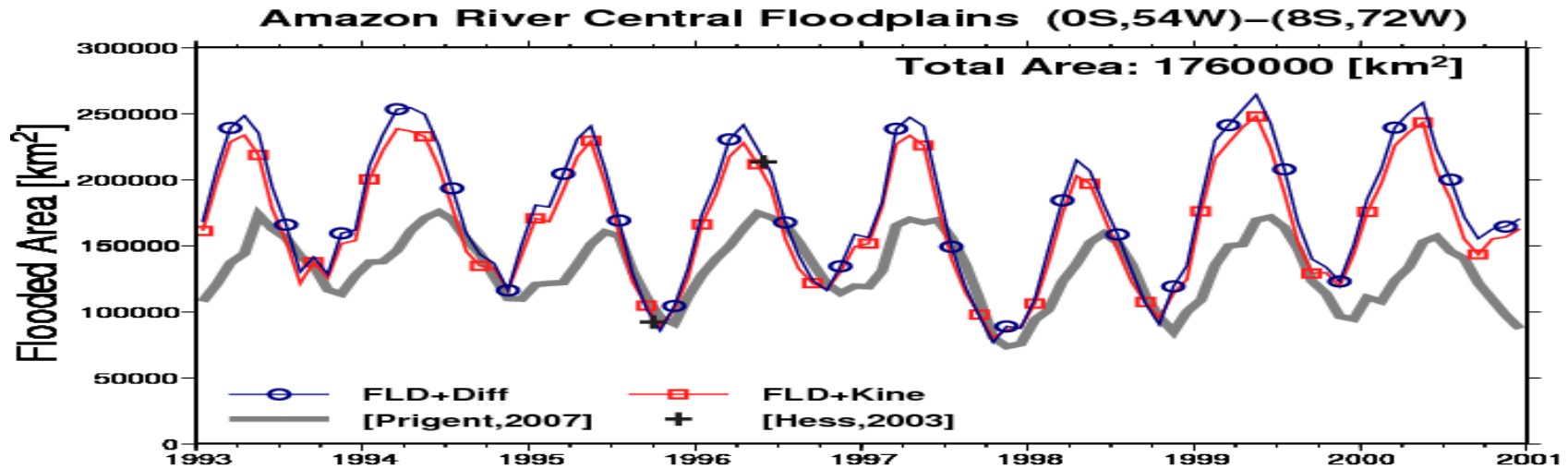
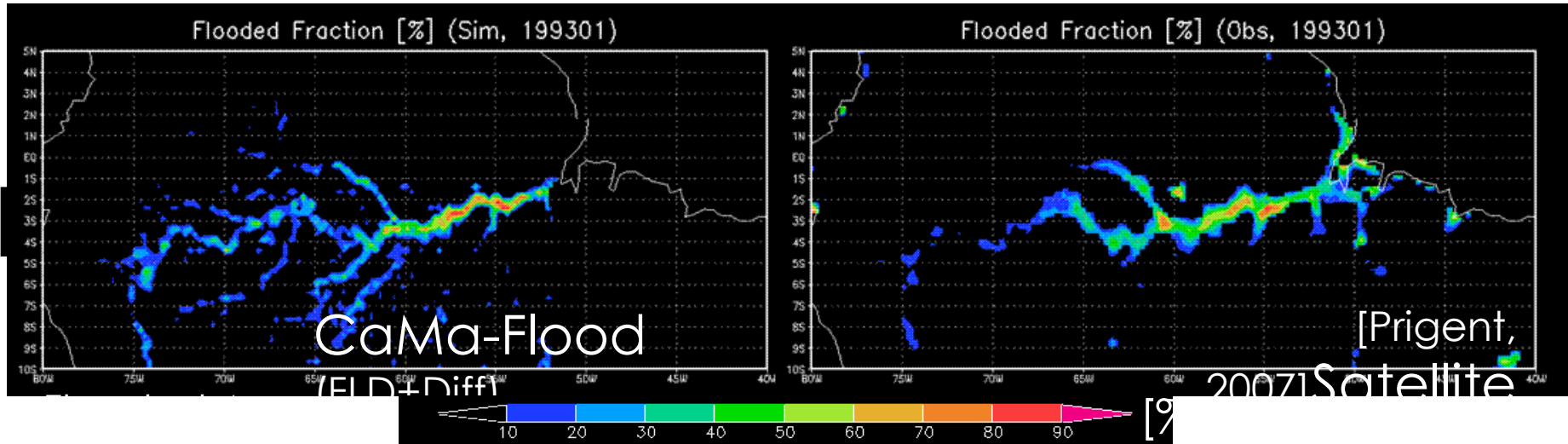
CaMa-Flood (Catchment-based Macro-scale Floodplain model)

- Distributed river routing model using River Network Map
- **Input:** LSM Runoff, **Output:** Water storage (Prognostic)
River discharge, Water level, Inundated area (Diagnosed)
- River and floodplain storage with sub-grid topographic parameters.
 - > Explicit representation of water stage in a single grid-box (25km size)



A physically based description of floodplain inundation dynamics in a global river routing model

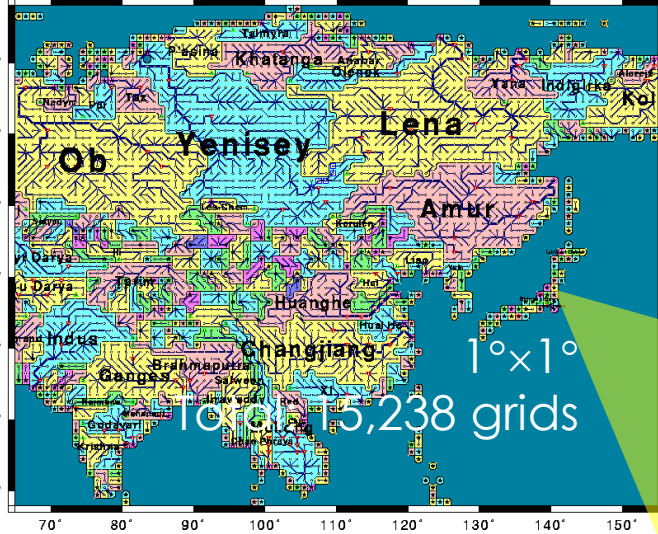
Spatial-temporal distribution of flooded area



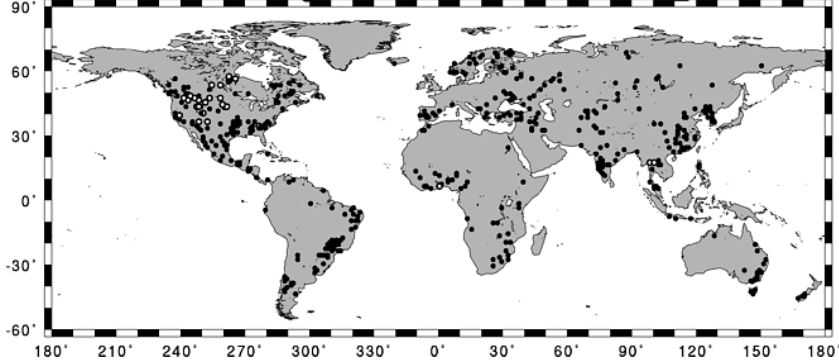
Representation of Anthropogenic Impact

1. Simulate both water availability (streamflow) and water use **at daily-basis**
2. Deal with interaction between **natural hydrological cycle** and **anthropogenic activities**
3. **Applicable** for future climate change simulation

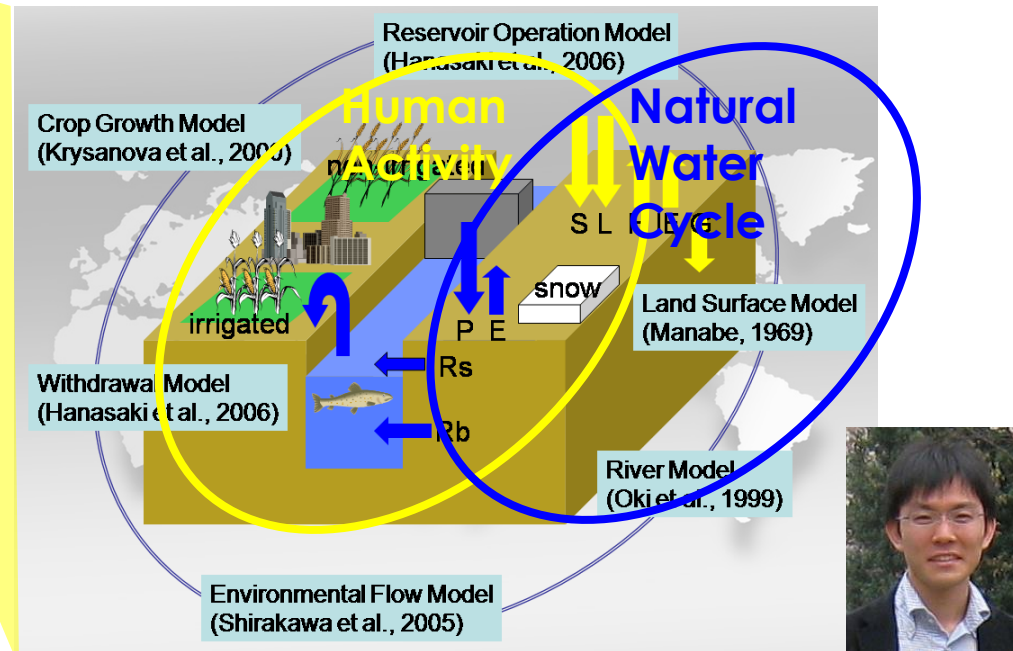
Rivers in Asia on TRIP in 1°x1° mesh



Reservoirs larger than 1000 MCM in The World



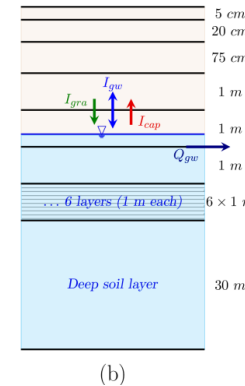
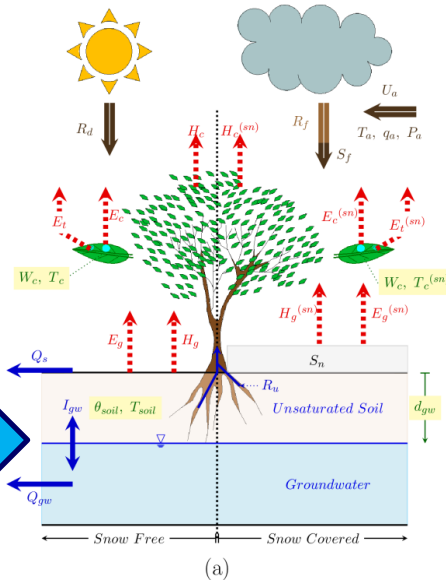
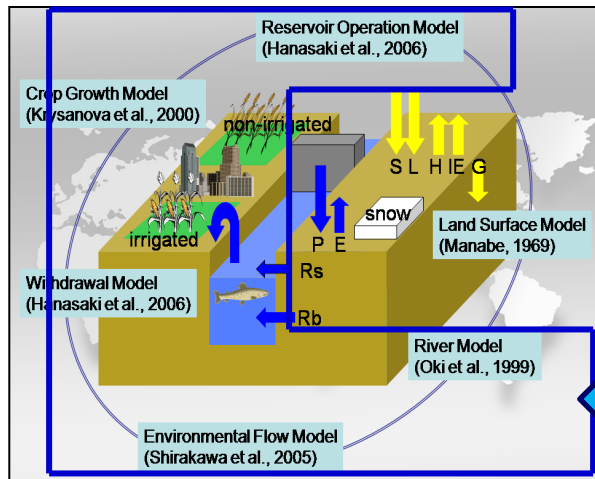
452 reservoirs, 4140 km³



Hanasaki et al., 2006, 2008

Representation of Anthropogenic Impact

- Land Surface Models (LSMs) are designed to be coupled with GCMs
 - **No Human Impacts (HI) representation**
- Numerous Global Hydrological Models (GHMs) with HI representation exist, but
 - Mostly designed for **offline simulations**
 - Simple ET parameterizations (**energy balance not considered**)
 - Vegetation dynamics/Carbon cycles are not accounted.



Water table dynamics
(Yeh and Eltahir, 2005)

Pumping scheme
Koirala et al.

- ✓ Land surface hydrology scheme is a simple **Bucket Model**
- ✓ **Vegetation** : accounted implicitly

- ✓ Further, **new irrigation scheme** for MATSIRO LSM is developed
- ✓ **Water table dynamics and a newly developed pumping scheme**

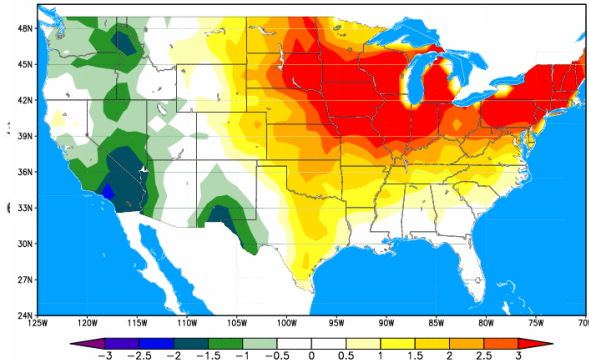
Pokhrel, Kim et al., 2012

Land-atmosphere Interaction in a Global Climate Model in Association with Human Activities

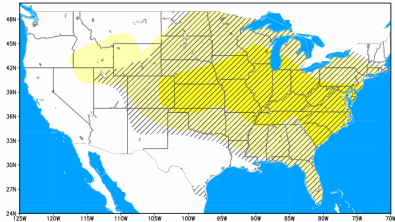
+ Spread of near surface temperature (2m Tair) among ensemble members becomes smaller by incorporating surface water-groundwater-human models in the AGCM.

+ Sub-seasonal forecast skill for near surface air temperature (Day16-30) was improved by using realistic land initializations in the fully coupled AGCM with surface-groundwater-human models.

T2m, GSWP2, July 30 – August 13



T2m, HUMAN-EXP, Realistic Soil Moisture IC.



With HI

(a) T2&Z500,HUMAN,Day1-15 (b) T2&Z500,HUMAN,Day16-30 (c) T2&Z500,HUMAN,Day31-45 (d) T2&Z500,HUMAN,Day46-60

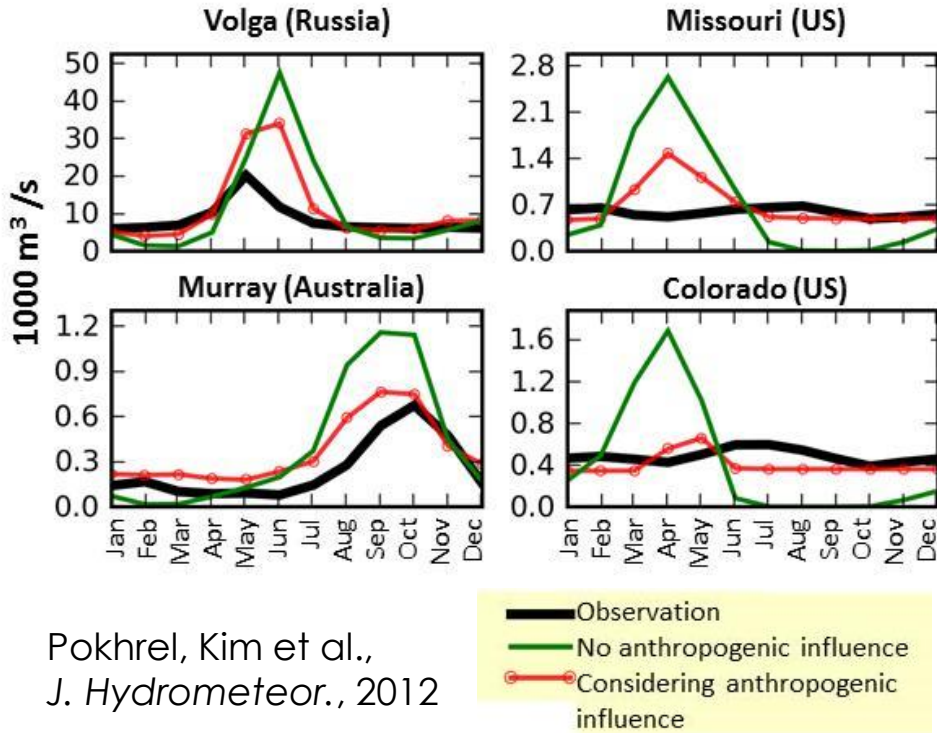


W/O HI

(e) T2&Z500,CTRL,Day1-15 (f) T2&Z500,CTRL,Day16-30 (g) T2&Z500,CTRL,Day31-45 (h) T2&Z500,CTRL,Day46-60

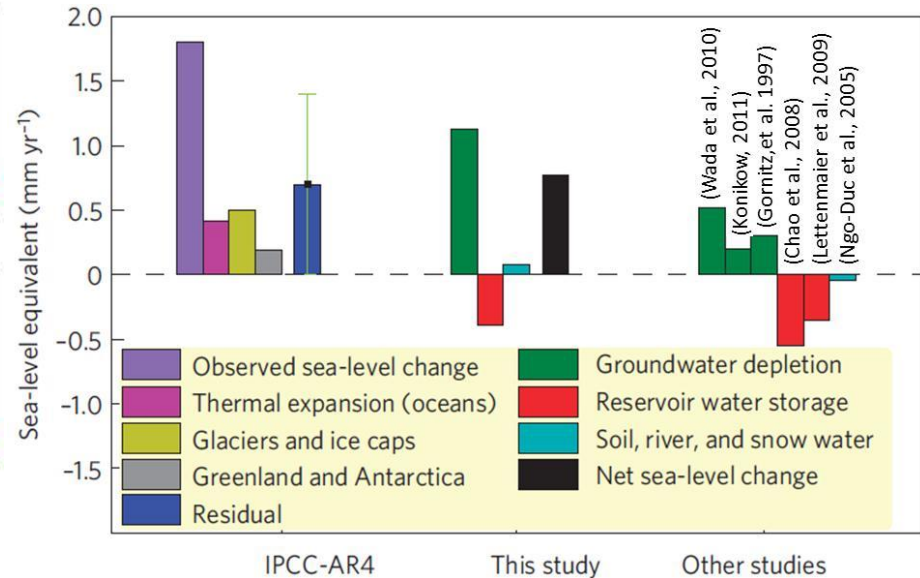


Representation of Anthropogenic Impact



Pokhrel, Kim et al.,
J. Hydrometeor., 2012

Anthropogenic influence on natural water cycles is better reflected with additional model components reproducing human-induced alterations, which lead the improved simulation of river discharge by the models.

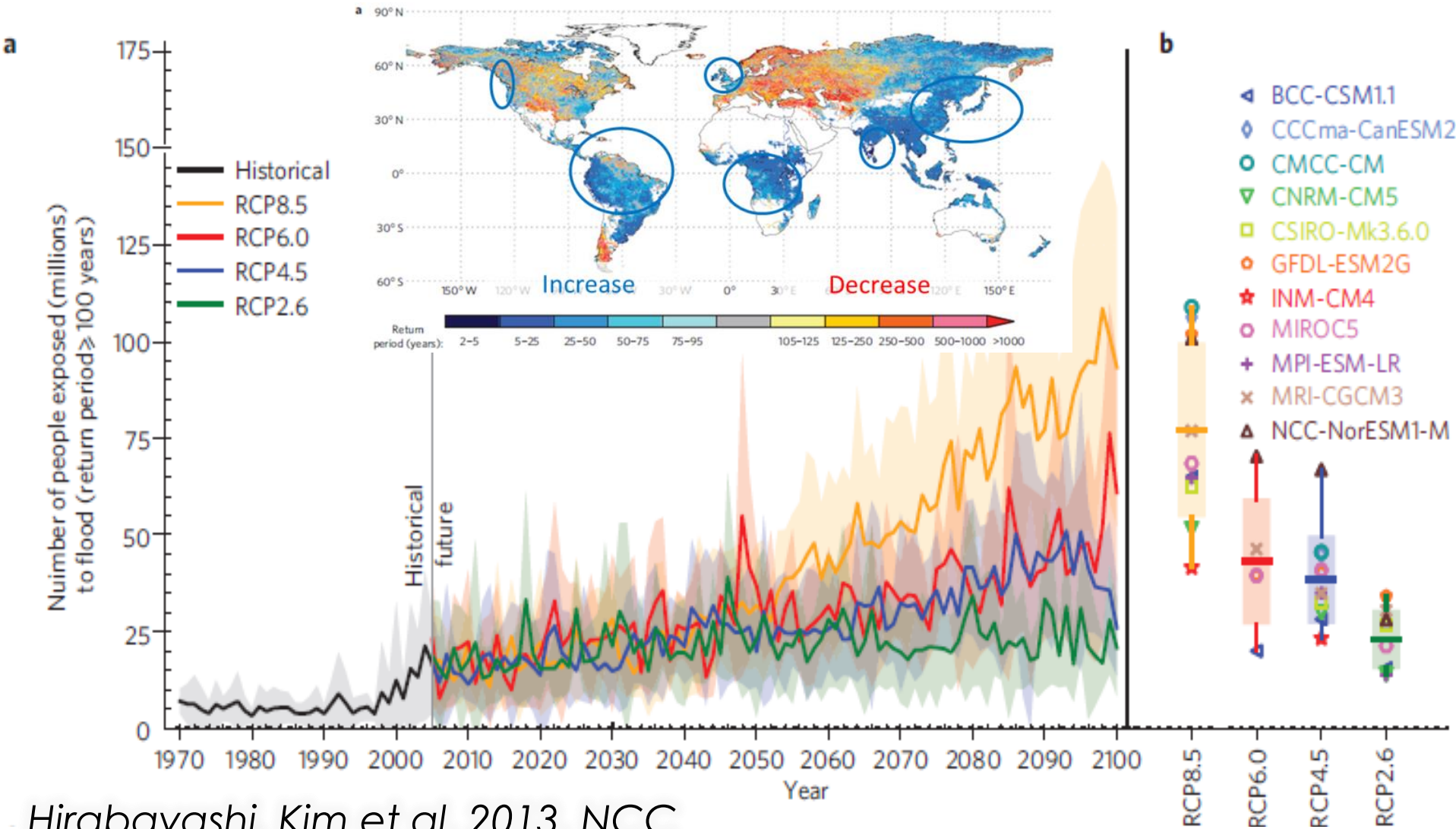


Pokhrel, et al., *Nature Geoscience*,
 2012

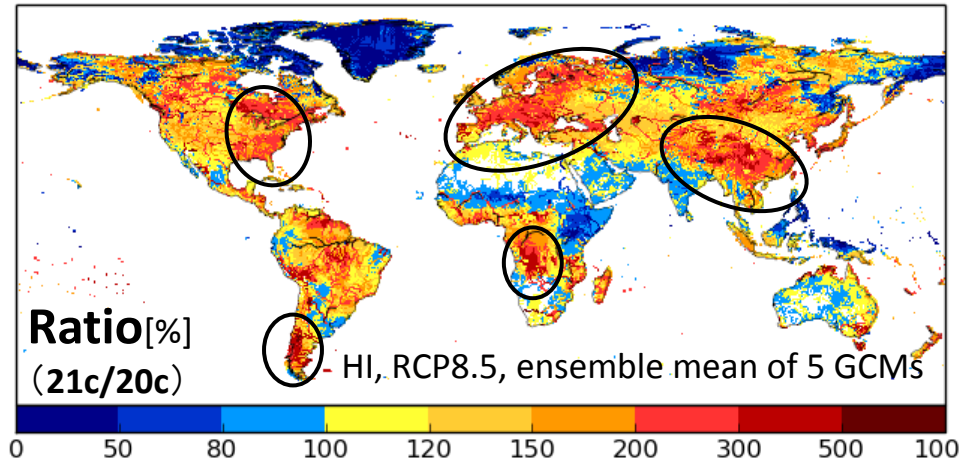
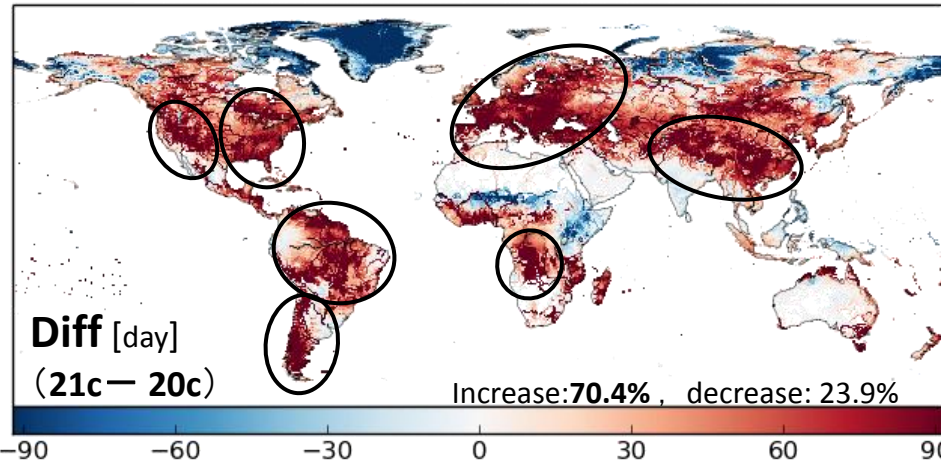
Estimated terrestrial water storage changes (1961-2003) indicate the largest contribution of the unsustainable groundwater use to net sea-level change.

Global Flood Risk under Climate Change

Population (in millions) exposed to severe flood disaster (1/100yr under current climate) significantly increases.



Global Drought Risk under Climate Change

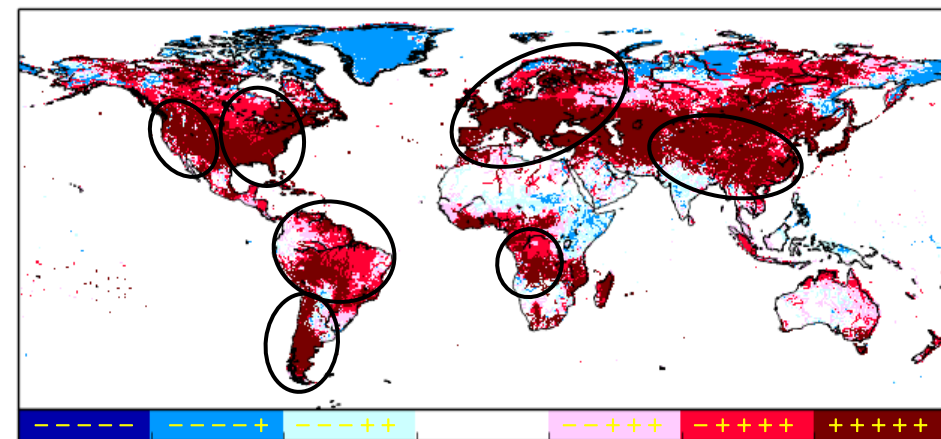


Increase by more than 90 days in **N. America, S. America, Central Africa, Europe and Asia**

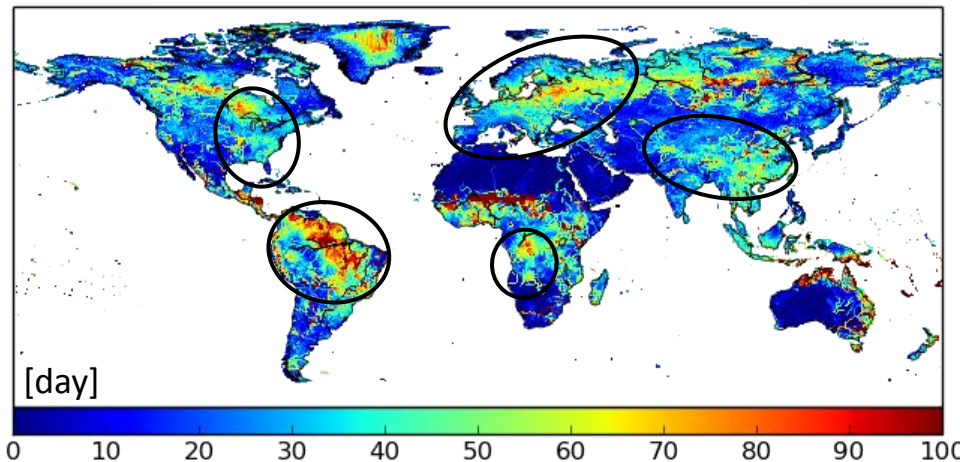
- More than twice (except western USA)
- Corresponds to highly populated area

⇒ **Expected drought-affected areas**

Agreement between 5 GCMs



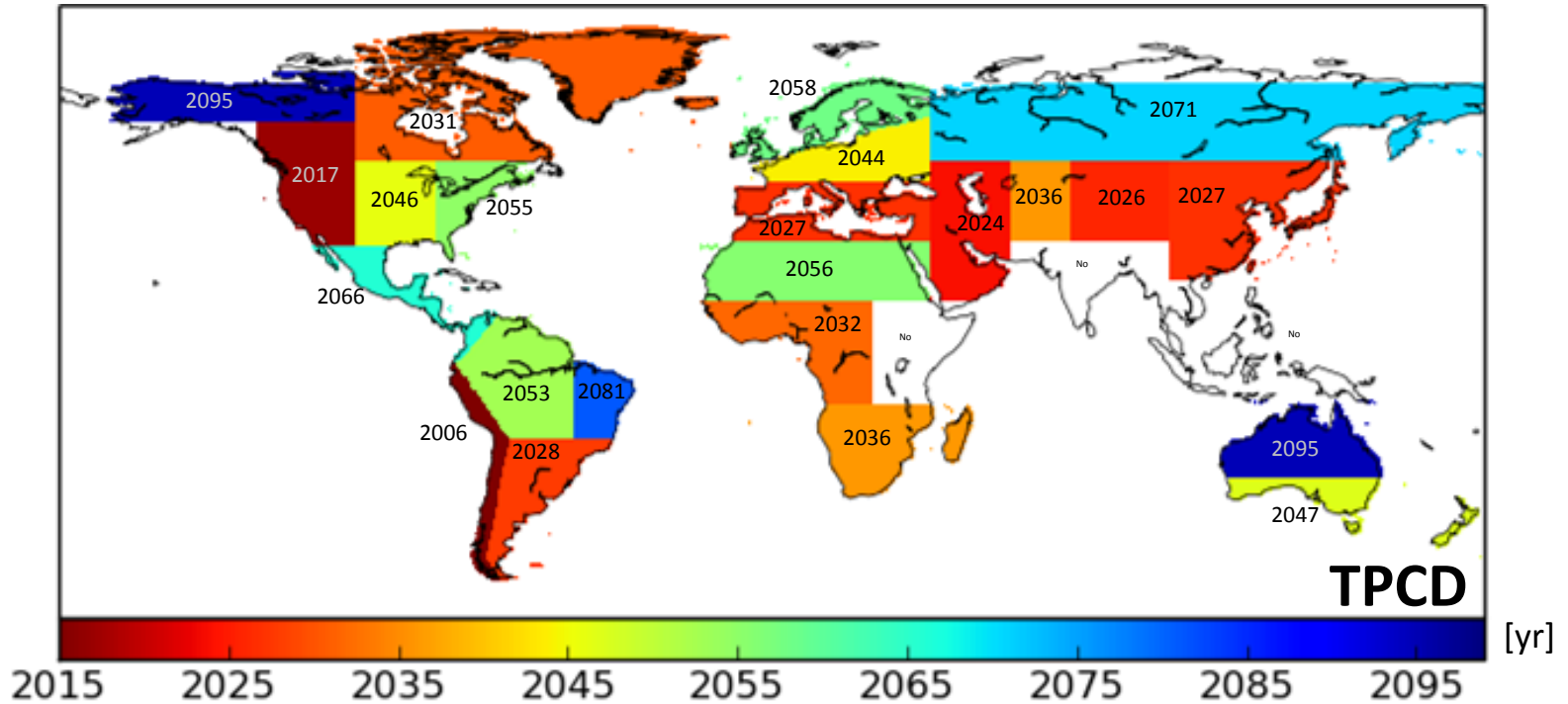
Std in change of DDyr between 5GCMs



→ Projections of large increases tend to agree (left) but variations exist in some regions (right)

How long do we have time to prepare?

RCP8.5
(5 GCMs)



[Method]

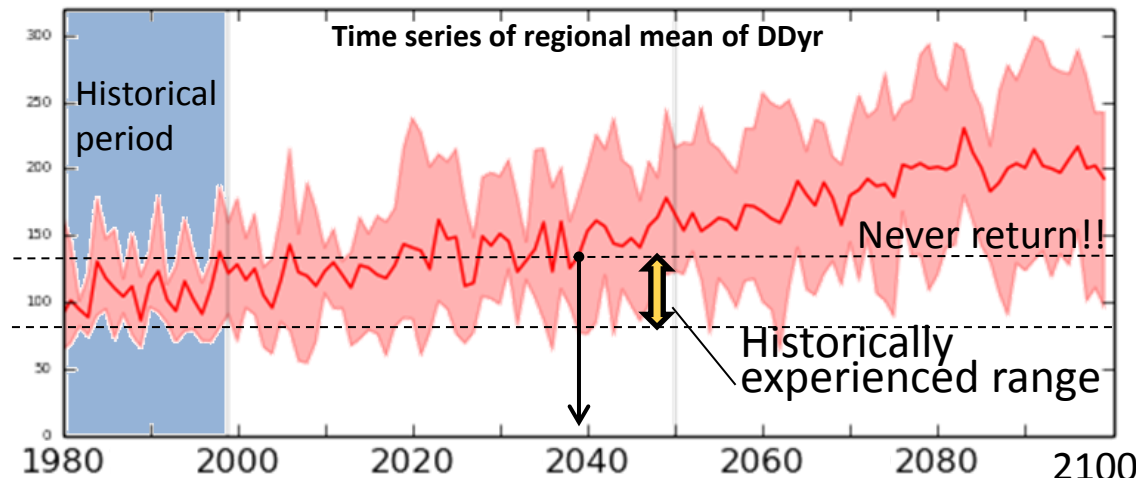
Timing of perception change regarding drought (TPCD)

Timing at which future drought will deviate from the range experienced and never return for a certain period.

[Mora et al. 2013]

[New!]

The first (global) estimate of the time left for us regarding extreme event.



Inter-Sectoral Impact Model Intercomparison Project

What?

Quantitative estimate of climate change impacts and their uncertainty at different levels of global warming, across different sectors and scales.

Why?

To inform both mitigation targets and adaptation policies. I.e. results should be aggregated into society-relevant metrics.

Who & When & Where?

Fast track during 2012/01 – 2013/01 with 39 impact models in 5 sectors.

How?

Multiple climate models, impact models, and scenarios in a consistent framework

More about ISI-MIP

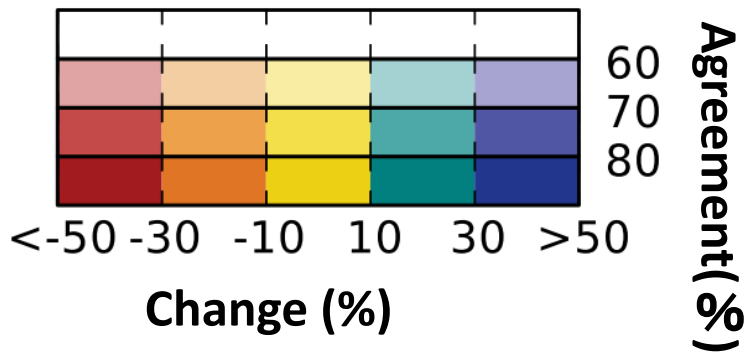
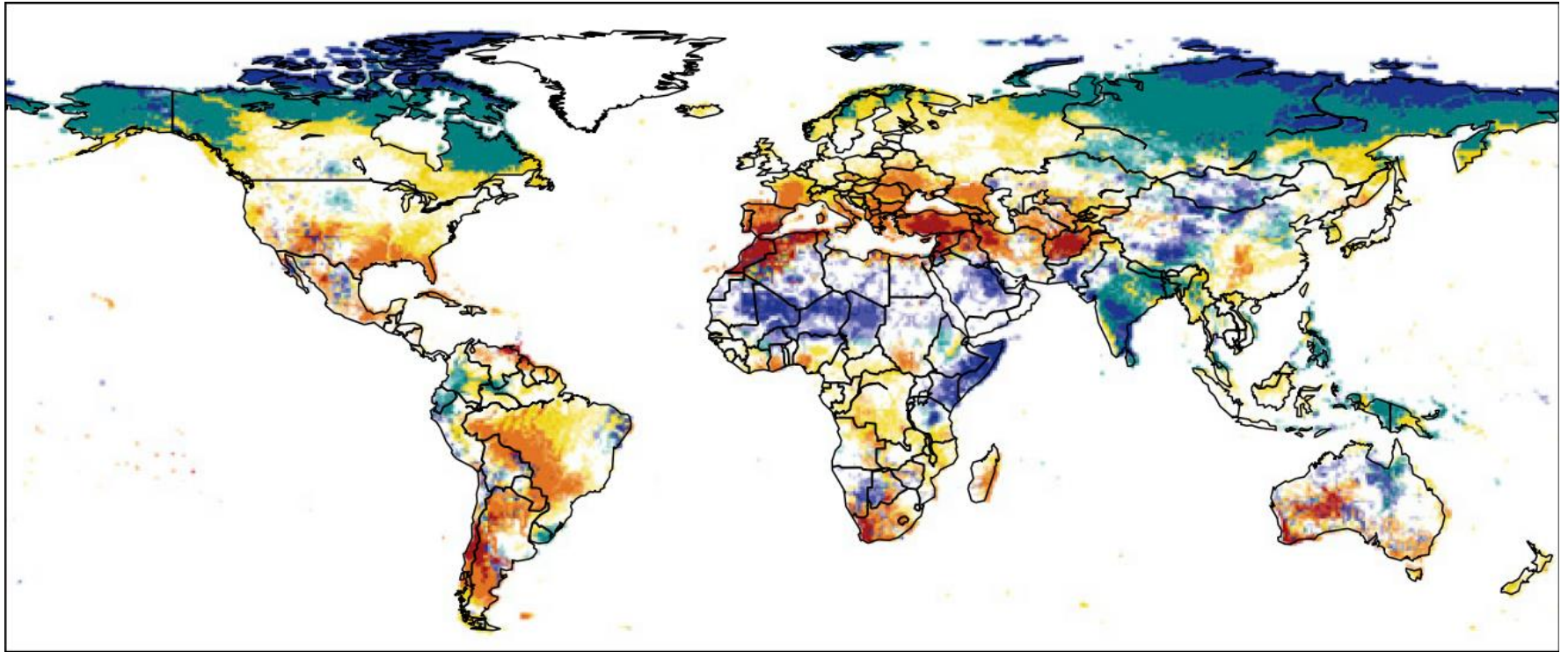


Long-term continuous off-line simulation with 5 GCMs

- Impact Models : 12 Hydrologic, 16 Agricultural
7 Ecosystem, 5 Health
- Analysis period : **1980-2099** (120yr) ← [Historical 1980-1999
Future 2000-2099
- Spatial resolution : $0.5 \times 0.5^\circ$
- Scenario : **RCP2.6, 4.5, 6.0, 8.5**
- Forcing : **ISI-MIP fast track forcing data**
(5GCMs) [Hempel et al. 2013]
- **with** and **without** anthropogenic activity

GCM	Resolution	Nation	Institute
HadGEM2-ES	192 × 145	UK	Met Office Hadley Centre
IPSL-CM5A-LR	96 × 96	France	Institut Pierre-Simon Laplace
GFDL-ESM2M	144 × 90	USA	NOAA Geophysical Fluid Dynamics Laboratory
MIROC-ESM-CHEM	128 × 64	Japan	JAMSTEC, AORI, NIES
NorESM1-M	144 × 96	Norway	Norwegian Climate Centre

Water Stress under Climate Change



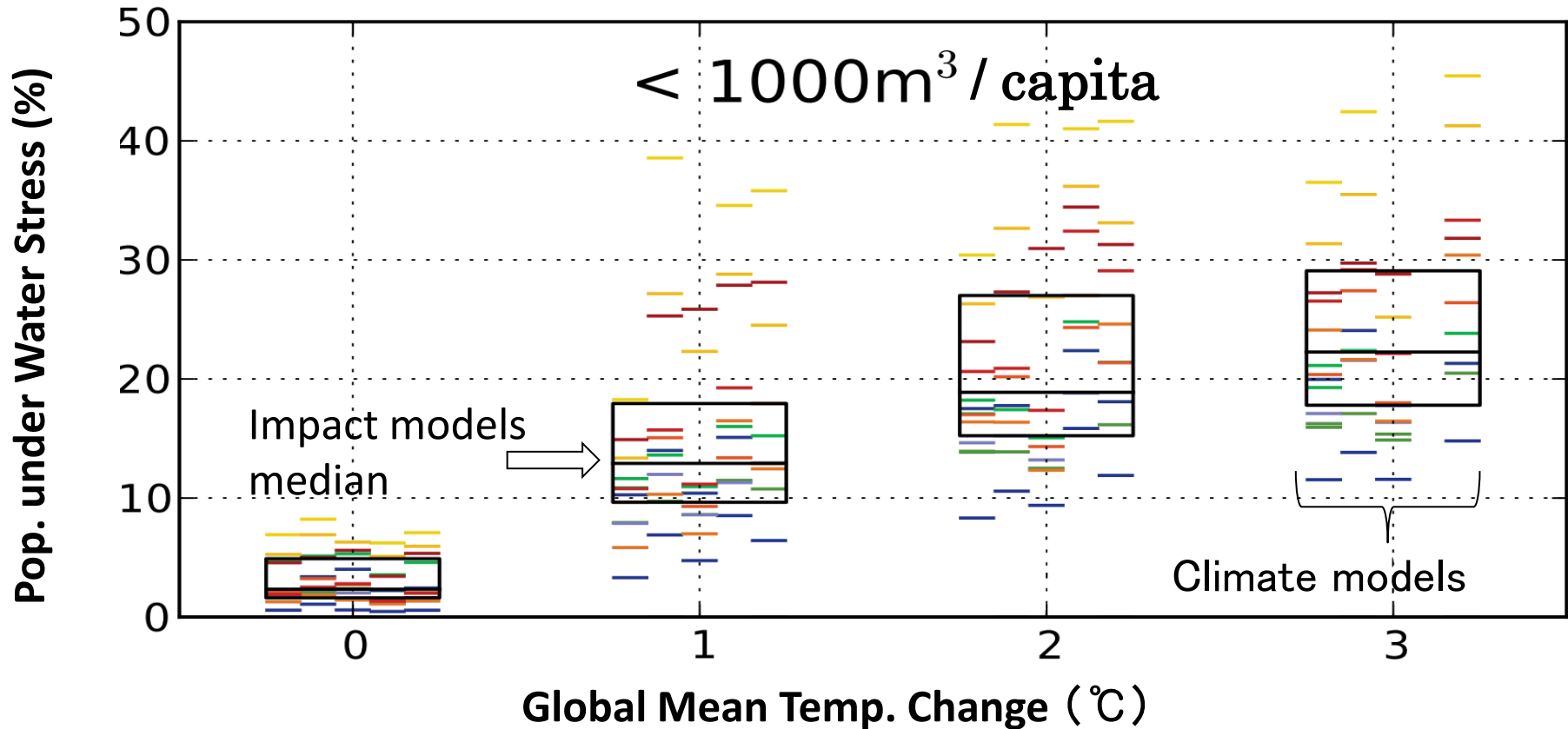
5GCMs × 12Hydrologic Models

- Future Discharge Change
- Uncertainty Estimation

Schewe et al., 2013

Water Stress under Climate Change

Considering Population Change

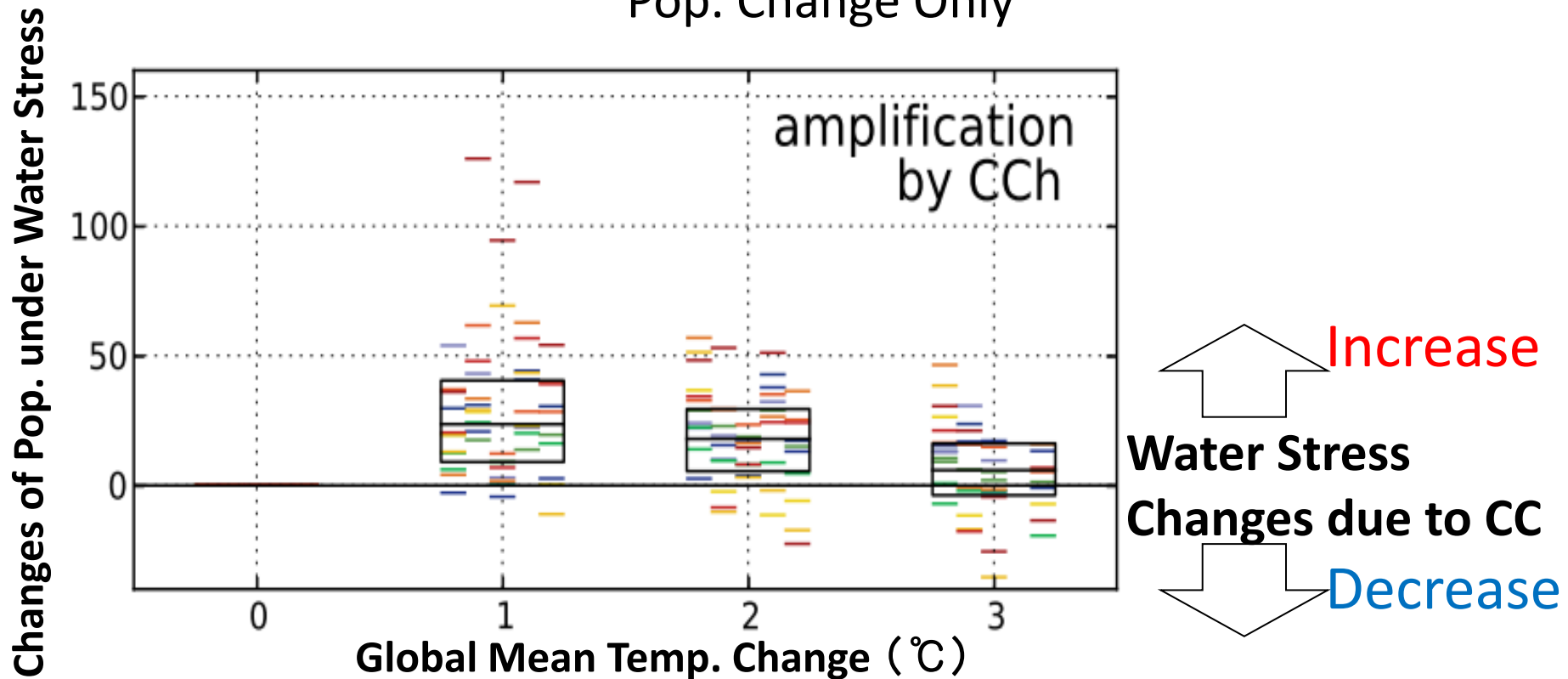


Uncertainty of Impact Model

> Uncertainty of Climate Model

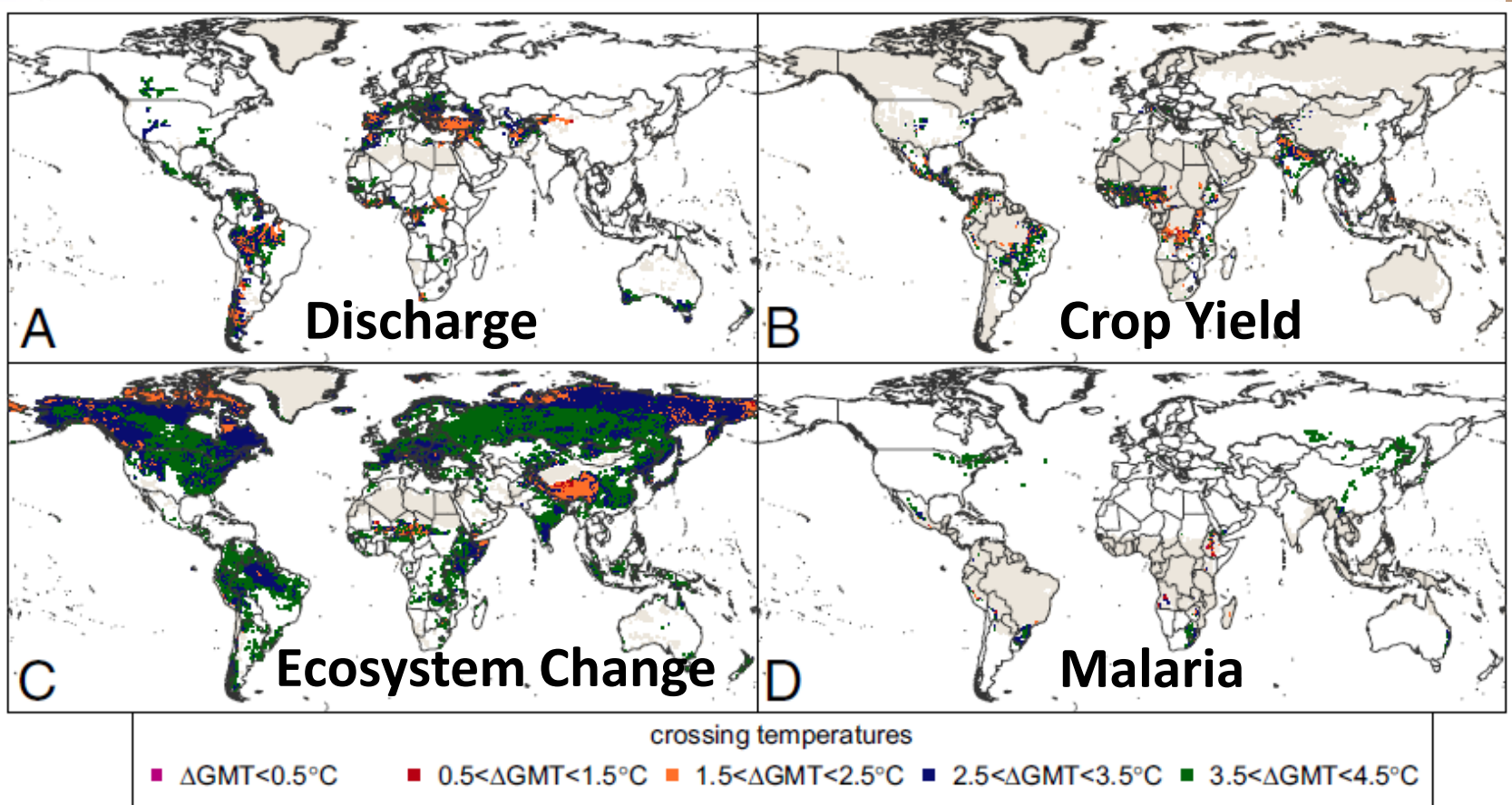
Water Stress under Climate Change

$$\text{Change} = \frac{(\text{Pop. \& Climate Change}) - (\text{Pop. Change Only})}{\text{Pop. Change Only}}$$



Additional 20-30% increase by climate change on the impact of population changes (MME@3°C & 2°C Warming).

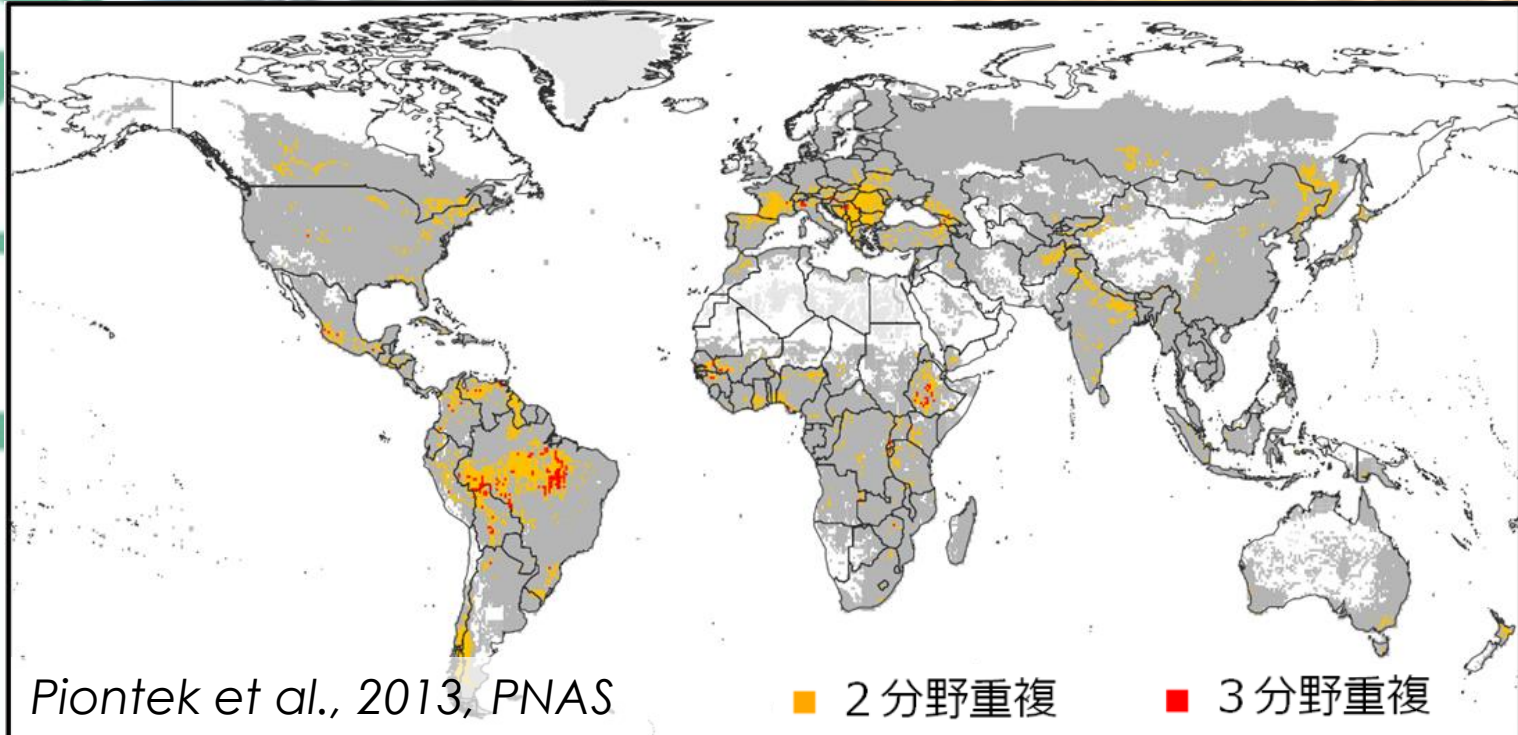
“Leaving the World as We Know it”



Hotspots under 4.5°C global mean temperature warming
With agreement $> 50\%$ between impact models of each sectors. ($> 10\%$ in gray)

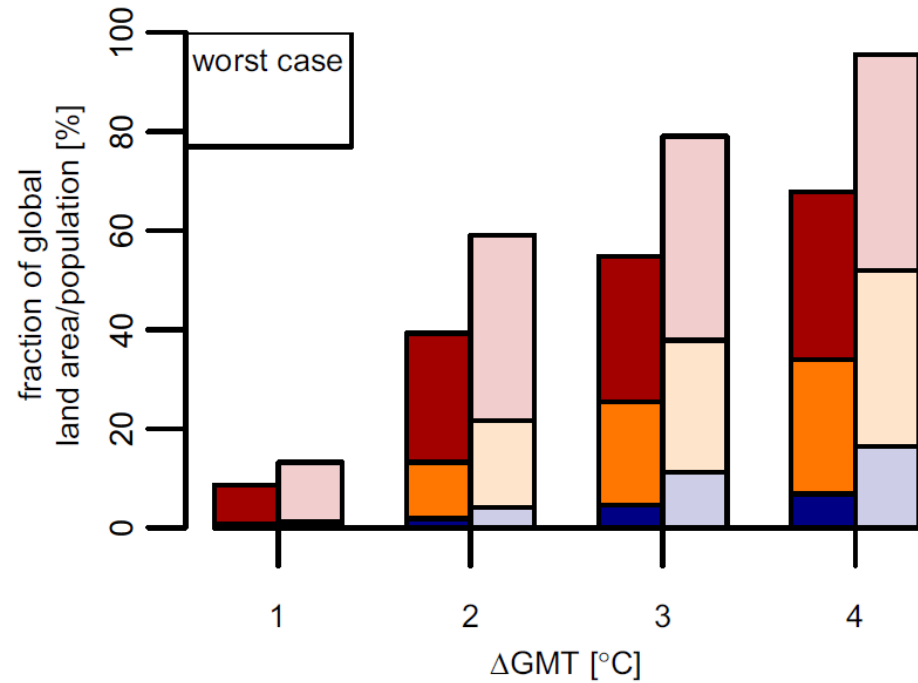
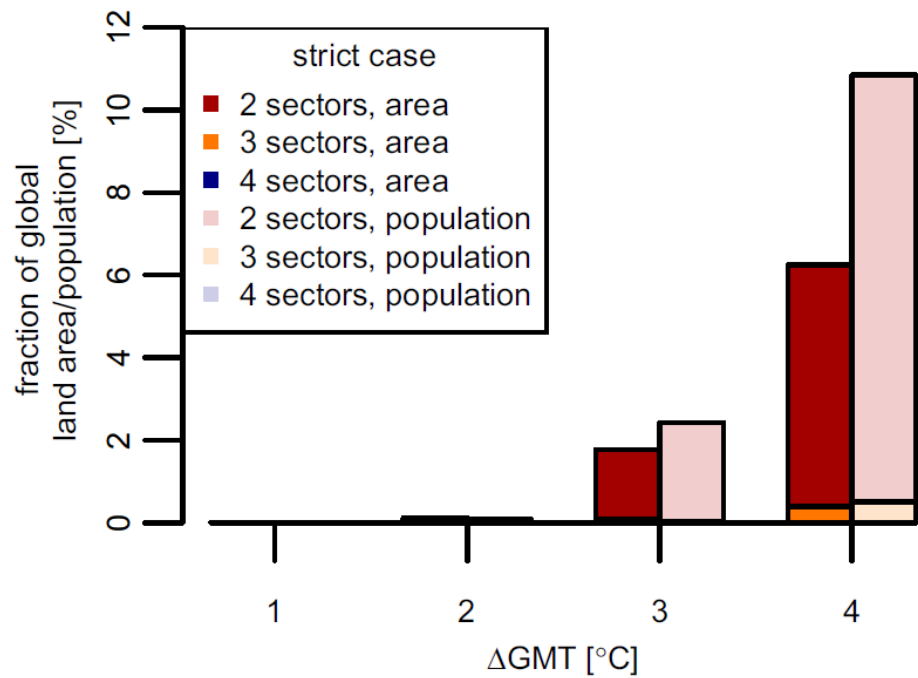
“Leaving the World as We Know it”

Multisectoral Hotspots



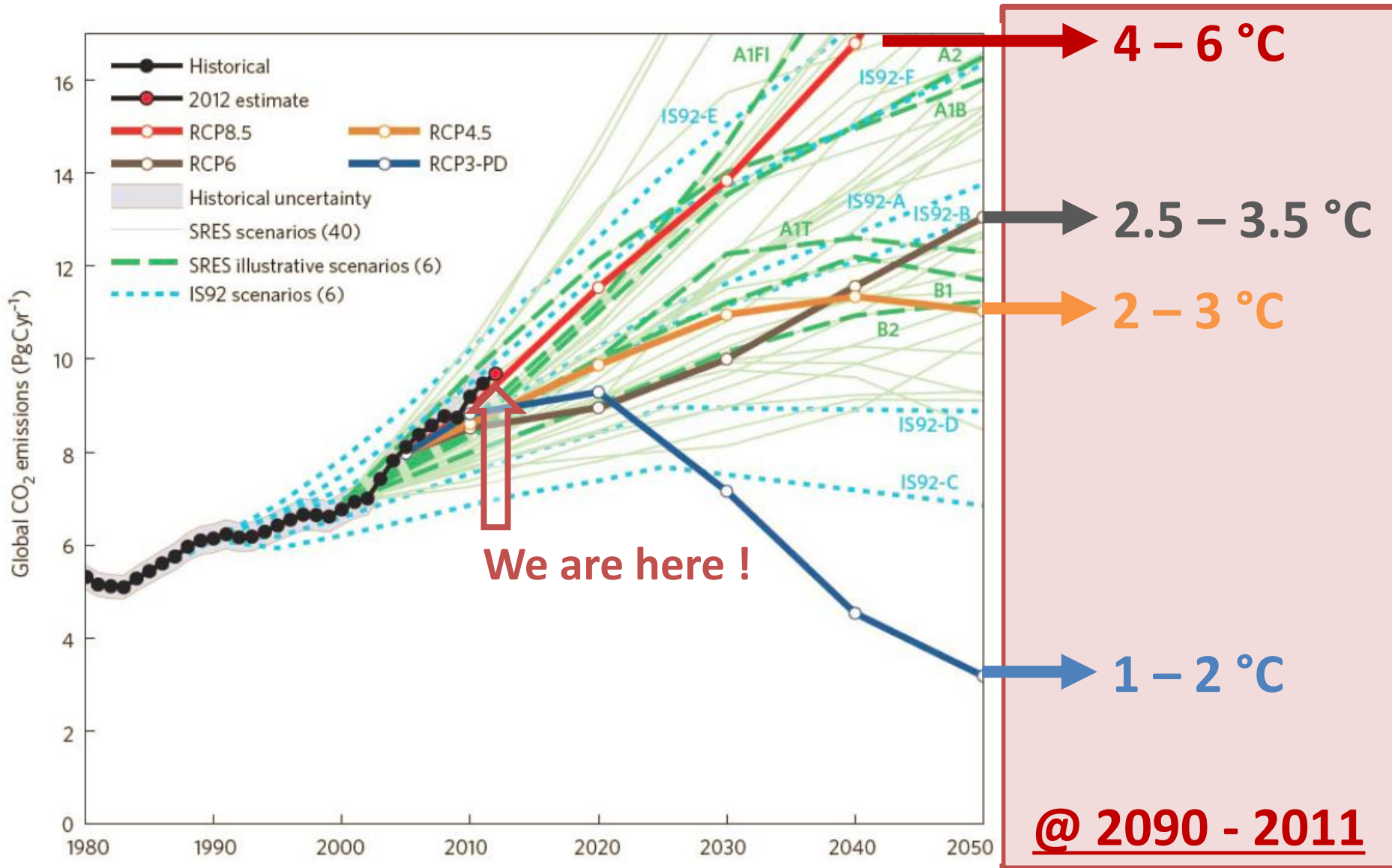
Hot spot when +4.5 GMT(°C) increases
50% of impact models agreement (10% for gray shaded)

“Leaving the World as We Know it”



Area and population affected by climate change for multi-sectors.
Population fixed at the level of 2000

ΔT from Pre-industrial



Paris Agreement @ COP21.2015.12.12

Limit 1.5 degree additional warming to pre-industrial

After 2025, developed countries will prepare 100B USD.

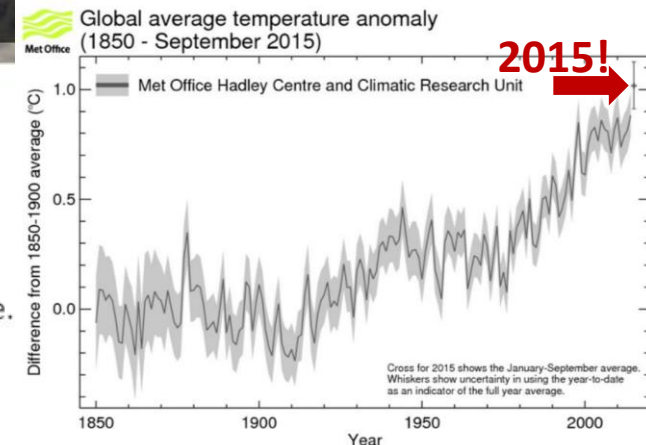
After 2050, human- and natural-induced emission will be balanced.

Global temperatures set to reach 1 °C marker for first time

9 November 2015 - Met Office data for 2015 so far shows that, for the first time, global mean temperature at the Earth's surface is set to reach 1 °C above pre-industrial levels

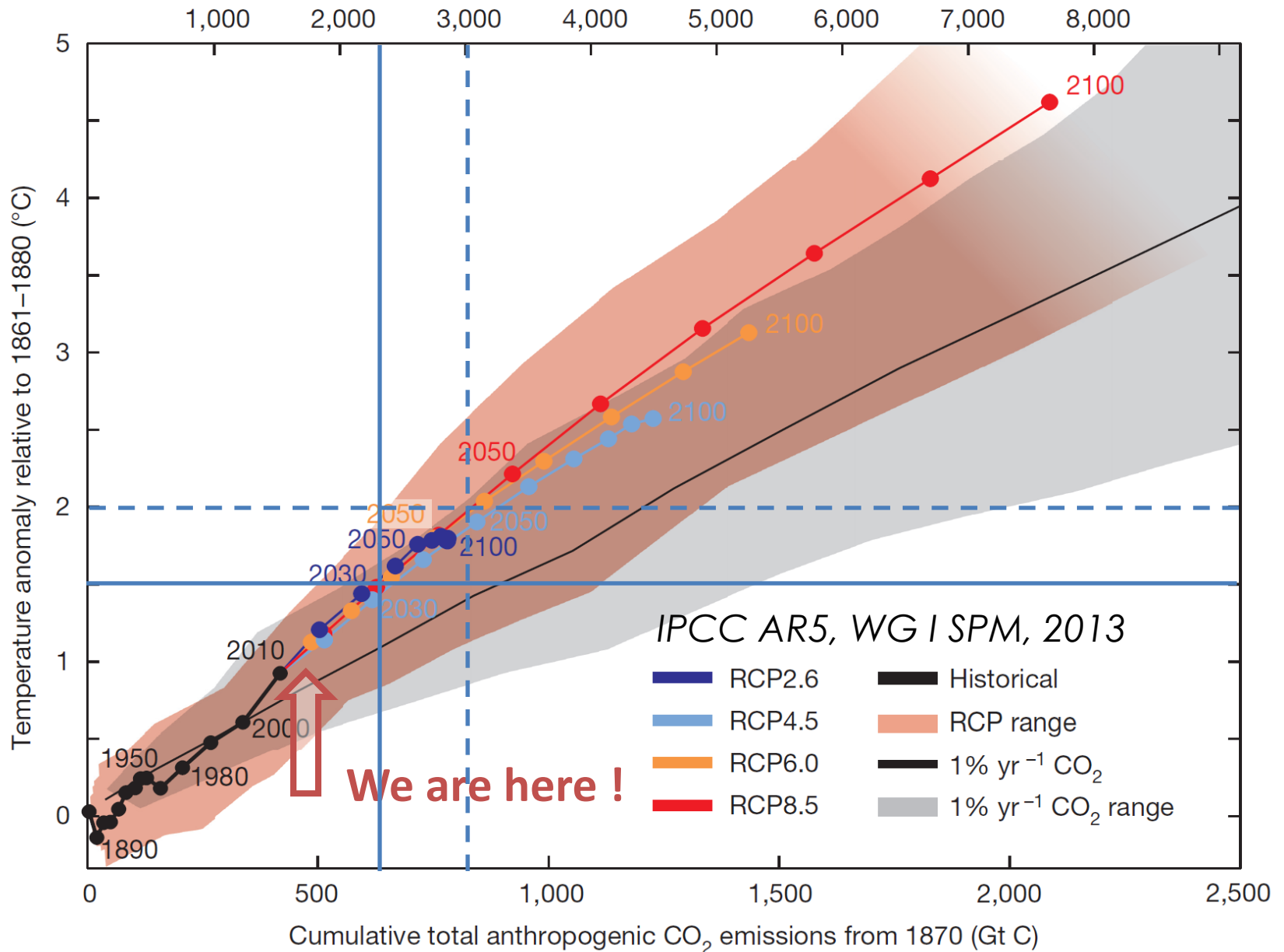
This represents an important marker as the world continues to warm due to human influence.

'Uncharted territory'



ΔT & CO₂ Emissions

Cumulative total anthropogenic CO₂ emissions from 1870 (Gt CO₂)



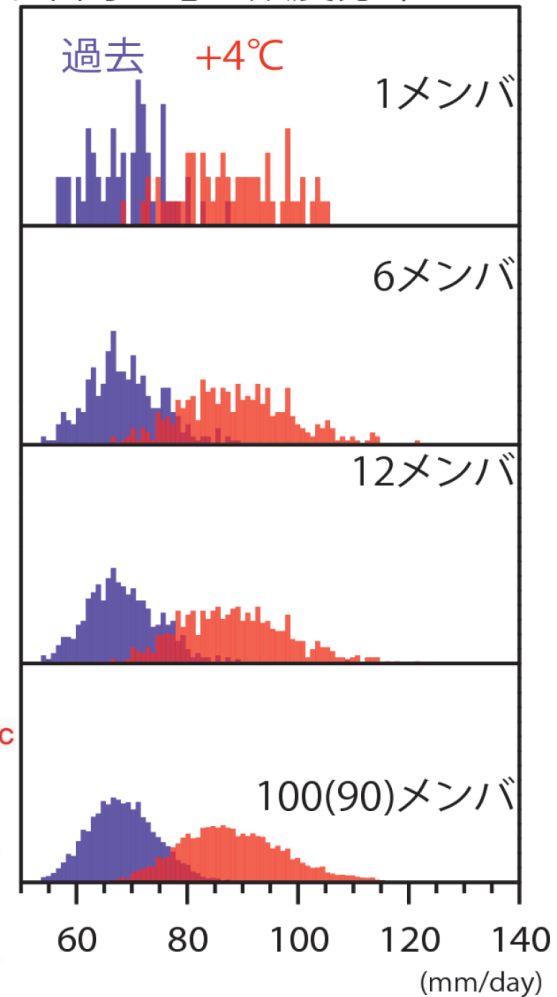
d4PDF: A Huge Database for CC Projection

Using hi-res AMIP-type experiments, 4 degree warming database were developed for global 60km and Japan 20km domain

Using massive number of simulation ensembles, changes of extreme events due to climate warming can be stochastically estimated.

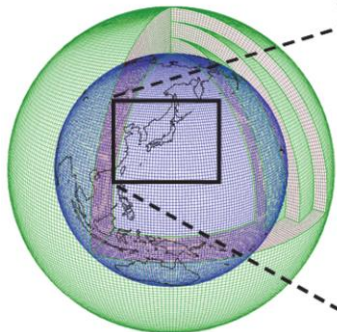
It provides a knowledge-base for disaster prevention, urban planning, environment preservation under projected warming climate.

中国南部で平均した「年最大日降水量」の頻度分布



AGCM

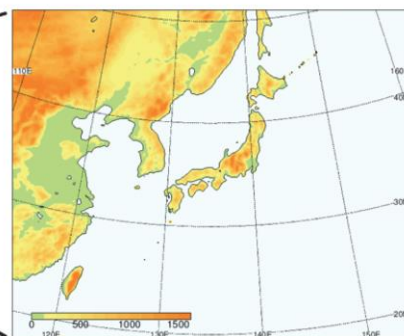
(水平解像度約60km)



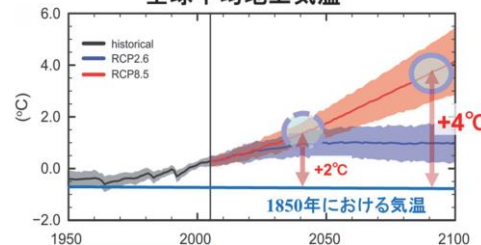
(画像: 気象庁提供)

NHRCM

(水平格子間隔20km)



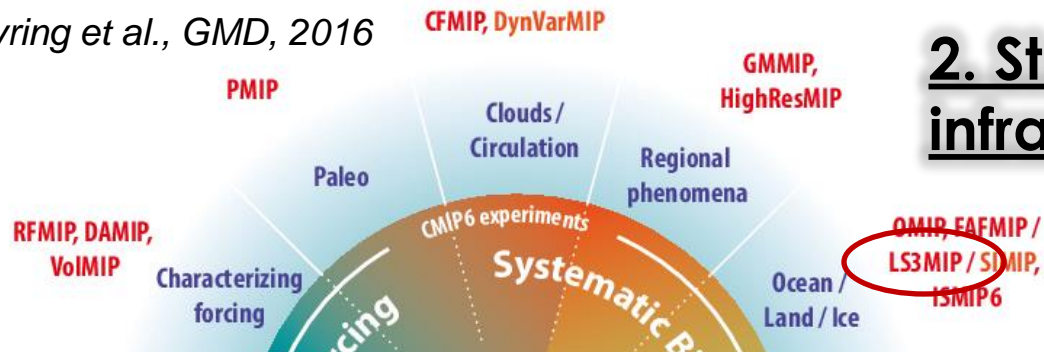
全球平均地上気温



CMIP6: a More Continuous and Distributed Organization

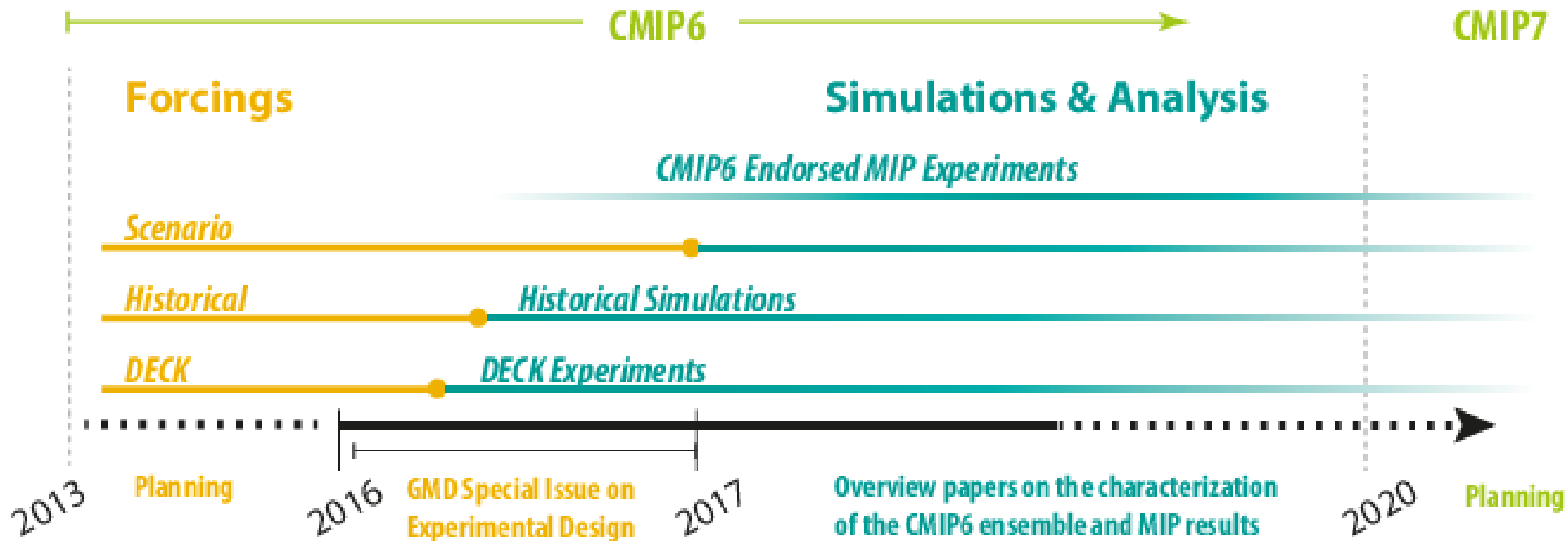
3. CMIP-Endorsed Model Intercomparison Projects (21 MIPs)

Eyring et al., GMD, 2016



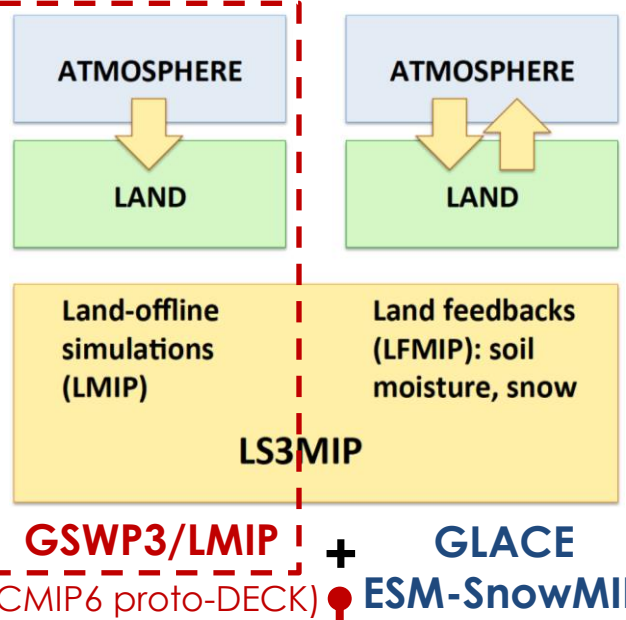
2. Standardization, coordination, infrastructure, documentation

1. Common Experiments



Global Soil Wetness Project Phase 3

Super-ensemble **land reanalysis** for 20 and 21st Century as inter-community service



WCRP + GEWEX Grand Challenges

- Cloud, Circulation & Climate Sensitivity
- Water Availability
- Climate Extremes
- Regional Climate Information
- Regional Sea-level Rise
- Changes in Cryosphere
- Precipitation Variability
- E/W Exchanges
- Uncertainty

Land Surface, Snow, Soil moisture
LS_{now} 3 MIP Model Intercomparison Project
 Land processes, forcings, and feedbacks in CMIP6 climate change simulations

to quantify the associated uncertainties and better constrain climate change projections for earth system models in CMIP6.

Thank you

A black and white photograph of a beach. The foreground shows a dark, pebbly or sandy beach with some debris. The middle ground features waves with white foam crashing onto the shore. The background is a dark, flat horizon line, possibly a distant city or landmass, under a vast, dramatic sky filled with large, textured clouds. The overall mood is somber and atmospheric.