HYDROLOGICAL APPROACH FOR SAND AND DUST STORMS

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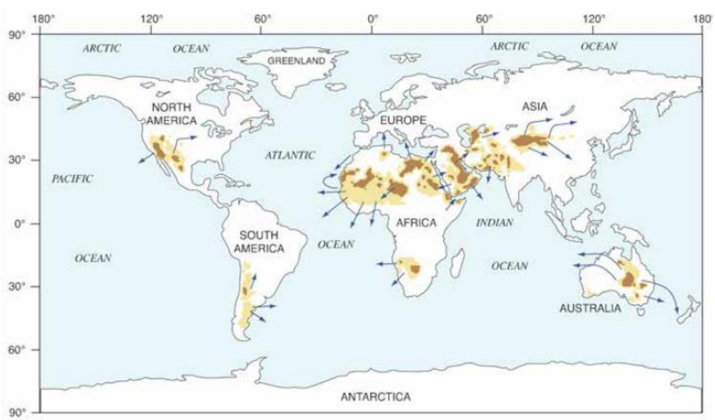
■ Sand and dust storms : Meteorological hazard

Sand and dust storm
(WMO homepage)

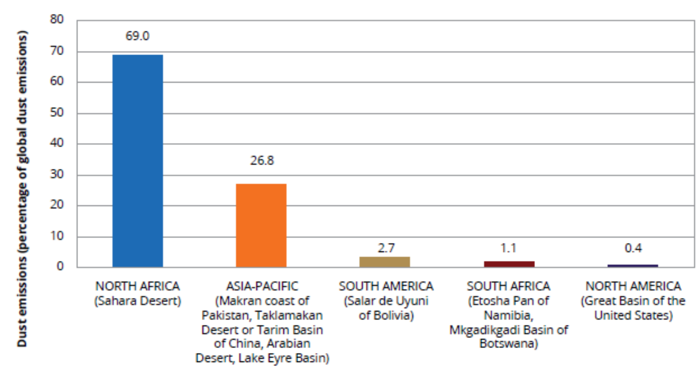
Common meteorological hazards in arid and semi arid region.

- More than 150 countries are affected directly.
  But only 45 countries have sand and dust source areas.
  This means it has wide transboundary impacts.

- Approximately 2 billion tons of dust are emitted.
  27% of global emission is from Asia and the Pacific region.



Dust sources and typical pathways
(Muhs et al., 2014)



Percentage of global sand and dust emissions by region (Akhlaq et al., 2012)

Sand and dust storms : Various damage

- Various damage were induced by sand and dust storms.
- Sandstorm widely spread with transboundary impacts

1. Health problem

- Organs for breathing are mainly affected.

ex. asthma, bronchitis, emphysema, silicosis

Sandstorm in Dubai
(Dubai, Public radio)

2. Damage in Agriculture

- Agricultural facilities are damaged.
- Livestock mortality increased after sandstorm.
- Soil erosion / Soil pollution

Crop damage after sandstorm
(China 2010, China Daily)

3. Damage in Industry

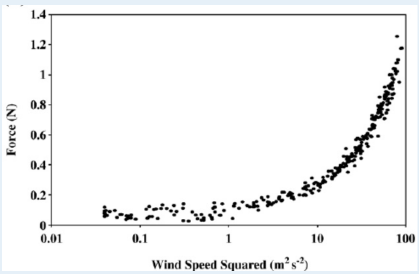
- Infrastructure are broken.
  Buildings, Power cut, etc…
- Disruption
  Traffic jam, Traffic accident
  Close of airport
- Cost of clean-up

Damage in traffic
(Dubai 2015, AHLAN)

■ Factors of sand and dust storms : Climate and land surface

Wind related factors

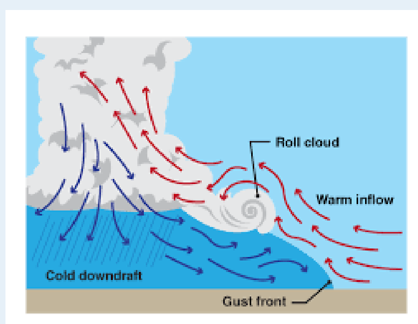
Stronger wind can bring bigger sediment/dust.



Shear stress and wind speed (Gillies et al. 2010)


Sand devil (NASA HP)

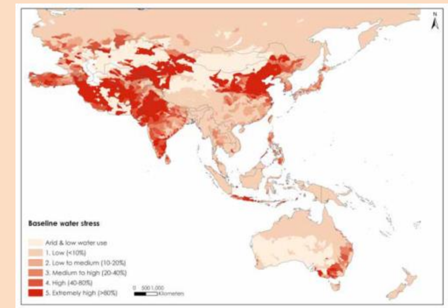

Sandstorm in Kenya (Kenya 2019)



Mechanism of gustfront (NOAA HP)

Dryness related factors

➤ Dryness factors
* Low precipitation
* High temperature
* Strong radiation
* Early snowmelt



PDSI in Asia and the Pacific in 2018 (ESCAP 2018)

Land surface factors


Desert with few vegetation


Particle size of surface soil

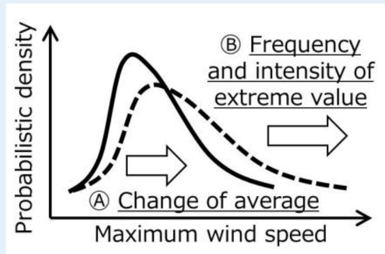
峠　嘉哉 (Yoshiya Touge)

■ Expected change in the future : climatic and human impact

Wind related factors

Weather extremes will increase and be enhances by climate change.

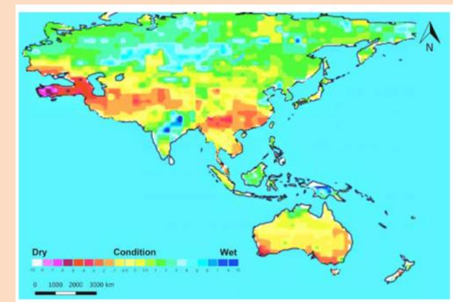
* Fraction of wind events exceeding thresholds
* Intensity of extremes
* Wind direction (sandstorm pathways)



Climate change impacts on extremes

Dryness related factors

* Increased frequency of drought
* Wider affected area by drought events
* Vegetation changes

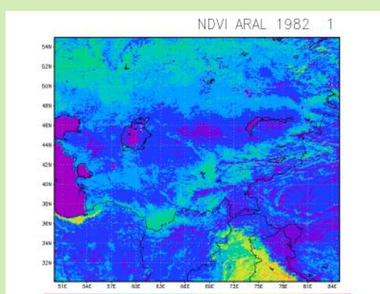


Projected PDSI in the future (ESCAP 2018)

Land surface factors

Less vegetation enhances sandstorm

Desertification in arid region (WMO)



Fewer vegetation due to climate change

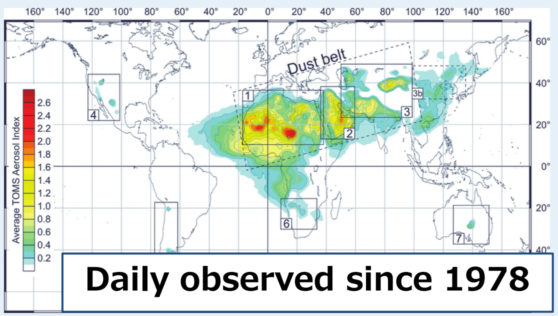
1960 2009
Shrinkage of inland lake (Aral Sea, NASA)

➢ Human impacts
* Overgrazing
* Deforestation
* Shrinking inland lakes

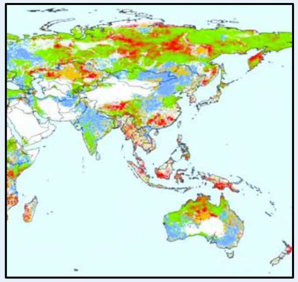
➢ Global dust emission
* 75% is from natural
* 25% is from human impacted desert

■ Mitigation and adaptation for sand and dust storm

Identifying and monitoring source area

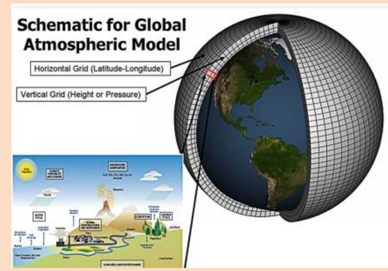


Average TOMS Aerosol Index (Varga 2012)



NDVI changes (1981-2006) (Bai et al., 2012)

Projecting and observing climate change



Global climate model (Climate Illuminated)

Meteorological station (Component & Resolution)

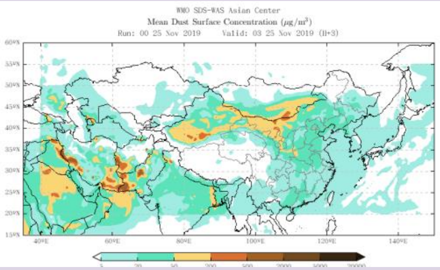
Sustainable land and water management

Trees Planting (China 2001, JICA)

Overgrazing in desert (Mongolia 2018, UNDP)

Early warning

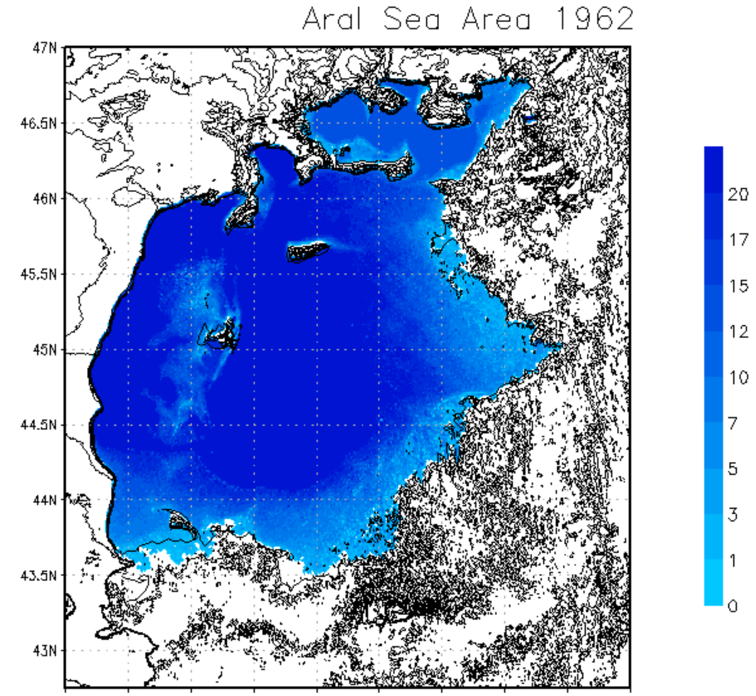
WMO website for forecast sandstorm (WMO HP)



Mean Dust Surface Concentration (WMO HP)

Hydrological modeling for inland lake toward sustainable water and land management

Tohoku University
Yoshiya Touge
Mbugua Jacqueline Muthoni



Historical change of Aral Sea calculated by hydrological numerical simulation (Touge et al, 2012)

■ Continental inland lakes : Sustainability of inland lakes

Desiccation of inland lakes

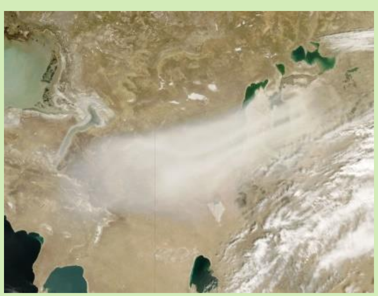
Aral Sea (NASA)

Urmia Lake (Iran)

Area and volume of inland lakes are decided by water inflow from the basin and evaporation on the surface. Therefore, the area and volume are easily affected by basin environment.

However, land use change from water body to desert affects surrounding environment significantly.

Sand and dust storm at former Aral Sea



Sandstorm in 2008 (NASA)

Sandstorm on May 2018 (The watchers)

Toxic SDS from ancient lake bed

＊ **Easy to fly up**

Diameter of sand and dust stored on ancient lake bed is small.

＊ **Toxic materials are included**

Salt is included into the sand.
Toxic materials flowed from the basin into the Aral Sea and stored with sand.

Continental inland lake : 3 stages of its changes

Sustainability of inland lakes

Water circulation
Border of sustainability

Environmental evaluation
Break point of environment

stage1
Lake: no change
Affection : no

Climate change & water use

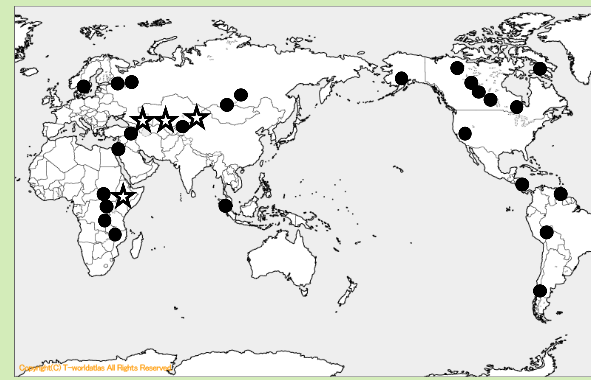
stage2
Lake: shrinks
Affection : exists but not serious

Future prospect & Observation

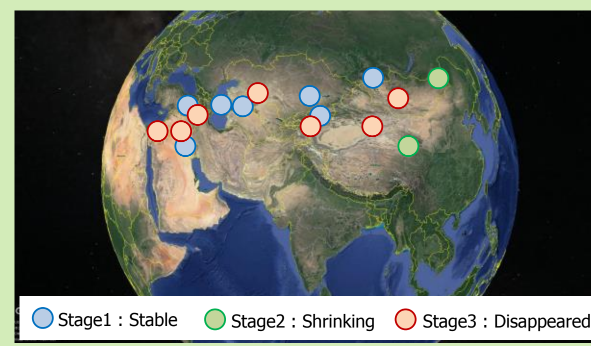
stage3
Lake: shrinks
Affection : exists and serious

Understanding change in past

Global inland lakes



Large inland lakes in the world

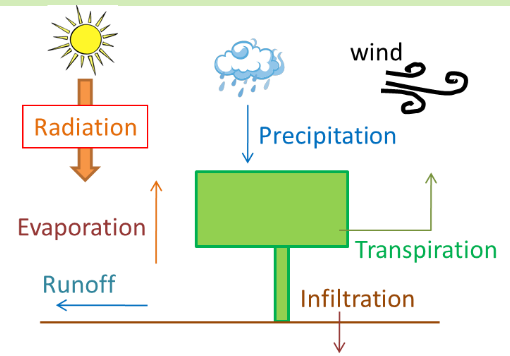


Sustainable stages of inland lakes in Asia

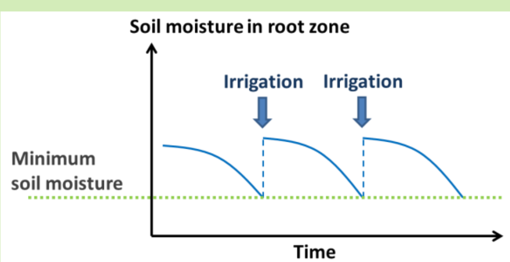
■ Hydrological model : Terrestrial water circulation model

- Physical water circulation model was developed.
  - It was integrated by several models.

Land Surface Model : SiBUC



Land surface model



Irrigation scheme in SiBUC

Vertical Water and Heat balance in mesh
"Mesh to River"

Input data

- Climatic data
  Present / Future climate
- Land Surface Parameter
  Irrigated area / crops

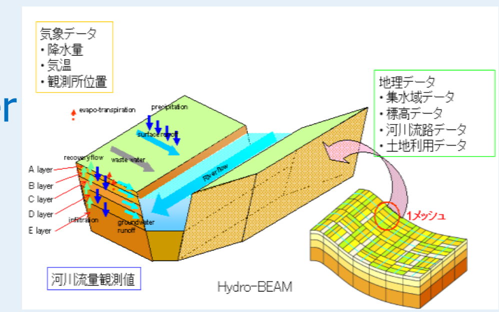
Output data

- Runoff to river
- Irrigation water needed

River Discharge Model : Hydro-BEAM

Horizontal water movement in river

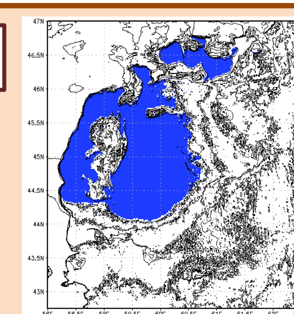
- Input
  Runoff to river
- Output
  River discharge



River Discharge Model

Aral Sea shrinkage model

Estimate Aral Sea changes by basin scale hydrological process.

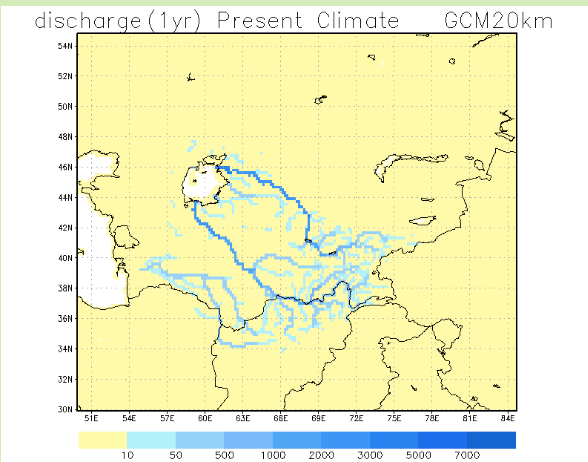


Sea Bathymetry

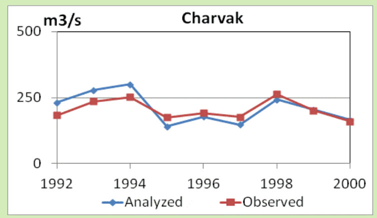
■ Water Balance in Basin : Results of the inland lake model

- Physical water circulation model was developed.
  - It was integrated by several models.

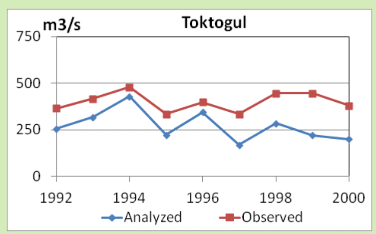
Water Flow in the Whole Basin



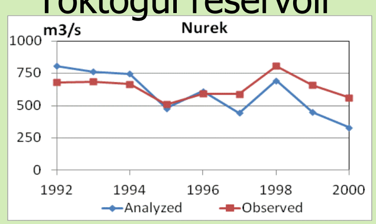
River Discharge



Charvak station



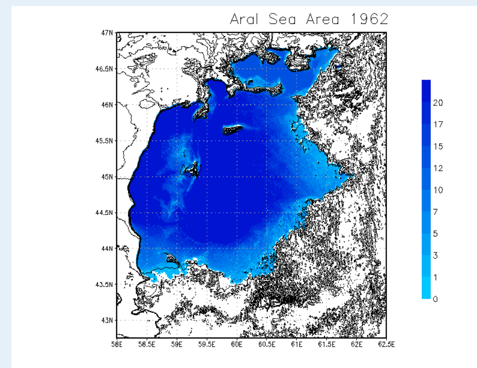
Toktogul reservoir



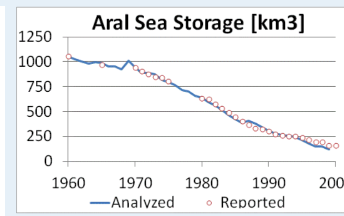
Nurek reservoir

Hydrological model was applied in whole basin. Climate change and human impact can be physically considered.

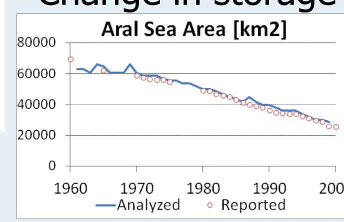
Aral Sea Desiccation Model



River Discharge



Change in storage



Change in area

Through basin scale water circulation analysis, considering climate variability and human impact, shrinkage of the Aral Sea was accurately reproduced in numerical analysis.

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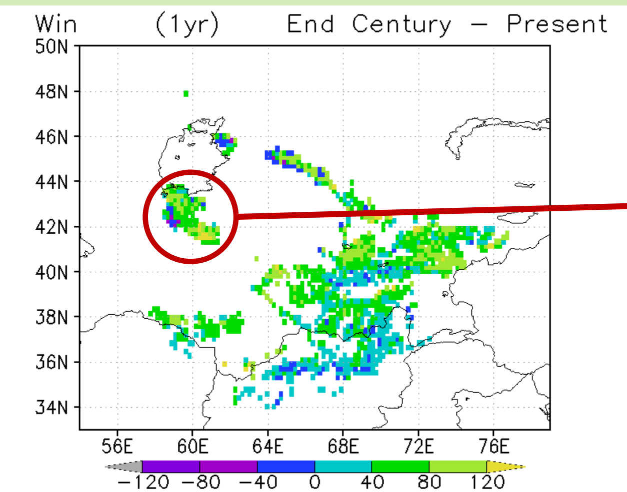
■ Impact of climate change : Irrigation water in the future

- Irrigation water requirement will be higher in the future.
  - Plants needs more water under warmer climate.
  - Required water will increase especially in drier zone.

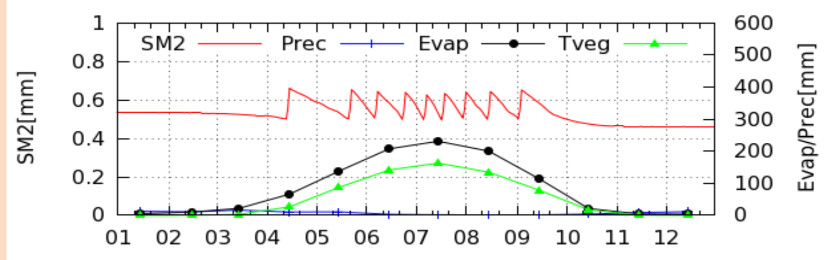
Analysis in whole basin



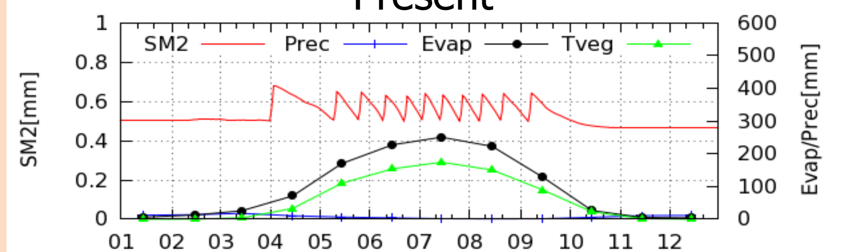
Changes of annual irrigation water requirement

Irrigation water requirement will increase in whole basin.

Climate change impacts on seasonal change



Present



End Century

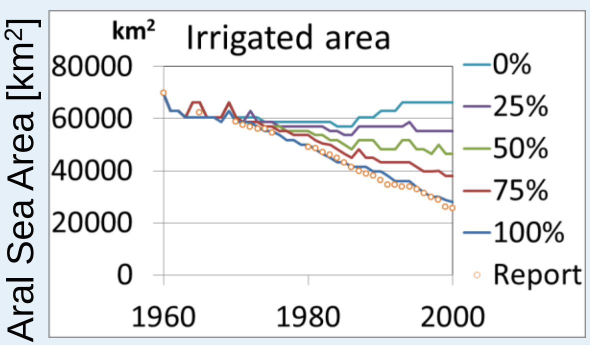
Amudarya Delta **(Extremely Arid)**

■ Impact of human activity : Scenario analysis of irrigation

- Scenario analysis was conducted in different irrigation scenario.
  - 1. Smaller irrigated area scenario
  - 2. Drip irrigation scenario
  - 3. Improving canal irrigation efficiency scenario

1. Smaller irrigated area

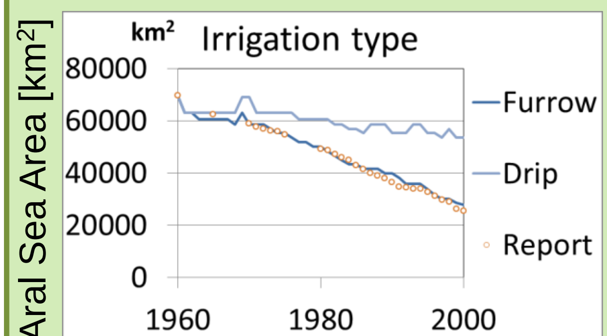
- "No-expansion" saves 23Gt/yr.
  => 1960s level of Aral Sea
- "50% expansion" saves 10Gt/yr.
  => 1982 level of Aral Sea



Annual change of Aral Sea area

2. Drip irrigation

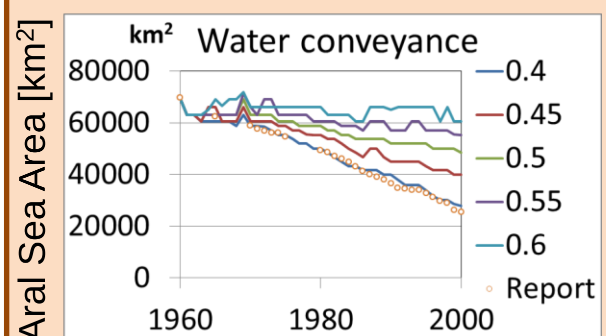
- "Drip Irrigation" saves 16Gt/yr.
  => 1976s level of Aral Sea



Annual change of Aral Sea area

3. Canal irrigation efficiency

- "10% improvement" : 12Gt/yr.
  => 1980 level of Aral Sea
- "20% improvement" : 22Gt/yr.
  => 1967 level of Aral Sea

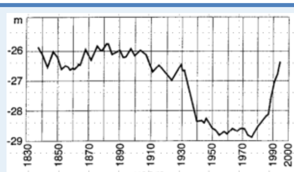


Annual change of Aral Sea area

■ Application to Other lakes

- Climate change impacts on lake level in Caspian Sea
  - Reproducing in the past : understanding water circulation
  - Future projection : Climate change impacts will be analyzed.
    - Evaporation on water surface will be enhanced.

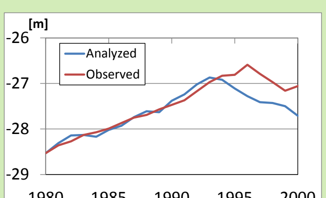
Change of Caspian Sea level

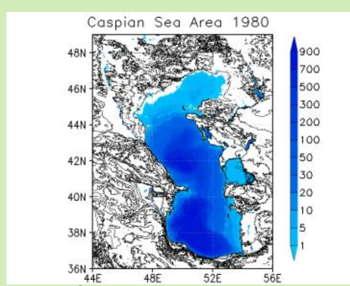


Caspian Sea level
(Klige and Myagkov, 1992)

Caspian Sea (GIWA, 2003)

Reproducing analysis

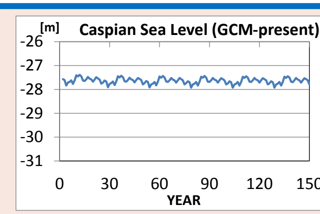




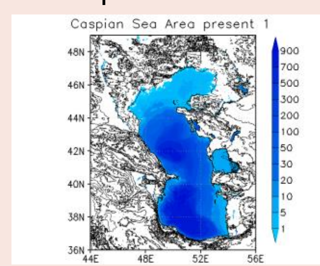
Reproducing change in the past (1980-2000)

Climate change analysis

Present (1979-2003)

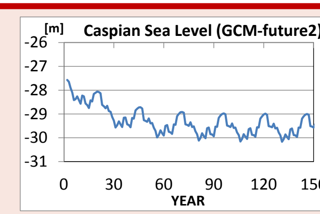


Caspian Sea level

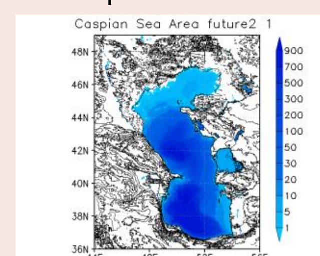


Caspian Sea area

End century (2075-2099)



Caspian Sea level



Caspian Sea area

■ Hydrological Approach : Contribution as hydrologist

- **Climatic event**
  - Understanding as average climatic condition
  - Understanding as soil drought event (Lower soil moisture event)
    - Source of dust is wider.
    - Source is generated in the area whichi is not source in usual cases.

- **Land use change**
  - Desiccation of inland lakes
  - Soil drought makes native plants dried. (Shorter time period)
  - Change in climatology will change types of plants. (Longer time period)

- **Observation**
  - Concept of toxic dust and toxic sandstorm needs filed observation.
    - Supported by Aral Sea Innovation Center.