Anthropogenic change in Central Asia

Climate change, glacial recession
Diversion of rivers, dessication of Aral Sea
Industrial irrigation and agriculture
Industrial hazardous waste:
agriculture, energy, mining, weapons
Health, safety, security risks

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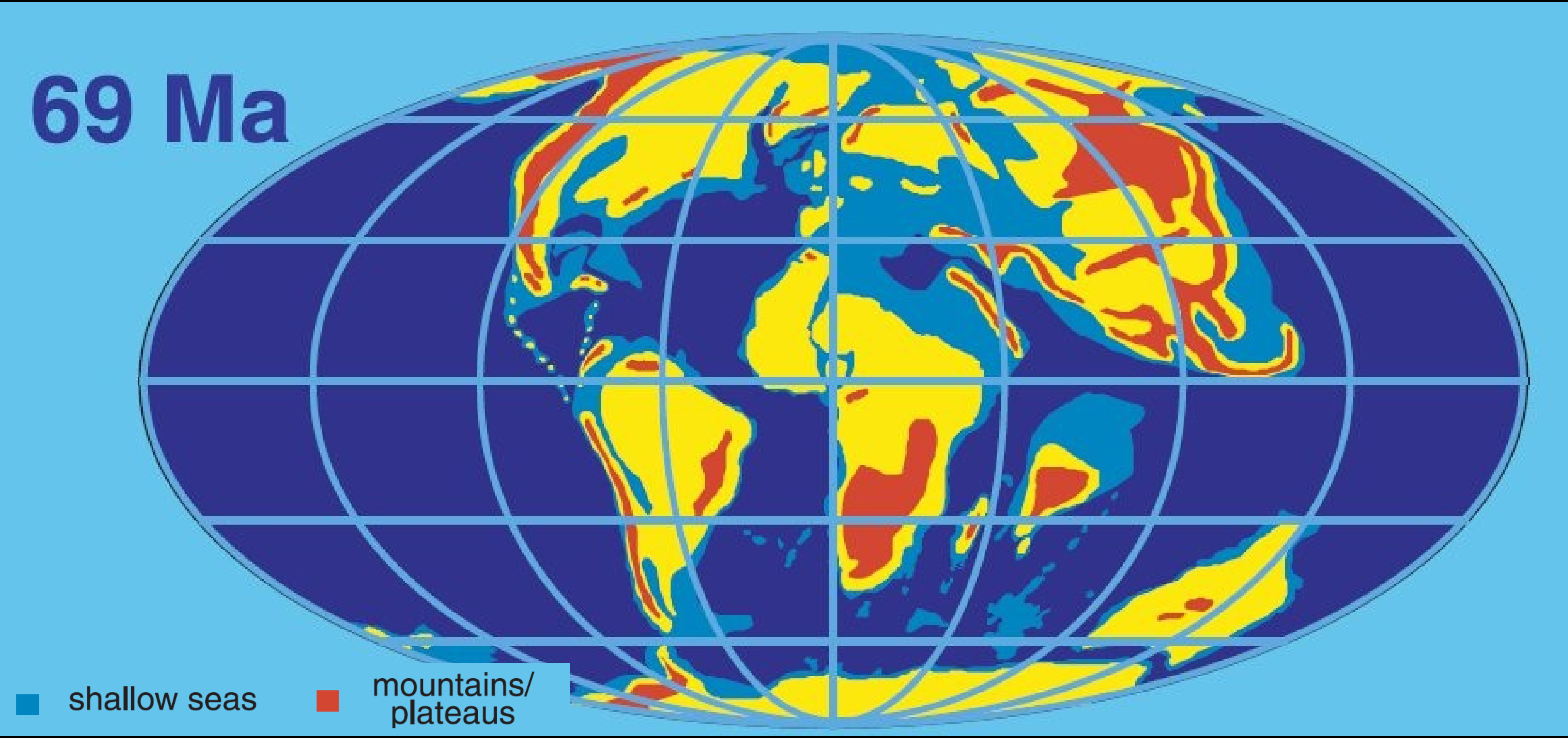
Views expressed are those of the author alone

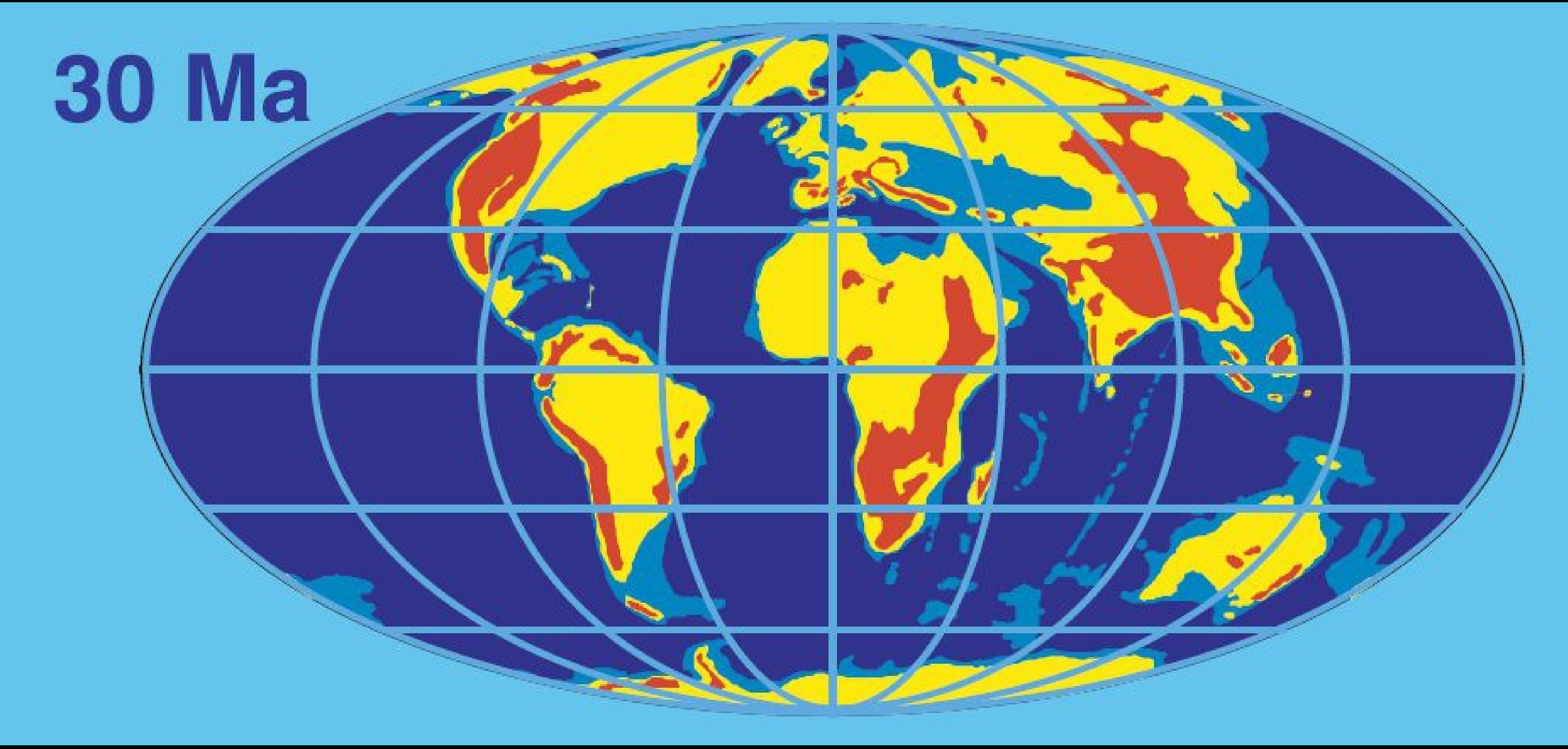
Coal pit fire, Turkmenistan. Source: *Climate Change in Central Asia, a visual synthesis*, Zoinet.org, 2013. (*CCCA*)

Creation of this world: India and Asia collide

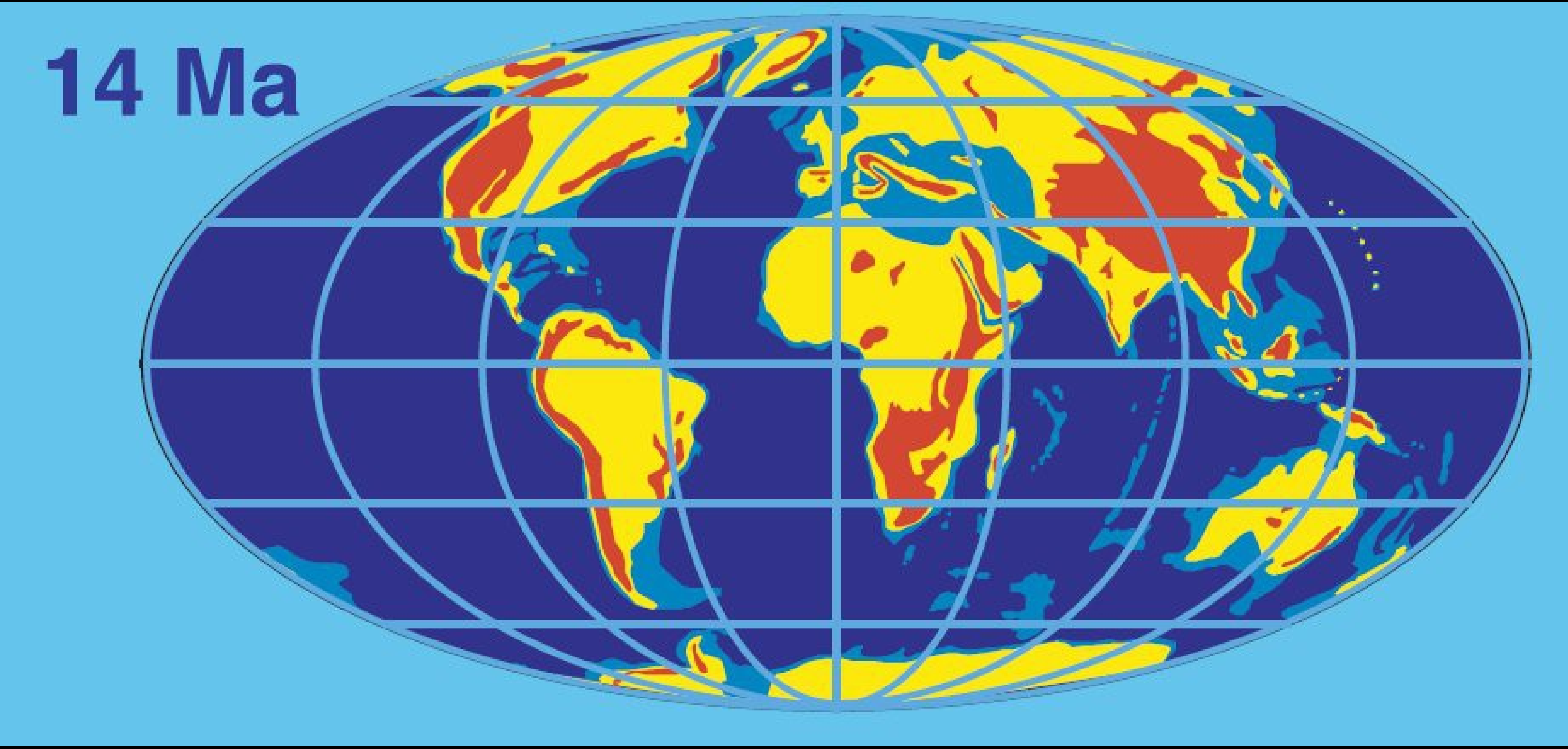
- **An important tectonic event: the collision of Indian and Eurasian plates at end of Eocene (~30 Ma)**
  - Very recent on geologic time scale, dated using isotopic analysis of deep ocean cores
  - Produced both the ice-free, forested poles of the Eocene and transition to polar ice caps and glacial-interglacial oscillation
  - Atmospheric pCO_2 range: 1000-2000 ppm to 170 ppm
- Orogeny of Himalayas isolated Central Asia from South Asia and ocean monsoons

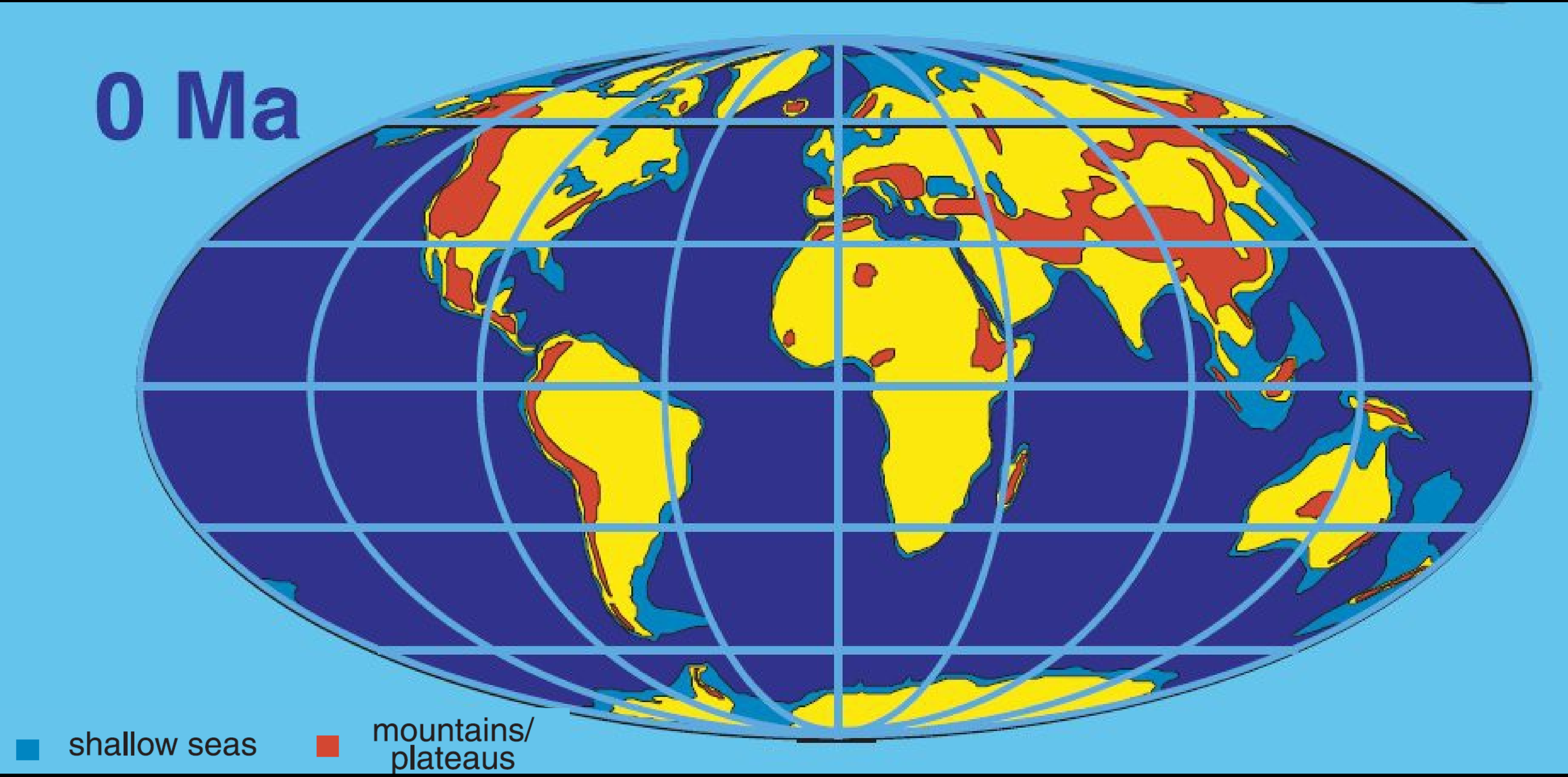

69 Ma
shallow seas
mountains/
plateaus

50 Ma



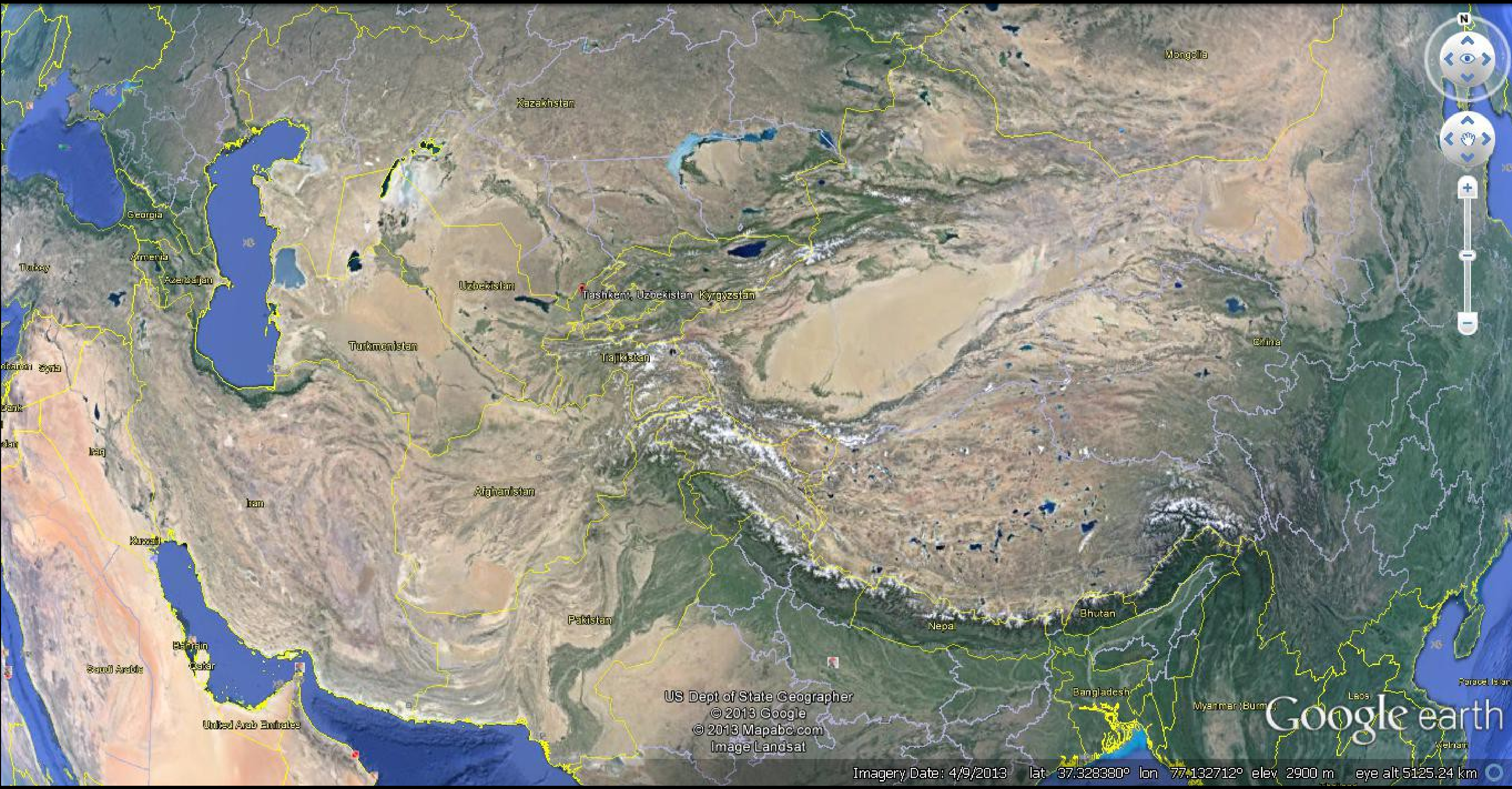
30 Ma

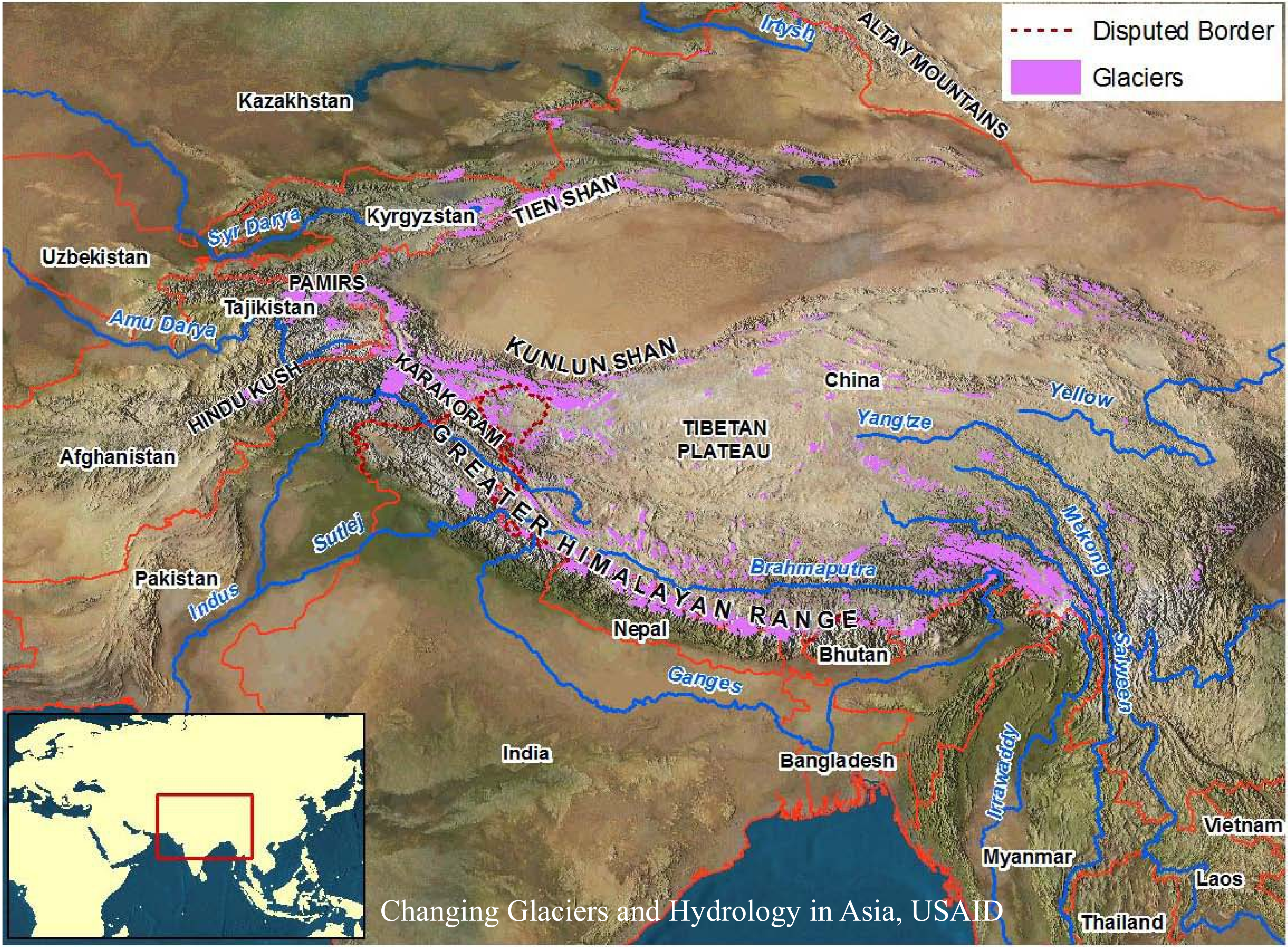

14 Ma



(Zachos et al 2008, Fig.1)

Orogeny and climate

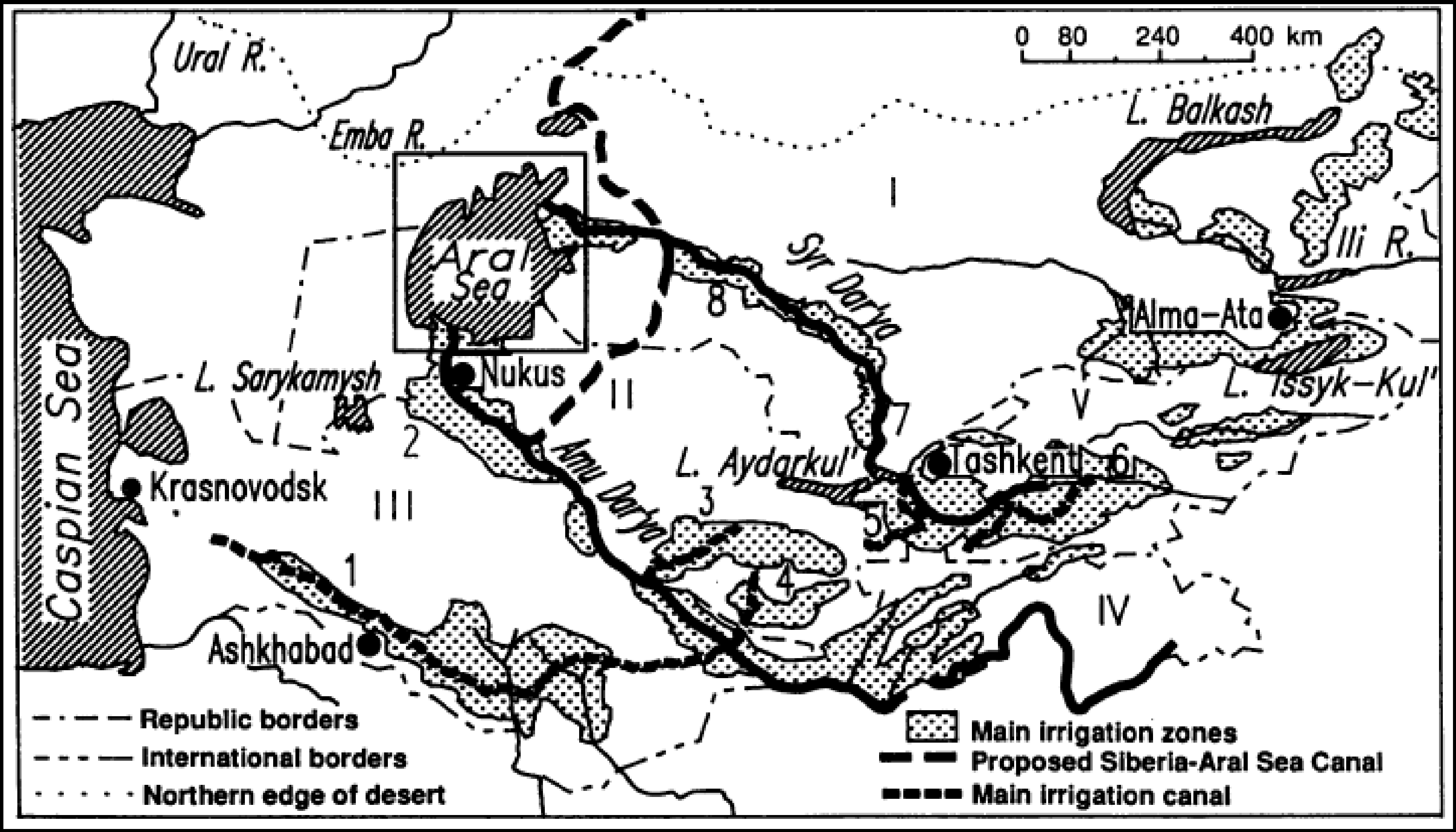




Changing Glaciers and Hydrology in Asia, USAID

Aral Sea basin

- Arid land, “endorrheic” region – no outlets
- Glacial and snowpack melt provides seasonal flow to major rivers
- Natural losses to groundwater along channels produce oases
- Heavily modified by irrigation engineering for millenia, most in past 60 years
- Recent exhaustion of Amu Darya, Syr Darya rivers and dessication of Aral Sea



Micklin 2008 Fig.1

(Micklin 2007 Fig.1)

Orogeny and climate

Hydrologic contrasts

- Extremely high ranges & peaks present a barrier to synoptic storms
- Ocean-facing ranges and south slopes receive heavy monsoon precipitation, accumulating snowpack, becoming glaciated
- Land-facing ranges and north slopes receive whatever weather reaches this region in the farthest interior, after precipitation on the steppes.
- Most of this precipitation falls in mountains due to “pluvial gradient” (due to 6°C cooling per 1000 m with elevation: cf. “lapse rate” of troposphere)
- Both north and south ranges acquire snowpack, glaciation
- Lowlands to north become arid dryland and desert


Mountain ranges and deserts in Central Asia
Kazakh steppes
Altai
KAZAKHSTAN
Moyunkum
Tien-Shan
Kyzylkum
KYRGYZSTAN
UZBEKISTAN
CHINA
Alai
TURKMENISTAN
TAJIKISTAN
Pamir
Karakum
Kopet Dag
Hindu Kush
Karakorum
PAKISTAN
Himalaya
IRAN
AFGHANISTAN
INDIA
Areas above 2000 m
Mountain systems
Deserts

Orogeny and climate

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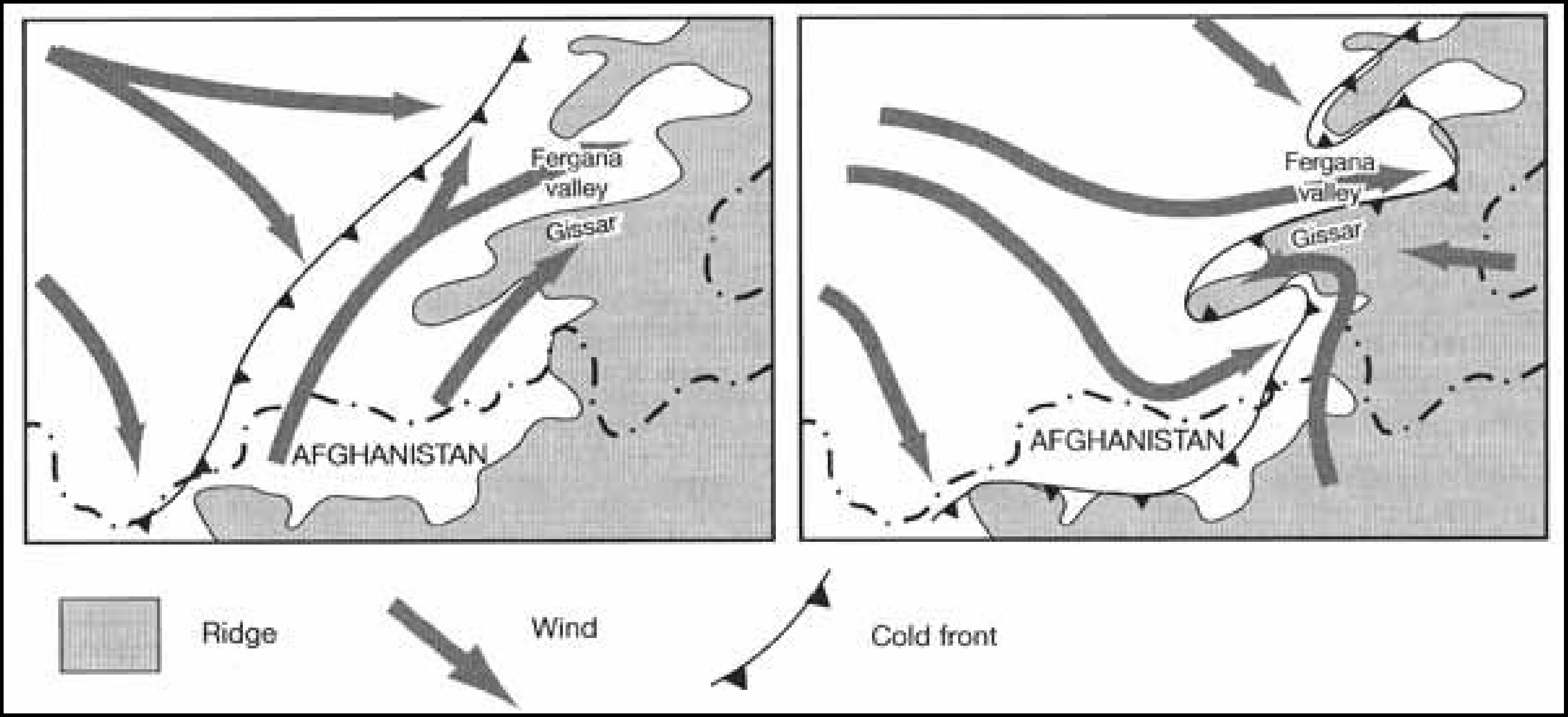
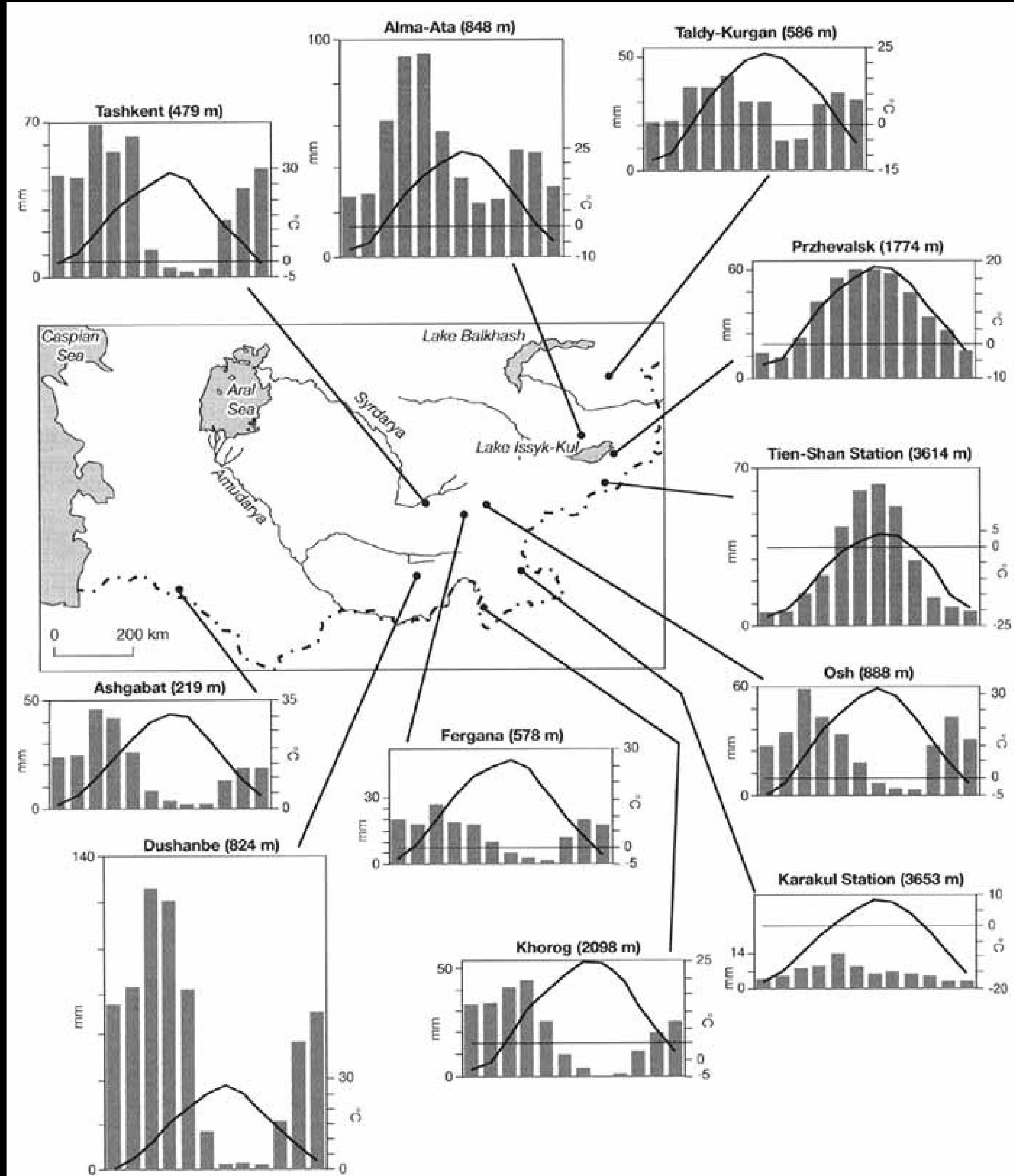
Orographic occlusion



From "Russia's Physical Geography" (http://www.rusnature.info)
Fig. 16.6 Schematic representation of orographic occlusion
in the Pamir-Alay. Modified from Lydolf (1977)

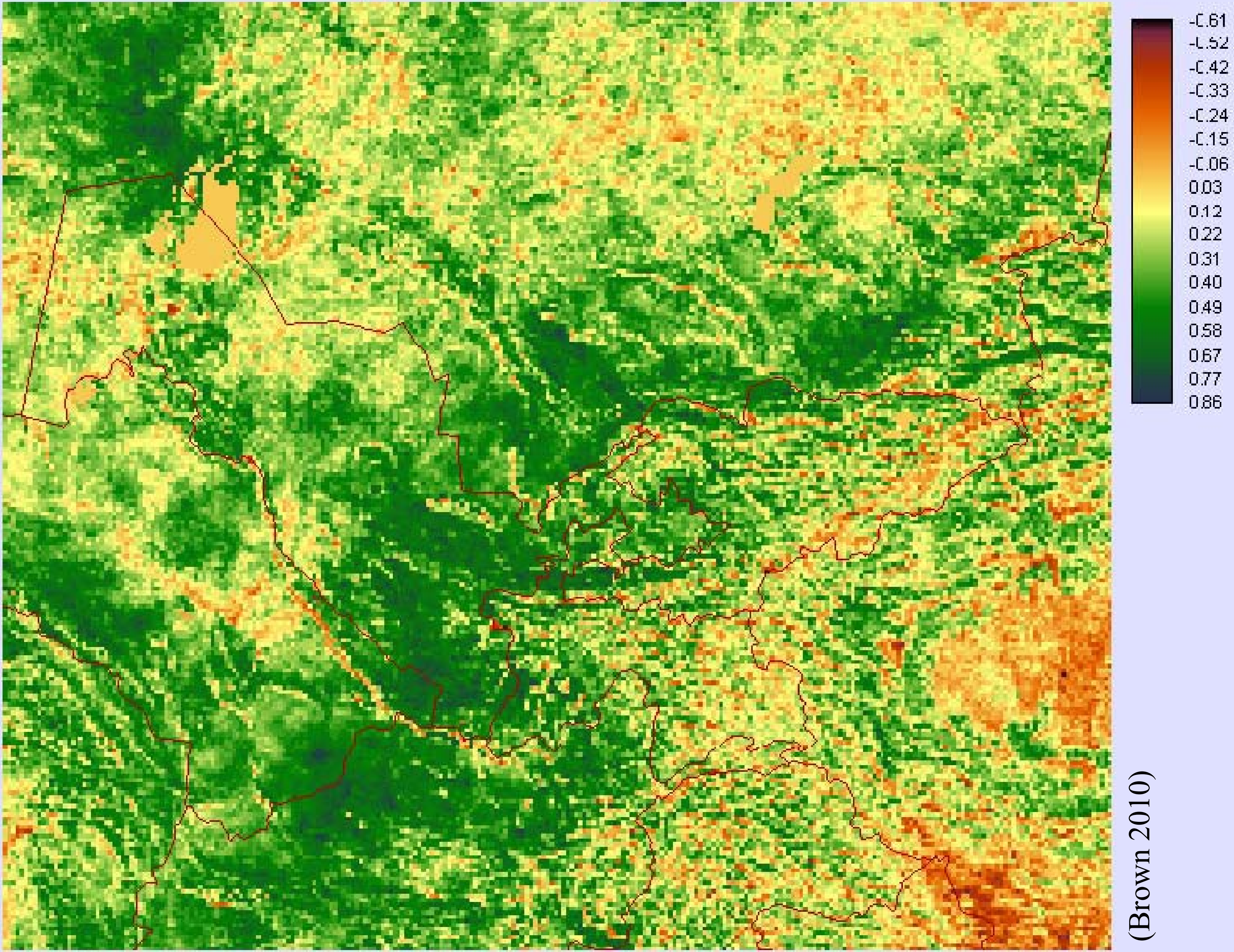


From "Russia's Physical Geography" (http://www.rusnature.info)
Fig. 16.5 Mean monthly temperatures (°C) and precipitation (mm) in the Central Asian mountains

Biomes and agriculture
(Williams & Balling 1996)

- Arid lowlands in northern region are in continental temperate zone: very cold winters <<0°C, very hot summers. Warmer winters >0°C in southern region lowlands. Biodiversity is low in both (~100 species / 100 km^2 diversity) but not desert: microclimates formed by small spatial variation (esp. elevation/depression ~1 m) create refugia and niches.
- Adaptation includes rapid growth when precipitation occurs. (Remote sensing: arid lowland NDVI is strongly correlated with precipitation.)
- Agriculture at oases and under irrigation is highly productive, and not correlated with precipitation. Ideal conditions for cotton.

Correlation (R) 82-03 winter precip vs annual NDVI



(Brown 2010)

Biomes and agriculture

(Williams & Balling 1996; www.rusnature.info)

- Steppes north of region show very high diversity (>1000 spp. / 100 km^2, ~50 spp. / m^2); highly productive agriculture, esp grains.
- Foothills and low ranges show rapidly decreasing air temperature, increasing precipitation and diversity, with elevation.
- Winter temperatures limit high altitude cultivation to 2000m except for cereals; southern ranges permit productive agriculture at 2000-3000 m. Small fields; small total cultivated area limited by topography.

Climate, elevation, crops

Region Annual precipitation increase with elevation	Pluvial gradient (mm/100 m)
The Chirchik valley	65–85
South-eastern slope of the Chatkalsky Ridge	30–35
Northern slope of the Alaysky Ridge	20
Gissar	90–100
Kopetdagh	10–12

Degree days (C)

Altitude (m)	Zeravshan	Gissar	Darvaz	Western Pamir	Eastern Pamir
1800	3050	3160	2970	3670	—
2200	2420	2430	2300	3100	—
2600	1670	1600	1580	2450	—
3000	820	820	920	1770	—
3400	—	—	—	1020	1150

Elevation range (m) for crops

Crop	Tien-Shan	Pamir-Alay
Cotton	850–1000	1000–1200
Cereals (barley, wheat, oats)	2800–3000	3000–3500
Corn	1200	1900
Apples and apricots	1800–2000	2500–2800
Grapes	1400	2300

From "Russia's Physical Geography" (http://www.rusnature.info)
Fig. 16.2-4 Pluvial gradient, degree days, elevation for crops

Climate variability and drought

- Drought is complex
  - Meteorological: prolonged negative precipitation anomaly
  - Agricultural: prolonged negative ecologic or crop anomaly (causes incl. soil, erosion, irrigation failures; also evapotranspiration anomaly e.g. due to wind)
  - Hydrological: prolonged depletion of reserves (aquifer, lakes, reservoirs) below statistical average (causes incl. Irrigation, diversions)
- Extreme cases of anthropogenic hydrological drought include the dessication of the Aral Sea

(Wikipedia)

Climate variability and drought

- Russian use of the term is principally meteorological drought: 20 days precip < 60% of mean, and temp > 2°C above mean
- Southern steppes agricultural productivity limited by frequency of drought (20%-30% of years)
- Aral Sea basin shows severe drought very frequently (>50% of years)
- Mountains show drought rarely (>10% of years)

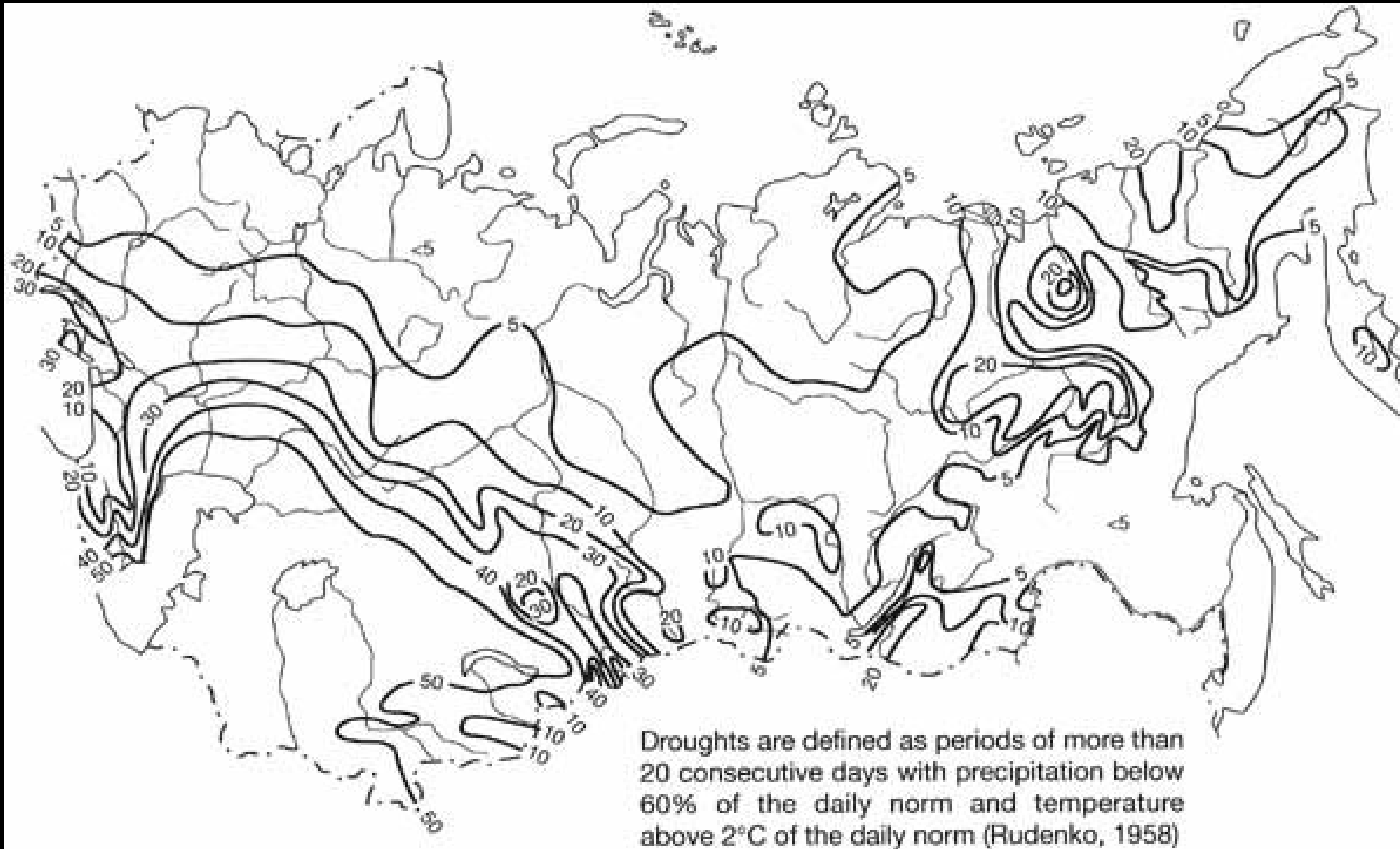


Fig.3.11 Frequency of droughts (% of all years) between the middle of the 19th and 20th Centuries. Modified from Rudenko (1958) (http://www.rusnature.info/geo/03_6.htm)

Glaciation, melt, and flow

(Armstrong 2010)

- Temperature falls linearly with elevation: ~6°C per 1000 m. Glaciers form at elevations where temperatures are predominantly < 0°C and precipitation falls: >3000 m in north, >4000 in south
- Dynamics of snow/ice are complex, both freezing and melting or evaporating; flow by simultaneous snow/ice/water/debris motion down to terminus. Speed is highly variable, many factors. Abrupt motion (e.g. avalanche, calving) is frequent.
- Terminus location is not a comprehensive indicator of glacier health; indicates only recent climate.
- Mass balance: accumulation above minus ablation below "equilibrium line altitude" (ELA) where mass balance = zero. Complex, time- consuming measurements, few long field studies. Net mass balance is the best indicator; often positive in this region. Glacier response time to change can be centuries.

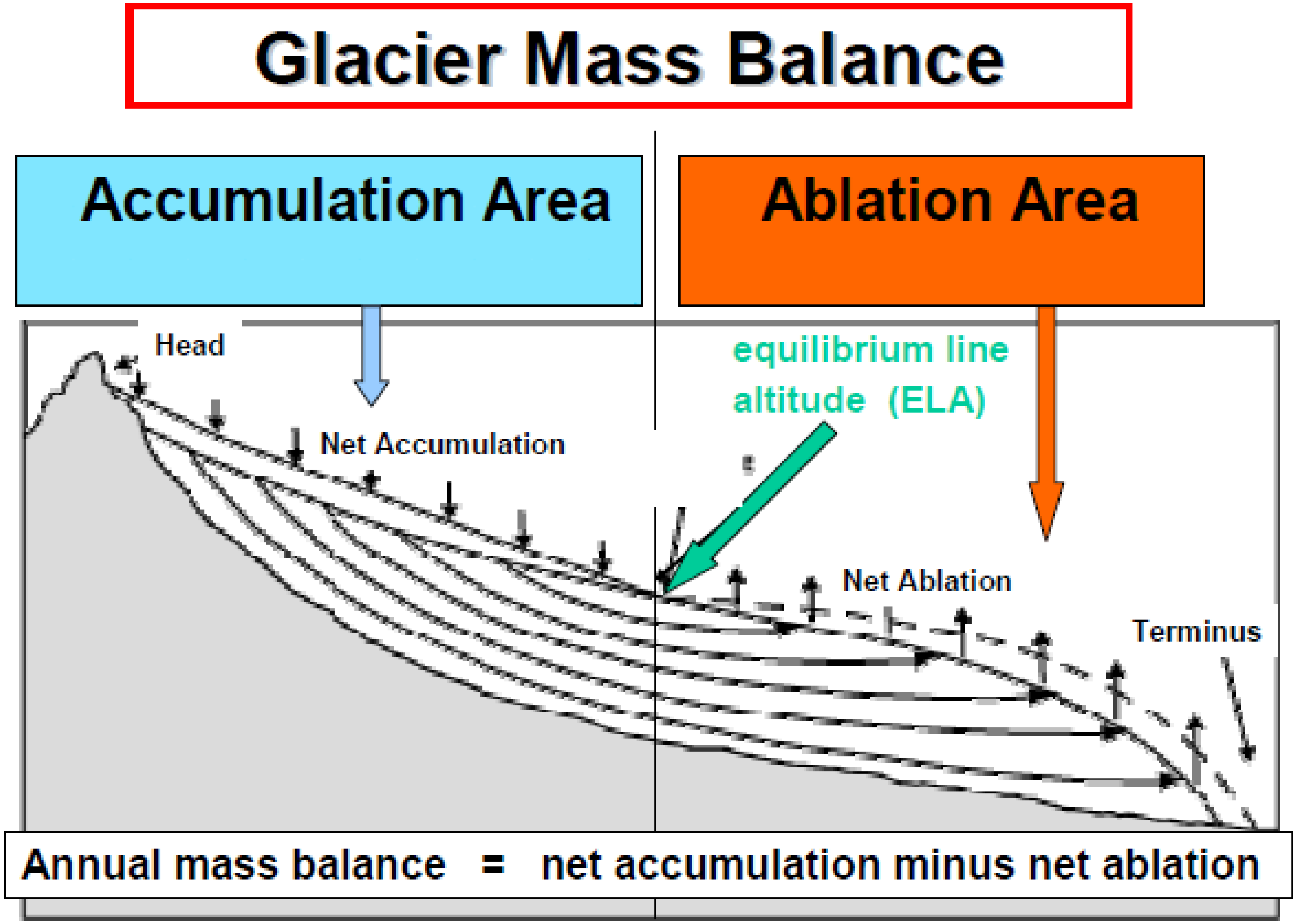


Figure 1. Glacier accumulation and ablation areas, and equilibrium line altitude (ELA).

(Armstrong 2010 Fig 1)

Runoff and river flow

(Northern Tian Shen Mtns, Aizen 1996)

- While topography and precipitation are variable, air temperature and major hydrologic events are generally synchronous across a (zonal) range or region
- Linear regression predicts seasonal melt and flow as function of temperature and glacial area as proportion of basin size
- Loss to groundwater varies 0% - 30% with basin size
- Typical hydrographs show two floods
  - Spring: melt of seasonal snow cover, wets subsurface
  - Summer: glaciers melt during precipitation maximum
- Correspond to two precipitation maxima <2500 m; higher altitudes show one summer maximum.
- Contributions to annual runoff: rain 7%-12%, glacial 18%-24% avg, 40%-70% max in summer. Surface runoff 18%, groundwater 36%-38% of total.

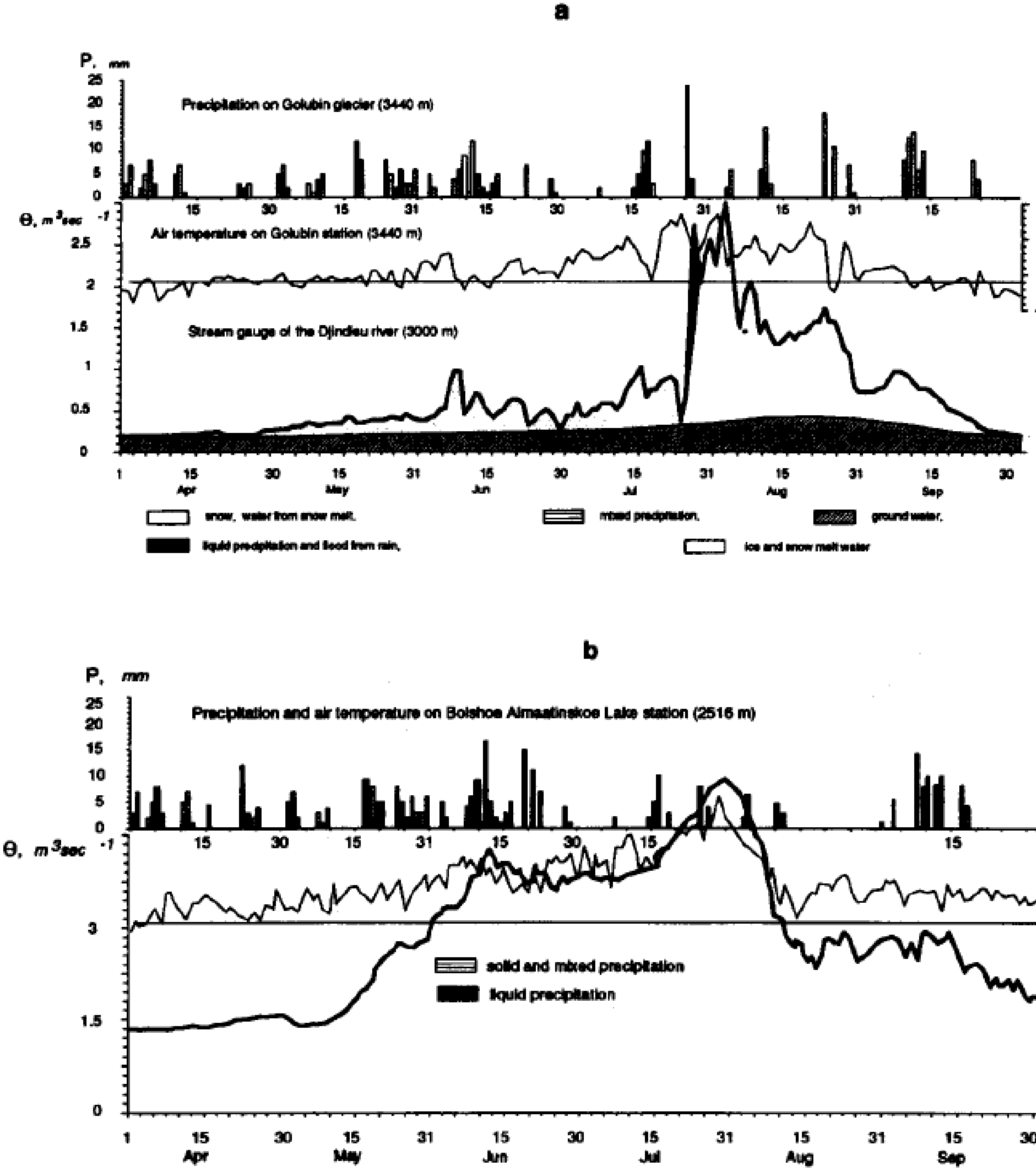


Fig. 8. Typical hydrograph, daily precipitation and air temperature for April–September 1965 of the Djindisu River, Ala Archa basin, northern slope of the Kirgizskiy Alatoo (a), and of the Bol. Almaatinka River, on Bol Almaatinskoe Lake, northern slope of the Zailiyskiy Alatau (b).

Aizen, Aizen, Meack 1996 Fig.8

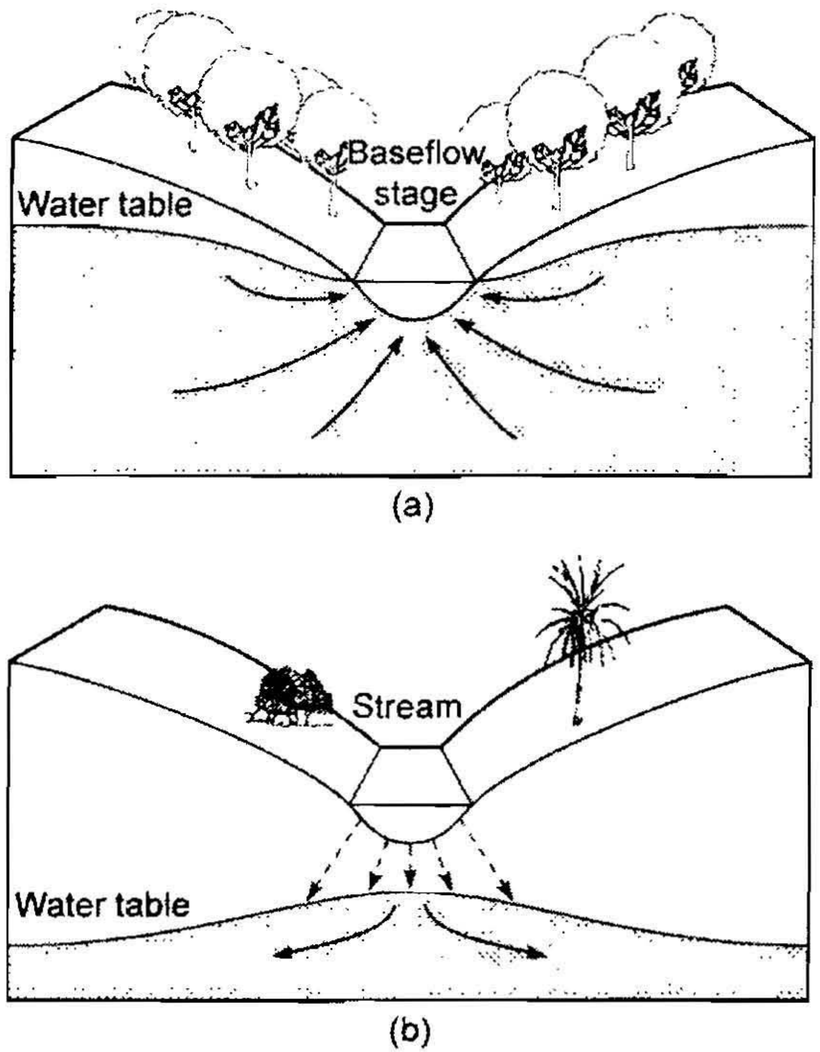
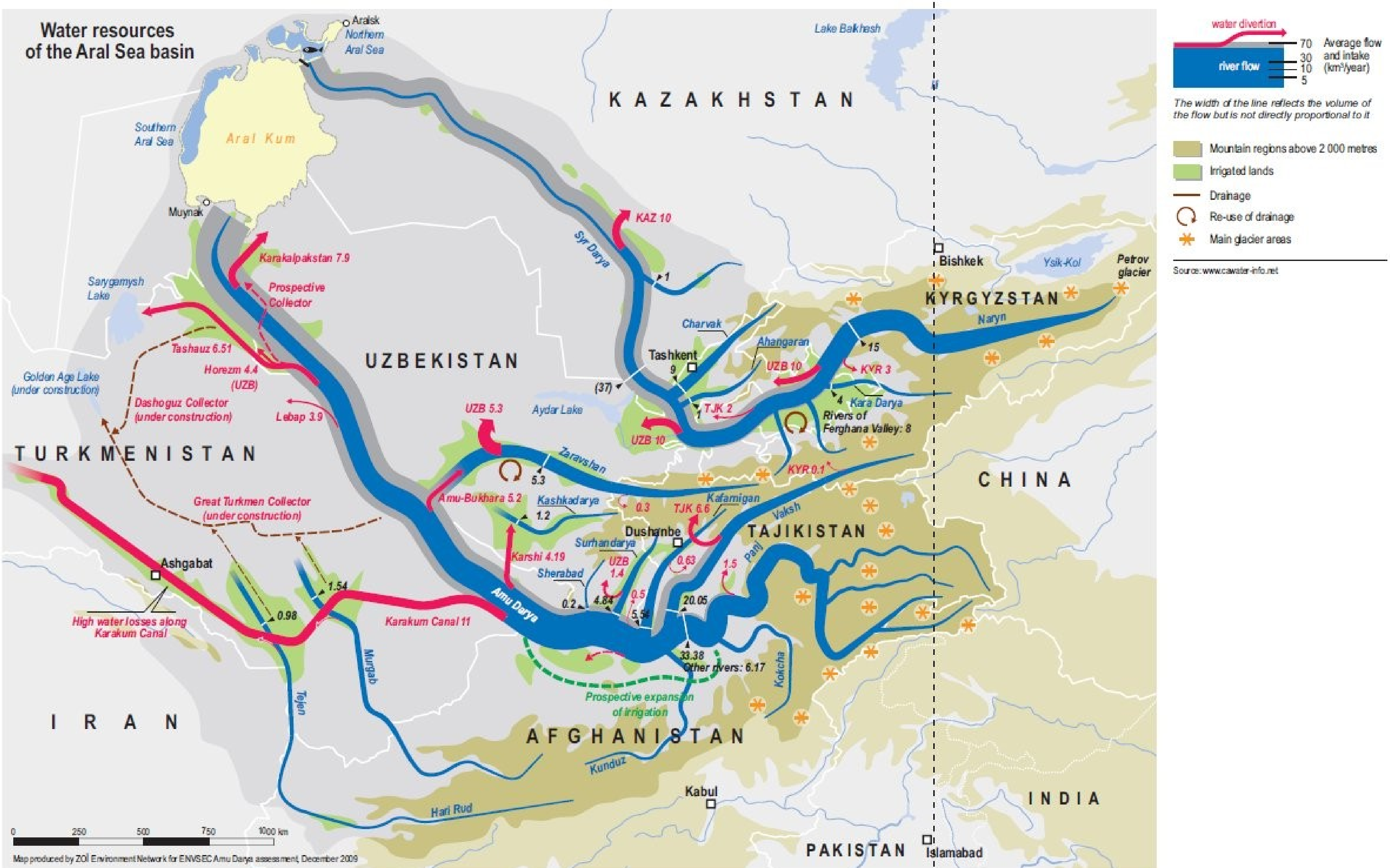


FIGURE 2.6 (a) Cross section of a gaining stream, typical of humid regions, where groundwater recharges the stream. (b) Cross section of a losing stream, typical of arid regions, where streams can recharge groundwater. (Reproduced from Fetter 1988.)

(Postel 2000 Fig 2.6)

River systems

- Syr Darya formed by tributaries Karin Darya, Naryn River in Tien Shan Mtns, 800,000 km^2 basin – only 200,000 km^2 contributing to flow of 37 km^3 per year
- Amu Darya forms in Pamirs, 535,000 km^2 basin, 97 km^3 per year flow. Tributaries include Panj River, border of Afghanistan and Tajikistan.
- Zeravshan River forms in western Pamirs, flows west to desert oases. Much smaller, approx 5% of the total.
- Soviet irrigation systems diverted flow among them.



CCCA, p.68 (ZoiNet.org 2013)

Panj River, border of Afghanistan and Tajikistan. (*CCCA*, Zoinet.org)

History of irrigation

(O'Hara 2000)

- Two large rivers provide 90% of the 125 km^3 annual water resources: Amu Darya, Syr Darya.
- Diversion of rivers into irrigation canals began 8000 ya; evidence indicates 3.6 Mha irrigated in Aral Sea deltas around 2000 ya
- 7th century Arab control improved engineering and prosperity.
  - (Supplement A: History of irrigation)
- Russian and Soviet empires changed Central Asia's hydrology permanently with further engineering
  - (Supplement B: Russian/Soviet history)
- Dessication of the Aral Sea
  - (Supplement C: Requiem for the Aral Sea)

(Micklin 2007 Fig.1)

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Dessication of Aral Sea

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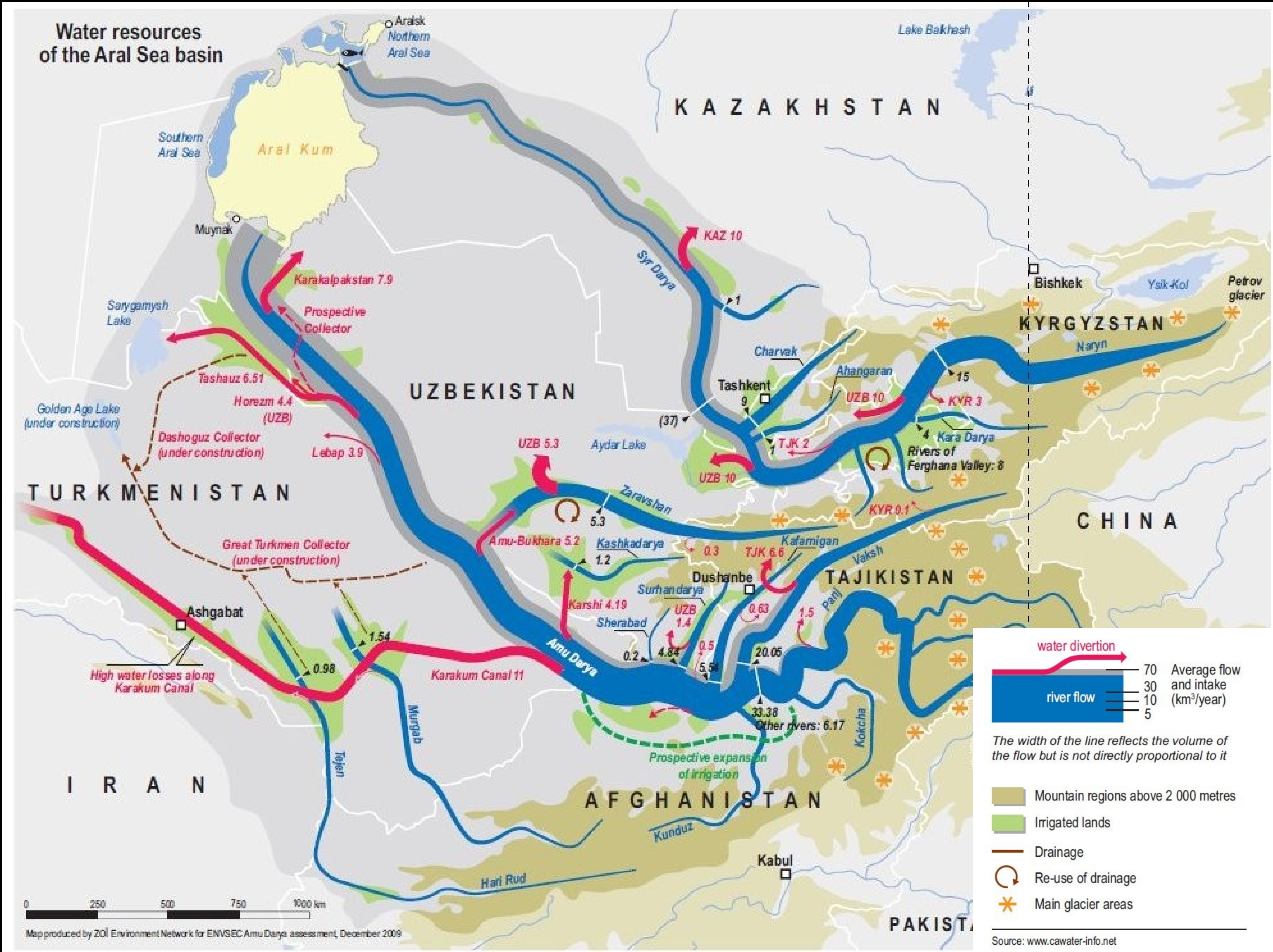

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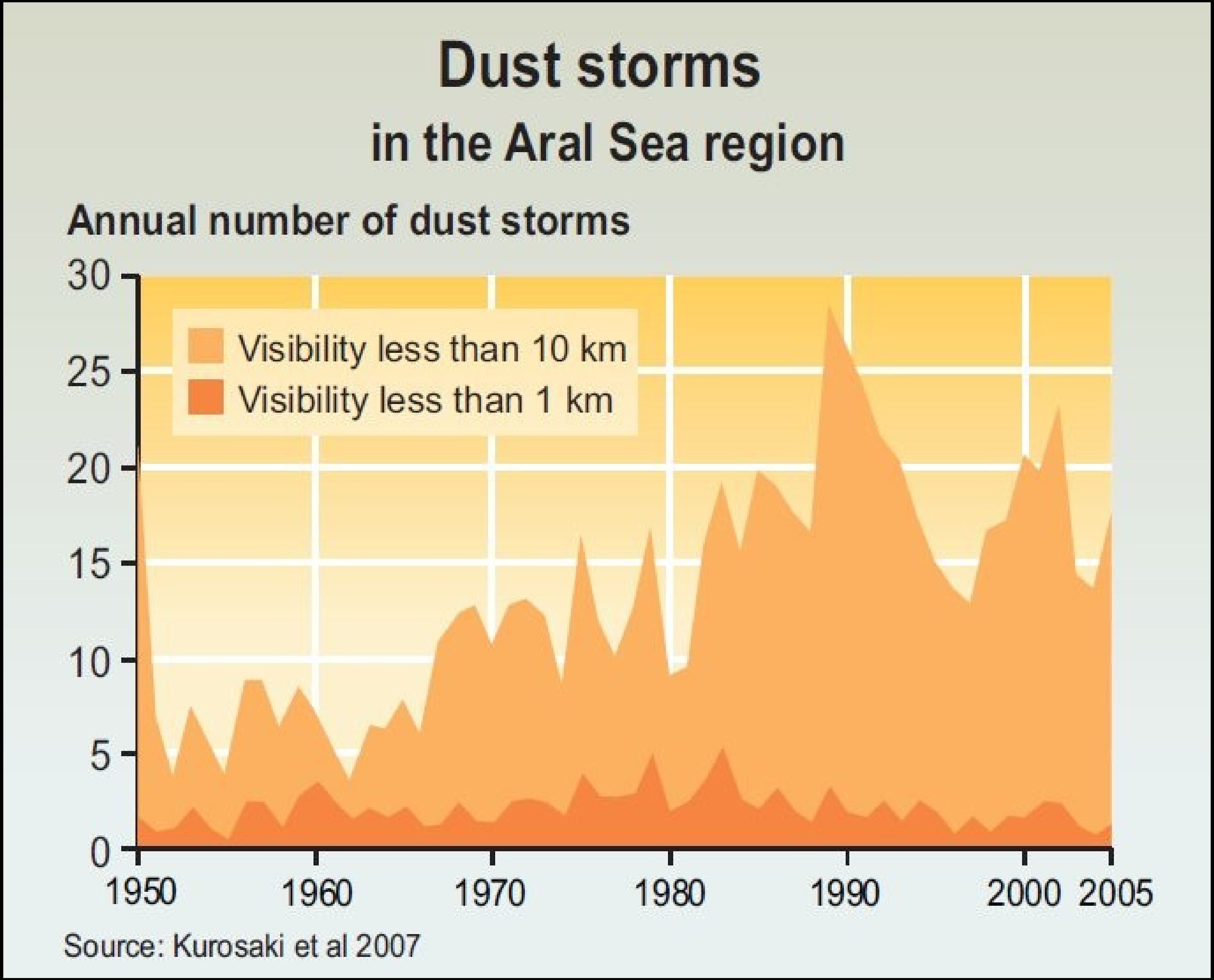
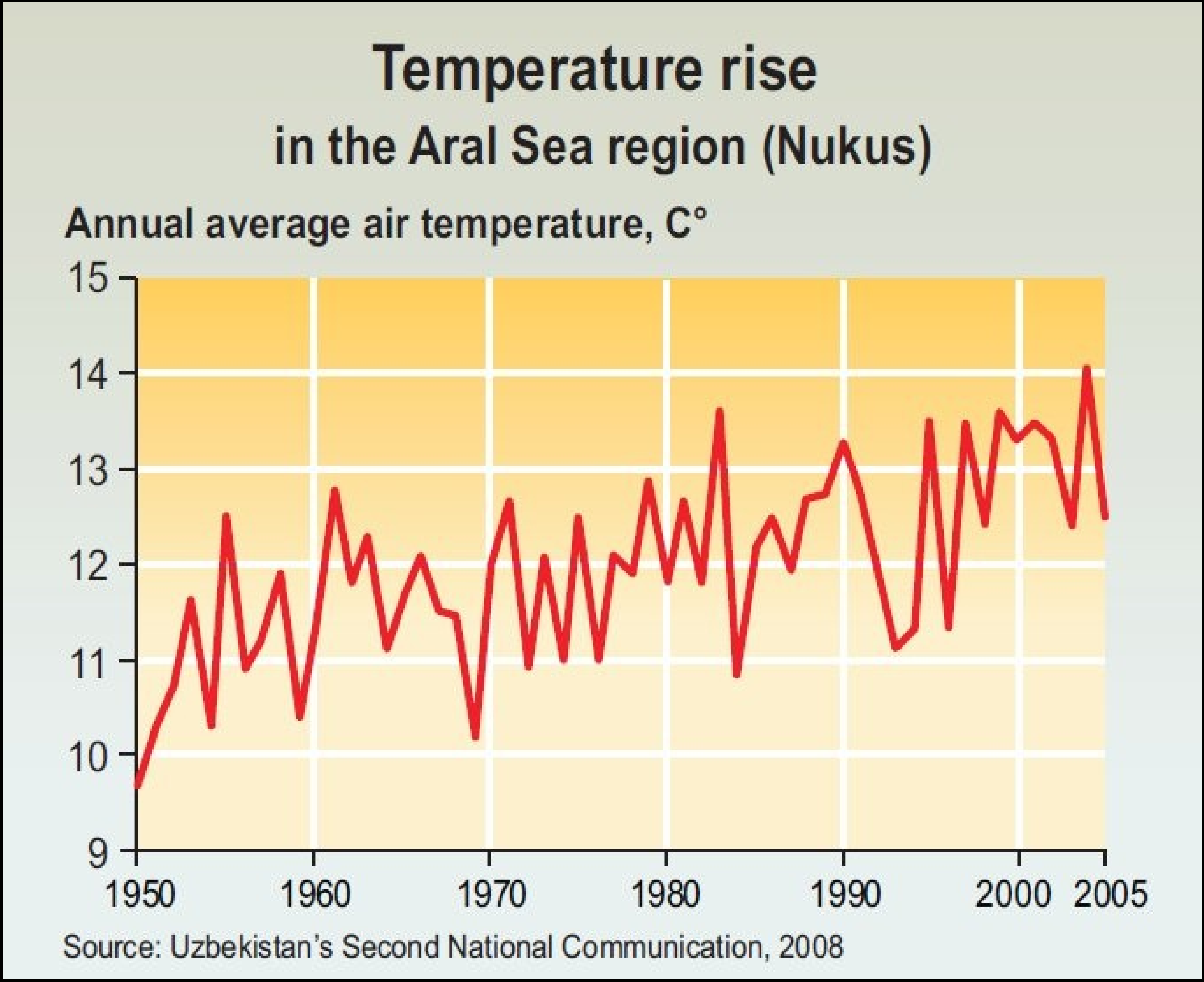

Dust storms
in the Aral Sea region
Annual number of dust storms
30
25
20
15
10
5
0
Visibility less than 10 km
Visibility less than 1 km
1950
1960
1970
1980
1990
2000
2005
Source: Kurosaki et al 2007


Temperature rise
in the Aral Sea region (Nukus)
Annual average air temperature, C°
15
14
13
12
11
10
9
1950
1960
1970
1980
1990
2000
2005
Source: Uzbekistan's Second National Communication, 2008

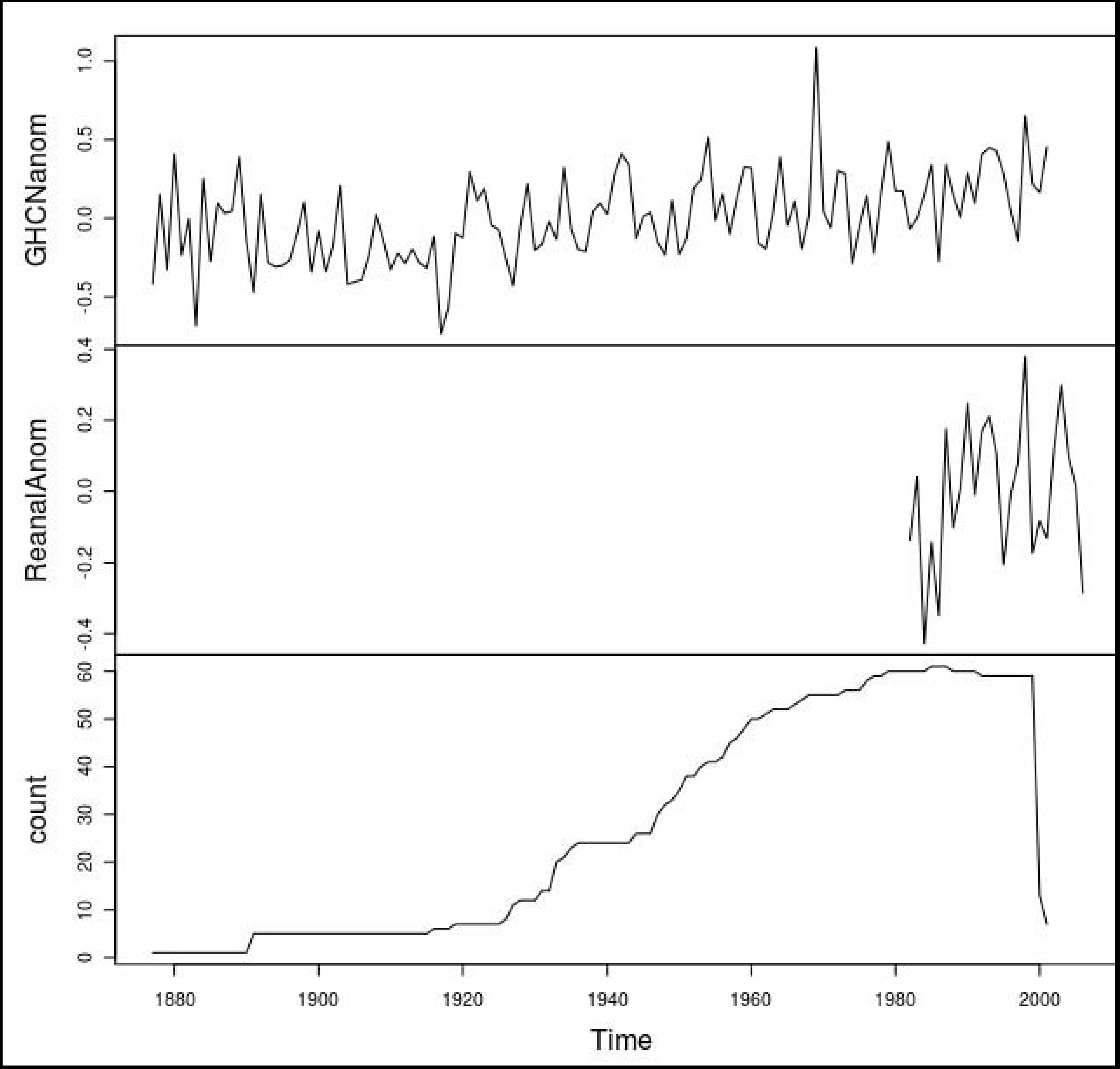
Dissolution of Soviet Union

(*CCCA* zoinet.org, 2013)

- Collapse of technical, managerial support
- Loss of technical resources
  - Among them, Soviet hydrologic engineers, and Central Asia's Soviet meteorology observation network
- Loss of central planning redistribution
- Transactions needed in absence of markets
- Self-sufficiency within national borders was a new goal – required food crops, not cotton
- Most food grown on small family plots for informal markets
- Rapid deterioration of already decrepit irrigation networks
- National borders have new significance

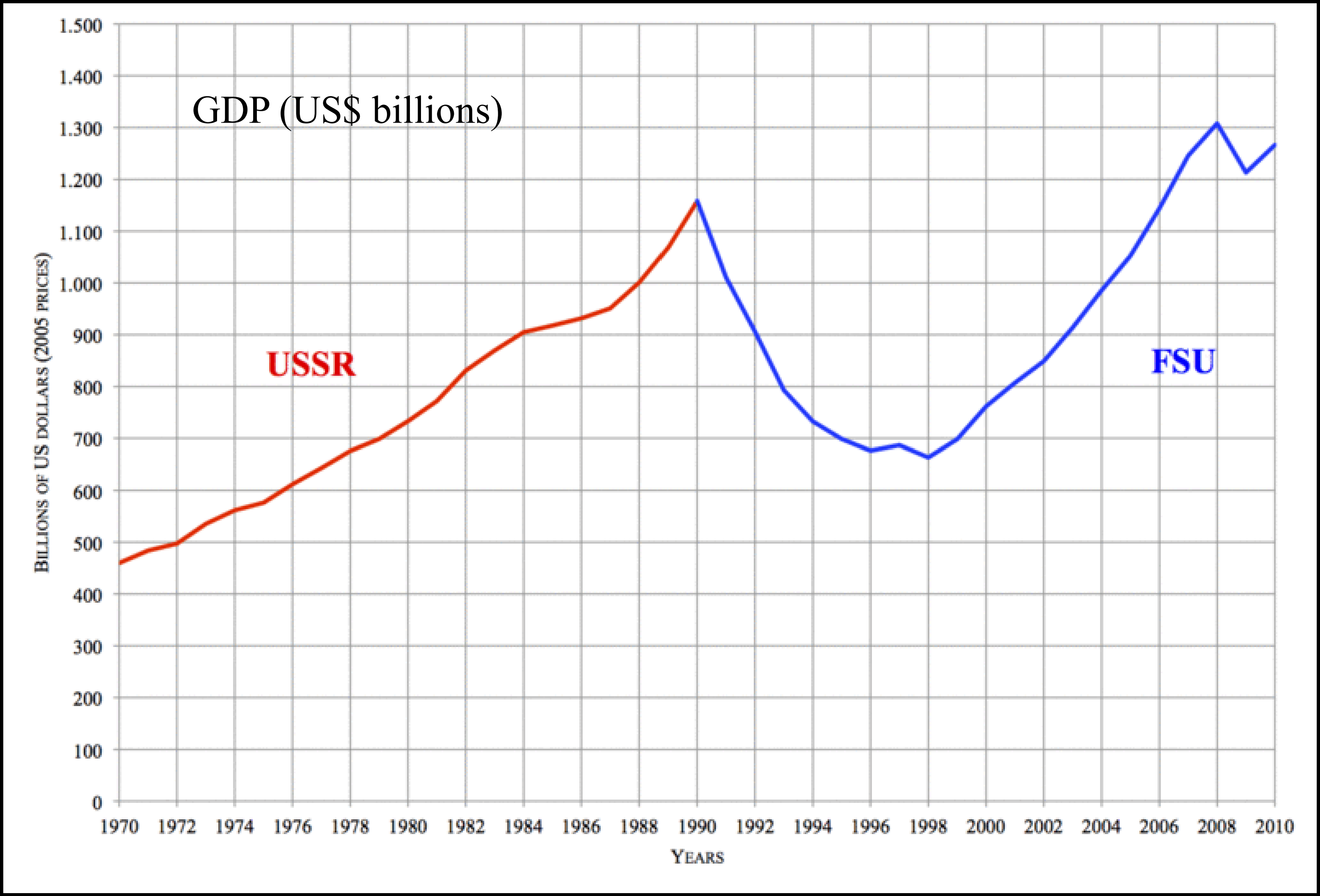
Border. CCCA, zoinet.org

Soviet-era meteorology stations



(GHCN station data - Brown 2010)

Dissolution of Soviet Union



Status at independence

- National entities were previously administrative regions
- Energy intensive (fossil resource rich) KZ, UZ, TM; energy "poor" (only renewable) KG, TJ
  - Longstanding inequities under Soviet command economy remain unresolved, incl water allocation
- Industrial cotton monoculture, limited foodcrops
  - Loss of Aral fishing industry: limited protein
  - Irrigation inefficiency: flooding, salination
  - Agricultural chemical toxicity
- Geological hazards
  - Earthquake, avalanche, flood (incl GLOF)
  - Interactions with glaciation dynamics
  - Natural toxic contamination of water – salts, metals
- Mining, energy, agriculture industries toxic waste
  -

1990/1991

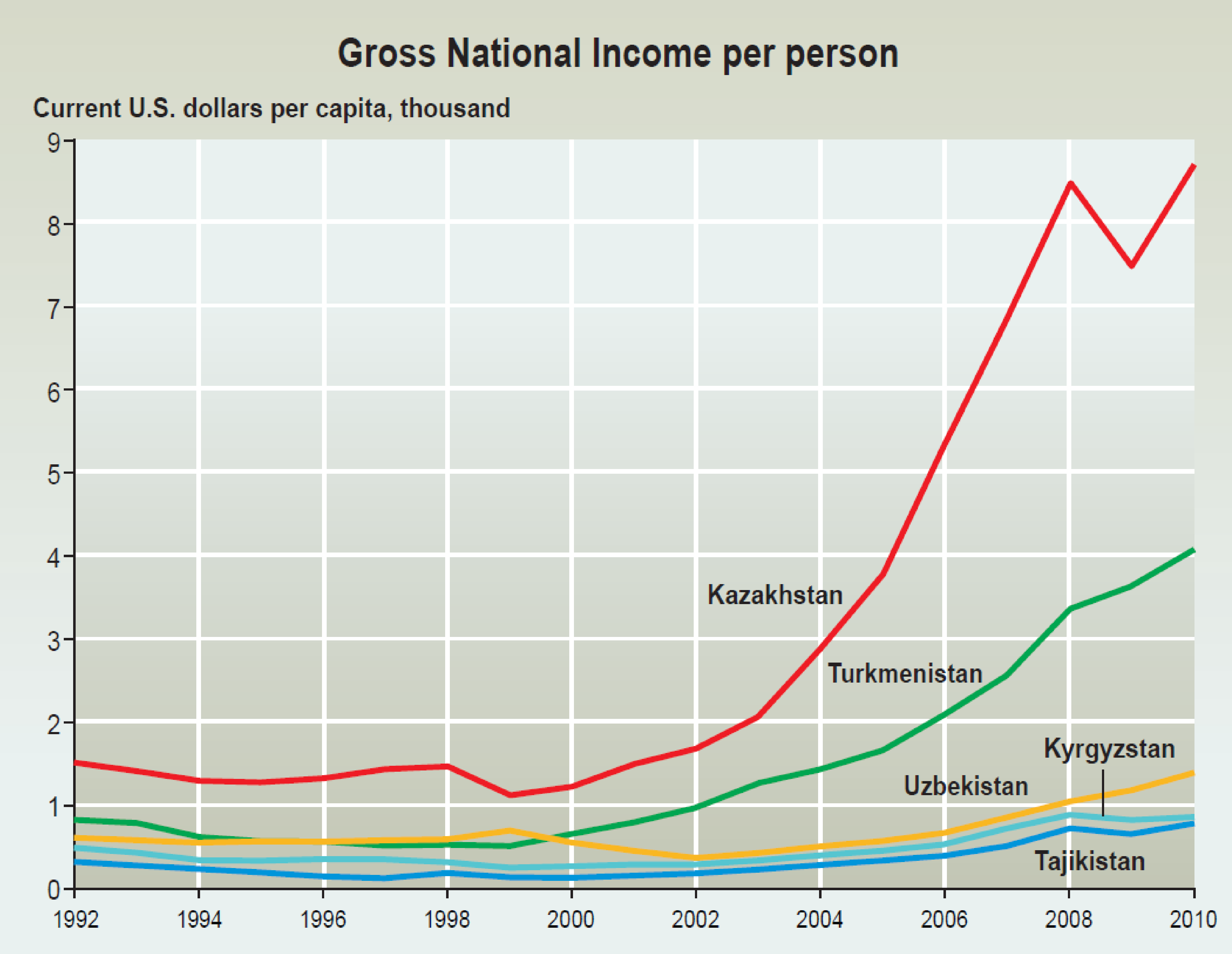
The end of the Soviet era

1991/1992

The beginning of the independence era

2012

Increasing fragmentation and border barriers



Source: World Development Indicators (data.worldbank.org/indicator)

Regional water planning

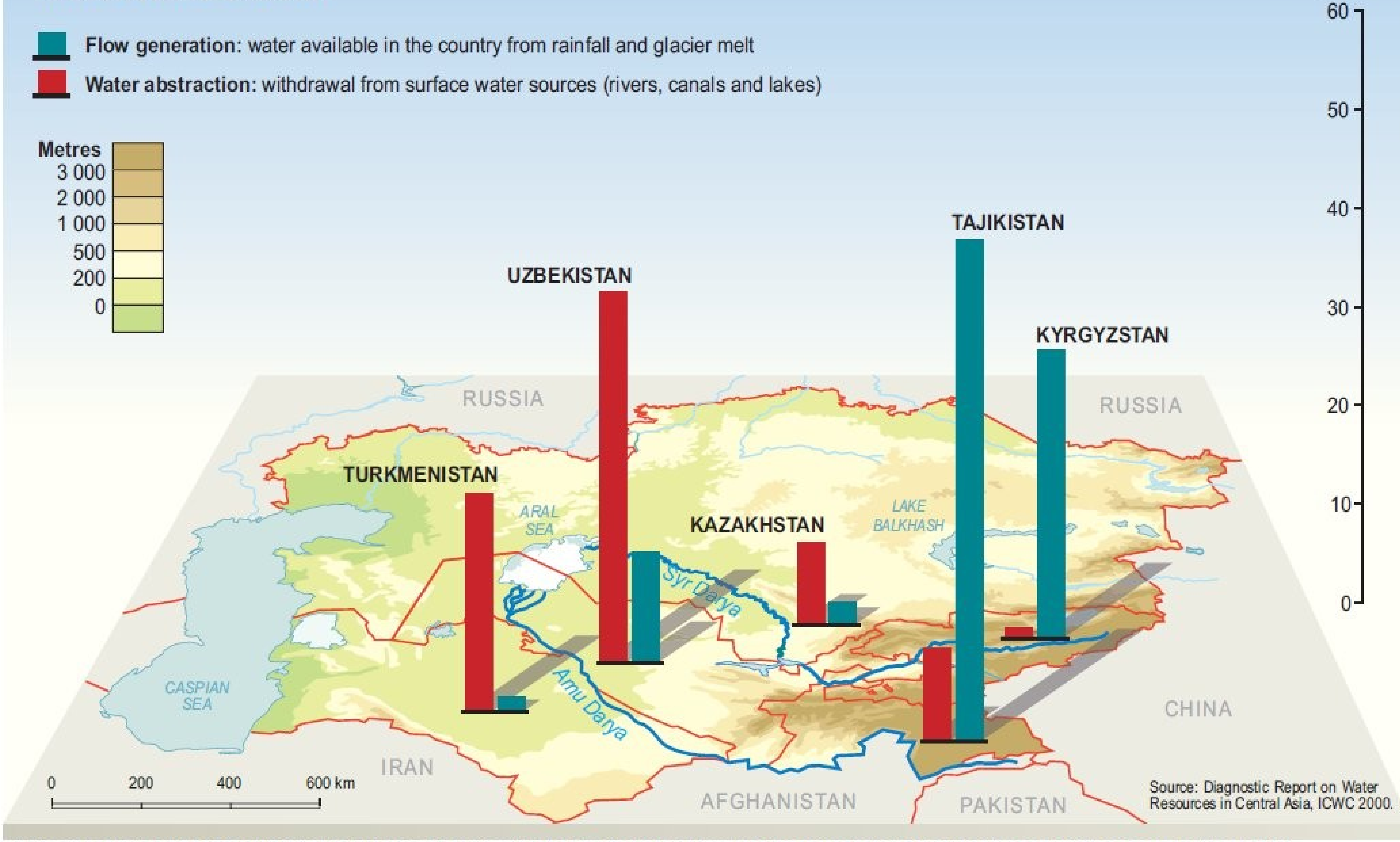
CCCA, zoinet.org

Irrigation's limits

(Postel 2000)

- Fresh surface flowing water is scarce (0.01% of planet's water) and finite, constant over time on scale of human history, divided among increasing human population. International agreements on water rights are urgently needed.
- Control of water for irrigated agriculture makes productivity less dependent on precipitation
- Arid lands become highly productive in oases and under irrigation but are vulnerable to degradation by salination
- Efficient use of limited water can add expense
- Pumping from aquifers for irrigation consumes a non-renewable resource and often non-renewable energy from fuels

Water withdrawal and availability in the Aral Sea basin



MAP BY VIKTOR NOVIKOV AND PHILIPPE REKACEWICZ - UNEP/GRID-ARENDAL - APRIL 2005

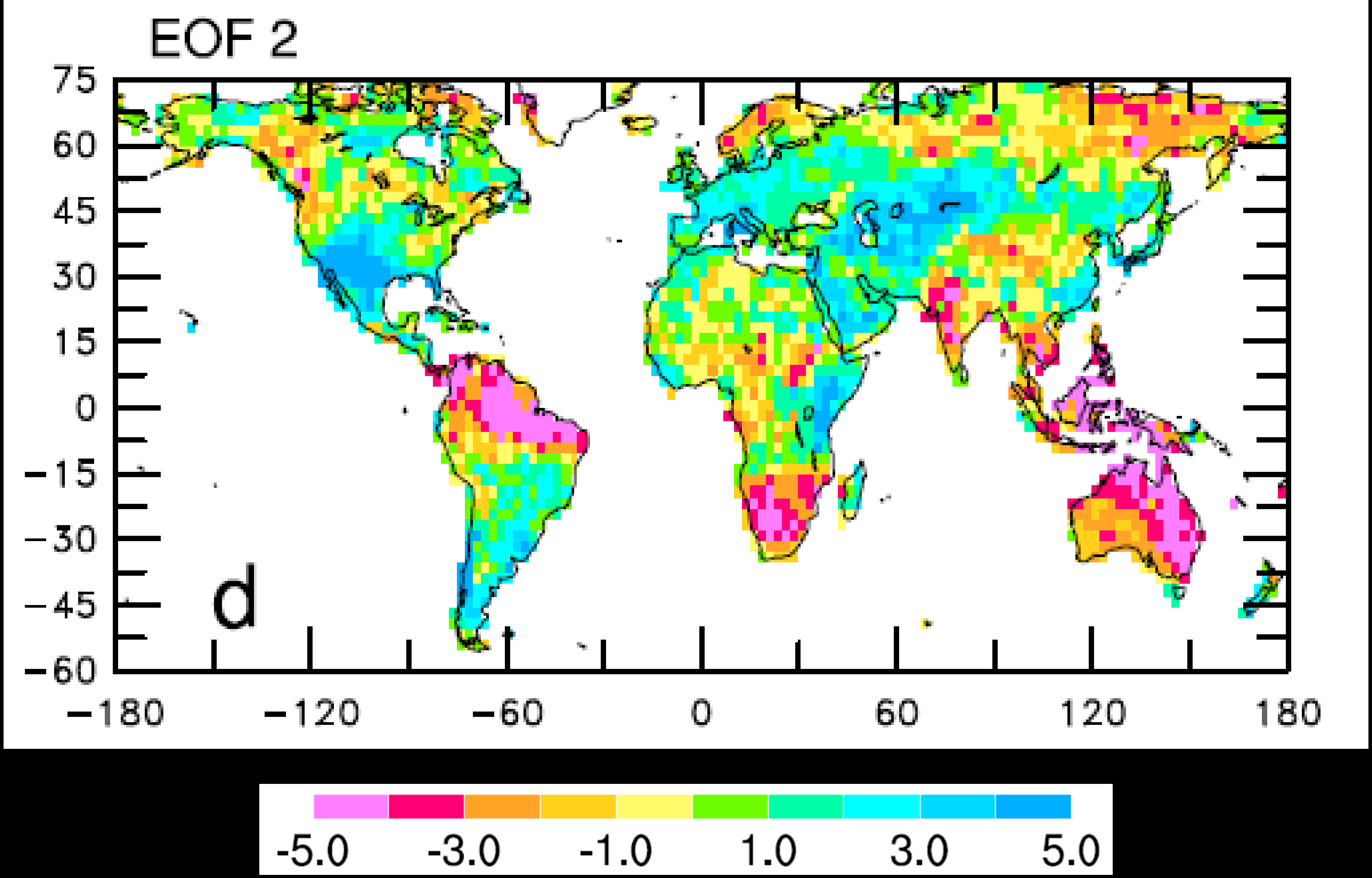
CCCA, zoinet.org

Transboundary surface waters in Central Asia

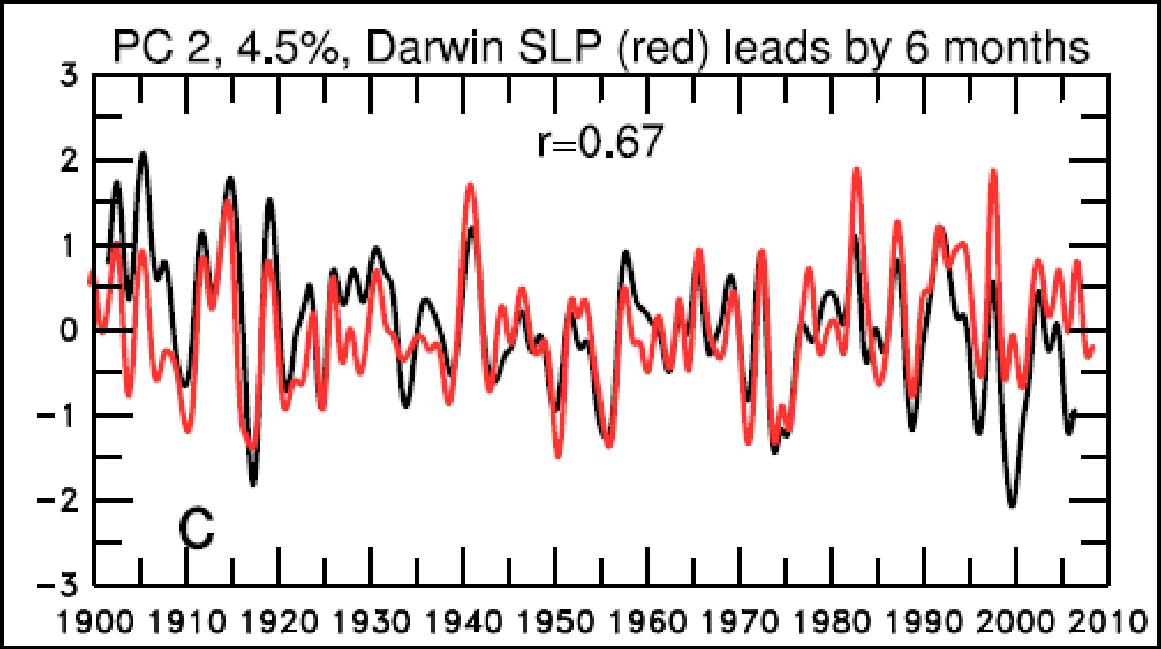

Borders
Soviet border until 1991
New borders after 1991
Fortified borders
Restricted access to the Pamirs
Risk of insecurity
Enclaves
Land transfers to China*
* Land transfers to China; currently being discussed and formalised
0
100
200
300 km
Map produced by ZOÏ Environment Network, February 2012
Land exchange between Kazakhstan and China
KAZAKHSTAN
Lake Balkhash
Taldykorgan
Ghulja
Chu
Ili
Kapchagay Lake
Almaty
Talgar Peak 4979
Khan Tengri 7010
7439 Jengish (Pobeda) Peak
Karakol
Ysyk-Kol
Bishkek
Balykchy
Turkestan
Taraz
Talas
Syr Darya
Shymkent
Talas
Toktogul
KYRGYZSTAN
Naryn
Naryn
Tien Shan
Aksu
1998 and 2002 from Kyrgyzstan to China
no detailed geographic information
5982 Dankova Peak
Tashkent
Angren
Namangan
Sarvan (TAJ)
Ferghana Valley
Barak (KYR)
Kokand
Ferghana
Osh
UZBEKISTAN
Khujand
Chong-Kara (UZB)
Jangy-ayyl (UZB)
Shakhimardan (UZB)
Jizakh
Kairagach (TAJ)
Batken
Vorukh (TAJ)
Sokh (UZB)
Kashgar
Hotan He
Yarkant He
CHINA
Taklamakan
Samarkand
5509 Piramida Peak
7134 Lenin Peak
2011 from Tajikistan to China
Panjakent
7495 Ismoil Somoni Peak
6974 Independence Peak
7719 Kongur Shan
TAJIKISTAN
Dushanbe
Murghab
Denov
Vakhsh
Kulob
Pamir
Hotan
Qurghonteppa
Khorog
Termiz
Amu Darya
Mazar-e Sharif
Disthegil Sar 7885
7282 Muztag
8611 K2
PAKISTAN
7788 Rakaposhi
AFGHANISTAN

Drought indicators
(Dai, Trenberth, Tian 2004; Dai 2011)

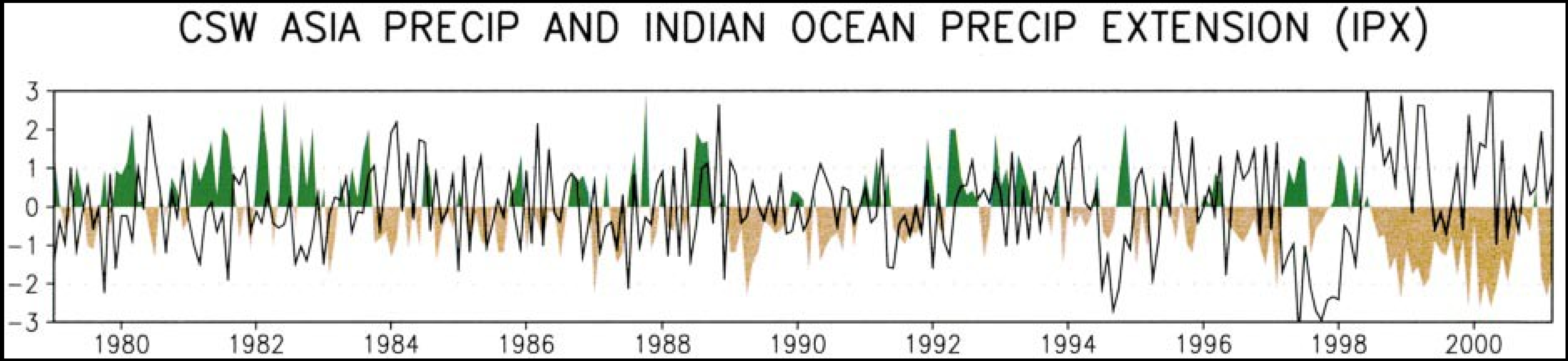
- Important agricultural meteorology product, various methods of observing current, historical drought (e.g. tree rings, thermal-band evapotranspiration)
- US Palmer Drought Severity Index (PDSI) is a standard agricultural drought indicator (Palmer 1965).
  - PDSI uses soils data to provide heuristic modification of precipitation data (based on US Midwest experience).
  - Generalized to global PDSI spatial distribution permitting historical reconstruction 1870-present of rising drought trend (Dai, Trenberth, Tian 2004)
- The PDSI global map time series, using statistical analysis, shows an important relationship to global meteorology patterns: *teleconnection* with El Nino (ENSO) in the tropical Pacific. Approx. 5% of the total variability of PDSI globally is explained by this pattern. The pattern shows strong influence in steppes of Russia and Kazakhstan (agricultural drought) and high mountains in Central Asia (meteorological drought).



1900-2008 PDSI analysis spatial EOF2. (Dai 2011 Fig 10d)



Darwin AU sea level atmospheric pressure (comparable to Pacific El Nino ENSO index) leads 1900-2008 PDSI analysis temporal EOF2 by six months, with moderately strong correlation (R=0.67). (Dai 2011 Fig 10c)

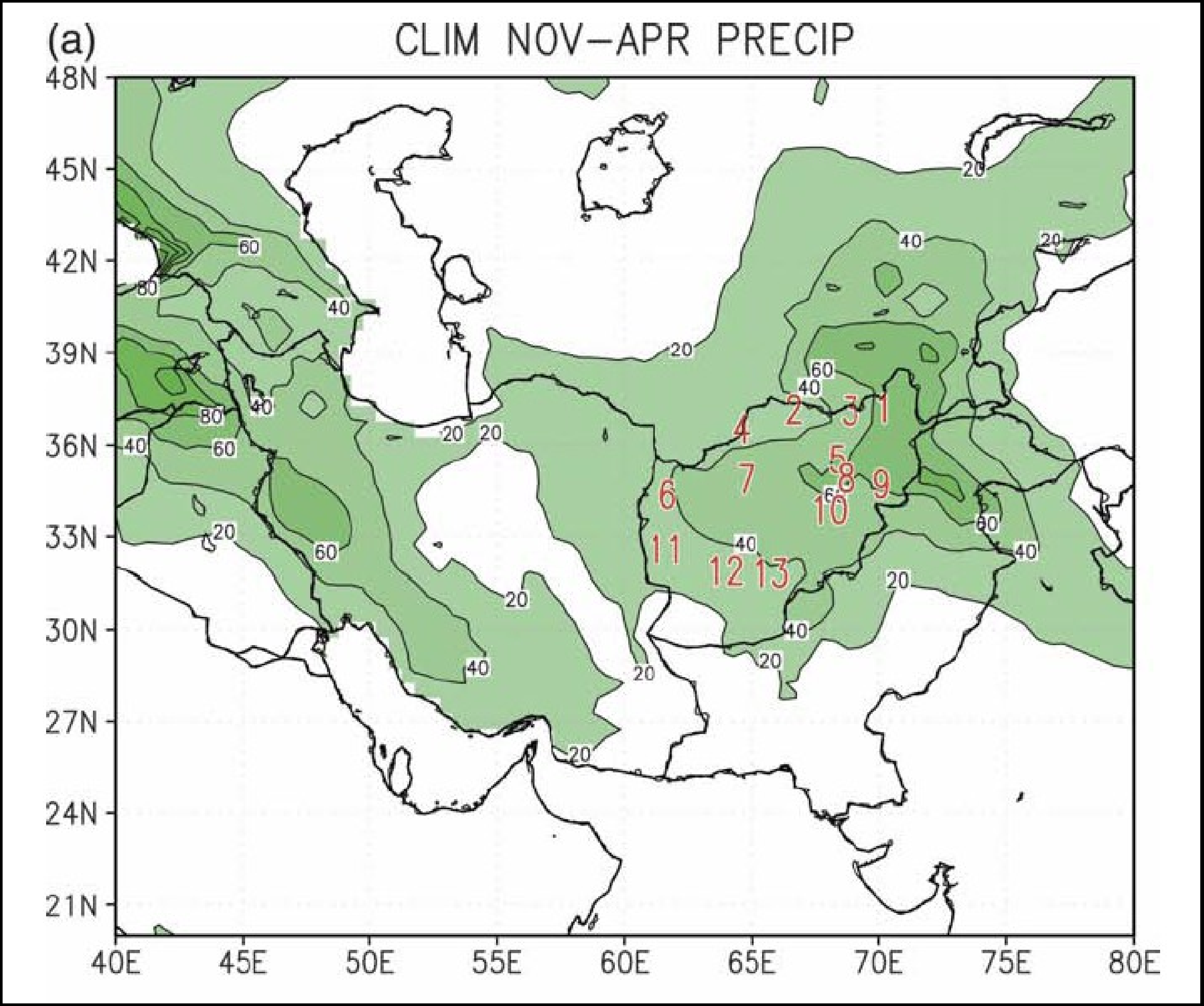


1998-2001 CSW Asia drought evolution. Shown are the normalized monthly precipitation anomalies for CSW Asia drought region (shaded) and the IPX region (line) from Jan 1979 to Mar 2001. Note persistence of drought (brown shading) since 1998. (Barlow Cullen Lyon 2001 Fig 1)

Drought forecasting

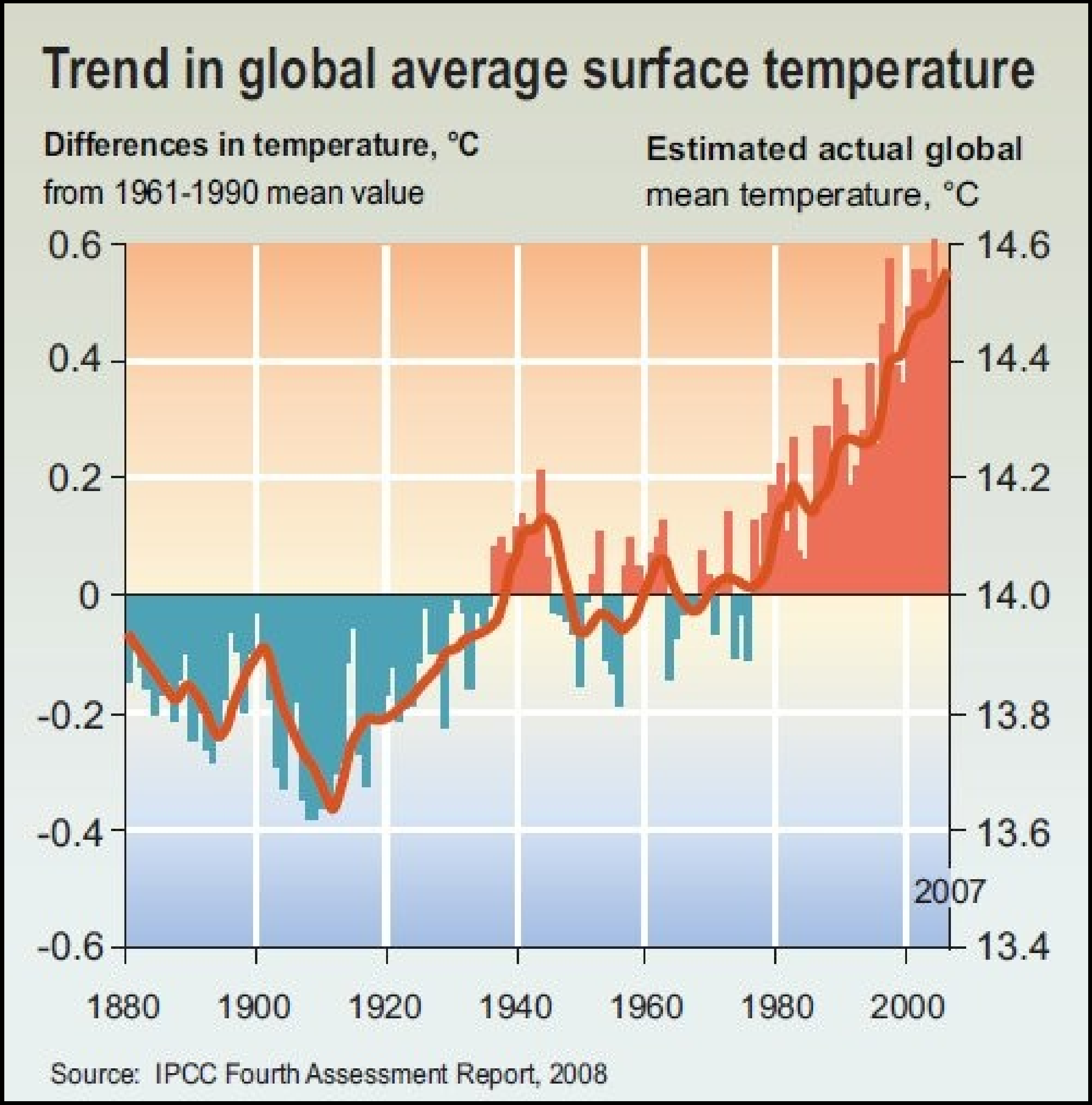
(Barlow, Tippett et al 2010)

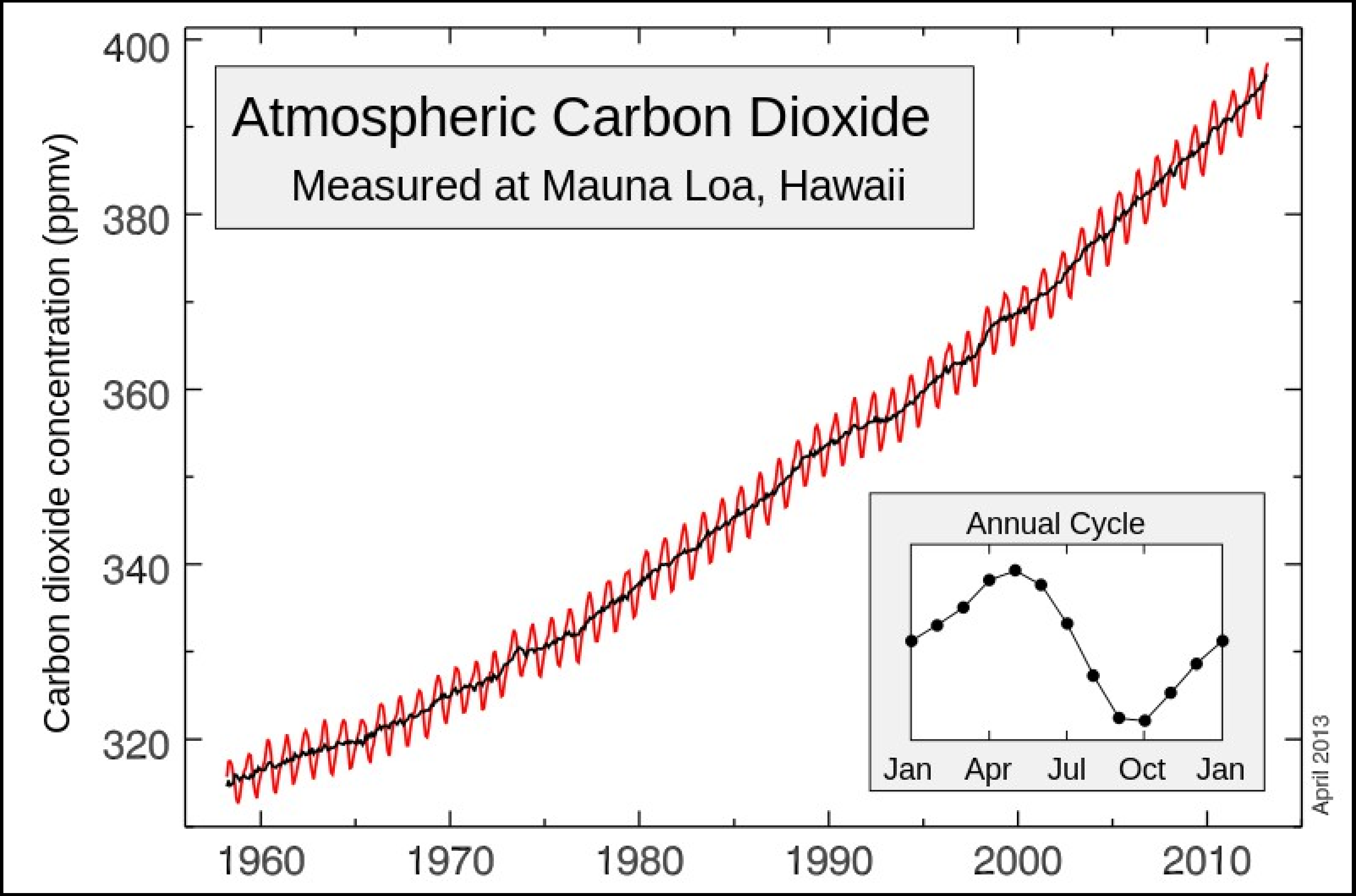
- Regional river flow and drought forecast is strongest using winter (NDJFMA) precipitation vs summer (JJAS) vegetation (NDVI). (Tippett, Barlow, Lyon 2003)
- Continental meteorologic drought forecast based on ocean-atmosphere dynamics (Pacific ENSO, North Atlantic NAO, Indian IPX, MJO) provides additional forecast of winter precipitation. (Agrawala et al 2001, Barlow et al 2005)
- Mountain cryosystem hydrology provides local detail to regional forecast; adaptation to change may be possible (Adger 2005)



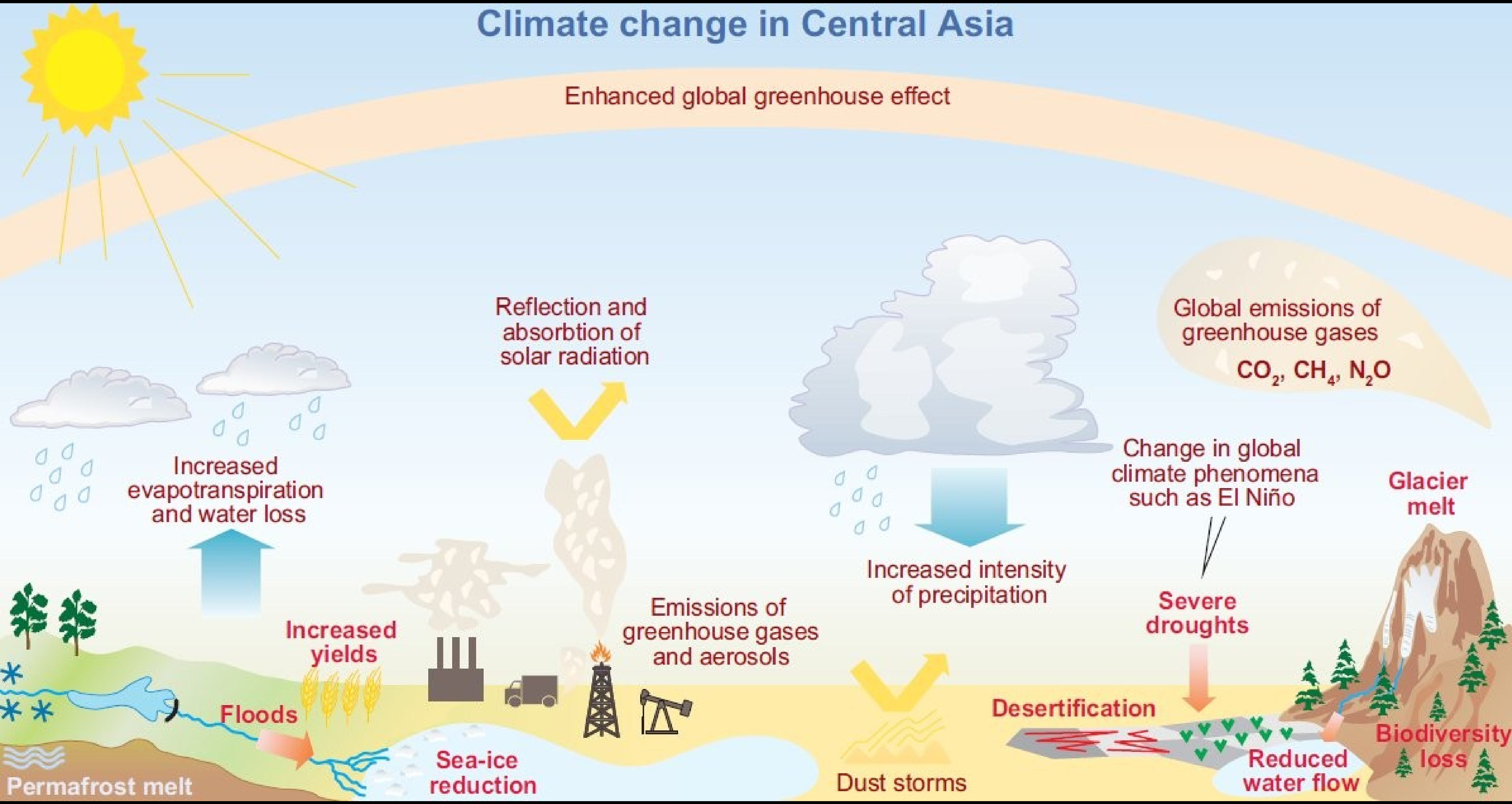
(Barlow, Wheeler, Lyon, Cullen 2005)

Climate change





(Keeling 1960-2012. Source: Wikipedia)



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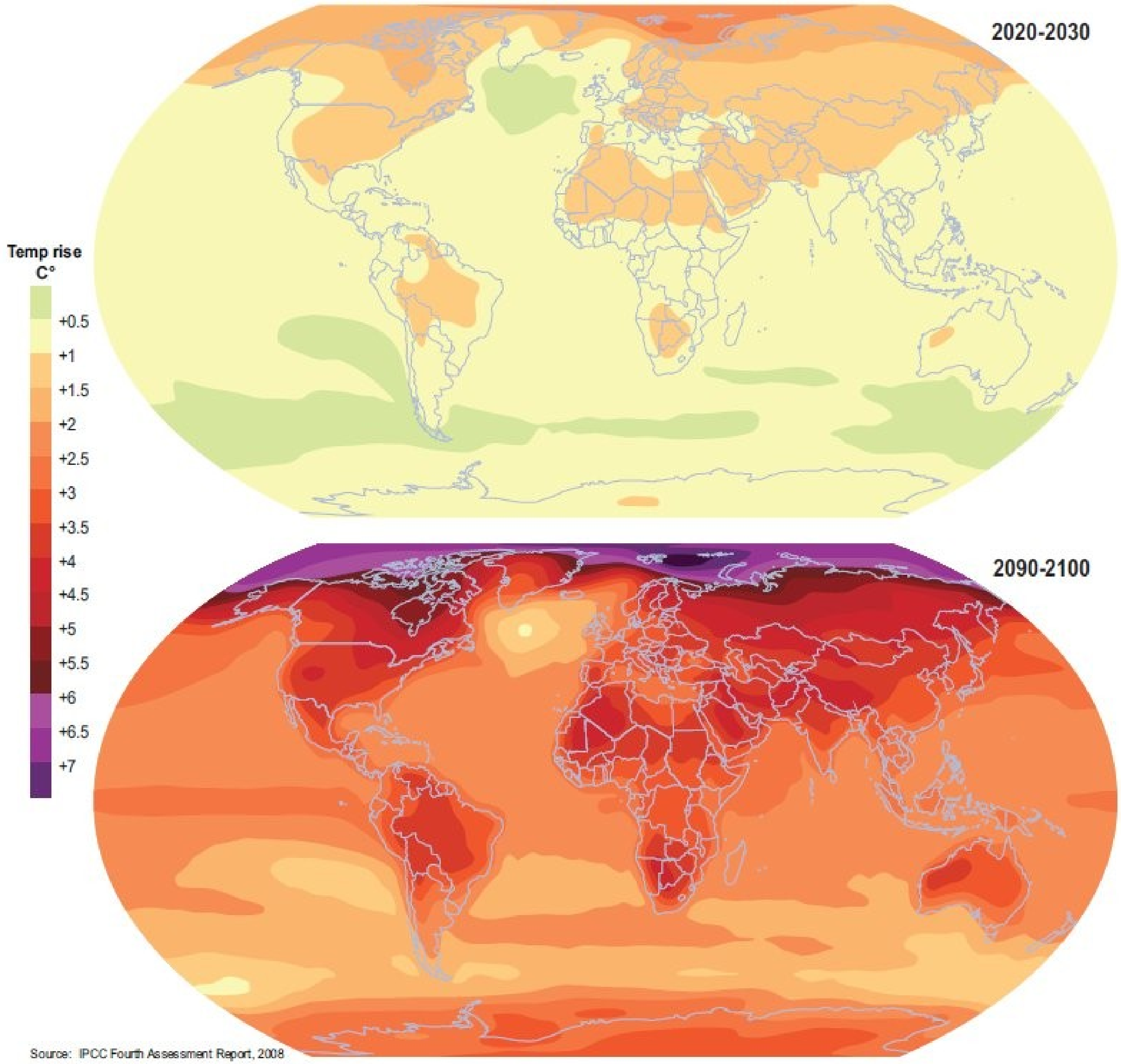
Global climate warming under A1B emission scenario



Source: IPCC Fourth Assessment Report, 2008

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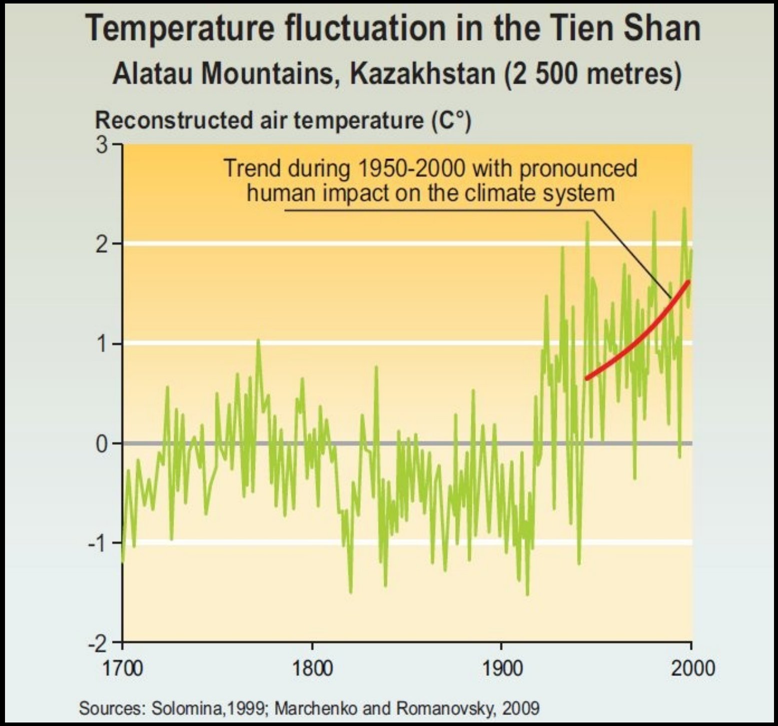
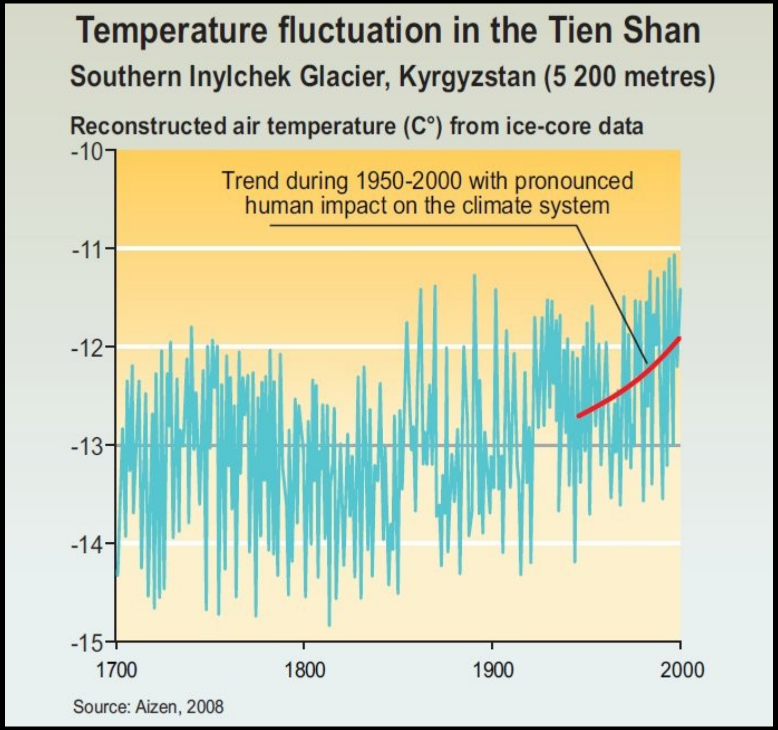
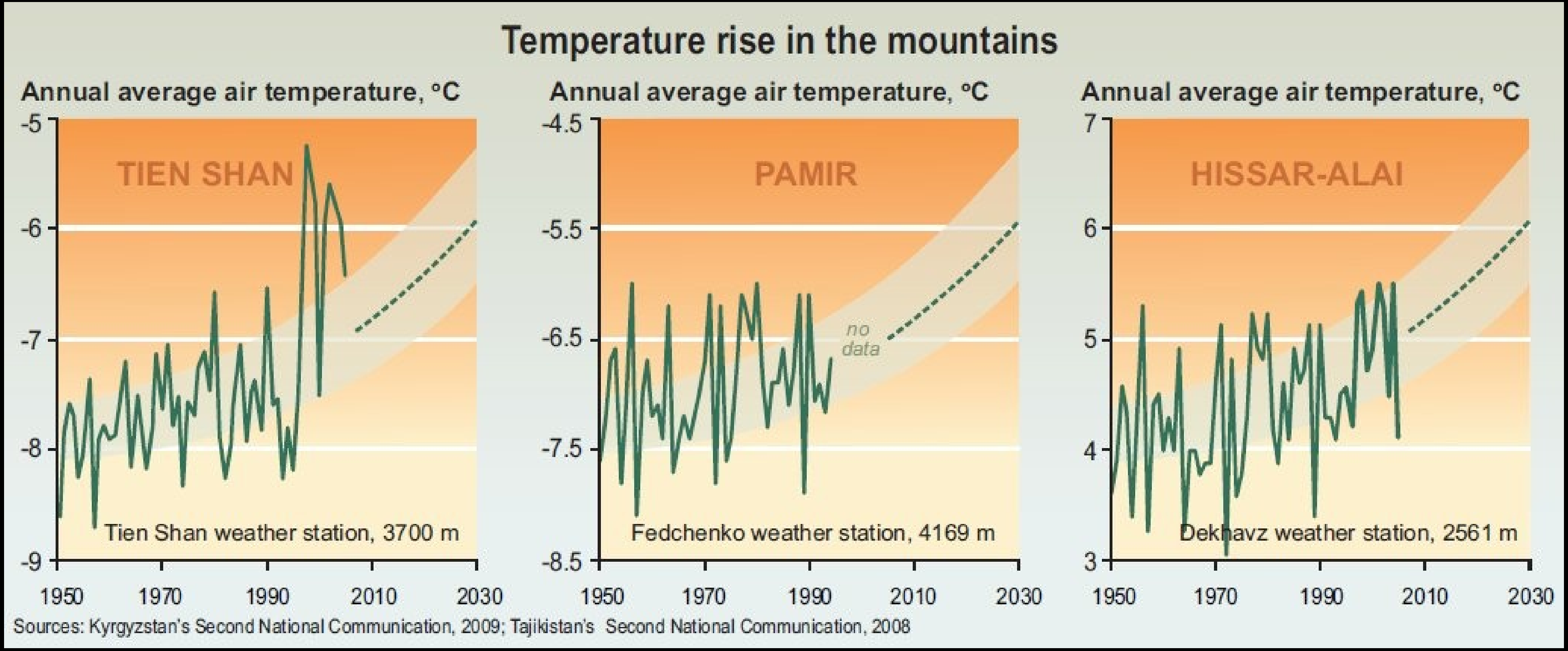
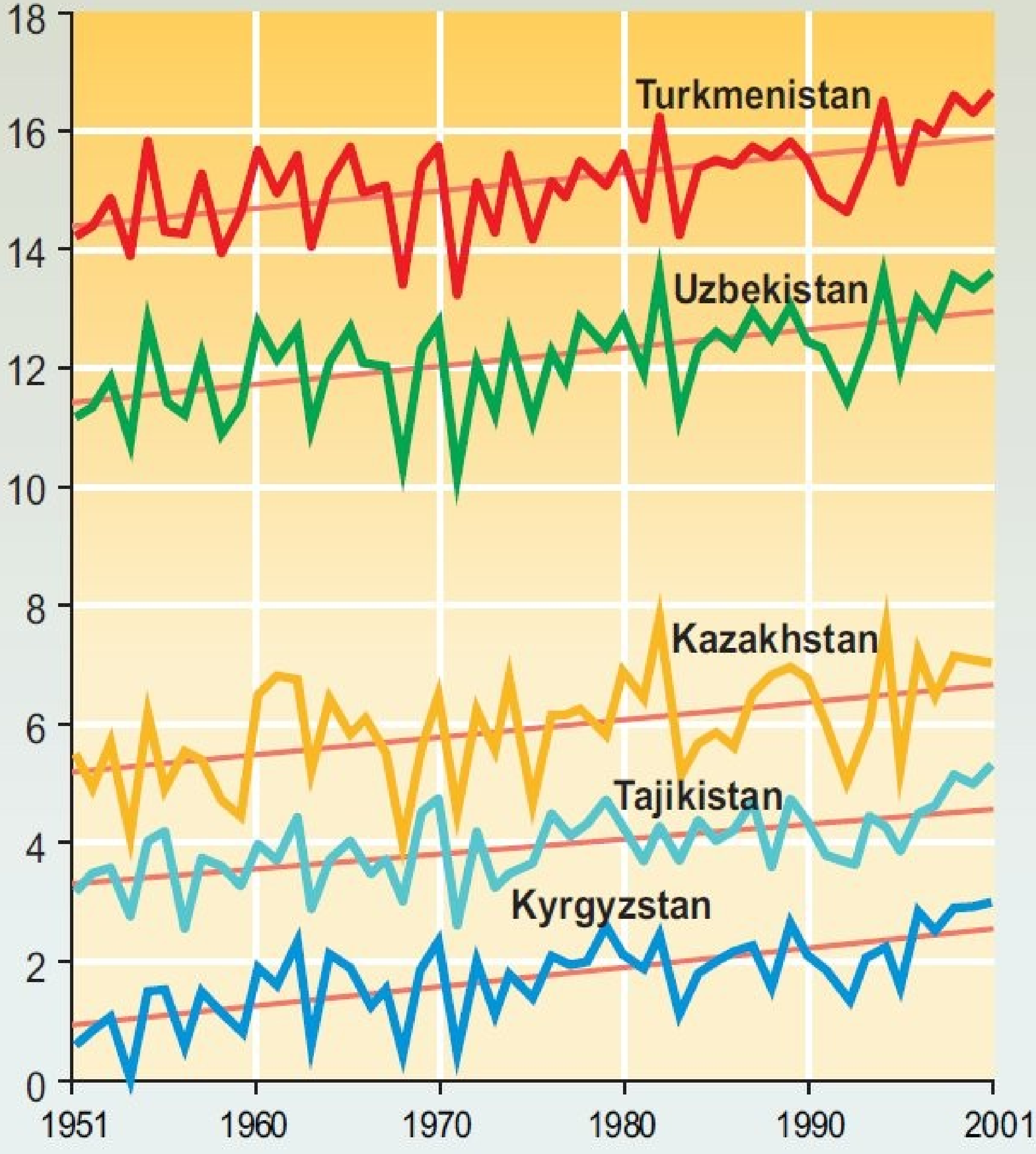

Temperature fluctuation in the Tien Shan
Alatau Mountains, Kazakhstan (2 500 metres)
Reconstructed air temperature (C°)
Trend during 1950-2000 with pronounced human impact on the climate system
3
2
1
0
-1
-2
1700
1800
1900
2000
Sources: Solomina,1999; Marchenko and Romanovsky, 2009


Temperature fluctuation in the Tien Shan
Southern Inylchek Glacier, Kyrgyzstan (5 200 metres)
Reconstructed air temperature (C°) from ice-core data
Trend during 1950-2000 with pronounced human impact on the climate system
-10
-11
-12
-13
-14
-15
1700
1800
1900
2000
Source: Aizen, 2008

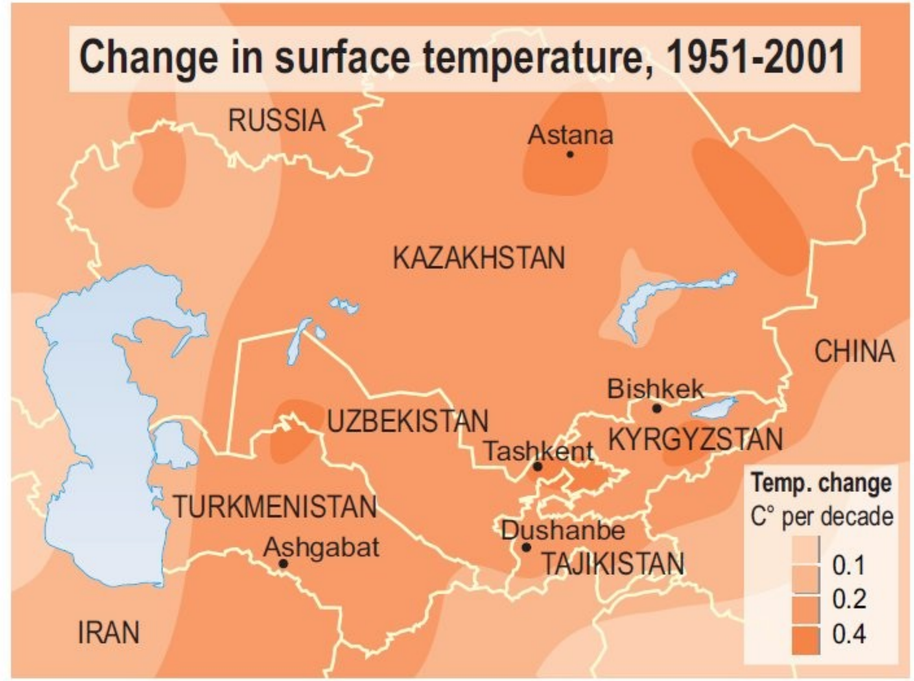

Temperature rise in the mountains
Annual average air temperature, °C
TIEN SHAN
Tien Shan weather station, 3700 m
-5
-6
-7
-8
-9
Annual average air temperature, °C
PAMIR
no data
Fedchenko weather station, 4169 m
-4.5
-5.5
-6.5
-7.5
-8.5
Annual average air temperature, °C
HISSAR-ALAI
Dekhavz weather station, 2561 m
7
6
5
4
3
1950
1970
1990
2010
2030
Sources: Kyrgyzstan's Second National Communication, 2009; Tajikistan's Second National Communication, 2008

Surface temperature trends

Country-averaged annual air temperature (C°)



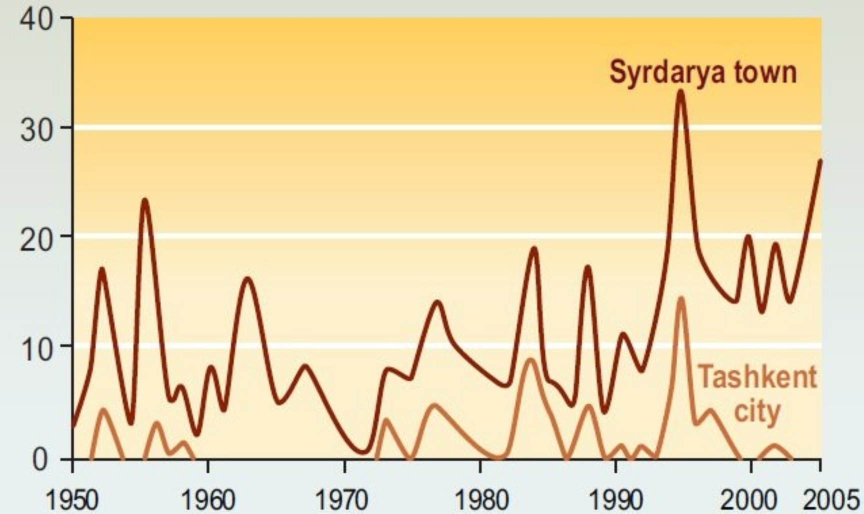
Source: U.K. Climate Research Unit data synthesis at: www.climatewizard.org



Sources: U.K. Climate Research Unit (data synthesis is available at: www.climatewizard.org), compilation of information from the Second (and the First) National Communications

Heat stress in Uzbekistan

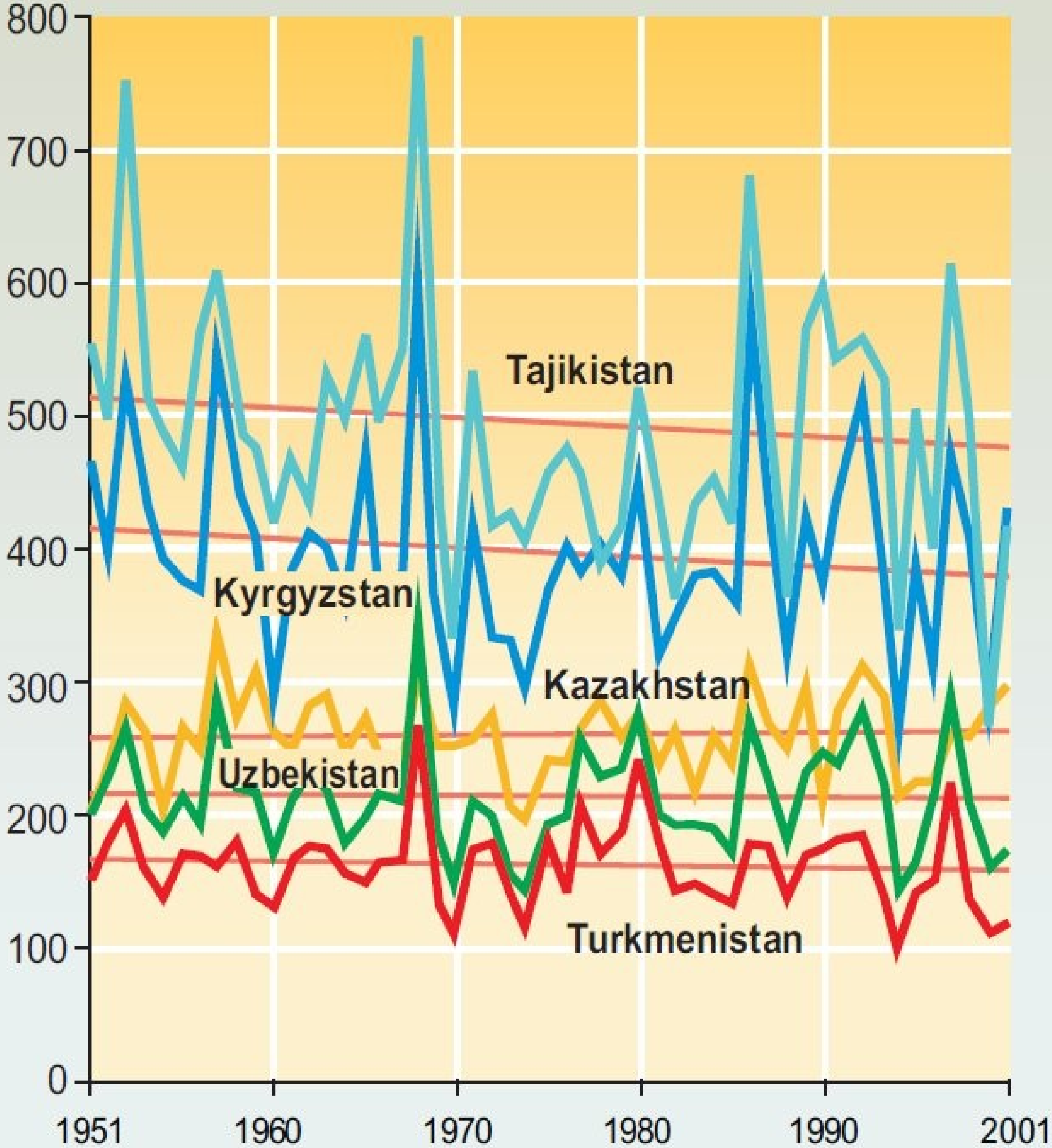
Days with strong thermal discomfort for urban dwellers



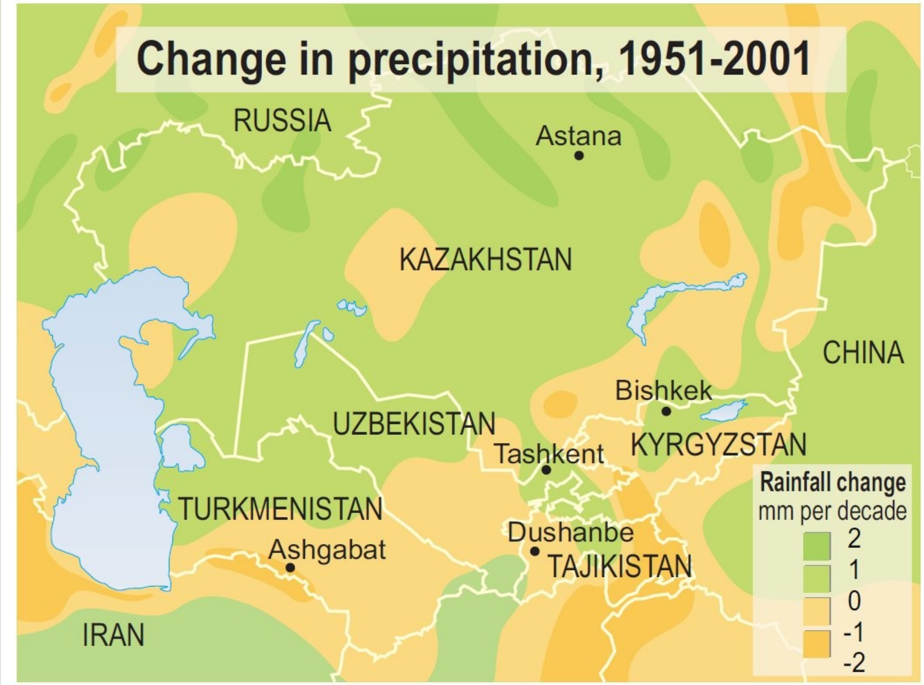
Source: Uzbekistan's Second National Communication, 2008

Precipitation variability and trends

Country-averaged annual precipitation, mm



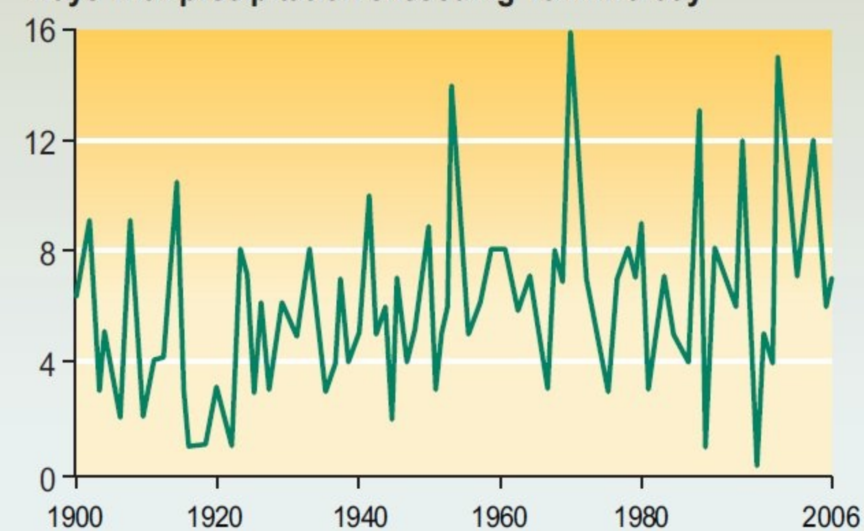
Source: U.K. Climate Research Unit data synthesis at: www.climatewizard.org



Sources: U.K. Climate Research Unit (data synthesis is available at: www.climatewizard.org), compilation of information from the Second (and First) National Communications

Intense precipitation in Tashkent, Uzbekistan

Days with precipitation exceeding 15 mm a day



Source: Uzbekistan's Second National Communication, 2008

Glacial water storage

CCCA, zoinet.org

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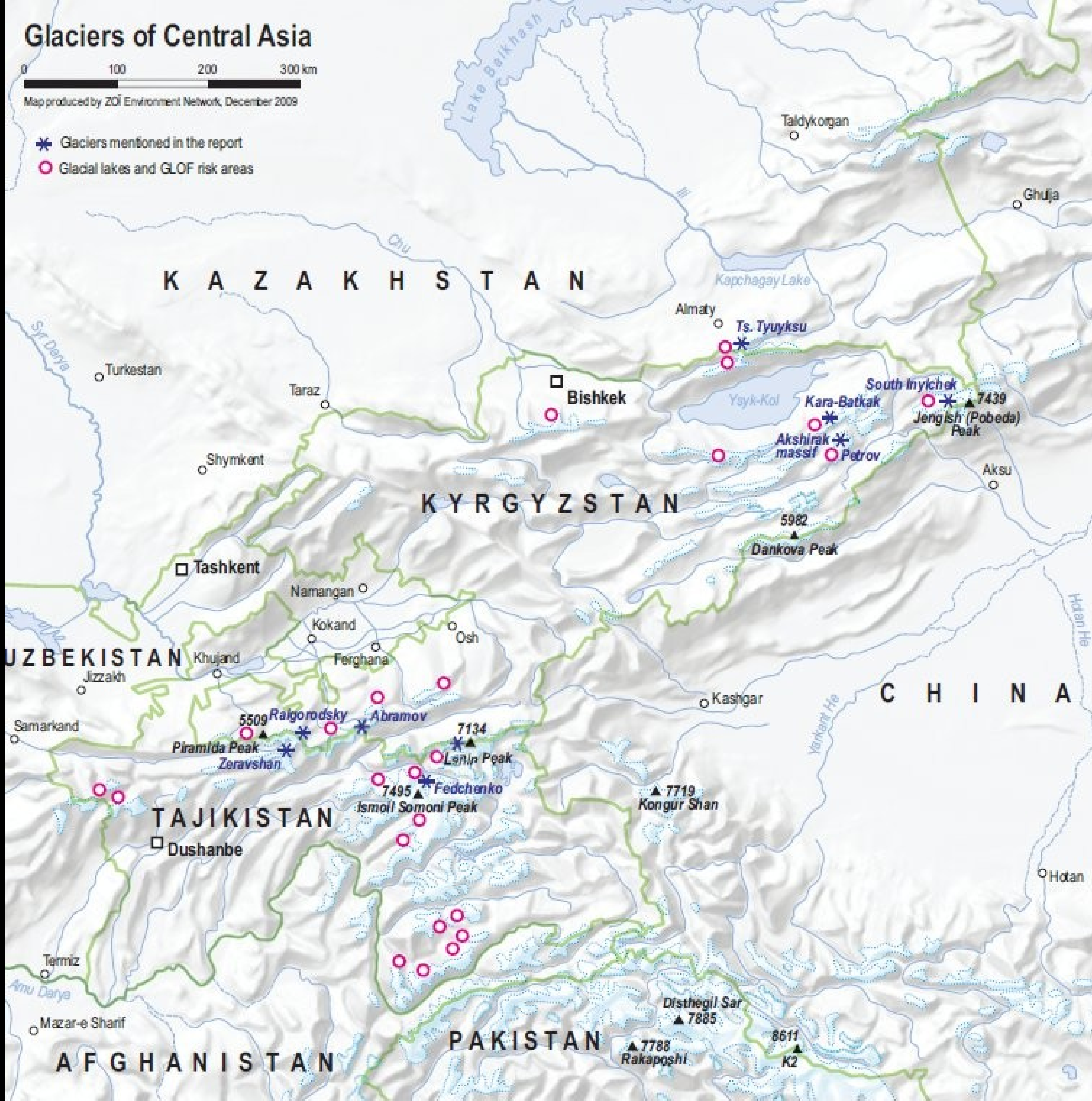

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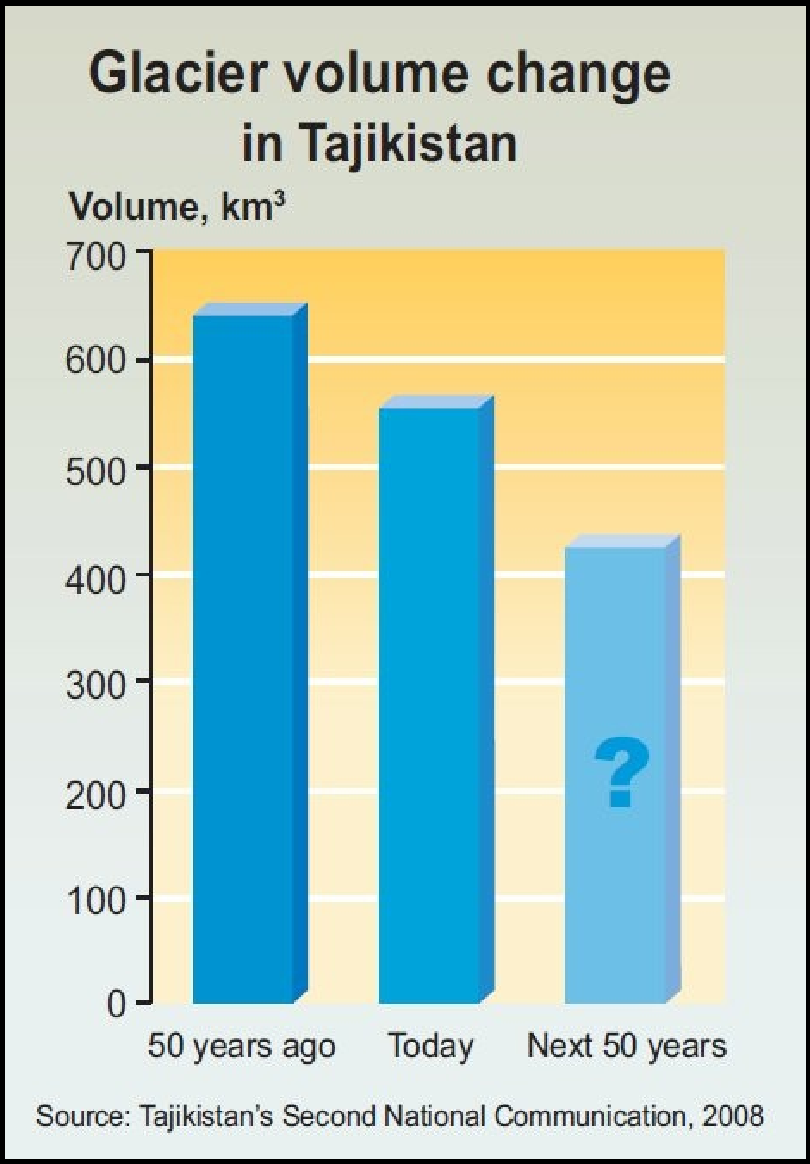
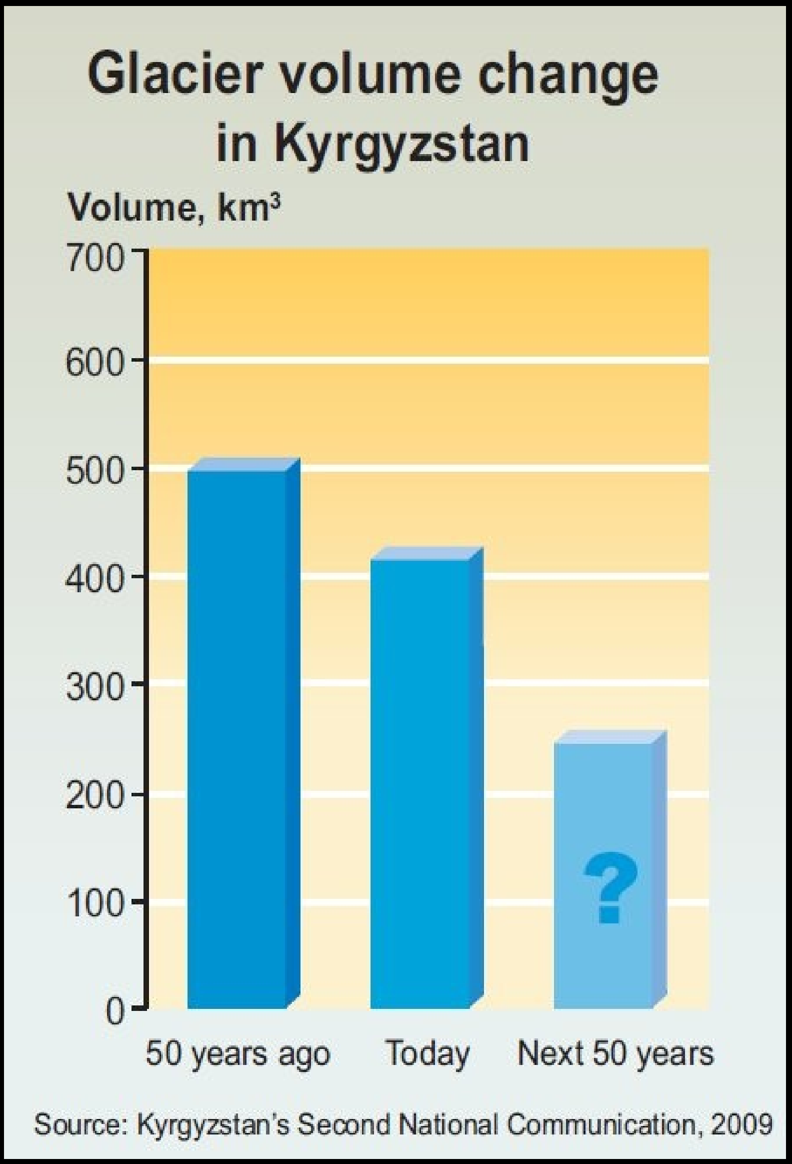
And glacial recession ...





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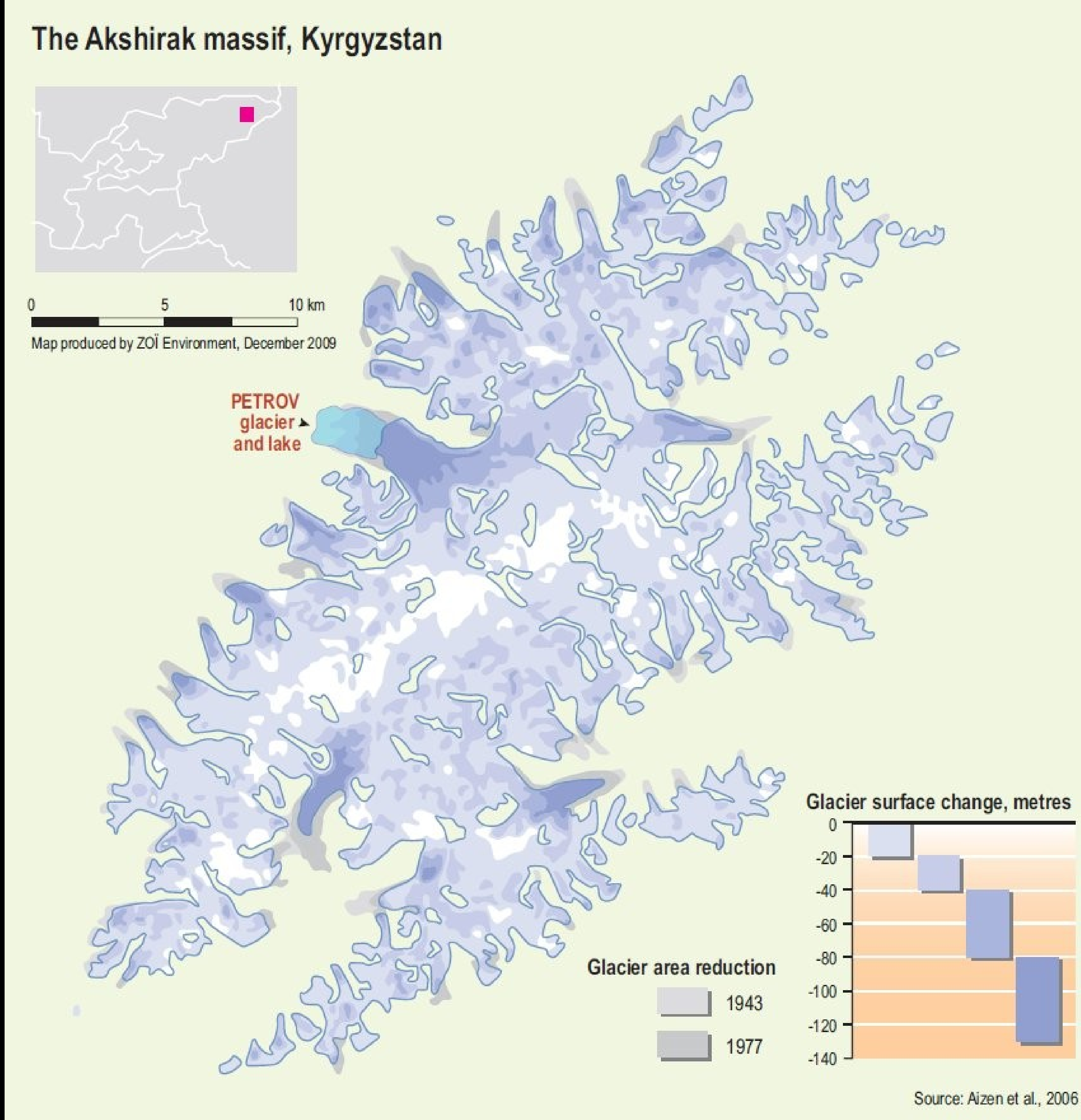
Observation of glacial recession

(Aizen et al 2006)

- Terminal moraine retreat is not reliable indicator, as discussed
- Direct, repeated measurement necessary
- Glacial coverage area, elevation measurement by remote sensing
  - Survey, various methods (to 1950s)
  - Aerial survey stereo photogrammetry
  - Satellite imaging, visible and hyperspectral
  - LiDAR (laser ranging) aerial survey
  - Synthetic Aperture Radar (SAR) aerial survey



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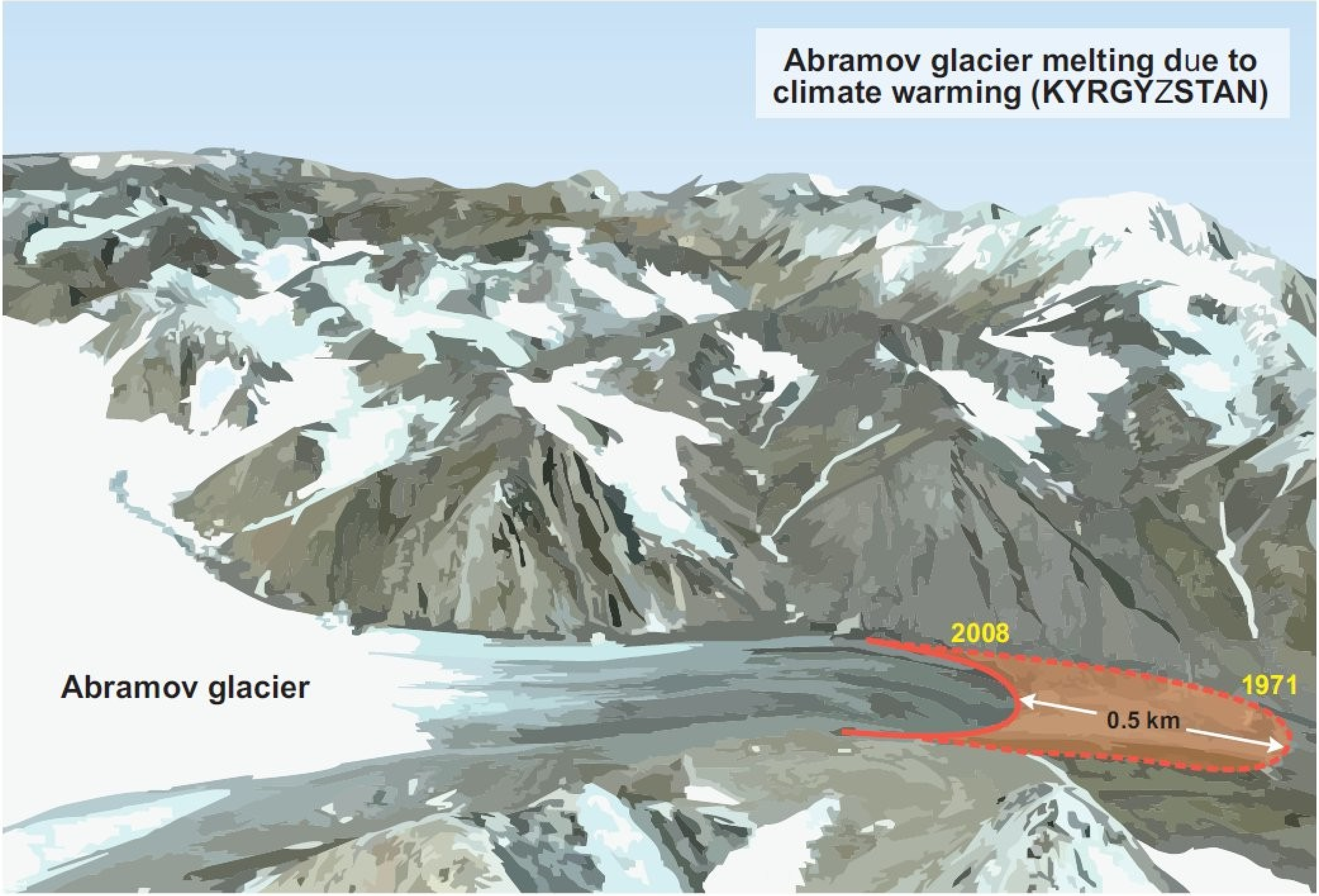
Petrov Glacier and Lake


Fedchenko Glacier, Tajikistan

CCCA, zoinet.org



Sources: Uzhydromet; Uzbekistan's Initial National Communication, 1999

Background image is based on the digital elevation model adapted from Google Earth

CCCA, zoinet.org

Source: Tajikhydromet

Background image is based on the digital elevation model adapted from Google Earth

CCCA, zoinet.org

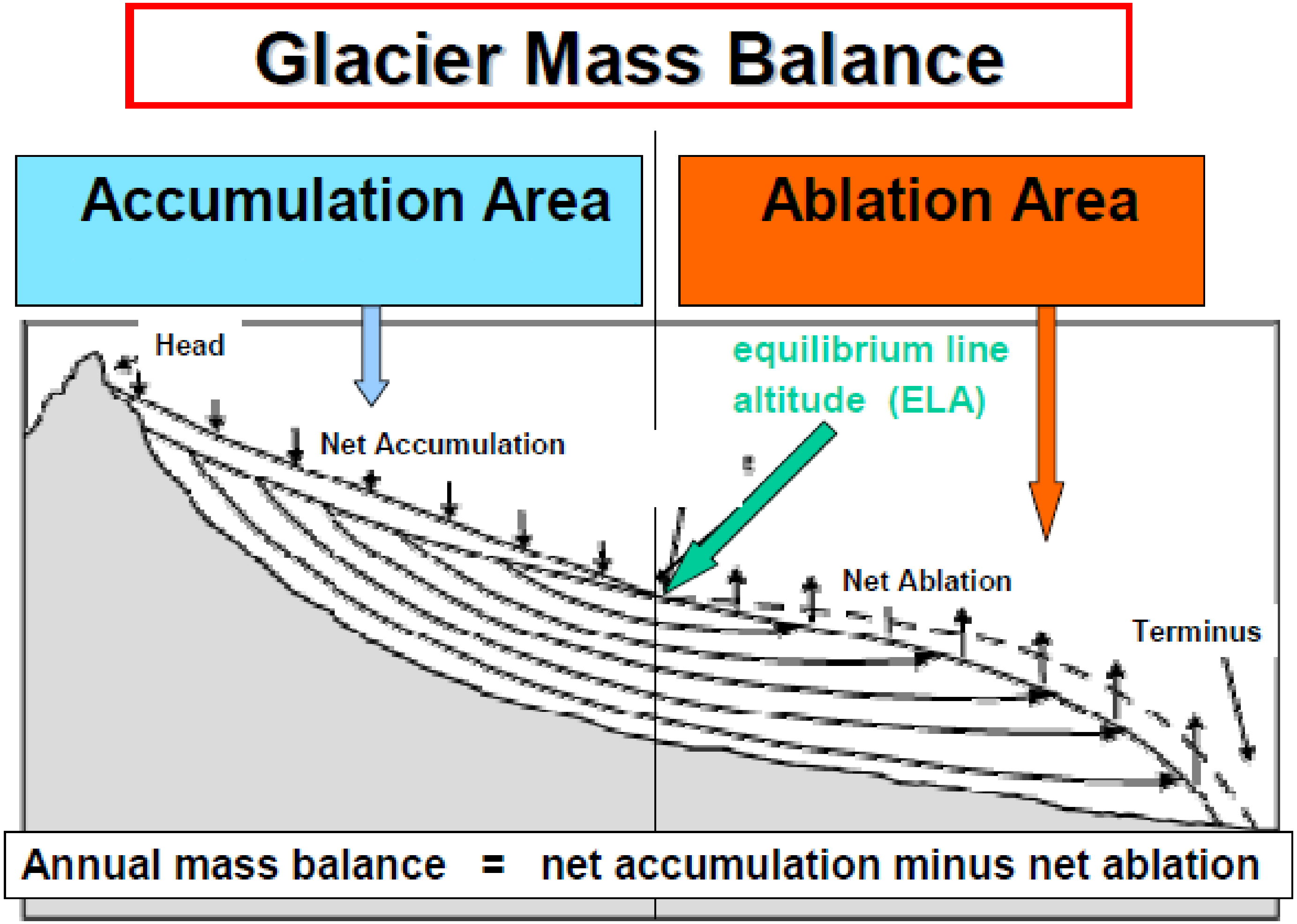


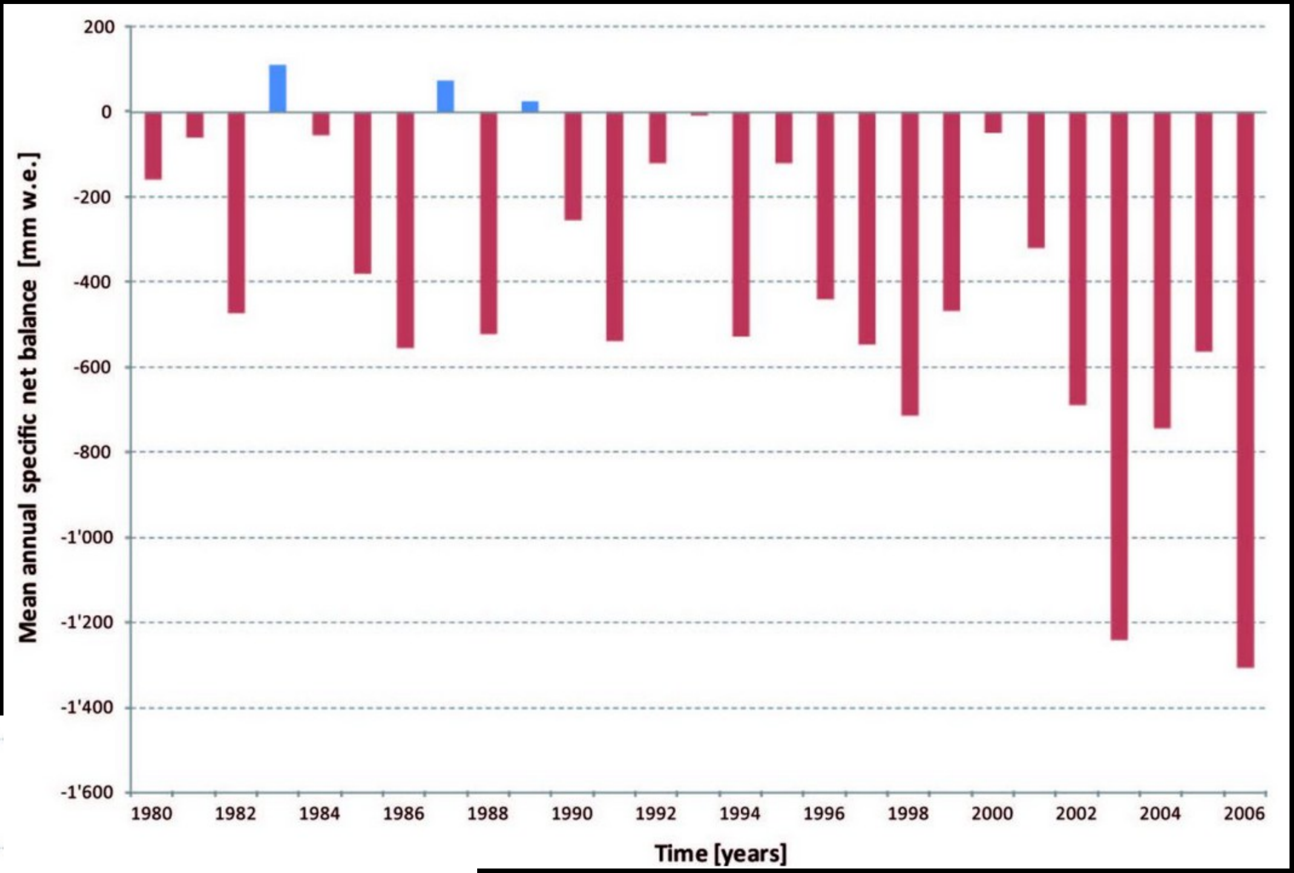
Figure 1. Glacier accumulation and ablation areas, and equilibrium line altitude (ELA).

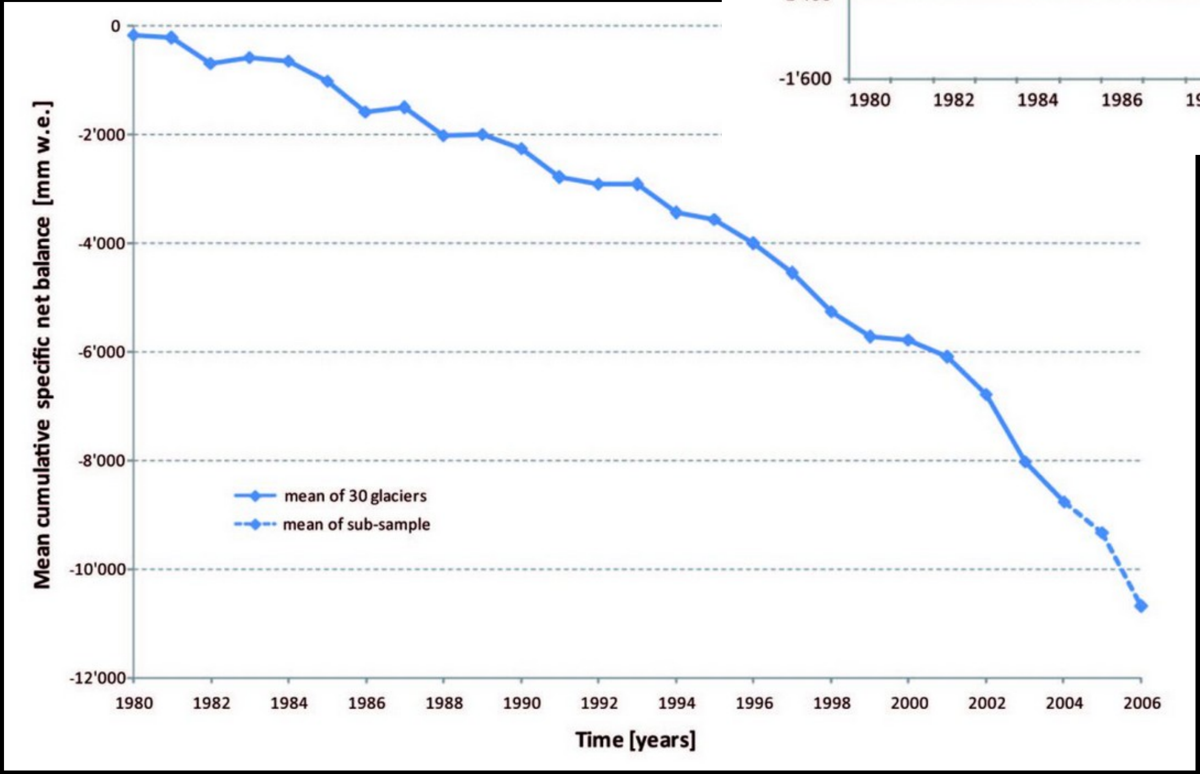
(Armstrong 2010 Fig 1)

WGMS
CAWA

World Glacier Monitoring Service
Central Asia Water Research Network
http://www.cawa-project.net

WGMS global
Mean Annual Specific
Net Mass Balance,
mm water eqivalent
(1980-2006)



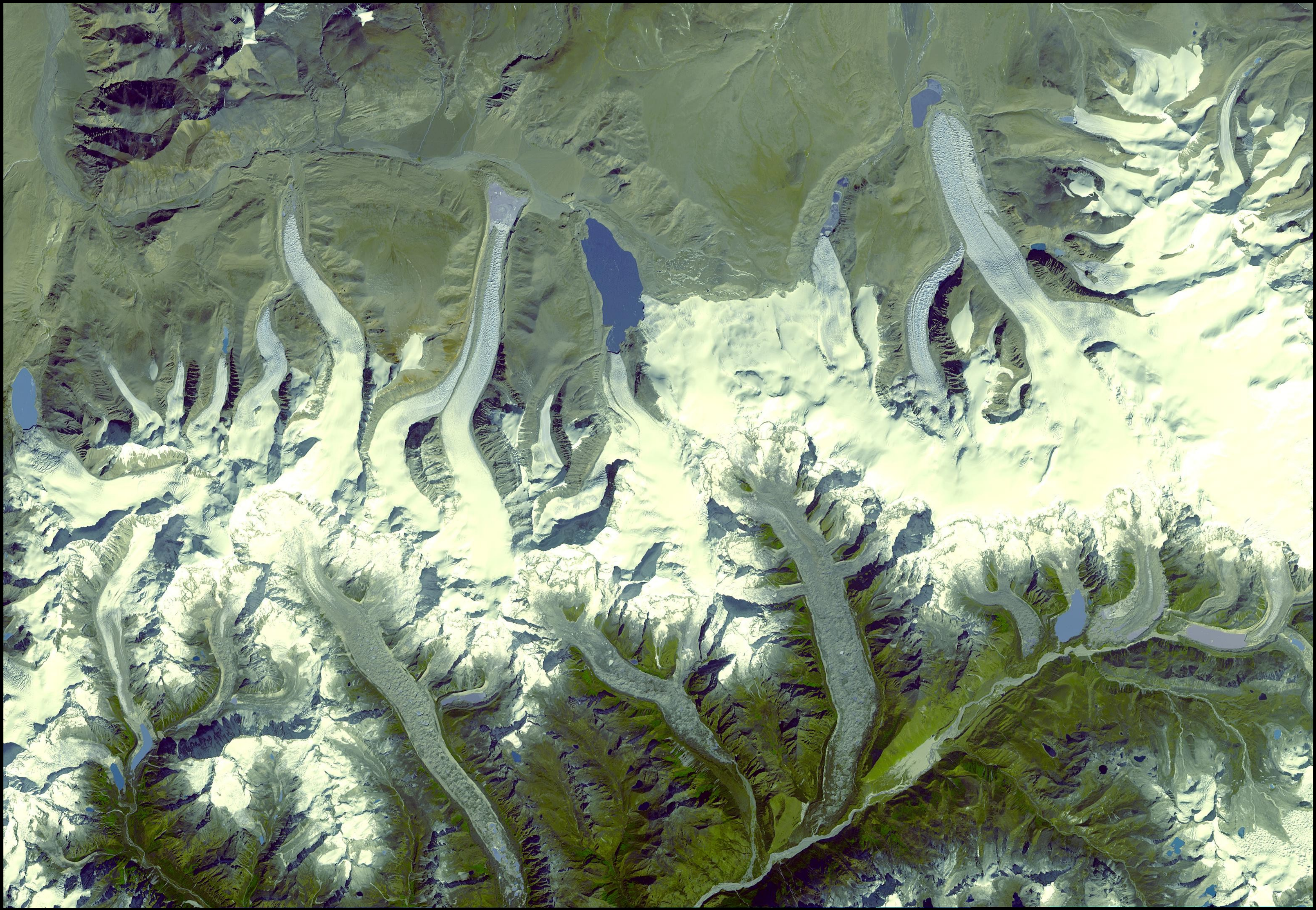


WGMS global
Cumulative Specific
Net Mass Balance,
mm water eqivalent
(1980-2006)

http://www.cawa-project.net/

ASTER satellite imagery

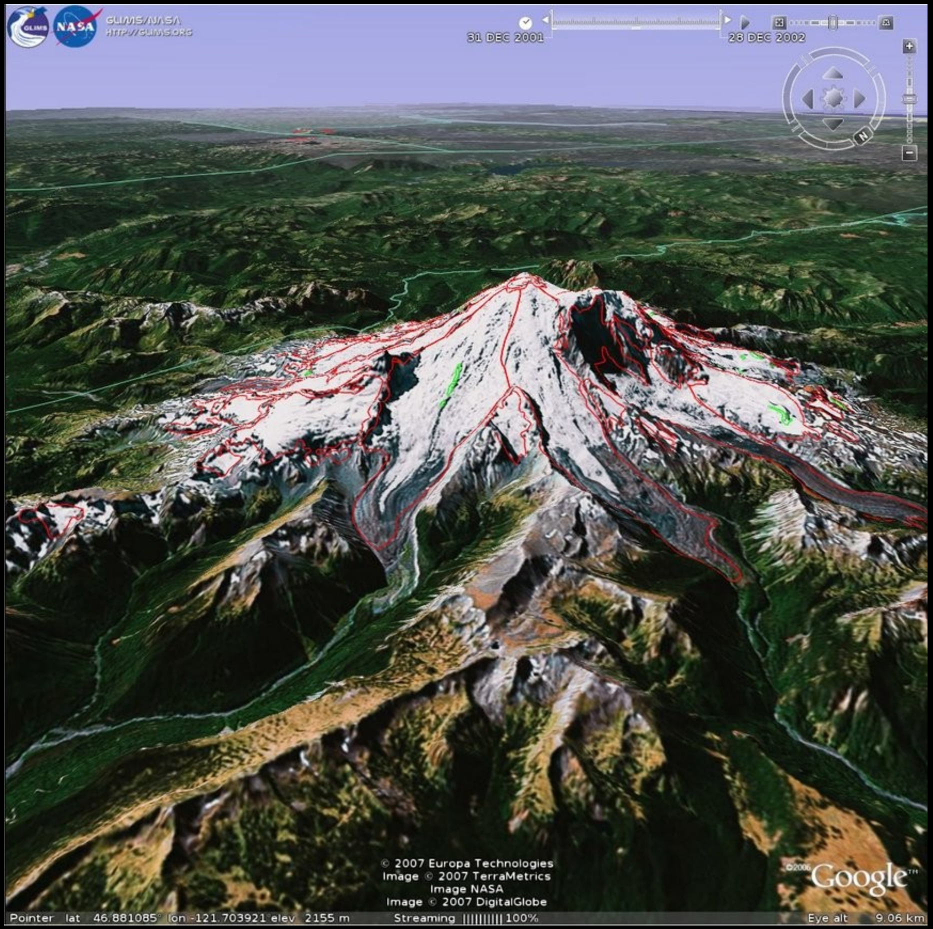
- Visible and infrared imaging
- High resolution
- Steerable camera
- Frequent return
- Stereo pair (forward, reverse off-nadir along-track)
  - Photogrammetry can generate Digital Elevation Model (DEM) synchronous with imagery
  - Makes it possible to measure volume as well as area, with frequent returns during rapid change



http://asterweb.jpl.nasa.gov/gallery/images/bhutan.jpg

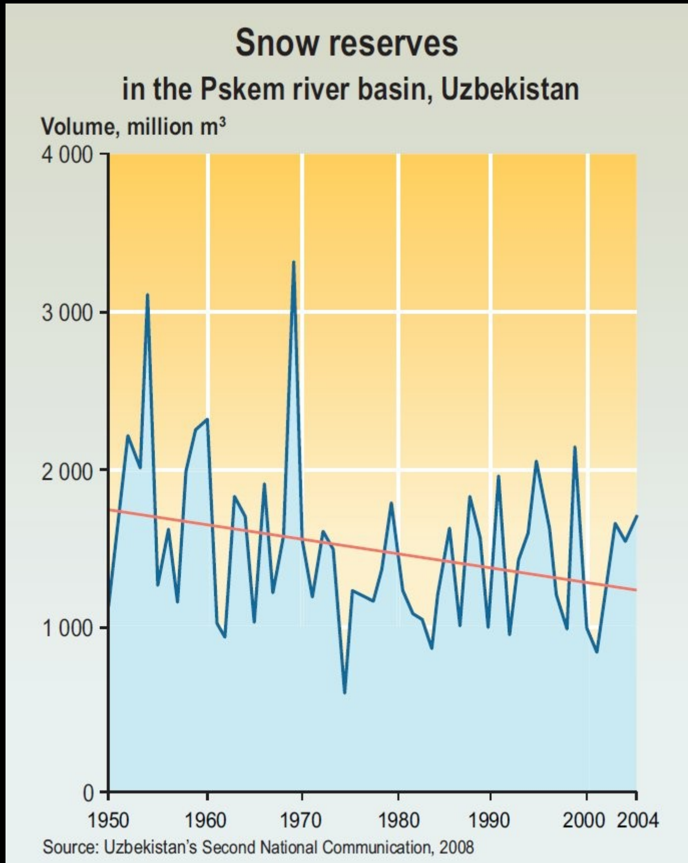
ASTER satellite image, Himalayan glaciers, Bhutan

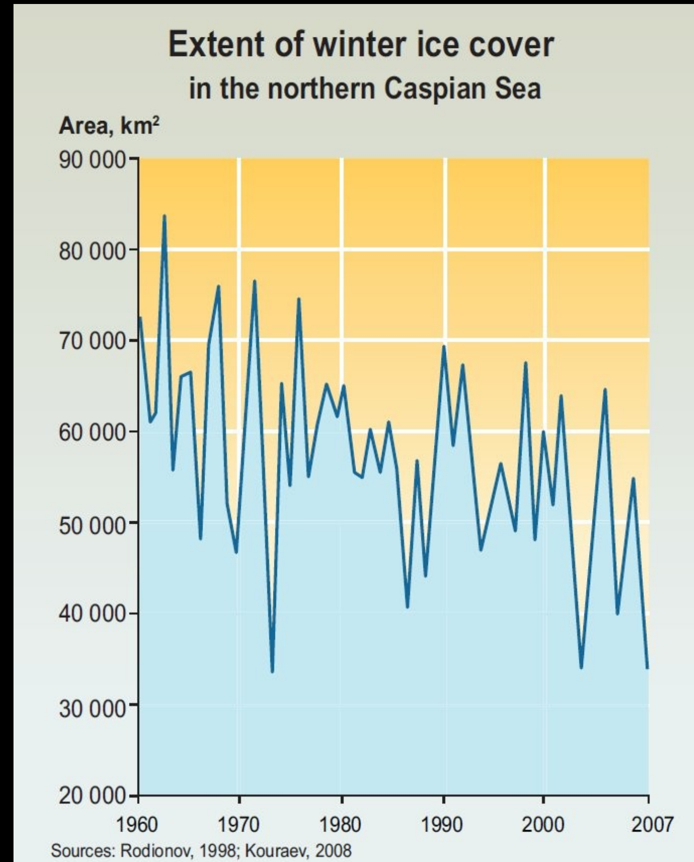
GLIMS: Global Land Ice Monitoring from Space - an ASTER project

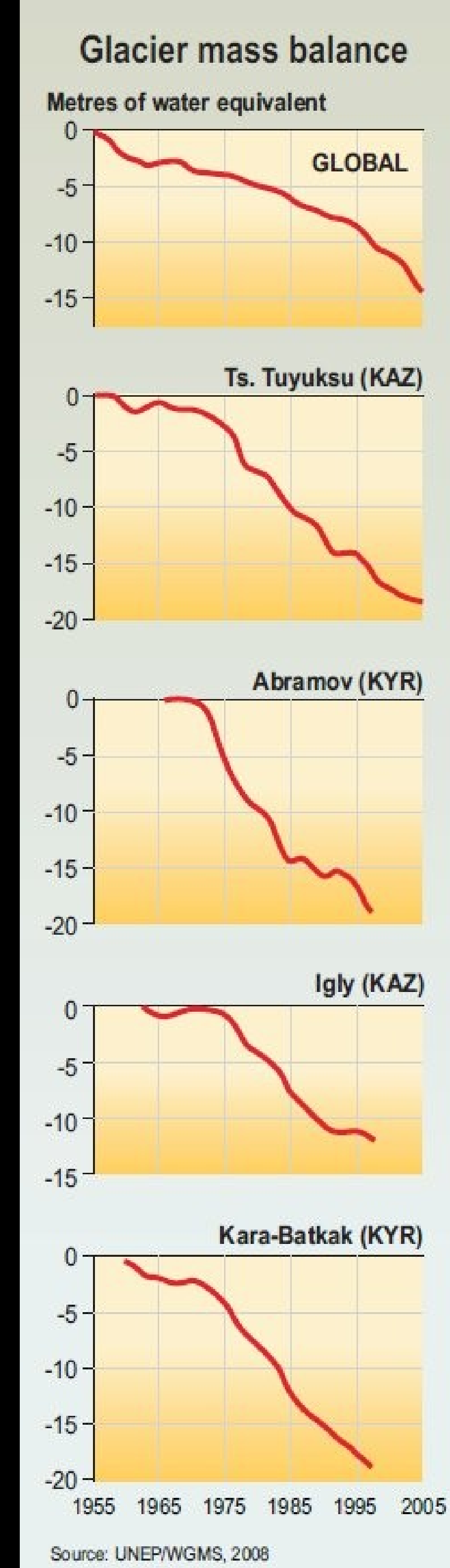


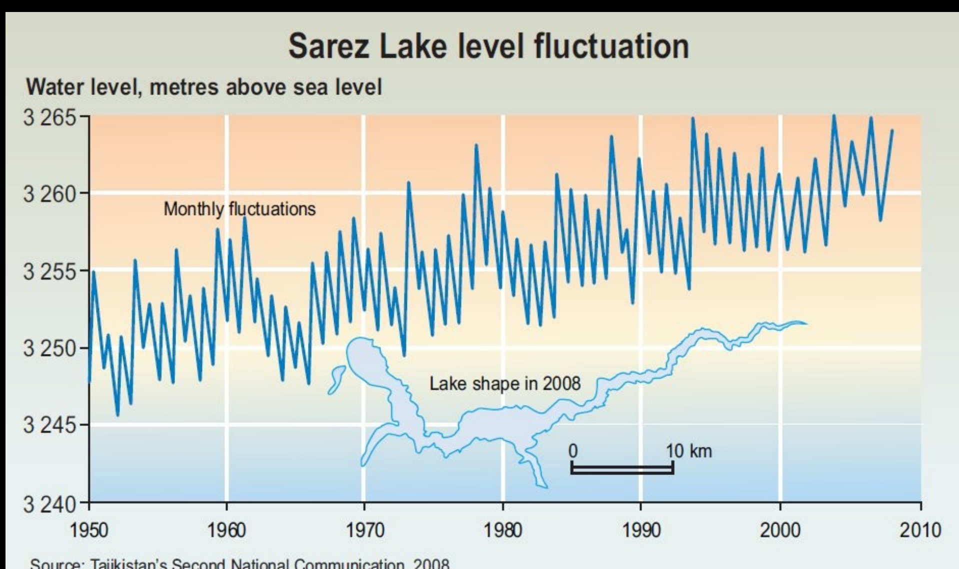
Glacier delineation, Mt Rainier (46.88 N 121.7 W)
GIS KML export to Google Earth

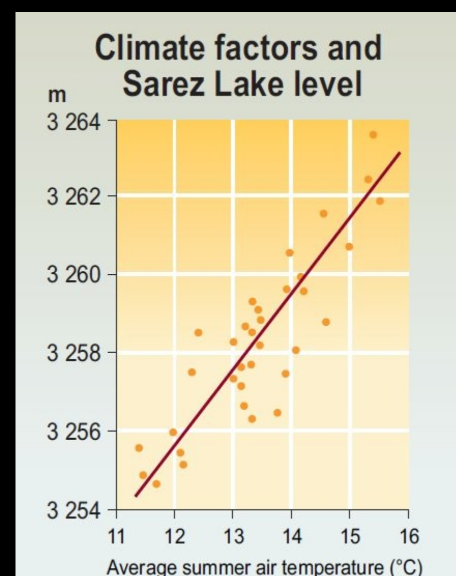
- GLIMSview software
- Archive of glacier remote sensing data
- Semi-automated delineation of glacier boundaries
- Modern web GIS integration, esp. KML





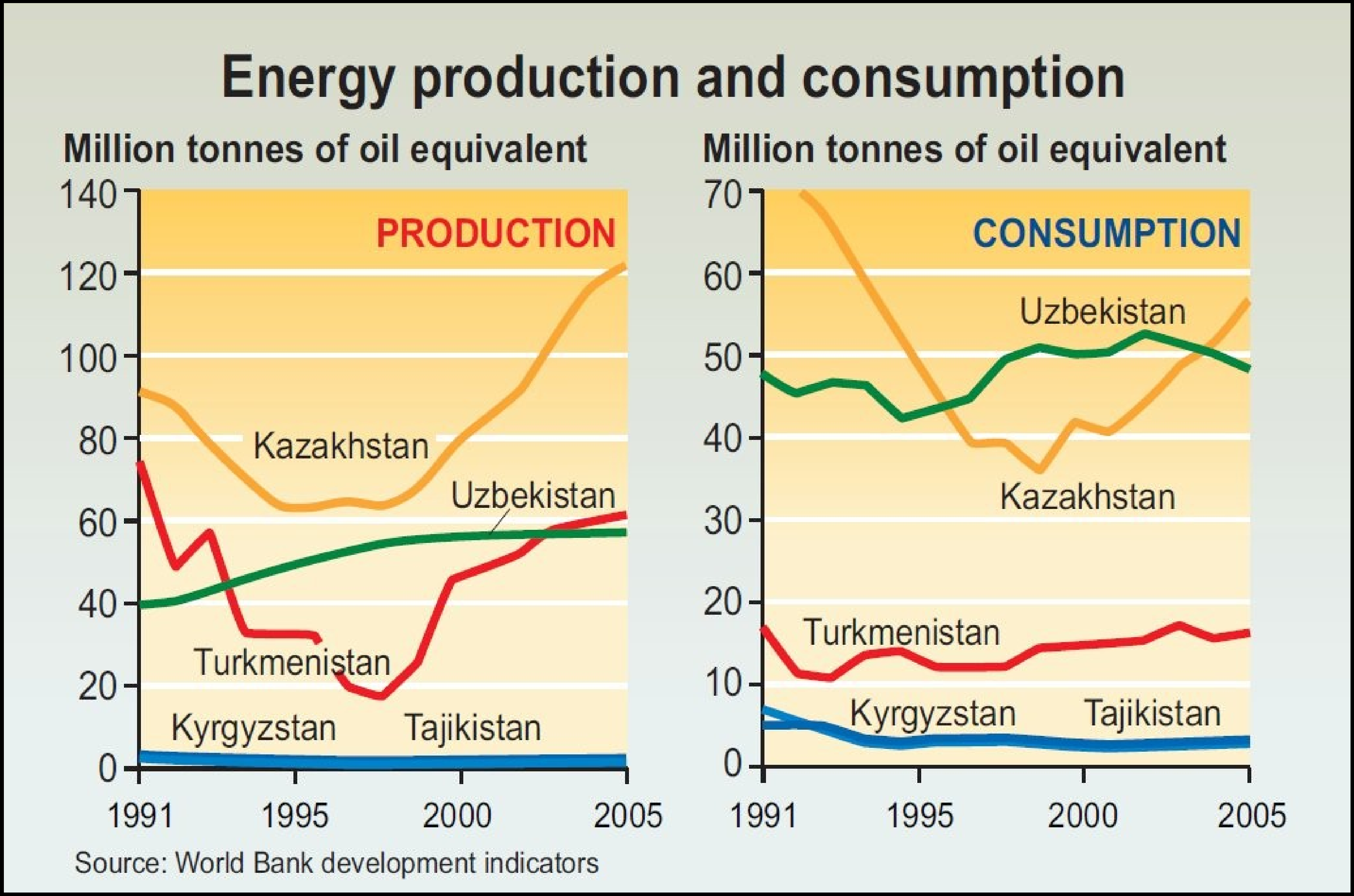






CCCA, zoinet.org

Anthropogenic climate change is strongly coupled to fossil fuels GHG
(Supplement D)



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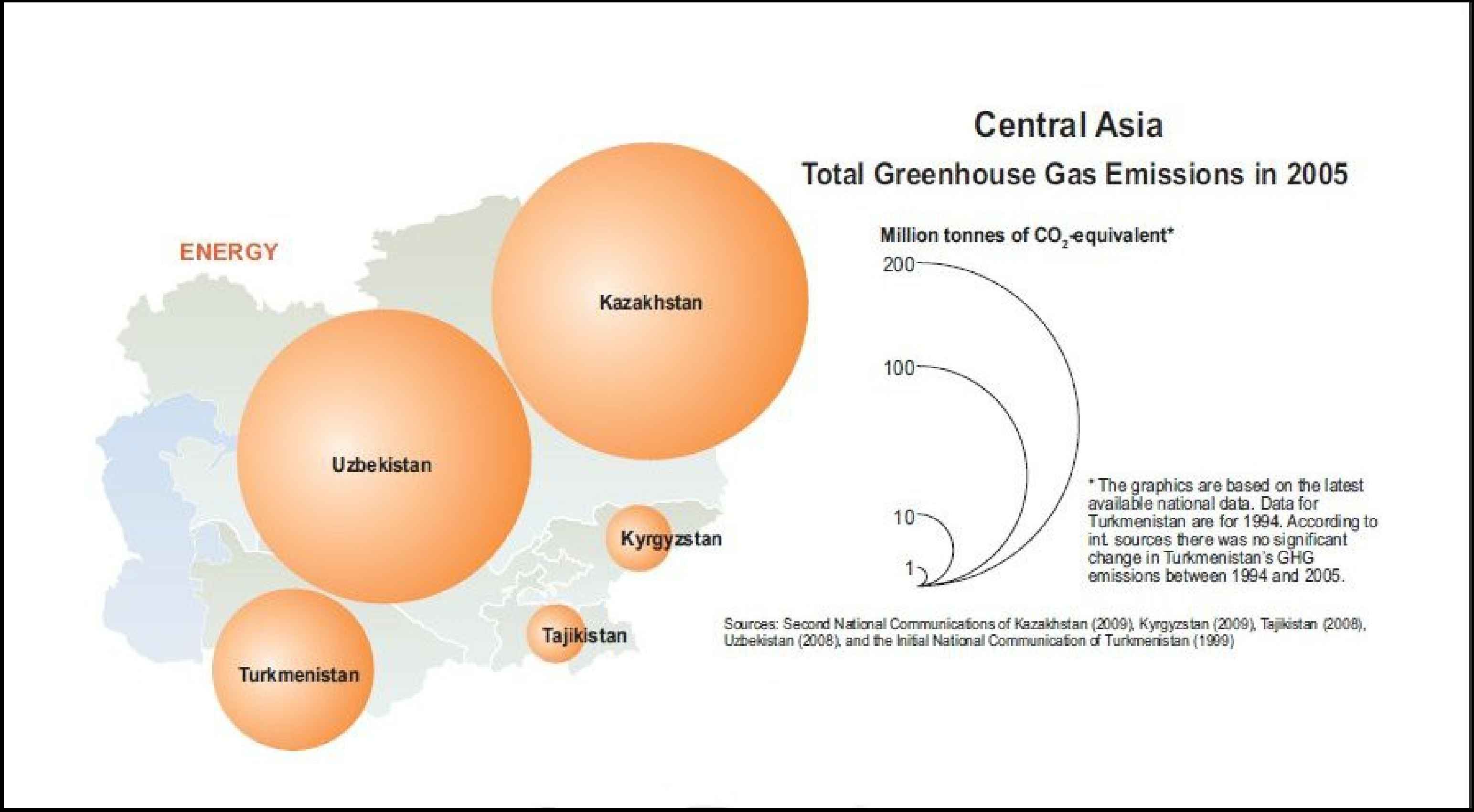
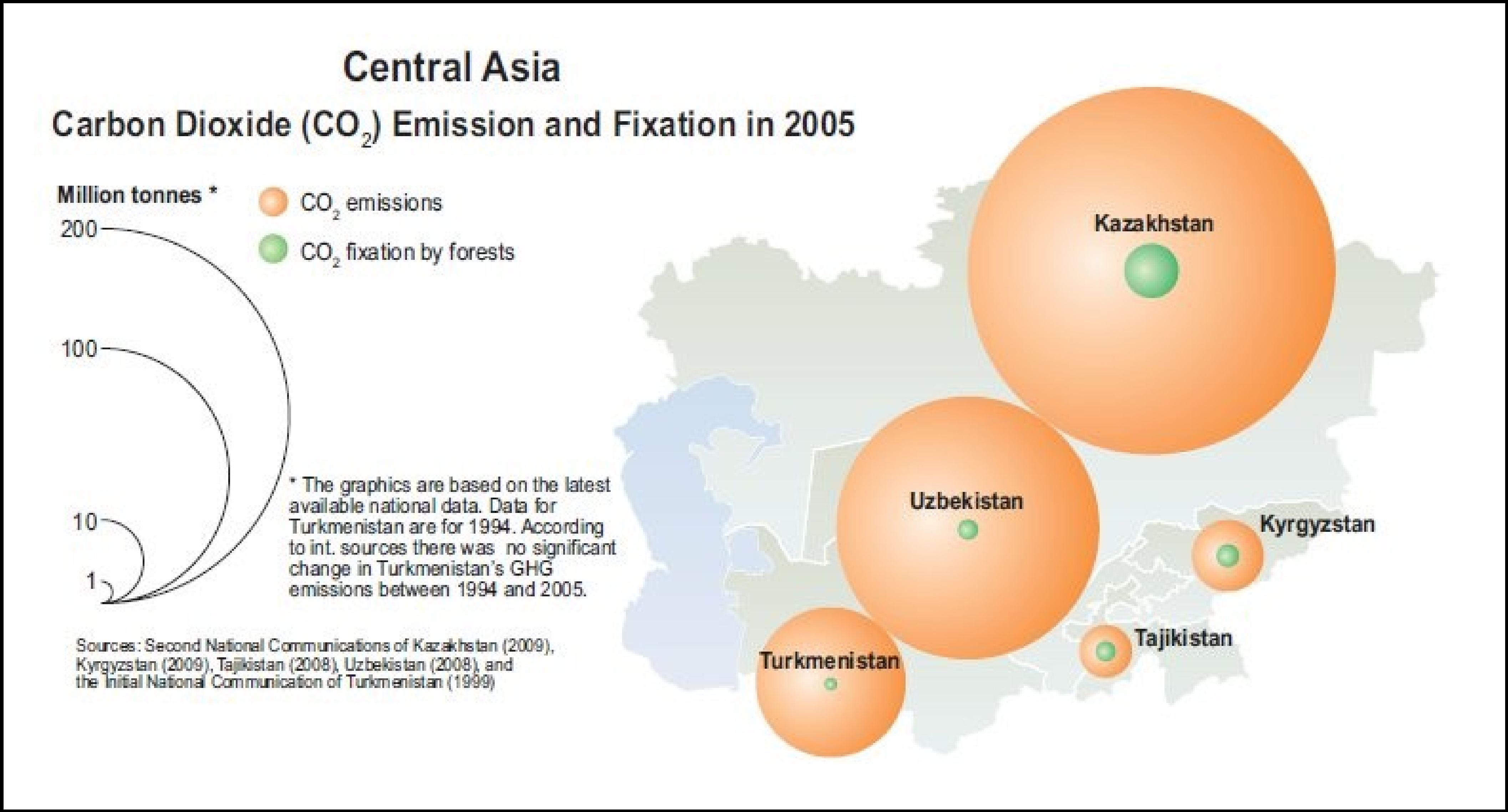
Energy and GHG emissions

- Central Asia is both producer and consumer of fossil fuels, with have and have-not nations. Although all emissions are important regionally, only Kazakhstan, Uzbekistan and Turkmenistan are exceptional globally.



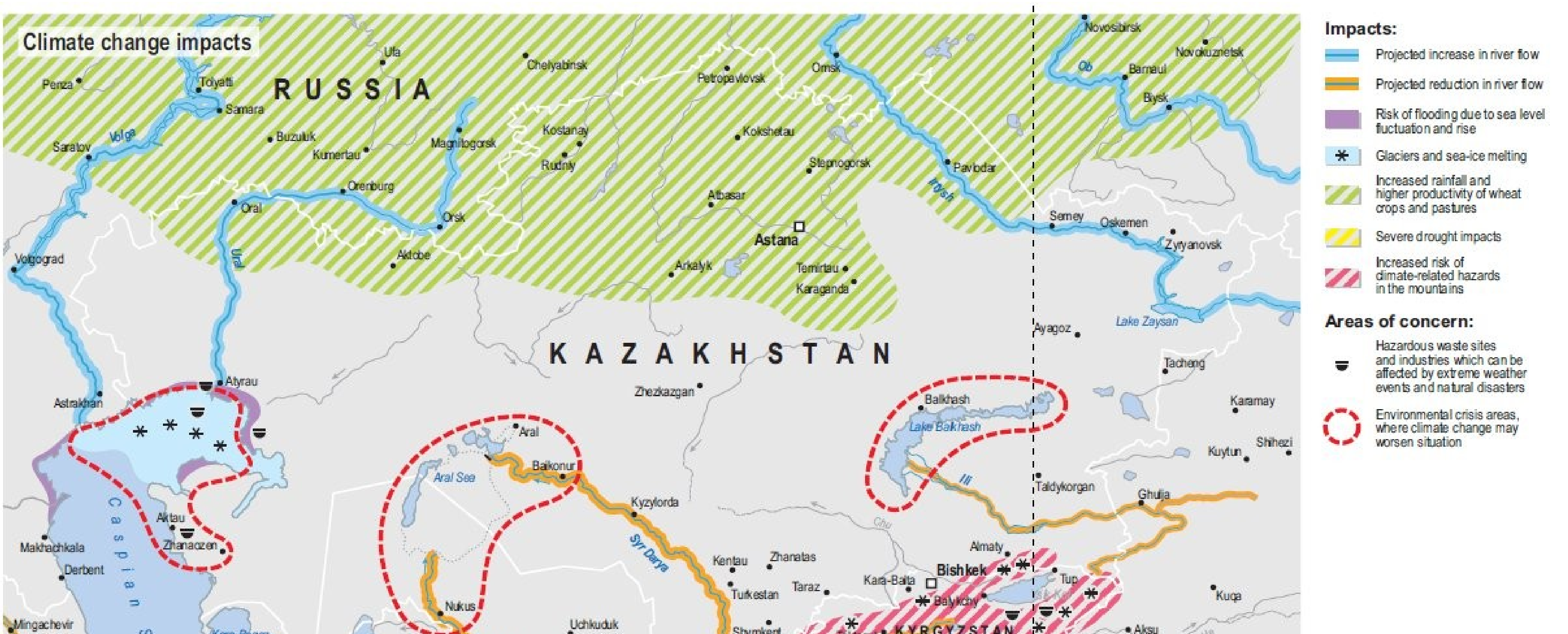
CCCA, zoinet.org



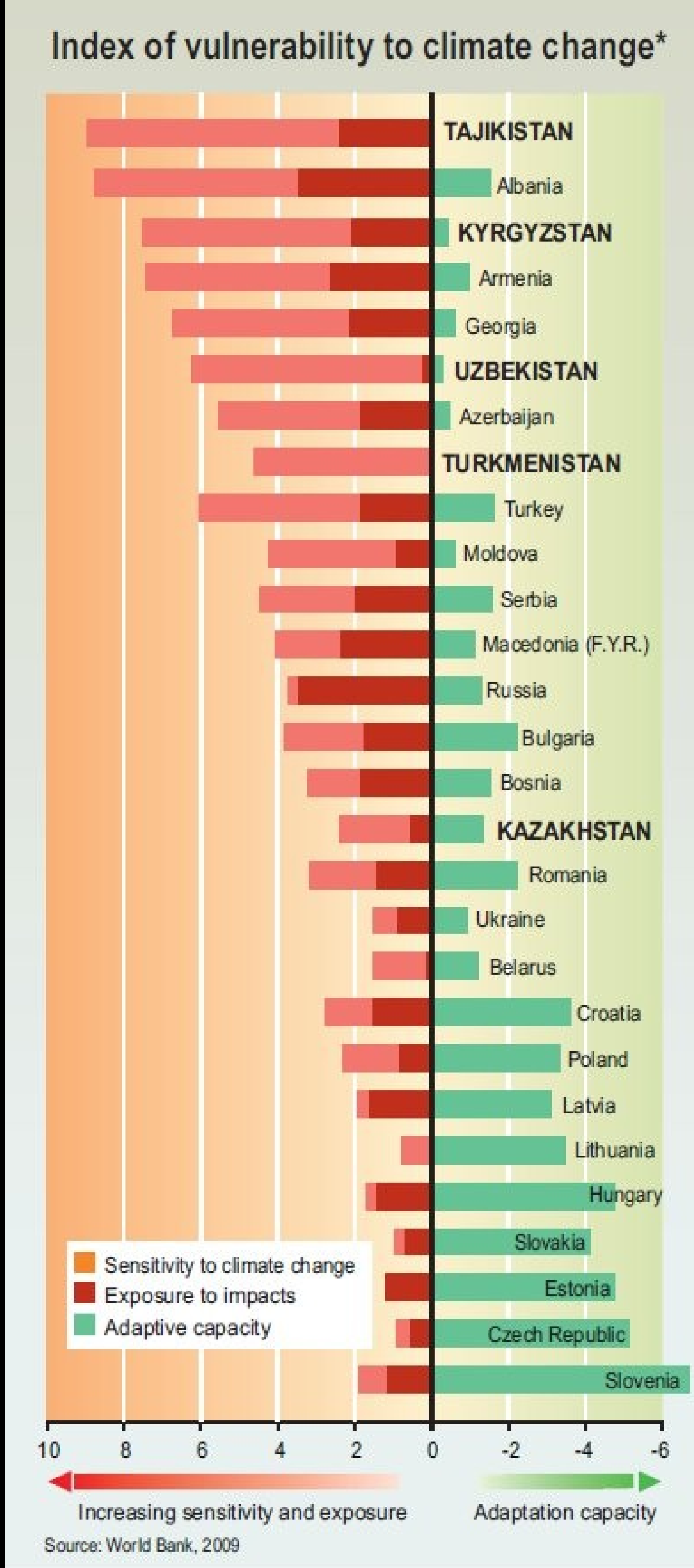
CCCA, zoinet.org

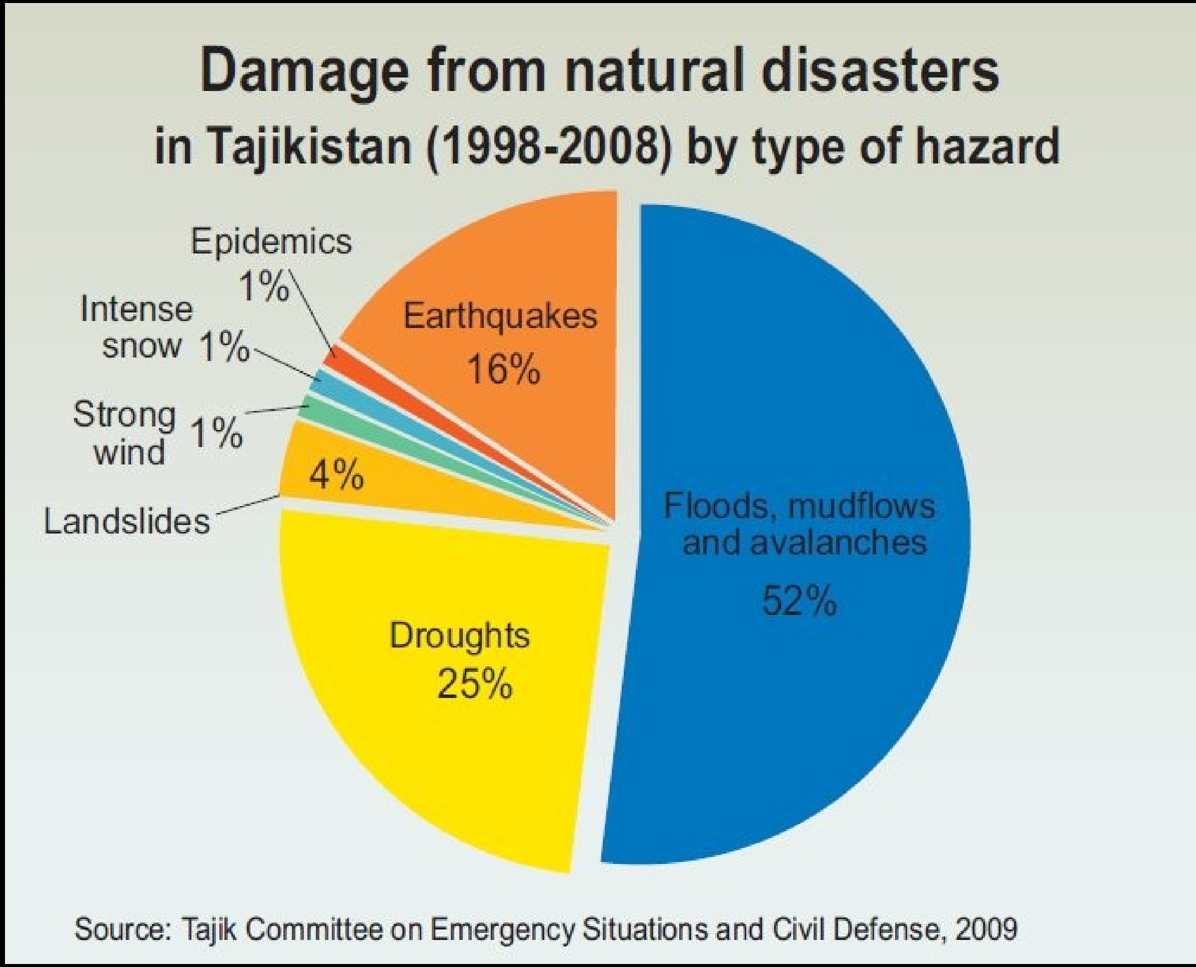
CCCA, zoinet.org

CCCA, zoinet.org

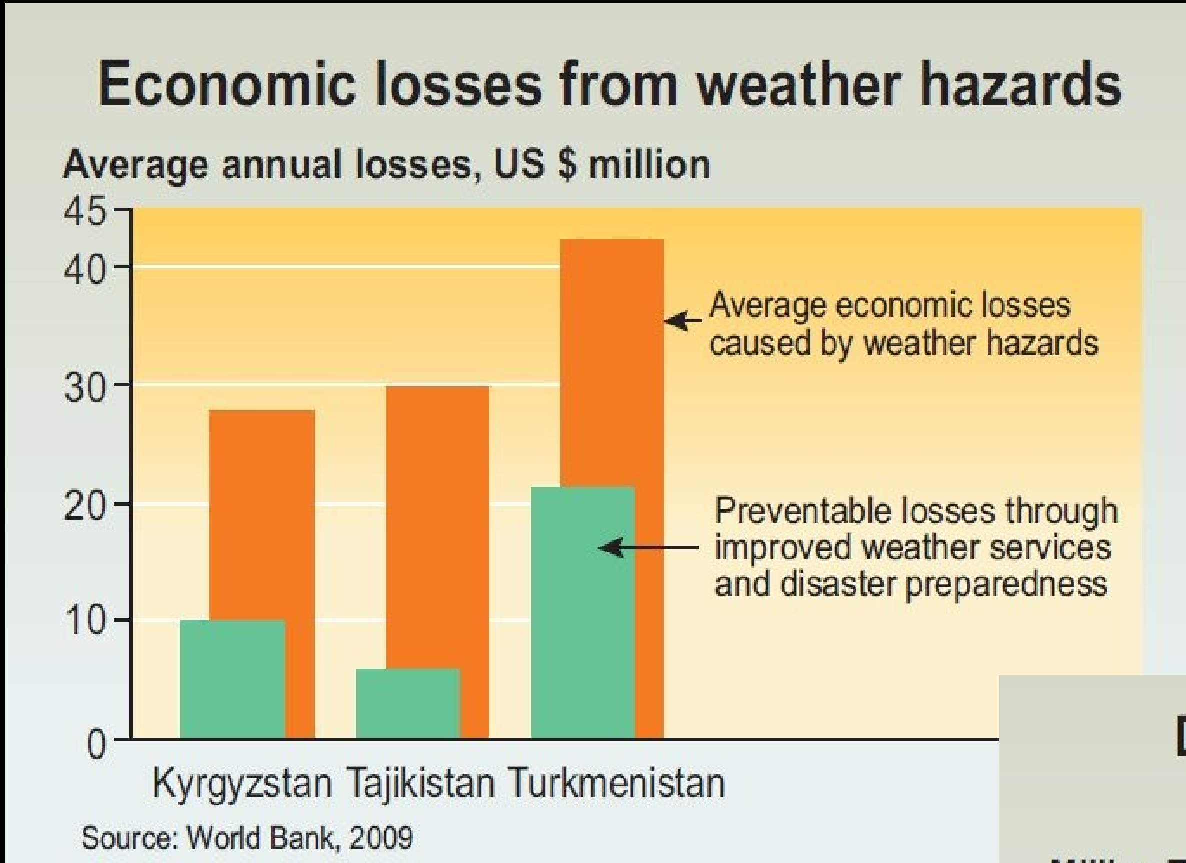


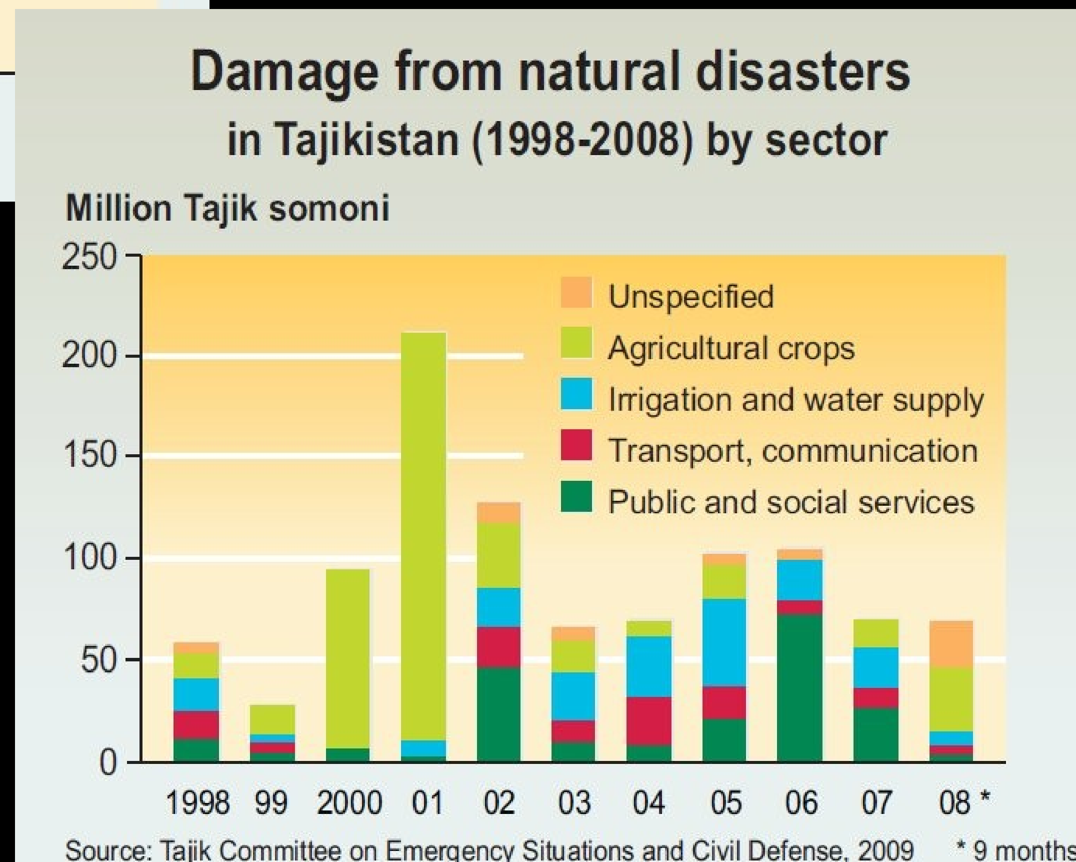
** Vulnerability to climate change is a combination of: i) exposure to hazards, measuring the strength of future climate change relative to today's climate, ii) sensitivity, indicating which economic sectors and ecosystem services are likely to be affected in view of climate change, e.g. renewable water resources, agriculture and hydropower production, and iii) adaptive capacity to climate change, e.g. social, economic, and institutional settings to respond to weather shocks and variability.*



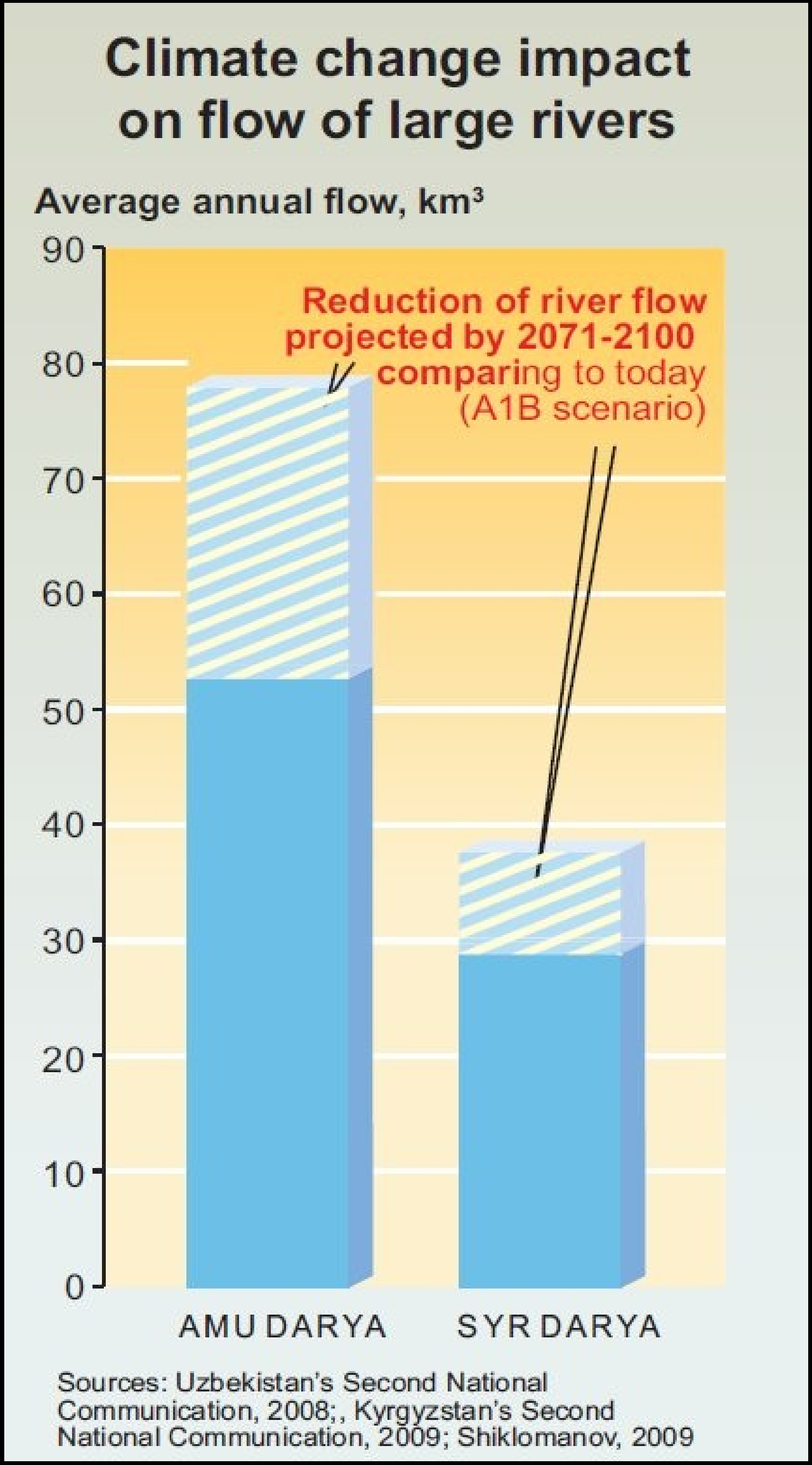


CCCA, zoinet.org

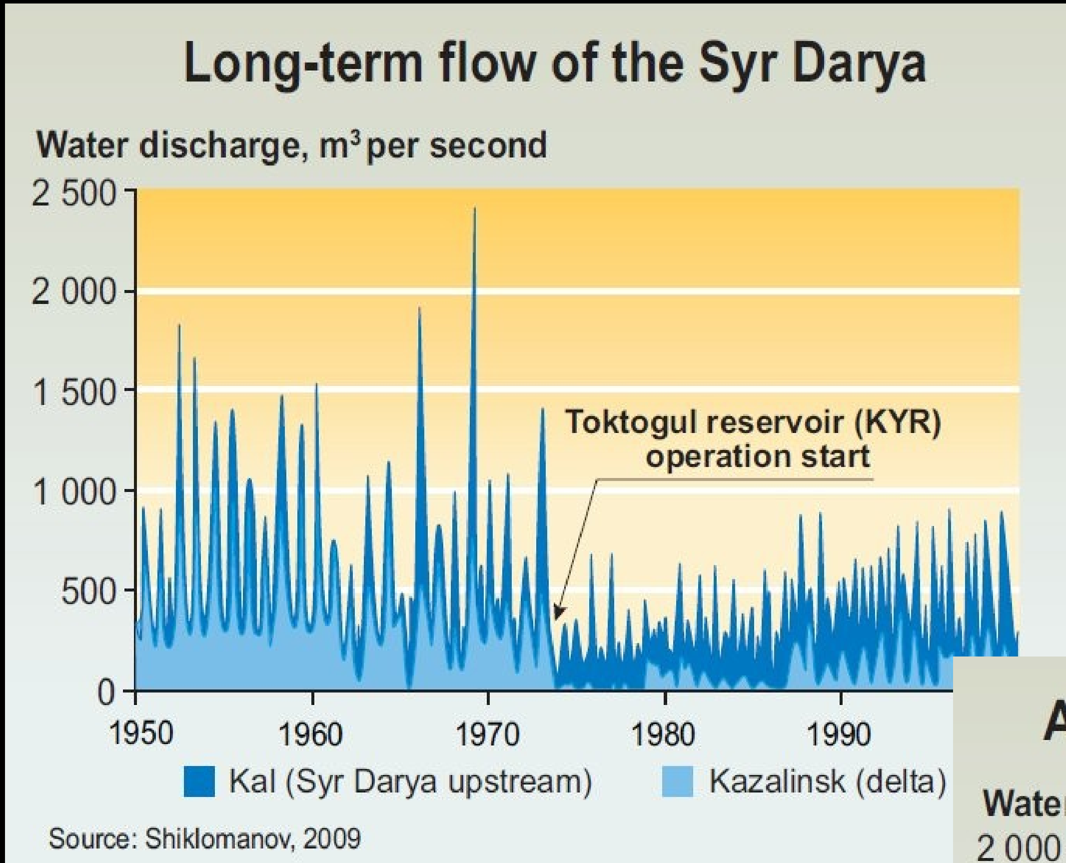


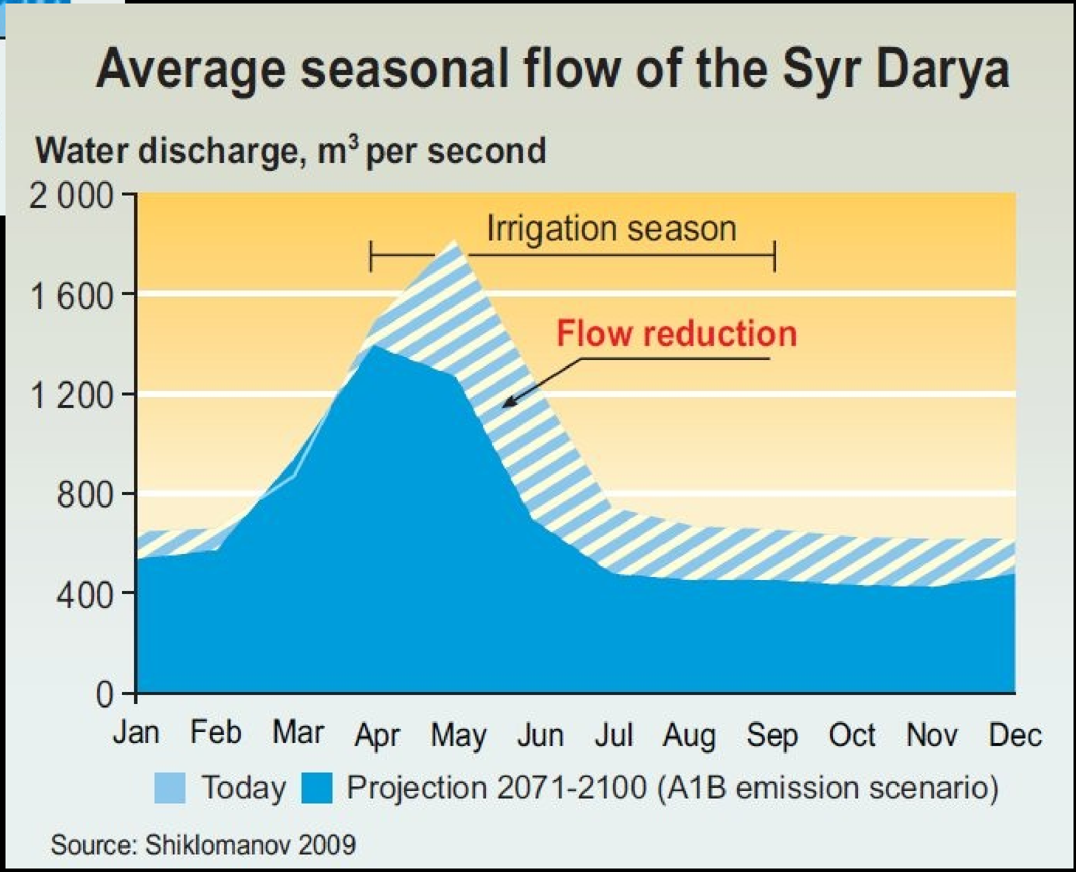


CCCA, zoinet.org



CCCA, zoinet.org





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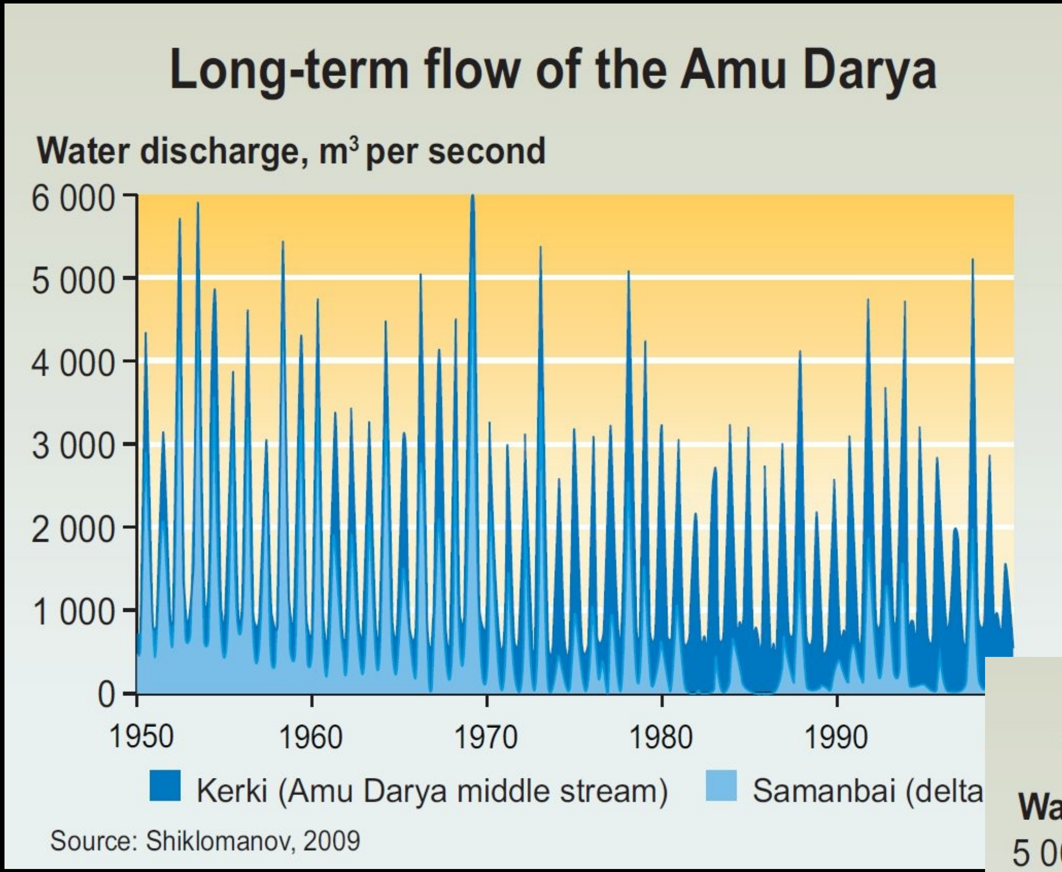

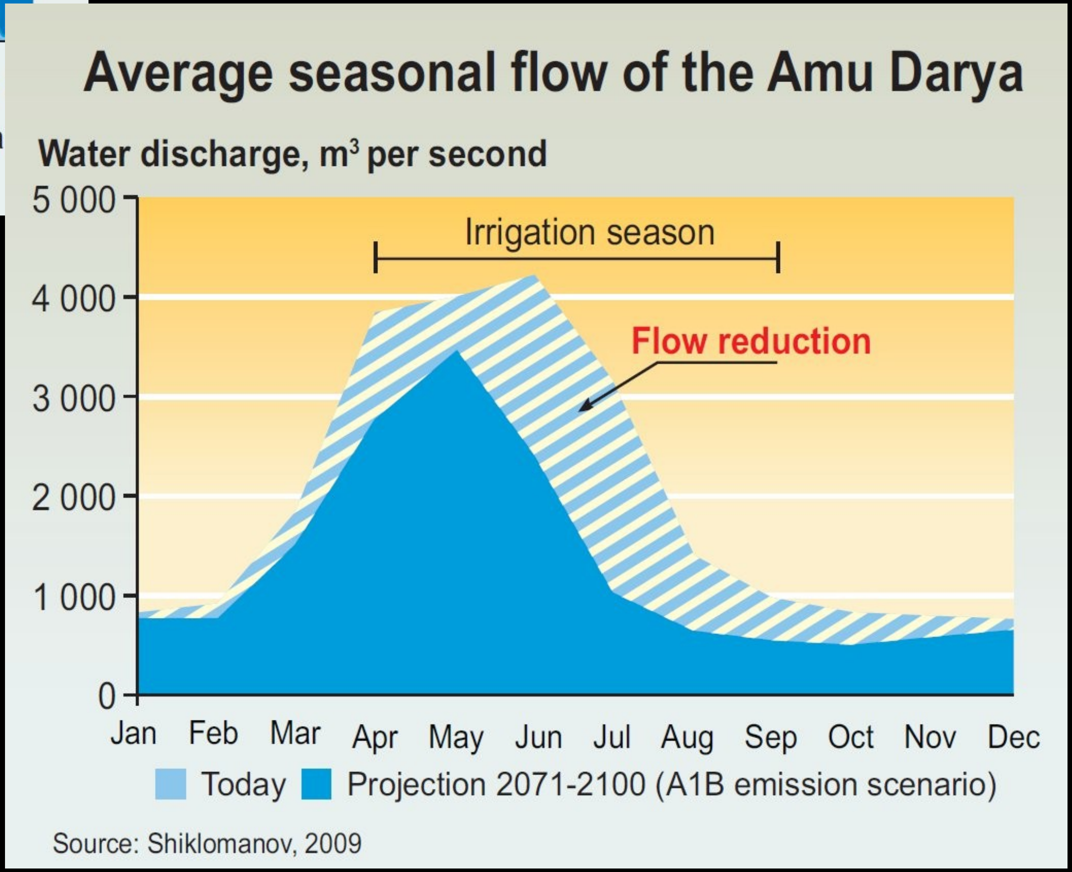

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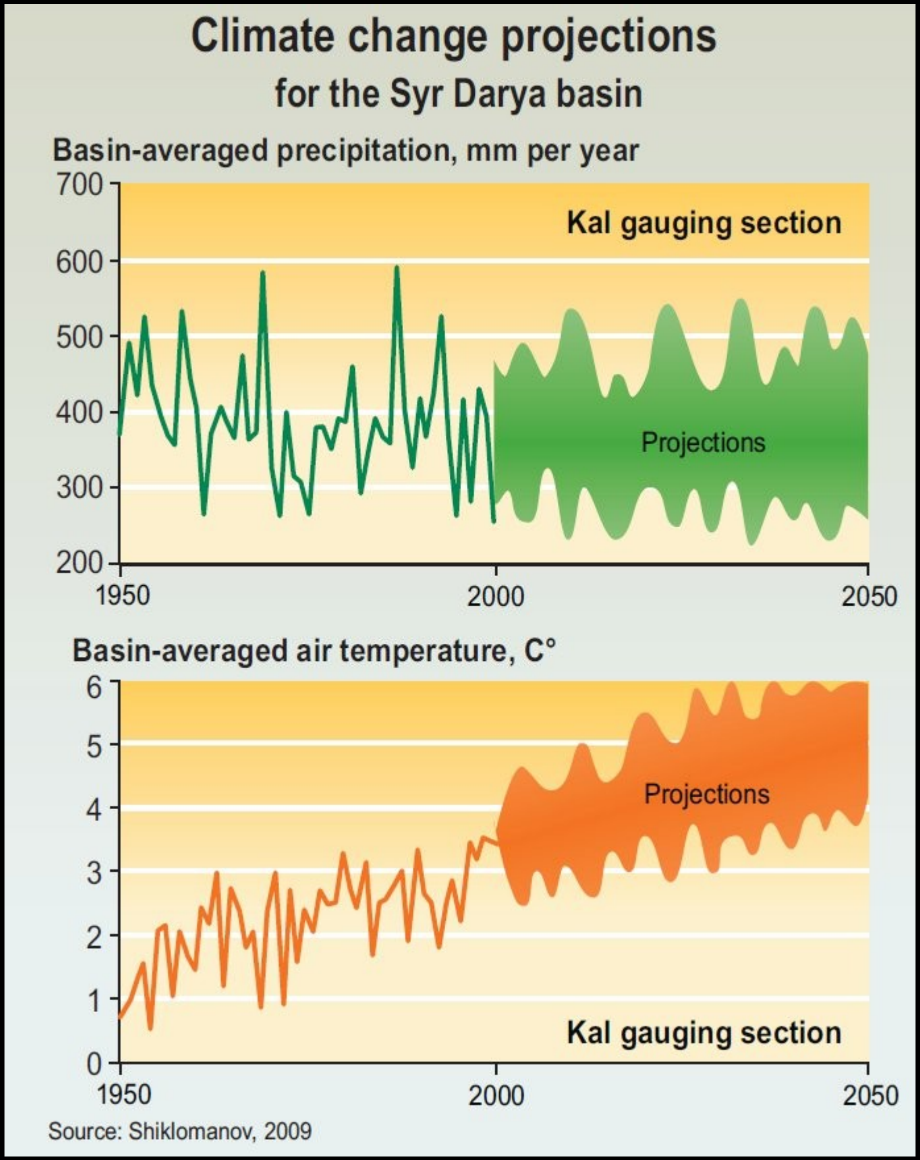

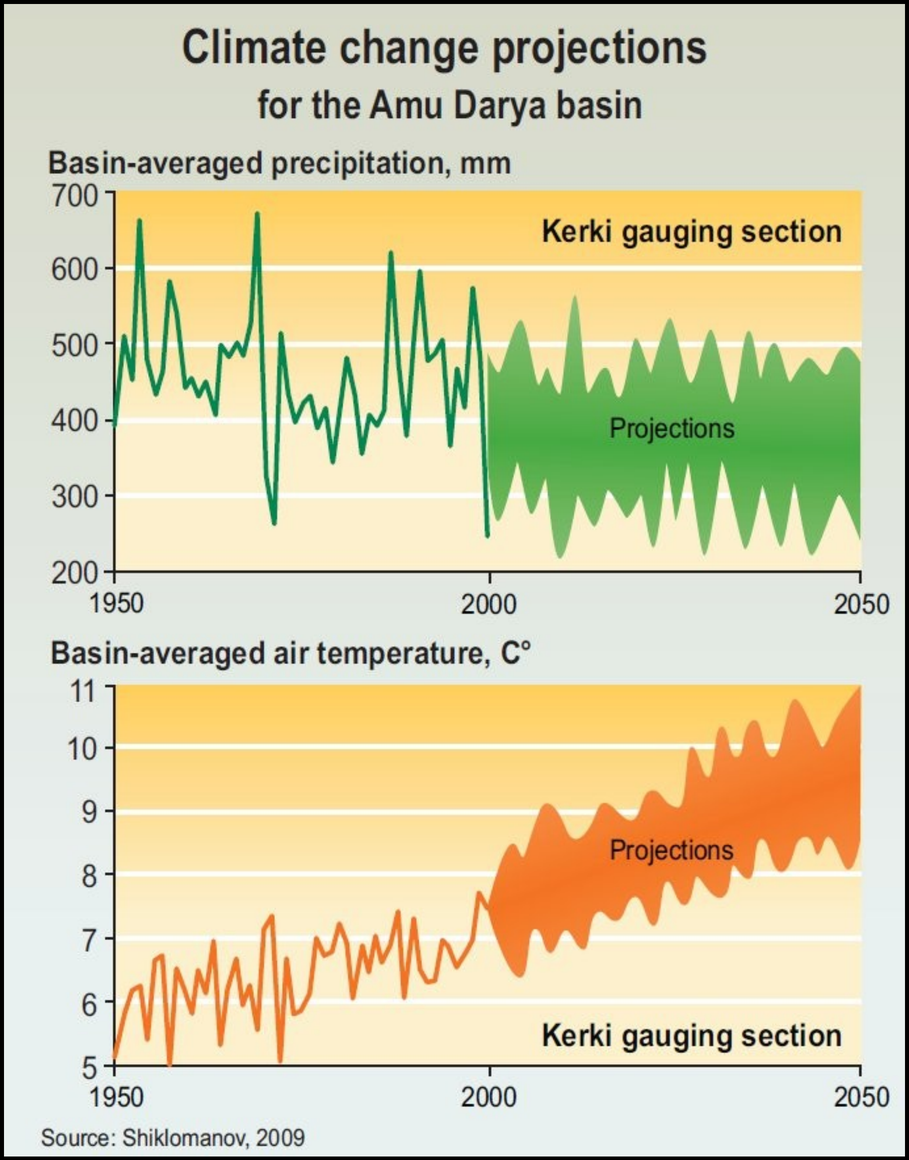

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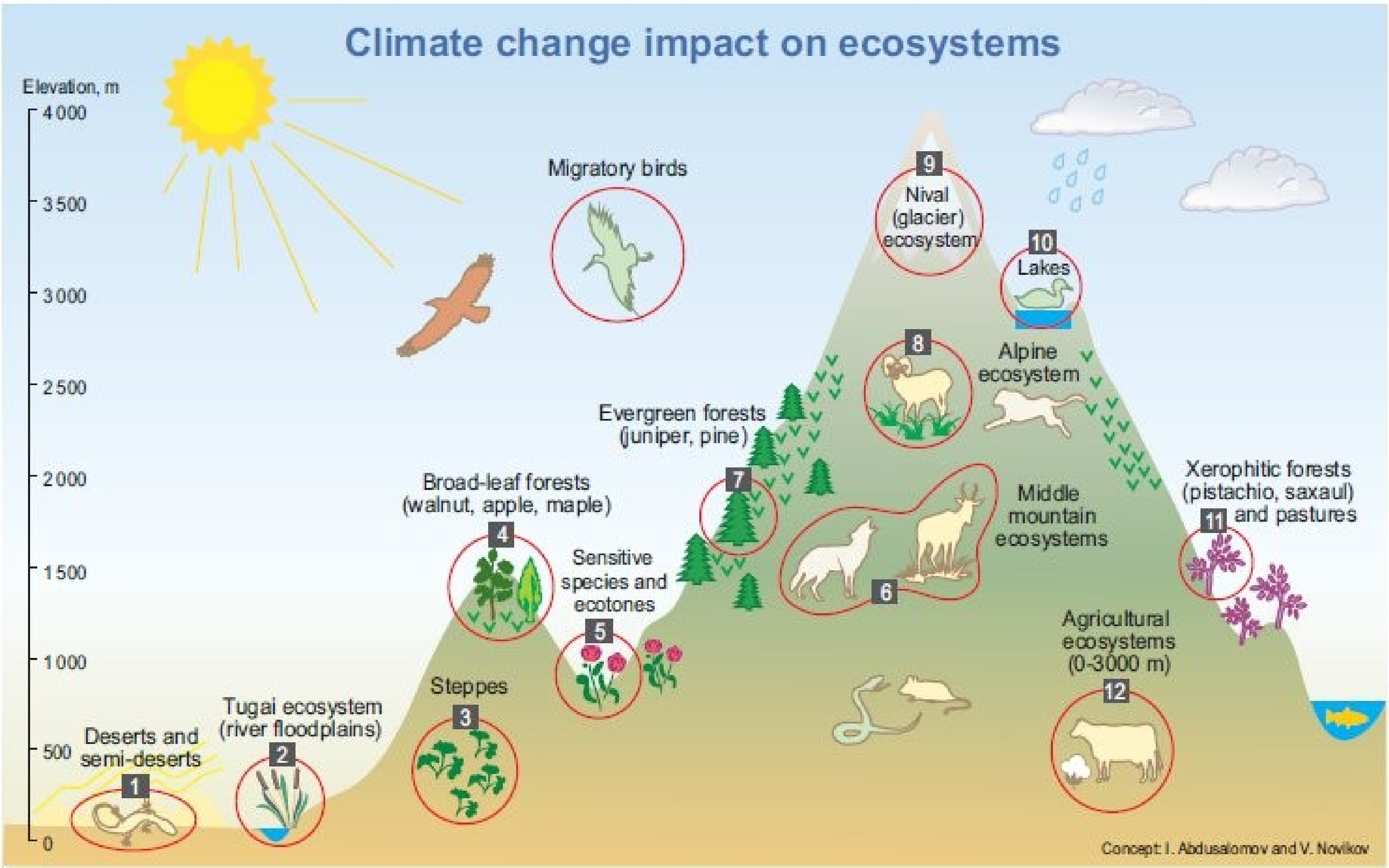
Biodiversity risk



1 - Increased climate aridity, expansion of desert areas
2 - Ecosystem degradation due to reduced river flow, increased risk of fires and diseases
3 - Increased ecosystem productivity in northern parts of Central Asia, northward shift of vegetation
4 - Forest degradation due to reduced runoff, increased risk of droughts and diseases
5 - Changes in species composition, risk of extinction of endangered and vulnerable species
6 - Alteration of food-chains, change in the balance of predators and herbivorous animals
7 - Shift of forest communities to higher altitudes, risk of fires
8 - Degradation and reduction of habitats, reduction of forage
9 - Glacier melt and vegetation succession, alpine habitat loss
10 - Physical and biological changes in high mountain lakes
11 - Changes in phenology (earlier ripening, fading), pest attacks
12 - Mixed negative and positive effects of climate warming

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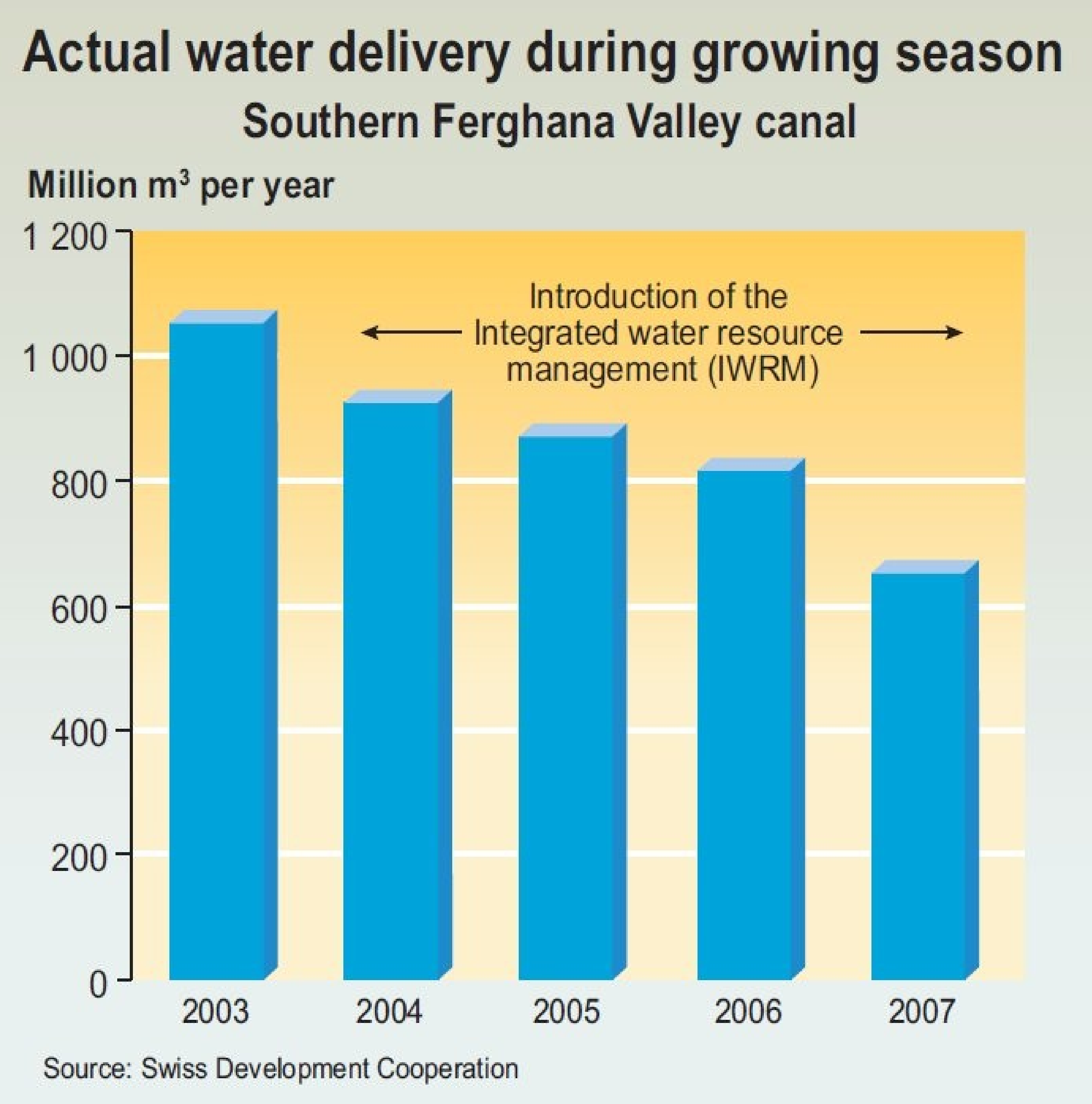

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	Adaptation options
WATER USE	• improved climate and water monitoring and forecasting • integrated water resource managment (IWRM) • revision of water consumption norms and regulations • broad introducation of efficient irrigation technologies • water re-use and re-cycling, drainage water managment • improved water quality control and pollution prevention • water saving incentives and training for farmers • rehabilitation of water pipelines and canals
AGRICULTURE	• improved agrometeorological and veterenary services, training, scientific and technical support for farmers • selection and introduction of drought- and pest-resistant and low water consumption crops, crops protection • conservation of valuable agro-biodiversity • water storage for reliable water supply in dry years • crop rotation and shift towards more suitable areas • rehabilitation of degraded pastures and croplands • remote sensing and mapping of pasture conditions • insurance, strategic food and forrage reserves
HEALTH	• malaria prevention and control • improved drinking water quality and sanitation facilities • new regulations for farmers working in the field in summer • public awareness and early warning • new urban planning principles, better microclimate control
TRANSPORT	• adjustment of hydropower plant operations according to stream flow change and projected climatic impacts

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AGRICULTURE	• conservation of valuable agro-biodiversity • water storage for reliable water supply in dry years • crop rotation and shift towards more suitable areas • rehabilitation of degraded pastures and croplands • remote sensing and mapping of pasture conditions • insurance, strategic food and forrage reserves
HEALTH	• malaria prevention and control • improved drinking water quality and sanitation facilities • new regulations for farmers working in the field in summer • public awareness and early warning • new urban planning principles, better microclimate control
TRANSPORT and ENERGY	• adjustment of hydropower plant operations according to stream flow change and projected climatic impacts • improved security of energy supply and transfer networks • revised road construction norms and traffic load • protection of vulnerable transport infrastructure
ECOSYSTEMS	• systematic research and monitoring • protection of important ecological corridors and sites • conservation of endangered species • public awareness, responsible eco-tourism
DISASTER RISK REDUCTION	• improved capacities for monitoring and forecasting of extreme weather events, hazard mapping • engineering protection measures and early warning • insurance and risk management, public awareness

Source: synthesis of the Second National Communications and the National Strategies/Action Plans on Climate Change

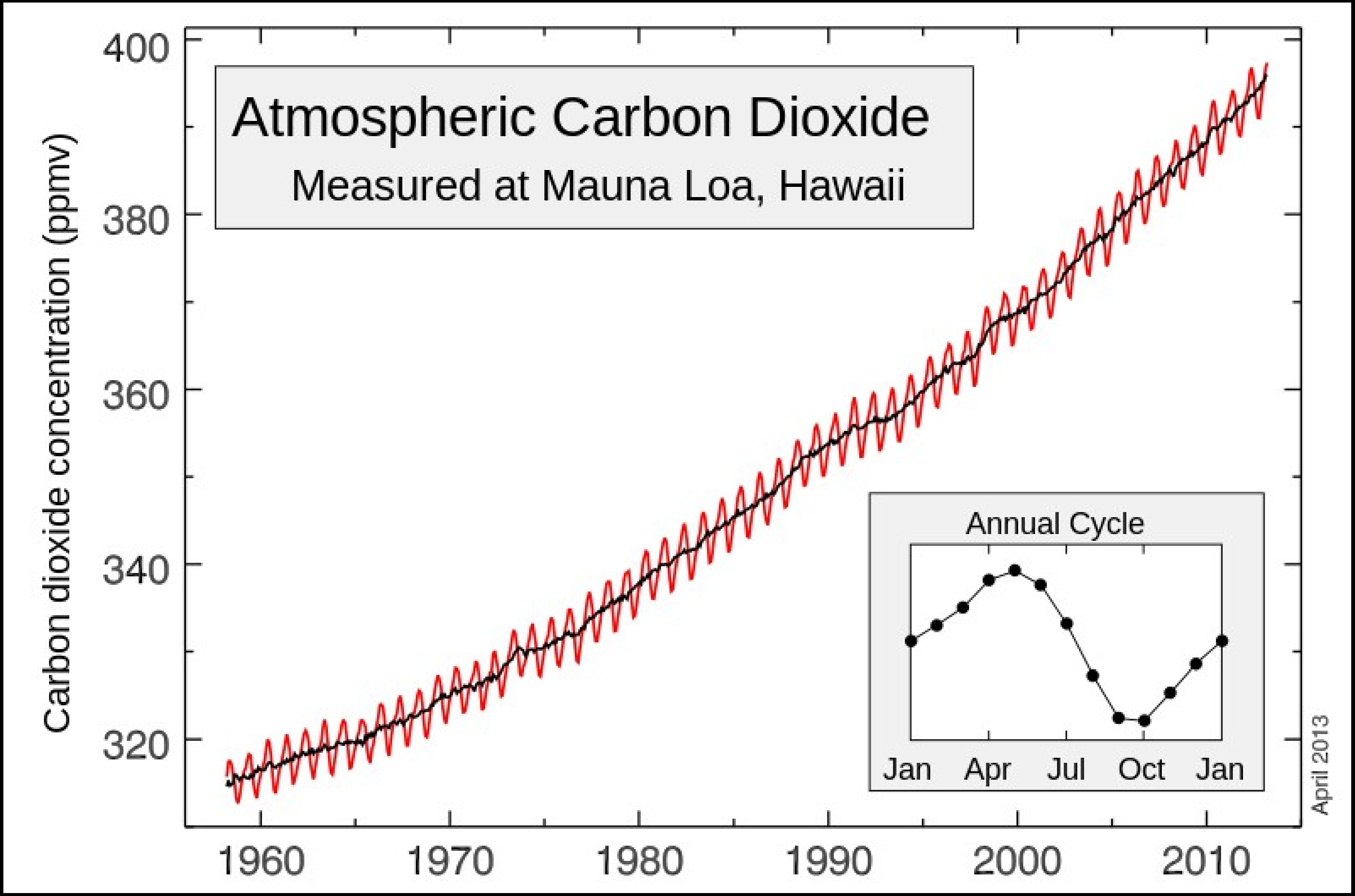
CCCA, zoinet.org

Science-led responses to environmental disasters

Discovery of Global Warming – S.Weart

http://www.aip.org/history/climate

- **Atmospheric ozone hole** – Successful science-led policy process for CFC control (Montreal Protocol 1987)
- **Climate change**: atmospheric GHG increase since LIA, rapidly accelerating at end of 20th century
  - GHG monitoring (Keeling 1960-); climate models; palaeoclimate; orbital observation; remote sensing imagery
  - Anthropogenic in origin; work moves from research to public education
- Science-led **International Panel on Climate Change (IPCC) policy process; Kyoto Protocol**, only partly successful
  - Renewable vs non-renewable energy financial and industrial interests
  - Inflexible US, Russia, China political positions


Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii
Carbon dioxide concentration (ppmv)
400
380
360
340
320
1960
1970
1980
1990
2000
2010
Annual Cycle
Jan
Apr
Jul
Oct
Jan
April 2013

(Wikipedia)

IPCC AR4 (2007) error on Southwest Asia glacial recession

- Himalayan Glaciers error
  - AR4 stated that the Himalayan glaciers could melt by 2035.
  - This figure was incorrect and probably a typo (should be 2350) in a single non-peer-reviewed source (World Wildlife Foundation).
  - The error was contained in a single sentence and in one graphic representation out of AR4’s nearly 3,000 pages.
  - When this error came to light, the IPCC expressed its regret and noted it on its website.

IPCC AR4 (2007) error on Southwest Asia glacial recession

- Himalayan Glaciers error
  - It did not appear in any of the IPCC summaries relied on by policymakers.
  - In those summaries, the language states: “Glacier melt in the Himalayas is projected to increase flooding, and rock avalanches from destabilized slopes, and to affect water resources within the next two to three decades. This will be followed by decreased river flows as the glaciers recede.”
  - This statement remains valid, as does the fact that widespread loss of glacial mass and reduction in snow cover will accelerate throughout the 21st century largely as a result of human activities that are warming our Earth’s atmosphere.

The facts of CA glacial recession
(Armstrong 2010, Aizen)

- Recent evaluation of Akshirak, Ala Archa ranges, Tien Shan:
  - Khromova (2003):
    - a few percent change in 1943-1977
    - >20% in 1977-2001
  - Aizen et al (2006):
    - 8.6% Akshirak, 10.6% Ala Archa 1977-2003
  - Bolch (2007):
    - N. Tien Shan >32% average change 1955-1999
  - Kotliakov & Severskiy (2009):
    - > 1/3 change in 1956-1990
    - Current rate of recession 0.6% - 0.8% per year
- Similar results (incl variability) for China glaciers. Data unavailable for most high-altitude Himalaya glaciers.
- Factors, independent of dynamics: elevation, debris cover, ice thickness, topography

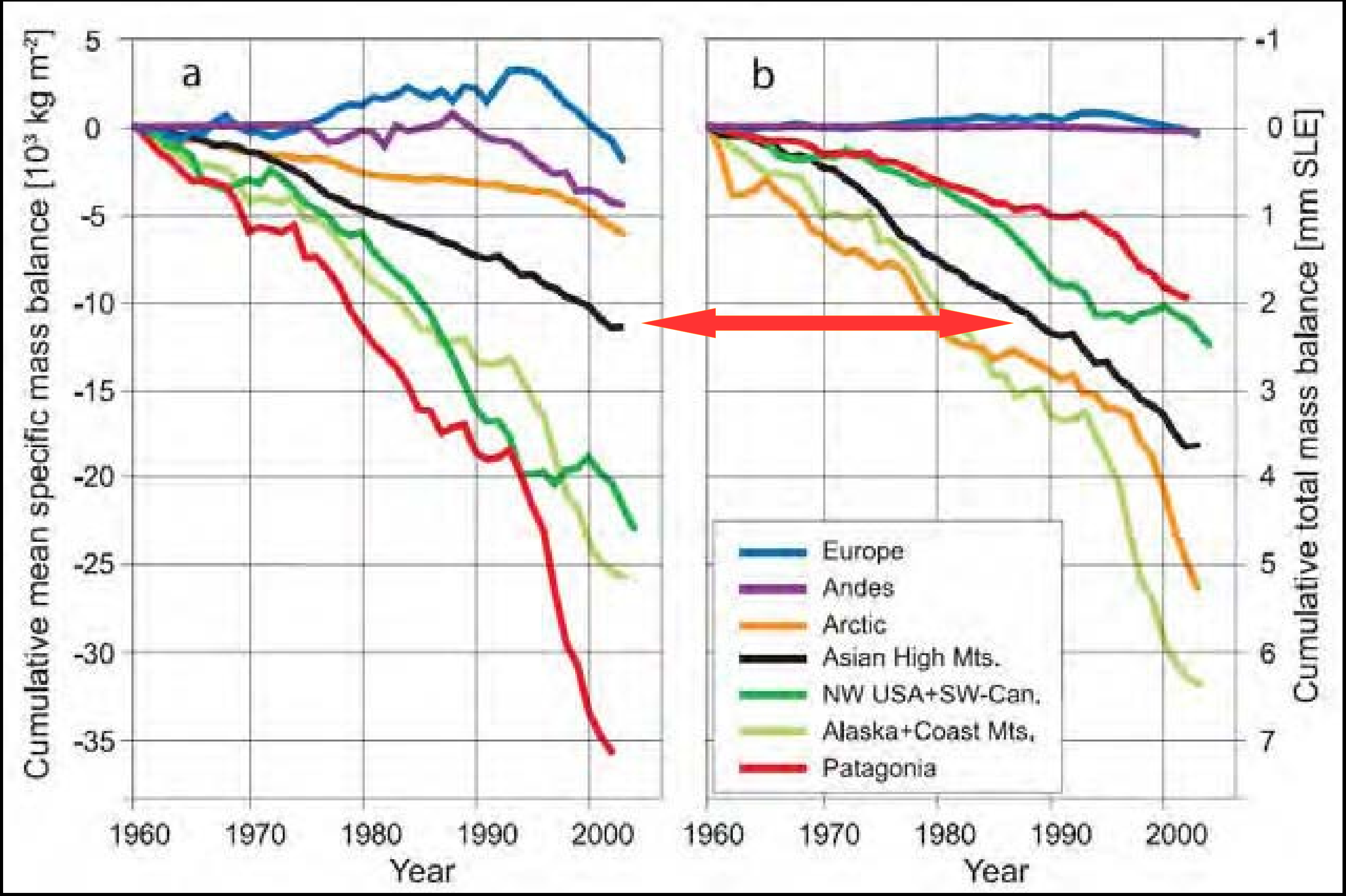
The facts of CA glacial recession

(Armstrong 2010, Aizen)

- Central Asia glacial recession has been going on since the end of the Little Ice Age (LIA, 1650-1850)
- Glacier dynamics are complex and highly variable, depending on size, topography and meteorological history.
- Response time of a glacier to change depends on its elevation and size. Large glacier systems at high altitude may have response times of centuries.
- Latitude and elevation are important – range systems should be treated as groups. Himalayas are not directly comparable to Tien Shan.
- Remote sensing (airphoto, satellite, LIDAR) is useful but must be used carefully, supported by ground truth

The facts of CA glacial recession
(Armstrong 2010, Aizen)

- While small isolated glaciers elsewhere (e.g. Patagonia) are receding more rapidly, glacial massifs in the Asian High Mountains are receding with lifetimes in centuries.
- River flow is expected to be stable until end of lifetime, due to increased glacial melt with increased air temperature; timing of floods likely to shift
- Slight precipitation increase with temperature may actually result in increased accumulation



a
b
Cumulative mean specific mass balance [10³ kg m⁻²]
Cumulative total mass balance [mm SLE]
5
0
-5
-10
-15
-20
-25
-30
-35
-1
0
1
2
3
4
5
6
7
1960
1970
1980
1990
2000
Year
Europe
Andes
Arctic
Asian High Mts.
NW USA+SW-Can.
Alaska+Coast Mts.
Patagonia

The facts of CA glacial recession

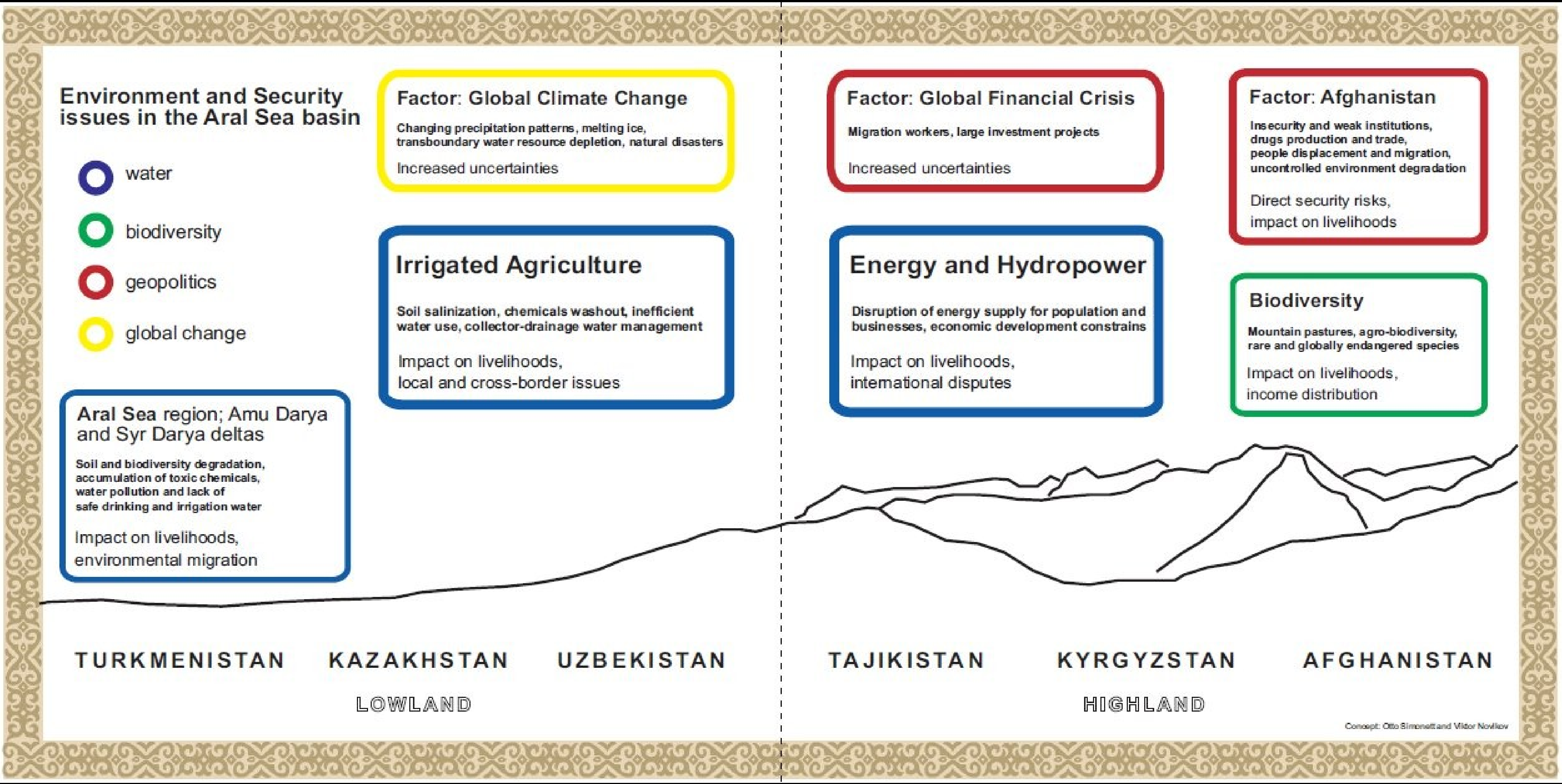
- Important real near-term climate change risks:
  - Glacial Lake Outburst Floods (GLOF) result from dammed meltwater. Relatively uncommon, but a serious risk.
  - Black carbon (soot) absorbs solar radiation strongly
    - Second-largest contributor to radiative forcing after CO_2
    - Black carbon on snow/ice can increase melt rate significantly, but measurements not yet available
- Glacier monitoring is necessary as planning data
  - **Replacement of lost Soviet meteorological network is urgent**
  - Completion of glacier inventory databases for region
  - Remote sensing by aerial/satellite imaging, LiDAR, SAR
  - Ground truth, data integration and modelling

Who can fix glacial recession?

- Climate change is global, but all models place most responsibility on historical and present top consumers of fossil fuels: US, CA, EU, RU, CN. KZ is also on this list.
  - These players must reduce, reuse etc and ultimately abandon fossil fuels.
  - Central Asia players must become much more efficient to survive economically – even KZ, UZ, TM
- A possible exception: glaciers are significantly darkened by black carbon soot, causing recession
  - Soot and dust aerosols are due to primitive farming/cooking/heating methods
  - Assistance is necessary to reduce rural (!) air pollution

Climate change, other change

- Much like other LDCs, CA economic concerns are foremost
- Legacy of environmental disaster zones requires “superfunds” that don't exist –
  - (as well as political sensitivities)
- War and instability makes positive change urgent and extremely difficult


Environment and Security issues in the Aral Sea basin
water
biodiversity
geopolitics
global change
Factor: Global Climate Change
Changing precipitation patterns, melting ice, transboundary water resource depletion, natural disasters
Increased uncertainties
Factor: Global Financial Crisis
Migration workers, large investment projects
Increased uncertainties
Factor: Afghanistan
Insecurity and weak institutions, drugs production and trade, people displacement and migration, uncontrolled environment degradation
Direct security risks, impact on livelihoods
Irrigated Agriculture
Soil salinization, chemicals washout, inefficient water use, collector-drainage water management
Impact on livelihoods, local and cross-border issues
Energy and Hydropower
Disruption of energy supply for population and businesses, economic development constrains
Impact on livelihoods, international disputes
Biodiversity
Mountain pastures, agro-biodiversity, rare and globally endangered species
Impact on livelihoods, income distribution
Aral Sea region; Amu Darya and Syr Darya deltas
Soil and biodiversity degradation, accumulation of toxic chemicals, water pollution and lack of safe drinking and irrigation water
Impact on livelihoods, environmental migration
TURKMENISTAN
KAZAKHSTAN
UZBEKISTAN
TAJIKISTAN
KYRGYZSTAN
AFGHANISTAN
LOWLAND
HIGHLAND
Concept: Otto Simonett and Viktor Novikov

Factors ...

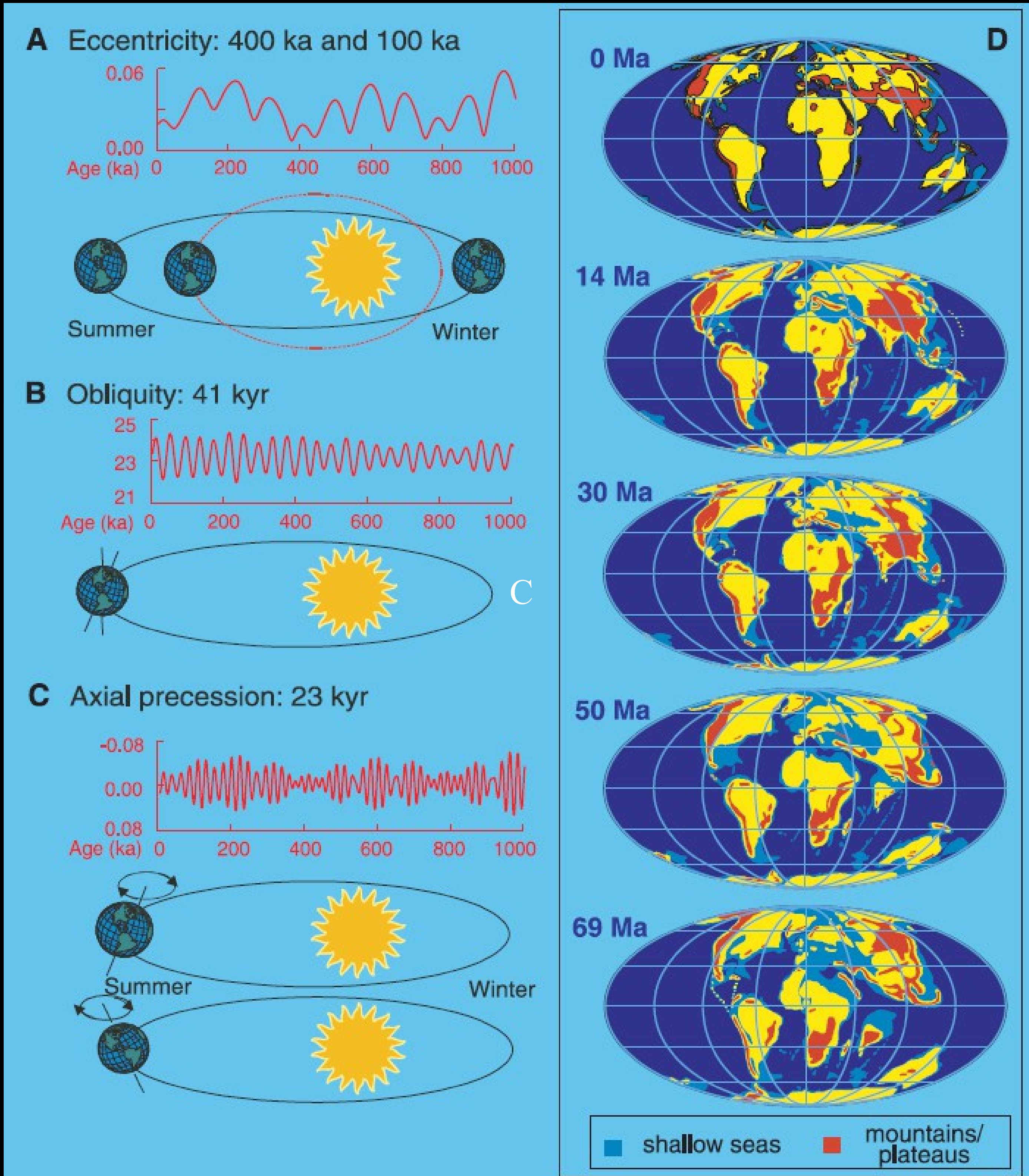
- Toxic waste legacy
  - (Supplement E)
- National political context
  - Includes population explosion
  - (Supplement F)
- International political context
  - Includes AF drug industry, border security
  - Regional instability and war
  - (Supplement G)

Why is Central Asia important?

(Supplement H)

Why is action urgent on Climate Change?

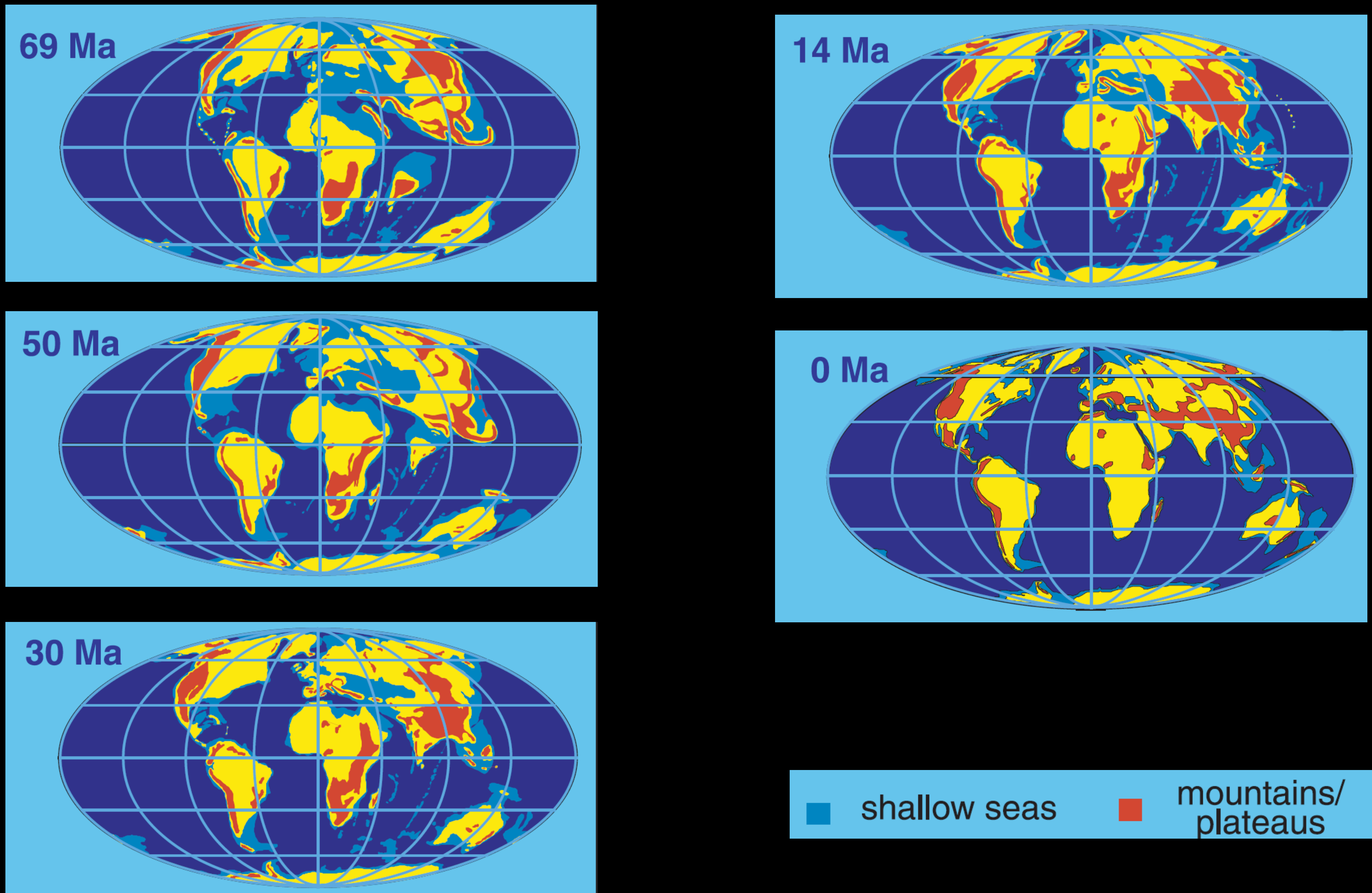
- Climate is a geologic as well as atmospheric system
- Over geologic time scales, Earth systems are ***not*** stable, but are periodic and predictable
  - Orbital geometry generates rapid oscillations (10K-100K years)
    - Eccentricity, obliquity, precession
    - Affects amount and distribution of solar radiation
  - Causes ice ages in recent times



(Source: Zachos et al 2001 fig 1)

Creation of this world: India and Asia collide

- **One important tectonic event: the collision of Indian and Eurasian plates at end of Eocene (~65 Ma)**
  - Very recent on geologic time scale, dated using isotopic analysis of deep ocean cores
  - Produced both the ice-free, forested poles of the Eocene and gradual transition to polar ice caps and glacial-interglacial oscillation
  - Atmospheric pCO_2 range: 1000-2000 ppm dropped to 170 ppm
- Orogeny of Himalayas isolated Central Asia from South Asia and ocean monsoons


69 Ma
50 Ma
30 Ma
14 Ma
0 Ma
shallow seas
mountains/
plateaus

Creation of this world: India and Asia collide

- Massive GHG warming took place in that period (65-50 Mya) due to long increase in CO_2, and sudden very large release of CO_2 in a few thousand years, creating Palaeocene-Eocene Thermal Maximum (PETM)
- **Atmosphere and ocean temperatures at least 12°C above today (figures show avg deep ocean temp)**
- The India-Eurasia collision which created Central Asia was responsible for an ice-free planet (Eocene)

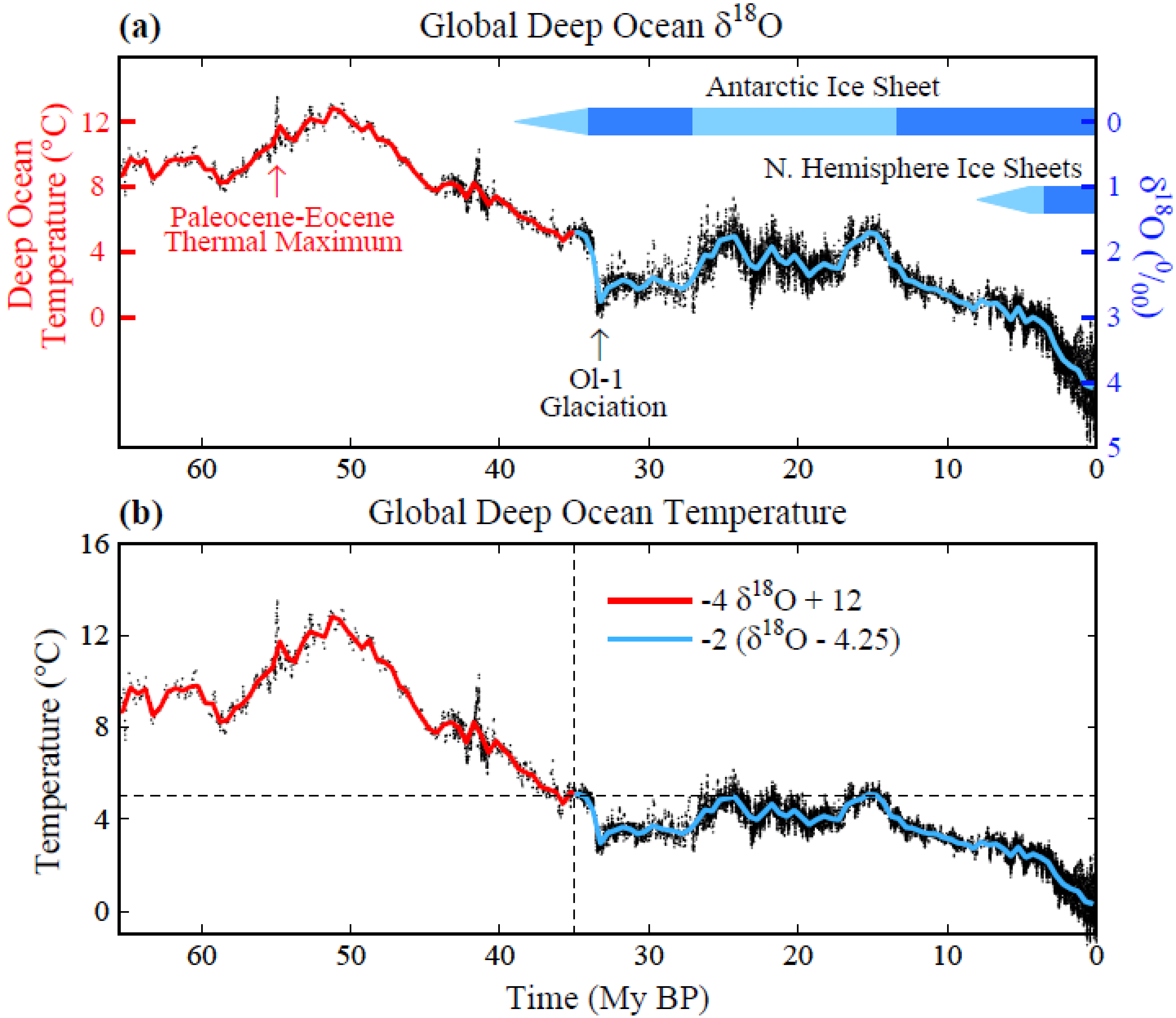


Fig. (3). Global deep ocean (**a**) $\delta^{18}O$ [26] and (**b**) temperature. Black curve is 5-point running mean of $\delta^{18}O$ original temporal resolution, while red and blue curves have 500 ky resolution.

"Target atmospheric CO2", Hansen et al 2008, Fig.3

Why is action urgent on Climate Change?

- PETM as an event was a very brief spike, <10,000 years, effects lasting ~200,000 years
- The PETM pCO_2 maximum may have been more like 2000-4000 ppmv based on isotope and temperature data.
- Huge CO_2 releases to atmosphere
  - Total about 5 Pg C = 5 GT C
  - Likely included CH_4 releases from clathrates
- **This is comparable to the expected result of humans burning all accessible fossil fuels by 2500 AD.**
  - Total 4000 GT C?

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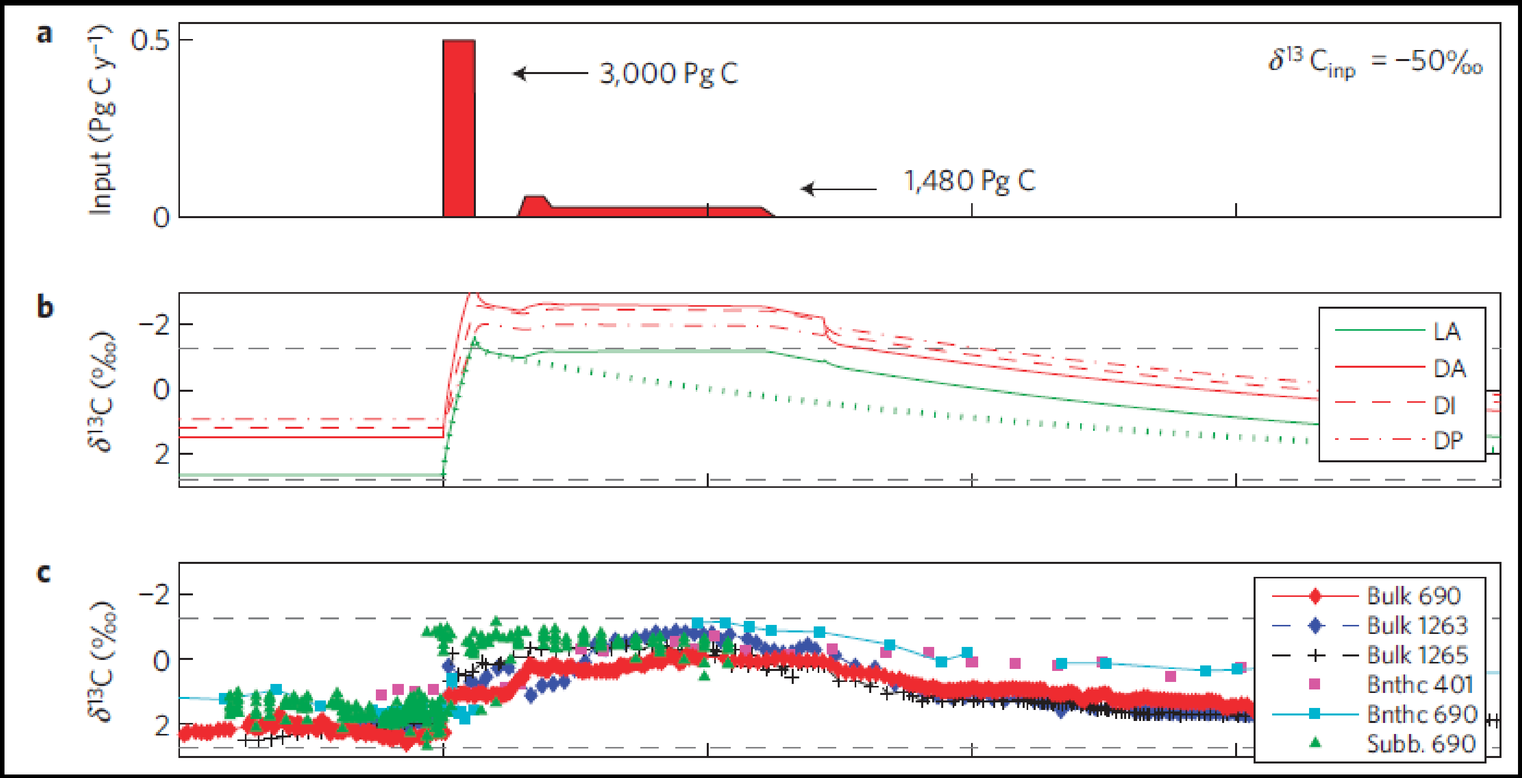
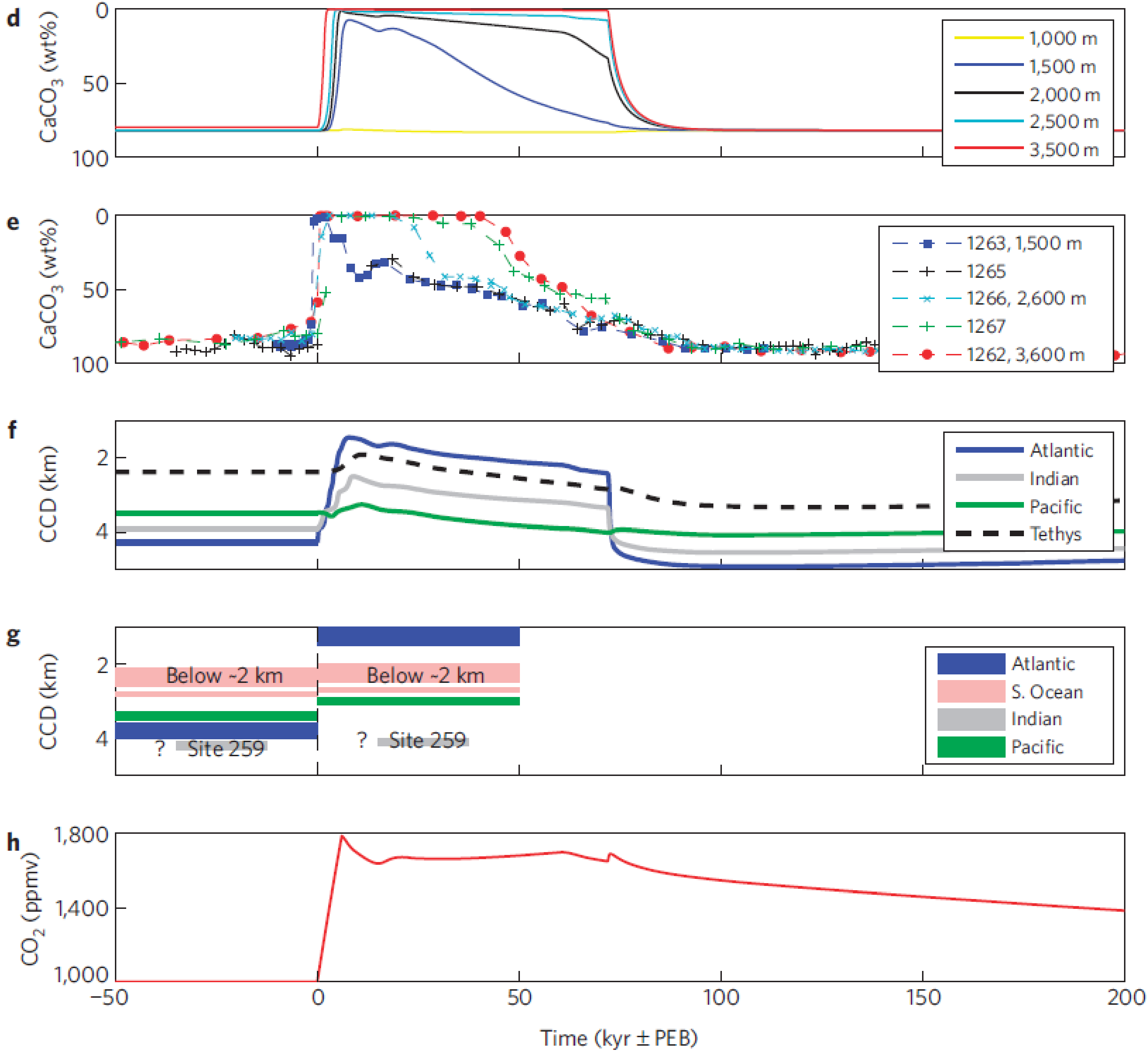
Carbon dioxide forcing alone insufficient to explain Palaeocene–Eocene Thermal Maximum warming

Richard E. Zeebe[1]*, James C. Zachos[2] and Gerald R. Dickens[3]

Figure 1 | PETM model simulations and palaeorecords. a, PETM carbon-release scenario (model input); $t = 0$ corresponds to the onset of the PETM. **b**, Simulated δ^{13}C of TCO_2 in the low-latitude surface Atlantic (LA), deep Atlantic, Indian and Pacific oceans (DA, DI, DP) using the carbon release shown in **a**, including the continuous release (solid green and red lines). In simulations without the continuous release (dotted green line), the duration of the δ^{13}C excursion was not captured in the model. **c**, Observed δ^{13}C in bulk $CaCO_3$, benthic and planktonic foraminifera[15–17]. **d**, Simulated wt% $CaCO_3$ at various depths in the deep Atlantic. **e**, Observed wt% $CaCO_3$ at Walvis Ridge, South Atlantic Ocean[10]. **f**, Simulated CCD in different basins. **g**, Observed CCD before and during the PETM main event (see Supplementary Information). **h**, Simulated atmospheric CO_2 (PEB: Palaeocene/Eocene boundary).





d
CaCO$_3$ (wt%)
0
50
100
1,000 m
1,500 m
2,000 m
2,500 m
3,500 m
e
CaCO$_3$ (wt%)
0
50
100
1263, 1,500 m
1265
1266, 2,600 m
1267
1262, 3,600 m
f
CCD (km)
2
4
Atlantic
Indian
Pacific
Tethys
g
CCD (km)
2
4
Below ~2 km
Below ~2 km
? Site 259
? Site 259
Atlantic
S. Ocean
Indian
Pacific
h
CO$_2$ (ppmv)
1,800
1,400
1,000
−50
0
50
100
150
200
Time (kyr ± PEB)

Creation of this world: India and Asia collide

- Weathering of the Himalayas slowly drew CO2 from the atmosphere, depositing it on ocean floors – bringing global temperatures down until polar ice caps reformed.
- The Palaeocene-Eocene Thermal Maximum (PETM) appears to be similar to damage to our planet that is within our reach.
- PETM is an urgent research problem in palaeoclimatology
  - Hansen, Storms of my Grandchildren (2009) Ch. 8
  - Hansen et al 2008
  - Zachos et al 2008
  - Zeebe et al 2009
- Oceanographers' view of PETM, past and future
  - Norris, Turner, Ridgewell 2013

Darwaza, Turkmenistan

CCCA, zoinet.org

Why is action urgent on Climate Change?

- We are burning fossil fuels at a tremendous rate – half of all conventional oil in a century – and are quickly going after unconventional fuels.
- We are unable and/or unwilling to change underlying technology to improve efficiency and find alternatives.
  - Fossil fuels remain the only option for modern warfare esp. by air
- We may be headed for an Eocene-like planet, in which life as we know it can survive only at the poles.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Brontothere, not brontosaur; but … thanks to PPFeyte@free.fr !

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Thank you!