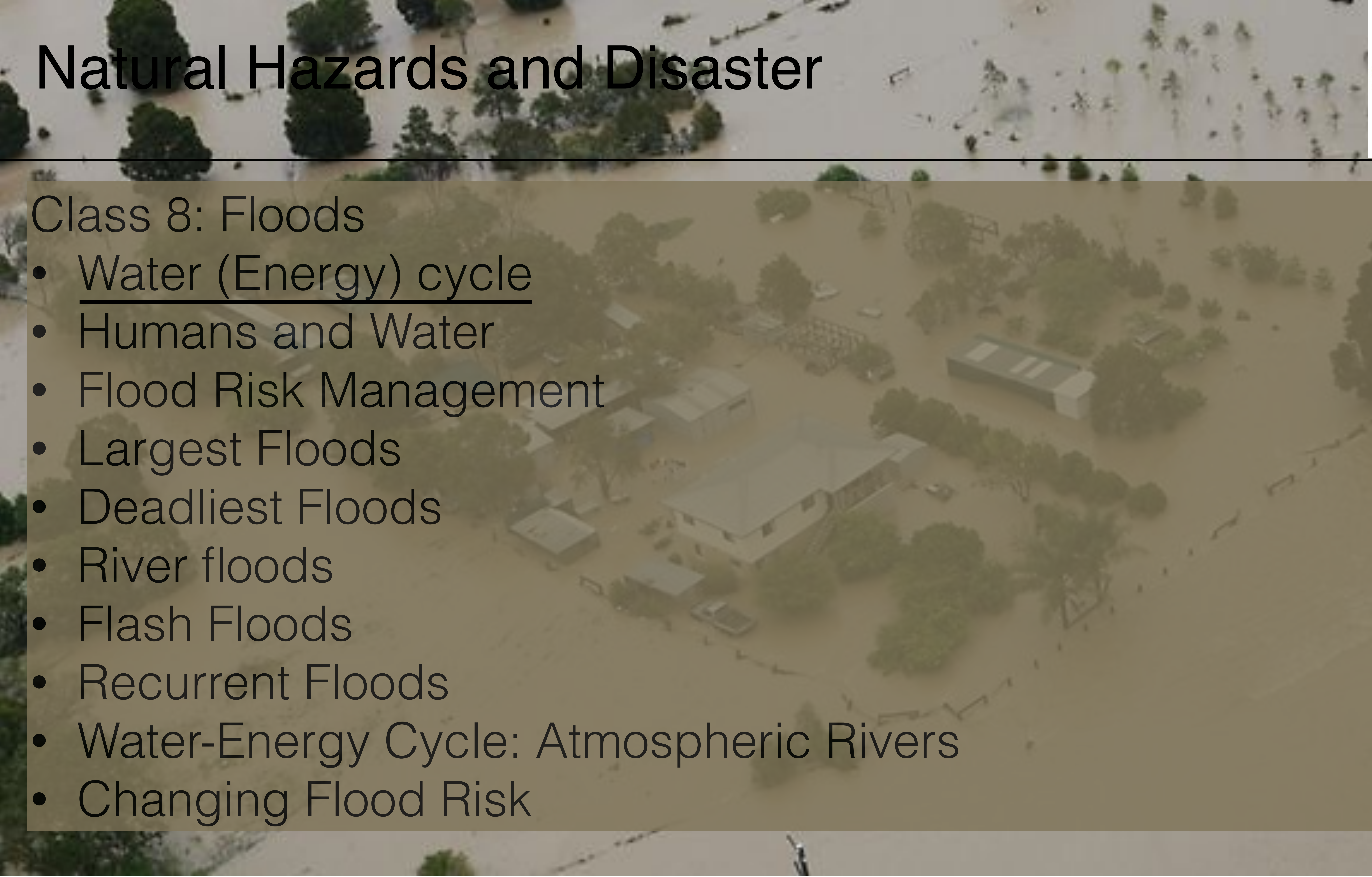
Cry me a river: Low water levels causing chaos in Germany

By DAVID RISING   October 27, 2018

BERLIN (AP) — A new island in Lake Constance. A river in Berlin flowing backward. Dead fish on the banks of lakes and ponds. Barges barely loaded so they don’t run aground.

A **hot, dry summer** has left German rivers and lakes at record low water levels, causing chaos for the inland shipping industry, environmental damage and billions of euros (dollars) in losses — a scenario that experts warn could portend the future as global temperatures rise.



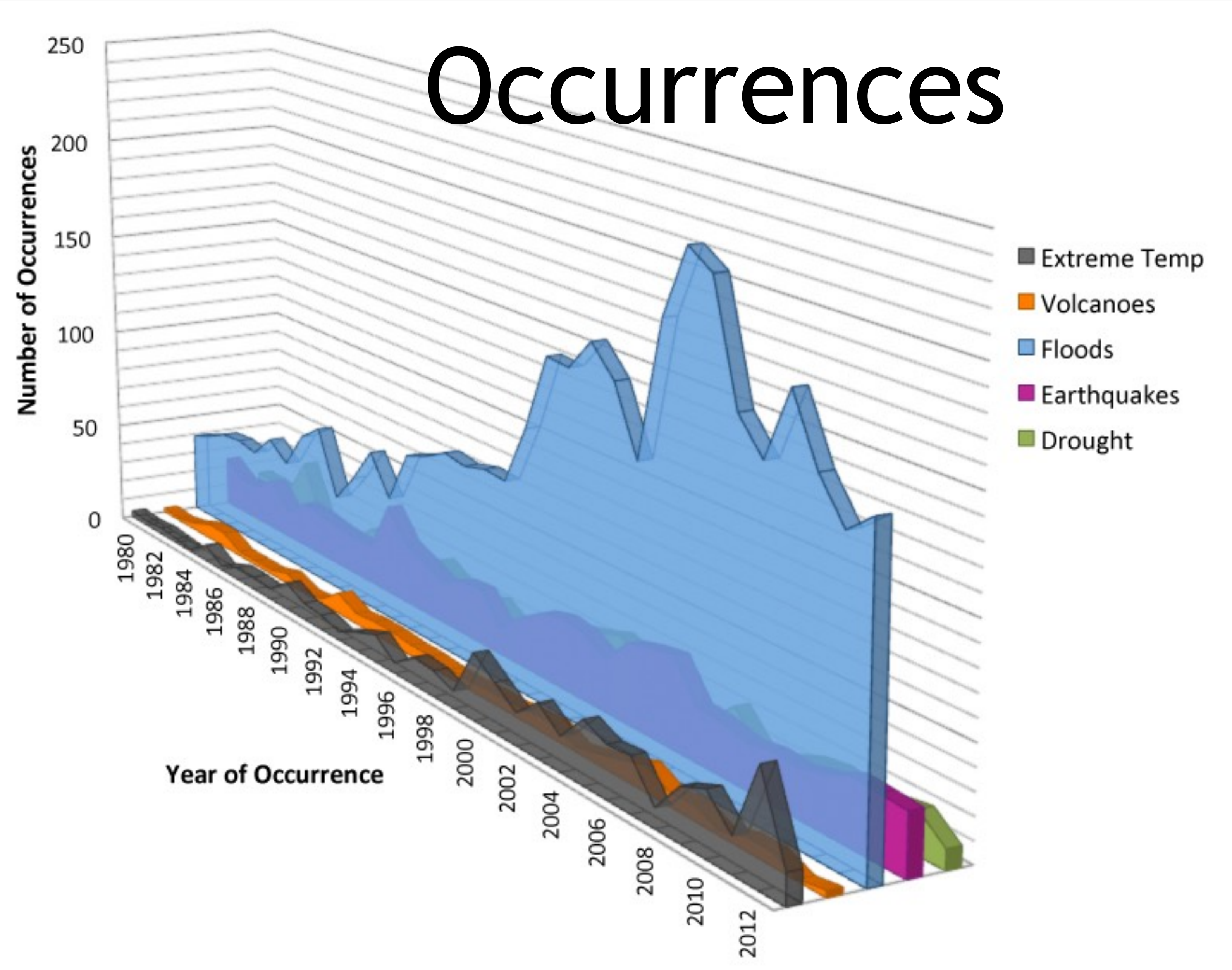
Natural Hazards and Disaster

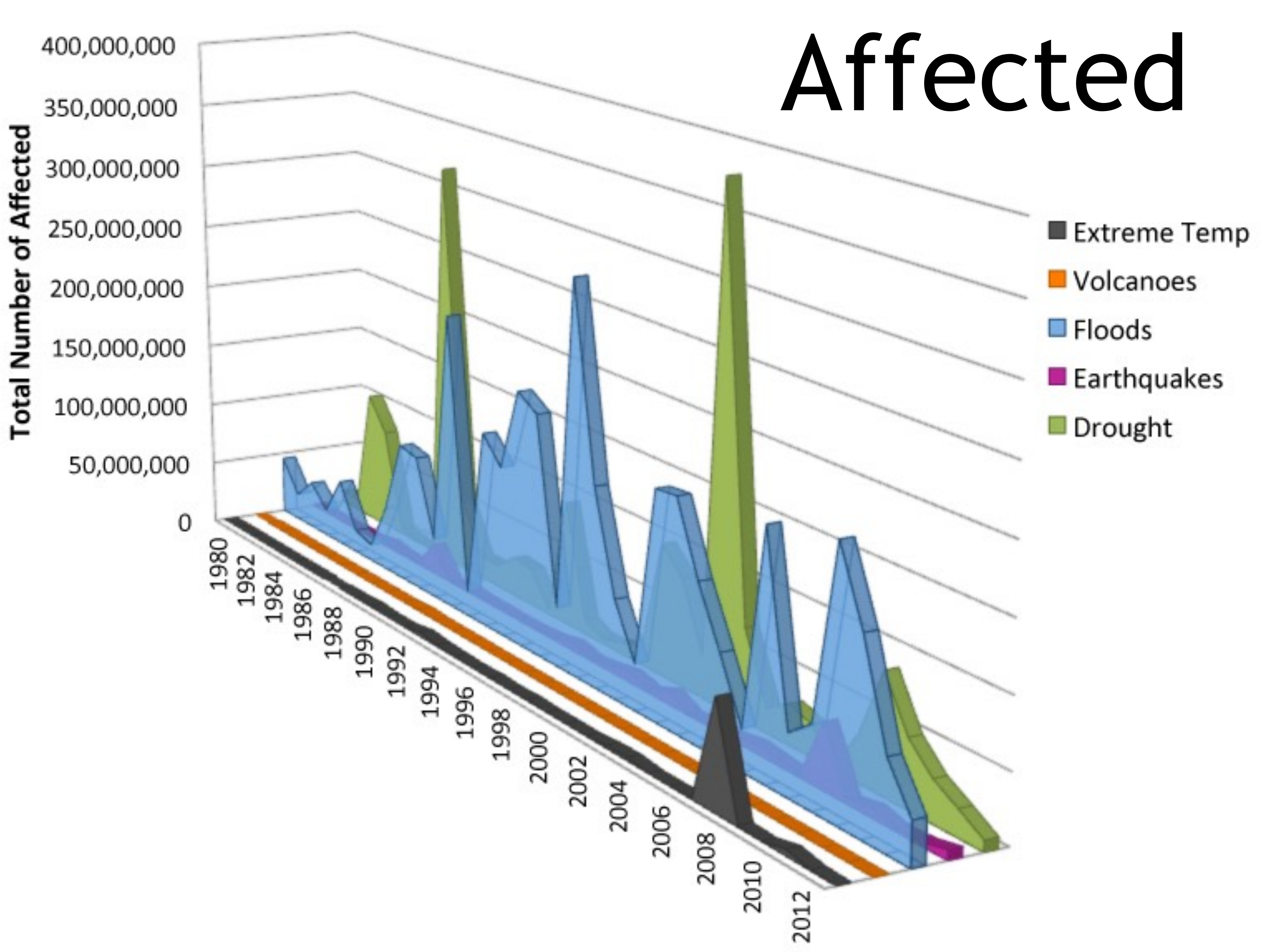
MITIGATION & ADAPTATION RESEARCH INSTITUTE
MARI
OLD DOMINION UNIVERSITY

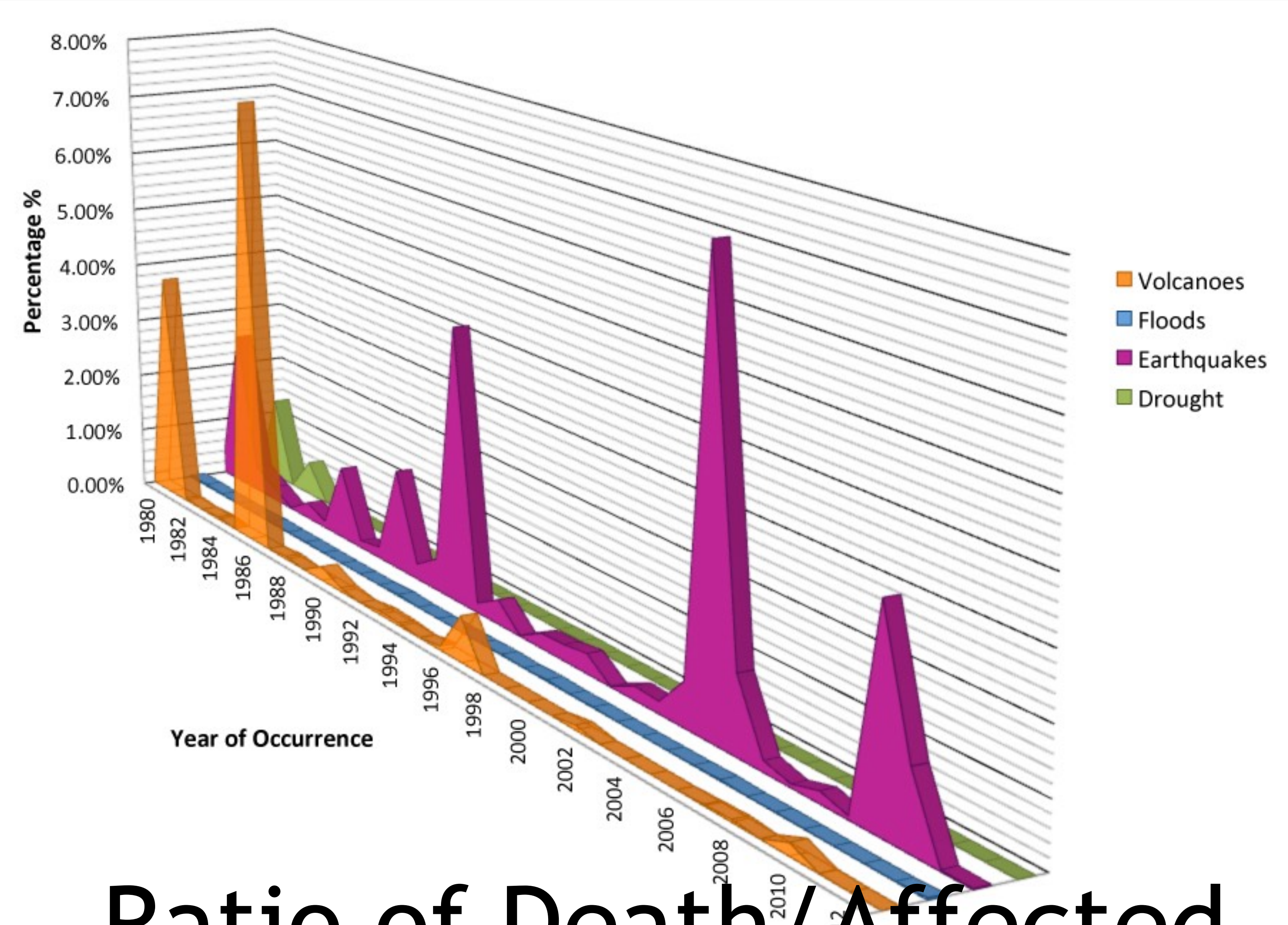
Class 8: Floods

- Water (Energy) cycle
- Humans and Water
- Flood Risk Management
- Largest Floods
- Deadliest Floods
- River floods
- Flash Floods
- Recurrent Floods
- Water-Energy Cycle: Atmospheric Rivers
- Changing Flood Risk

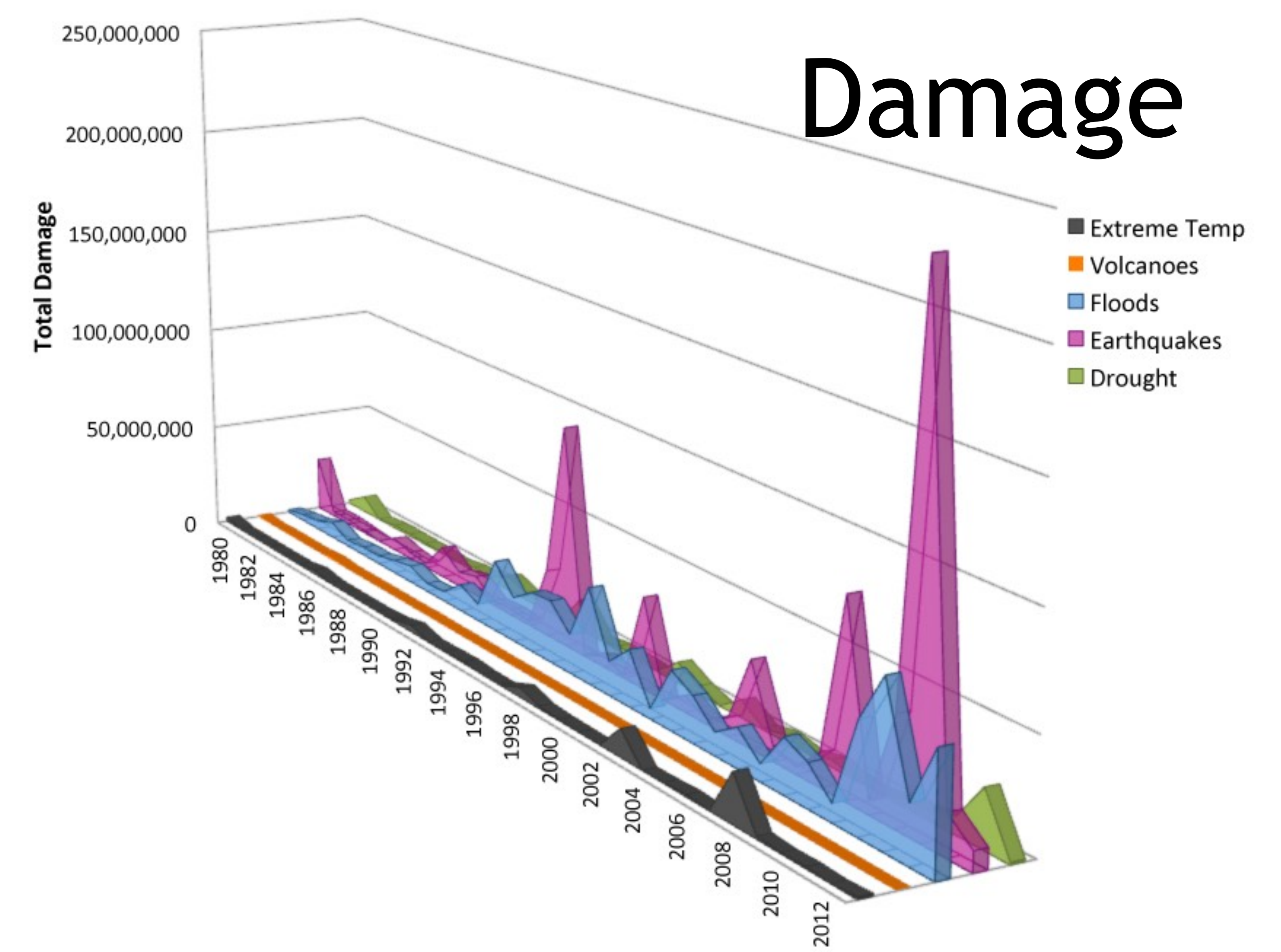
Comparison

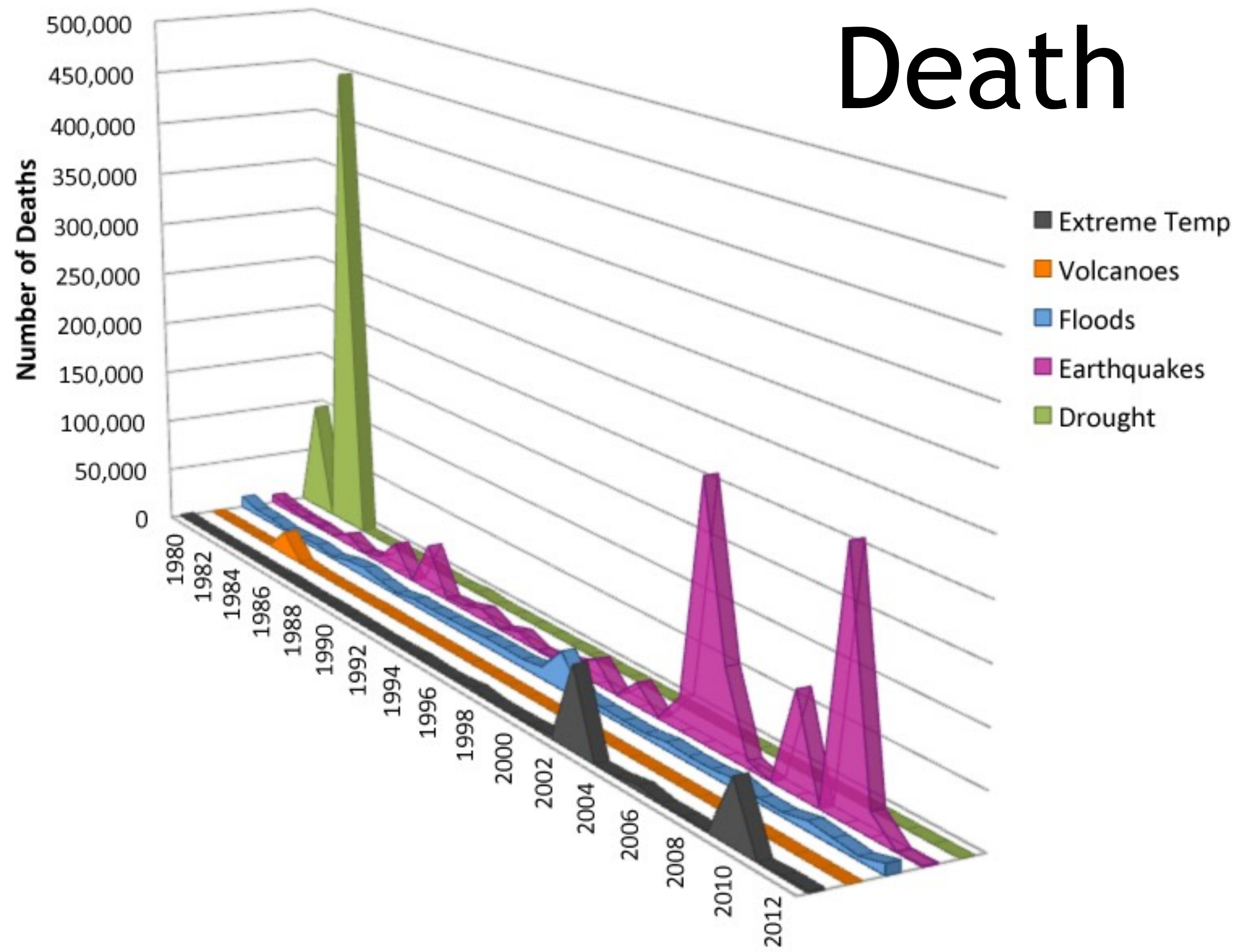

Occurrences


Affected



Ratio of Death/Affected

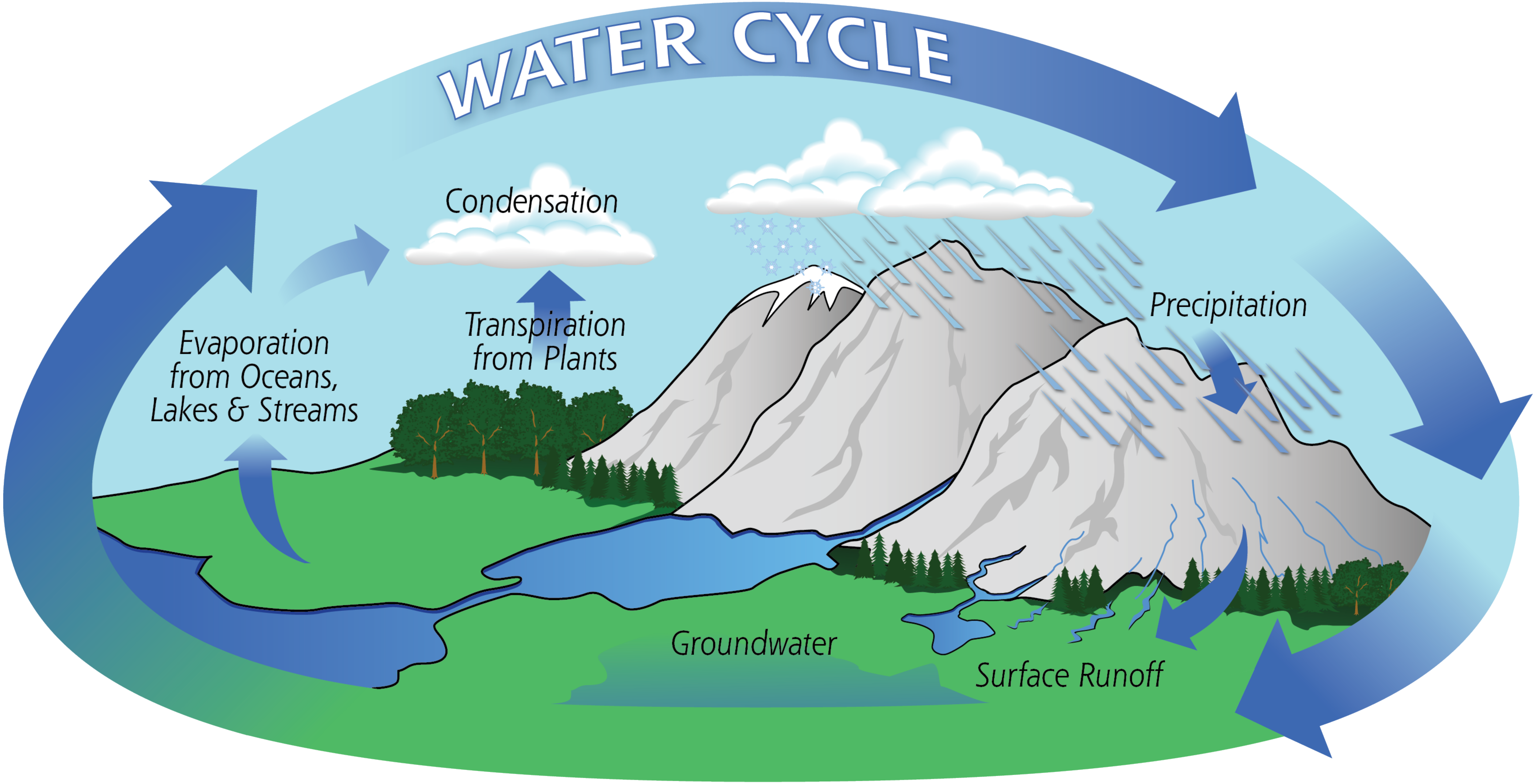

Damage


Death

International Disaster Database

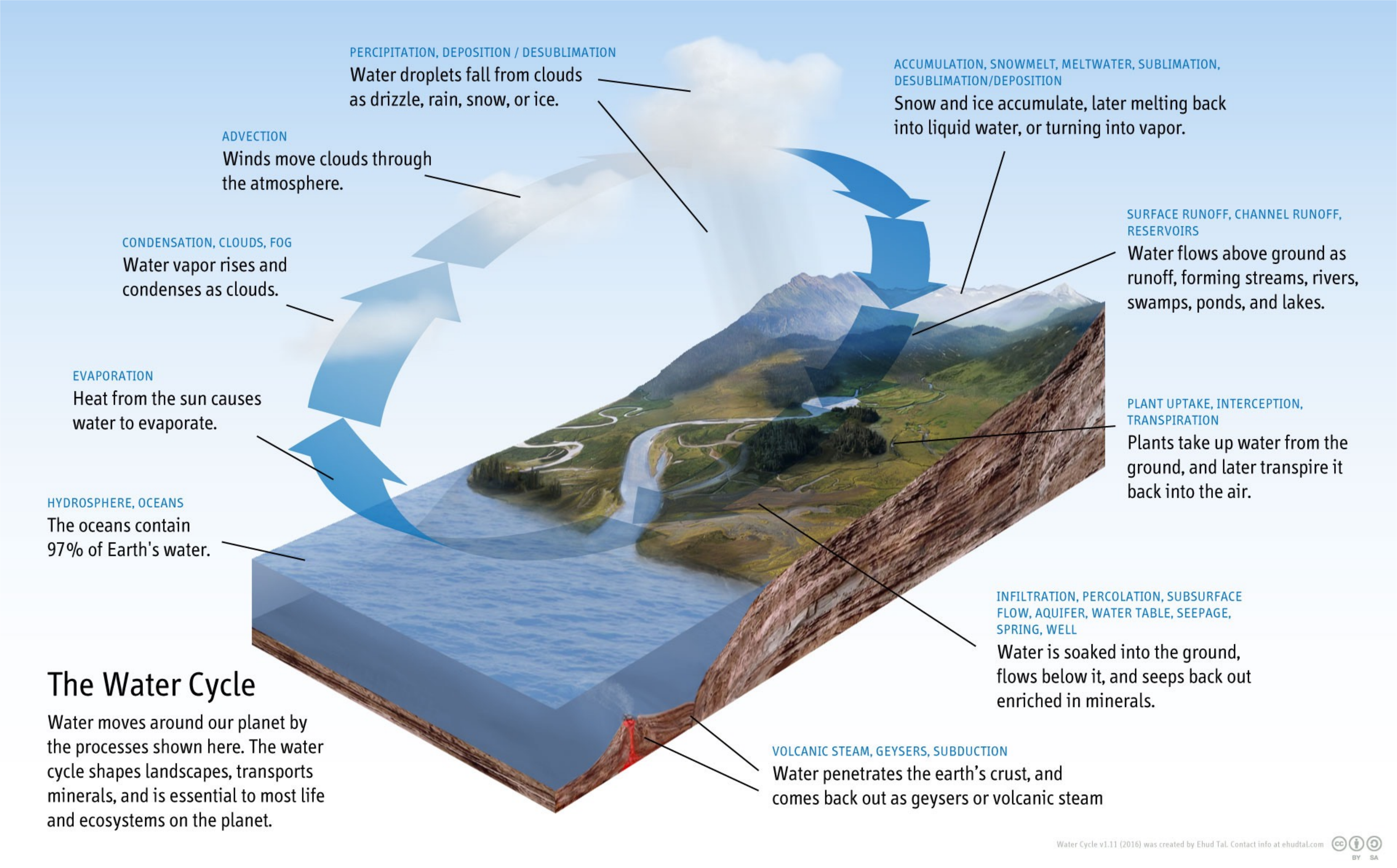
http://www.emdat.be/advanced search/.

Water Cycle



https://pmm.nasa.gov/education/sites/default/files/article_images/Water-Cycle-Art2A.png

Water Cycle



PERCIPITATION, DEPOSITION / DESUBLIMATION
Water droplets fall from clouds as drizzle, rain, snow, or ice.

ADVECTION
Winds move clouds through the atmosphere.

CONDENSATION, CLOUDS, FOG
Water vapor rises and condenses as clouds.

EVAPORATION
Heat from the sun causes water to evaporate.

HYDROSPHERE, OCEANS
The oceans contain 97% of Earth's water.

The Water Cycle

Water moves around our planet by the processes shown here. The water cycle shapes landscapes, transports minerals, and is essential to most life and ecosystems on the planet.

ACCUMULATION, SNOWMELT, MELTWATER, SUBLIMATION, DESUBLIMATION/DEPOSITION
Snow and ice accumulate, later melting back into liquid water, or turning into vapor.

SURFACE RUNOFF, CHANNEL RUNOFF, RESERVOIRS
Water flows above ground as runoff, forming streams, rivers, swamps, ponds, and lakes.

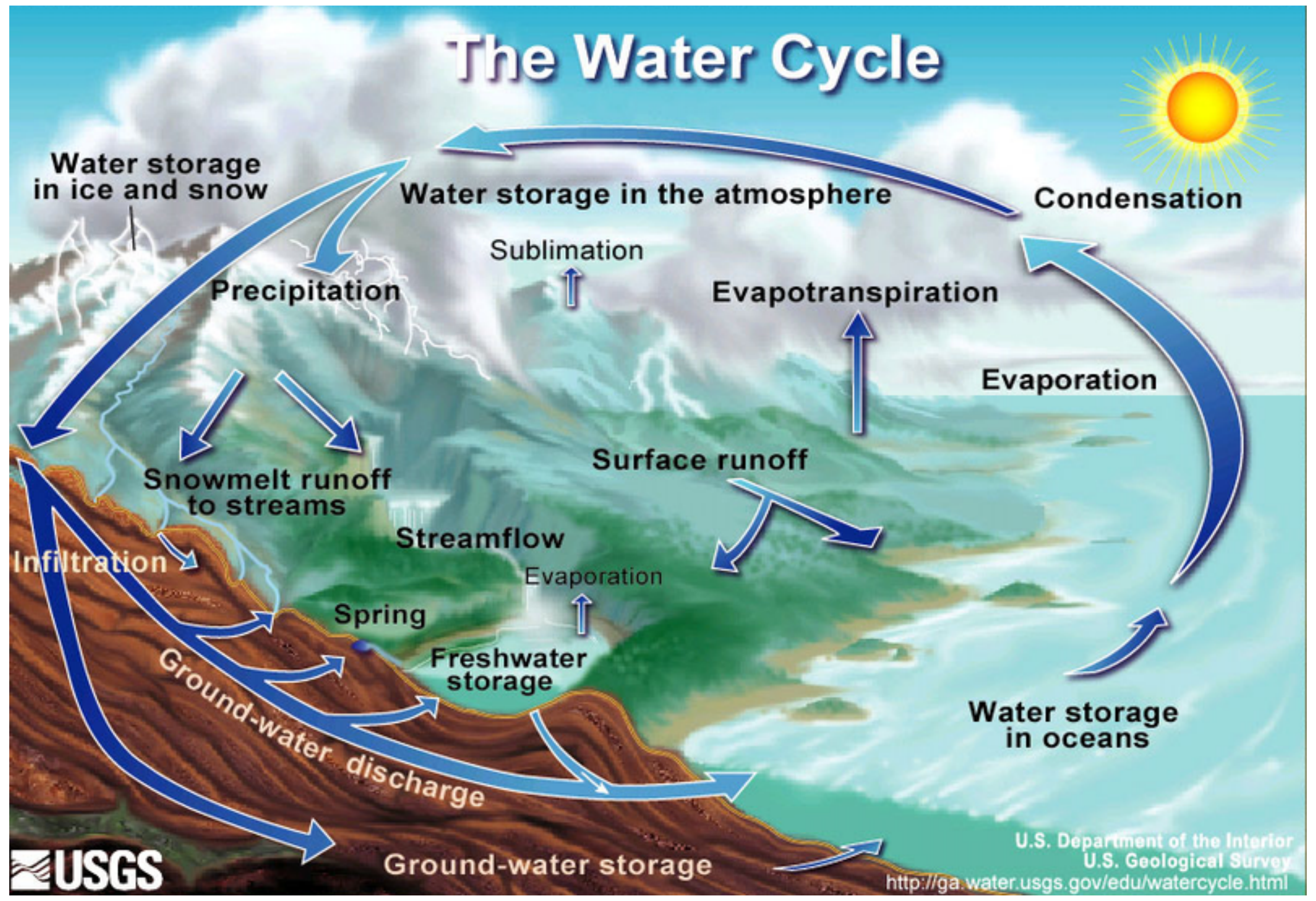
PLANT UPTAKE, INTERCEPTION, TRANSPIRATION
Plants take up water from the ground, and later transpire it back into the air.

INFILTRATION, PERCOLATION, SUBSURFACE FLOW, AQUIFER, WATER TABLE, SEEPAGE, SPRING, WELL
Water is soaked into the ground, flows below it, and seeps back out enriched in minerals.

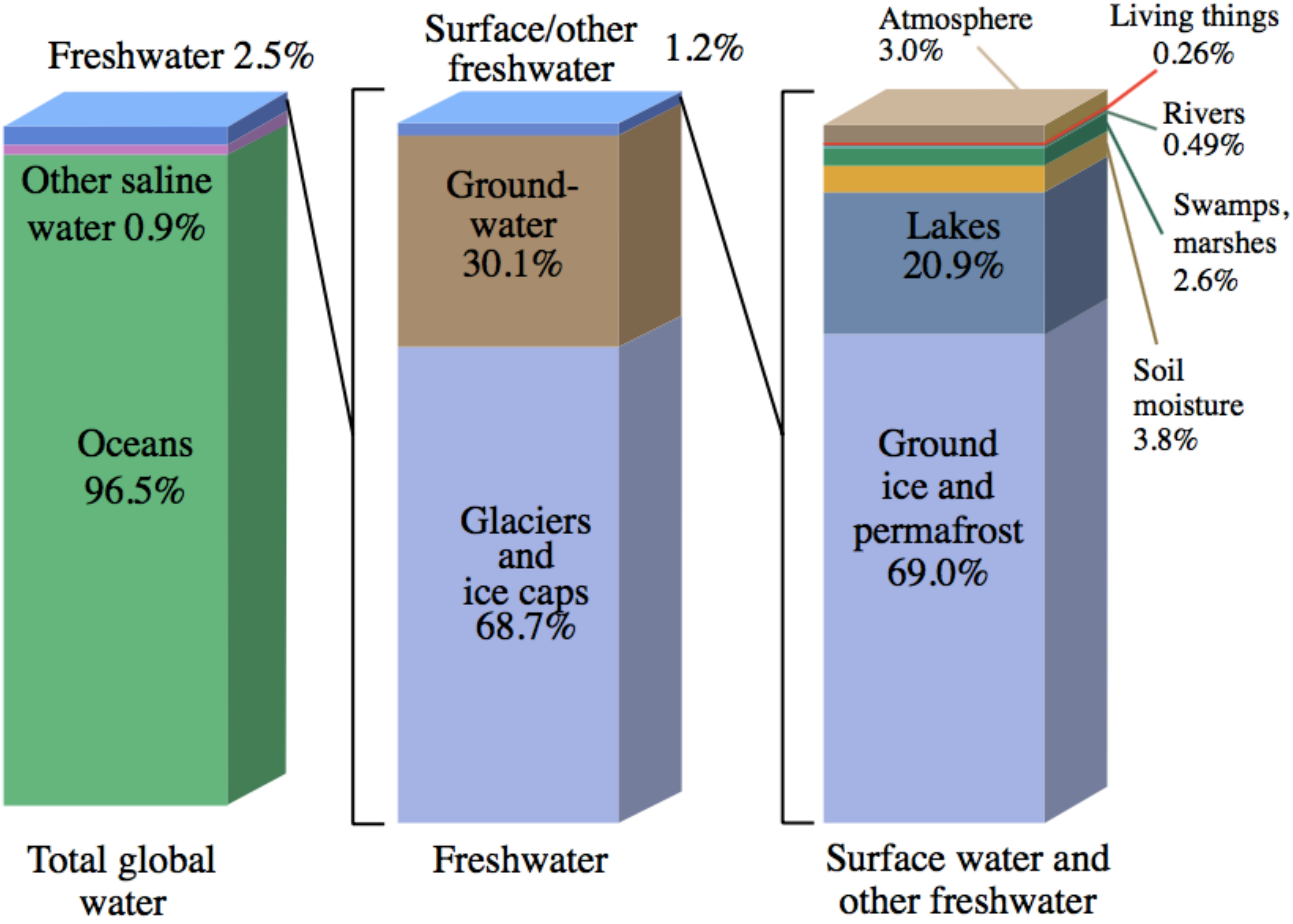
VOLCANIC STEAM, GEYSERS, SUBDUCTION
Water penetrates the earth's crust, and comes back out as geysers or volcanic steam

https://en.wikipedia.org/wiki/Water_cycle#/media/File:Diagram_of_the_Water_Cycle.jpg

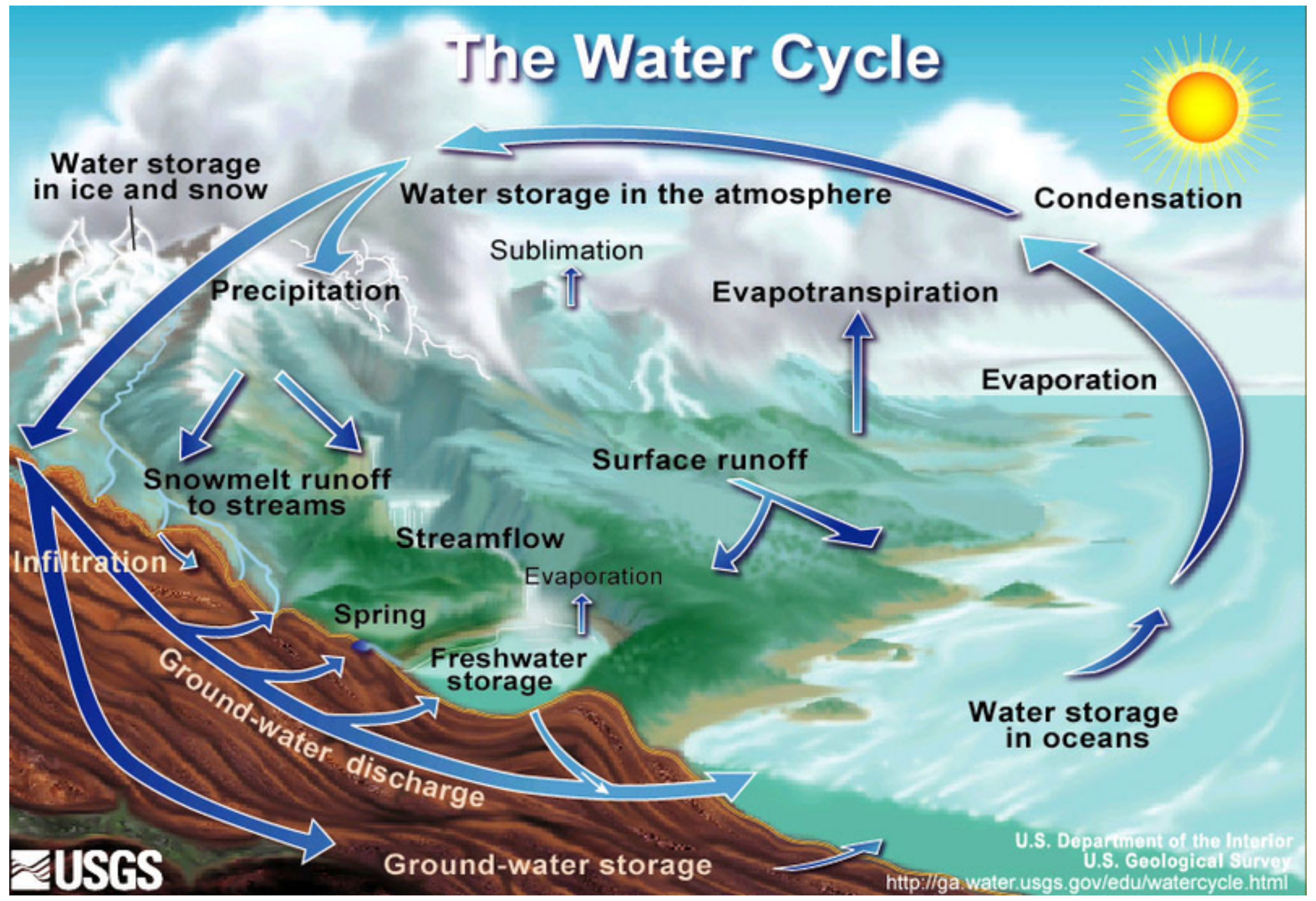
Water Cycle



https://scied.ucar.edu/longcontent/water-cycle



Water Cycle

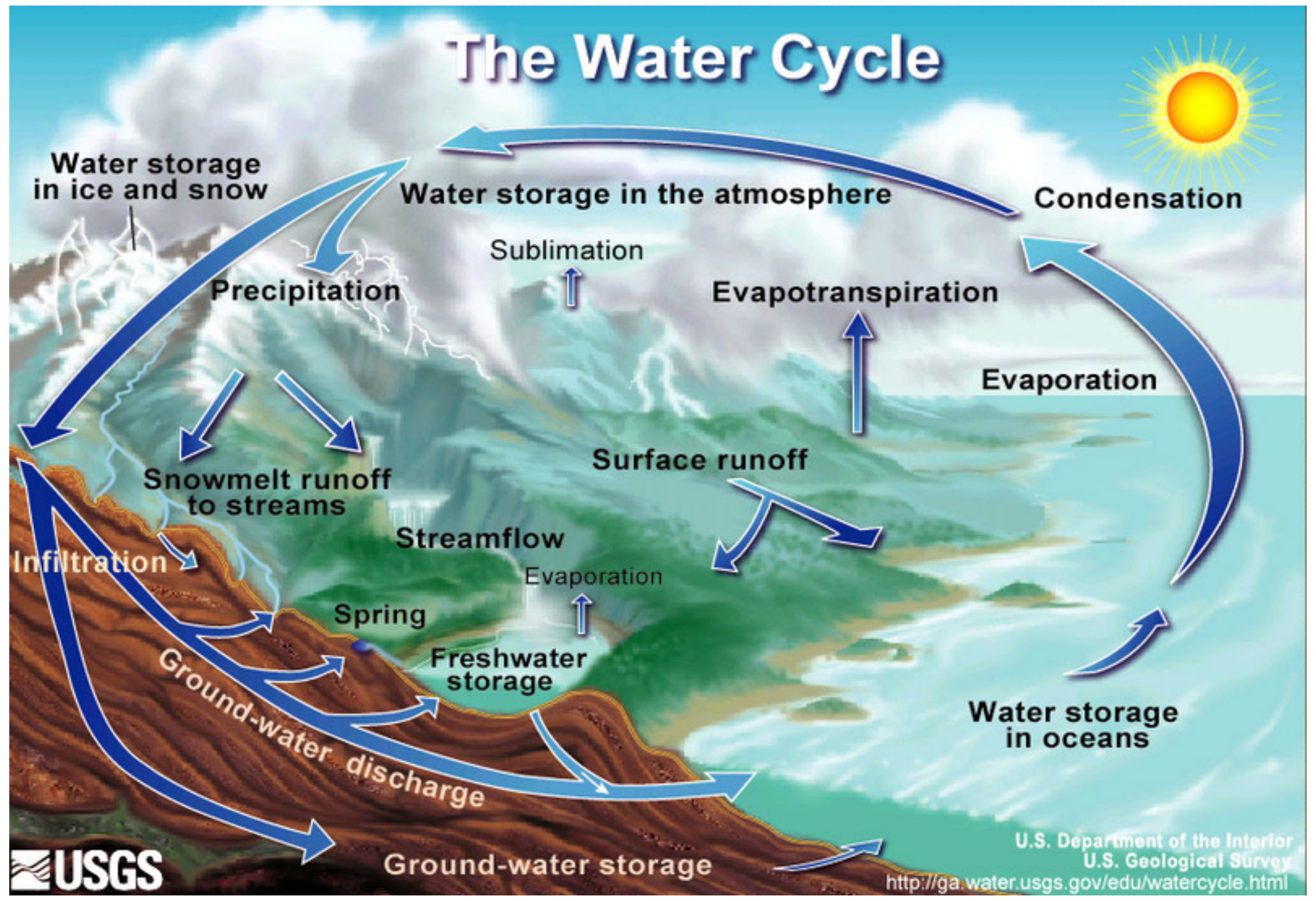


https://scied.ucar.edu/longcontent/water-cycle

Table 1: Amounts of water in the cycle

Reservoir	Volume	% of a larger reservoir
All of Earth's water	1,386,000,000 to 1,460,000,000 km^3	NA
Oceans	1,338,000,000 to 1,400,000,000 km^3	97% of total water
Fresh water	35,030,000 km^3	2.5 to 3% of total water
Ice & snow	43,400,000 km^3	-
Ice caps, glaciers, and permanent snow	24,064,000 to 29,000,000 km^3	68.7% of fresh water about 2% of total water
Antarctic ice & snow	29,000,000 km^3	about 90% of all ice
Greenland	3,000,000 km^3	about 10% of all ice
Mountain Glaciers	100,000 km^3	-
Ground water (saline+fresh)	23,400,000 km^3	-
Ground water (saline)	-	54% of ground water
Ground water (fresh)	10,530,000 km^3	30.1% of fresh water 46% of ground water
Surface water (fresh)	350,300 km^3	1% of fresh water
Lakes	-	87% of surface fresh water
Swamps	-	11% of surface fresh water
Rivers	-	2% of surface fresh water
Atmosphere	12,000 to 15,000 km^3	-

Water Cycle



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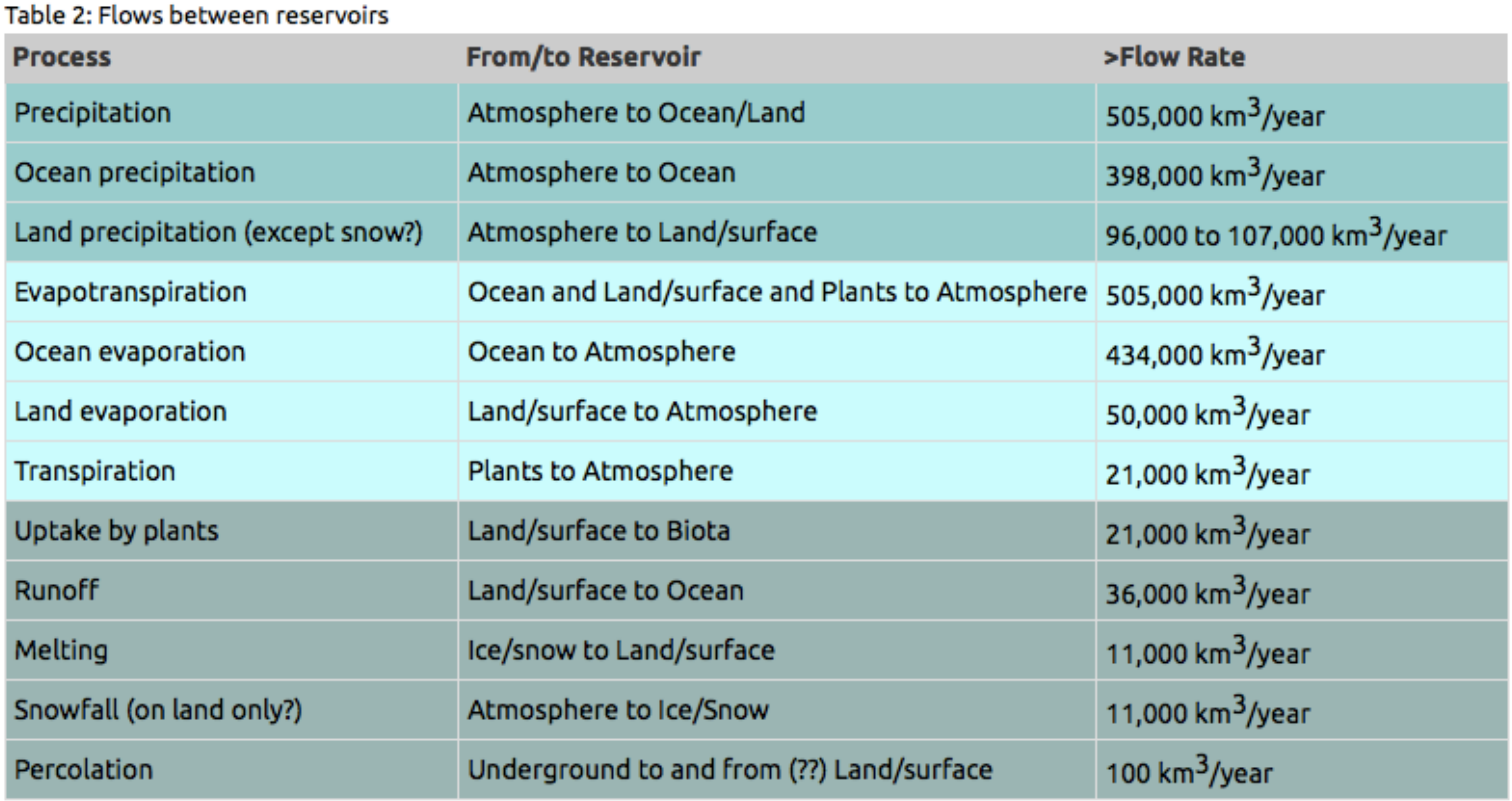
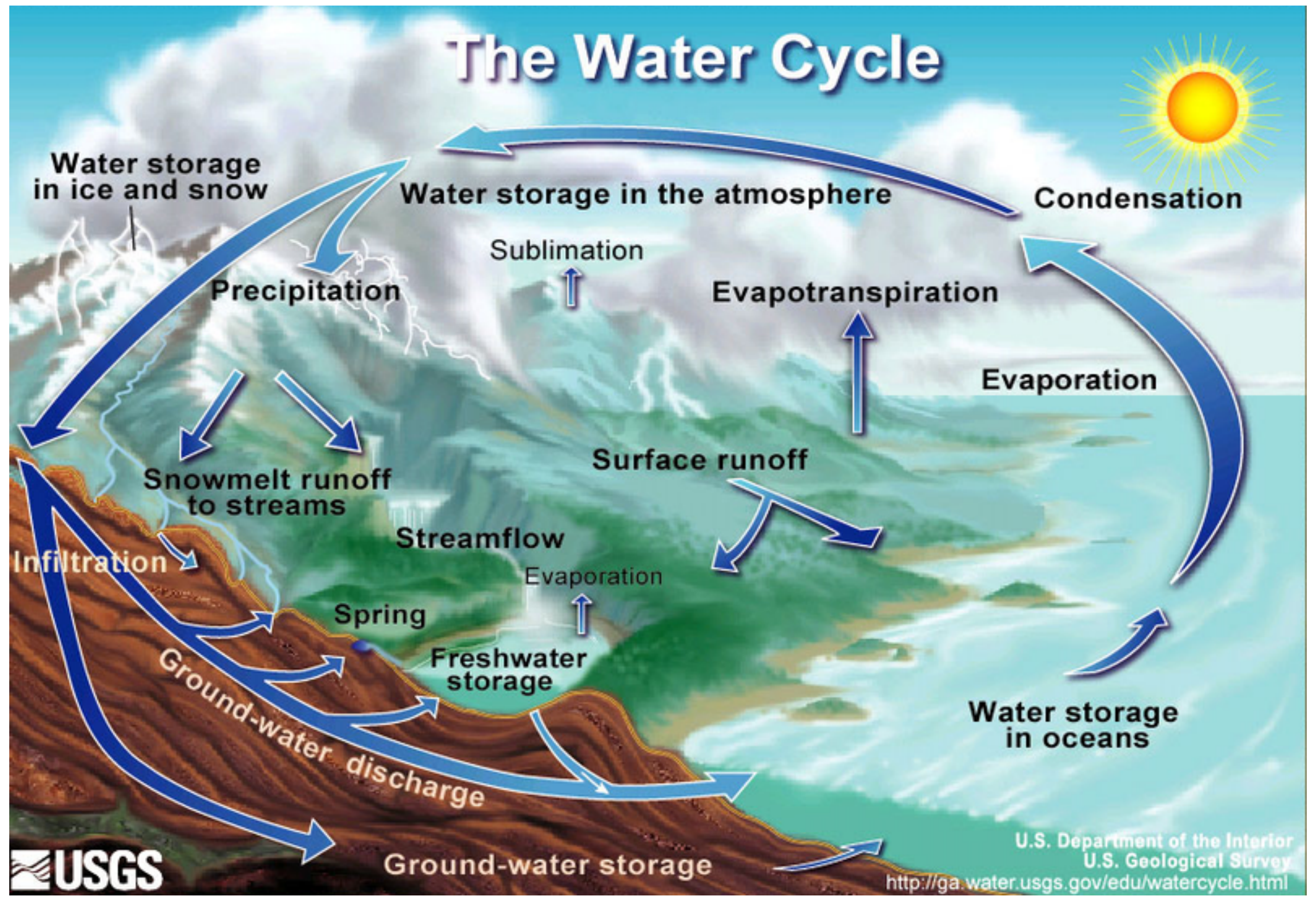


Table 2: Flows between reservoirs

Process	From/to Reservoir	>Flow Rate
Precipitation	Atmosphere to Ocean/Land	505,000 km^3/year
Ocean precipitation	Atmosphere to Ocean	398,000 km^3/year
Land precipitation (except snow?)	Atmosphere to Land/surface	96,000 to 107,000 km^3/year
Evapotranspiration	Ocean and Land/surface and Plants to Atmosphere	505,000 km^3/year
Ocean evaporation	Ocean to Atmosphere	434,000 km^3/year
Land evaporation	Land/surface to Atmosphere	50,000 km^3/year
Transpiration	Plants to Atmosphere	21,000 km^3/year
Uptake by plants	Land/surface to Biota	21,000 km^3/year
Runoff	Land/surface to Ocean	36,000 km^3/year
Melting	Ice/snow to Land/surface	11,000 km^3/year
Snowfall (on land only?)	Atmosphere to Ice/Snow	11,000 km^3/year
Percolation	Underground to and from (??) Land/surface	100 km^3/year

Water Cycle



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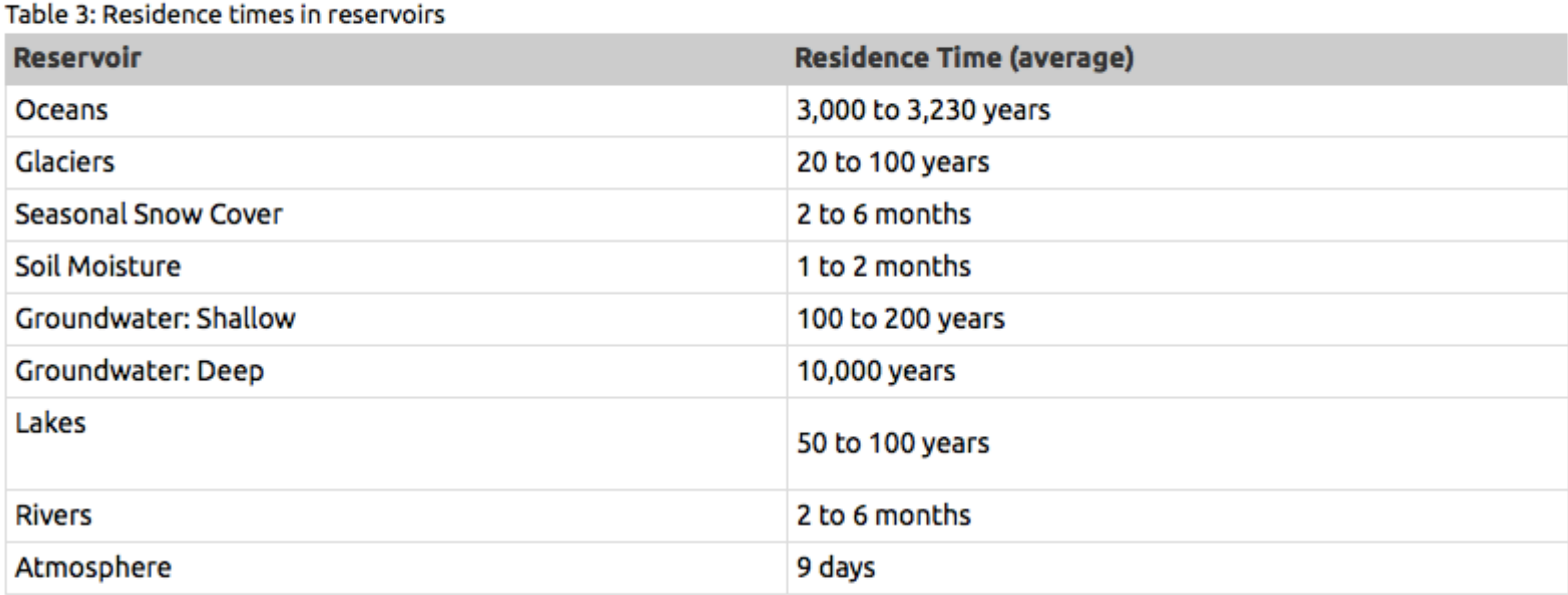
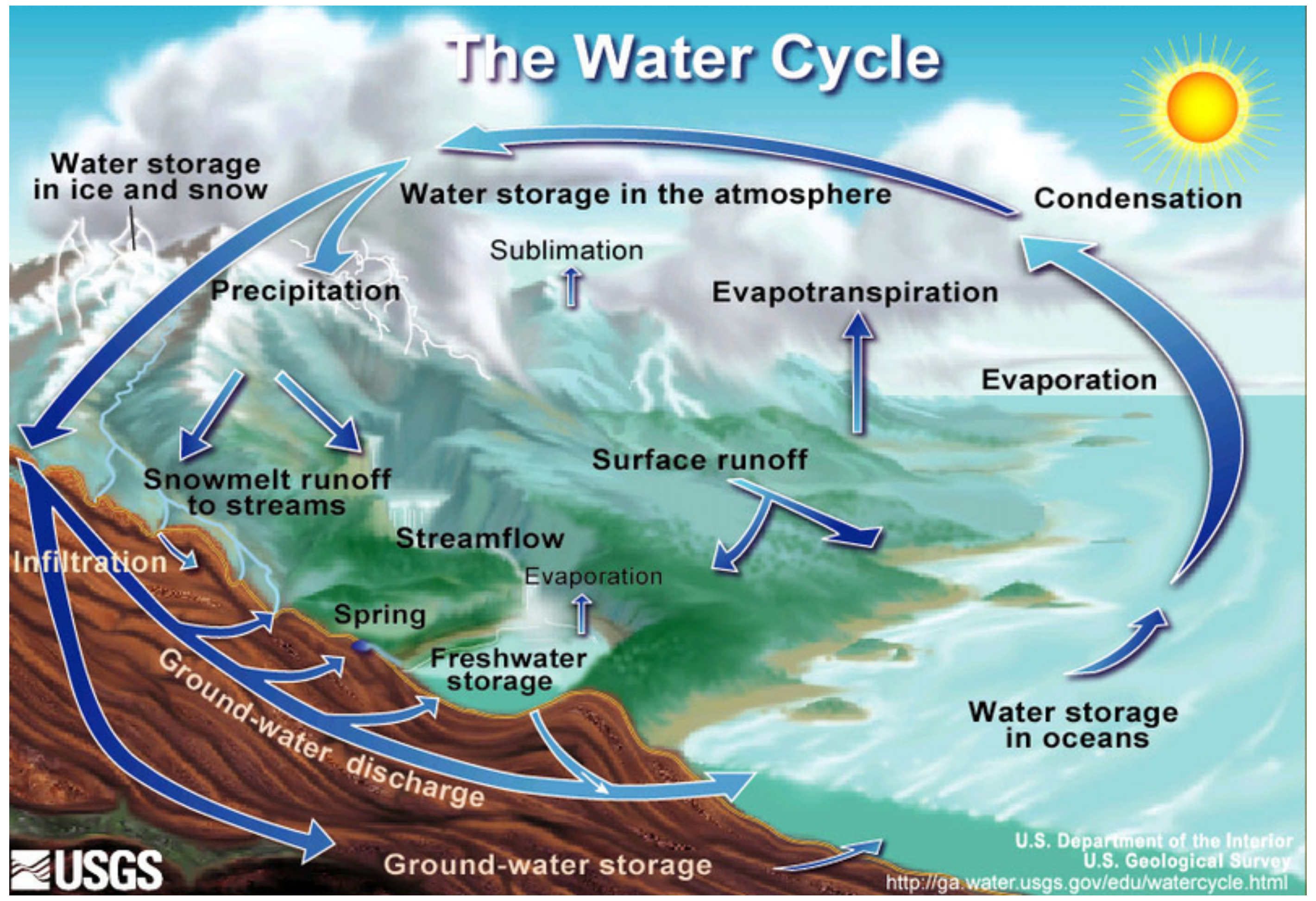


Table 3: Residence times in reservoirs

Reservoir	Residence Time (average)
Oceans	3,000 to 3,230 years
Glaciers	20 to 100 years
Seasonal Snow Cover	2 to 6 months
Soil Moisture	1 to 2 months
Groundwater: Shallow	100 to 200 years
Groundwater: Deep	10,000 years
Lakes	50 to 100 years
Rivers	2 to 6 months
Atmosphere	9 days

Water Cycle



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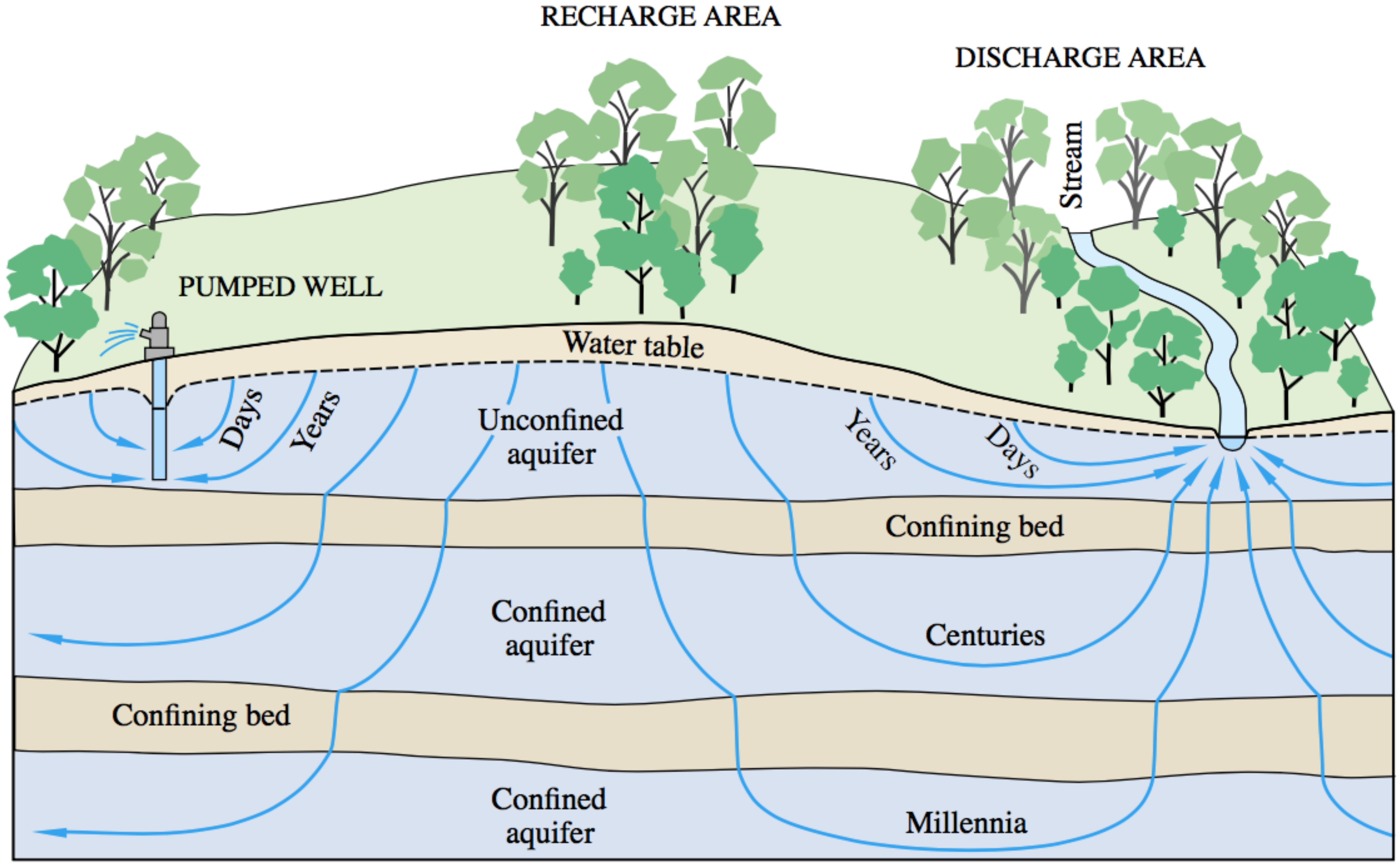
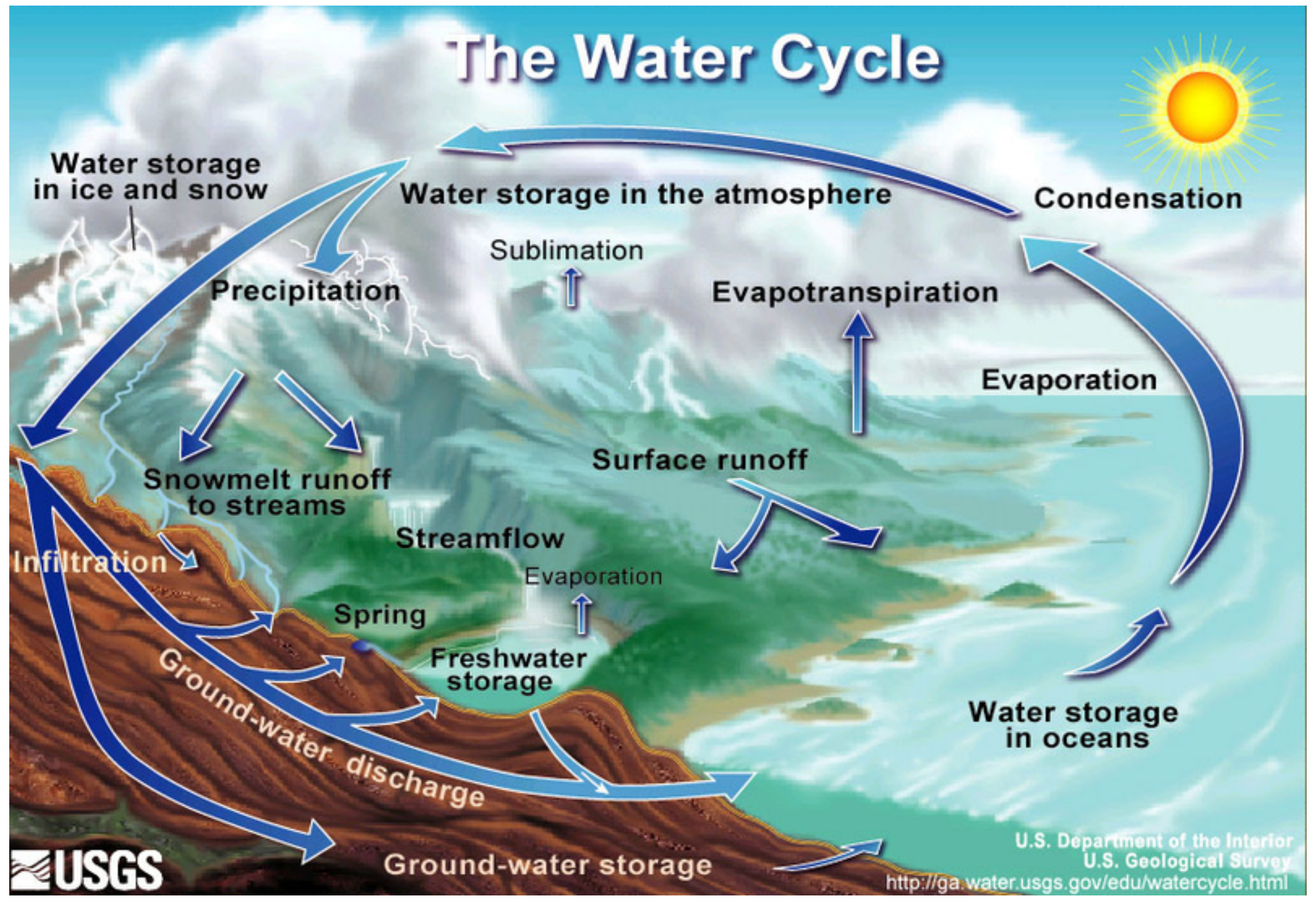
Aquifers are either confined or unconfined



Water Cycle



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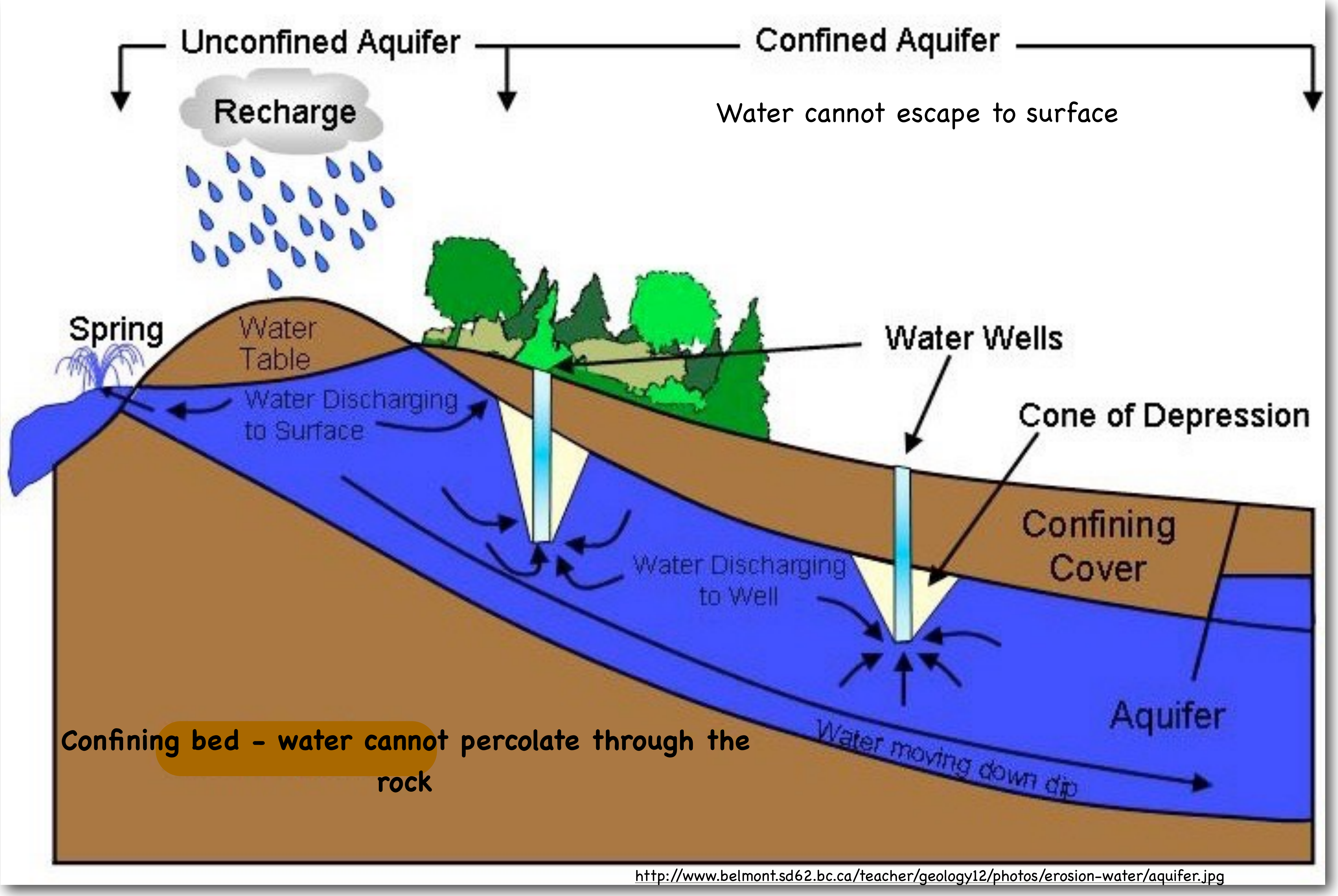


Water cannot escape to surface

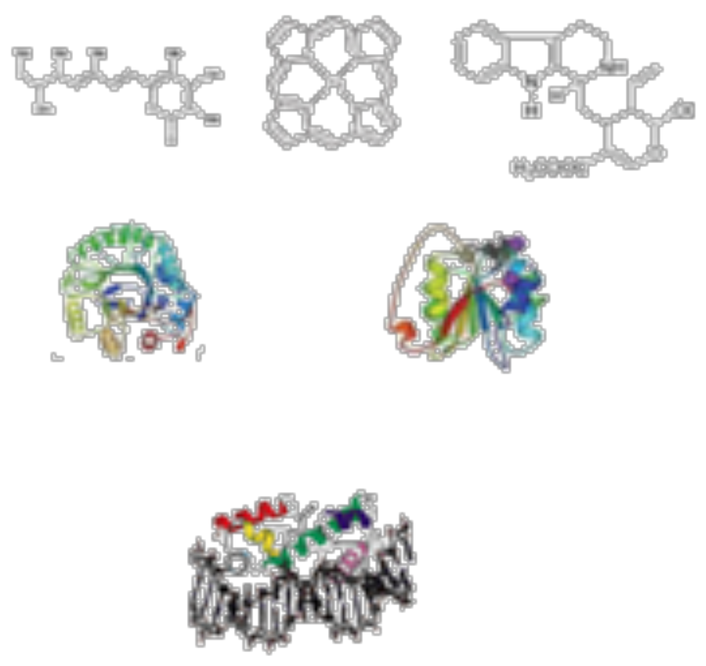
Confining bed - water cannot percolate through the rock

http://www.belmont.sd62.bc.ca/teacher/geology12/photos/erosion-water/aquifer.jpg

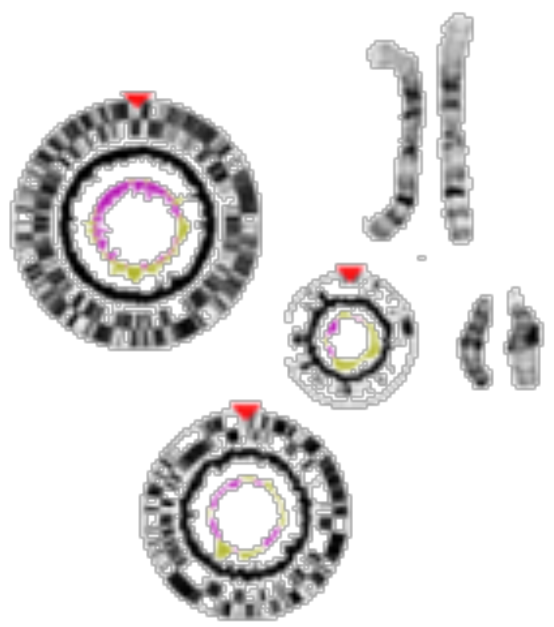
Aquifers are either confined or unconfined

So what happens if we pump the water out faster than it is being recharged by rain and snow?

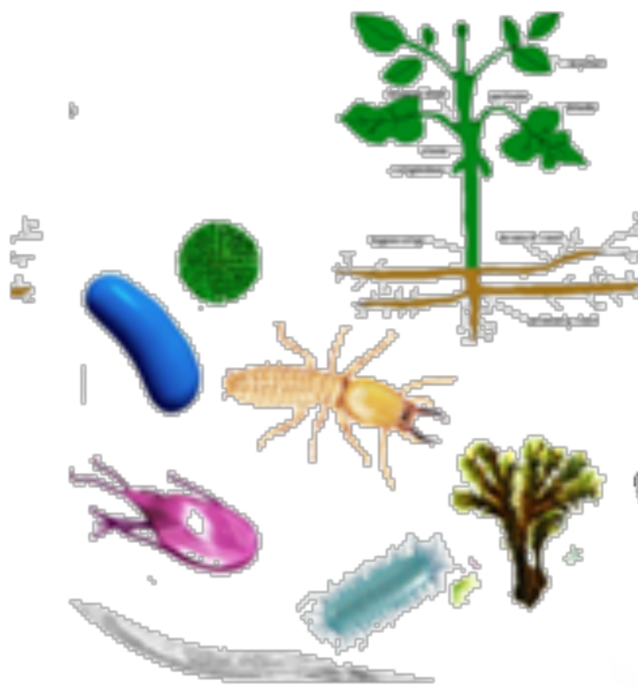
Water-Energy Cycle



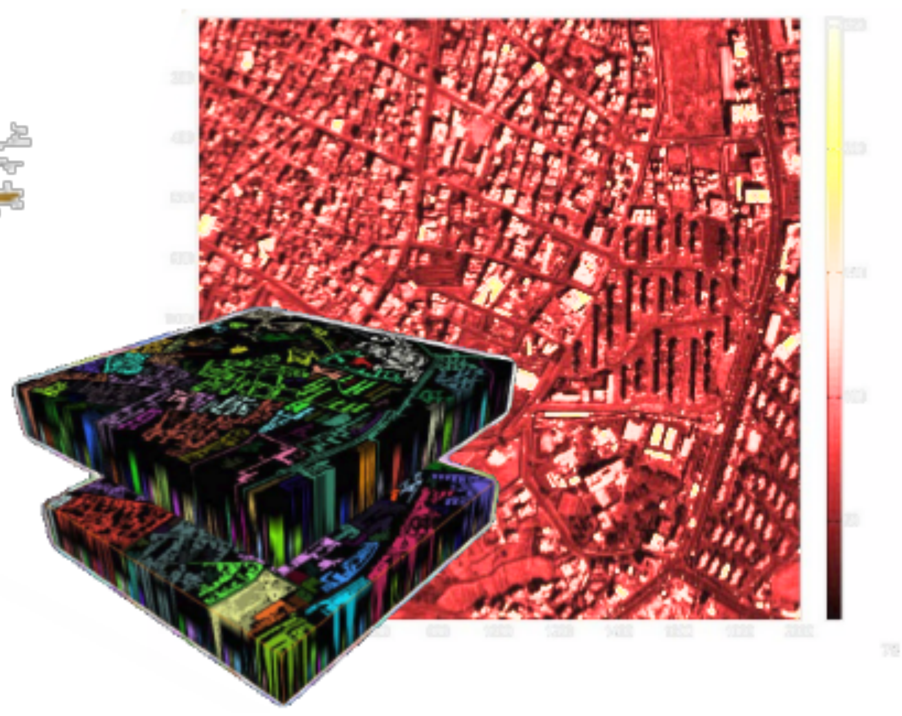
Biomolecular Mechanisms, Models and Networks



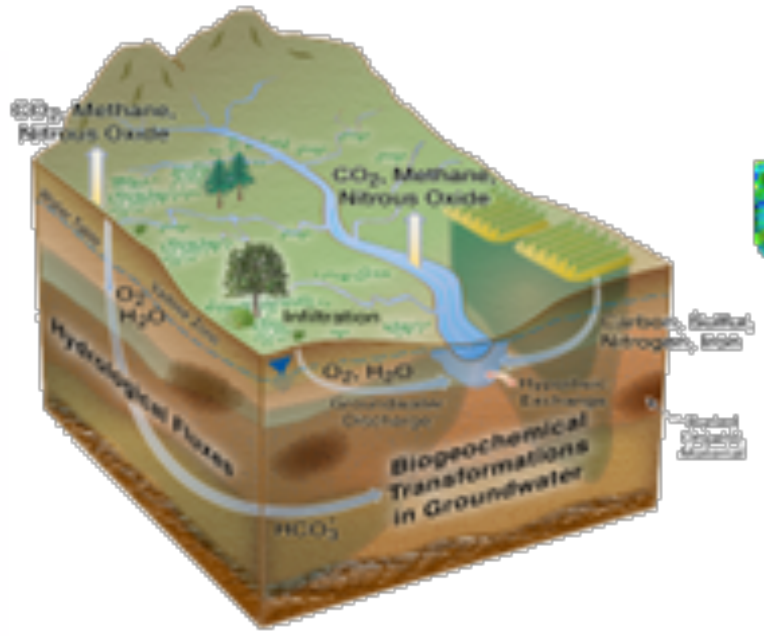
Genomics and Functional Genomics



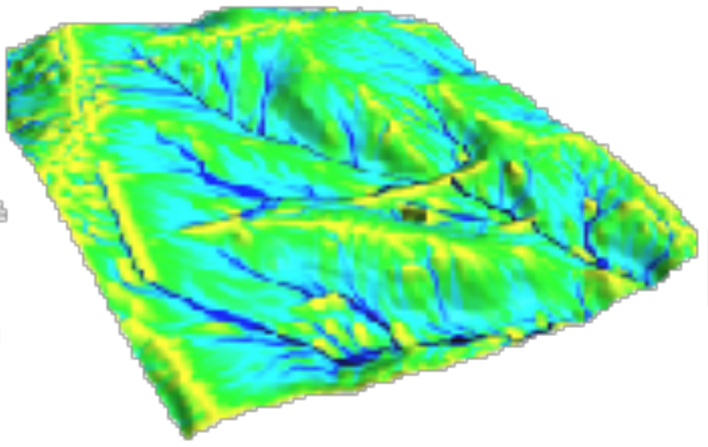
Organismal Biology, Dynamics and Interactions



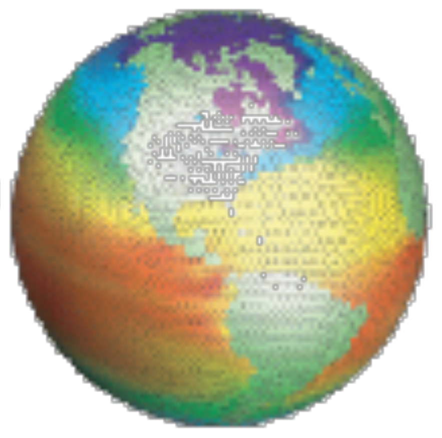
Human earth-system interactions



Terrestrial Ecology and Subsurface Biogeochemistry



Watershed Hydrobio, Dynamic Vegetation observation and models

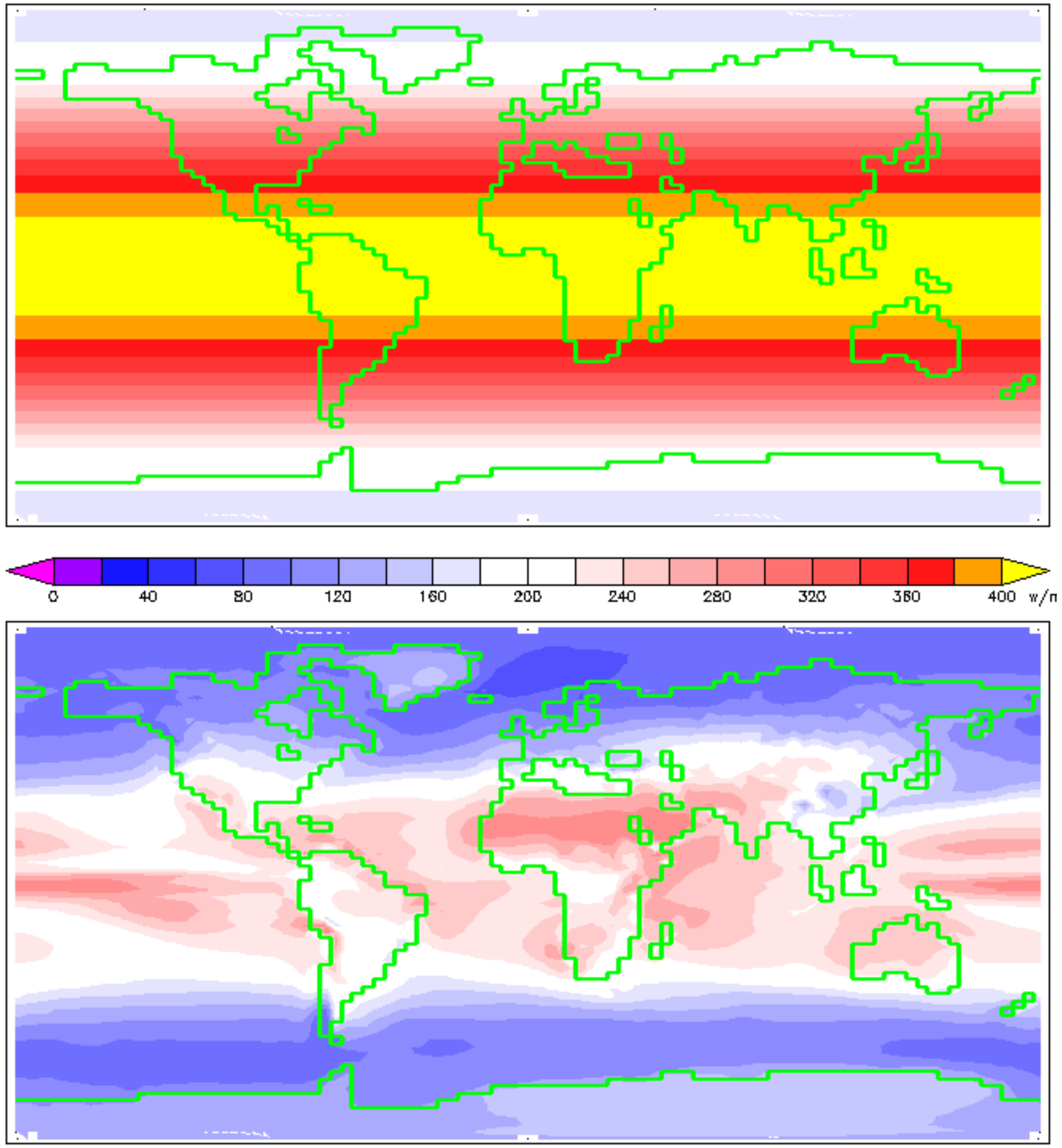


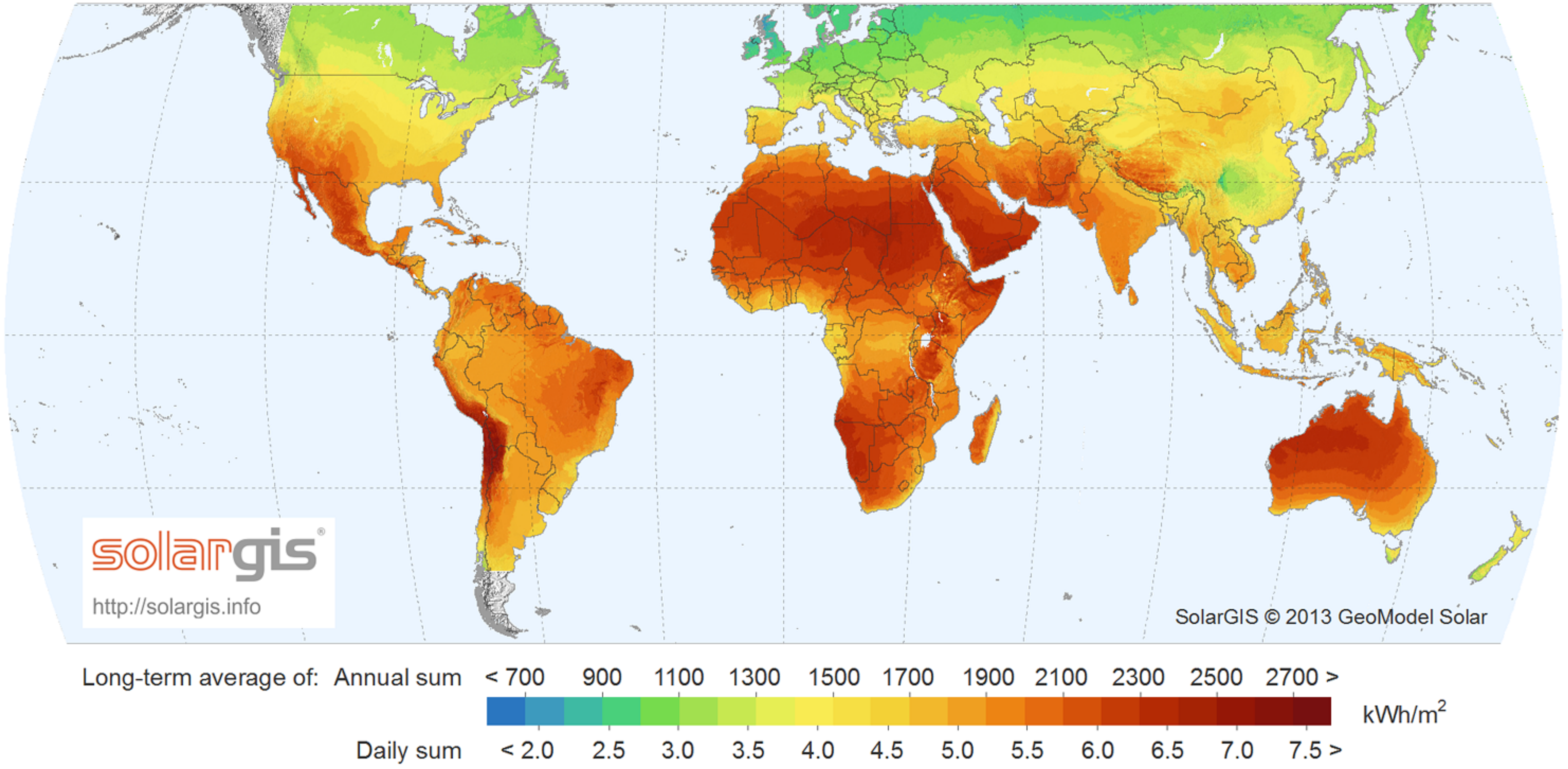
Land atmosphere, Earth System observation and models

Femtoseconds (10^{-15} s)
Angstroms (10^{-10} m)

Years (10^{12} s)
Kilometers (10^{7} m)

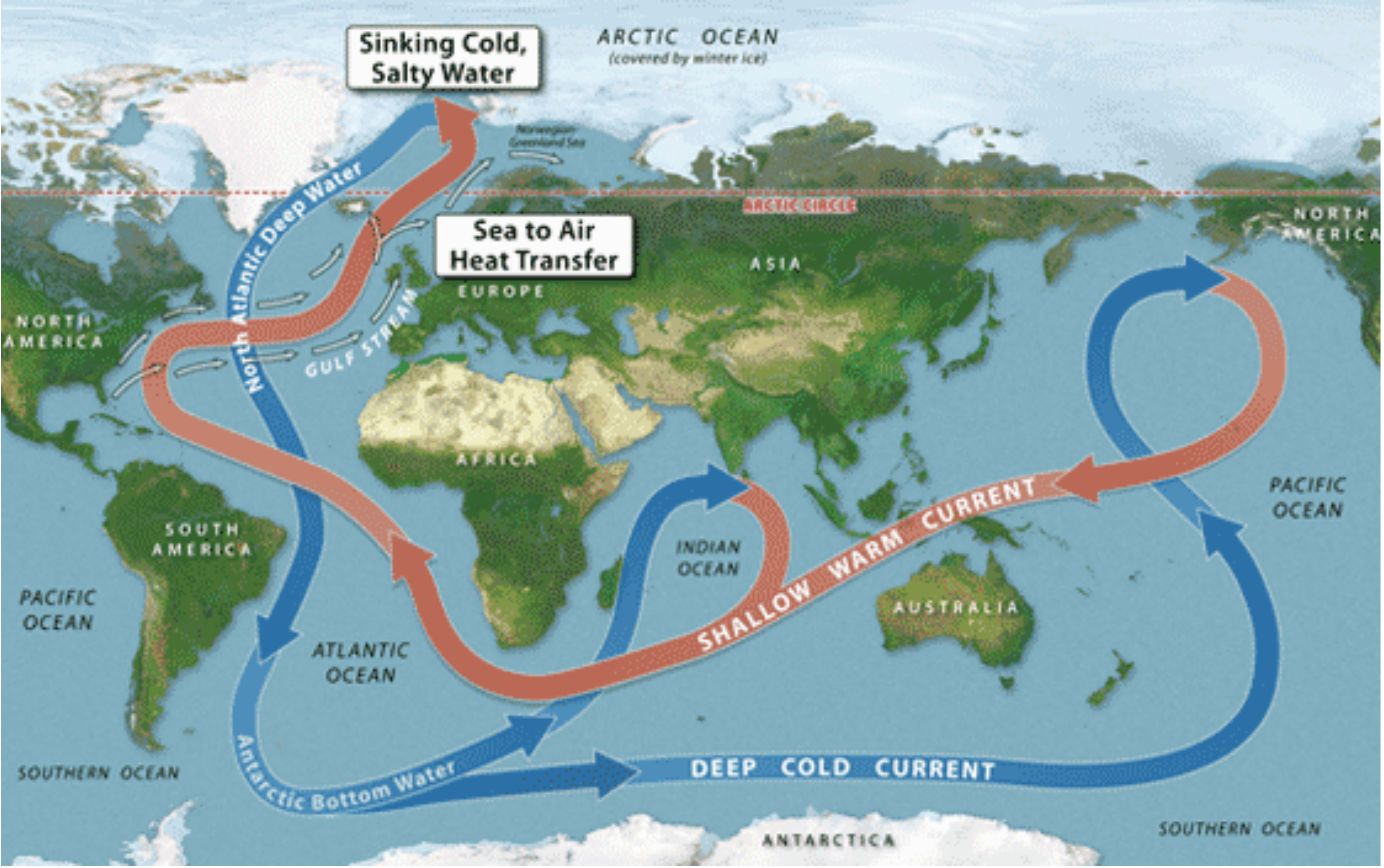
Water-Energy Cycle





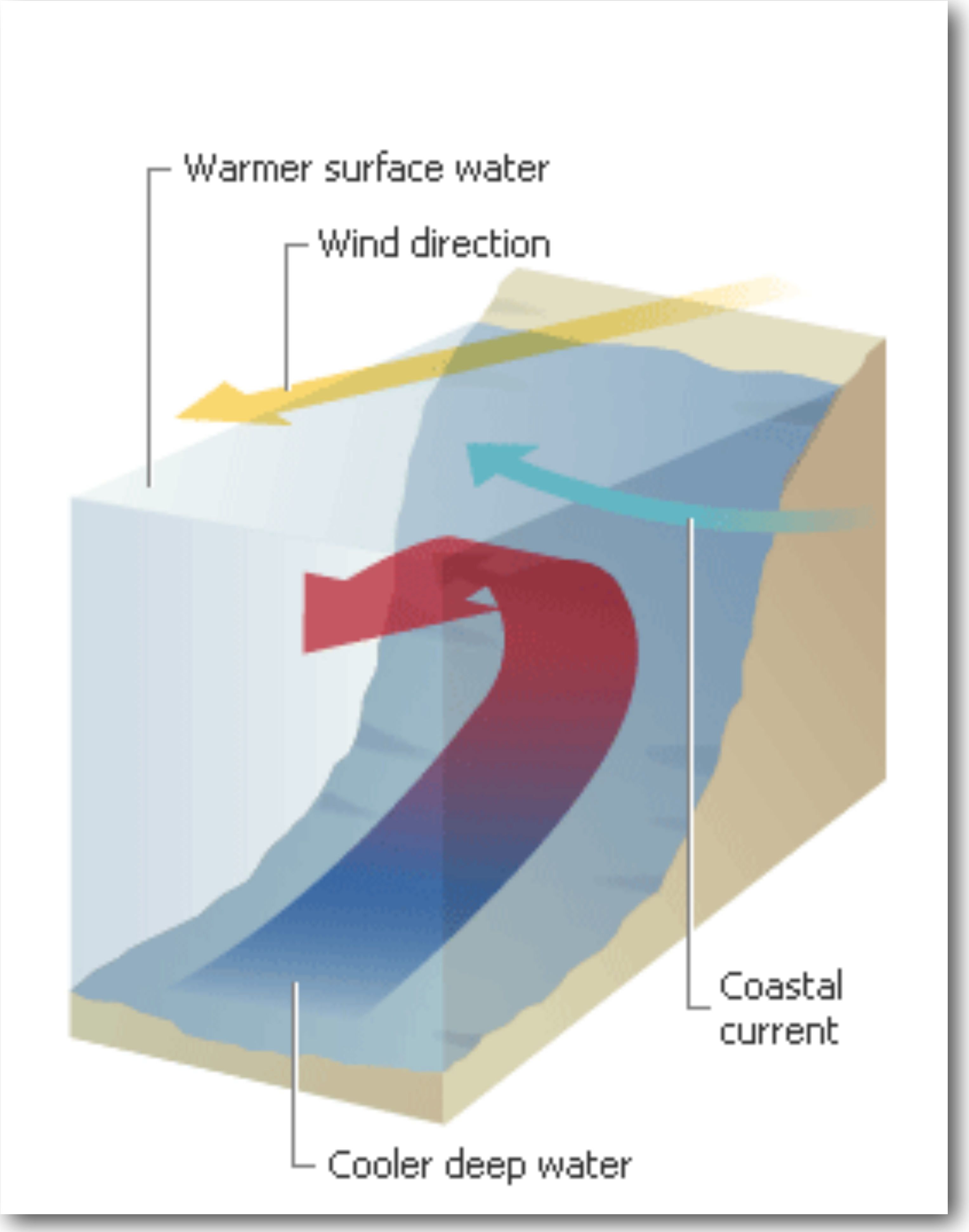
Water-Energy Cycle

Ocean circulation



Water-Energy Cycle

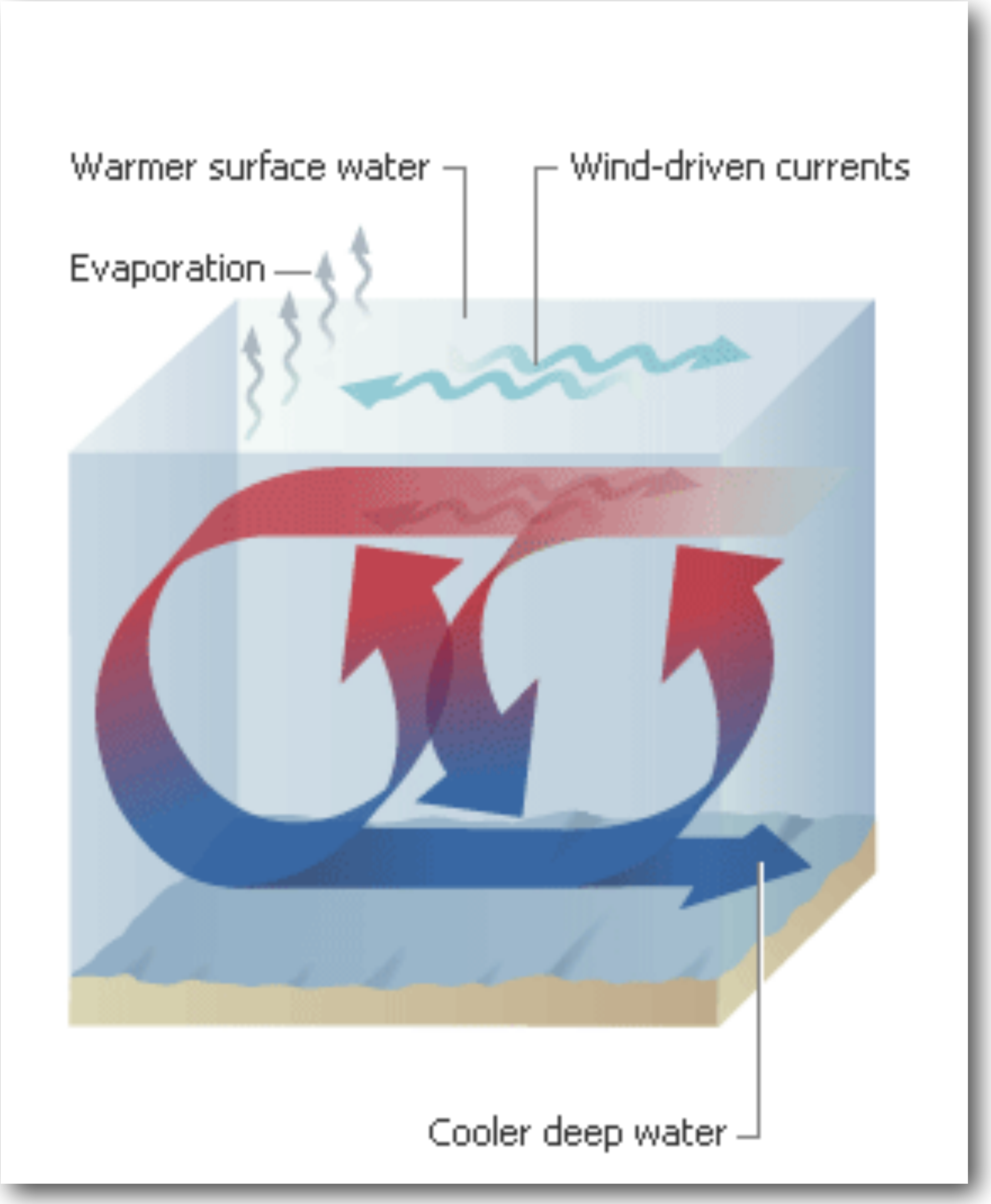
ocean circulation driven by:
(a) wind



http://images.encarta.msn.com/xrefmedia/aencmed/targets/illus/ilt/T014098A.gif

upwelling of cold water as wind pushes warmer water offshore

(b) evaporation



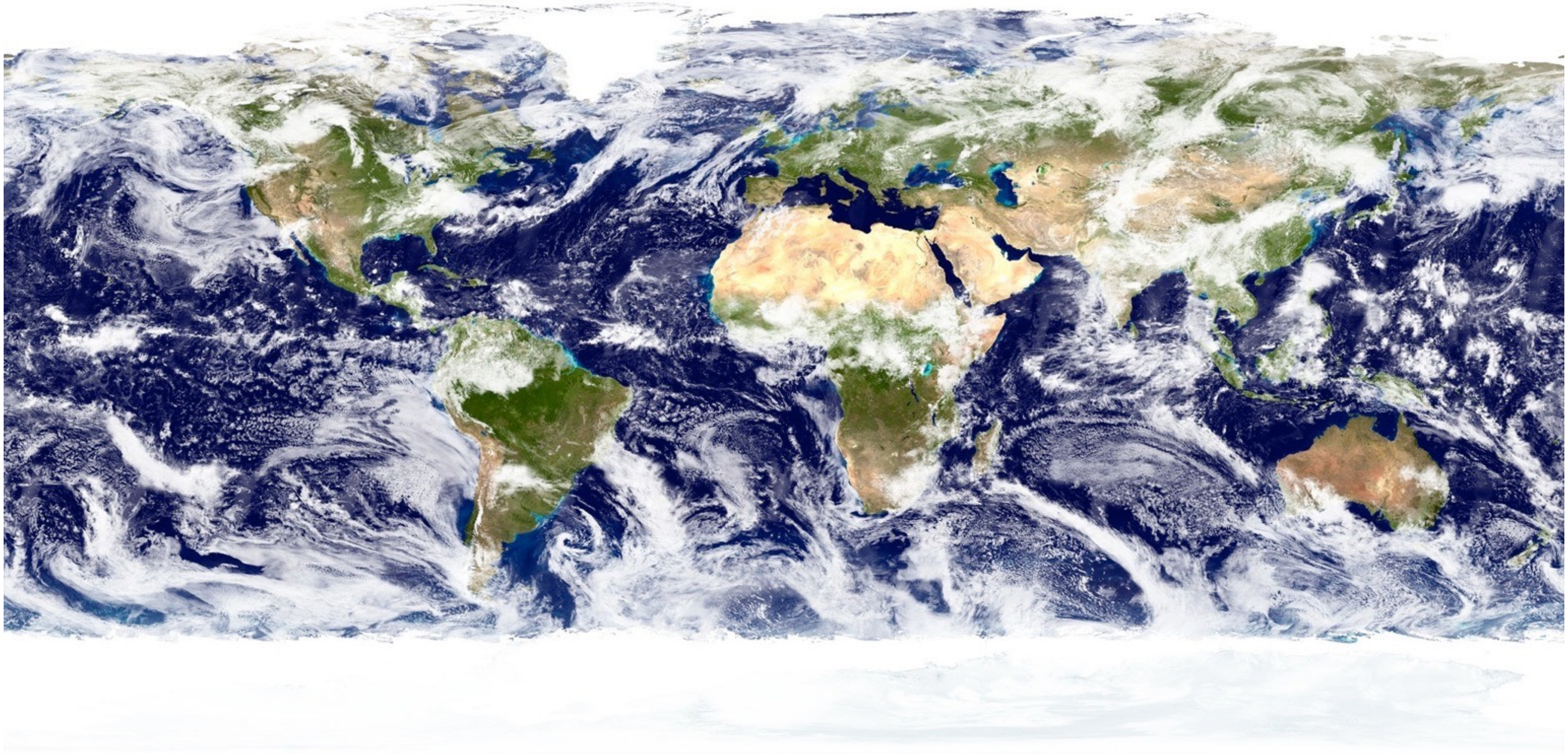
"thermo-haline" circulation

caused by changes in temperature (thermo)and salt (haline) content

colder, salty water is denser
- sinks to bottom of ocean

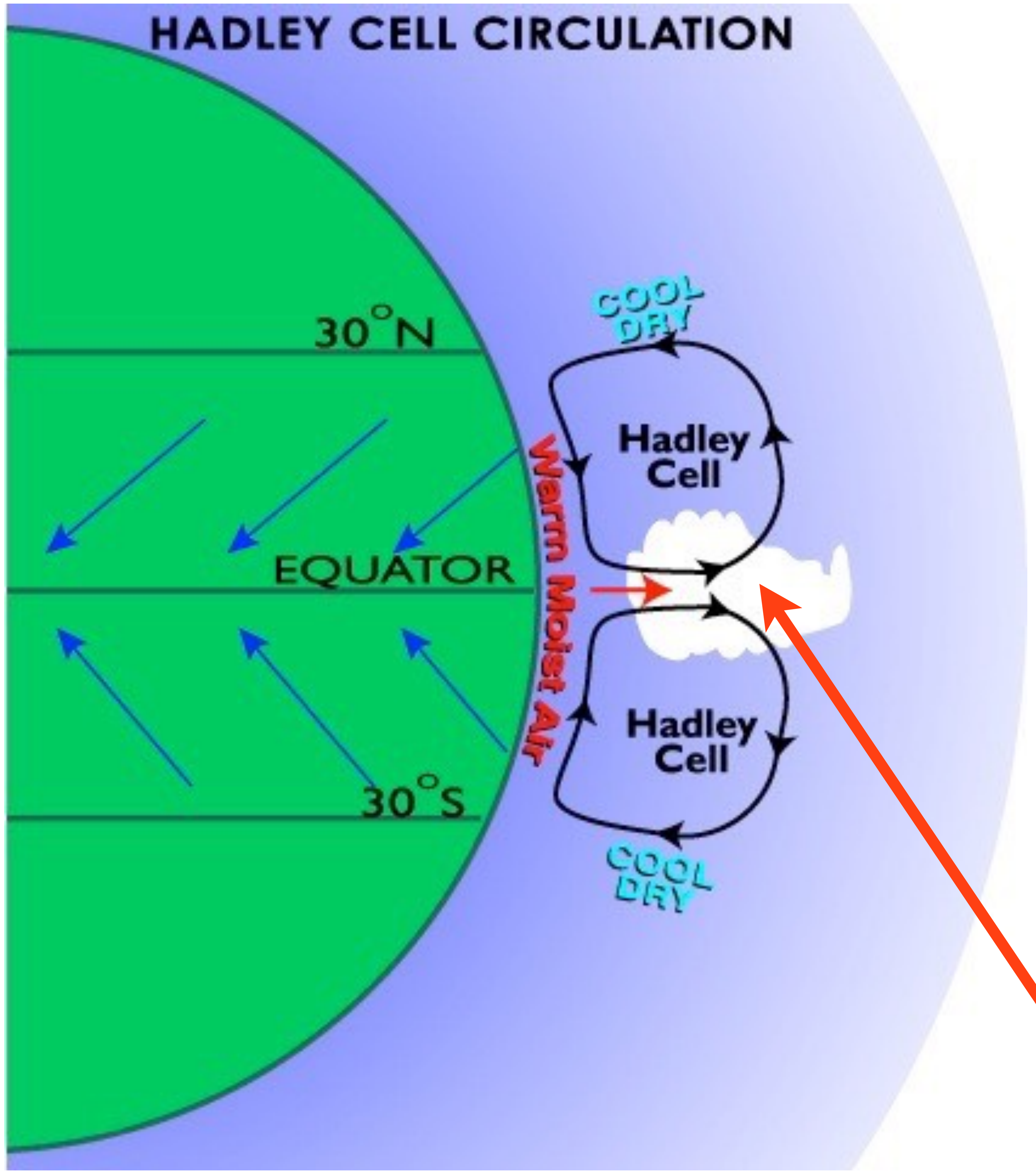
warm, fresh water is less dense
- stays near surface of ocean

Atmospheric circulation



http://earthobservatory.nasa.gov/Features/BlueMarble/Images/land_ocean_ice_cloud_2048.jpg

Hadley cells in tropical zones influence predominant wind direction across entire planet

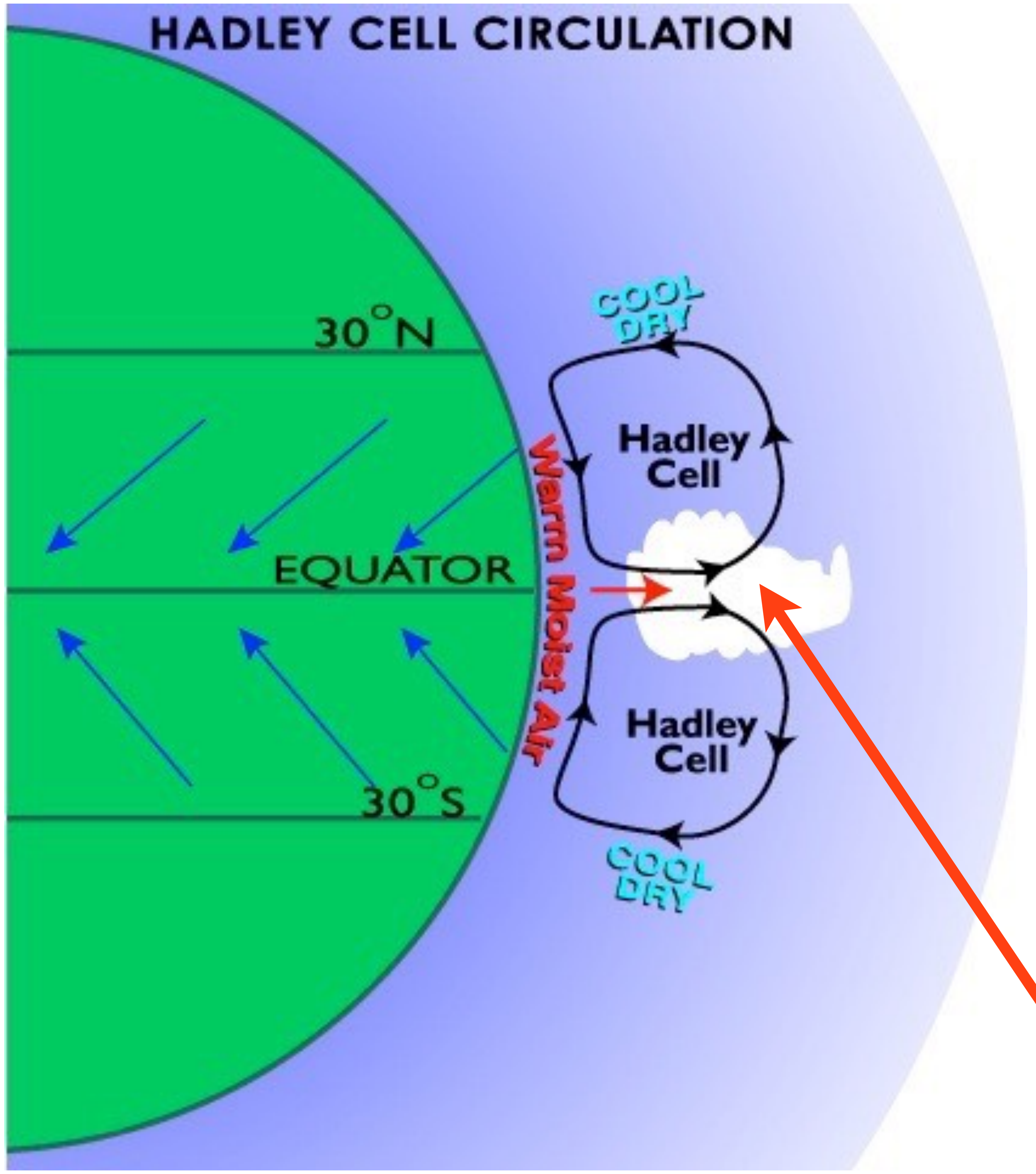


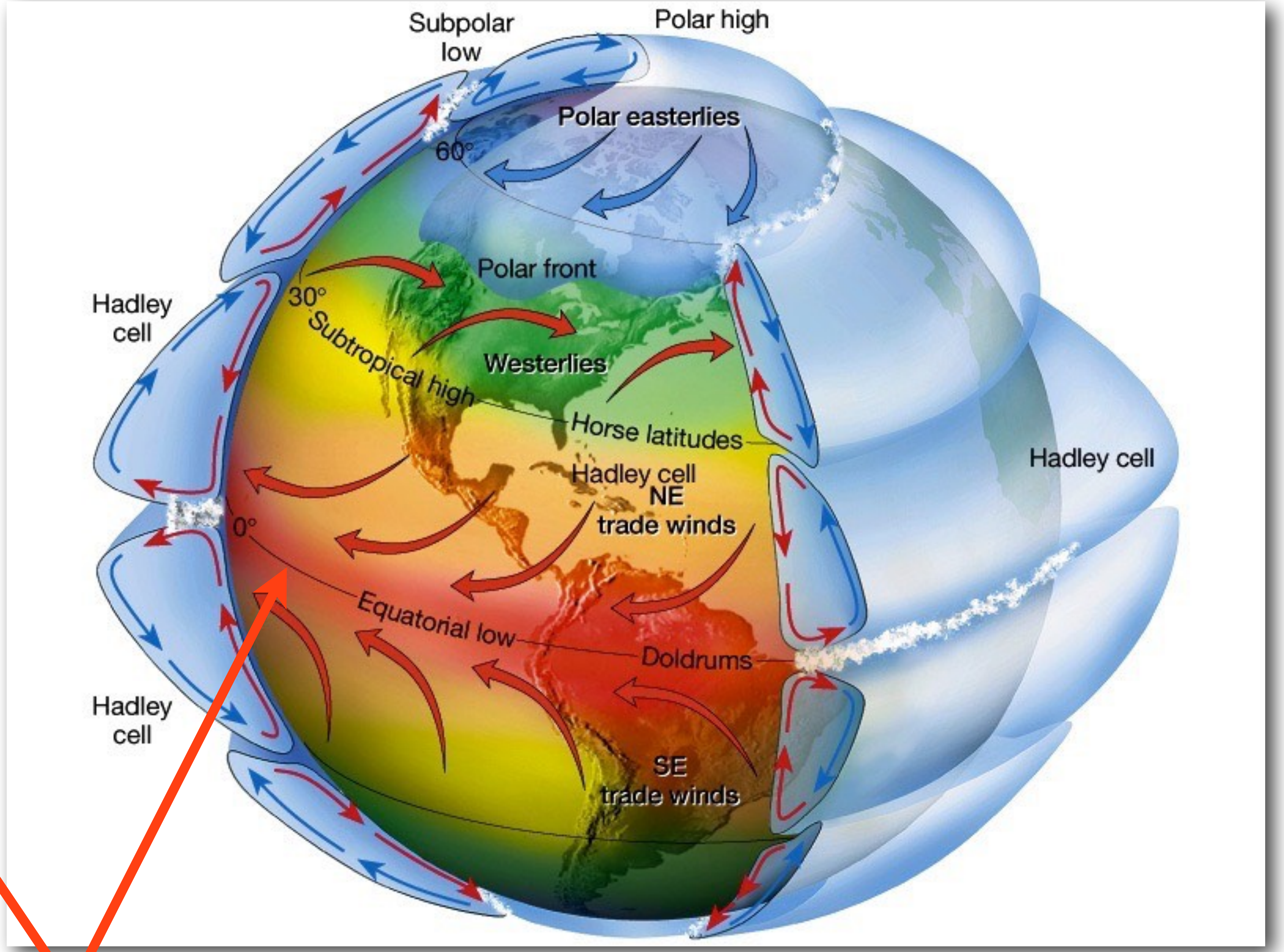
http://www.newmediastudio.org/DataDiscovery/Hurr_ED_Center/Easterly_Waves/Trade_Winds/Trade_Winds_fig02.jpg

Form in the Trade Winds belt (on either side of equator, between 30°N and 30°S)

equatorial “doldrums”
- where warm, moist air rises

Hadley cells in tropical zones influence predominant wind direction across entire planet





equatorial “doldrums”
- where warm, moist air rises

http://www.geology.um.maine.edu/ges121/lectures/20-monsoons/hadley.jpg

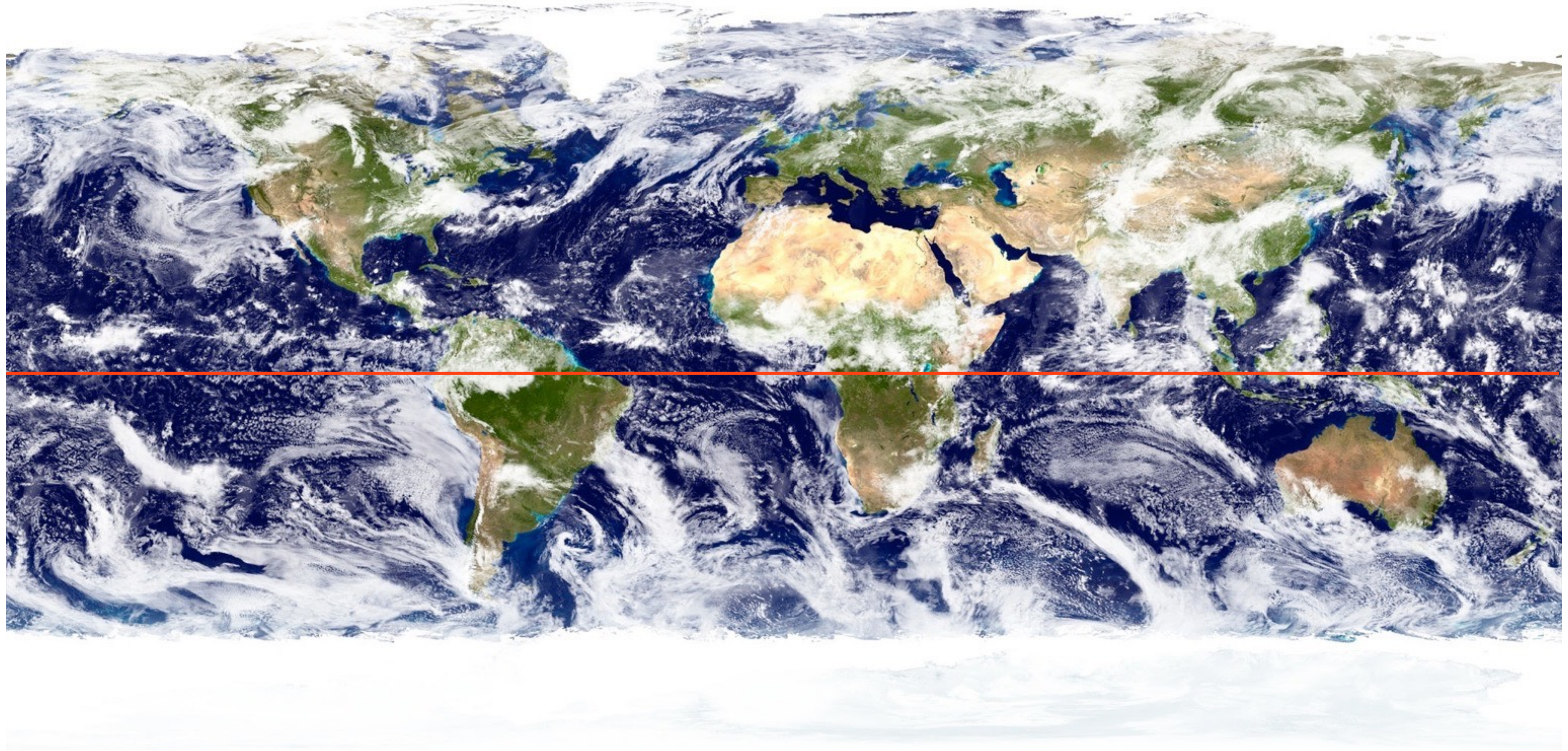
Water-Energy Cycle

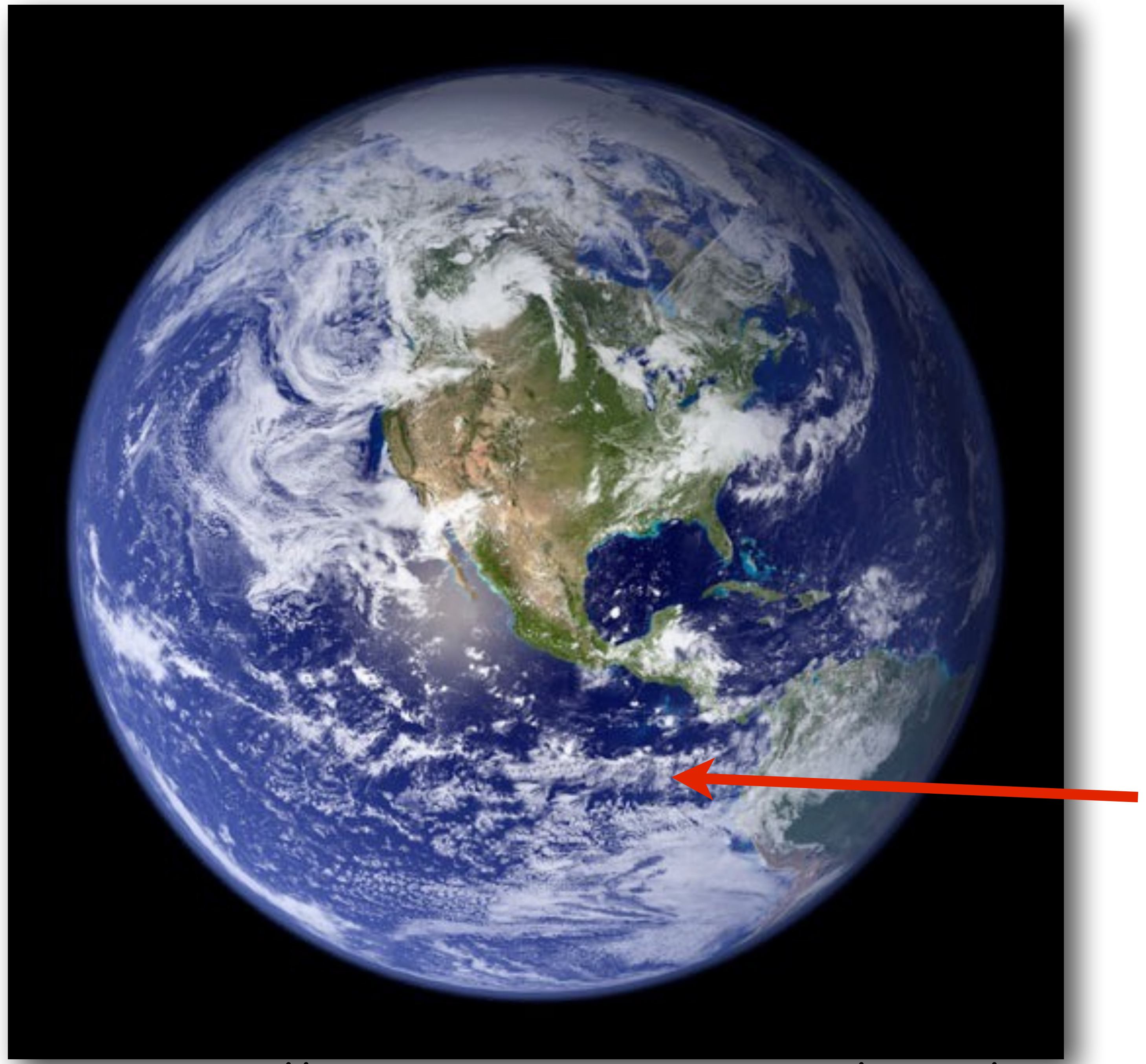
Hadley cells together with Coriolis Force (more later on this) influence prevailing wind direction

prevailing winds NE to SW

equatorial “doldrums” →

prevailing winds SE to NW



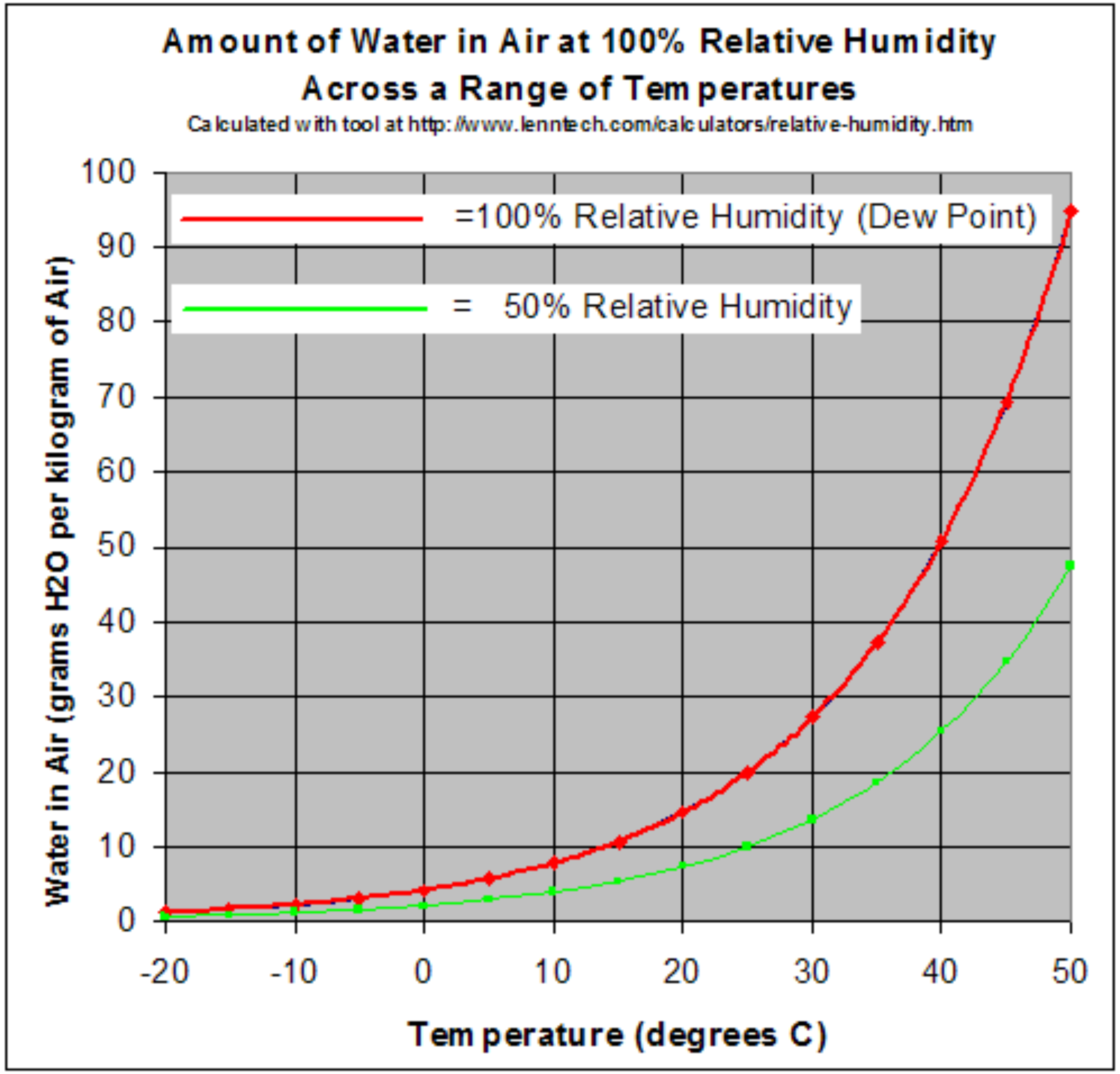


equatorial “doldrums”

http://veimages.gsfc.nasa.gov/2429/globe_west_540.jpg

Water-Energy Cycle

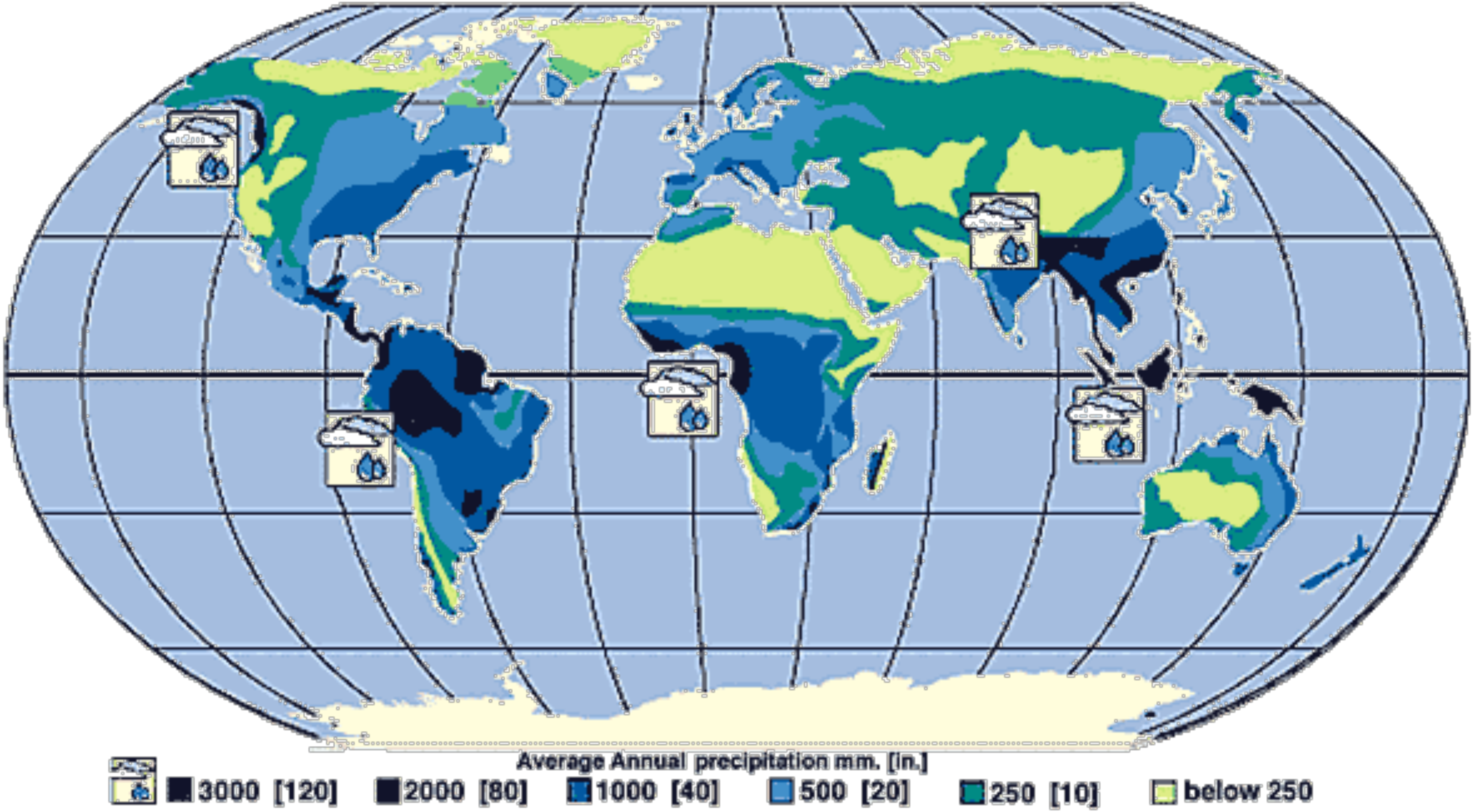
Atmospheric Water Content


Amount of Water in Air at 100% Relative Humidity Across a Range of Temperatures

Calculated with tool at http://www.lenntech.com/calculators/relative-humidity.htm

Temperature		Max. Water Content	
(^{o}C)	(^{o}F)	(10^{-3} kg/m^3)	(10^{-3} lb/ft^3)
-25	-13	0.64	0.040
-20	-4	1.05	0.066
-15	5	1.58	0.099
-10	14	2.31	0.14
-5	23	3.37	0.21
0	32	4.89	0.31
5	41	6.82	0.43
10	50	9.39	0.59
15	59	12.8	0.8
20	68	17.3	1.07
30	86	30.4	1.9
40	104	51.1	3.2
50	122	83.0	5.2
60	140	130	8.1

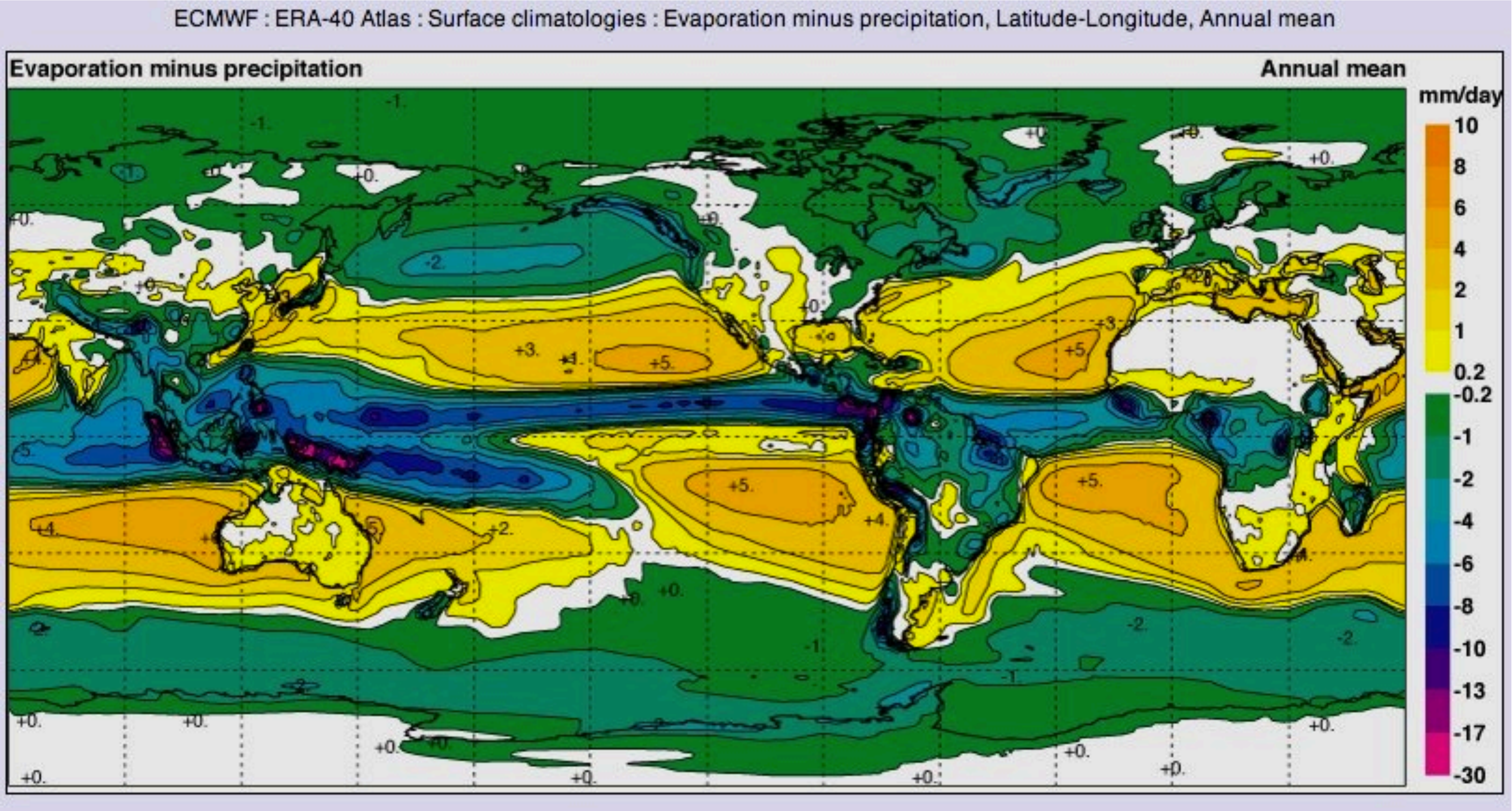
Water-Energy Cycle



Credit: Earth Forum, Houston Museum of Natural Science

https://water.usgs.gov/edu/watercyclesummary.html

Water-Energy Cycle


ECMWF : ERA-40 Atlas : Surface climatologies : Evaporation minus precipitation, Latitude-Longitude, Annual mean

Evaporation minus precipitation

Annual mean

NASA & European Centre for Medium-Range Weather Forecasts (ECMWF) - ERA-40 Atlas

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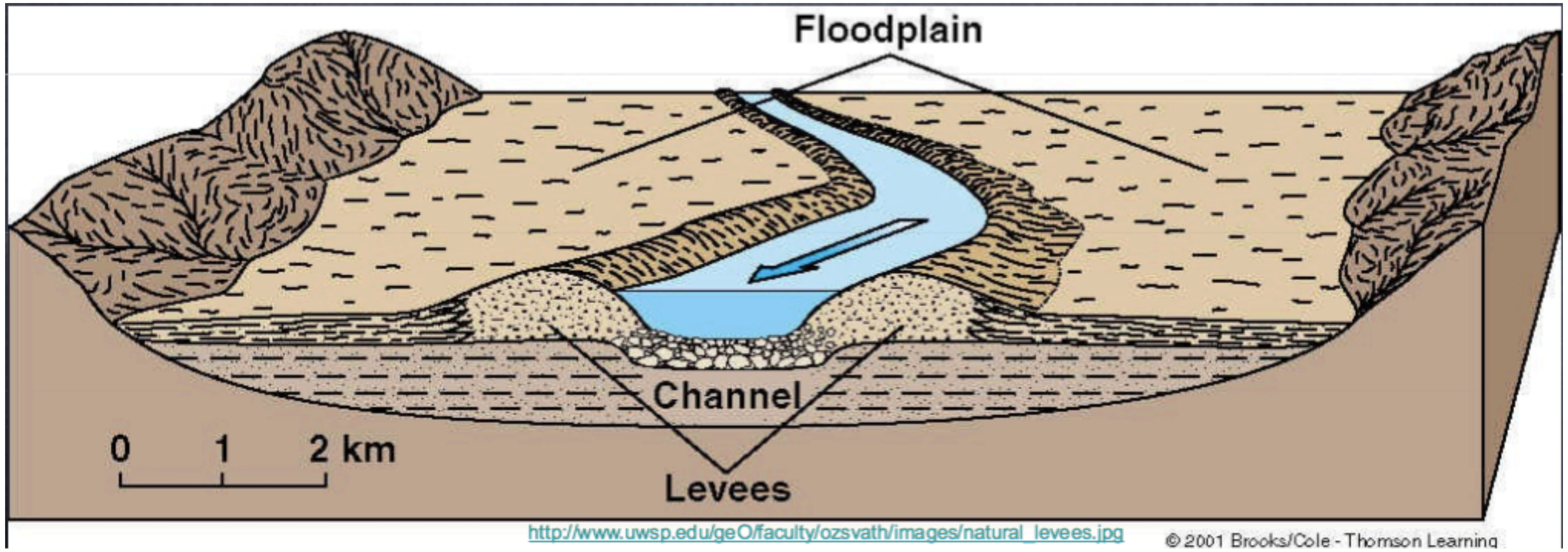
Humans and Water



http://www.uwsp.edu/geO/faculty/ozsvath/images/natural_levees.jpg

© 2001 Brooks/Cole - Thomson Learning

Floodplains are flat areas adjacent to rivers where previous floods have left silty deposits.

Agriculture on the Willamette River floodplain near Peoria, Oregon, U.S.A.

Flooding of the Cedar River floodplain near Cedar Rapids, Iowa, U.S.A., in June 2008.

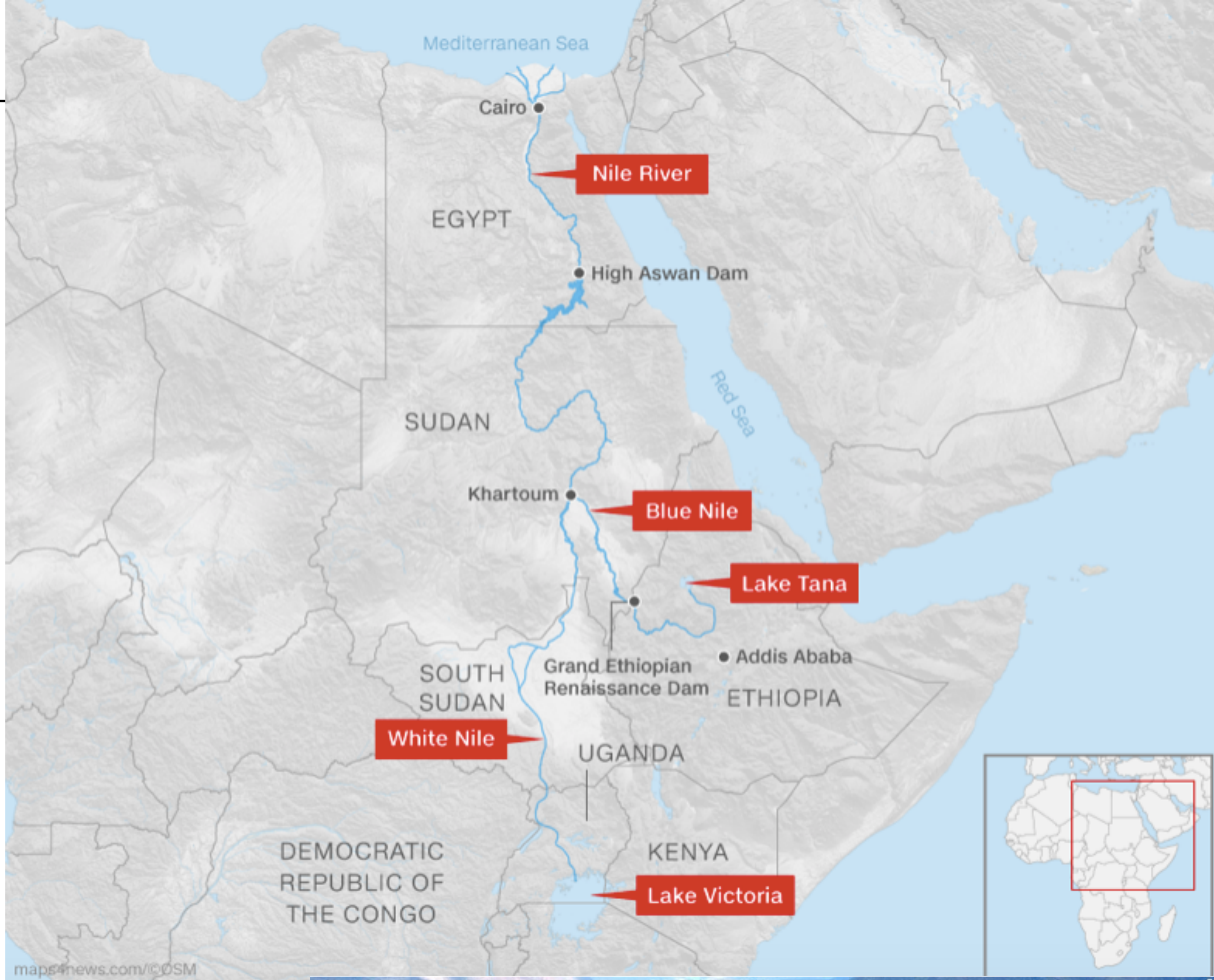
Humans and Water


Delta on Kachemak Bay, Alaska, at low tide

Ebro Delta, Spain

A river delta is a low-lying plain or landform at the mouth of a river close to where the river flows into an ocean or a lake. Delta are very important to human activities because of ecosystem services (fish and wildlife), agriculture (on highly fertile soil), dense, diverse vegetation, and logistics.

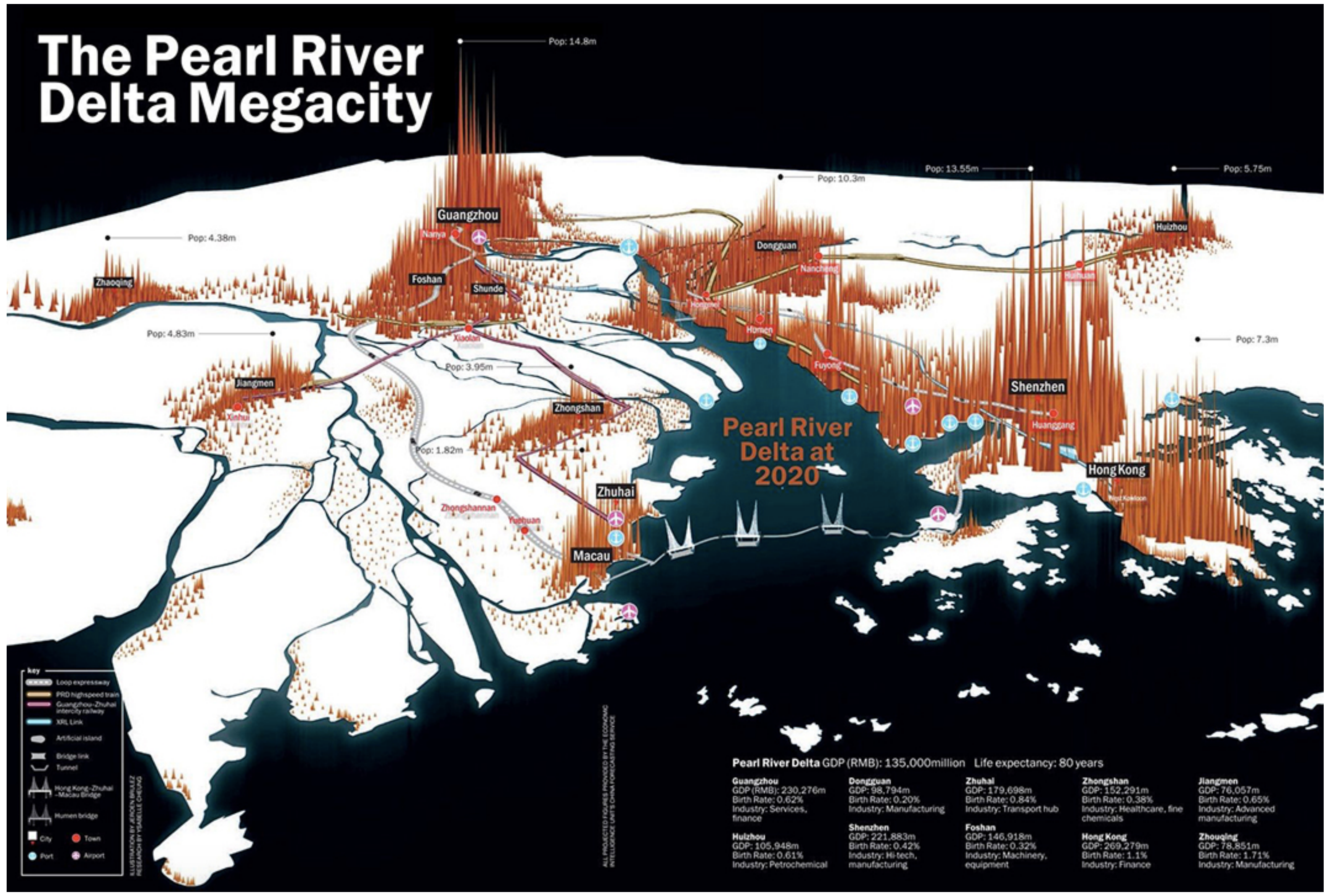
Humans and Water

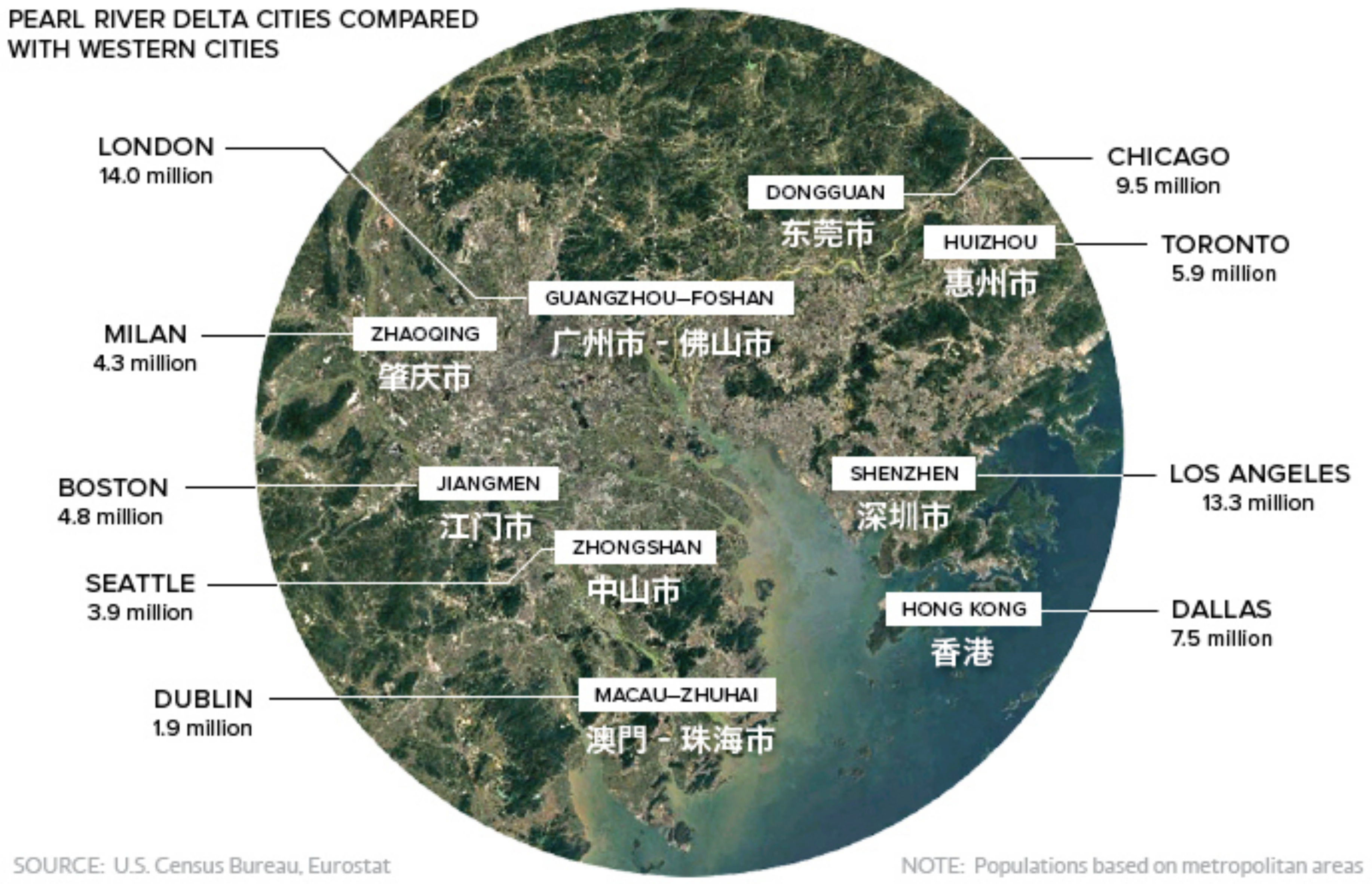


Nile River

https://www.cnn.com/2018/10/19/africa/ethiopia-new-dam-threatens-egypts-water/index.html

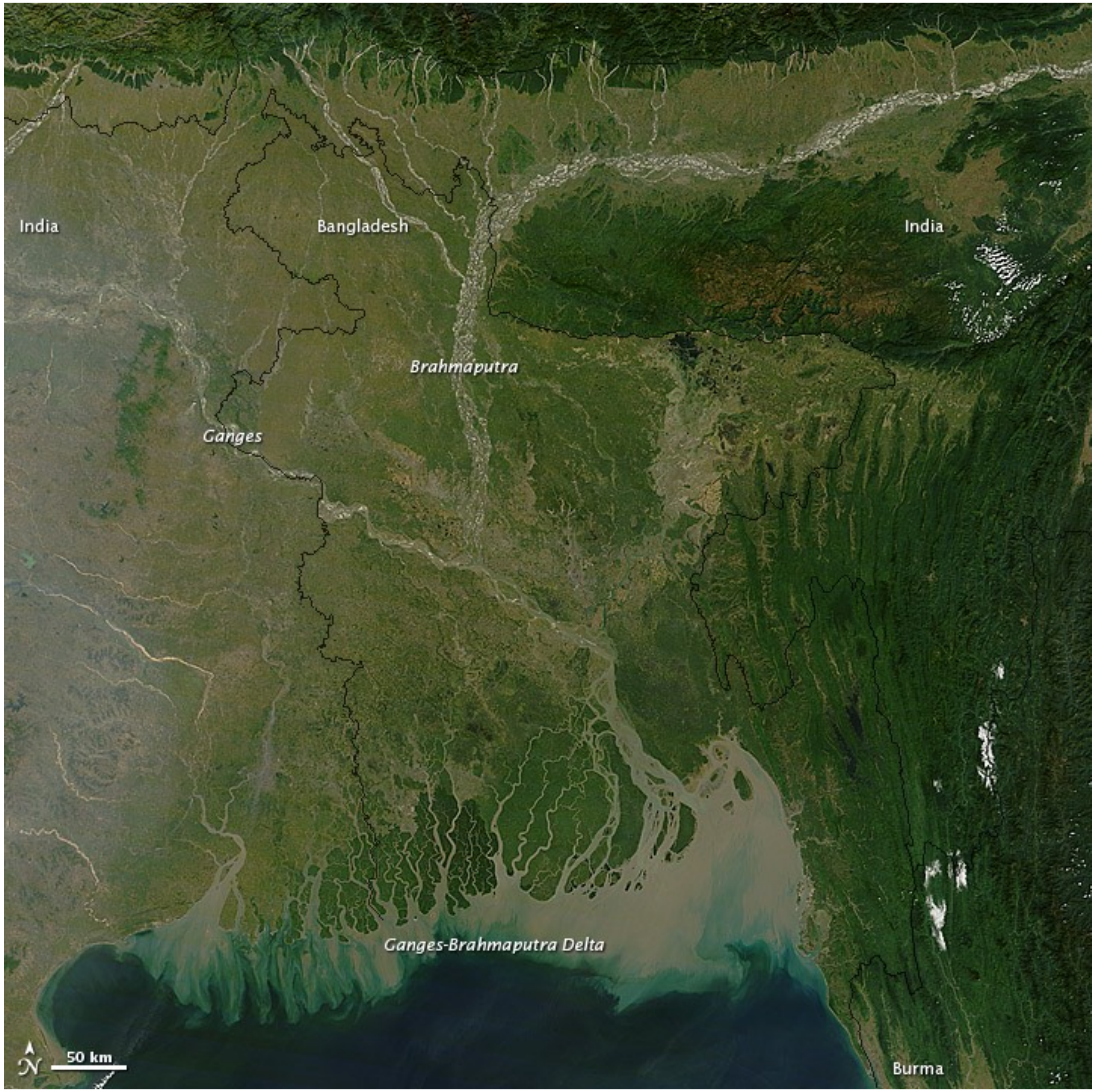
Humans and Water





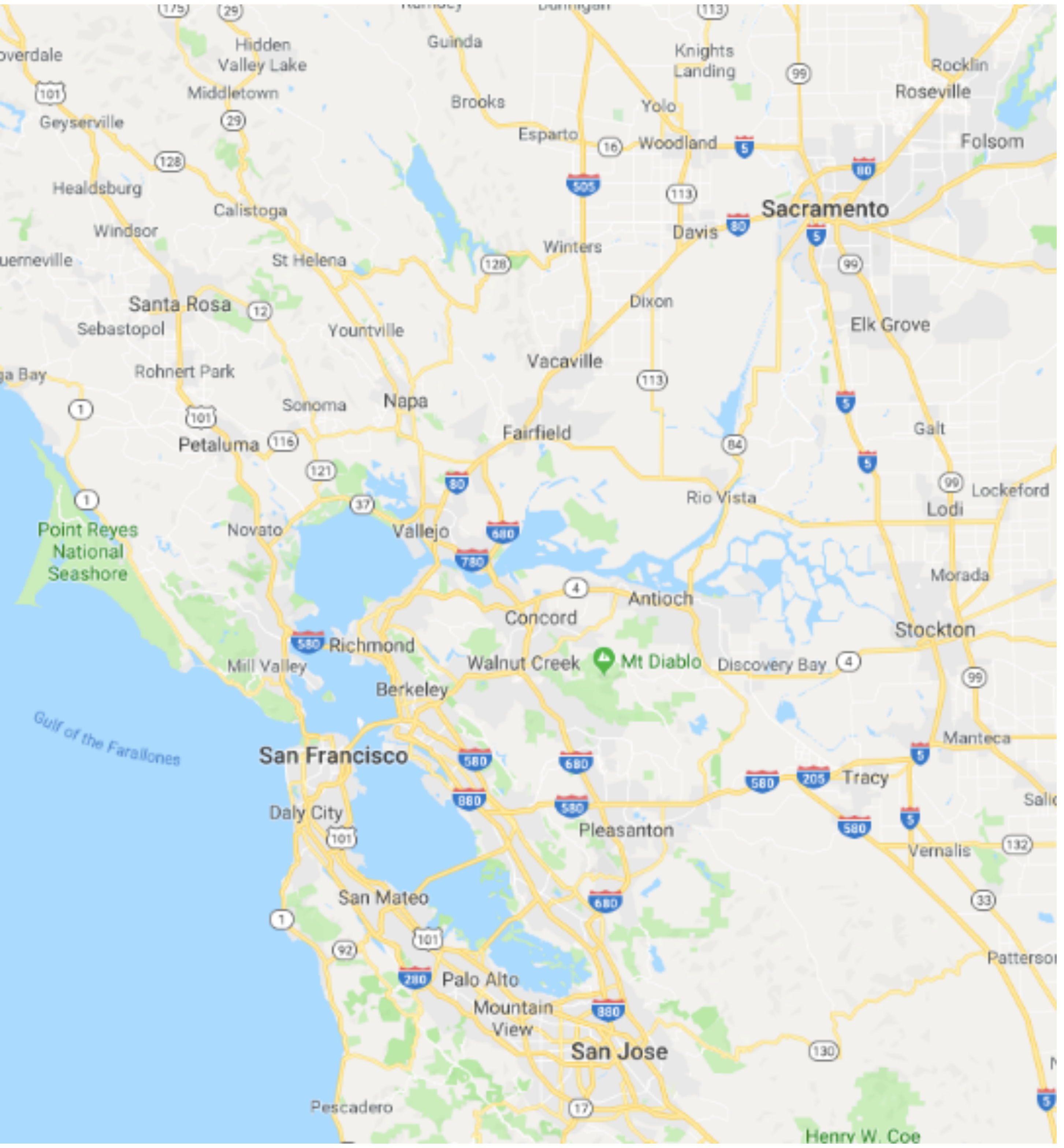
http://www.visualcapitalist.com/pearl-river-delta-megacity-2020/

Humans and Water



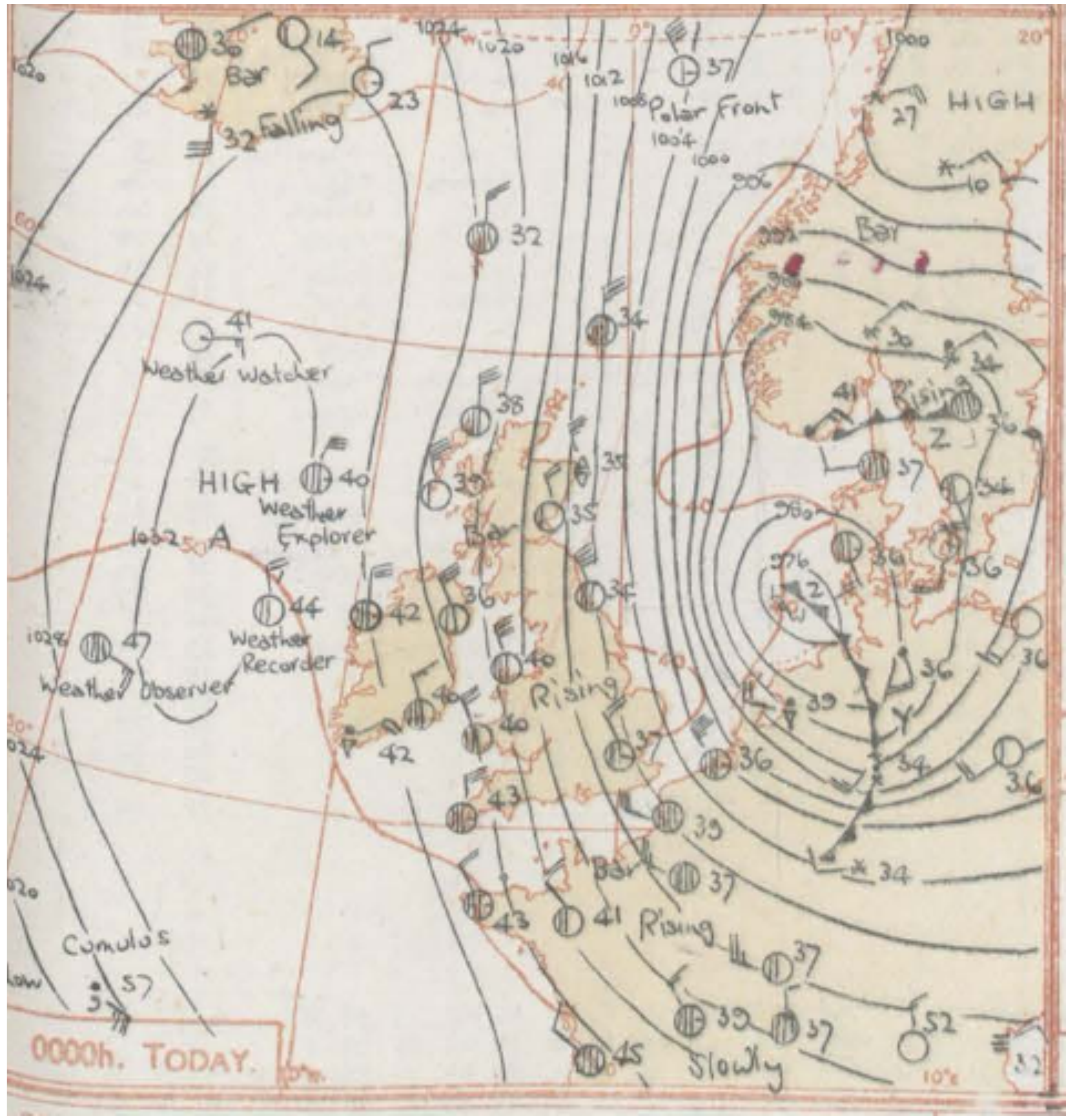
Humans and Water

Humans and Water



Humans and Water

River Deltas and Storm Surges



North Sea Flood,
January 31-February 1, 1953

Natural Hazards and Disaster

Class 8: Floods

- Water (Energy) cycle
- Humans and Water
- Flood Risk Management
- Largest Floods
- Deadliest Floods
- River floods
- Flash Floods
- Recurrent Floods
- Water-Energy Cycle: Atmospheric Rivers
- Changing Flood Risk

Floods Risk Management

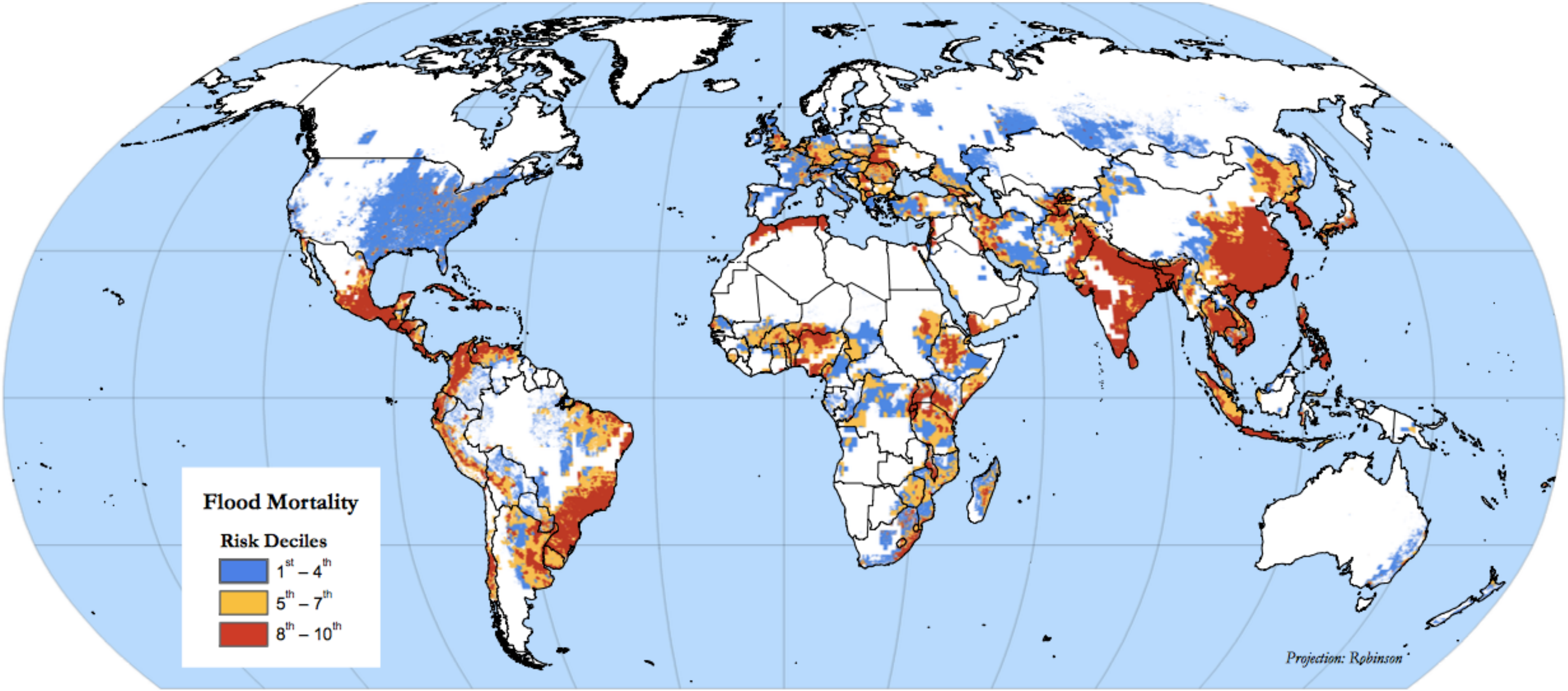
Too often, individuals ignore warnings and build their homes in high flood risk areas, or try to cross flooded areas only to be swept away.

Rio Branco city, Brazil, when the River Acre, which meanders through the city, reached a flood crest of 18.4 m above normal stage on March 4, 2015.

Flood warning signs are not merely ‘suggestions.’ They are meant to be taken seriously.

More than 150 individuals in the U.S.A. alone are killed each year while attempting to drive or walk through flooded streets. Most of those deaths could have been avoided if flood warning signs had been heeded.

Floods Risk Management



Mortality risk is found by weighting the value of population exposure to floods for each grid cell by a vulnerability coefficient to obtain an estimate of risk. The vulnerability weights are based on historical losses in previous disasters. The mortality weights are applied to population exposure to obtain mortality risks. The weights are an aggregate index relative to losses within each region and country wealth class (classifications based on 2000 GDP) over the 20-year period from 1981 –2000.

Dilley, Maxx, Robert S. Chen, Uwe Deichmann, Arthur L. Lerner-Lam, and Margaret Arnold. 2005. Natural Disaster Hotspots: A Global Risk Analysis. Washington, D.C.: World Bank.

Floods Risk Management

Evacuation Saves Lives: Early warning and evacuation procedures move vulnerable populations away from flood zones.

May 2009 flooding of the Brahmaputra River, Bangladesh, after Cyclone Aila. Towns and agricultural lands remained flooded through July 2009.

Residents rescued by boat in southern Louisiana, U.S.A.after more than 50 cm of rain in two days in August 2016. Although the flooding caused 9 fatalities and destroyed thousands of homes, evacuation of 20,000 people saved hundreds of lives.

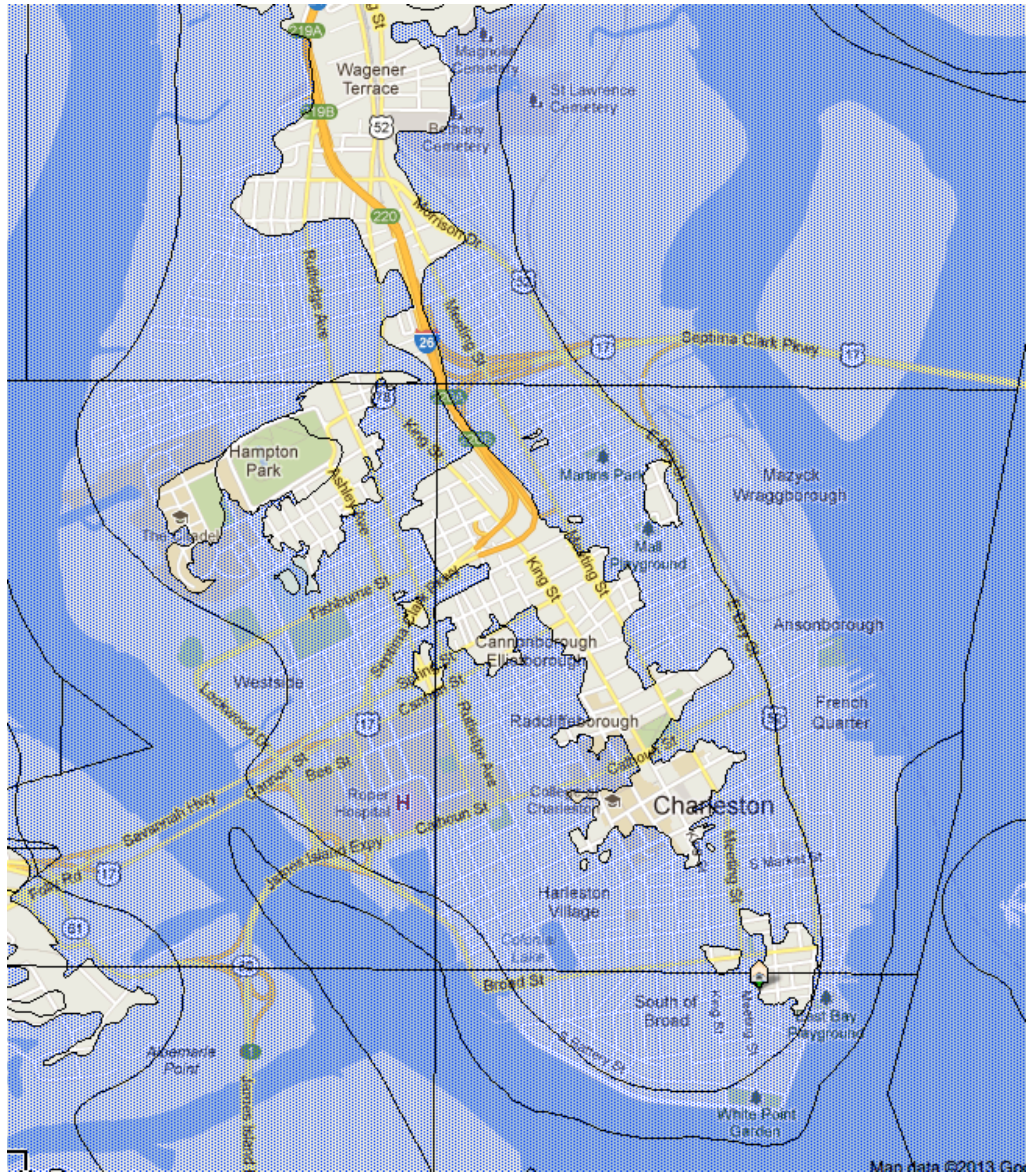
Floods Risk Management

Population Relocation? If frequent flooding cannot be avoided, should entire populations be relocated?

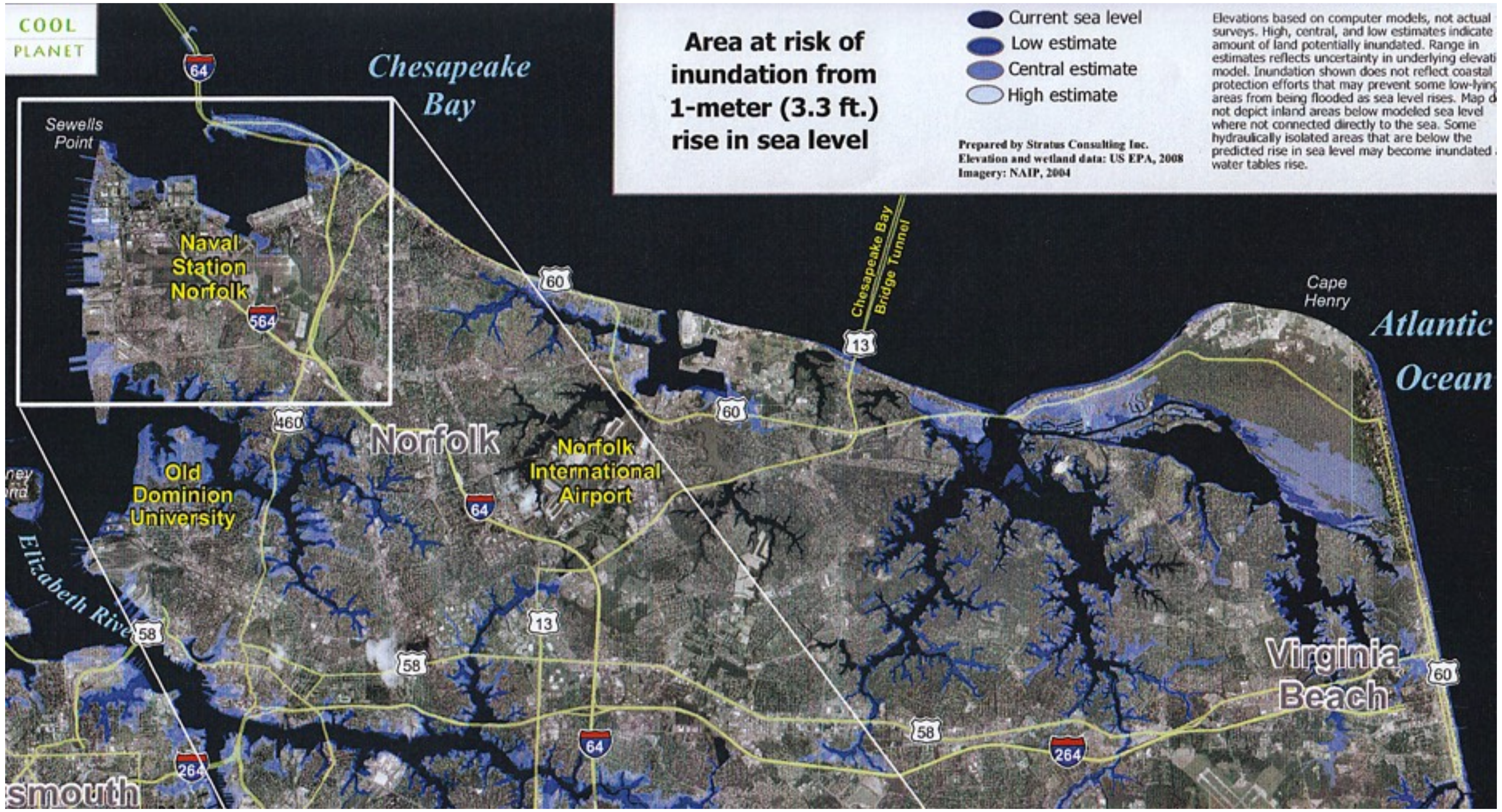
A flooded town in the Lockyer Valley, Queensland, Australia after an 8 m-high flash flood. Heavy and persistent rains during a very strong La Niña event in December 2010 and January 2011 had already saturated the catchment area of the Lockyer and Brisbane Rivers before storms produced rainfall of 40-50 mm (almost 2 inches) in a 30 minute period on January 10, 2011, triggering the flash flood.

Floods Risk Management

Designated Flood Zones: Cities around the world are creating flood zone maps that show the probability of future flooding.



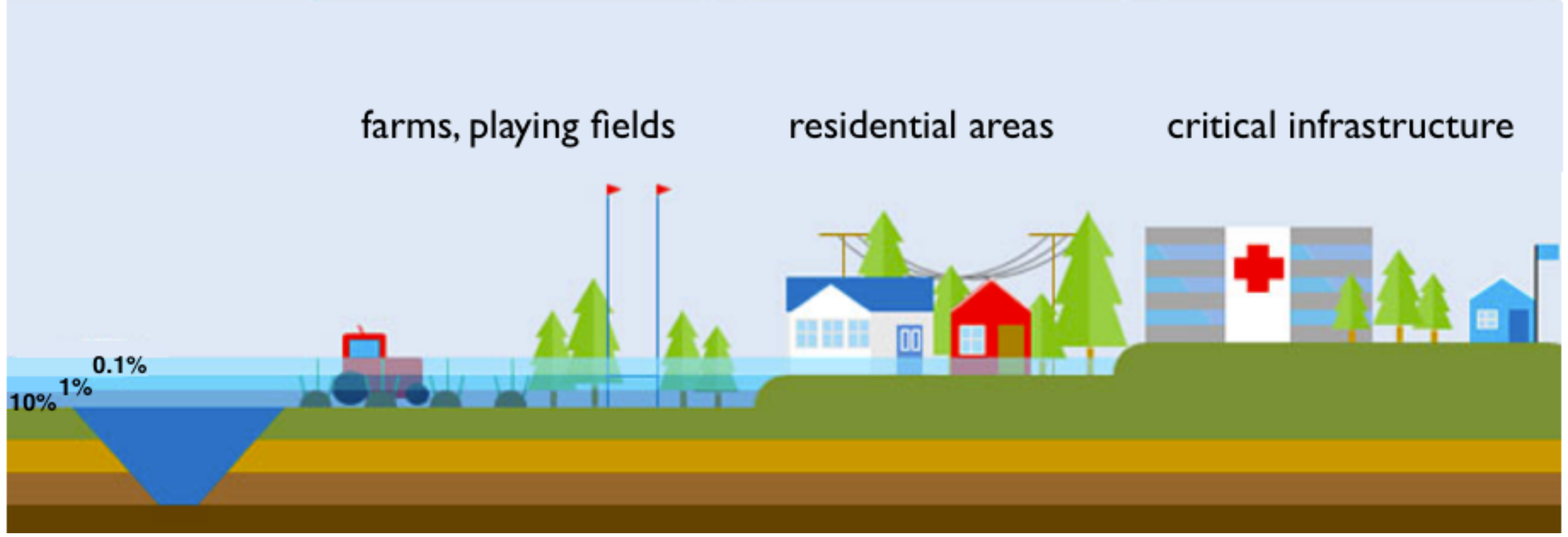
Designated flood zones for the City of Charleston, SC, U.S.A. Darker blue = Atlantic Ocean mean sea level; light blue = developed areas at risk of flooding. The city has flooded more than 20 times since its founding in 1670, most recently in December 2015.



Flood risk map for the city of Norfolk, VA. Areas in blue = risk of flooding from 1 m sea level rise.

Floods Risk Management

Floodplain Management: Allowing river floodwater to access its floodplain can help prevent flooding of towns and cities.



A floodplain management scheme that allows flooding of farmland in 10- and 100-year flood events. Recommendations for the construction of new, and retrofitting of existing, properties are usually included.

Georgia Power Company released excess rainwater into the Chattahoochee River from two dams above Columbus, GA on December 25, 2015 as part of the city's flood mitigation plan, deliberately flooding the city's riverwalk in order to protect residences.

Flood Mitigation Plans: To be successful, flood mitigation requires a comprehensive approach that involves cooperation between people and governments.

A flash flood of the Santa Cruz River in Tucson, AZ, in October 2015. Over the past 100 years, the river channel has been encased in a concrete-like soil-cement. Restoration of the river to a more natural state is part of the city's flood mitigation plan.

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Largest Floods

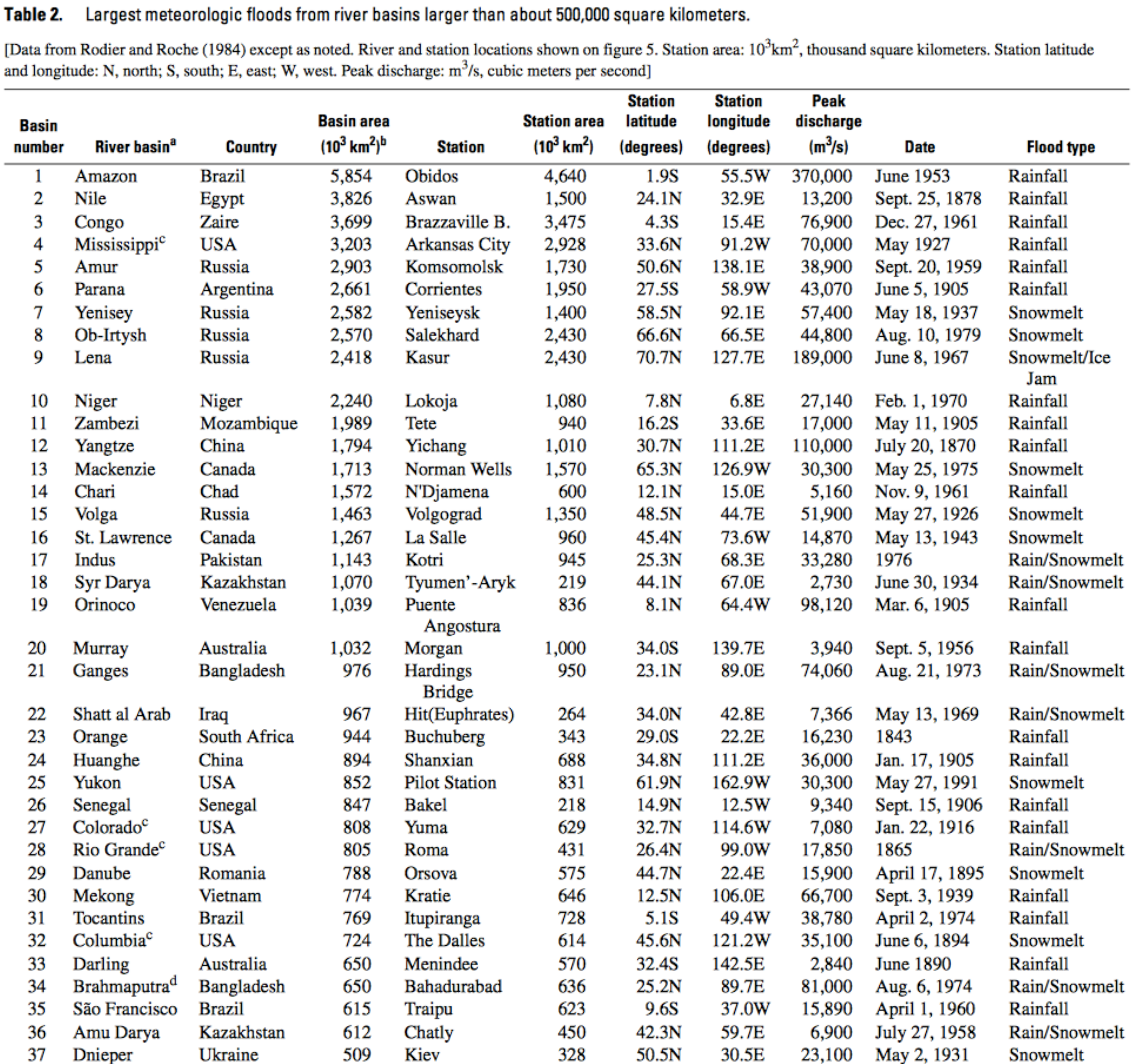
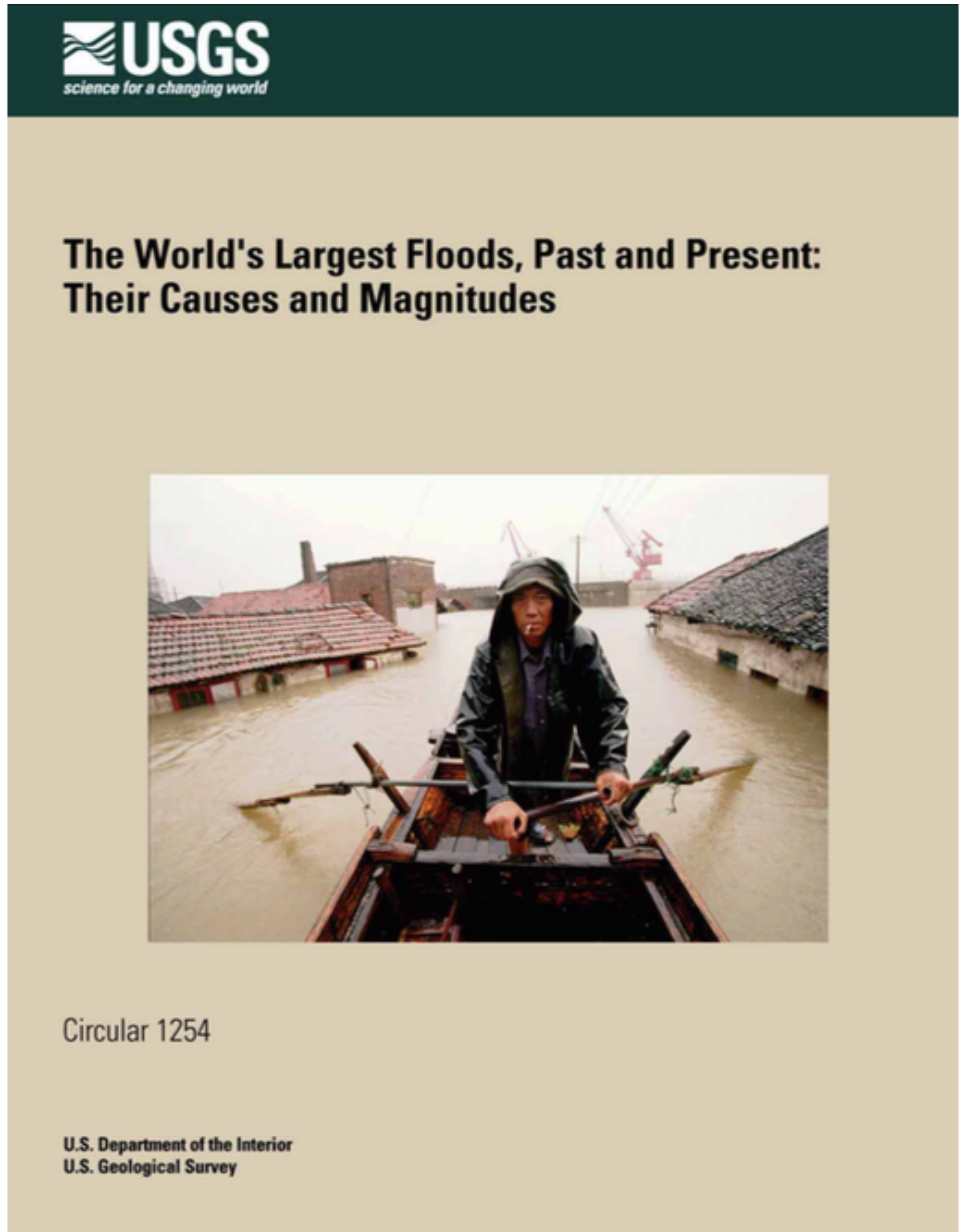


Table 2. Largest meteorologic floods from river basins larger than about 500,000 square kilometers.

[Data from Rodier and Roche (1984) except as noted. River and station locations shown on figure 5. Station area: 10^3km^2, thousand square kilometers. Station latitude and longitude: N, north; S, south; E, east; W, west. Peak discharge: m^3/s, cubic meters per second]

Basin number	River basin[a]	Country	Basin area (10^3 km^2)[b]	Station	Station area (10^3 km^2)	Station latitude (degrees)	Station longitude (degrees)	Peak discharge (m^3/s)	Date	Flood type
1	Amazon	Brazil	5,854	Obidos	4,640	1.9S	55.5W	370,000	June 1953	Rainfall
2	Nile	Egypt	3,826	Aswan	1,500	24.1N	32.9E	13,200	Sept. 25, 1878	Rainfall
3	Congo	Zaire	3,699	Brazzaville B.	3,475	4.3S	15.4E	76,900	Dec. 27, 1961	Rainfall
4	Mississippi[c]	USA	3,203	Arkansas City	2,928	33.6N	91.2W	70,000	May 1927	Rainfall
5	Amur	Russia	2,903	Komsomolsk	1,730	50.6N	138.1E	38,900	Sept. 20, 1959	Rainfall
6	Parana	Argentina	2,661	Corrientes	1,950	27.5S	58.9W	43,070	June 5, 1905	Rainfall
7	Yenisey	Russia	2,582	Yeniseysk	1,400	58.5N	92.1E	57,400	May 18, 1937	Snowmelt
8	Ob-Irtysh	Russia	2,570	Salekhard	2,430	66.6N	66.5E	44,800	Aug. 10, 1979	Snowmelt
9	Lena	Russia	2,418	Kasur	2,430	70.7N	127.7E	189,000	June 8, 1967	Snowmelt/Ice Jam
10	Niger	Niger	2,240	Lokoja	1,080	7.8N	6.8E	27,140	Feb. 1, 1970	Rainfall
11	Zambezi	Mozambique	1,989	Tete	940	16.2S	33.6E	17,000	May 11, 1905	Rainfall
12	Yangtze	China	1,794	Yichang	1,010	30.7N	111.2E	110,000	July 20, 1870	Rainfall
13	Mackenzie	Canada	1,713	Norman Wells	1,570	65.3N	126.9W	30,300	May 25, 1975	Snowmelt
14	Chari	Chad	1,572	N'Djamena	600	12.1N	15.0E	5,160	Nov. 9, 1961	Rainfall
15	Volga	Russia	1,463	Volgograd	1,350	48.5N	44.7E	51,900	May 27, 1926	Snowmelt
16	St. Lawrence	Canada	1,267	La Salle	960	45.4N	73.6W	14,870	May 13, 1943	Snowmelt
17	Indus	Pakistan	1,143	Kotri	945	25.3N	68.3E	33,280	1976	Rain/Snowmelt
18	Syr Darya	Kazakhstan	1,070	Tyumen'-Aryk	219	44.1N	67.0E	2,730	June 30, 1934	Rain/Snowmelt
19	Orinoco	Venezuela	1,039	Puente Angostura	836	8.1N	64.4W	98,120	Mar. 6, 1905	Rainfall
20	Murray	Australia	1,032	Morgan	1,000	34.0S	139.7E	3,940	Sept. 5, 1956	Rainfall
21	Ganges	Bangladesh	976	Hardings Bridge	950	23.1N	89.0E	74,060	Aug. 21, 1973	Rain/Snowmelt
22	Shatt al Arab	Iraq	967	Hit(Euphrates)	264	34.0N	42.8E	7,366	May 13, 1969	Rain/Snowmelt
23	Orange	South Africa	944	Buchuberg	343	29.0S	22.2E	16,230	1843	Rainfall
24	Huanghe	China	894	Shanxian	688	34.8N	111.2E	36,000	Jan. 17, 1905	Rainfall
25	Yukon	USA	852	Pilot Station	831	61.9N	162.9W	30,300	May 27, 1991	Snowmelt
26	Senegal	Senegal	847	Bakel	218	14.9N	12.5W	9,340	Sept. 15, 1906	Rainfall
27	Colorado[c]	USA	808	Yuma	629	32.7N	114.6W	7,080	Jan. 22, 1916	Rainfall
28	Rio Grande[c]	USA	805	Roma	431	26.4N	99.0W	17,850	1865	Rain/Snowmelt
29	Danube	Romania	788	Orsova	575	44.7N	22.4E	15,900	April 17, 1895	Snowmelt
30	Mekong	Vietnam	774	Kratie	646	12.5N	106.0E	66,700	Sept. 3, 1939	Rainfall
31	Tocantins	Brazil	769	Itupiranga	728	5.1S	49.4W	38,780	April 2, 1974	Rainfall
32	Columbia[c]	USA	724	The Dalles	614	45.6N	121.2W	35,100	June 6, 1894	Snowmelt
33	Darling	Australia	650	Menindee	570	32.4S	142.5E	2,840	June 1890	Rainfall
34	Brahmaputra[d]	Bangladesh	650	Bahadurabad	636	25.2N	89.7E	81,000	Aug. 6, 1974	Rain/Snowmelt
35	São Francisco	Brazil	615	Traipu	623	9.6S	37.0W	15,890	April 1, 1960	Rainfall
36	Amu Darya	Kazakhstan	612	Chatly	450	42.3N	59.7E	6,900	July 27, 1958	Rain/Snowmelt
37	Dnieper	Ukraine	509	Kiev	328	50.5N	30.5E	23,100	May 2, 1931	Snowmelt



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The World's Largest Floods, Past and Present: Their Causes and Magnitudes

Circular 1254

U.S. Department of the Interior
U.S. Geological Survey

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[b] Basin areas from Vörösmarty et al. (2000).

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Connor and Costa, 2011

Largest Floods

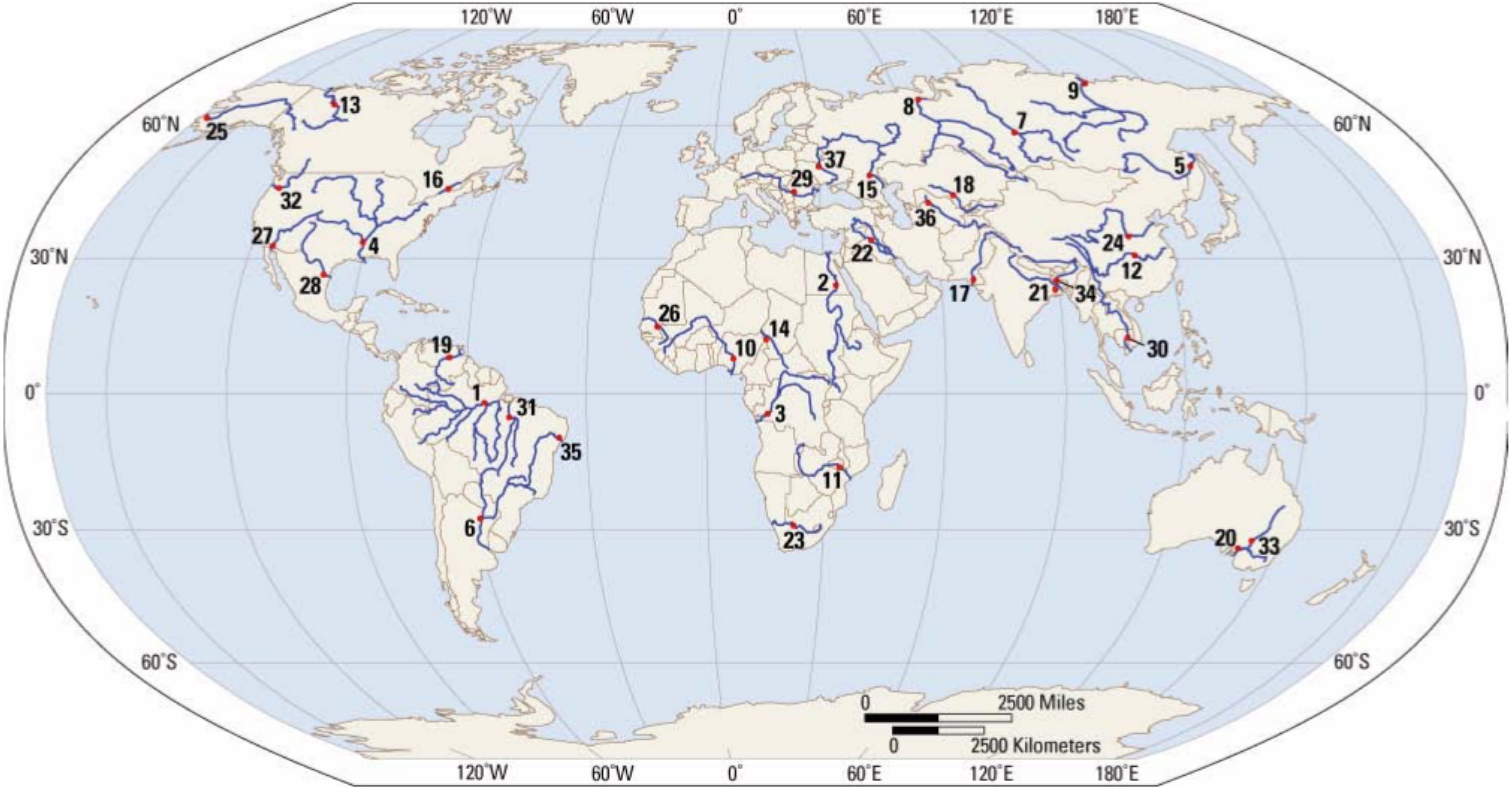


Figure 5. This map shows rivers with drainage basins larger than 500,000 square kilometers. Map numbers are keyed to table 2.

Connor and Costa, 2011

Largest Floods

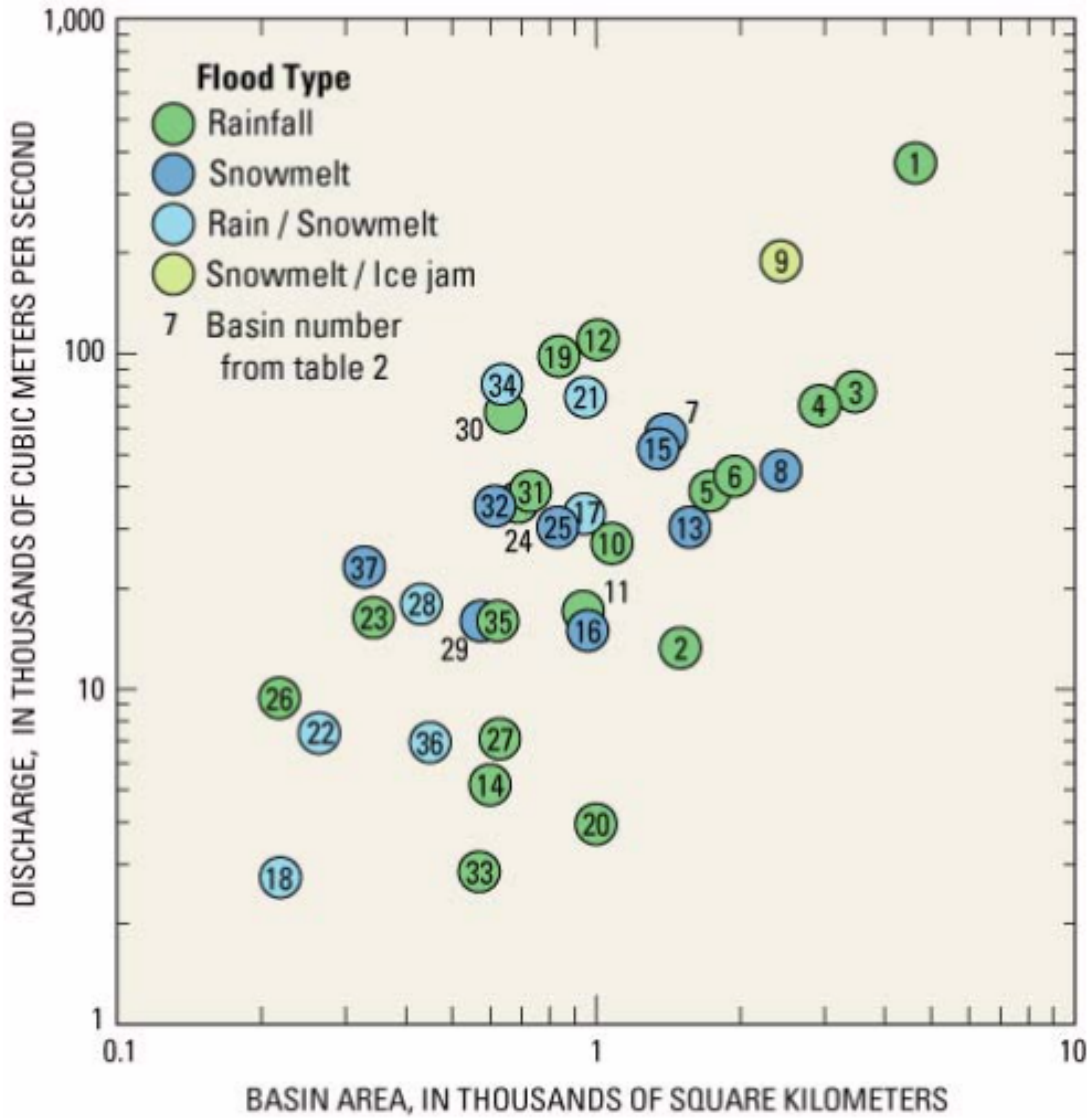
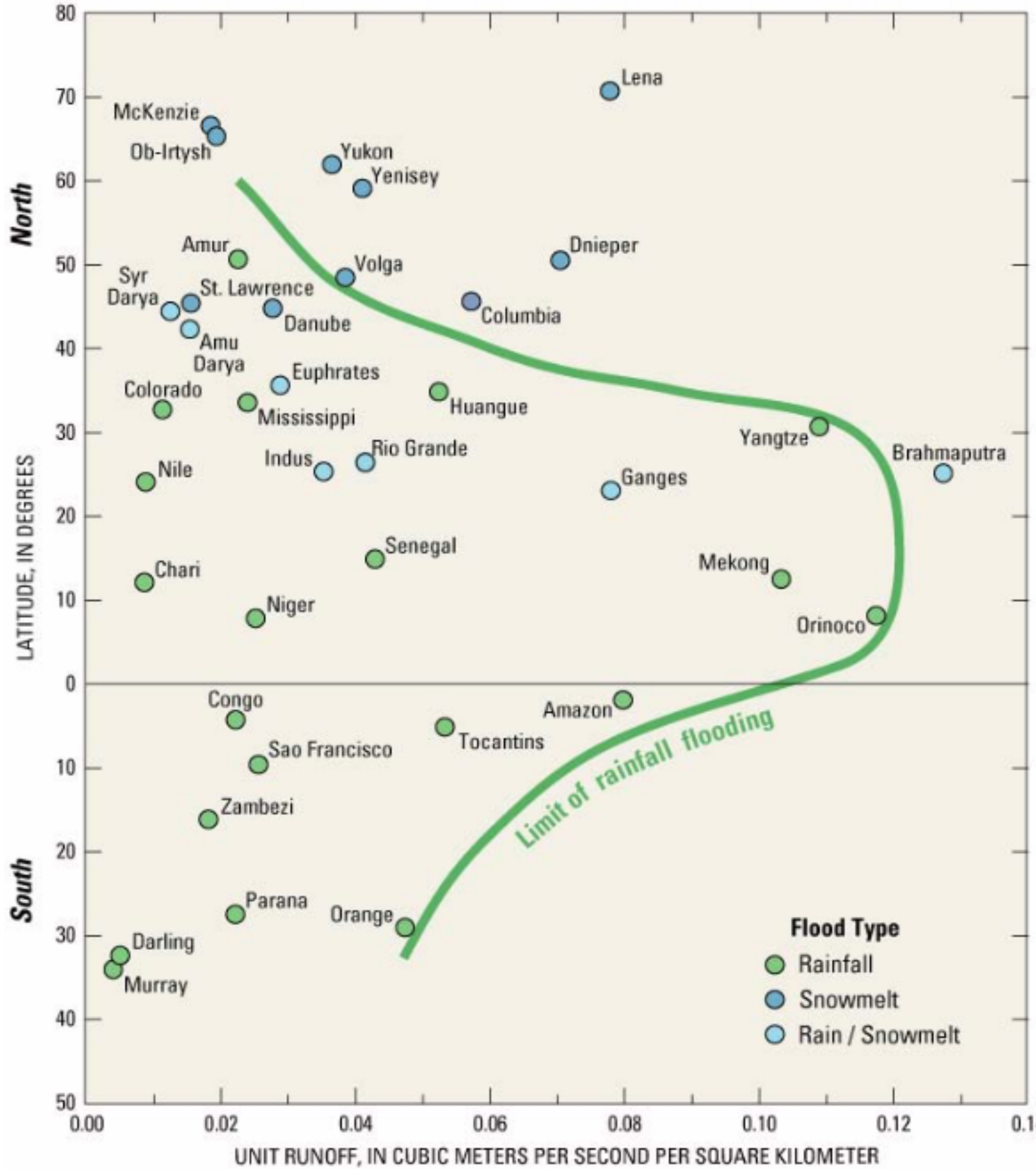


Figure 6. In general, larger river basins produce larger floods, but larger unit discharges in the moist tropics can result in floods of disproportionately large size. Numbers refer to basin numbers in figure 5 and table 2.

Figure 7. Nearly all of the largest floods caused by rainfall have occurred in basins south of latitude 40 degrees N. North of that, snowmelt- and ice-jam-related floods have predominated. Data from table 2.



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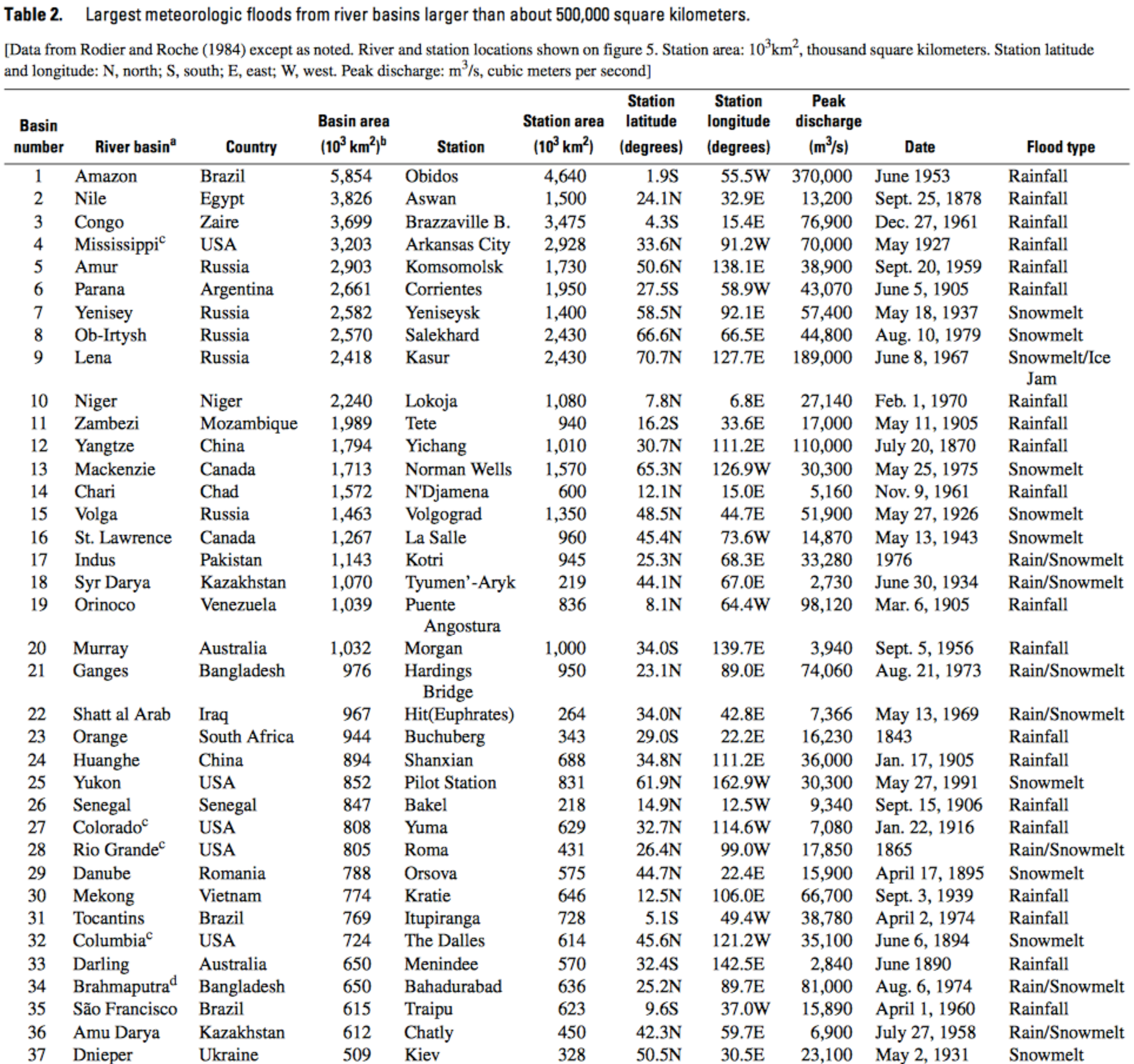

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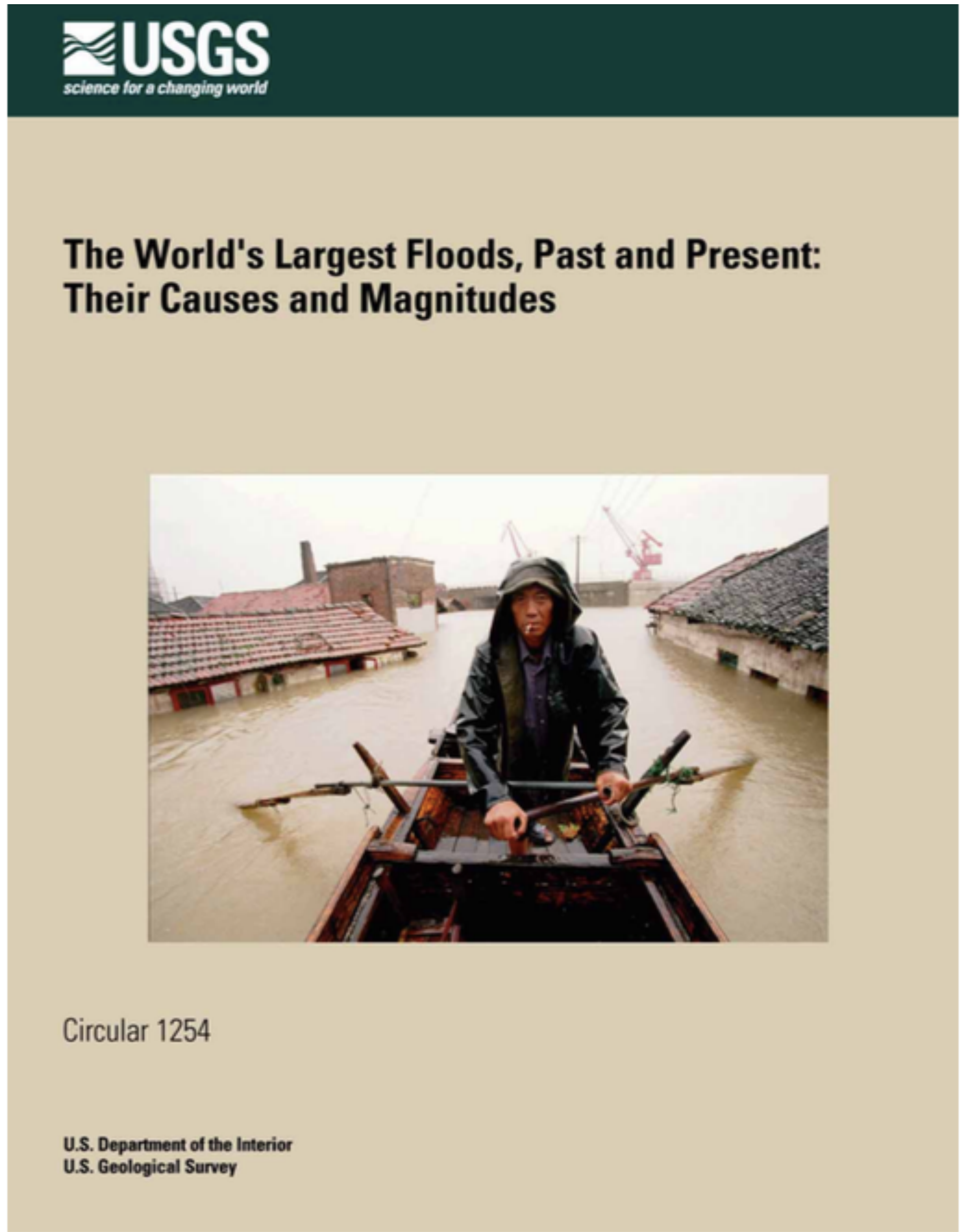

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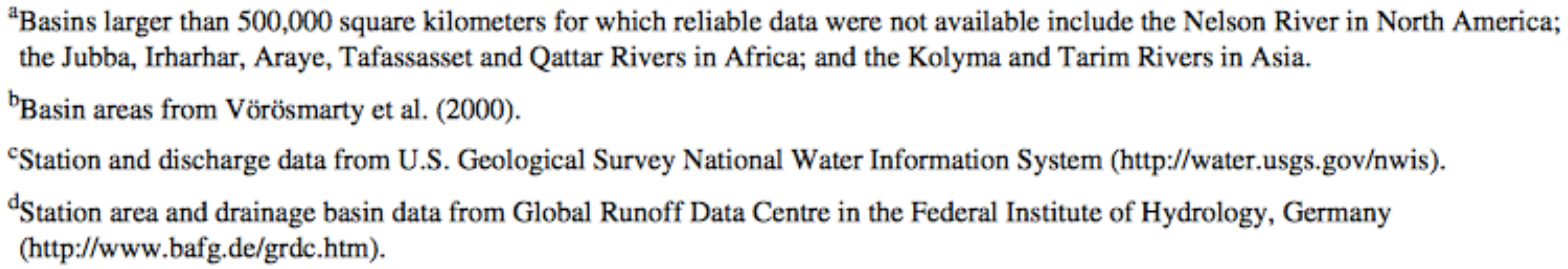

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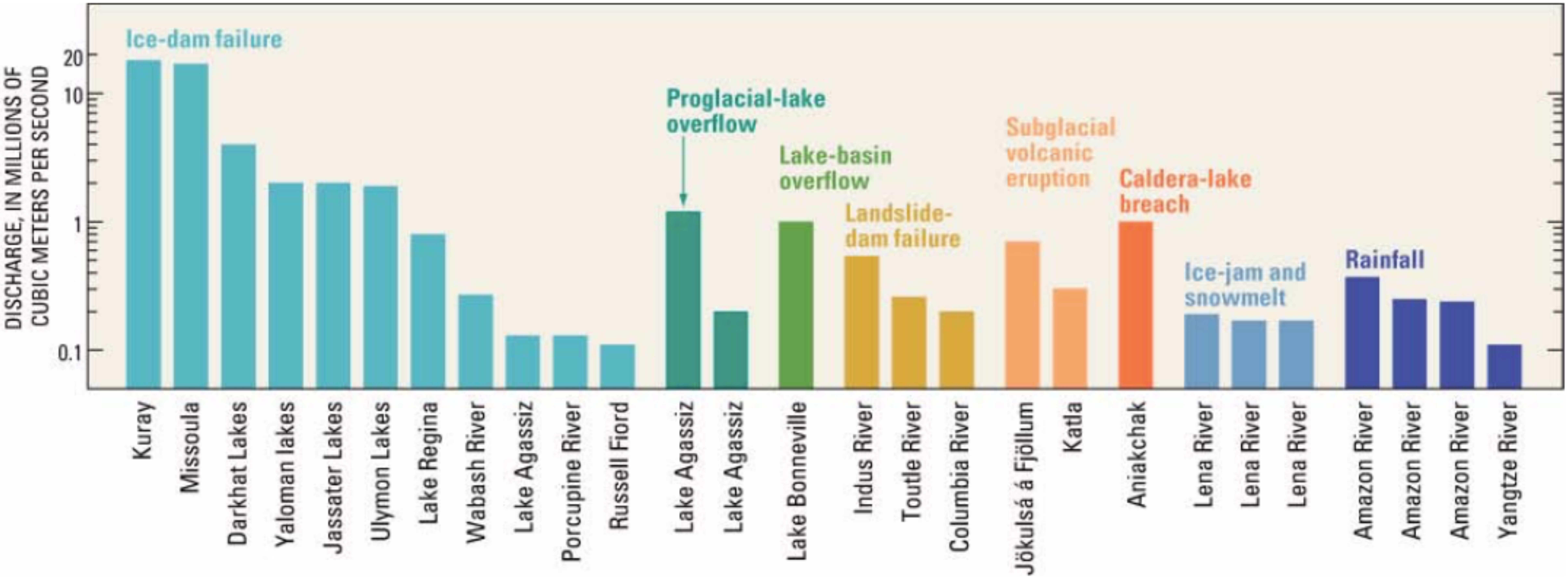

Figure 1. Most of the largest known floods of the Quaternary Period resulted from breaching of dams formed by glaciers or landslides. See table 1 for details of each flood.

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Largest Floods

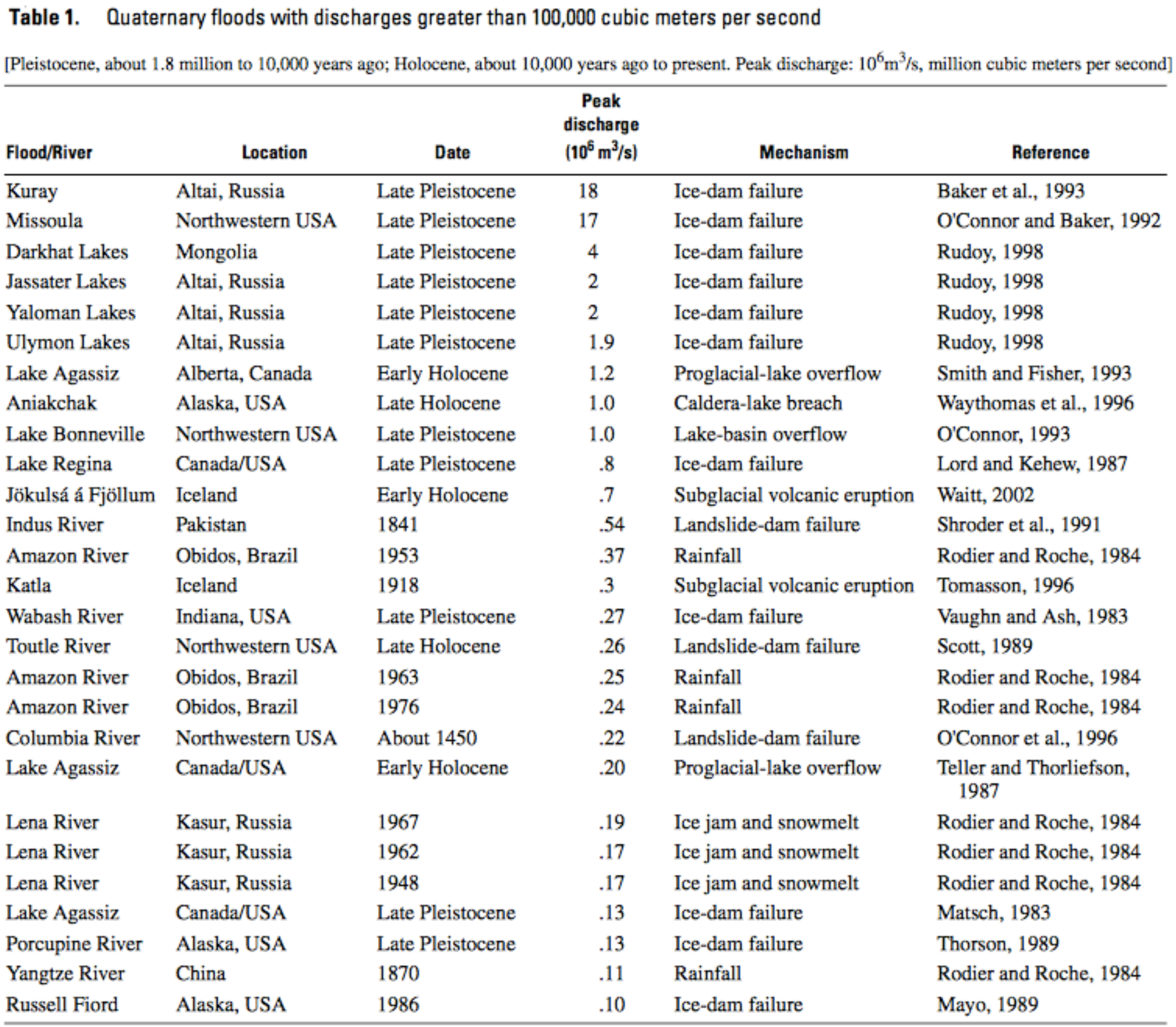


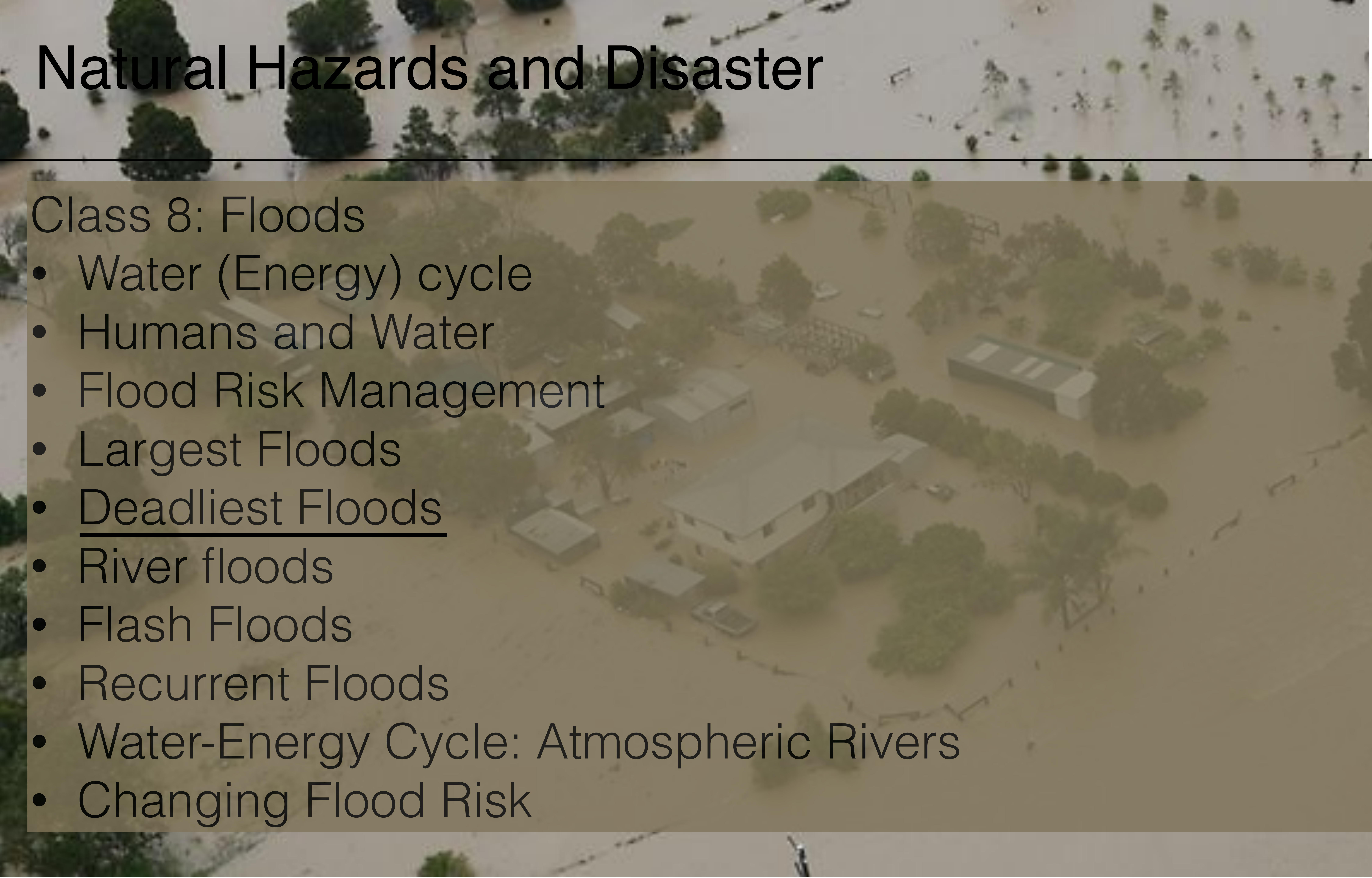
Table 1. Quaternary floods with discharges greater than 100,000 cubic meters per second

[Pleistocene, about 1.8 million to 10,000 years ago; Holocene, about 10,000 years ago to present. Peak discharge: $10^6 m^3/s$, million cubic meters per second]

Flood/River	Location	Date	Peak discharge ($10^6 m^3/s$)	Mechanism	Reference
Kuray	Altai, Russia	Late Pleistocene	18	Ice-dam failure	Baker et al., 1993
Missoula	Northwestern USA	Late Pleistocene	17	Ice-dam failure	O'Connor and Baker, 1992
Darkhat Lakes	Mongolia	Late Pleistocene	4	Ice-dam failure	Rudoy, 1998
Jassater Lakes	Altai, Russia	Late Pleistocene	2	Ice-dam failure	Rudoy, 1998
Yaloman Lakes	Altai, Russia	Late Pleistocene	2	Ice-dam failure	Rudoy, 1998
Ulymon Lakes	Altai, Russia	Late Pleistocene	1.9	Ice-dam failure	Rudoy, 1998
Lake Agassiz	Alberta, Canada	Early Holocene	1.2	Proglacial-lake overflow	Smith and Fisher, 1993
Aniakchak	Alaska, USA	Late Holocene	1.0	Caldera-lake breach	Waythomas et al., 1996
Lake Bonneville	Northwestern USA	Late Pleistocene	1.0	Lake-basin overflow	O'Connor, 1993
Lake Regina	Canada/USA	Late Pleistocene	.8	Ice-dam failure	Lord and Kehew, 1987
Jökulsá á Fjöllum	Iceland	Early Holocene	.7	Subglacial volcanic eruption	Waitt, 2002
Indus River	Pakistan	1841	.54	Landslide-dam failure	Shroder et al., 1991
Amazon River	Obidos, Brazil	1953	.37	Rainfall	Rodier and Roche, 1984
Katla	Iceland	1918	.3	Subglacial volcanic eruption	Tomasson, 1996
Wabash River	Indiana, USA	Late Pleistocene	.27	Ice-dam failure	Vaughn and Ash, 1983
Toutle River	Northwestern USA	Late Holocene	.26	Landslide-dam failure	Scott, 1989
Amazon River	Obidos, Brazil	1963	.25	Rainfall	Rodier and Roche, 1984
Amazon River	Obidos, Brazil	1976	.24	Rainfall	Rodier and Roche, 1984
Columbia River	Northwestern USA	About 1450	.22	Landslide-dam failure	O'Connor et al., 1996
Lake Agassiz	Canada/USA	Early Holocene	.20	Proglacial-lake overflow	Teller and Thorliefson, 1987
Lena River	Kasur, Russia	1967	.19	Ice jam and snowmelt	Rodier and Roche, 1984
Lena River	Kasur, Russia	1962	.17	Ice jam and snowmelt	Rodier and Roche, 1984
Lena River	Kasur, Russia	1948	.17	Ice jam and snowmelt	Rodier and Roche, 1984
Lake Agassiz	Canada/USA	Late Pleistocene	.13	Ice-dam failure	Matsch, 1983
Porcupine River	Alaska, USA	Late Pleistocene	.13	Ice-dam failure	Thorson, 1989
Yangtze River	China	1870	.11	Rainfall	Rodier and Roche, 1984
Russell Fiord	Alaska, USA	1986	.10	Ice-dam failure	Mayo, 1989

Connor and Costa, 2011

Natural Hazards and Disaster



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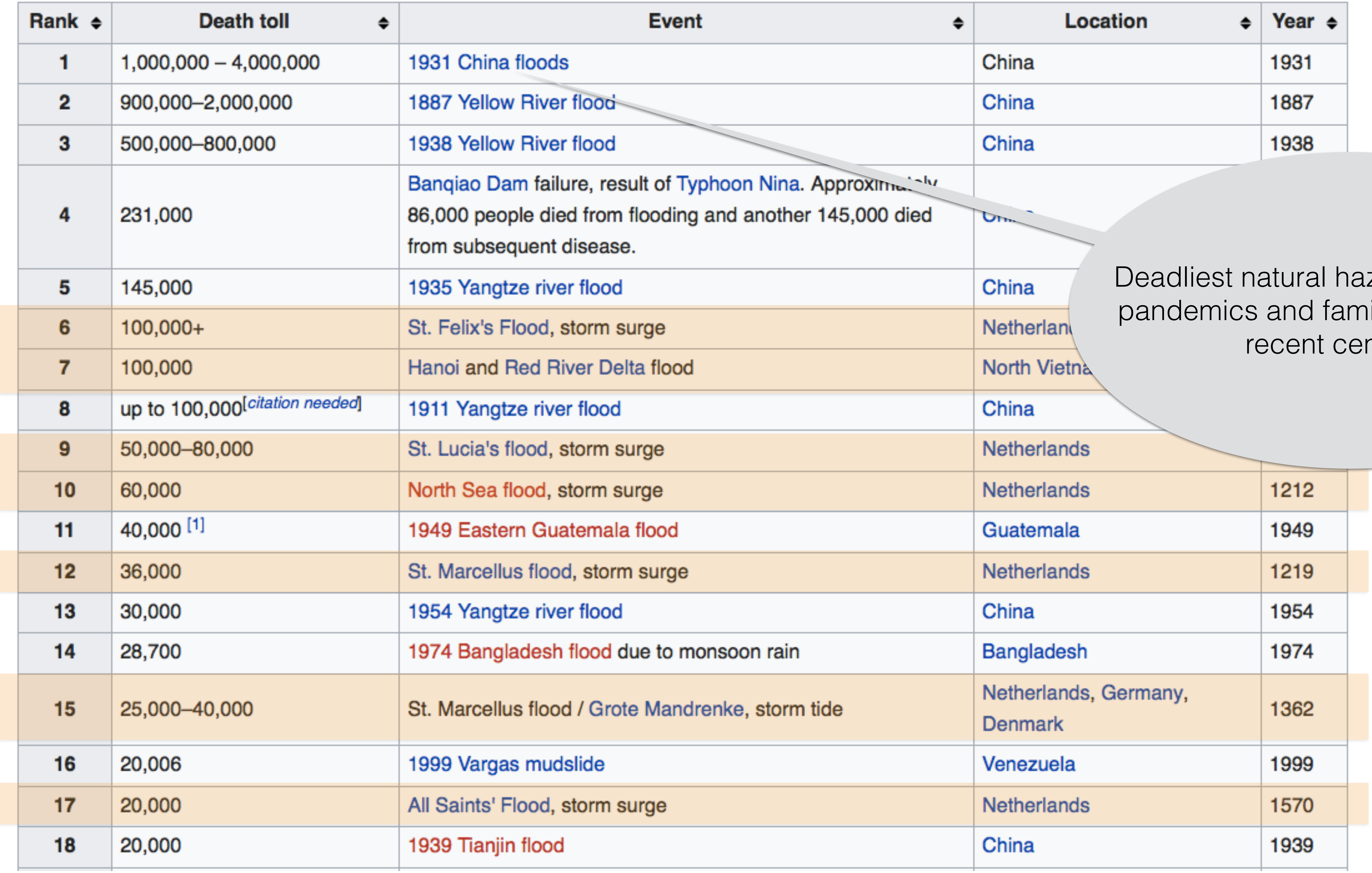
Deadliest Floods

Rank	Death toll	Event	Location	Year
1	1,000,000 – 4,000,000	1931 China floods	China	1931
2	900,000–2,000,000	1887 Yellow River flood	China	1887
3	500,000–800,000	1938 Yellow River flood	China	1938
4	231,000	Banqiao Dam failure, result of Typhoon Nina. Approximately 86,000 people died from flooding and another 145,000 died from subsequent disease.	China	1975
5	145,000	1935 Yangtze river flood	China	1935
6	100,000+	St. Felix's Flood, storm surge	Netherlands	1530
7	100,000	Hanoi and Red River Delta flood	North Vietnam	1971
8	up to 100,000[*citation needed*]	1911 Yangtze river flood	China	1919
9	50,000–80,000	St. Lucia's flood, storm surge	Netherlands	1287
10	60,000	North Sea flood, storm surge	Netherlands	1212
11	40,000 [1]	1949 Eastern Guatemala flood	Guatemala	1949
12	36,000	St. Marcellus flood, storm surge	Netherlands	1219
13	30,000	1954 Yangtze river flood	China	1954
14	28,700	1974 Bangladesh flood due to monsoon rain	Bangladesh	1974
15	25,000–40,000	St. Marcellus flood / Grote Mandrenke, storm tide	Netherlands, Germany, Denmark	1362
16	20,006	1999 Vargas mudslide	Venezuela	1999
17	20,000	All Saints' Flood, storm surge	Netherlands	1570
18	20,000	1939 Tianjin flood	China	1939

Deadliest Floods



Rank	Death toll	Event	Location	Year
1	1,000,000 – 4,000,000	1931 China floods	China	1931
2	900,000–2,000,000	1887 Yellow River flood	China	1887
3	500,000–800,000	1938 Yellow River flood	China	1938
4	231,000	Banqiao Dam failure, result of Typhoon Nina. Approximately 86,000 people died from flooding and another 145,000 died from subsequent disease.	[illegible]	[illegible]
5	145,000	1935 Yangtze river flood	China	[illegible]
6	100,000+	St. Felix's Flood, storm surge	Netherlan	[illegible]
7	100,000	Hanoi and Red River Delta flood	North Vietna	[illegible]
8	up to 100,000[citation needed]	1911 Yangtze river flood	China	[illegible]
9	50,000–80,000	St. Lucia's flood, storm surge	Netherlands	[illegible]
10	60,000	North Sea flood, storm surge	Netherlands	1212
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Deadliest natural hazard (discounting pandemics and famines) recorded in recent centuries.

Deadliest Floods

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2	900,000–2,000,000	1887 Yellow River flood	China	1887
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5	145,000	1935 Yangtze river flood	China	1935
6	100,000+	St. Felix's Flood, storm surge	Netherlands	1530
7	100,000	Hanoi and Red River Delta flood	North Vietnam	1971
8	up to 100,000[*citation needed*]	1911 Yangtze river flood	China	1919
9	50,000–80,000	St. Lucia's flood, storm surge	Netherlands	1287
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18	20,000	1939 Tianjin flood	China	1939

Deadliest Floods

19	14,000	Christmas flood, storm surge	Netherlands, Germany, Denmark	1717
20	10,000–100,000	St. Elizabeth flood, storm surge	Netherlands, Belgium	1421
21	8,000–15,000	Burchardi flood	Germany, Denmark	1634
22	10,000	Great Iran Flood	Iran	1954
23	10,000	1824 St. Petersburg flood	Russia	1824
24	several thousands	North Sea flood, storm surge	Netherlands	1014
25	several thousands	St. Juliana flood, storm surge	Netherlands	1164
26	several thousands	St. Agatha flood, storm surge	Netherlands	1288
27	several thousands	St. Clemens flood, storm surge	Netherlands	1334
28	several thousands	St. Mary Magdalene's flood	Central Europe	1342
29	several thousands	All Saints flood, storm surge	Netherlands	1532
30	several thousands	North Sea flood, storm surge	Netherlands	1703
31	5,700 [2]	2013 North India floods	India	2013
32	6,200	Sichuan, Hubei, Anhui flood	China	1980
32	5,000	Cojup valley, Cordillera Blanca mountain range, landslide by massive avalanche	Peru	1941
33	5,000–10,000	Rajputana flood	India	1943
34	4,892 [1]	1968 Rajasthan, Gujarat monsoon rain	India	1968
35	4,800	1951 Manchuria flood	China	1951
36	3,838	1998 Eastern India, Bangladesh monsoon rain	India, Bangladesh	1998

Deadliest Floods

36	3,838	1998 Eastern India, Bangladesh monsoon rain	India, Bangladesh	1998
37	3,814	1989 Sichuan flood	China	1989
38	3,800	1978 Northern India monsoon rain	India	1978
39	3,656	1998 Yangtze river flood	China	1998
40	3,500	1948 Fuzhou flood	China	1948
41	3,084	1993 South Asian monsoon rain	Nepal, India, Bangladesh, Pakistan	1993
42	3,076	2004 Eastern India, Bangladesh monsoon rain	India, Bangladesh	2004
43	3,000	1992 Afghanistan flood, mainly, Gulbahar, Kalotak, Shutul, Parwan, flash flood, mudslide	Afghanistan	1992
44	2,910	1950 Pakistan flood	Pakistan	1950
45	1,828	2011 Southeast Asian floods	Asia	2011
46	2,775	1996 China flood, torrential floods, mud-rock flows	China	1996
47	2,566	1953 Japan flood, mainly Kitakyushu, Kumamoto, Wakayama, Kizugawa, massive rain, flood, mudslide	Japan	1953
48	2,400	North Sea flood, storm surge	Netherlands	838
49	1,000-8,000	2016 Indian floods by monsoon rain	India	2016
50	2,379	1988 Bangladesh monsoon rain	Bangladesh	1988
51	2,209	Johnstown Flood	United States (Pennsylvania)	1889
52	2,142	North Sea flood of 1953 storm surge	Netherlands, United Kingdom, Belgium	1953

Natural Hazards and Disaster

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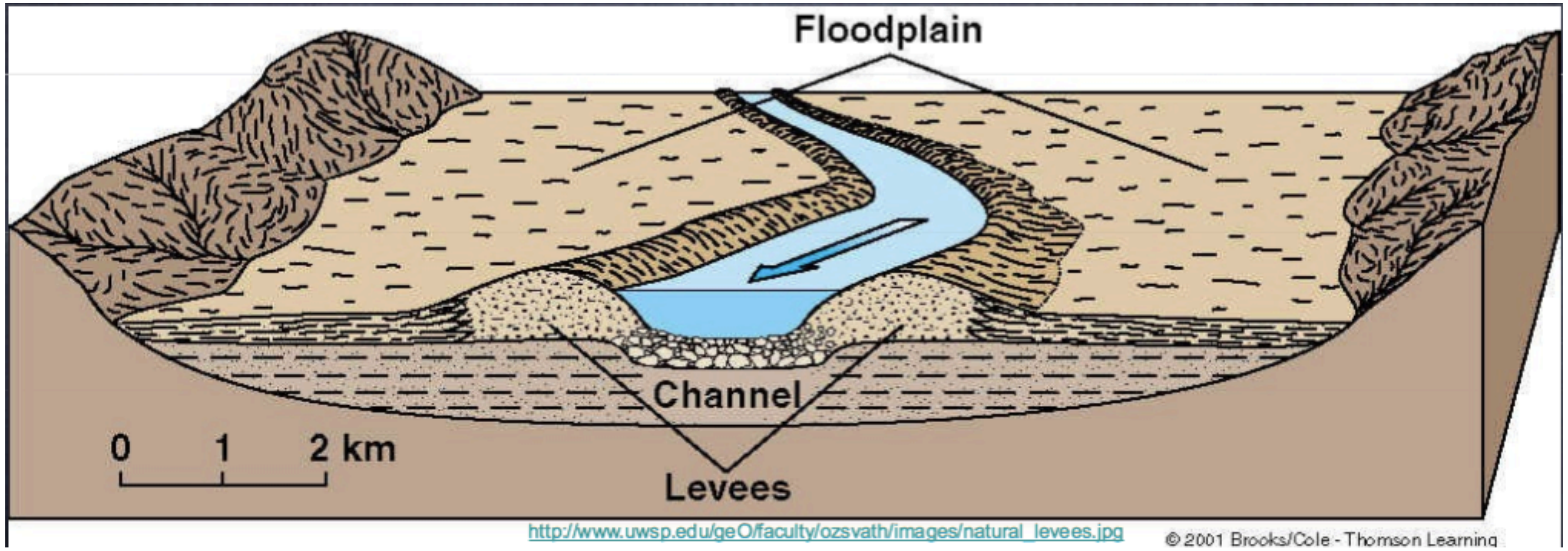
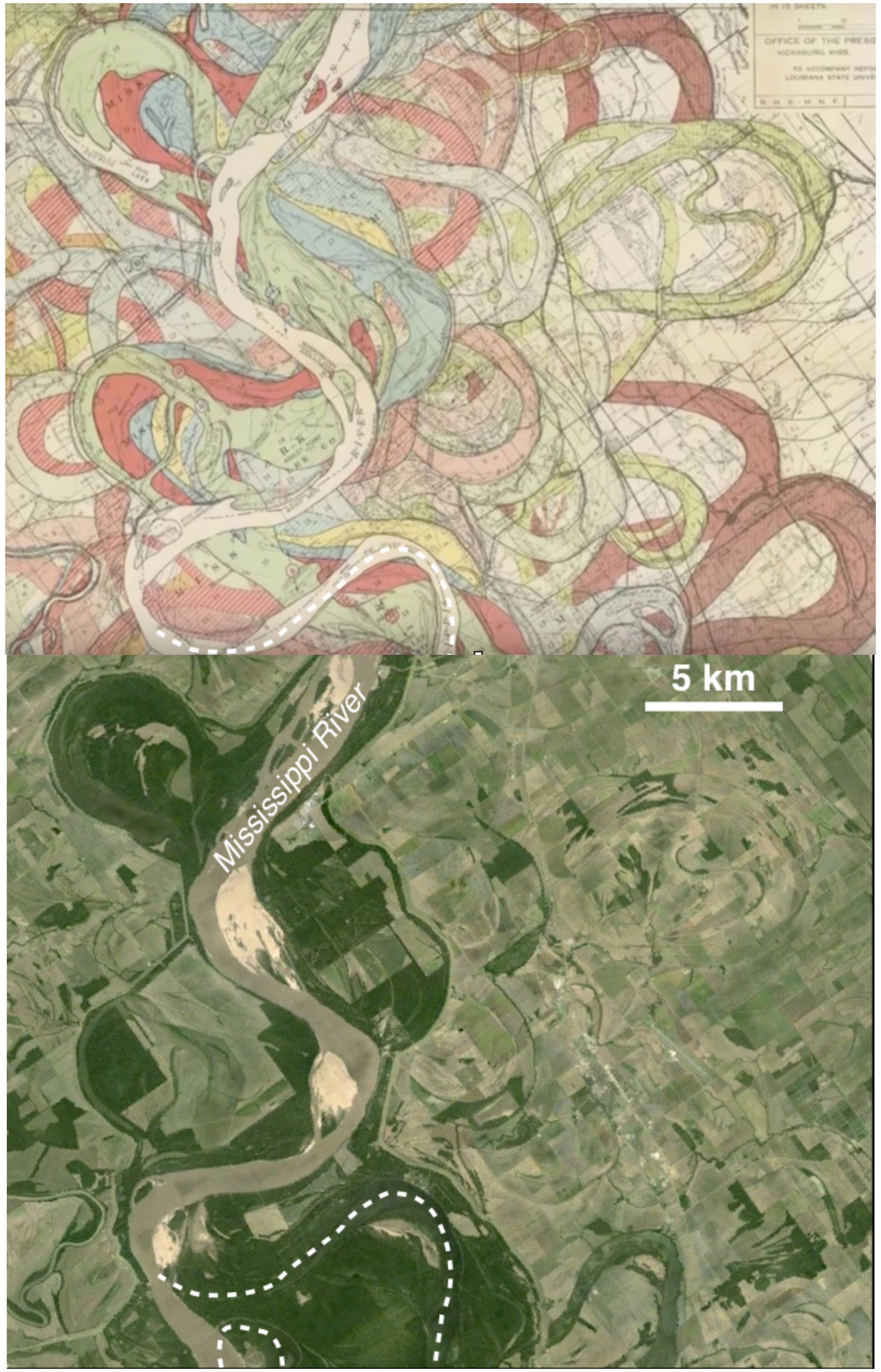
River Floods



http://www.uwsp.edu/geO/faculty/ozsvath/images/natural_levees.jpg

Floodplains are flat areas adjacent to rivers where previous floods have left silty deposits.

Rivers meander across their floodplains over time, leaving abandoned meander channels.



Top: 1944 geological map of prior meanders of the Mississippi River. Colors are abandoned meander loops from different times. Bottom: Satellite image of same area in 2014. The river has abandoned one of its 1944 meanders (dashed line at bottom of image).

River Floods

Levees are natural or man-made barriers along river banks. They work until a flood exceed the design level and breaches the levee.

A breached levee on the Ganges River is repaired one bowlful of dirt at a time, after Cyclone Aila in July 2009 caused the river to breach the barrier.

A breached levee on the Elbe river in Germany in June 2013.

Flood water breached the 17th Street Canal levee in New Orleans, on August 29, 2005. This breach was one of more than 50 levee failures around the city.

River Floods

Flooding in the Mississippi River system can affect the entire region shaded pale green, between the Rocky Mountains in the west and Appalachians in the east.

Left: Mississippi River flooding in Memphis, TN, in Spring 1927. Flood waters breached 145 levees, caused 246 deaths in seven U.S. states, and displaced 700,000 people for several months. Right: In December 2015, the Mississippi River inundated broad areas of its floodplain, including these homes in Pacific, MO.

Evacuation by canoe from Arnold, MO, after levee failure along the Mississippi in December 2015.

River Floods

Great Mississippi and Missouri Flood of 1993: April to October 1993; 78,000 km^2 flooded, $15 billion damage

Jefferson City, Missouri, near the Missouri Capitol building during the "Great Flood of 1993".

Aerial view of the Missouri River flooding on July 30, 1993, in the vicinity of Cedar City and Jefferson City Memorial Airport immediately north of Jefferson City, Missouri, looking south (photograph from the Missouri Highway and Transportation Department).

Confluence of Mississippi and Missouri Rivers, August 1993. Extensive floods in the Mississippi River Basin during the spring and summer of 1993 caused $20 billion in damages. (Photograph, Srenco Photography, St. Louis, Mo.)

Flooding of the Mississippi River in late July, 1993. Top: At the confluence with the Missouri River, near St. Louis. Bottom: Near Cedar City, MO.

Natural Hazards and Disaster

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Class 8: Floods

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Flashfloods

Flash floods occur unpredictably.after severe thunderstorms or a sudden release of snow melt.

The village of Boscastle in Cornwall, U.K. inundated by a flash flood on August 16, 2004 after thunderstorms dropped heavy rain several km away, in the catchment area of the normally small stream.

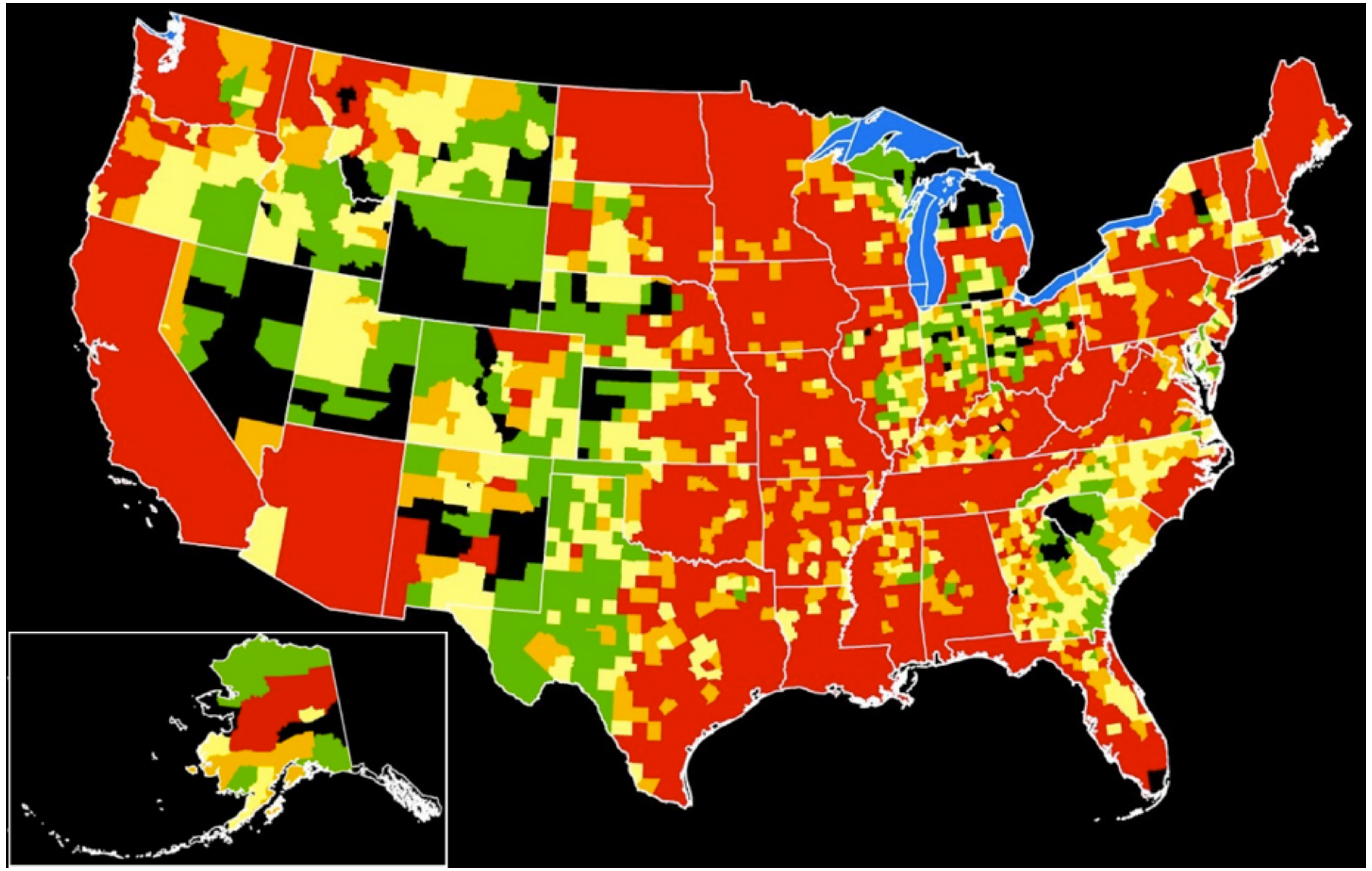
2 minutes after flood water starts to rise...

60 seconds later.

A flash flood in Toowoomba, near Brisbane, Australia, in January 2011 carried away cars that were parked by a stream and caused more than 20 deaths in the area. In Brisbane city the flood crest was 4.46 m, a little lower than record crests in the 1890’s.

Flashfloods

Flash Floods In The Desert: Otherwise dry rivers in desert regions flood when surface runoff exceeds river channel capacity.



U.S. presidential disaster declarations related to flooding by region for 1965-2003. Green = 1; yellow = 2; orange = 3; red = 4 or more.

The Blanco River, TX, rose by almost 8 m in a day on May 24, 2015 during a flash flood, sweeping away roads, trees, and houses.

Natural Hazards and Disaster

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Recurrent Floods

Snowmelt Floods

Rapid snowmelt during exceptional warm periods or heavy rain often causes floodplain inundation.

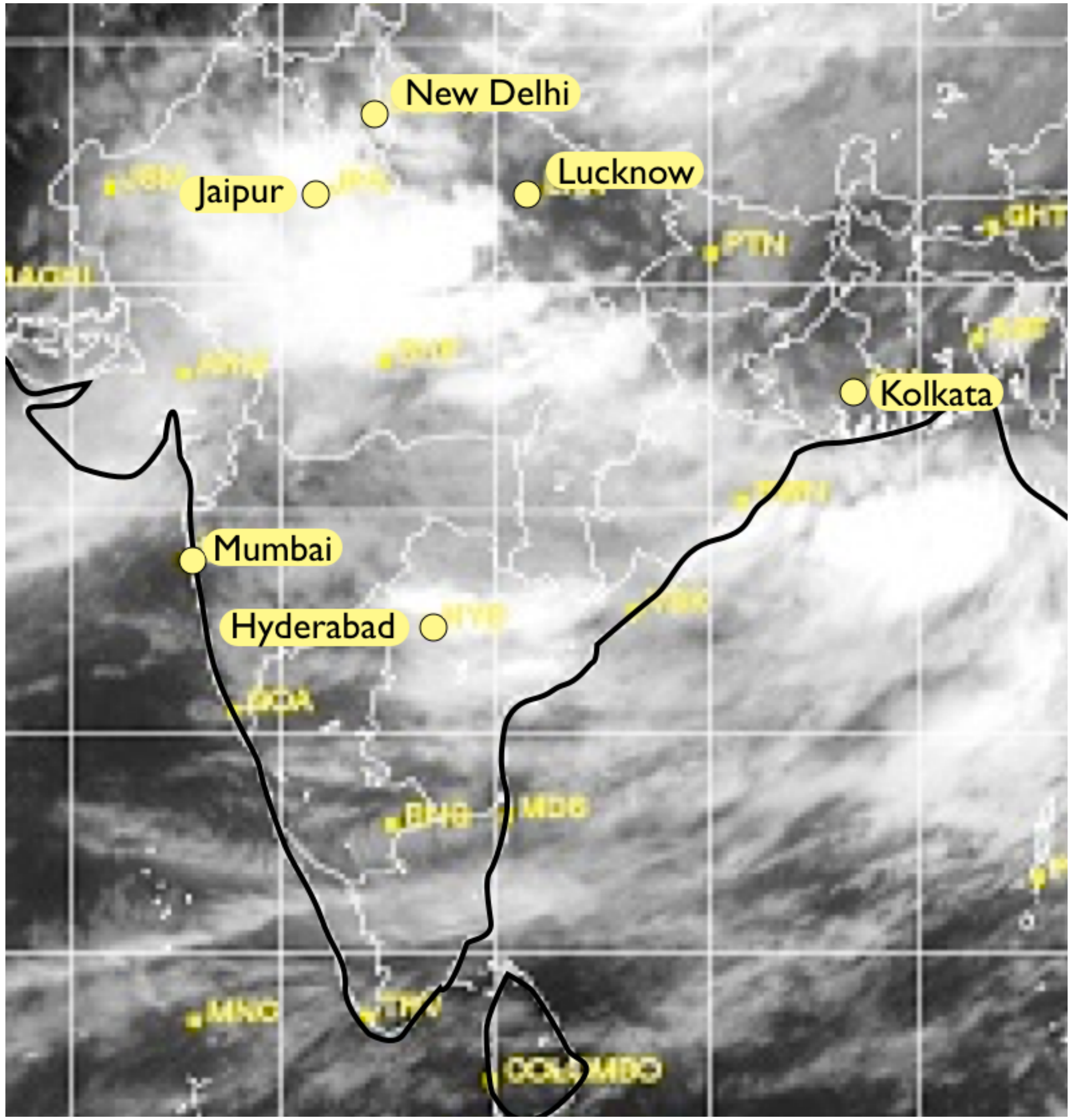
Unlike the Missouri and Mississippi Rivers, which drain southward, the Red River of the North drains northward, into Lake Winnipeg, Canada.

The Red River of the North breached levees and inundated Grand Forks, ND in April 1997. Several other cities, including Fargo, ND and Manitoba, Canada, were also flooded.

Recurrent Floods

Monsoon

Monsoons are seasonal prevailing winds that bring heavy summer rains to southeast Asia.



Monsoon rain clouds over India, July 2012.

Monsoon rain disrupts New Delhi, July 2015.

Part of a village in Uttarakhand, India, destroyed by flash flooding of the Ganges River in June 2013 after exceptionally heavy monsoon rains.

Natural Hazards and Disaster

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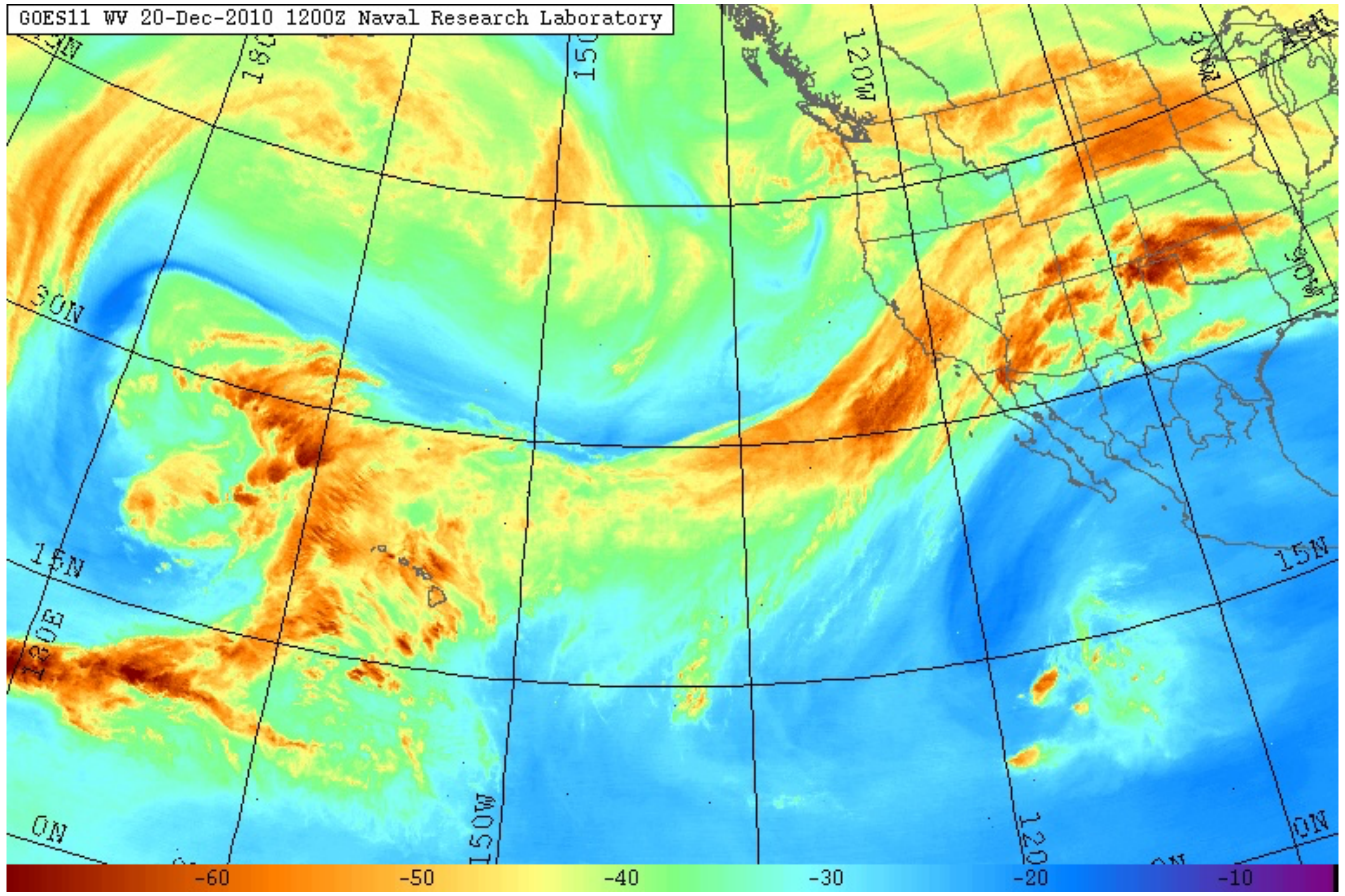
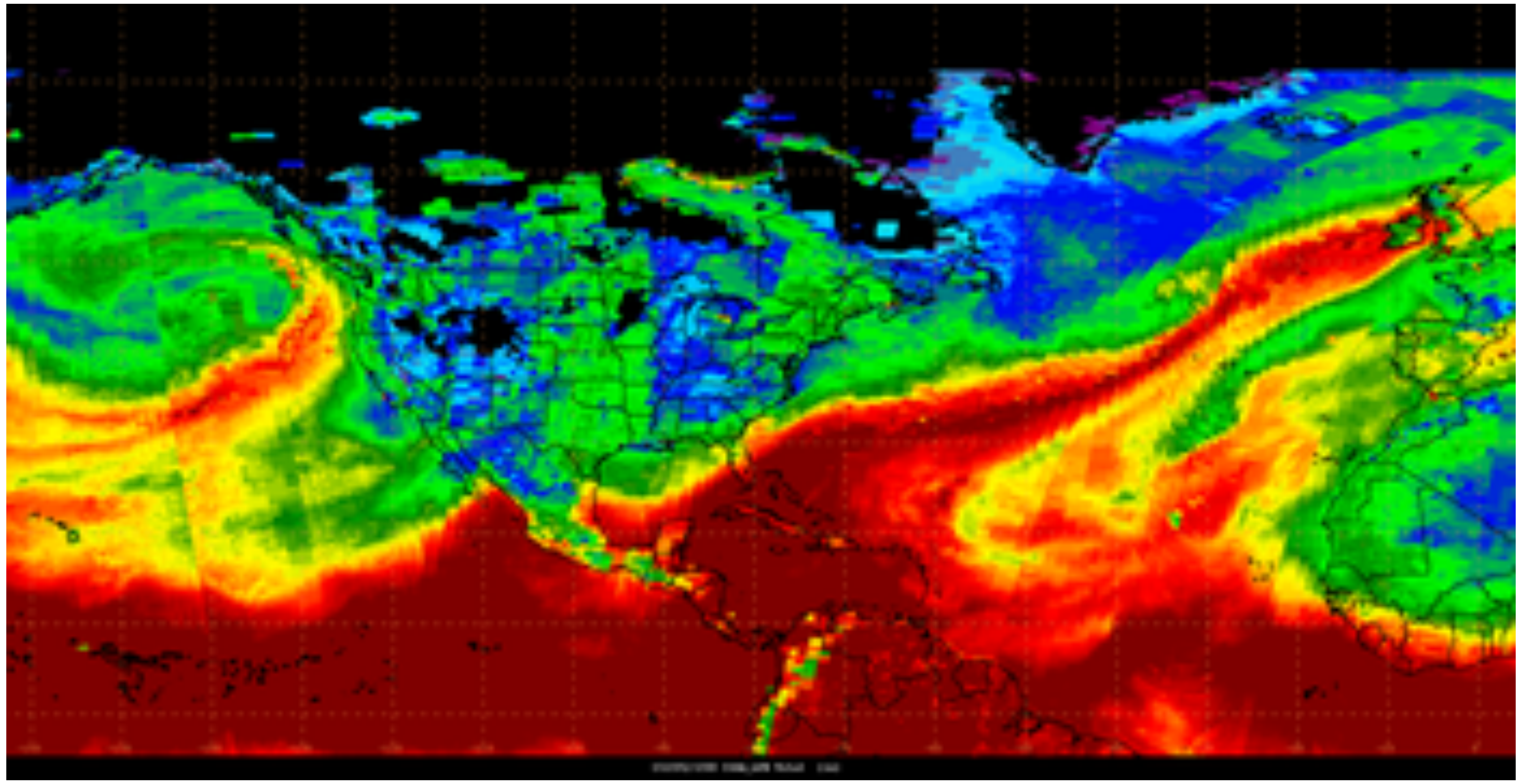
Water-Energy Cycle: Atmospheric Rivers

Energy flows determine flows in the Water Cycle …



Imagery of water vapor in the atmosphere above the Pacific Ocean from NOAA's GOES11 satellite in December 2010. The narrow band of high water vapor (red, arrowed) was moving northeastward.



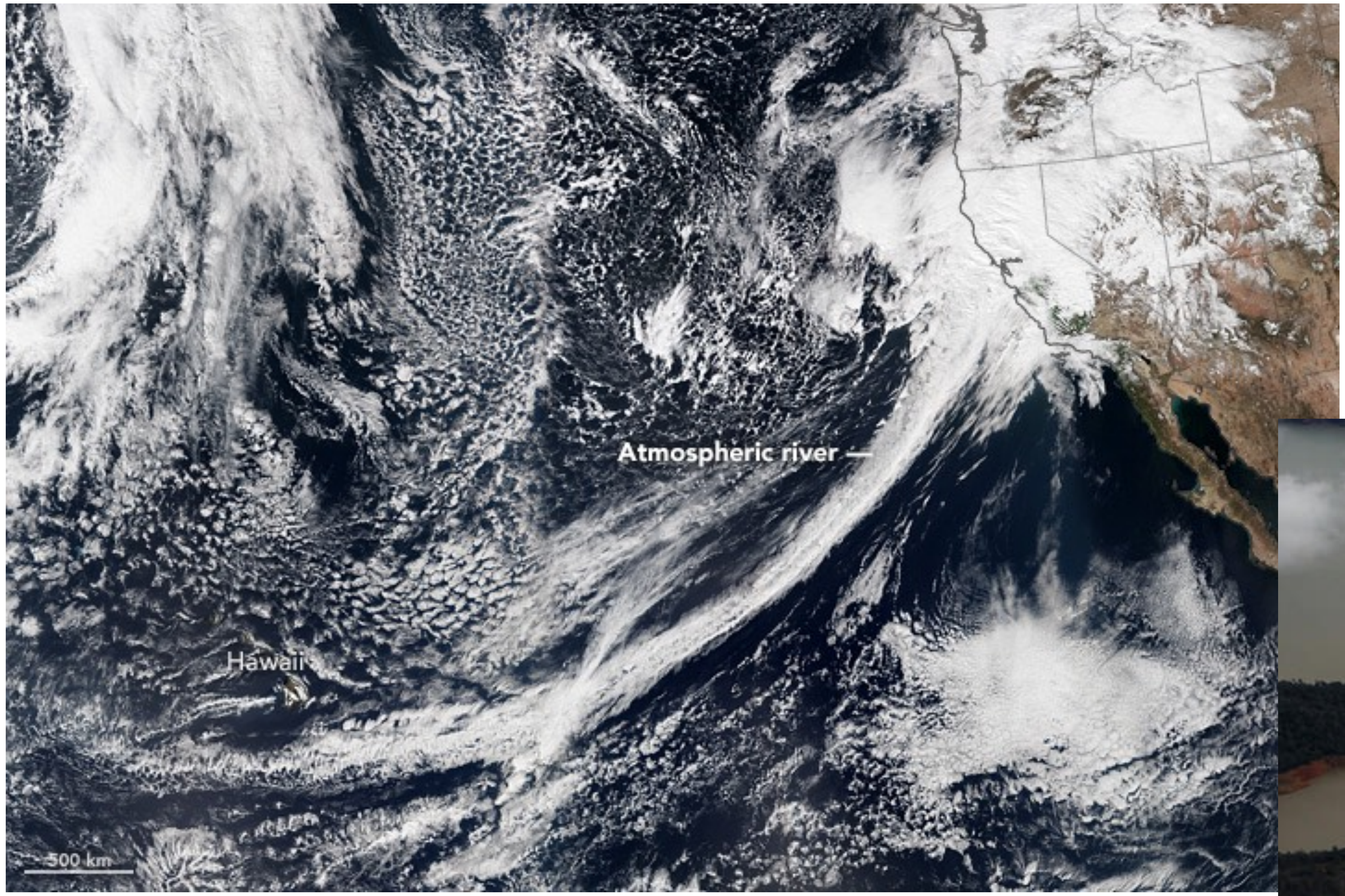
Satellite water vapor image for December 5, 2015, shows an intense atmospheric river (red color) moving across the north Atlantic toward the U.K.

Flooding in Cumbria, UK, in December 2015 caused by rain from the atmospheric river in the Figure above and associated Extratropical Storm Desmond.

Water-Energy Cycle: Atmospheric Rivers

Energy flows determine flows in the Water Cycle …

Atmospheric Rivers can cause mega floods



Atmospheric rivers January-February 2017

Lake Oroville Dam

Water-Energy Cycle: Atmospheric Rivers

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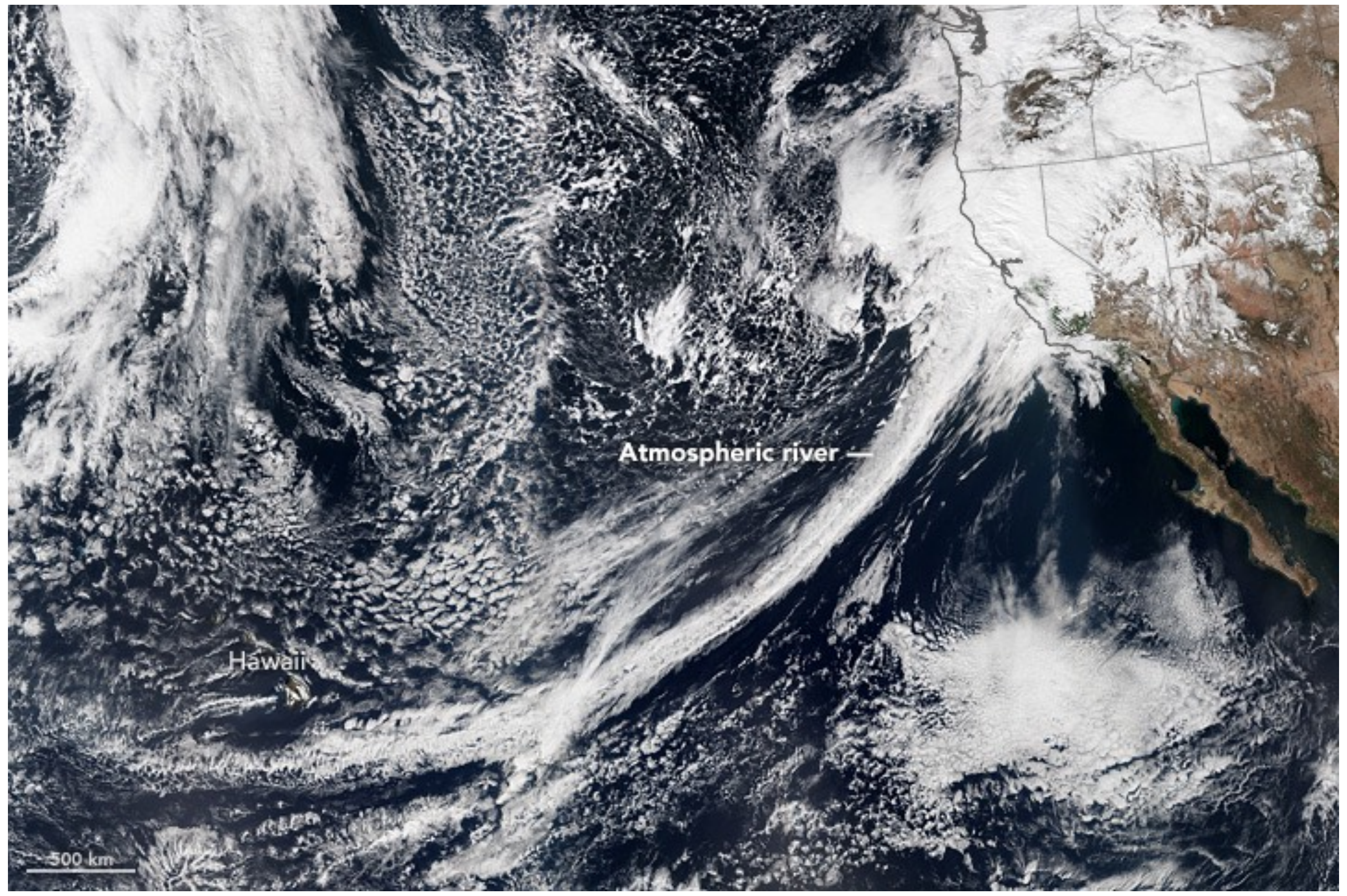
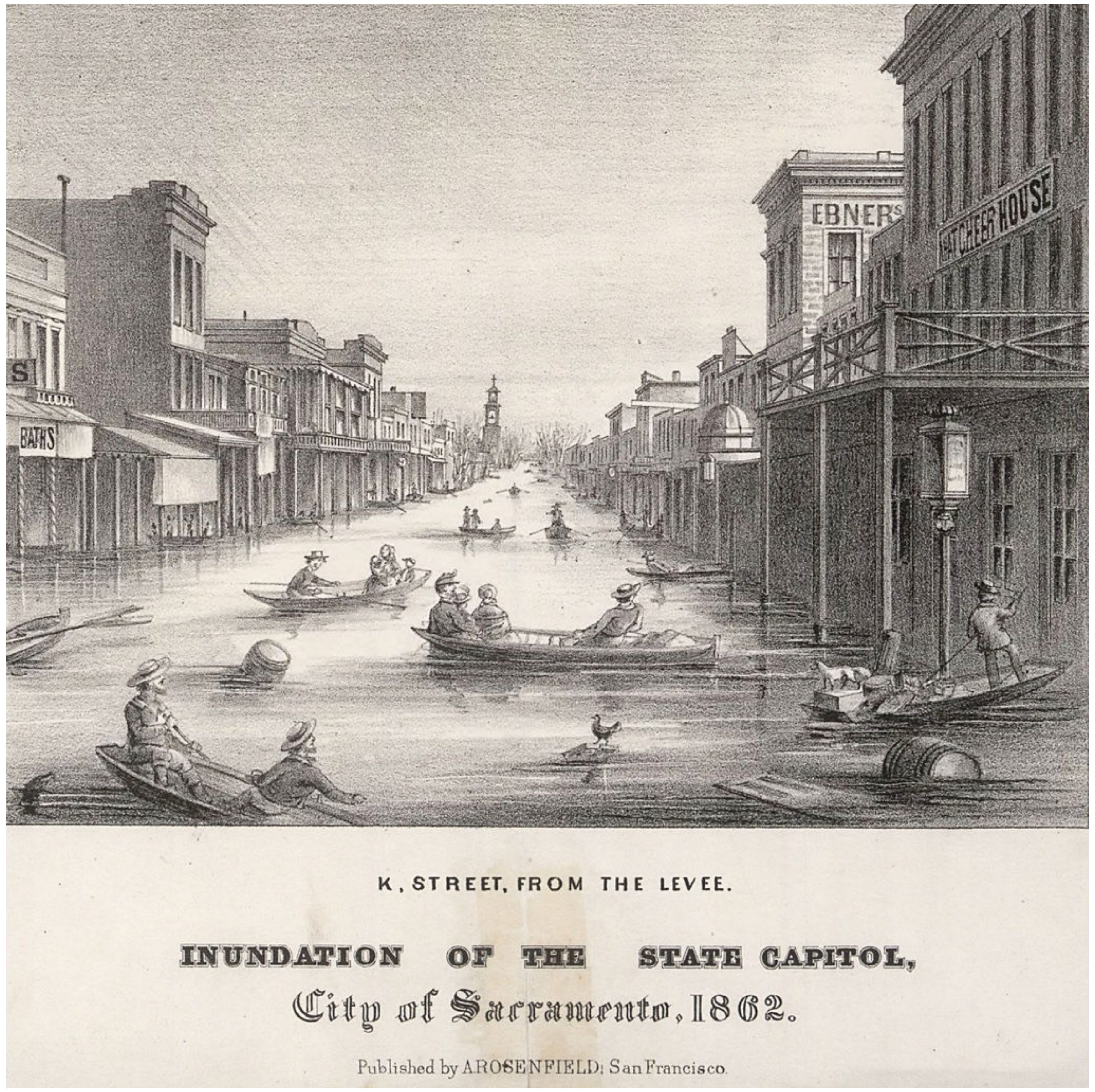
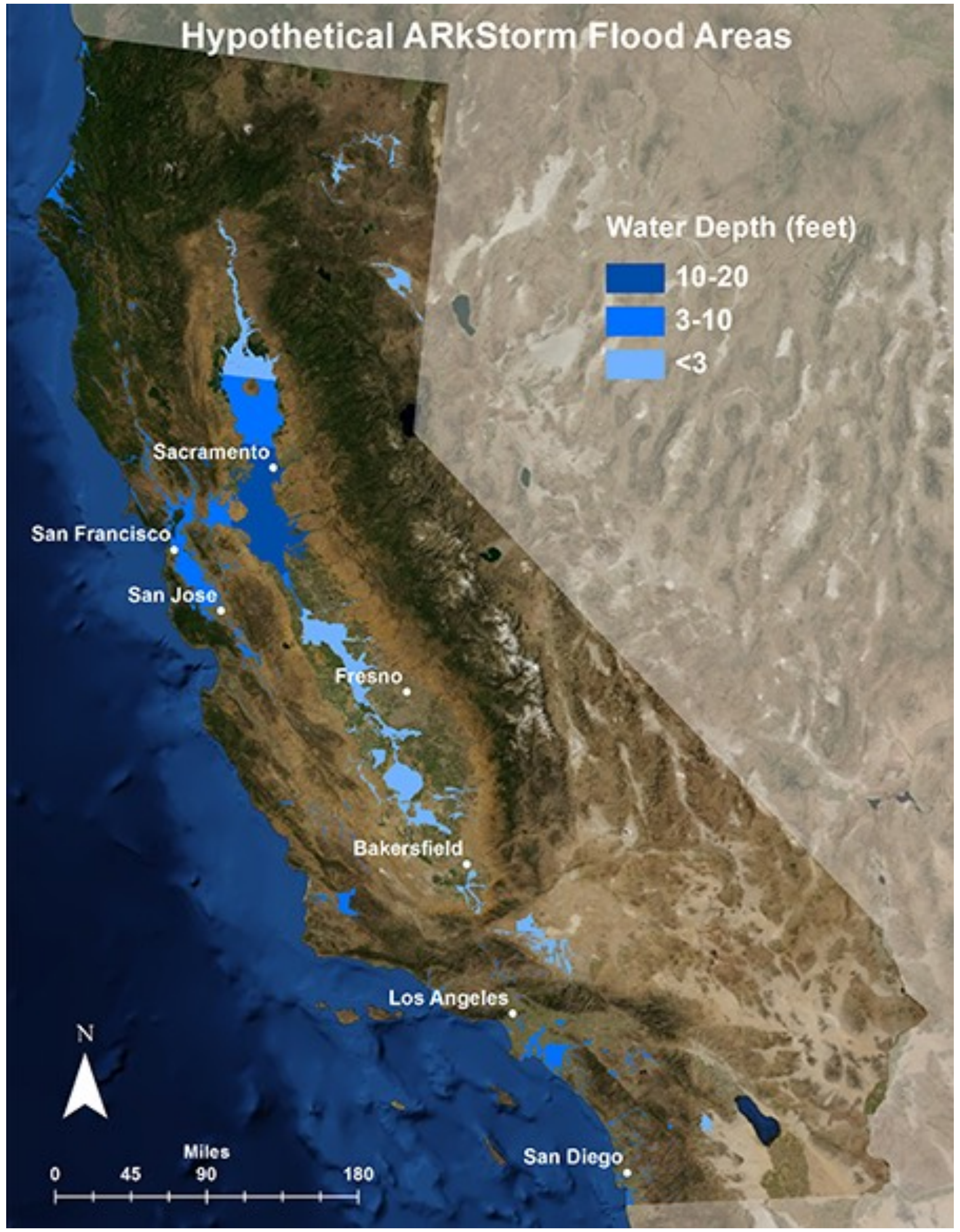




Atmospheric rivers
December 1861-January1862



Natural Hazards and Disaster

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Changing Flood Risk

We are replacing homeostasis with disequilibrium

Changing Flood Risk

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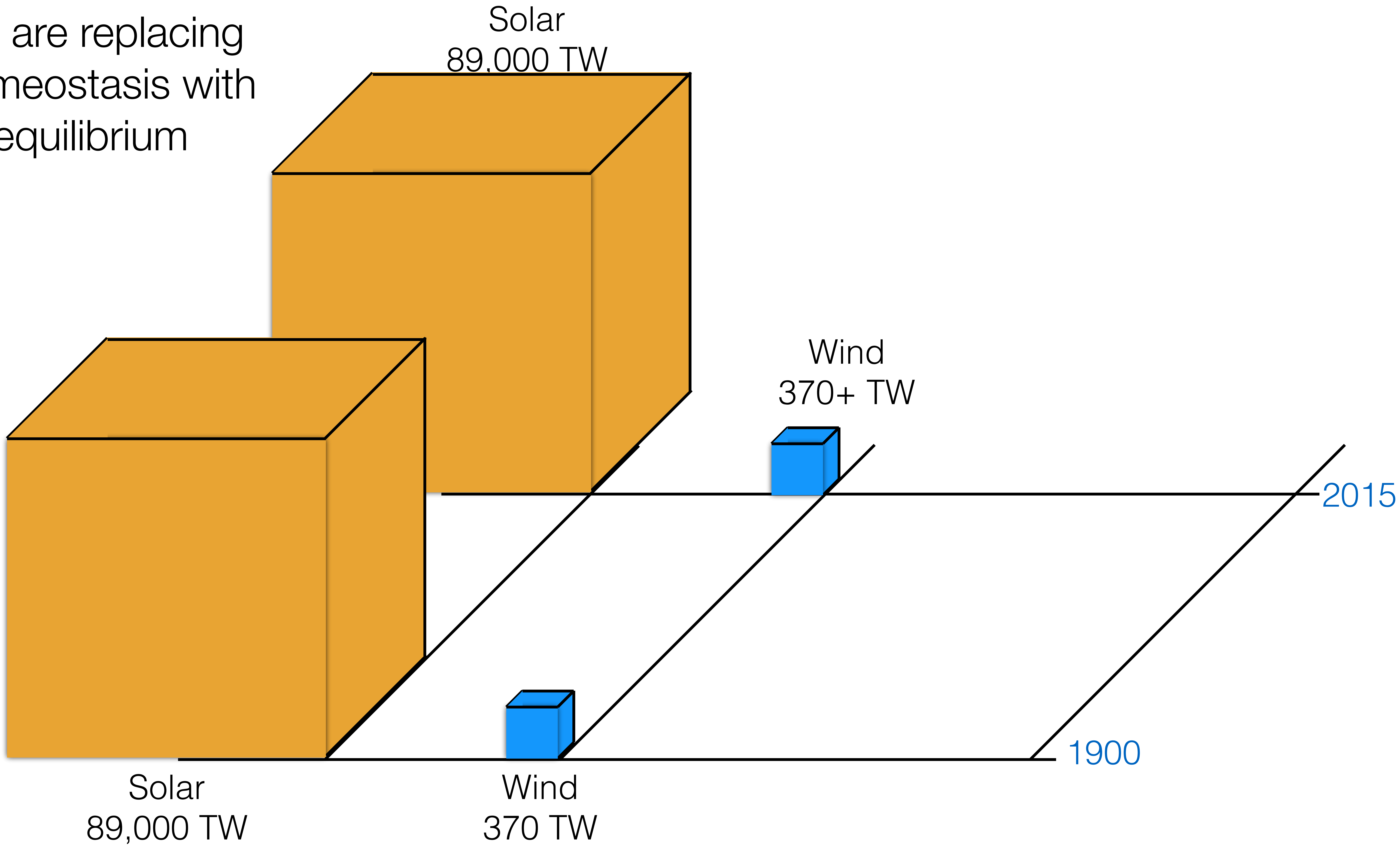

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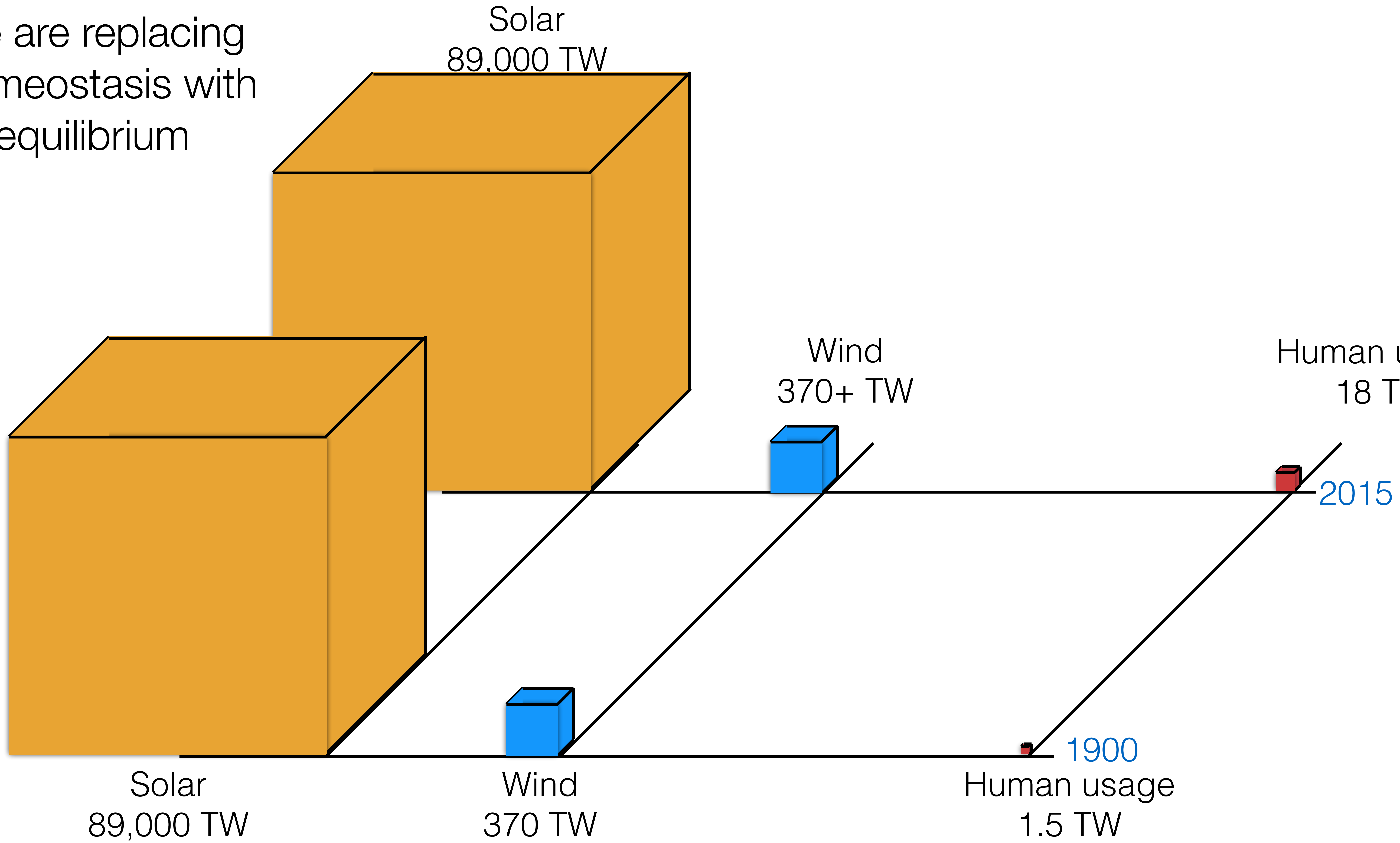


Changing Flood Risk

We are replacing homeostasis with disequilibrium

Solar

Mount Tambora, 1815

Human usage
18 TW

2015

1900

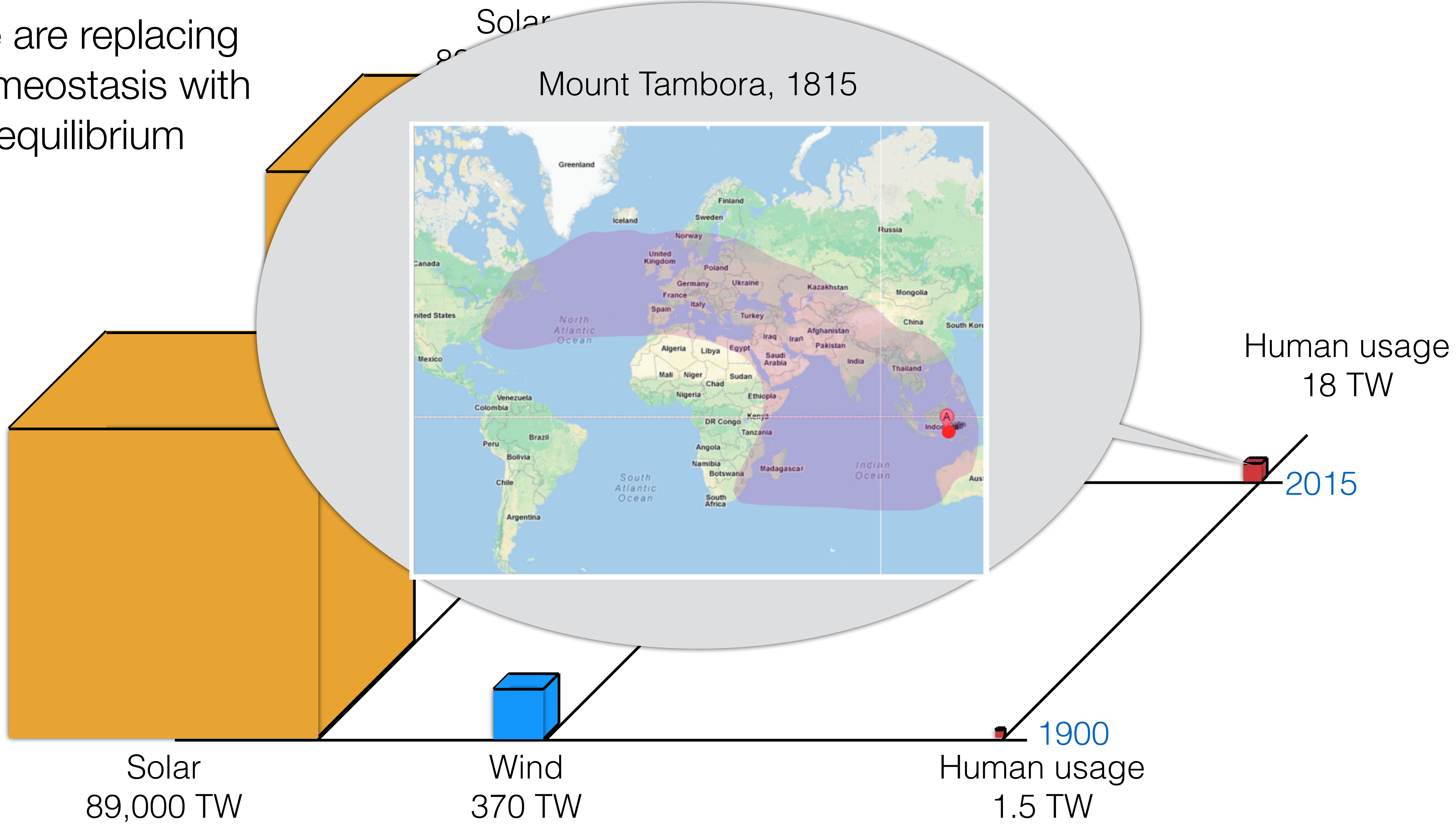
Solar
89,000 TW

Wind
370 TW

Human usage
1.5 TW

Changing Flood Risk

We are replacing homeostasis with disequilibrium



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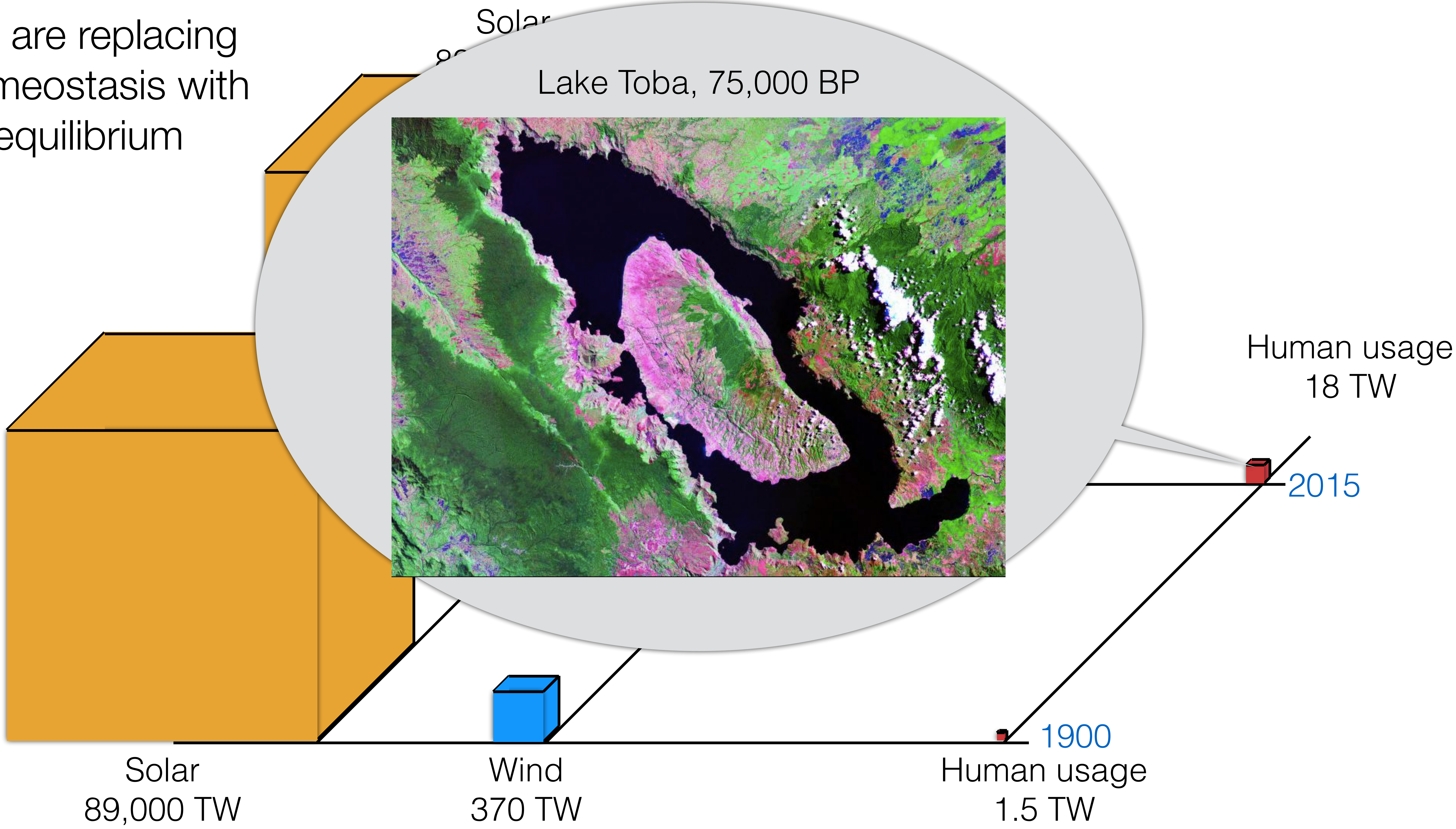
Lake Toba, 75,000 BP

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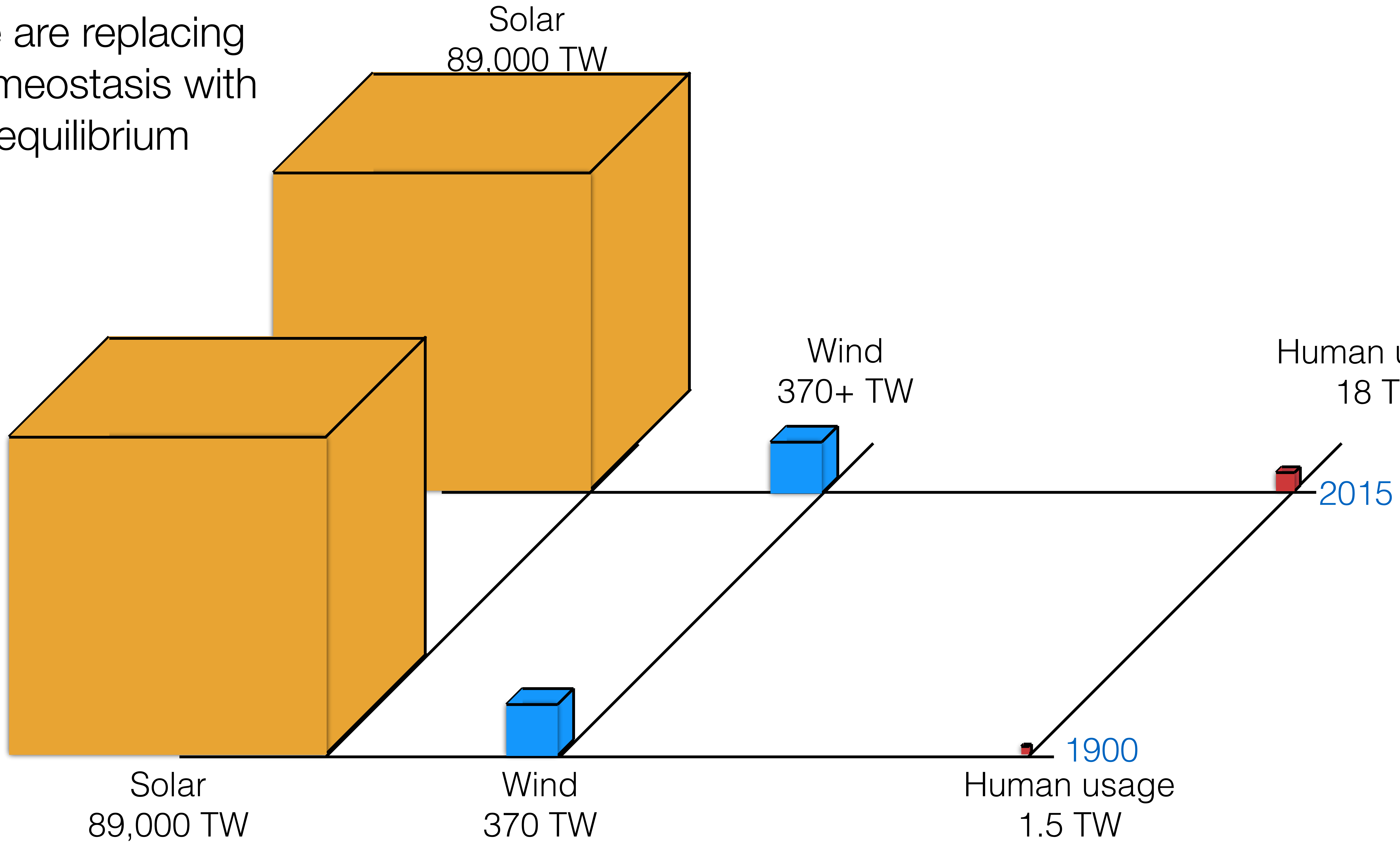

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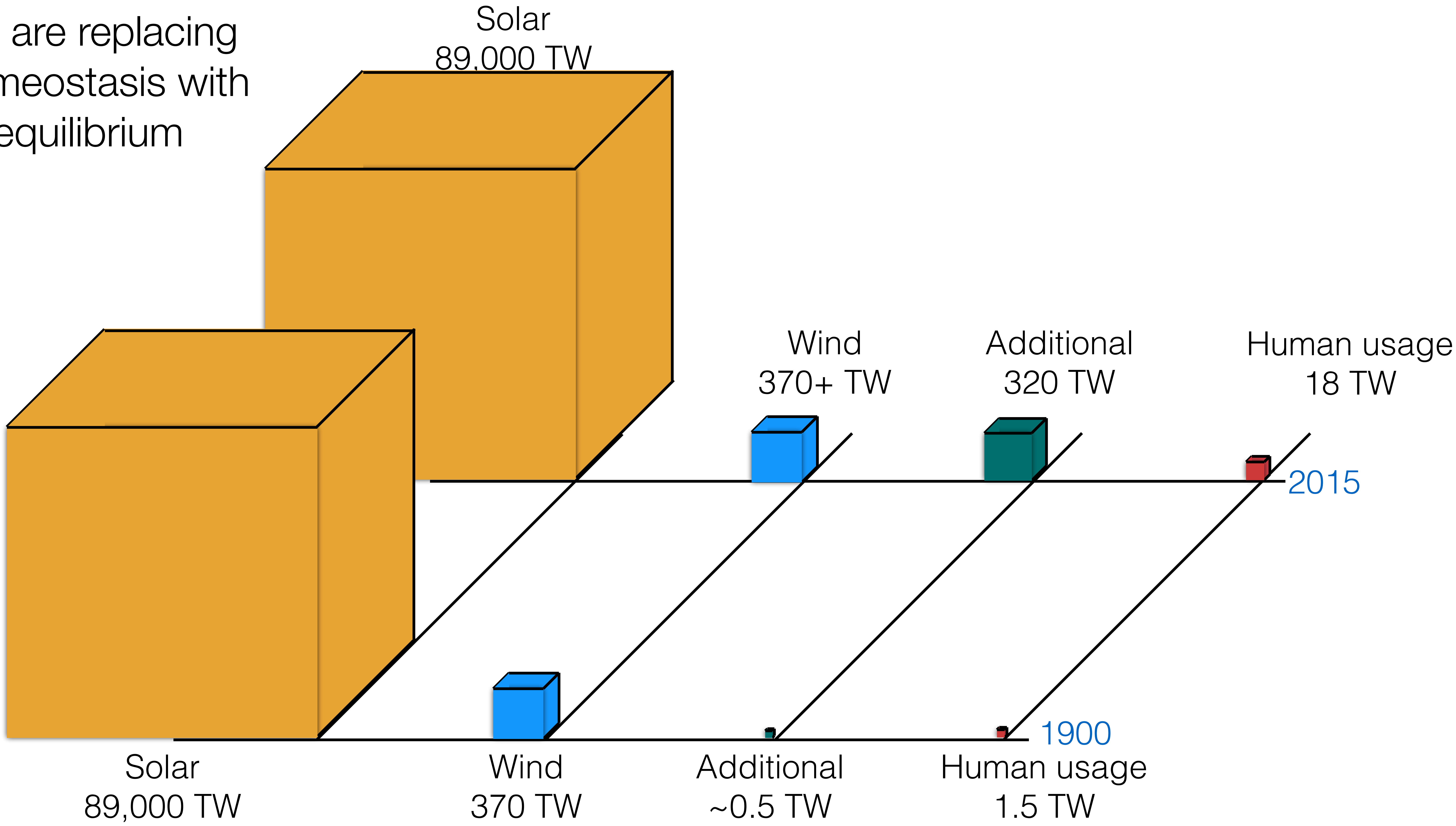

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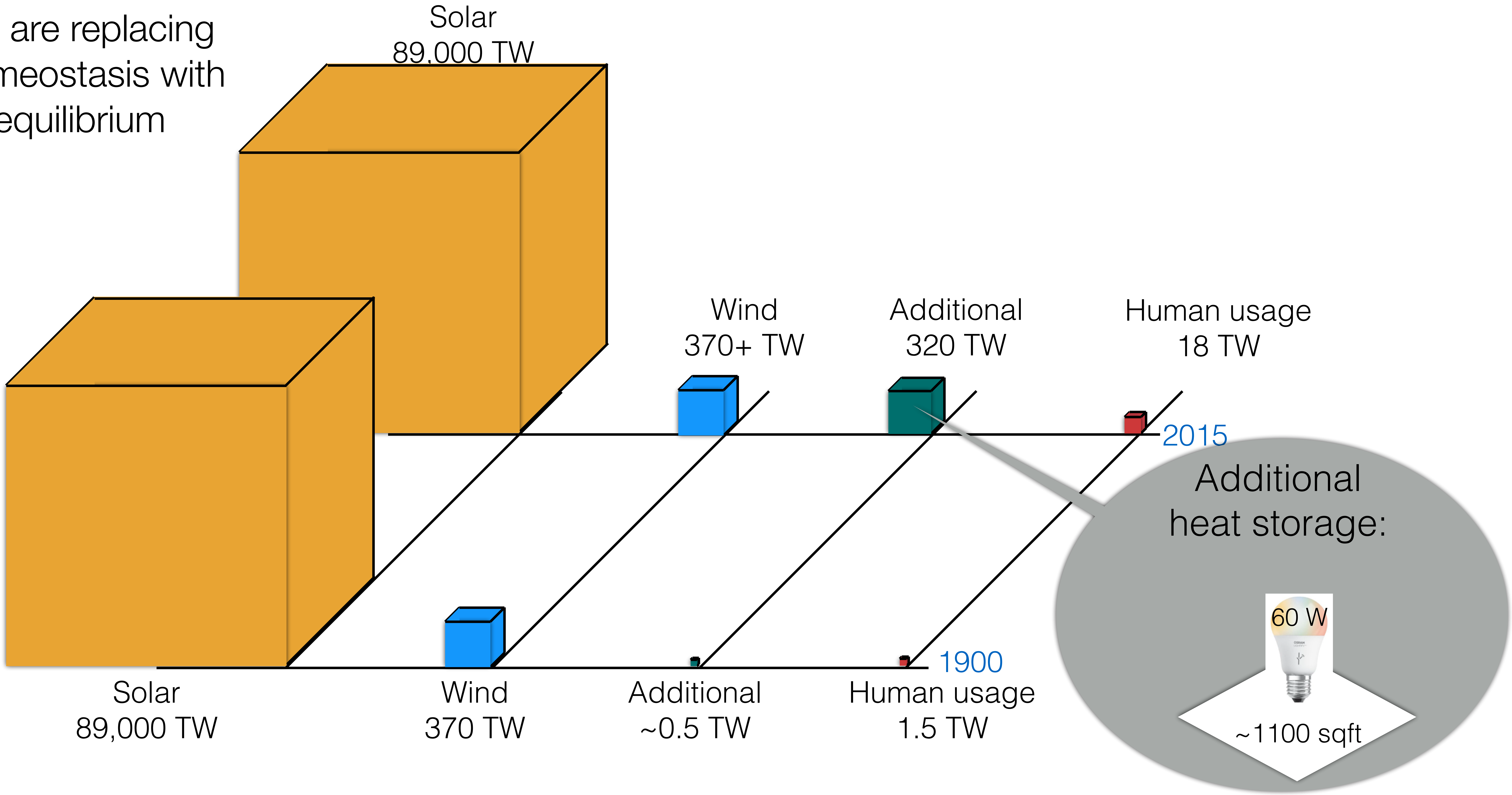

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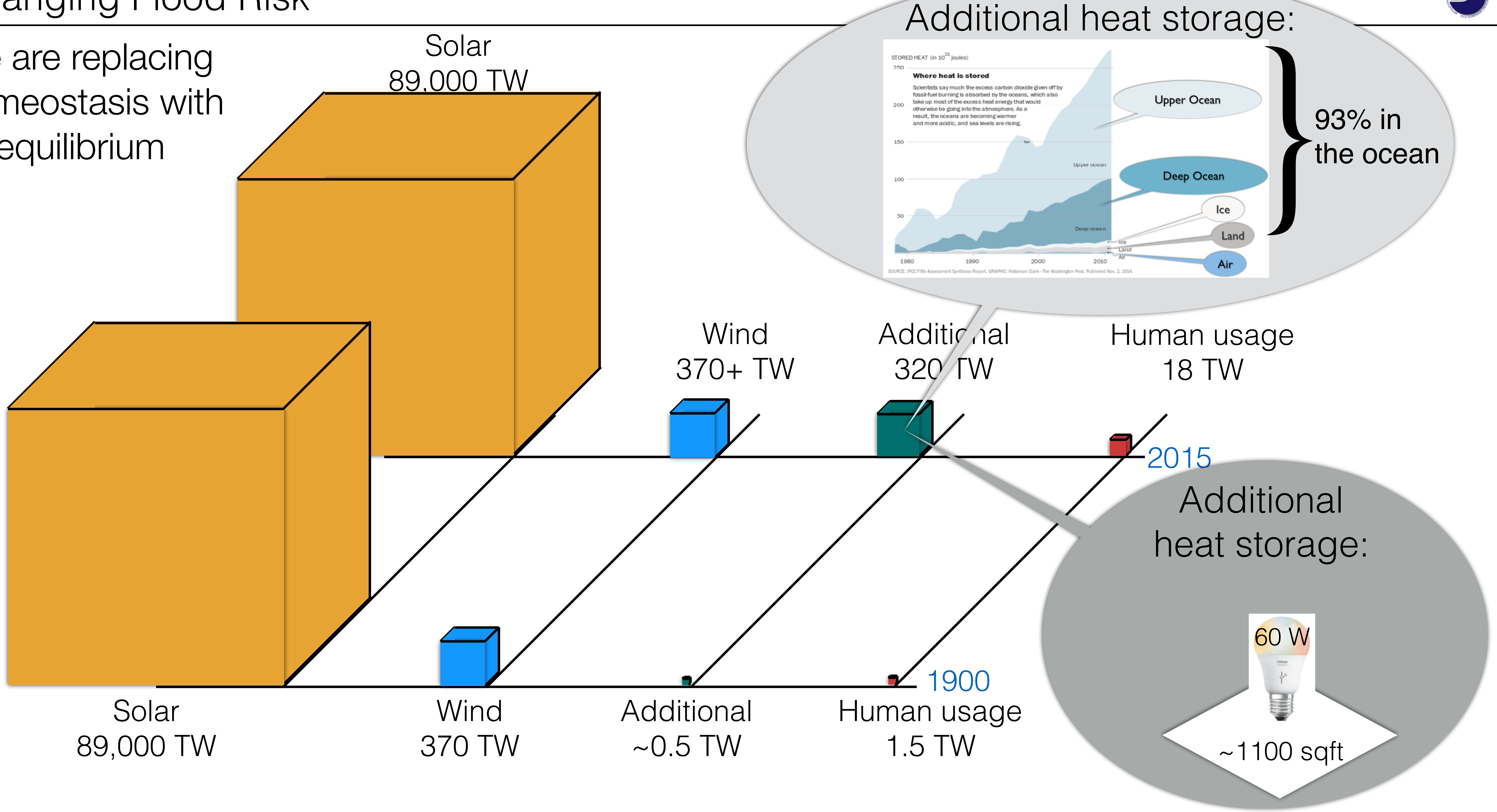

Where heat is stored

Scientists say much the excess carbon dioxide given off by fossil-fuel burning is absorbed by the oceans, which also take up most of the excess heat energy that would otherwise be going into the atmosphere. As a result, the oceans are becoming warmer and more acidic, and sea levels are rising.

SOURCE: IPCC Fifth Assessment Synthesis Report. GRAPHIC: Patterson Clark - The Washington Post. Published Nov. 2, 2014.

Changing Flood Risk

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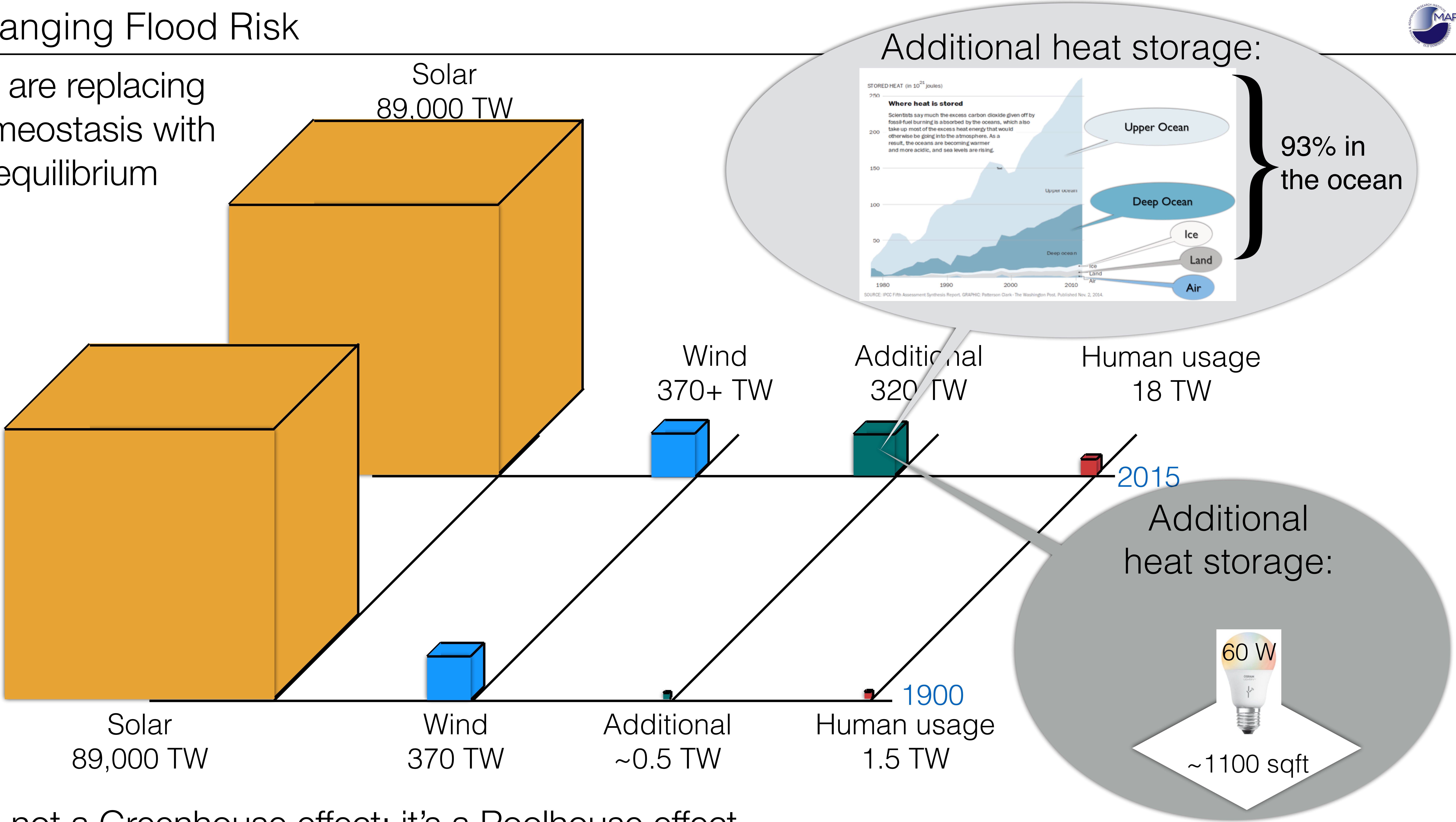

Additional heat storage:

STORED HEAT (in 10^{21} joules)

Where heat is stored

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93% in the ocean

It’s not a Greenhouse effect; it’s a Poolhouse effect

Changing Flood Risk

In a Dissipative System, small changes can change the characteristics of the system …

Changing Flood Risk

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Energy flows from fossil fuels => humanity => life-support system.

This impacts other flows in a “re-engineered” system and amplifies imbalances:

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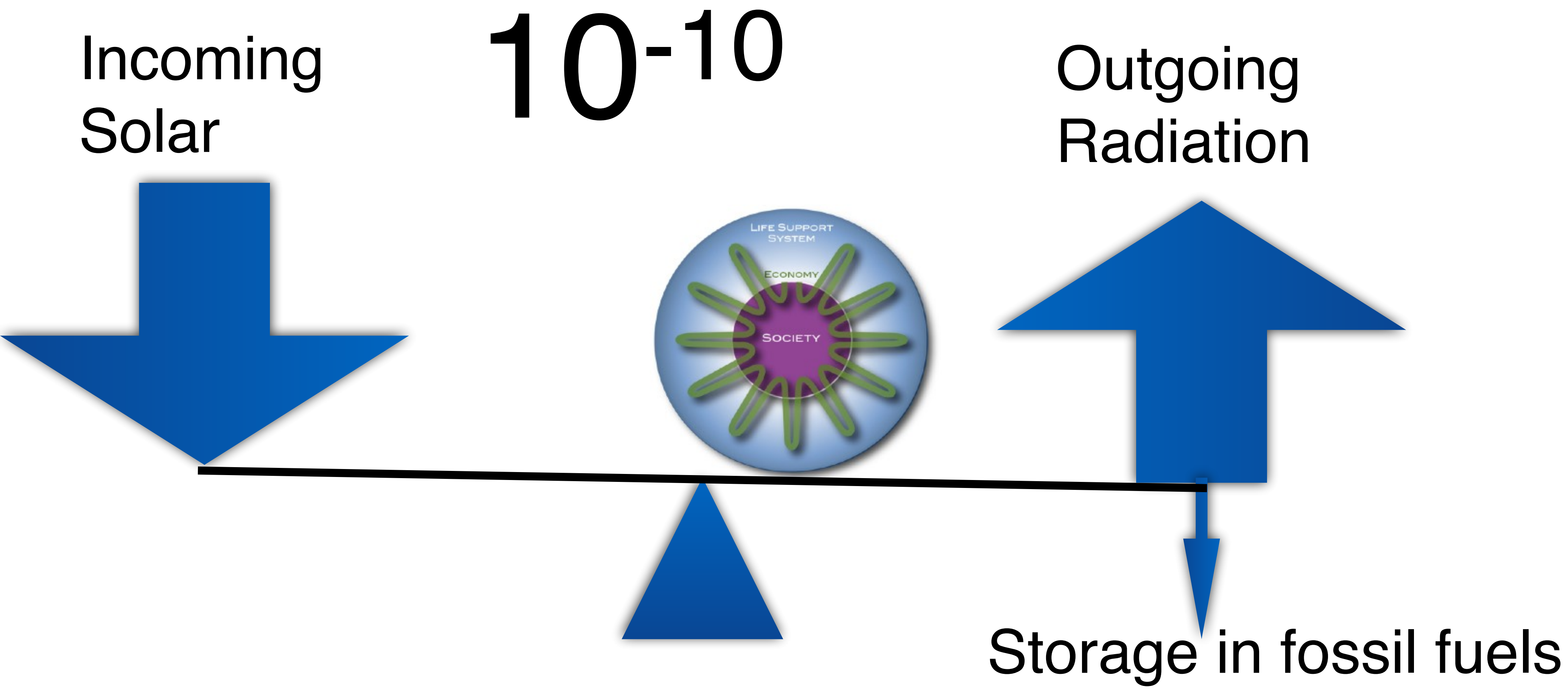

Incoming Solar

10^{-10}

Outgoing Radiation

Storage in fossil fuels

Imbalance on the order of 10^{-10}

Last 200 Million years

Changing Flood Risk

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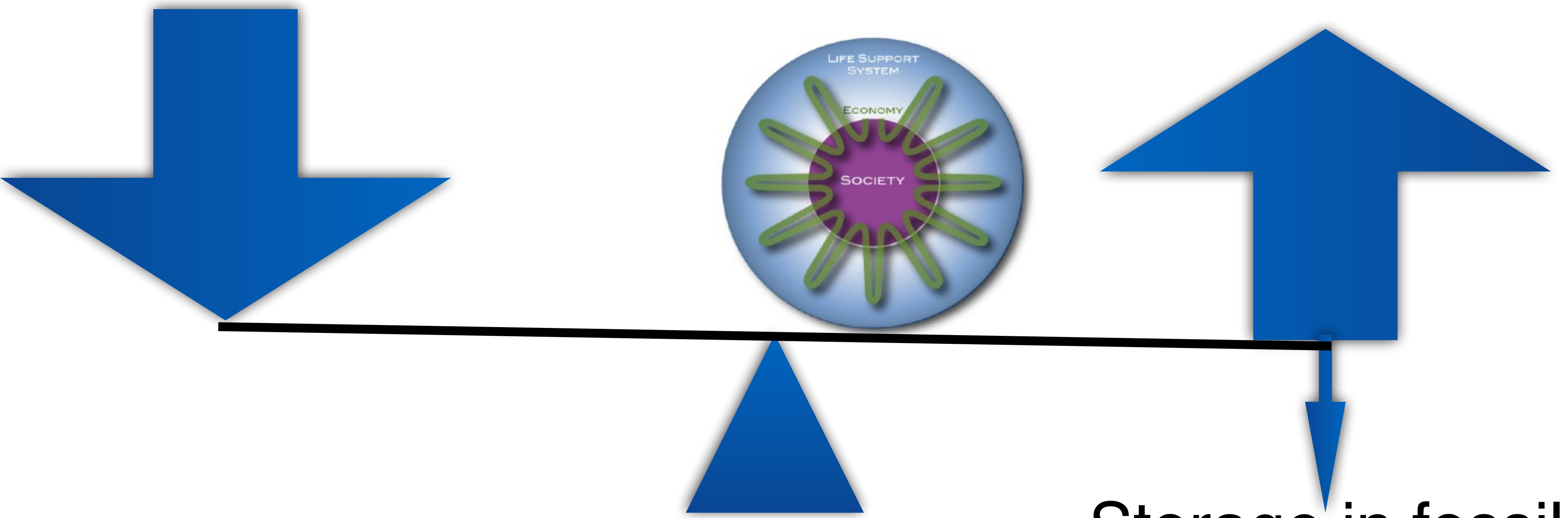

Incoming Solar

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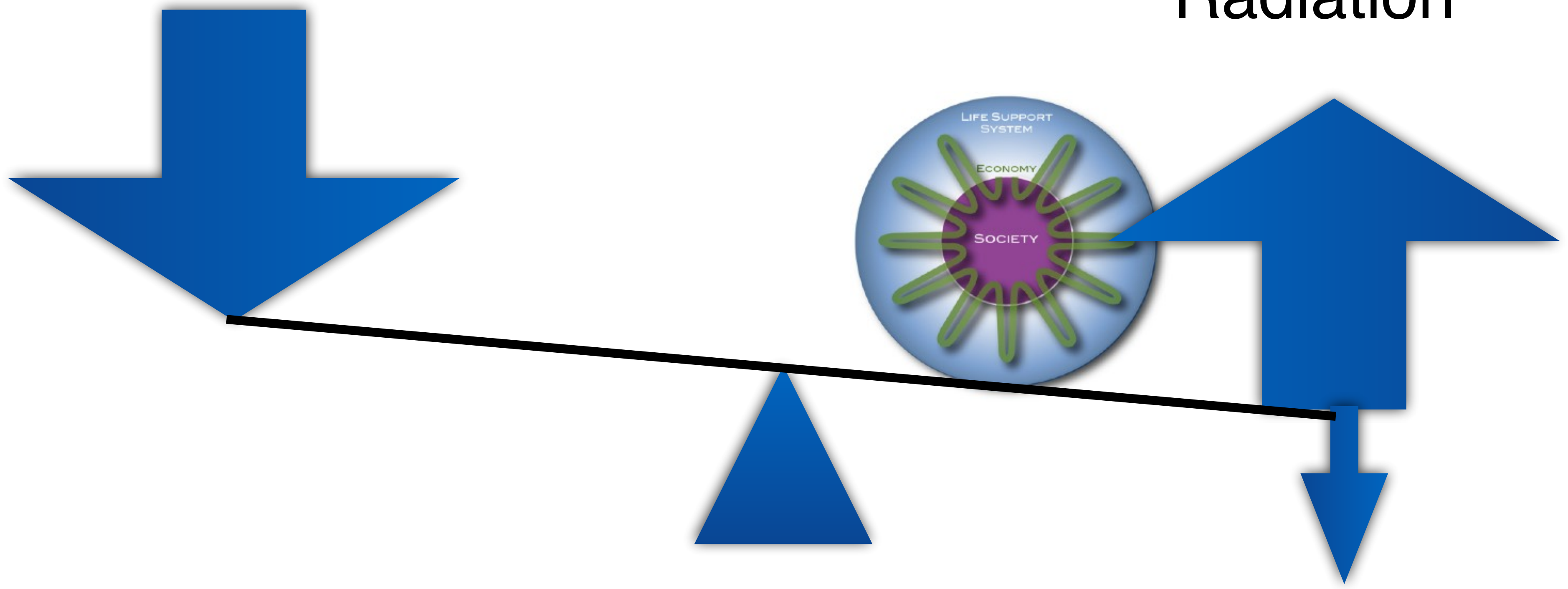

Incoming Solar

10^{-3}

Outgoing Radiation

Storage in heat

Imbalance on the order of 10^{-3}

Last 70 years

Changing Flood Risk

St Vincent and the Grenadines: Preparing for surprises

October 2016

Changing Flood Risk

St Vincent and the Grenadines: Preparing for surprises

- Carry out high-resolution LIDAR survey
- Identify possible flood zones and landslide areas under extreme events
- Advice/regulate new constructions to be in safe areas

October 2016

Changing Flood Risk

Preparing for Surprises: Extreme flood in Gauteng, South Africa, November 10-11, 2016

Changing Flood Risk

Preparing for Surprises: Extreme flood in Gauteng, South Africa, November 10-11, 2016

THE CONVERSATION 19 OCTOBER 2017

South Africa: Why Cape Town's Drought Was So Hard to Forecast

Tagged: Climate • Environment • Science • South Africa • Southern Africa • Sustainable Development

Photo: *Ashraf Hendricks/GroundUp*

Theewaterskloof Dam in drought stricken Western Cape on 11 May 2017.

ANALYSIS

By Bruce Hewitson, University of Cape Town, Chris Jack and Piotr Wolski

Cape Town's drought and associated water shortage has officially escalated to the level of a disaster. The hope for a natural solution ended with the close of the main rainy season in September, and it is clear that water in the dams supplying the city will not last until the next rains in May-June next year.

The city had promised alternative sources of supply, the plans are not entirely realistic. Its main strategy now is to severely restrict water use through rationing.

RELATED TOPICS

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Environment »

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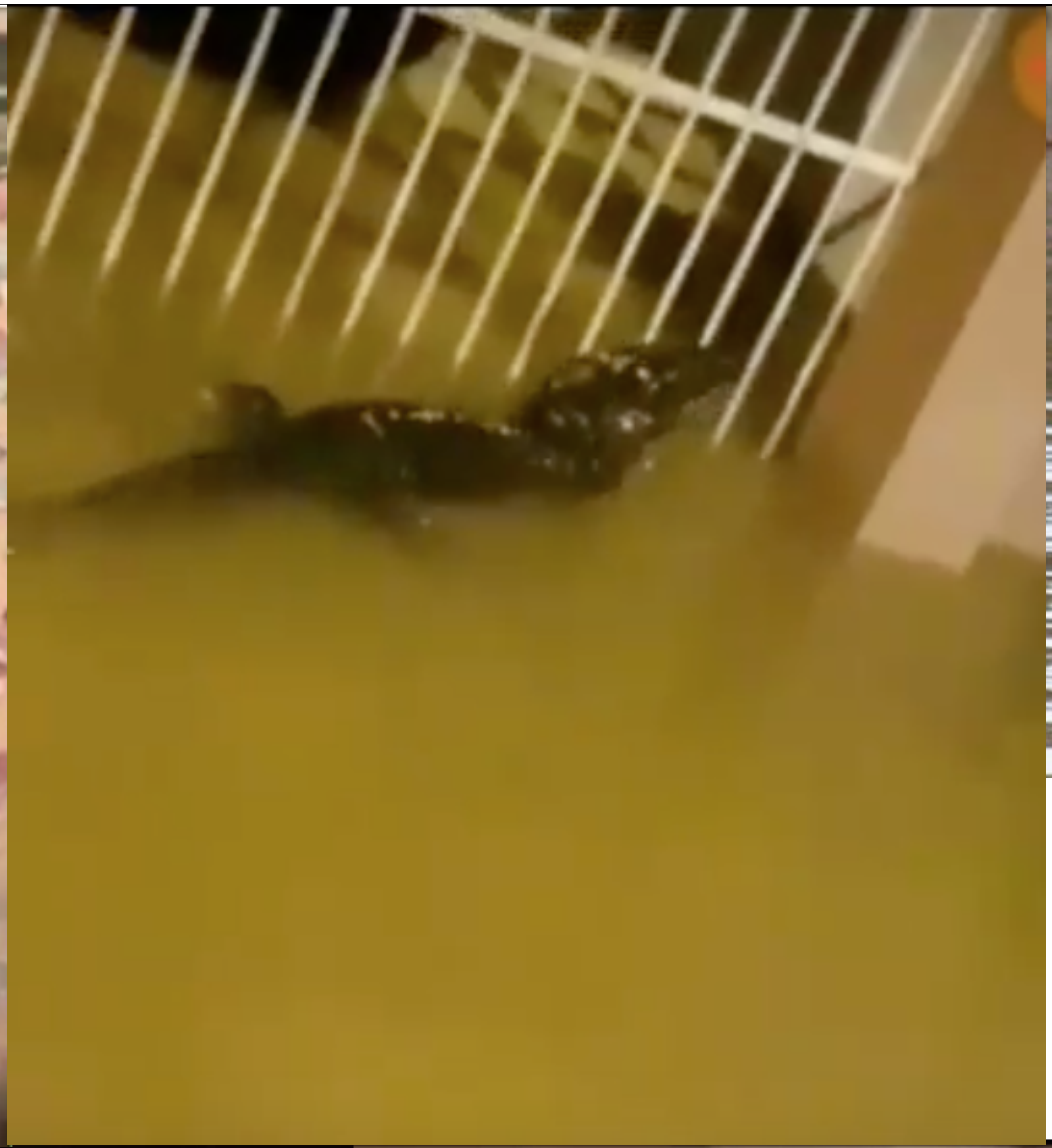
- Sudan: Sudan Selected General Rapporteur of 7th Islamic Conference of Environment Ministers

Changing Flood Risk



Trinidad and Tobago Flood, October 19, 2018

Changing Flood Risk

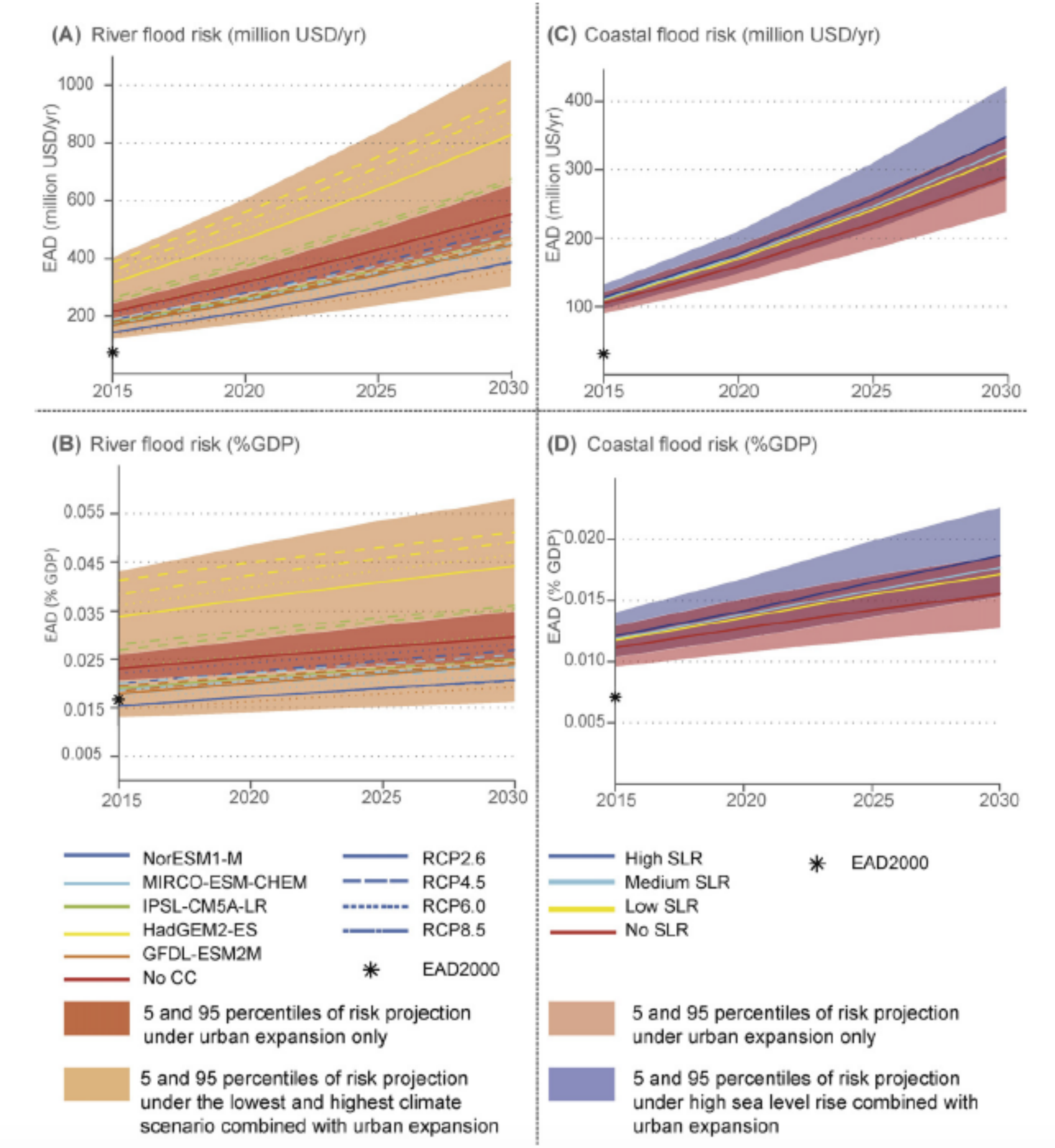
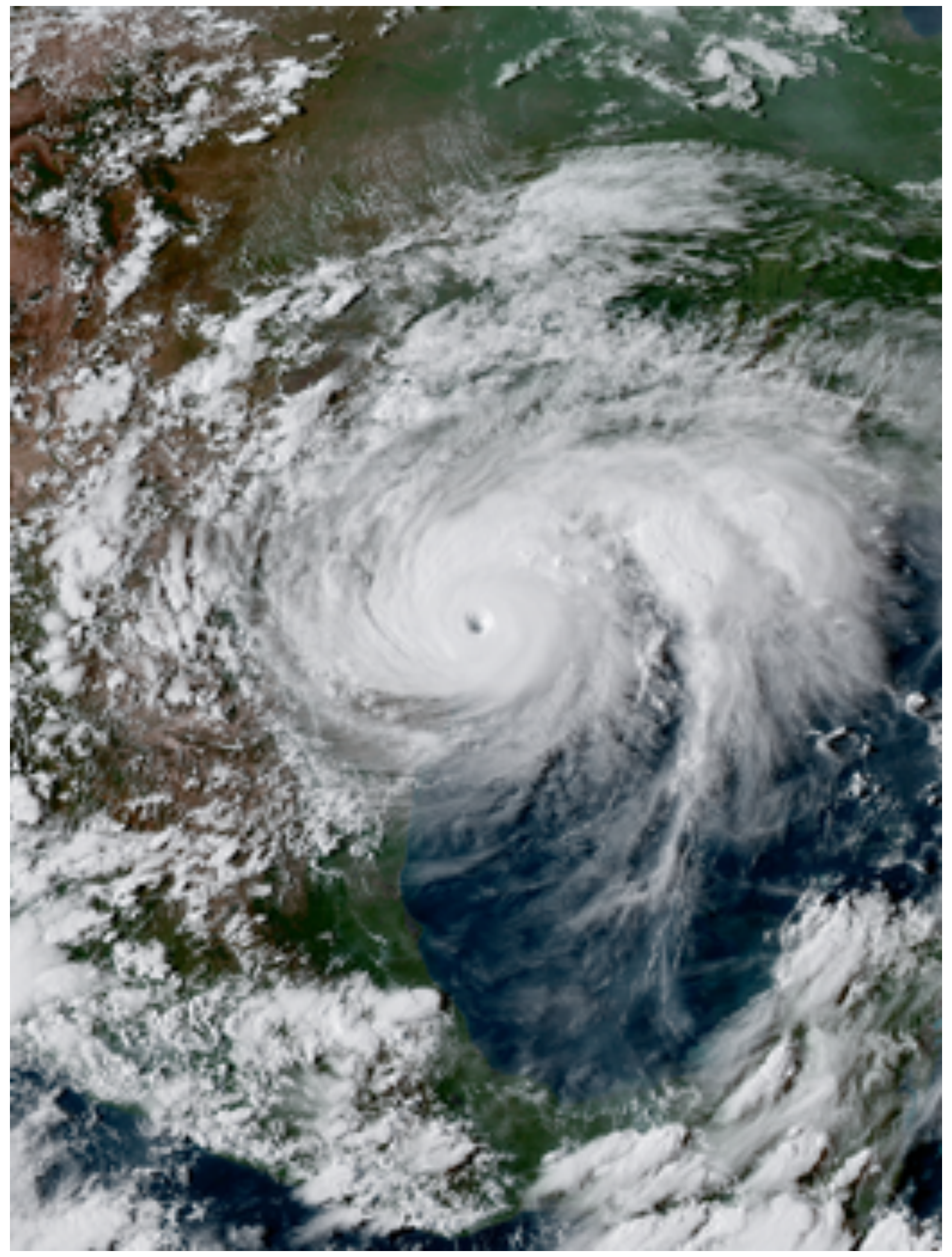


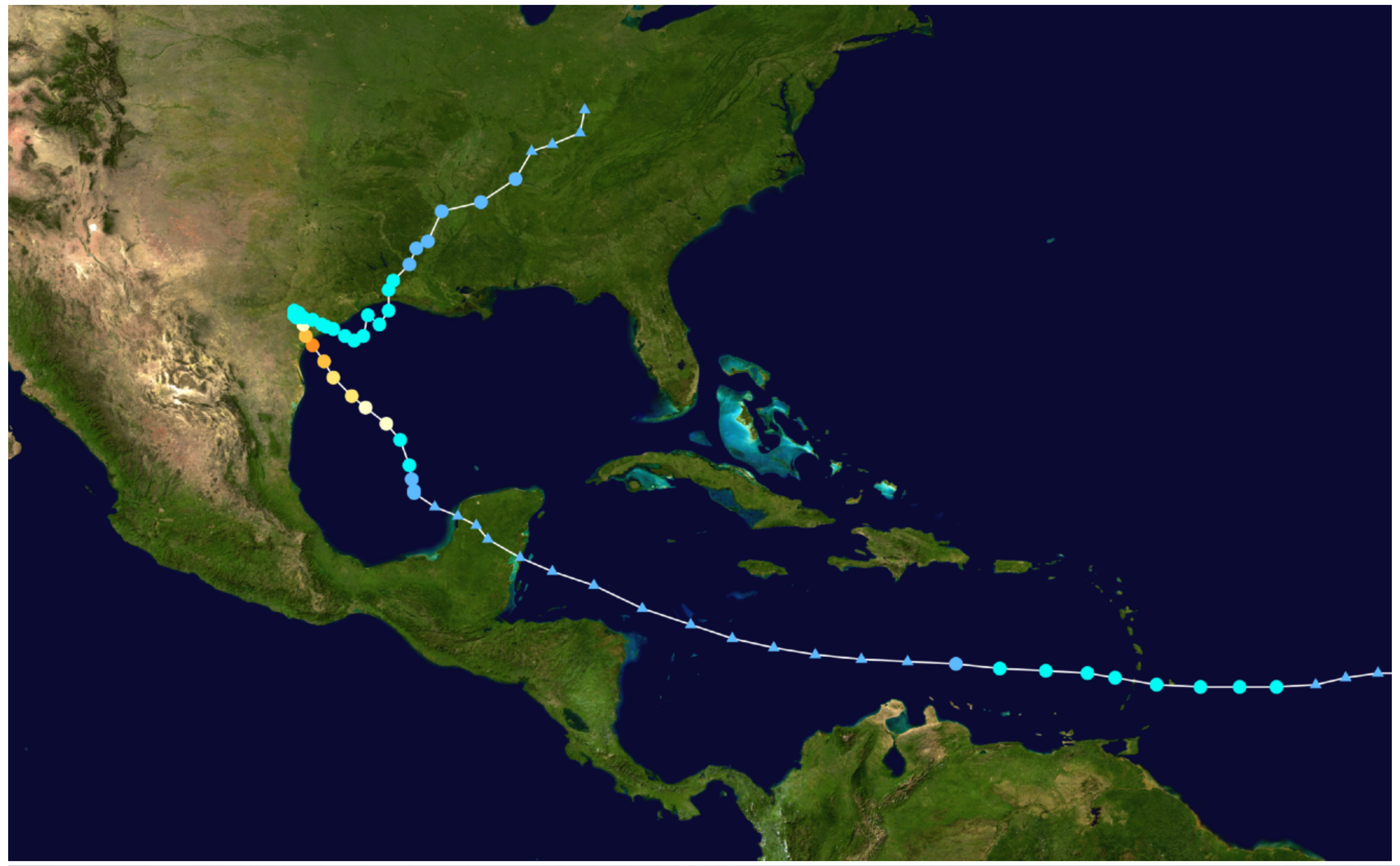
Fig. 6. Projections of changes in flood risk (EAD; expected annual damage) between 2015 and 2030. River flood risk is shownunder 20 different projections of climate change (5 GCMSand 4 RCPs) and for all projections of urban expansion. Absolute values are shown in (A), while values normalized to GDP are shown in (B). The light red shaded band shows the 5th–95th percentiles for the projections with no climate change (i.e. urban expansion only). The light orange shaded band shows the 5th–95th percentiles over the lowest and highest risk projection when the urban projections are combinedwith the 20 climate change projections. Coastal flood risk is shown under different scenarios of sea level rise (SLR) and for all projections of urban expansion using absolute values (C) and normalized to GDP (D). The red shaded band shows the 5th–95th percentiles for the projectionswith no SLR (i.e. urban expansion only). The blue shaded band shows the 95th percentile and 5th percentile when the urban projections are combined with high SLR.

Muis et al., 2015

Changing Flood Risk

Energy flows determine flows in the Water Cycle …





A warming ocean can cause more and stronger hurricanes