GLOBAL ENERGY and WATER EXCHANGES and its Science Goals

Peter van Oevelen

Based upon inputs from entire GEWEX community

The Global Energy and Water EXchanges (GEWEX) project of the World Climate Research Programme

- One of 6 core projects that supports global climate research collaboration
- GEWEX is dedicated to understanding Earth's water cycle and energy fluxes at, and below the surface and in the atmosphere. We are a network of scientists gathering information on and researching the global water and energy cycles, which will help to predict changes in the world's climate. The International GEWEX Project Office, or IGPO, supports these activities by planning meetings, implementing research goals, and producing a quarterly newsletter to keep the GEWEX community informed.

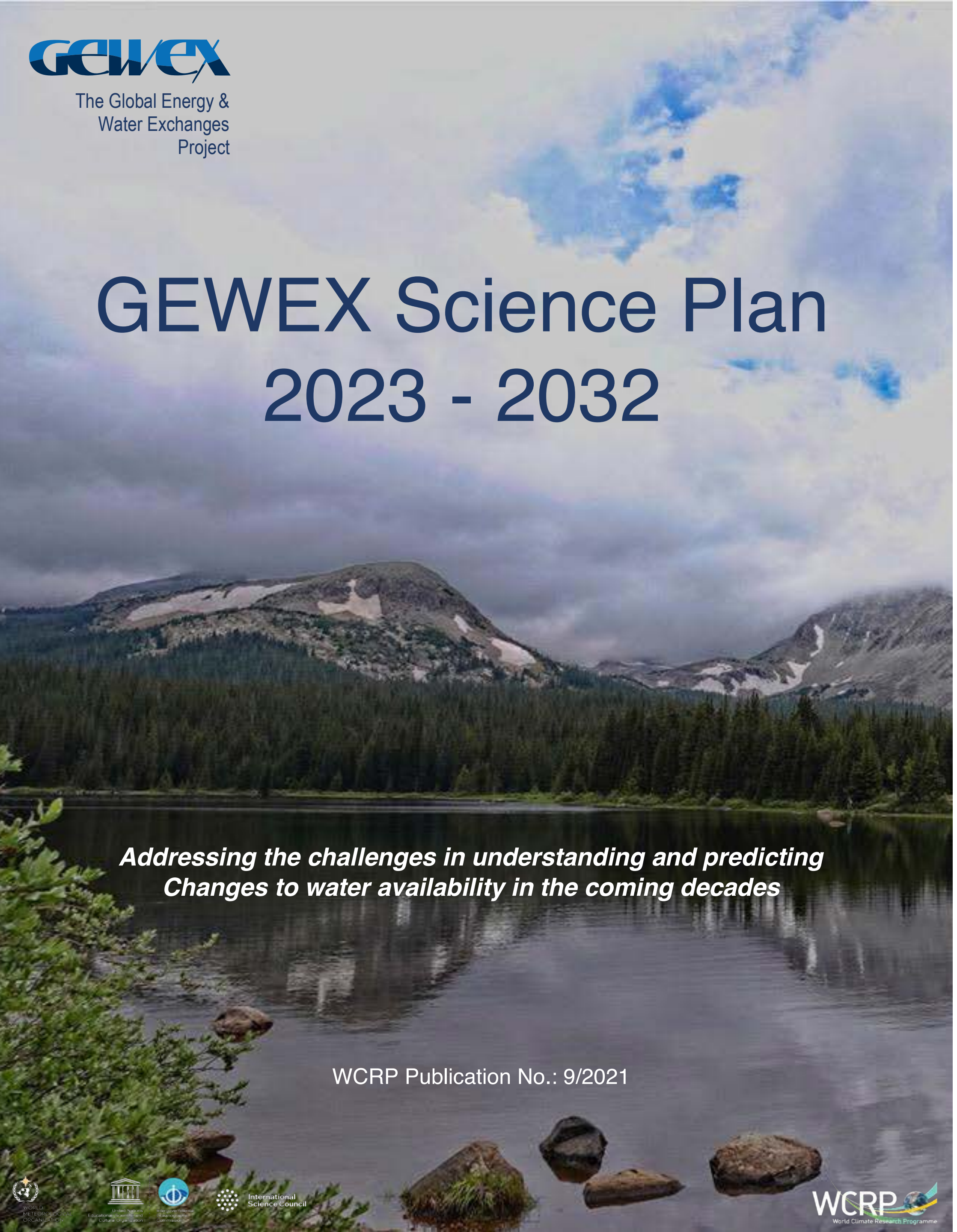
- OUR MISSION IS TO OBSERVE, UNDERSTAND AND MODEL THE HYDROLOGICAL CYCLE AND ENERGY FLUXES IN THE EARTH'S ATMOSPHERE AND AT THE SURFACE.

GEWEX Science Priorities

GEWEX Science Plan 2023-2032

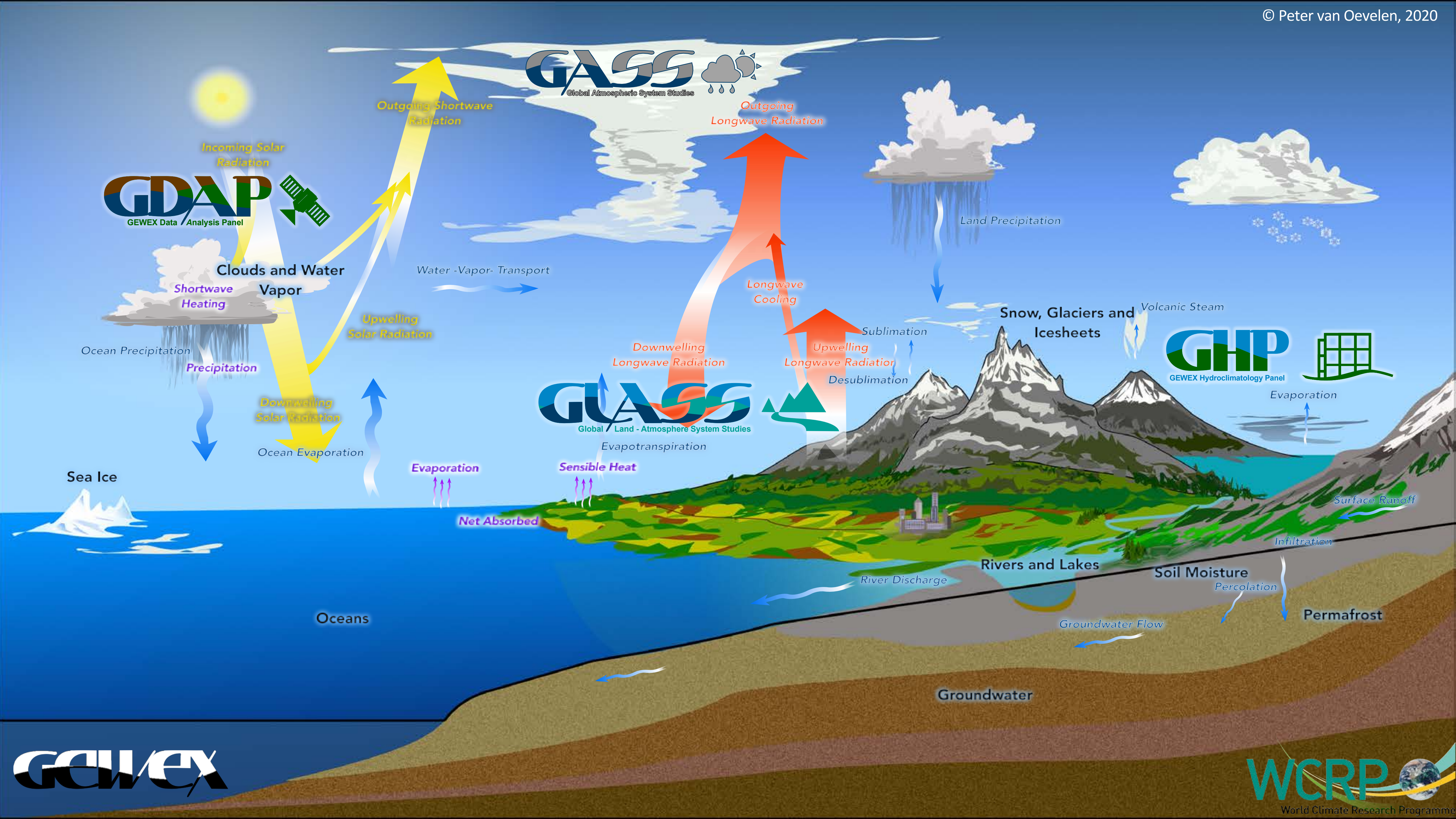
Addressing the challenges in understanding and predicting changes to water availability in the coming decades

An Earth Observation Perspective



https://www.gewex.org/about/science/gewex-science-goals/

- https://www.gewex.org/gewex-content/uploads/2022/05/GEWEX-science-plan-v8.pdf



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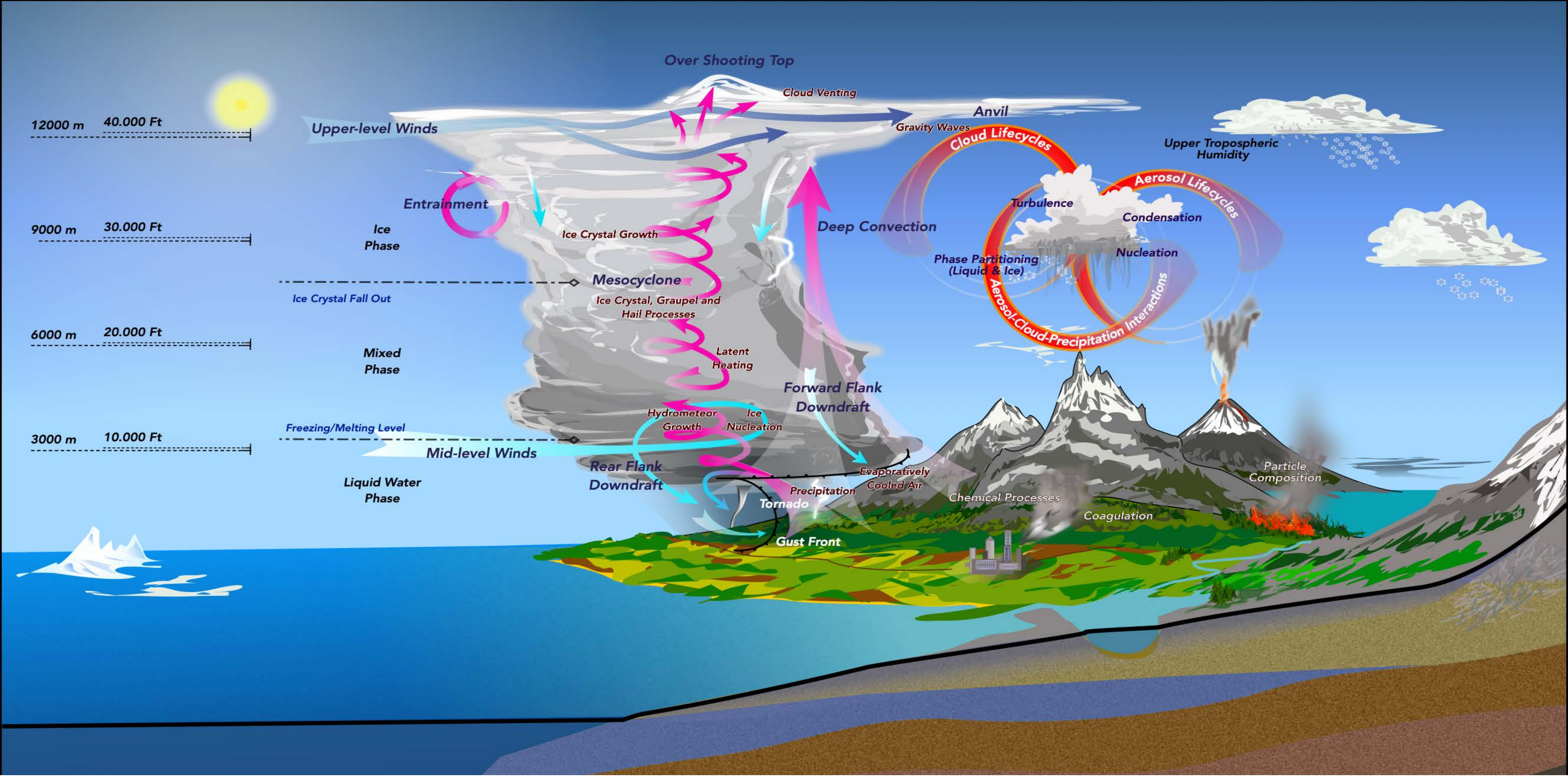
GASS
Global Atmospheric System Studies
Outgoing Shortwave Radiation
Outgoing Longwave Radiation
Incoming Solar Radiation
GDAP
GEWEX Data Analysis Panel
Land Precipitation
Clouds and Water Vapor
Water -Vapor- Transport
Shortwave Heating
Longwave Cooling
Upwelling Solar Radiation
Snow, Glaciers and Icesheets
Volcanic Steam
Sublimation
Ocean Precipitation
Precipitation
Downwelling Longwave Radiation
Upwelling Longwave Radiation
Desublimation
GHP
GEWEX Hydroclimatology Panel
Evaporation
GLASS
Global Land - Atmosphere System Studies
Downwelling Solar Radiation
Ocean Evaporation
Evapotranspiration
Sea Ice
Evaporation
Sensible Heat
Surface Runoff
Net Absorbed
Infiltration
Rivers and Lakes
Soil Moisture
River Discharge
Percolation
Oceans
Permafrost
Groundwater Flow
Groundwater
GEWEX
WCRP
World Climate Research Programme



GEWEX

The GEWEX Panels:

- GEWEX Data Analysis Panel — *Global Datasets Analysis and Assessments*
- Global Atmospheric System Studies — *Atmospheric Processes - Dynamics*
- Global Land–Atmosphere System Studies — *Land-Atmosphere Interactions and Processes*
- GEWEX Hydroclimatology Panel — *Regional Focused Processes and Hydroclimate Projects*

WCRP
World Climate Research Programme

GEWEX Science Goals

Goal # 1: Determine the extent to which Earth's water cycle can be predicted

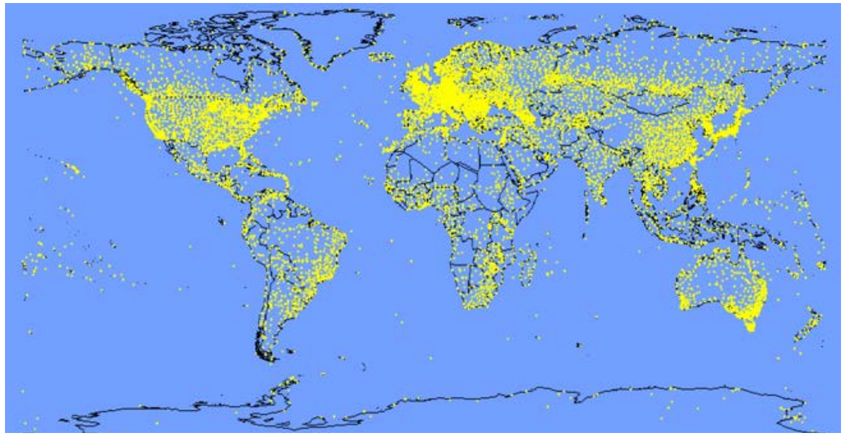
a) **Reservoirs:** What is the rate of expansion of the fast reservoirs (atmosphere and land surfaces), what is its spatial character, what factors determine this and to what extent are these changes predictable?

b) **Flux exchanges**: To what extent are the fluxes of water between Earth's main reservoirs changing and can these changes be predicted and if so on what time/space scale?

c) **Precipitation Extremes:** How will local rainfall and its extremes change under climate change across the regions of the world?

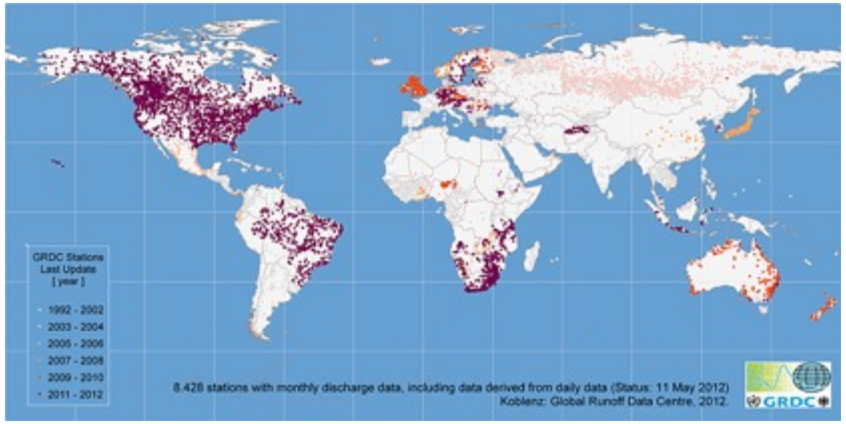
GEWEX

Inadequacy of Surface Observations

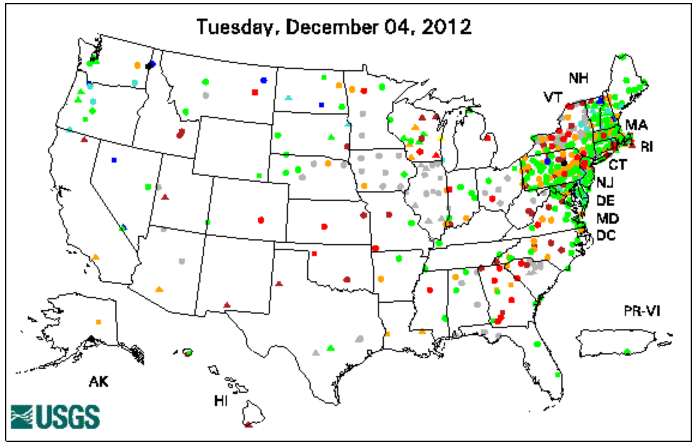


Global Telecommunication System meteorological stations. Air temperature, precipitation, solar radiation, wind speed, and humidity only.

Eight countries make groundwater data publicly available through the Global Groundwater Monitoring Network.



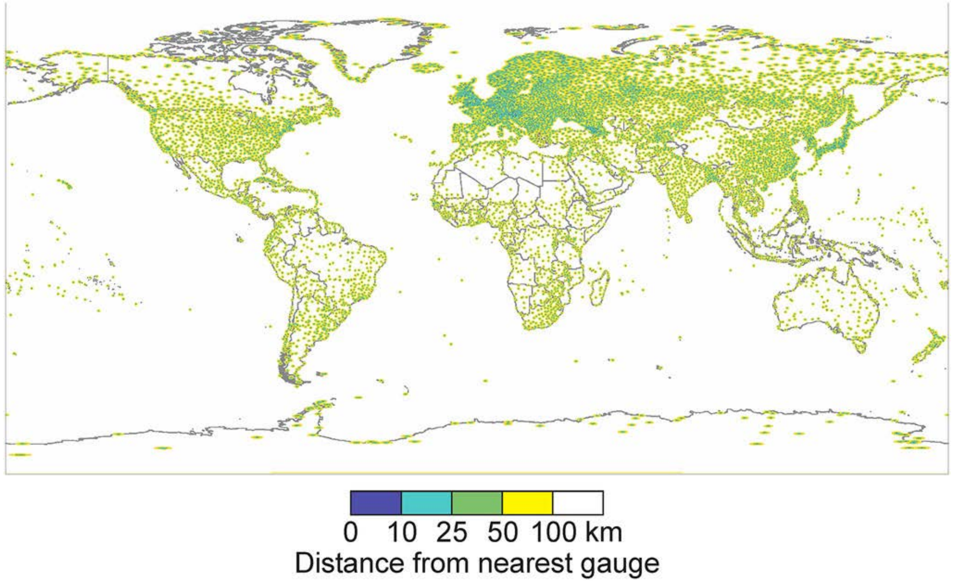
River flow observations from the Global Runoff Data Centre. Lighter circles indicate greater latency in the data record.



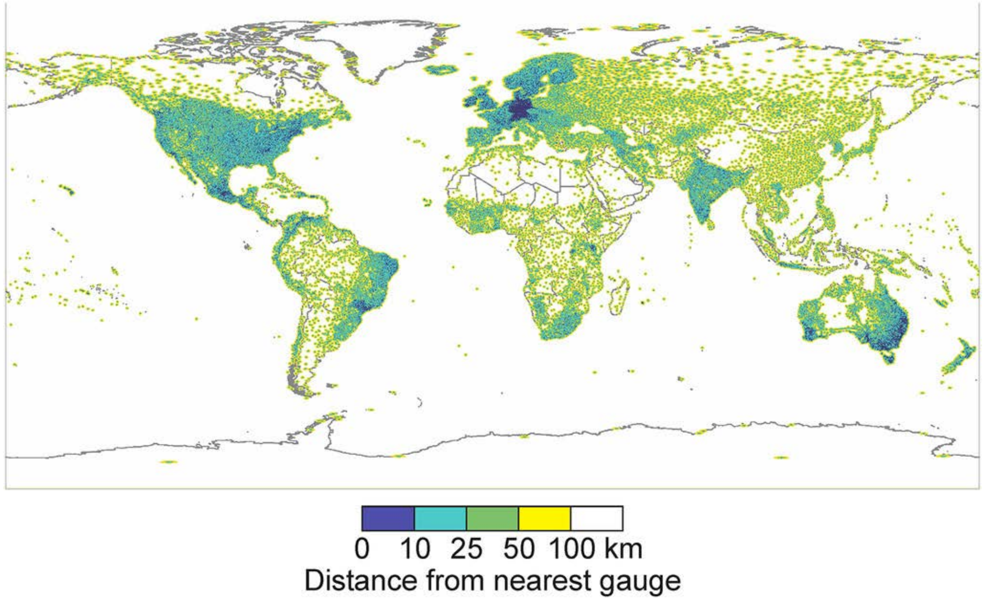
USGS Groundwater Climate Response Network.

Issues include coverage gaps, delays, measurement continuity and consistency, data format and QC, political restrictions

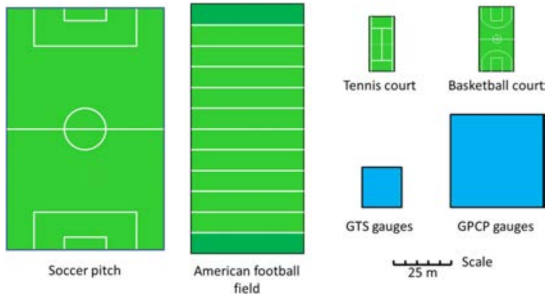
So, How Much of the Earth's Surface *Is* Covered by Rain Gauges?



Map showing the distance to nearest GTS gauge, typical of 3-hourly/daily measurements available in near–real time; blank areas in the figure are beyond 100 km from the nearest gauge. (8 – 12K first class stations)



Map showing the distance to nearest GPCC gauge, typical of all regular and reliable gauge measurements; blank areas in the figure are beyond 100 km from the nearest gauge. (~65K-100K stations)

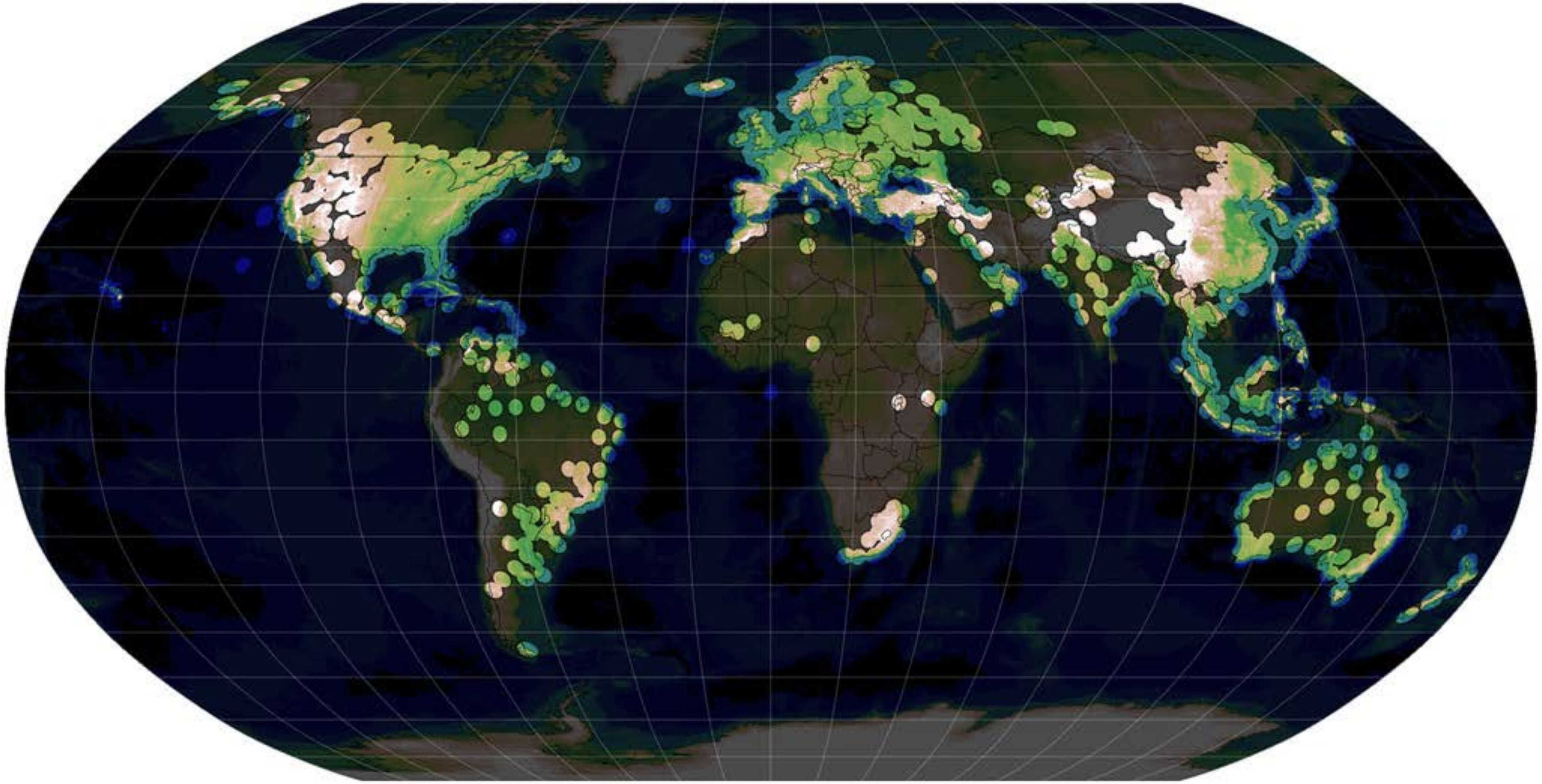


	Dimensions	Area	Equivalent gauges[a]
Soccer pitch	105 × 68 m	7140.0 m²	178,500–562,204
Center circle of soccer pitch	9.15-m radius	263.0 m²	6,575–20,709
American football	109.7 × 48.8 m	5353.4 m²	133,834–421,524
Tennis court	23.78 × 10.97 m	260.9 m²	6,522–20,541
Basketball (FIBA)	28.0 × 15.0 m	420.0 m²	10,500–33,071

[a] Range based upon 400- to 127-cm² orifice areas.

Kidd, C., Becker, A., Huffman, G. J., Muller, C. L., Joe, P., Skofronick-Jackson, G., & Kirschbaum, D. B. (2017). So, How Much of the Earth's Surface Is Covered by Rain Gauges?, *Bulletin of the American Meteorological Society*, *98*(1), 69-78. Retrieved Jul 6, 2022, from https://journals.ametsoc.org/view/journals/bams/98/1/bams-d-14-00283.1.xml

Rain Radars – Global Coverage (2017)



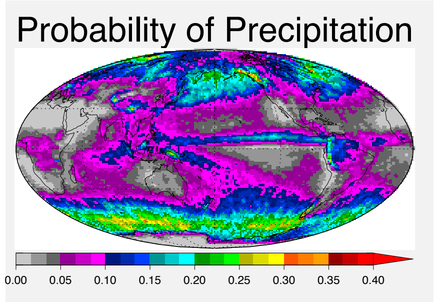
A map of weather radar coverage in the world (in Robinson projection). To compute and map the areas "illuminated" by radar, we used the wradlib library (https://wradlib.org), assuming each radar has a range of 200 km irrespective of bandwidth, polarization, and local terrain. Most radar locations included in this map have been retrieved from a WMO database (WMO 2019). Note that not all operational radars are included in the database. Additional radar locations have arbitrarily been added for China (manually digitized from WMO 2013), the Philippines (I. Crisologo 2018, personal communication), Vietnam (locations estimated in 2017 from the webpages of the National Centre for Hydro-Meteorological Forecasting in Vietnam, www.nchmf.gov.vn/Web/en-US/73/Default.aspx), and Myanmar (locations estimated in 2017 from the webpages of the Department of Meteorology and Hydrology in Myanmar, www.moezala.gov.mm/radar-image).

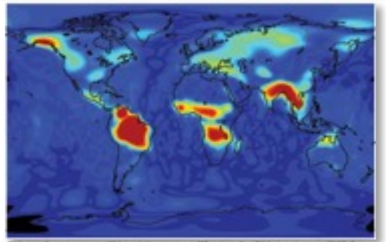
Saltikoff, E., Friedrich, K., Soderholm, J., Lengfeld, K., Nelson, B., Becker, A., Hollmann, R., Urban, B., Heistermann, M., & Tassone, C. (2019). An Overview of Using Weather Radar for Climatological Studies: Successes, Challenges, and Potential, *Bulletin of the American Meteorological Society*, *100*(9), 1739-1752. Retrieved Jul 6, 2022, from https://journals.ametsoc.org/view/journals/bams/100/9/bams-d-18-0166.1.xml

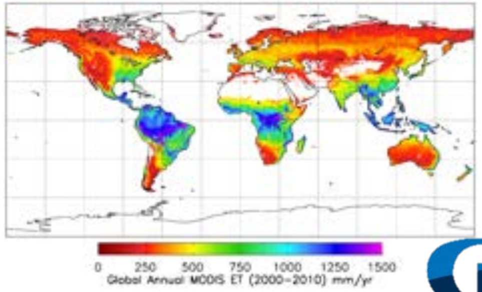
Surface Water balance

ΔS=P - Q - ET

- **Precipitation (P)**
  - In situ: Rain gauges, Snotel
  - RS (TRMM, CloudSat, AMSR-E, IR, GPM….)
- **Change in storage (ΔS)**
  - In situ: Groundwater recharge/flow, soil moisture, standing water, wells
  - RS (GRACE (-FO), SWOT, AMSR-E→SMOS→SMAP, CIMR)
- **Runoff (Q)**
  - In situ: Stream gauges, Global Runoff Data Center,
  - RS (SWOT, ..)
- **Evaporation/Evapotranspitation (ET)**
  - In Situ: Fluxnet
  - RS Quickscat, AMSR-E, MODIS, CERES, AIRS, FLEX etc.
    (RS of ET also requires surface net radiation)
- **Global accuracy/consistency/ability**
- See also: M. F. McCabe et al. (2017): The future of Earth observation in hydrology







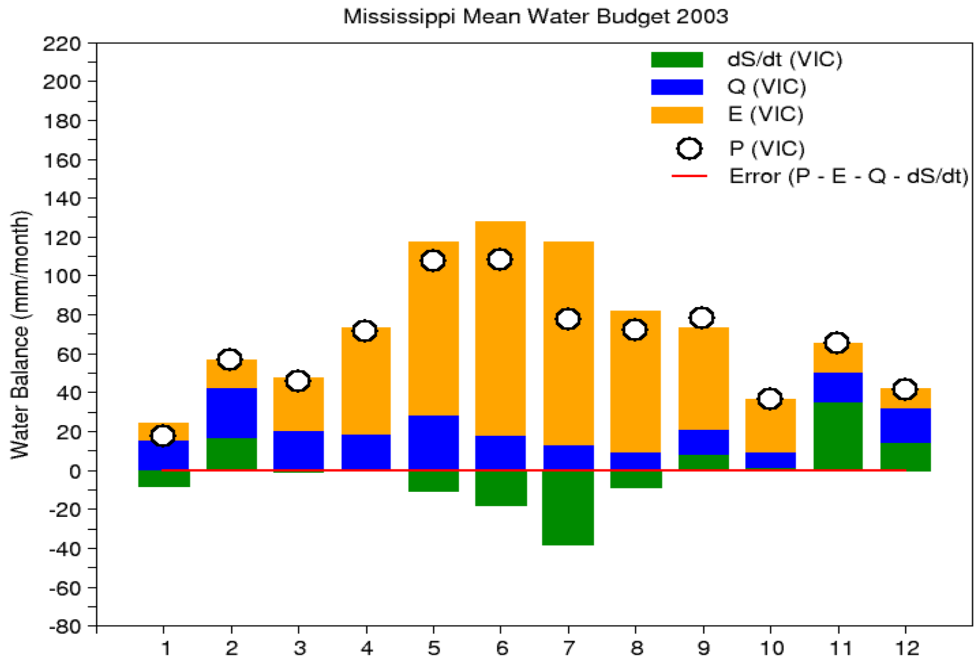
After E.F. Wood 2017

A challenge for Hydrology:

Creating Climate Data Records for the terrestrial water budget using in-situ, remote sensing observations and LSM?

$$\frac{dS}{dt} = P - ET - Q$$

What the budget should look like?
(from off-line modeling, forced closure)

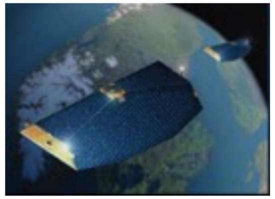


After E.F. Wood 2017

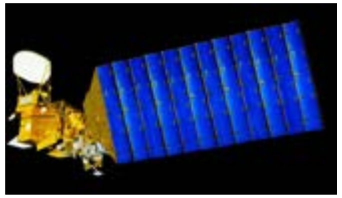
EGU 2010, HS4.8, 10234, 11:45am, May 5

Potential Remote Sensing Datasets

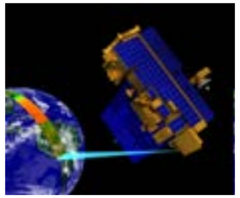
dS/dt from GRACE type mission



ET from SRB/ISCCP → LandFlux GLEAM



P from TRMM/CMORPH PERSIANN → GPM



Q from TOPEX/POSEIDON/JASON → SWOT

Goal # 2 (GS2): Quantify the inter-relationships between Earth's energy, water and carbon cycles to advance our understanding of the system and our ability to predict it across scales

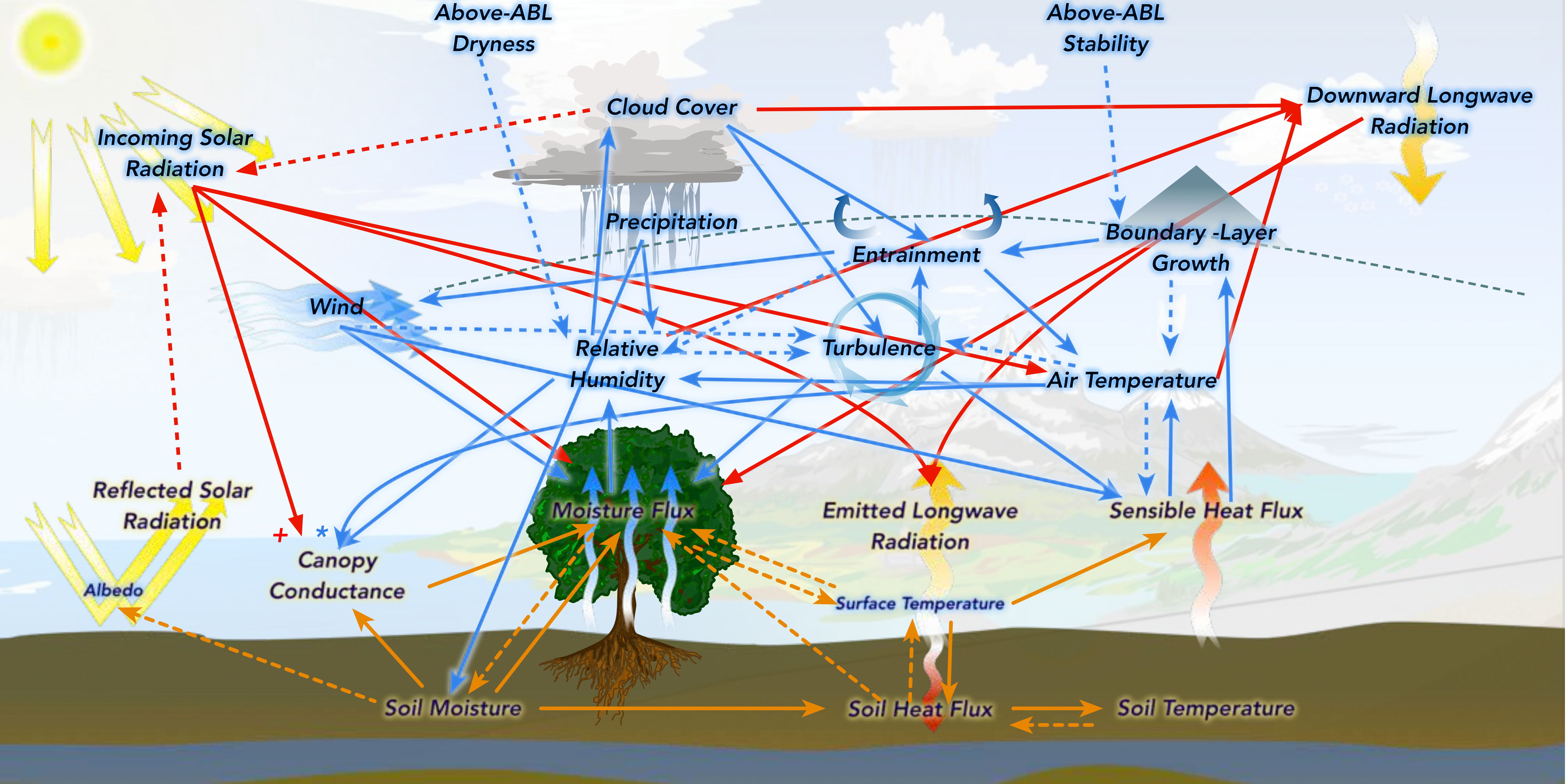
a) **Forcing-feedback understanding**: How can we improve the understanding of climate forcings and feedbacks formed by energy, water and carbon exchanges?

b) **ABL process representation**: To what extent are the properties of the atmospheric boundary layer (ABL) defined by sensible and latent energy and water exchanges at the Earth's surface versus within the atmosphere (i.e., horizontal advection and ABL-free atmosphere exchanges)?

c) **Understanding Circulation controls:** To what extent are exchanges between water, energy and carbon determined by the large-scale circulations of the atmosphere and oceans?

d) **Land-atmosphere interactions**: How can we improve the understanding of the role of land surface-atmospheric interactions in the water, energy and carbon budgets across spatiotemporal scales?

Local Land-Atmosphere Interactions – All Processes



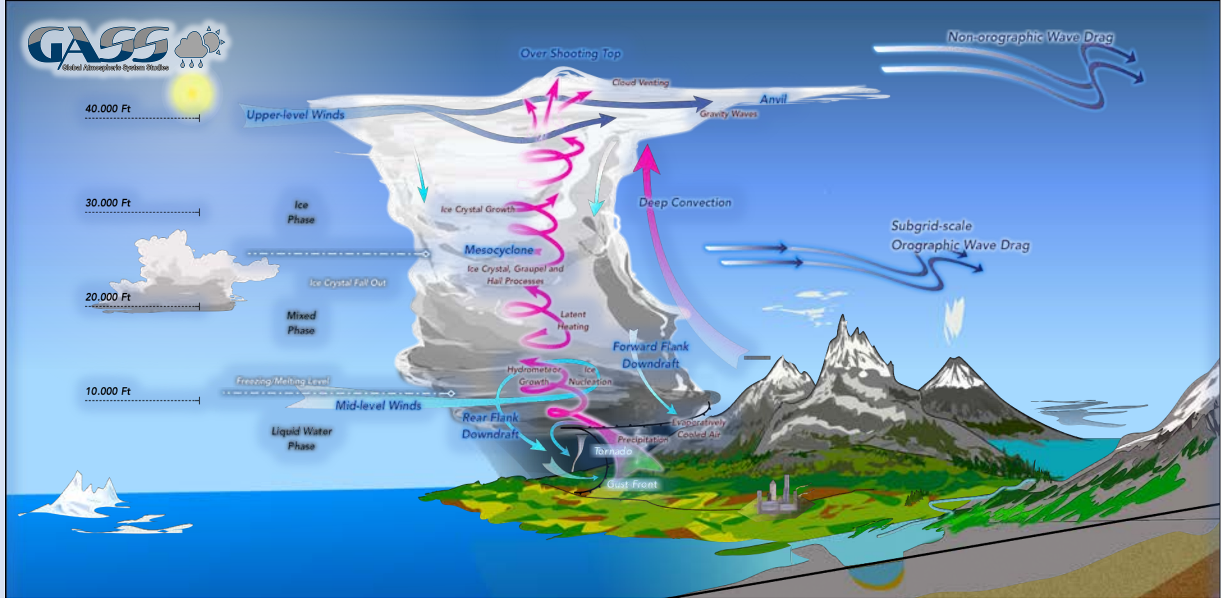
+ Positive Feedback for C3 & C4 Plants, Negative Feedback for CAM Plants

* Negative Feedback Above Optimal Temperature

Radiation	Positive Feedback
Land Surface Processes	Negative Feedback
Surface Layer & ABL	

After: Ek and Mahrt, 1994
Ek and Holtslag, 2004

Priorities



- 1) Atmospheric Boundary Layer
  - Land-Atmosphere Interactions

- 2) Convection in particular deep convective processes and MCSs -> Precipitation

- 3) Earth Energy Imbalance (Budget): consistent observations are key!

GEWEX

Example: Precipitation Processes – bringing together the observations and models

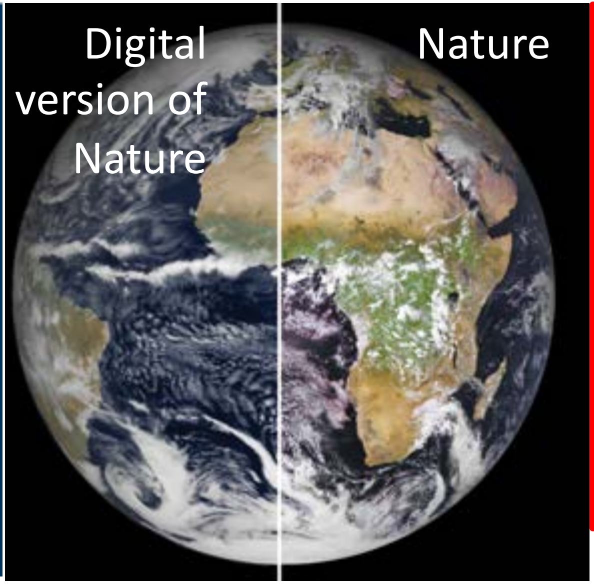
- Direct EO Measurements e.g. GPCP, TRMM, GPM …
- Understanding clouds and precipitation processes e.g. Cloudsat, AOS, Earthcare
- Aerosols and water vapor e.g. Earthcare, SSM/I, AIRS, IASI, CrIS etc.
- Rain gauge data e.g. GPCC
- Attenuation between cell phone towers
- Global Climate Models precipitation representation
- ReAnalysis

See assessments:

- Precipitation:
  - https://www.gewex.org/gewex-content/uploads/2021/07/Joint_IPWG-GEWEX_Precipitation_Assessment_web.pdf
- Water Vapor:
  - https://www.wcrp-climate.org/WCRP-publications/2017/WCRP-Report-16-2017-GVAP-v1.3_HiRes.pdf

Example – Atmosphere Observing System AOS (pre-phase A)

- AOS is a synergistic Earth *System* (ES) Science observatory
- The reach of AOS across the Earth sciences is wide. The synergy provided from multiple measurements is the essential strategy of AOS in creating a needed system of observations.
- This AOS approach offers a more integrated assessment of those interactions identified as central to the main weather and climate science challenges of the decade.
- AOS is also timely. It is occurring when i) ES models are evolving to the km scale thus better aligning to a scale of the AOS observations, ii) Higher resolution Earth analysis systems are also advancing in parallel to better exploit Earth observations and iii) new & evolving capabilities of the PoR provide better & more quantitative 'two-way' links to AOS



i) Digital Twin Earth,
ii) Destination Earth
iii) Slingo et al., 2022; *Nature Comms*, **Ambitious partnership needed for reliable climate prediction,** calls for an international focus on k-scale ES model advancement
iv)Van den Heever & Stephens,2022; **How bad will future rains be?**, *AGU advances (submitted)* introduces the notion of '**The decade of convection**"

Goal # 3 (GS3): Quantify anthropogenic influences on the water cycle and our ability to understand and predict changes to Earth's water cycle.

a) **Anthropogenic forcing of continental scale water availability**: To what extent has the changing greenhouse effect modified the water cycle over different regions and continents?

b) **Water management influences**: To what extent do water management practices and land use change (e.g., deforestation) modify the water cycle on regional to global scales?

c) **Variability and trends of water availability**: How do water & land use and climate change affect the variability (including extremes) of the regional and continental water cycle?

Anthropogenic influences on the water cycle

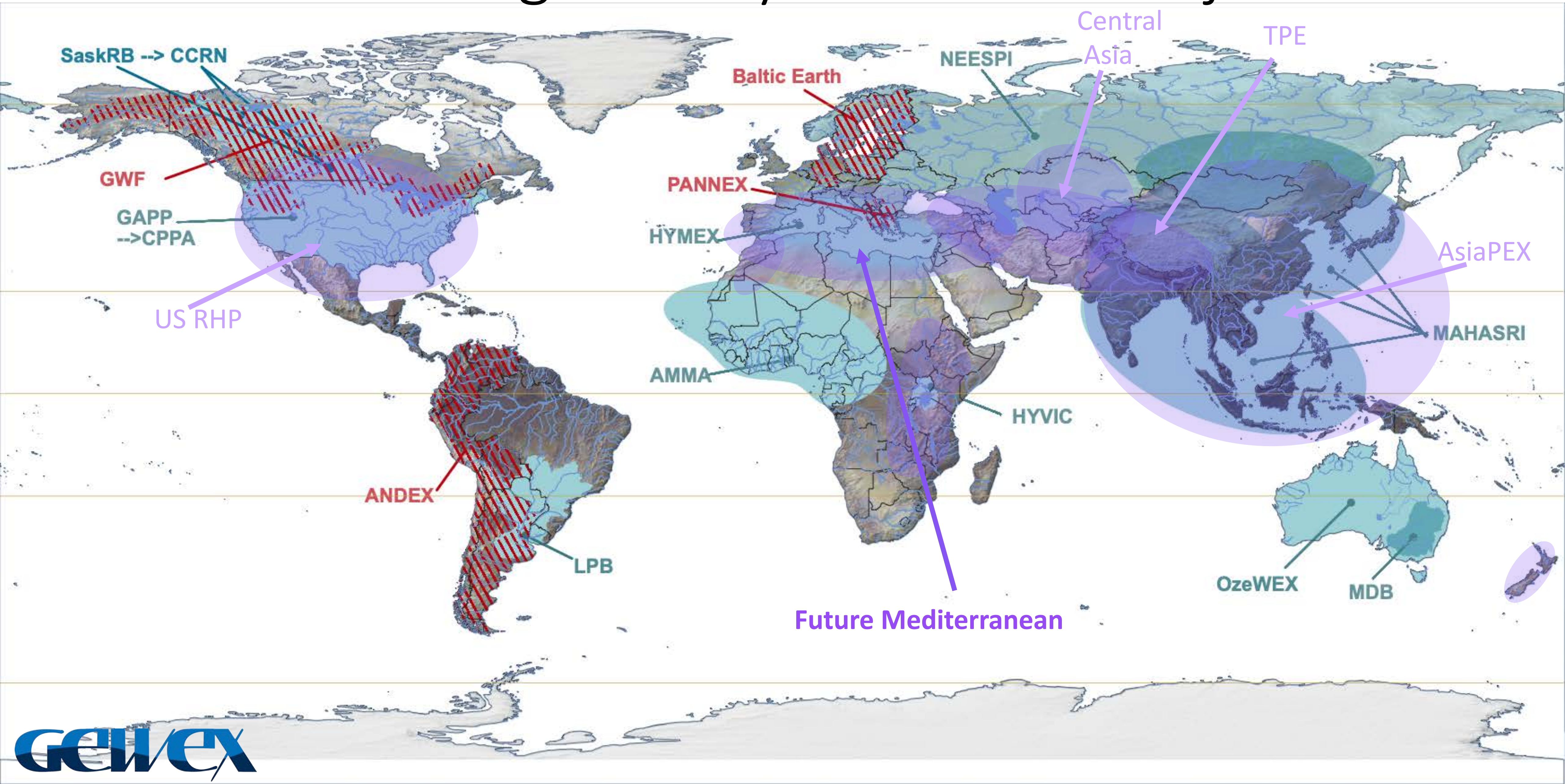
- Requires a multidisciplinary approach with a variety of observational methods (incl. EO in broadest sense but also citizen science, socio-economic indicators etc.) – consistency and continuity in observations
  - Irrigation, Land use and land cover change incl. urbanization, land use practices, water management
- Primary a retrospective and descriptive approach as prediction is difficult (think stock market)
- Huge potential within Digital Twin concept (bringing together the numerous information channels) → High Resolution Modeling key

Why High Resolution Modeling?

- Climate change is more than a change in the mean state -> the (change in) distribution of phenomena (incl. extremes) is as important
- We want to understand the genesis of events and their evolution both in occurrence and manifestation under climate change -> prediction and projection
- Actual representation of the processes and phenomena closer to ‘reality’ ->

GEWEX

Envisioned Regional Hydroclimate Projects



Example: Baltic Earth - BEAR

- BEAR principles
- BEAR reports wrap together the currently available published scientific knowledge. They do not document unpublished research results.

  The essence of the work is the synthesis of material drawn comprehensively from the available scientifically legitimate literature (e.g. peer-reviewed literature, conference proceedings, and reports of scientific institutes).

  The work should encompass the knowledge about what scientists agree on but also identify cases of disagreement or knowledge gaps.

Summary

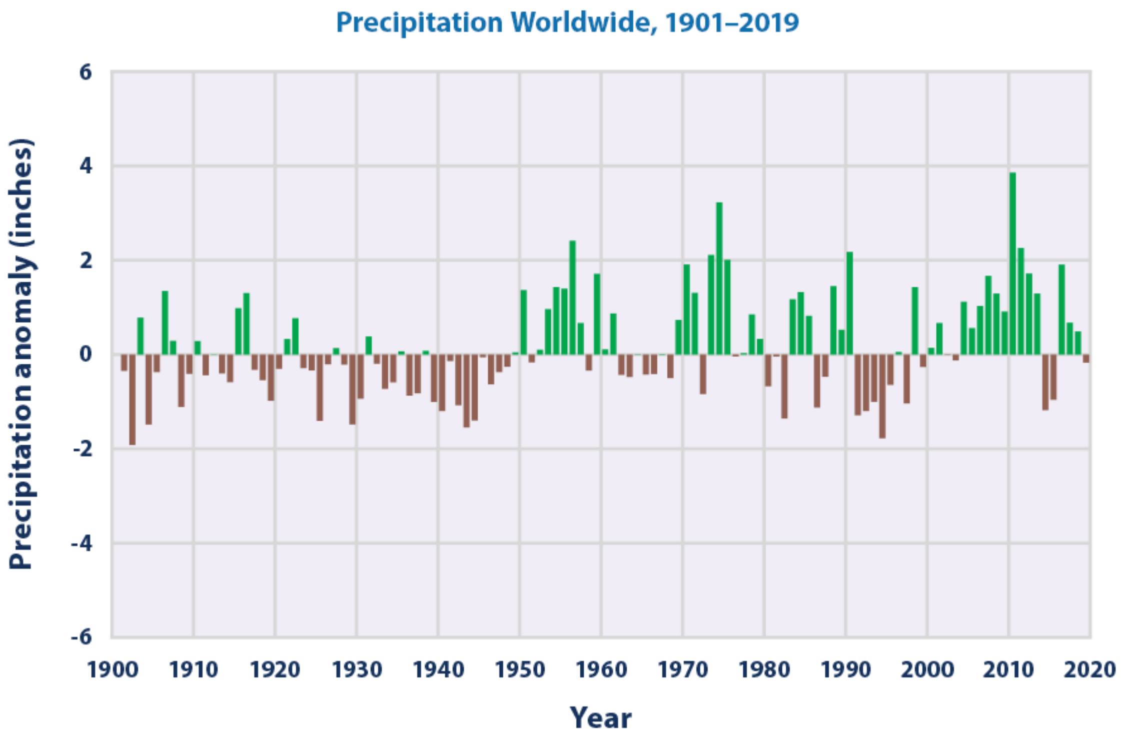
- What we need?
  - **Assessments** of data sets related to (global) water and energy fluxes and their **consistency** (hard to fund but essential)
  - **Uncertainty and error characterization** and understanding in flux observations from -space borne- observations (again mostly global)
  - GEWEX/GDAP has played a big role in supporting global data sets such as ISCCP and GPCP now it is time to let those evolve 'on their own', and shift the focus to where and how to improve these (type of) products in a **long term consistent** approach
  - Support of in situ observational networks in the long term
  - Modeling and observations into a digital twin framework – (enabling End to End approach including Research to Operations to Research)
  - Requirements for **process studies** are *not necessarily the same* as for **climate data records**

Contacts

- GEWEX: gewex@gewex.org
- WCRP: wcrp@wmo.int
- YESS: Young Earth System Scientists: contact@yess-community.org
- YHS: Young Hydrologic Society: younghydrologicsociety@gmail.com

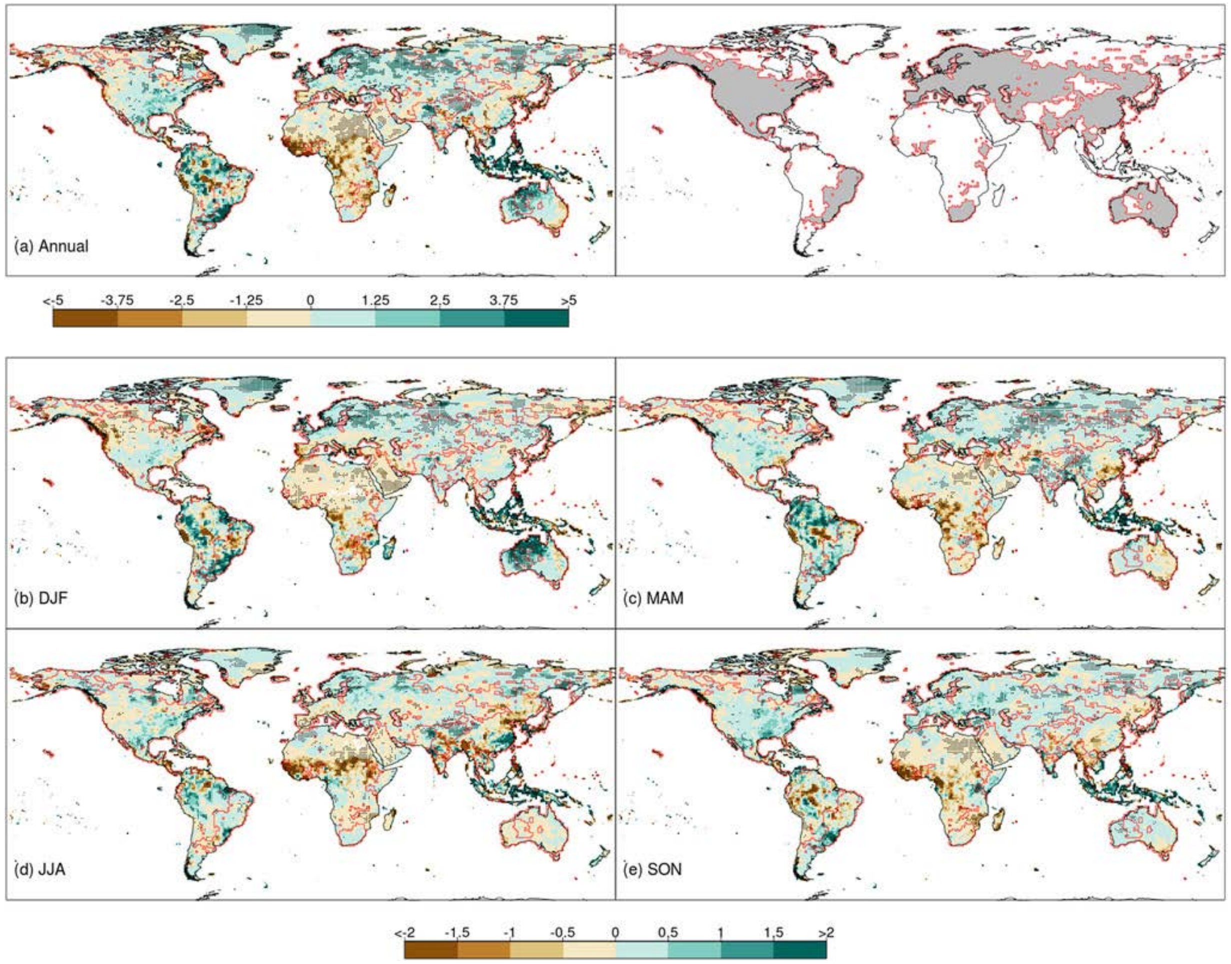
THANK YOU

Global Precipitation



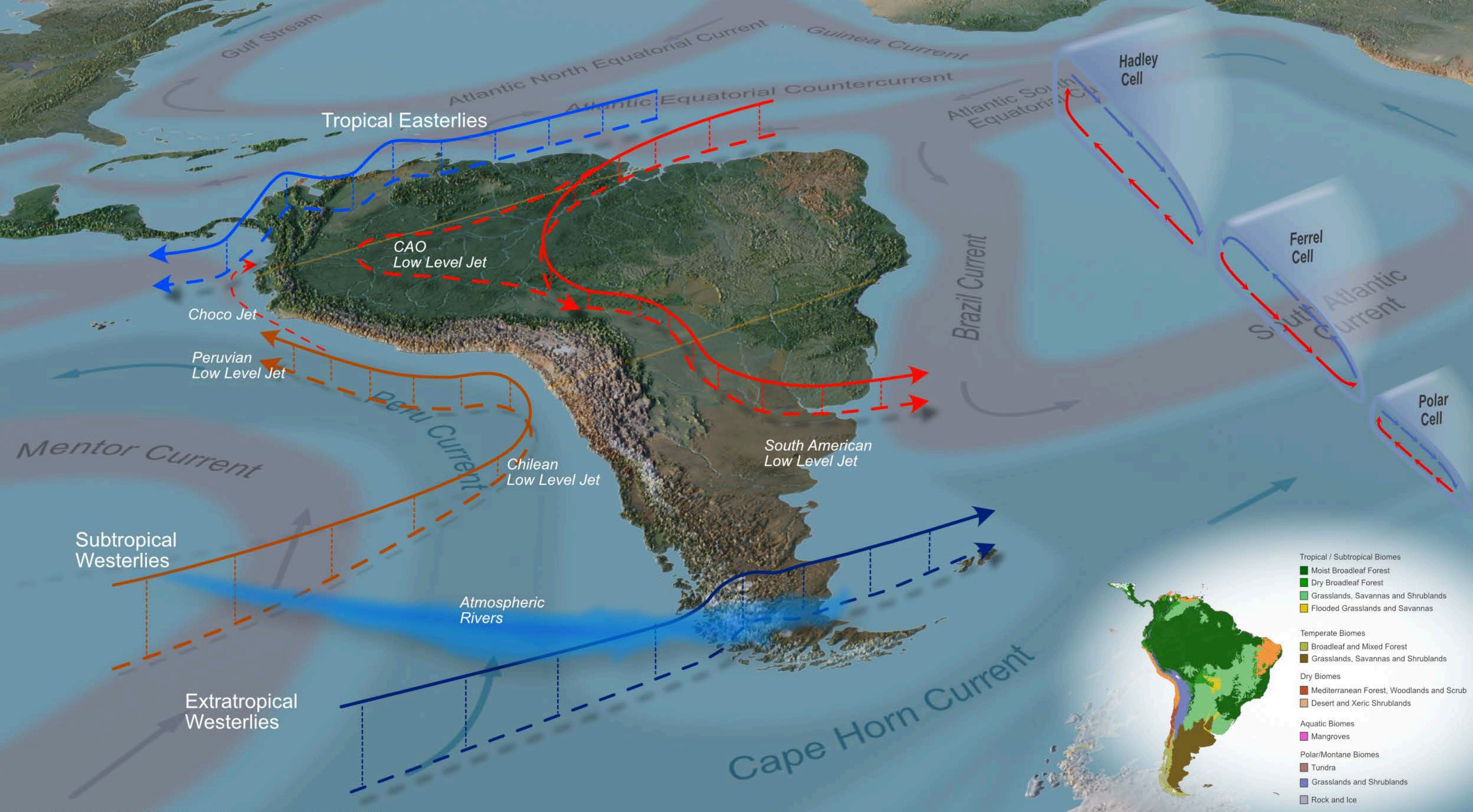
Data source: Blunden, J., and D.S. Arndt (eds.). 2020. State of the climate in 2019. B. Am. Meteorol. Soc. 101(8):S1–S429. https://doi.org/10.1175/2020BAMSStateoftheClimate.1.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.



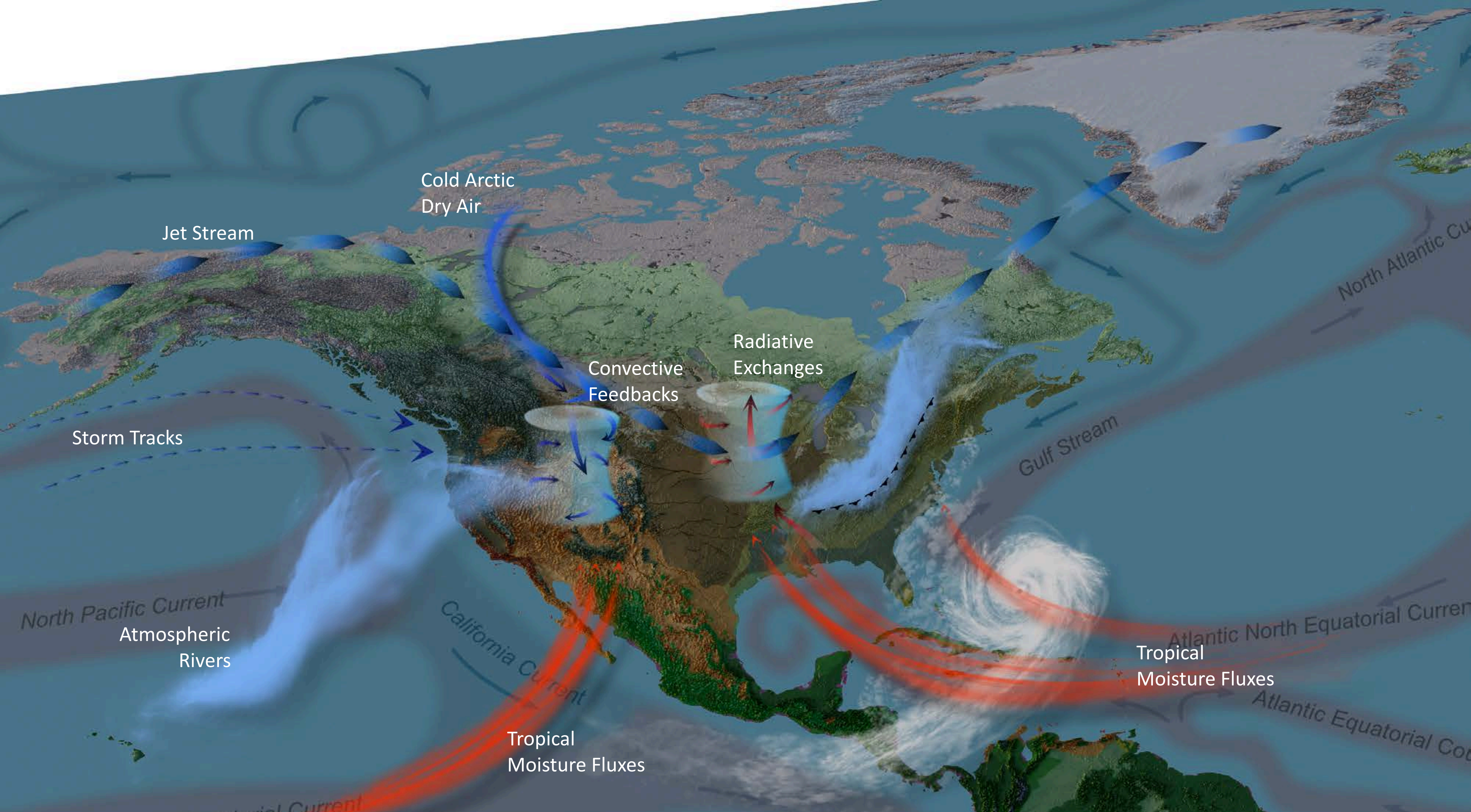
Trends over 1950–2016 in (a) annual (mm yr−1) and (b)–(e) seasonal (mm season−1) totals of daily precipitation data from REGEN-ALL. The stippling indicates significant grids based on modified Mann–Kendall test and the red contours enclose the grids with high-quality observations (see text for details). (top right) Shaded regions identify the data quality mask, and the white (empty) land grids in seasonal changes are due to too few wet days for calculating trends.

Contractor, S., Donat, M. G., & Alexander, L. V. (2021). Changes in Observed Daily Precipitation over Global Land Areas since 1950, *Journal of Climate*, *34*(1), 3-19. Retrieved Jul 2, 2022, from https://journals.ametsoc.org/view/journals/clim/34/1/jcliD190965.xml

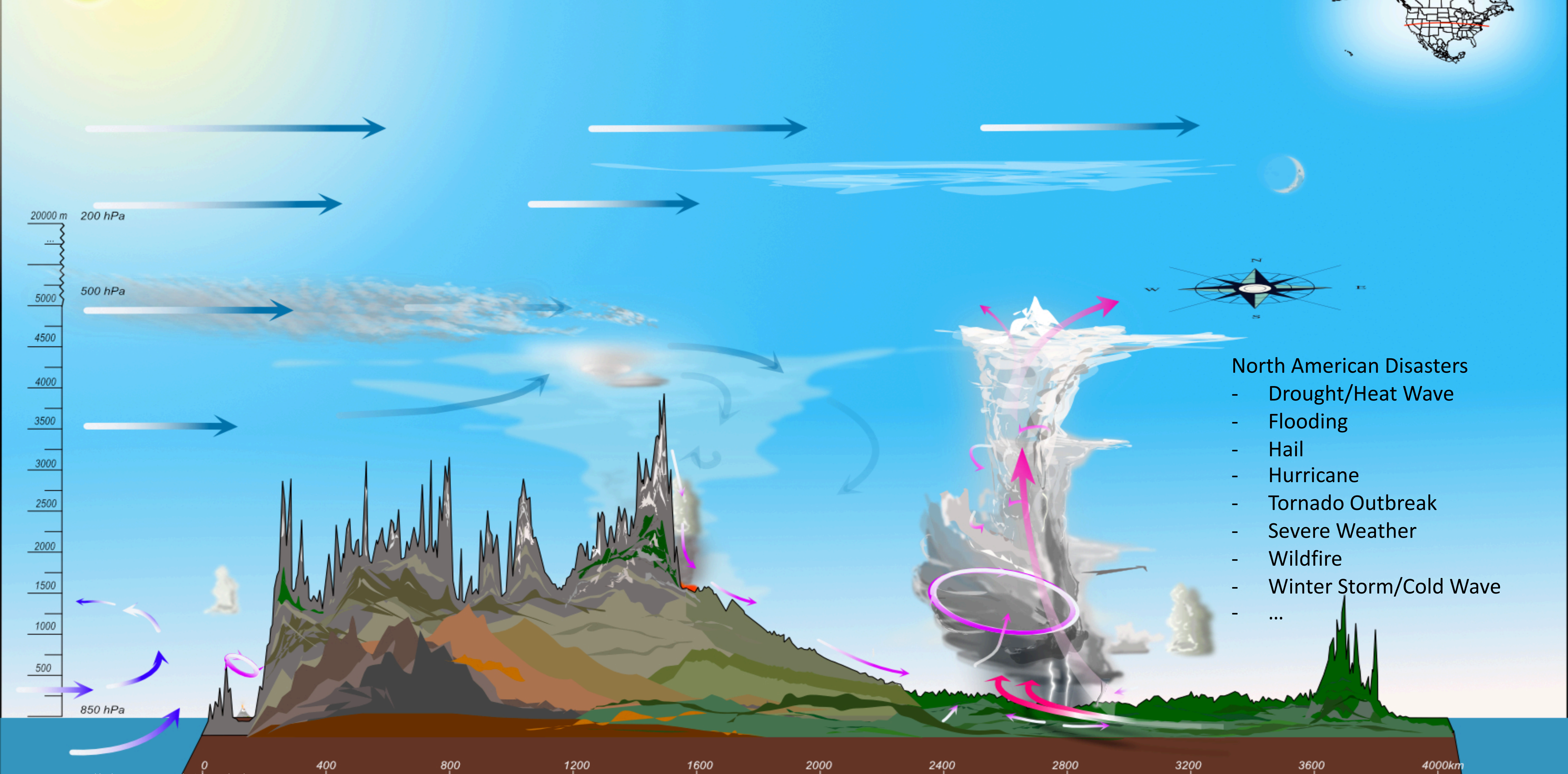


Gulf Stream
Atlantic North Equatorial Current
Guinea Current
Atlantic Equatorial Countercurrent
Tropical Easterlies
Hadley Cell
Ferrel Cell
Polar Cell
CAO
Low Level Jet
Choco Jet
Peruvian
Low Level Jet
Peru Current
Mentor Current
Brazil Current
South Atlantic Current
Chilean
Low Level Jet
South American
Low Level Jet
Subtropical
Westerlies
Atmospheric
Rivers
Extratropical
Westerlies
Cape Horn Current
Tropical / Subtropical Biomes
Moist Broadleaf Forest
Dry Broadleaf Forest
Grasslands, Savannas and Shrublands
Flooded Grasslands and Savannas
Temperate Biomes
Broadleaf and Mixed Forest
Grasslands, Savannas and Shrublands
Dry Biomes
Mediterranean Forest, Woodlands and Scrub
Desert and Xeric Shrublands
Aquatic Biomes
Mangroves
Polar/Montane Biomes
Tundra
Grasslands and Shrublands
Rock and Ice

Cross Section South America from Chile via Argentina, Uruguay to Brazil
32.3°S 71.5°W – 32.3°S 52.3° W

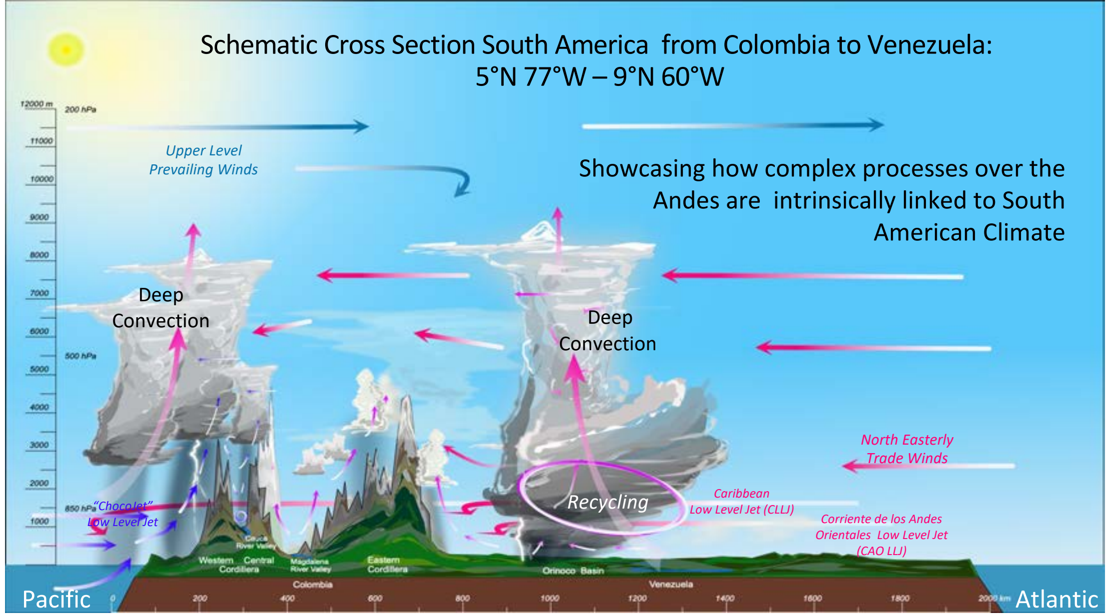

Cold Arctic
Dry Air
Jet Stream
Convective
Feedbacks
Radiative
Exchanges
Storm Tracks
North Pacific Current
Atmospheric
Rivers
California Current
Tropical
Moisture Fluxes
Gulf Stream
North Atlantic Cu
Atlantic North Equatorial Curren
Tropical
Moisture Fluxes
Atlantic Equatorial Co

Cross Section from San Francisco to Washington DC (~40d N)



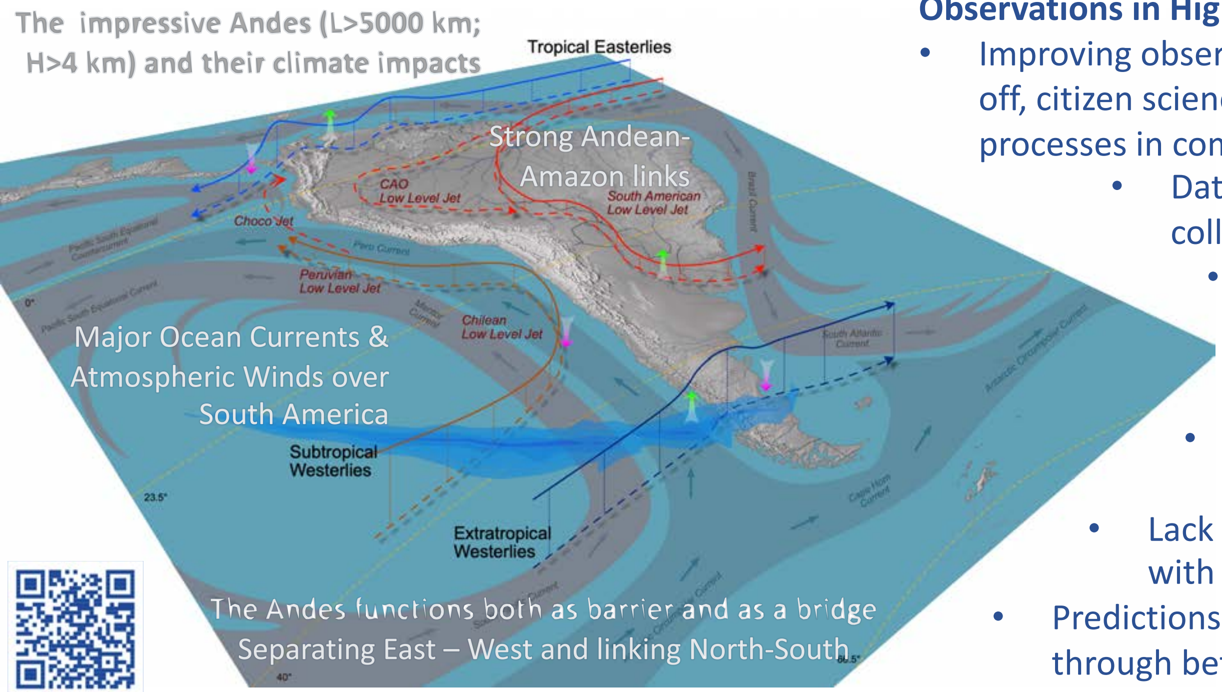
ANDEX – A new South American initiative to develop a regional hydroclimate project in the Andean region

https://www.gewex.org/project/andex/



Key Objectives

- Strengthen a regional scientific network, connecting scientists and practitioners
- Engage climate applications and policy communities in translating state of the art scientific knowledge
- Improve observational networks and monitoring programs
- Transfer state of the art scientific knowledge to applications and policy
- Improve understanding of regional weather, climate variability and change
- Improve climate predictions and weather & hydrological forecasting – high res. modeling (<<4km)



Observations in High Mountain Regions

- Improving observations and observational networks (e.g. radiosondes, rain radar, snowpack, run-off, citizen science etc.) paramount in improving our knowledge, models and predictions for processes in complex terrain and linking global and regional phenomena
  - Data sharing and open access increases capacity and capabilities and fosters collaboration – linking to global initiatives e.g. Digital Earth
    - Integrating local and indigenous knowledge supports broader understanding and wider applicability of climate information

Key messages for Policy and Decision Makers

- Sustainable development needs robust knowledge, long-term support and smart investments
- Lack of key observations hinders a comprehensive understanding of Andean hydro-climate, with implications for maladapted policy and investment
- Predictions in high mountainous terrain suffer from large uncertainties that can only be tackled through better understanding ⇆ better observations & more appropriate models (ensembles)

ANDEX is an initiative by South American scientists from the Andean countries to develop a regional hydroclimate project under the umbrella of the Global Energy and Water Exchanges Project (GEWEX) of the World Climate Research Programme

GEWEX Hydroclimatology Panel

World Climate Research Programme

- All models are wrong but some are useful

- Where are high res models useful?