Explaining and Predicting Earth System Change

38th session of the Working Group on Numerical Experimentation (WGNE-38)
São Paulo, Brazil

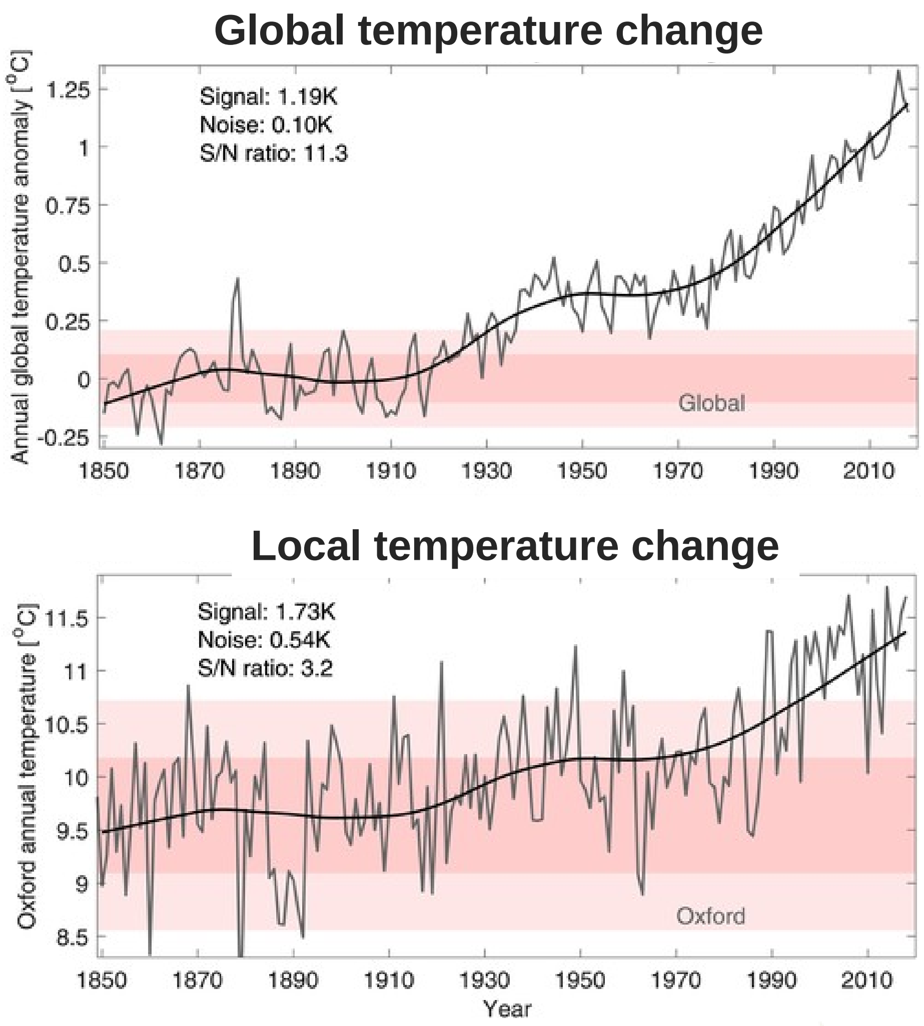
Kirsten Findell and Rowan Sutton (EPESC Co-Chairs)
November 2023

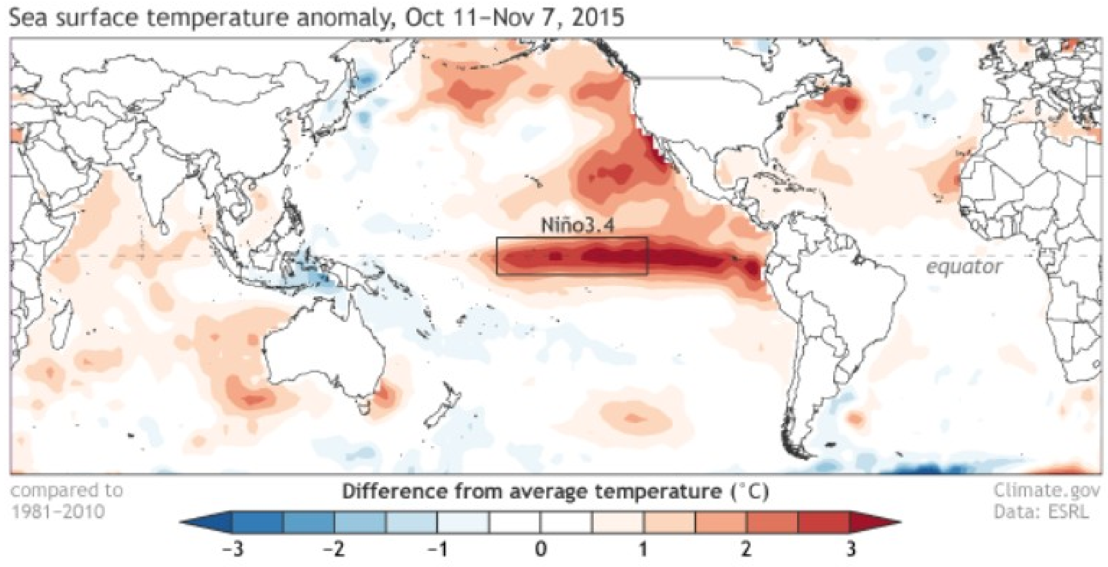
World Meteorological Organization · International Science Council · unesco Intergovernmental Oceanographic Commission · WCRP World Climate Research Programme

WCRP Lighthouse Activity on Explaining and Predicting Earth System Change

The **signal** of anthropogenic climate change is **emerging** progressively from the background of **natural variability**

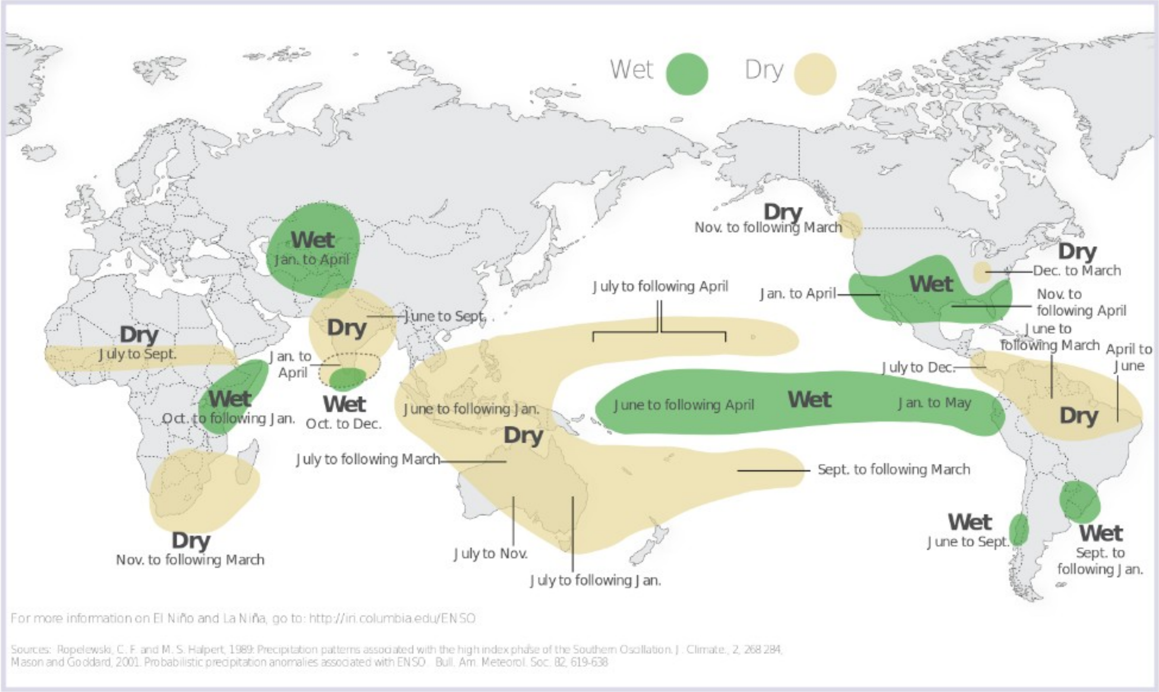
- on multi-annual timescales,
- on progressively smaller spatial scales,
- in a greater range of variables.





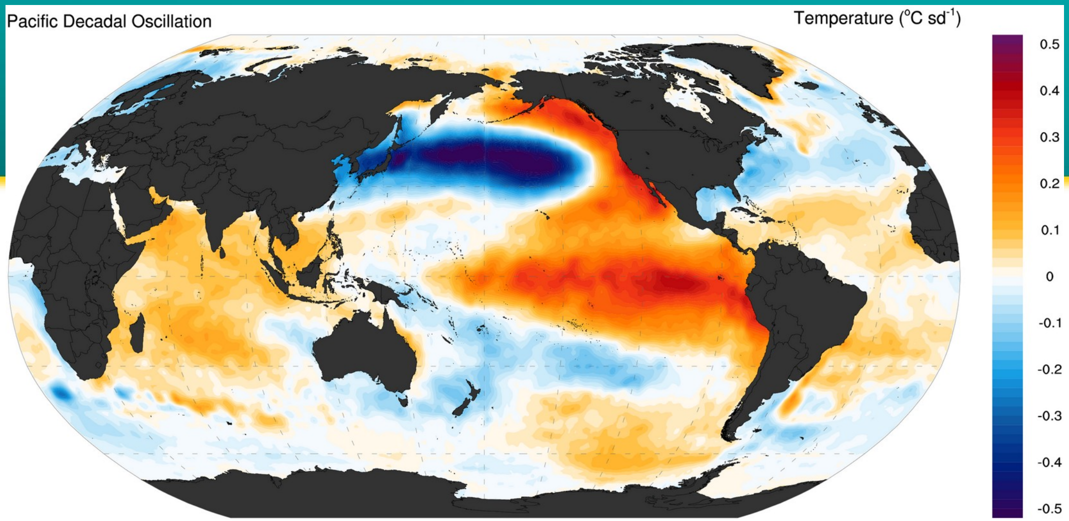
El Niño and Rainfall

El Niño conditions in the tropical Pacific are known to shift rainfall patterns in many different parts of the world. Although they vary somewhat from one El Niño to the next, the strongest shifts remain fairly consistent in the regions and seasons shown on the map below.

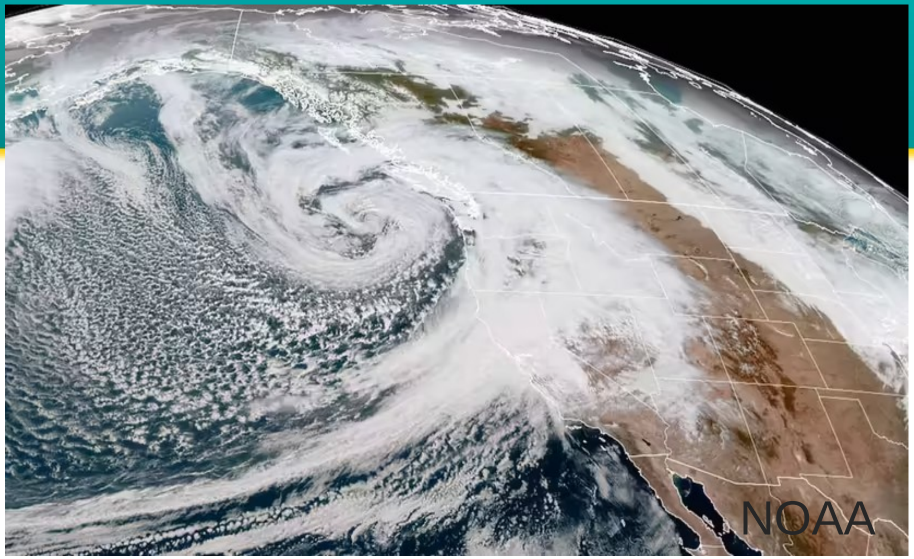


We know that changes in atmospheric and oceanic circulation patterns can have enormous impacts on weather and climate all over the world

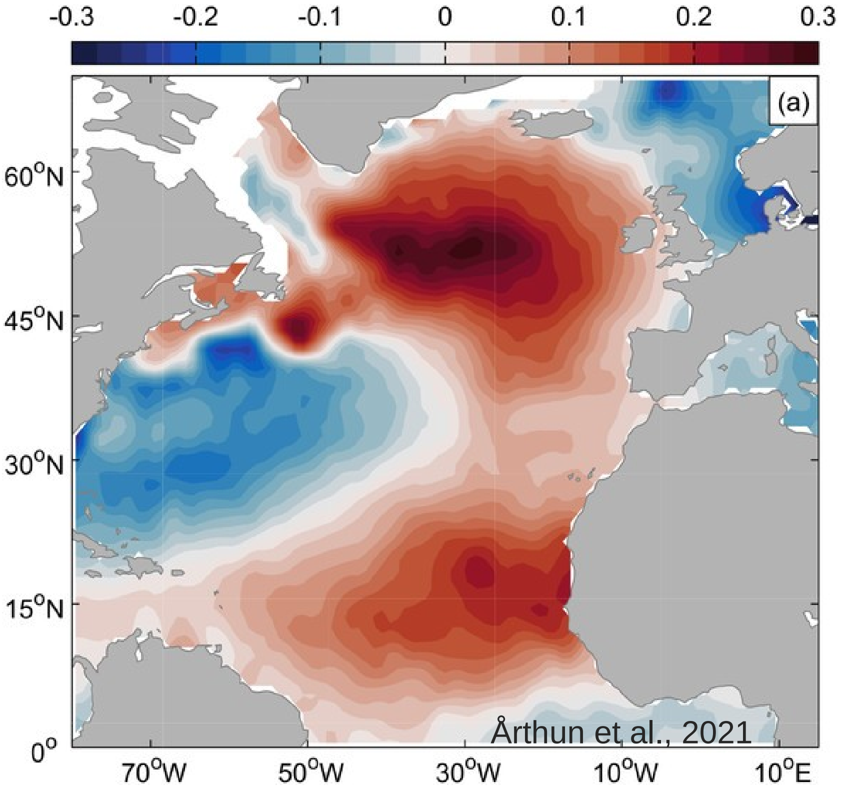
International Science Council unesco WCRP World Climate Research Programme

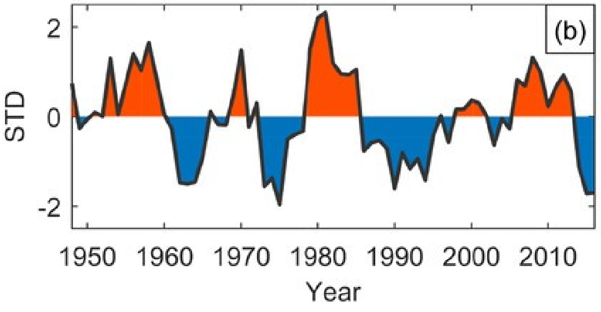


By Giorgiogp2 - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=18754081



- *These play a key role in shaping extreme events and hazards*
- *Yet capabilities for quantitative explanation and prediction of changes on multi-annual timescales are limited*





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Explaining and Predicting Earth System Change

Overarching objective:

To design, and take major steps toward delivery of, an integrated capability for quantitative observation, explanation, early warning and prediction of Earth System Change on global and regional scales and annual to decadal (A2D) timescales

A specific priority is to understand *A2D variability and change in* ***atmosphere and ocean circulation*** *and their influence on hazards*

We need these capabilities and knowledge to inform adaptation and improve resilience

Photo: Pakistan Red Crescent

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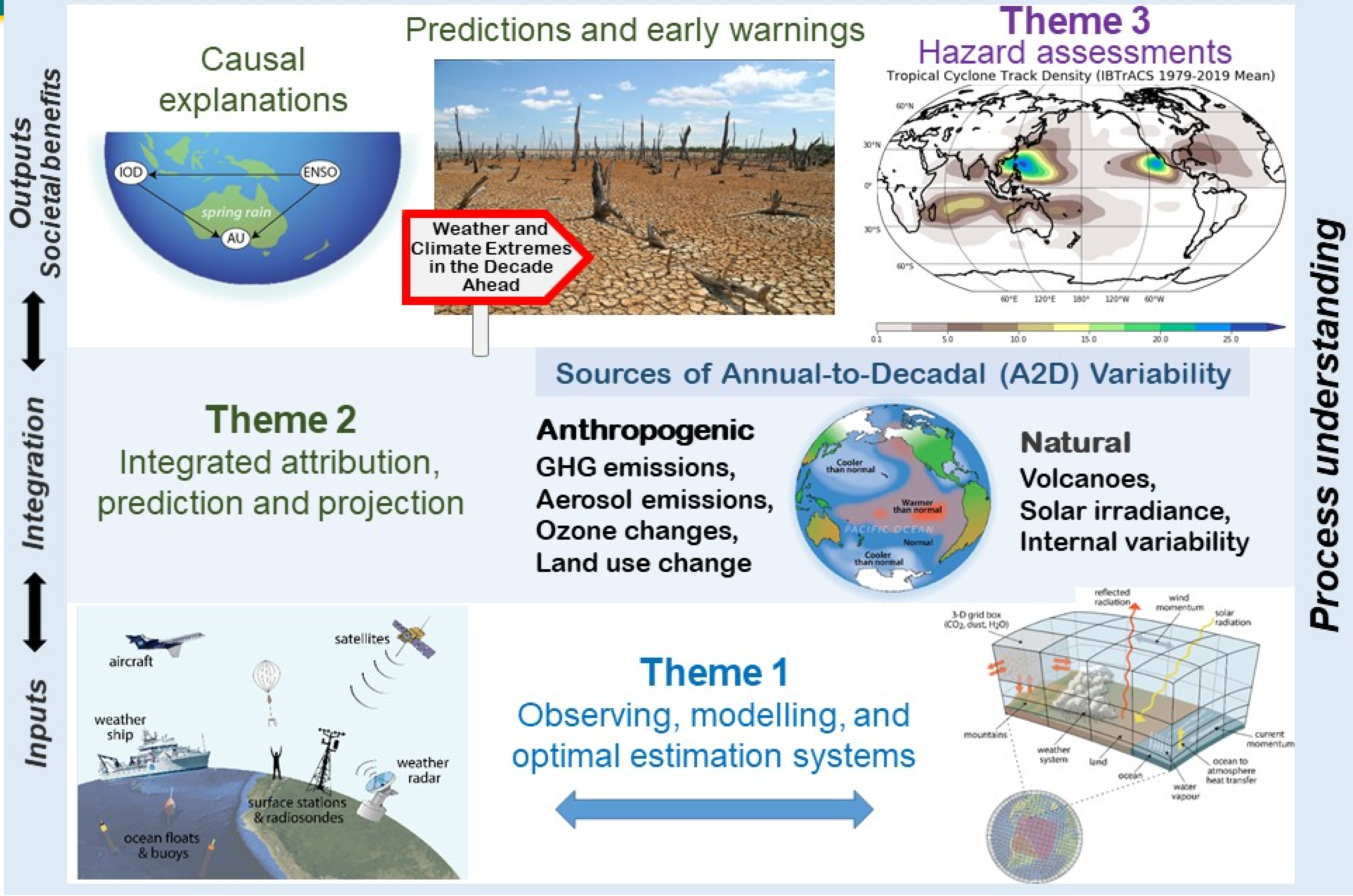
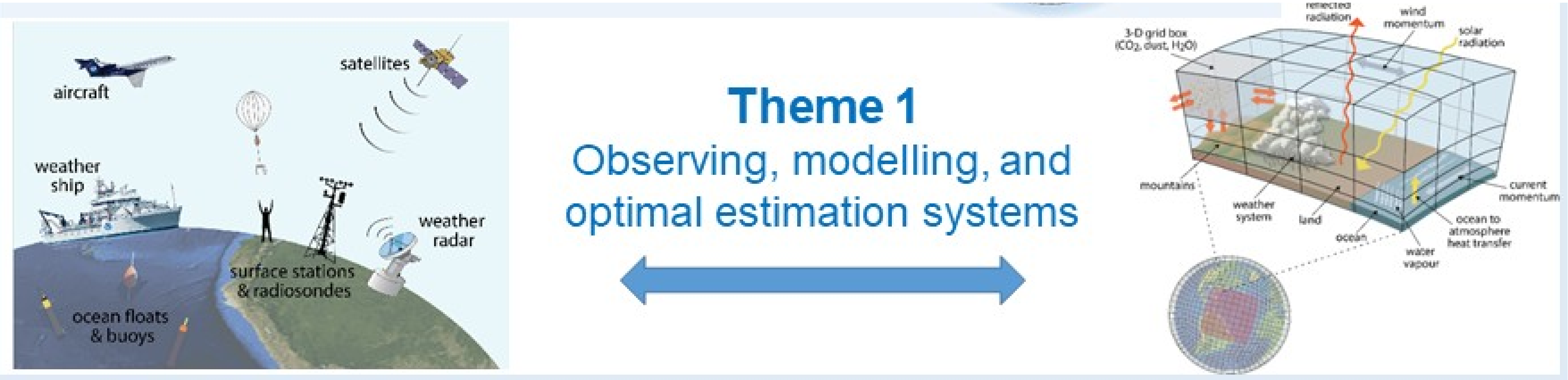


Findell et al. *BAMS*, January 2023

Theme 1: **Monitoring and Modeling Earth System Change**

We seek **tighter integration of models and observations to monitor and understand Earth system change**



- How can we address persistent biases in model simulations?
- How can we address under-utilization of diverse observational data?
- Which enhanced observations will offer the greatest improvements in predictive and explanatory skill? Where should those enhancements be targeted?

WG1: Towards tighter integration of obs and modeling systems

Specific Opportunity (Kushner et al.):

- Develop coordinated data analysis approach for EPESC activities at early stage

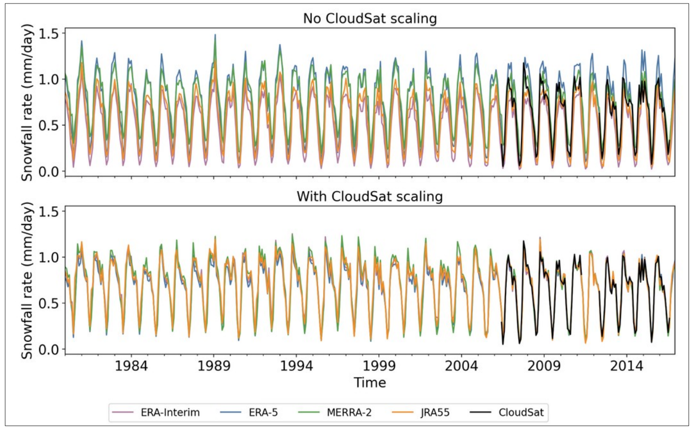
Gaps:

- Process analysis for data sparse regions.
- Bridging inconsistent reanalysis and remote-sensing datasets.

Next steps

- Develop data survey and EPESC climate variable inventory.

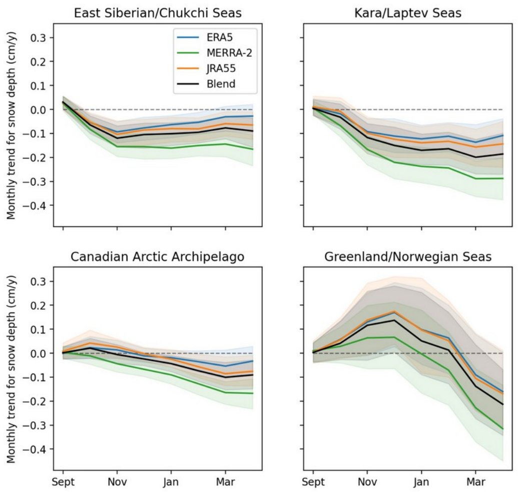
Calibrate Reanalysis Snowfall with CloudSat



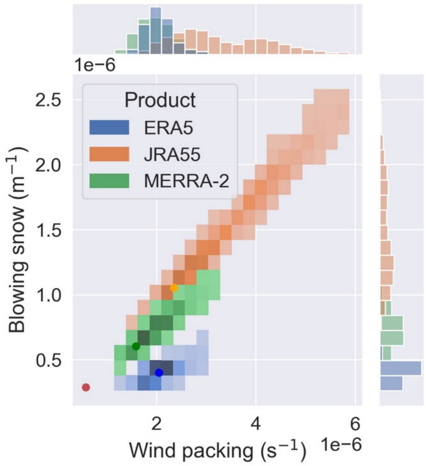
Snow on sea-ice analysis (U Toronto, CSA, NASA)

Cabaj et al. 2020, 2023; Petty et al. 2023

Develop multi-dataset climatology and trend analysis



Automatically tune snow model parameters (MCMC)



WG1: Trends in Earth’s Energy Imbalance (EEI)

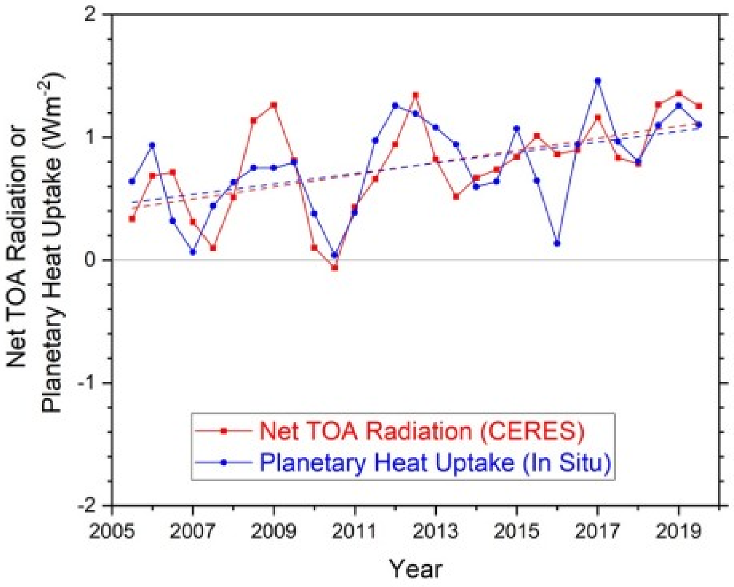
Specific Opportunity (Meyssignac et al.):

- Understanding the mechanistic causes that lead to the time variability and trend in EEI between 2002 and 2020 through obs, reanalyses, and models

Gap:

- GEWEX EEI assessment focusses on refining the EEI mean and monitoring its trend and variability, but does not deal with explanations of the causes for the observed EEI variability.

- Why did EEI double?
- Is it a forced signal?
- Can we trace its cause through the coupled ocean-atmosphere-cryosphere?
- What are its consequences, for droughts, heat waves, sea level rise and other impacts?



Geophysical Research Letters

Satellite and Ocean Data Reveal Marked Increase in Earth’s Heating Rate 2021

Norman G. Loeb[1], Gregory C. Johnson[2], Tyler J. Thorsen[1], John M. Lyman[2,3], Fred G. Rose[4], and Seiji Kato[1]

Figure 1. Comparison of overlapping one-year estimates at 6-month intervals of net top-of-the-atmosphere annual energy flux from the Clouds and the Earth's Radiant Energy System Energy Balanced and Filled Ed4.1 product (solid red line) and an in situ observational estimate of uptake of energy by Earth climate system (solid blue line). Dashed lines correspond to least squares linear regression fits to the data.

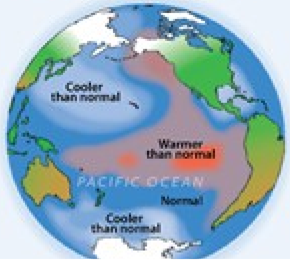
Theme 2: **Integrated Attribution, Prediction and Projection**

We seek to **identify and attribute the primary drivers of Earth system change on A2D scales** (e.g., anthropogenic vs internal sources of variability)

Theme 2
Integrated attribution, prediction and projection

Sources of Annual-to-Decadal (A2D) Variability

Anthropogenic
GHG emissions,
Aerosol emissions,
Ozone changes,
Land use change



Natural
Volcanoes,
Solar irradiance,
Internal variability

- Advocate for the generation of large ensembles of single-forcing experiments
- The goal: to integrate attribution and prediction capabilities to provide seamless information for decision making

WG2 Integrated Attribution, Prediction, and Projection

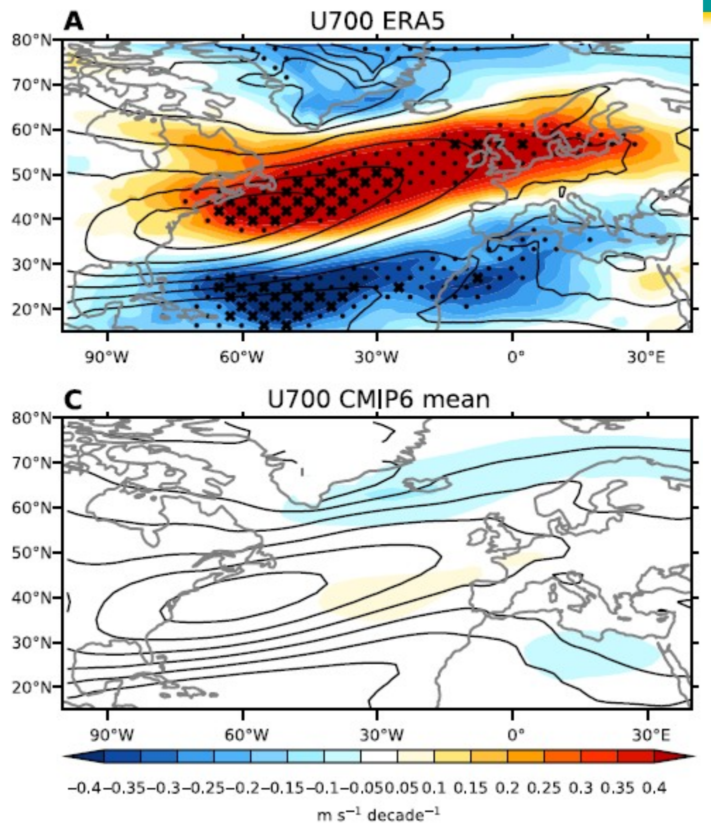
Understand trends and A2D variability in atmospheric circulation.

Priority science themes:

1. Summer northern hemisphere trends in atmospheric circulation
2. A2D variability in North Atlantic atmosphere and ocean circulation (especially in winter)
3. Trends in the Southern Annular Mode (collaboration with **SPARC**)
4. Trends in tropical circulation

Key implementation steps:

- Complete LESFMIP simulations (end 2023)
- Analysis of LESFMIP simulations, prioritising understanding drivers of circulation change (including the signal-to-noise paradox)
- Near real-time estimates of radiative forcings to update LESFMIP simulations (end 2024)
- Collaboration with **DCPP** on attribution of predictable signals
- Contribute attribution statements to **WMO Annual-to-Decadal update** (2025 onwards)



1951-2020 winter trends
Colors: Observed and modeled trends in zonal wind
Crosses: ERA5 value outside CMIP6 distribution
Contours: Climatology

Blackport & Fyfe 2022

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Theme 3: **Assessment of Current and Future Hazards**

We seek to **understand how internal variability and external forcings influence the characteristics and occurrence of meteorological hazards** on A2D scales in different regions

- Focus on a subset of hazards (e.g. tropical cyclones, heatwaves, droughts)
- Make use of large ensembles
- The goal: to use observations, models and process understanding to deliver robust assessments of current and future hazards for specific regions and hazard classes

WG3: Assessment of Current and Future Hazards

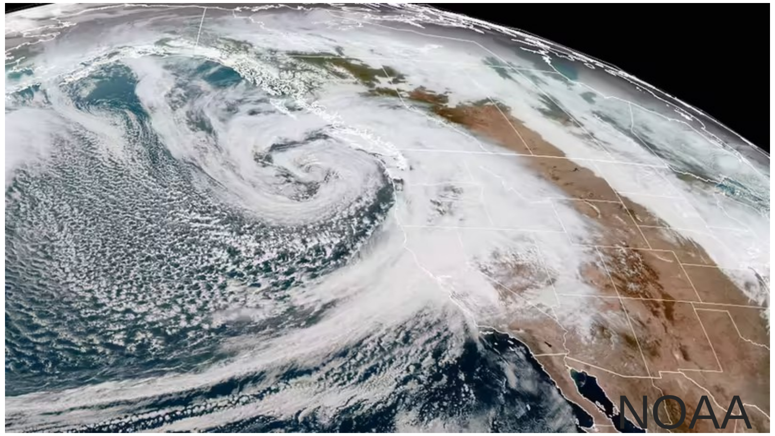
Identified a set of **priority hazards** (with leads and teams):

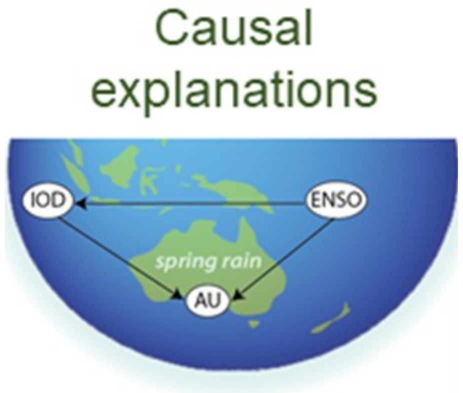
1. Tropical Cyclones
2. Extreme precipitation and droughts
3. Heatwaves *(through the cross-cutting activity)*
4. Compound extremes

*Discussions underway with **Safe Landing Climates LHA** about collaboration on heat, fire, and drought hazards*

Key methodological aspects will address:

- Hazard-related circulation and processes
- Hazard likelihoods
- Hazard attribution
- Variability, predictability and prediction of hazards (includes collaboration with DCPP)

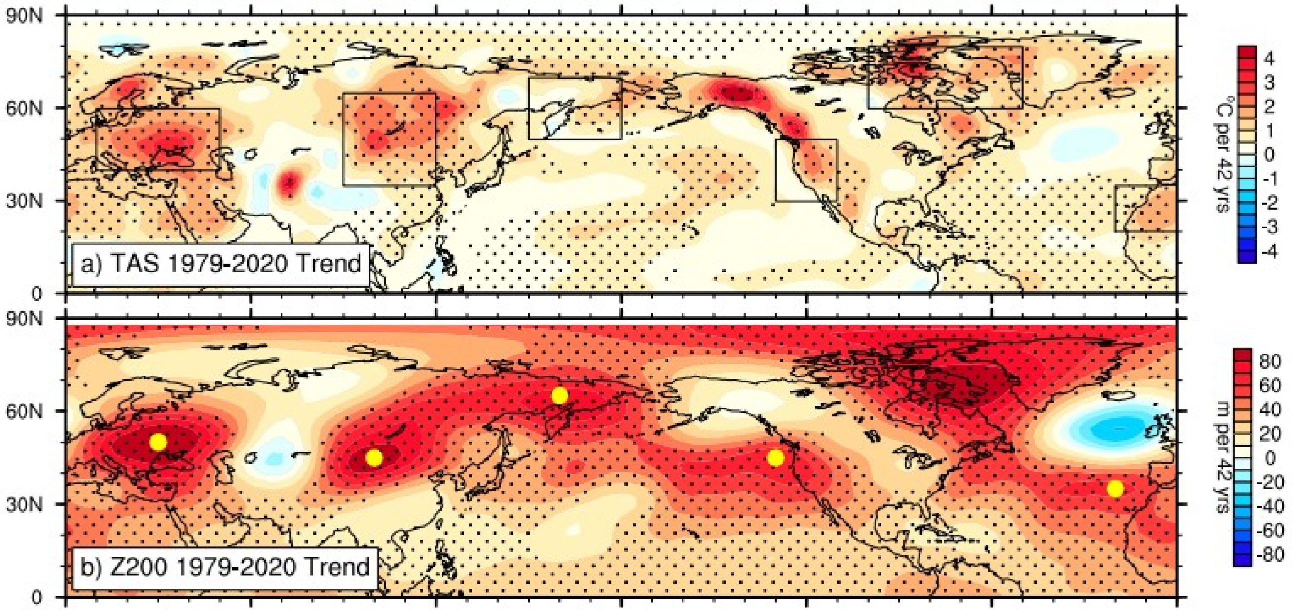




Cross-WG case study:
Summer circulation, heatwaves and droughts

Teng et al., 2022

- Increasing occurrence of record breaking heatwaves and droughts worldwide
- Uncertainty around the roles of many processes, especially changing atmospheric circulation, but also changes in the oceans and in atmosphere-land interactions



- *Focused on improving our ability to understand, attribute and predict summer circulation changes and heatwaves on annual-to-decadal scales.*
- Opportunities here to collaborate with **Safe Landing Climates LHA**, **SPARC**, and **GEWEX**.
- Individual WGs will have specific foci for this cross-cutting study.

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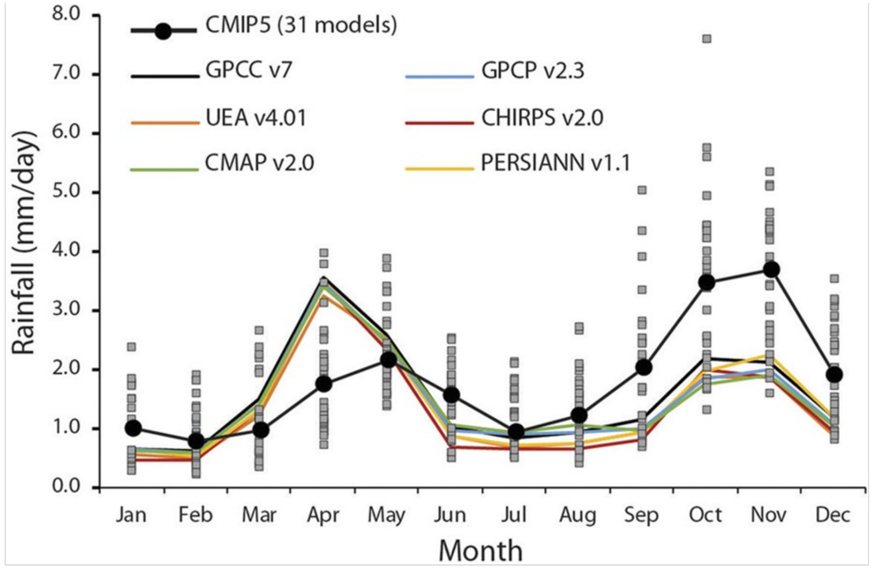
- A developing case study on East African rains



Lyon, J. Climate, 2020

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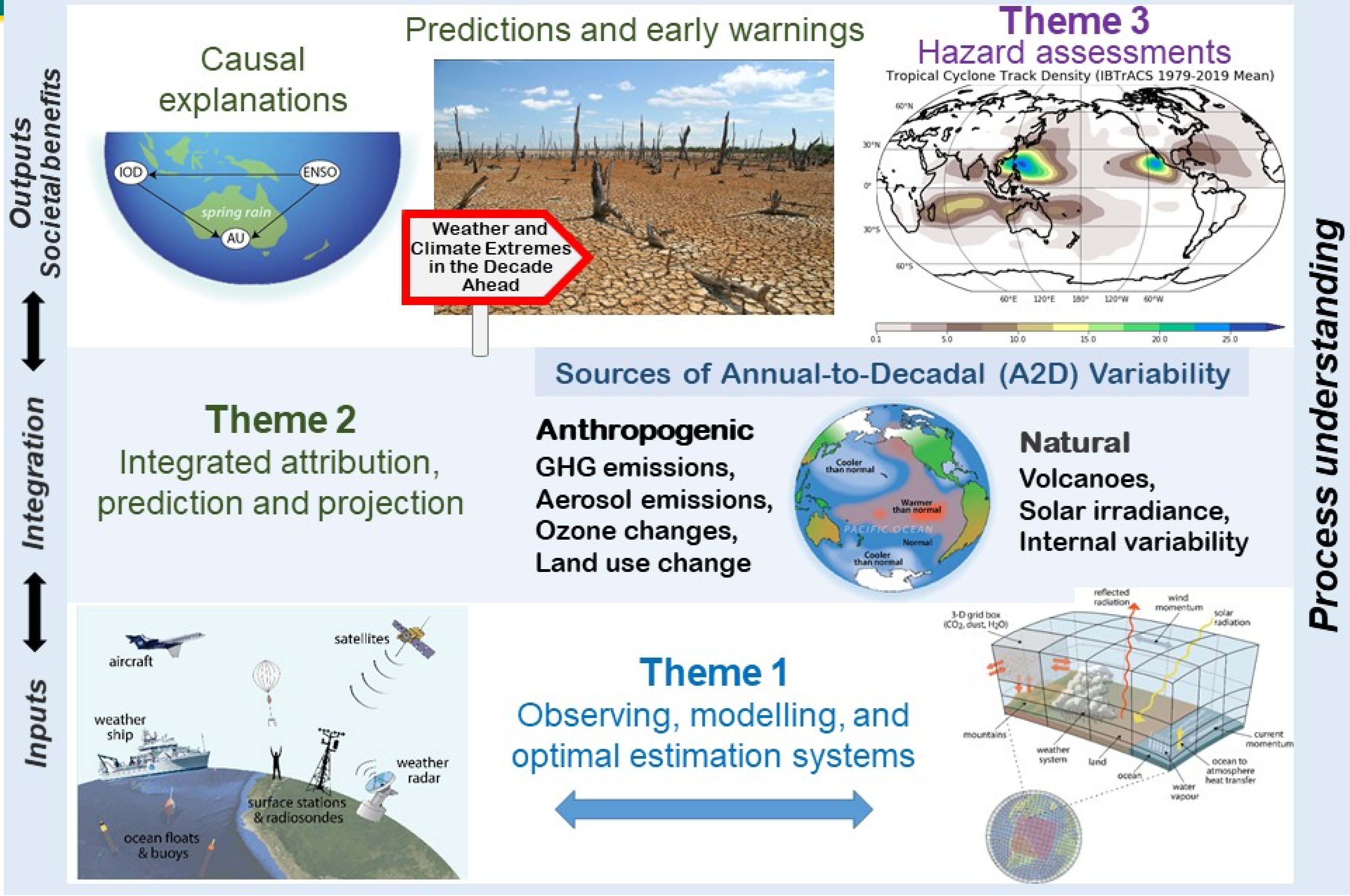


Findell et al. *BAMS*, January 2023

Outputs and Outcomes

- Near-term outputs (2024 onwards):
  - Contributions to WMO State of the Climate and Global Annual-to-Decadal climate update reports
  - Advice to GCOS on observational requirements for explaining and predicting Earth system change

Outputs and Outcomes

Benefits to society:

- Quantitative process-based explanation of ongoing and emerging changes in the climate system
- Understanding and quantification of changes in classes of meteorological hazards on A2D scales
- Improved predictions and early warnings

Nile Upper Egypt- Flickr/Michael Gwyther-Jones

These efforts will help us integrate attribution and prediction capabilities to provide seamless information for decision making for near-term climate needs

EPESC Structure

SSG Co-chairs
Kirsten Findell & Rowan Sutton

Explaining and Predicting Earth System Change Lighthouse Activity

Scientific Steering Group

Working Group I
Observing and Modelling Earth System Change

Working Group II
Integrated Attribution, Prediction and Projection

Working Group III
Assessment of current and future Hazards

WGI Co-chairs
Paul Kushner
Anca Brookshaw

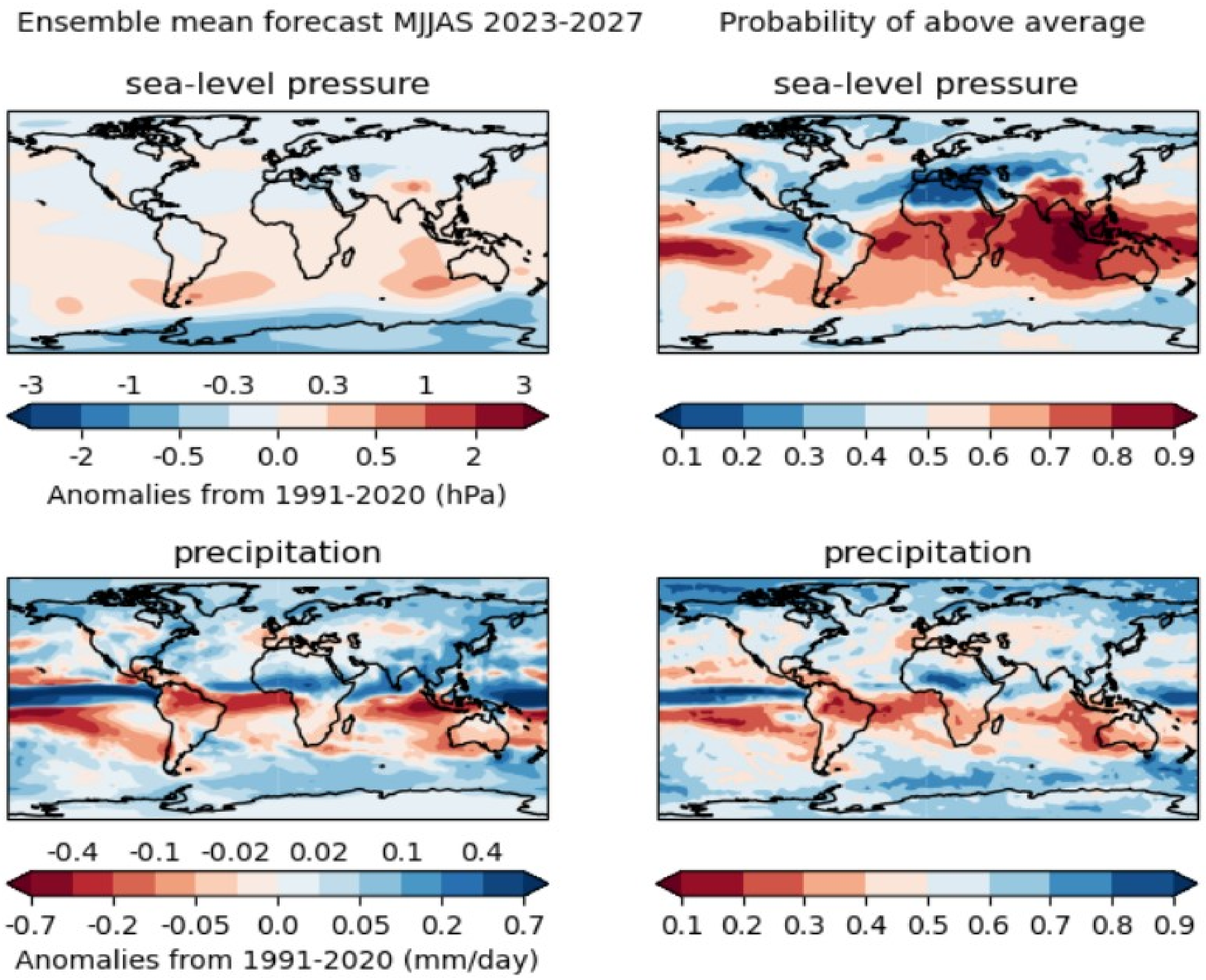
Co-chairs:
Doug Smith
Scott Osprey

Co-chairs
Zhuo Wang
James Risbey

Thank you.

WMO Annual-to-Decadal Climate Update 2023

May-Sept 2023-2027



- These predicted regional changes in circulation and precipitation could have very large impacts.
- Physical understanding and attribution of signals is crucial.
- *Ultimately we need an operational capability for integrated attribution and prediction.*

Issued annually in May (since 2020)

Recent progress

- Published an expanded science plan (Findell et al., 2023)
- Large Ensemble Single Forcings Model Intercomparison Project (LESFMIP; Smith et al., 2022) > 10 centres contributing
- Webinar series:
  - Record breaking extreme events (September 22)
  - Triple La Niña (November 22)
  - Global and regional changes in drought (February 23)
  - HILL events (March 23)
  - Marine heatwaves (May 2023)
  - Earth's Energy Imbalance (July 2023)
- Presentation at COP27 in the Session on Climate Information for Near-Term Preparedness
- An EPESC session at AGU 2022
- First in person workshop in Exeter, UK, in March 2023 where we identified priorities, activity plans and teams ; also involved joint sessions with DCPP

WG1: Towards tighter integration of obs and modeling systems

Specific Opportunity (Kushner et al.):

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Gaps:

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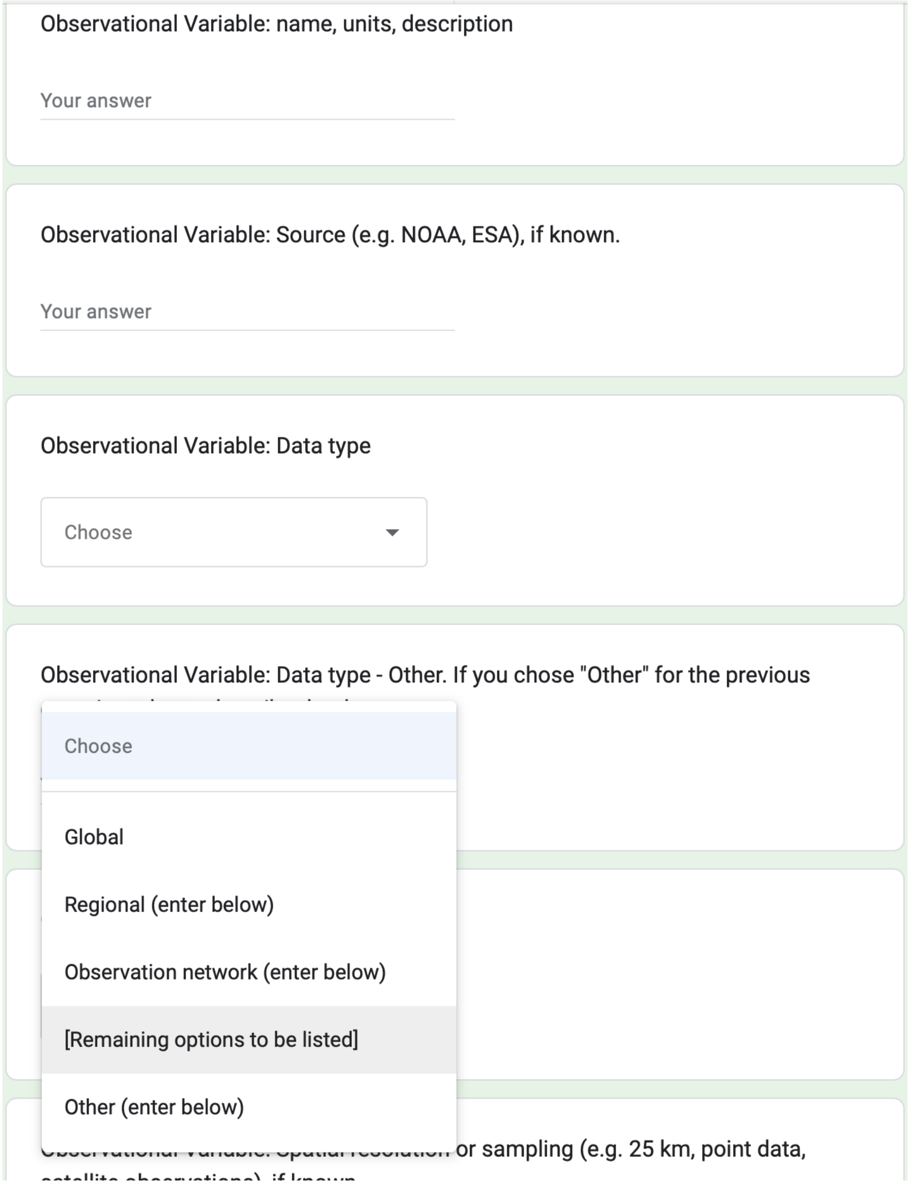

Linkages with Core Projects, Lighthouse Activities etc.

- **Good links established with GEWEX, SPARC.**
- **Good links established with SLC LHA.**

- **More opportunities:**
  - **with My Climate Risk & RifS (WG3)**
  - **With CLIVAR (especially WG1 and WG2)**
  - **With ESMO (WG1)**