Explaining and Predicting Earth System Change

44th Session of the WCRP Joint Scientific Committee

Rowan Sutton & Kirsten Findell

May 2023

Climate Center, Brussels, Belgium

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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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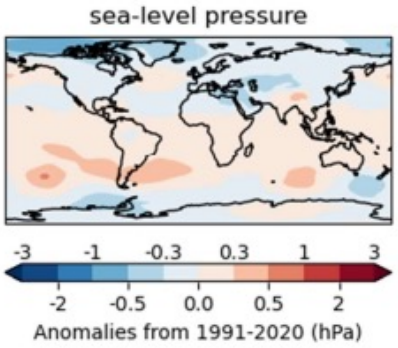
International Science Council

WCRP World Climate Research Programme

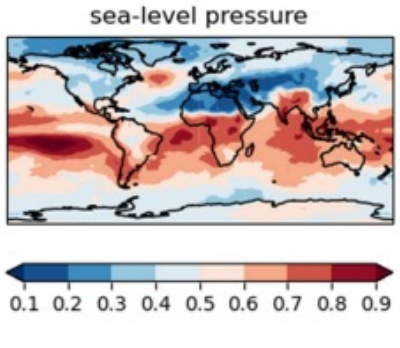
WMO Annual-to-Decadal Climate Update 2022

May-Sept 2022-2026

Ensemble Mean

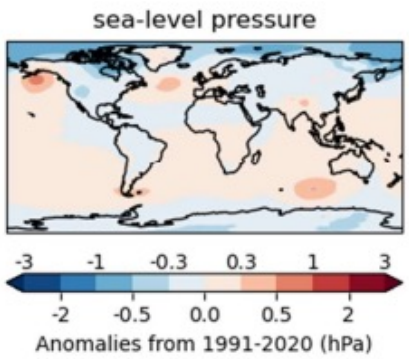


Probability of above average

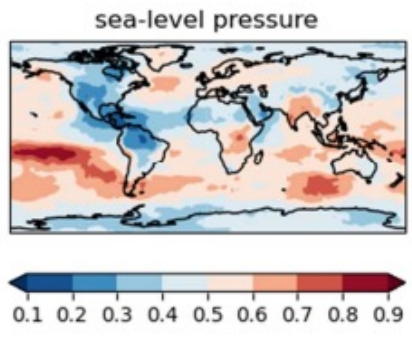


Nov-Mar 2022-2026

Ensemble Mean



Probability of above average



Anomalies relative to 1991-2020

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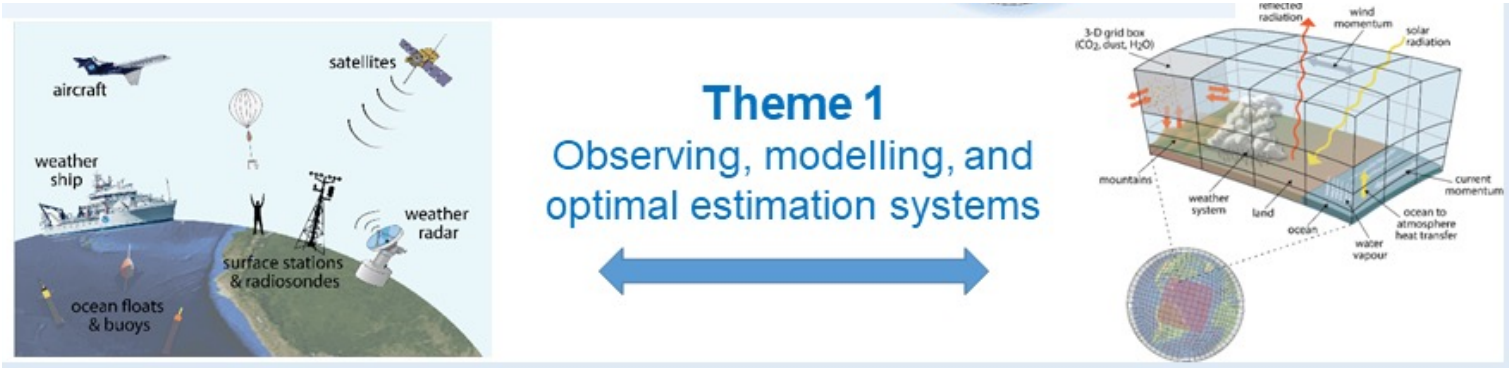
Theme 1: **Monitoring and Modeling Earth System Change**

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?

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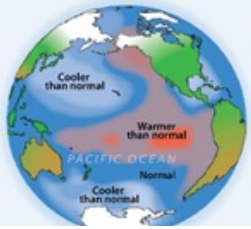
Theme 2: **Integrated Attribution, Prediction and Projection**

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

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

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WCRP Lighthouse Activity on Explaining and Predicting Earth System Change

Outputs
Societal benefits

Integration

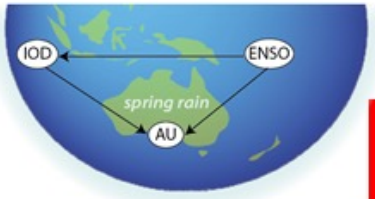
Inputs

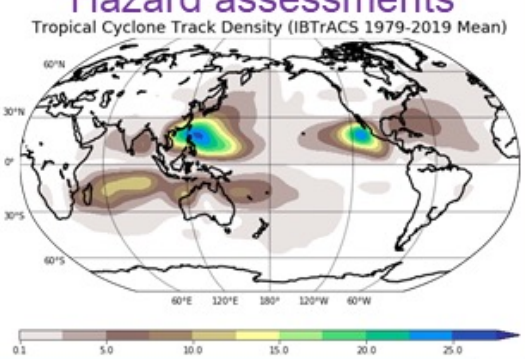
Process understanding

Theme 3
Hazard assessments

Predictions and early warnings

Causal explanations





Sources of Annual-to-Decadal (A2D) Variability

Theme 2
Integrated attribution, prediction and projection

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GHG emissions,
Aerosol emissions,
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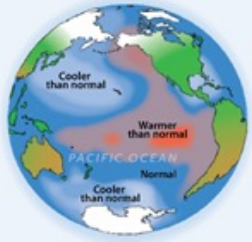

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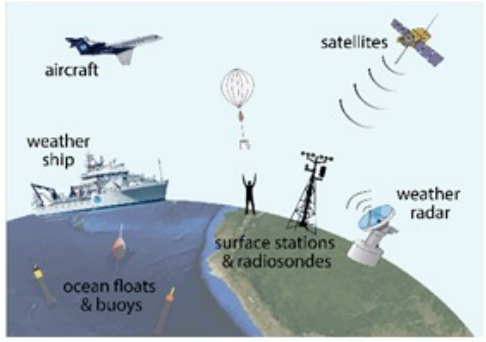
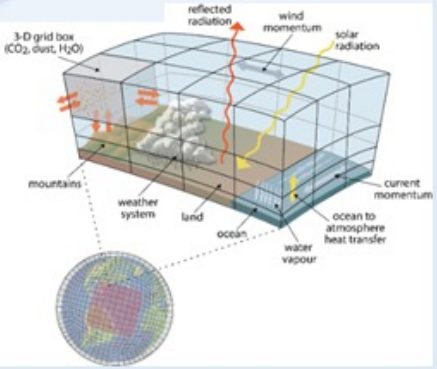


Theme 1
Observing, modelling, and optimal estimation systems



Findell et al. *BAMS*, January 2023

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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

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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

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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 Patrick Heimbach Anca Brookshaw	Co-chairs: Doug Smith Scott Osprey	Co-chairs Zhuo Wang James Risbey

Progress and achievements over the last year

- 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)
- Presentation at COP27 in the Session on Climate Information for Near-Term Preparedness
- An EPESC session at AGU 2022
- ***EPESC held our first in person workshop in Exeter, UK, in March 2023 where we identified priorities, activity plans and teams*** ; also involved joint sessions with DCPP

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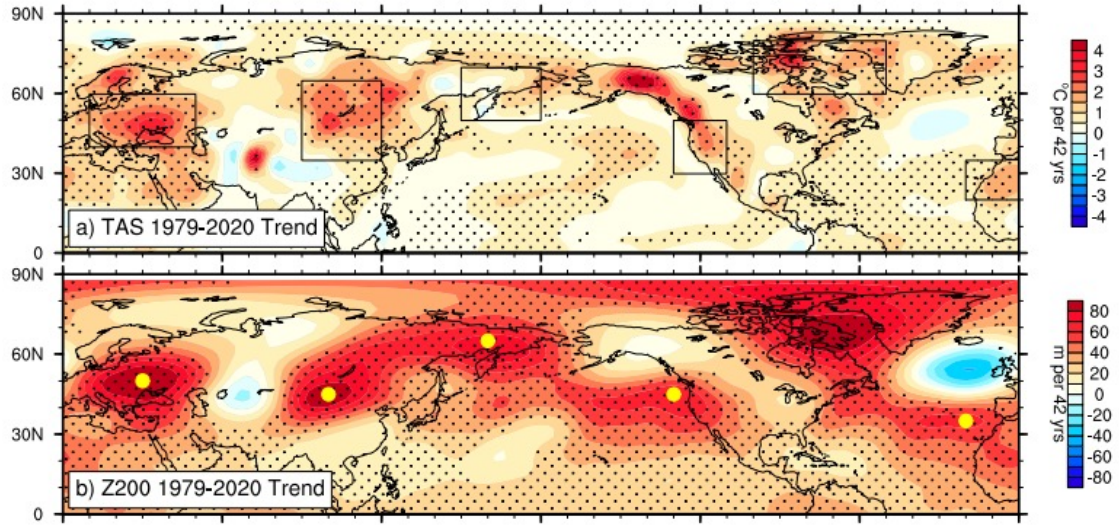
Planned activities

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

- 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

Teng et al., 2022



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

Key research questions:

- What are the causes of trends in summer northern hemisphere **atmospheric circulation**?
- What is the role of **soil/vegetation-atmosphere interactions** in the onset and amplification of heatwaves? What can observation-based datasets tell us about the representation of these processes in models (and in reanalyses)?
- Can we quantify the **relative impact of large-scale atmospheric patterns/dynamics and local mechanisms on heatwaves**? And their feedbacks?
- Are **observational datasets accurate enough** to answer these questions? Are there important missing variables that could be covered?

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WG1: Observing and Modelling Earth System Change

- Project on **tighter integration of observing and modeling systems**: focused on the development of a workflow aimed at determining the strengths, limitations, and applicability of existing datasets relevant to the other research topics of interest across the three working groups of EPESC.

  Paul Kushner et al

- Case study on the recent **trend in Earth's Energy Imbalance**: focused on understanding the causes, impacts, and implications
  - Opportunities to collaborate with the **GEWEX** EEI Assessment team.

  Benoit Meyssignac et al

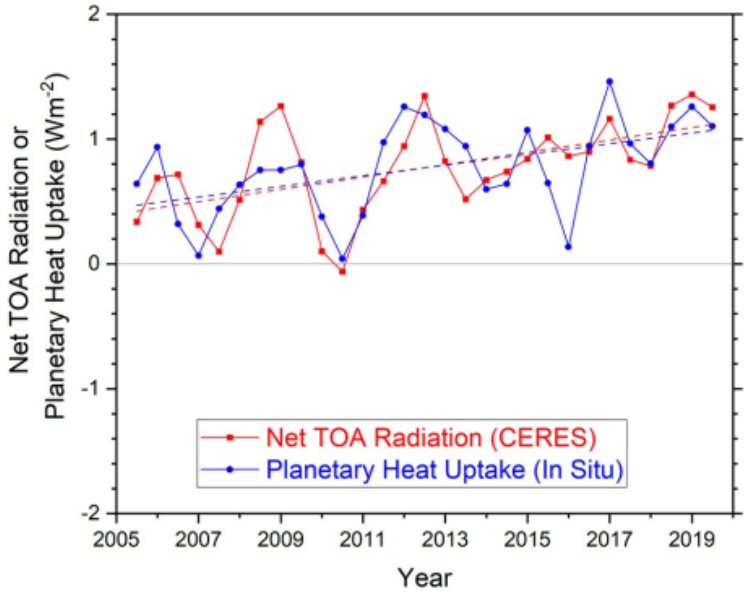
WG1: Trends in Earth's Energy Imbalance (EEI)

Specific Opportunity:

- 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 on the explanation of the causes for the observed EEI variability.



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.

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

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Gap:

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

Science questions:

1. Do we understand the cause of the doubling in EEI?
2. Can we trace the chain of different processes in the coupled ocean-atmosphere-cryosphere system that leads to such an increase?
3. Can we quantify what part is forced and what part is internal variability?
4. Do we understand the consequences of this doubling in EEI?
5. What is the link to extreme weather (e.g., drought, heat waves, etc.), sea level rise and other impacts?

WG2 Integrated Attribution, Prediction, and Projection

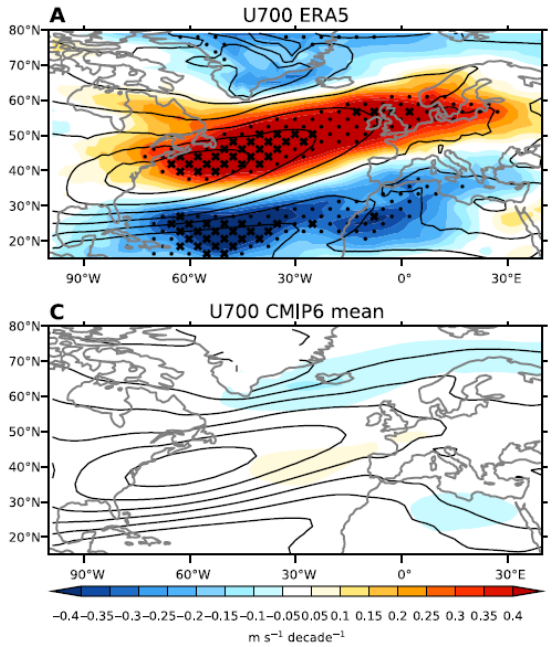
The cross-cutting priority is to understand trends and A2D variability in atmospheric circulation.

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**)

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

Blackport & Fyfe 2022

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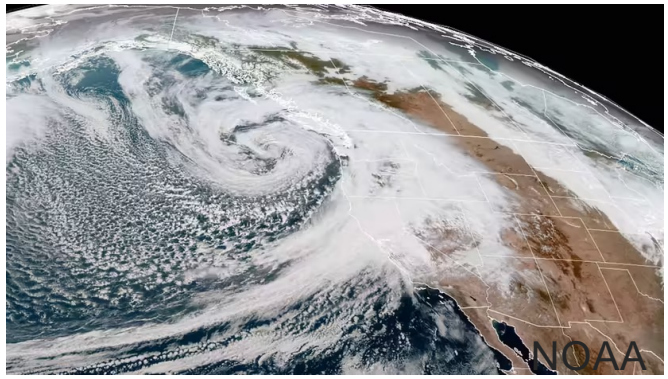
WG3: Assessment of Current and Future Hazards

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

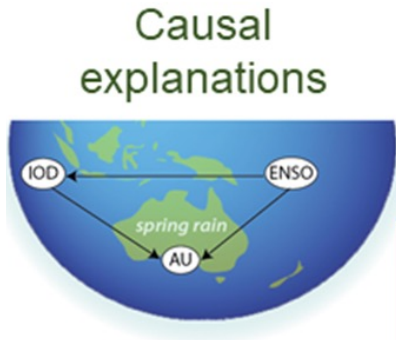
1. Tropical Cyclones
2. Extreme precipitation and droughts
3. Heatwaves *(through the cross-cutting activity)*
4. Compound extremes

*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)



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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)**

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Partnerships with entities outside of WCRP

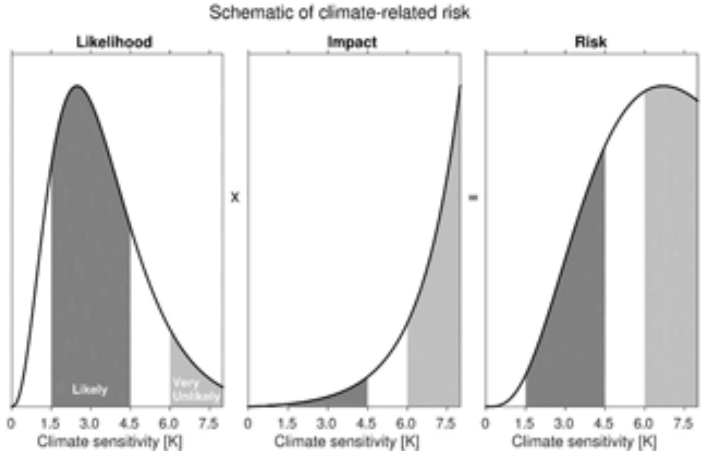
- EPESC Member Shoshiro Minobe has proposed to the **PICES** leadership that he serve as an ex-officio member of their Working Group 49 (Climate Extremes and Coastal Impacts in the Pacific) which already has strong ties with **CLIVAR**. This cross membership is intended to facilitate collaboration between EPESC, **PICES**, and **CLIVAR** on the topic of marine heatwaves.

Emerging issues

- ***To enable the development of effective collaborations we urgently need a collaboration platform (with capabilities such as those offered by Slack) to enable live discussions, sharing of results etc without having to rely on cumbersome email.***
- Key challenge is to secure research funding aligned to the goals of EPESC. Various research proposals are in preparation.
- It was hard to generate momentum without in-person discussions. Our March workshop in Exeter was extremely valuable in addressing this problem and highlights the importance of face-to-face meetings.

Circulation change as a class of HILL event

- Key societal needs for early warning of high impact events
- Even where likelihood is considered low, such events merit attention because of the high risks involved



Sutton, ESD, 2018

- Identifying **Early Warning Indicators (EWI)** for HILL events requires specific consideration
- Potential EPESC topic: **EWIs of circulation change**

Thank you!

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WCRP LHA EPESC – Theme 1
Trends in Earth's Energy Imbalance (EEI)

Coordinated research activities:

- Gather relevant members from the observation, reanalysis and modeling communities across WCRP to design experiments in order to explain the recent increase in EEI.
- This has already begun for AMIP (e.g., CERESMIP, led by Gavin Schmidt),
- Explore possibilities from large ensembles, initialized predictions, D&A studies, high resolution global simulations?
- Explore latest atmosphere and ocean reanalysis products
- Propose a workshop on this EEI EPESC LHA activity to engage a broad science community and raise awareness of this critical problem within WCRP.

Roadmap: duration of activity ~5 years

- from now to Dec. 2023: contact core people to involve in the activity and set up the content of the activity
- from 2024-2029: conduct community activity around the EEI analysis through
  - coordinated research activities
  - synthesis papers
  - conference sessions
  - summer school

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WCRP LHA EPESC – Theme 1
Trends in Earth's Energy Imbalance (EEI)

Core team:

- **EPESC:**
  - WG1: Benoit Meyssignac, Patrick Heimbach, Maria Paz Chidichimo, Andrea Storto, Anca Brookshaw;
  - TBC: Lijing Cheng, Johanna Baehr, … (others?)
  - WG2: TBD; we expect in particular people from WG2.1 (single forcing large ensembles) and 2.3 (attribution to processes)
- **GEWEX GDAP EEI** assessment:
  - B. Meyssignac, N. Loeb and others (T. Boyer, M. Hakuba, S. Kato)
- **Invited people:**
  - Norman Loeb (NASA/Langley), Tim Andrews (MetOffice), Gavin Schmidt (NASA/GISS), …
- **ESMO, WGNE, WGCM, GCOS, …**
  - TBD