Explaining and Predicting Earth System Change

A WCRP Lighthouse Activity

Kirsten Findell and Rowan Sutton (EPESC Co-Chairs)

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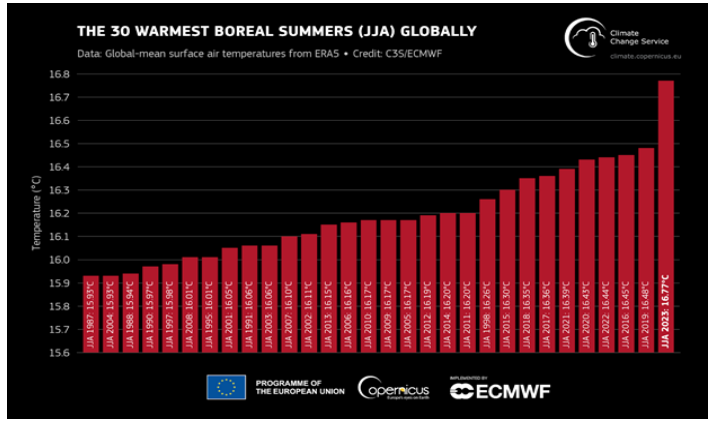
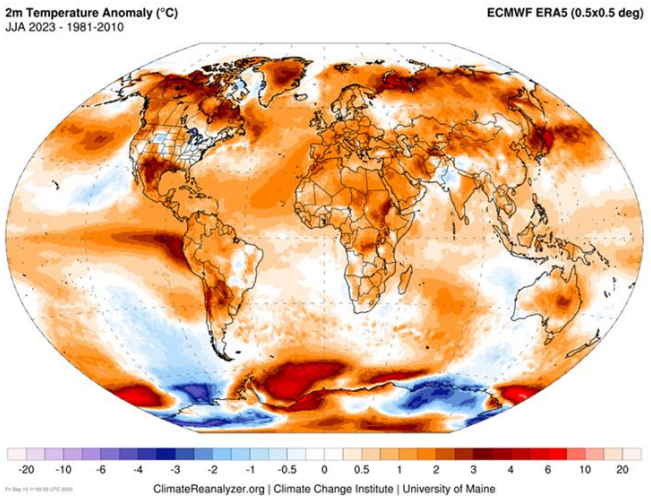
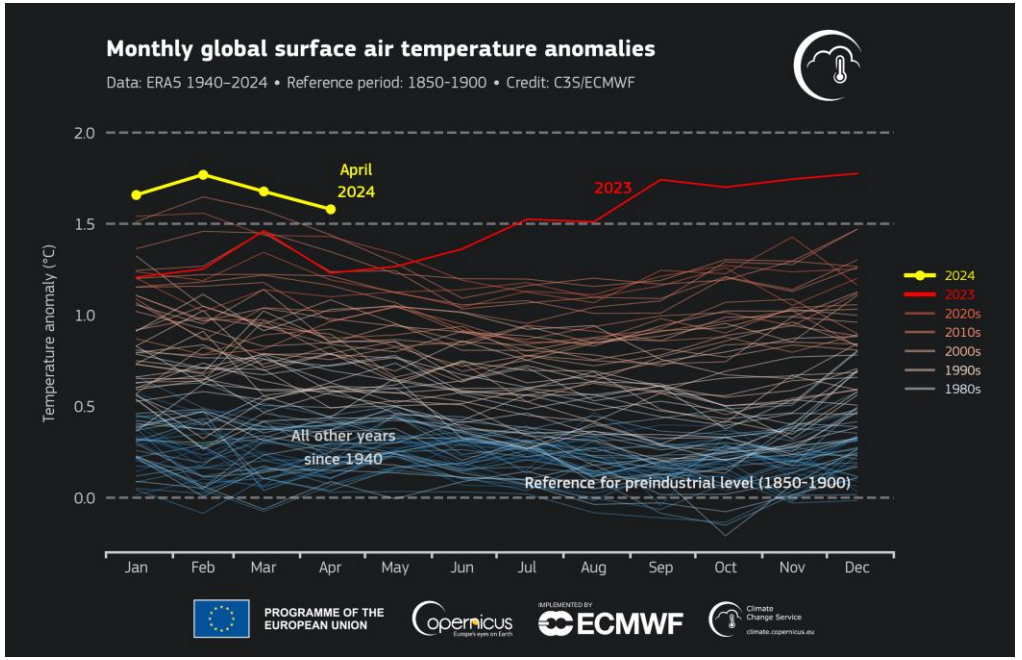
Why EPESC? - A timely reminder of our ignorance







- What were the short and long-term causes?
- Is this a one-two year anomaly or a lasting regime change?
- What are the immediate and longer-term impacts & implications?
- Why did we fail to predict it?

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Why EPESC? - A timely reminder of our ignorance

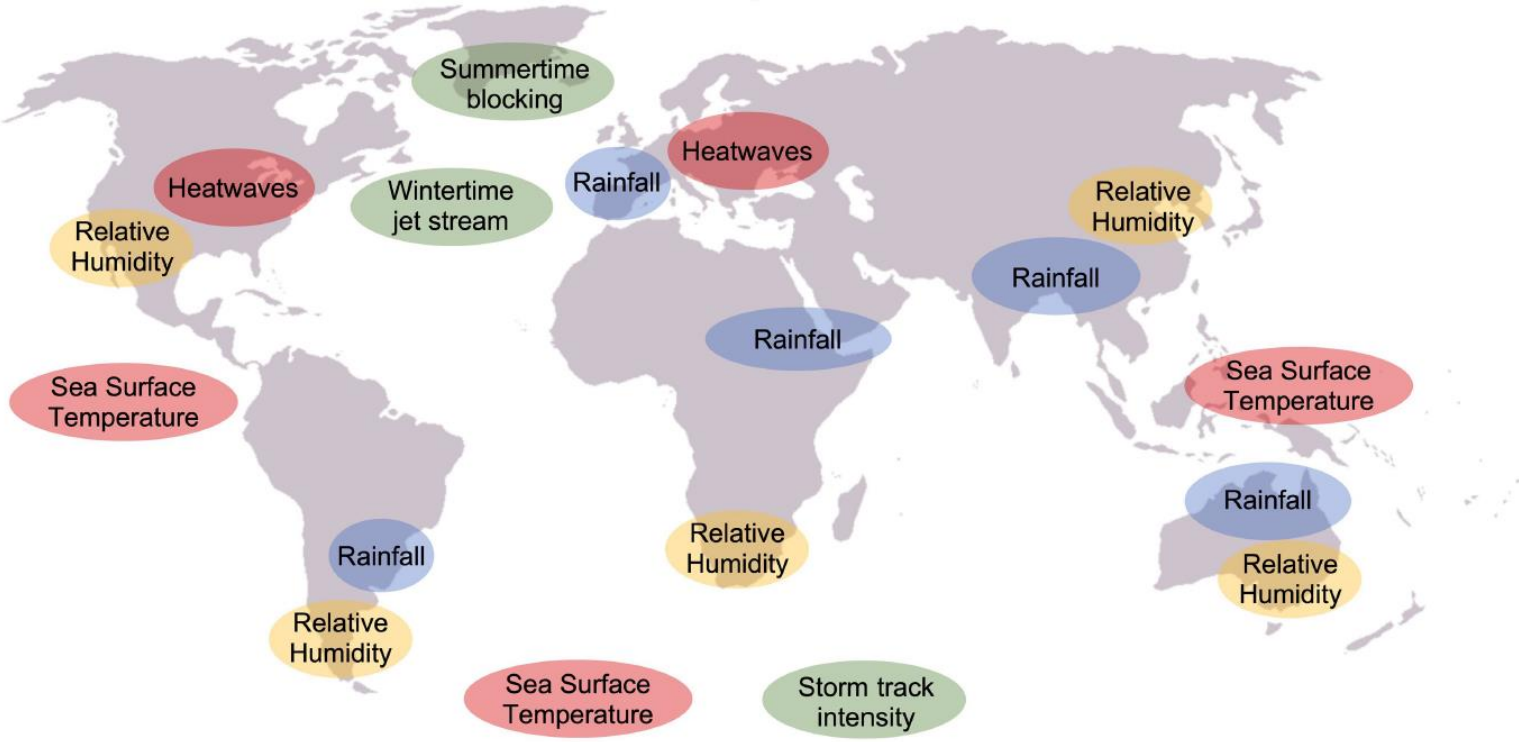

FIGURE 1
The location of known model-observation discrepancies in historical trends discussed in section 3.

Shaw et al, Frontiers in Climate, 2024

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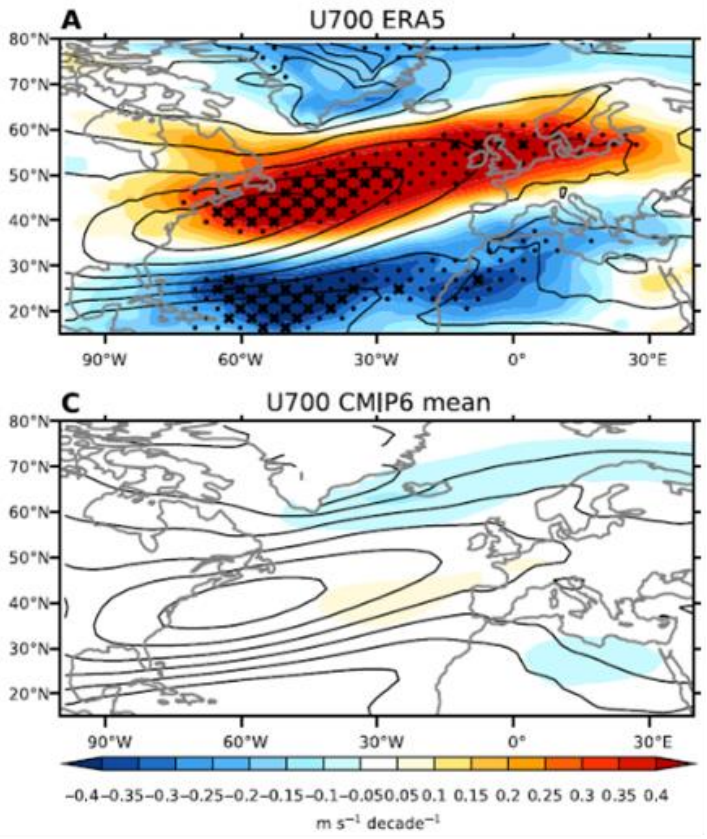
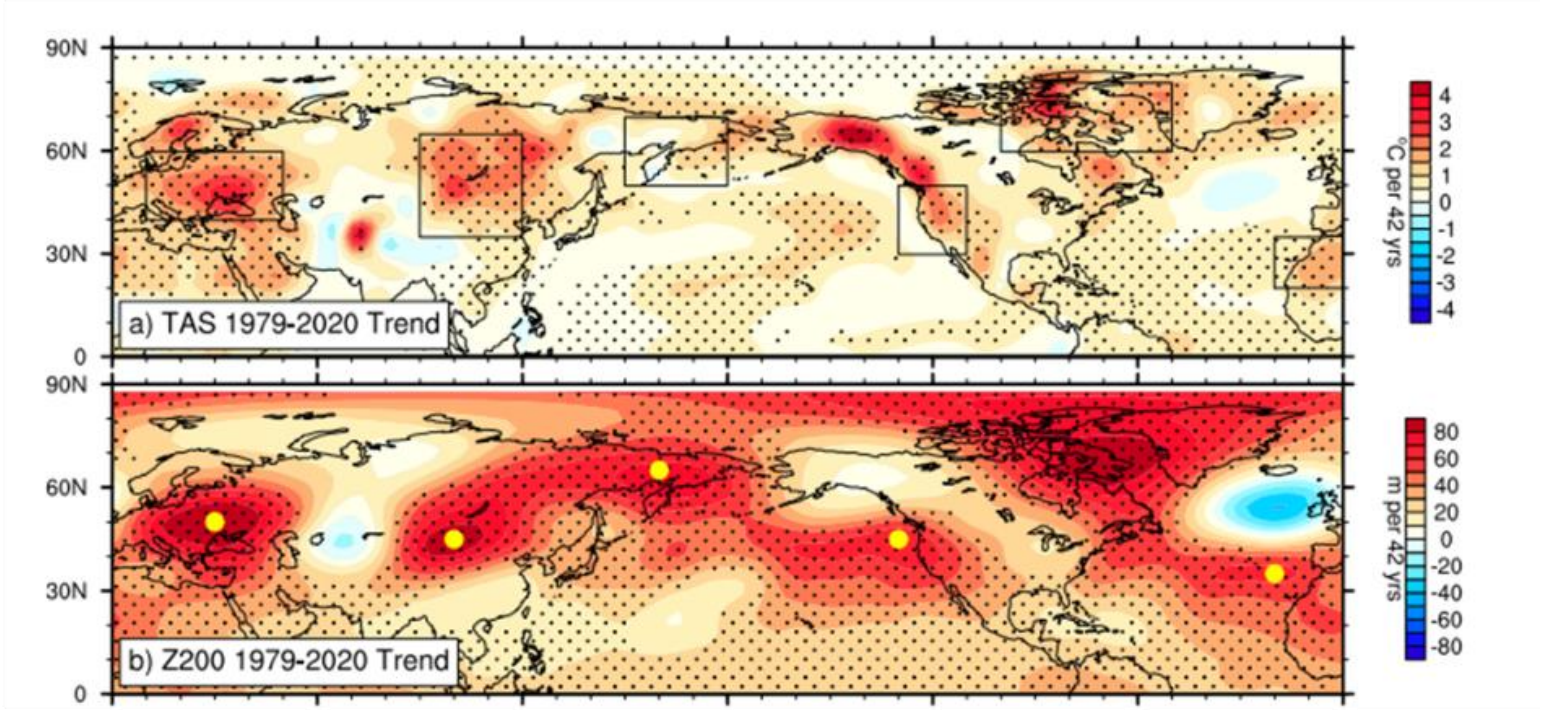
Challenges in understanding circulation change



1951-2020 winter trends

Blackport & Fyfe 2022



Summer Northern Hemisphere trends 1979-2020

Teng et al, 2022

Ocean circulation is equally uncertain and important!

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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

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EPESC Structure

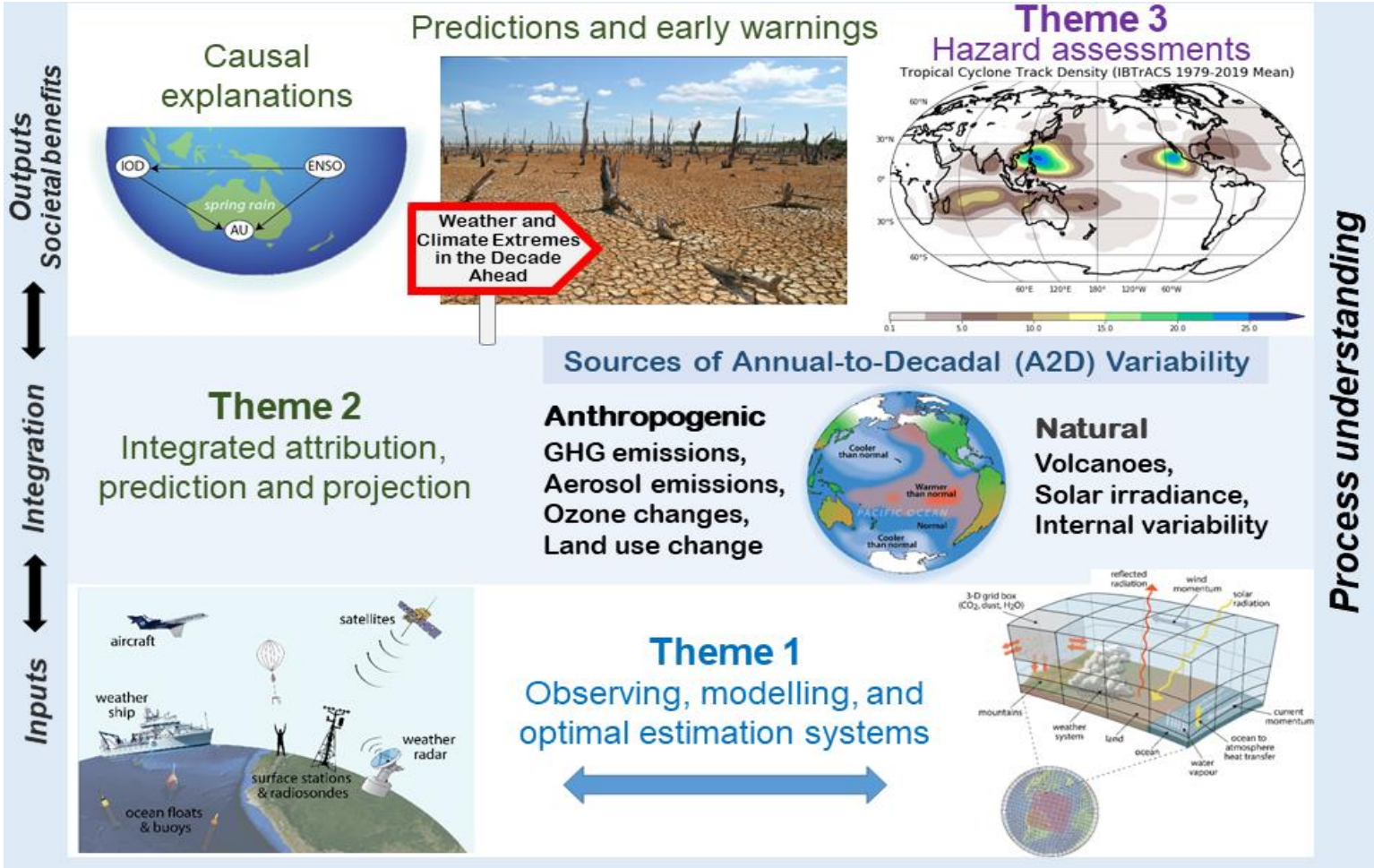
SSG Co-chairs
Kirsten Findell & Rowan Sutton

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
Co-chairs Anca Brookshaw Paul Kushner*	Co-chairs Doug Smith Scott Osprey	Co-chairs Zhuo Wang James Risbey

**Thanks to Patrick Heimbach, WG1 co-chair through Sept 2023 and still on the SSG.*



Findell et al. *BAMS*, 2023

This update is heavily informed by a science meeting held virtually and in Barcelona May 16-17.

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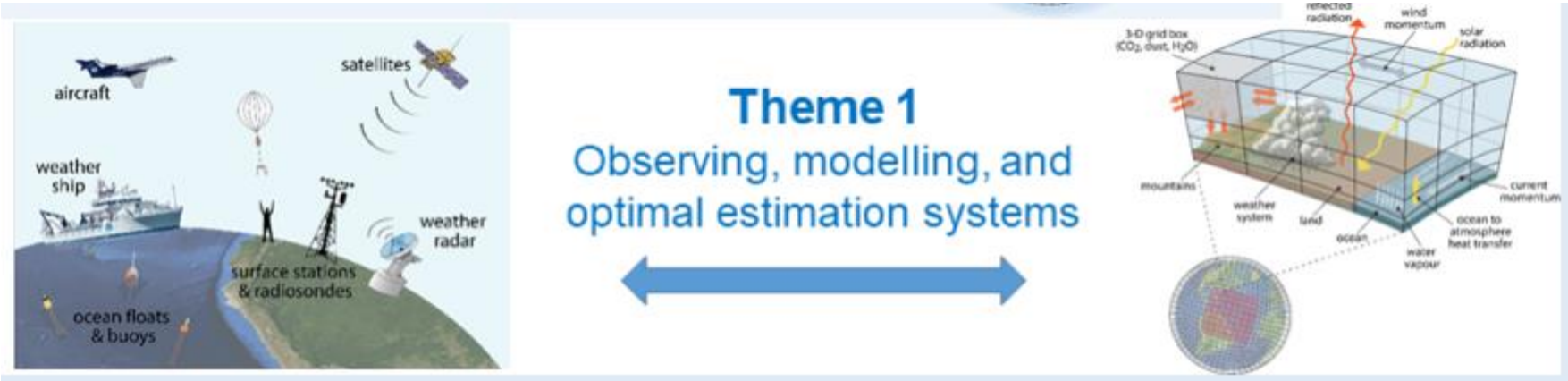
Theme 1: **Monitoring and Modeling Earth System Change**

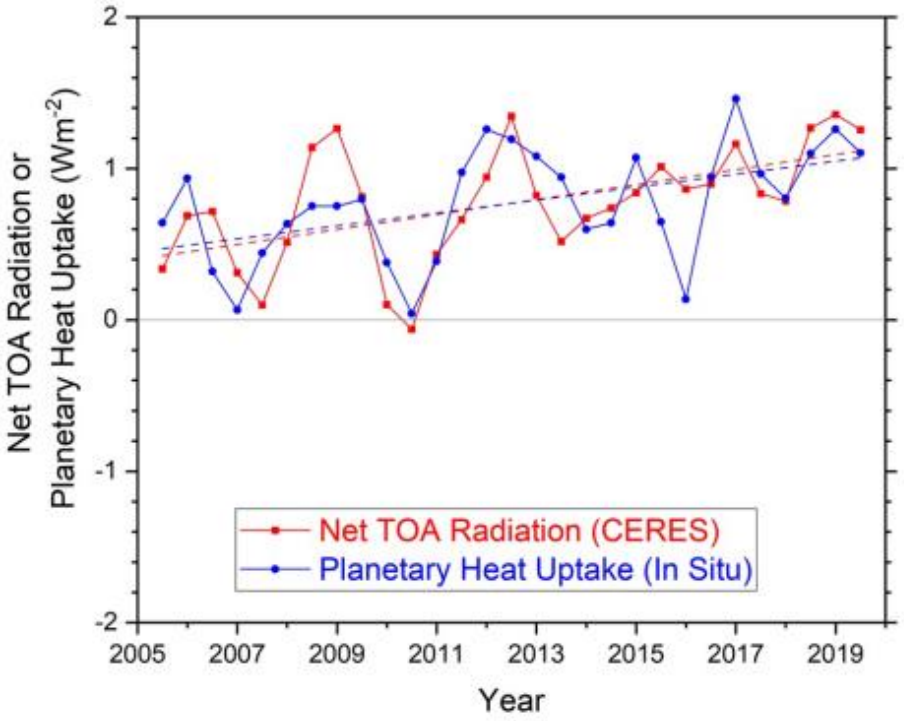
We seek **tighter integration of models and observations to monitor and understand Earth system change**



- 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?

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

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



- 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?

Lead: Benoit Meyssignac
Benoit is also involved in the GEWEX EEI Assessment. He will ensure the efforts are collaborative and complimentary.

March 2024: Meyssignac, Loeb et al. submitted a proposal to International Space Sciences Institute: *Causes and consequences of the current trend in Earth's energy imbalance*

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]

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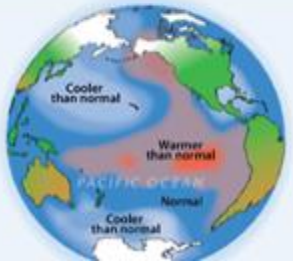
Theme 2: Integrated Attribution, Prediction and Projection

Theme 2
Integrated attribution, prediction and projection

Sources of Annual-to-Decadal (A2D) Variability

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

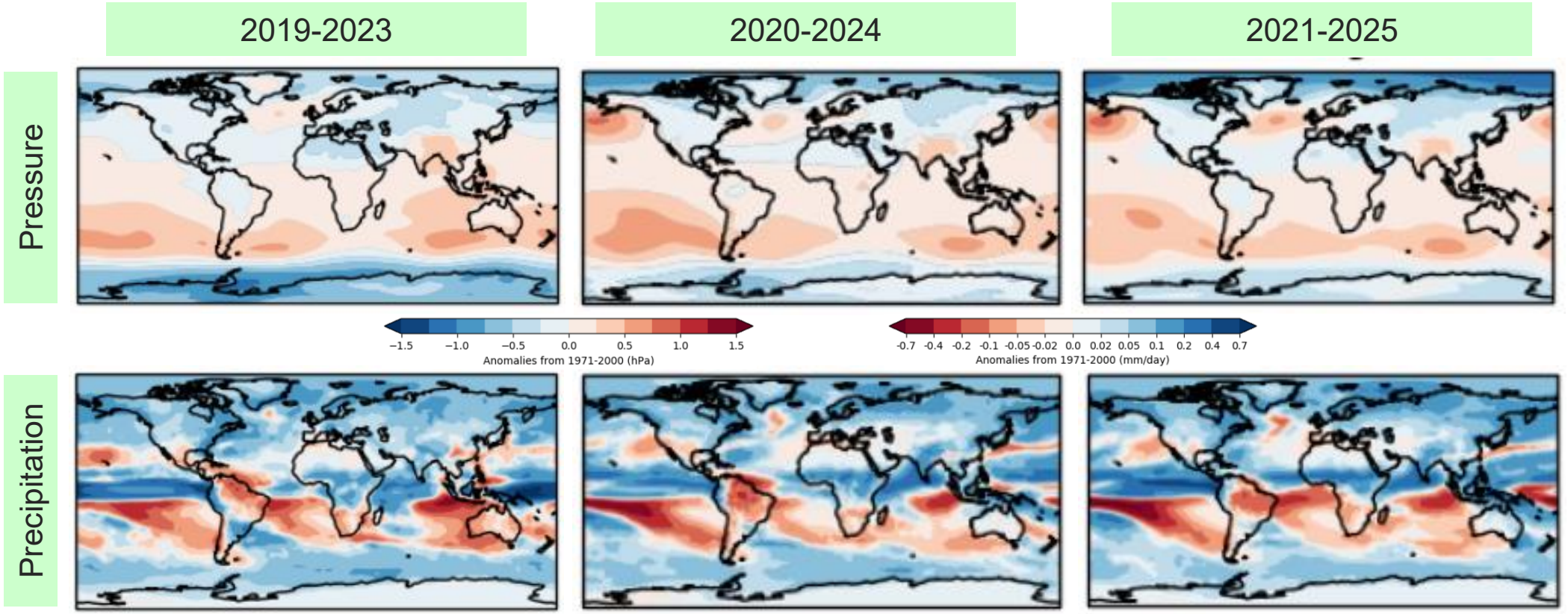


Natural
Volcanoes,
Solar irradiance,
Internal variability

Overall WG2 objectives:

- To provide a **process-based** understanding of recent multi-annual to decadal climate changes and quantify the roles of **internal variability** and **external drivers** including **greenhouse gases, aerosols, solar, volcanoes, ozone, land-use**...
- Assess predictability, sources of skill, drivers and mechanisms – hence gain **confidence in predictions and projections**
- Make regular inputs to **WMO Global Annual to Decadal Climate Update** and **WMO State of Climate** reports

Multi-annual forecasts



Consistent forecasts for the coming 5 years

What drives the signals?

How much confidence do we have?

WG2 Integrated Attribution, Prediction, and Projection

The over-arching priority is to understand trends and A2D variability in atmosphere or atmosphere-ocean circulation

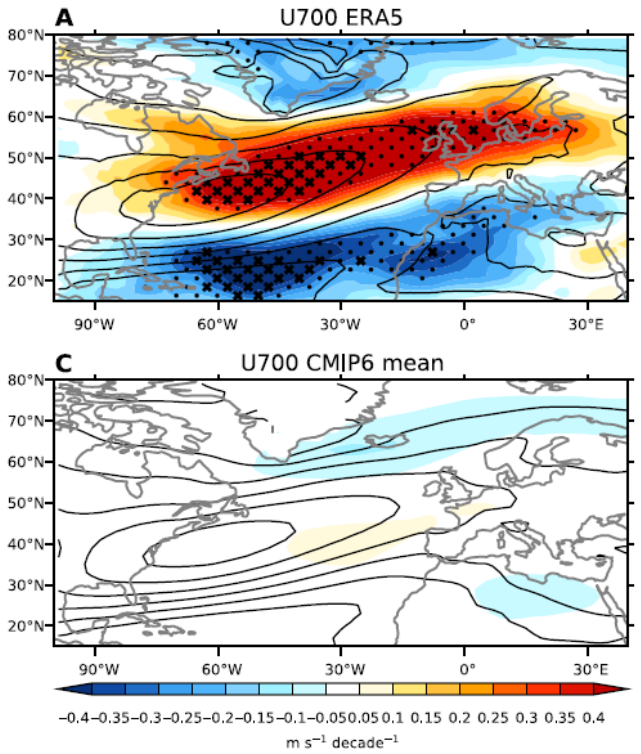
Priority science themes & leads:

1. North Atlantic atmosphere and ocean circulation: Chaim Garfinkel, Isla Simpson
2. SAM circulation trends and extremes: Leandro Diaz, Amy Butler
3. Summer northern hemisphere atmospheric circulation: June-Yi Lee, Markus Donat
4. Tropical circulation variability and trends: Andrea Dittus, Annalisa Cherchi

Key implementation steps:

- Complete **LESFMIP** (Large Ensemble Single Forcing MIP) simulations:
  - We don't currently have the tools to attribute A2D changes in climate
  - Need large ensembles because of signal to noise error
  - Need to assess multiple drivers

Experiment name	Description
hist-GHG	Well-mixed greenhouse-gas-only historical simulations (WMGHGs)
hist-aer	Anthropogenic-aerosol-only historical simulations (BC, OC, SO2, SO4, NOx, NH3, CO, NMVOC)
hist-sol	Solar-only historical simulations (solar irradiance)
hist-volc	Volcanic-only historical simulations (stratospheric aerosol)
hist-totalO3	Ozone-only historical simulations (stratospheric and tropospheric ozone)
hist-lu	Historical simulations with only land use changes



1951-2020 winter trends

Blackport & Fyfe 2022

Large Ensemble Single Forcing Model Intercomparison Project (LESFMIP)

Status of simulations and data upload to ESGF

Size = ensemble size

Target = target completion data (✓ if already completed)

ESGF = target date for publishing data to ESGF (✓ if already completed)

		1.1 hist-GHG	1.2 hist-aer	1.3 hist-sol	1.4 hist-volc	1.5 hist-totalO3	1.6 hist-lu	3.1 historical	3.2 hist-nat	4.1 All minus GHG	4.2 All minus aer	4.3 All minus sol	4.4 All minus volc	4.5 All minus totalO3	4.6 All minus lu
ACCESS-ESM1-5	Size	10-40	10-40	10-40	10-40	10-40	10-40	40	10-40						
	Target		Apr23	Apr23	Apr23	Apr23	Apr23	Apr23	Apr23						
	ESGF														
CanESM5	Size	50	30	50	50	10		65	50						10
	Target	✓	✓	✓	✓	✓		✓	✓						✓
	ESGF	✓	✓	✓	✓	✓		✓	✓						✓
CESM2	Size	15	15		5			50			3				
	Target														
	ESGF														
CMCC-CM2-SR5	Size	10	10		10			10							
	Target														
	ESGF	Feb24	Feb24		Feb24			✓							
E3SM-2-1	Size	10	10	10	10	10	10	10							
	Target	Mar24	Mar24	Mar24	Mar24	Mar24	Mar24	Mar24							
	ESGF	Jun24	Jun24	Jun24	Jun24	Jun24	Jun24	Jun24							
FGOALS-g3	Size														
	Target														
	ESGF														
GISS-E2-1-G	Size	40	40	40	40	40	40								
	Target	✓	✓	✓	May24	May24	Jun24								
	ESGF	Sep23	Oct23	Mar24											
HadGEM3-GC31-LL	Size	50	50	50	50	50	50	50	50		50		50		
	Target	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓		
	ESGF	✓	✓	✓	✓	✓	May24	✓	✓		May24		May24		
IPSL-CM6A-LR	Size	14	13	0	0			32	14						
	Target	32	32					✓	32						
	ESGF														
MIROC6	Size	50	50	10	10	10	10	50	50						
	Target	✓	✓	✓	✓	✓	✓	✓	✓						
	ESGF	✓	Jul31	✓	✓	✓	Jul31	✓	✓						
MPI-ESM1-2-LR	Size	30	30	30	30	30	30	50	30						
	Target	✓	✓	✓	✓	✓	✓	✓	✓						
	ESGF	✓	✓	✓	✓	✓	?	✓	Jun24						
NorESM2-LM	Size	20	20	20	20	20	20	20	20						
	Target	✓	✓	✓	✓	✓	✓								
	ESGF	Nov23	Nov23	Nov23	Nov23	Nov23	Nov23	Mar24	Mar24						

- 12 groups committed
- Many check marks!!!
- Mainly DAMIP simulations but >10 ensemble members
- Additional runs to assess non-linearity and sensitivity to background state

We are looking into hosting a Hackathon focused on analysis of these LESFMIP simulations

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WG2 Integrated Attribution, Prediction, and Projection

The top priority is to understand trends and A2D variability in atmosphere or atmosphere-ocean circulation

Key implementation steps:

- Complete **LESFMIP** simulations
- Analysis of LESFMIP simulations, prioritising understanding drivers of circulation change (including the signal-to-noise paradox)

The Signal-to-Noise Paradox in Climate Forecasts: Revisiting Our Understanding and Identifying Future Priorities

Antje Weisheimer, Laura H. Baker, Jochen Bröcker, Chaim I. Garfinkel, Steven C. Hardiman, Dan L. R. Hodson, Tim N. Palmer, Jon I. Robson, Adam A. Scaife, James A. Screen, Theodore G. Shepherd, Doug M. Smith, and Rowan T. Sutton

BAMS 2024

- Near real-time estimates of radiative forcings to update LESFMIP simulations – *required for operational attribution*
- Collaboration with **DCPP** on attribution of predictable signals
- Collaboration with **APARC's LEADER** (Large Ensembles for Attribution of Dynamically-driven ExtRemes) project on priorities 1 and 2 (North Atlantic + SAM)
- Contribute attribution statements to **WMO Annual-to-Decadal update**

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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
- 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**

Priority Hazards

1. Tropical Cyclones
2. Extreme precipitation & droughts
3. Heatwaves
4. Compound extremes

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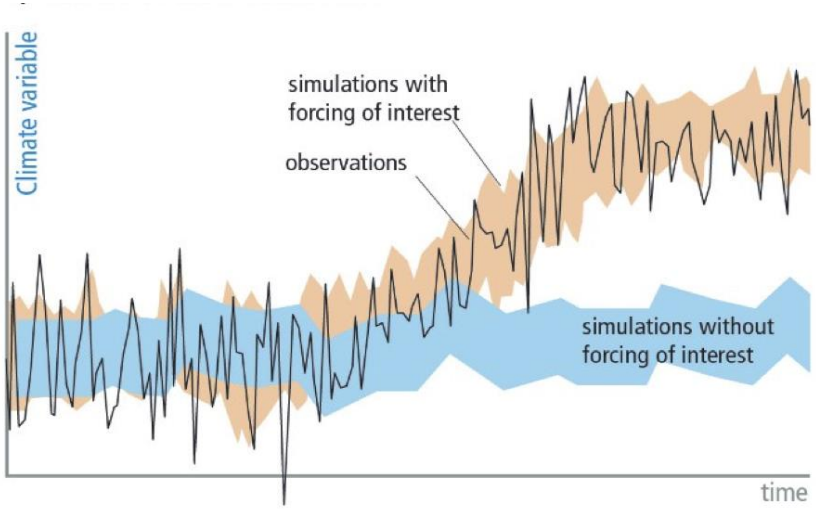
WG3: Assessment of Current and Future Hazards



- **Objectives**:
  1. Quantifying the current likelihood of specific weather and climate hazards
  2. Quantifying changes in weather and climate hazards on multi-annual to decadal timescales
  3. Understanding the processes connecting changes in hazards to natural and anthropogenic drivers of climate variability and change
  4. Advancing capabilities to predict and project changes in hazards

➢ *Extreme event & hazard attribution on A2D scale*

➢ *Links between hazards & large-scale circulation*

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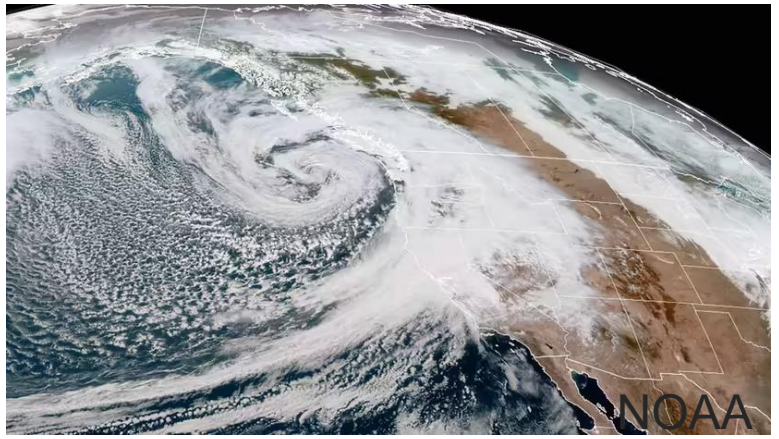
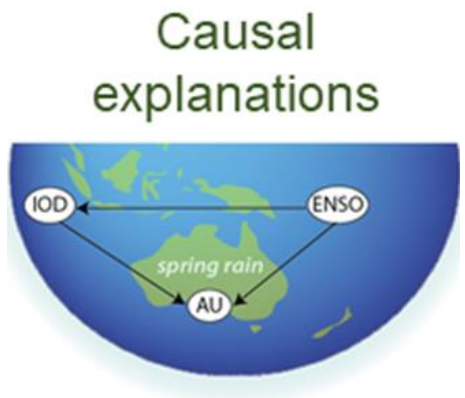
WG3: Assessment of Current and Future Hazards

Research Themes and leads:

- Variability, predictability, and prediction: Antje Weisheimer
- Extreme precipitation and droughts: Wenxia Zhang
  - Detection, attribution and understanding;
  - High-resolution convection-permitting modelling
- Tropical cyclones: Zhuo Wang, Hamish Ramsey
  - Impacts of individual anthropogenic forcings on TC activity
  - ENSO-TC relationship.
- Attribution methodology: Yukiko Imada
  - working with the new IDAG WCRP activity
- Compound extremes: Gabriele Messori
  - recent EGU session





- *Substantive progress on all themes, despite having a small group of participants!*

Cross-Cutting Activities

- Trends in summer circulation and heatwaves
- New group on **Explaining and Predicting changes in African climate**
  - initial focus on trends in East African rains

► *A direct outcome of the OSC in Kigali!*

- 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)
  - Trends in northern hemisphere summer circulation and climate extremes (April 2024).

- Shoshiro Minobe is leading a new EPESC-initiated paper:
  "**Exceptional climate in 2023-24: Beyond the new Normal**"
- Collaborations with various other WCRP groups, especially APARC & GEWEX

EXPECT - Towards an Integrated Capability to **Ex**plain and **Pre**di**ct** Regional Climate Changes

This project is funded by the European Union's Horizon Europe research and innovation programme under grant agreement no.101137656.

EXPECT is closely aligned with the goals of the **WCRP Lighthouse Activity "Explaining and Predicting Earth System Change"**

PI: Markus Donat, Barcelona Supercomputing Center

EXPECT - Towards an Integrated Capability to **Ex**plain and **Pre**dict Regional Climate Changes

Proposal submitted in response to Horizon Europe Call
HORIZON-CL5-2023-D1-01-01: Further climate knowledge through advanced science and technologies for analysing Earth Observation and Earth System Model data

Start date: 01/04/2024, duration: 4 years
14 partners

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

IPMA

IAA INSTITUTO DE ASTROFÍSICA DE ANDALUCÍA

ECMWF EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

VU VRIJE UNIVERSITEIT AMSTERDAM

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University of Reading

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EXPECT goals and objectives

The overarching goal of EXPECT is

- to **develop a prototype operational capability for integrated attribution and prediction** of climate phenomena
- by **exploiting novel data and technologies** to provide trustworthy assessments and predictions of regional climate change including extremes.

The project will

- **address key knowledge gaps** that currently hinder understanding of regional climate changes on inter-annual, decadal and multi-decadal time scales, and
- will **develop new methods** to explain and credibly predict such changes

The research will be underpinned and enabled by **designing the infrastructure needed to flexibly and efficiently exploit large data volumes** from EO and climate simulations.

Integrated Attribution and Prediction aims to

(1) elucidate and explain what factors and processes drive observed and predicted changes in climate,
(2) critically assess how key processes are represented in climate models,
(3) understand and explain the predicted signals (which typically combine a complex interplay of different drivers), and
(4) use this knowledge to calibrate predictions to provide more reliable and useful information to society.

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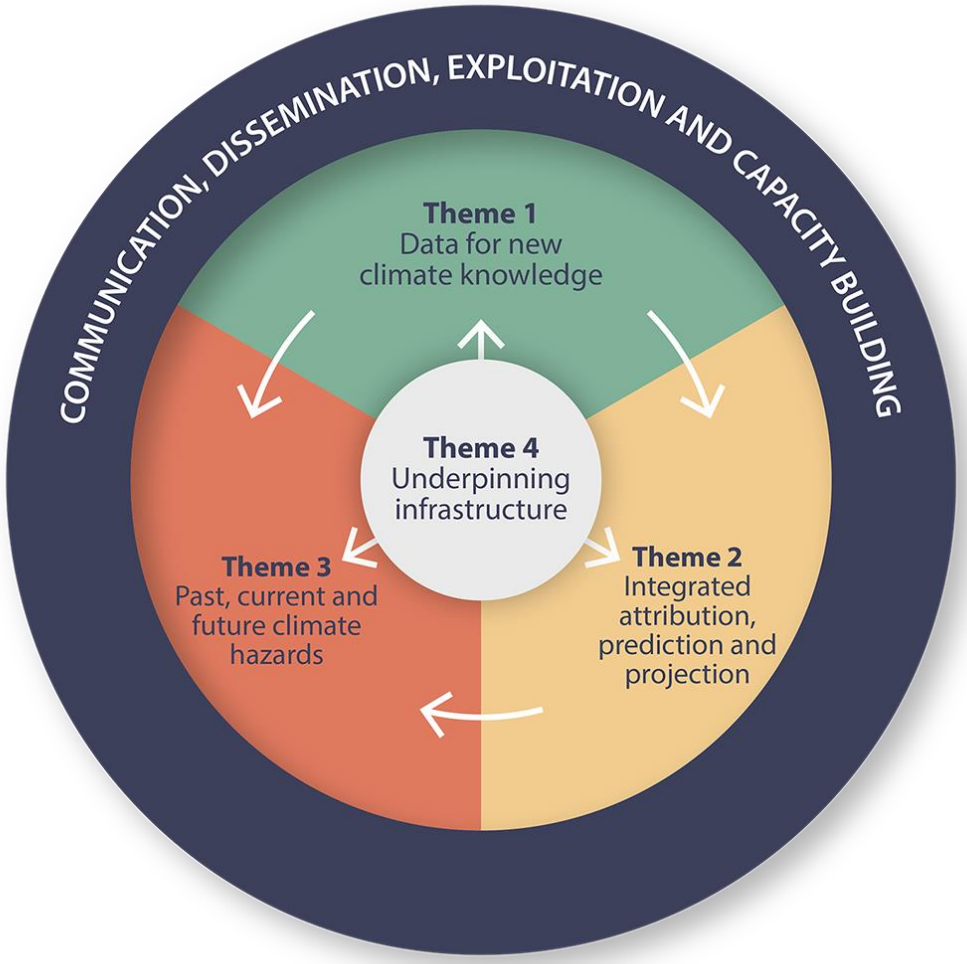
EXPECT Structure



Four Research Themes:

Theme 1: Data for the generation of new climate knowledge
Theme 2: Integrated attribution, prediction and projection
Theme 3: Past, current and future climate hazards
Theme 4: Underpinning infrastructure for the efficient and flexible analysis of large climate datasets

+ Communication, Dissemination, Exploitation, Capacity Building

+ Project management

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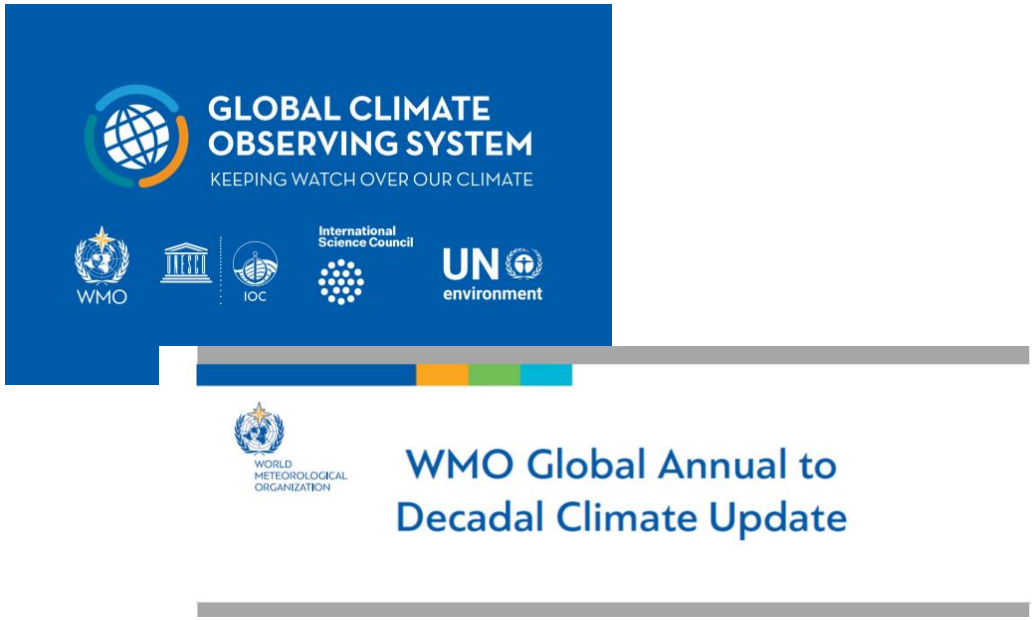
Outputs and Outcomes

- 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**



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

These efforts will help us to provide seamless information for decision making

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Thank you.

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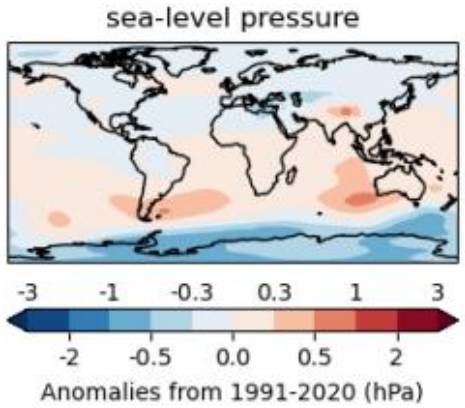
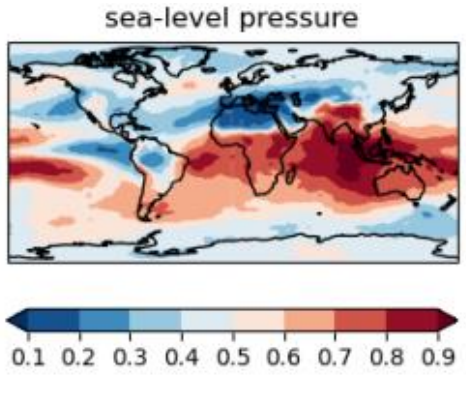
WMO Annual-to-Decadal Climate Update 2023

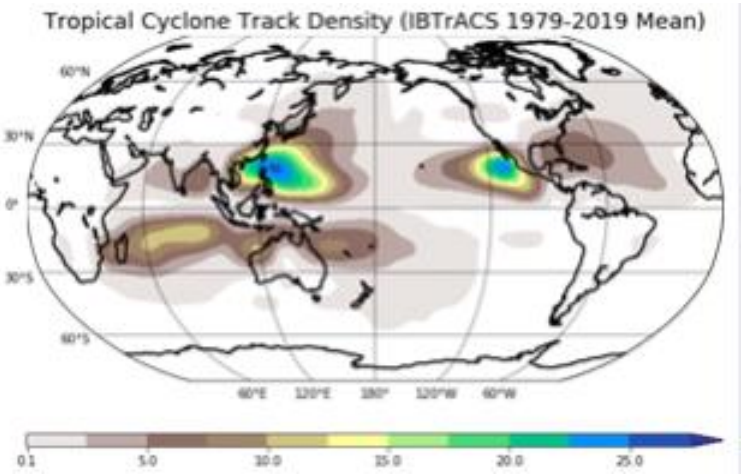
May-Sept 2023-2027

Ensemble Mean



Probability of above average





Anomalies relative to 1991-2020

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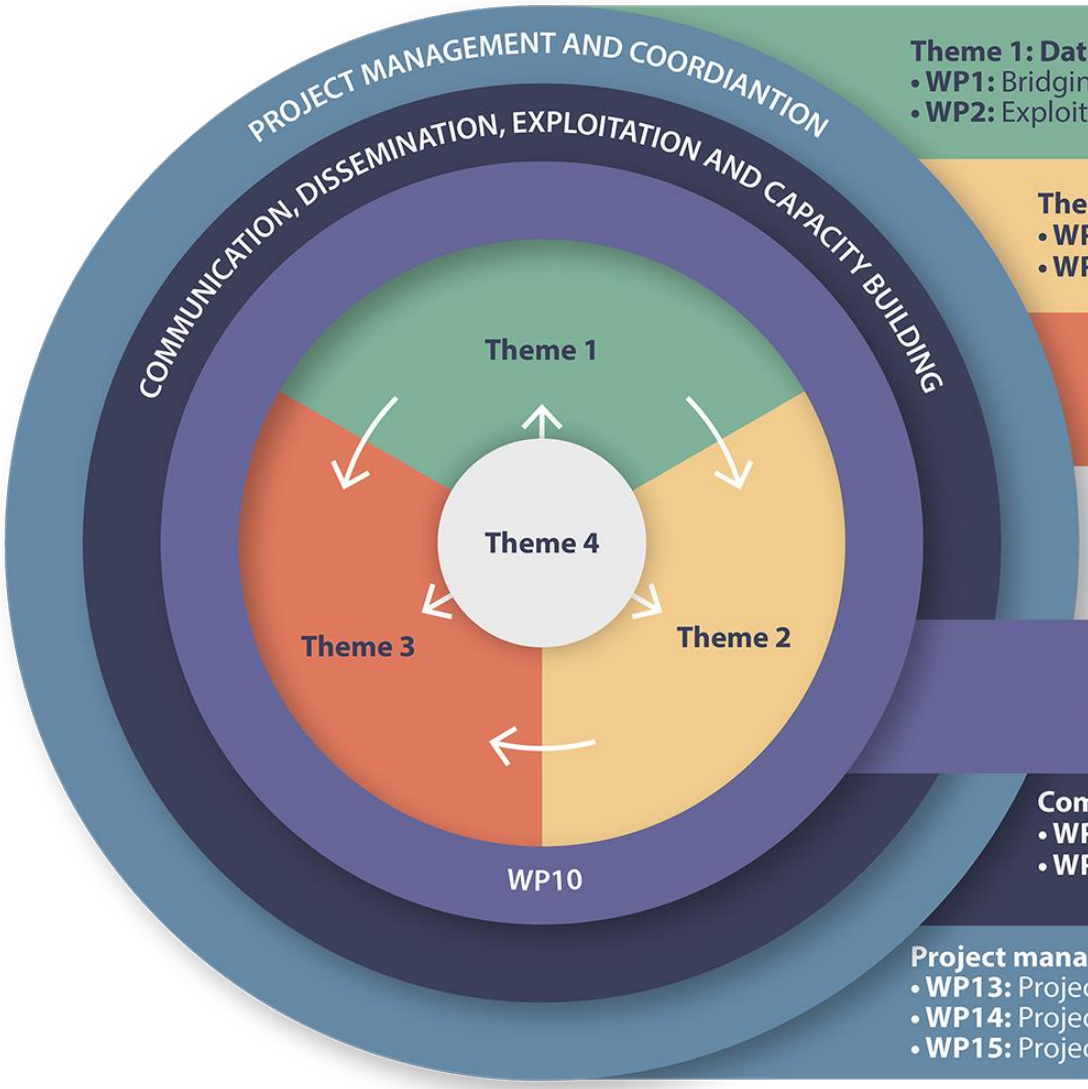
EXPECT seven specific objectives

1) **Combine** in novel ways state-of-the-art **Earth observation data and climate simulations** to generate new knowledge and better predictions of changes in regional climate.
2) Assess **how natural and anthropogenic forcings, atmospheric circulation drivers and local processes combine to control European climate** and its summertime extremes.
3) Advance understanding and robustly quantify the **drivers of European heatwaves, droughts, and persistent extreme precipitation events**.
4) Advance the capability to carry out **distributed analytics across a variety of large data from observations and simulations held in different repositories**.
5) Integrate new capabilities from O1-O4 to **drive a step-change improvement in predictions and projections of future climate in the coming years to decades**, with a focus on European summer climate extremes.
6) **Build human capacity** in an accessible manner and **train the scientific community** in advanced climate data analysis
7) Actively **communicate and disseminate** the integrated attribution, prediction and projection results to stakeholders and decision-makers

EXPECT Themes and Work Packages



Theme 1: Data for new climate knowledge
- **WP1:** Bridging EO and ESMs for new climate knowledge and improved predictions
- **WP2:** Exploiting and expanding new climate knowledge and methods from bridging EO and ESMs

Theme 2: Integrated attribution, prediction and projection
- **WP3:** Drivers of annual to decadal changes in climate
- **WP4:** Integrated attribution, prediction and projection

Theme 3: Past, current and future climate hazards
- **WP5:** Explaining past and present weather and climate hazards using existing EO and model data
- **WP6:** New knowledge on past and future hazards based on integration of derived EO and new high-resolution models

Theme 4: Underpinning infrastructure
- **WP7:** Infrastructure fundamentals
- **WP8:** FAIRness: standards and protocols
- **WP9:** Distributed analytics

Cross-cutting
- **WP10:** Synthesis and dissemination of integrated attribution, prediction and projection results

Communication, dissemination, exploitation and capacity building
- **WP11:** Laying the foundation for communication and dissemination
- **WP12:** Boosting communication and disseminating project outcomes, future exploitation and capacity building

Project management and coordination
- **WP13:** Project management and coordination I
- **WP14:** Project management and coordination II
- **WP15:** Project management and coordination III

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