



**Barcelona  
Supercomputing  
Center**  
*Centro Nacional de Supercomputación*



**EXCELENCIA  
SEVERO  
OCHOA**

# Digital Twin: Climate information for climate change adaptation

Francisco J. Doblas-Reyes

# Outline

- Context for climate adaptation
- Climate information for climate change adaptation and the user role
- Sources of climate information and the user-provider interaction
- Challenges in the production of climate information and Destination Earth
- Linkages
- Some questions

# How I felt after a bit of broad search



# The international context

Policy and programmes that drive the adaptation to climate change research and development.



## Global level policies

- UNFCCC Paris Agreement
- Sendai Framework for Disaster Risk Reduction
- Sustainable Development Goals



## European level policies

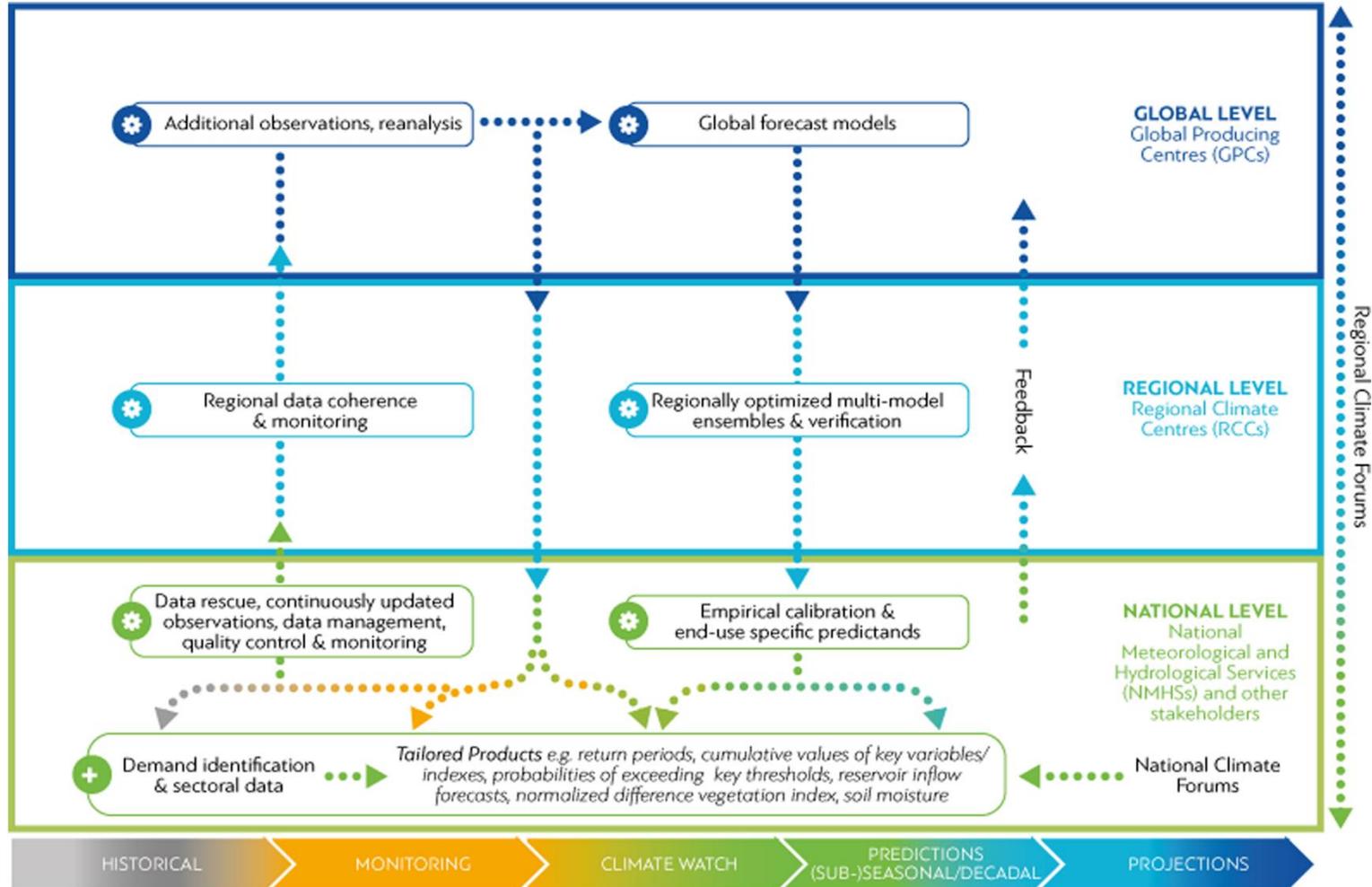
- EU Climate Adaptation Strategy (new one in 2021)
- EU Regulation on governance of the Energy Union and Climate action and the Climate Law
- EU Water Framework Directive
- EU Floods Directive
- EU Biodiversity strategy
- EU Common Agricultural Policy

## European level programmes

- LIFE+, Copernicus, Horizon 2020/Europe, Green Deal, Digital Europe

# The WMO context

WMO's **Climate Services Information System**, a key pillar of GFCS, illustrates the tension between local demand and coarser credibility.



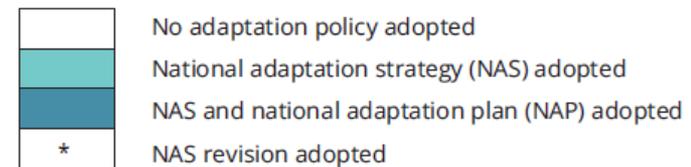
# The national context

European countries are promoting adaptation, although at difference paces.

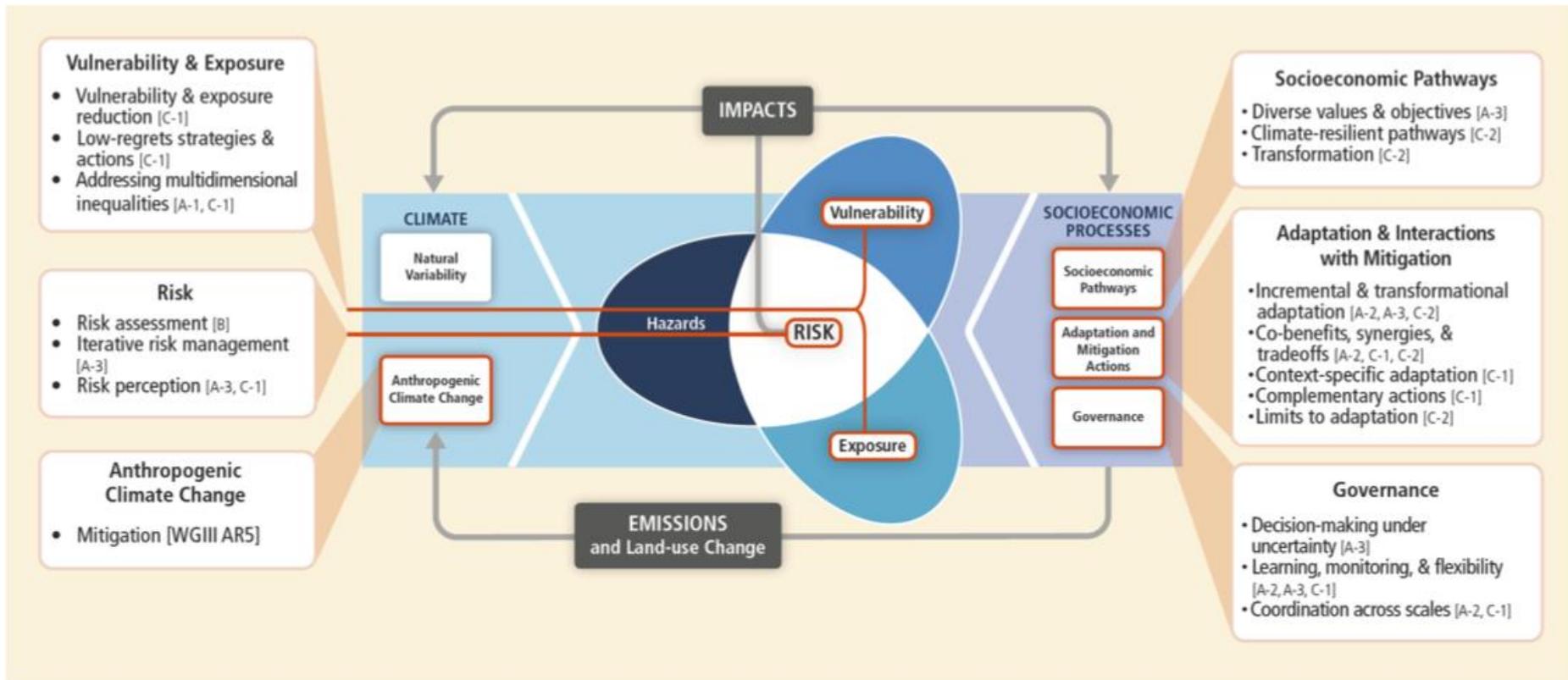
What climate information is it used for the purpose?

EEA Member States	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Austria													*		
Belgium															
Bulgaria															
Croatia (1)															
Cyprus															
Czechia															
Denmark															
Estonia															
Finland										*					
France											*				
Germany															
Greece (2)															
Hungary (3)														*	
Ireland (4)															*
Italy															
Latvia (5)															
Lithuania															
Luxembourg														*	
Malta (6)															
Netherlands (7)													*		
Poland															
Portugal											*				
Romania												*			
Slovakia														*	
Slovenia															
Spain															
Sweden (8)														*	
United Kingdom															
Iceland															
Liechtenstein															
Norway															
Switzerland															
Turkey															

Overview of the adoption of national adaptation strategies and plans by EEA member countries



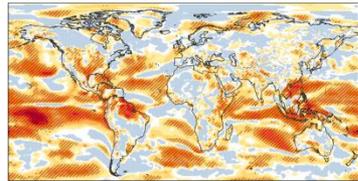
# The general scientific context



# Some definitions



- **Climate data**: numerical values representing ECVs and associated magnitudes; includes metadata and documentation



- **Climate information**: the result of processing climate data according to the available climate knowledge



- **Climate knowledge**: climate information put in context and generated in a co-production process



- **Climate service**: ensemble of processes through which climate knowledge is generated

- **Climate change adaptation**: in natural (human) systems, the process of adjustment to current (and future) climate and its effects (in order to moderate harm or exploit benefits)

# Climate information requirements

- **Saliency**: *It refers to the relevance of information for an actor's decision choices. Often interesting scientific questions are far from a real-world situation.*
- **Credibility**: *It refers to whether an actor perceives information as meeting standards of scientific plausibility and technical adequacy. Sources must be trustworthy and/or believable.*
- **Legitimacy**: *It refers to whether an actor perceives the climate information process as unbiased and meeting standards of political and procedural fairness.*

Power

Reputation

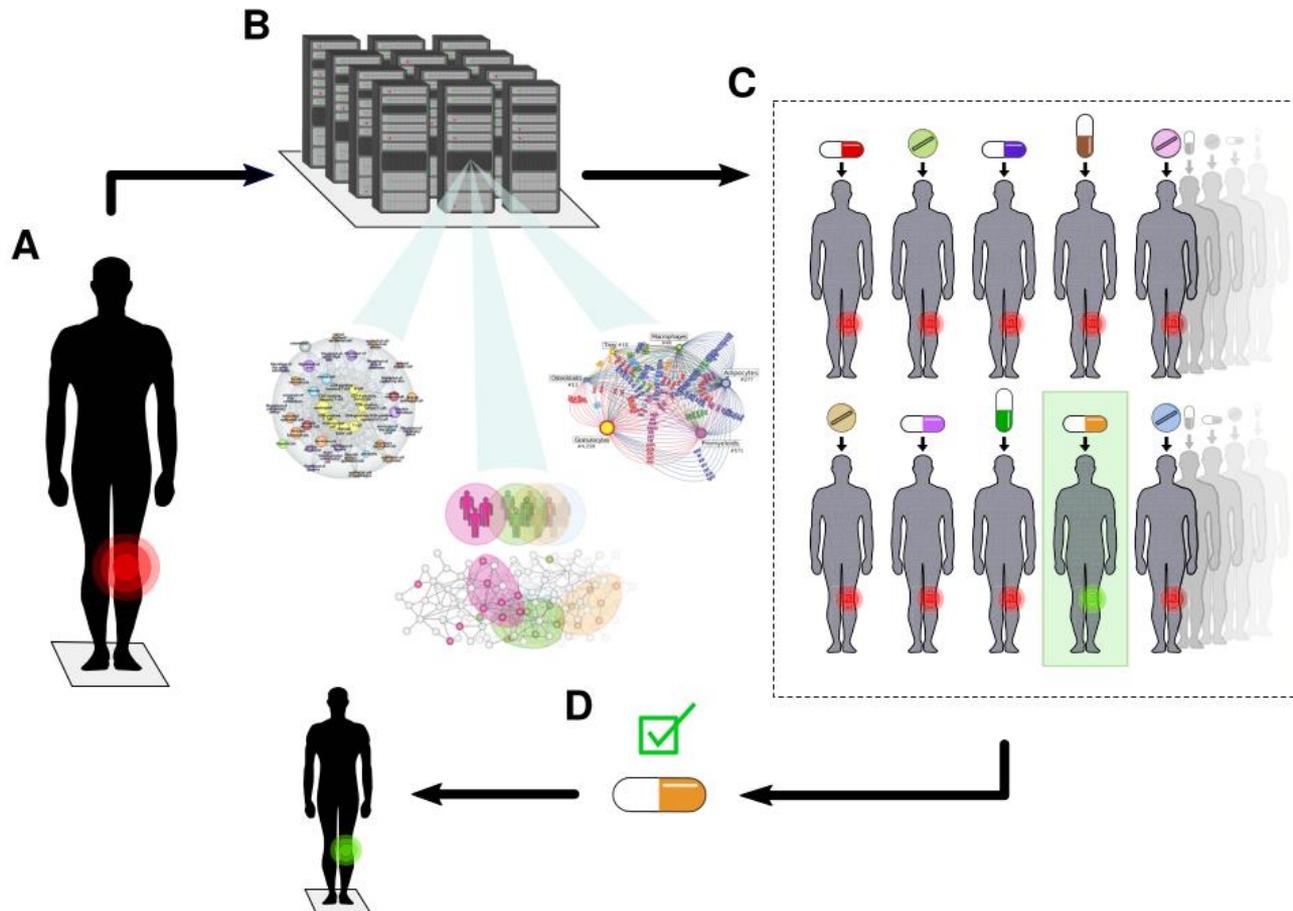
Values

Transparency

Standards

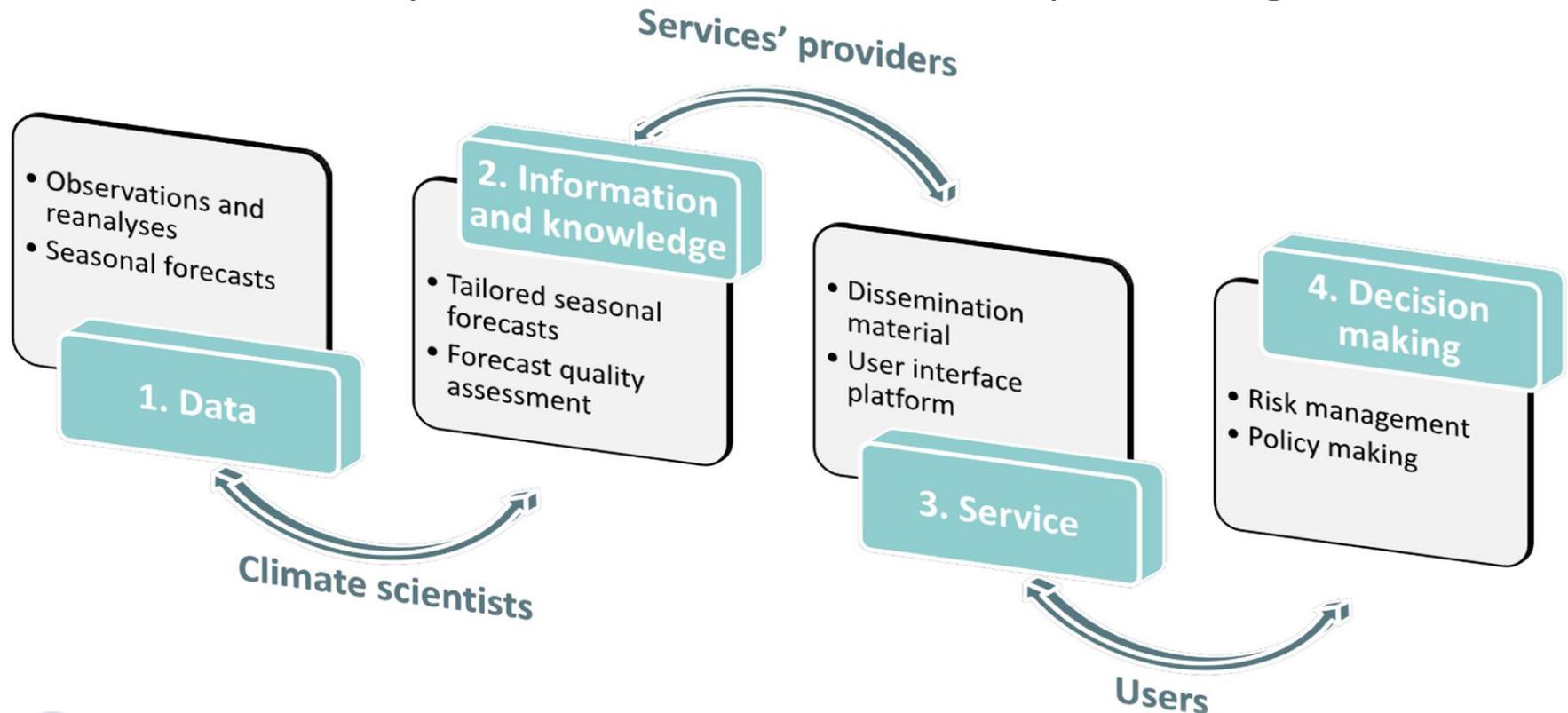
# Some inspiration

The **digital twin for personalised medicine** starts from the identification of a local sign of disease in a patient (red circle). **The user comes first.**



# The research-provider-service paradigm

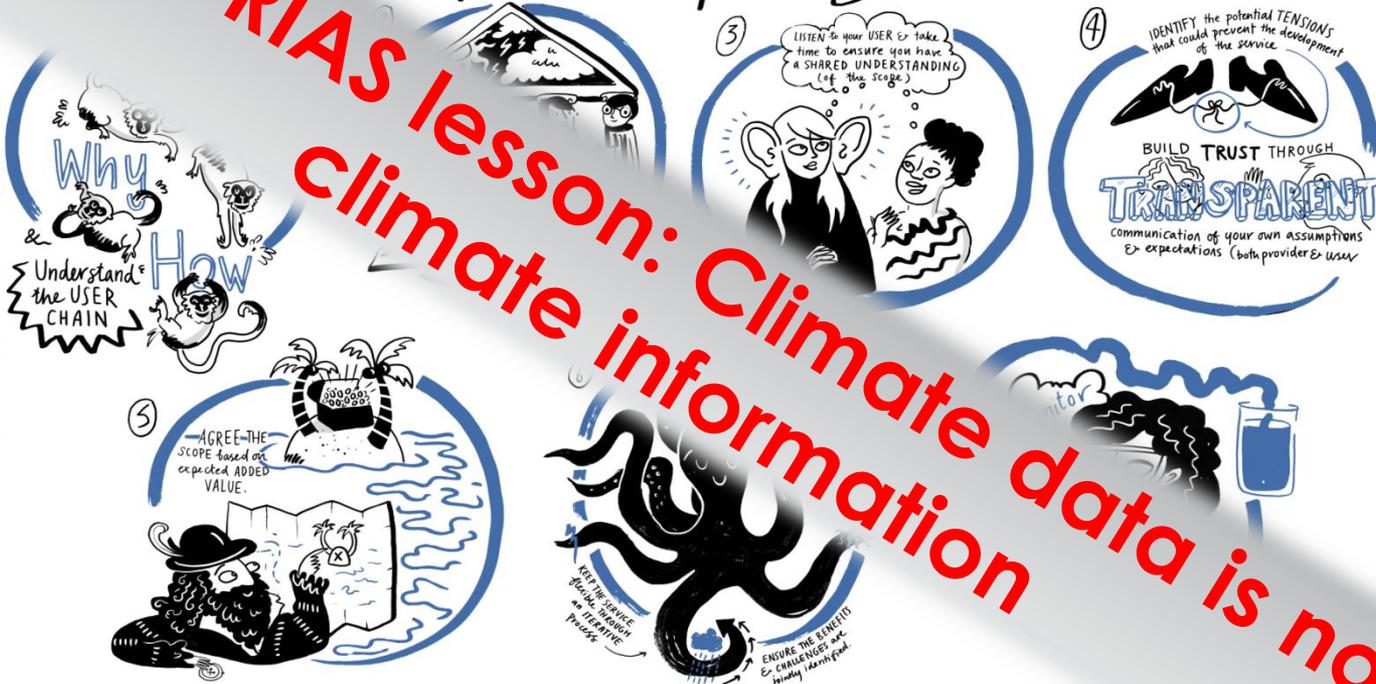
A service-oriented climate adaptation agenda requires the traditional chain “**research-operations-service provision**” to move **both ways** so that not only information quality is demonstrated, but user requirements are adequately addressed and value illustrated. This leaves a space for **transdisciplinary research**. This chain should not preclude basic research to take place though.



# The research-provider-service paradigm

SUCCESSFUL CLIMATE SERVICE

Principles



**EUPORIAS lesson: Climate information data is not**

Scribner

18/10/2004  
Sixth Symposium

# Barriers to use climate information

Some limitations for the use of climate information in different socio-economic sectors. **Information quality  $\neq$  impact.**



**Possible solution:** synthesize climate data into a piece of information that can be integrated in decision-making.



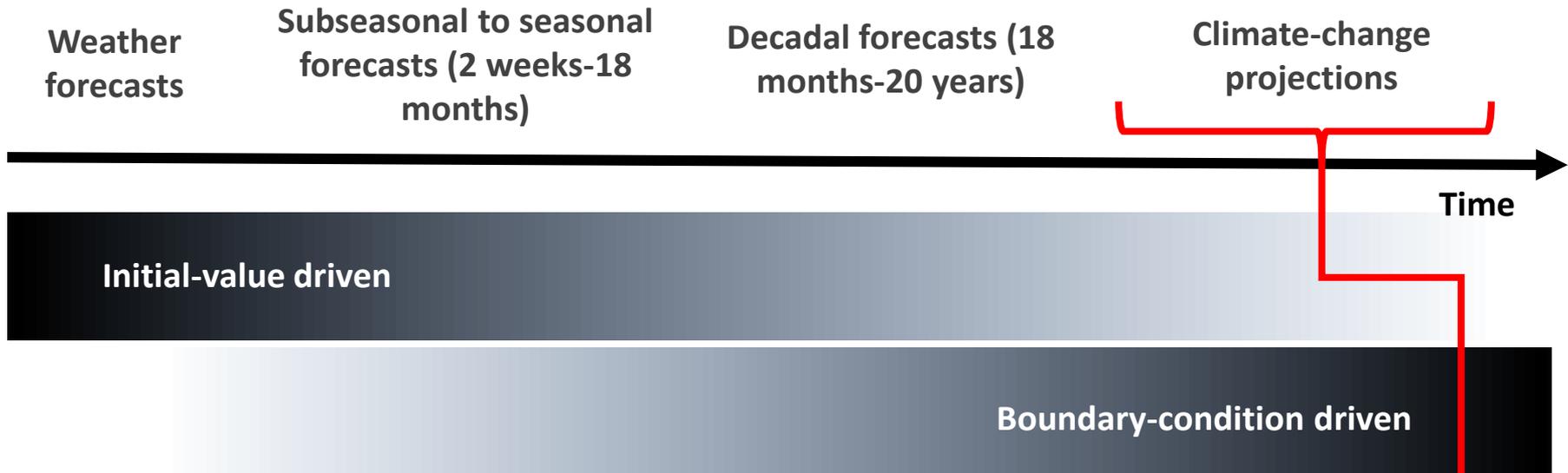
## Climate services

**What:** development and incorporation of climate information for planning, policy-making and practice at the global, regional and national scale.

**Implementation:** co-production.

**Barriers:** locality, operationalisation, evolving role of the regulator, variety in adaptation strategy types, vocabulary, etc.

# Climate time scales



## The user



## The data provider

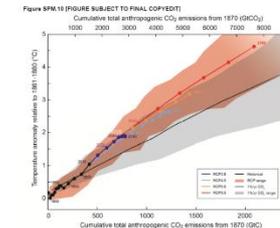


## The knowledge producer



## The assessed knowledge

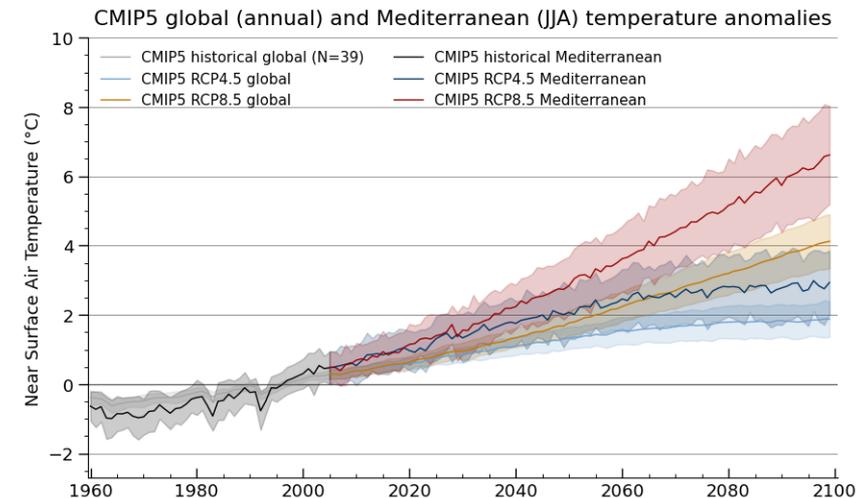
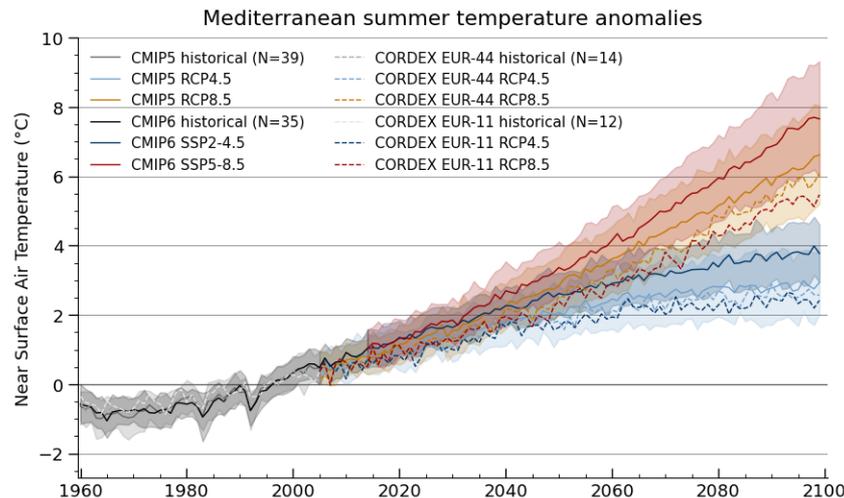
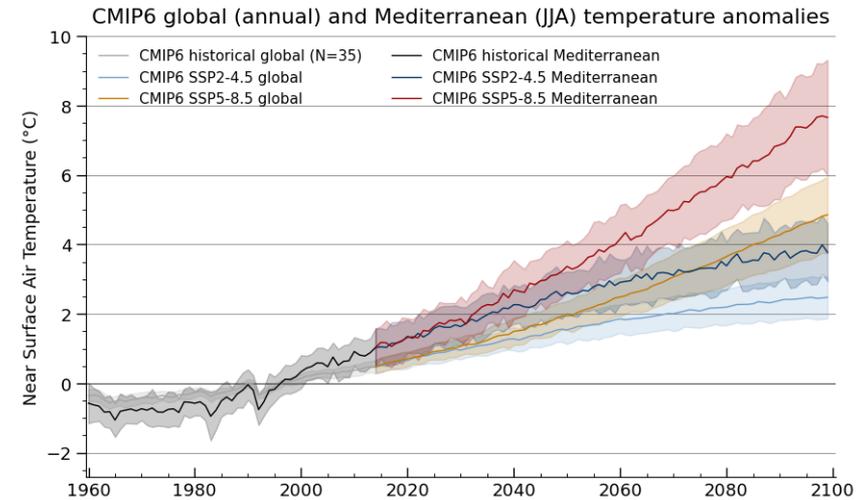
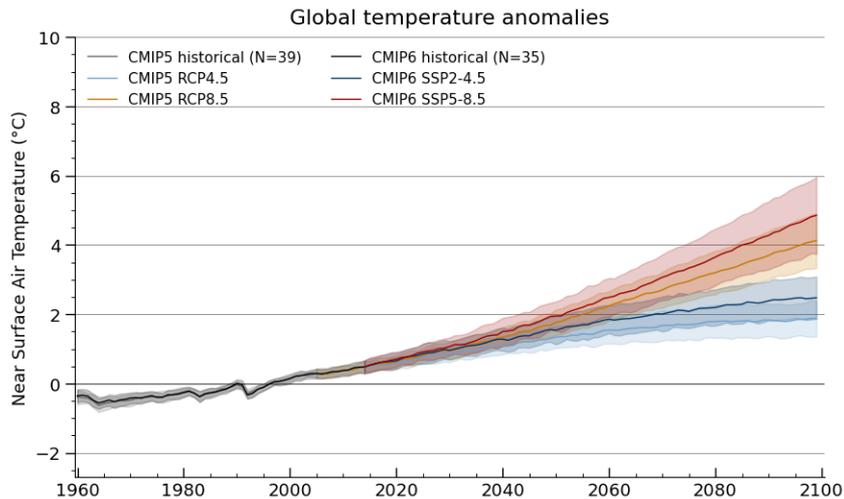
Approved Figure SPM.10 From IPCC AR5  
Summary for Policymakers  
Global Temperature Anomaly Vs.  
Cumulative Manmade CO2 Emissions



e.g. IPCC SPM and SyR preparation

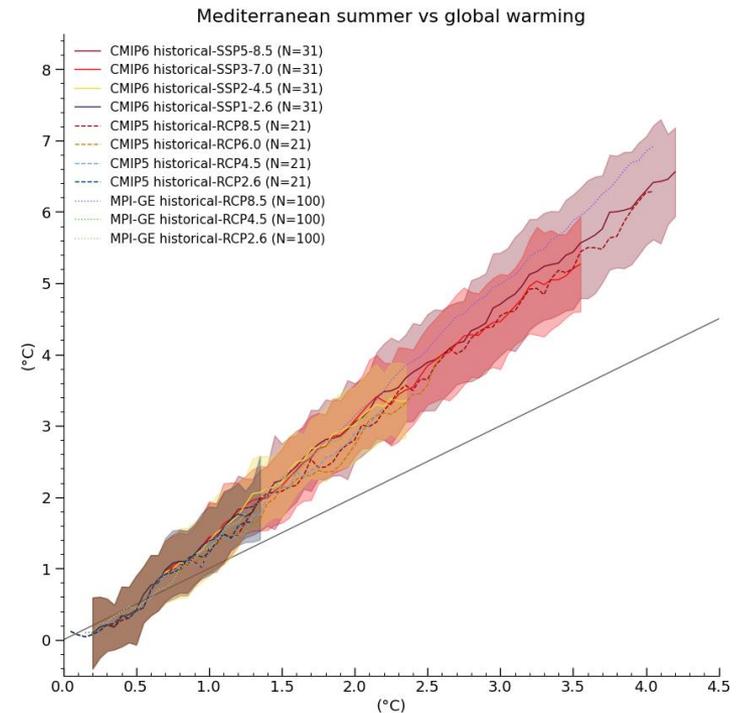
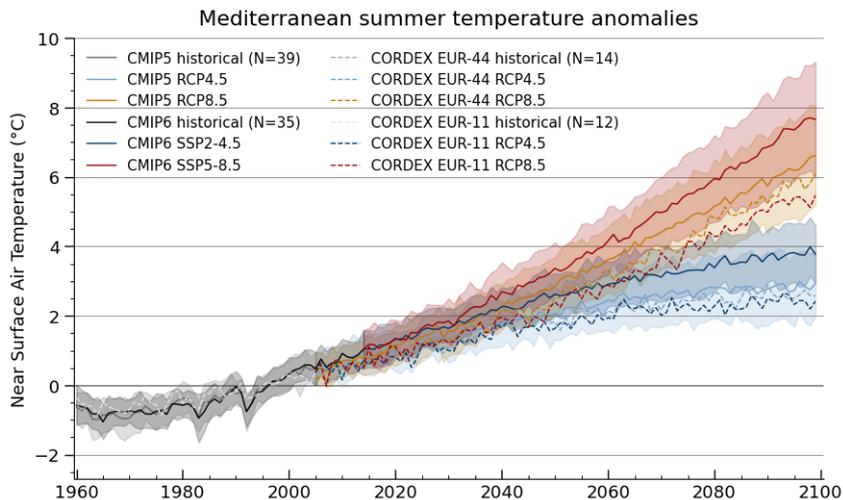
# The IPCC WGI dilemma

Global annual mean and Mediterranean land summer temperature.



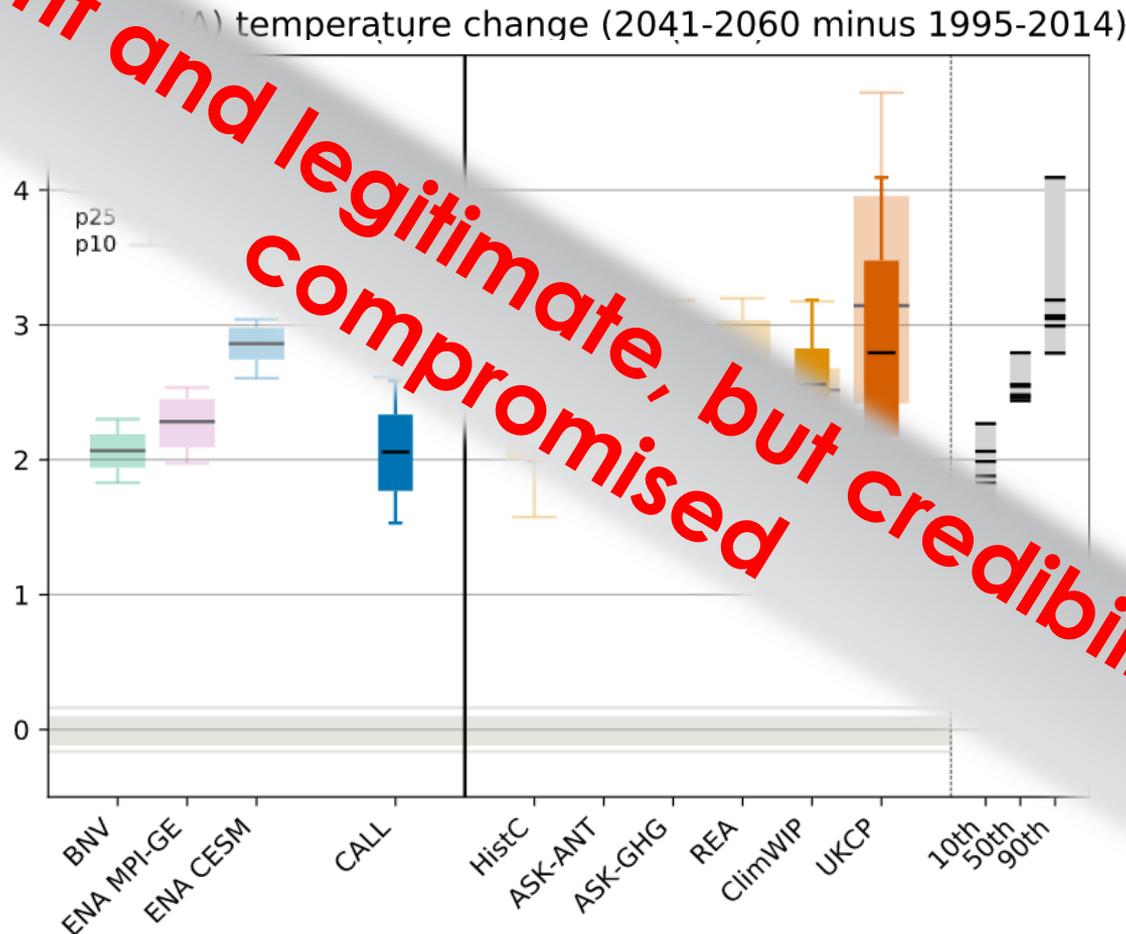
# The IPCC WGI dilemma

At least Mediterranean summer land **temperatures scale with global mean temperature in a consistent way for CMIP5 and CMIP6**. However, users become extremely confused in a situation like this.



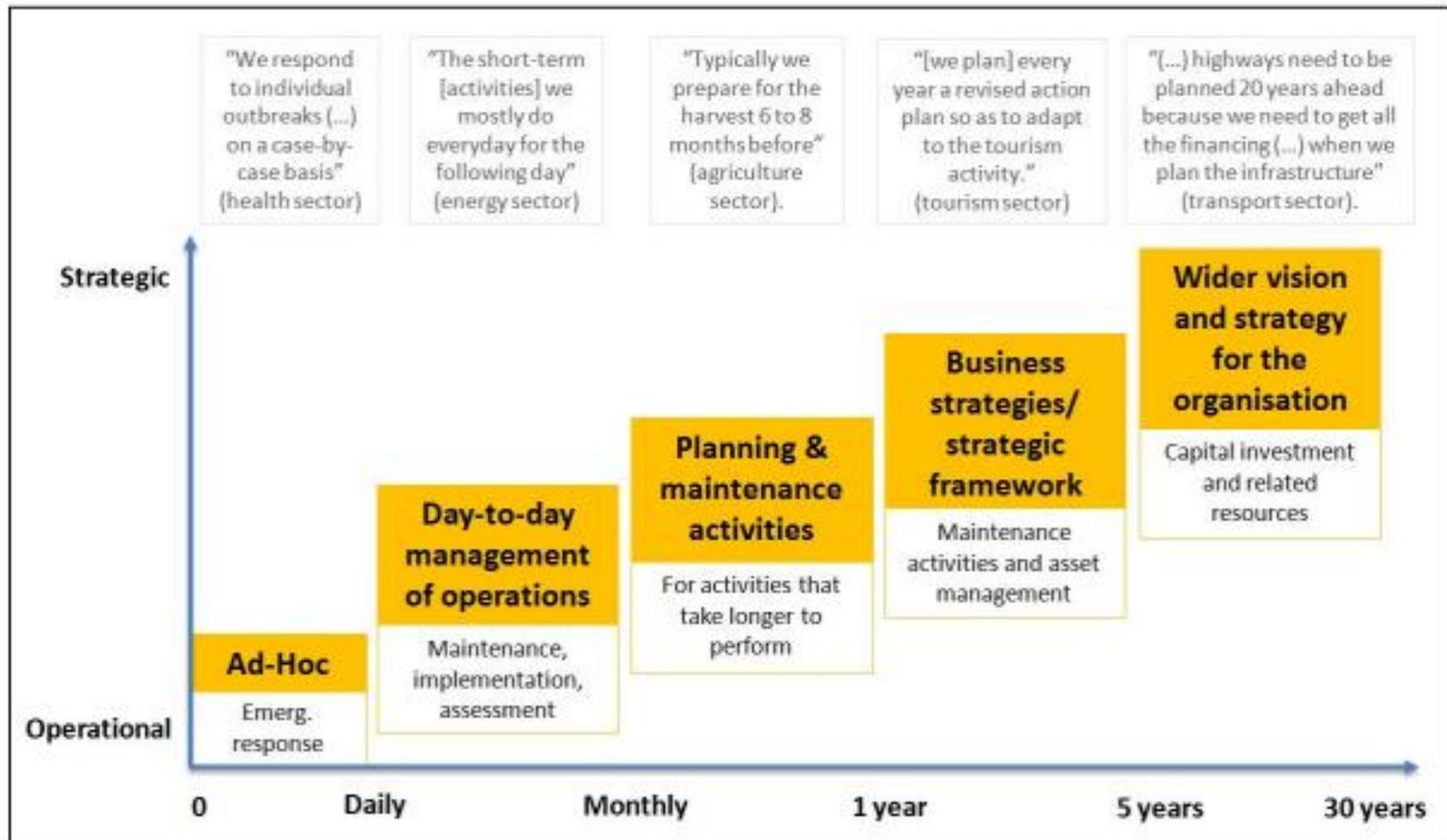
# Synthesis of different lines of evidence

Different approaches for Mediterranean land summer temperature projections. The range between methods is non-negligible. **What synthesis from the lines of evidence is possible?** Expert judgement enters the ensemble and model design and the choice of the approach.



# User engagement: problem boundaries

Users of climate information are involved in increasingly strategic decisions as the time horizon expands



# Climate information chain: logistic services

Logistics and handling of seasonal products are affected by climate. The BSC works in a research project to design a service with three objectives:

- Work with stakeholders (some times the user only wants to understand) to assess how climate variability affects a range of decisions.
- Test a prototype of action-oriented service based on climate data for a period of up to a few years.
- Walk together with stakeholders through the adaptation across the jungle of climate data and information to identify their strategic vulnerabilities and reach a common understanding of what this means.

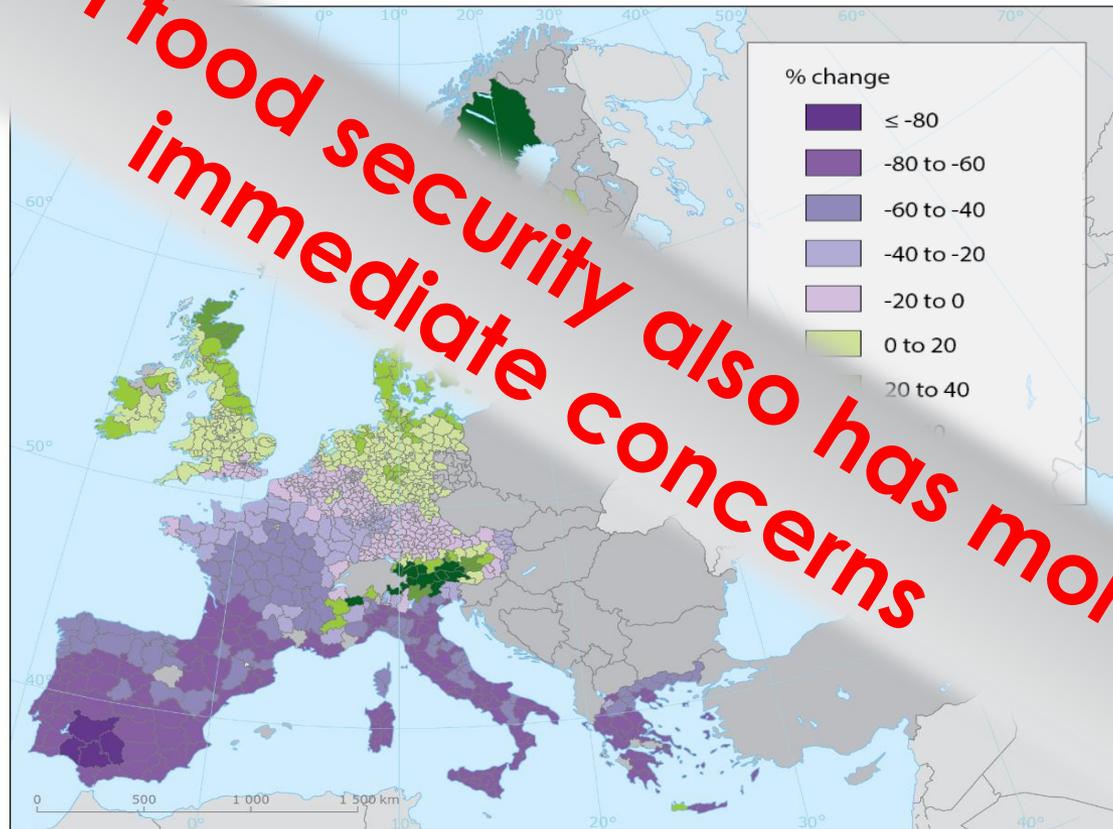
Seamless user engagement looking at quality assurance, standards, synthesis, interpretation, traceability, user uncertainty



# Climate change affects food production

Agricultural income in Europe is projected to decrease by the end of Century, with farmland value suffering most in southern Europe. Some farmland risks of being abandoned due to economic conditions.

Projected change in farmland value by 2100



# Climate change affects food production

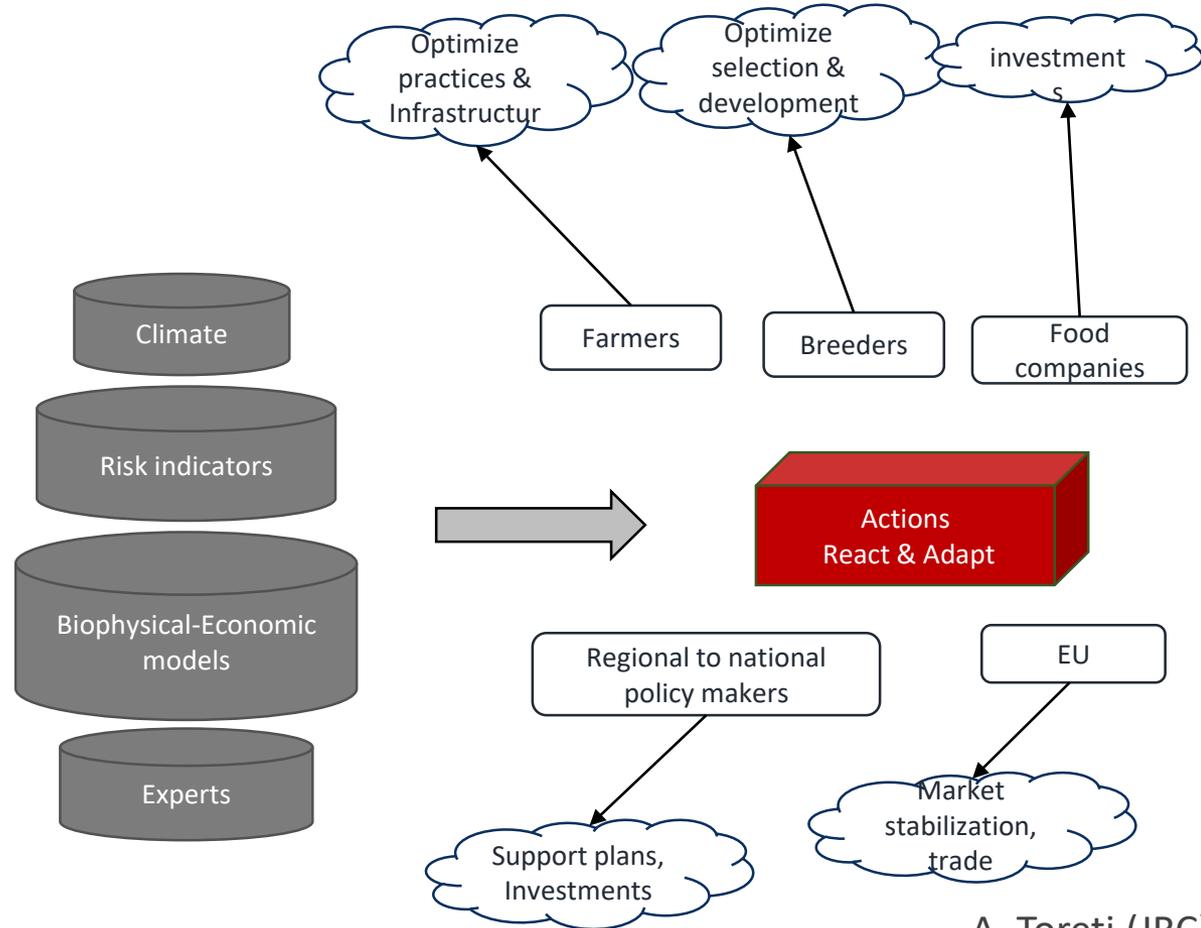
Events such as the 2018 in Europe should serve as warning call. **Concurrent climate extremes may shock the global market with decadal effects.** Tailored co-designed climate services are needed as part of a dynamically evolving adaptation strategy. Innovative integrated Earth System modelling approaches with dynamic human effects as well as dynamic economic at different spatial scales.

## Crop failure and bankruptcy threaten farmers as drought grips Europe

Abnormally hot temperatures continue to wreak devastation across northern and central parts of the continent



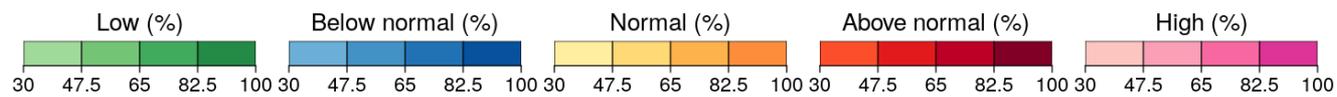
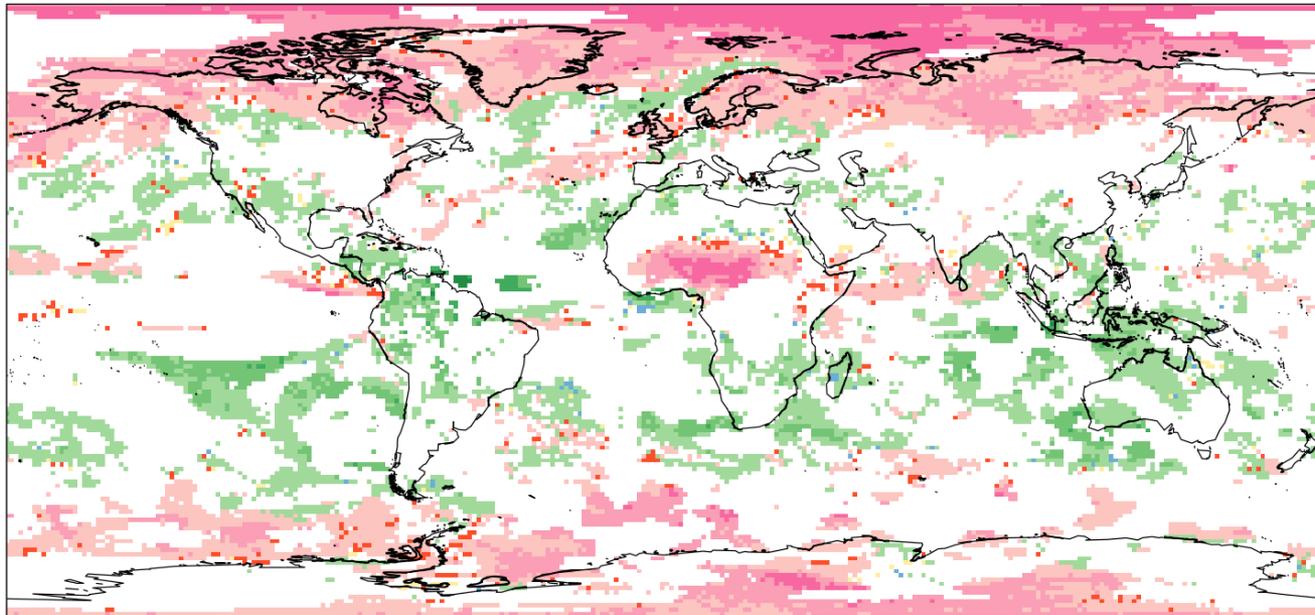
▲ A blighted wheat field in Täby, central Sweden. Photograph: Christine Olsson/AFP/Getty Images



# Global decadal climate predictions

Some of the WMO recognised global producing centres of decadal predictions contribute with the **definition of standards** for decadal predictions data and products, the **evaluation** of the European multi-model and the illustration of the decadal prediction **use** in the agricultural sector (in collaboration with JRC-Ispra).

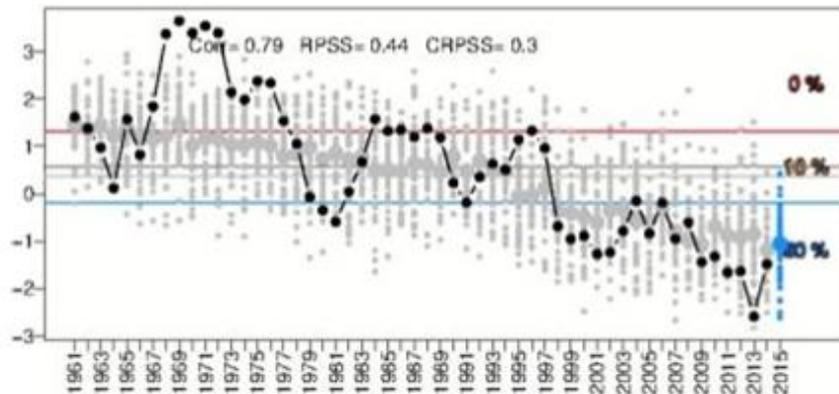
Probability of the most likely quintile category (masked where FairRPSS < 0) - pr - Multi-model-2 - Annual mean  
Start date: 2018 - Forecast period: years 1-5 - Reference period: 1981-2010



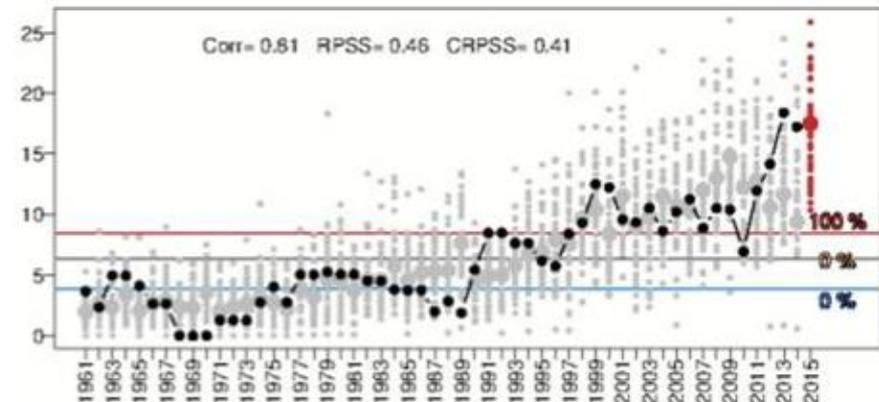
# Global decadal climate predictions

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SPEI6



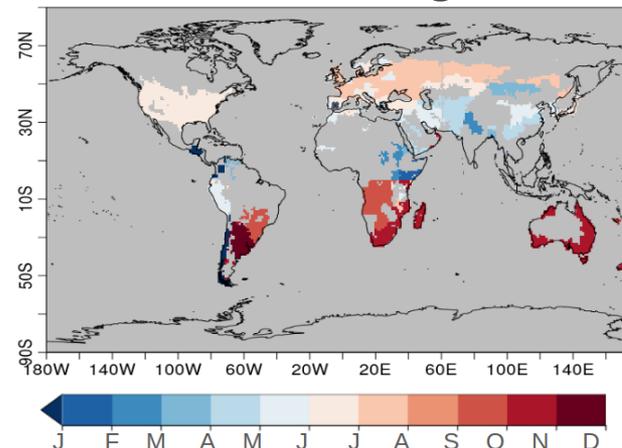
HMDI3



Indicators:

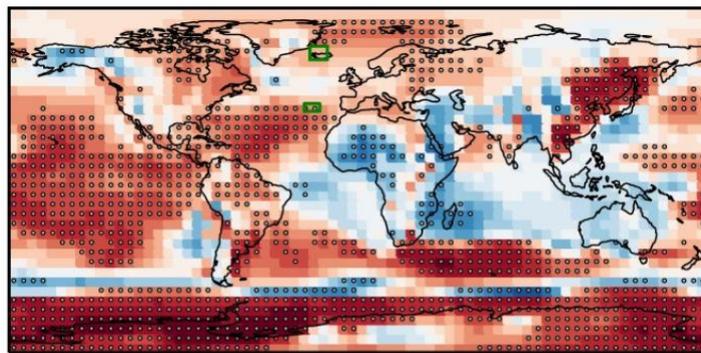
- Drought: Standardized Precipitation Evapotranspiration Index (SPEI6)
- Heat Stress: Heat Magnitude Day Index (HMDI3)

Wheat harvesting month

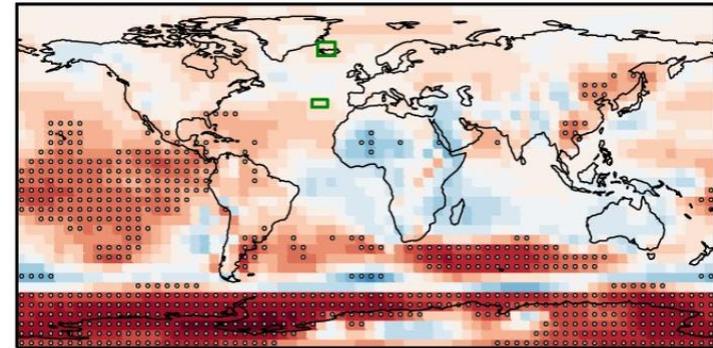
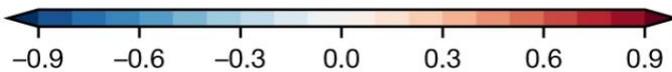


# Why could we expect this to be a DT?

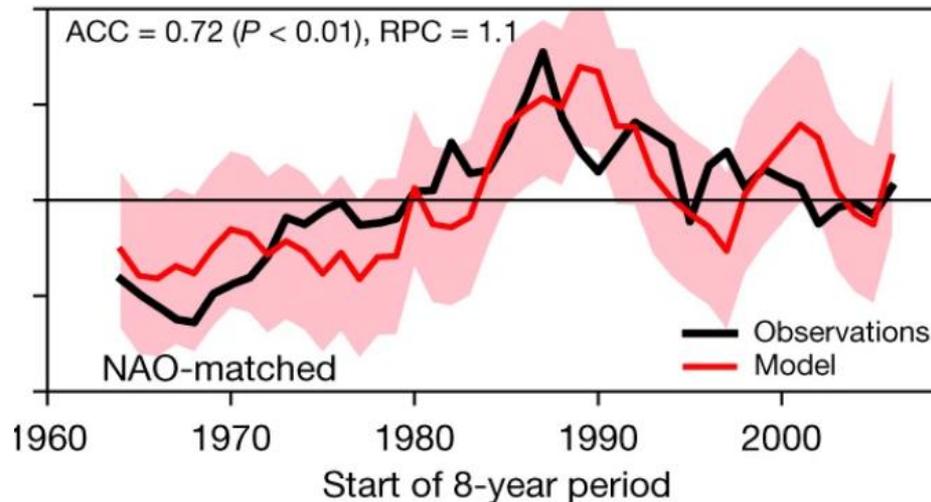
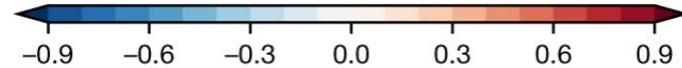
Skill of decadal predictions is highly sensitive to ensemble size due to the low signal-to-noise ratio (multi-model sea level pressure correlation with more than 100, left, and 10 members, right). Careful member selection (160 members) unveils **untapped skill for northern European precipitation predictions for the next nine years** (bottom).



ACC



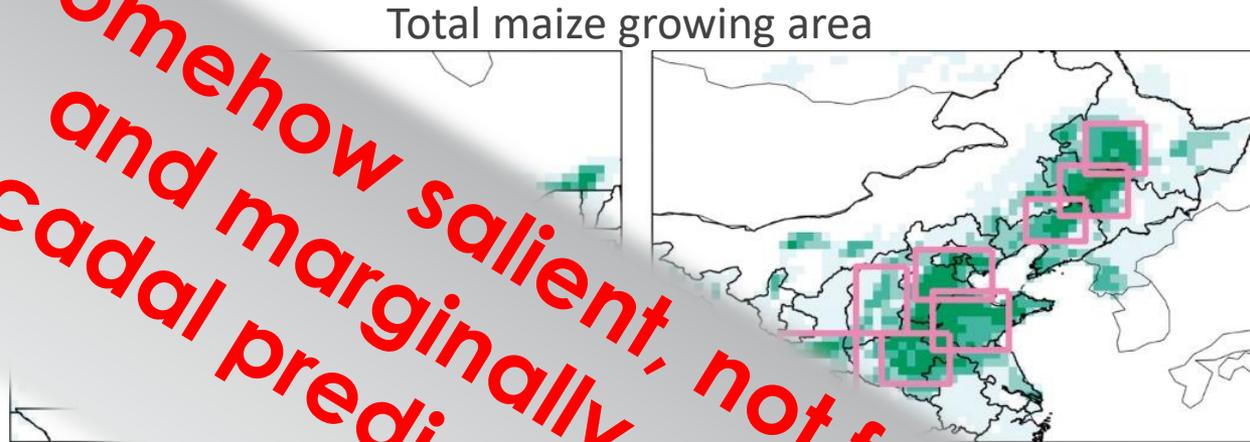
10-member ACC



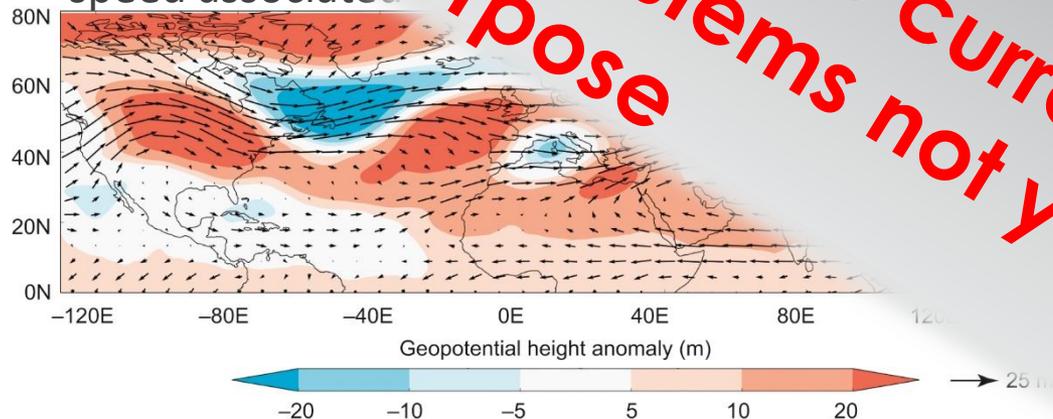
# There is life beyond skill

Decadal predictions can be used as **surrogates** to estimate probabilities of extreme compound events leading to **multi-bread basket failures**.

**Somehow salient, not fully legitimate and marginally credible current decadal prediction systems not yet fit for purpose**



June-to-August 2000 wind speed associated

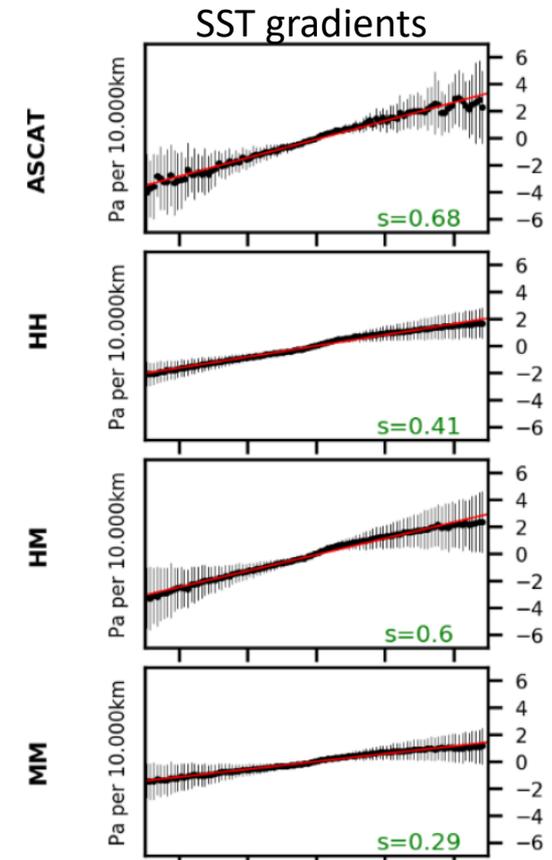
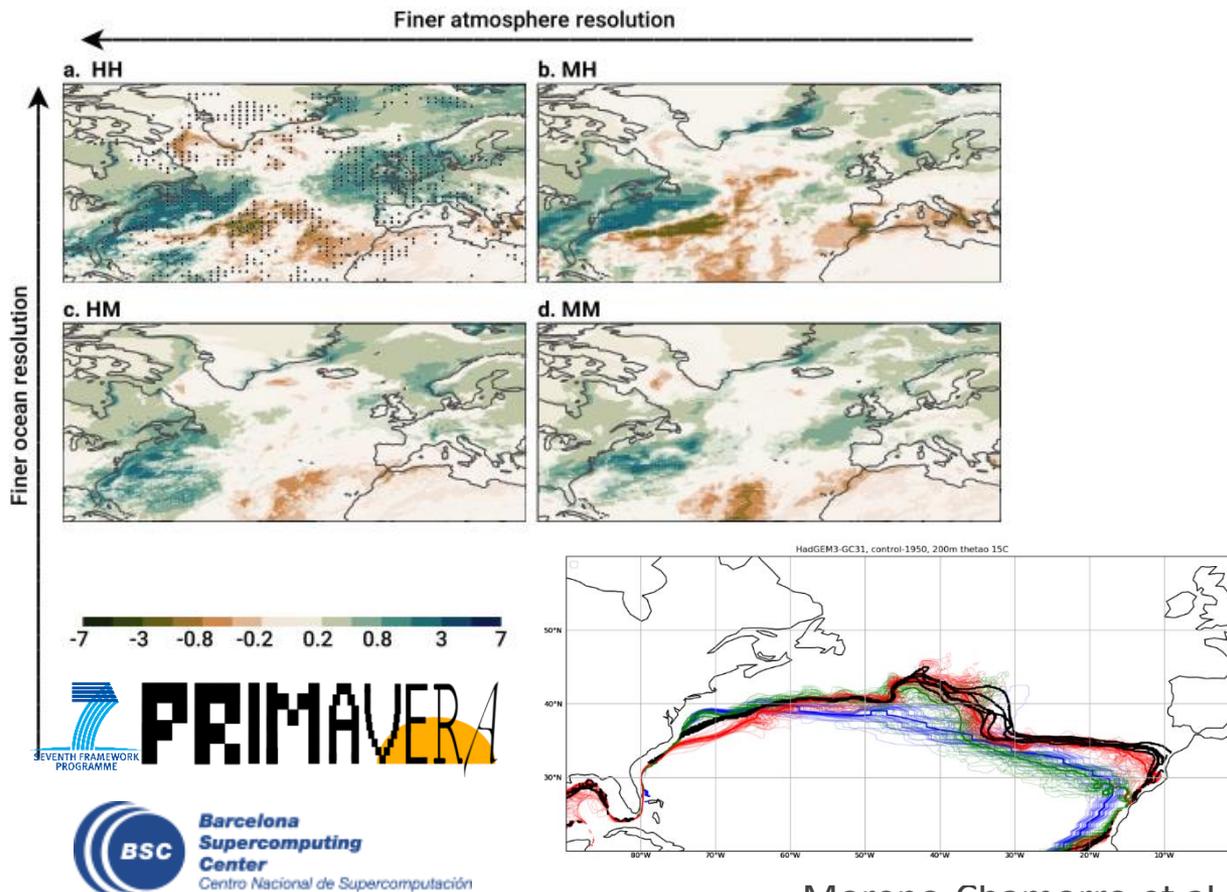


# How to go beyond in decadal prediction?

From a user perspective (e.g. JRC) **credibility and usability of decadal predictions are seriously compromised by current model quality** (understood in the most general sense possible). Progress will not be possible without larger ensembles, higher resolution along with more realistic processes, better initialisation, etc.

Winter precipitation differences 2030-2050 and 1960-1980

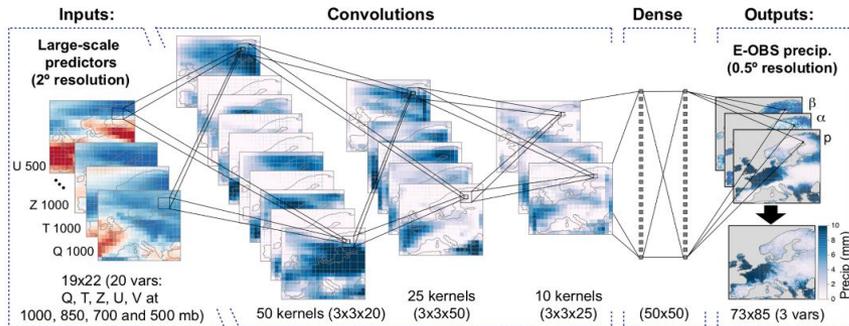
High-pass filtered wind stress divergence versus downwind SST gradients



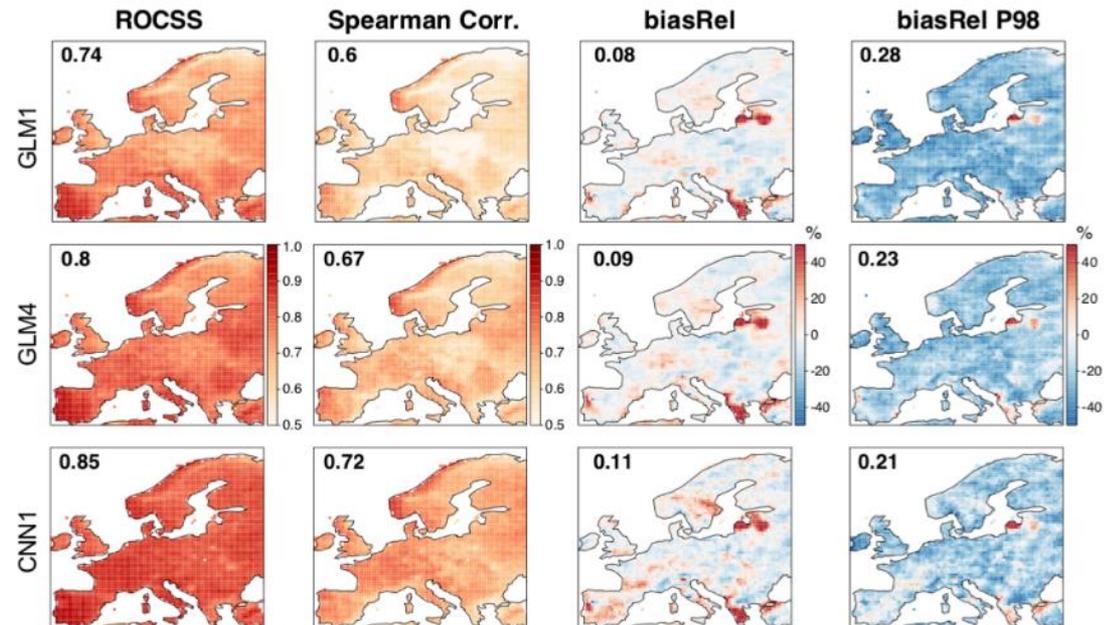
Moreno-Chamorro et al., Grist et al., Tsartsali et al. (submitted)

# And as for locality, add innovation to the DT

Traditional dynamical downscaling is beyond reach in a fit-for-purpose decadal prediction system (large ensembles, high resolution global models, 3,000 years of simulation at a minimum). **Machine learning** might come to the rescue.



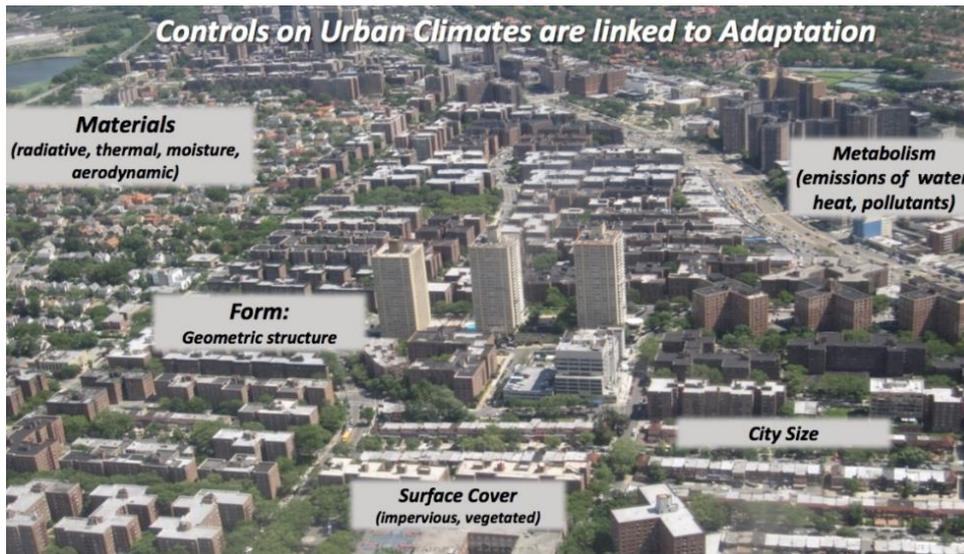
Validation of downscaled historical precipitation (EOBS reference) using generalised linear methods and convolutional neural networks with ERA-Interim. Inset numbers for spatial averages of absolute values.



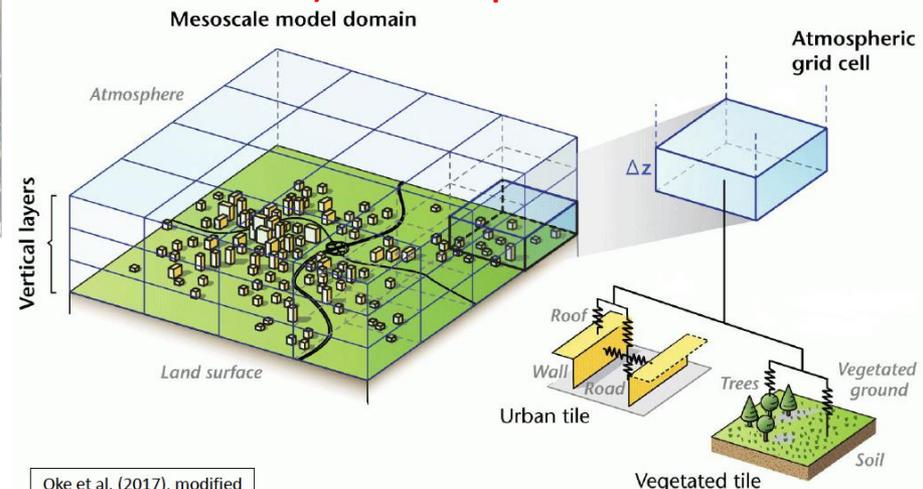
# However, local is complex

Simulations of **future urban climate at fine spatial scales** have strong requirements:

- Integrate with urban expansion and population growth scenarios, human behaviour, city characterization (satellite based like <http://www.wudapt.org/>)
- Include coastal hazards for coastal cities
- Observations for urban climate and structure (citizen science, new sensors)
- Climate change effects in the near future (i.e. coming decades)



The current modelling paradigm needs to evolve taking into account models that **include urban processes (biophysics, human), targeted downscaling (with uncertainties) and impact models.**



Oke et al. (2017), modified

# Evaluation and quality control

BSC leads the contract responsible of the development of the evaluation and quality control (EQC) function of the climate data store (CDS) of the Copernicus Climate Change Service (C3S) to:

- Provide a user-led overarching EQC service for the whole CDS
- Provide an independent quality assessment

- CDS **datasets**: pro technical and scie purpose, and an a
- CDS **toolbox**: asse purpose of the so datasets
- CDS **service**: perf infrastructure (e.g availability)
- CDS **users**: user re users' satisfaction needs into viable user-oriented evc



**ActiFast Soluble Tablets**  
Paracetamol

Please read right through this leaflet before you start using this medicine. This medicine is available without prescription, but you still need to use Panadol ActiFast Soluble Tablets carefully to get the best results from them.

- Keep this leaflet, you may need to read it again.
- If you have any questions, or if there is anything you do not understand, ask your pharmacist.

**In this leaflet:**

1. What Panadol ActiFast Soluble Tablets do
2. Check before you take Panadol ActiFast Soluble Tablets
3. How to take Panadol ActiFast Soluble Tablets
4. Possible side effects
5. How to store Panadol ActiFast Soluble Tablets
6. Further information

**1. What Panadol ActiFast Soluble Tablets do**  
Panadol ActiFast Soluble Tablets are used for the relief of headache, tension headache, migraine, backache, rheumatic and muscle pain, toothache and period pain. They also relieve sore throat and the fever, aches and pains of colds and flu.

The active ingredient is paracetamol which is a painkiller and also reduces your temperature when you have a fever.

**3. How to take Panadol ActiFast Soluble Tablets**

- ✓ **Adults (including the elderly) and children aged 16 years and over:** Take 1-2 tablets dissolved in water every 4 to 6 hours as needed. Do not take more than 8 tablets in 24 hours.
- ✓ **Children aged 10-15 years:** Give 1 tablet dissolved in water every 4 to 6 hours as needed. Do not give more than 4 tablets in 24 hours. Do not give for more than 3 days at a time, unless your doctor tells you to.
- ! Do not take more frequently than every 4 hours.
- ! Do not take more than the recommended dose.
- ! Do not give to children under 10 years.

**If you take too many tablets**  
Immediate medical advice should be sought in the event of an overdose, even if you feel well, because of the risk of delayed, serious liver damage. If your symptoms continue or your headache becomes persistent, see your doctor.

**4. Possible side effects**

Like all medicines, Panadol ActiFast Soluble Tablets can have side effects but not everybody gets them. A small number of people have had side effects. Stop taking the medicine and tell your doctor immediately if you experience:

- Allergic reactions which may be severe such as skin rash and itching, sometimes with swelling of the mouth or face or shortness of breath
- Skin rash or peeling, or mouth ulcers
- Breathing problems. These are more likely if you have experienced them before when taking other painkillers such as ibuprofen and aspirin
- Unexplained bruising or bleeding
- Nausea, sudden weight loss, loss of appetite and yellowing of the eyes and skin.

If you do get any side effects, even those not mentioned in this leaflet, tell your doctor or pharmacist.

**2. Check before you take Panadol ActiFast Soluble Tablets**

**✗ Do not take Panadol ActiFast Soluble Tablets:**

- if you have ever had an allergic reaction to paracetamol or to any of the other ingredients (listed in Section 6)
- if you are taking other medicines containing paracetamol.

**! Ask your doctor before you take this medicine:**

- if you have liver or kidney disease, including alcoholic liver disease
- if you have been told by your doctor that you have an intolerance to some sugars
- if you are on a controlled sodium diet. Each tablet contains 427 mg of sodium.

**! If you are taking other medicines**

Talk to your doctor or pharmacist before taking these tablets if you are taking any prescribed medicines, particularly metoprolol or domperidone (for nausea/feeling sick) or vomiting (being sick) or colestyramine (to lower blood cholesterol). If you take blood thinning drugs (anticoagulants e.g. warfarin) and you need to take a pain reliever on a daily basis, talk to your doctor because of the risk of bleeding. But you can still take occasional doses of Panadol ActiFast Soluble Tablets at the same time as anticoagulants.

**! Pregnancy and breast feeding**

Talk to your doctor before taking Panadol ActiFast Soluble Tablets if you are pregnant. You can take this product whilst breast feeding.

31039448

**5. How to store Panadol ActiFast Soluble Tablets**

Keep out of the reach and sight of children. Do not use this medicine after the 'EXP' date shown on the pack. Store below 25°C.

**6. Further information**

Active ingredient: Each tablet contains Paracetamol 500 mg.  
Other ingredients: Sorbitol powder (E 420), saccharin sodium, sodium bicarbonate, polyvidone, sodium lauryl sulphate, dimeticone, citric acid and sodium carbonate.

Packs of Panadol ActiFast Soluble Tablets contain 24 effervescent tablets.

The marketing authorisation holder is GlaxoSmithKline Consumer Healthcare (UK) Trading Limited, Brentford, TW8 9GS, UK, and all enquiries should be sent to this address.

The manufacturer is GlaxoSmithKline Dunganvarn Ltd., Co. Waterford, Ireland or Famar SA, Anthousis Av., 153 44, Pallini Attiki, Greece.

This leaflet was last revised in December 2016. Panadol and ActiFast are registered trademarks owned by or licensed to the GSK group of companies.



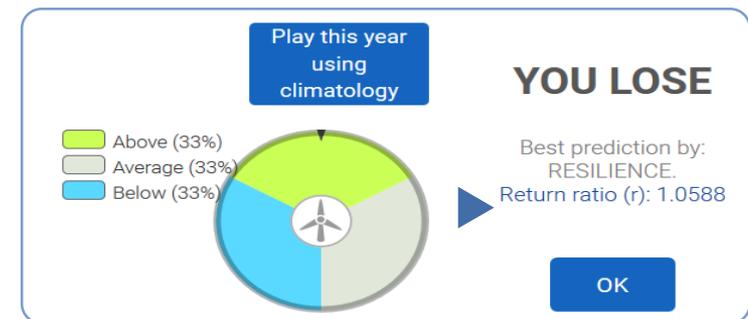
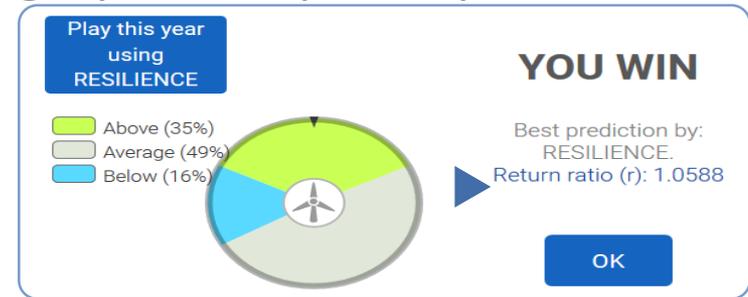
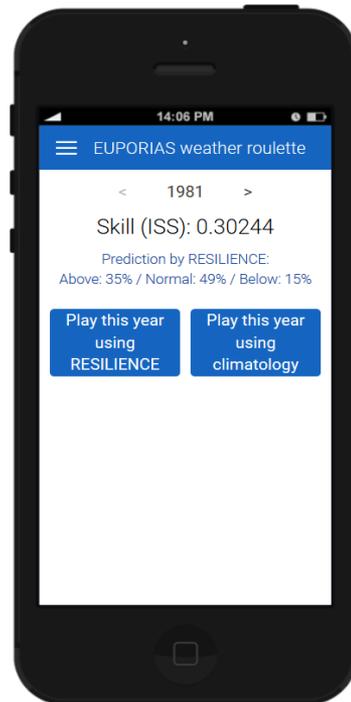
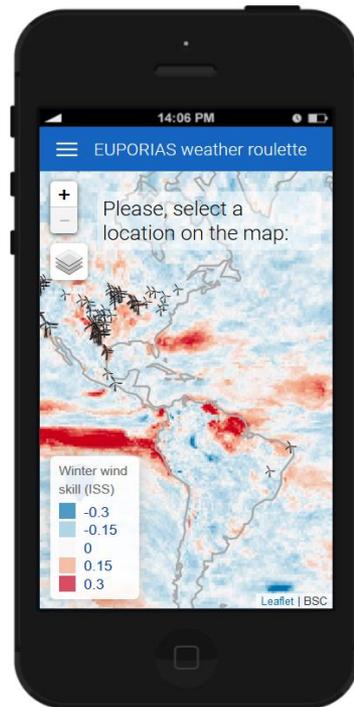
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# The communication challenge

**Gamification** is useful to illustrate the challenges of using and the value of seasonal climate predictions addressed to the wind energy sector:

- Play against a reference taken from climatological frequencies.
- The bets are proportional to the predicted probabilities.
- The amount invested in the observed category is multiplied by 3.



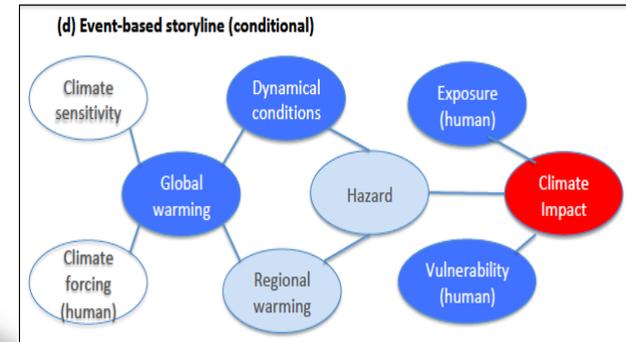
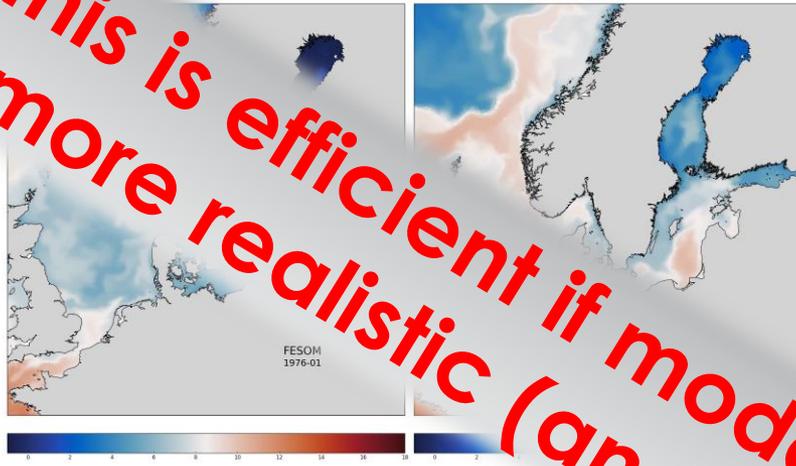
[play.google.com/store/apps](https://play.google.com/store/apps)  
[demo.predictia.es/roulette-app/mobile.html](https://demo.predictia.es/roulette-app/mobile.html)

# The communication challenge

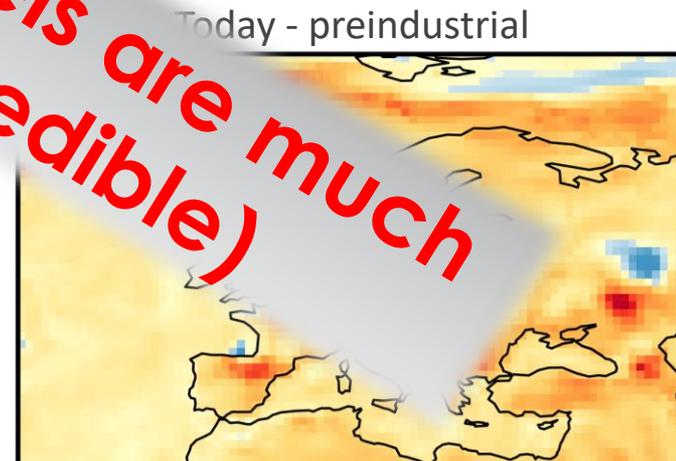
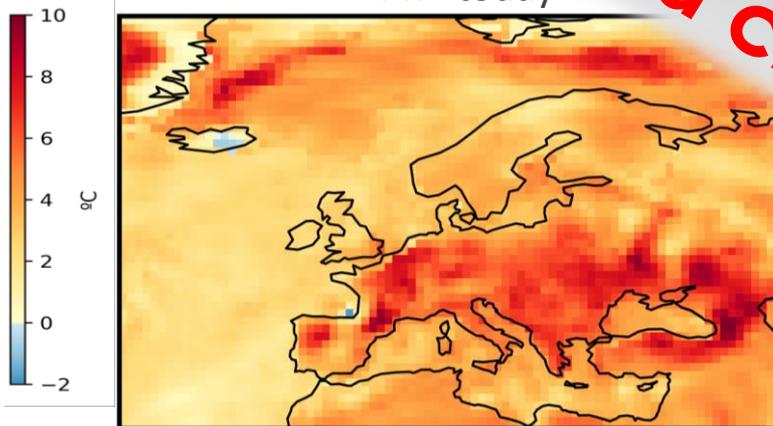
Use of **storylines** to communicate changes in extreme events, uncertainty and attribution. Same dynamical situation with different thermodynamical conditions illustrate a tangible change. **The information is more efficient when the context is simplified.**

**But this is efficient if models are much more realistic (and credible)**

Climate-change signal for January (SST)



Climate-change signal for 25 July 2019 (T2m)



# UKCP18

The UK Climate Projections 2018 undertook an extensive programme of user requirements. Participants were selected to represent communities and not individuals. The lists below come from user group workshops in 2016-17. Satisfying all of them was beyond scope.

**Model: surface variables**

- Cloud cover
- Evaporation
- Hail
- Lightning
- Radiation (sunshine, short/long wave)
- Runoff
- Snowfall
- Soil moisture
- Dry/Wet bulb temperature
- Wind speed at surface
- Wind gusts

**Model: Ocean/sea variables**

- Ice sheet dynamics, sea ice melt
- Local thermal expansion
- Ocean pH, salinity, temperature
- Sea level rise
- Storm surge
- Stratification
- Tidal range
- Wave direction/height/period

**Climate indices**

- Convective available potential energy
- Storminess
- Temperature degree days
- Weather patterns

**Hydrological metrics**

- Flood risk
- Future coastline
- Fluvial flows and levels
- Groundwater recharge
- Soil moisture deficit
- Surface water runoff
- Water quality
- Water stress

**Impacts metrics**

- Air quality
- Heat Stress
- Urban heat island effect
- Vegetation growth
- Earth movements
- Soil stability
- Erosion risk



Royal Botanical Gardens, Edinburgh, Feb 2017

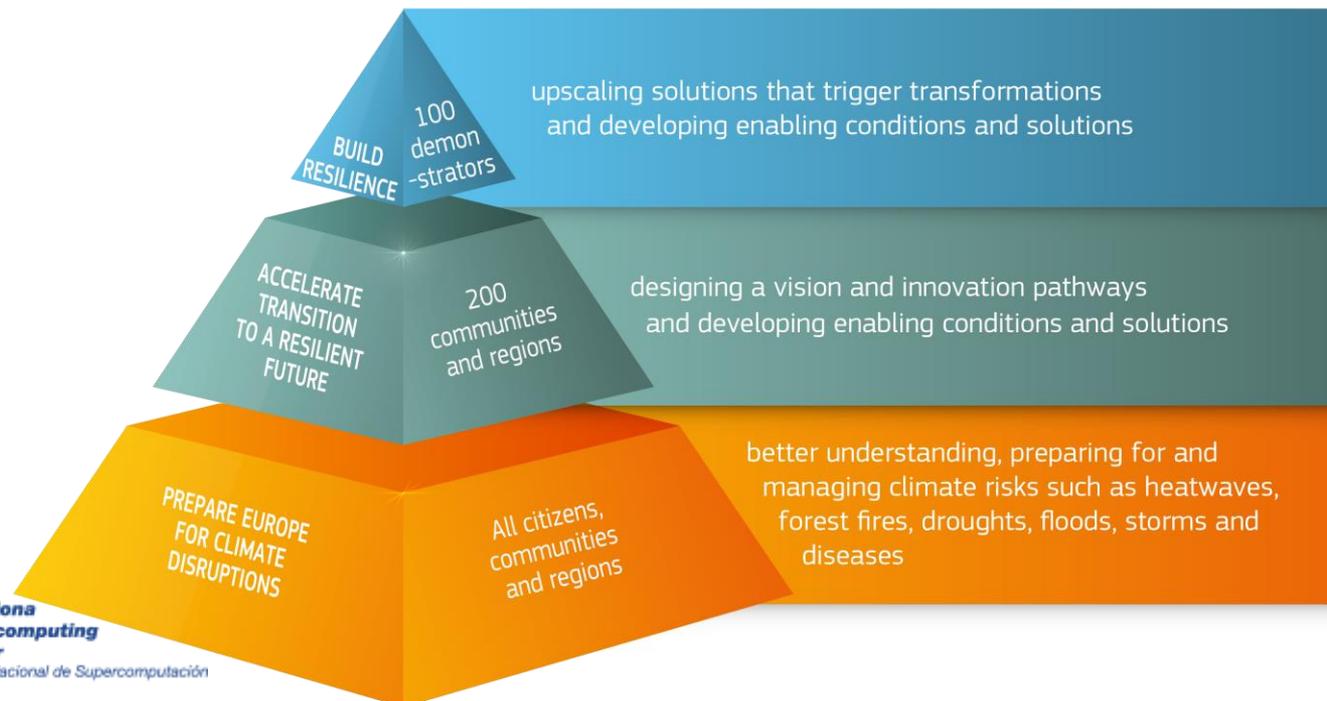


Met Office Exeter, October 2017

# Horizon Europe Mission

The Mission on Adaptation to Climate Change, Including Societal Transformation: “A Climate Resilient Europe” to prepare for climate disruptions and accelerate the transformation to a resilient and just Europe by 2030.

One of the three targets is “by 2030, all local administrative units (LAU) and regions (NUTS) will have access to climate risk profiles and enhanced early warning systems for all relevant risks, will have adopted comprehensive climate risk management plans, and will have community infrastructure and services that are safe and operable and accessible under critical conditions”.



# Horizon Europe Mission

The Mission should **contribute to and leverage efforts undertaken to shape Europe's digital future, such as Destination Earth** and the establishment of EU-wide digital data spaces (e.g., data space for climate change adaptation):

- by testing and deploying innovative solutions
- by becoming a testbed for a potential data space for climate change adaptation

The Mission will act as a **cataliser** via the focus on the development of solutions at the local level, addressing and taking into account the challenges and needs of **citizens**. The Mission, which goes beyond the traditional R&D remit, can:

- be the testbed for the new Destination Earth advances and developments: Use-Test-Feedback-Improve
- connect Destination Earth with European citizens leading to uptake, ownership, empowerment, and capacity building

Mission report available [here](#).



# Copernicus Climate Change Service (C3S)

Interactions with users reveal challenges and limitations of current practices:

- Users need information on a **variety of time horizons**; the scientists'/service providers' distinctions between timescales (often aligned to sources of predictability, or to prediction tools) is not useful, or helpful, for user applications.
- User **timelines/deadlines** are driven by a variety of factors; more often than not these do not match providers' production schedules.
- **Information** from equally valid sources, even when fully relevant, is **often inconsistent**.
- The **large amounts of data** (not just by volume, but simply in the number of realisations of possible outcomes) is already **overwhelming** many users.
- The **needs of different sectors** of socio-economic activity are not fully distinct from each other, or independent, yet the solutions on offer often disregard this reality.

# Copernicus Climate Change Service (C3S)

The way forward: include the adaptation sector needs at the design stage.

## Model design

(e.g. complexity: components which allow two-way coupling between climate and socio-economic activities)

## Experiment design

(e.g. sample and quantify the effect of all sources of uncertainty, to facilitate risk assessment)

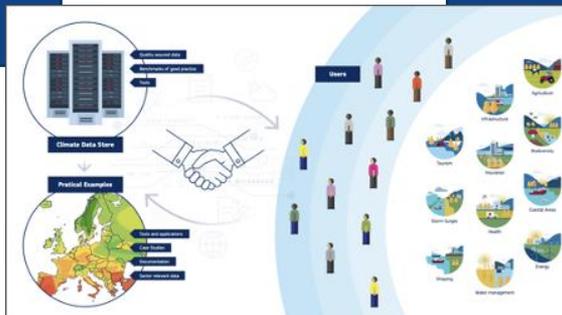
The user problem

## Design of diagnostics

(e.g. efficiently calculate user-relevant diagnostics at model run time)

## Design of technological solutions

(e.g. schedule of operational production, data volume reduction tools, etc.)



# EuroHPC

LUMI announced its infrastructure on 21<sup>st</sup> of October 2020. More about the pre-exascale machines coming soon.

**LUMI**

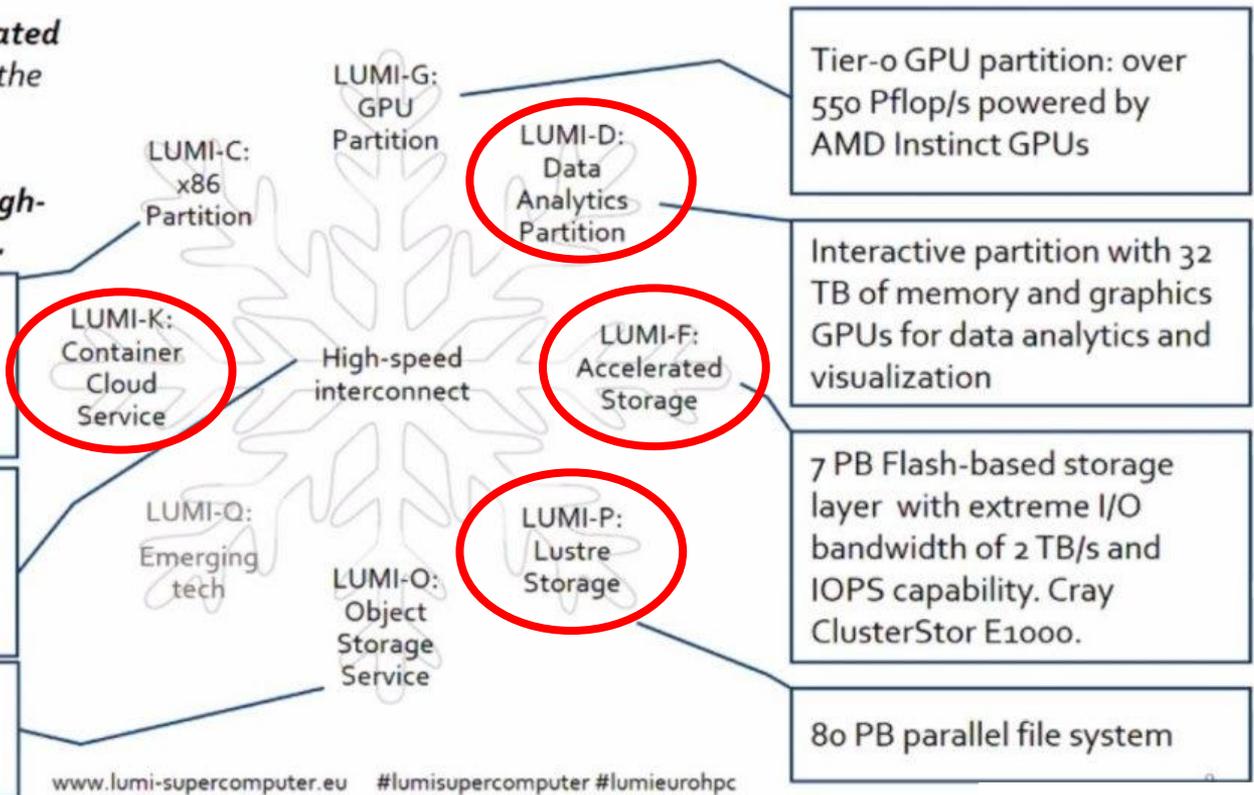
## LUMI, the Queen of the North

*LUMI is a Tier-0 GPU-accelerated supercomputer that enables the convergence of high-performance computing, artificial intelligence, and high-performance data analytics.*

- Supplementary CPU partition
- ~200,000 AMD EPYC CPU cores

Possibility for combining different resources within a single run. HPE Slingshot technology.

30 PB encrypted object storage (Ceph) for storing, sharing and staging data



# Ideas on climate information for discussion

- User engagement: intensive, transdisciplinary, dealing with risk aversion.
- Tension between increasing user demand and the need for domestication of knowledge.
- Sources: international, and this applies to climate records (observations, reanalysis) but especially to sectorial data.
- Uncertainties: observational, model, user-based.
- Strike a balance between FAIR, principles (e.g. transparency, reproducibility) and standards.
- Capacity building to make the most of developments and services: e.g. the Digital Twin will likely not be a perfect copy of reality.
- Trust, transparency, ownership, governance.
- Users have already substantial information, DT might be a small delta.
- Transpose the salience, credibility and legitimacy principles.

**Destination Earth “blows a soul to your infrastructure”**

# Some questions

- If Destination Earth is expected to start from policy-making requirements on climate change adaptation, **are the relevant actors (e.g. action-oriented agencies in member states) aware of the programme?**
- Sectors (and uses within sectors) can be hugely diverse and impact models be very complex and uncertain. **Hard sectoral choices might be needed while commonalities have to be identified.**
- A credible service needs to build a legitimate reputation based on credible products. **How is this going to happen in an increasingly crowded arena?**
- As for the accessibility to both data and platforms, the devil is in the detail. **What role for EuroHPC, EOSC, Copernicus and public cloud providers?** Climate adaptation users will be a multi-faceted, fragmented set of elements (even if we only consider policy makers), **how will access to resources and platforms be governed and managed?**
- How to address the problem of accessing (including documentation, curation, anonymization, etc.) **non-climate data?**