www.bsc.es

Climate prediction at different timescales: An overview of the current activities at the BSC

Pablo Ortega

Climate Prediction Group
Earth Sciences Department

* trabajo desarrollado entre 2010-2018 en IC3 + BSC-ES

The MareNostrum 4 Supercomputer

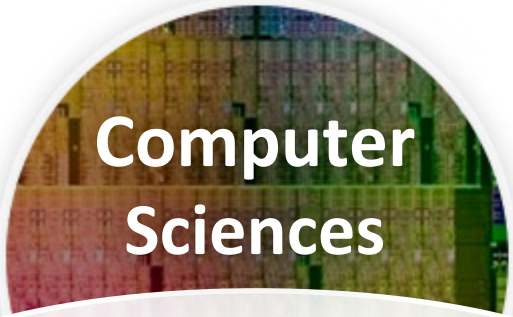
The most heterogeneous cluster in the world aimed at generating scientific knowledge

Nearly **165,888 cores**	**390.8 TB** of main memory	**3 PB** of disk storage

80% PRACE **16% RES** **4% BSC-CNS**

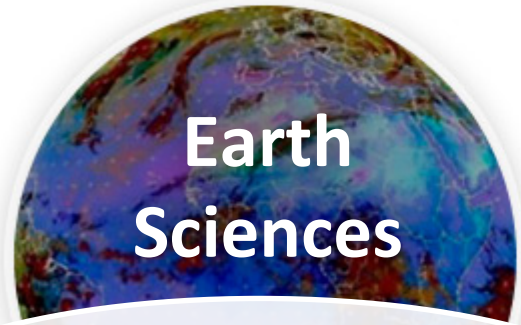
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Mission of BSC scientific departments



Computer Sciences

To influence the way machines are built, programmed and used: programming models, performance tools, Big Data, computer architecture, energy efficiency



Earth Sciences

To develop and implement global and regional state-of-the-art models for short-term air quality forecast and long-term climate applications

Life Sciences

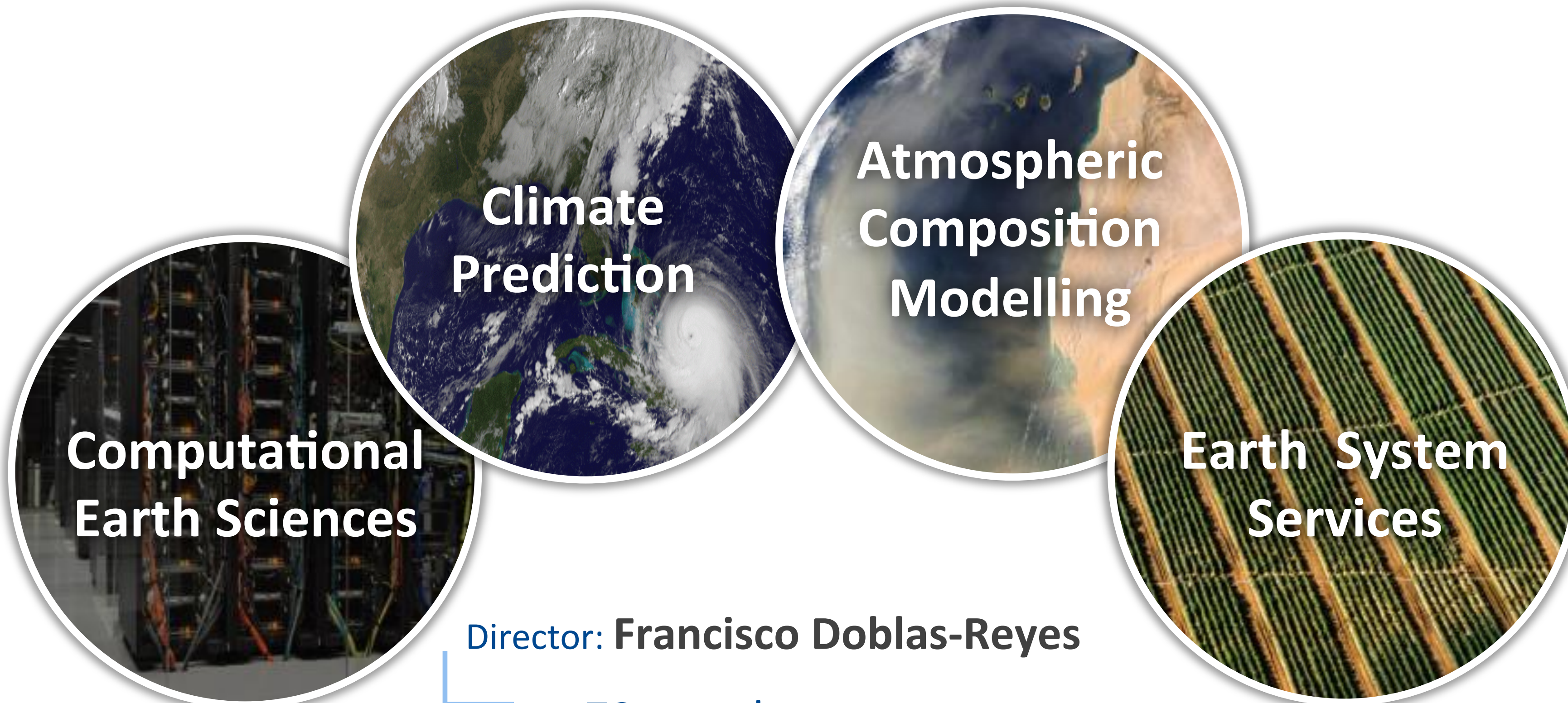
To understand living organisms by means of theoretical and computational methods (molecular modeling, genomics, proteomics)

CASE

To develop scientific and engineering software to efficiently exploit super-computing capabilities (biomedical, geophysics, atmospheric, energy, social and economic simulations)

Earth Science Department

Environmental modelling and forecasting, with a particular focus on weather, climate and air quality



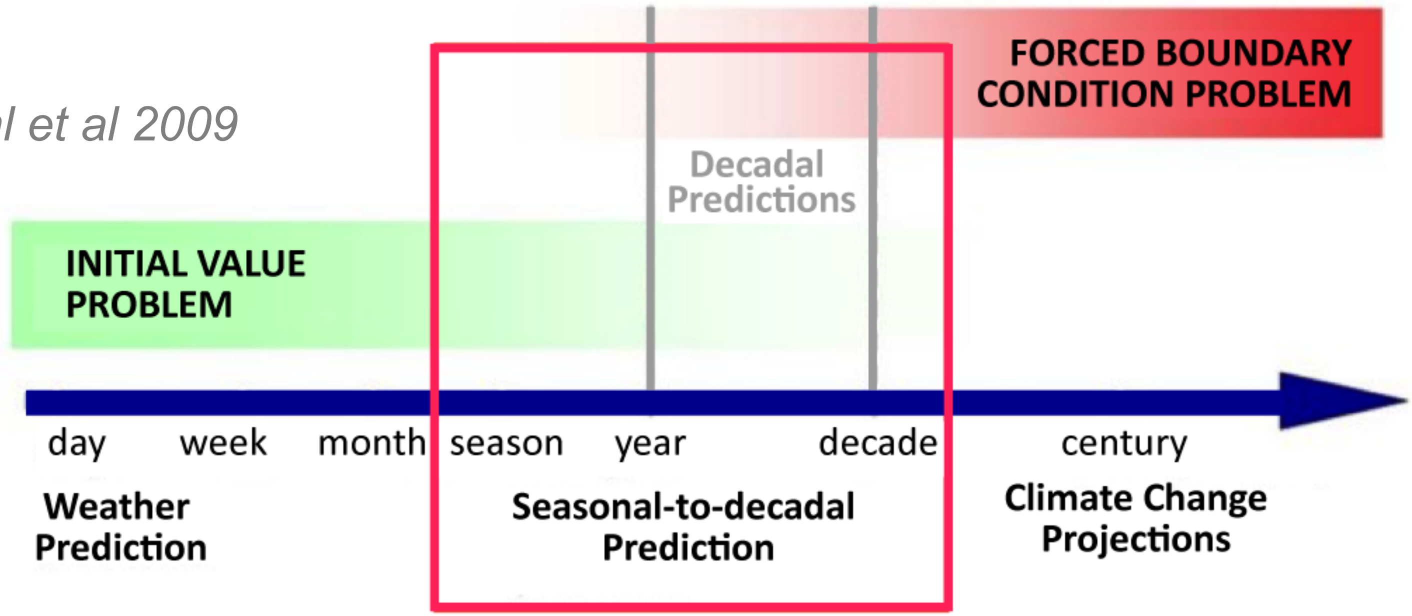
Director: **Francisco Doblas-Reyes**

- 72 people
- Leading: H2020 projects, COPERNICUS contracts, ERC Consolidator Grant and hosts an AXA Chair

BSC Barcelona Supercomputing Center
Centro Nacional de Supercomputación

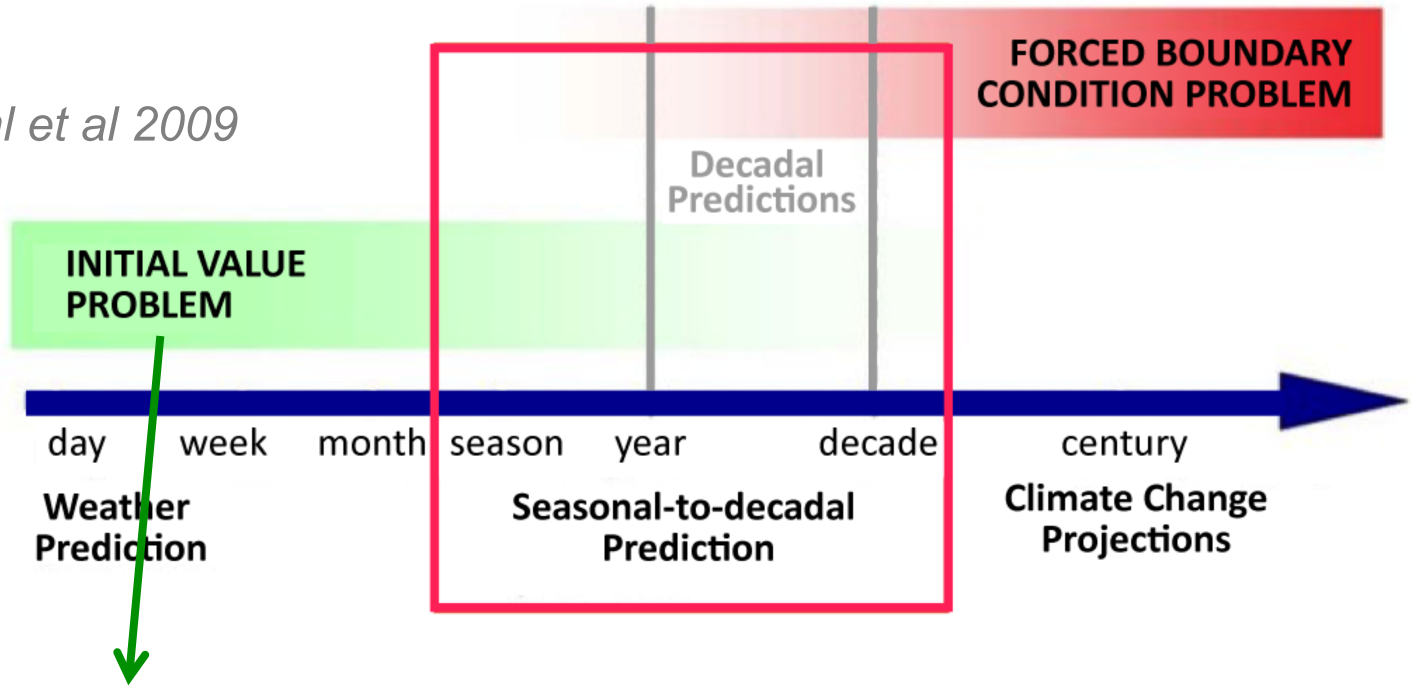
Cornerstones of Climate Prediction

Meehl et al 2009

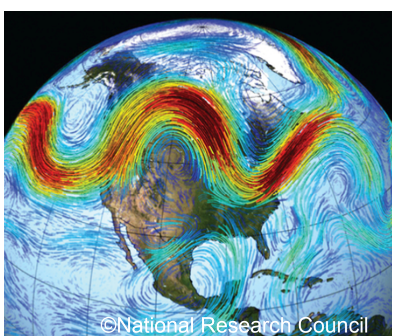


Cornerstones of Climate Prediction

Meehl et al 2009



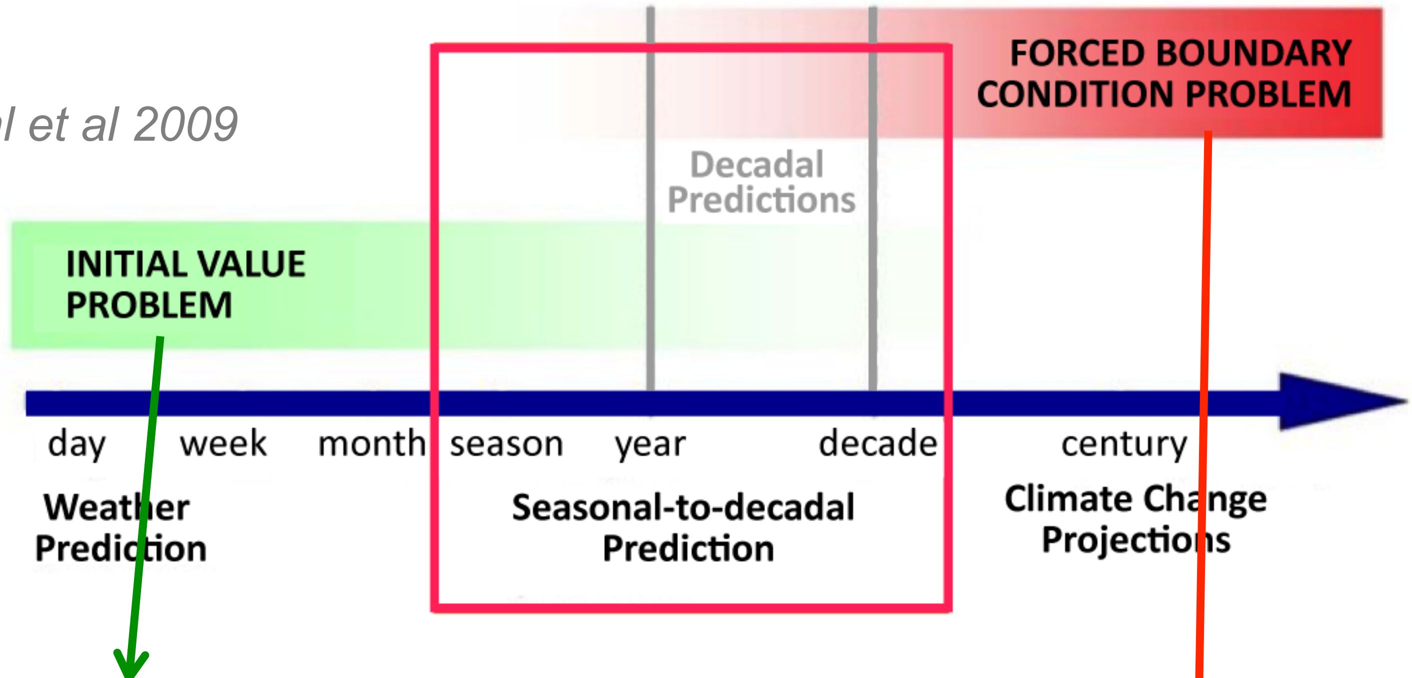
Current Meteorological state



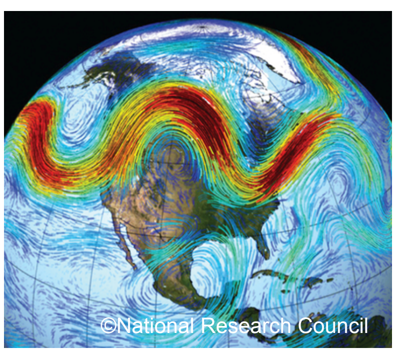
Correct Initialization of internal sources of predictability

Cornerstones of Climate Prediction

Meehl et al 2009

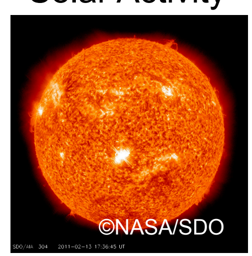


Current Meteorological state



Correct Initialization of internal sources of predictability

Solar Activity



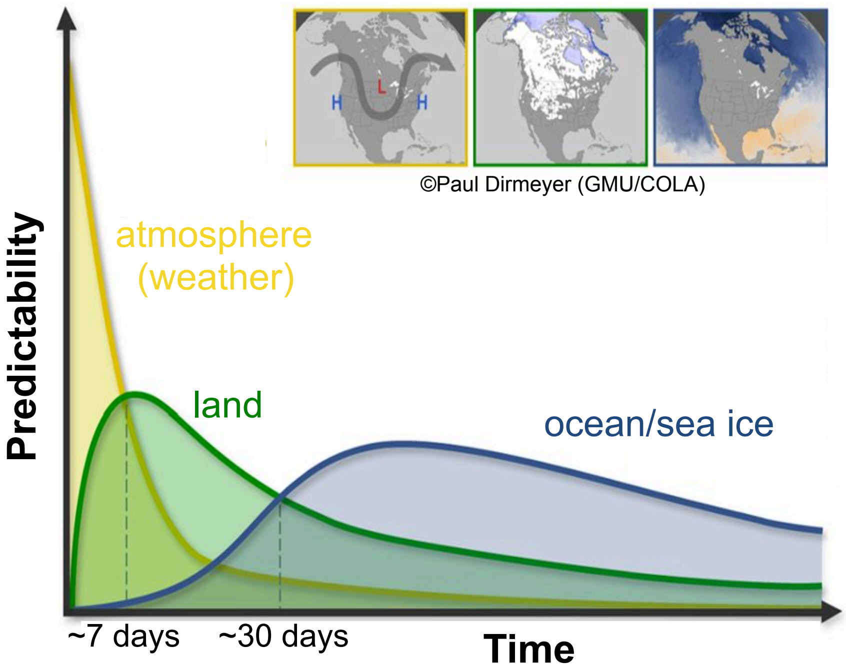
GHGs

Volcanic Aerosols

Good guess of future changes in the forcing

Internal sources of Climate Predictability

Mariotti et al 2018



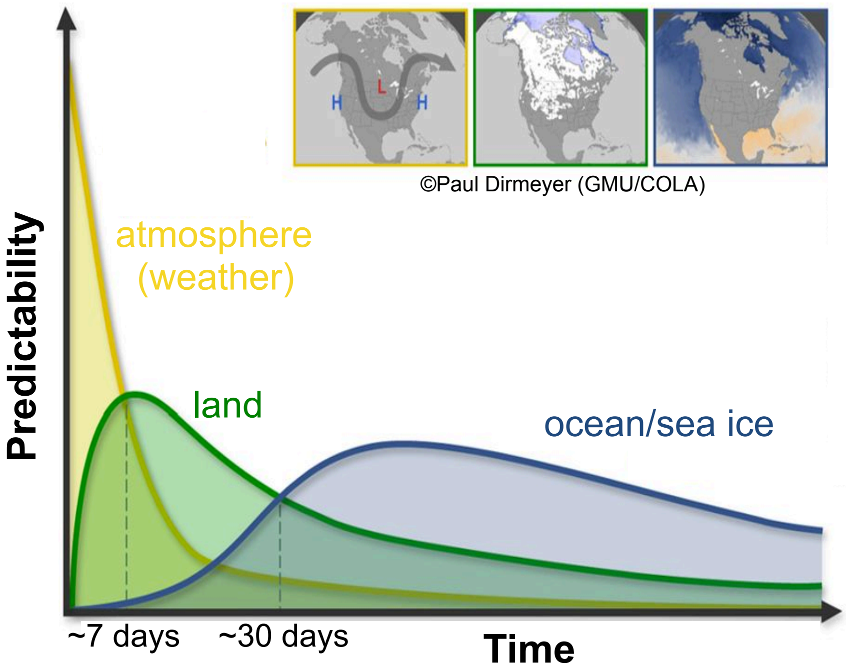
Weather prediction → time horizon → **~ 10 days**

Because of the chaotic nature of atmospheric variability

Internal sources of Climate Predictability

Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA

Mariotti et al 2018



Weather prediction → time horizon → **~ 10 days**

Because of the chaotic nature of atmospheric variability

Climate prediction → time horizon → **Weeks Decades**

It relies on the longer memory of other elements of the climate system

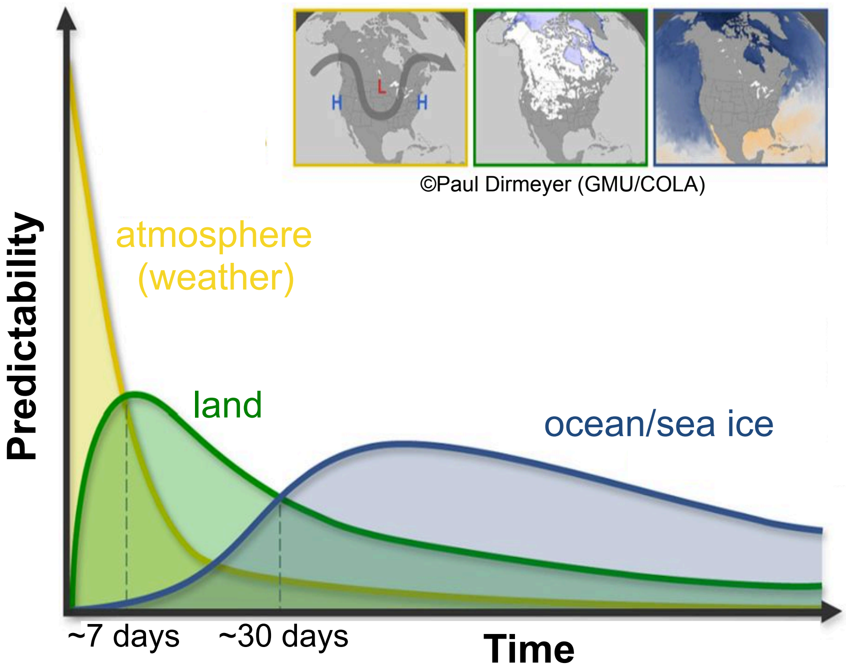
ocean

sea ice

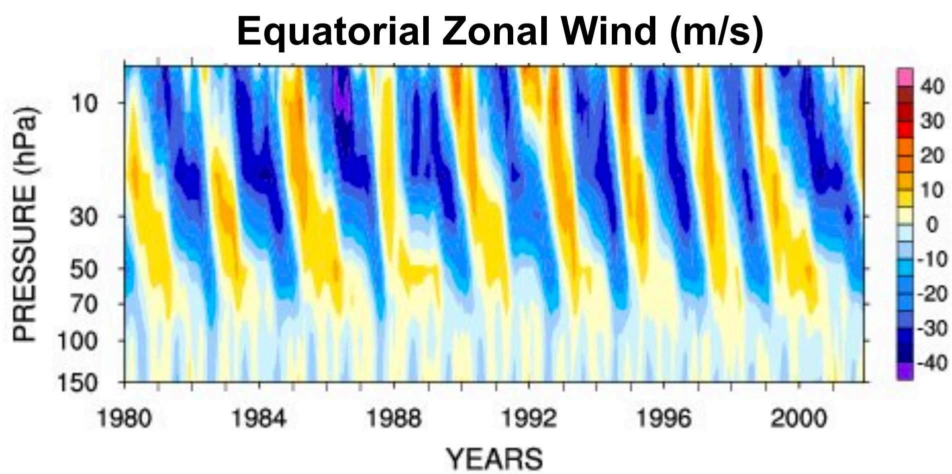
soil moisture

Internal sources of Climate Predictability

Mariotti et al 2018

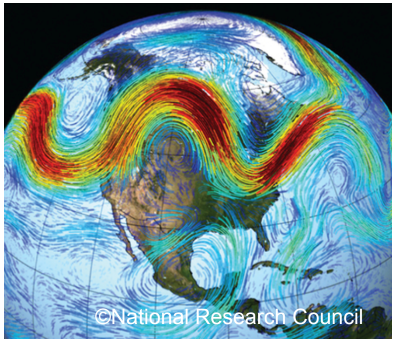


The **atmosphere** can also provide **memory** beyond monthly timescales: the **QBO**



Monier & Weare (2011)

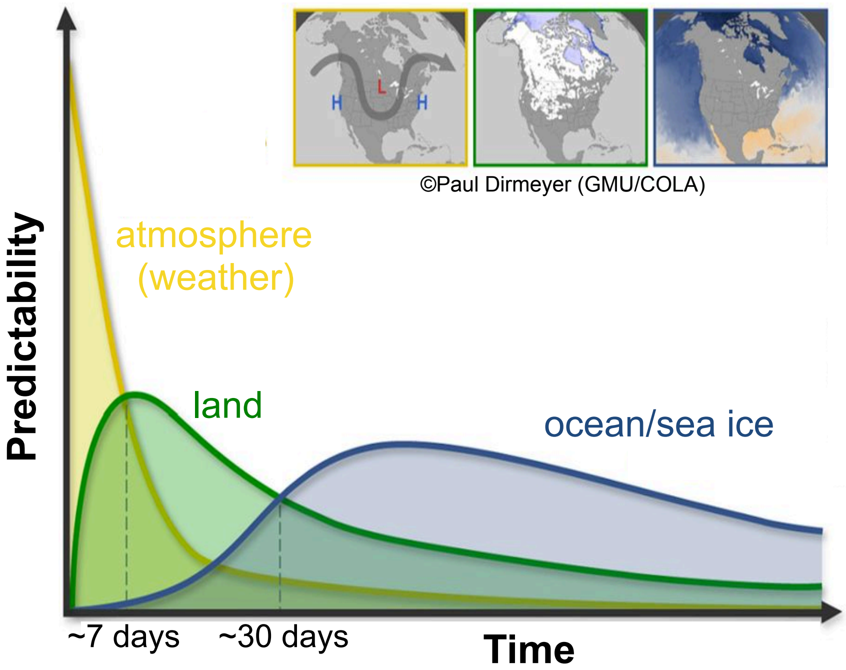
atmosphere



Through its key role on wave propagation that can further impact the polar vortex strength, the **Quasi-biennial Oscillation** can contribute to Northern Hemisphere predictability at <u>seasonal and interannual timescales</u>.

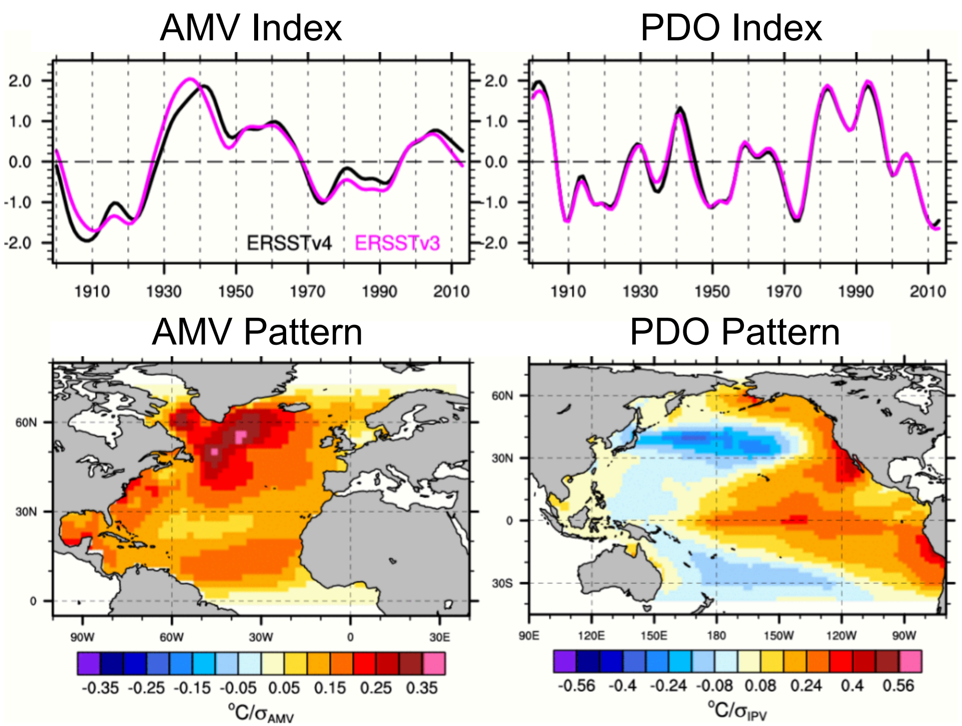
Internal sources of Climate Predictability

Mariotti et al 2018



ocean

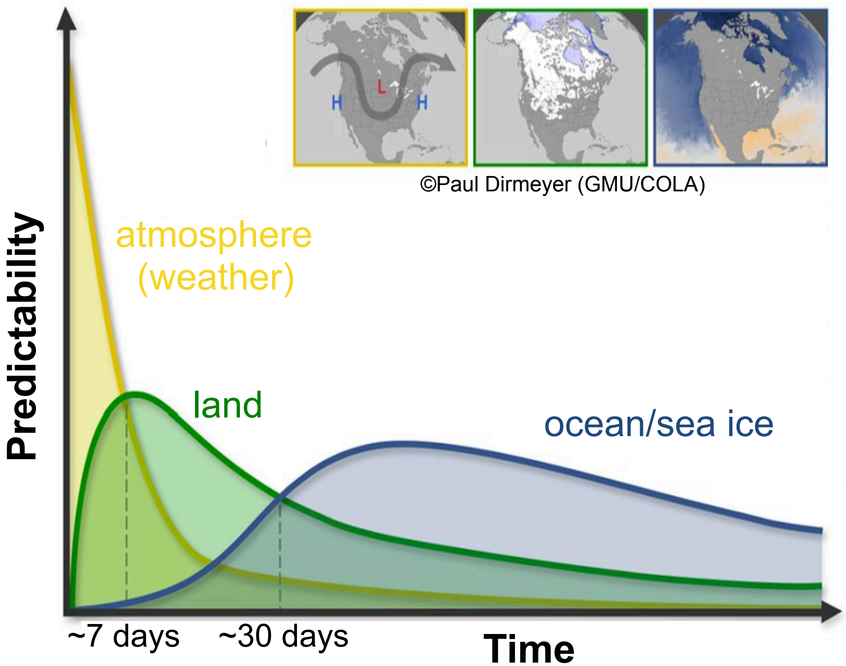
The **ocean** exhibits modes of **decadal variability** both in the **Atlantic** and **Pacific** basins



Cassou et al,
Technical Note for DCPP-Component C

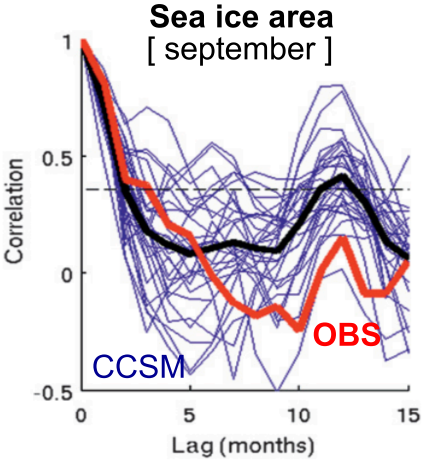
Internal sources of Climate Predictability

Mariotti et al 2018



sea ice

Re-emergence mechanisms in Arctic **sea ice** can provide memory and thus predictability at **seasonal scales**

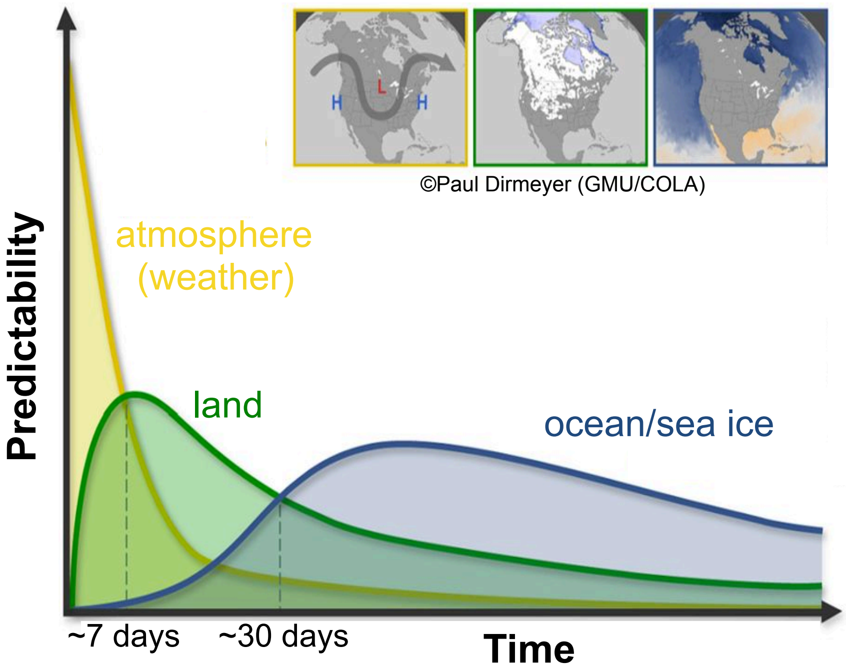


Blanchard-Wrigglesworth et al 2011

Internal sources of Climate Predictability

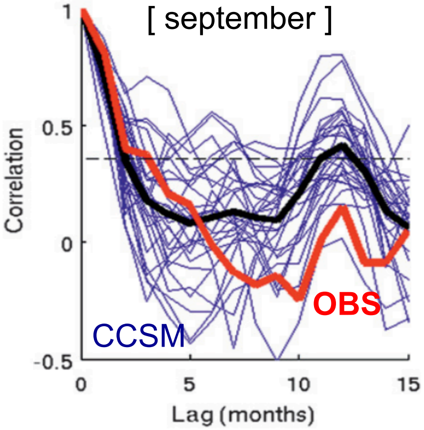
Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA

Mariotti et al 2018



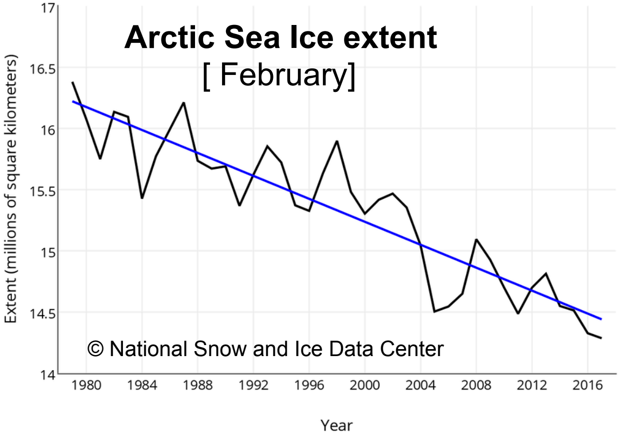
sea ice

Re-emergence mechanisms in Arctic **sea ice** can provide memory and thus predictability at **seasonal scales**



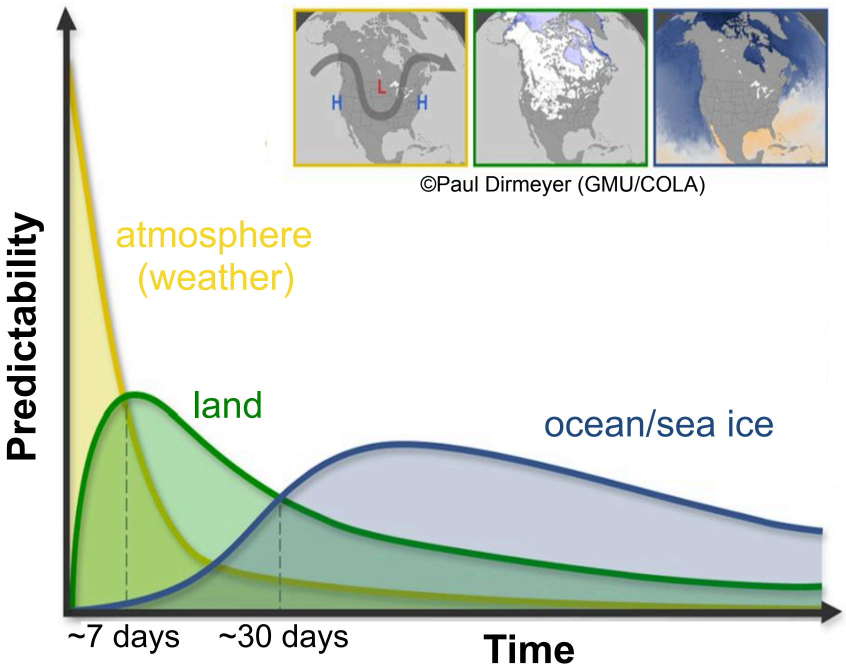
Blanchard-Wrigglesworth et al 2011

And at longer time-scales Arctic sea ice is experiencing a long-term **decline**

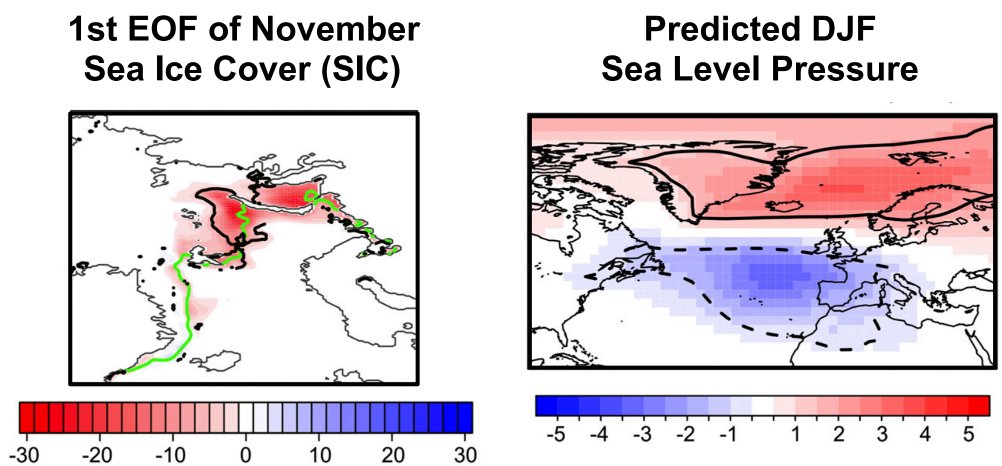


Internal sources of Climate Predictability

Mariotti et al 2018



While many studies report **important impacts** of Arctic sea **on the climate of the mid-latitudes**



García-Serrano et al 2014

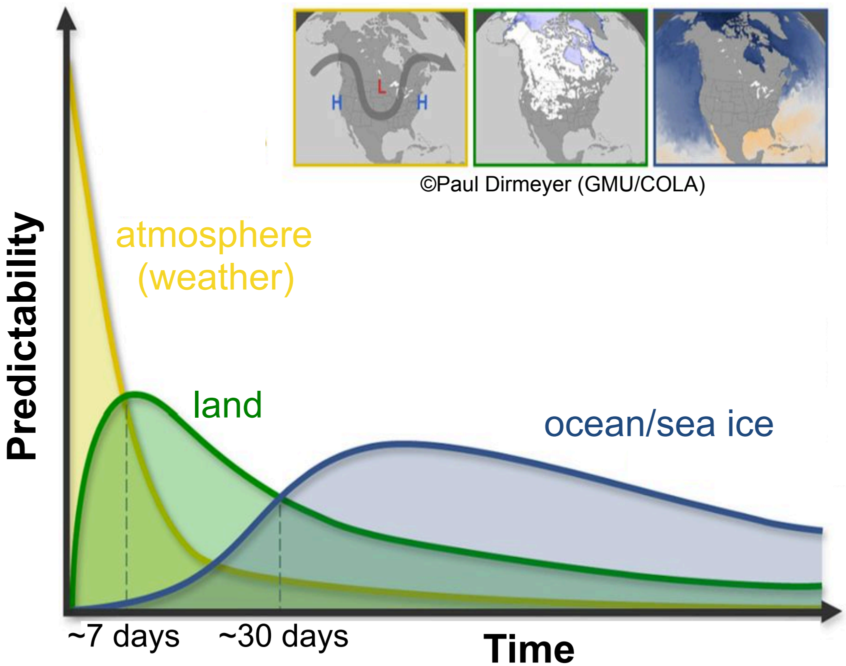
sea ice

For example, on Europe at **seasonal timescales** through an influence of Barents-Kara Sea SIC changes on the **North Atlantic Oscillation**

Internal sources of Climate Predictability

Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA

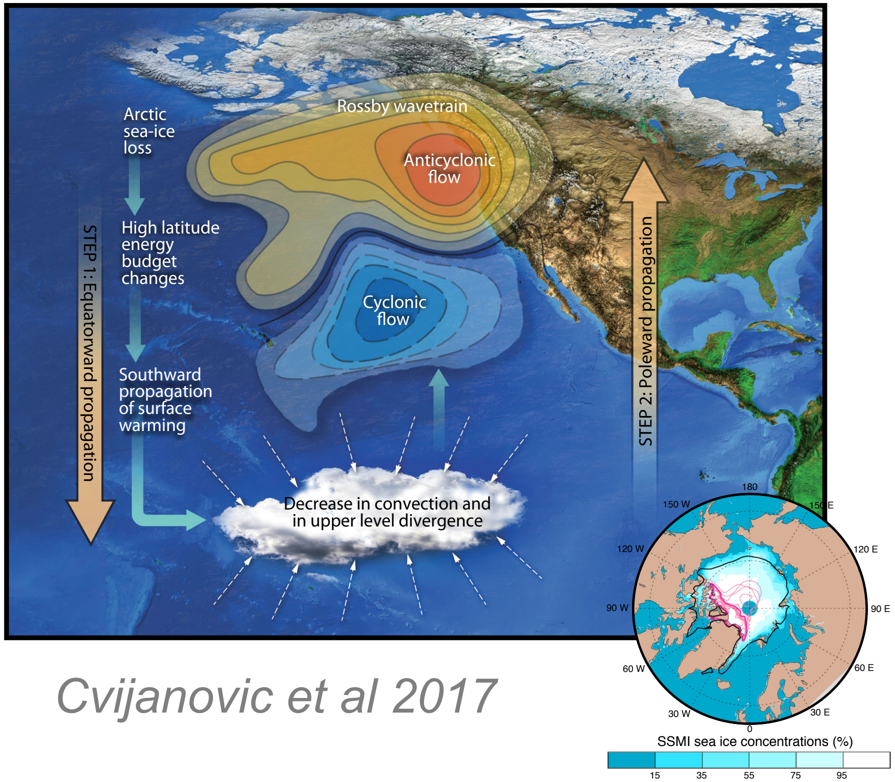
Mariotti et al 2018



sea ice

While many studies report **important impacts** of Arctic sea **on the climate of the mid-latitudes**

Response to an overall Arctic sea ice reduction



Cvijanovic et al 2017

Or even explaining a **long-term intensification of Californian droughts**

Introducing our main prediction tool

Model Components

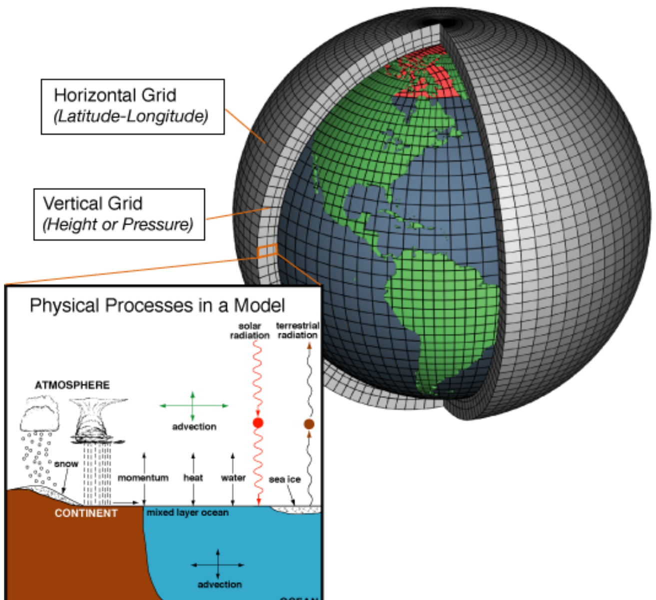
IFS (Atmospheric Model):
T255 (0.75º) ~80km
L91 (top 0.01hPa) ~mesosphere
IFS-HTESSEL (Land Model)

NEMO (Ocean Model):
Nominal 1° Resolution
L75 levels (thousands km deep)
PISCES (Biogeochemistry Model)

LIM (Sea-ice Model):
Multiple (5) ice category

IFS-HTESSEL

EC-EARTH
Global Coupled model



Introducing our main prediction tool

Model Components

IFS (Atmospheric Model):
- T255 (0.75º) ~80km
- L91 (top 0.01hPa) ~mesosphere
- *IFS-HTESSEL (Land Model)*

NEMO (Ocean Model):
- Nominal 1° Resolution
- L75 levels (thousands km deep)
- *PISCES (Biogeochemistry Model)*

LIM (Sea-ice Model):
- Multiple (5) ice category

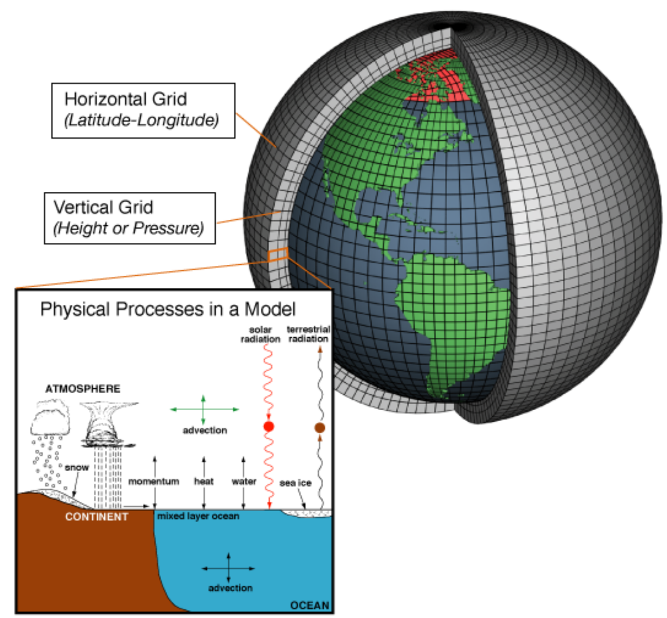
IFS-HTESSEL

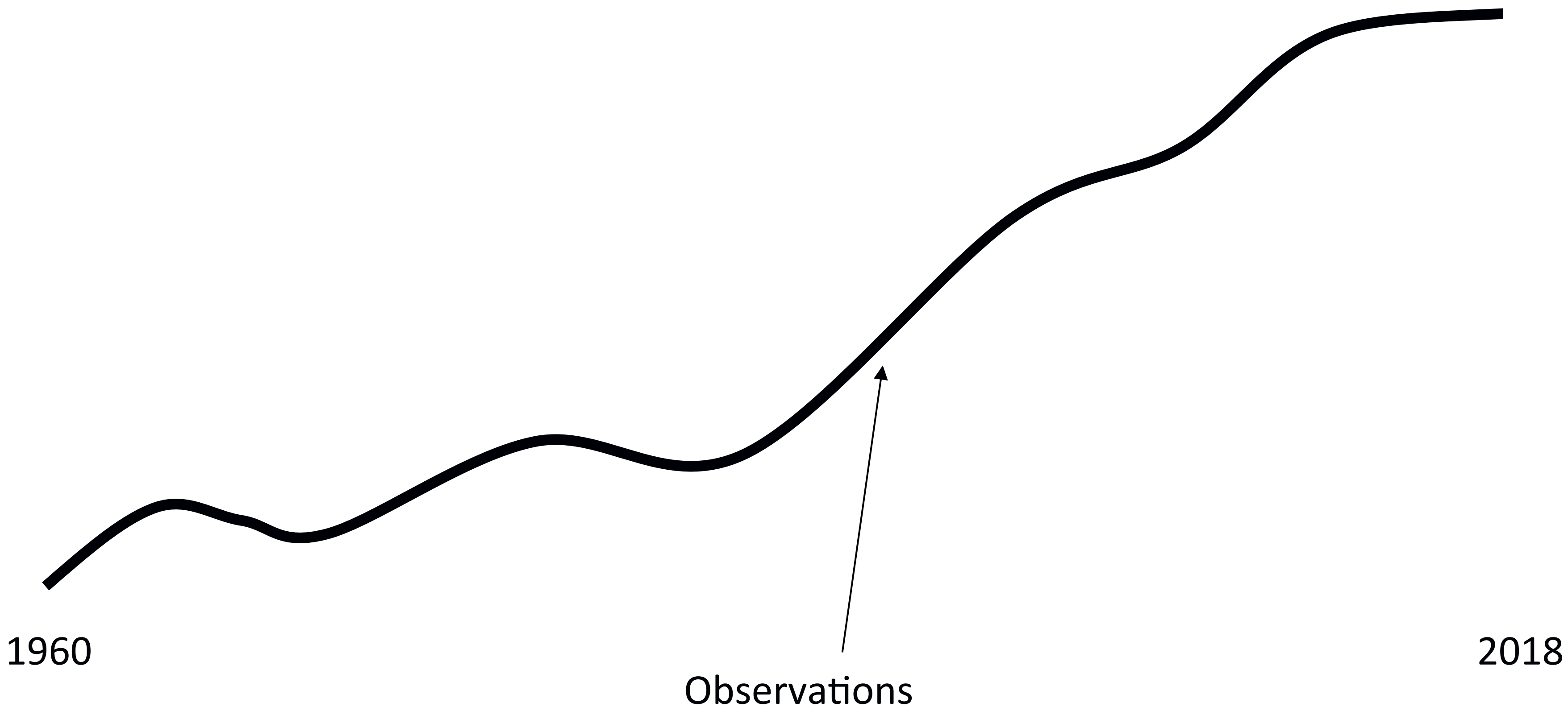
EC-EARTH Global Coupled model

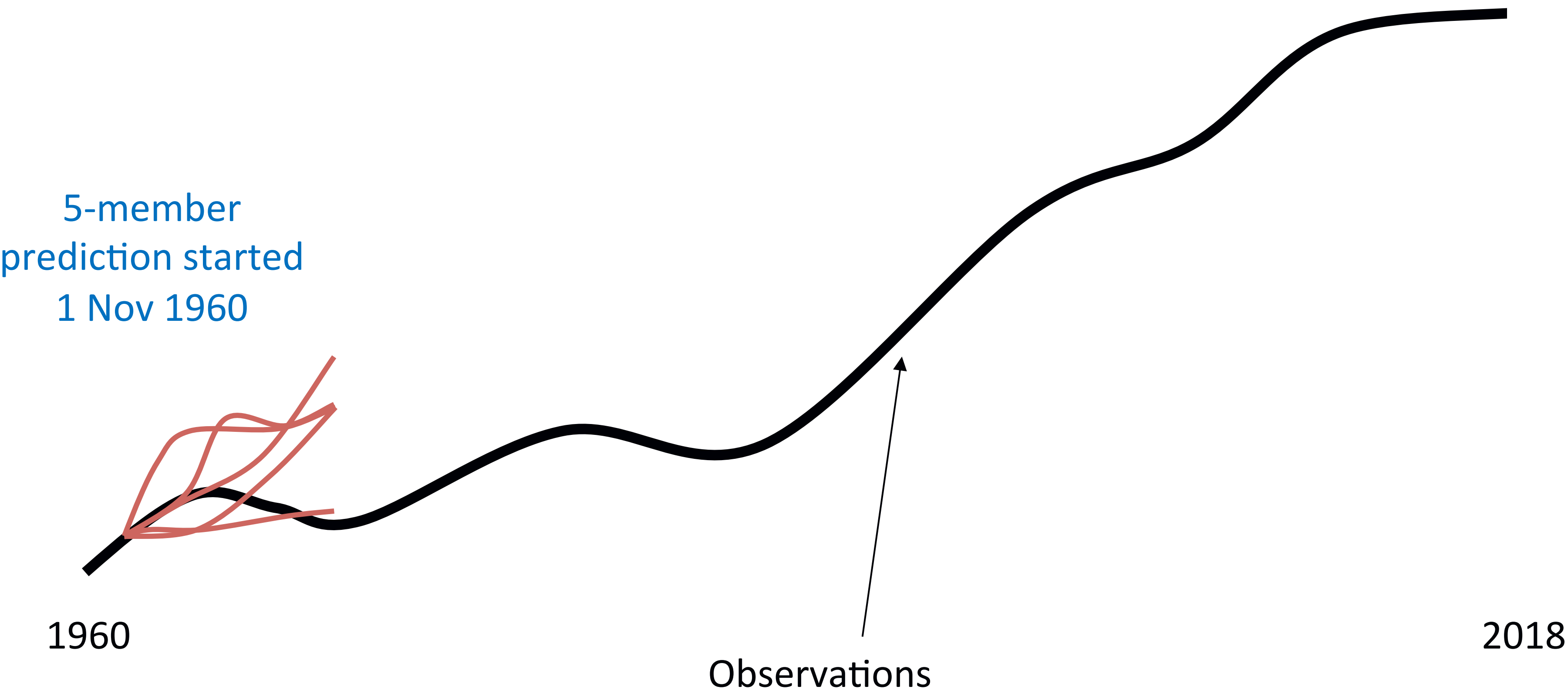
Initial Conditions

produced in-house

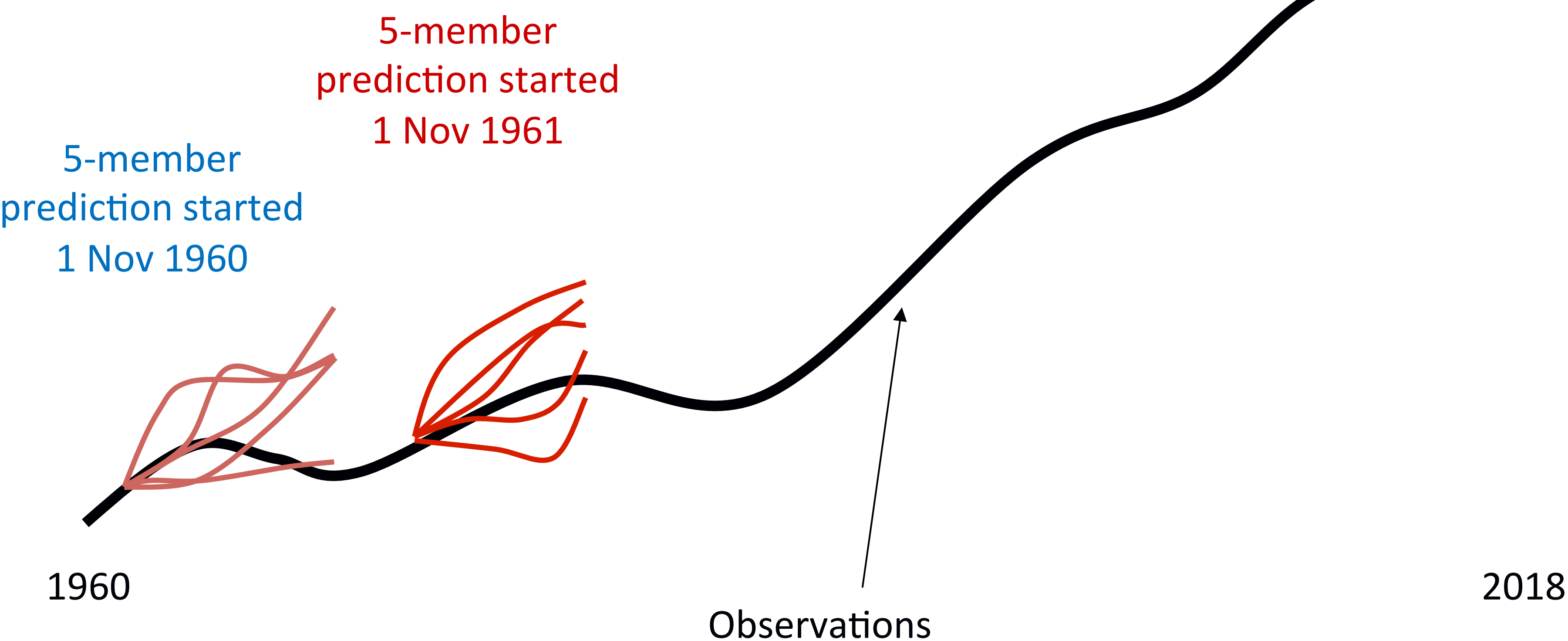
Atmosphere reanalysis (**ERA-Interim**)	Sea Ice reanalysis (**IC3/BSC**)
Land reanalysis (**ERA-Land**)	Ocean reanalysis (**ORAS4**)



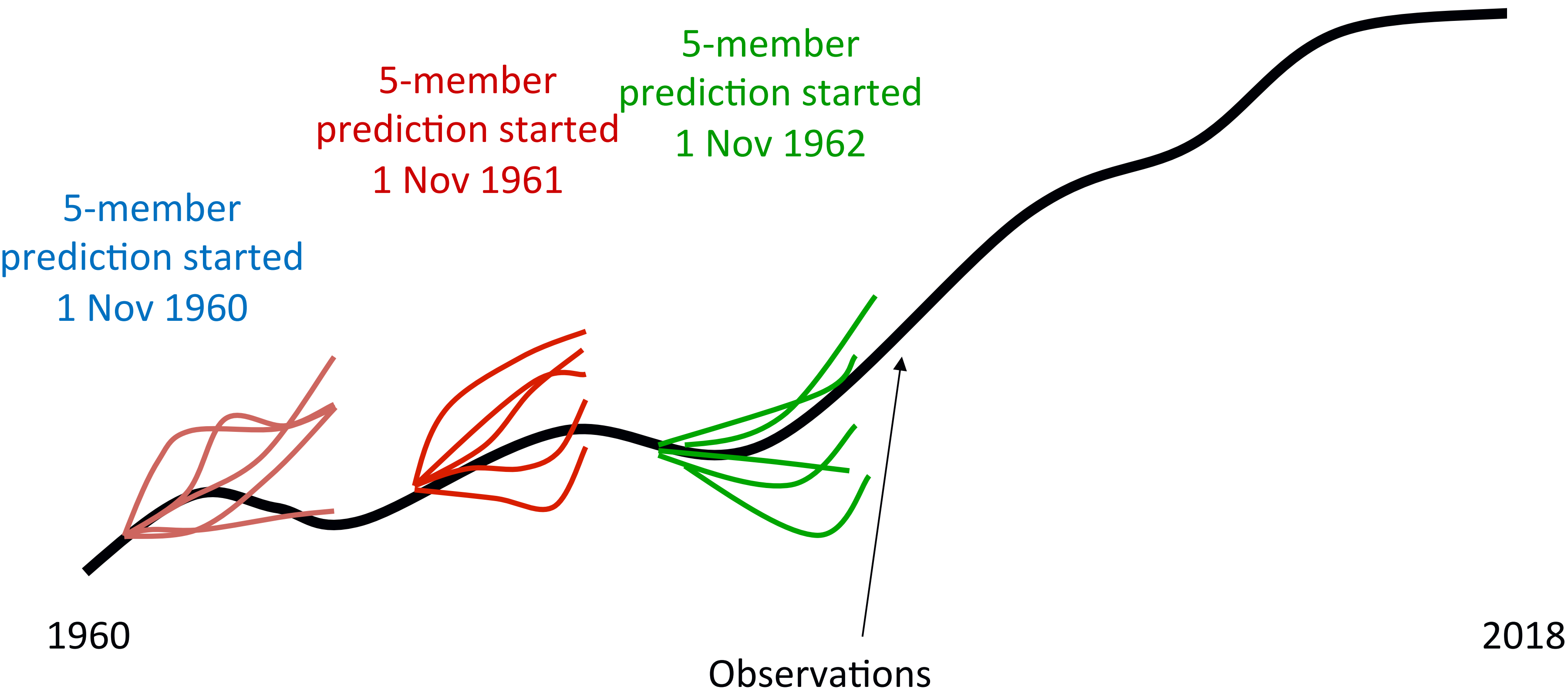

1960
2018
Observations


5-member
prediction started
1 Nov 1960
1960
2018
Observations

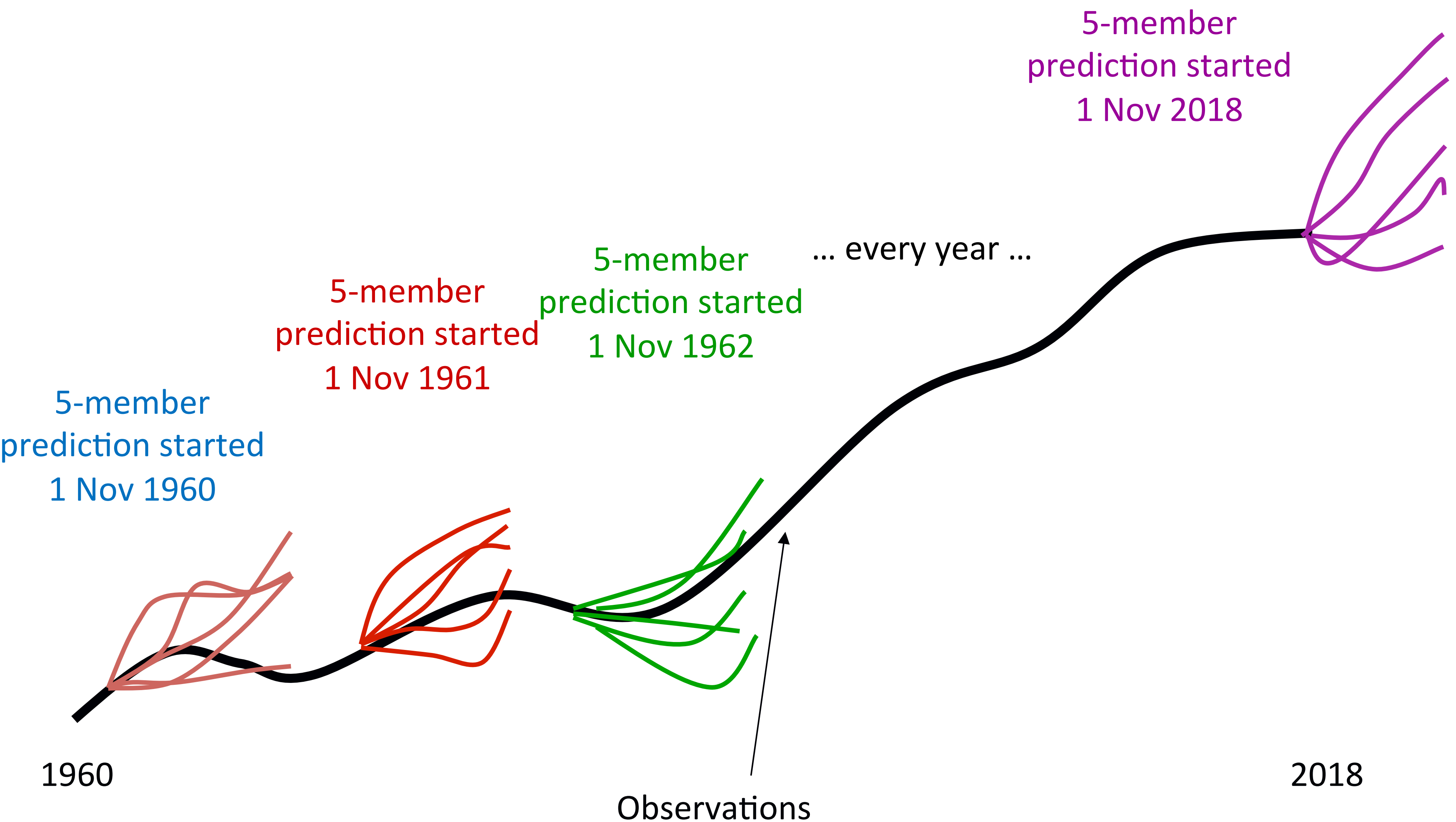
Introduction to Climate Prediction Systems



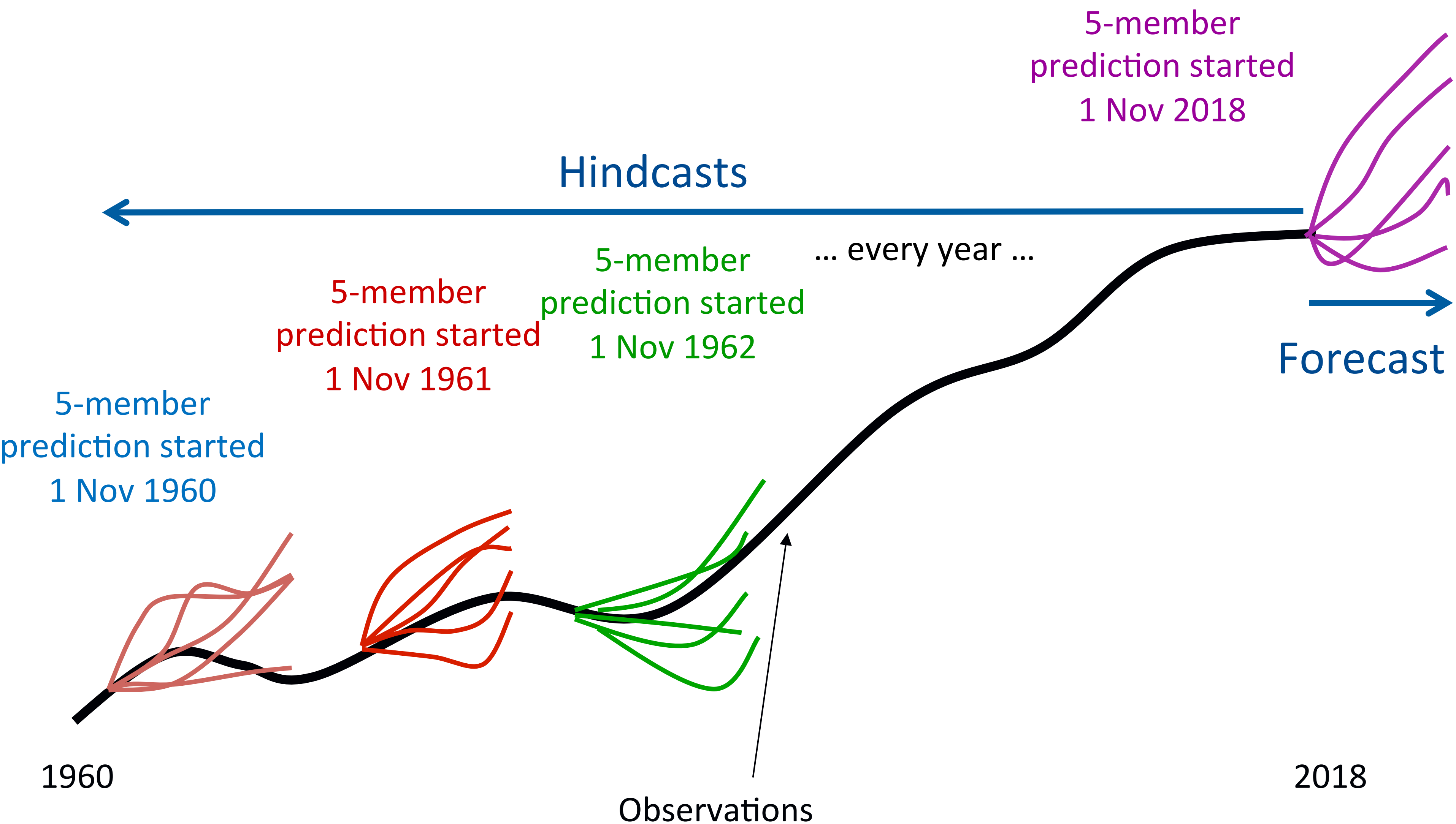
Introduction to Climate Prediction Systems



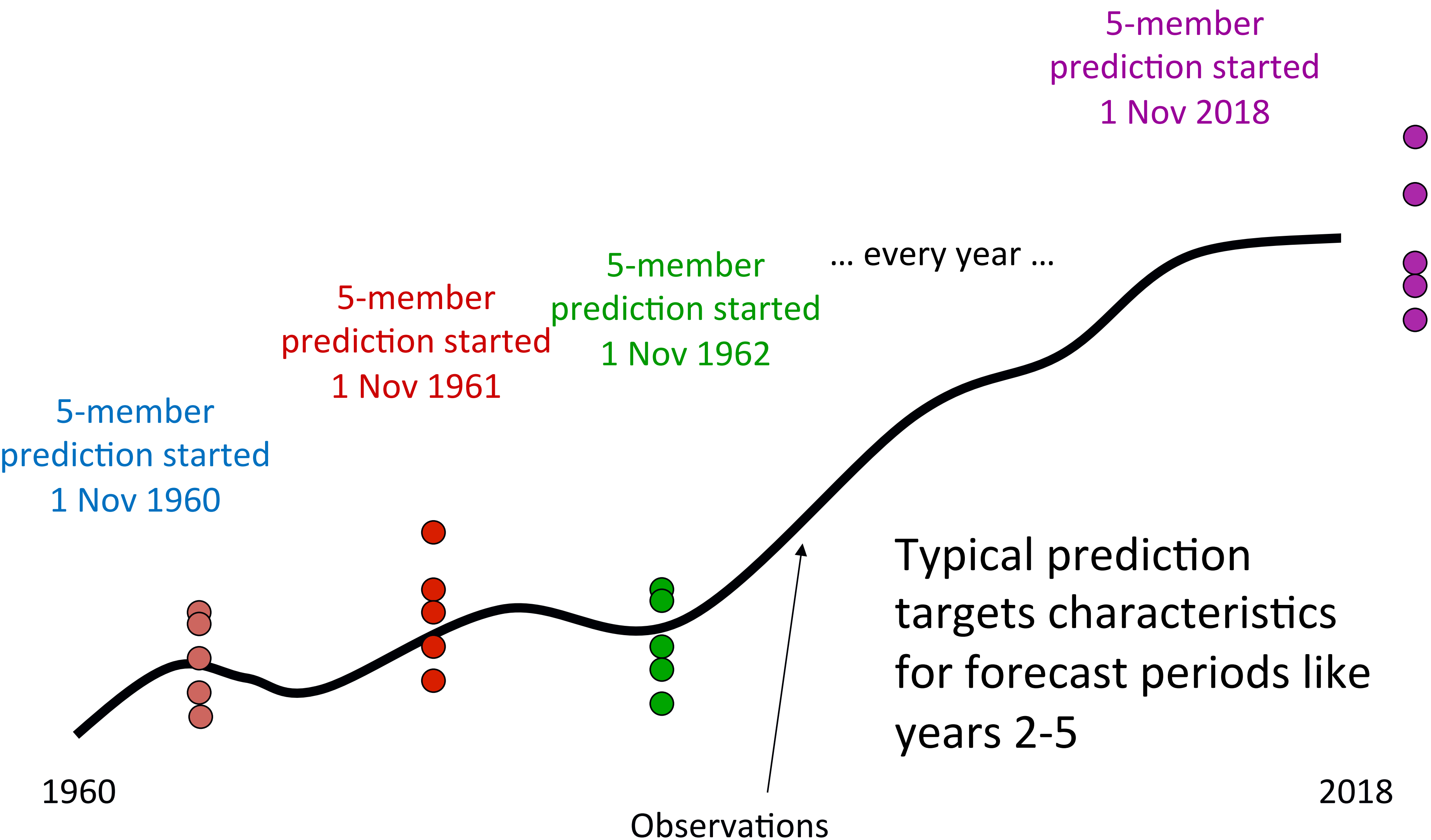
Introduction to Climate Prediction Systems



Introduction to Climate Prediction Systems



Introduction to Climate Prediction Systems

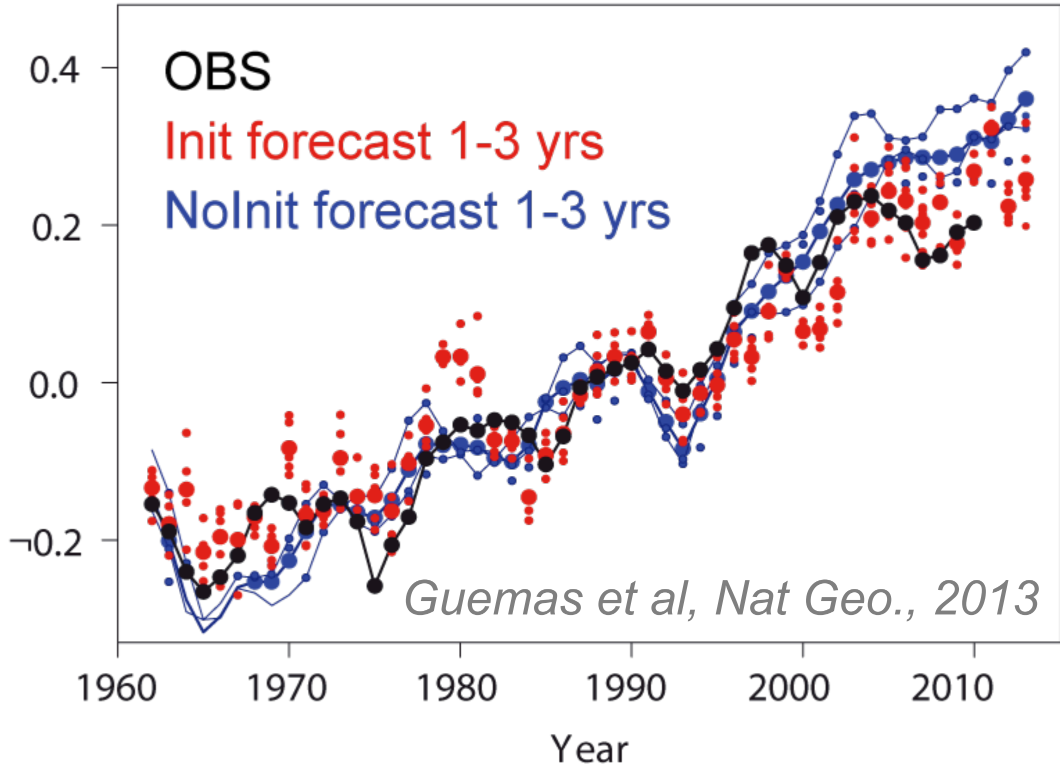


Typical prediction targets characteristics for forecast periods like years 2-5

Two examples in decadal prediction (II)

Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA

Predictive skill of **global mean surface-air temperature** (Ec-Earth2.3)

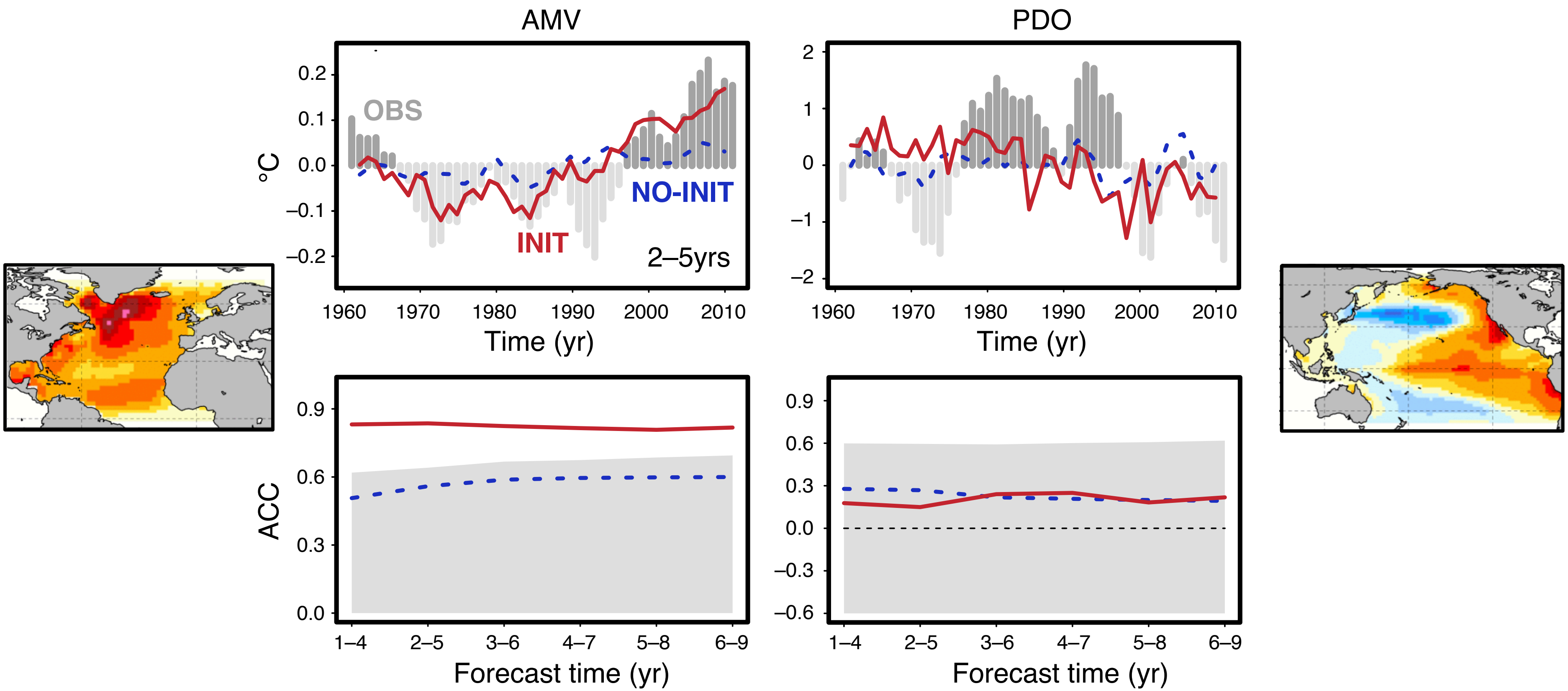


Initialised forecasts with EC-Earth reproduce the global temperature, and **describe more accurately** than the non-initialized ones the recent **HIATUS** period, which suggests a **key contribution of internal climate variability**

Two examples in decadal prediction (II)

Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA

Predictive skill of **modes of multi-annual climate variability** (in CMIP5)

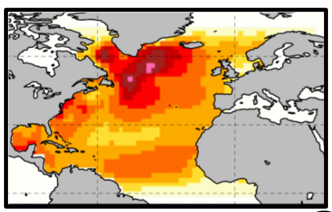


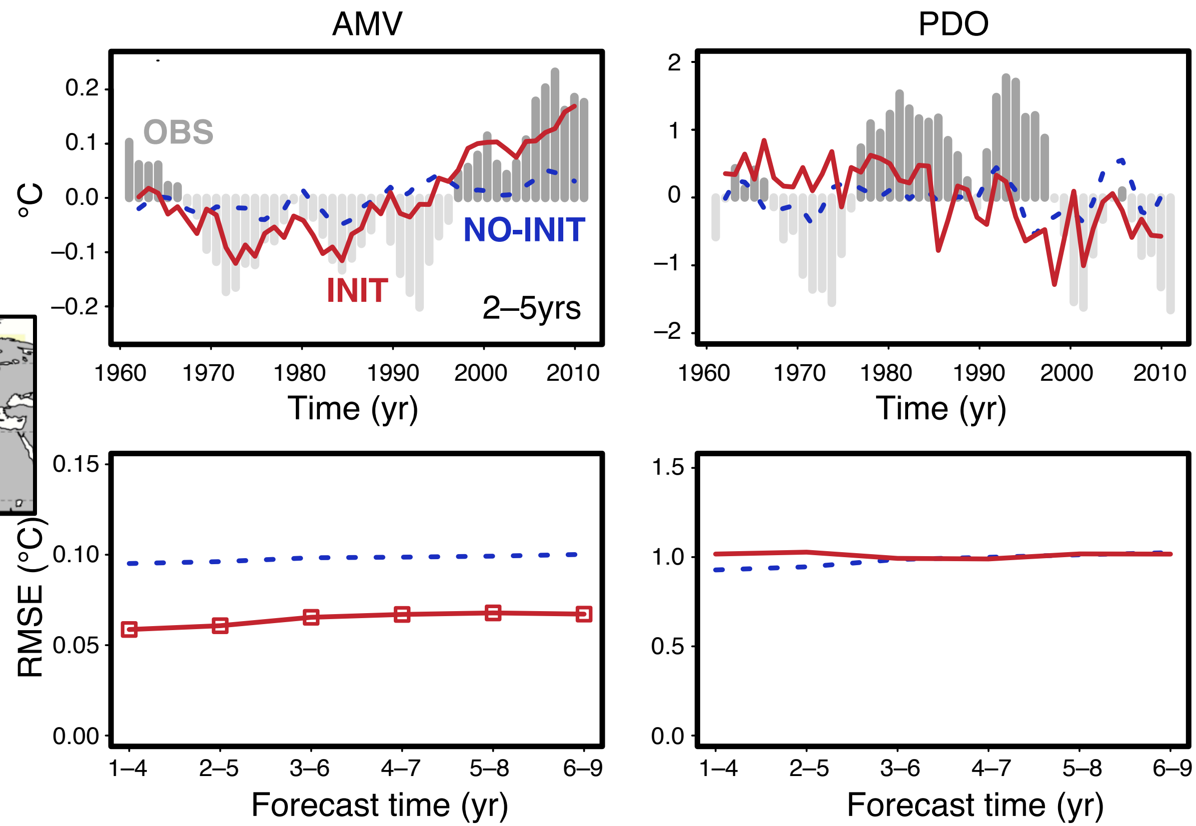
Doblas-Reyes et al, Nat. Comm., 2013

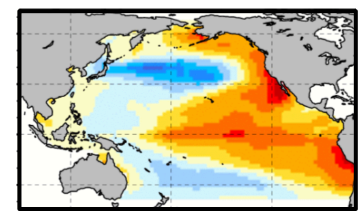
Only in the **Atlantic Ocean**, the **initialized forecasts** show significant **predictive skill** and beat persistence, for forecast times of **up to 10 yrs**

Two examples in decadal prediction (II)

Predictive skill of **modes of multi-annual climate variability** (in CMIP5)







Doblas-Reyes et al, Nat. Comm., 2013

Only in the **Atlantic Ocean**, the **initialized forecasts** show significant **predictive skill** and beat persistence**,** for forecast times of **up to 10 yrs**

Towards Real Time Decadal Climate Prediction

Multi-model decadal forecast exchange

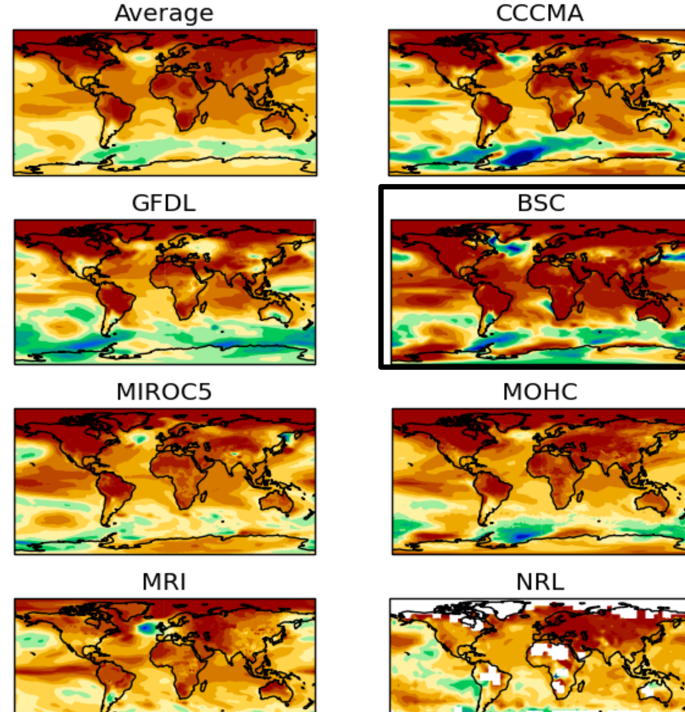
The Met Office coordinates an informal exchange of near-real time decadal predictions. Many institutions around the world are developing decadal prediction capability and this informal exchange is intended to facilitate research and collaboration on the topic.

The contributing prediction systems are a mixture of dynamical and statistical methods. The prediction from each institute is shown below, alongside an average of all the models. When possible, observations for the period of the forecast are also shown. Currently three variables are included: surface air temperature, sea-level pressure and precipitation. These are shown as differences from the 1971-2000 baseline. More diagnostics, including ocean variables are planned for the future. Please use the drop-down menus below to explore the data collected to date.

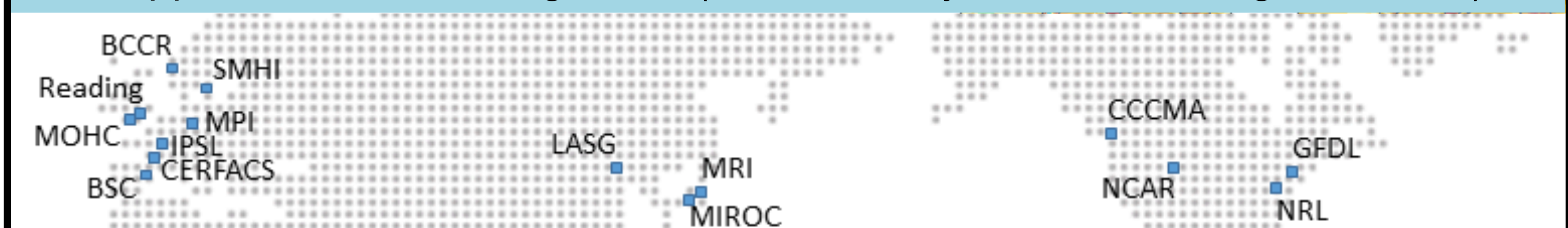
This work is supported by the European Commission SPECS project.

Smith et al. (2013, ClimDyn)

2015 predictions for 2016 SAT



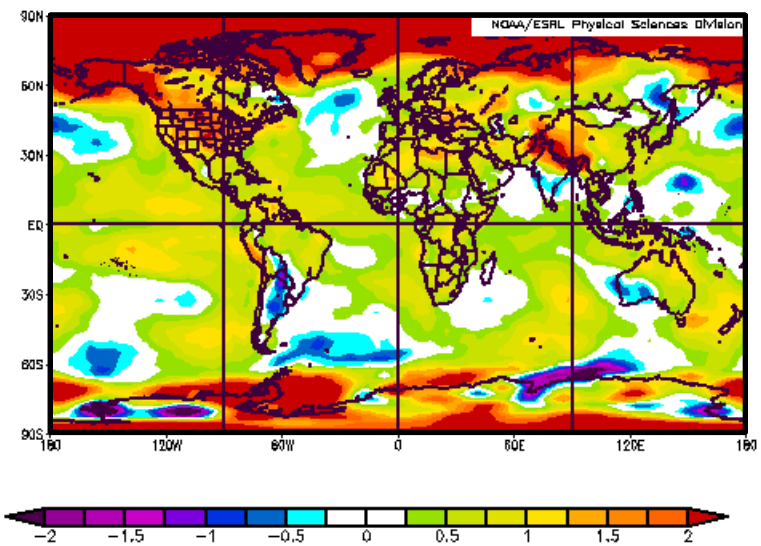
15 centers will contribute to Annual Decadal Climate Prediction Exchange
4 applied for WMO-designation (**BSC** the only non meteorological center)



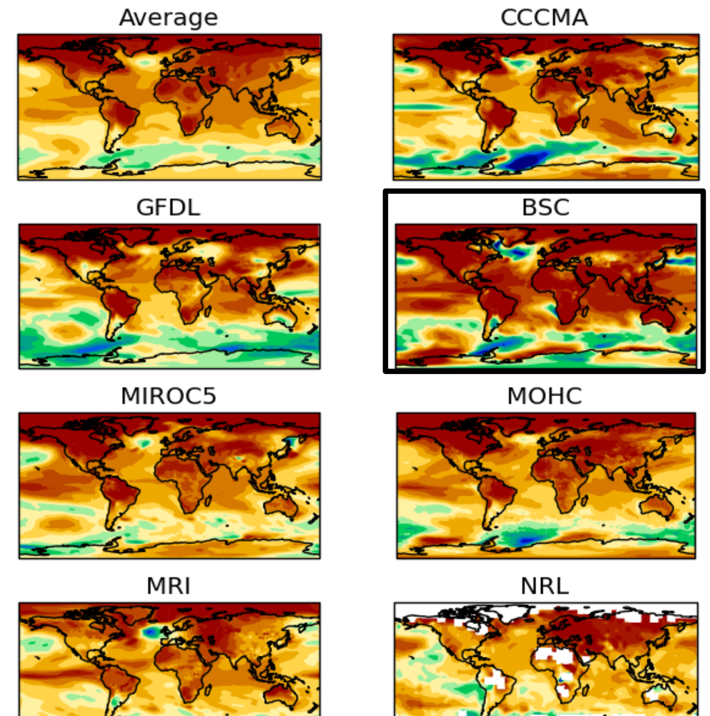
Towards Real Time Decadal Climate Prediction

Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA

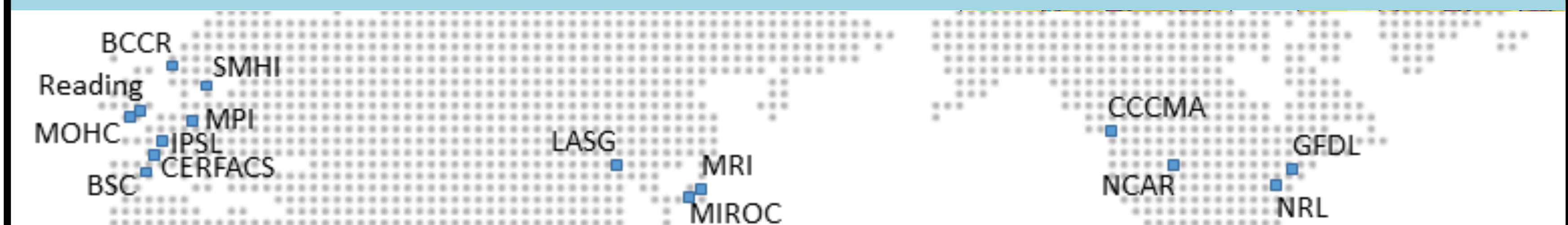
NCEP/NCAR Reanalysis
Jan-Dec 2016 SAT Anomaly



2015 predictions for 2016 SAT



15 centers will contribute to Annual Decadal Climate Prediction Exchange
4 applied for WMO-designation (**BSC** the only non meteorological center)



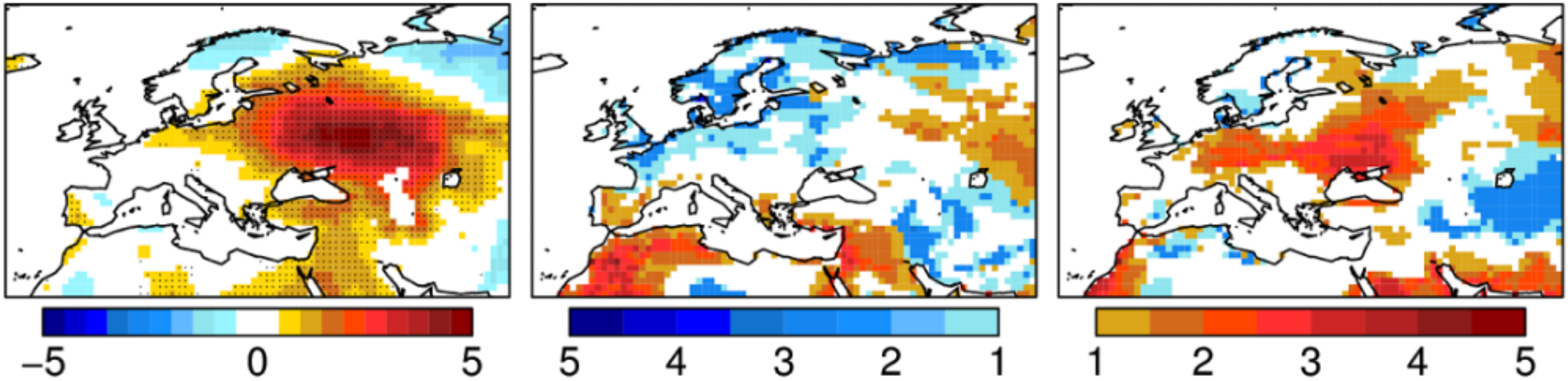
Met Office

Case study: Heat wave in Eastern Europe during summer 2010

Two seasonal forecasts (initialized May 1st):

1) Climatological Land Surface Conditions **(CLIM)**
2) Reanalysed ERAi-Land Conditions **(REAS)**

Observed JJA SAT | Odds* JJA SAT (**CLIM**) | Odds JJA SAT (**REAS**)



Prodhomme et al. (2016)

*Odds~Probability of a extreme event to occur wrt climatology

Soil moisture initialization is therefore **essential** for the representation of such **extreme events**

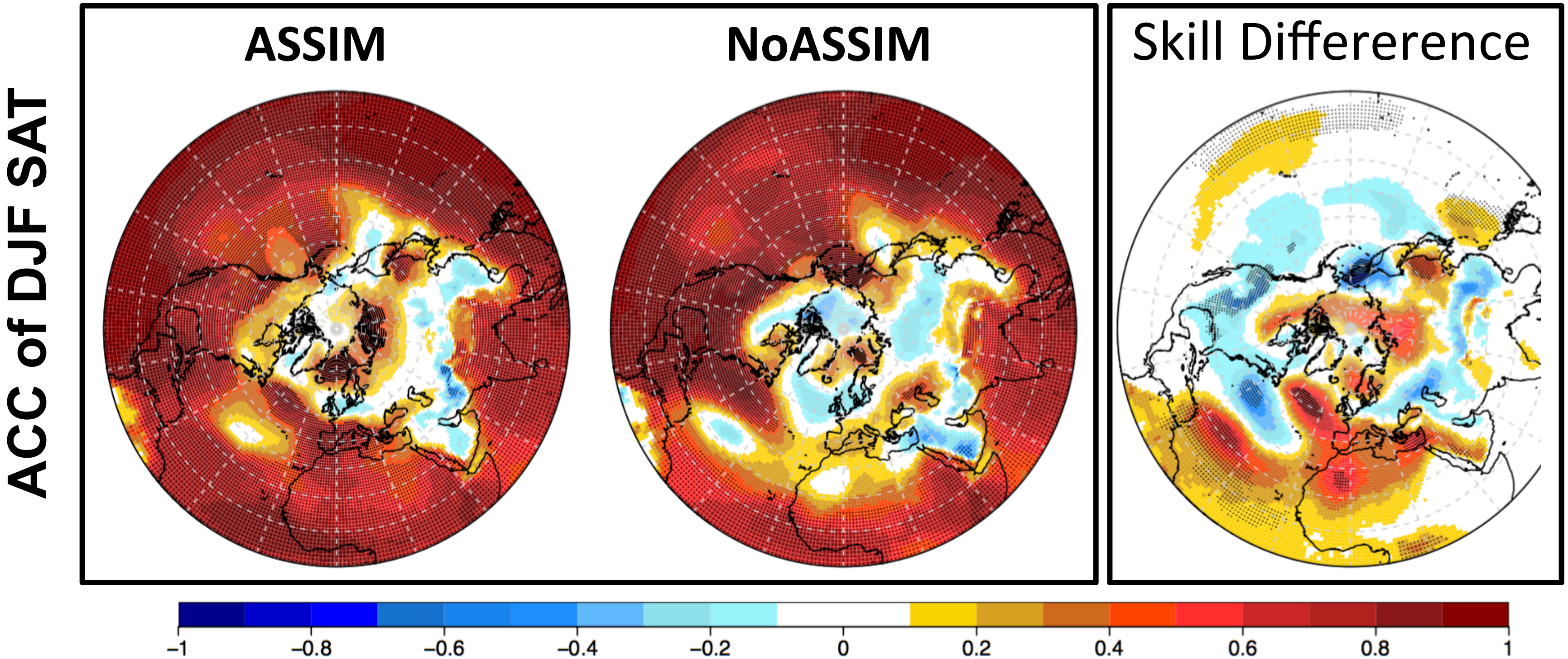
Seasonal Prediction: role of Sea Ice

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

EXCELENCIA SEVERO OCHOA

Two initialization methods for sea-ice (initialized Nov 1st):

1) With sea ice cover assimilation (**ASSIM**)
2) Without assimilation (**NoASSIM**)



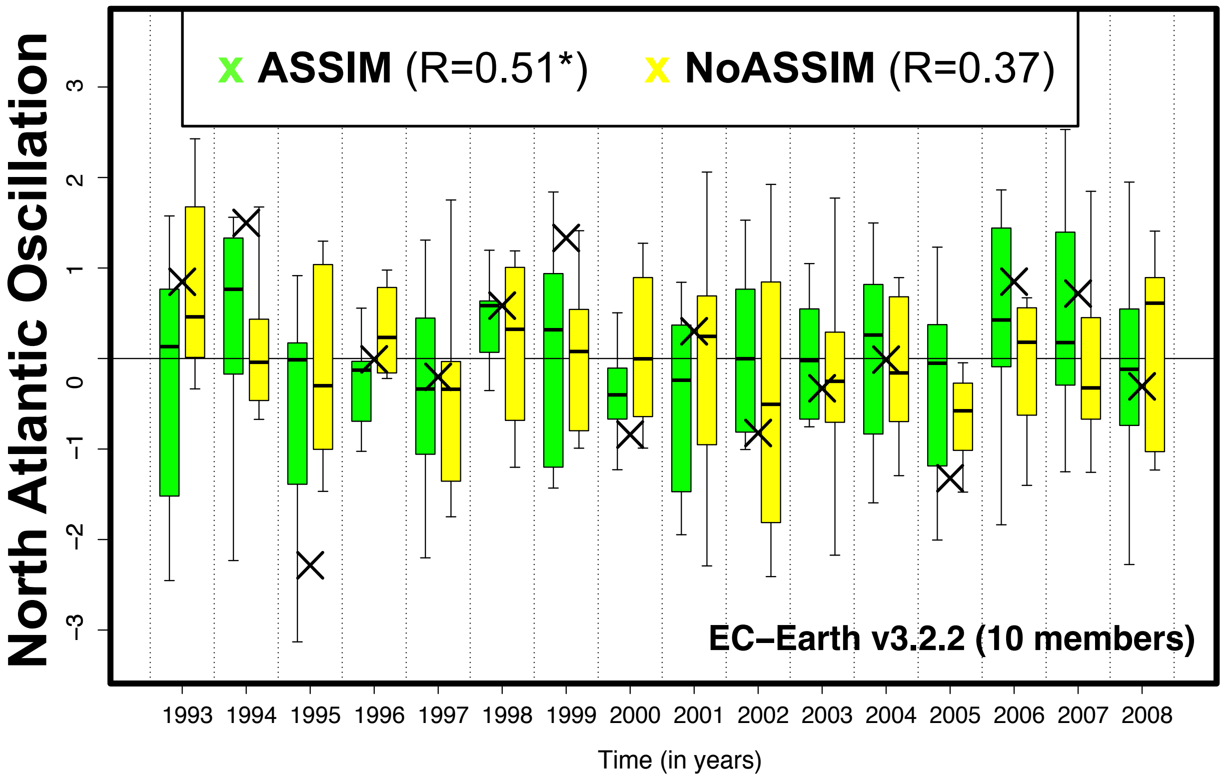
A **better sea-ice** initialization can **improve** the skill in the **Mediterranean area and Scandinavia…**

Seasonal Prediction: role of Sea Ice

Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA

Two initialization methods for sea-ice (initialized Nov 1st):

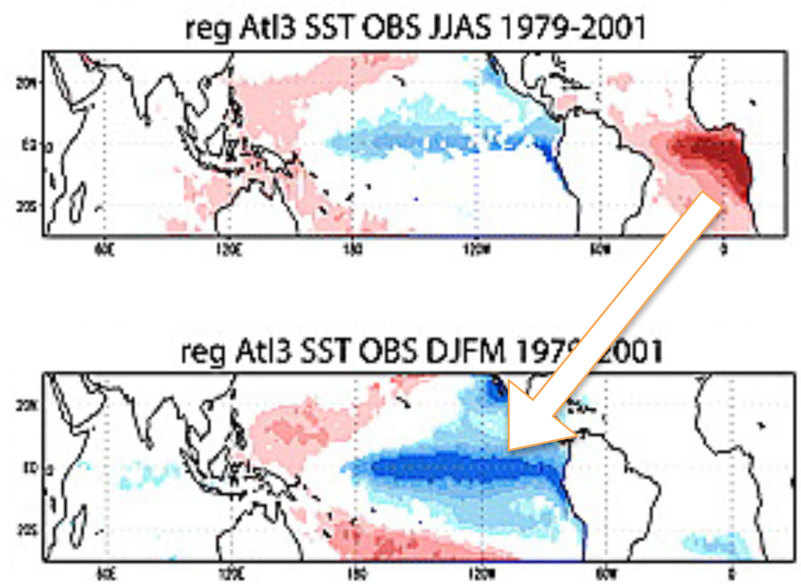
1) With sea ice cover assimilation (**ASSIM**)
2) Without assimilation (**NoASSIM**)



… which might be related to **improved NAO** predictive **skill**

Seasonal Prediction: Interbasin Teleconnections

Observed teleconnection of Atlantic Niño with winter NIÑO

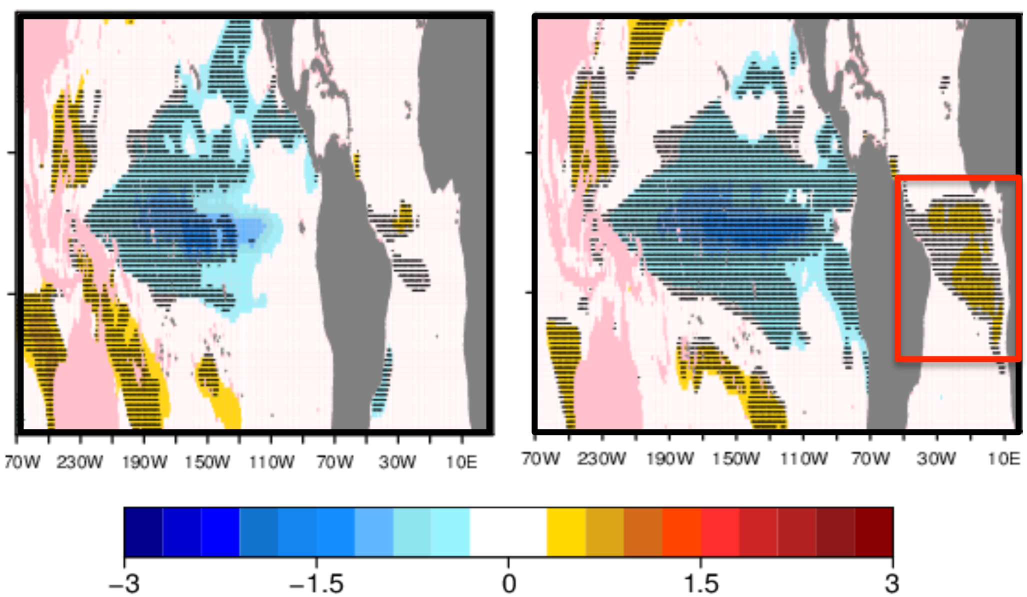


Rodriguez-Fonseca et al. (2009)

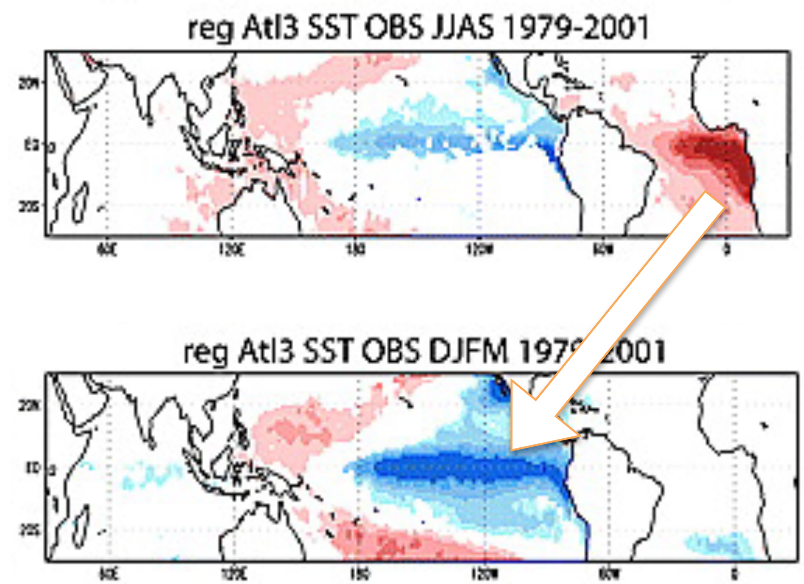
Regression JJA ATL3 vs OND T2M

Control

Wind forced in TA
(to correct the bias)



Observed teleconnection of Atlantic Niño with winter NIÑO

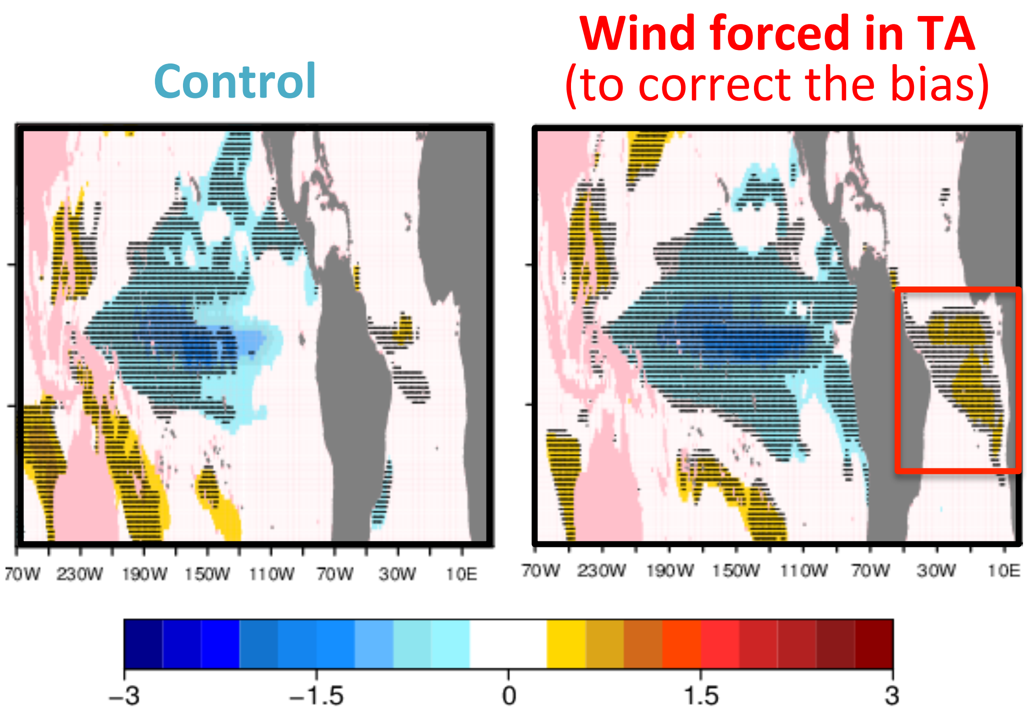


Rodriguez-Fonseca et al. (2009)

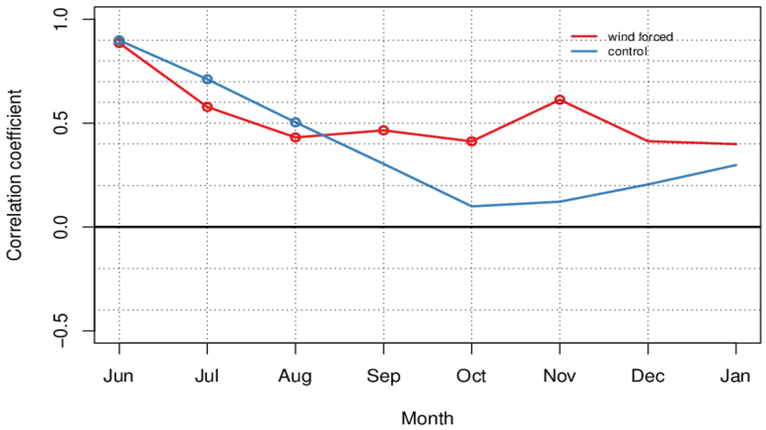
Seasonal Prediction: Interbasin Teleconnections

Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA

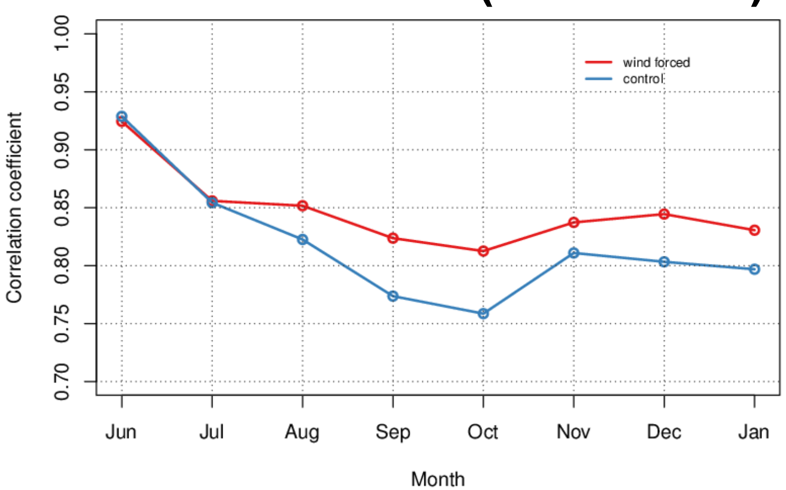
Regression JJA ATL3 vs OND T2M



Skill in ATL3 (1980-2009)



Skill in NIÑO3 (1980-2009)

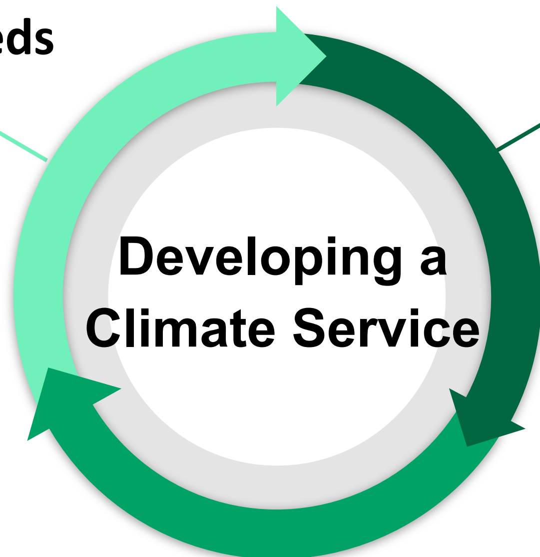


A **realistic** representation of **TA variability** can **improve** the skill in **ENSO**

Example of **climate service** for the agriculture sector: **wine yields**

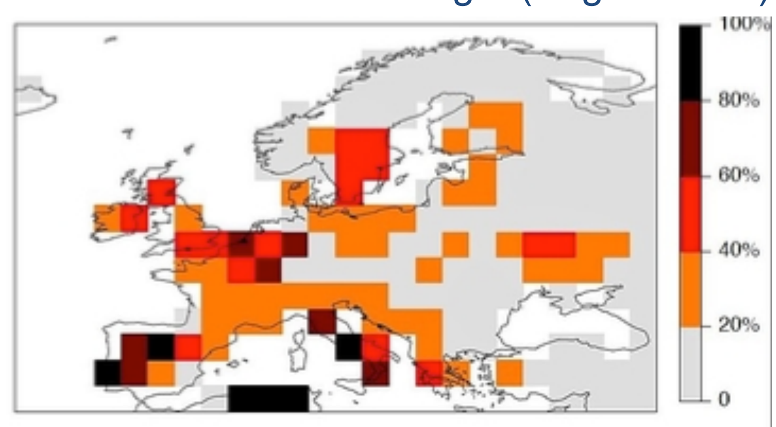
Engaging with the users to understand their needs

No se puede mostrar la imagen. Puede que su equipo no tenga suficiente memoria para abrir la imagen o que ésta esté dañada. Reinicie el equipo y, a



Scientific research and development of tailored indicators

Prediction of extreme drought (August 2017)



Tools and assessment of decision making processes

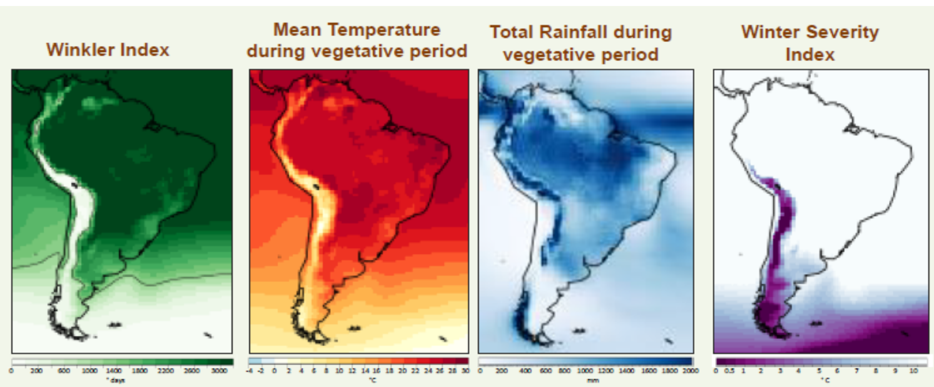
*Terrado, M., I. Christel, D. Bojovic, A. Soret and F. Doblas-Reyes (2017) "Climate change communication and user engagement: **a tool to anticipate climate change**". Published in Handbook of Climate Change Communication*

Decadal climate prediction → Climate Services II

Bodegas Torres (and other wineries) are looking for **new vineyard locations**

They have purchased high elevation terrains near the Pyrenees

They are considering South America, in areas with no current wine production



VIÑAS DEL VERO

SOGRAPE VINHOS

RAIMAT

CODORNÍU

Bodegas Torres is thus requesting **local climate information** (with uncertainty assessments) relevant for the **vegetative cycle of grapes**.

Other applications from climate prediction

Example of **climate service** for the agriculture sector: **wine yields**

Weather forecast	Climate predictions			Climate projections
	Sub-seasonal	Seasonal	Decadal	
1-15 days	10-60 days	1-15 months	2-30 years	20-100 years

Applications

Siting, choice of scion variety and rootstock.

Assessment of water needs

Grow cycle management

Pathogen pressure, abiotic stresses

Crop forcing

Productivity, quality

Wine style

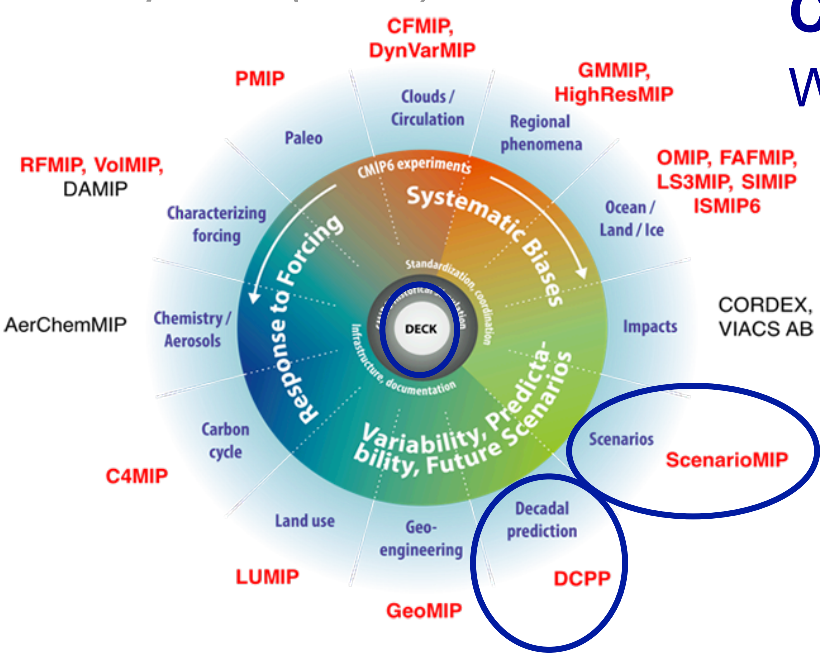
Harvest date and duration

Time

Adapted from: Antonio Graça, SOGRAPE VINHOS SA, 2014

Next decadal climate prediction activities

Simpkins (2017)



Contributions to CMIP6

With EC-Earth 3.2 in standard resolution (~1°)

DCPP Component A:
Retrospective Predictions [1960-2017]

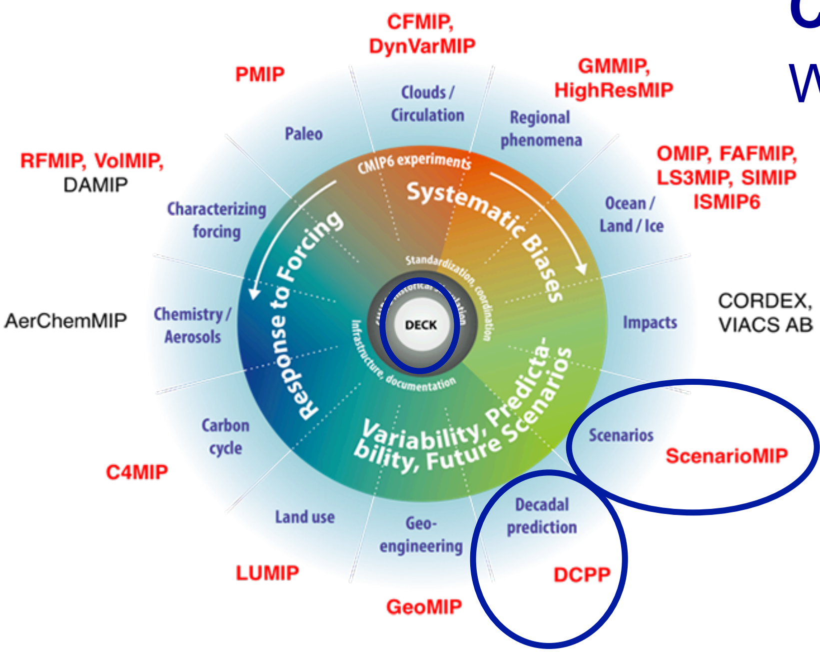
DCPP Component B:
Near-real time Forecasts [2018 onwards]

DECK+ScenarioMIP:
Historical+SPSS2-4.5 [1850-2100]

Next decadal climate prediction activities

Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA

Simpkins (2017)



Contributions to CMIP6

With EC-Earth 3.2 in standard resolution (~1°)

DCPP Component A:
Retrospective Predictions [1960-2017]

DCPP Component B:
Near-real time Forecasts [2018 onwards]

DECK+ScenarioMIP:
Historical+SPSS2-4.5 [1850-2100]

WCRP CMIP6
World Climate Research Programme

Other H2020 activities

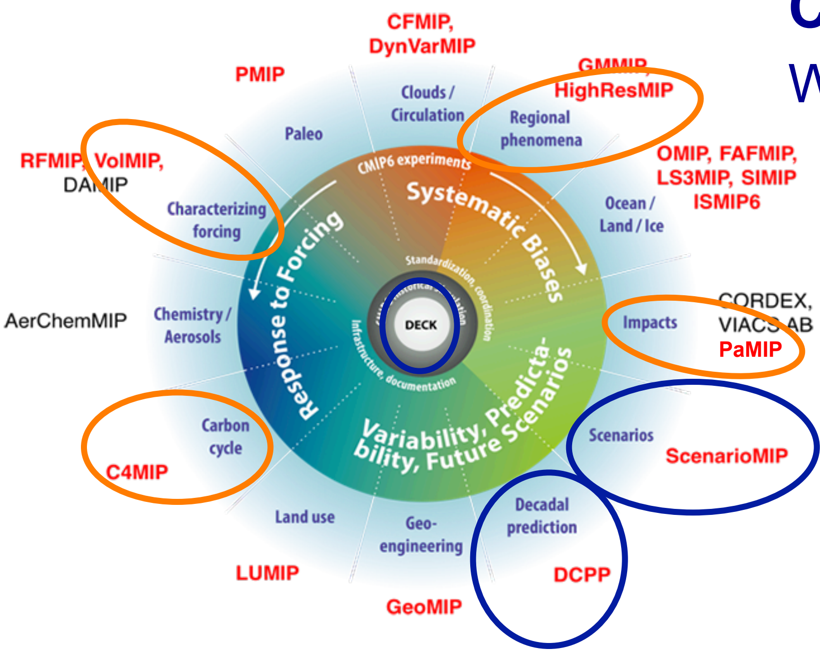
With EC-Earth 3.2 in high resolution (~0.25°)

EUCP
European Climate Prediction system

DCPP Component A-like:
Retrospective Predictions [1960-2017]

Next decadal climate prediction activities

Simpkins (2017)



Contributions to CMIP6

With EC-Earth 3.2 in standard resolution (~1°)

DCPP Component A:
Retrospective Predictions [1960-2017]

DCPP Component B:
Near-real time Forecasts [2018 onwards]

DECK+ScenarioMIP:
Historical+SPSS2-4.5 [1850-2100]

Other CMIP6 contributions

VolMIP: Evaluating the predictability associated to volcanoes

C4MIP: Investigating the predictability of the carbon cycle

HiResMIP: Determining the advantages of super high resolution (1/12°)

PaMIP: Constraining the long-term impacts due to Arctic Sea Ice decline

Concluding remarks

Climate Prediction relies on the **proper initialization** of regions with internal seasonal to multi-annual climate variability, usually associated with persistence in the ocean, land cover, sea ice and even the atmosphere.

Seasonal-to-Decadal Climate Predictions provide important **strategic information** to guide future decisions by **stakeholders and policymakers**

Coordinated prediction efforts, like the multi-model decadal predictions within CMIP6, will provide an invaluable framework to:

- identify the **regions/variables robustly predictable**

- better **understanding** the origin of **systematic errors**

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

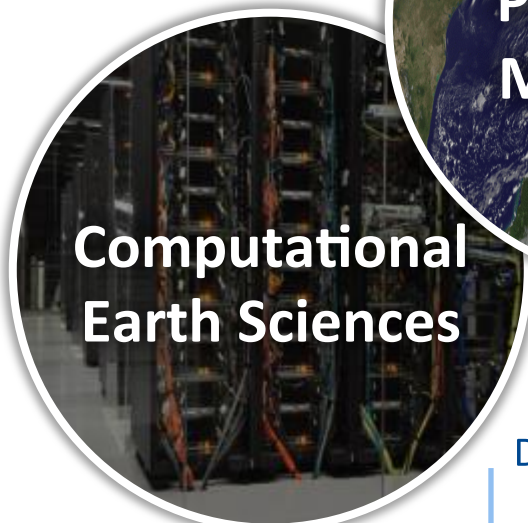
Thank you!

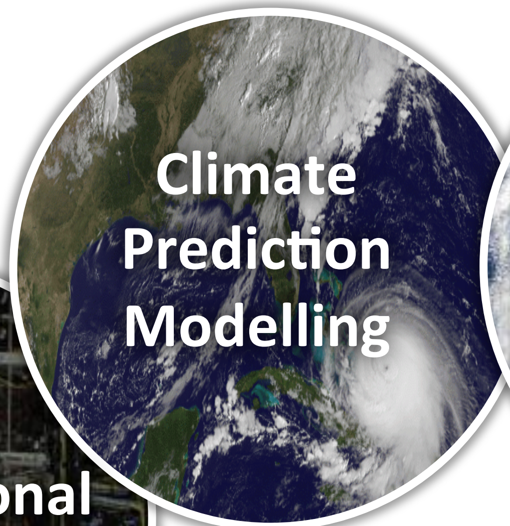
pablo.ortega@bsc.es

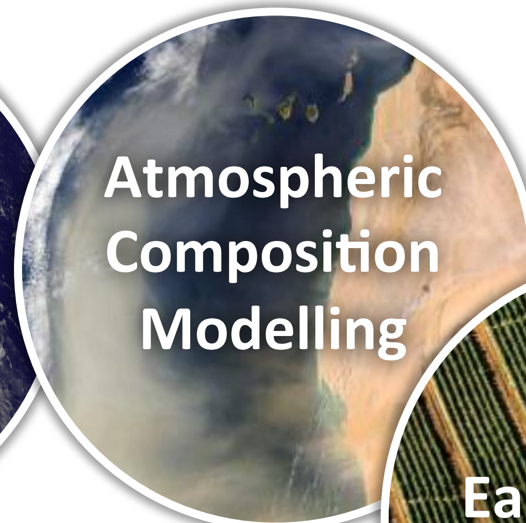
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Earth Science Department

Environmental modelling and forecasting, with a particular focus on weather, climate and air quality



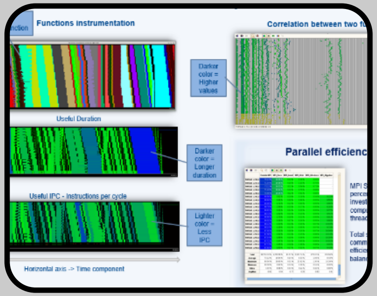




Director: **Francisco Doblas-Reyes**

- 72 people
- Leading: H2020 projects, COPERNICUS contracts, ERC Consolidator Grant and hosts an AXA Chair

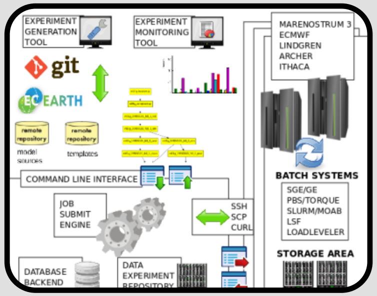
Computational Earth Sciences Work Lines



Performance Team

Performance analysis and optimizations for **parallel computing**

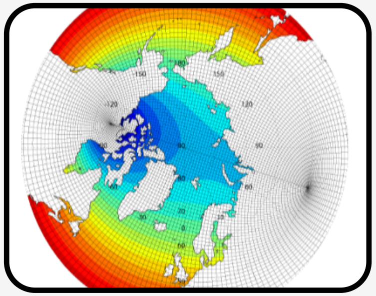
Development of **new computational methods** and **optimizations** for Earth System Models.



Models and Workflows Team

Development of HPC **user-friendly software framework**

Support the development of **atmospheric research software**



Data and Diagnostics Team

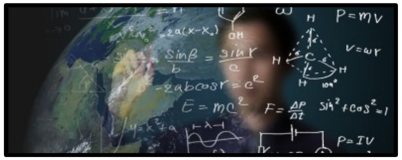
Big Data and **machine learning** research for Earth Sciences

Provision of **data services**

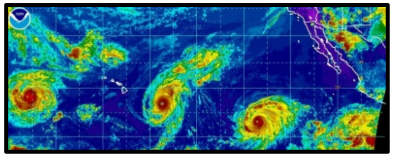
Improvement of **visualization tools**

Climate Prediction Research Lines

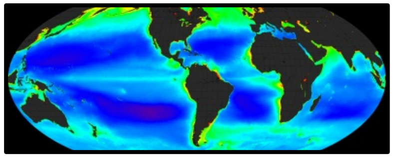
Sea ice and ocean variability, **prediction** and impacts



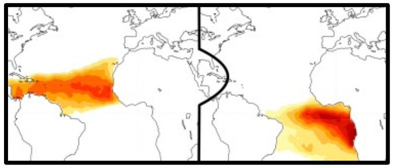
Climate model **initialization** and data **assimilation**



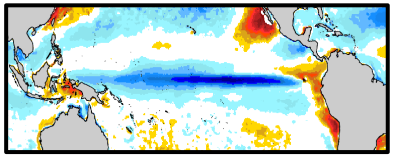
Tropical **cyclones**



Ocean **biogeochemistry** and climate feedbacks



Inter-basin teleconnections



Bias development and **initial shock** mechanisms

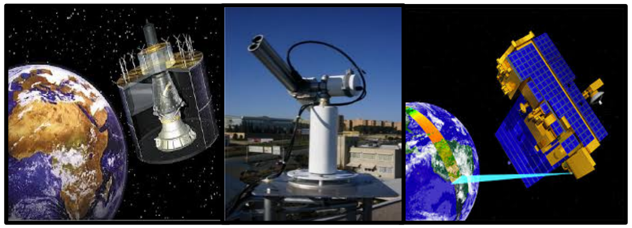
Atmospheric Composition Research Lines

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

EXCELENCIA SEVERO OCHOA

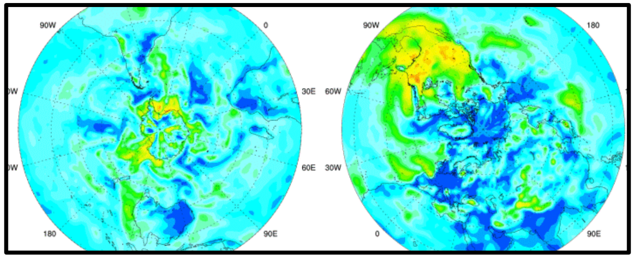
Development of high-quality and high-resolution **emission models** of primary gases and aerosols

Prediction and understanding of the behaviour of **pollutants in the atmosphere,** with special emphasis on **urban areas**



Assimilation of observations into atmospheric chemistry models

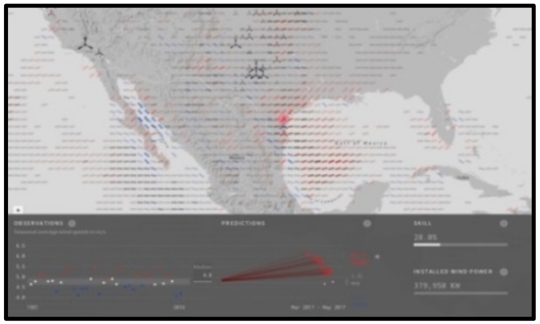
Assessment of **sand and dust storm** impacts upon key sectors of society and economy



Impact of **aerosol-radiation-cloud interactions** upon weather forecasts and regional climate

Earth System Services Research Lines

Knowledge and Technology Transfer



Prediction tools/**visualization**

Dissemination material

Climate Services

Wind energy

Agriculture

Air quality Services

Urban development

Dust Storms

Job Opportunities at BSC

https://www.bsc.es/about-bsc/employment/vacancies

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Job Opportunities:

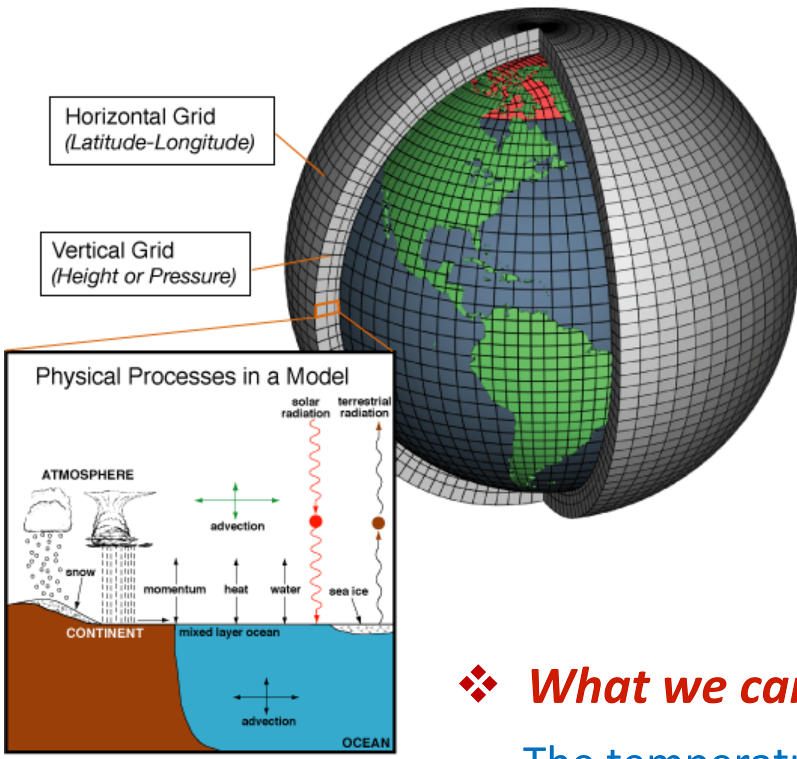
- AC: PhD on soil dust emission: field campaigns, theory & modeling
- CP: Climate Forecaster (post-doc)
- ESS: Air quality Analyst (post-doc)

Potential topics for research internships:

- Analysis and evaluation of HR air quality simulations over coastal areas: identification of limiting factors concerning the meteorology and chemistry (AC)
- Simulation and evaluation of particulate matter concentrations at surface level from global aerosol models (AC).
- Analysis of the uncertainties in the observational products of ocean biogeochemistry: primary production, carbon uptake (CP)
- Sensitivity of prediction skill to the initialization of the coupler (CES,CP)
- Testing the reliability of atmospheric nudging in the CMIP6 coupled version of EC-Earth (CES,CP)

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Weather vs Climate predictions



Coupled climate model

(atmosphere + land + ocean + sea ice)

initialised with current observations

Predictions for the next few week/ season

❖ ***What we can NOT expect from climate predictions***

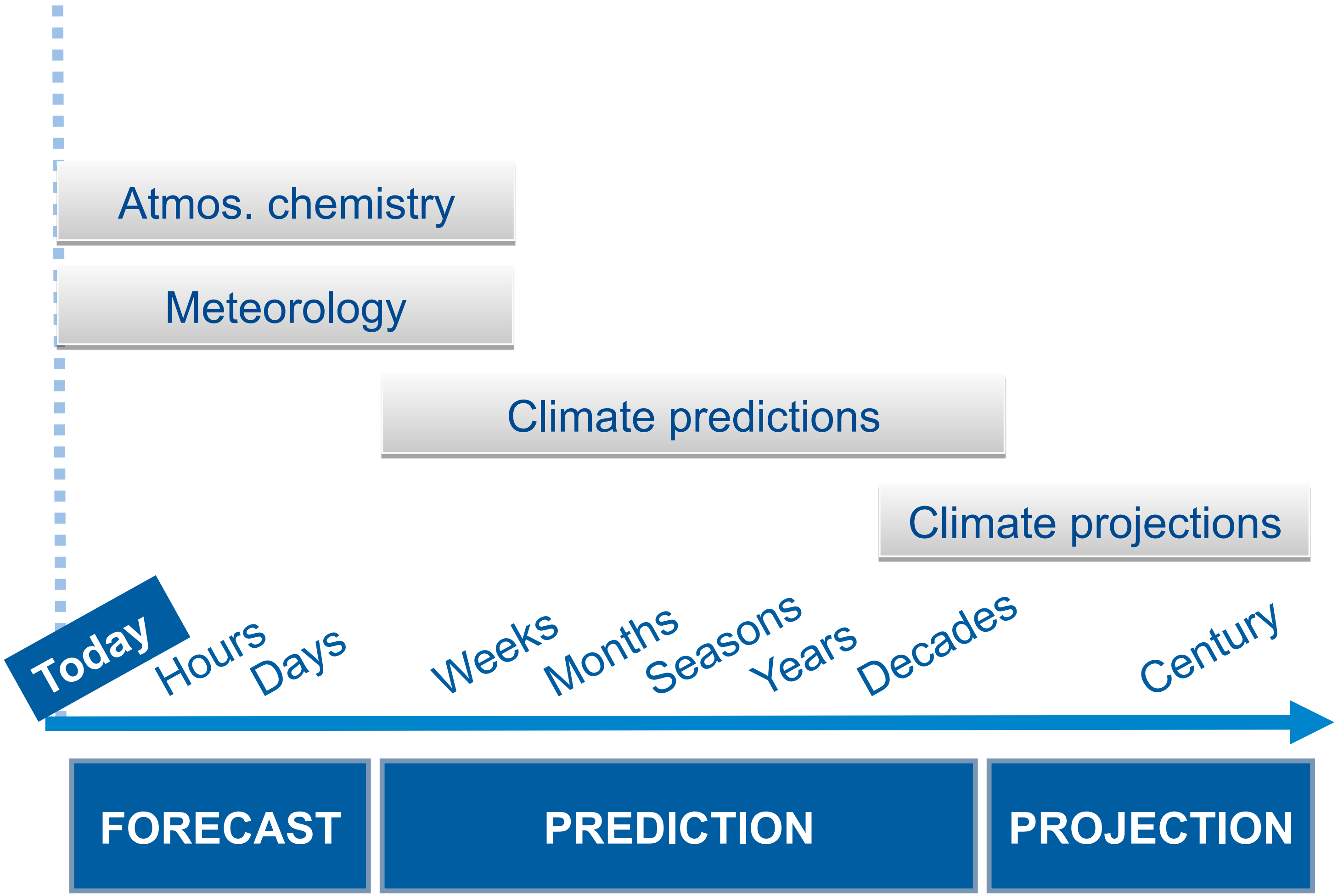
The temperature in Albacete on 27th February

✓ ***What we can expect from climate predictions***

How likely next winter is going to be colder/warmer than normal

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Temporal Scales



Barcelona Supercomputing Center
Centro Nacional de Supercomputación

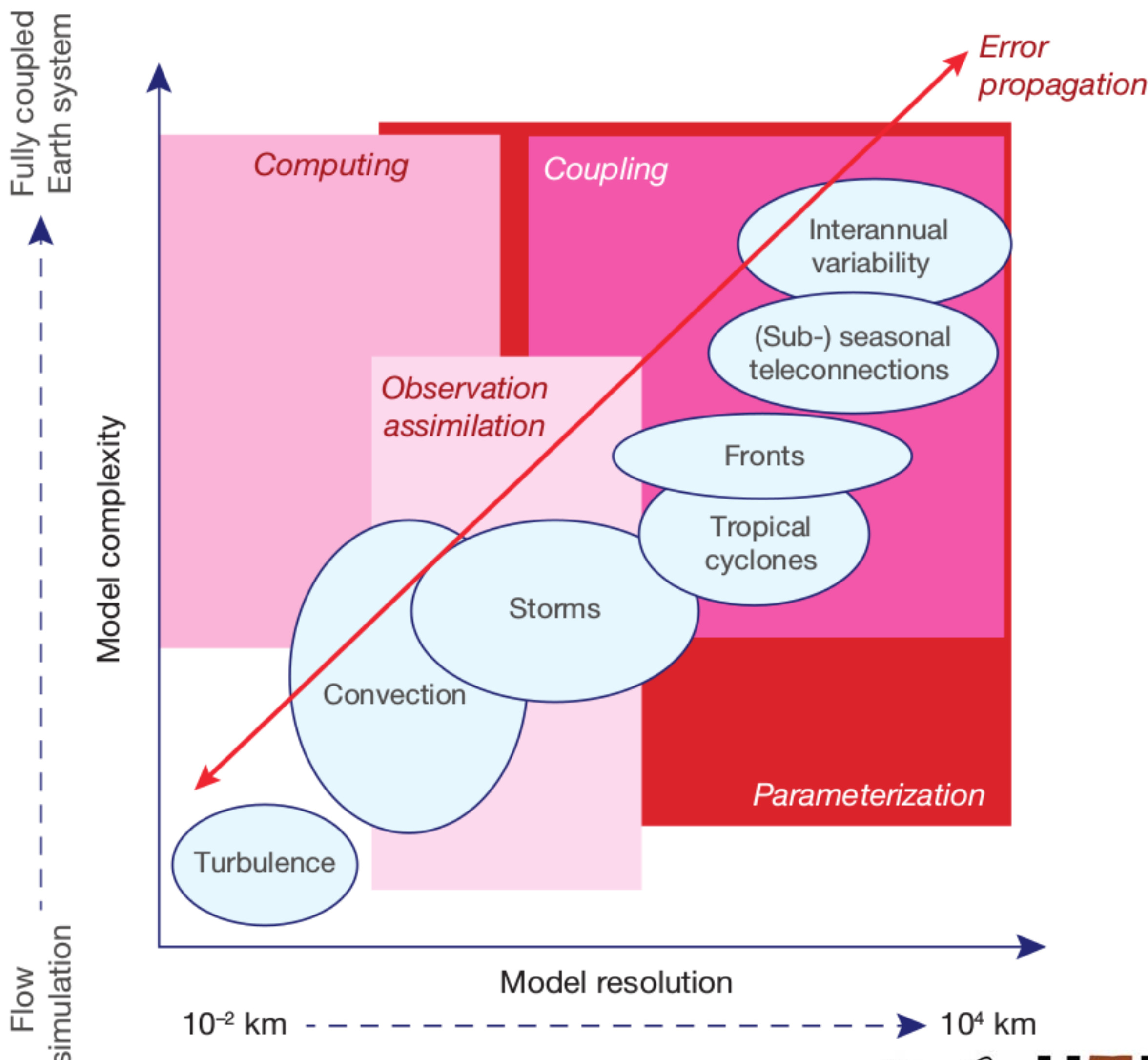
Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA

WCRP
World Climate Research Programme

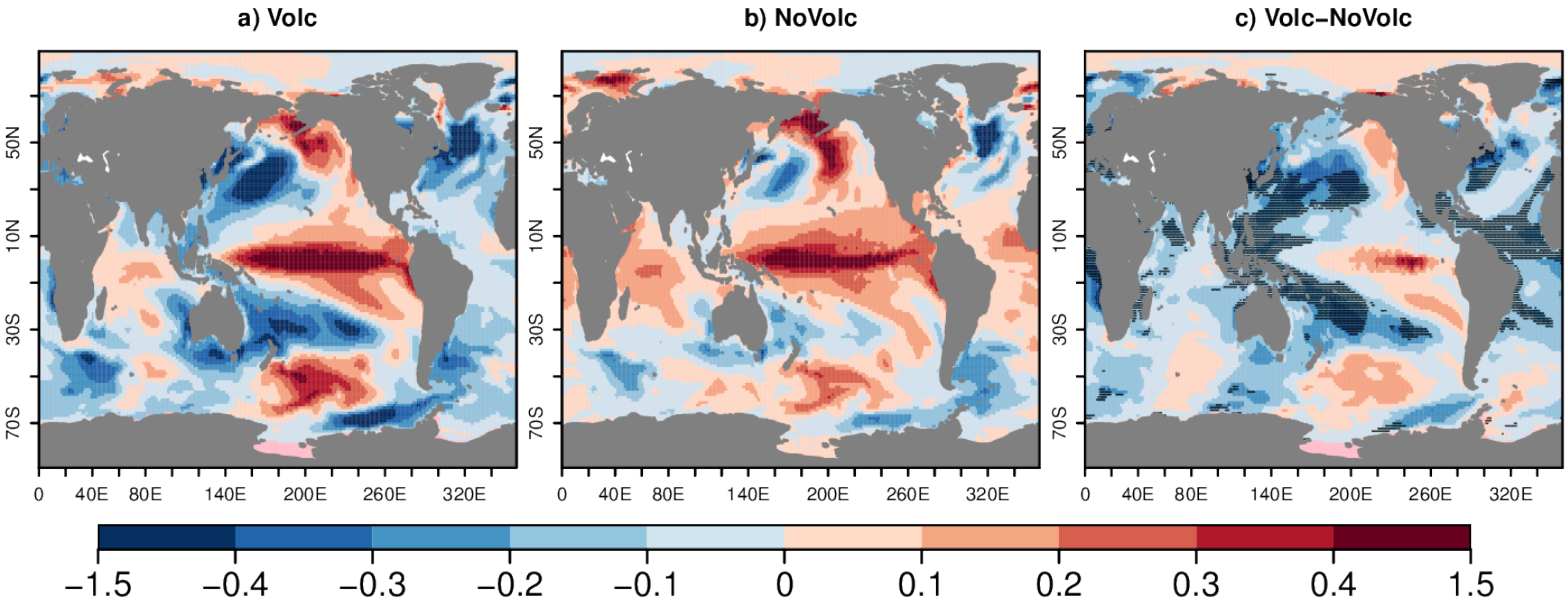
Near-Term Climate Prediction

The Grand Challenge on Near-Term Climate Prediction will support research and development to improve multi-year to decadal climate predictions and their utility to decision makers. It will furthermore support the development of organizational and technical processes for future routine provision of decadal prediction services that can assist stakeholders and decision-makers.

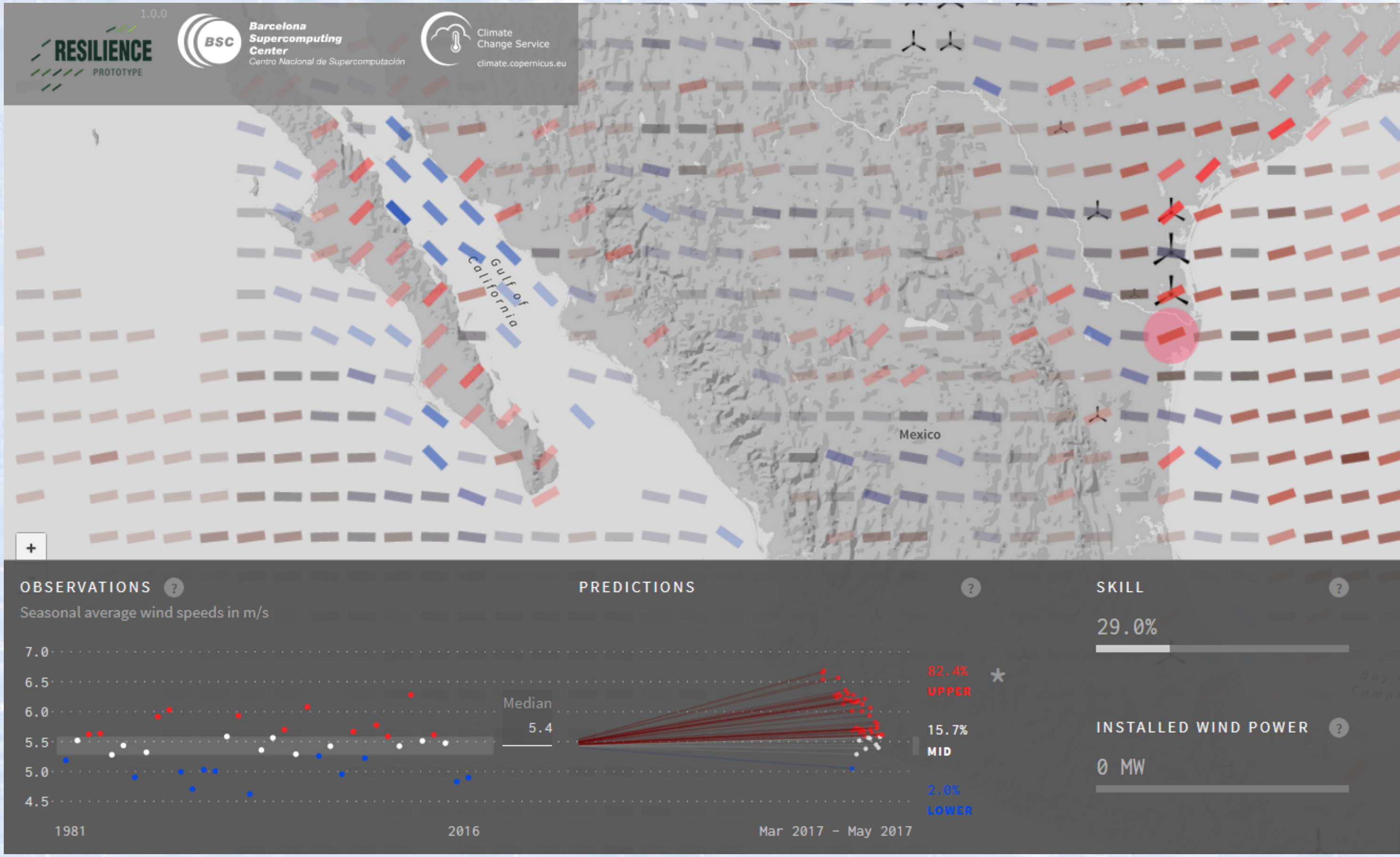
Increment of resolution



Mean SST anomaly - first forecast year following the Agung (1963), El Chichon (1982) and Pinatubo (1991) eruptions in EC-EARTH2.3 decadal hindcasts. Stippling 95% statistically significant differences.



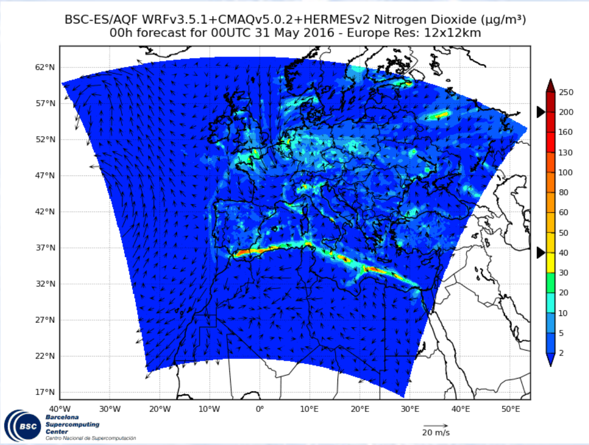
RESILIENCE prototype for wind

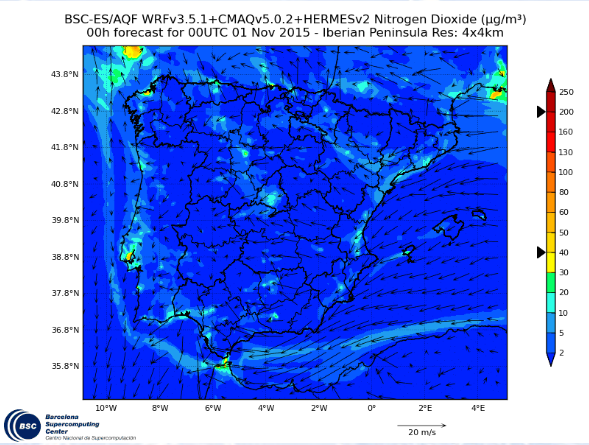


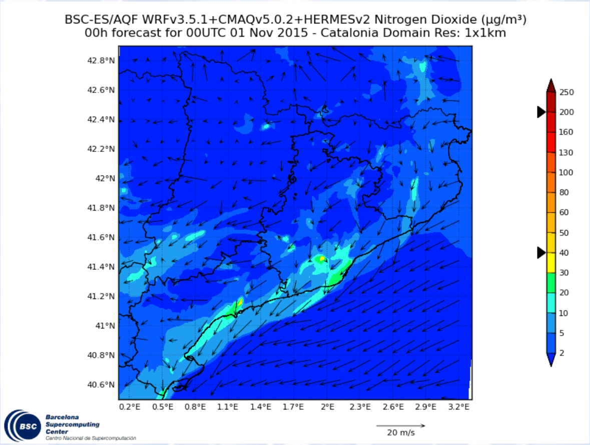
http://www.bsc.es/ess/resilience/

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

CALIOPE air quality operational forecast

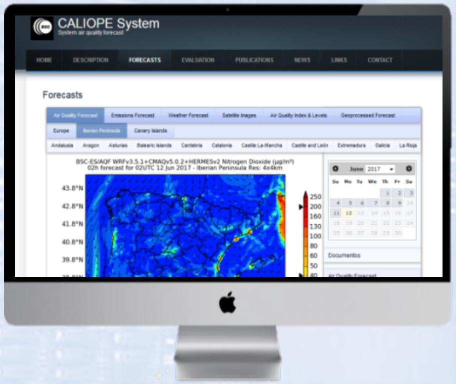


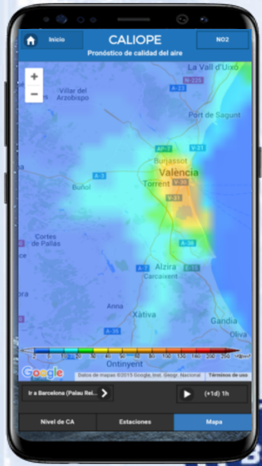




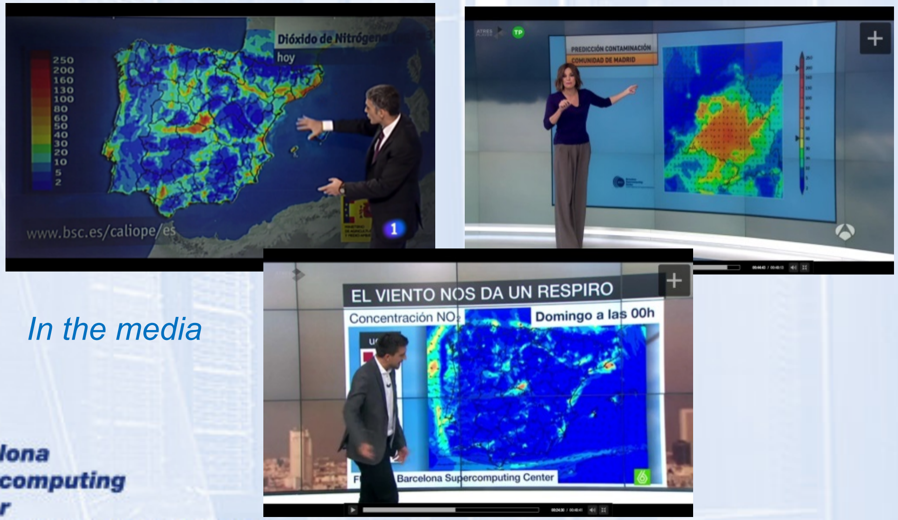
Multiscale models from global to local scales

Web / App





In the media



Seasonal predictions for hurricanes

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

www.seasonalhurricanepredictions.org