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Climate Prediction and Earth System Services



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Earth System Services Group**



Barcelona, 4 February, 2016

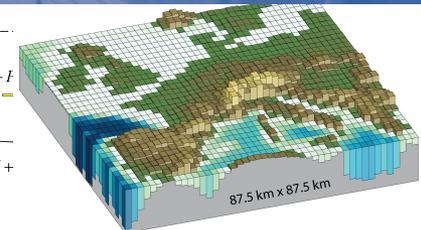
$$\frac{d\vec{v}}{dt} = -2 \cdot \vec{\Omega} \times \vec{v} -$$

$$\frac{dT}{dt} = \frac{R \cdot T \cdot \omega}{c_p p_s \sigma} + f$$

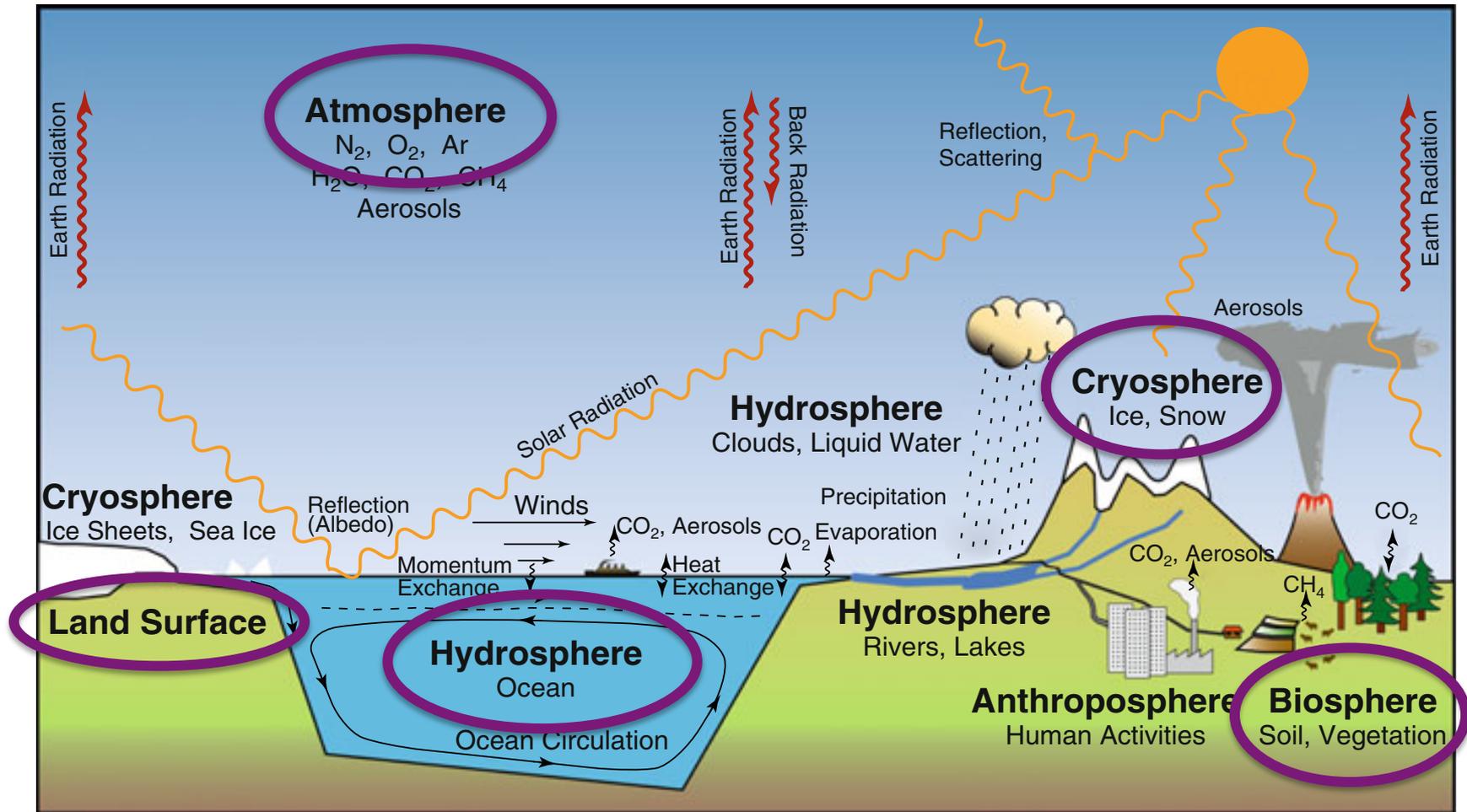
$$\frac{dq}{dt} \approx \frac{p_q}{p_s}$$

$$\frac{dp_s}{dt} = p_s \cdot (\vec{\nabla} \cdot \vec{v} +$$

$$\frac{d\Phi}{d\sigma} = -\frac{R \cdot T}{\sigma}$$



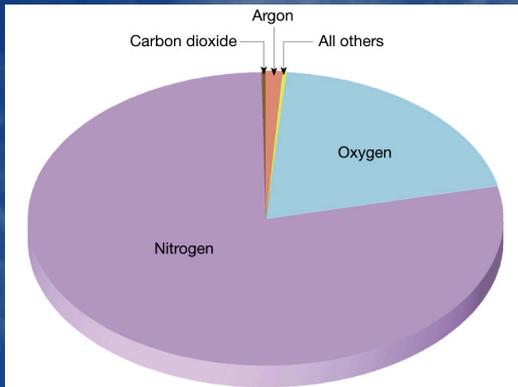
Earth climate system



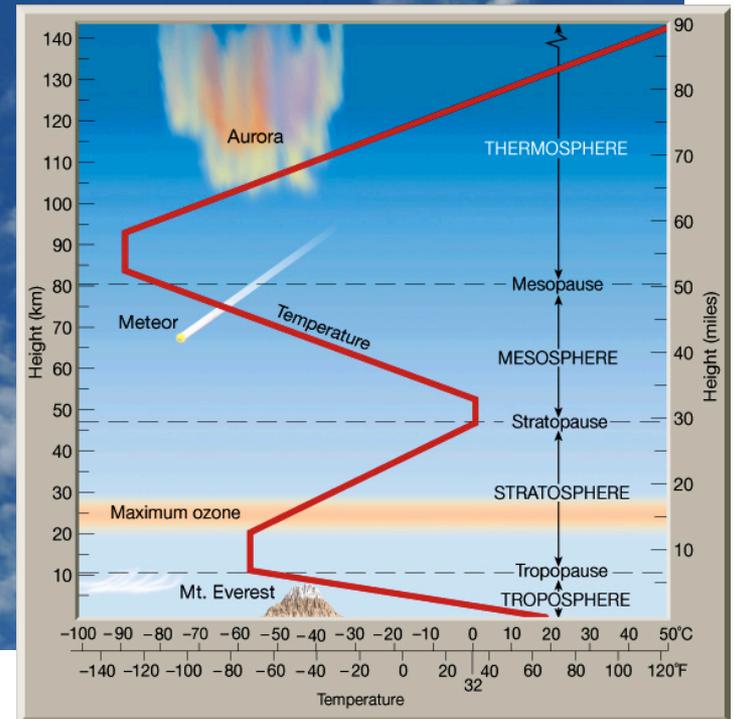
The Earth's climate is a complex nonlinear system that is constituted of **five interactive components** primarily driven by the solar energy

Atmosphere

Gaseous part (N_2 , O_2 and Ar) above the surface including trace amounts of other gaseous (CO_2 , CH_4 , ...), liquid and solid substance (H_2O , ...).



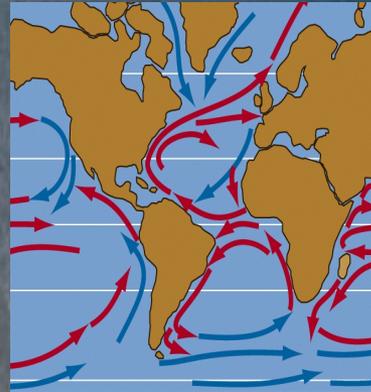
Stratopause \approx
50 km \ll 6378 km
= radius of Earth



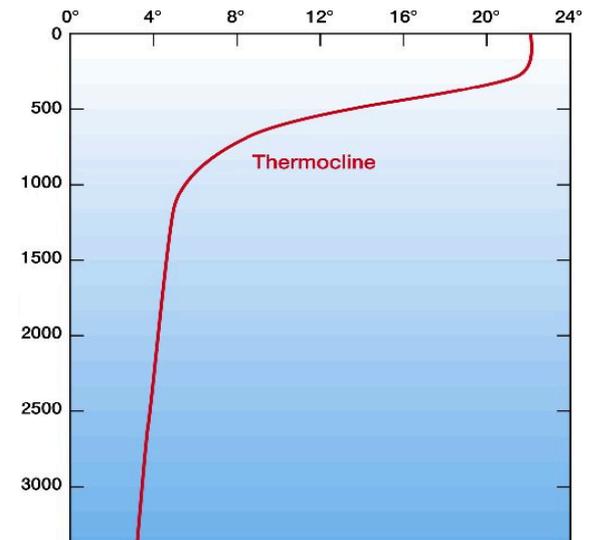
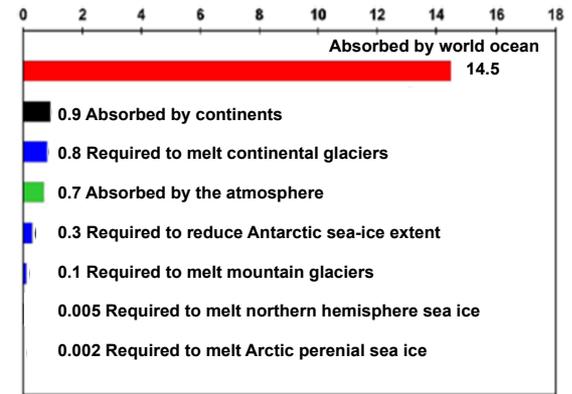
Hydrosphere (oceans + lakes + rivers + groundwater)

All reservoirs of liquid water above and below the surface (in the crust)

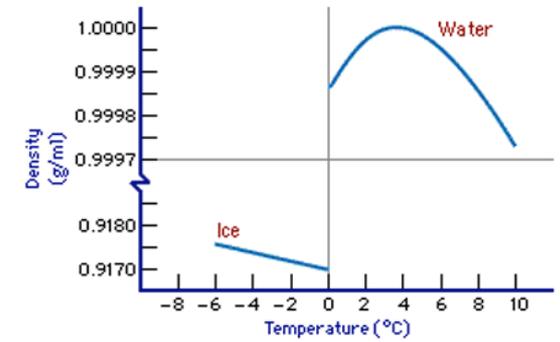
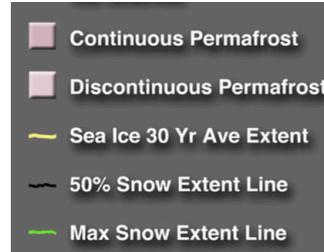
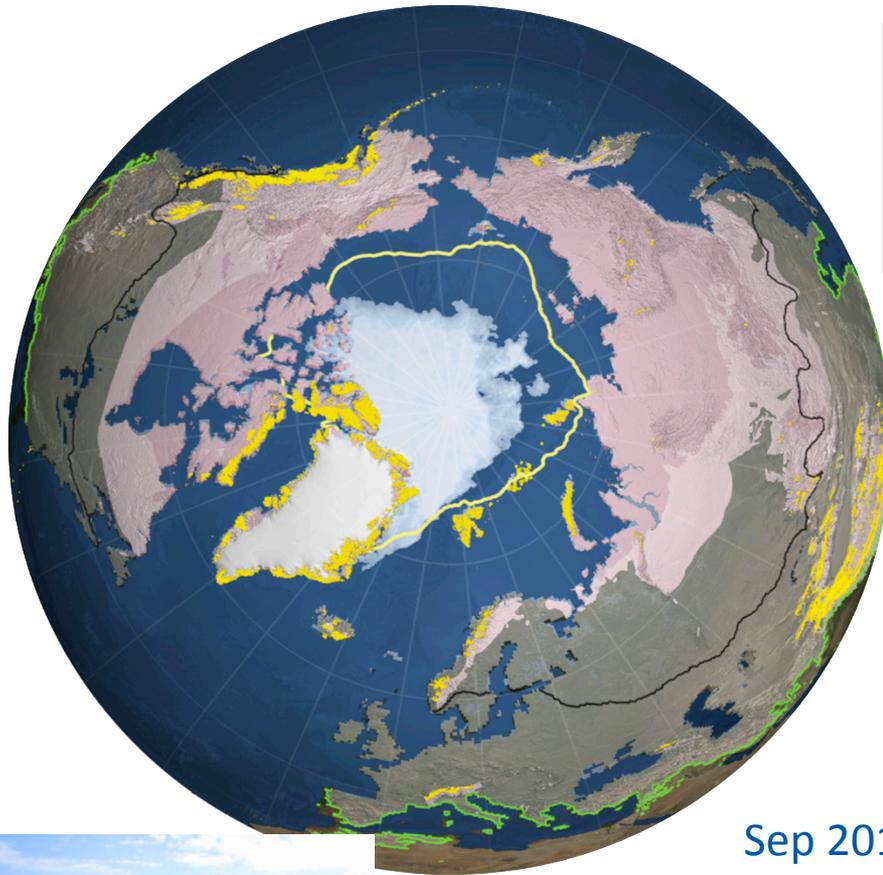
The oceans are main source of moisture and key reservoirs of heat and carbon.



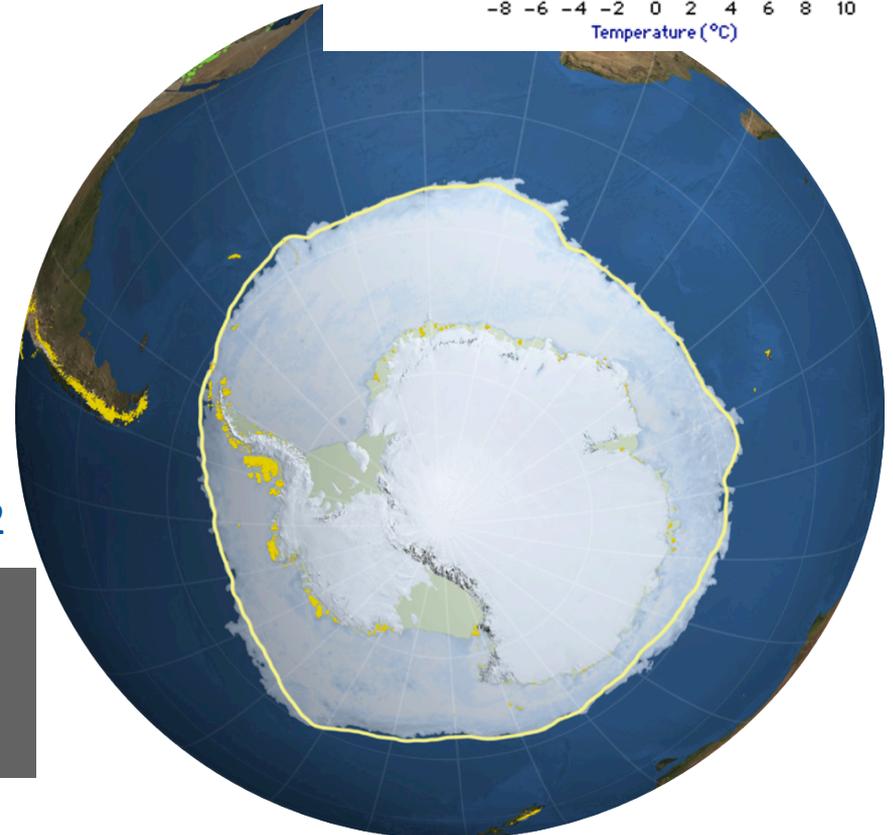
Estimates of Earth's heat balance components (10^{22} J) for 1955-1998 period (Levitus, et al., 2005).



Cryosphere (sea ice, snow, glaciers, permafrost, ..)



Sep 2012



Land surface and biosphere

Focus on land surface hydrology
Organic cover of the land masses



Mount St. Helens, Washington, USA

[download large image](#) (5 MB, JPEG, 4108x4166)

acquired August 20, 2013



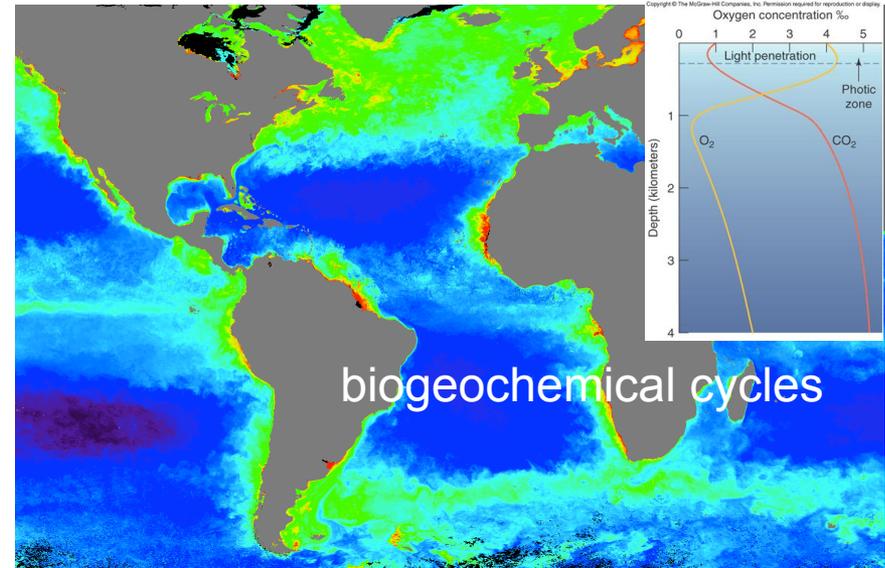
[download large image](#) (1 MB, JPEG, 2054x2083)

acquired June 17, 1984

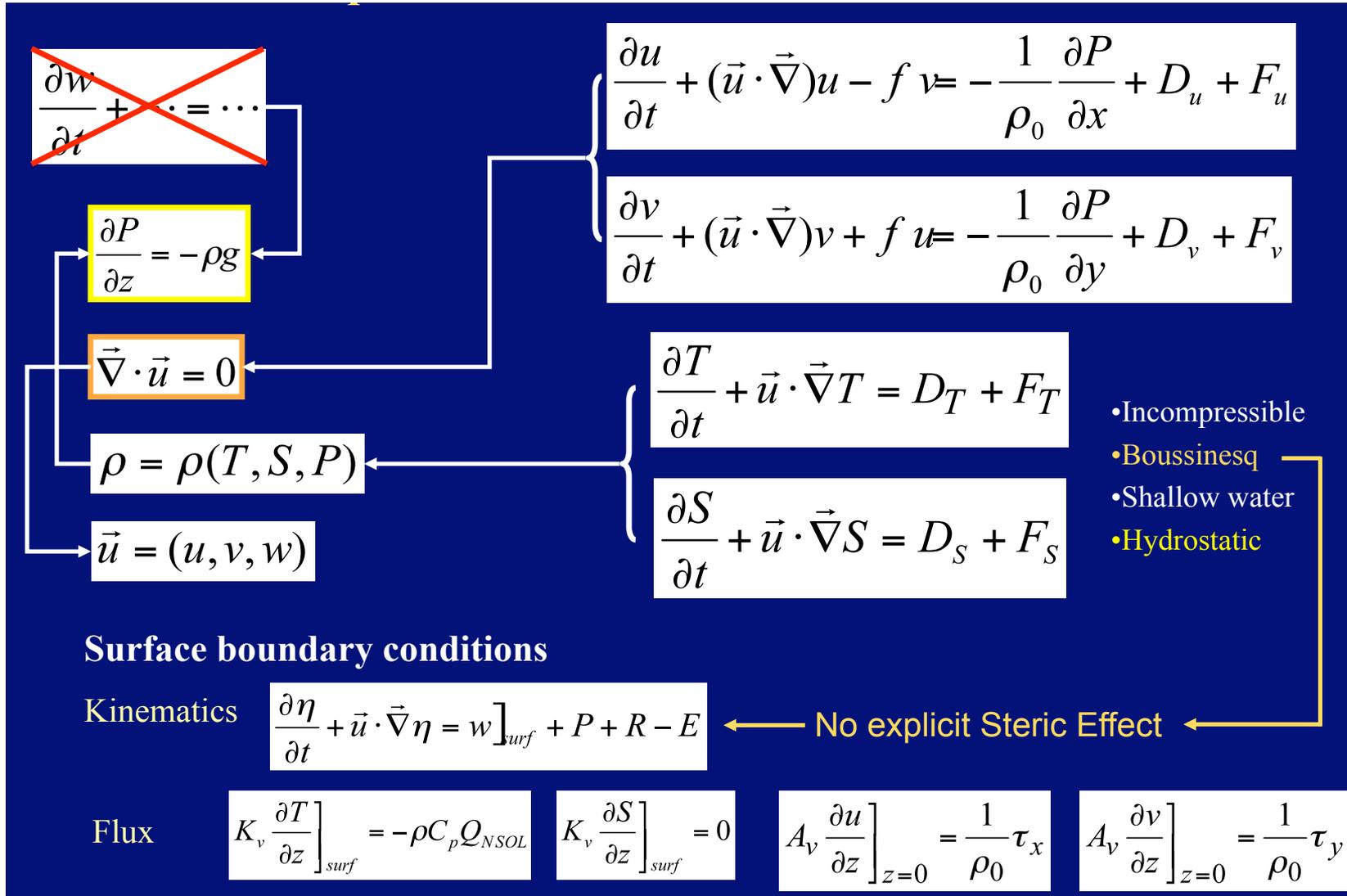
and marine organisms



focus on evapotranspiration and



Governing conservation equations → dynamical models



Numerical (approximative) models

$$\frac{D_r u}{Dt} - \frac{uv \tan \phi}{r} - 2\Omega \sin \phi v + \frac{c_{pd} \theta_v}{r \cos \phi} \frac{\partial \Pi}{\partial \lambda} = \boxed{-\left(\frac{uw}{r} + 2\Omega \cos \phi w\right)} + S^u$$

$$\frac{D_r v}{Dt} + \frac{u^2 \tan \phi}{r} + 2\Omega \sin \phi u + \frac{c_{pd} \theta_v}{r} \frac{\partial \Pi}{\partial \phi} = \boxed{-\left(\frac{vw}{r}\right)} + S^v$$

$$\boxed{\frac{D_r w}{Dt}} + c_{pd} \theta_v \frac{\partial \Pi}{\partial r} + \frac{\partial \Phi}{\partial r} = \boxed{\left(\frac{u^2 + v^2}{r}\right) + 2\Omega \cos \phi u} + S^w$$

Atmospheric momentum equations in spherical coordinates
 → impossible to solve analytically under realistic conditions

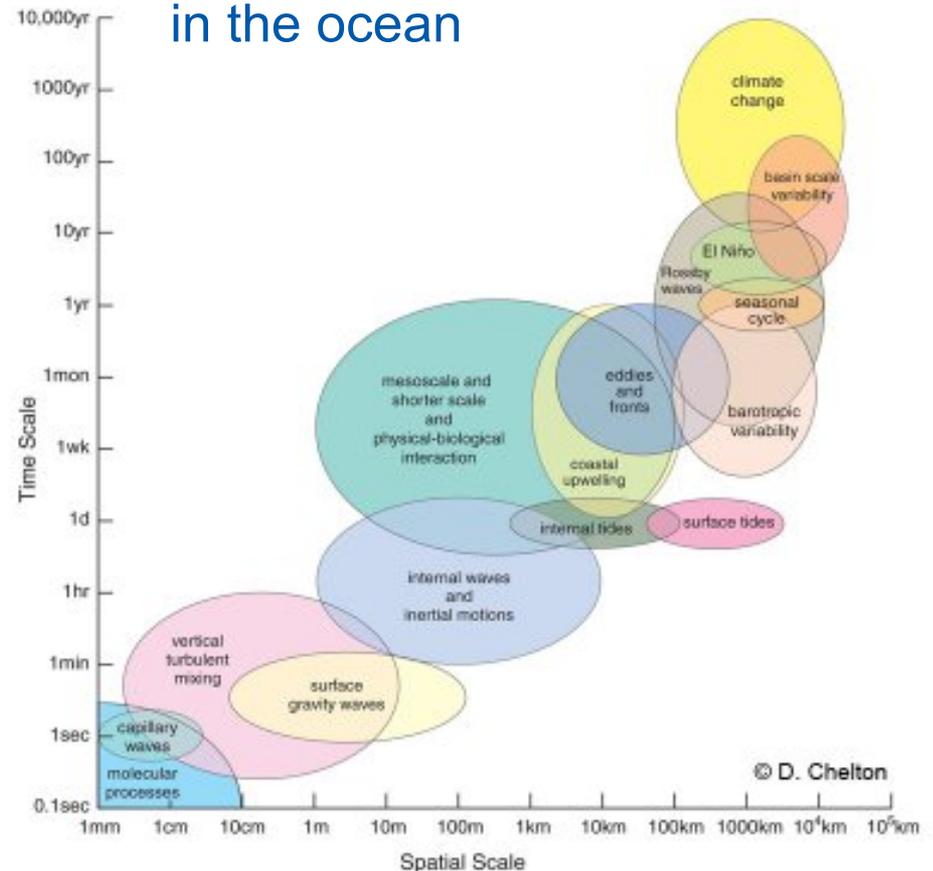
- **Discretization and numerical methods are needed to solve the governing equations of the climate system, i.e., to make weather and climate predictions**

$$\frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x} = 0 \quad \longrightarrow \quad C_{m,n+1} = C_{m,n} - \frac{u \Delta t}{2 \Delta x} (C_{m+1,n} - C_{m-1,n}).$$

Some characteristic time and spatial scales

Component of the Climate System	Process	Characteristic time scale	Characteristic spatial scale
Atmosphere	Collision of droplets during cloud formation	10^{-6} – 10^{-3} s	10^{-6} m
	Formation of convection cells	10^4 – 10^5 s	10^2 – 10^4 m
	Development of large-scale weather systems	10^4 – 10^5 s	10^6 – 10^7 m
	Persistence of pressure distributions	10^6 s	10^6 – 10^7 m
	Southern Oscillation	10^7 s	10^7 m
	Troposphere–stratosphere exchange	10^7 – 10^8 s	global
Hydrosphere	Gas exchange atmosphere–ocean	10^{-3} – 10^6 s	10^{-6} – 10^3 m
	Deep water formation	10^4 – 10^6 s	10^4 – 10^5 m
	Meso-scale oceanic gyres	10^6 – 10^7 s	10^4 – 10^5 m
	Propagation of Rossby waves	10^7 s	10^7 m
	El Niño	10^7 – 10^8 s	10^7 m
	Turnover of deep water	10^9 – 10^{10} s	global
Cryosphere	Formation of permafrost	10^7 – 10^9 s	1 – 10^6 m
	Formation of sea ice	10^7 – 10^8 s	1 – 10^6 m
	Formation of land ice masses	10^8 – 10^{11} s	10^2 – 10^7 m
Land surface	Changes in reflectivity	10^7 – 10^8 s	10^2 m – global
	Isostatic equilibration of the crust by covering ice masses	10^8 – 10^{11} s	10^6 m – global
Biosphere	Exchange of carbon with the atmosphere	10^4 – 10^8 s	10^{-3} m – global
	Transformation of vegetation zones	10^9 – 10^{10} s	10^2 – 10^7 m

Spatial and temporal scales in the ocean

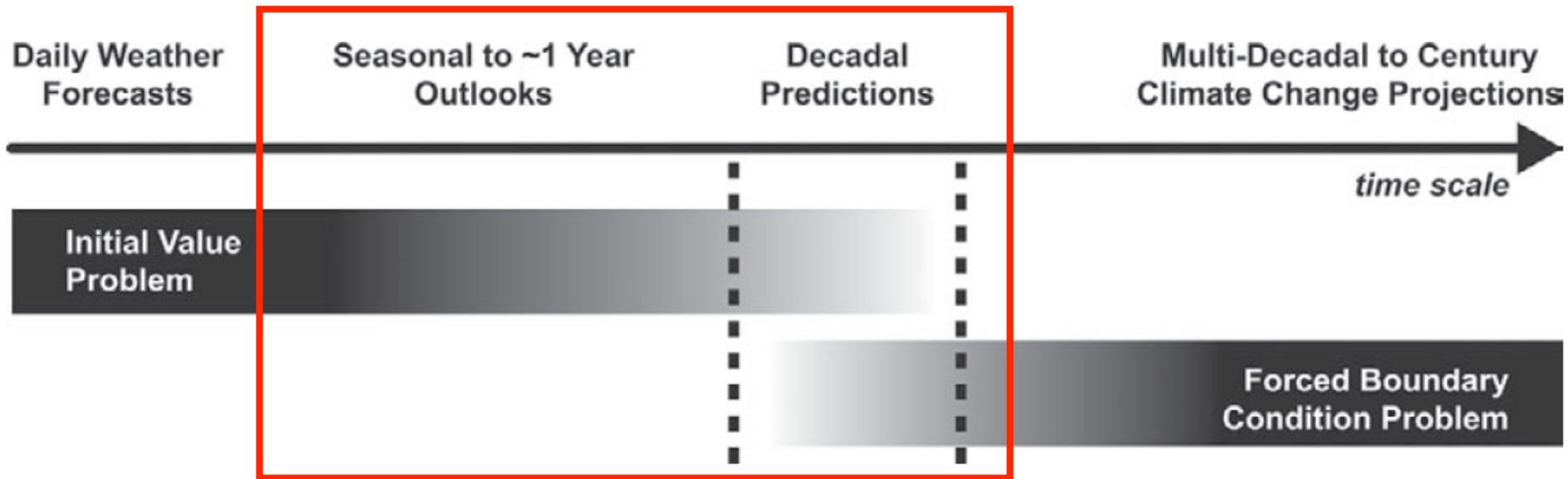


Filtering of fast processes is key for stable integration of climate models

Climate time scales → climate prediction

Medium-range weather forecast – hourly to daily forecasts up to 2 weeks ahead

Climate predictions group focuses on weekly to annual forecasts on sub-seasonal (<3 months), seasonal (3-6 months), inter-annual (multi-year) and multi-decadal times scales up to 30 years ahead



Range where memory of the initial state and boundary forcing are both critical.

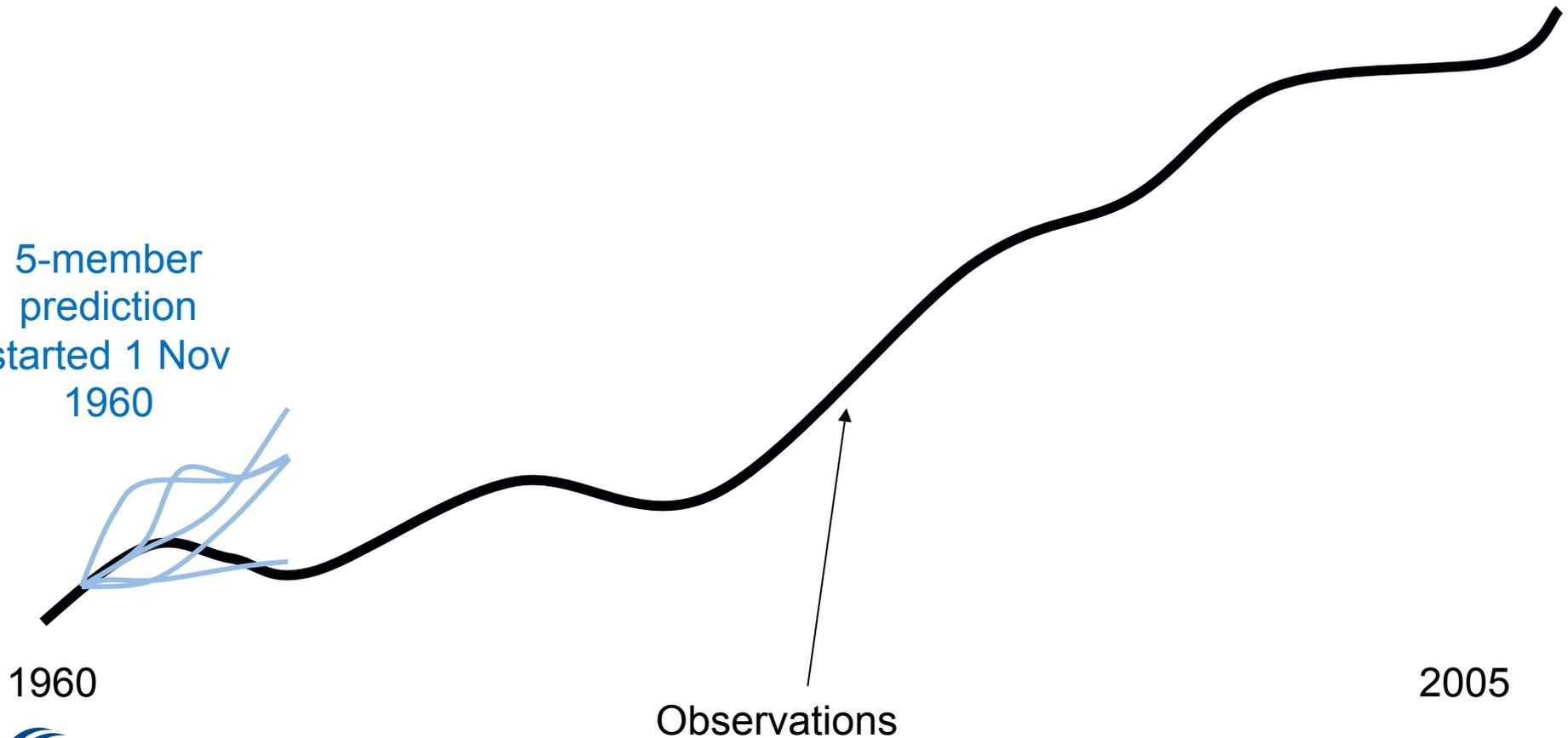
Climate system predictability

- Key climate memory (initial conditions=**IC**) on seasonal to inter-annual timescales is in the **sea ice** and **land surface (snow cover and soil moisture)**
- Key climate memory (**IC**) on inter-annual to centennial timescales is in the **ocean (SST, mixed layer heat content, ..)**
- **External radiative forcing and atmospheric composition** (solar activity, greenhouse gases, aerosols)
→ dynamic boundary conditions (BC) are crucial along with static BC (topography + bathymetry)

Methodology of using HPC model for climate prediction

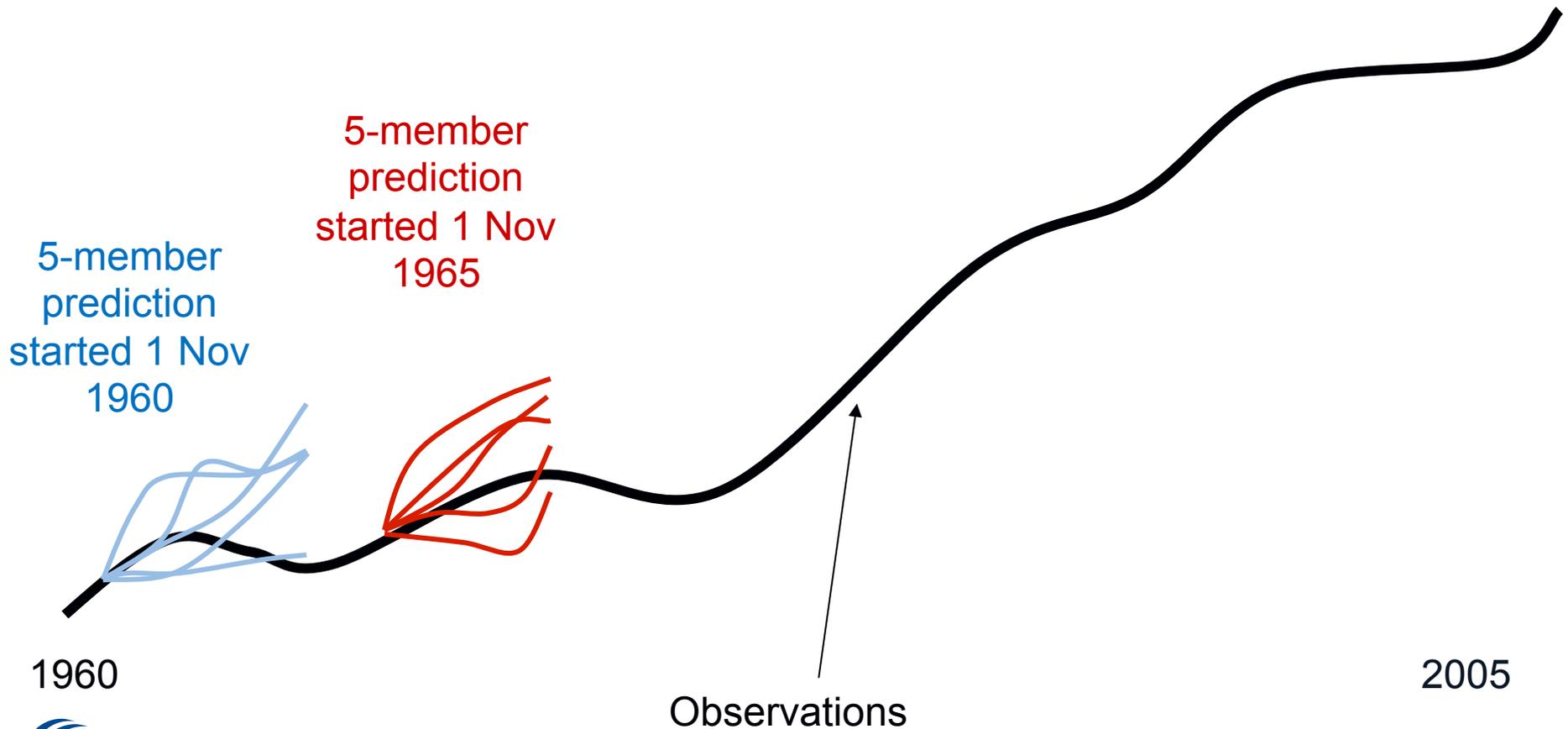
Experimental setup : 1 grid-point

5-member
prediction
started 1 Nov
1960



Methodology of using HPC model for climate prediction

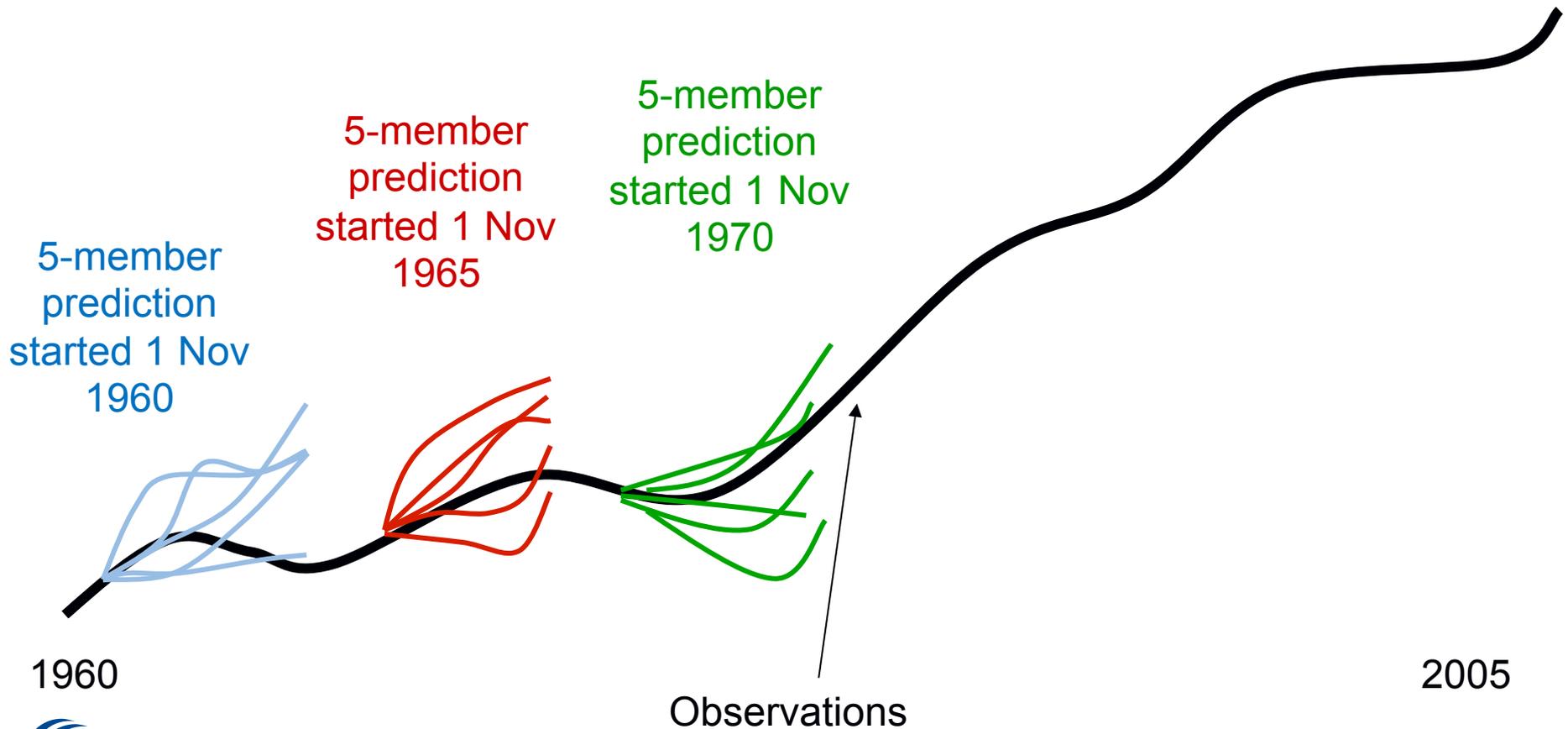
Experimental setup : 1 grid-point



Methodology of using HPC model for climate prediction

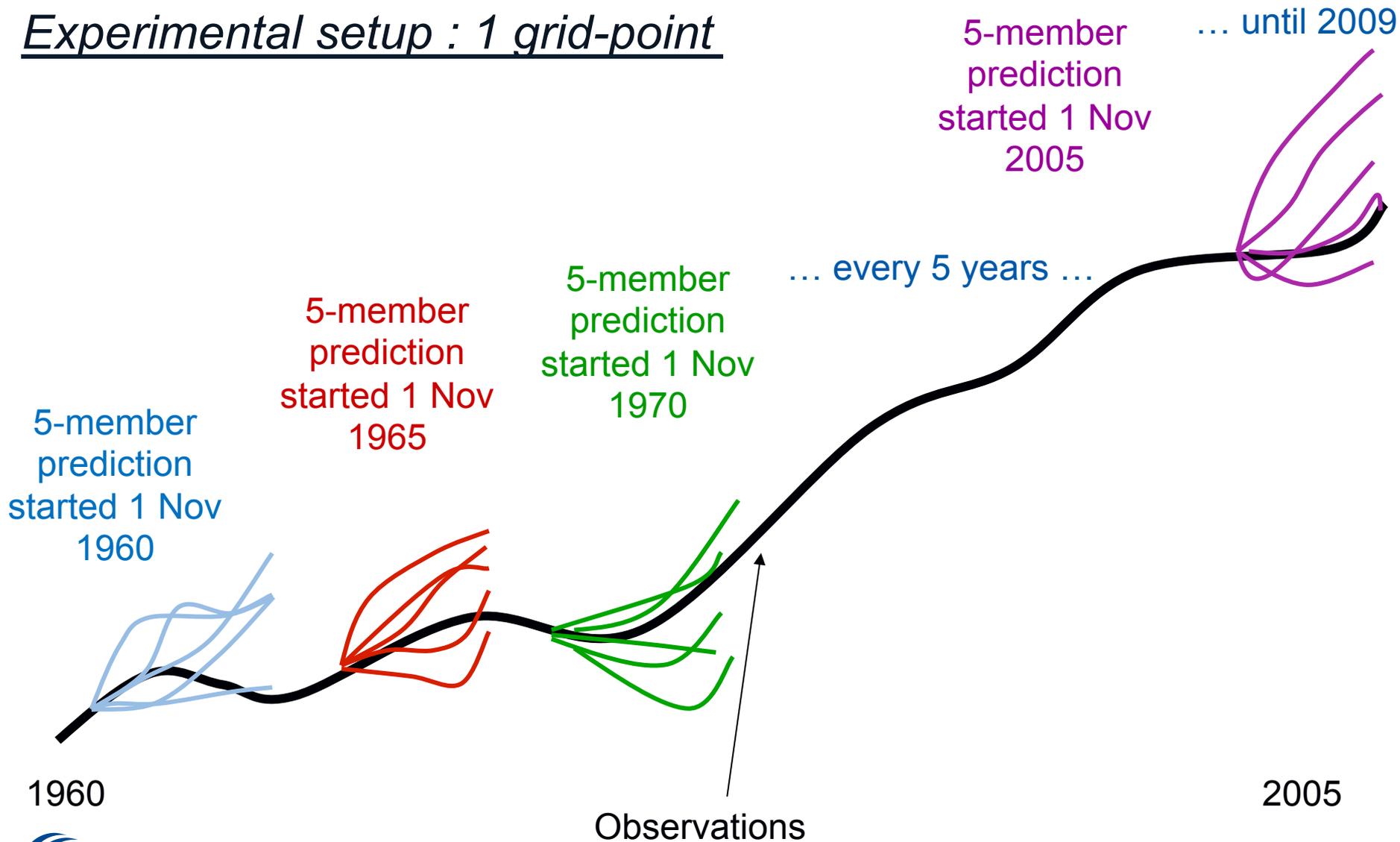
Experimental setup : 1 grid-point

... until 2009



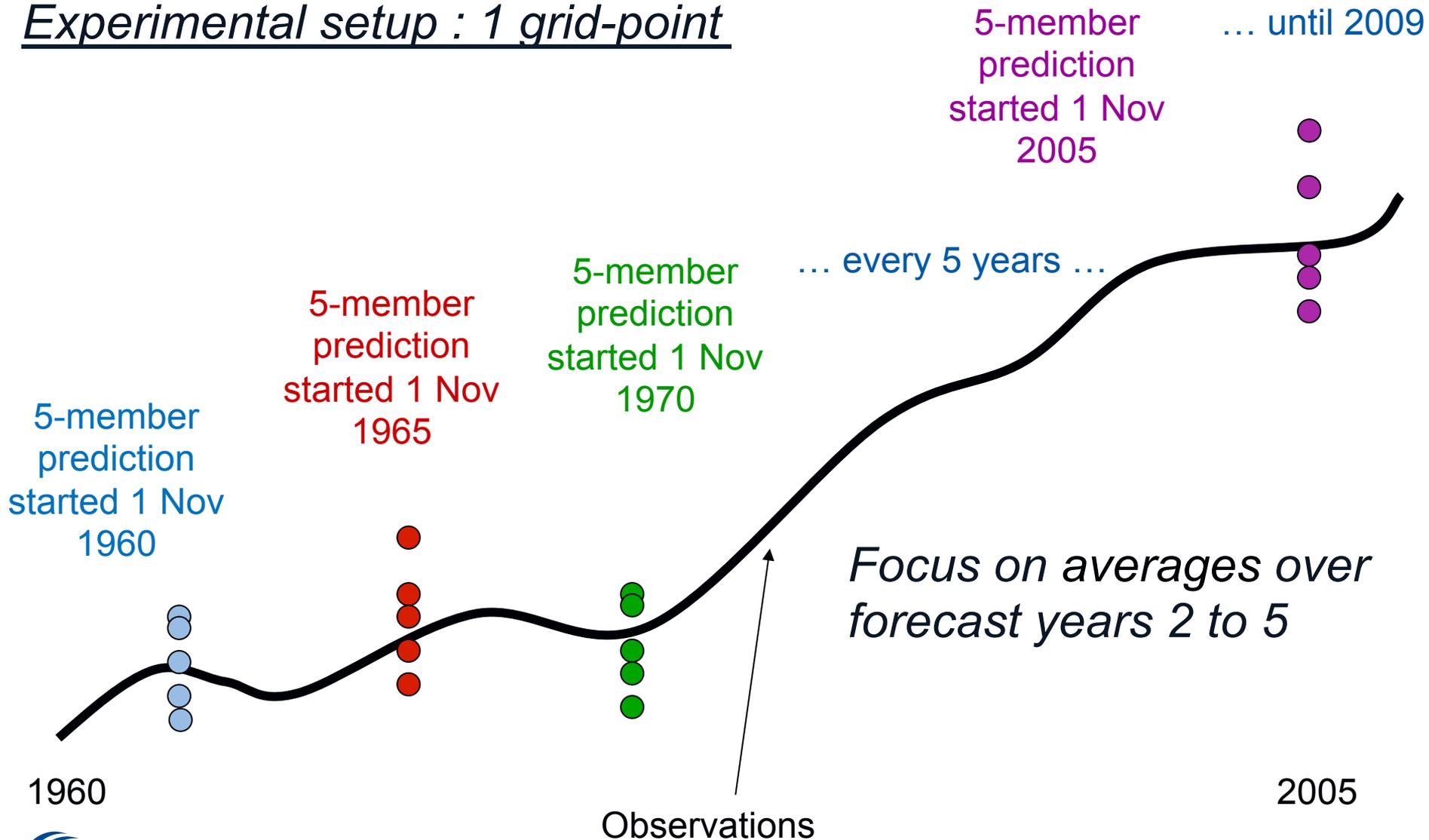
Methodology of using HPC model for climate prediction

Experimental setup : 1 grid-point



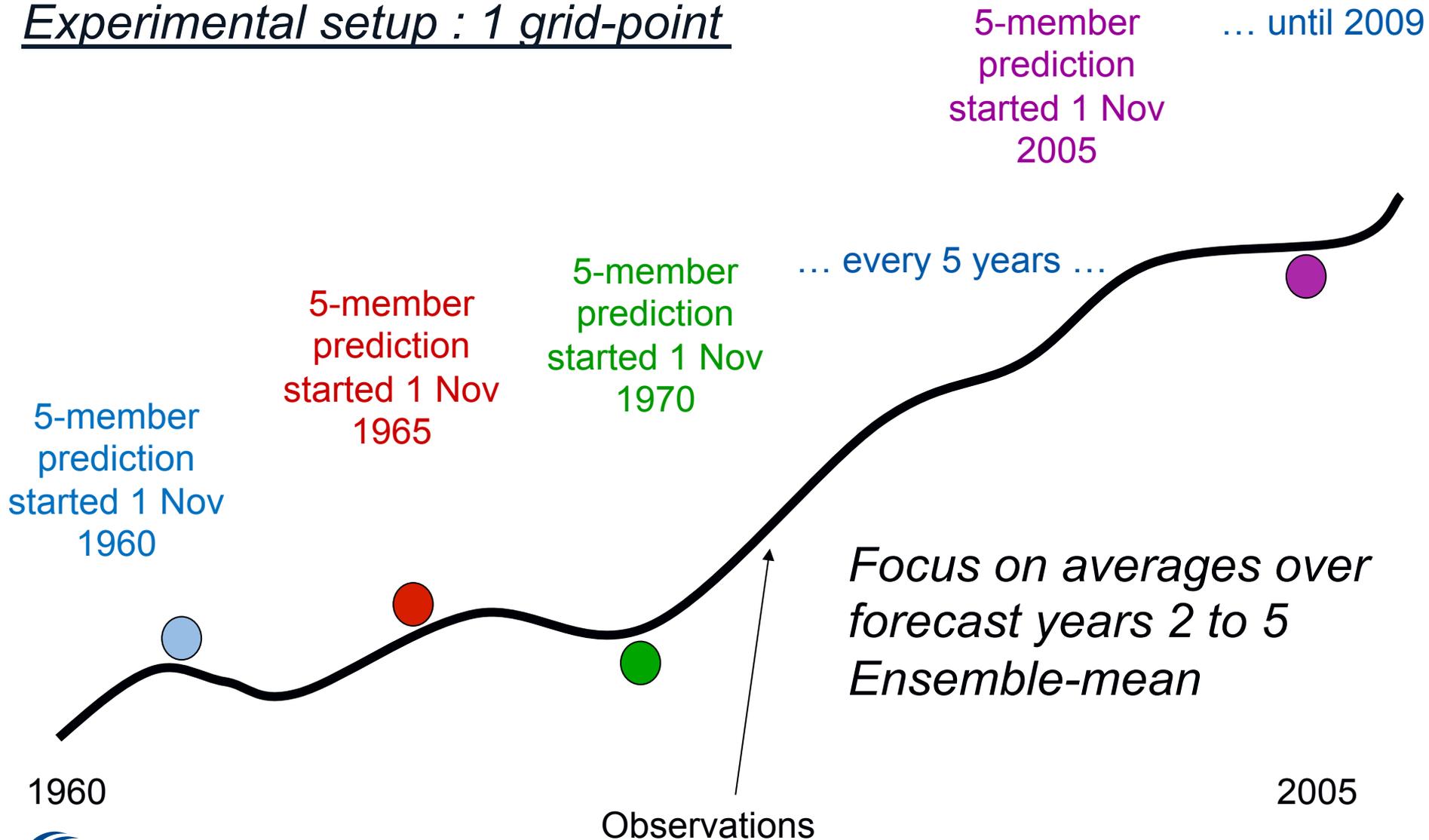
Methodology of using HPC model for climate prediction

Experimental setup : 1 grid-point



Methodology of using HPC model for climate prediction

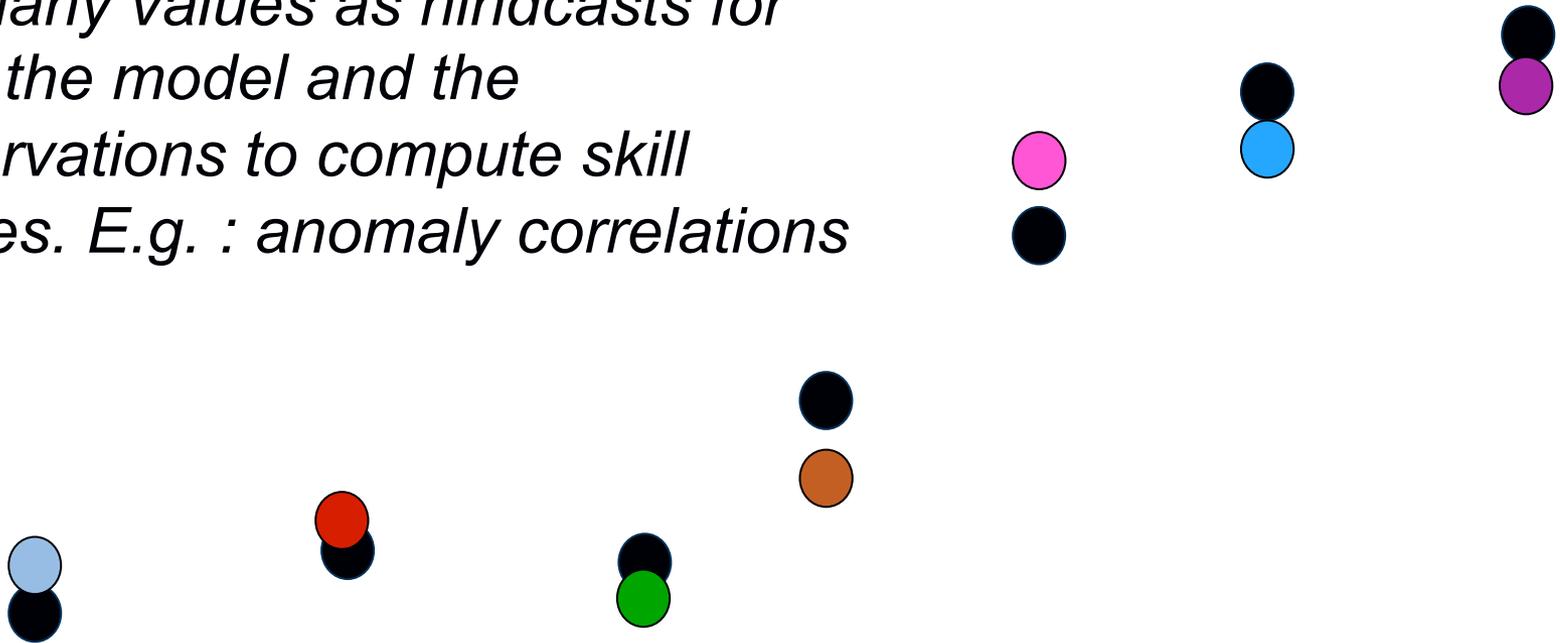
Experimental setup : 1 grid-point



Methodology of using HPC model for climate prediction

Experimental setup : 1 grid-point

As many values as hindcasts for both the model and the observations to compute skill scores. E.g. : anomaly correlations

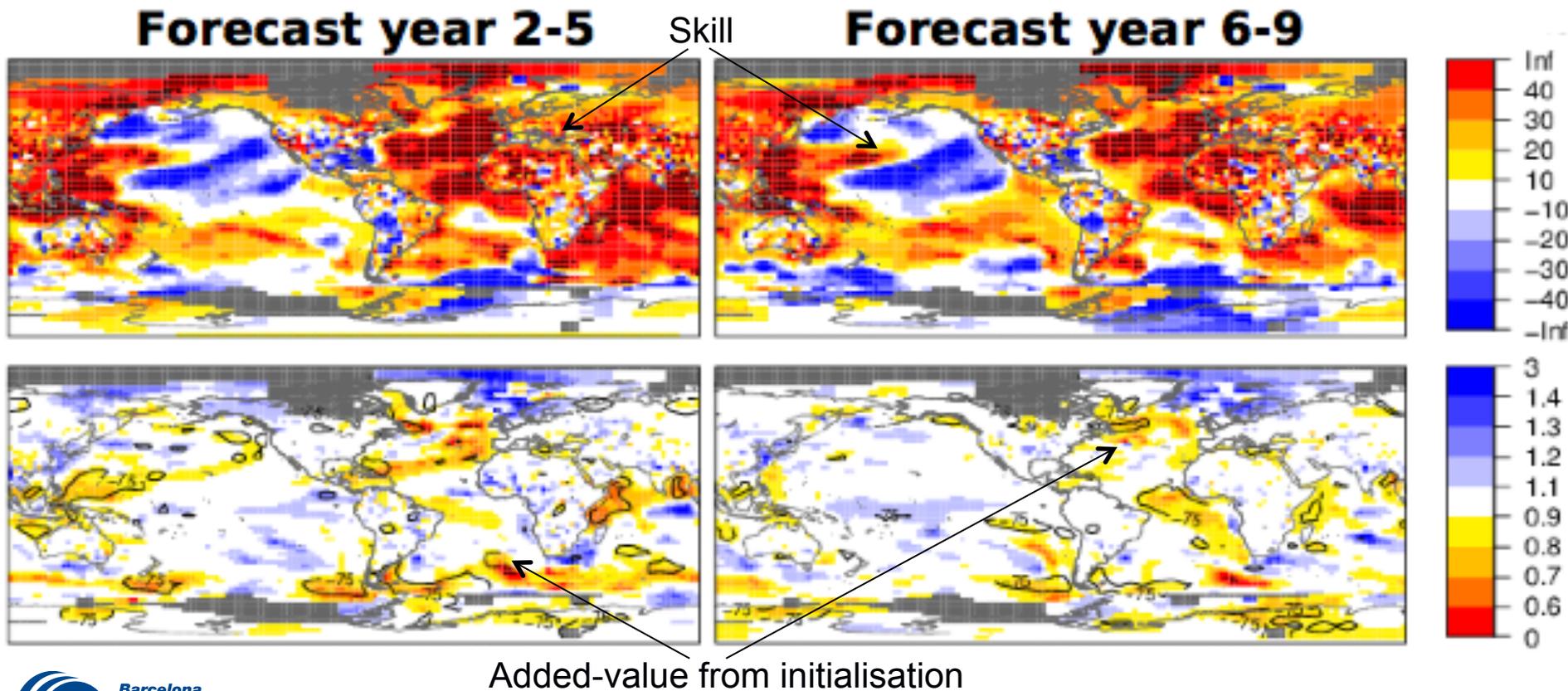


1960

2005

Typical decadal forecast skill – IPCC AR5

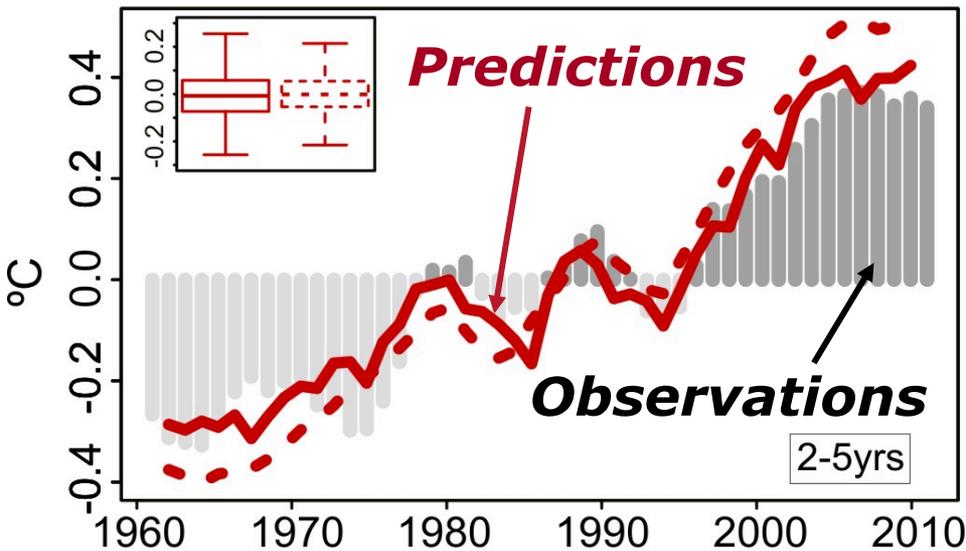
(Top row) Root mean square skill score (RMSSS) of the ensemble mean of the initialised predictions and (bottom row) ratio of the root mean square error (RMSE) of the initialised and uninitialised predictions for the near-surface temperature from the multi-model CMIP5 experiment (1960-2005) for (left) 2-5 and (right) 6-9 forecast years. Five-year start date interval.



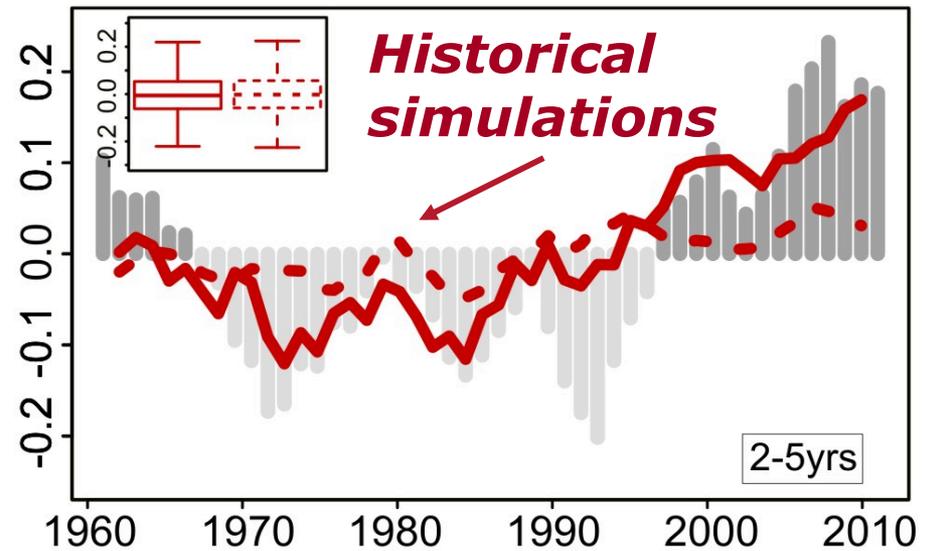
Impact of initialization : CMIP5 decadal predictions

CMIP5 decadal predictions. Global-mean T2m and AMV against GHCN/ERSST3b for forecast years 2-5.

Global mean surface atmospheric temperature

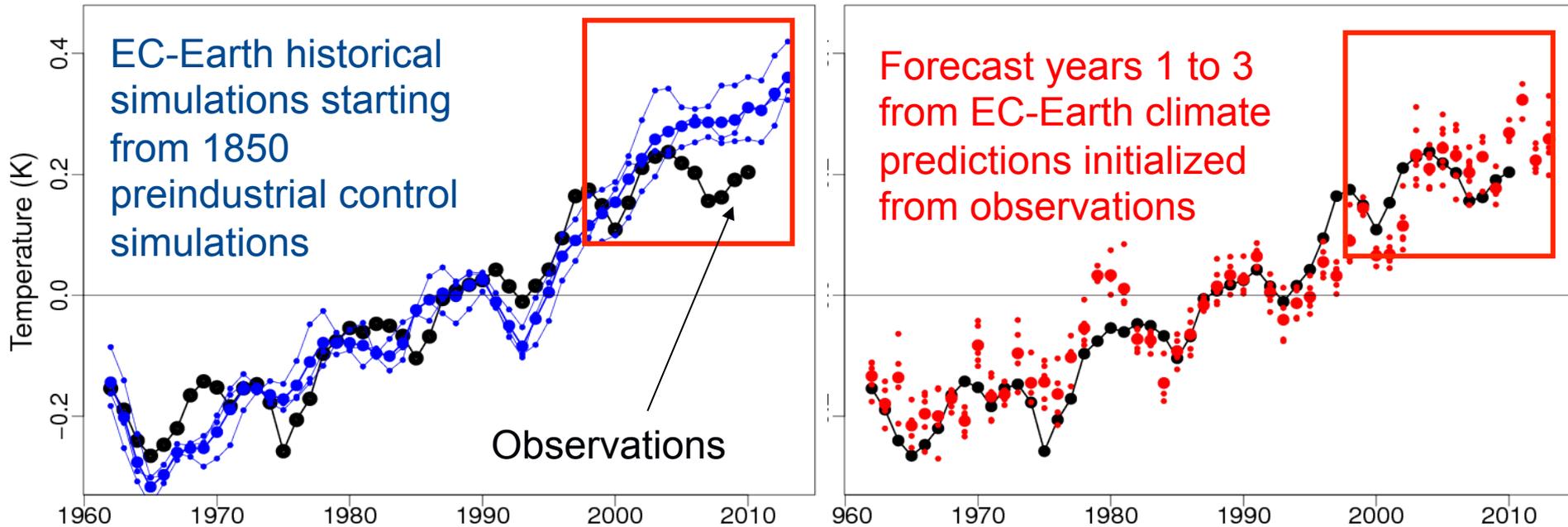


Atlantic multidecadal variability (AMV)



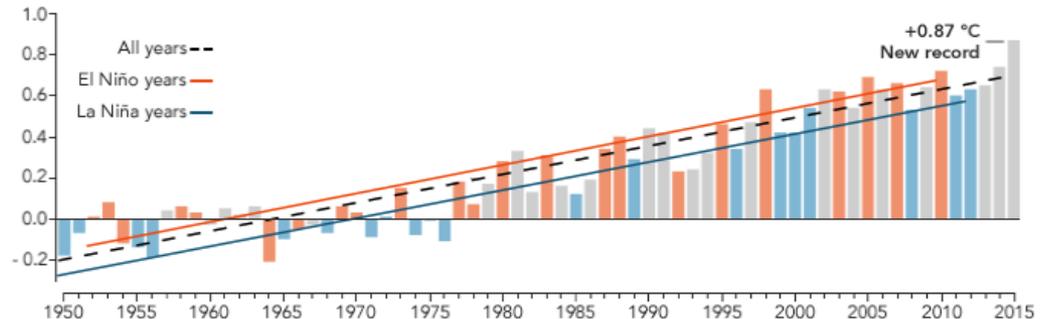
The early 21st century hiatus in surface global warming

Crucial role of initialization from observations in capturing the plateau (temporary quasi pause in warming)



Guemas et al (2013)
Nature Climate Change

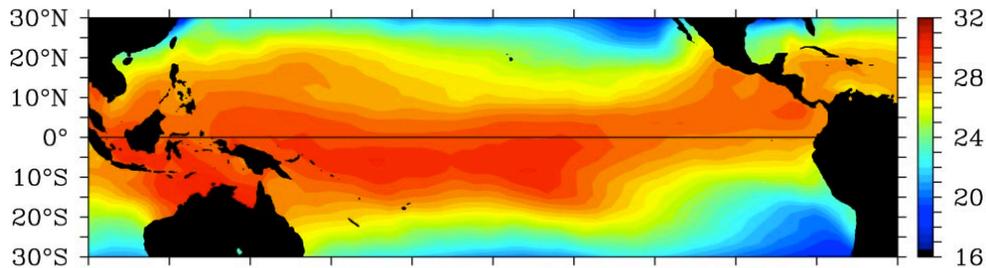
Annual Temperature vs 1951-1980 Average (°C)



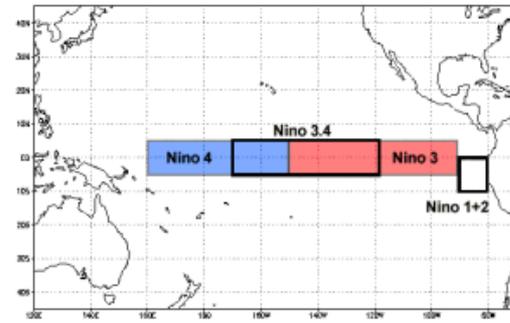
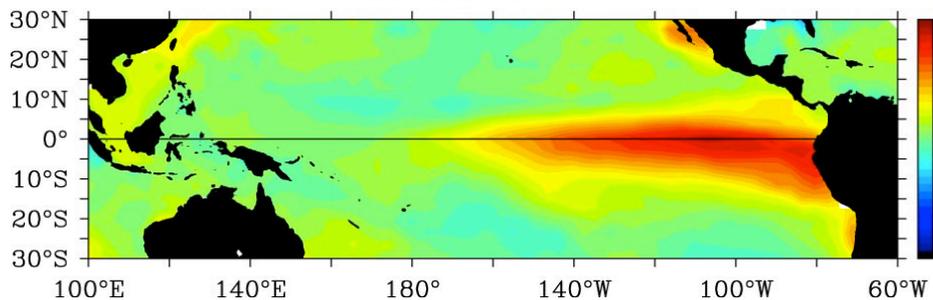
Tropical climate dynamics and predictions

- « El Niño - Southern Oscillation (ENSO) phenomenon is the dominant mode of internal climate variability in the tropics
 - quasi-periodic, 2-7 years (interannual), warming/cooling of waters in the tropical Eastern Pacific strongly affects global climate

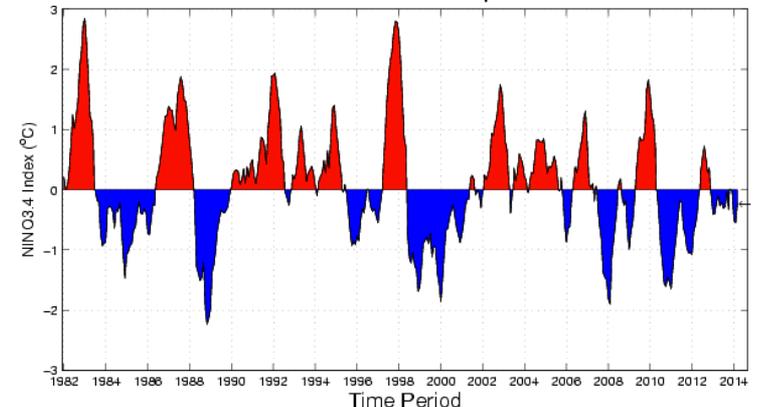
Sea Surface Temperature
December 1997



Sea Surface Temperature Anomaly
December 1997

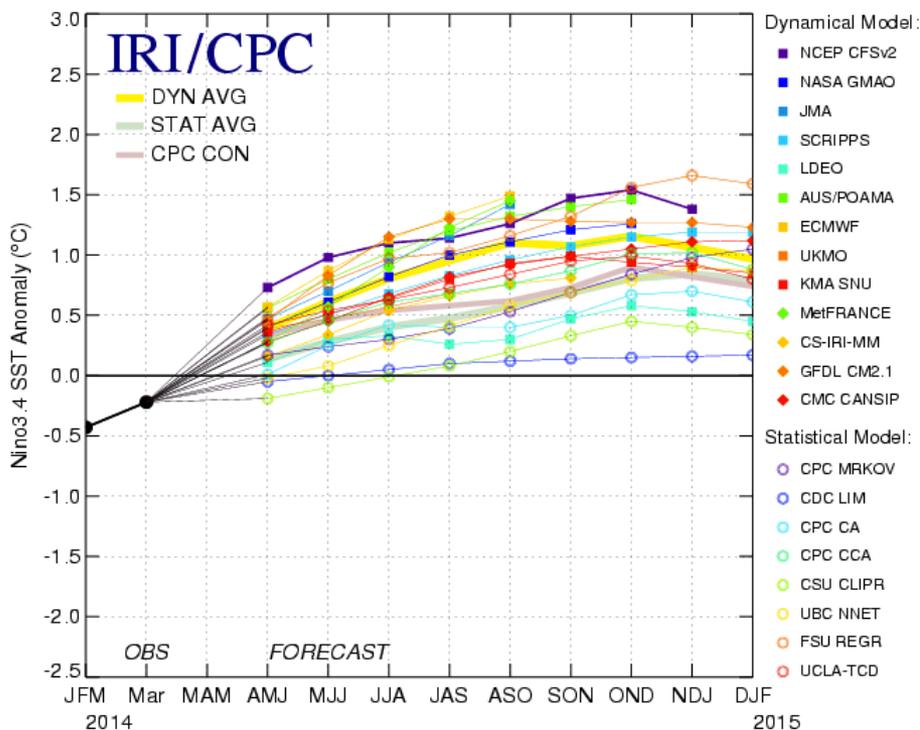


Historical Sea Surface Temperature Index

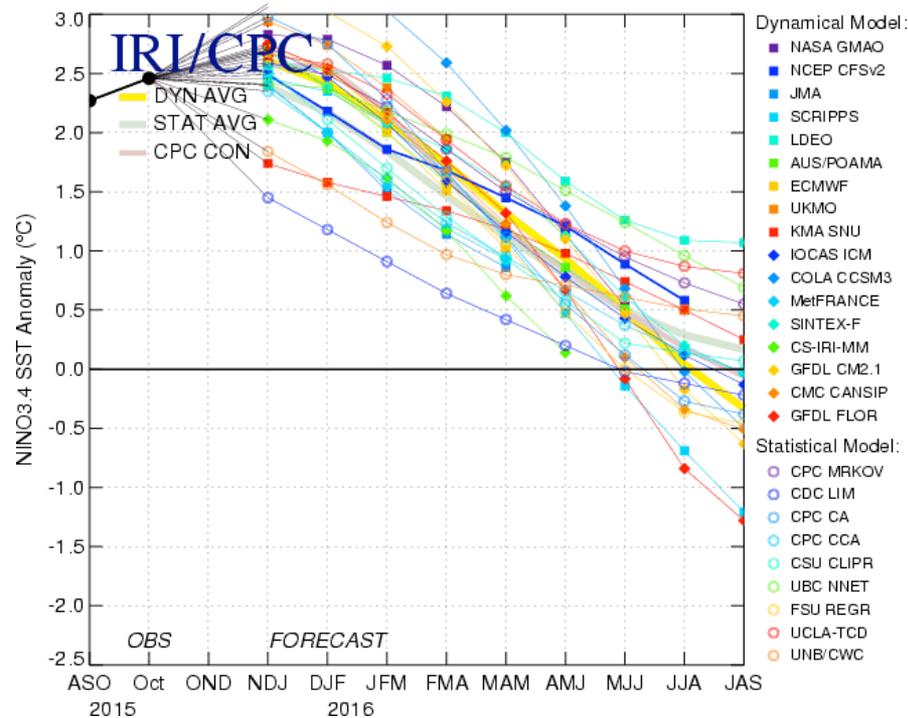


ENSO predictions – initial and boundary value problem

Mid-Apr 2014 Plume of Model ENSO Predictions

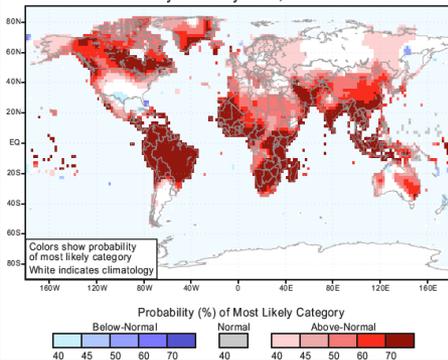


Mid-Nov 2015 Plume of Model ENSO Predictions

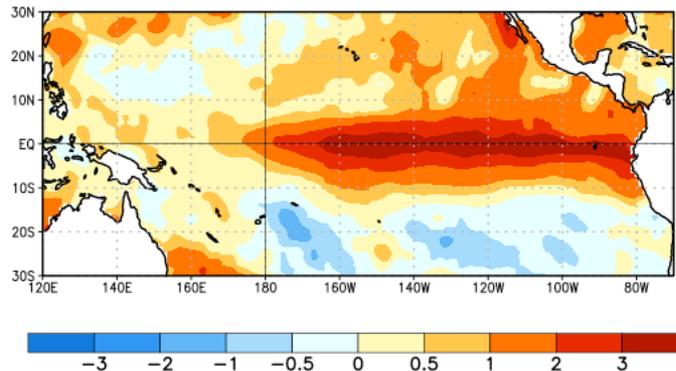


Current El Niño substantially warms surface of the globe

IRI Multi-Model Probability Forecast for Temperature for December-January-February 2016, Issued November 2015

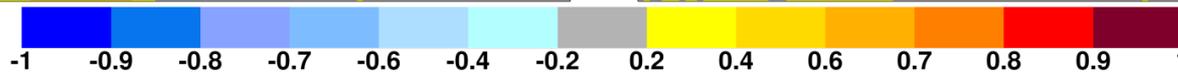
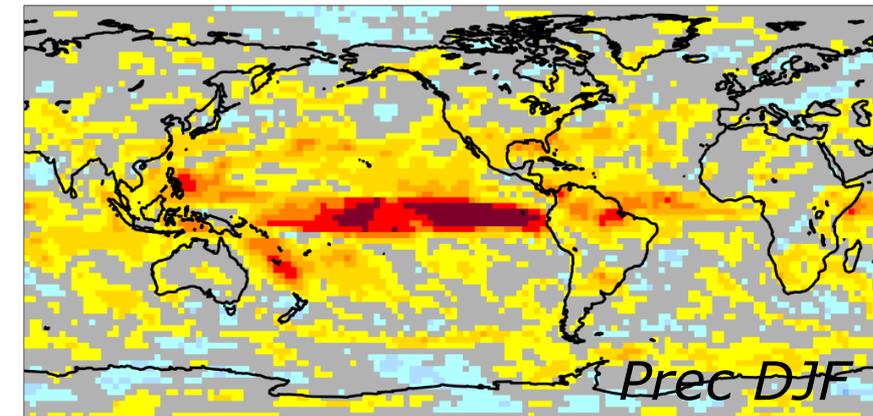
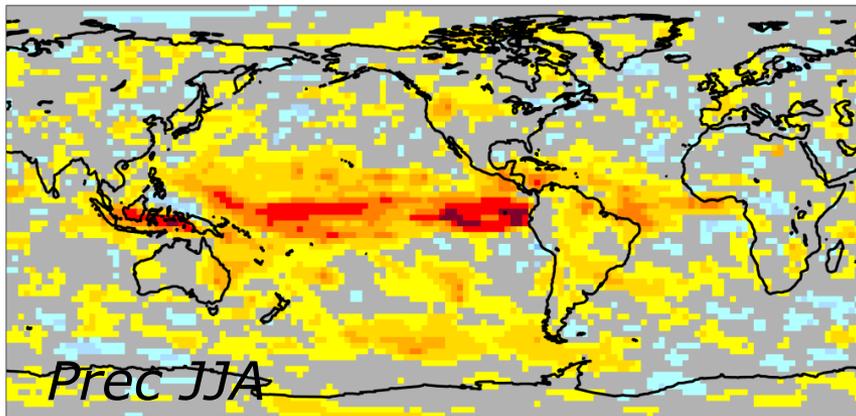
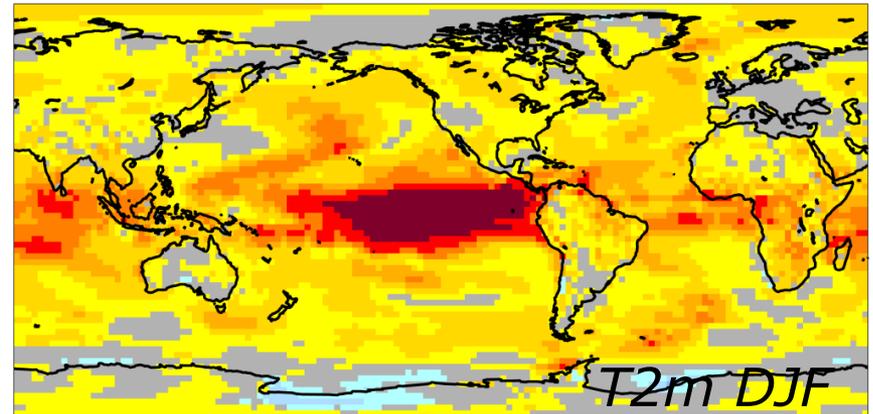
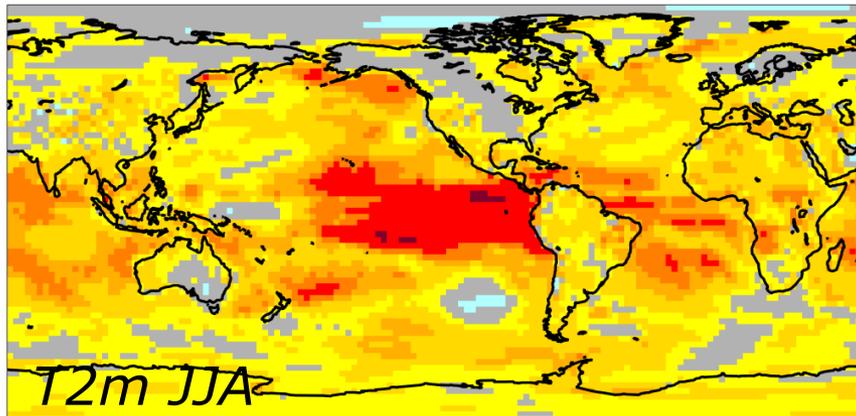


02 DEC 2015



Typical seasonal forecast skill

Correlation of the ensemble mean for the ENSEMBLES multi-model (45 members) wrt ERA40-ERAInt (T2m over 1960-2005) and GPCP (precip over 1980-2005) with 1-month lead



Current and planned activities

- **Work on initialisation:** generate a set of initial conditions (for ocean and sea ice) and compare different initialisation techniques (e.g. full field versus anomaly initialisation)
- **Improving model processes:** Inclusion and/or testing of model components (biogeochemistry, vegetation, aerosols, sea ice) or new parameterizations, model parameter calibration, increase in resolution
- **Calibration and combination:** empirical prediction (better use of current benchmarks), local knowledge.
- **Forecast quality assessment:** provide skill scores practical to the user, reliability as a main target, process-based verification, attribution of climate events with successful predictions, diagnostics of model weaknesses with failing predictions
- **More sensitivity to the users' needs:** going beyond downscaling, better documentation (e.g. use the IPCC language), demonstration of value and outreach → building versatile climate services as a part of Earth system services

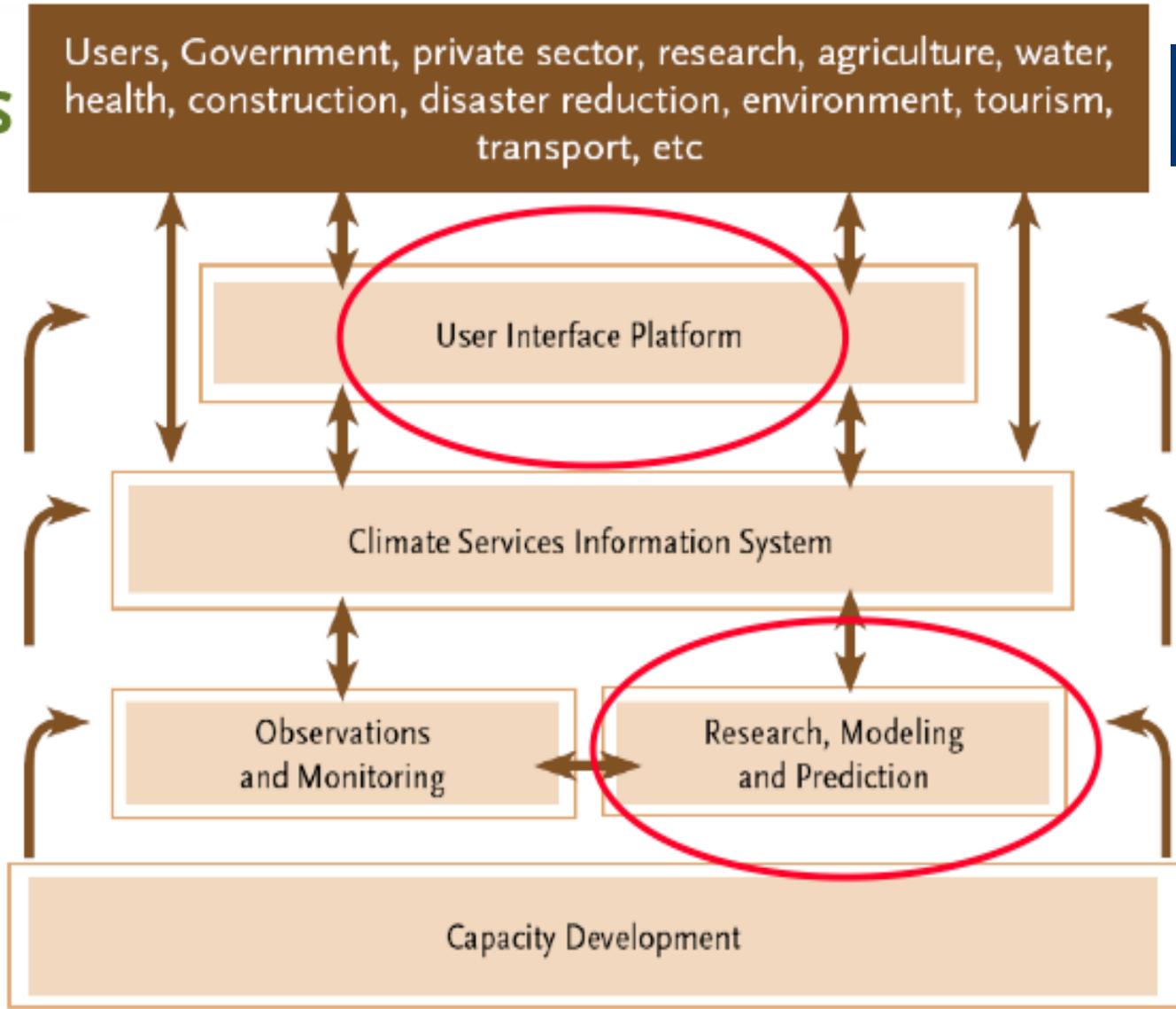
Global Framework on Climate Services



Users, Government, private sector, research, agriculture, water, health, construction, disaster reduction, environment, tourism, transport, etc



Climate services provide climate information to assist decision making by individuals and organizations firstly in the priority areas



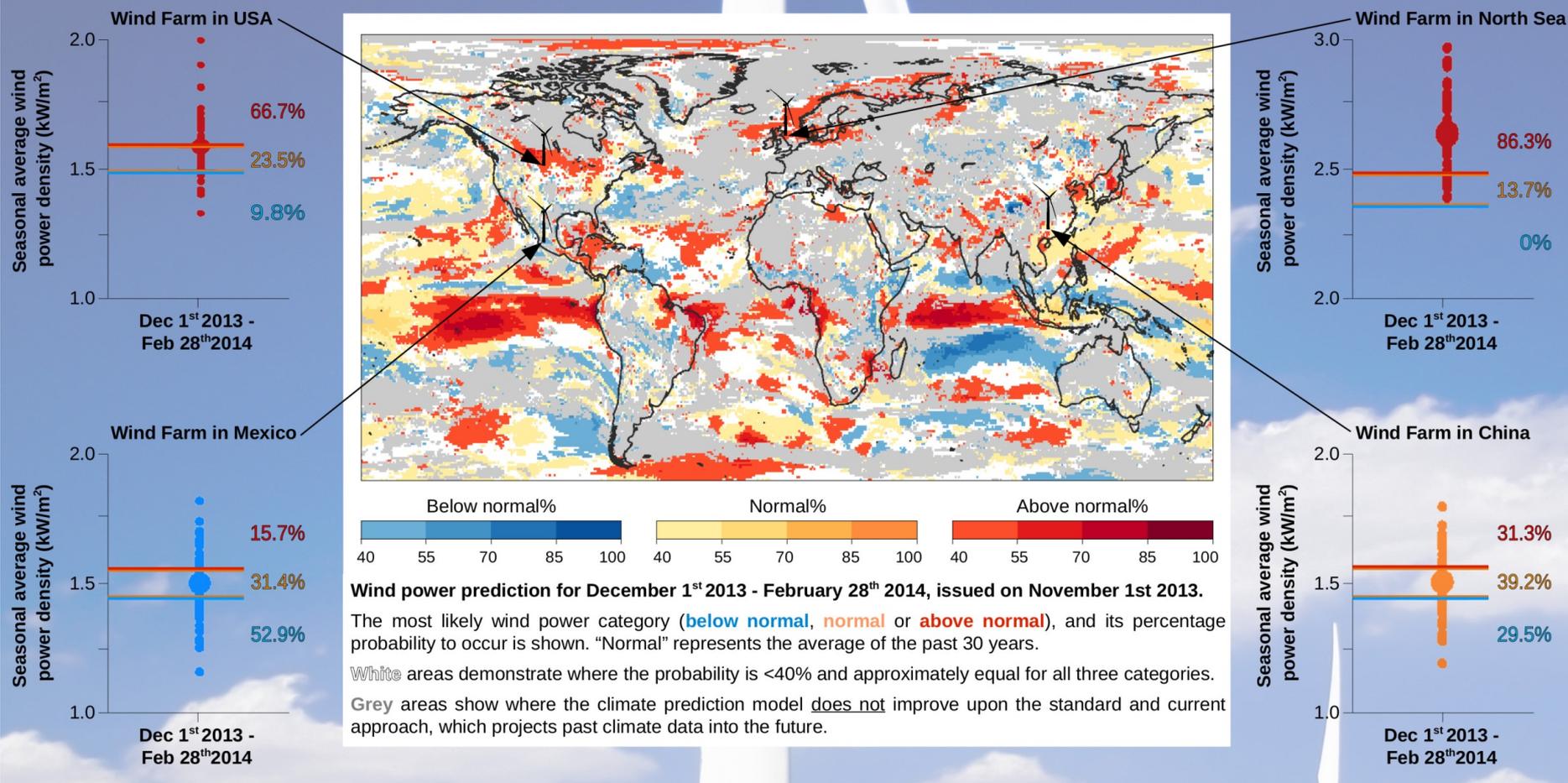
www.gfcs-climate.org

Climate prediction services for energy sector

- Climate predictions, e.g. provide estimate of the wind speed and power over a target period and region
- Wind speed predictions gauge the potential future energy production critical for estimating future energy prices, defining management strategies, planning maintenance, ..
- Whereas short-term meteorological forecasts are a widespread service for the wind energy sector, longer term climate predictions are not yet commonly used
 - Earth System Services group provide seasonal wind speed predictions, based on ECMWF's S4 seasonal prediction system
 - global predictions are run seven months into the future, started every month ⇒ we can provide service information for any location in the world

Seasonal climate prediction of wind power

Illustrative examples of seasonal wind power predictions



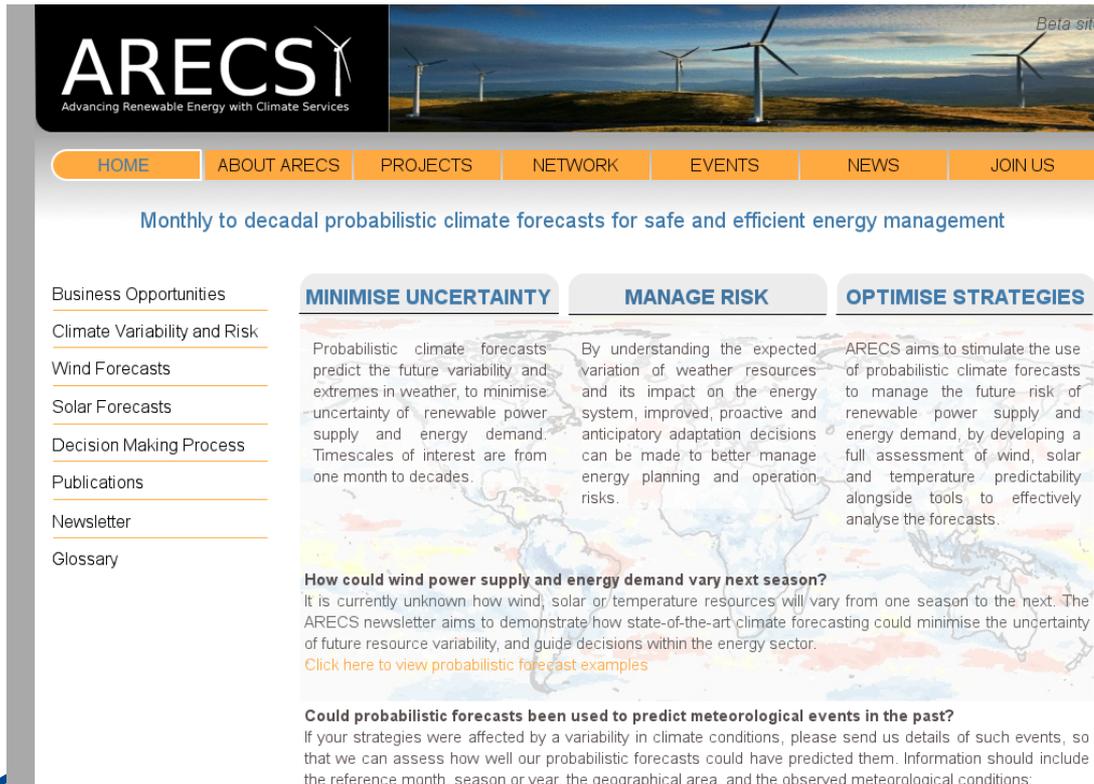
Climate services for the benefit of renewable energy

Advancing Renewable Energy with Climate Services (ARECS)

Join the initiative at: www.arecs.org

- ✓ Monthly, seasonal and decadal wind and solar forecasts
- ✓ Provide feedback, register your needs
- ✓ Receive a quarterly, seasonal wind forecast newsletter

Website



ARECS
Advancing Renewable Energy with Climate Services

HOME ABOUT ARECS PROJECTS NETWORK EVENTS NEWS JOIN US

Monthly to decadal probabilistic climate forecasts for safe and efficient energy management

Business Opportunities
Climate Variability and Risk
Wind Forecasts
Solar Forecasts
Decision Making Process
Publications
Newsletter
Glossary

MINIMISE UNCERTAINTY
Probabilistic climate forecasts predict the future variability and extremes in weather, to minimise uncertainty of renewable power supply and energy demand. Timescales of interest are from one month to decades.

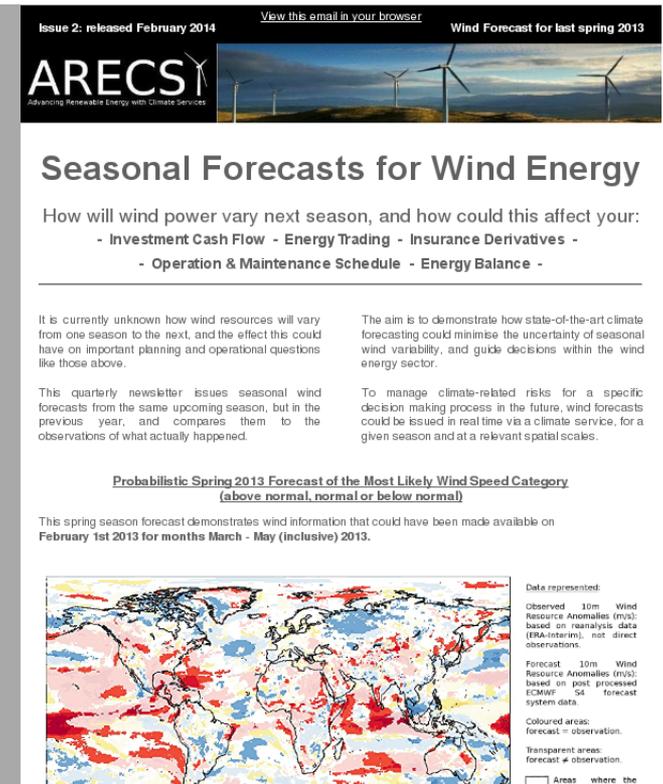
MANAGE RISK
By understanding the expected variation of weather resources and its impact on the energy system, improved, proactive and anticipatory adaptation decisions can be made to better manage energy planning and operation risks.

OPTIMISE STRATEGIES
ARECS aims to stimulate the use of probabilistic climate forecasts to manage the future risk of renewable power supply and energy demand, by developing a full assessment of wind, solar and temperature predictability alongside tools to effectively analyse the forecasts.

How could wind power supply and energy demand vary next season?
It is currently unknown how wind, solar or temperature resources will vary from one season to the next. The ARECS newsletter aims to demonstrate how state-of-the-art climate forecasting could minimise the uncertainty of future resource variability, and guide decisions within the energy sector.
[Click here to view probabilistic forecast examples](#)

Could probabilistic forecasts be used to predict meteorological events in the past?
If your strategies were affected by a variability in climate conditions, please send us details of such events, so that we can assess how well our probabilistic forecasts could have predicted them. Information should include the reference month, season or year, the geographical area, and the observed meteorological conditions.

Newsletter



Issue 2: released February 2014
View this email in your browser
Wind Forecast for last spring 2013

ARECS
Advancing Renewable Energy with Climate Services

Seasonal Forecasts for Wind Energy

How will wind power vary next season, and how could this affect you:
- Investment Cash Flow - Energy Trading - Insurance Derivatives -
- Operation & Maintenance Schedule - Energy Balance -

It is currently unknown how wind resources will vary from one season to the next, and the effect this could have on important planning and operational questions like those above.

The aim is to demonstrate how state-of-the-art climate forecasting could minimise the uncertainty of seasonal wind variability, and guide decisions within the wind energy sector.

This quarterly newsletter issues seasonal wind forecasts from the same upcoming season, but in the previous year, and compares them to the observations of what actually happened.

To manage climate-related risks for a specific decision making process in the future, wind forecasts could be issued in real time via a climate service, for a given season and at a relevant spatial scales.

Probabilistic Spring 2013 Forecast of the Most Likely Wind Speed Category (above normal, normal or below normal)

This spring season forecast demonstrates wind information that could have been made available on February 1st 2013 for months March - May (inclusive) 2013.

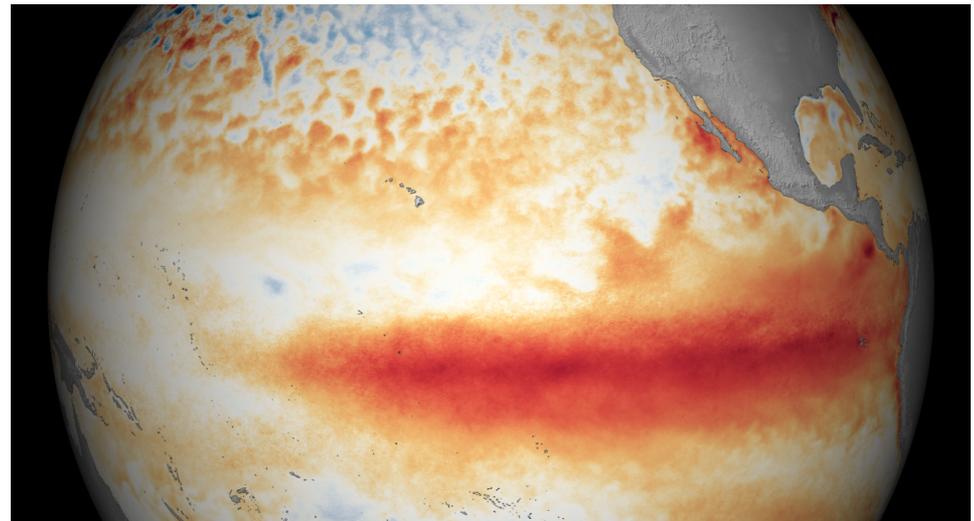
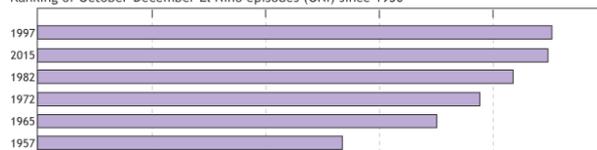
Data represented:
Observed 10m Wind Resource Anomalies (m/s): based on reanalysis data (ERA-Interim), not direct observations.
Forecast 10m Wind Resource Anomalies (m/s): based on post processed ECMWF - SA - forecast system data.
Coloured areas: forecast = observation.
Transparent areas: forecast ≠ observation.
Areas where the

Summary and future directions

Key areas of BSC climate prediction and services

- New data assimilation techniques (for single climate component and coupled system) for new reanalyses and initial conditions
- Improving climate model with inclusion of additional processes and increased resolution
- New bias correction, calibration and combination methods
- Forecast quality assessment and development of empirical models
- Expansion of climate services for growing spectrum of stakeholders → climate data is being processed into actionable climate information

Ranking of October-December El Niño episodes (ONI) since 1950



January 2016 compared to 1981-2010

Difference from average temperature (°C)
-9 0 9