BRICS special session on the Digital Earth project

# The INMCM Earth System Model as a climate change prediction tool

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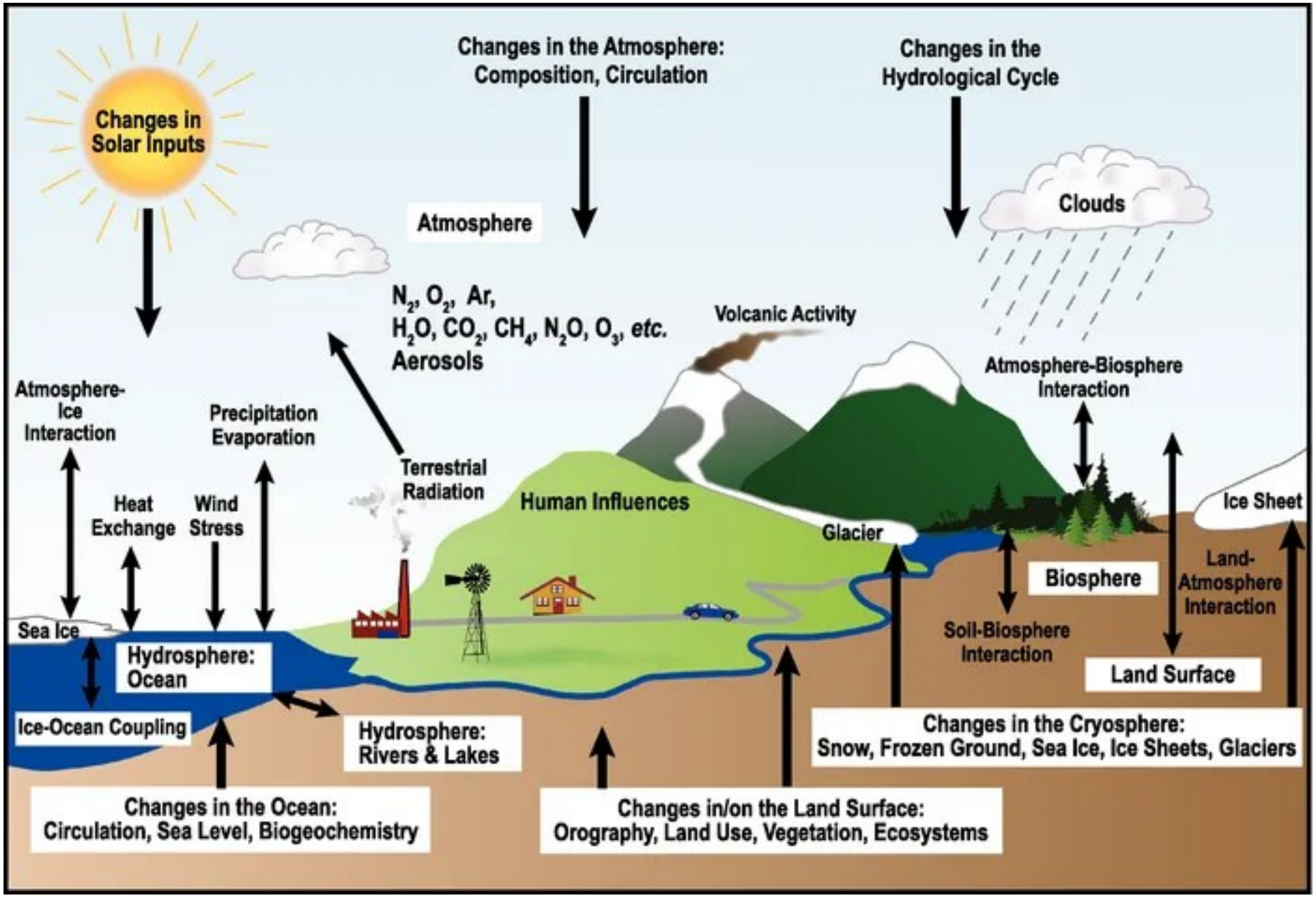

Changes in Solar Inputs
Changes in the Atmosphere: Composition, Circulation
Changes in the Hydrological Cycle
Atmosphere
Clouds
$N_2$, $O_2$, Ar,
$H_2O$, $CO_2$, $CH_4$, $N_2O$, $O_3$, *etc.*
Aerosols
Volcanic Activity
Atmosphere-Biosphere Interaction
Atmosphere-Ice Interaction
Precipitation
Evaporation
Terrestrial Radiation
Heat Exchange
Wind Stress
Human Influences
Glacier
Ice Sheet
Biosphere
Land-Atmosphere Interaction
Sea Ice
Hydrosphere: Ocean
Soil-Biosphere Interaction
Land Surface
Ice-Ocean Coupling
Hydrosphere: Rivers & Lakes
Changes in the Cryosphere: Snow, Frozen Ground, Sea Ice, Ice Sheets, Glaciers
Changes in the Ocean: Circulation, Sea Level, Biogeochemistry
Changes in/on the Land Surface: Orography, Land Use, Vegetation, Ecosystems

**ESM core** - models of hydro- thermo dynamics of atmosphere/ocean based on Navier – Stokes equations that are solved numerically on supercomputers

$$\frac{du}{dt} - \left(f + \frac{u}{a}\operatorname{tg}\varphi\right)v + \frac{1}{a\cos\varphi}\left(\frac{\partial\Phi}{\partial\lambda} + \frac{RT}{\pi}\frac{\partial\pi}{\partial\lambda}\right) = F_u,$$

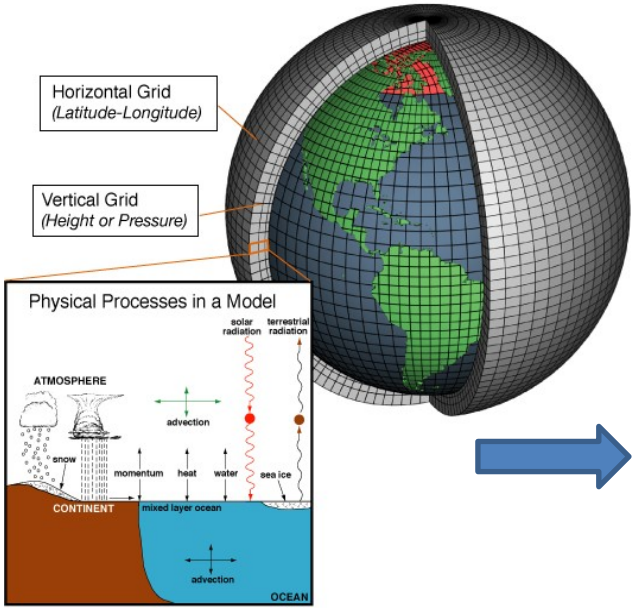
$$\frac{dv}{dt} + \left(f + \frac{u}{a}\operatorname{tg}\varphi\right)u + \frac{1}{a}\left(\frac{\partial\Phi}{\partial\varphi} + \frac{RT}{\pi}\frac{\partial\pi}{\partial\varphi}\right)\frac{\partial\Phi}{\partial\varphi} = F_v,$$

$$\frac{\partial\Phi}{\partial\sigma} = -\frac{RT}{\sigma},$$

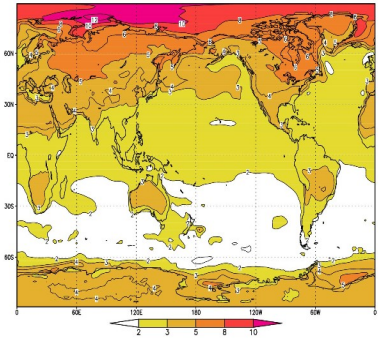
$$\frac{dT}{dt} - \frac{RT}{\pi c_p}\left(\frac{\partial\pi}{\partial t} + \frac{u}{a\cos\varphi}\frac{\partial\pi}{\partial\lambda} + \frac{v}{a}\frac{\partial\pi}{\partial\varphi} + \frac{\pi\dot{\sigma}}{\sigma}\right) = F_T + \varepsilon,$$

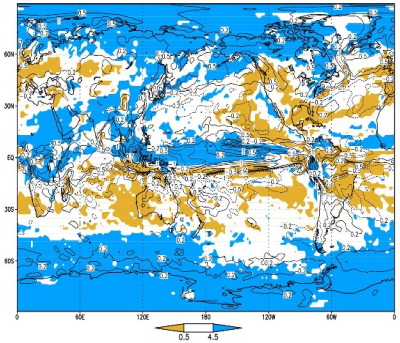
$$\frac{dq}{dt} = F_q - (C - E),$$

$$\frac{\partial\pi}{\partial t} + \frac{1}{a\cos\varphi}\left(\frac{\partial\pi u}{\partial\lambda} + \frac{\partial\pi v\cos\varphi}{\partial\varphi}\right) + \frac{\partial\pi\dot{\sigma}}{\partial\sigma} = 0,$$









+ Physical parameterizations
+ Sub grid scale parameterizations for process that are not solved explicitly (grid size ~ 100km)

# INM RAS EARTH SYSTEM MODEL *

- **Atmospheric and ocean dynamics, sea ice**
- **Atmosphere and ocean boundary layer**
- **Land surface model**
- **Aerosols**

**Optional or under development:**

- **Carbon cycle (land, vegetation, ocean and atmosphere).**
- **Methane cycle (wetland emissions, atmospheric methane, methane hydrates) .**
- **Dynamical vegetation.**
- **Atmospheric chemistry**
- **Atmospheric electricity.**
- **Continental ice.**
- **Ocean biochemistry.**

**INM-CM – member of AMIP1,2 CORE2 and CMIP2,3,5,6**

**Volodin, E. M., Mortikov, E. V., Kostrykin, S. V., Galin, V. Y., Lykossov, V. N., Gritsun, A. S., Diansky, N. A., Gusev, A. V., and Iakovlev, N. G.: Simulation of the present day climate with the climate model INMCM5, Clim. Dyn., V49, 3715, https://doi.org/10.1007/s00382-017-3539-7, 2017b.**

***with contributions from RCC MSU, IAP RAS, RSHU, KSC.**

# Sources of long-range predictability in climate system

## ➢Initial conditions:

Low frequency modes of atmospheric, oceanic and coupled climate dynamics (ENSO, Madden-Julian oscillation, stratospheric sudden warmings, QBO, ocean AMOC oscillation, Pacific decadal oscillation, Atlantic Multidecadal oscillation).

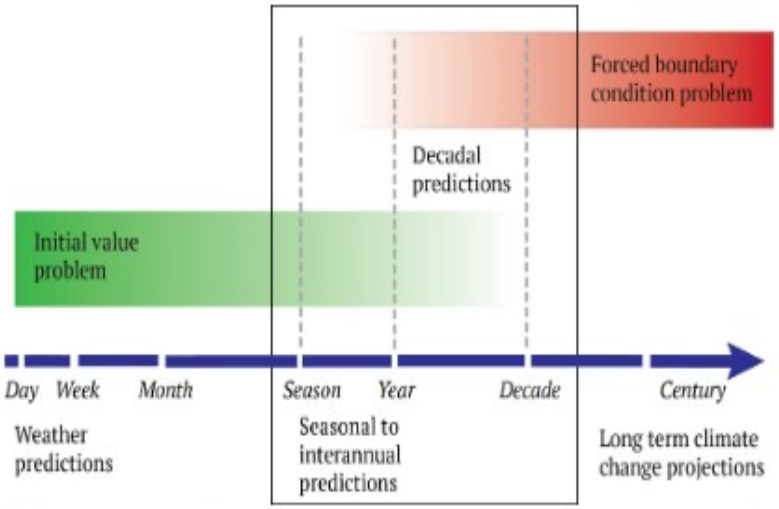



Figure 1. Decadal predictions need to take into account both initial conditions of the climate system as well as the evolution of long-term forcings. Based on Fig. 2 (Box 11.1) in AR5-WG1.

**https://www.wcrp-climate.org/gc-near-term-climate-prediction**

## ➢ External forcings:

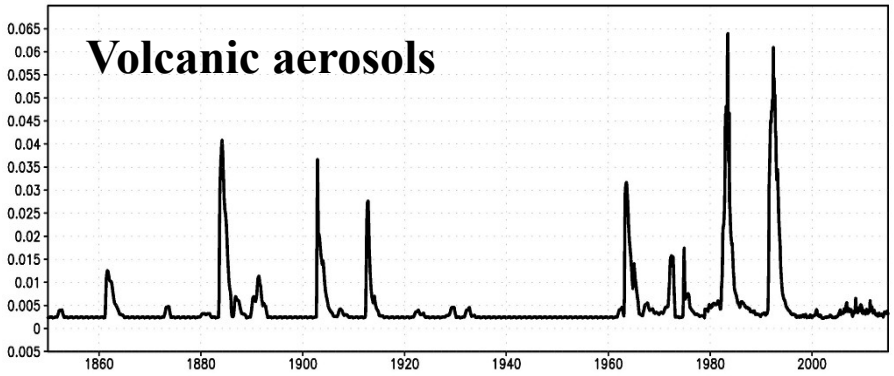
Anthropogenic GHG, aerosols and land use forcings, natural solar and orbital forcings, volcanic ac

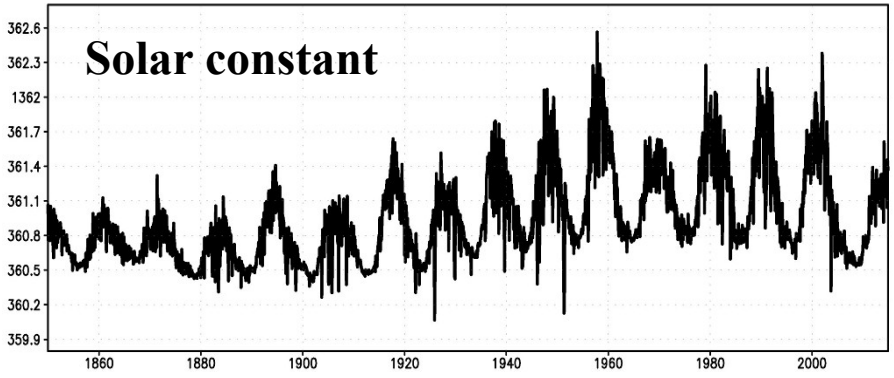
# Historical experiments

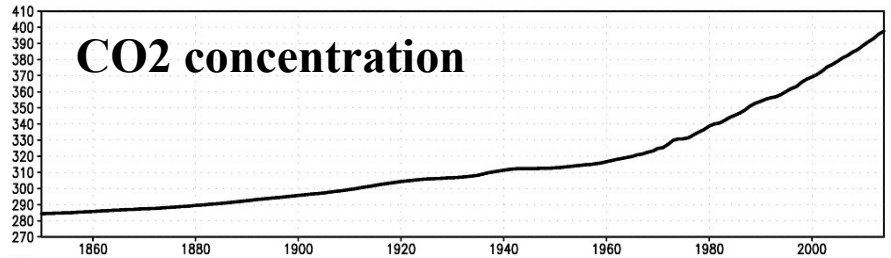
**Model starts from preindustrial experiment data, calculation for 1850-2014 (165yrs).**

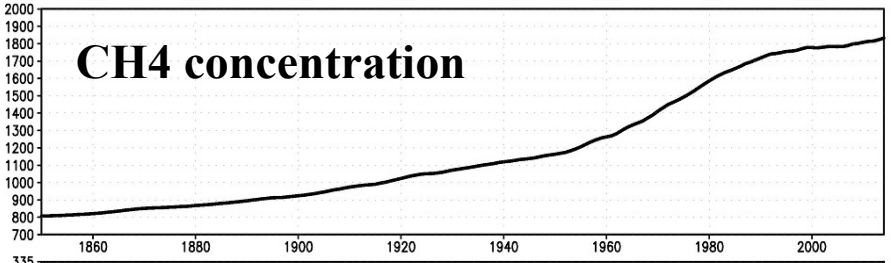
**Scenario prescribes:**

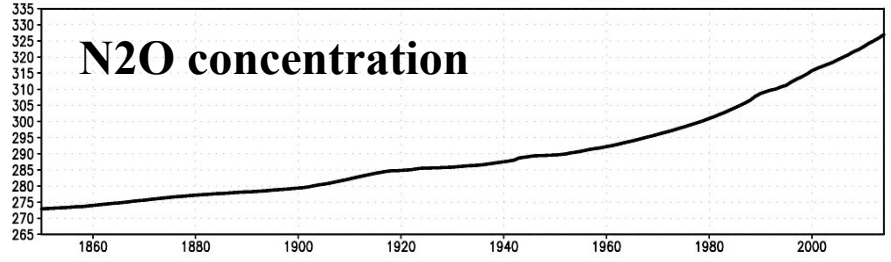
– GHG and aerosols emissions/concentrations,
– Land use and correspondent forcings,
– Solar radiation,
– Stratospheric volcanic aerosols,
– ….



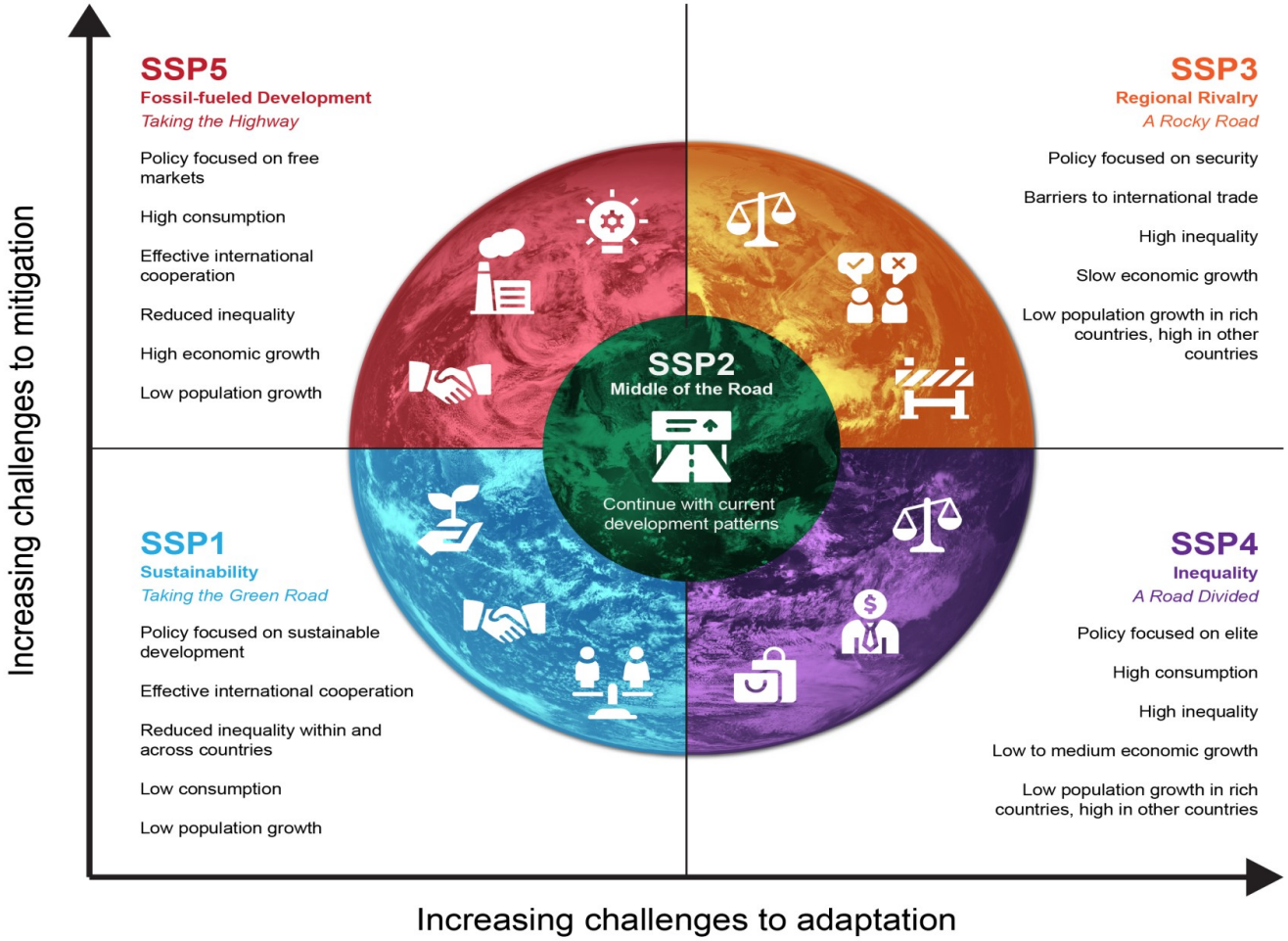



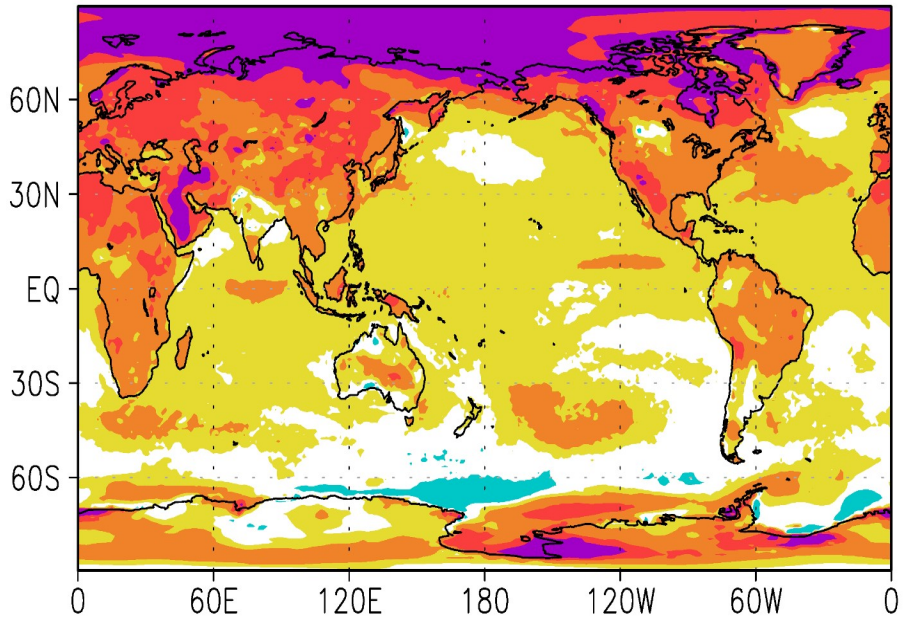
# Scenario experiments

## Socioeconomic Pathways + Radiative forcing level in 2100

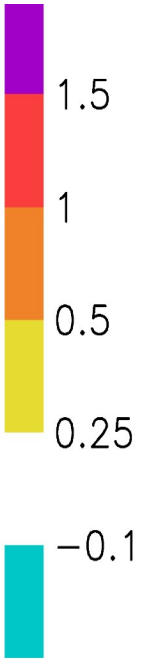
**Model starts from historical experiment data, calculation for 2015-2100.**

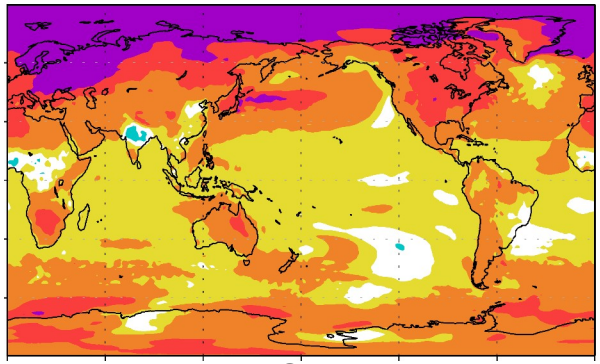


# Changes of the globally averaged T2m in 1991-2020 relative to 1961-1990 (ERA5 vs INM-CM6M + CMIP6)

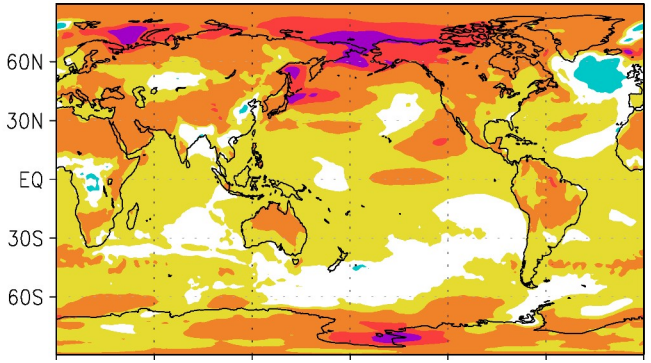



ERA5

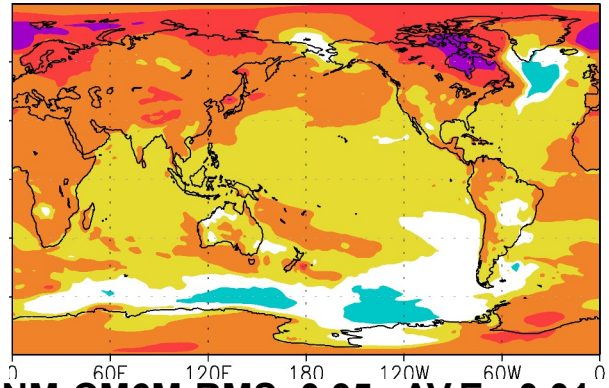


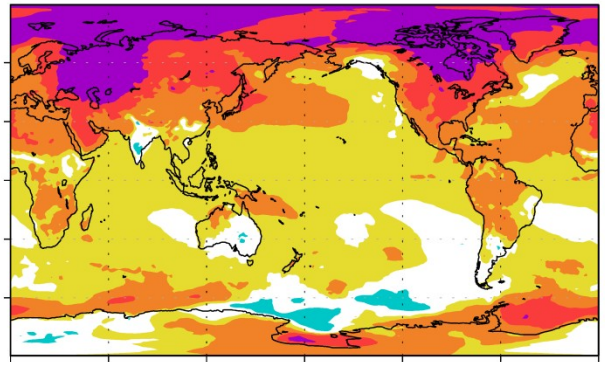
MPI AWI-M: RMS=0.37, AV.E=+0.11



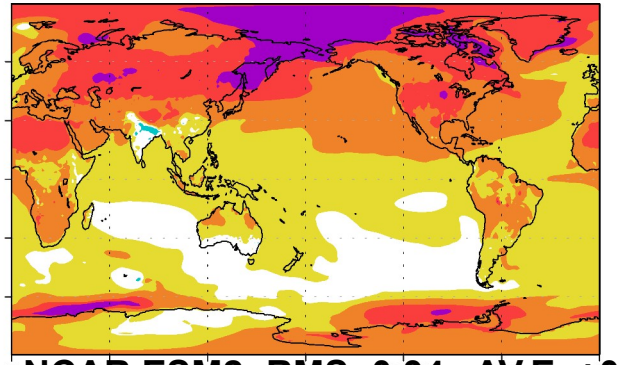

MPI ESM-M: RMS=0.37, AV.E=-0.09



INM-CM6M:RMS=0.35, AV.E=-0.01

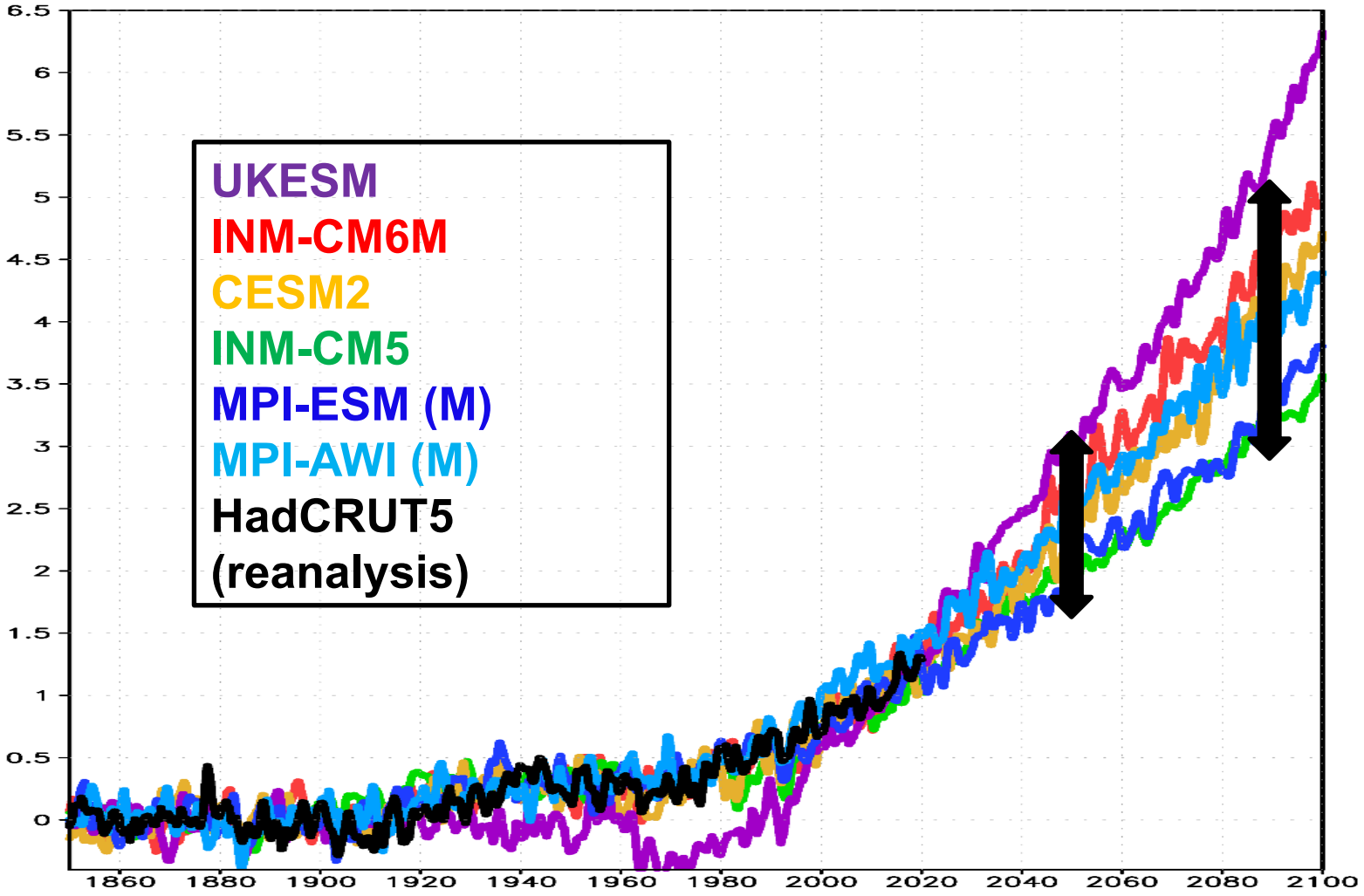


GFDL ESM4: RMS=0.32, AV.E=0.03



NCAR ESM2: RMS=0.34, AV.E=+0.05

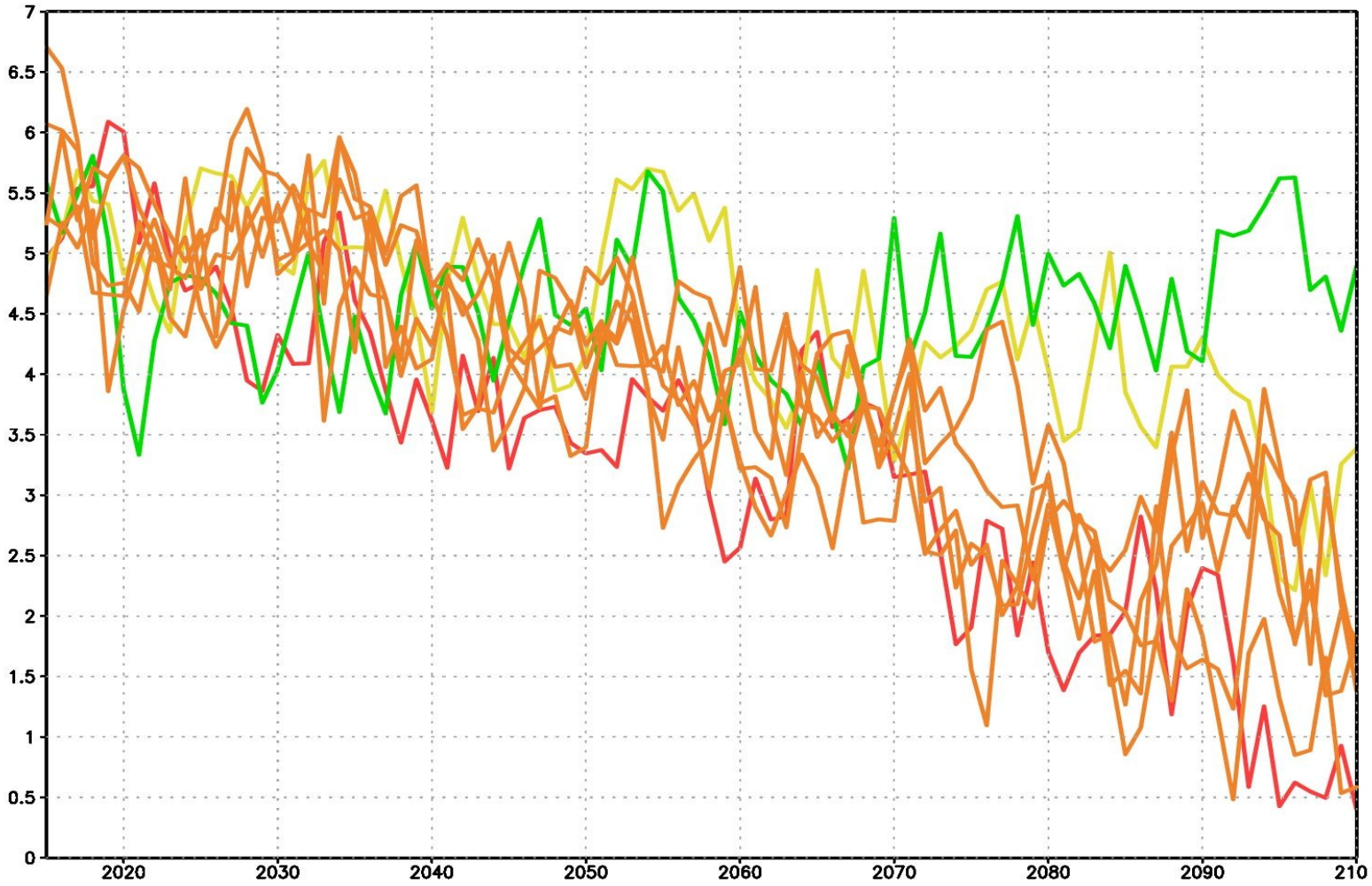
# Globally averaged Earth surface temperature (t2m,K)*




**Range of the forecasts for 2040-2060: 2.3±0.65K, for 2040-2060rr: 4±1.2K**

* Relative to 1850-1900, CMIP6 forcings, scenario for 2014-2100 – SSP3-7.0

**Timeseries of September Arctic sea ice extent (mln km2) due to different scenarios:**
**ssp 1-2.6 (green), ssp 2-4.5 (yellow), ssp 3-7.0 (orange), ssp 5-8.5 (red)**



# Decadal predictions

- Atmosphere, soil and land reanalysis data (ERA40/ ERA-Interim/ ERA5)
- Ocean and sea ice reanalysis data (ORAS5/ SODA3.4[2)

Model climatology

Technique of model bias eliminating:

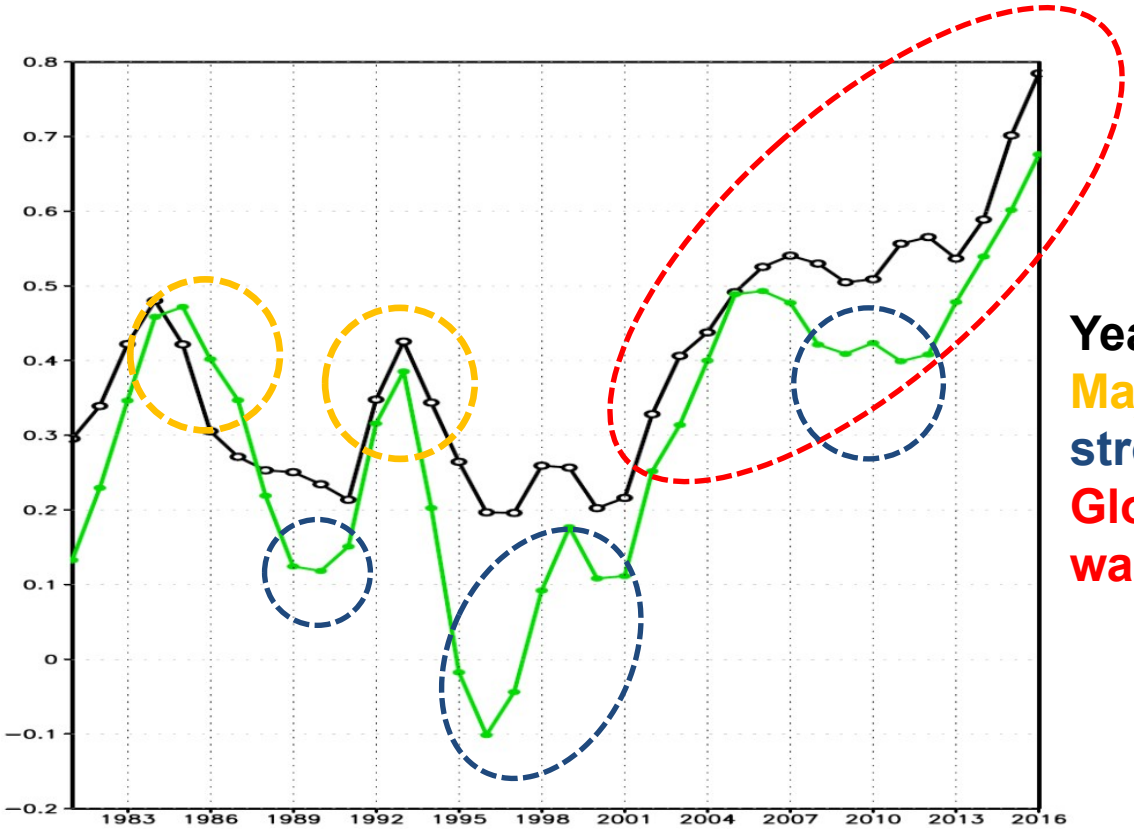
$$W_{1NOV1980} = \overline{W_{M_{1NOV}}} + \left( W_{R_{1NOV1980}} - \overline{W_{R_{1NOV}}} \right)$$

INM-CM

**Decadal predictions**

Experiments are initialized on 1st November 1960-2021
Duration of each experiment – 5 years (15 years each 5th year)
15 ensemble members

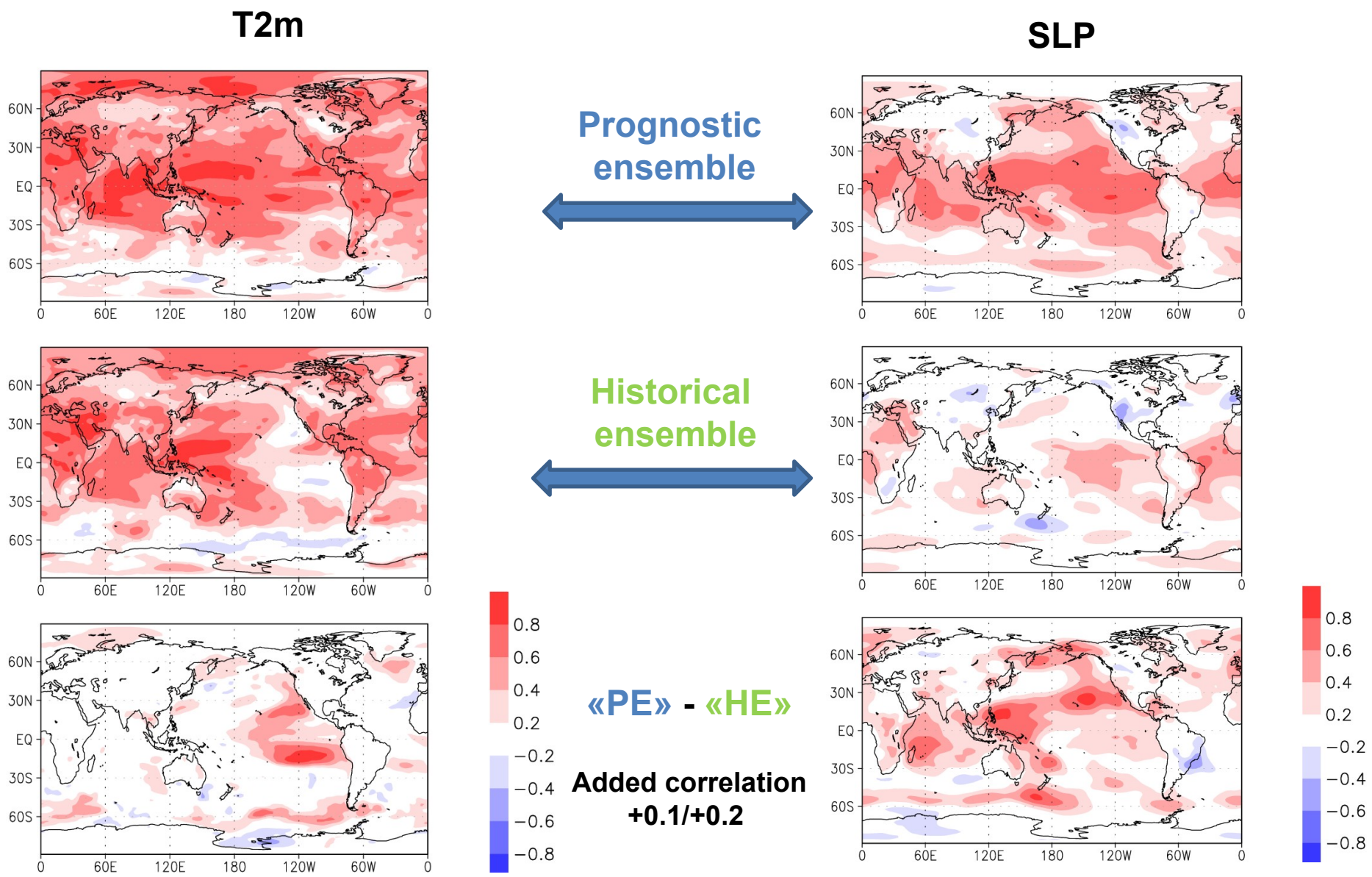
# Global spatial correlation for the next year T2m (w.r.t. ERA5 data)




**Year of**
**Major eruptions,**
**strong La/El Nino,**
**Global T2m warming trend**

**Prognostic and Historical ensembles**

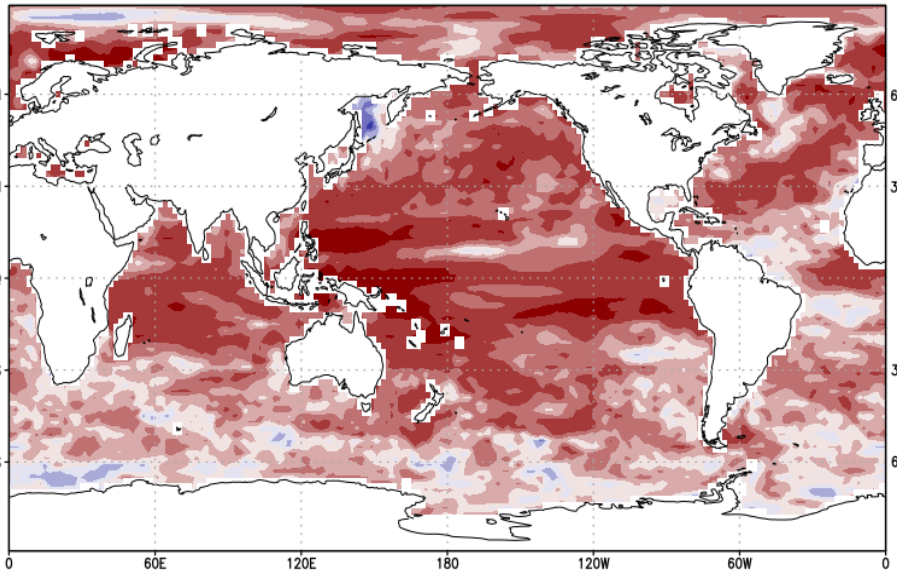
# ACC for the next year average anomaly (1980-2020 hindcasts, w.r.t. ERA5)

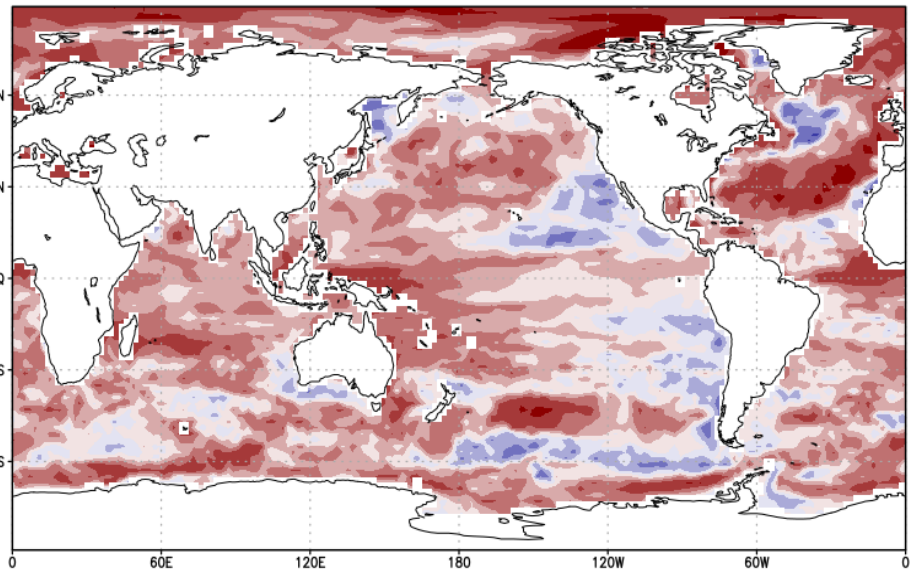


ACC of the upper 0-300m layer heat content anomaly

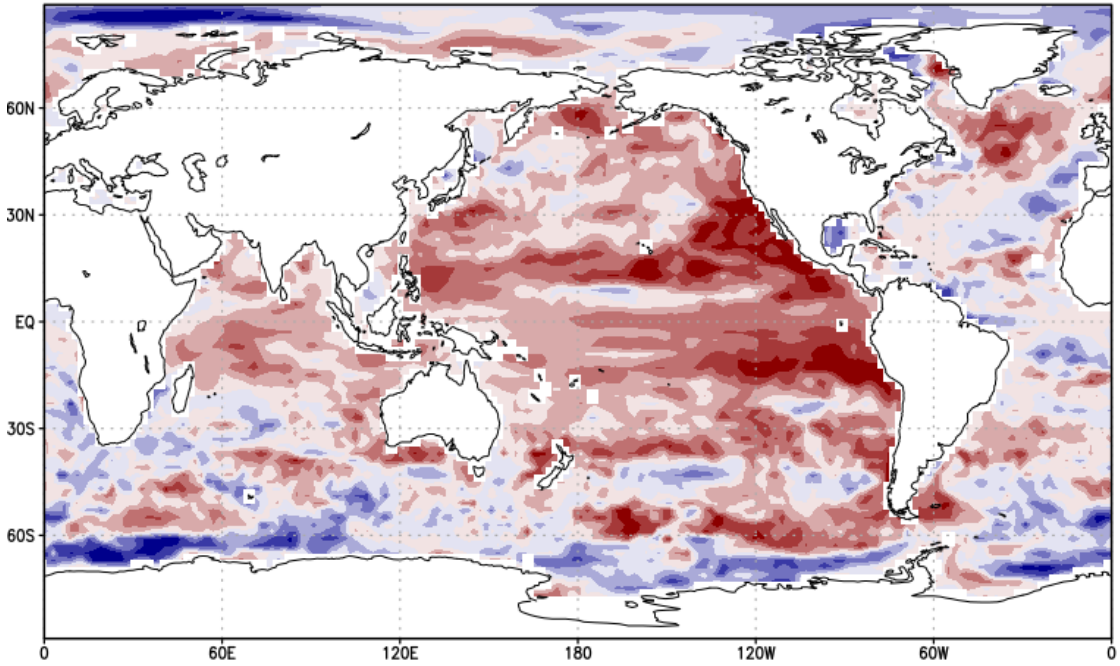
Decadal

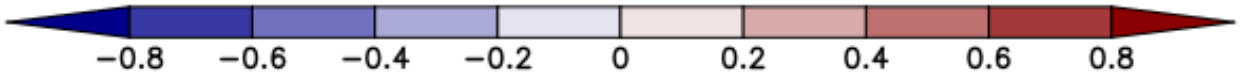
Historical




Dec - Hist




**1st year of experiments**
1981-2020

# Seasonal predictions

- Atmosphere, soil and land reanalysis data (ERA5)
- Ocean and sea ice reanalysis data (SODA3.4.2/ NEMO-HMC)

Model climatology

Technique of model bias eliminating:

$$W_{1NOV1980} = \overline{W_{M_{1NOV}}} + \left( W_{R_{1NOV1980}} - \overline{W_{R_{1NOV}}} \right)$$

Full-field initialization:

$$W_{1NOV1980} = W_{R_{1NOV1980}}$$

INM-CM

**Seasonal predictions**

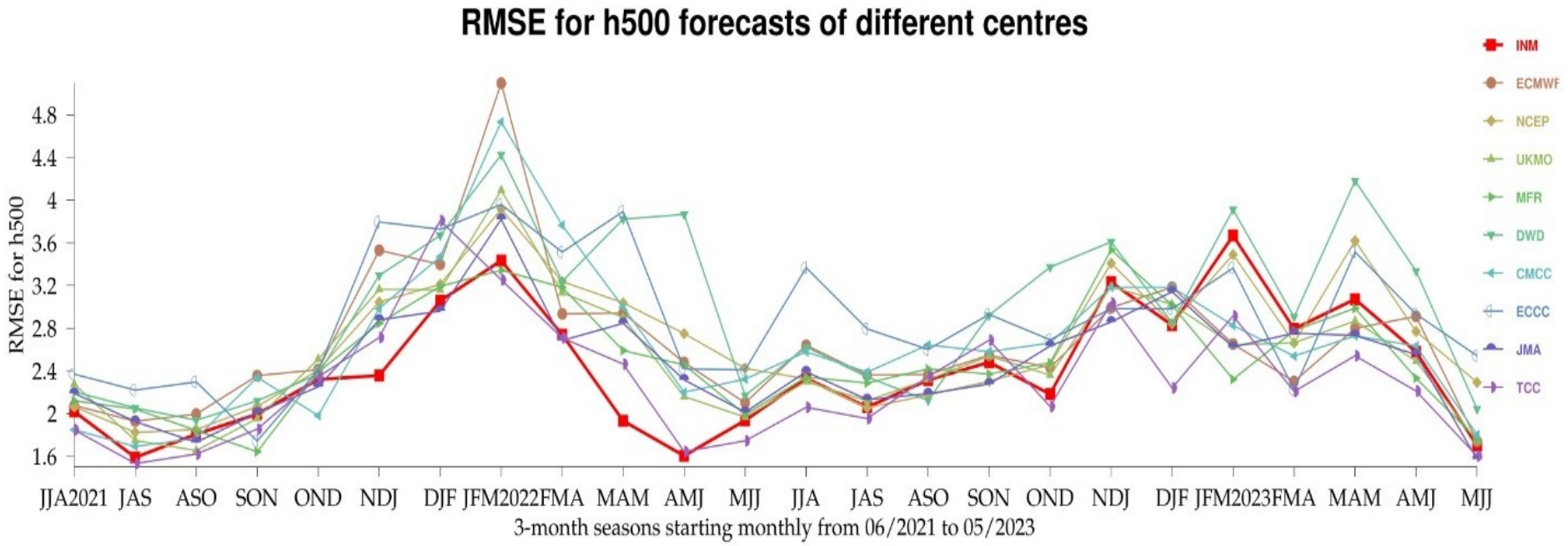
Experiments are initialized on the 22nd day of every month

Duration of each experiment – 4 months (9 months)

Anomaly initialization: 20 (hindcasts) / 20 (forecasts) ensemble members

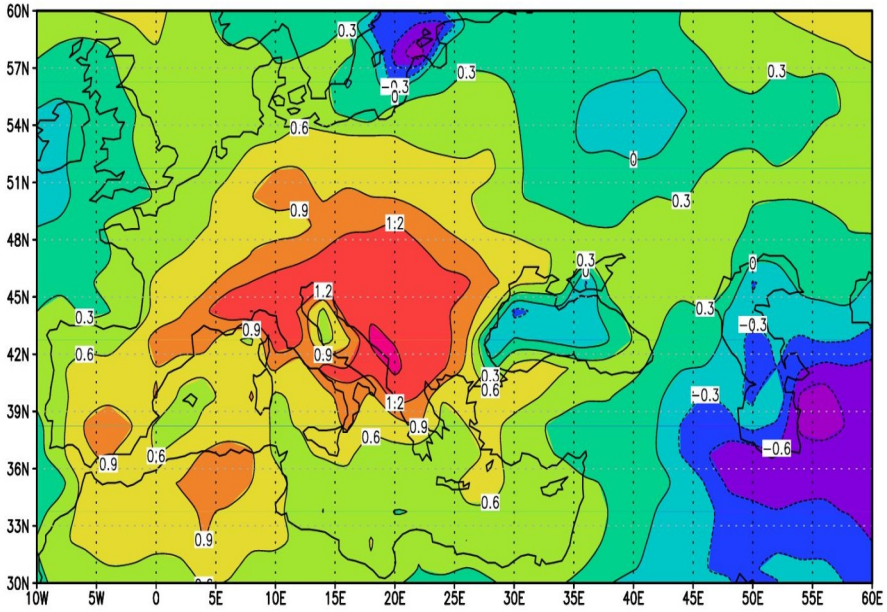
Full-field initialization: 10 (hindcasts) / 30 (forecasts) ensemble members

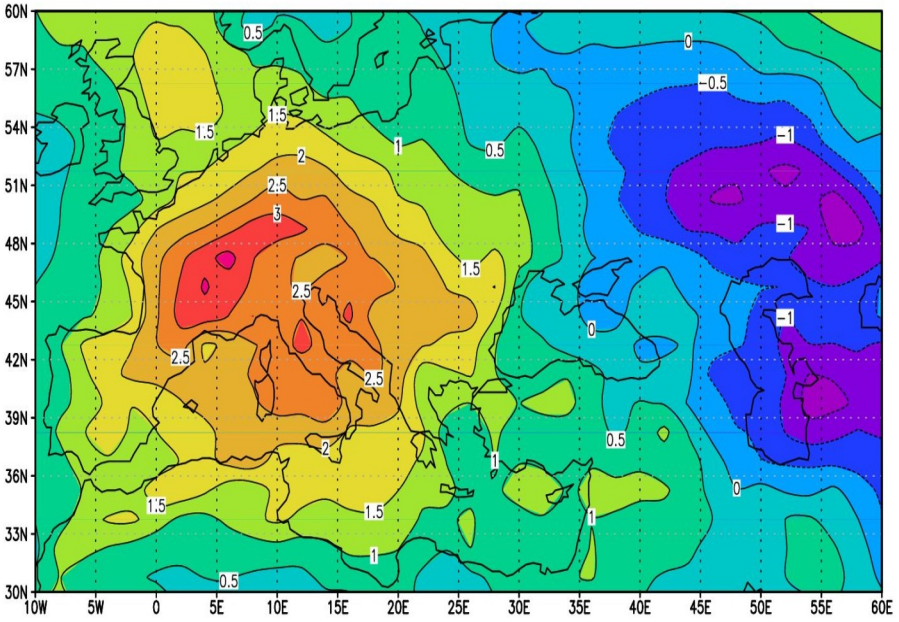
# Seasonal forecast system based on Earth system model INM-CM5 (Russian HydrometCenter)




- Hindcasts for 1980-2021, quasi-operation forecast for 2021-23
- Statistical correction procedure for T2m and precipitation seasonal forecasts for North Eurasia.

# Summer 2003 season: heat wave in Europe



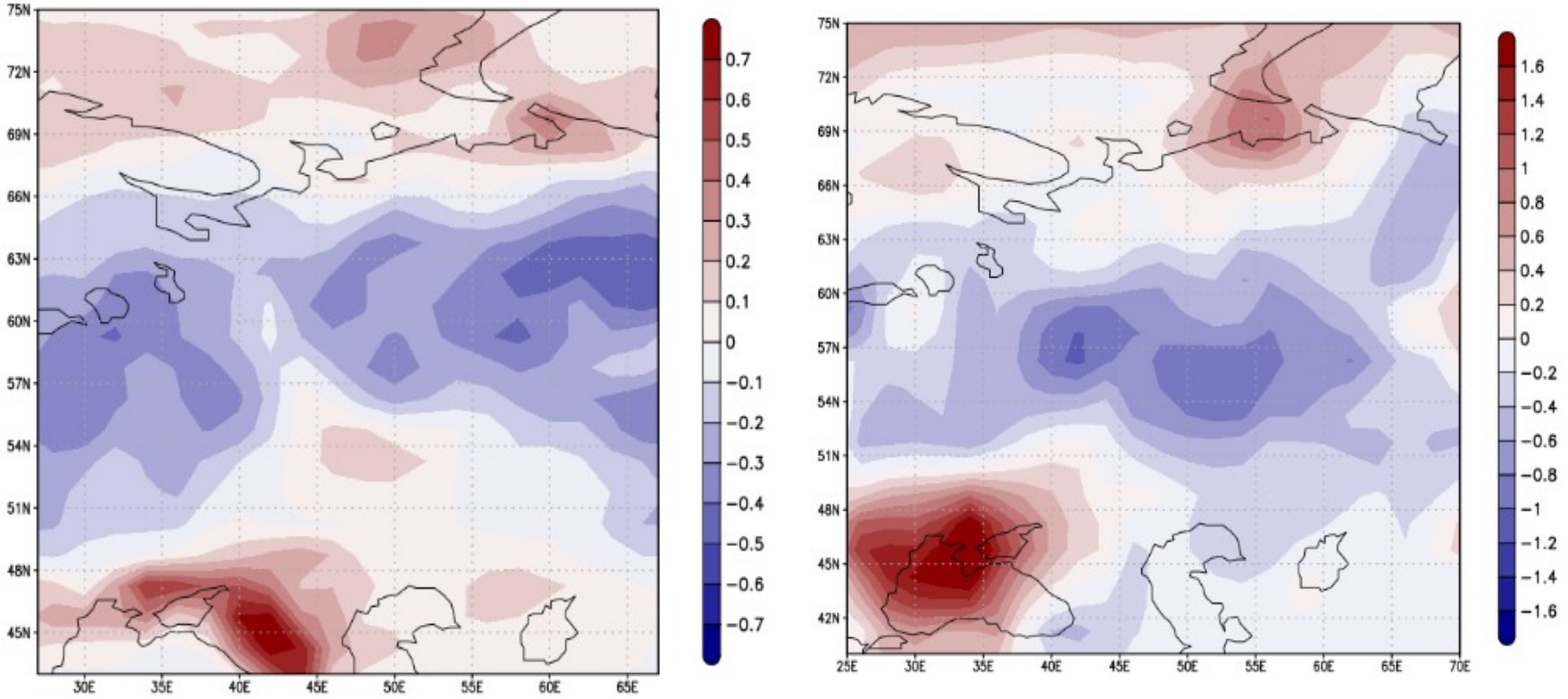

T2m anomaly in May-August 2003:

INM-CM5 seasonal forecast (top)

ERA5 data (right)

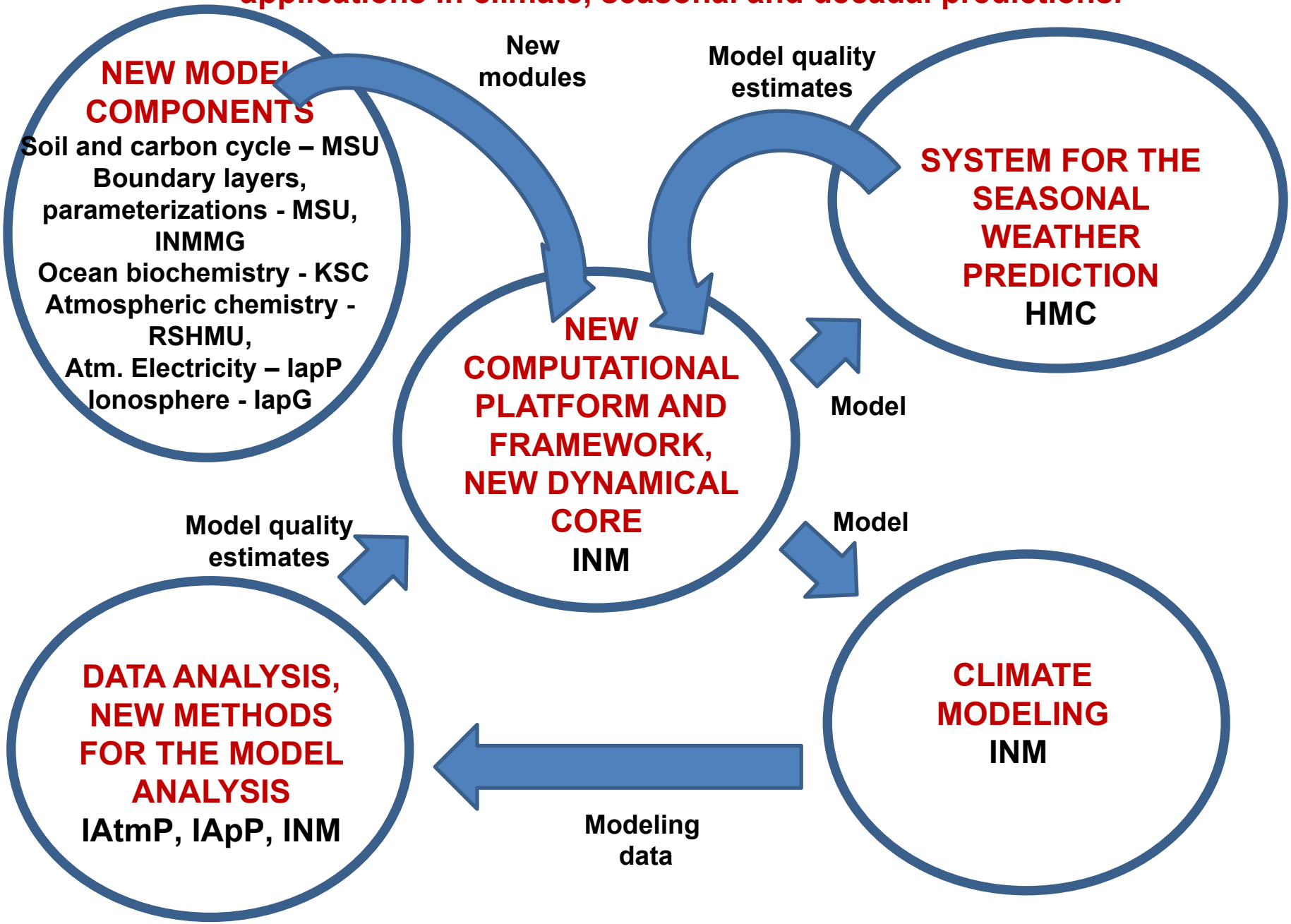
# Summer 2021 season

- Negative precipitation anomaly for European Russia
- Positive precipitation anomaly for Black sea




Precipitation anomaly in 06-08.2021.
Left – climate model INM-CM5,
Right – GPCP2.3 reanalysis data

**The INMCM Earth System Model is constantly evolving tool with applications in climate, seasonal and decadal predictions.**



**Thank you!**

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