ECMWF | 50

Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD

ICON-Seamless: Towards Coupled Forecasts for NWP, Climate and Paleo

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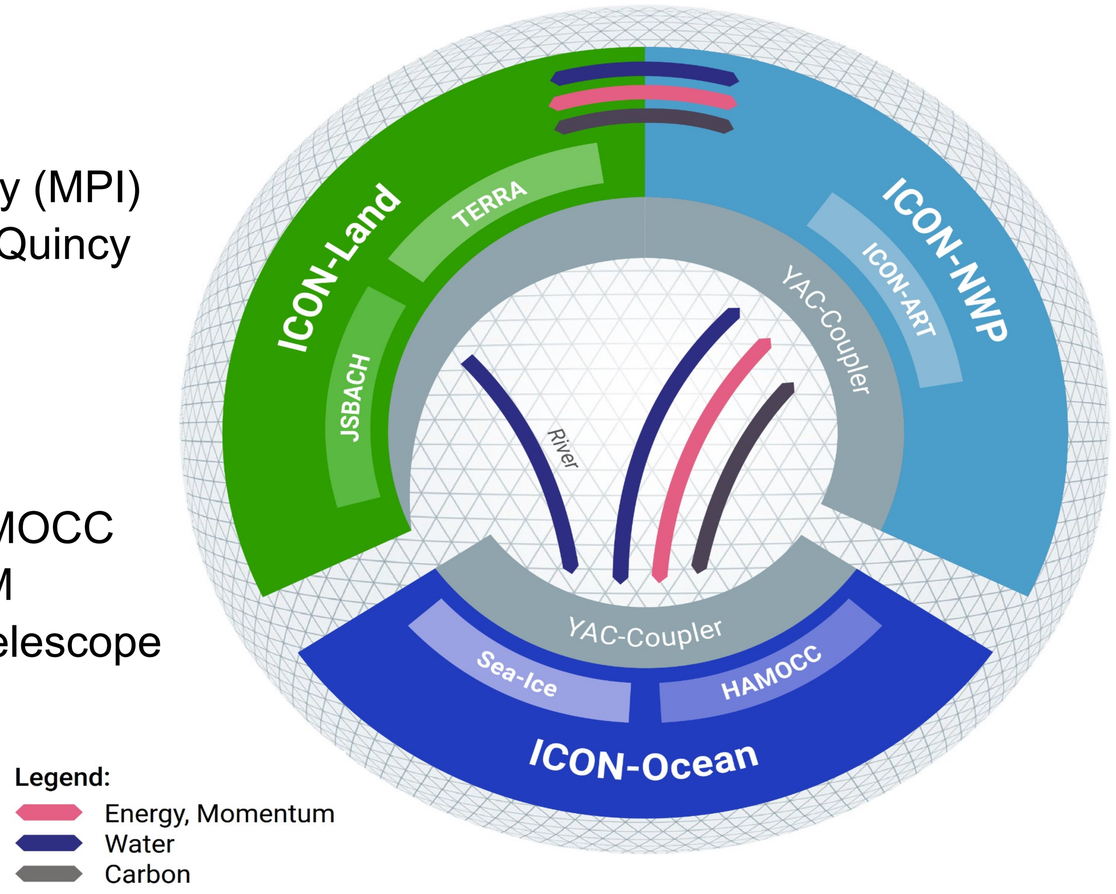
*In recent years, significant efforts have been made to develop ICON into a fully coupled ocean-atmosphere system for numerical weather prediction (NWP), climate, and paleo applications. Key advancements include the coupling to the **ICON-O ocean model**, a **sea-ice model** with thermodynamics and rheology on the ICON grid, and **ocean data assimilation**—initially with 3DVar, with a later transition to EnVar combined with LETKF. Additional developments include improved water conservation with **river-runoff**, a second land scheme (**JSBACH**) and enabling a CO_2 cycle through the adaption of the **Hamburg Ocean Carbon Cycle Model** (HAMOCC).*

*Recent enhancements include the implementation of **Kepler and VSOP87** orbits for paleo simulations, which improved NWP accuracy, and efforts to reduce **biases in precipitation, cloud representation, and ocean mixing**. Current work focuses on a pre-operational coupled NWP suite, **CMIP7** preparations, **seasonal forecasting**, **past warm periods**, and eddy-permitting coupled simulations to investigate teleconnections and the pattern effect.*

ICON-seamless

- atmosphere: ICON-NWP
  - TKE (DWD)
  - total turbulent energy (MPI)
- land: TERRA, JSBACH, Quincy
- ocean: ICON-O
- sea-ice
- river routing
- coupler: YAC
- ocean carbon cycle: HAMOCC
- ocean wave model: WAM
- ocean limited area and telescope
- trace gases: ICON-ART



Paleo: Last Interglacial (LIG) 127ka ago

After a spin-up of ICON-coupled for 500 years using pre-industrial conditions, a second experiment using LIG conditions with an adopted Earth orbit was run for another 200 years. The cooling in January and warming in July (see below) results from the change in perihelion from early January (now) to late July (LIG).
To facilitate this first paleo ICON simulation, Kepler and VSOP87 orbits were added.

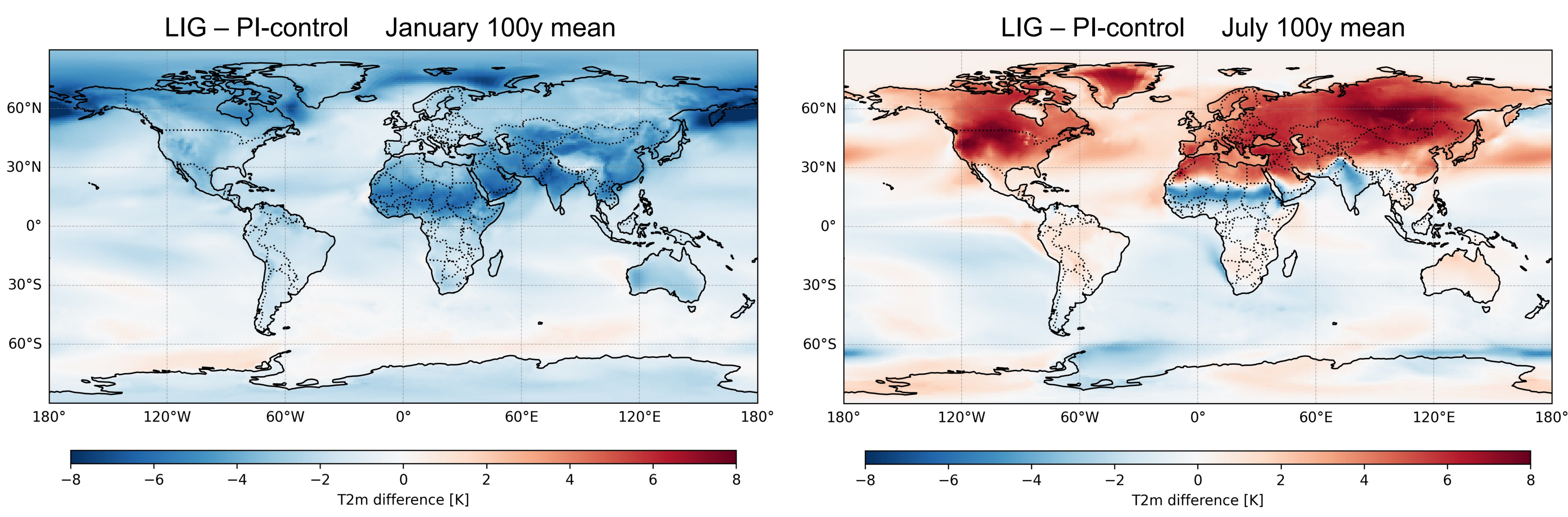


Figure 1: Difference of a LIG and a PI-control simulations at resolutions 80km/40km (atmo/ocean). The mean January and July of is taken from the last 100 simulation years.

NWP with ocean data assimilation

A coupled NWP prototype with data assimilation is in development based on the ICON-seamless framework plus ocean data assimilation initially with 3DVar and a later transition to EnVar combined with LETKF. Early results with 80km/40km (atm/oce) resolutions are shown and13km/20km is planned for operations.

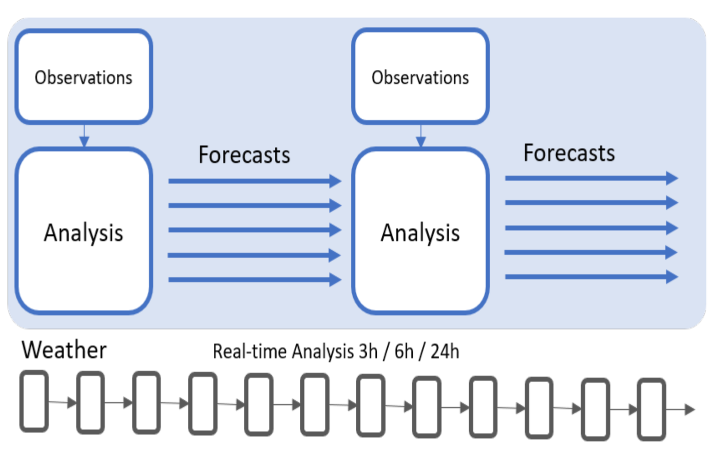


Figure 2: Illustration of the data assimilation cycle with 3h atmosphere and 24h ocean windows.

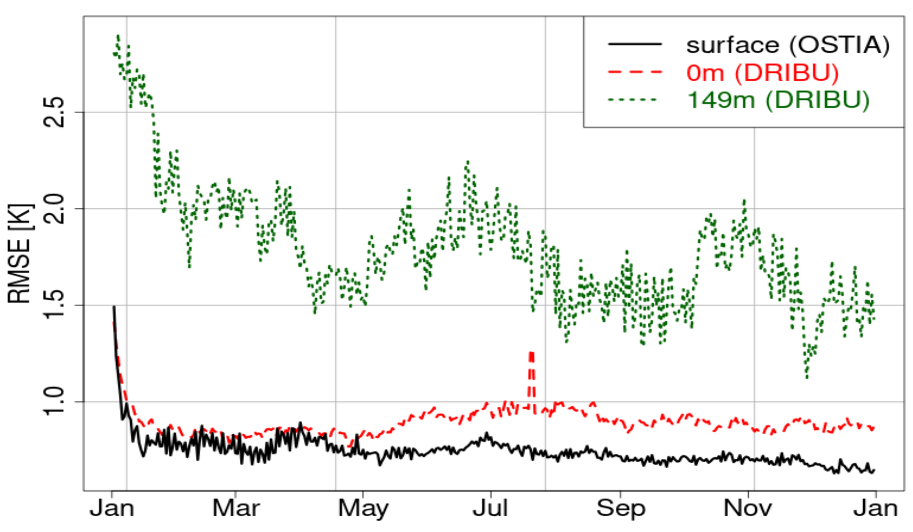


Figure 3: First annual coupled DA experiment for the year 2022. RMSE errors compared to OSTIA SSTs and drift buoys DRIBU are shown to reduce over time.

Climate prediction

An ICON-seamless version with land/turbulence schemes JSBACH/VDIFF "ICON-XPP" was configured and tuned for seasonal, decadal and climate prediction. Here we show various RMSE scores for CMIP6 models compared to ICON-XPP at atmo/ocean resolutions 160km/40km and 80km/20km.

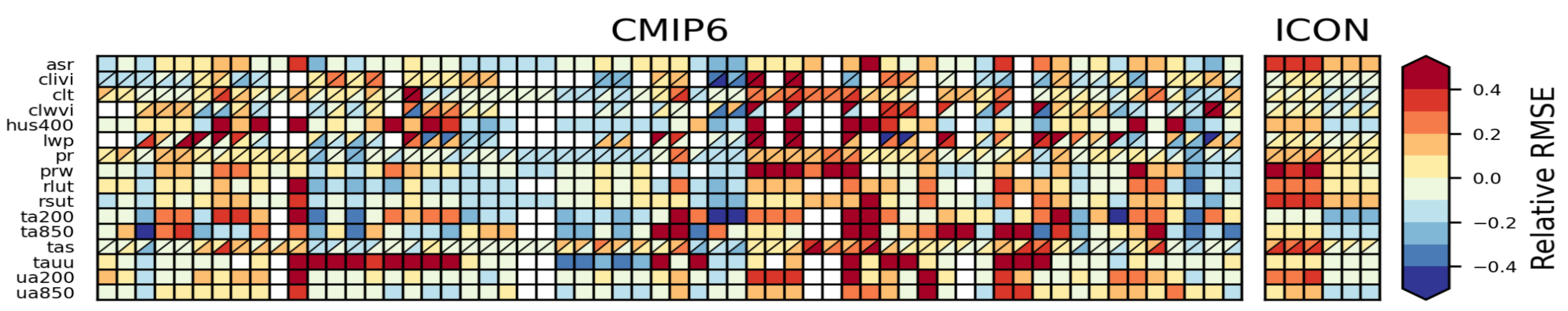


Figure 4: Various RMS scores for CMIP6 and ICON-XPP with respect to the median of CMIP6 scores. ICON was run at atmo/oce resolutions 160km/40km (left 3 ensemble members) and 80km/20km (right 3 members).

Model bias: dry Amazon, wet tropical oceans

ICON in coupled and atmosphere-only simulations has a unique bias of too much precipitation over tropical oceans and too little over tropical land such as Indonesia, India and the Amazon. The land bias is related to the diurnal cycle with too much precipitation in the afternoon and not enough during night. Resolution, reducing ocean evaporation and modifications to the convective parameterisation can help.

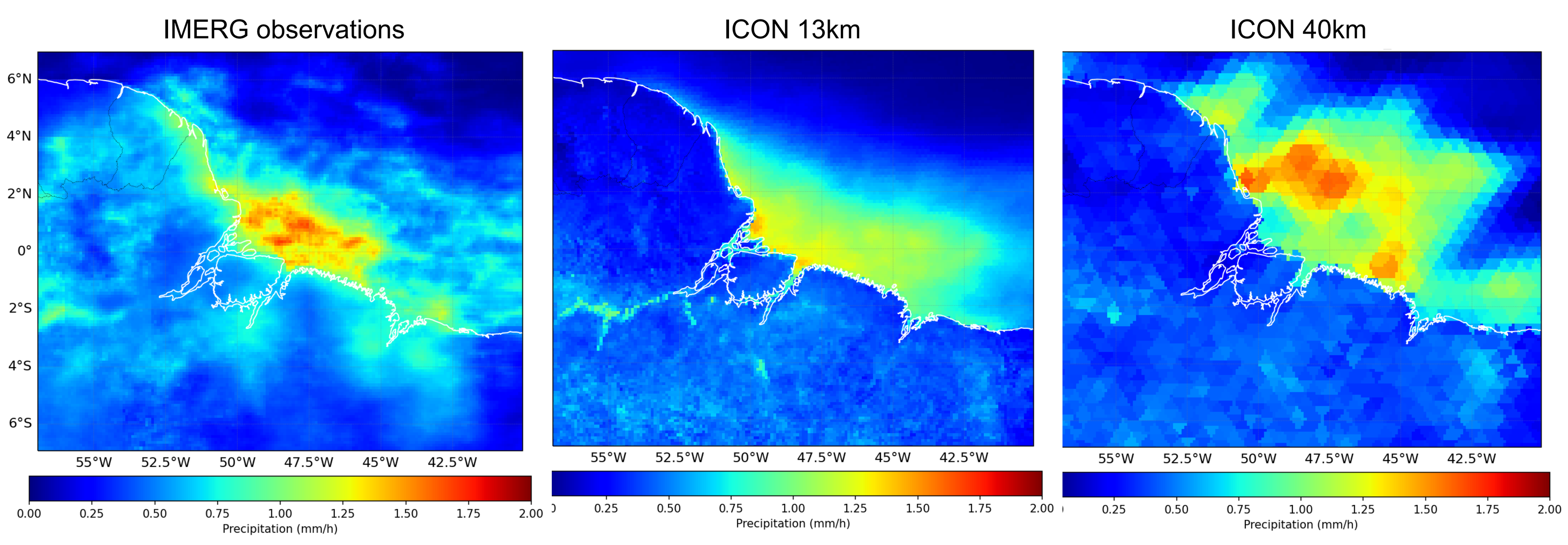


Figure 5: Precipitation in the Amazon for March 2023 (monthly mean). IMERGE observation and atmosphere-only ICON at 13km and 40km is shown.

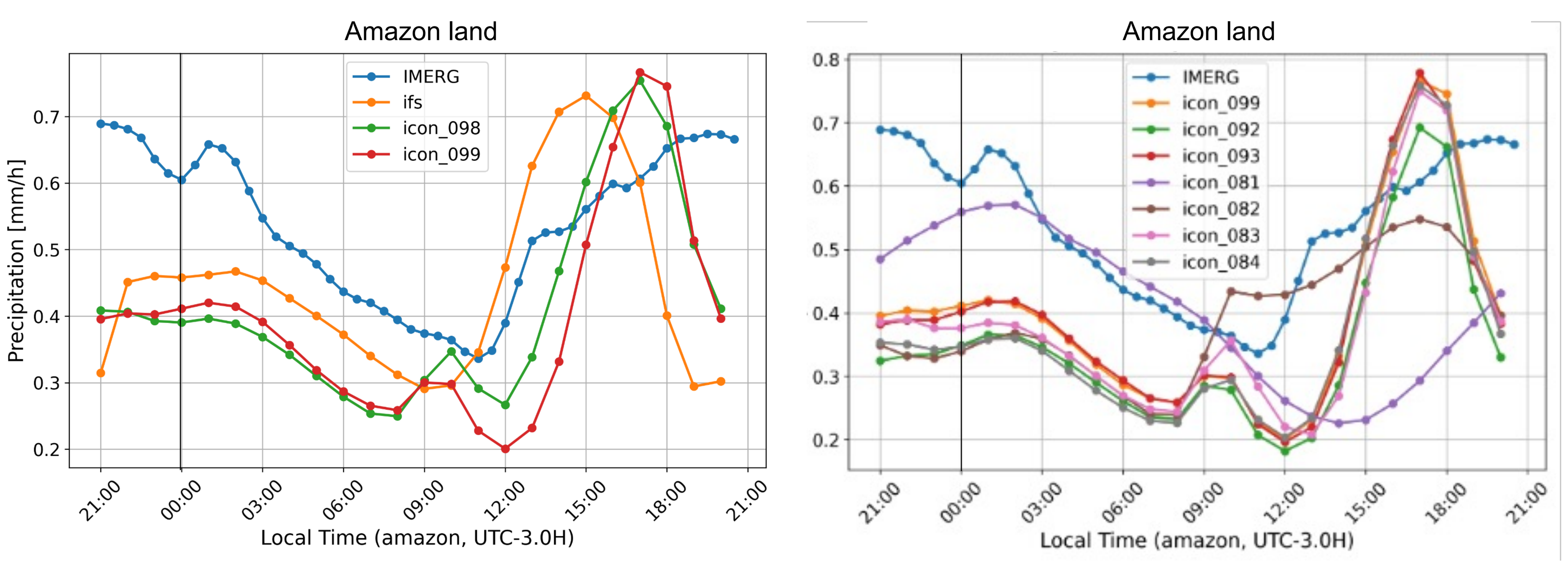


*Figure 6: **(left)** Monthly mean diurnal cycle of precipitation for March 2023 for **IMERG** observations, **IFS** and ICON at **13km** and **40km** resolution. **(right)** Various sensitivity experiments were performed with ICON at 40km. Most have little impact but **turning off deep convection** and setting the **CAPE time-scale to 3h**.*

Conclusion

- ICON ready for resolutions of 100m (LES) and 1km (LAM) to 100km (climate).
- Beyond operational NWP, ICON is currently been extended for coupled applications from paleo to climate projection with an upcoming upgrade to an operational coupled forecast and data assimilation system.

Müller et al 2025: ICON: Towards vertically integrated model configurations for numerical weather prediction, climate predictions and projections (BAMS).

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