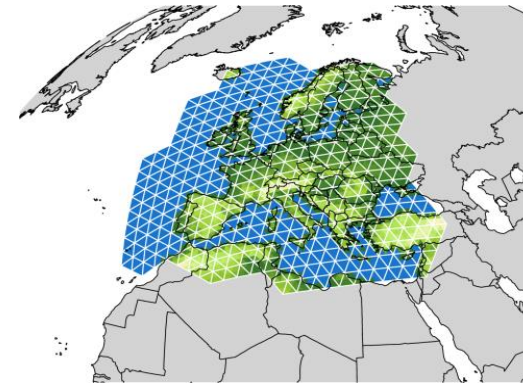


ICON for NWP: Recent activities and advances



Günther Zängl and Daniel Rieger, on behalf the ICON development team @ DWD

COSMO-GM 2026, Rome, September 16, 2026

→ Major improvements of DWD's operational system

- Retuning of entrainment and detrainment profiles in convection scheme
- Further development of adaptive parameter tuning
- Bugfix: use t_s rather than t_{skin} for bare-soil evaporation
- Bugfix for vertical localization in global DA
- Revision of SST perturbations in global EPS and EPS parameter perturbations in ICON
- Retuning of stratospheric humidity relaxation in global DA
- Simplified prognostic 2D aerosol scheme
- Coming soon: increase EPS resolution from 26/13 km to 20/10 km

→ Further important developments in ICON (see WG PHY overview)

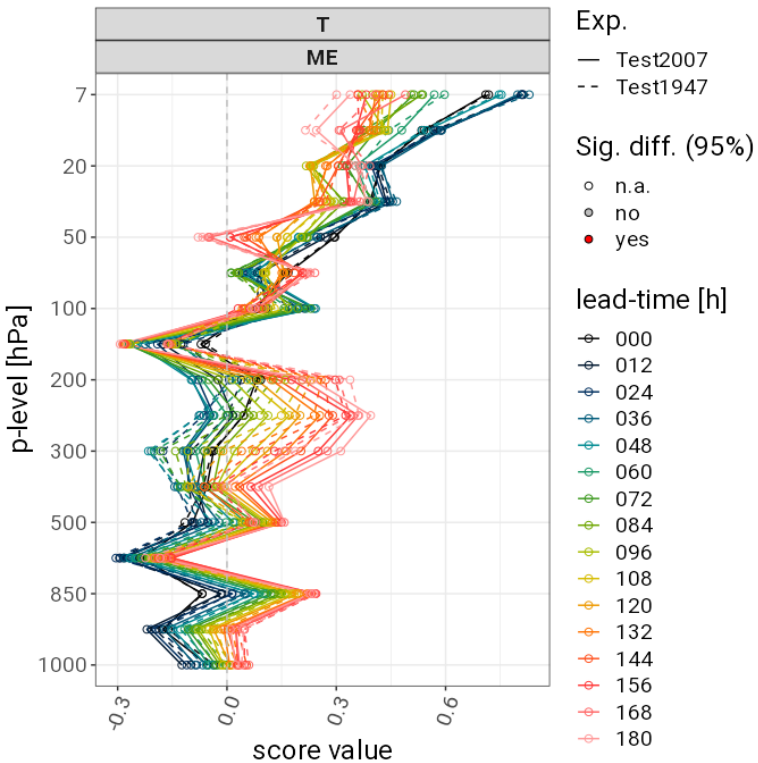
- TKESV scheme (Dmitrii, Ekaterina)
- Two-moment cloud ice scheme, dusty cirrus parameterization (Axel, Jochen)
- New Extpar data for soil properties (HiHydroSoil), Van Genuchten scheme for hydraulic soil properties (Linda, Jürgen)
- Extension of skin temperature scheme to snow-covered areas

→ News on Open Development and ICON Documentation

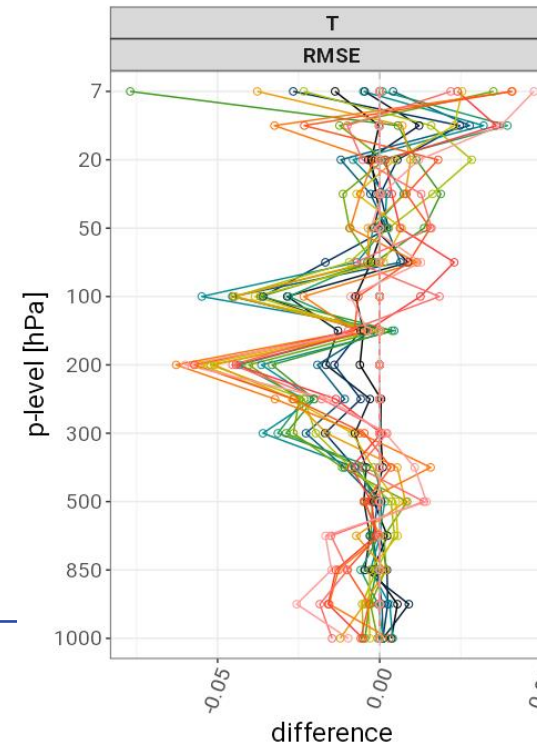


- ➔ RH-dependence not only for entrainment, but also for detrainment
- ➔ Reduction of land-sea difference for initial downdraft mass flux
- ➔ Shift of detrainment from tropopause region towards middle troposphere; improves wind and temperature profile primarily in tropics

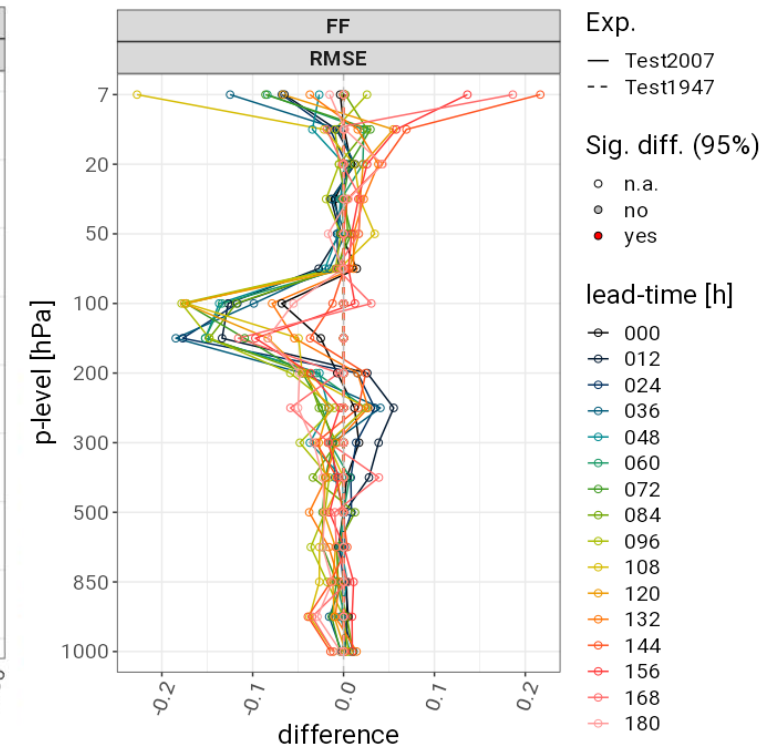
2025/01/01 - 2025/03/23
INI: ALL UTC, DOM: TR



2025/01/01 - 2025/03/23
INI: ALL UTC, DOM: TR



2025/01/01 - 2025/03/23
INI: ALL UTC, DOM: TR



Verification period: 2025/01/01 - 2025/03/23
INI: 00, 12UTC, SIGN. TEST: TRUE
Data selection by initial-date
Reduction of RMSE [%]

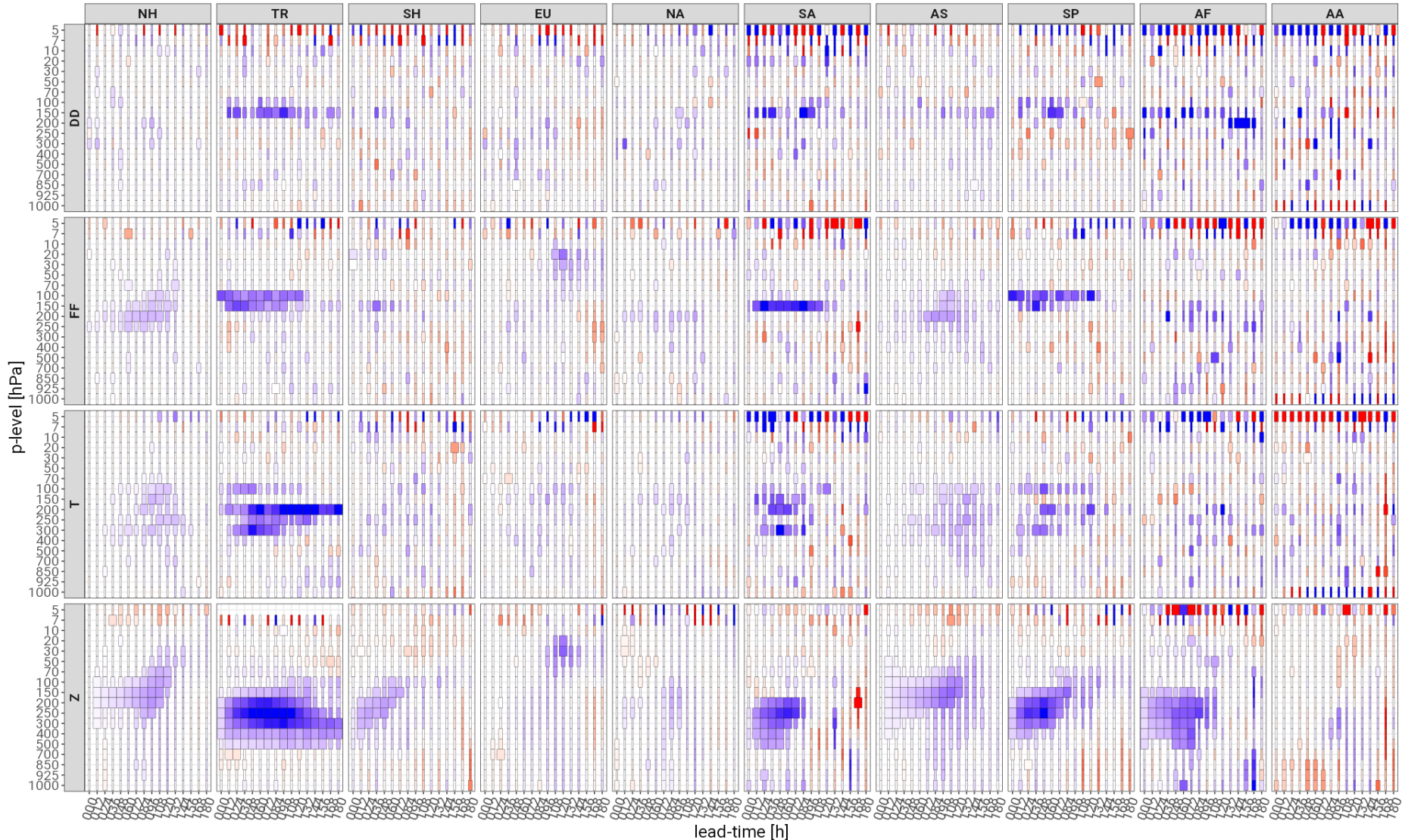
Blue:
new configuration better

wind direction

wind speed

temperature

geopotential

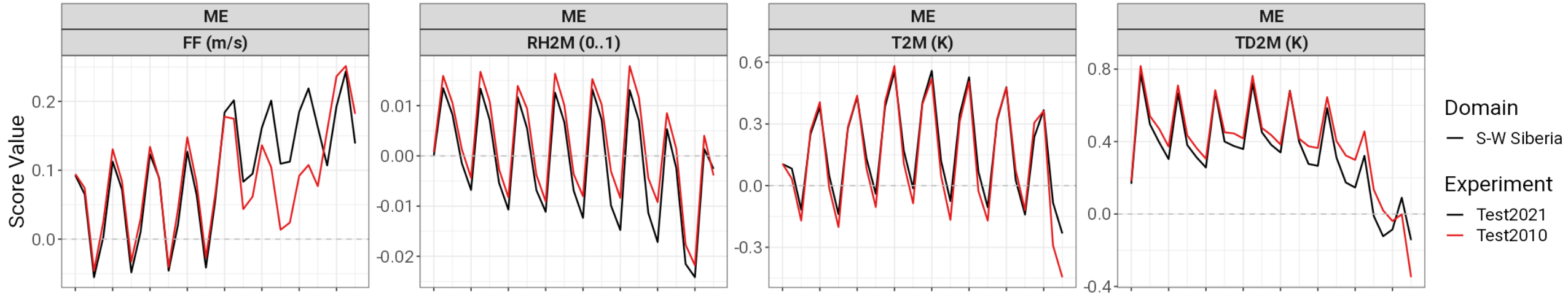


- ➔ **Modification of predictors:**
 - Longer filtering time scales for average DA increments of T and RH
 - Reduces bias differences between 00 and 12-UTC forecasts in regions with large diurnal cycle biases
 - Wind-speed dependent weights for filtered wind-speed DA increments
 - Giving less weight to DA increments occurring at weak winds avoids misinterpretation of 'low wind speed bias in calm situations' as 'small surface friction bias'
- ➔ Option to restrict adaptive surface friction to grid points having an SSO-stdev below a certain threshold (to be chosen similar to the cutoff used in DA)
- ➔ (Not yet in operations) Modified predictor for adaptive snow albedo, giving more weight to daytime than nocturnal temperature biases; to be used in combination with skin temperature on snow
- ➔ **New publication: Zängl (2026)** <https://doi.org/10.1002/qj.70269>

Example for reduction of bias differences between 00- and 12-UTC forecasts

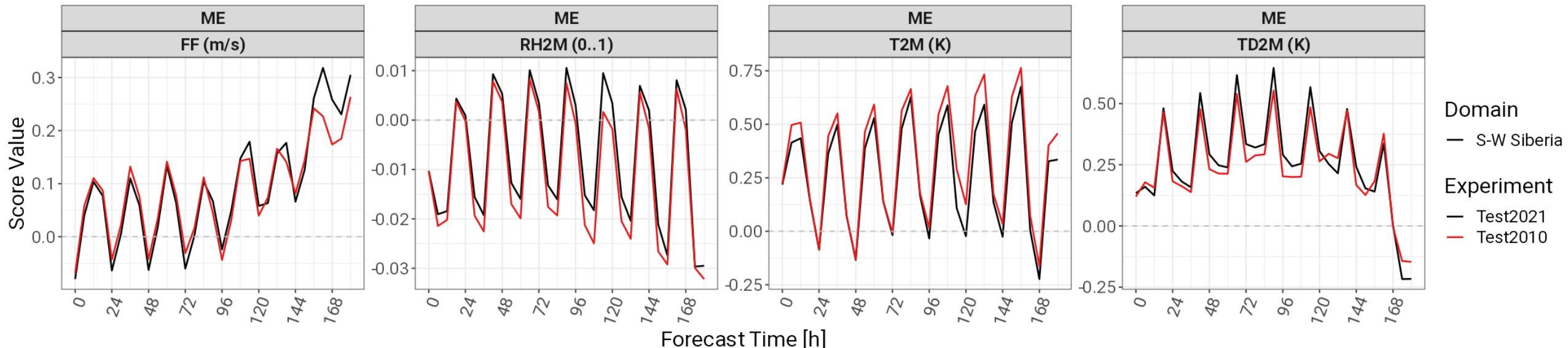
2025/05/01-00UTC - 2025/07/23-00UTC

INI: 00 UTC, DOM: S-W Siberia , STAT: ALL



2025/05/01-00UTC - 2025/07/23-00UTC

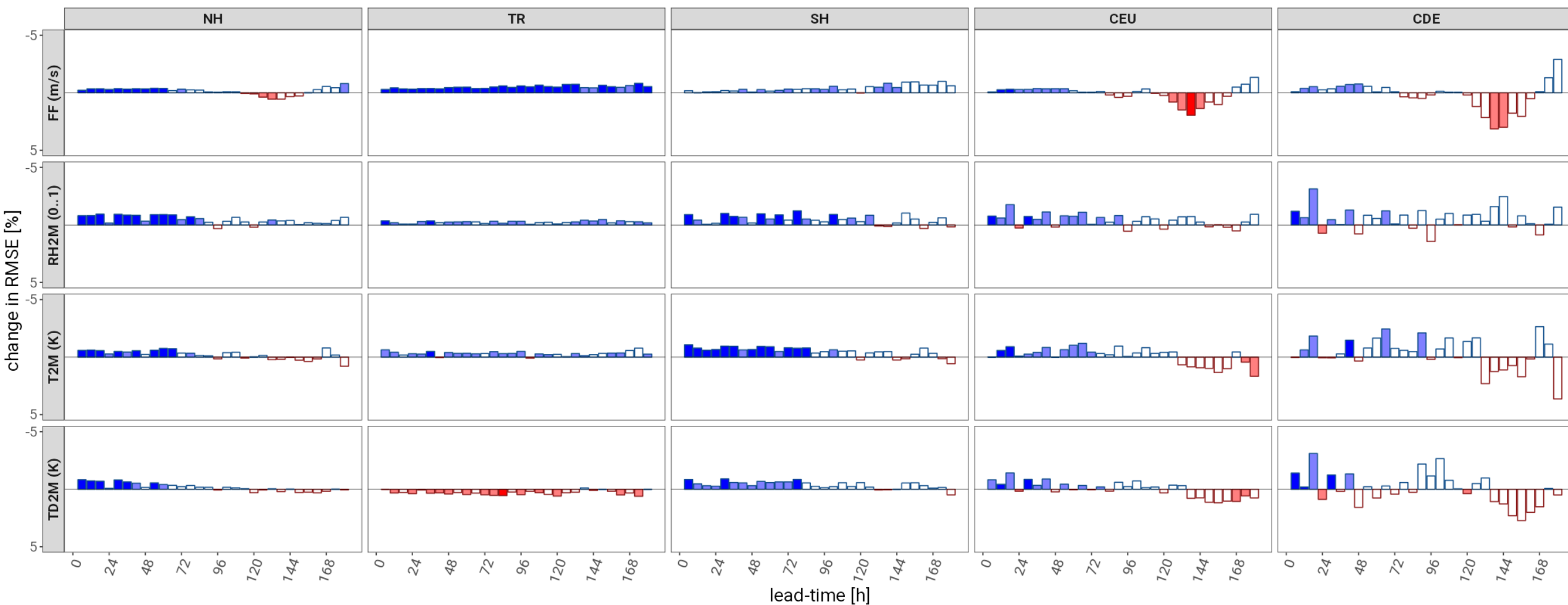
INI: 12 UTC, DOM: S-W Siberia , STAT: ALL



Forecasts initialized from 2025/05/01 to 2025/07/23
Reduction of RMSE [%], INI; 00, 12UTC, SIGTEST: TRUE

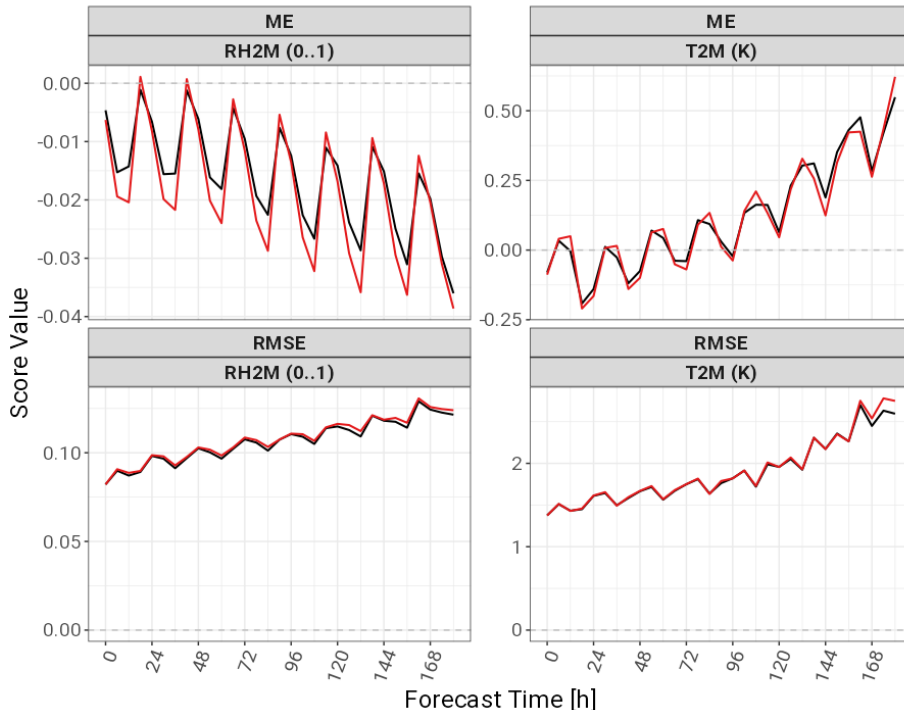
Blue: revised APT configuration better

Test2010 better Test2021 better Significance 0.00 0.25 0.50 0.75 1.00



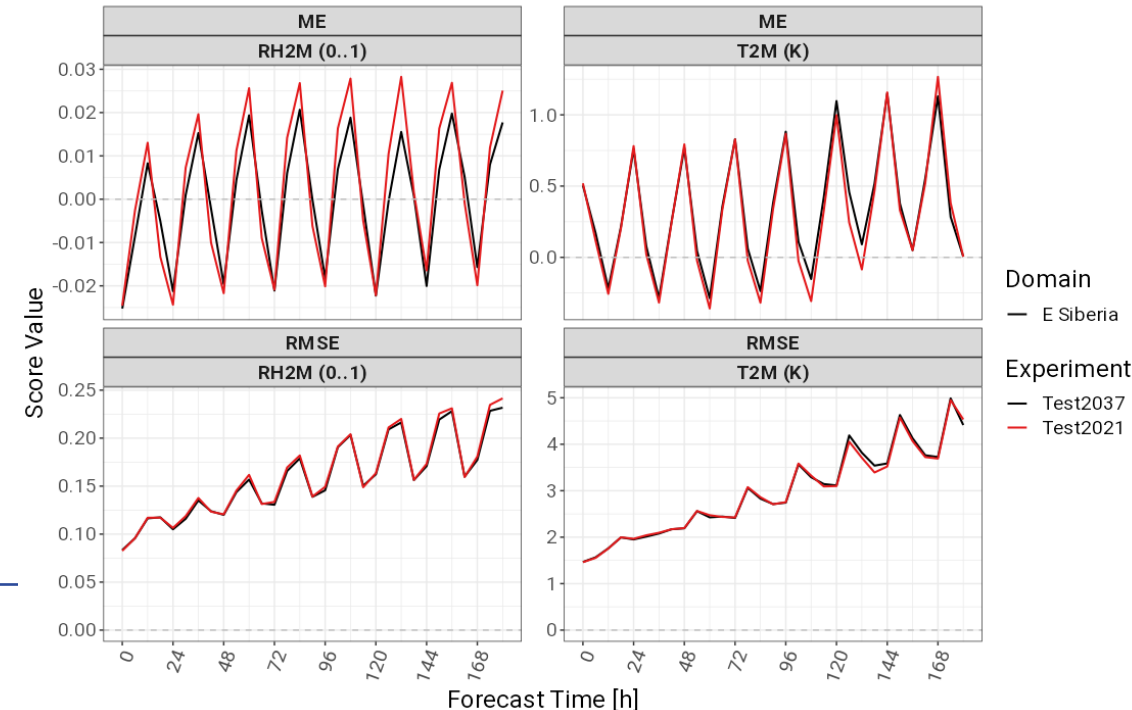
- ➔ Bare-soil evaporation should be based on t_s (soil-top temperature) rather than skin temperature; this was overlooked previously when implementing the skin temperature
- ➔ Impact: less evaporation during daytime, more at night
- ➔ This reduces the prevailing diurnal cycle bias in our forecasts

2025/05/01-00UTC - 2025/07/23-00UTC
INI: 00 UTC, DOM: N Southamerica , STAT: ALL



T2M and RH2M,
N-South America and
E-Siberia;
black = with bugfix

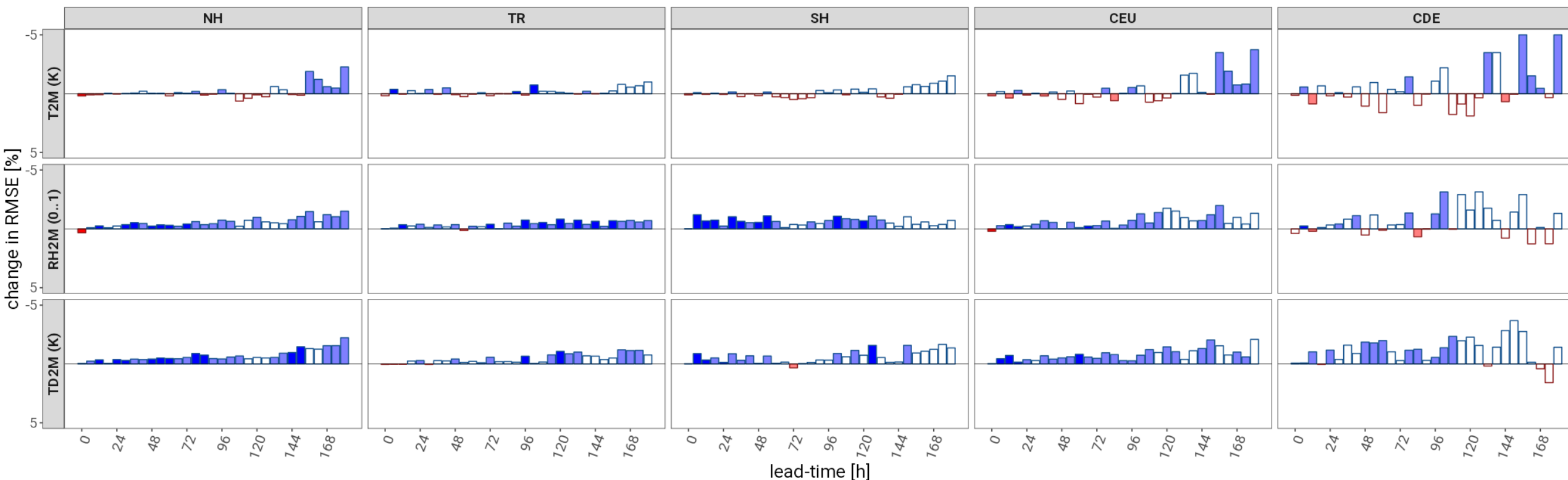
2025/05/01-00UTC - 2025/07/23-00UTC
INI: 00 UTC, DOM: E Siberia , STAT: ALL



Blue: corrected implementation better

Forecasts initialized from 2025/05/01 to 2025/07/23
Reduction of RMSE [%], INI; 00, 12UTC, SIGTEST: TRUE

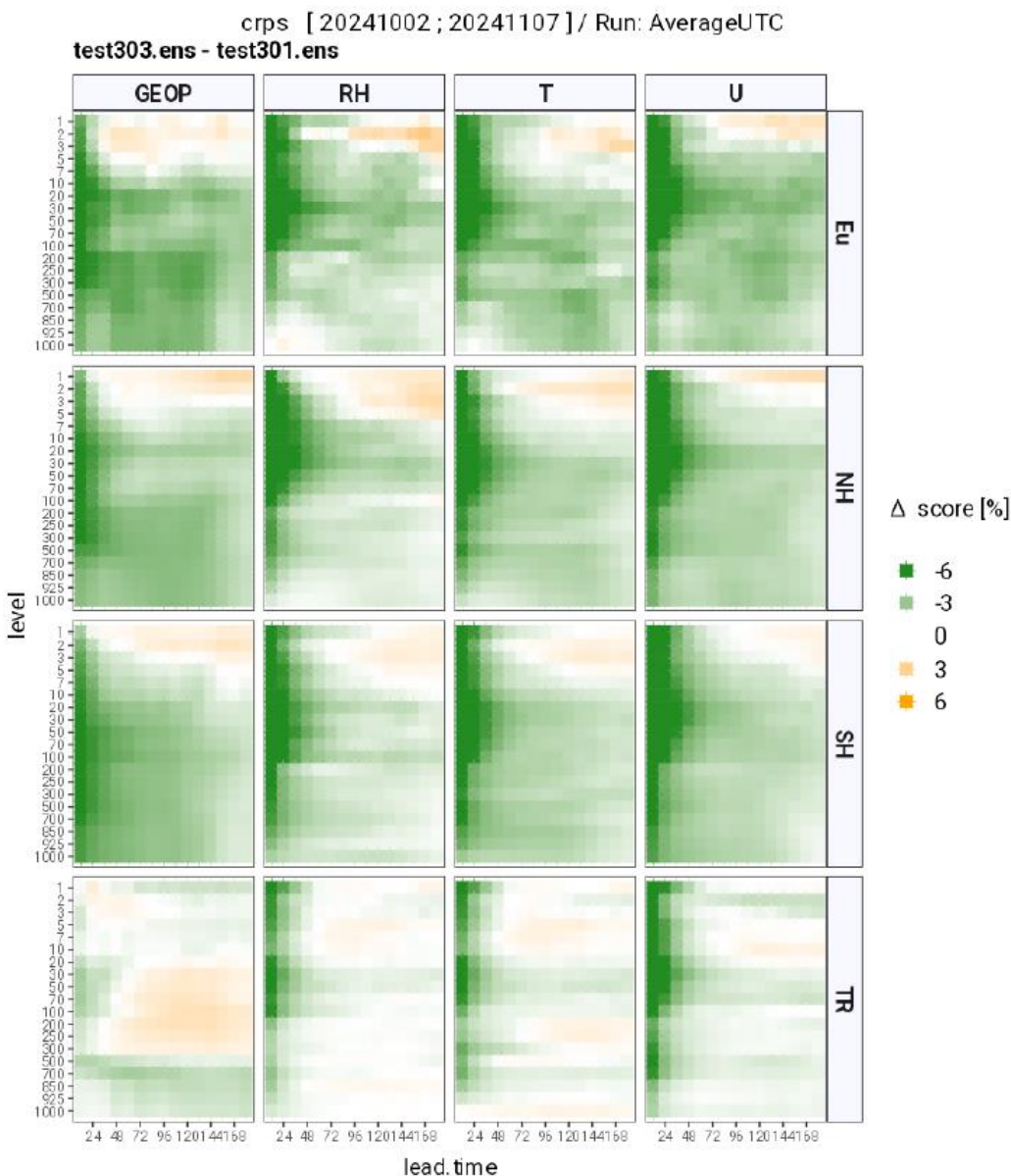
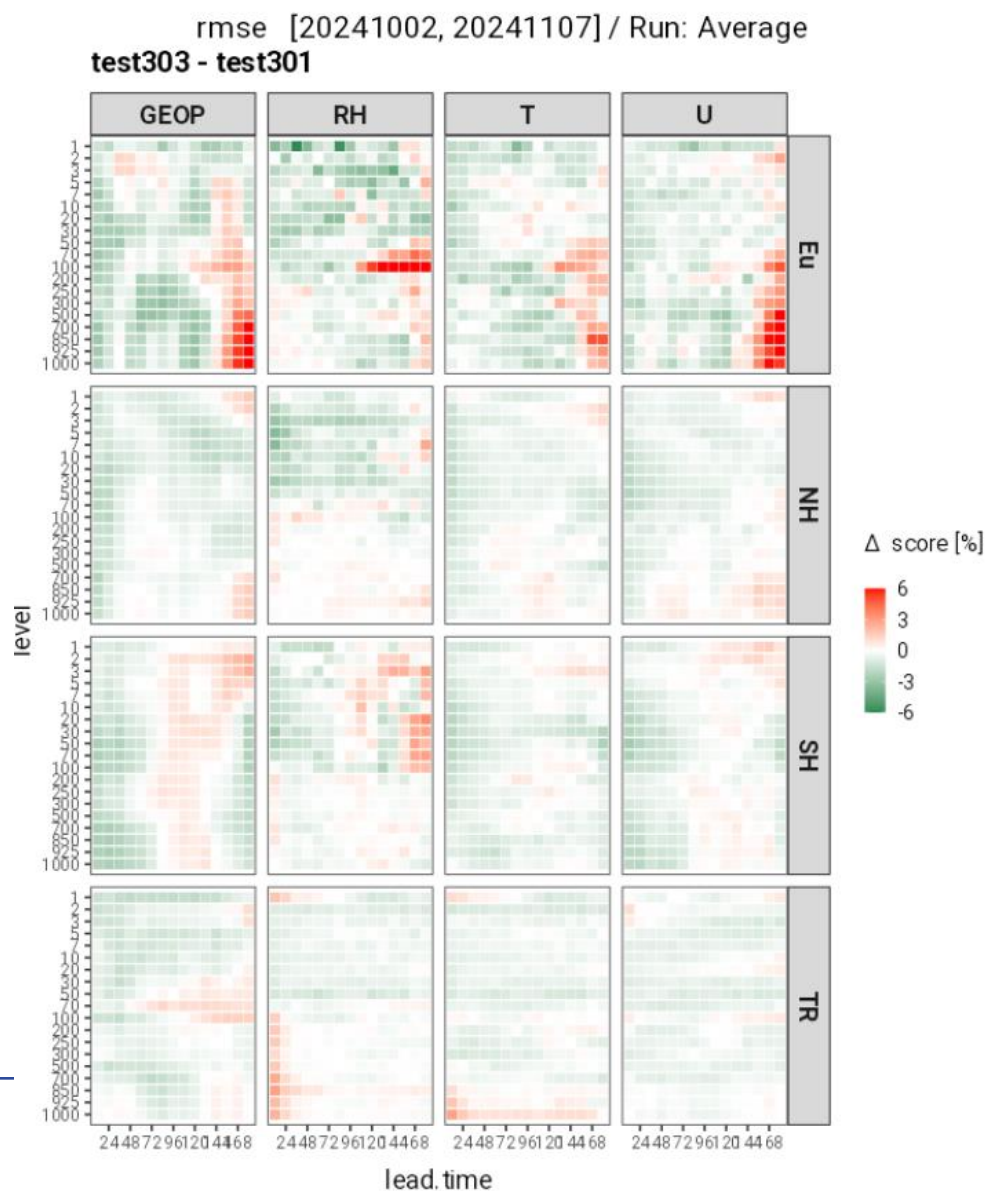
Significance 0.00 0.25 0.50 0.75 1.00 ■ Test2021 better ■ Test2037 better



- Small coding error with huge impact
- Prior to the fix, excessive ensemble spread was needed to get sufficient weight of the Ensemble B-matrix
- As a compensation, the additive inflation applied within the LETKF was reduced

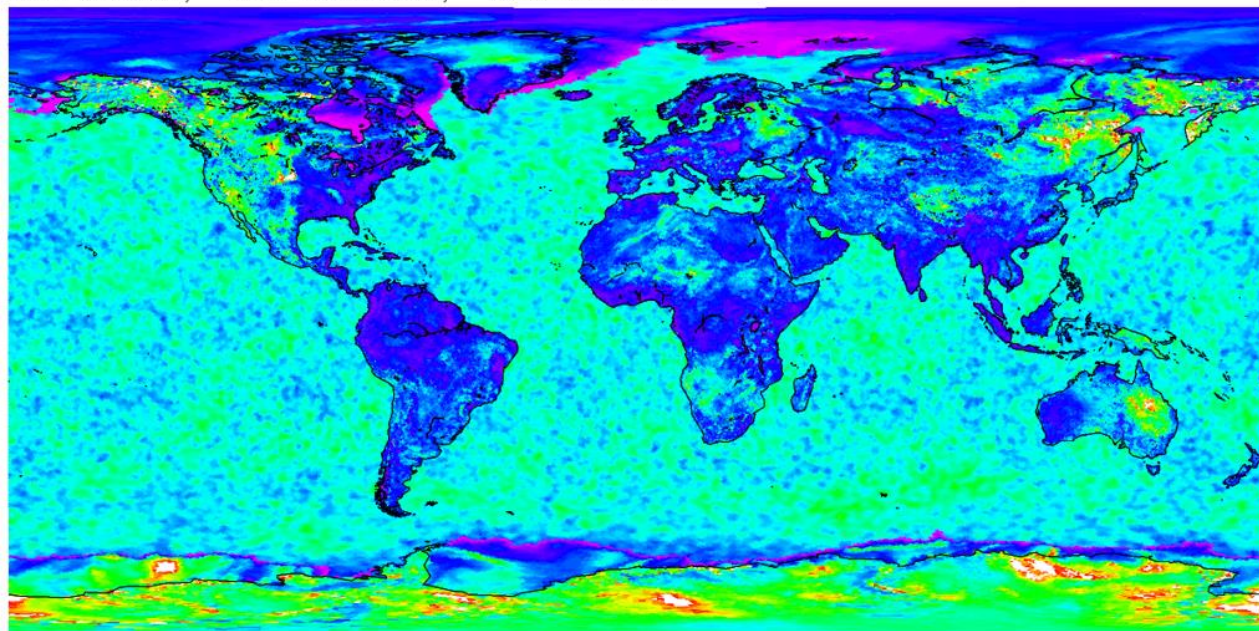
```
!-----
!  Normalise
!-----
if (bugfix_vloc) then
  a = 1._wp / sqrt (sum (c1% cg (:,i,j,k,d)**2))
else
  a = 1._wp / sqrt (sum (c1% cg (:,i,j,k,d)))
end if
c1% cg (:,i,j,k,d) = c1% cg (:,i,j,k,d) * a
```

- Impact: more consistent assimilation of many types of data, reduced O-B errors
- Reduced ensemble spread partly degrades CPRS against observations, but RMSE is consistently improved, particularly for geopotential
- On the other hand, the striking over-dispersiveness appearing in the EPS analysis verification (prior to the bugfix) is greatly improved
- Moreover, the deterministic analysis verification shows consistent improvements

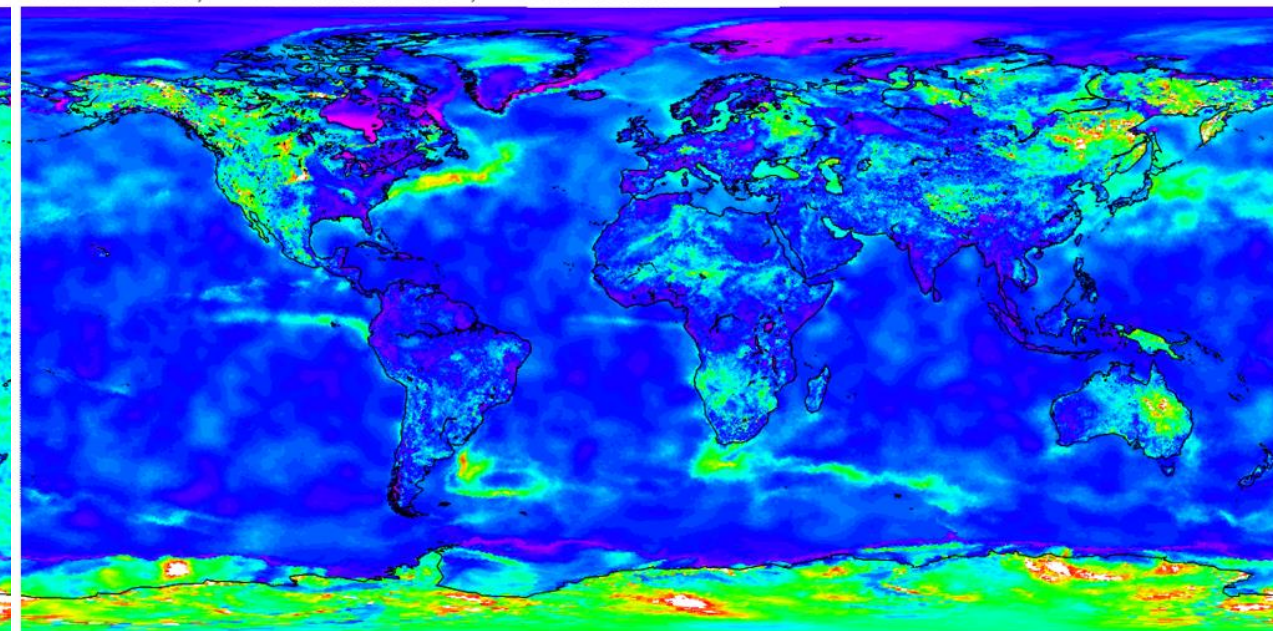


- Prior to the change, the stochastic SST perturbations imposed as part of the LETKF had a globally uniform amplitude and were – at least in the tropics and subtropics – unrealistically large (spread about 1.1 K; left figure)
- New implementation is based on climatological SST variability patterns derived from ERA40, combined with a (user-specified) background spread of 0.5 K (right)

MAX: 6.73492 ; MIN: 0.00103733 ; AVG: 0.952009



MAX: 6.71889 ; MIN: 0.000992633 ; AVG: 0.68687



Spread of T_G in K

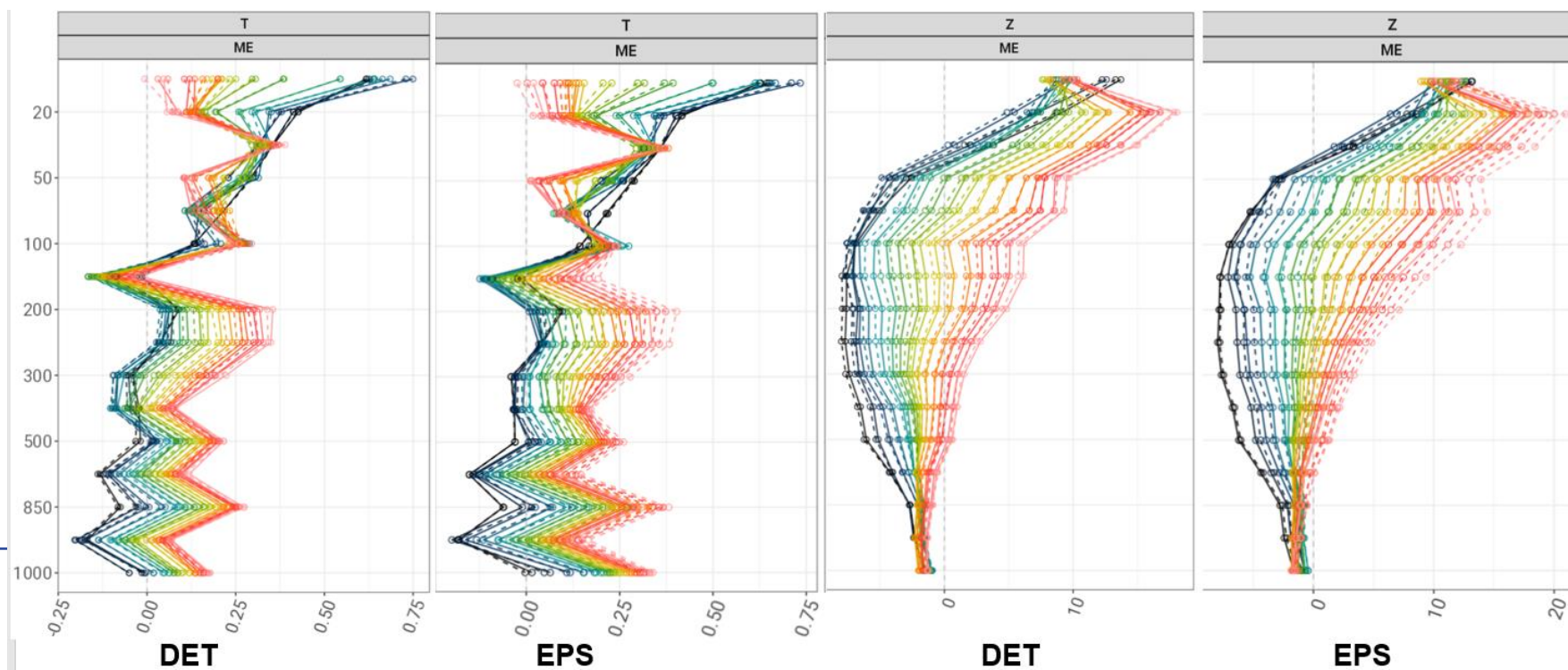


Harald Anlauf

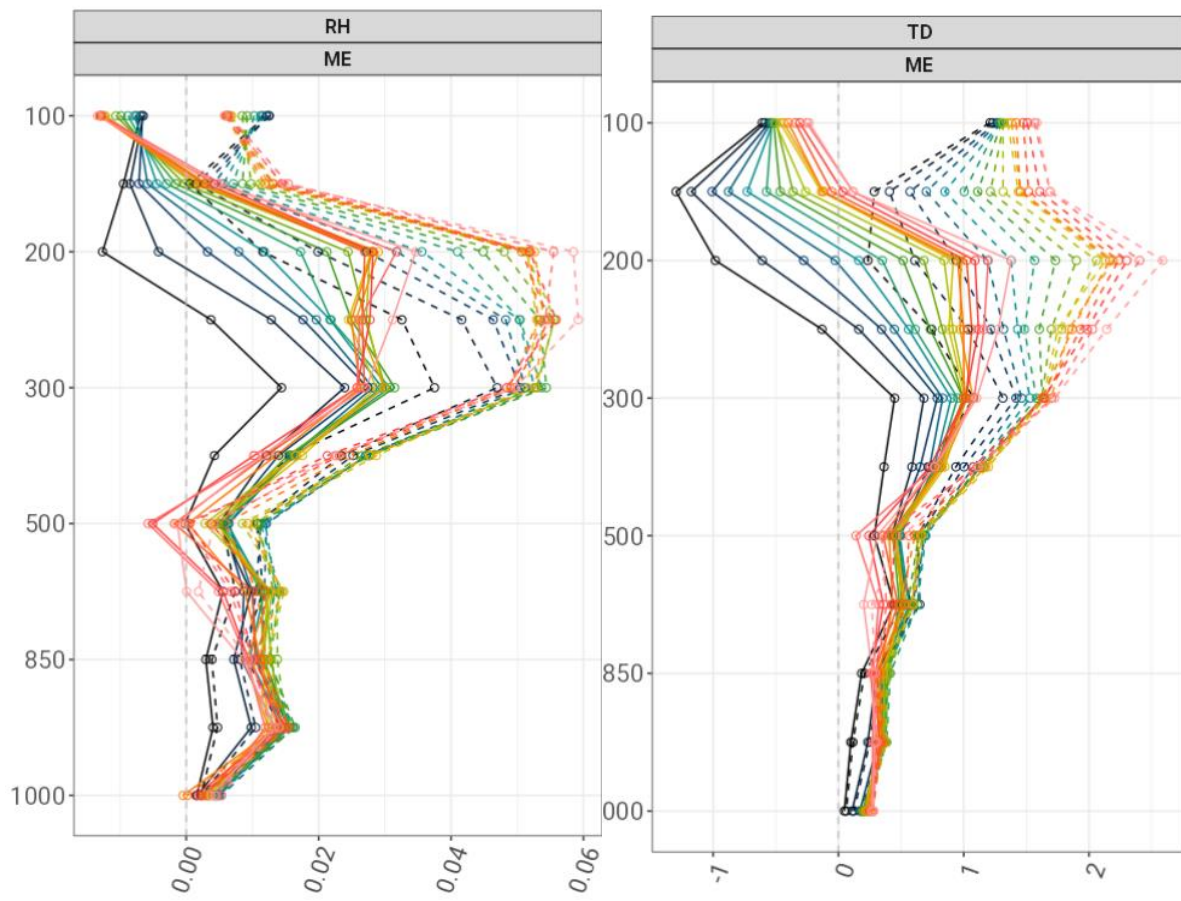
- ➔ To maintain sufficient atmospheric ensemble spread in the forecasts, a few physics parameter perturbations were increased, particularly the two most effective ones in the convection scheme
- ➔ The reduced SST perturbations allowed bringing the EPS-mean temperature bias close to that of the deterministic forecast (before, the EPS was systematically warmer, particularly in the tropics)

Bias profiles for
temperature and
geopotential in
the tropics

solid lines:
revised
implementation



- ➔ Most of the widely used approximations for saturation pressure w.r.t water and ice get increasingly inaccurate at low temperatures (below about -50°C)
- ➔ Processing humidity data from radiosondes thus requires careful consideration of the processing done by the vendor in order to avoid inconsistencies



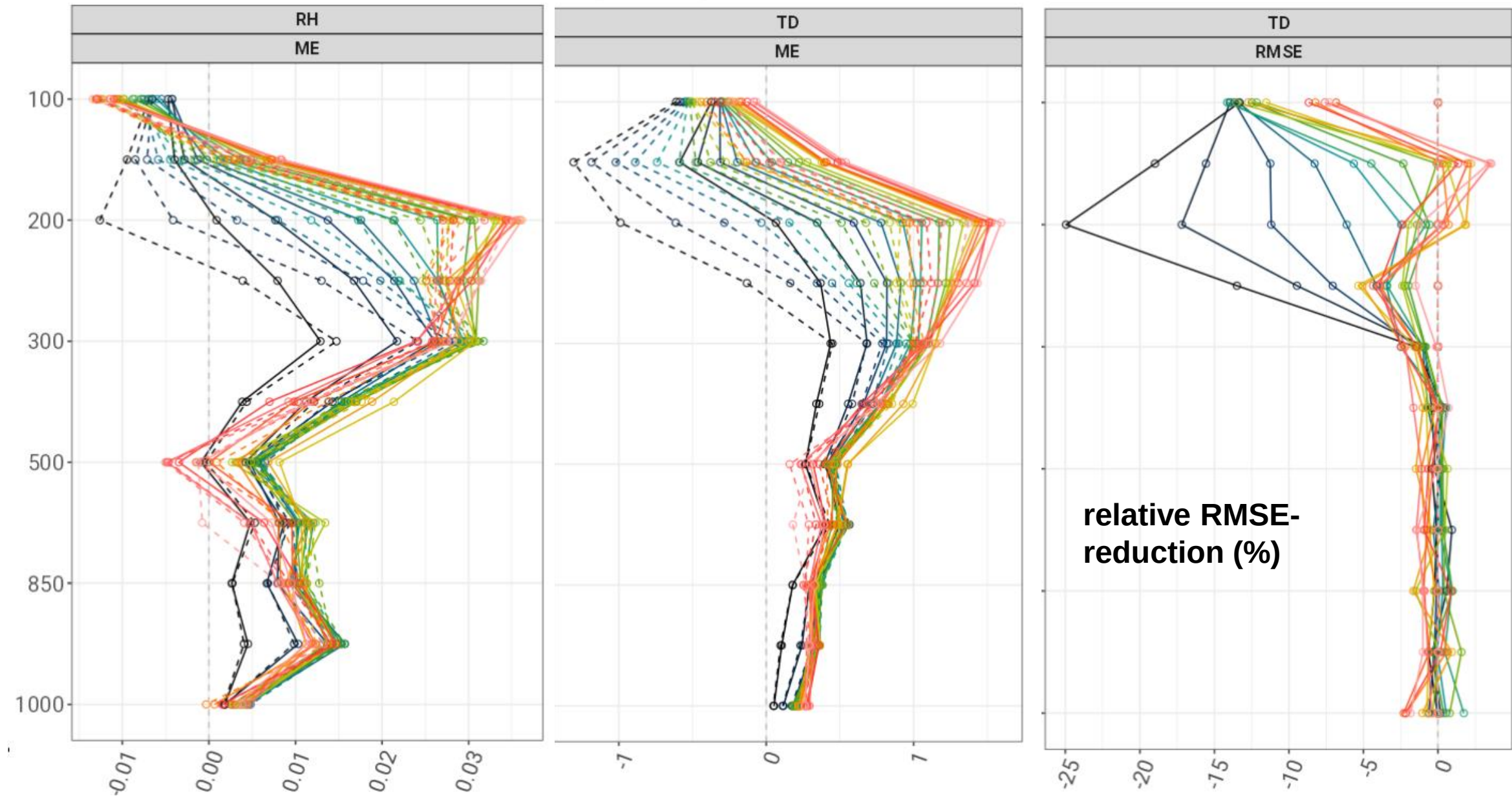
Verification of ICON forecasts (1.5. – 15.7.25) against radiosonde data for Europe, bias of RH and dew point

solid: corrected processing (Hardy formula)
dashed: previous processing without correction

The forecasts are the same, it is just the processing of the radiosonde data that differs!

So far, the radiosonde verification indicated a false moist bias in the upper troposphere

- We assimilate (almost) no moisture data above the tropopause
- Due to diffusive moisture transports across the tropopause, a free-running model would get too moist in the extratropical lower stratosphere
- Thus, we complement the assimilation of 'real' moisture data with a relaxation towards climatology above the tropopause
- So far, this relaxation was tuned to be way too strong because the verification falsely indicated a marked moist bias in the lower stratosphere
- The resulting dry bias in the analyses is now fixed by reducing the relaxation coefficient



- ➔ **Motivation: doing better than the (outdated) Tegen climatology without adding much computational cost (+0.5%)**
- ➔ **Approach: change 2D AOD fields from the climatology into prognostic variables with source and sink terms; advection is performed with vertically averaged winds**
- ➔ **Aerosol categories and optical properties are taken over from Tegen**
- ➔ **Most evident improvements are related to emission changes since the 1990's**
 - **Less anthropogenic sources in Europe**
 - **Increased anthropogenic sources in parts of China and India**
 - **Increased wildfire activity at high northern latitudes in summer**

Prognostic equation for 2D-AOD $\psi_j(x, y)$ (red: tuning parameters)

$$\frac{\partial \psi_j(x, y)}{\partial t} = \underbrace{\overline{\mathbf{v}_{H,j}} \nabla \psi_j(x, y)}_{\text{advection}} + \underbrace{S_{e,j} + S_{w,j}}_{\substack{\text{sources \& sinks} \\ \text{(emission, nucleation,} \\ \text{washout)}}} + \underbrace{f_{diff} \cdot \Delta \psi_j(x, y)}_{\text{artificial diffusion}} + \underbrace{\frac{\psi_{clim,j}(x, y) - \psi_j(x, y)}{\tau_{clim,j}}}_{\text{relaxation to climatology}}$$

Horizontal transport of 2D-AOD: Using vertically averaged wind

Artificial diffusion: ‘Accounting’ for the effects of vertical wind shear

Parameterized emissions: based on Kok et al. 2014 (mineral dust) and Grythe et al. 2014 (sea salt)

Prescribed emissions: based on EDGAR (Crippa et al. 2016) for SO₂, NO_x, NH₃, BC, OC

Sulfate nucleation: simple parameterization if conditions are favorable for nucleation

Wildfire climatology (10y): seasonal averages of wildfire emissions (SO₂, BC, OC); quadratic regression

Seasonal Hotspots

Large wildfire locations are remarkably constant in the last decade

Climatological dataset

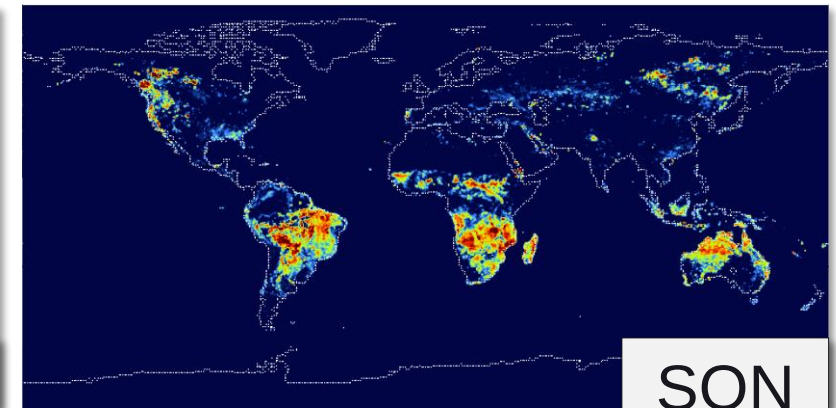
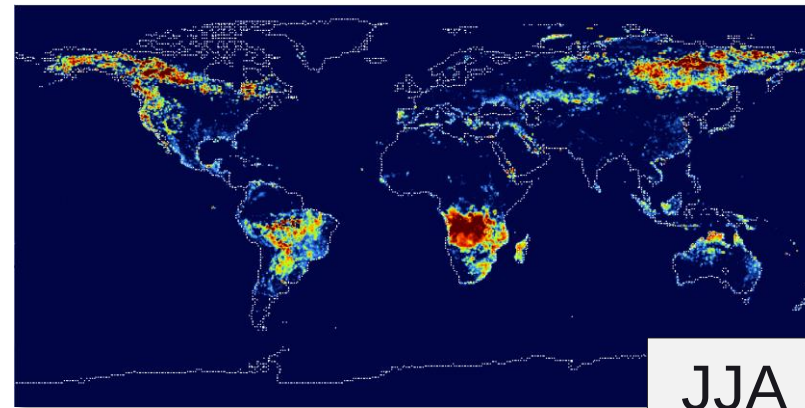
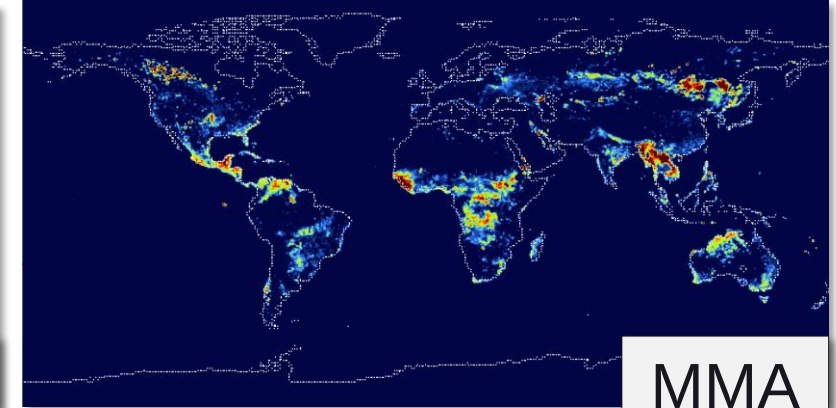
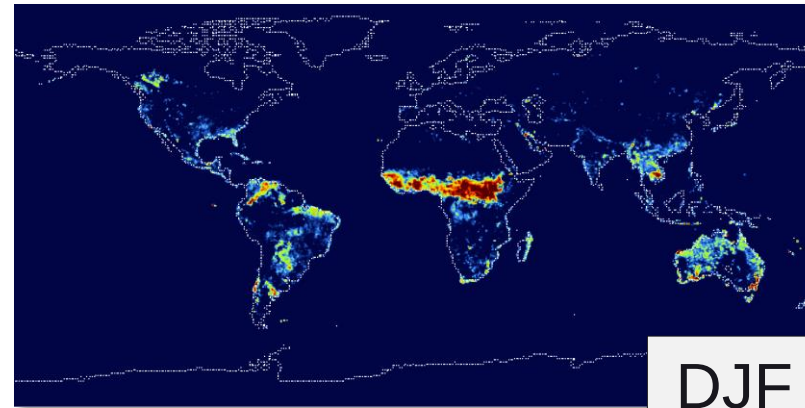
10y seasonal averages 2015-2024
Wildfire emissions of SO_2 , BC, OC
Available in Extpar/Zonda

Inclusion in ICON

Quadratic regression
AOD source with empirical factor

One the right

Seasonal cycle (qualitative)

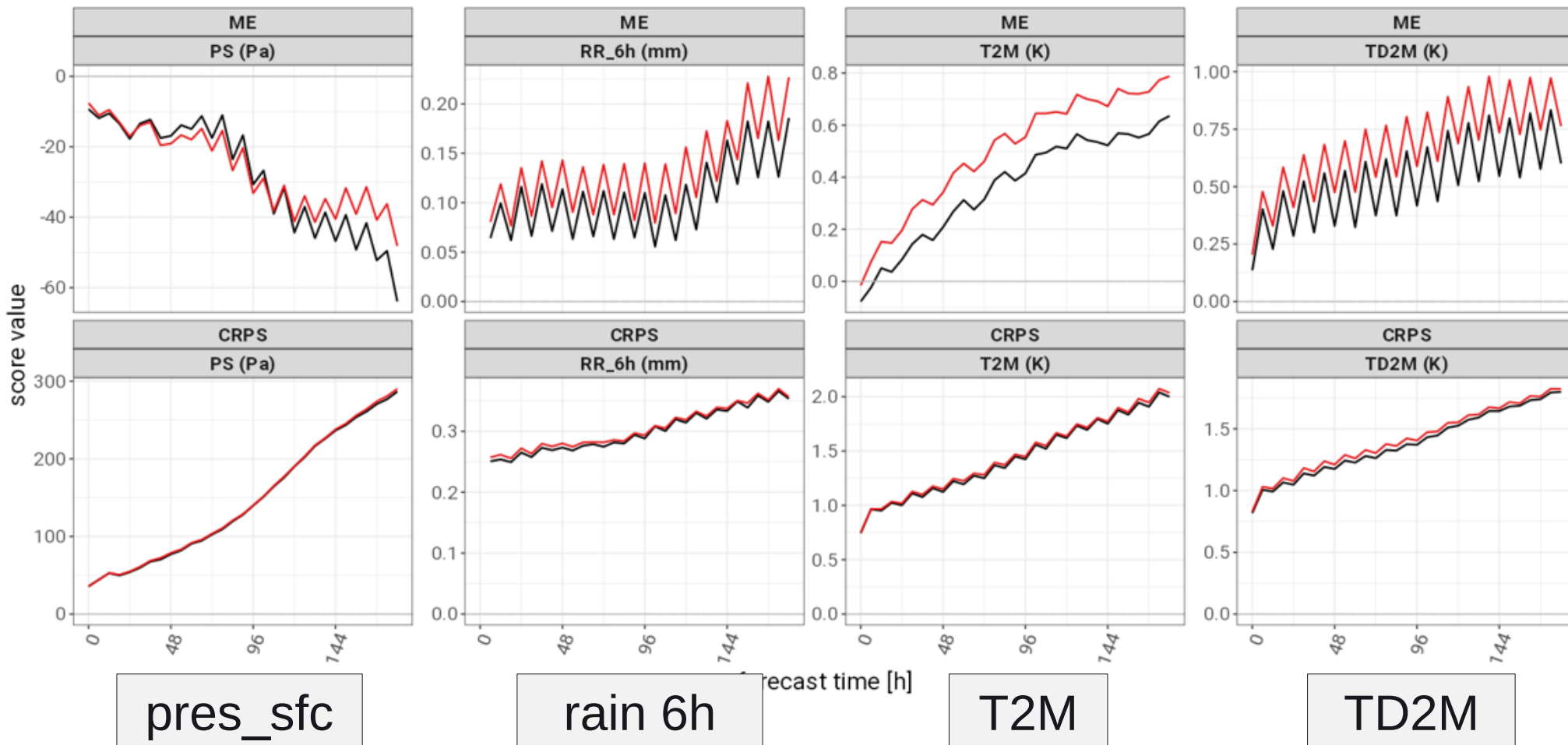


Summer

2025/05/01 00UTC - 2025/07/23 00UTC
INI: ALL UTC, DOM: N Northamerica, STAT: ALL

ME

CRPS



➔ Enhance resolution from 26/13 km (global/EU) to 20/10 km, including ICON-ART mineral dust forecasts

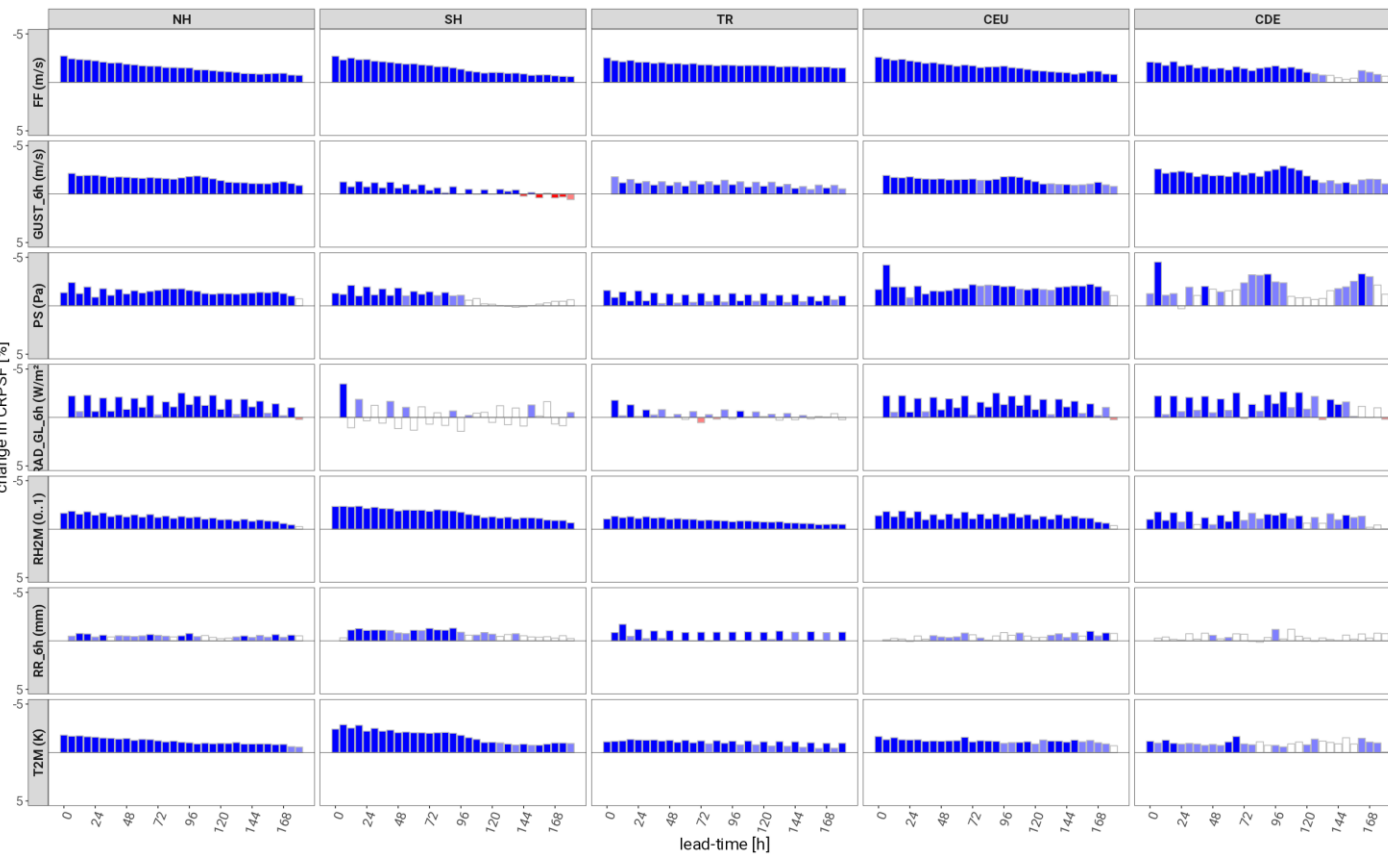
➔ Slightly enlarge EU-nest domain in order to cover IMS forecast domain (lat BC)

Forecasts initialized from 2026/03/20 00UTC - 2026/07/28 12UTC

Change in CRPSF [%],

INI: 00, 12UTC, SIGTEST: TRUE, STATIONS: ALL

Significance 0.00 0.25 0.50 0.75 1.00 11995 lower ICON lower



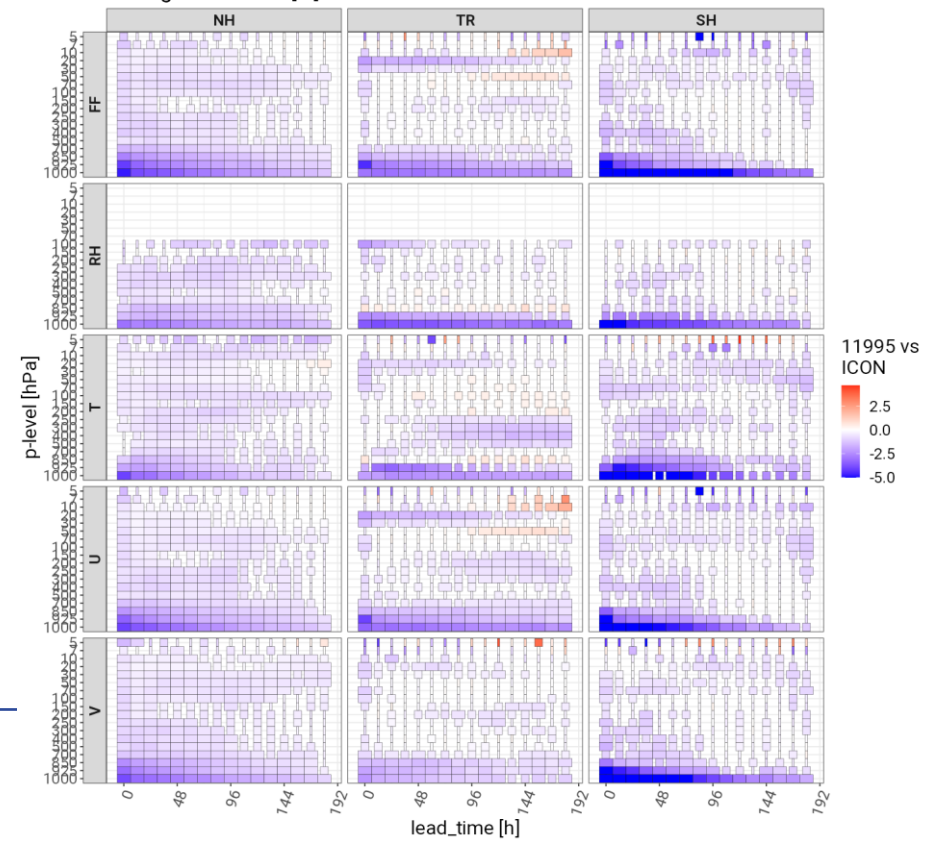
Verification period: 2026/03/20 - 2026/07/28

INI: 00, 12UTC, SIGN. TEST: TRUE

Data selection by initial-date

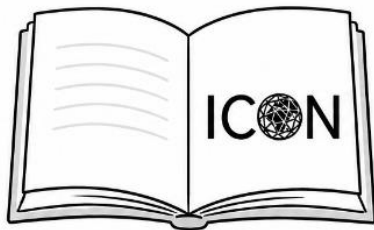
Change in CRPSF [%]

Radiosonde CRPS



OPEN SOURCE

THE RESULT IS OPEN.



FINISHED BOOK

OPEN DEVELOPMENT

THE PROCESS IS OPEN.



WRITING WORKSHOP

AI GENERATED

“ ICON will continue to move towards Open Development. This is done in close collaboration with the open development team.

ICON Coordination

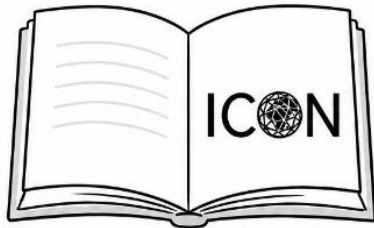
https://gitlab.dkrz.de/icon/wiki/-/wikis/2026_03_05

Recommendations Open Development Team

- Clear and concise guidelines documented on <https://docs.icon-model.org>
- Push <https://exchange.icon-model.org>
- Cleanup issues, merge requests, maintainer group
- Homogenize workflow and testing strategy & get to one common repository
- Enforce development workflows and guidelines for everyone
- Establish additional roles (~community management)
- Organize semi-annual meetings
- Establish an open monthly virtual ICON Coffee
- Establish red lines for contributions and community interaction
- Collect & establish existing informal “topic groups”

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Development. This is
with the open develop

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https://gitlab.dkrz.de/icon/wiki/-/wikis/2026_03_05

Investments into Open Development are already paying off by enabling a clear, transparent, and healthy development process.

Namelist Overview

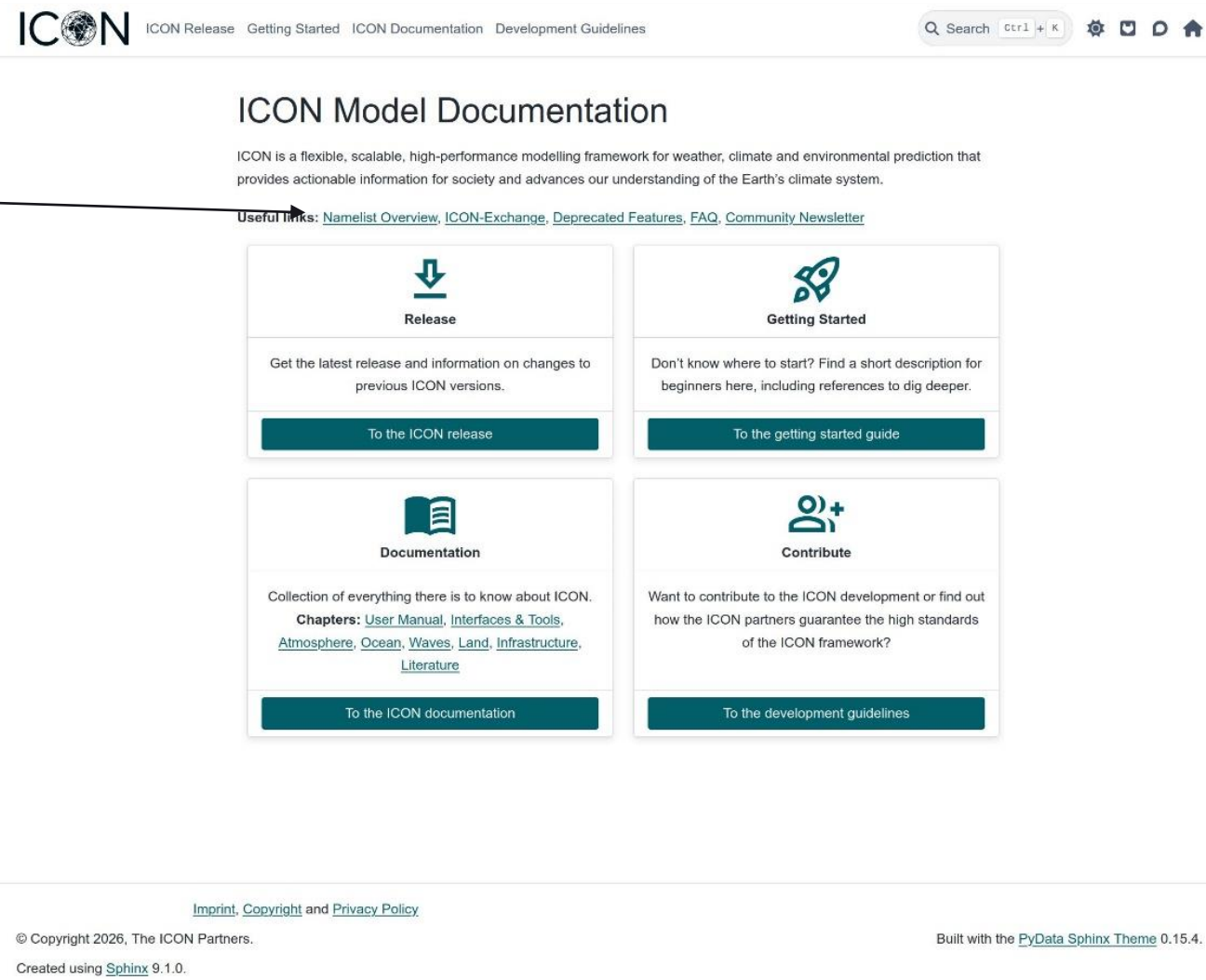
- Moved from PDF
- Parameters can be referenced in docs

Deprecation

- Announcements with dates, reasons etc.
- Alternatives

Release

- Download
- Release Notes
enforced by CI



The screenshot shows the 'ICON Model Documentation' website. At the top, there is a navigation bar with links: 'ICON Release', 'Getting Started', 'ICON Documentation', and 'Development Guidelines'. A search bar is also present. The main content area is titled 'ICON Model Documentation' and includes a brief description of the framework. Below this, there are four main sections, each with an icon and a button:

- Release** (download icon): 'Get the latest release and information on changes to previous ICON versions.' Button: 'To the ICON release'.
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At the bottom, there are links for 'Imprint', 'Copyright and Privacy Policy', and footer information: '© Copyright 2026, The ICON Partners.' and 'Built with the [PyData Sphinx Theme](#) 0.15.4. Created using [Sphinx](#) 9.1.0.'

Documentation

- Varying coverage
- Nicely covered e.g.: Building; ecRad, ...

Contribute

- Guidelines for developer, reviewer, documentation

Exchange

- Community support platform
- *Also for Licensees!*

Namelist Overview

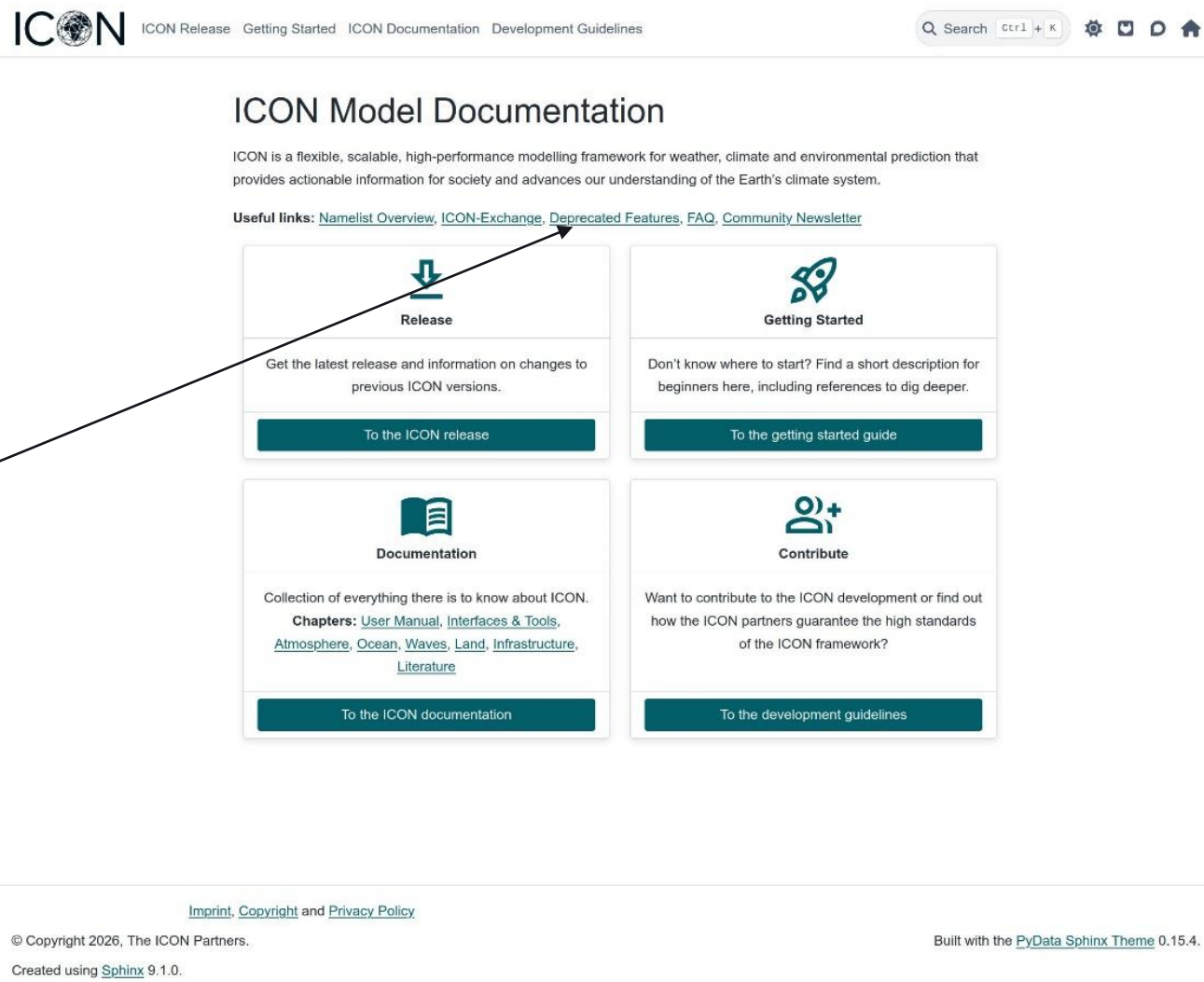
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ICON Model Documentation

ICON is a flexible, scalable, high-performance modelling framework for weather, climate and environmental prediction that provides actionable information for society and advances our understanding of the Earth's climate system.

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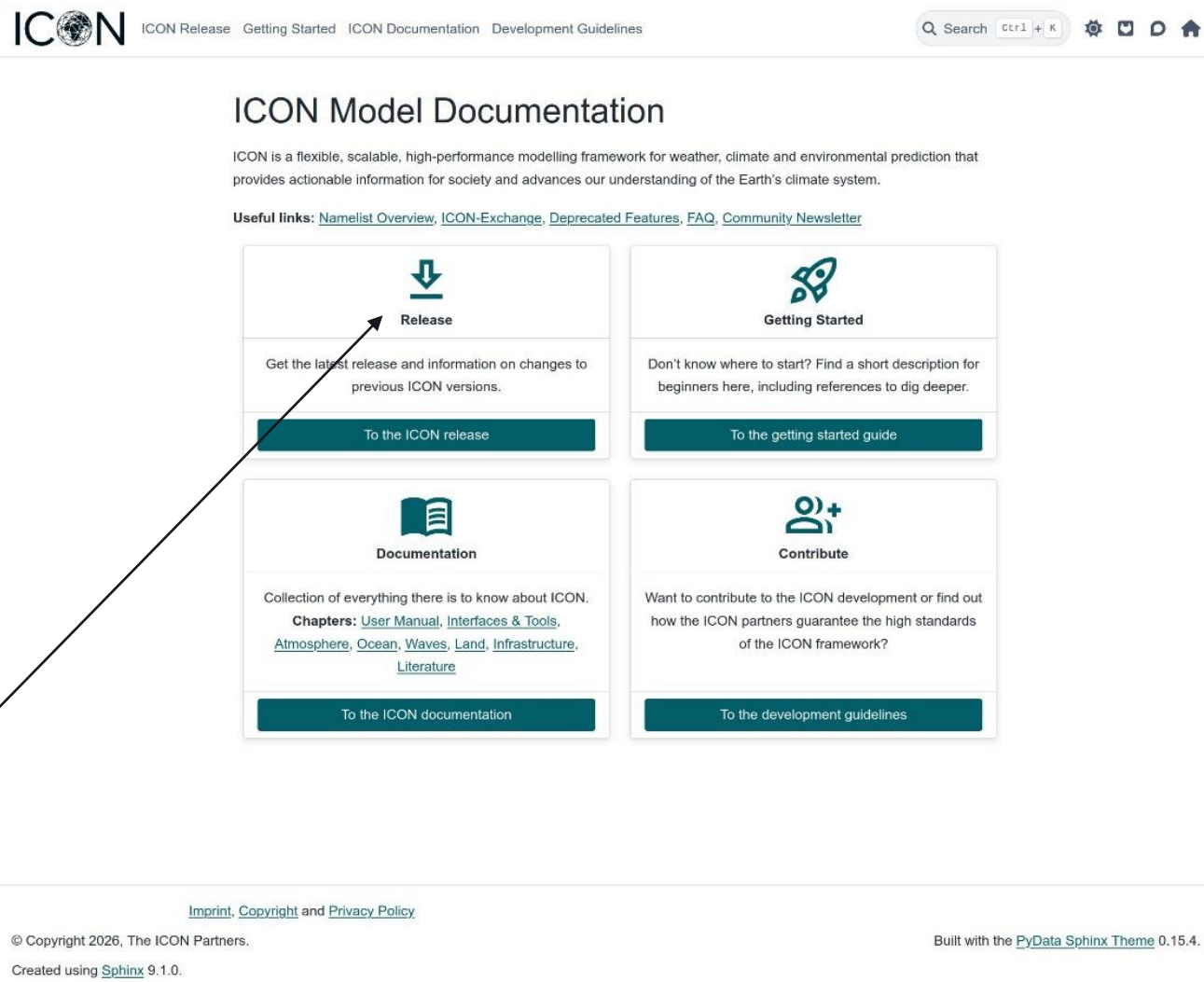
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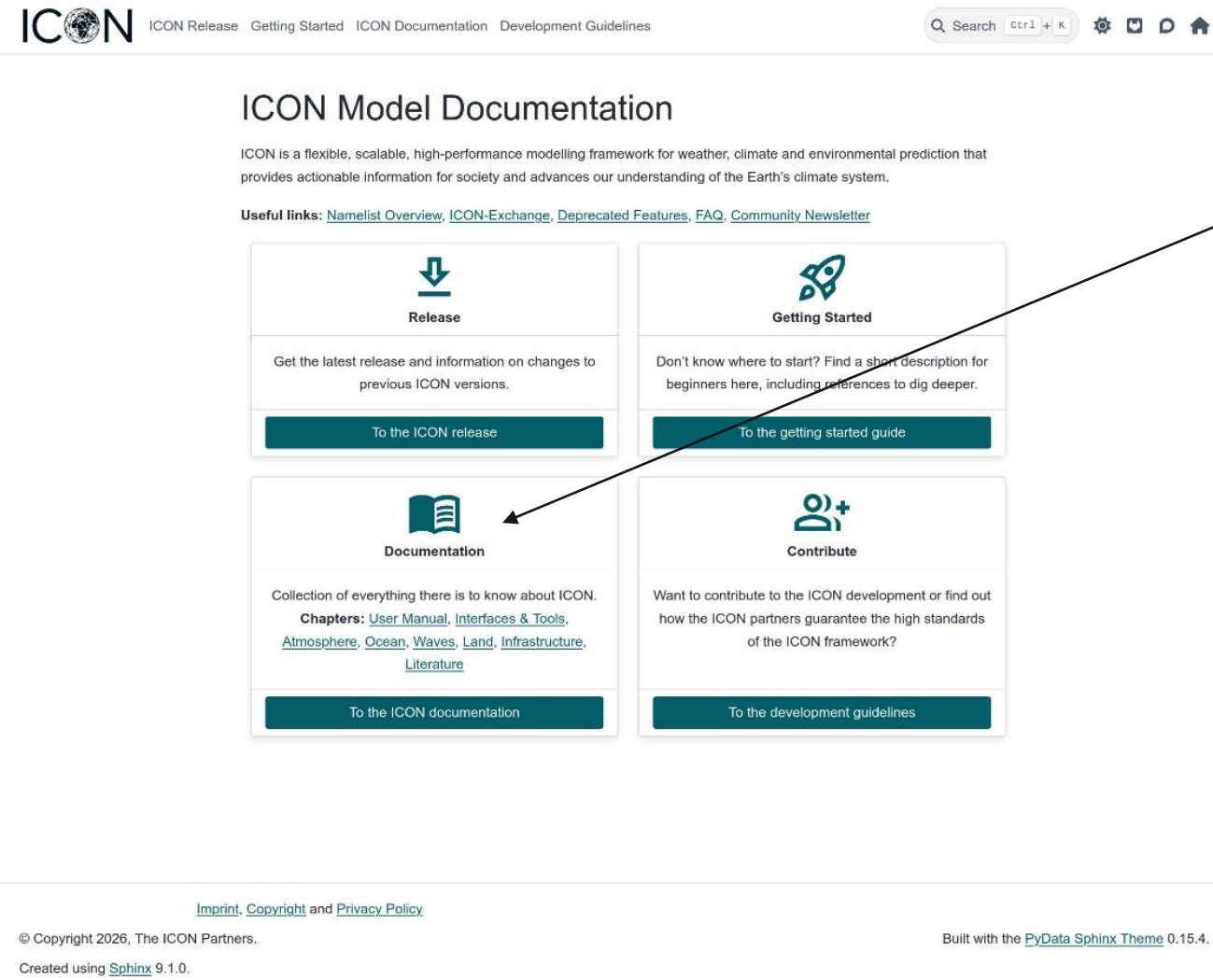
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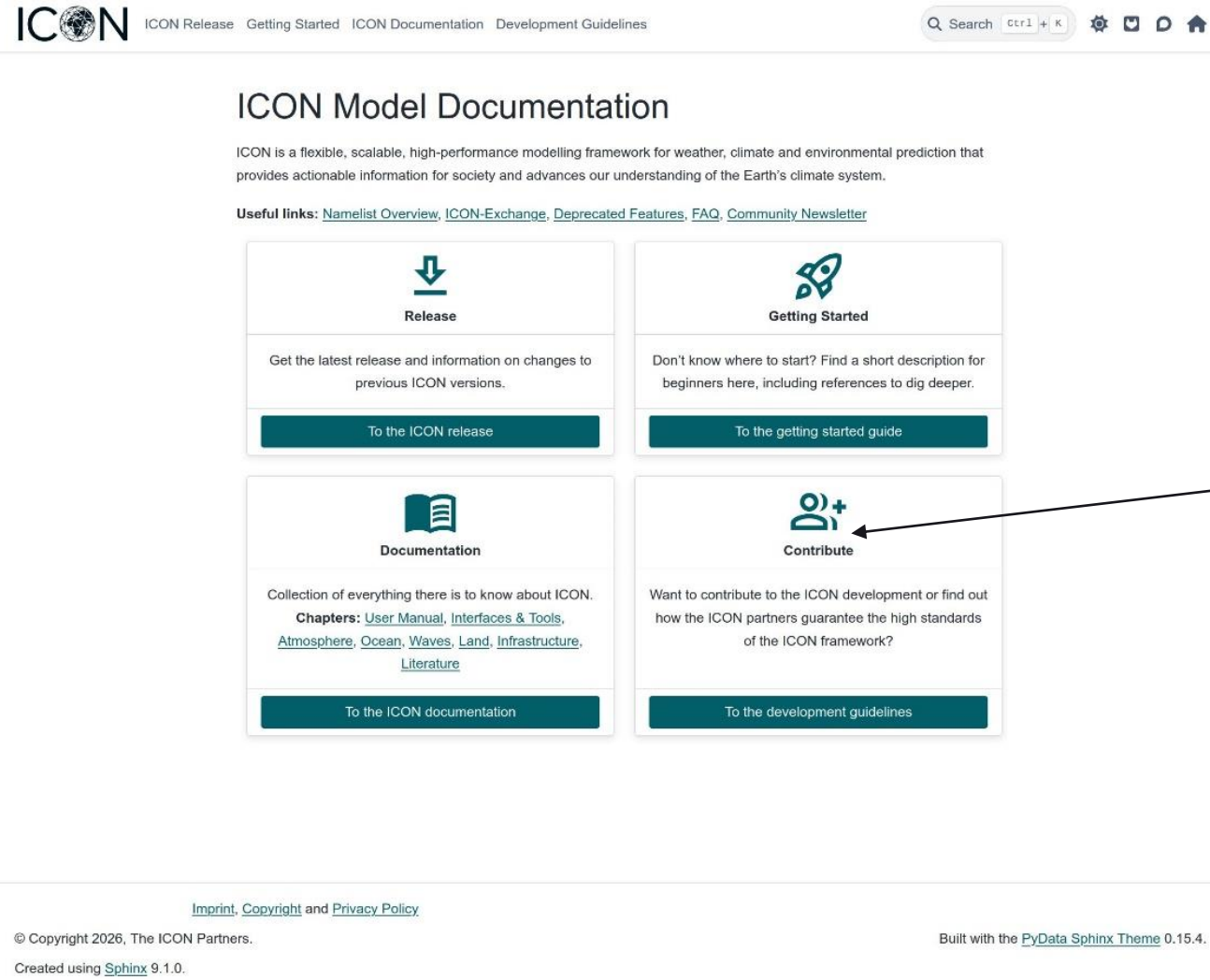
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Built with the [PyData Sphinx Theme](#) 0.15.4.

Documentation

- Varying coverage
- Nicely covered e.g.: Building; ecRad, ...

Contribute

- Guidelines for developer, reviewer, documentation

Exchange

- Community support platform
- *Also for Licensees!*

Namelist Overview

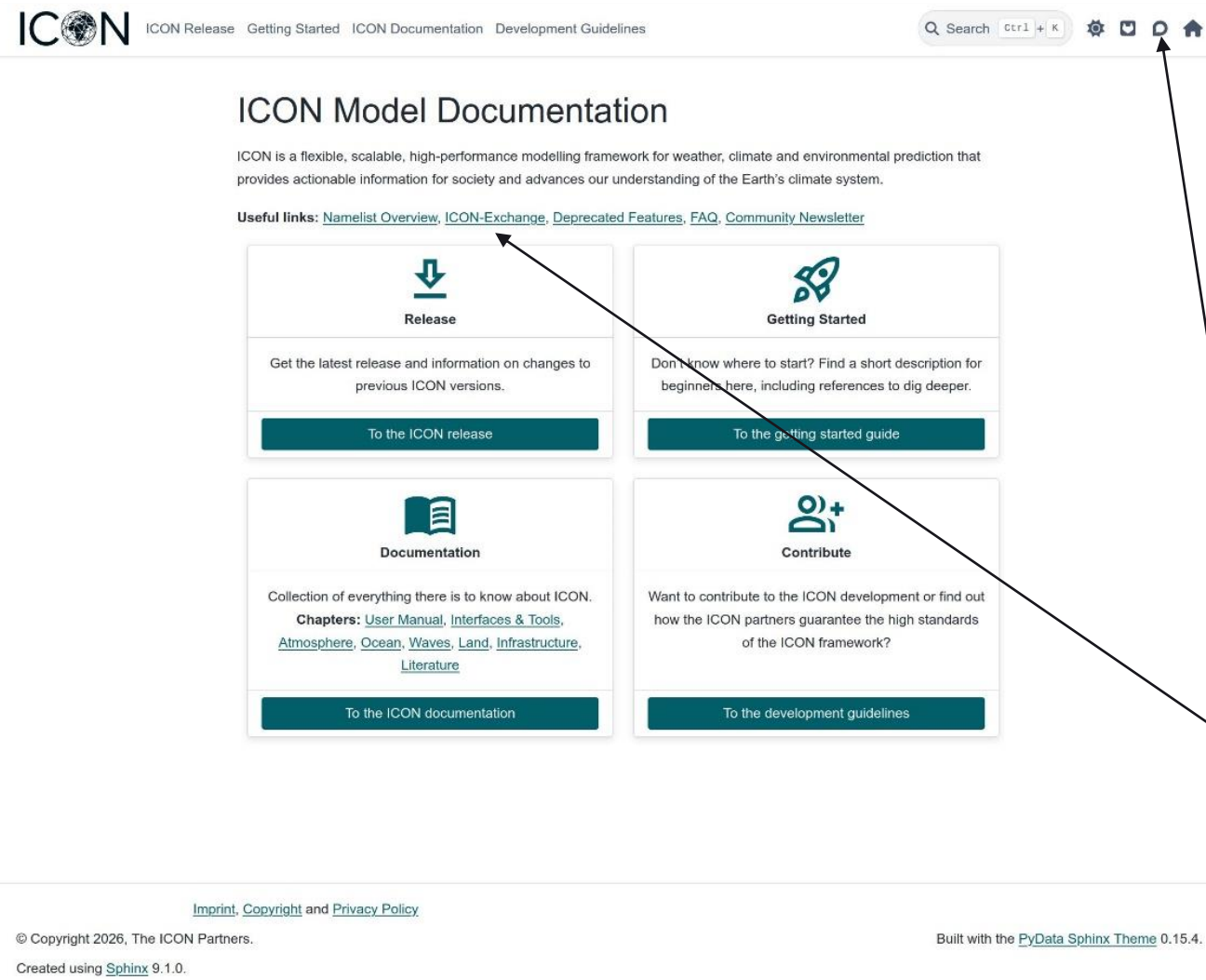
- Moved from PDF
- Parameters can be referenced in docs

Deprecation

- Announcements with dates, reasons etc.
- Alternatives

Release

- Download
- Release Notes
enforced by CI



The screenshot shows the 'ICON Model Documentation' website. At the top, there is a navigation bar with links: 'ICON Release', 'Getting Started', 'ICON Documentation', and 'Development Guidelines'. A search bar is also present. The main content area is titled 'ICON Model Documentation' and includes a brief description of the framework. Below this, there are four main sections, each with an icon and a button:

- Release** (download icon): 'Get the latest release and information on changes to previous ICON versions.' Button: 'To the ICON release'.
- Getting Started** (rocket icon): 'Don't know where to start? Find a short description for beginners here, including references to dig deeper.' Button: 'To the getting started guide'.
- Documentation** (book icon): 'Collection of everything there is to know about ICON. Chapters: [User Manual](#), [Interfaces & Tools](#), [Atmosphere](#), [Ocean](#), [Waves](#), [Land](#), [Infrastructure](#), [Literature](#).' Button: 'To the ICON documentation'.
- Contribute** (person with plus icon): 'Want to contribute to the ICON development or find out how the ICON partners guarantee the high standards of the ICON framework?' Button: 'To the development guidelines'.

At the bottom, there are links for 'Imprint', 'Copyright and Privacy Policy', and footer information: '© Copyright 2026, The ICON Partners.' and 'Built with the PyData Sphinx Theme 0.15.4. Created using Sphinx 9.1.0.'

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