

ICON · EXTPAR · TERRA

Advances in ICON External Parameter Generation and Land-Surface Modelling

High-Resolution Soil & Water-Body Processing · Operational Production with Zonda
Standalone TERRA Diagnostic Framework

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Why this matters for ICON



1 High-res aggregation

Soil (250 m) and water-body (30 m) data → fractional fields on unstructured ICON grids without memory explosion.



2 Operational production

Migration of EXTPAR to Zonda + post-processing → consistent NetCDF & GRIB2 for 20+ grids.



3 TERRA diagnostics

Standalone test harness for isolated, reproducible testing of land-surface physics.

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Global high-resolution data → ICON fractions



Glo-30 Water-Body Mask

Global 30 m resolution

Grid size	648 000 × 1 296 000 (30m)
Pixels	~840 billion
Classes	0 = Land, 1 = Lake, 2 = River
Target	FR_LAND, FR_LAKE, FR_RIVER
ICON grid	R03B07 · ~2.95 M cells



SoilGrids / HiHydroSoil

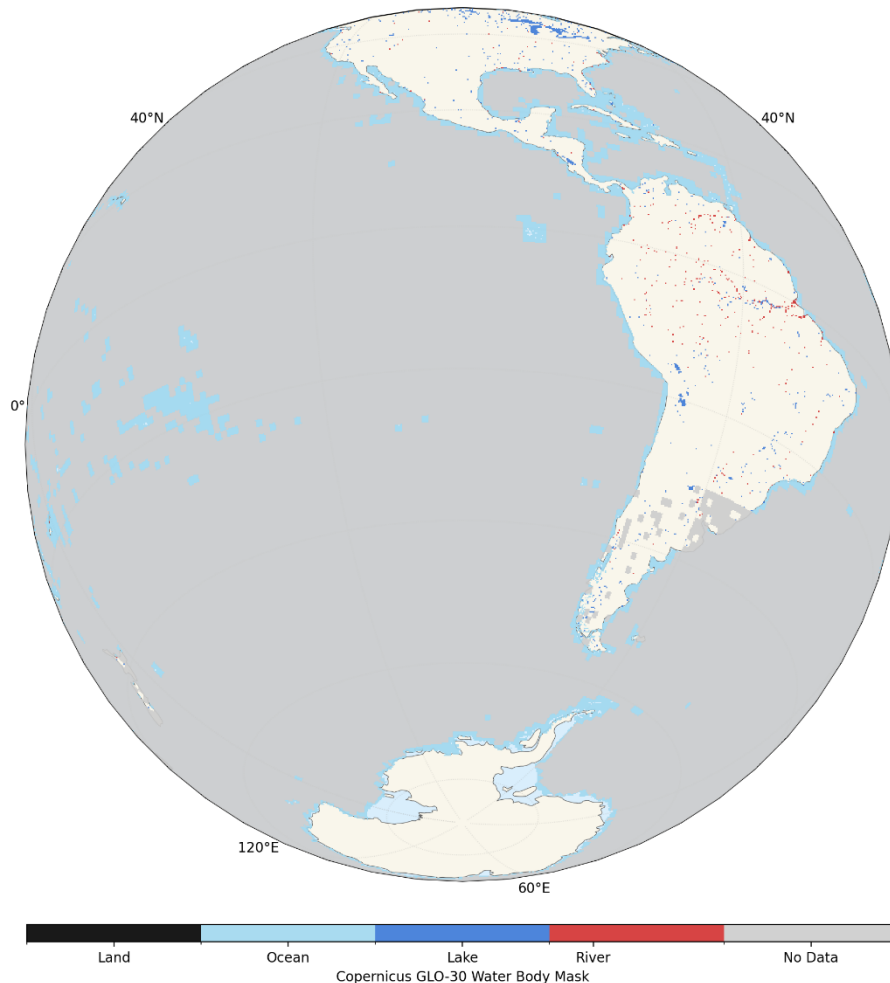
Global 250 m soil properties

Source	SoilGrids / HiHydroSoil
Resolution	~250 m global
Variables	KSAT, texture, thermal...
Output	mean / min / max / var



Global HiRes Water-Body-Mask

Global Copernicus GLO-30 WBM
(Orthographic projection - Center -100.0°E, -30.0°N)



- Copernicus GLO-30 **DEM** available in EXTPAR GIT-LFS (Ch. Steger)
- Download and pre-process WBM data from Copernicus data server (1x1deg tiles)
- Result: Global WBM-File in GeoTIFF and NetCDF with 30m resolution

Glo-30 → FR_LAND, FR_LAKE, FR_RIVER

~840 bn

pixels (30 m)

2.95 M

ICON cells (R03B07)

3

output fractions

OpenMP

parallel tiles

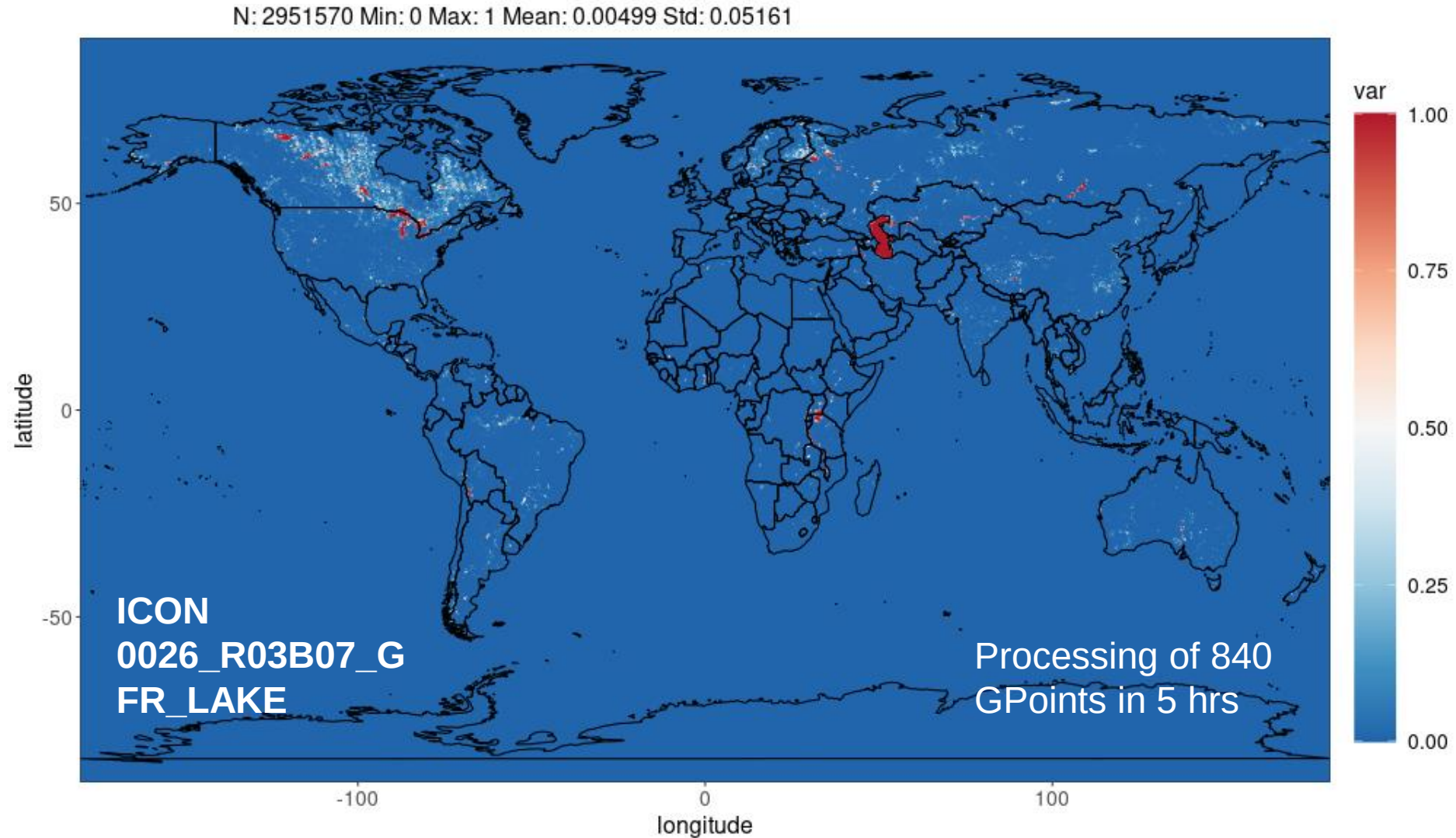
Memory-safe design

Geographic tiles (e.g. $10^\circ \times 10^\circ$) + row-wise batches · single NetCDF open before OpenMP · native ICON search (find_nc / walk_to_nc) with thread-private start cells · atomic accumulation of land / lake / river counts · final normalisation to fractions.



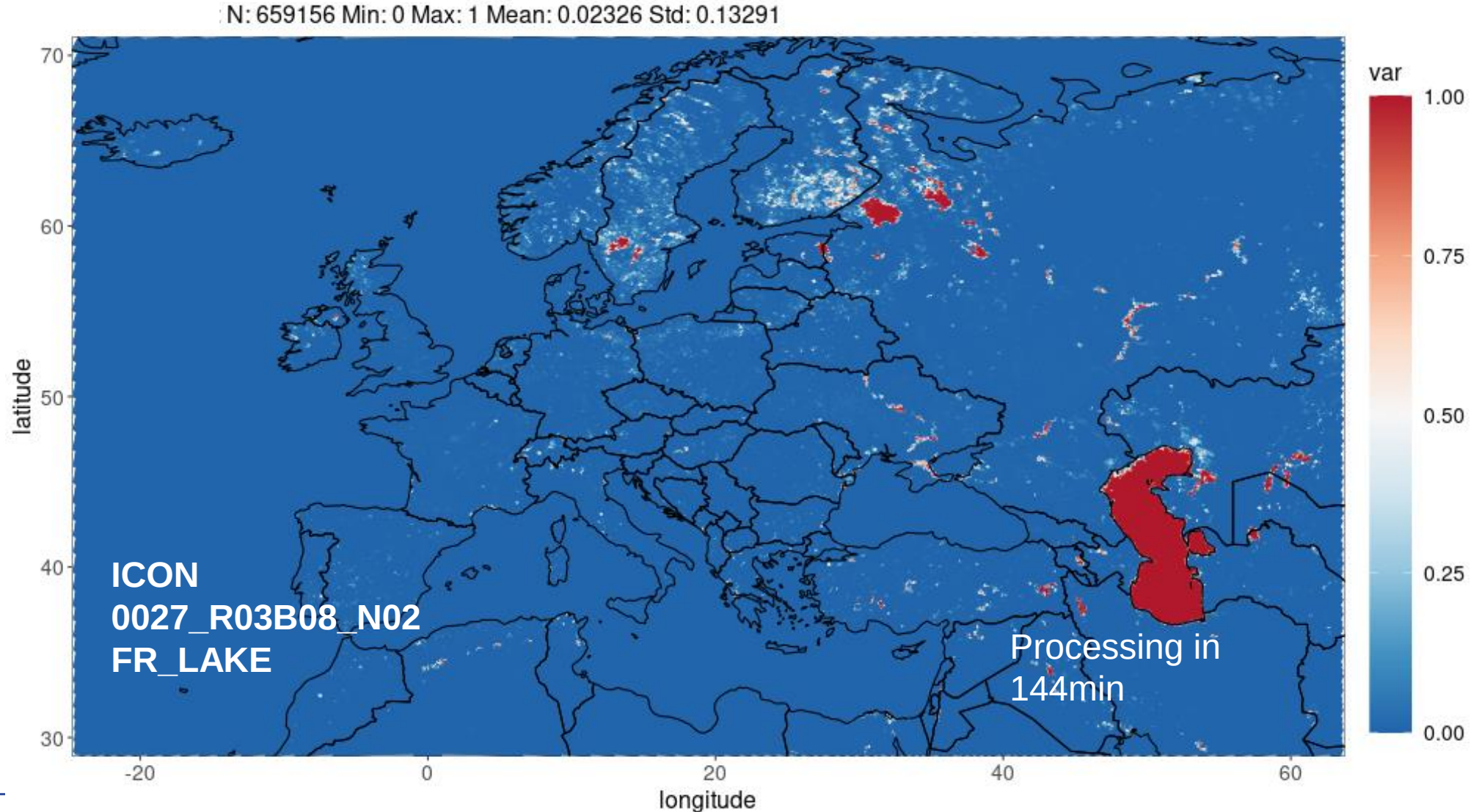
Global HiRes Water-Body-Mask

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



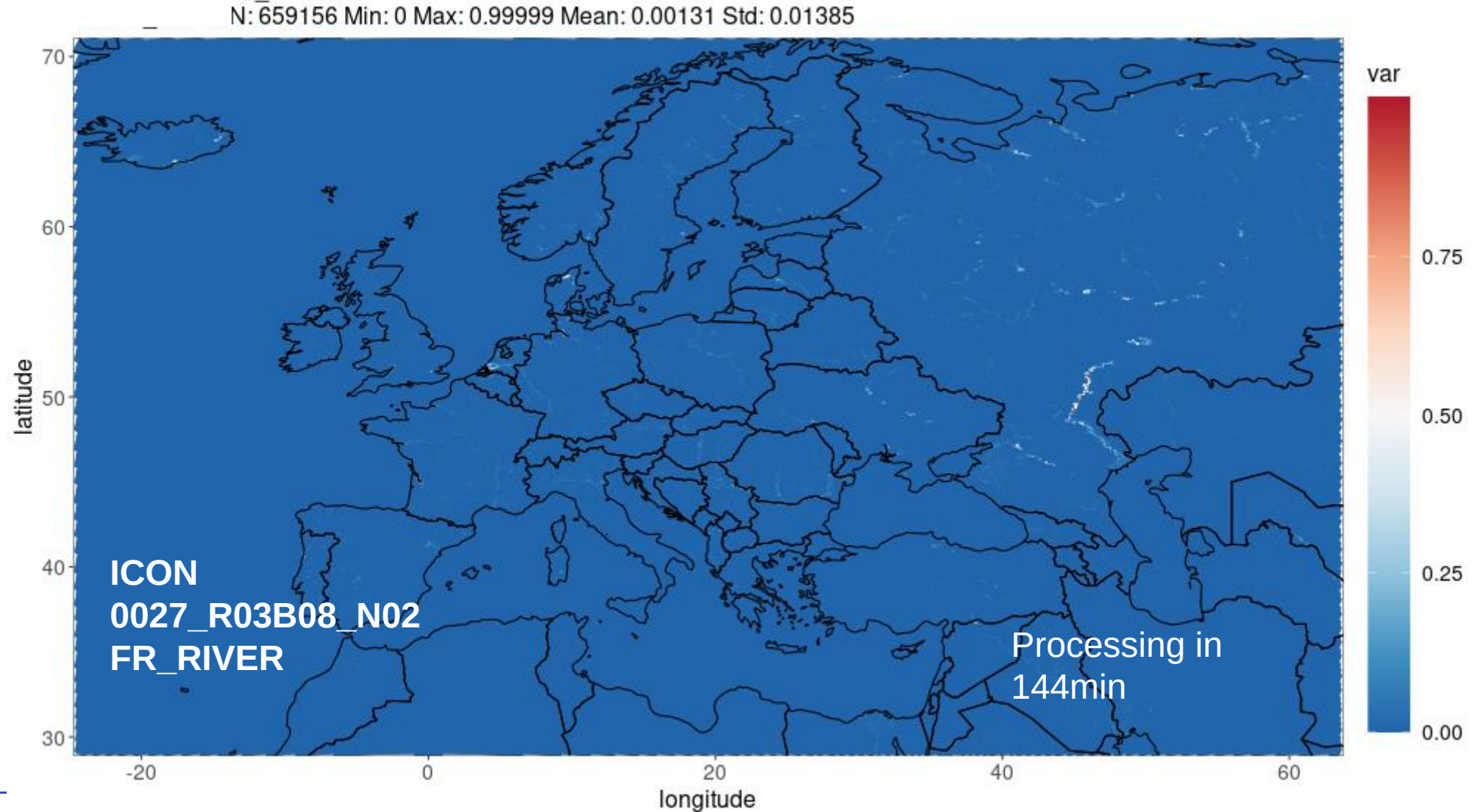
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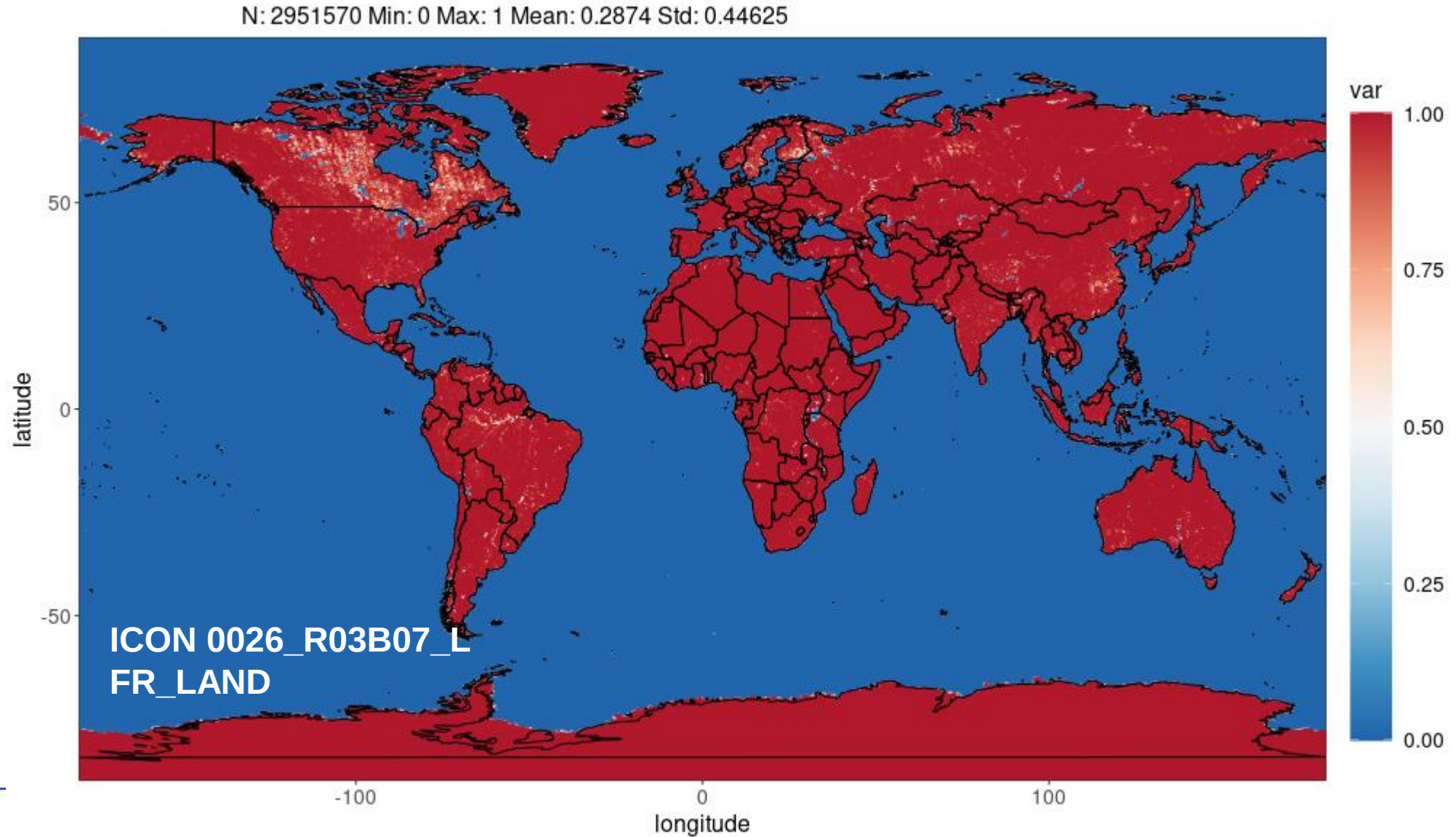


Global HiRes Water-Body-Mask

Deutscher Wetterdienst
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Global HiRes Water-Body-Mask



From Python experiments to production Fortran

1

Python + BallTree

sklearn BallTree
(haversine)
Full / batch neighbor
search
joblib Parallel

Failed



4

Fortran + ICON

mo_search_icongrid
find_nc / walk_to_nc
OpenMP + batches

Success

What works today

Water-body pipeline

- ▶ Batch / tile reading stable
- ▶ Fractions of lake, land, river
- ▶ OpenMP optimized
- ▶ Buffer NetCDF output ready

Soil path

- ▶ Row-wise OpenMP blocks
- ▶ HiHydroSoil + SoilGrids + stats
- ▶ Mean / min / max / variance
- ▶ soil hydraulics and thermal parameters

Still hardening

- ▶ GitHub- TestCase
- ▶ Full end-to-end validation
- ▶ Production namelist wiring
- ▶ Zonda / GRIB2 hand-over

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Migration to Zonda (zonda_batch) + EXTPAR 5.21



Result: consistent external-parameter files for >20 global, nested and limited-area grids, publicly available on the MPI grid server.

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MOTIVATION: WHY ISOLATE TERRA?



Tight Coupling

TERRA is deeply embedded in the full ICON infrastructure (config, MPI, OpenACC, lookup tables).



Hard to Debug

Reproducing a single-column failure requires a complete model run and complex diagnostics.



Slow Iteration

Physics development and regression tests are slowed by the full model build and runtime cost.

SOLUTION ARCHITECTURE



Design Principle

Reuse pre-compiled ICON object files and module files where possible. Only the test driver is compiled locally. Dummy modules supply missing namelist parameters and physical constants that are normally set by the full model.

↔ **ICON vs STANDALONE TERRA**

Comparison for Snow-Melt Case

Single-column standalone test reproduces the full ICON result with high fidelity

Inputs

Bit-identical

Soil T / Moisture

Excellent

Snow (single-layer)

Very good

Latent heat flux

~0.7 % diff.

$dt = 240 \text{ s} \cdot ke_{\text{soil}} = 7 \cdot ke_{\text{snow}} = 3 \cdot nvec = 1 \text{ (standalone)}$

DETAILED COMPARISON – STATE VARIABLES & FLUXES

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Quantity	ICON	Standalone	Agreement
t_s / t_sk (new)	272.5072 K	272.5072 K	Excellent
t_so profiles (1–8)	all layers	match $\sim 1e-15$	Excellent
w_so / w_so_ice	all layers	match $\sim 1e-14$	Excellent
w_snow (new)	0.42022373	0.42022373	Excellent
rho_snow / w_i	identical	identical	Excellent
runoff_s	0.11388275	0.11387996	$\sim 0.0025 \%$
runoff_g	0.00129749	identical	Exact
zshfl_s / zshfl_sfc	8.28 / 5.95	identical	Exact
zlhfl_snow / zqhfl_sfc	$-0.5876 / -2.07e-7$	$-0.5918 / -2.09e-7$	$\sim 0.7 \%$
qv_s	$3.27759e-3$	$3.27800e-3$	$\sim 0.012 \%$



Output from ICON

```

] --- Fluxes ---
] runoff_s      = 1.13882754648836182E-001
] runoff_g      = 1.29749054147425703E-003
] resid_wso     = 0.00000000000000000E+000
] zshfl_s       = 8.28428374571883452E+000
] zlhfl_s       = 0.00000000000000000E+000
] zshfl_snow    = 5.95254934372527789E+000
] zlhfl_snow    = -5.87582532066384666E-001
] lhfl_bs       = -0.00000000000000000E+000
] lhfl_pl(ke_soil) = -0.00000000000000000E+000-0.00000000000000000E+000-0.00000000000000000E+000
] plevap        = 0.00000000000000000E+000
] rstom         = 4.00000000000000000E+003
] zshfl_sfc     = 5.95254934372527789E+000
] zlhfl_sfc     = -5.87582532066384666E-001
] zqhfl_sfc     = -2.07296712671153538E-007
] --- Flags ---
] ldiffl_qi     = F
] ldepo_qw      = T
] lres_soilwatb = F
] lacc          = F

```

Output from standalone diagnostics

```

--- Fluxes ---
runoff_s      = 1.13879962726070386E-001
runoff_g      = 1.29749054147425703E-003
resid_wso     = 0.00000000000000000E+000
zshfl_s       = 8.28428374571883452E+000
zlhfl_s       = 0.00000000000000000E+000
zshfl_snow    = 5.95254934372527789E+000
zlhfl_snow    = -5.91834837136643976E-001
lhfl_bs       = -0.00000000000000000E+000
lhfl_pl(ke_soil) = -0.00000000000000000E+000-0.00000000000000000E+000-0.00000000000000000E+000
plevap        = 0.00000000000000000E+000
rstom         = 4.00000000000000000E+003
zshfl_sfc     = 5.95254934372527789E+000
zlhfl_sfc     = -5.91834837136643976E-001
zqhfl_sfc     = -2.08796908497669441E-007
--- Flags ---
ldiffl_qi     = F
ldepo_qw      = T
lres_soilwatb = F
lacc          = F

```

CONCLUSIONS & OUTLOOK



Feasible Isolation

TERRA can be extracted into a practical, single-column test harness without rewriting the physics.



Faster Development

Enables rapid iteration, regression tests and targeted debugging of soil, snow and flux processes.



Verification Tool

Provides a controlled environment for comparing numerical behaviour against full ICON runs.



Next Steps

Extend coverage to multi-layer snow cases, discuss to add to icon-tools or icon gitlab