Research Updates at ECMWF

Aristofanis Tsiringakis with contributions from the entire Research Department

25th September 2023, EWGLAM, Reykjavik

The strength of a common goal

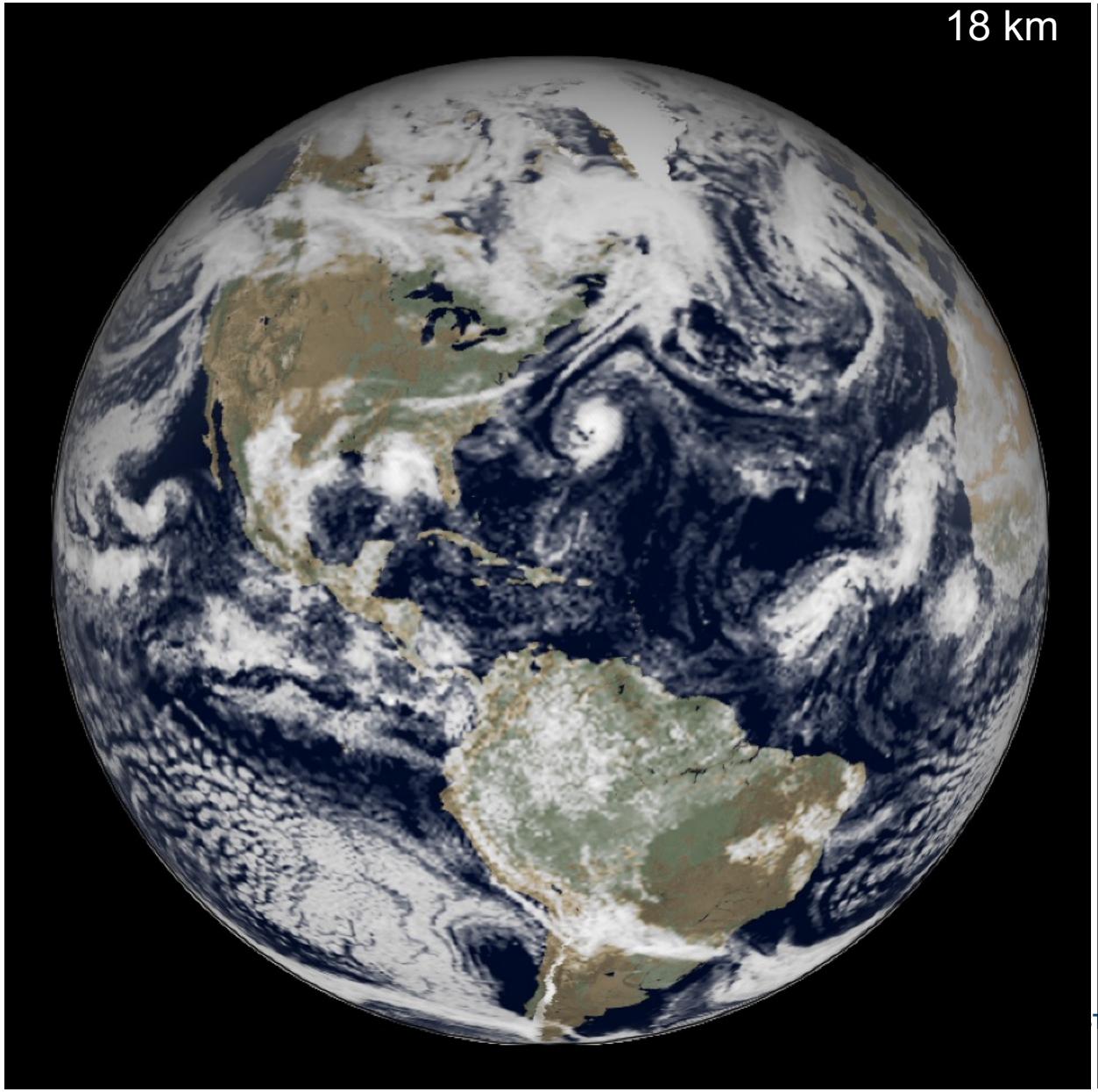
IFS Cycle 48r1

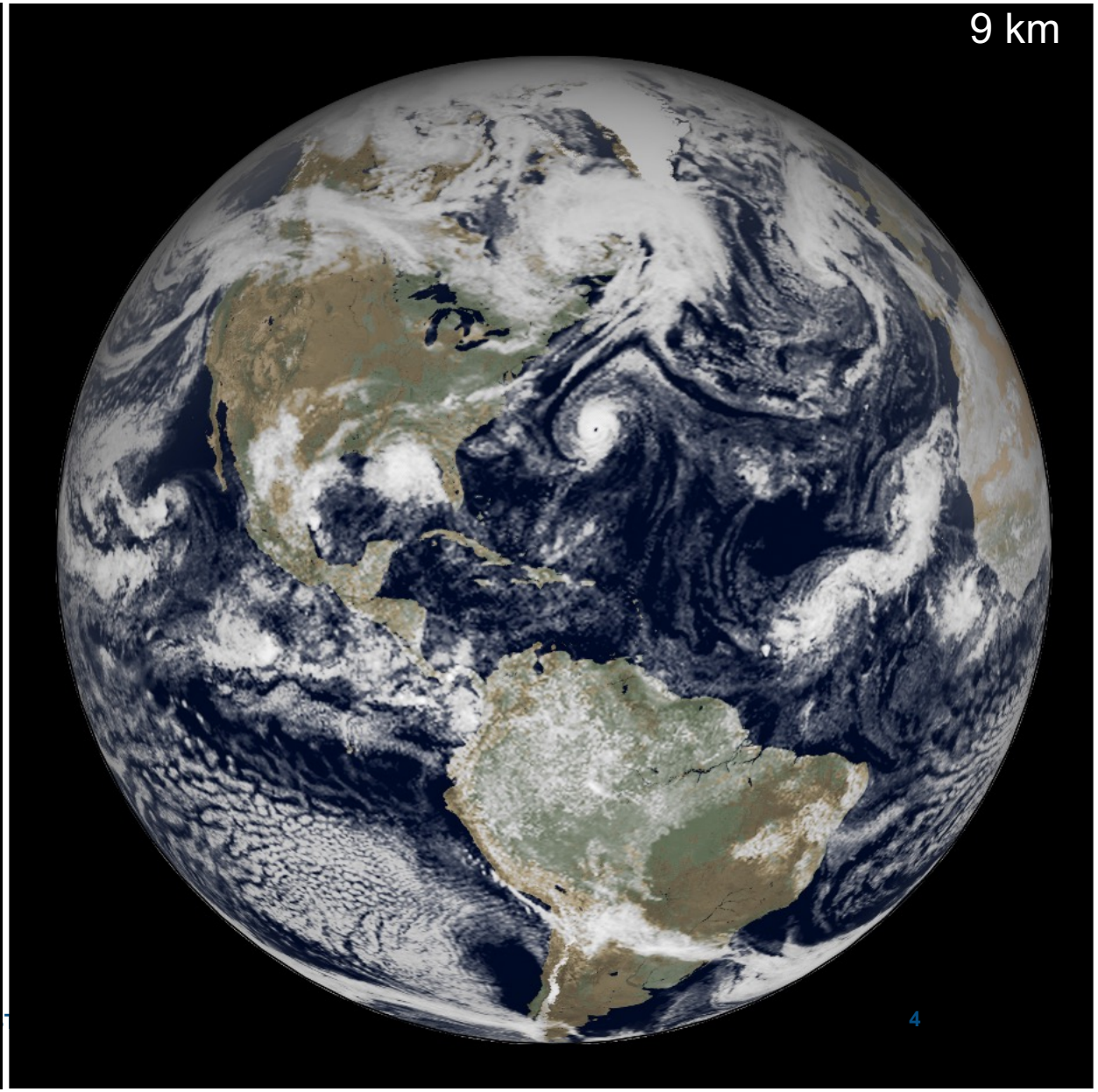
Implemented in June 2023

Cycle 48r1 features…

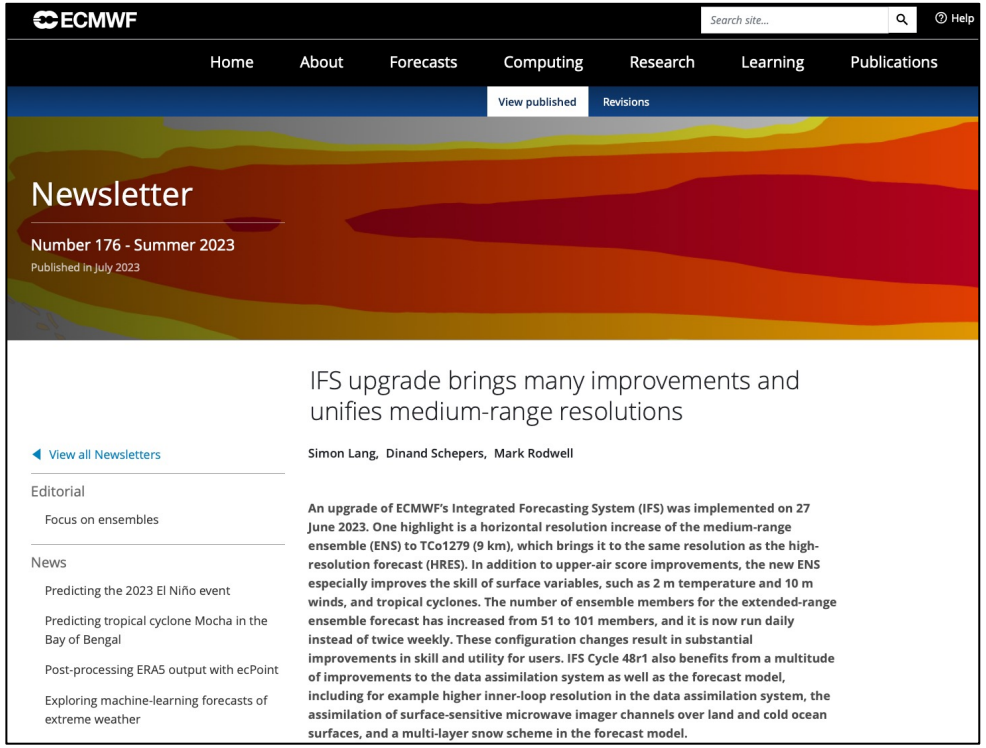
- …higher inner-loop resolution in the data assimilation system of 40 km and assimilation of surface-sensitive microwave imager channels over land and cold ocean surfaces;
- …a multi-layer snow scheme and updated IFS climate fields for orography, land–sea mask, lake depth and glaciers mask;
- … a major change in the partitioning of low-level orographic drag processes to the surface drag which includes revisions of the subgrid orography fields and the orographic low-level flow blocking, and gravity wave drag parametrizations;
- … the new Hybrid Linear Ozone (HLO) scheme which improves stratospheric wind forecasts;
- …a switch to the Object-Oriented Prediction System (OOPS) which will facilitate the development of ECMWF's data assimilation capabilities in the future.
- …a revised parametrization of microphysical processes to allow supercooled drizzle drops to be formed;
- …a new vertical Finite Element discretisation which is applicable to both the hydrostatic and non-hydrostatic dynamical core;
- …improved water and energy conservation properties in the IFS dynamics via global mass fixers;
- …a shallower sponge layer at the top of the forecast model, starting at 0.7 hPa instead of 10 hPa;
- …a new streamlined algorithm for the computation of semi-Lagrangian advection departure points.

Medium range ensemble : 18 km to 9 km (same as HRES)
Extended range ensemble : 50+1 members twice weekly to 100+1 members every day



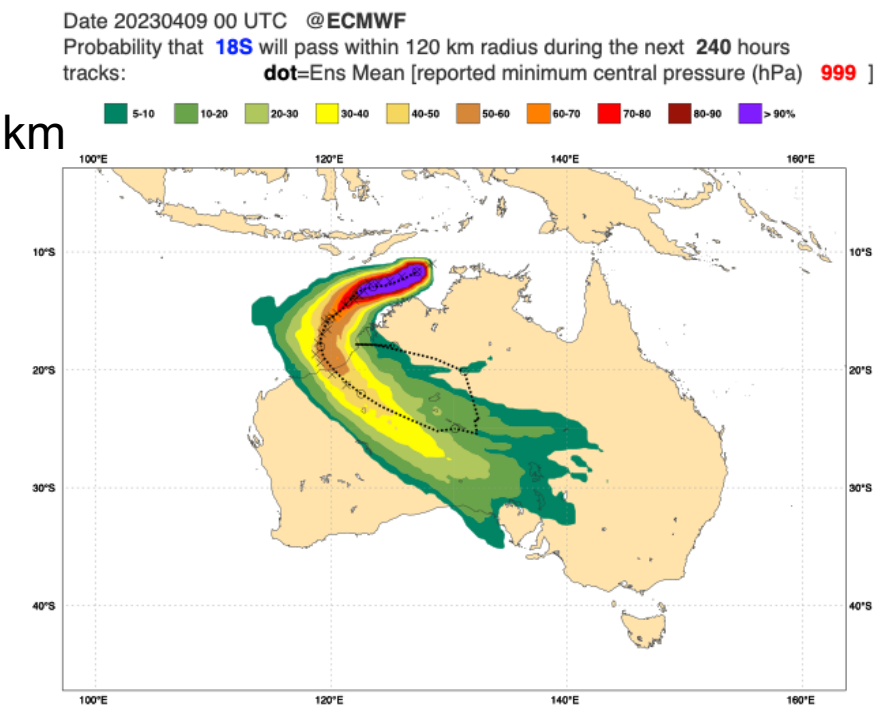


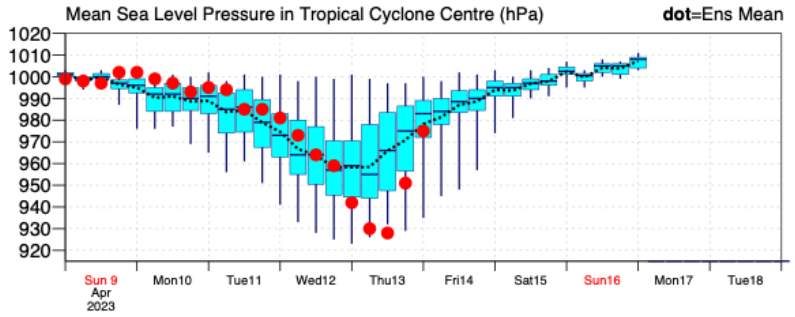
Medium range ensemble scorecard for IFS cycle 48r1



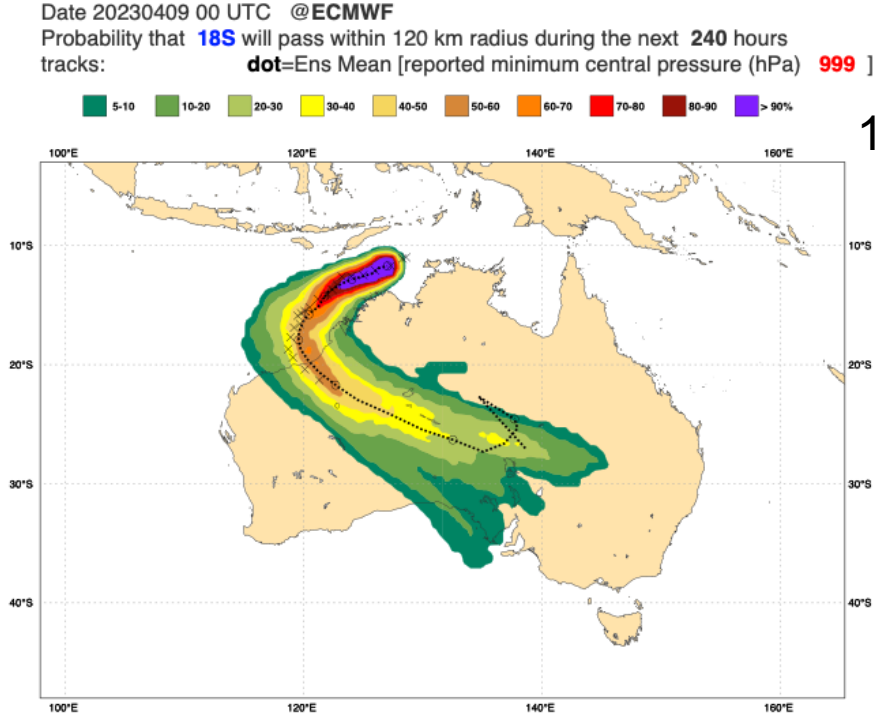
https://www.ecmwf.int/en/newsletter/176/earth-system-science/ifs-upgrade-brings-many-improvements-and-unifies-medium

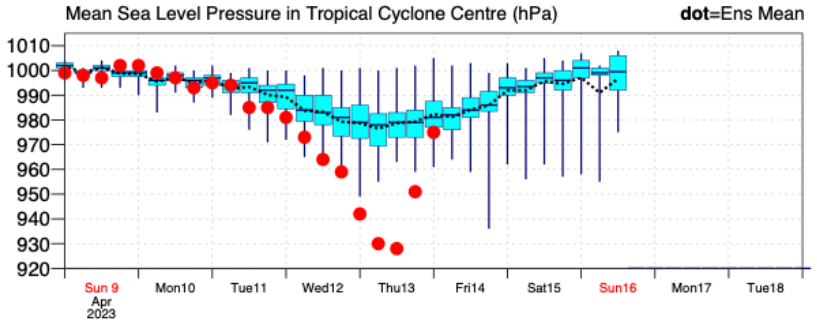
9 km





18 km



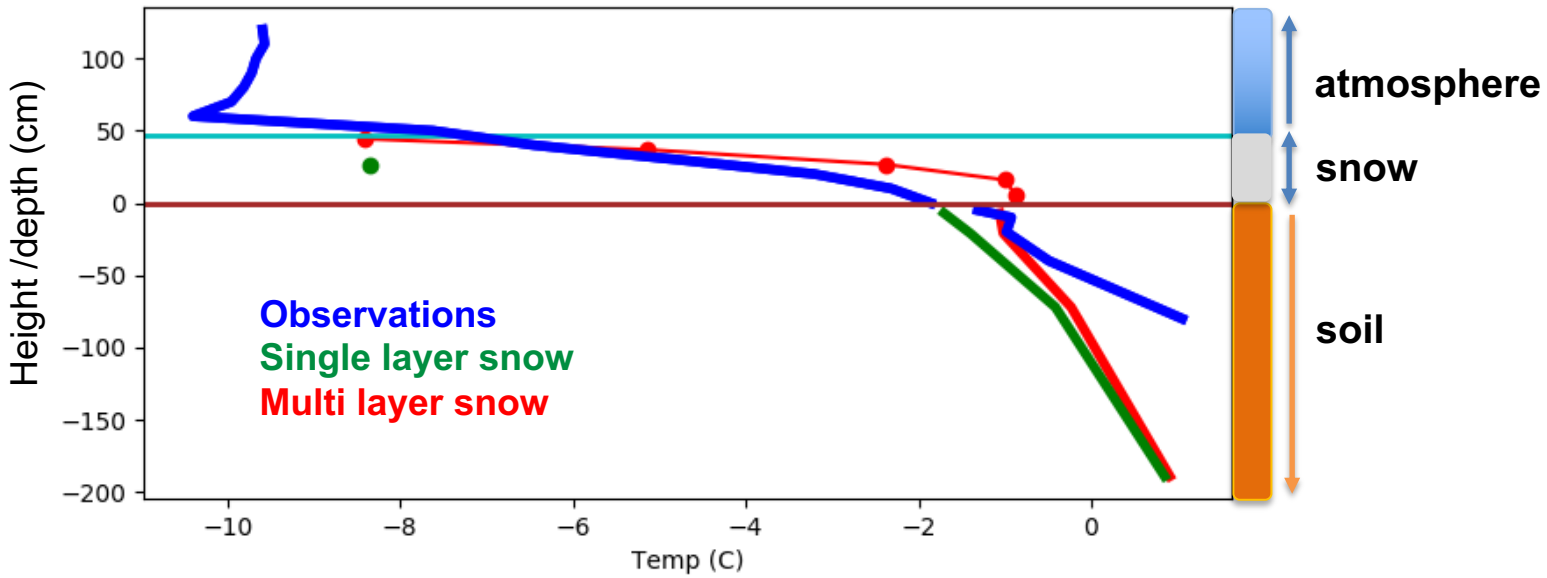


Tropical cyclone Ilsa, forecast from 9 April 2023, 00 UTC, in (a) the IFS Cycle 48r1 ensemble forecast with a resolution of 9 km, and (b) the IFS Cycle 47r3 ensemble forecast with a resolution of 18 km. Shown are the strike probability (top) and mean sea level pressure (MSLP) in the centre of Ilsa (bottom).

Multi-layer snow scheme – improved coupling

- **New snow scheme with up to 5 layers replacing single-layer snow scheme**
- **Improved coupling** of the atmosphere and the soil underneath

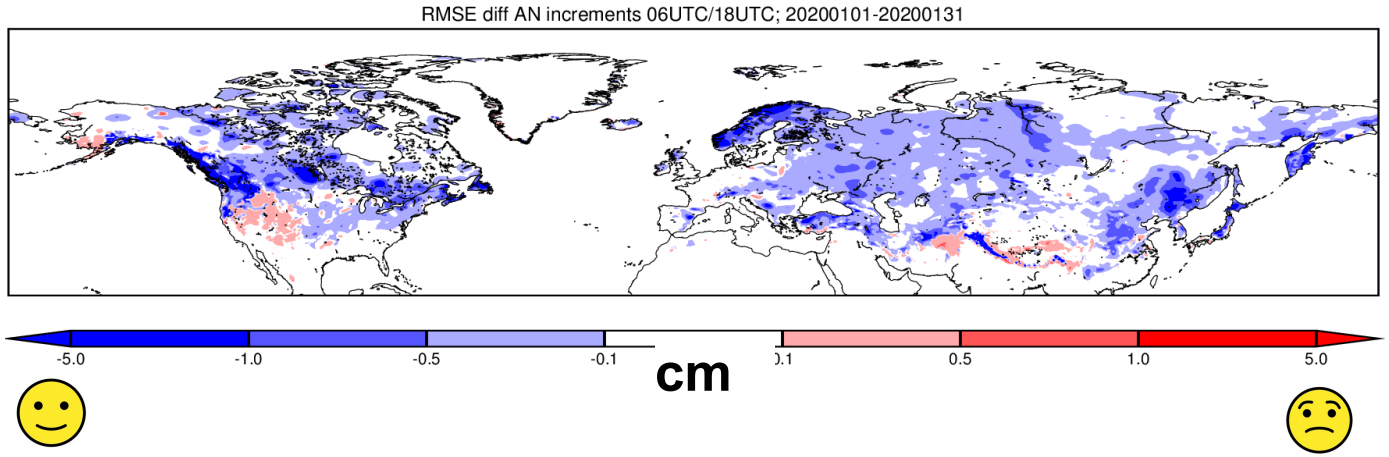
Temperature profile in the near-surface atmosphere, snow and soil layer at Sodankyla, Finland



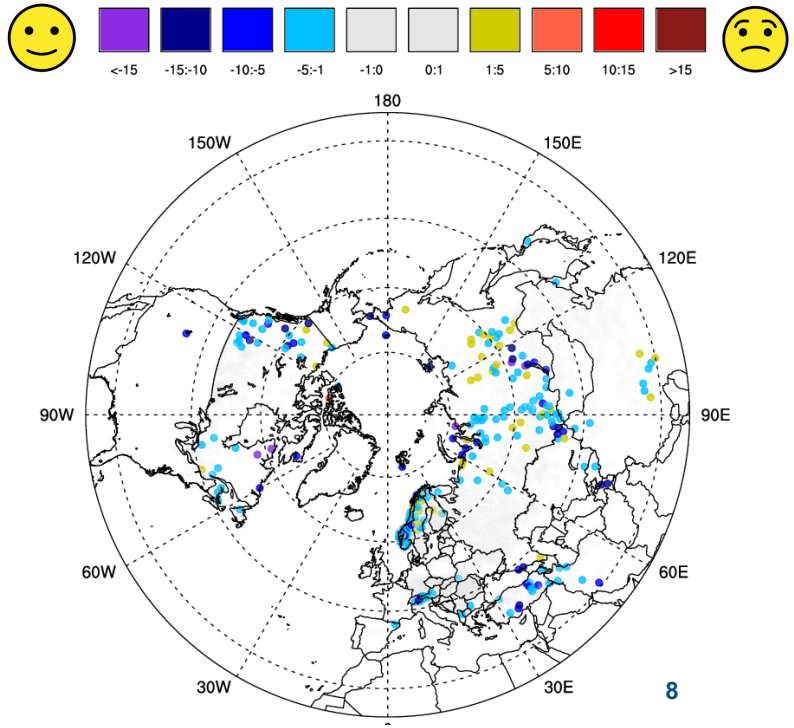
Multi-layer snow scheme – improved snow forecast

- **Improved snow depth in short-range forecasts**
- **Snow depth bias reduces for increased forecast range**

RMS difference between multi-layer and single-layer snow scheme in analysis increments (12h forecast – analysis), January 2020



RMSE difference of forecasts at day 5 (compared with synop station), Winter 19/20

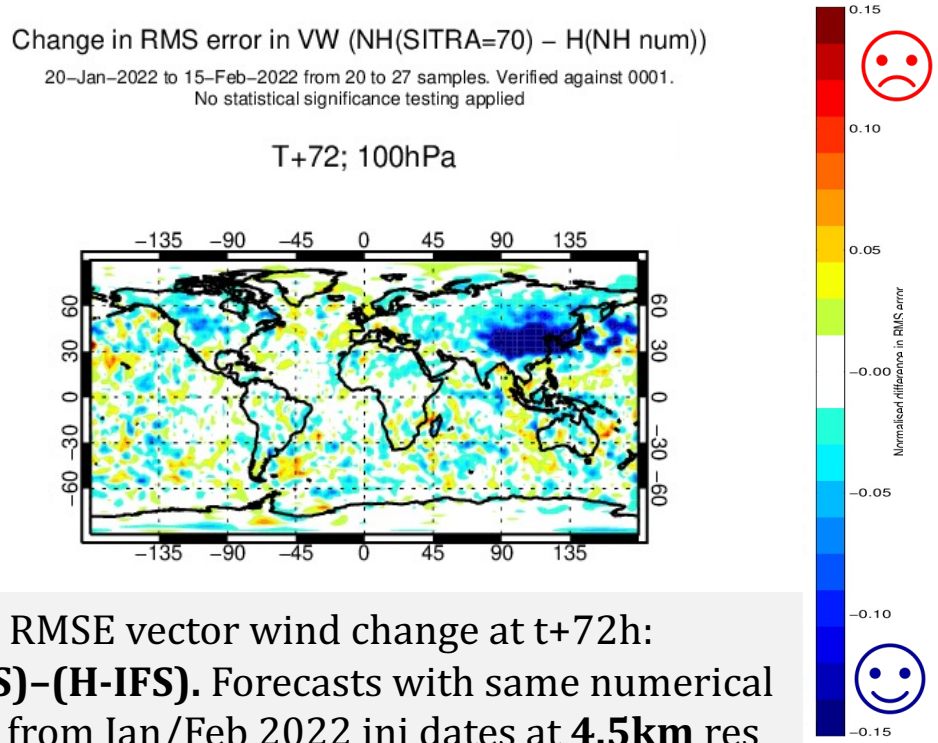


IFS Cycle 49
and beyond

Numerical Methods

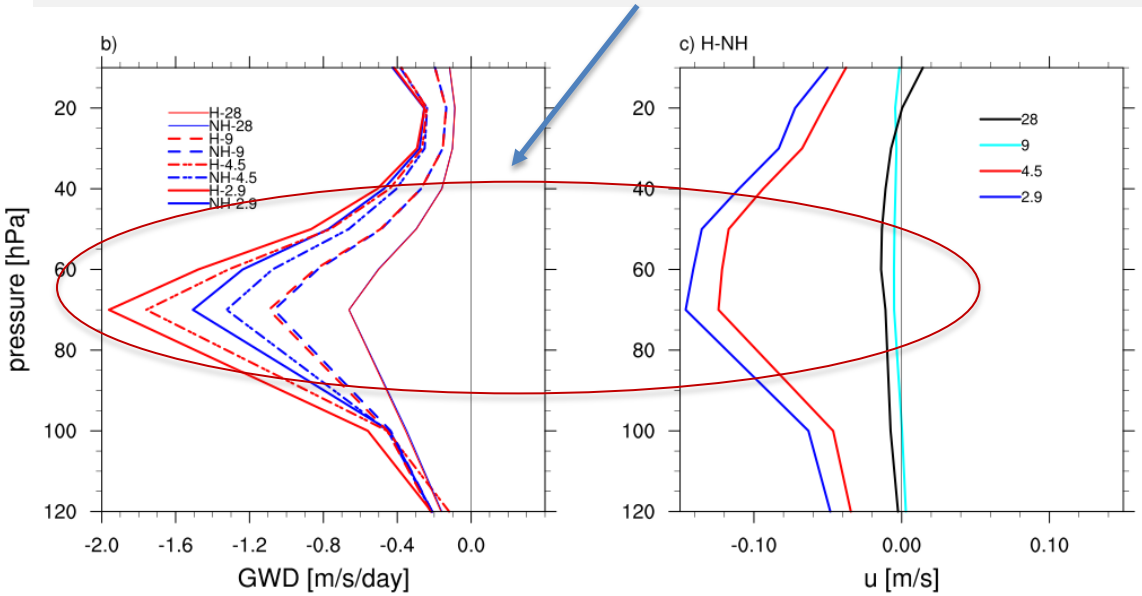
ECMWF

Non-hydrostatic and km-scale research with IFS at ECMWF



100hPa RMSE vector wind change at t+72h: **(NH-IFS)–(H-IFS).** Forecasts with same numerical options from Jan/Feb 2022 ini dates at **4.5km** res

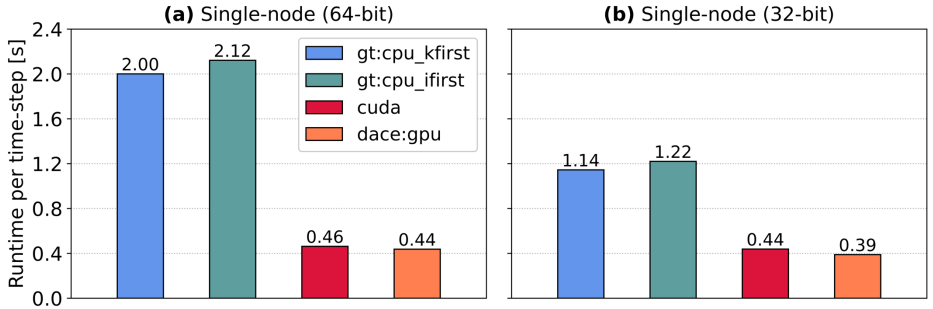
Left: Resolved GW drag in the stratosphere: H-IFS (red lines) and NH-IFS (blue lines) at 2.9 km, 4.5 km, 9 km and 28 km grid-spacings, averaged over the Tibetan plateau.
Right: H-NH averaged difference for zonal winds. Stronger wind deceleration in NH-IFS due to stronger GW-flux



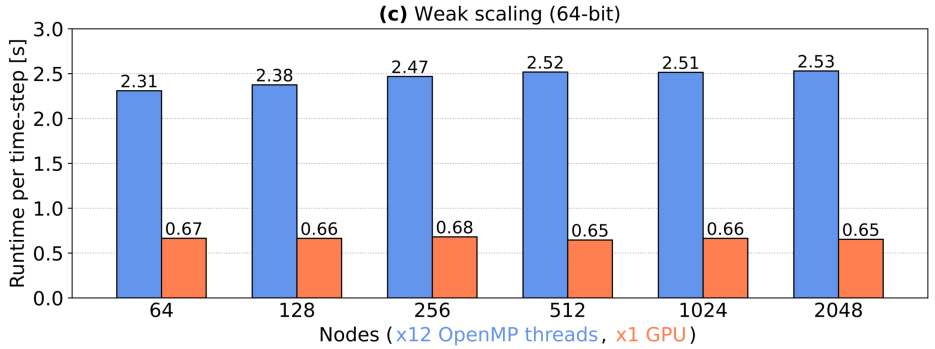
- Improvements in NH-IFS (talk by Jozef) enable direct comparisons between H-IFS and NH-IFS
- Given the extra cost of the NH-IFS there is no justification to activate NH-IFS in operations:
  - Impact of NH is neutral, apart from mid-winter when the surface wind over Tibet is strong (no difference at 9km with O-grid, differences from 4.5km and below)
  - Lack of additional predictive capability of extreme events such as TCs up to 2.9km

Highlights of other work in numerical methods and dynamics

- **Investigations of de-centring semi-implicit scheme**
  - Off-centring is not used in IFS (due to Tanguay-Ritchie continuity) but a small amount equal to 0.05 improves model/obs fit in 4D-Var and its robustness
  - Reduces the “wind deceleration effect” of the H-IFS model over Tibetan plateau in winter
  - Improves stratospheric scores + QBO in seasonal forecast (currently investigated)
- **New non-hydrostatic dycore FVM developed with domain-specific Python library GT4Py**
  - First (single node) global version for quasi-uniform IFS octahedral grid is available
  - Multi-node performance study with GT4Py Version 1 (for LAM domains with regular grids) showing optimal scaling up to 2048 GPUs (figure below on the right)



GT4Py automatically generates targeted code, e.g. CUDA (for Nvidia GPUs) or C++ (CPU). Runtimes on GPU backends (red/orange) vs CPU (blue/green) and (a) 32-bit vs (b) 64-bit.



Demonstration of FVM GT4Py Version 1 weak-scaling on either CPUs or GPUs on CSCS Piz Daint supercomputer

Land Data Assimilation System

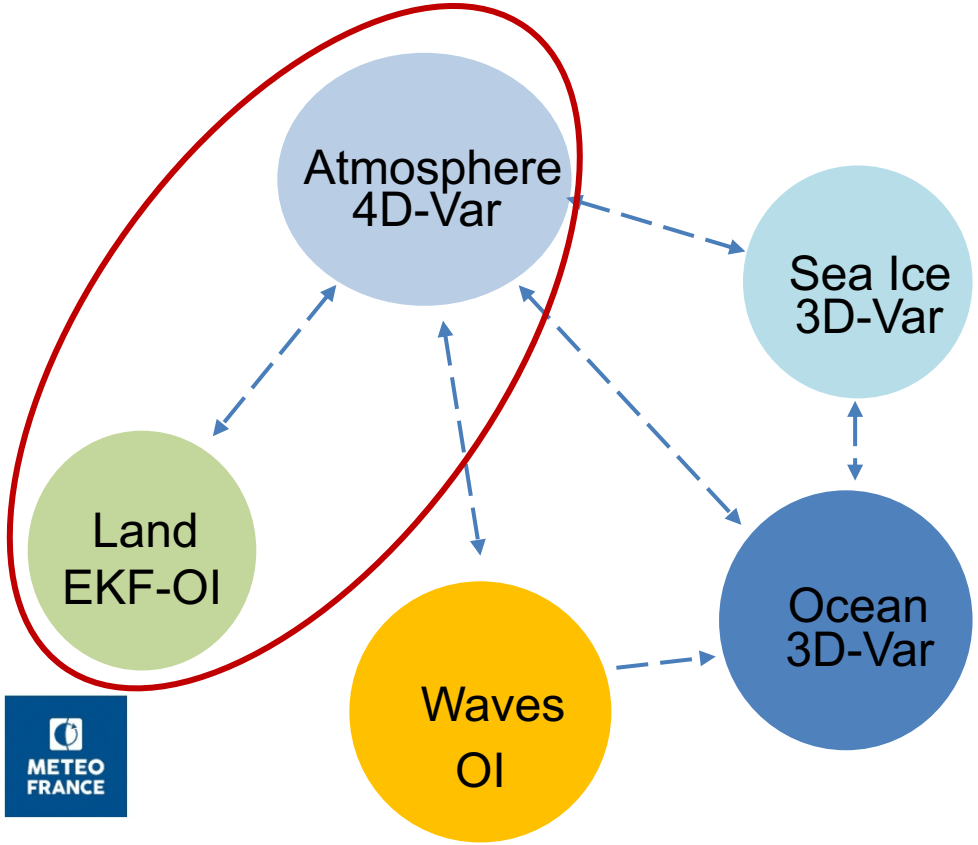
ECMWF

CERISE Horizon Europe project

Funded by the European Union

CERISE: CopERnIcus climate change Service Evolution (2023-2026)

→ **Support the long-term evolution of C3S for**
- regional and global climate reanalysis and
- multi-system seasonal prediction,
towards an Earth system approach with a focus on land-atmosphere coupling.



https://www.cerise-project.eu/

ECMWF · Norwegian Meteorological Institute · SMHI · Deutscher Wetterdienst · cmcc · Barcelona Supercomputing Center · The Danish Meteorological Institute · Estellus · IPMA · NILU · Met Office

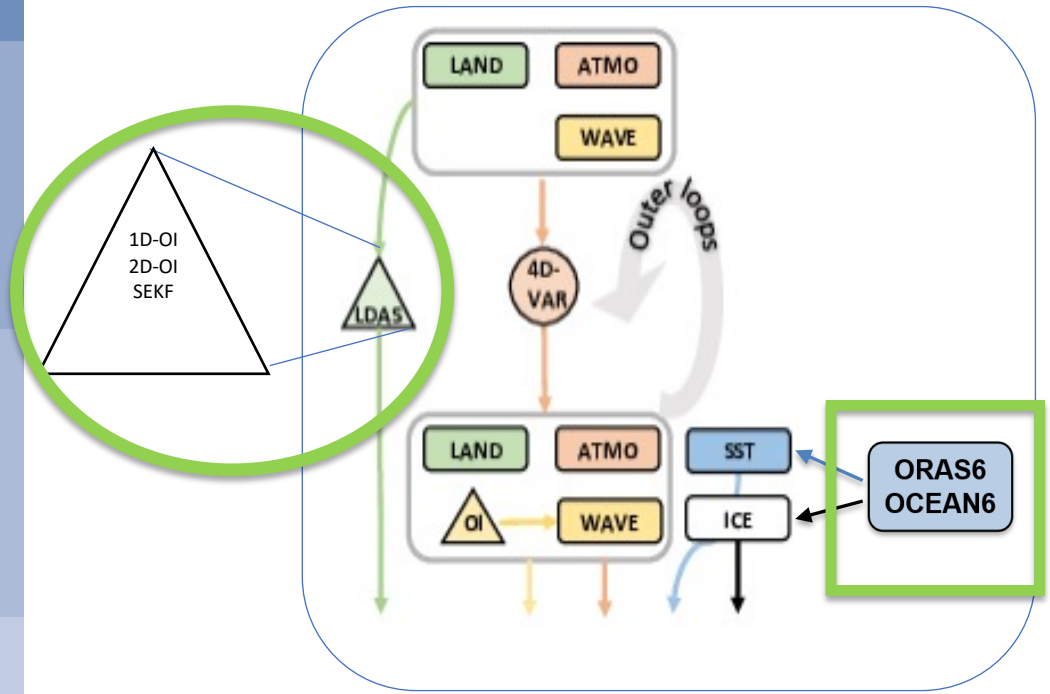
The CERISE project (grant agreement No101082139) is funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Commission. Neither the European Union nor the granting authority can be held responsible for them.

ECMWF coupled data assimilation

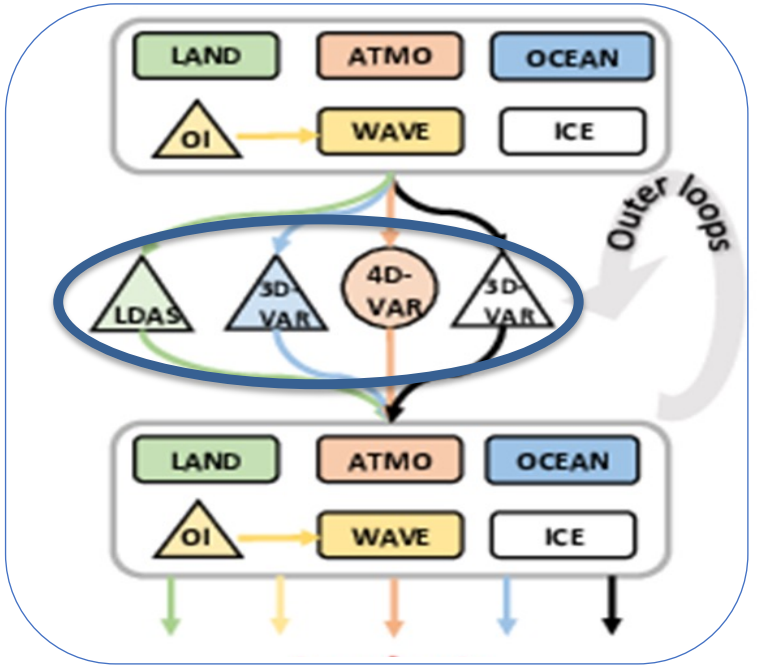
Funded by the European Union

Weakly coupled data assimilation for
- Land-atmosphere-waves (ERA5)
- Land-atmosphere-waves-ocean-sea ice (NWP & ERA6)

Enhanced outer coupled data assimilation for
- Land-atmosphere-waves-ocean-sea ice
→ future NWP and ERA7

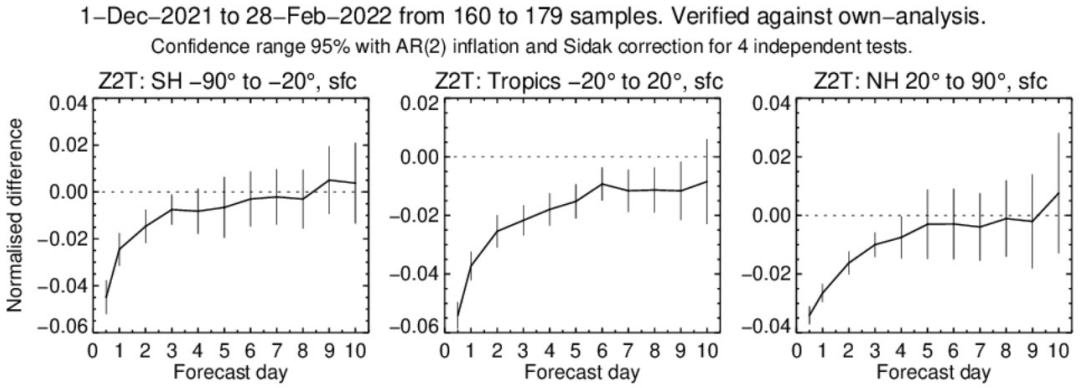


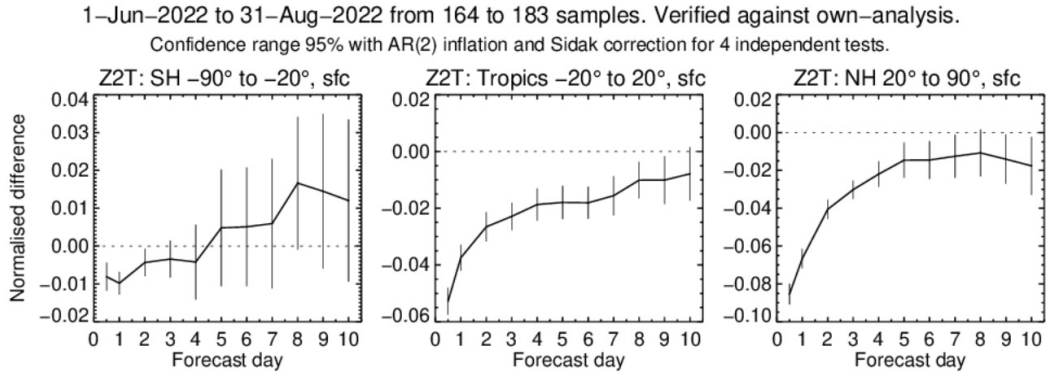
Current → Future



Land data assimilation improvements for NWP

P. de Rosnay, K. Ochi and E. Pinnington et al.





- T2m lapse rate correction in the land DA system
- Doubling B in the soil moisture analysis
- Snow data assimilation: IMS thinning, IMS DA in mountainous areas, snow cover model

→ T2m forecasts error reduction (winter & summer)

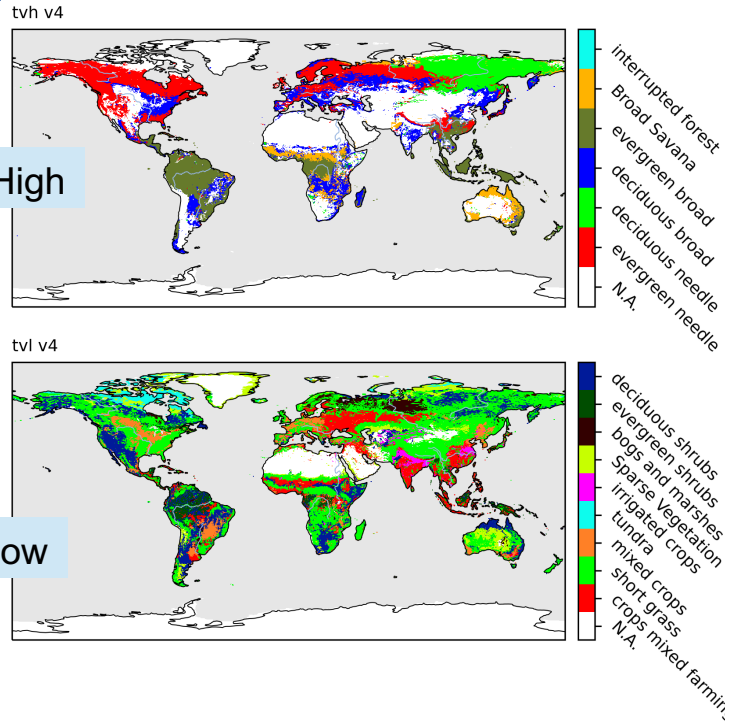
→ IFS cycle 49r1 (operational in 2024)

Coupled Processes

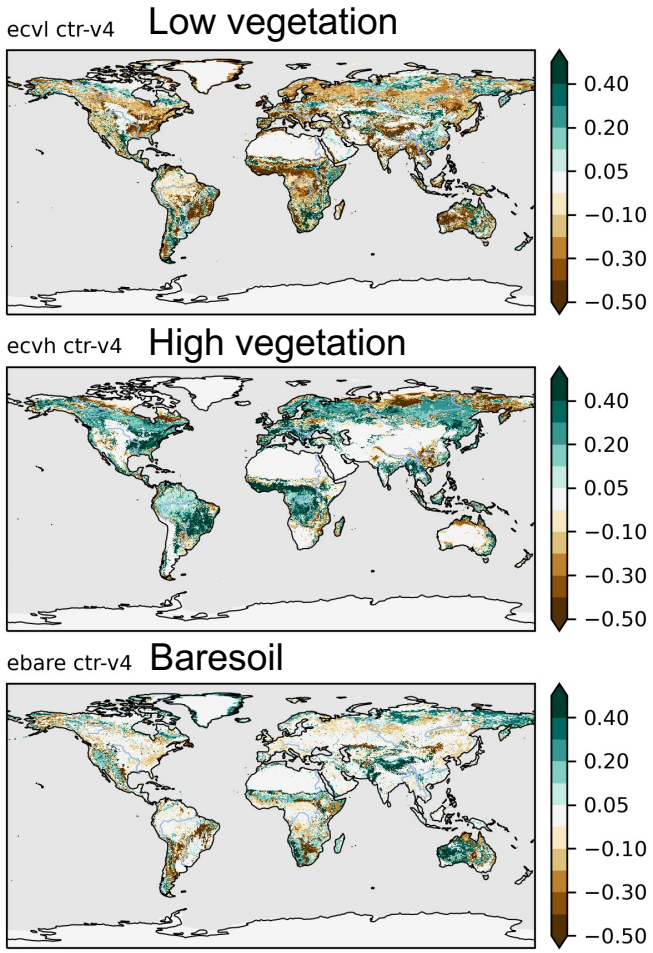
ECMWF

Changes in the land use land cover maps based on the C3S/ESACCI products and the impact on forecast and offline simulations

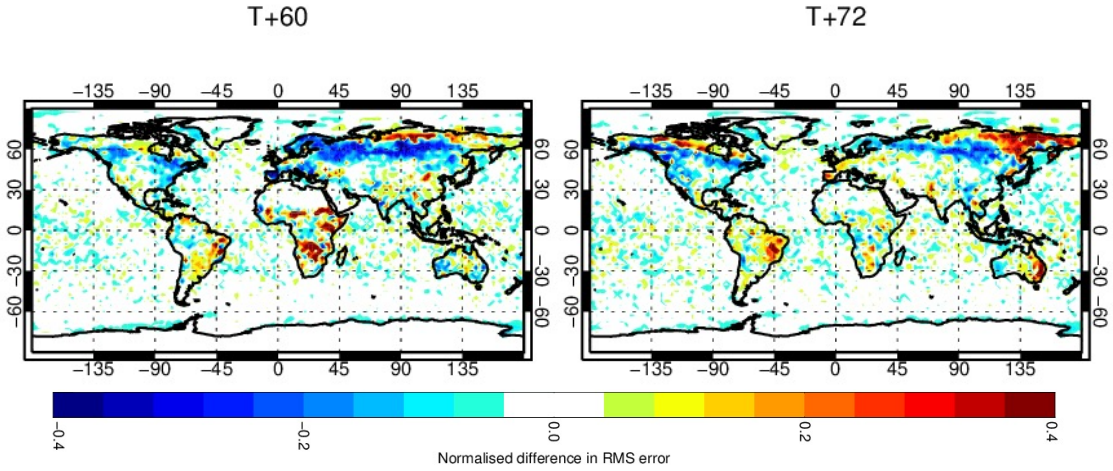
New ESACCI-V4 Vegetation Types



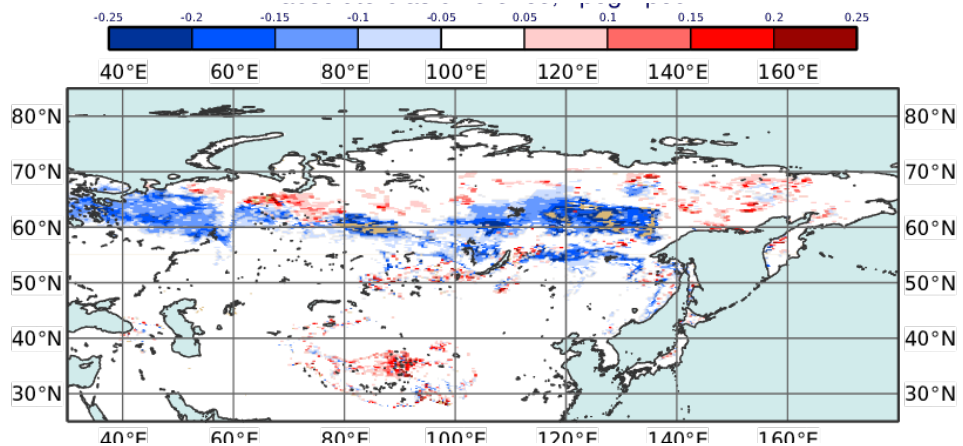
Effective vegetation cover difference (operational-GLCCv1.2 - ESACCI_V4)



Forecasts simulations: Change in RMS error of 2m Temperature for Spring



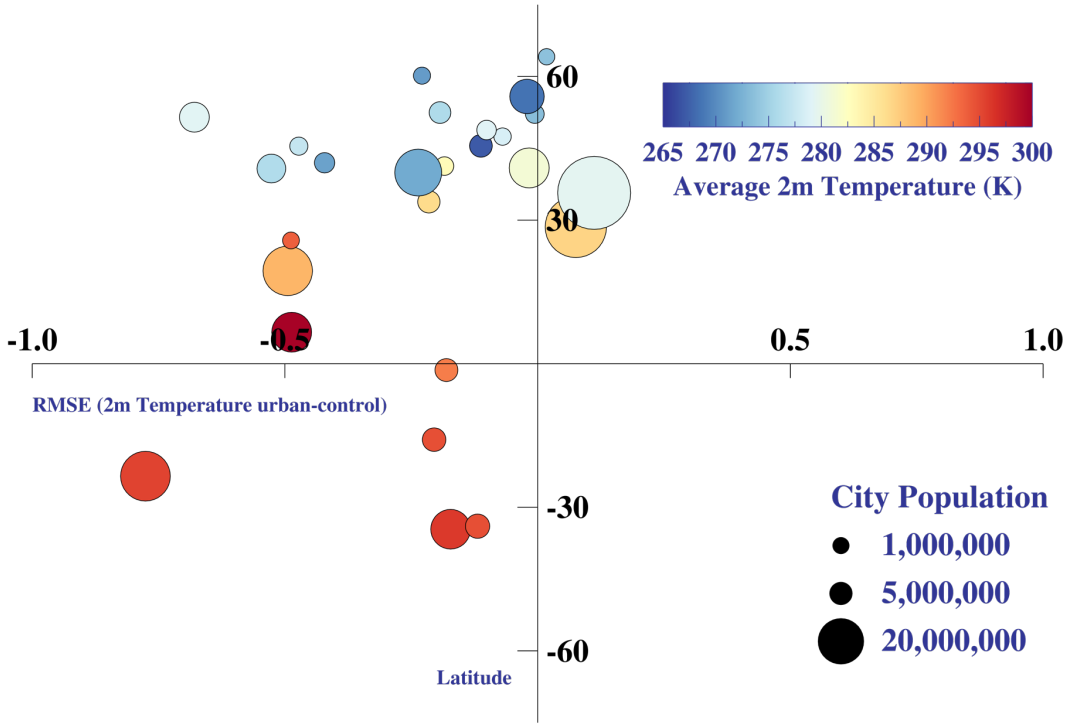
Offline simulations: snow cover (absolute bias diff 2010-2018)



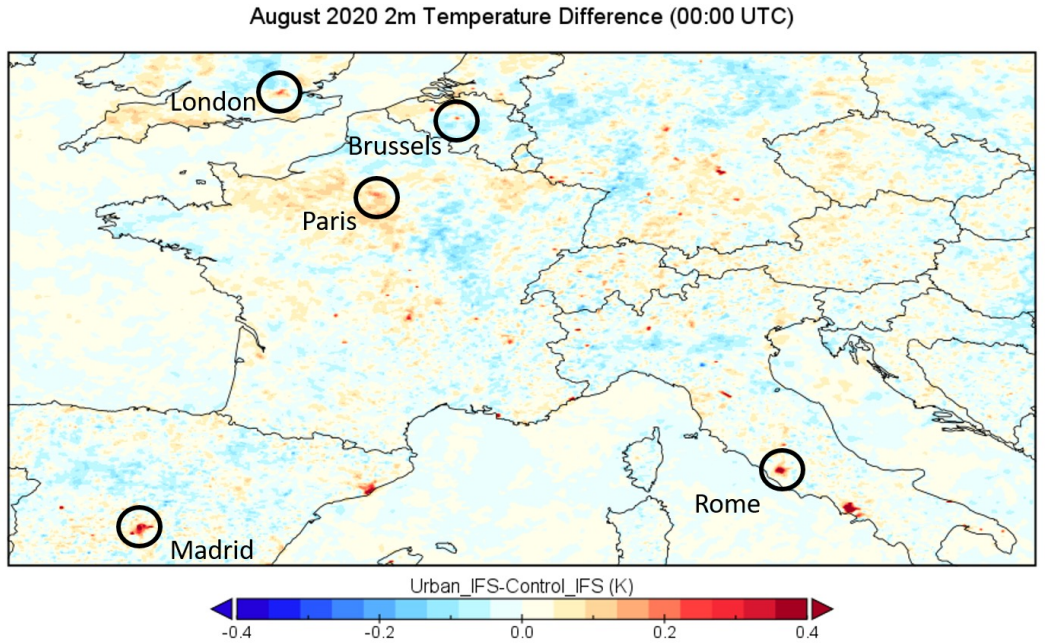
S. Boussetta, G. Arduini and G. Balsamo

An Urban Scheme for the IFS

- A single-layer urban canopy model has been developed for both ECLand and the coupled IFS (CY49R1)
- Case Study – July/August 2020 Heatwave



Urban improvement ← → Urban degradation



- SYNOP 2m temperature and 10m wind evaluation show model improvement when using the urban scheme at 9km
- Analysis comparisons show the scheme to be viable for implementation producing neutral scores with improvements over urban conurbations. (McNorton *et al.*, submitted to JAMES)

JAMES | Journal of Advances in Modeling Earth Systems

Research Article | Open Access

An Urban Scheme for the ECMWF Integrated Forecasting System: Single-Column and Global Offline Application

J. R. McNorton, G. Arduini, N. Bousserez, A. Agustí-Panareda, G. Balsamo, S. Boussetta, M. Choulga, I. Hadade, R. J. Hogan

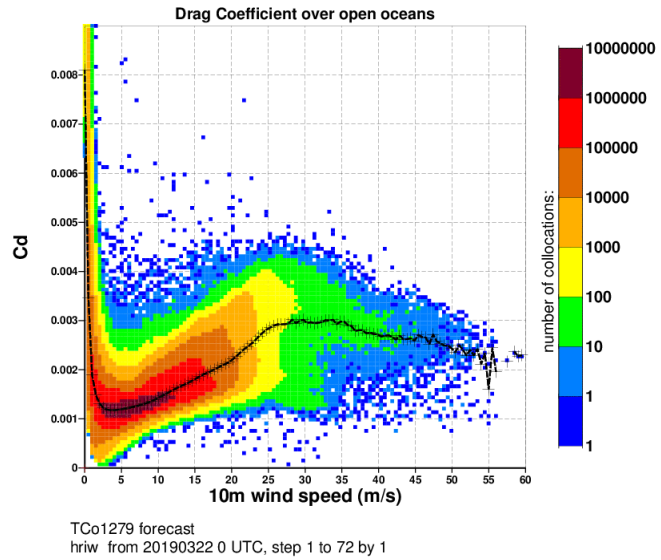
Ocean and Waves

ECMWF

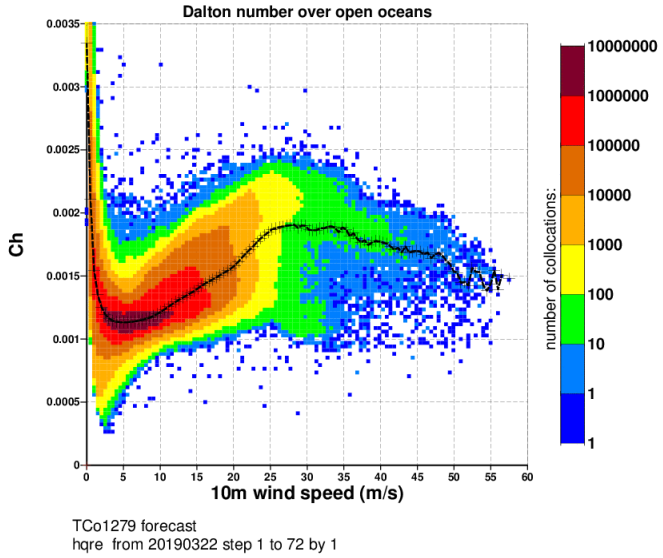
Wave model driven changes

- ecWAM refactoring for first open-source release.
- Changes related to surface stress (wind input) and sea state effect on heat and moisture exchange.
- Different forecast ranges were tested from days to months.
- Results are encouraging and are now prepared for implementation in CY49R1.

New drag coefficient:

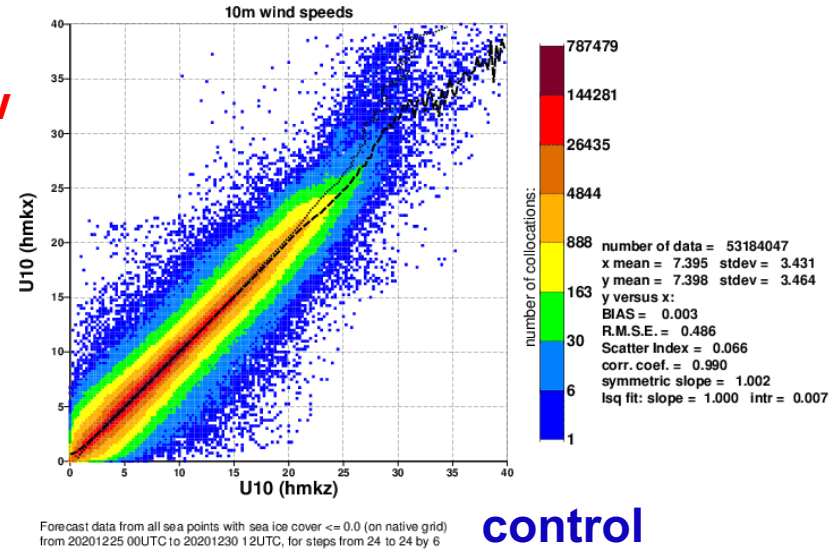


New heat exchange coefficient:



Impact of surface winds:
Stronger winds in stormy conditions:

new



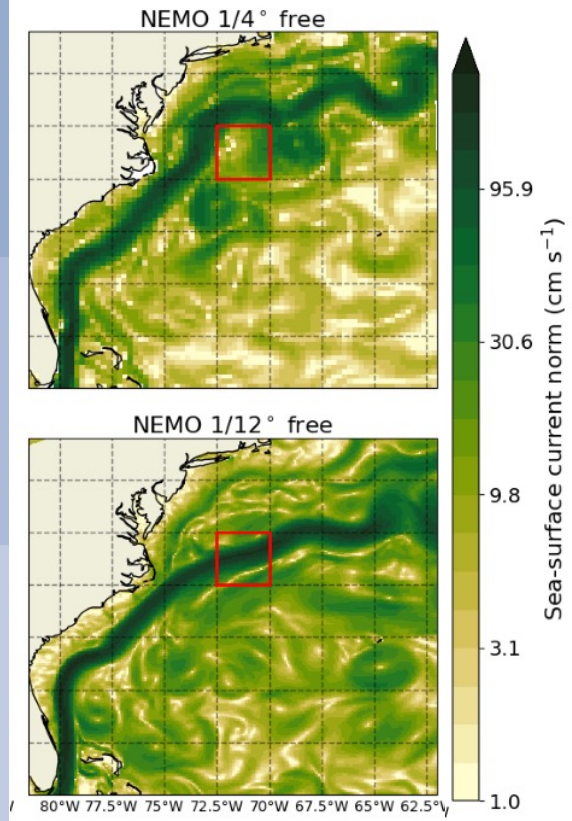
control

Tco1279 forecasts step 24

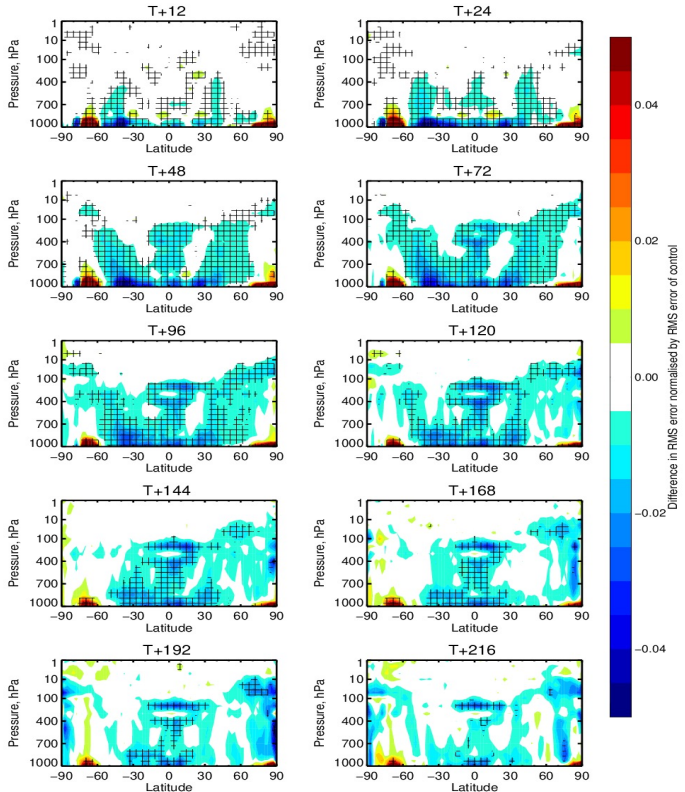
Jean Bidlot

Progress with new ocean model NEMO4-SI3

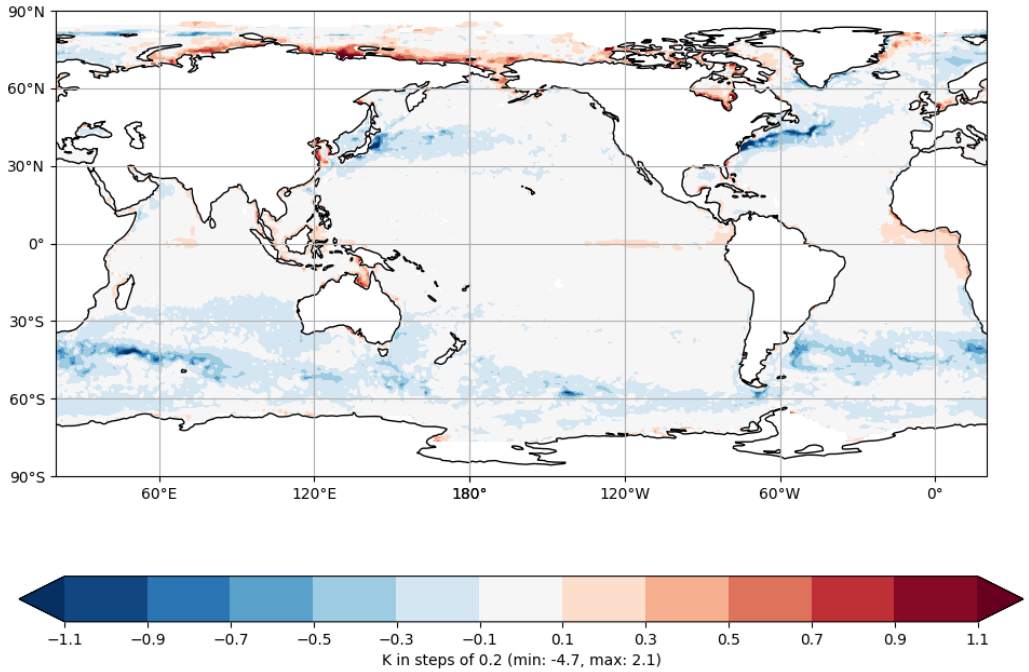
- Updated ocean and multicategory sea ice model for:
  - coupled NWP; ocean analysis (reanalysis)
  - reduced rmse (blue) with improved representation of Gulf Stream and Southern Ocean
  - more responsive sea ice model – winter improved, summer melt in Arctic is too rapid
- Ongoing testing for all forecast systems
- Preparations for 1/12°



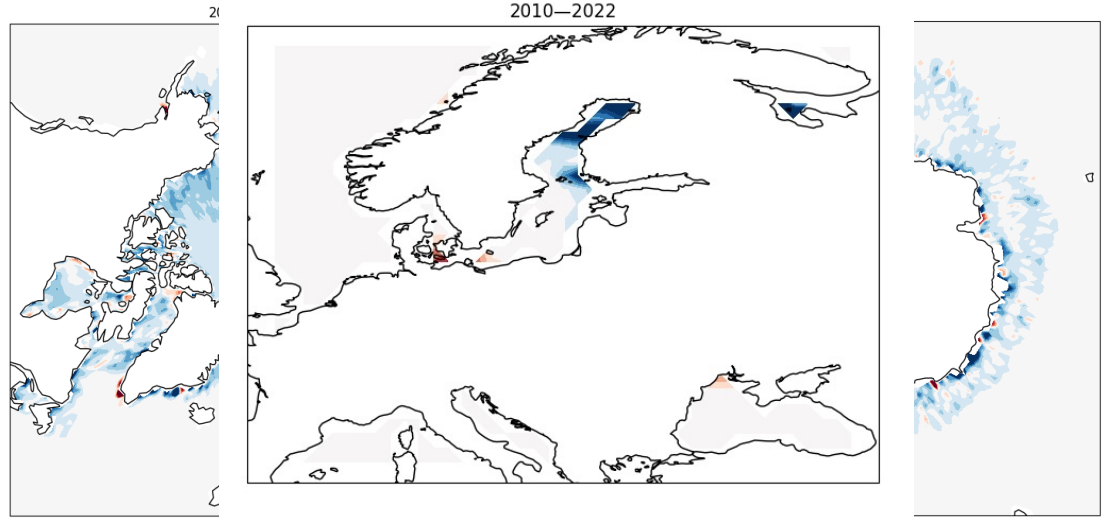
Change in RMS error T (NEMO4 – NEMO3.4)
Verified against ERA5



Change in RMS error SST (NEMO4 – NEMO3.4)
Verified against esa cci SST



Change in RMS error sea ice conc (NEMO4 – NEMO3.4)
Verified against osisaf cdr siconc

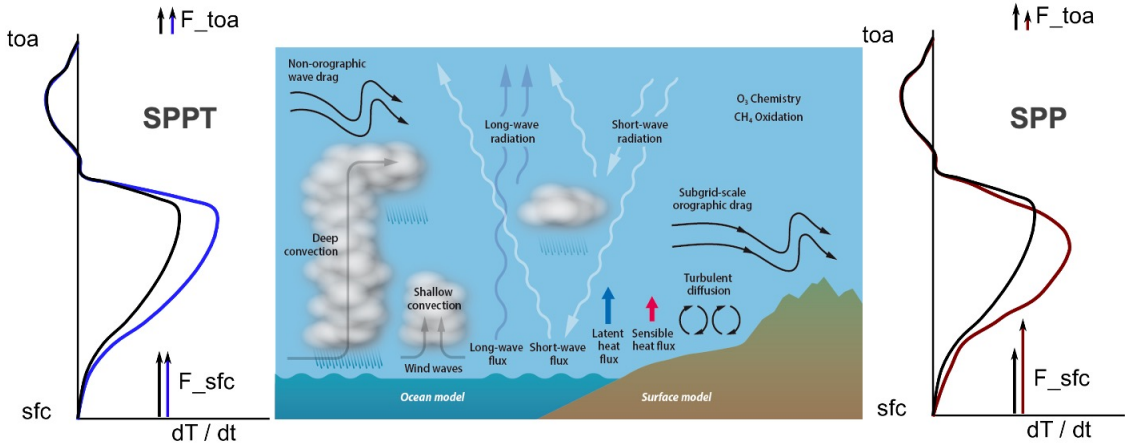


Model Uncertainty

ECMWF

SPP ready for operational implementation in 49r1

- A multiyear effort with milestones documented in Ollinaho et al (2017), Leutbecher et al (2017), Lang et al (2021)
- Further developments over the last year to get also good results for extended-range and seasonal forecasts
- Extensive testing of the impact of the switch from SPPT to SPP with CY48R1 on medium-range, extended-range and seasonal ensembles as well as EDA and km-scale extreme cases

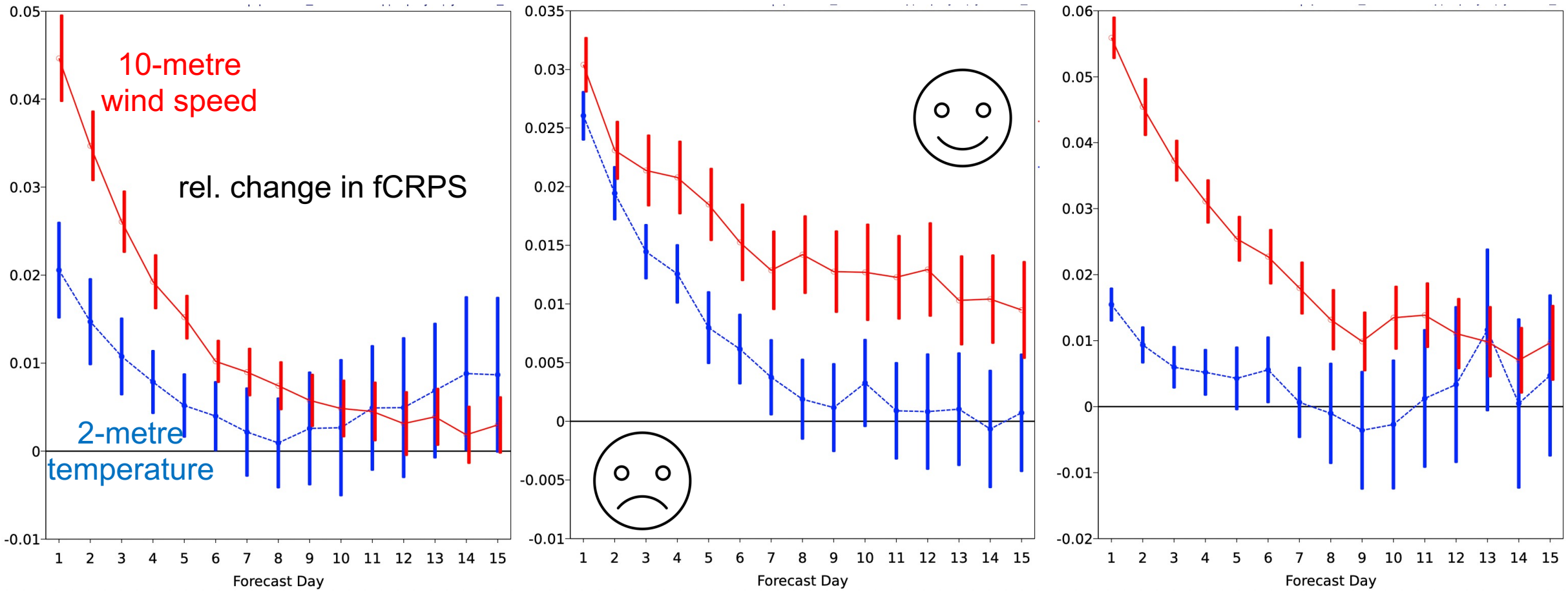


perturbations close to sources of errors

local conservation

consistent flux perturbations

Impact of SPPT → SPP on SYNOP weather parameter probabilistic skill @ 9km, 8-member, fc only



STOCHDP: *Stochastically perturbed semi-Lagrangian (SL) departure point estimate (DPE)*

Diamantakis & Magnusson (2016):

- Convergence rate of the iterative DPE is flow-dependent
- Slowest convergence ←→ most complex flow (strong shear / curvature)

Model uncertainty (MU) scheme, “STOCHDP”:

- use the DPE convergence rate to attribute MU by:

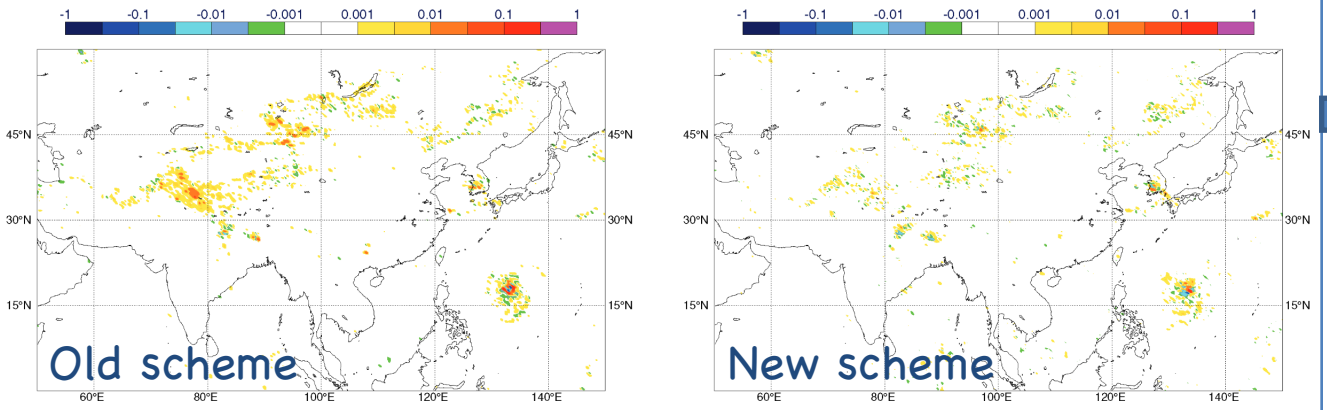
Final DPE — random number

$$D^{*} = D^{(f)} + r\left(D^{(f)} - D^{(f-i)}\right), i = 1..f-1$$

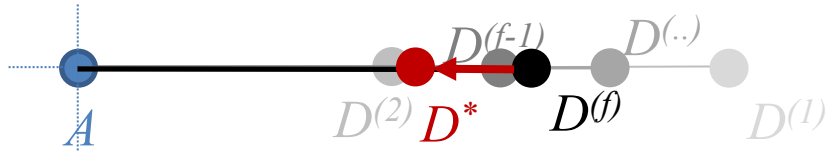
Perturbed DPE — Δ between final and earlier DPE

Diamantakis & Vana (2022):

- Faster converging SLDP scheme => from 5 to 3 iterations
- Fig 1b: differences in DPE (iterations 3 and 2)



STOCHDP:



- Old SLDP scheme: STOCHDP acted on $D^{(5)}$ - $D^{(3)}$
- New SLDP scheme: STOCHDP acts on $D^{(3)}$ - $D^{(2)}$

➢ Testing underway: sensitivities to random pattern & resolution, skill impact in ENS

Extended-Range Forecasts

ECMWF

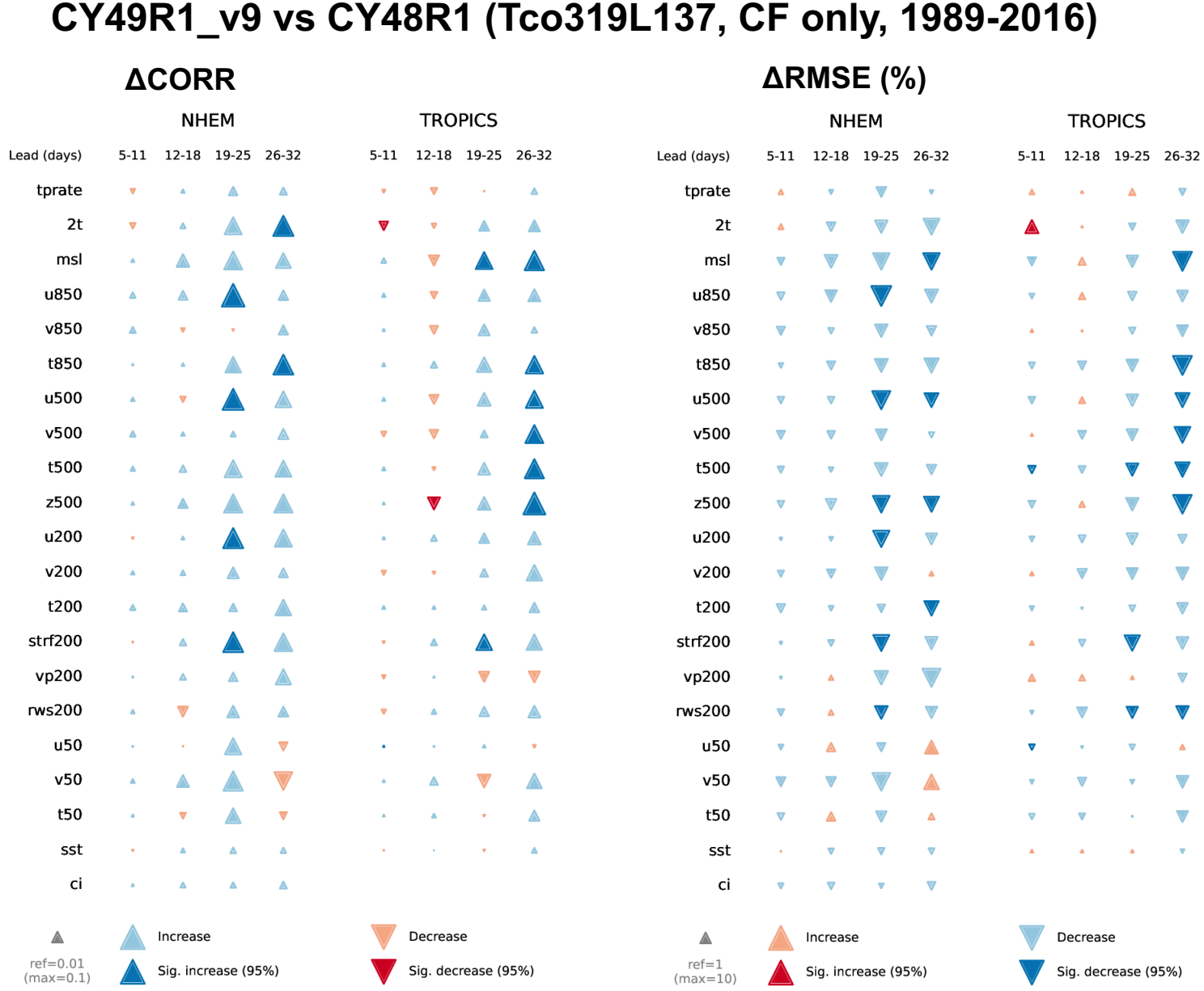
Funded by the European Union

Recent developments in the extended-range team

- Coordination of Cycle 49R1 and assessment of extended-range forecast skill
- Design and assessment of new re-forecast configurations for 49r1, including offline land DA initialization
- Develop nudging-based ocean initial condition generation to address challenges related to higher-resolution modelling
- Evaluation of trends in extended-range forecasts and investigation of causes of spurious SST trends in the Pacific
- Development and testing of systems required to run 30-year atmosphere-only IFS simulations (EERIE project)
- Starting developing verification and calibration methods and sea-ice product prototypes based on medium-range, extended-range and seasonal forecasts (ACCIBERG project)
- Develop novel diagnostics for land parameters (CERISE project).
- Research on sources of extended-range predictability and tropical/extratropical, high-latitudes/mid-latitude and stratosphere/troposphere interactions

Extended-range evaluation of CY49R1

- CY49R1_v9 includes all main science contributions for extended-range reforecasts (SPP, land-surface, wave, physics packages).
- Weekly mean anomaly scores are generally improved in NHEM and TROPICS at extended-range (see scorecards).



Km-scale modelling with the IFS

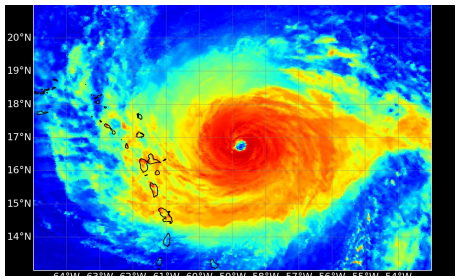
ECMWF

Km-scale modelling projects at ECMWF

U.S. DEPARTMENT OF ENERGY
INCITE
LEADERSHIP COMPUTING

Short forecasts pioneering physics for km-scale

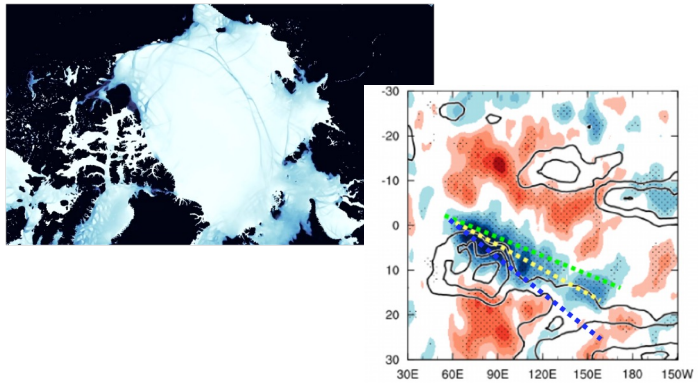
Multiple case studies up to IFS (2.8km/1.4km) + NEMO (12km)



next GEMS

Multidecadal coupled simulations

In 2024, 30 years of IFS (4.4km) + NEMO (12km) IFS (4.4km) + FESOM (5km)

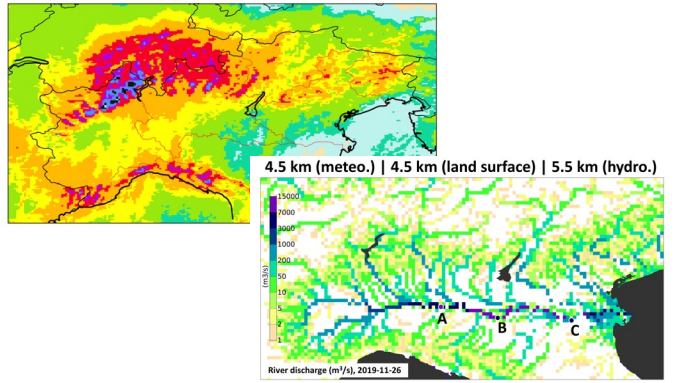


Destination Earth
EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

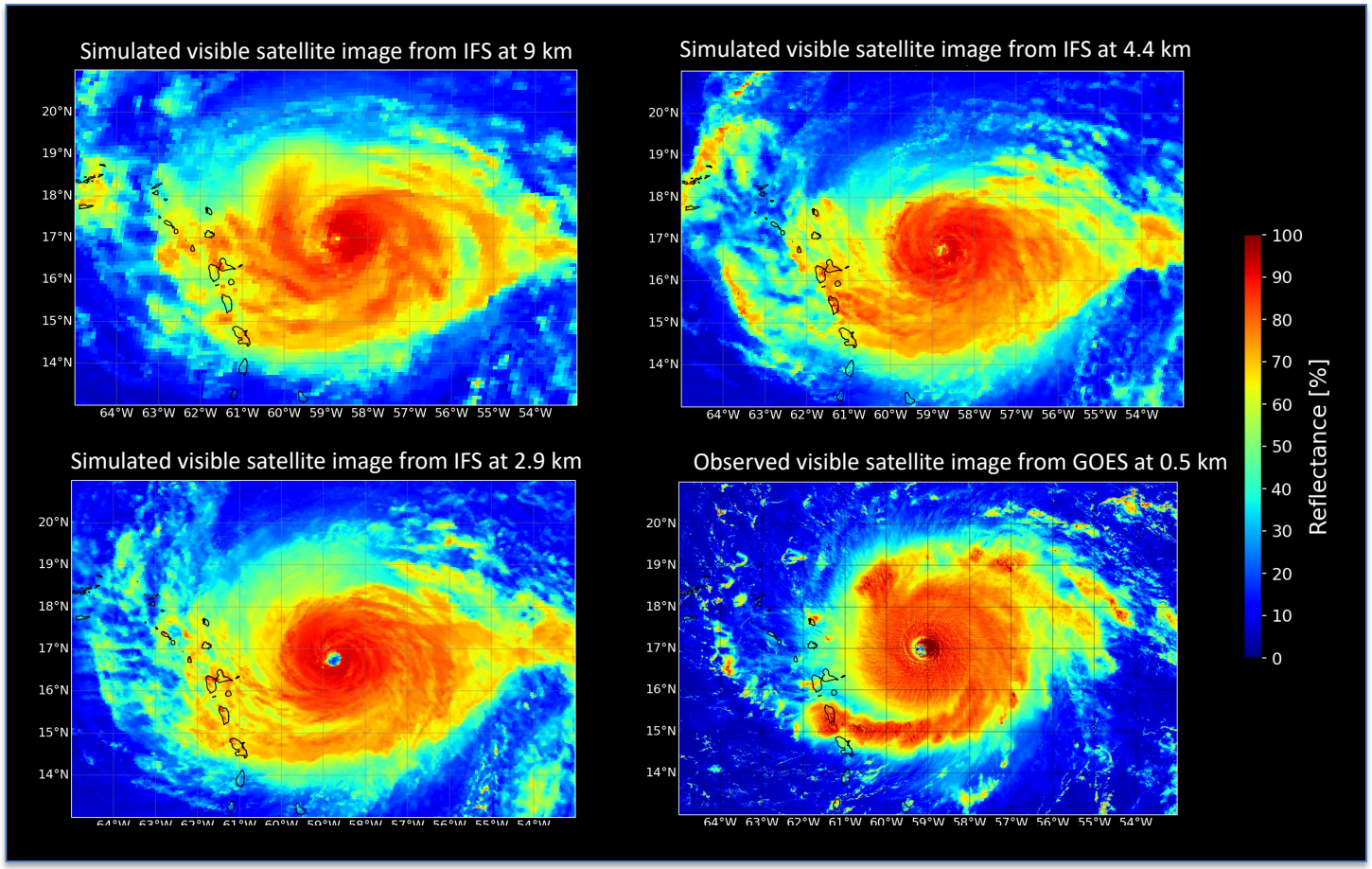
DestinE Phase I 2022-2024

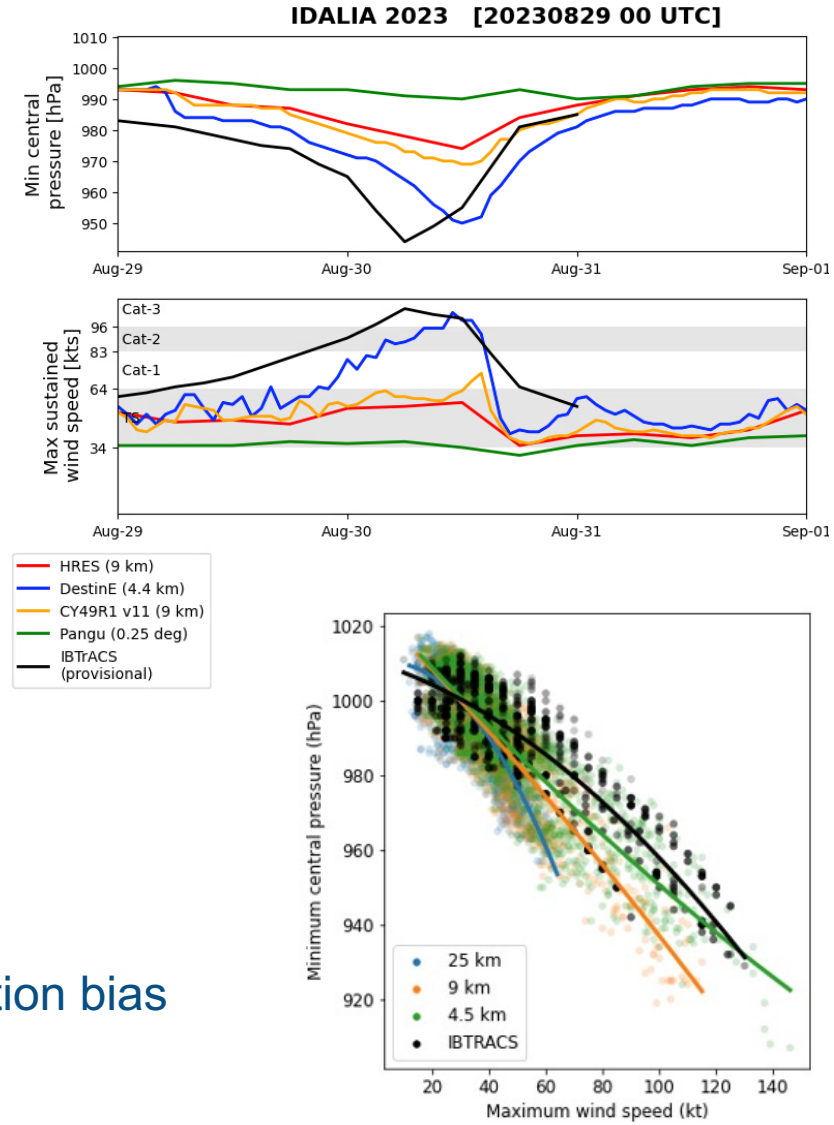
Pathway to operational use

In 2024, 5-day fc with IFS (4.4km) + NEMO (25km)



How kilometer-scale benefits the representation of tropical cyclones?

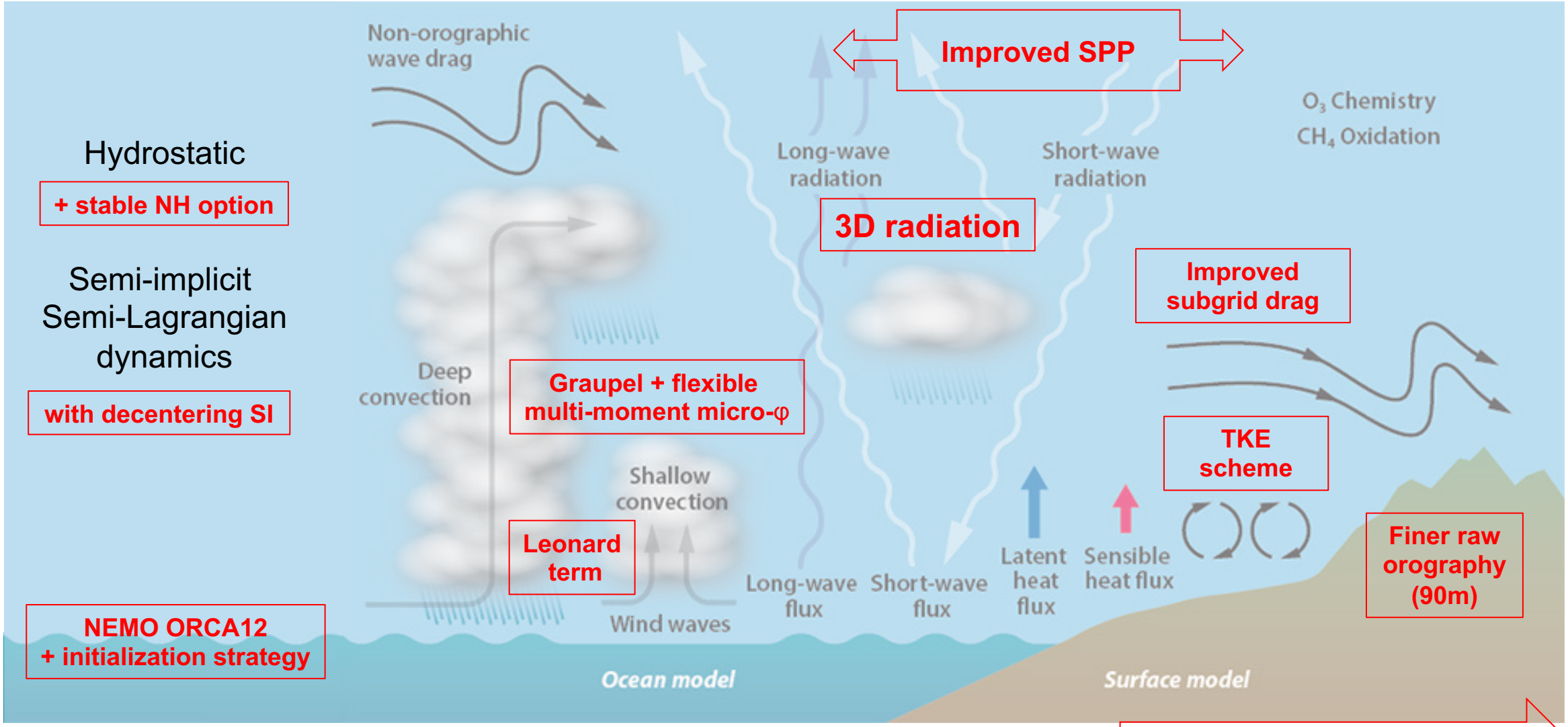




… improved mesoscale features, intensity but lingering slow propagation bias

ECMWF

Next 4 years of km-scale modelling at ECMWF



ECMWF

Conclusions

- Cycle 48r1 was a strong cycle in particular due to the increase in resolution of the ensemble
- A lot of new developments coming in cycles 49r1 and 49r2 (e.g., land cover, surface data assimilation, SPP, NEMOV4, SI3 for sea ice and revise the ocean data assimilation and others)
- Km-scale modelling with the IFS is progressing well thanks to the efforts in DestinE, INCITE and nextGEMS

Many thanks!