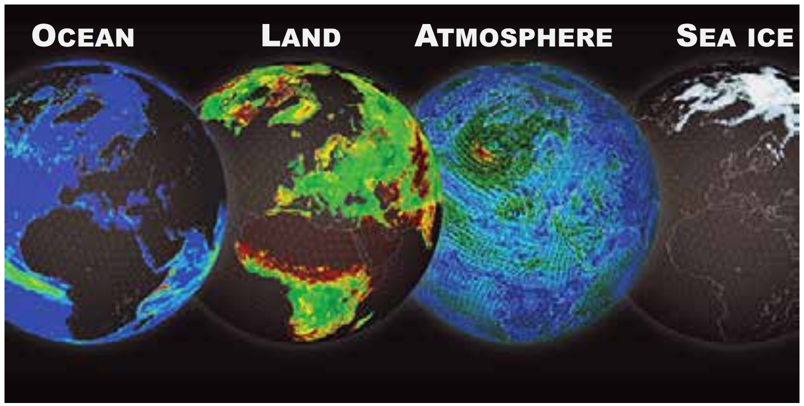
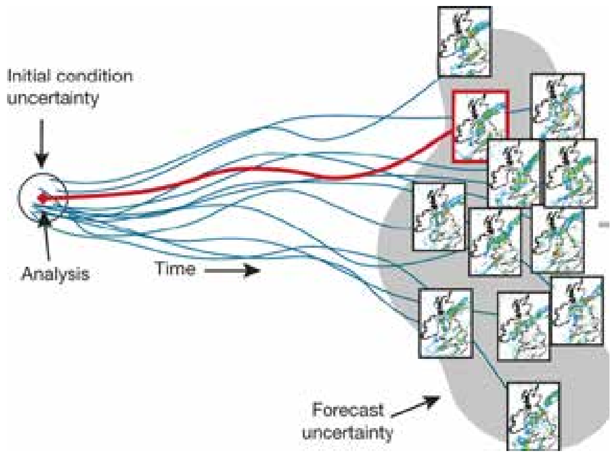
Modelling and prediction capabilities

Irina Sandu

&

ECMWF and Member States colleagues





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Weather and climate modelling capabilities diverged in the past….

Weather forecasting

Purpose Weather:
Predict states (and uncertainties) over short time scales given initial conditions

Climate prediction

Purpose Climate:
Predict mean changes in state (and uncertainties) over long time scales given external forcing

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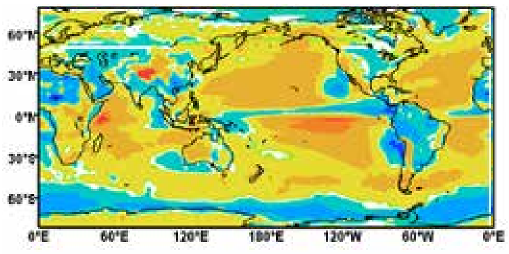
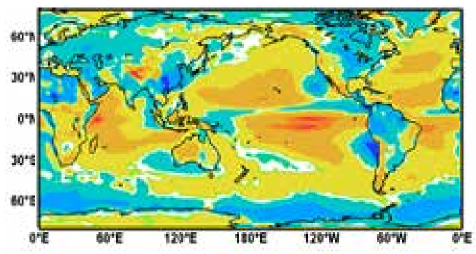
Global model shortwave radiation systematic errors are virtually identical across models, across resolutions, across timescales

Annual mean top-of-atmosphere SW radiation difference from CERES-EBAF

CMIP3 mean (bias=4.5 Wm^{-2})

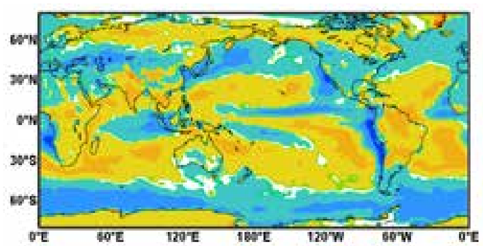


CMIP5 mean (bias=2.5 Wm^{-2})

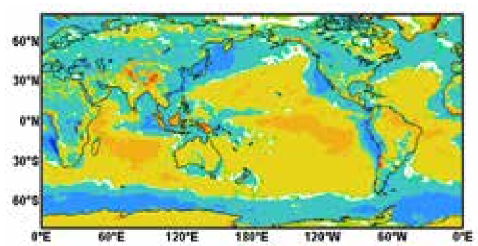


Li et al. 2013

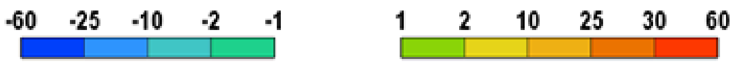
ECMWF 80km 1yr fc (bias=0.2 Wm^{-2})



ECMWF 9km 24hr fc (bias=0.6 Wm^{-2})



Forbes et al. 2016



Albedo too low Albedo too high (Wm^{-2})

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Weather and climate modelling capabilities,
but are now gradually converging….

Today they share many nearly identical elements & related challenges (numerics, physics, ocean, atmosphere, cryosphere, land, conservation, composition, uncertainty representation)

Weather forecasting

Shared infrastructure

Climate prediction & monitoring

ECMWF

Weather and climate modelling capabilities, but are now gradually converging….

Today they share many nearly identical elements & related challenges (numerics, physics, ocean, atmosphere, cryosphere, land, conservation, composition, uncertainty representation)

Weather forecasting

Shared infrastructure

Climate prediction & monitoring

Improving weather forecasting systems leads to improved climate prediction & monitoring

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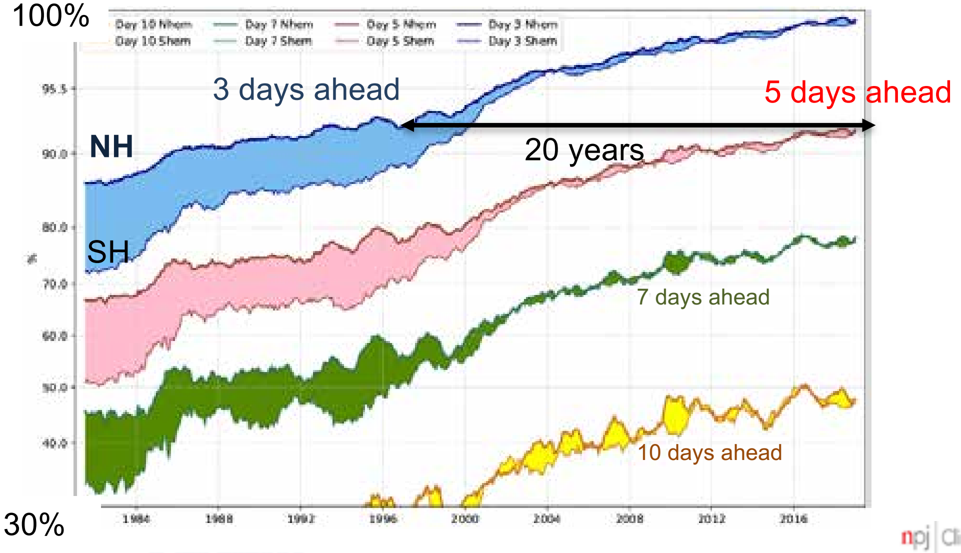
Improvements to NWP systems : better predictions from days to months ahead

Anomaly correlation geopotential height 500hPa

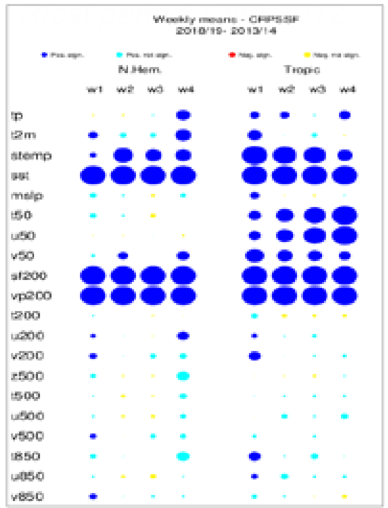


REVIEW

Bauer et al, nature, 2015

The quiet revolution of numerical weather prediction

S2S: Progress in monthly prediction
2018/19 vs 2013/14



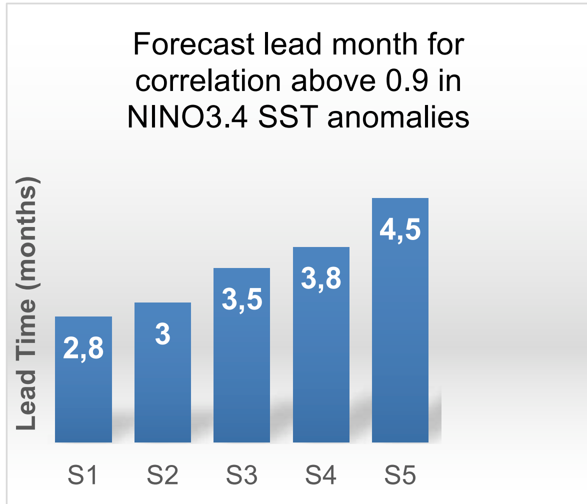
npj Climate and Atmospheric Science

Vitart and Robertson, 2018

PERSPECTIVE OPEN

The sub-seasonal to seasonal prediction project (S2S) and the prediction of extreme events

20 years or progress in ENSO prediction



Stockdale et al., 2018

COMBINED advances in NWP key ingredients:

- science (physics, numerics, uncertainty, data assimilation)
- resolution
- utilisation of observations
- supercomputing

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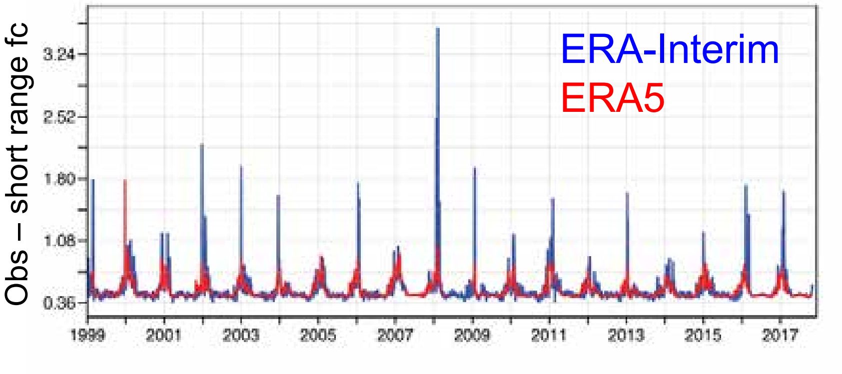
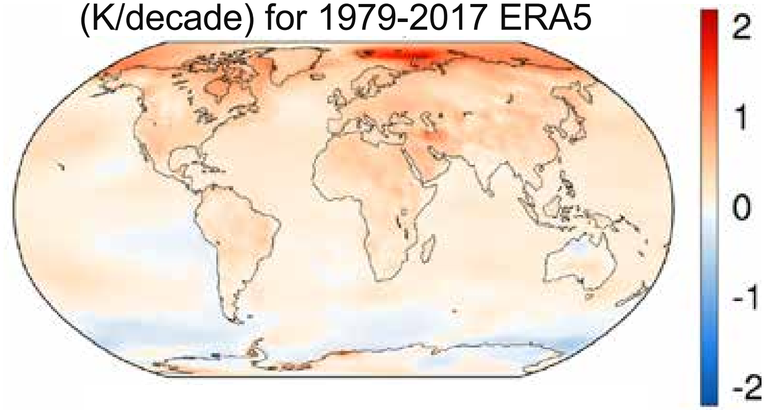
Improvements to NWP systems: better reanalysis & monitoring

Much better representation of Sudden Stratospheric Warming events, due to changes in the Semi-Langrangian scheme (*Diamantakis, 2014*)



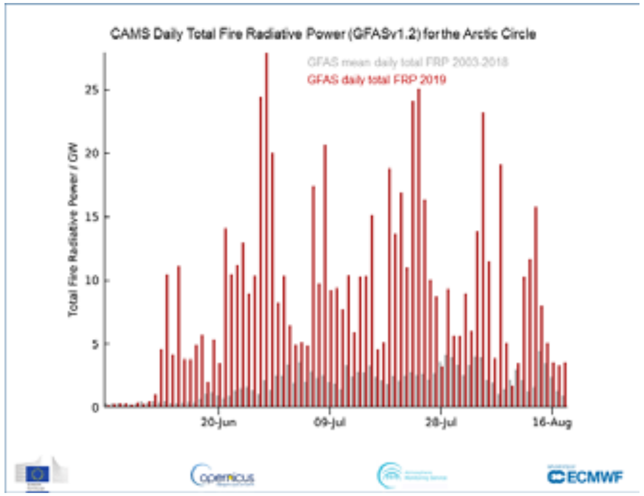
Linear trends in 2m temperature (K/decade) for 1979-2017 ERA5



Modern reanalysis, e.g. ERA5 ~ 32km, 137 levels, Copernicus atmospheric monitoring service (CAMS) reanalysis ~ 80km, 60 levels

Great tools for climate & atmospheric monitoring & model evaluation

CAMS Total Fire Radiative Power Arctic Circle



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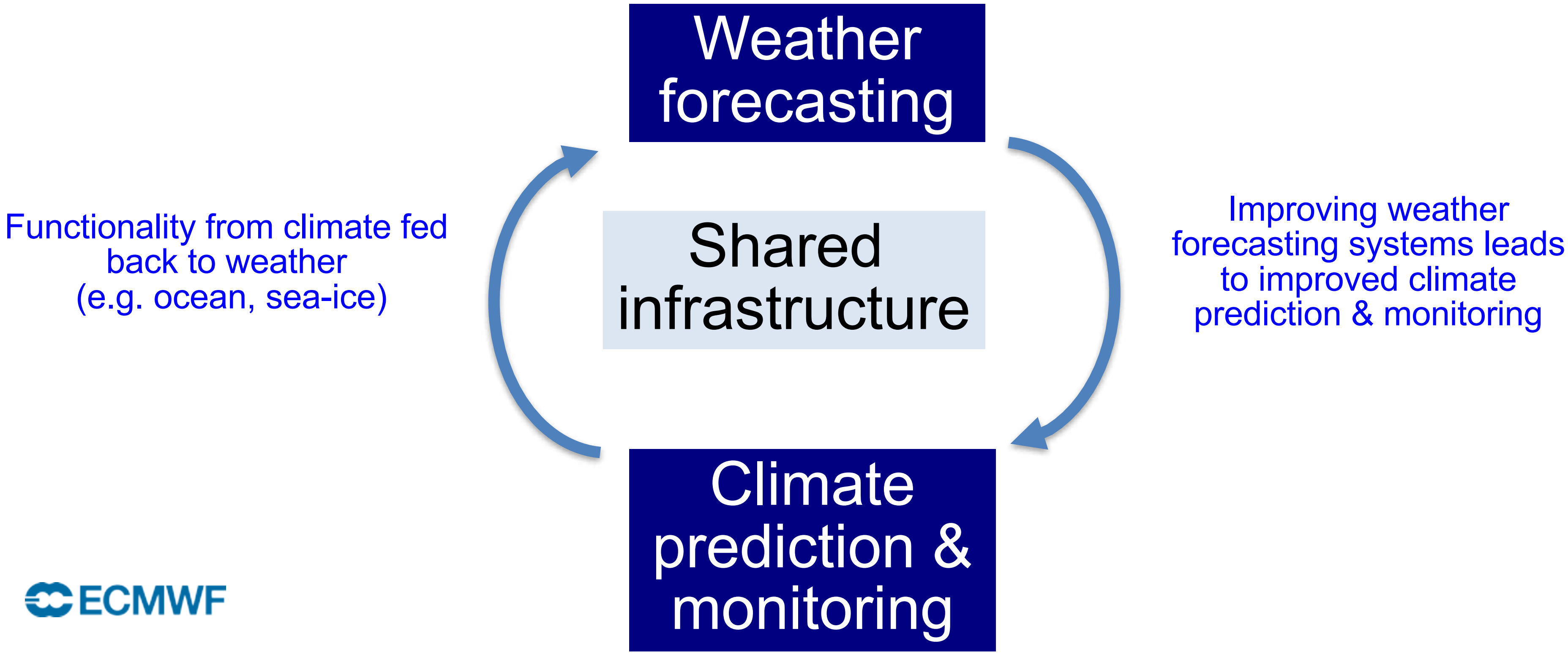
opernicus
Europe's eyes on Earth

Weather and climate modelling capabilities, but are now gradually converging….

Today they share many nearly identical elements & related challenges (numerics, physics, ocean, atmosphere, cryosphere, land, conservation, composition, uncertainty representation)



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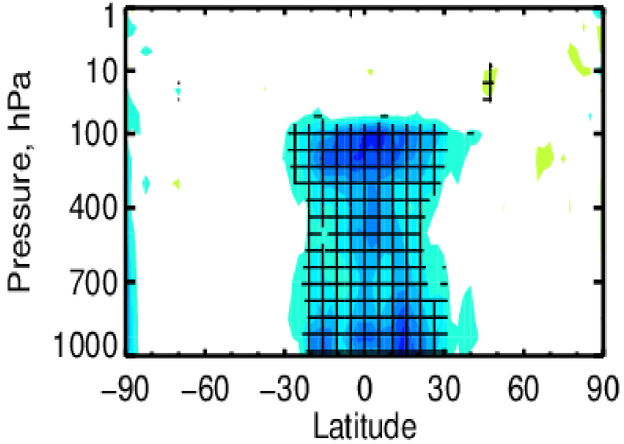
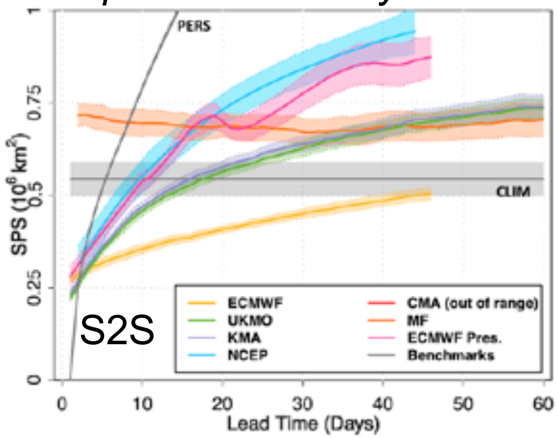
Improvements to forecast skill by incorporating ocean and sea-ice components

Reduction in wind RMSE
day 5

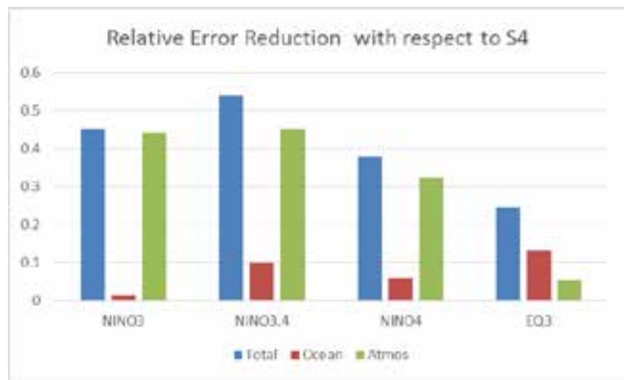


Arctic sea-ice edge
Spatial Probability Score



Zampieri et al., 2019, 2018

Progress in ENSO Prediction (2011-2016)



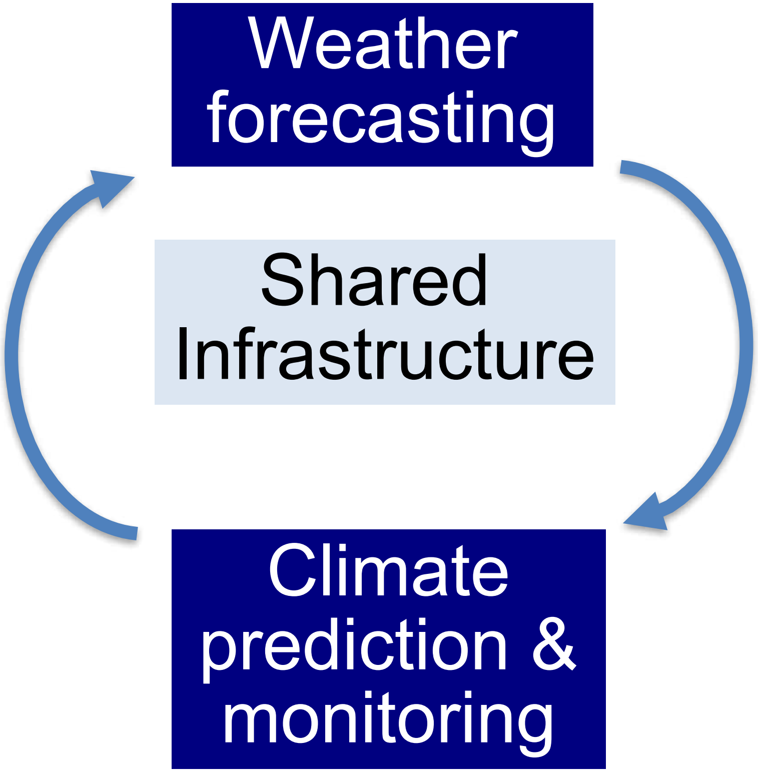
Coupled Atmosphere/Land Ocean

Ocean coupling
medium-range forecasts

Sea-ice model
monthly timescales

Coupled model development
Seasonal timescales

Why weather and climate modelling capabilities should converge even further?



Commonalities of challenges in weather and climate

- **Observation/assimilation**: key to model improvement, initialization
- **Physical processes**: key for eliminating systematic errors
- **Coupling**: drives how Earth-system components interact: fluxes, budgets
- **Ensembles**: uncertainty representation
- **Computing**: key to running realistic models in the future

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Challenges in the use of microwave observations in polar regions

APPLICATE.eu
Advanced prediction in polar regions and beyond

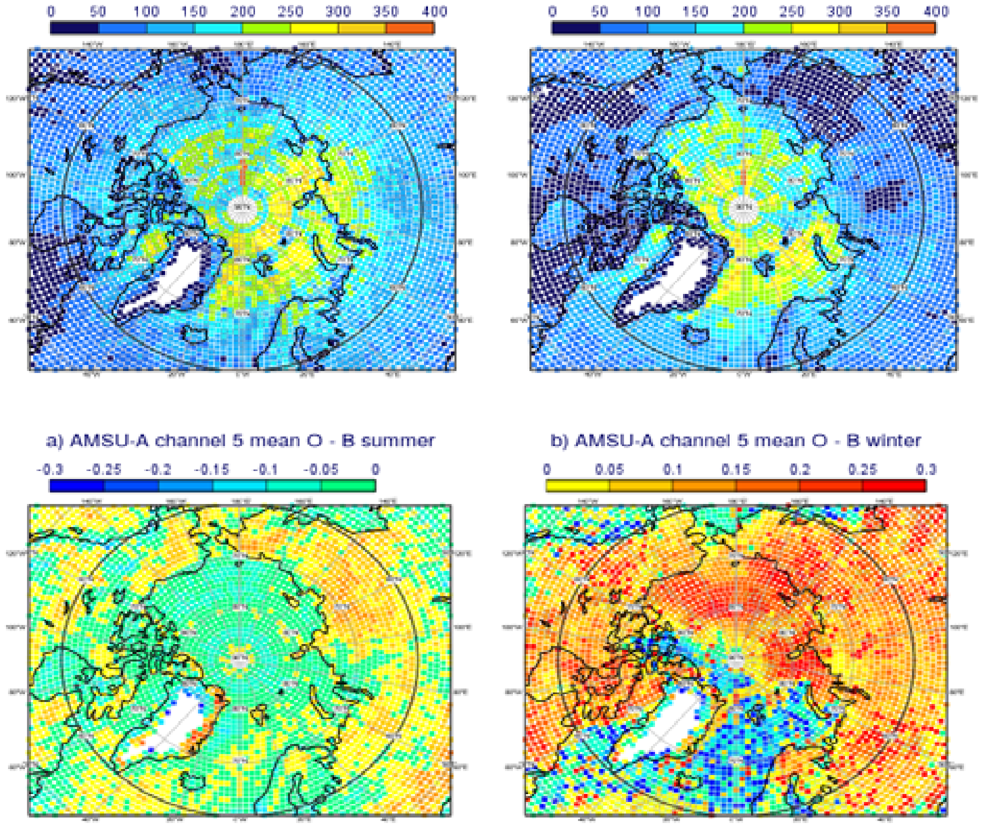
Summer 2016

Winter 2017/2018

Nb obs

Obs - fc

NOAA-15
AMSU-A channel 5
(peaks 500-700hPa)



- better coverage from polar orbiting satellites than anywhere else
- Much less effective use in winter than in summer due to challenges over snow and sea-ice
- Improving their use will improve not only weather fc but also future reanalysis, and hence climate monitoring

Lawrence et al, 2019

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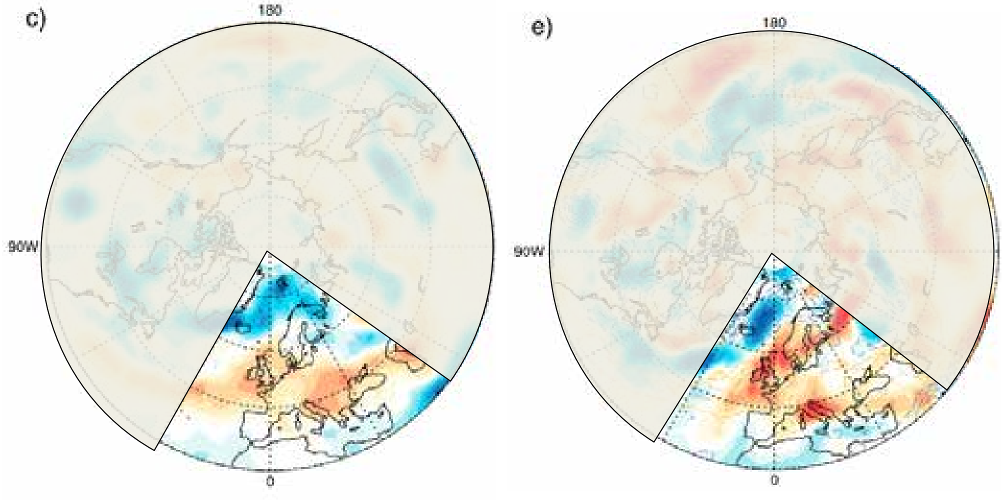
Orographic drag parametrizations → Better weather forecasts / More realistic model climate

Cyclones track density biases during DJF

CMIP5 – ERA-INTERIM

UM – UM-no mountains



Climate model biases in the jet stream regions during winter partly result from missing blocking effects of large-scale mountains

Pithan et al., GRL, 2016

Any yet, orographic drag parametrizations remain a challenge and are largely poorly constrained

npj | Climate and Atmospheric Science www.nature.com/npjclimatsci

PERSPECTIVE OPEN

Impacts of orography on large-scale atmospheric circulation

Irina Sandu[1], Annelize van Niekerk[2], Theodore G. Shepherd[3], Simon B. Vosper[2], Ayrton Zadra[4], Julio Bacmeister[5], Anton Beljaars[1], Andrew R. Brown[1], Andreas Dörnbrack[6], Norman McFarlane[7], Felix Pithan[8] and Gunilla Svensson[9]

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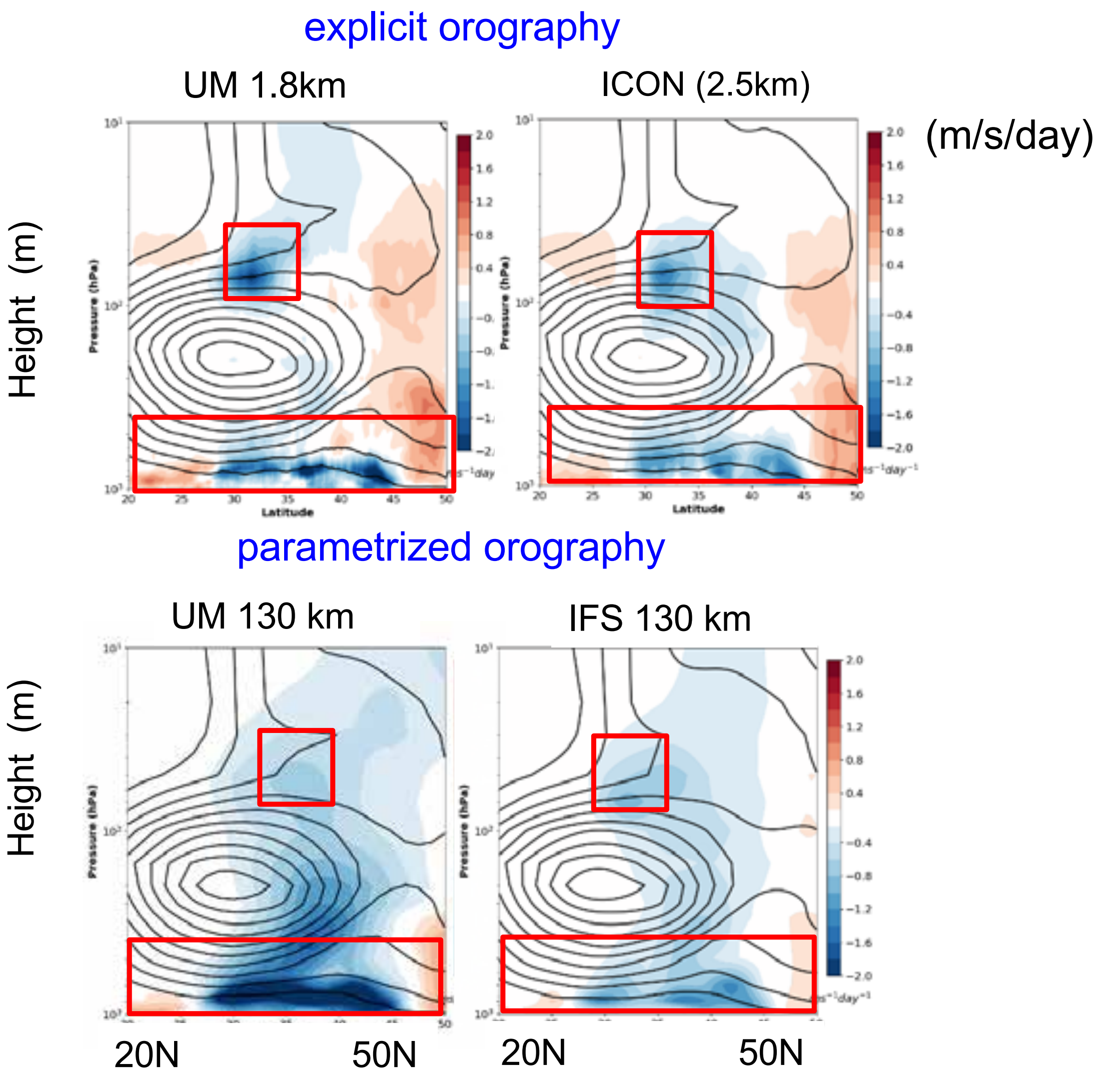
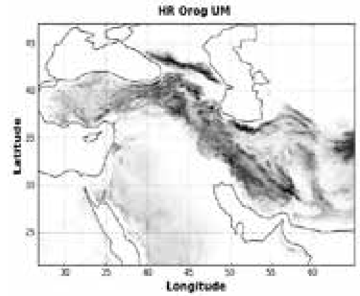
Using NWP techniques & km-scale simulations to constrain orographic drag



COORDE – a GASS/WGNE intercomparison

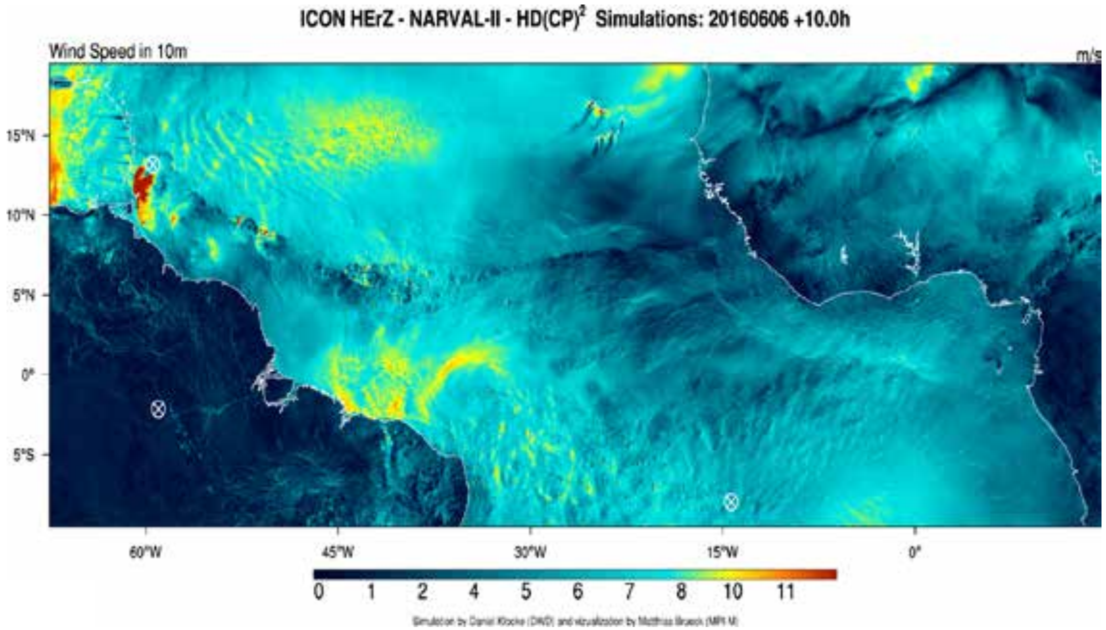


Met Office
ECMWF
KIAPS
DWD
気象庁
Japan Meteorological Agency
NCEP
METEO FRANCE
Environment Canada

Van Niekerk et al., 2018, 2020

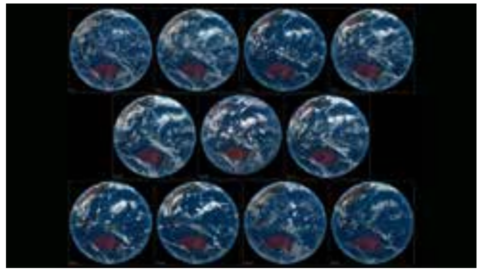
The Holy Grail: towards global storm-resolving resolutions

[Courtesy Thomas Jung and Sergej Danilov, AWI]



[Courtesy Bjorn Stevens and Daniel Klocke, MPI-M/DWD]

- Representation of the global mesoscale (in the atmosphere/ocean/sea-ice)
- Multi-scale scale interactions of convection
- Land-surface heterogeneity
- Orographic effects and gravity waves
- Better link to applications



DYAMOND, Stevens et al., 2019

PERSPECTIVE *Palmer and Stevens, PNAS, 2019*

The scientific challenge of understanding and estimating climate change

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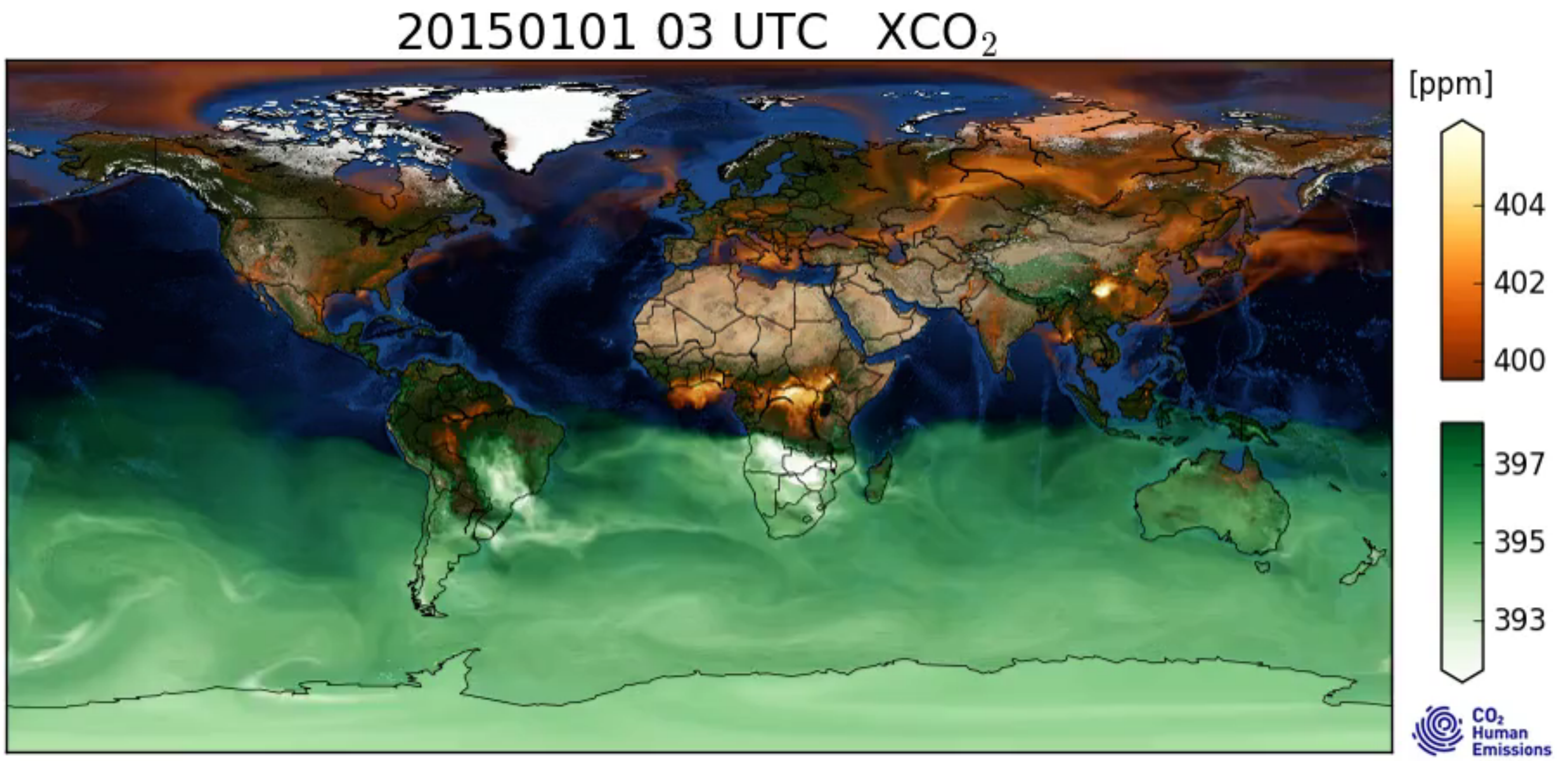
https://www.esiwace.eu/

The Holy Grail: towards monitoring of human CO2 emissions



CO_2 above global mean

CO_2 below global mean

Inverse modelling of the CO2 emissions

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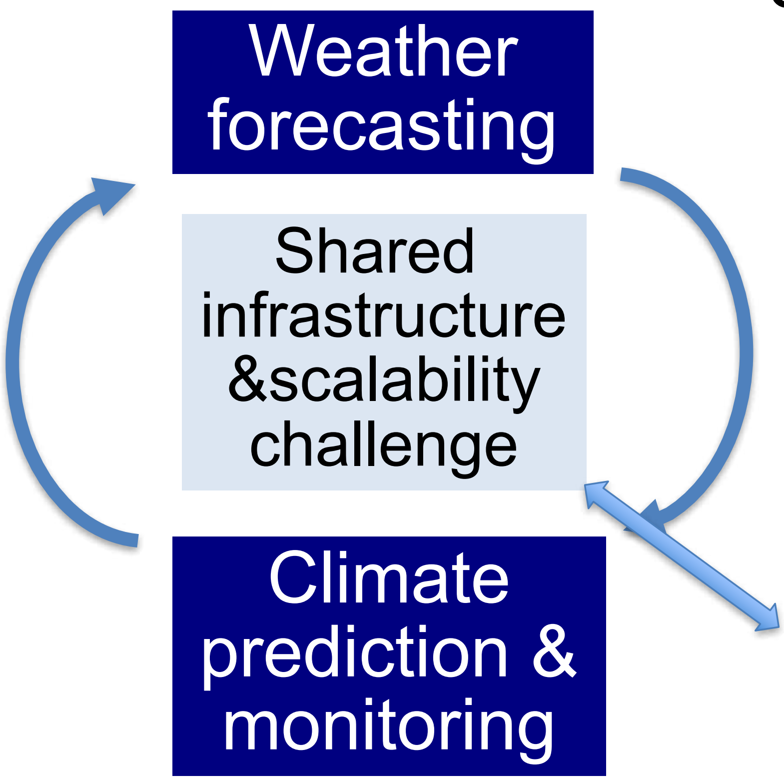
https://www.che-project.eu/news/animation-co2-variability

Why weather and climate modelling capabilities should converge even further?



Commonalities of challenges in weather and climate

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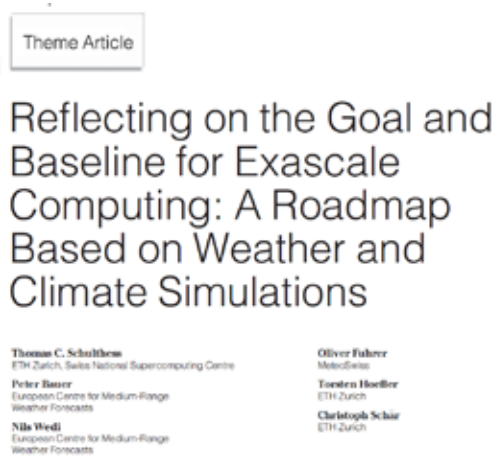
Theme Article

Reflecting on the Goal and Baseline for Exascale Computing: A Roadmap Based on Weather and Climate Simulations

Thomas C. Schulthess
ETH Zurich, Swiss National Supercomputing Centre

Peter Bauer
European Centre for Medium-Range Weather Forecasts

Nils Wedi
European Centre for Medium-Range Weather Forecasts

Oliver Fuhrer
MeteoSwiss

Torsten Hoefler
ETH Zurich

Christoph Schär
ETH Zurich

O(x000) too slow/big data

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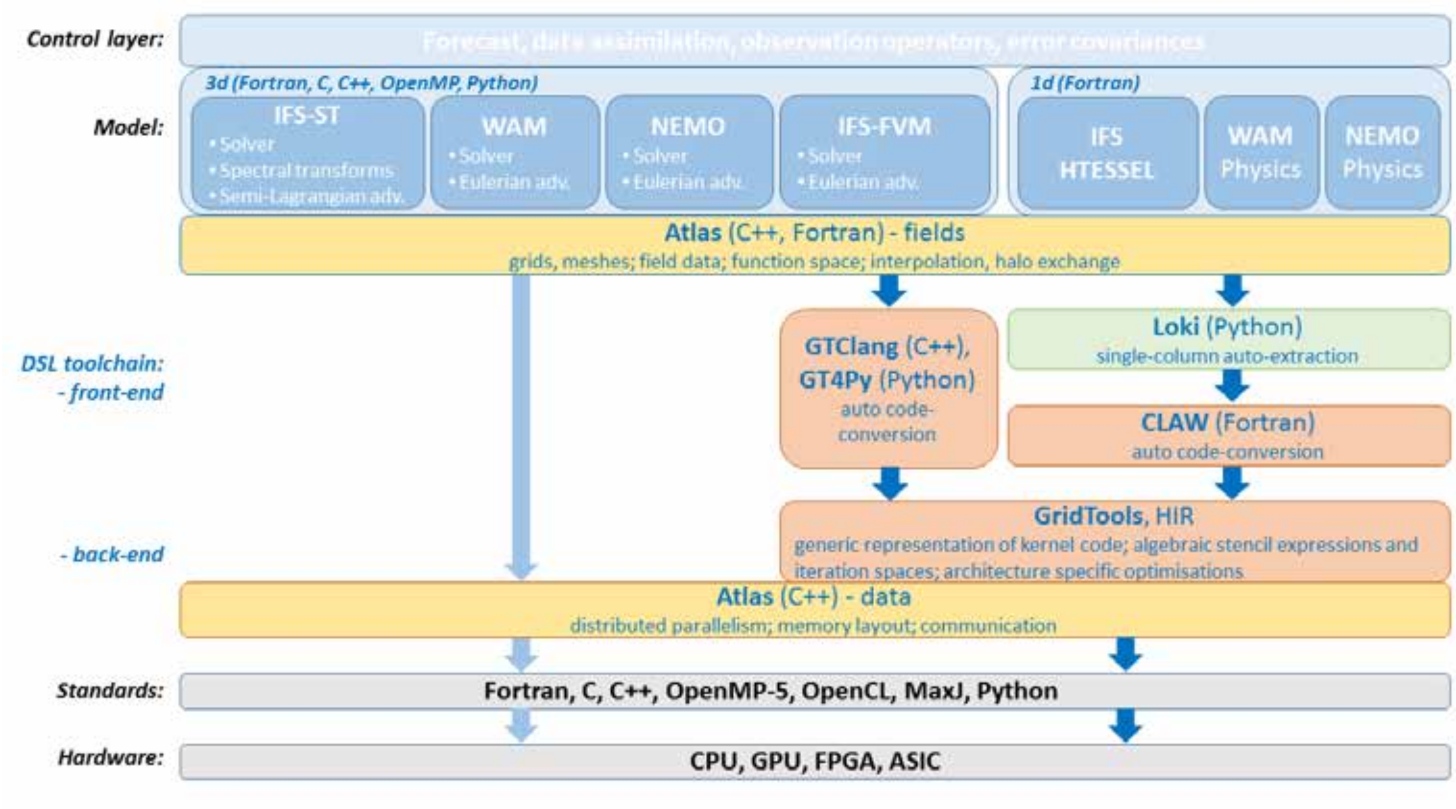
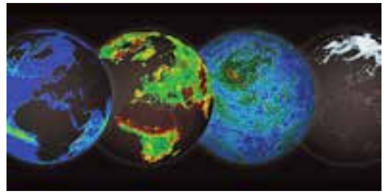
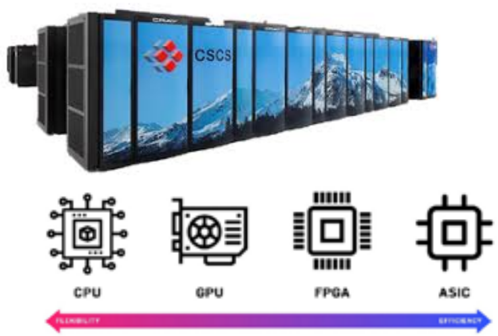
Performance and portability of the codes





Translation (tool-chain)



Structure and components necessary for the transition of the IFS to separate applied science from hardware sensitive code level – 'separability of concerns'

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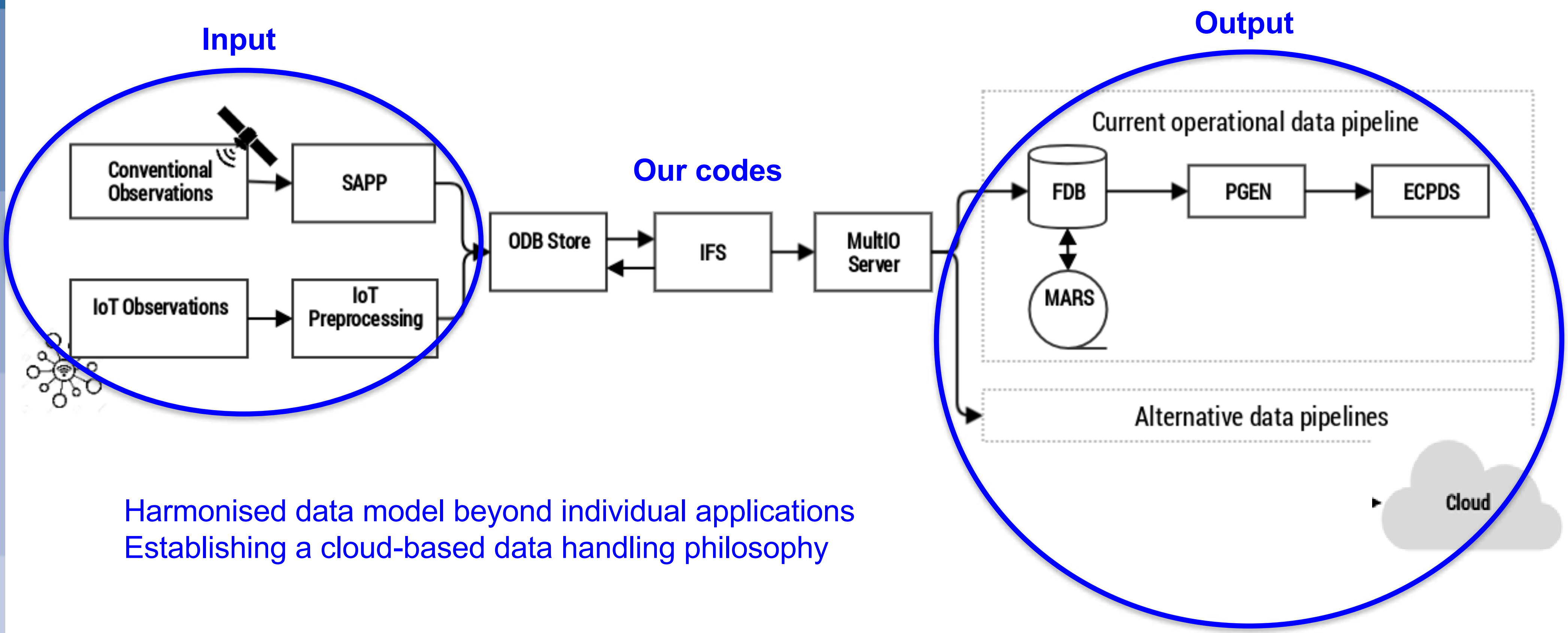
A vision of data-centric workflows



Harmonised data model beyond individual applications
Establishing a cloud-based data handling philosophy

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Holistic approach for weather and climate computing

2014 | 2016 | 2018 | 2020 | 2022 | 2024 | 2026 |

→ **Science of prediction**

Advancing Weather Science

→ **Concepts portability/performance/ data centric workflow**

ESCAPE · nextgenio · EuroEXA · LEXIS · ESCAPE 2 · MAESTRO DATA ORCHESTRATION · EPiGRAM HS

→ **Adaptation of leading models to (pre-)exascale; common strategies for community**

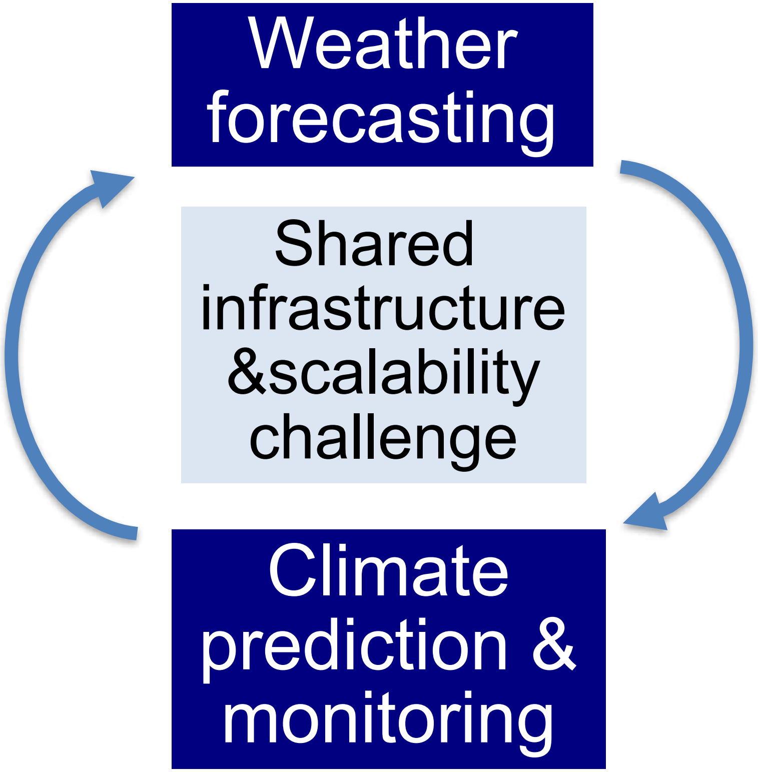
esiwace · is-enes · esiwace2

→ **Redesign entire prediction philosophy**

ExtremeEarth

1. Full-sized applications with required speed/volume and power footprint
2. Ingestion of downstream applications, all ensembles
3. Domain-specific, distributed computing capability, interactive workflows

Why should weather and climate modelling capabilities converge even further?



ARPEGE-NH, DYAMOND, 2.5km, courtesy Philippe Marginaud, Meteo-France

Benefits weather prediction, climate modelling & services, in particular in terms of assessment of impacts on economic and social sectors (e.g. renewable energy)

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Copernicus Europe's eyes on Earth

irina.sandu@ecmwf.int

&

ECMWF and Member States colleagues

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Acknowledgements

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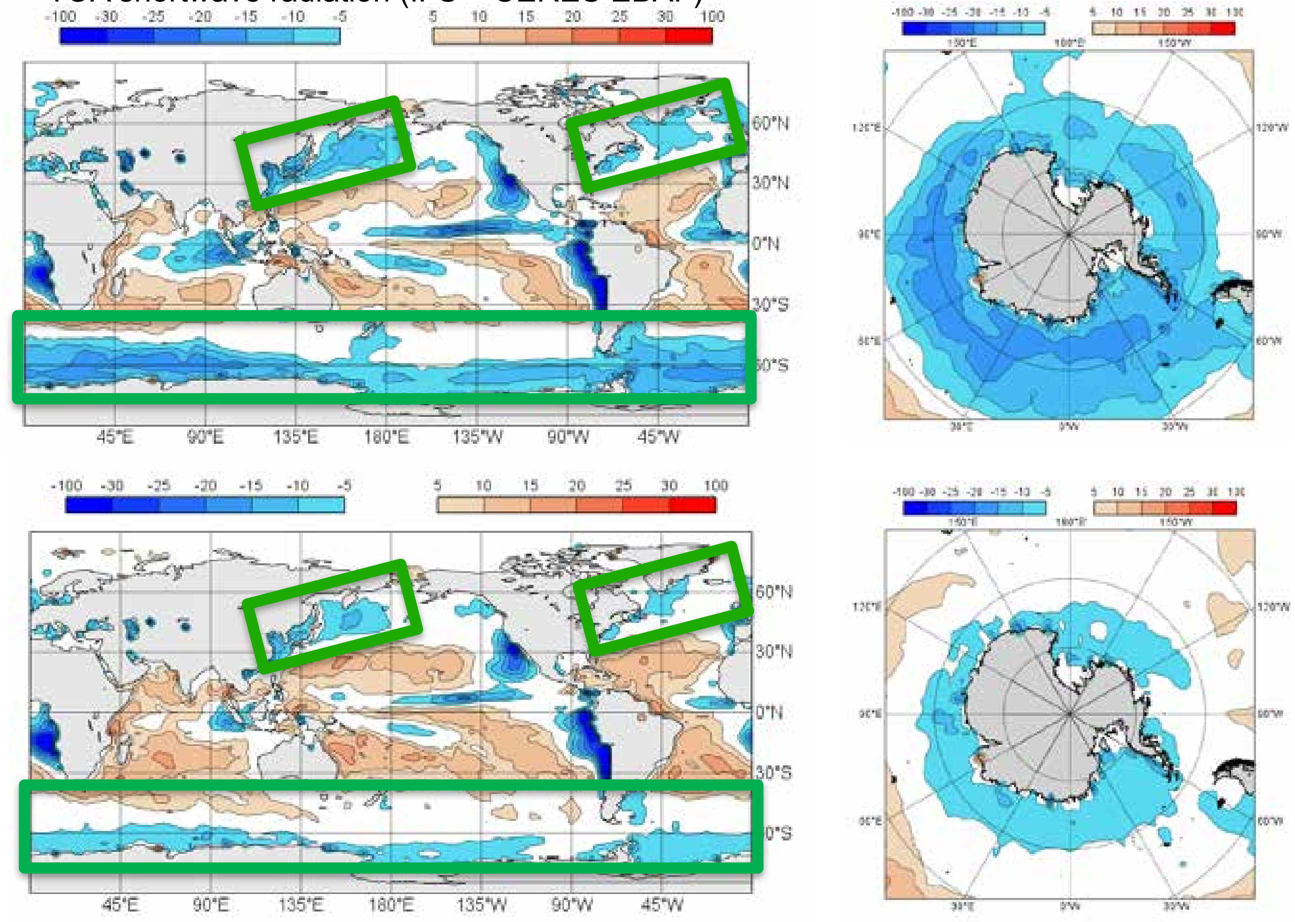
Improved storm track/Southern Ocean shortwave radiation bias
Implementation in IFS 45r1 (operational June 2018)

TOA shortwave radiation (IFS – CERES EBAF)

IFS 43r1

IFS 45r1



Southern Ocean (and NH stormtrack) shortwave bias significantly reduced

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