# ECMWF: modelling and data assimilation

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# ECMWF 2016-2025 strategy: overview

Forecast targets by 2025:

- Ensemble predictions of **high impact weather** up to two weeks ahead
- Seamless approach, aiming towards predictions of **large scale patterns and regime transitions** up to four weeks ahead and **global-scale anomalies** up to a year ahead

Research goals by 2025:

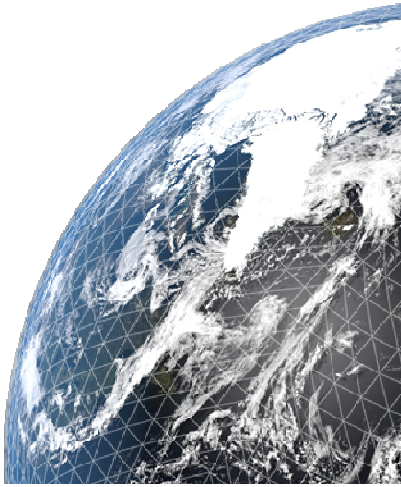
- Research at frontiers of knowledge
- Ensemble-based analyses and predictions that raise the international bar for quality and operational reliability reaching a 5 km horizontal resolution

Together - More collaboration:

- Partnering with National Met Services, universities and research institutes (OpenIFS)
- Pooling expertise to improve scalability

Continued support:

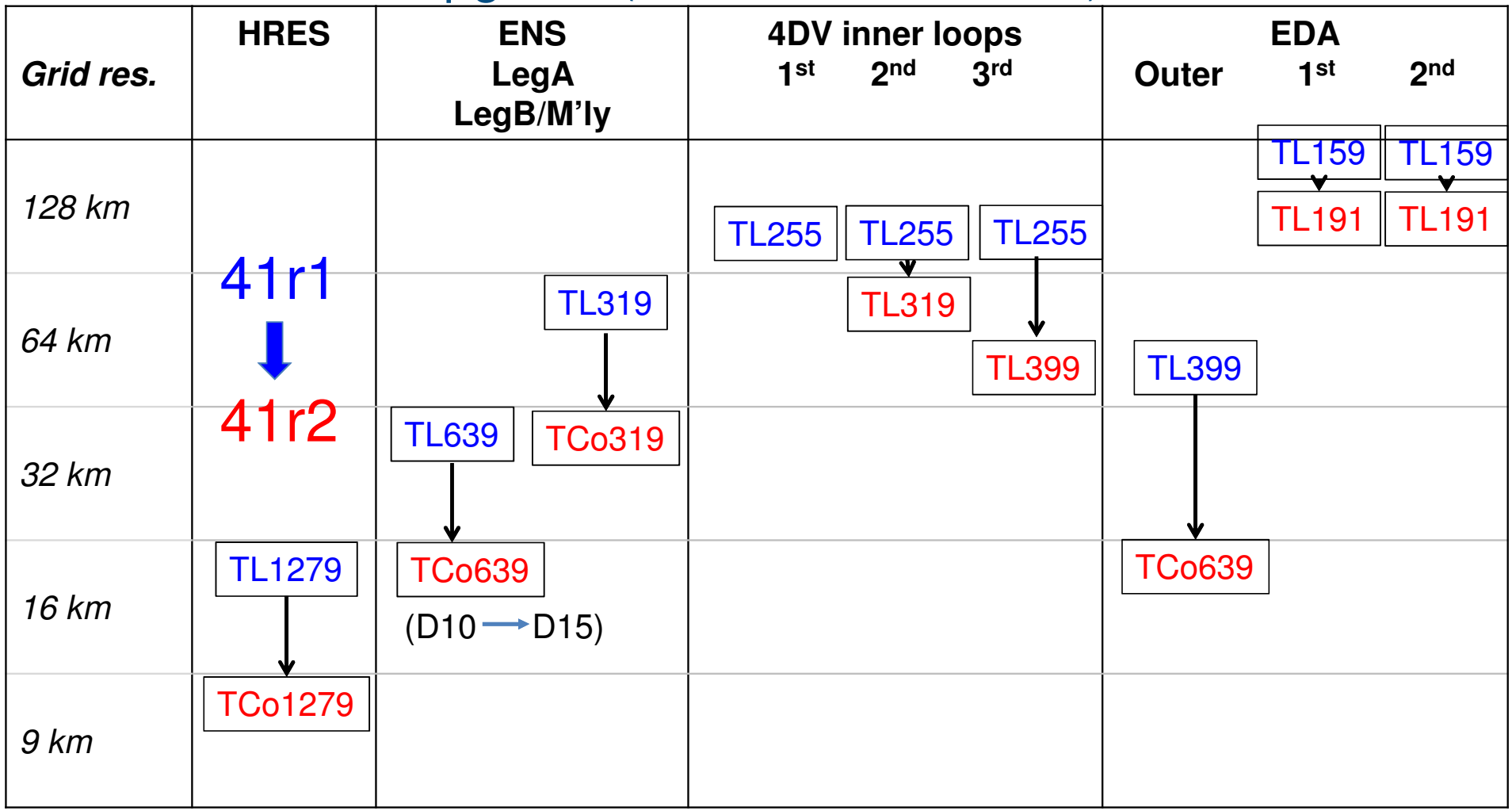
Dedicated HPC, software, and data resources for Member States
Advanced training



# Outline

1. Highlights of recent model upgrades
   a. 8 March 2016 (CY41R2) - increased horizontal resolution
   b. 22 Nov 2016 (CY43R1) - increased ocean resolution
   c. 11 July 2017 (CY43R3) – humidity background errors from EDA, TC structure, new radiation scheme, aerosol climatologies
2. On-going R&D activities and challenges (CY45R1 and beyond….)

# Horizontal resolution upgrade (March 2016 – CY41R2)



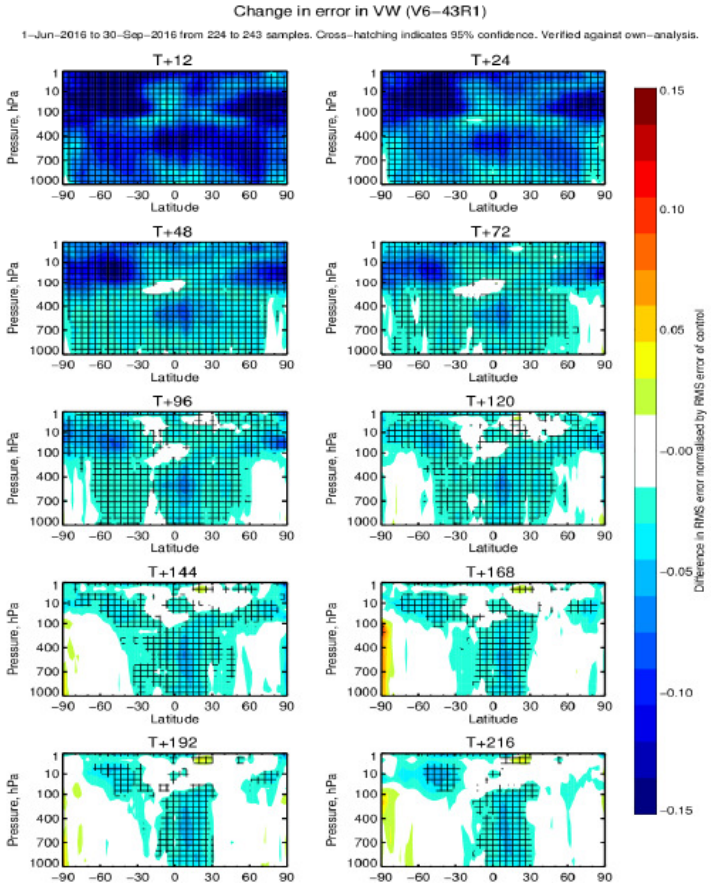



*Holm et al., ECMWF Newsletter 147*

# 4DVar Development

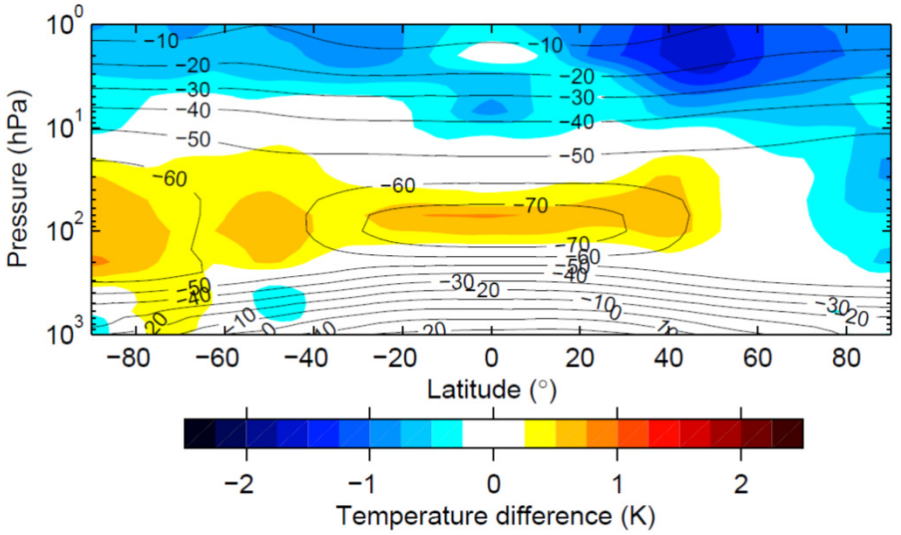
- Hybrid **B** modelling: introduction of EDA estimated humidity errors (CY43R3; previously fixed statistical functions of background state)

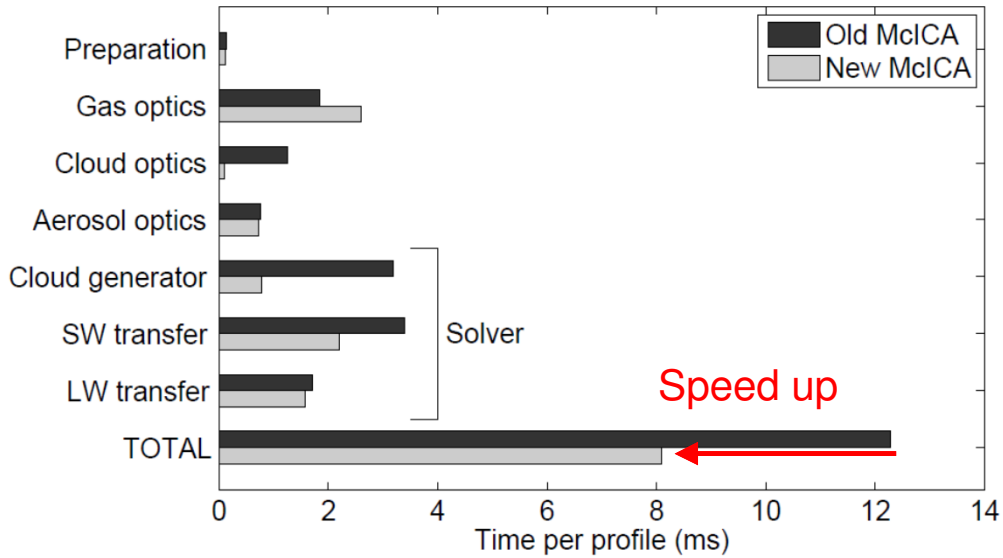
  - Change in RMSE of wind vector forecast
  - Largest improvement in tropical winds since…
  - Confirmed against observations (SATOB winds)
  - Humidity tracer advection is believed to be the main driver
  - To be extended to cloud condensate (Q1/Q2 2018)



# New radiation scheme (ECRAD)

- Flexible and modular: easy to test future changes (16000 lines of code)
- Better solution to longwave equations improves stratosphere
- 31-34% faster
- Reduction in McICA noise leads to slight reduction in temperature errors



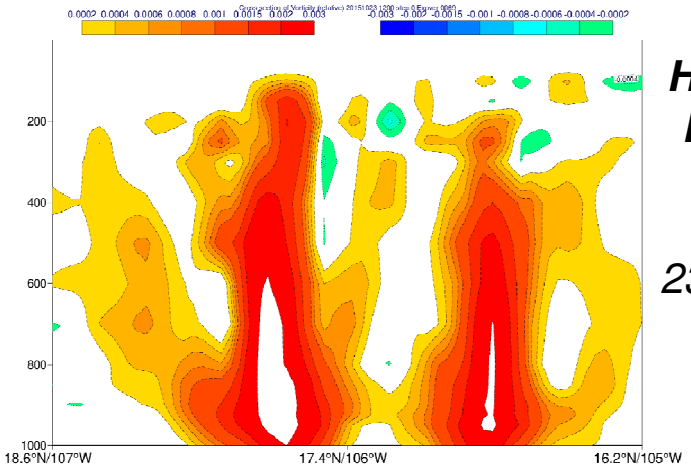



*Hogan and Bozzo, TM787, 2017*

# Tropical Cyclone Initialization

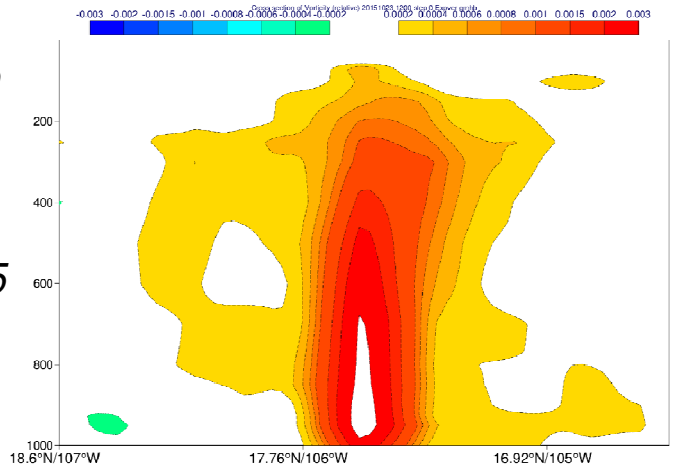
- **Adaptive observation error for dropsonde winds** leading to more cautious observation use.
- **Smoother filtering of EDA background error variances** through spectral truncation to T159 followed by **a new wavelet signal-to-noise filter**.

*Before…*




***Hurricane Patricia:*** *Vorticity analysis 23/10/2015 12 UTC*

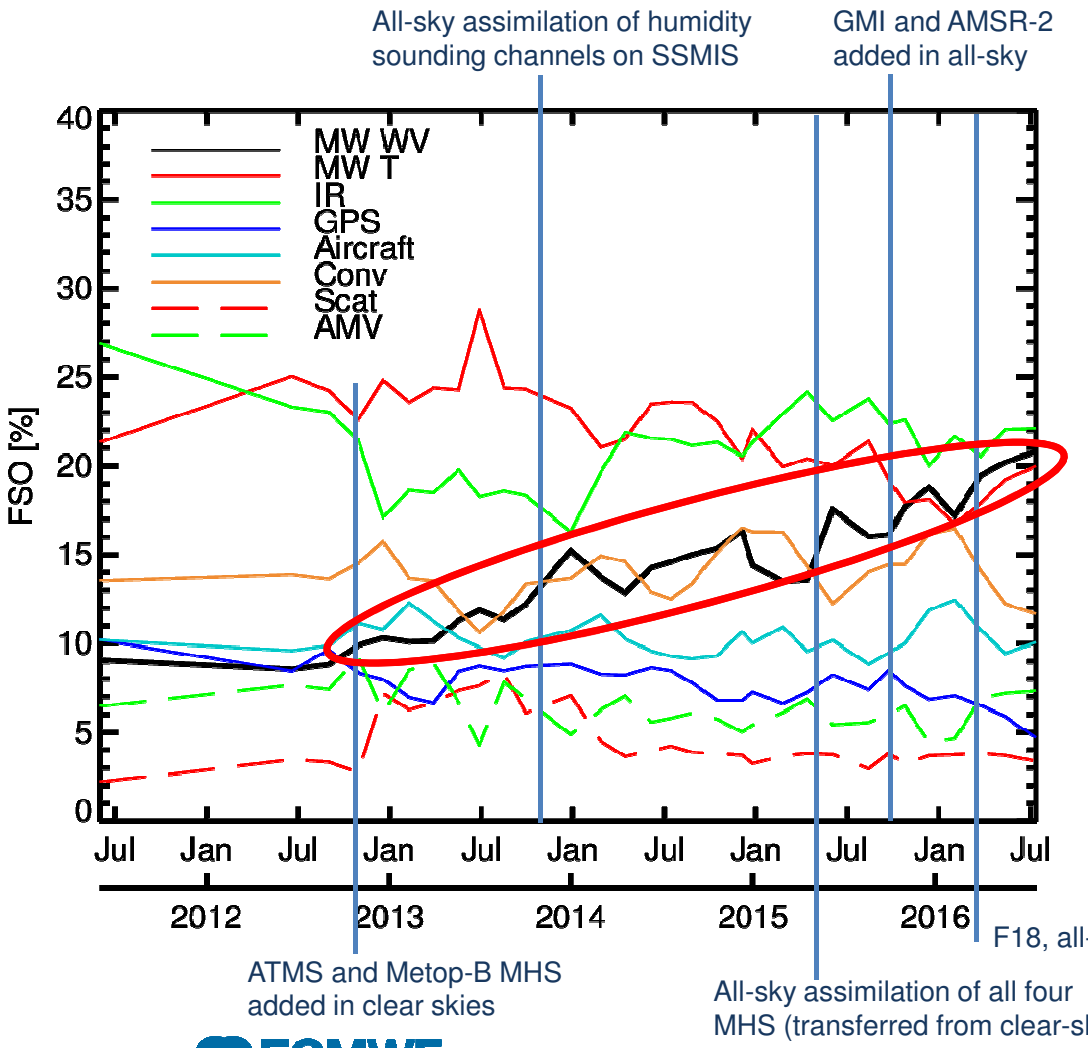
*…after*



# Future directions...

- DA science (oper & reanalysis; maximize use of in situ and satellite obs, algorithms, EDA, higher res inner loops)
- Physical processes (resolved and unresolved)
- Increased coupling (land/ocean/atmospheric composition/meteorology)
- Uncertainty – parameter perturbations, ENS, EDA
- Predictability and seamless ensembles (EDA/ENS/monthly/seasonal)
- Climate monitoring, ERA-Interim replacement: ERA5
- Scalability and infrastructure

# Observation changes: the rise of all-sky!




- Growing importance of microwave humidity observations (MHS, ATMS, MWHS-2, SSMIS, AMSR2, GMI, SAPHIR).
- Extending this to infrared water vapour information.
- Extending to all-sky microwave temperature observations.
- Also investigating radar, lidar, and possible lightning observations (EarthCARE, Aeolus, GOES-R, MTG).

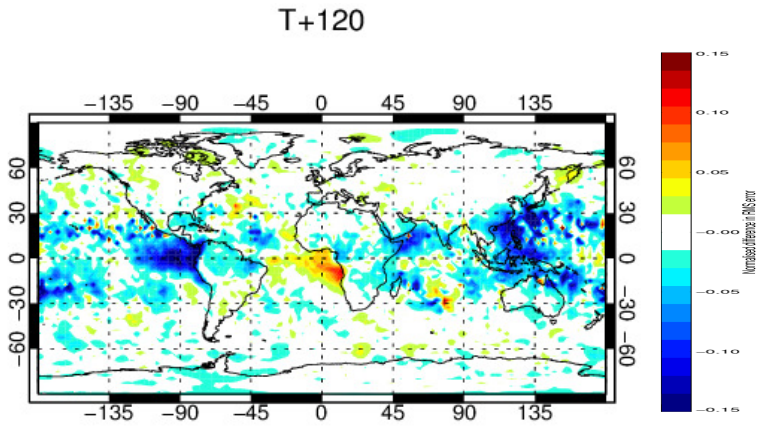
# CY45R1 Ocean Coupling in HRES
# (full coupling tropics; partial coupling extra-tropics)

Forecast improvements at Day+5 (**1 year**) (blue colors indicate RMSE reduction) due to the HRES coupling of the NEMO+LIM Ocean and sea-ice model to the atmospheric model integrations

Evaluated on one full year of TCo1279 daily forecasts (April 2015-March 2016).

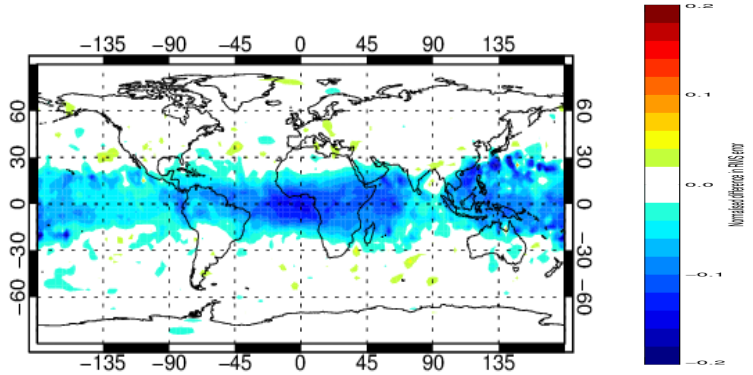
Largely positive in Tropical regions. Guinea Gulf demands attention (feedback w. stratocumulus region *)

*HRES MSLP*
*improvement from Ocean-coupling*



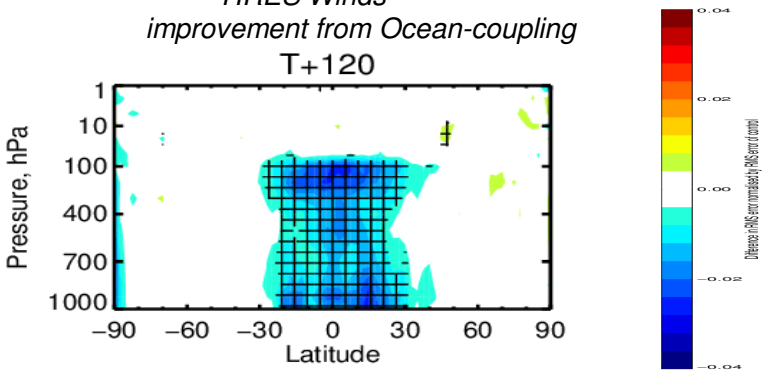

**Tropics pressure about 5-10 % (*)**

*HRES Z500*
*improvement from Ocean-coupling*



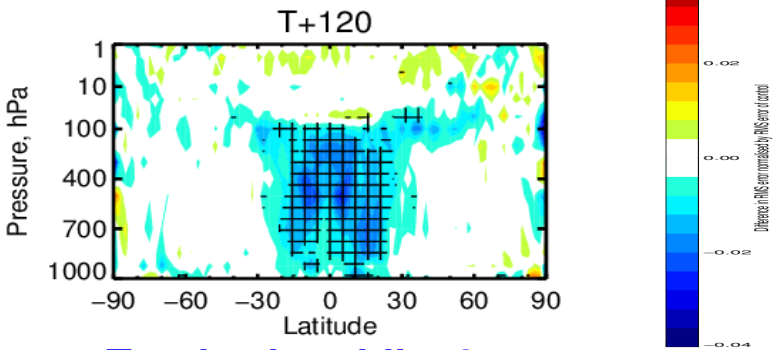

**Tropics Z500 about 5-10 %**

*HRES Winds*
*improvement from Ocean-coupling*




**Tropics winds 2-4 %**

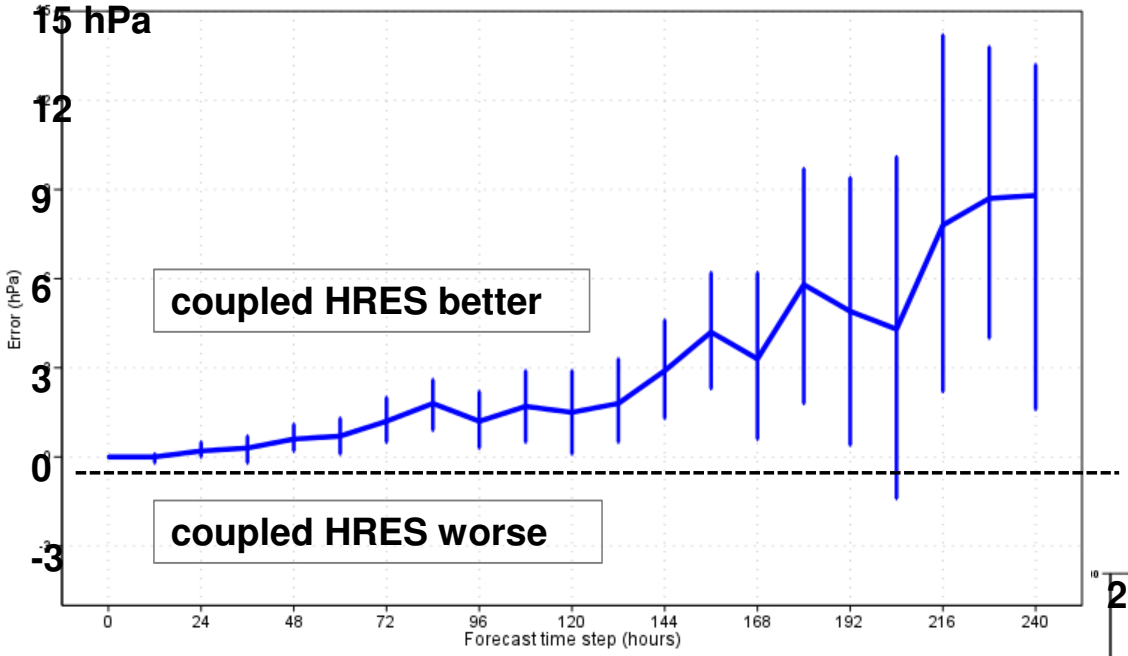
*HRES Relative Humidity*
*improvement from Ocean-coupling*



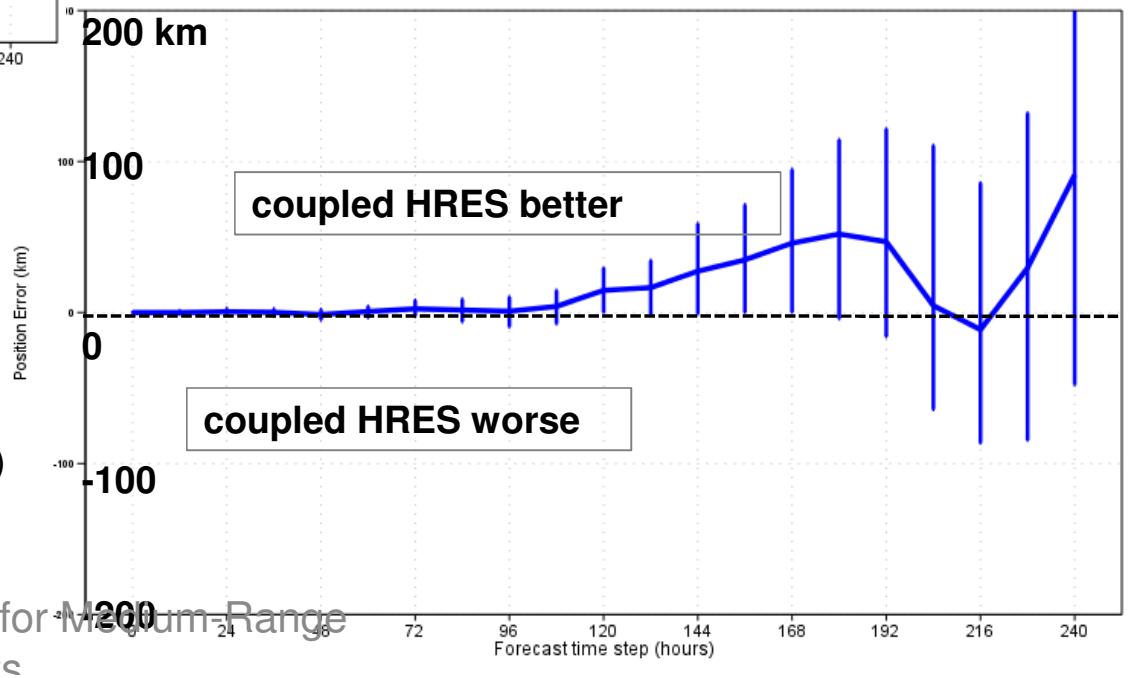

**Tropics humidity 2 %**

ECMWF
Kristian Mogensen & CP

# Improvement of tropical cyclones




**Difference of the mean absolute intensity errors (hPa)**
VT: 2016-05 to 2017-01 (homogeneous samples/all basins)
**Bars: 95% confidence interval**

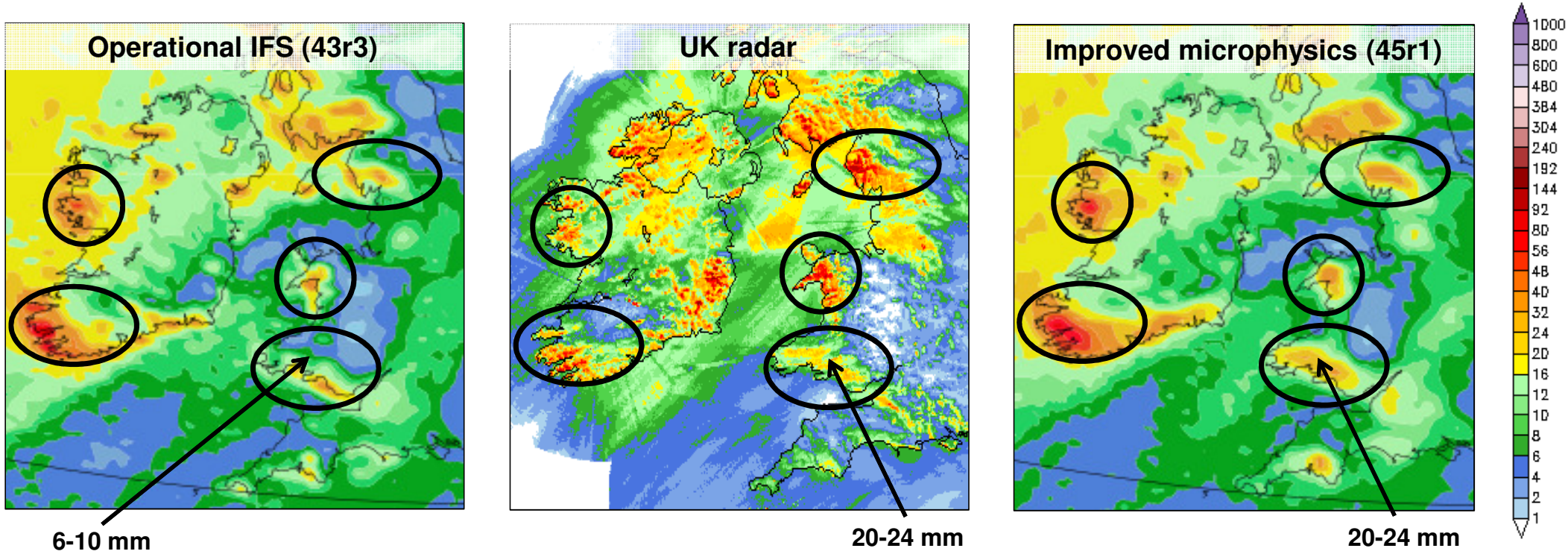



**Difference of the mean position error (km)**
VT: 2016-05 to 2017-01 (homogeneous samples/all basins)
**Bars: 95% confidence interval**

# Warm-rain microphysics numerics package (45r1)

## Improvements in precipitation along coast lines/lakes and over orography

Example case study 14 May 2017 00Z 48hr forecast accumulated precipitation (mm)

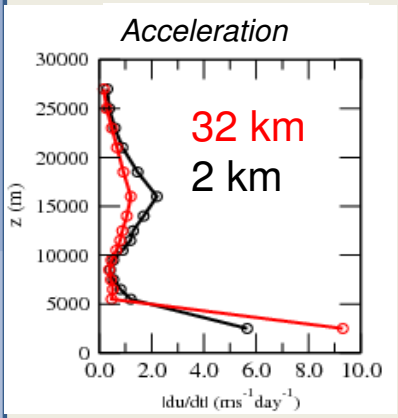


# Advancing science in partnership (grey-zone)

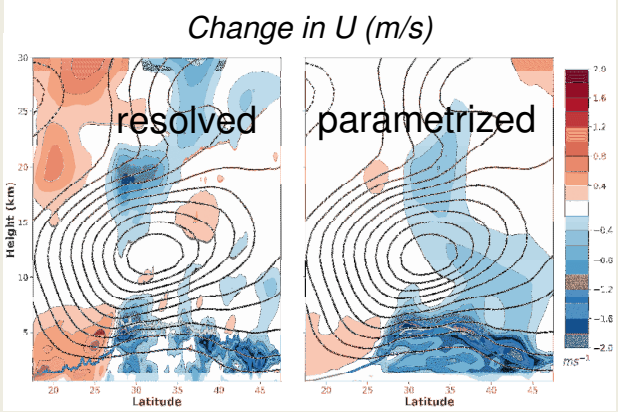
## Orographic drag - Metoffice

2 - 5 km simulations of Rockies and Himalayas, used to evaluate parametrized drag in UM & IFS

### Rockies (UM)



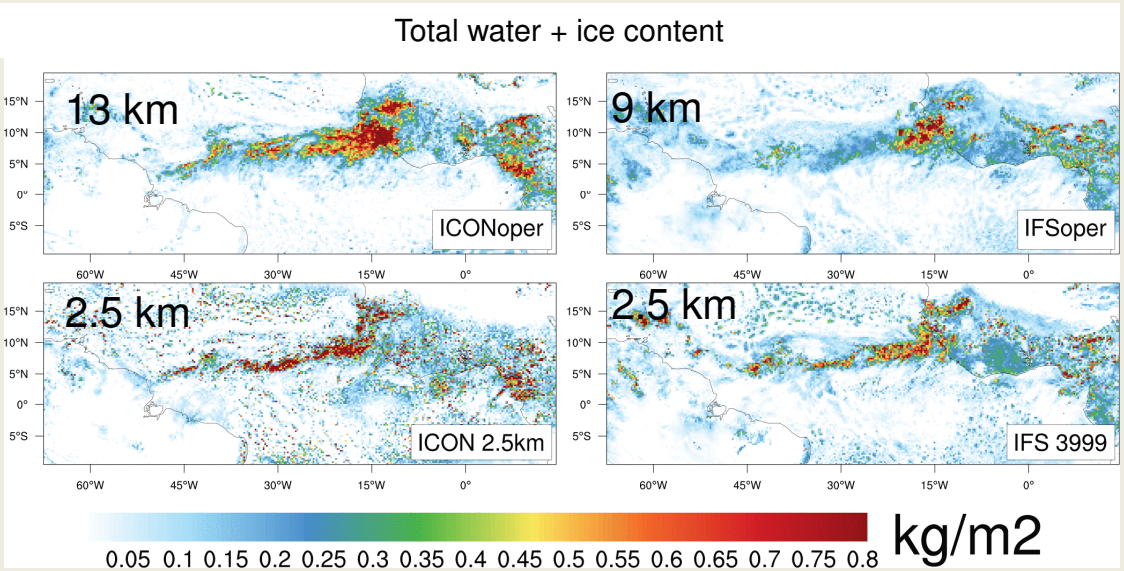

### Himalayas (UM)




*Vosper et al., Van Niekerk et al., in preparation*

## Convection - DWD

1, 2.5, 5, ~ 9 km of Tropical Atlantic with ICON & IFS

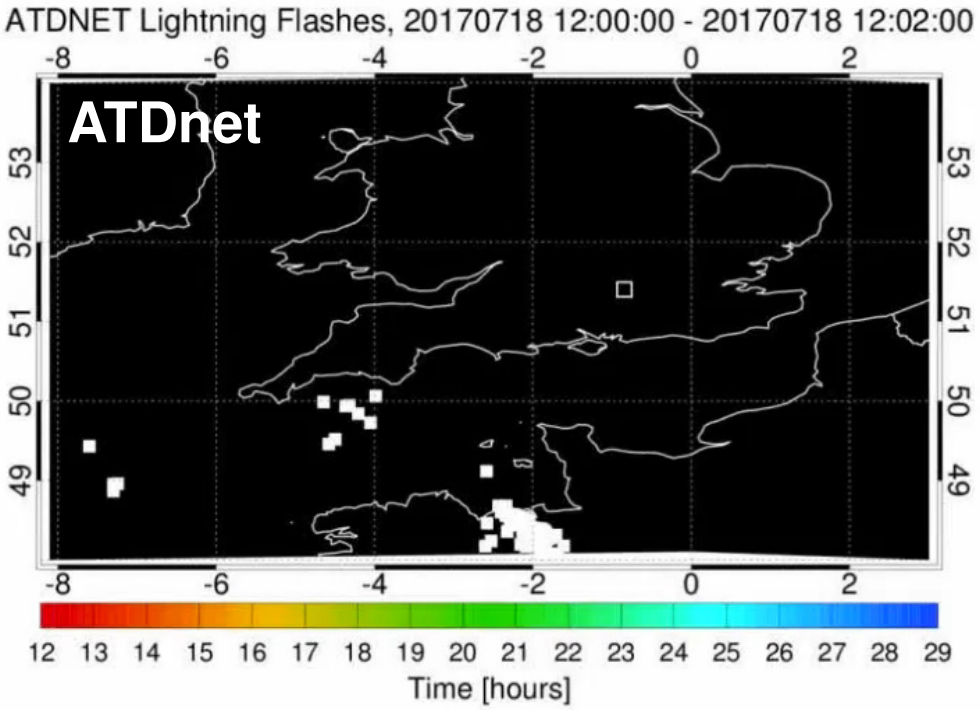


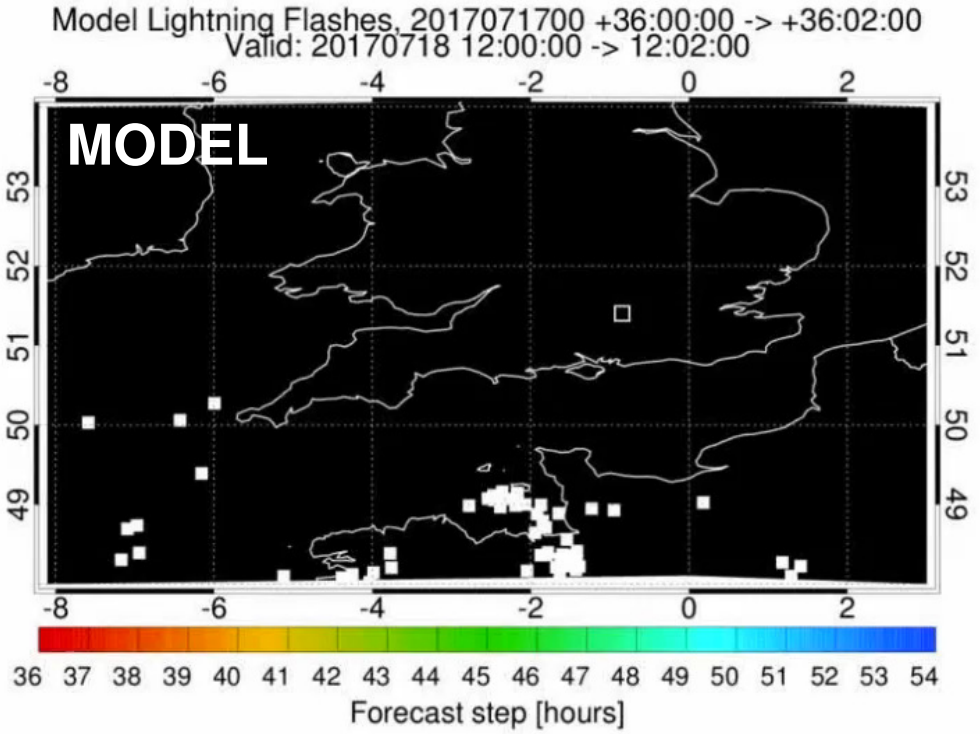

*Courtesy Daniel Klocke and Nils Wedi*

ECMWF

**Comparison of model with ATDnet (Met Office) lightning flashes.**

**18h animation of 2-mn flash data starting from 18 July 2017 at 1200 UTC.**
**TCo1279 L137 model forecast +36h → +54h.**

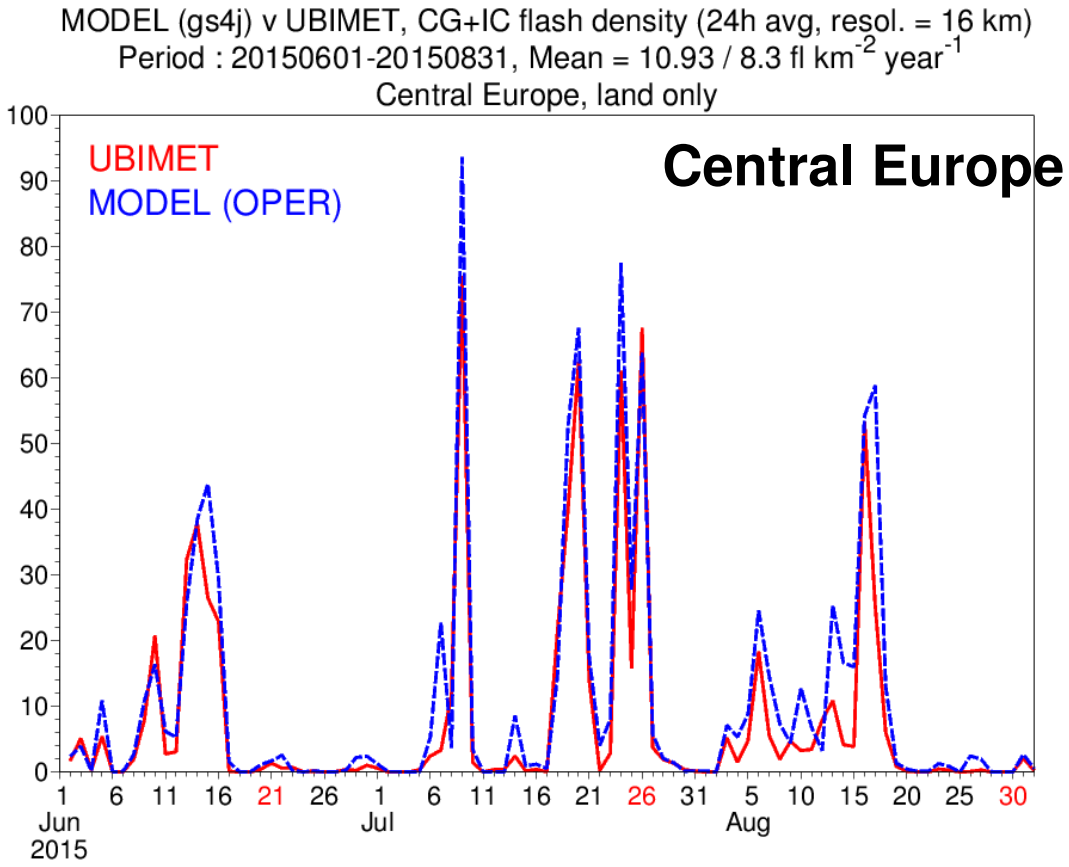


# New ground-based lightning observations from UBIMET

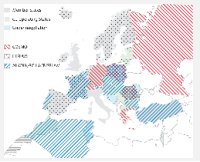
**Simulated flash densities vs UBIMET (LINET) obs. over Europe in summer 2015.**

Based on 24h forecasts (TCo639 L137, cycle 43R3+).



# ECMWF Scalability Programme

**Governance:** ECMWF, Member states, Regional consortia



**Projects:**

## Observation processing:
- Lean workflow in critical path
- Object based data store
- Screening/bias correction

## Data assimilation:
- Flexible algorithms (C++)
- IFS integration
- Coupling with ocean and sea-ice
- Parallel minimization

## Numerical methods:
- Numerical methods
- h/v/t-discretization, multiple grids
- Prognostic variables, coupling

## Model output processing:
- Broker-worker workflow
- Near-memory processing
- Data compression

## Code adaptation:
· Benchmarking · Vectorization · Programming models · Precision · DSL/libraries · Transition to operations

## Computer architecture support:
· Benchmarking · Novel architectures · Compilers · Vendor support · Transition to operations

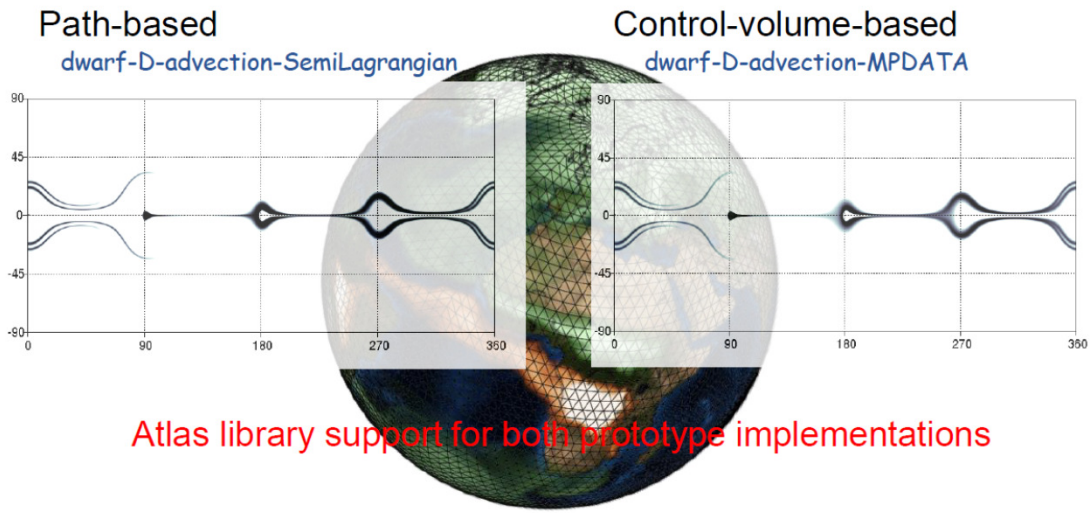
# ESCAPE: Dwarfs

Funded by the European Union

**ESCAPE dwarf concept:**

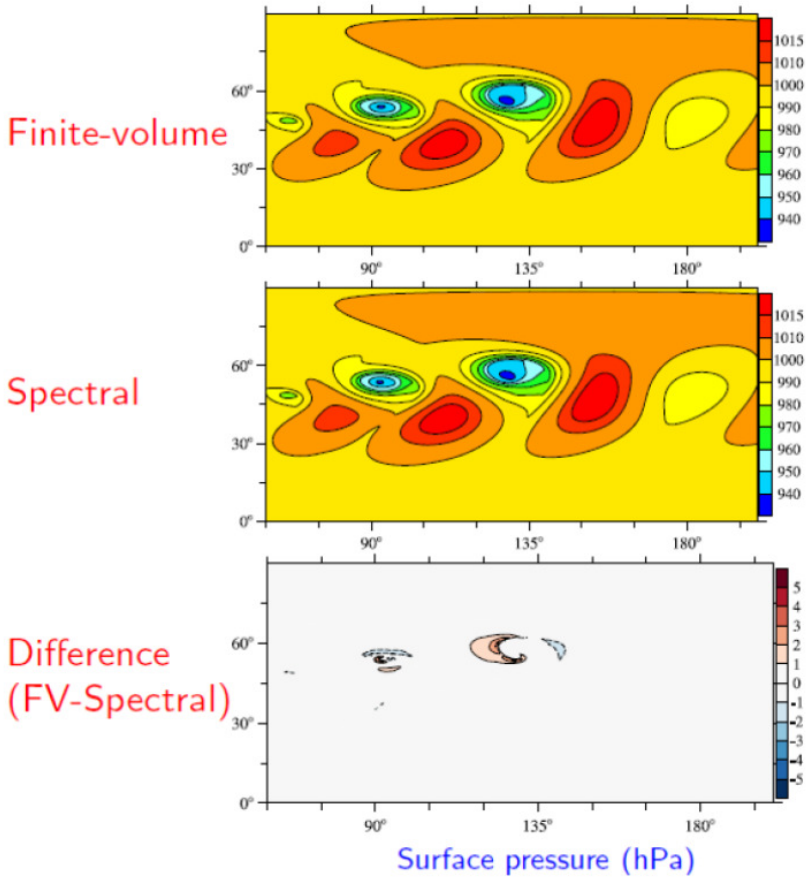
- Extract key functional components, adapt to new processors
- Build in algorithmic flexibility for future IFS

Rossby-Haurwitz test case after 7 days



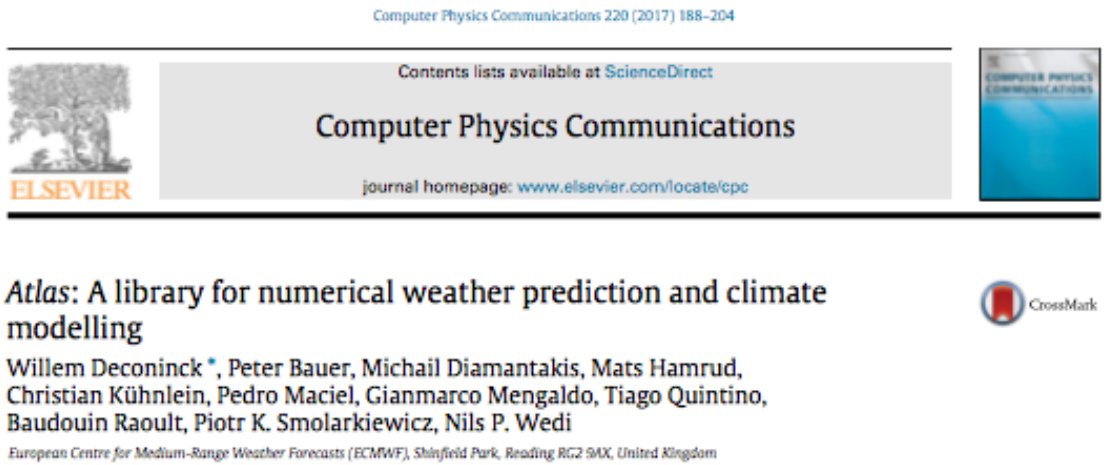

Atlas library support for both prototype implementations

Dry baroclinic instability, FVM (O640) versus the spectral IFS ($T_{co}639$):



# Atlas for LAM grids

- Grid coordinates are called (x,y), and are not necessarily same as (lon,lat) !!!
- It is up to a Projection to translate between (x,y) and (lon,lat). This is a member of the Grid object.
- Rotation is implemented by a Projection!
- Currently implemented projections:
  - “lonlat” ( a.k.a. no projection)
  - “rotated_lonlat”
  - “lambert”
  - “mercator”
  - “rotated_mercator”
  - “schmidt”
  - “rotated_schmidt” (as used in ARPEGE)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journal homepage: www.elsevier.com/locate/cpc

*Atlas*: A library for numerical weather prediction and climate modelling

Willem Deconinck *, Peter Bauer, Michail Diamantakis, Mats Hamrud, Christian Kühnlein, Pedro Maciel, Gianmarco Mengaldo, Tiago Quintino, Baudouin Raoult, Piotr K. Smolarkiewicz, Nils P. Wedi

*European Centre for Medium-Range Weather Forecasts (ECMWF), Shinfield Park, Reading RG2 9AX, United Kingdom*

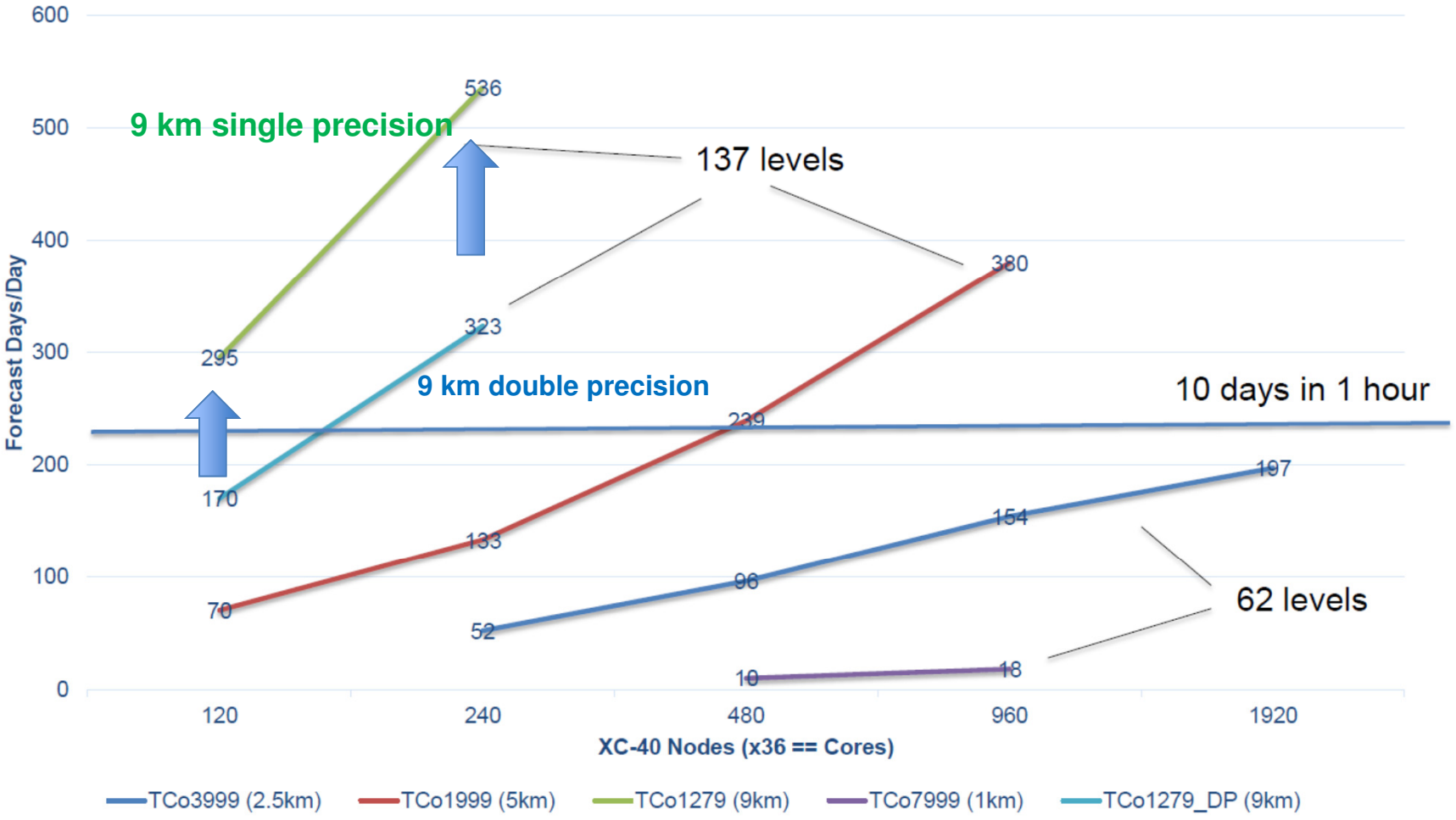
```
void print_gridpoints( Grid grid ) {

  for( PointXY& p : grid.xy() ) {
    Log::info() << p.x() << " " << p.y() << std::endl;
  }

  for( PointLonLat& p : grid.lonlat() ) {
    Log::info() << p.lon() << " " << p.lat() << std::endl;
  }
}
```

# ESiWACE: Single precision IFS

Funded by the
European Union



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