ECMWF: research developments and future plans

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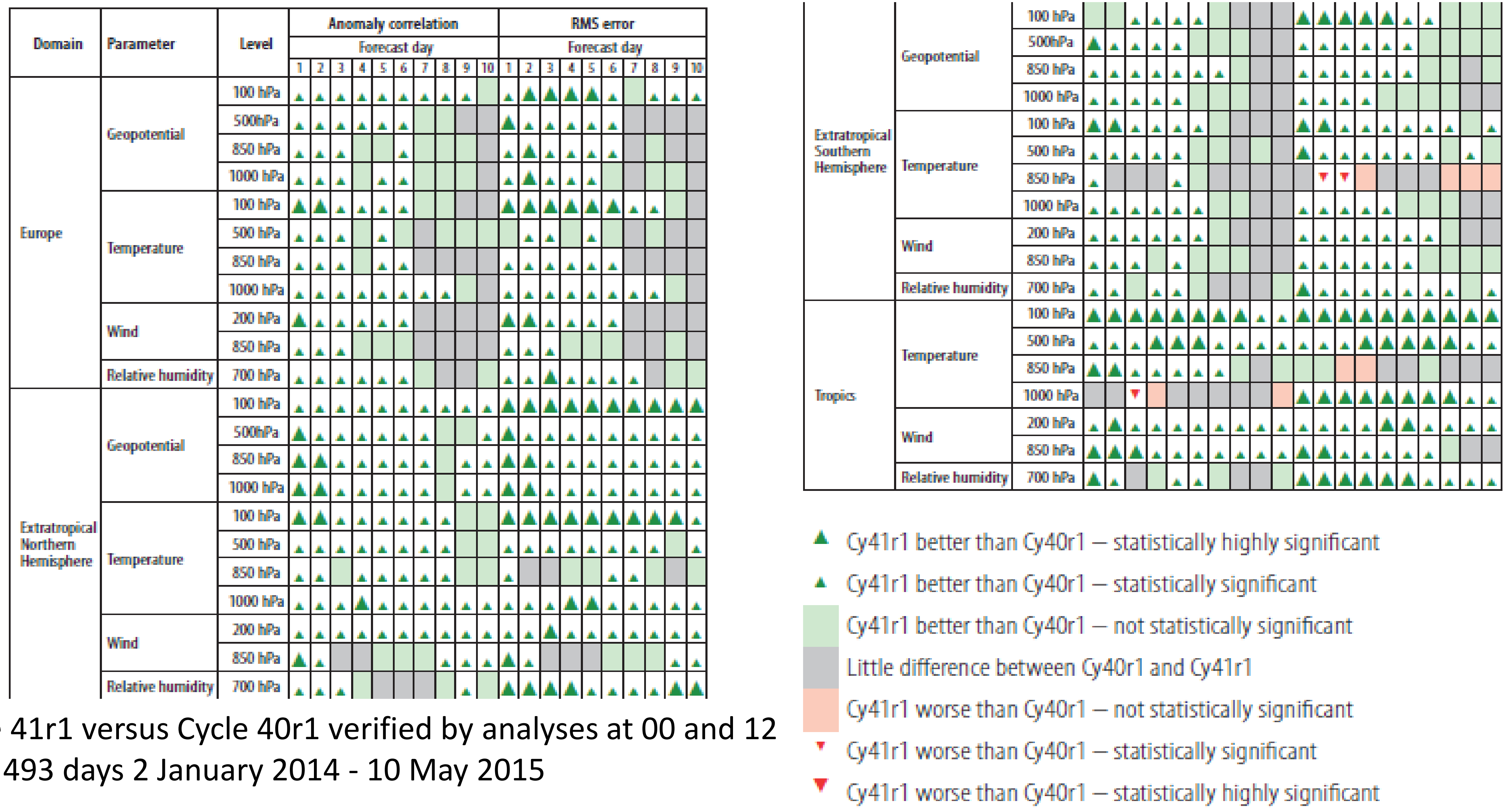
Outline

1. IFS upgrade Cy41r1 - 12 May 2015
2. Resolution upgrade Cy41r2 – 8 March 2016
3. Future challenges

Performance summary (41r1)

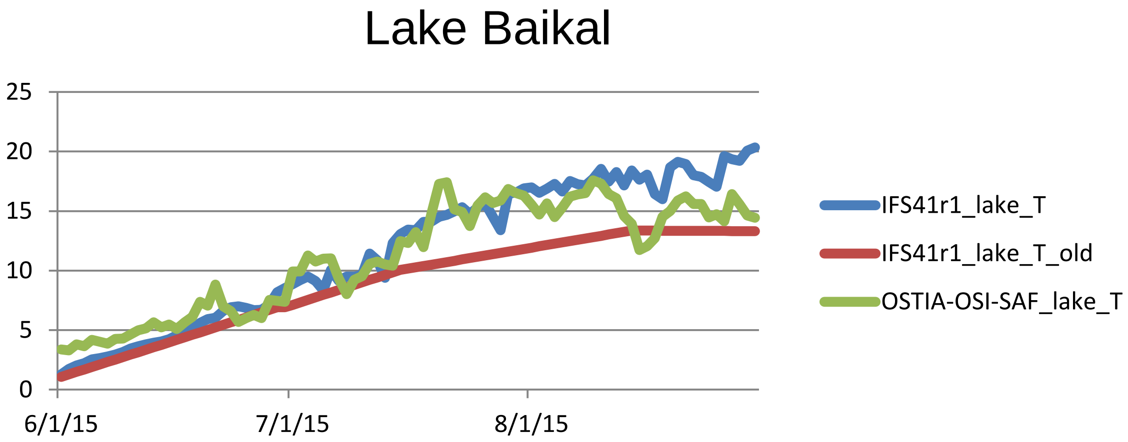


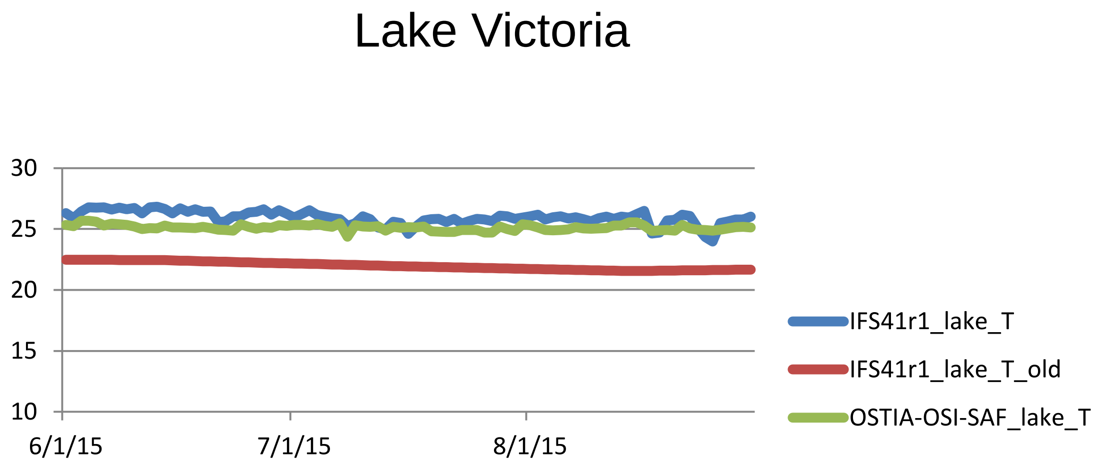
Cycle 41r1 versus Cycle 40r1 verified by analyses at 00 and 12 UTC; 493 days 2 January 2014 - 10 May 2015

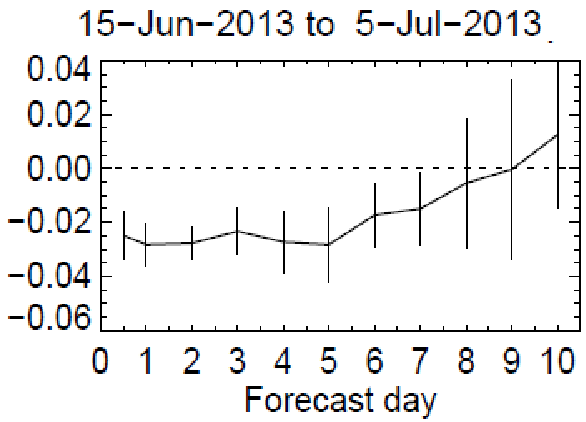
Cy41r1 (May 2015) Highlights

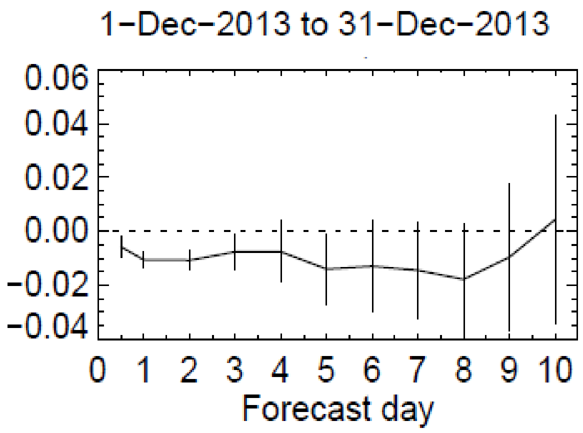
MOD	New surface climate fields (land-sea mask, sub-grid orography) Improved SL-trajectory (stratospheric noise) Microphysics upgrade (drizzle, heavy rain, precipitation-type) Revised detrainment in convection scheme MACC-II CO_2/O_3/CH_4 climatologies; RRTM upgrade Lake model: Flake
SAT	All-sky microwave humidity assimilation upgrade
4DVAR	4DVAR upgrade of inner loop resolutions (255L-255L-255L grid) EDA improved noise filtering, reduced sampling window ASCAT assimilation
ENS	ENS re-forecasts: from 5-member once to 11-member twice weekly Monthly forecast (leg B) extended to D+46 (from D+32) Active use of wave modified stress in coupled mode

Impact of water bodies (lake model)









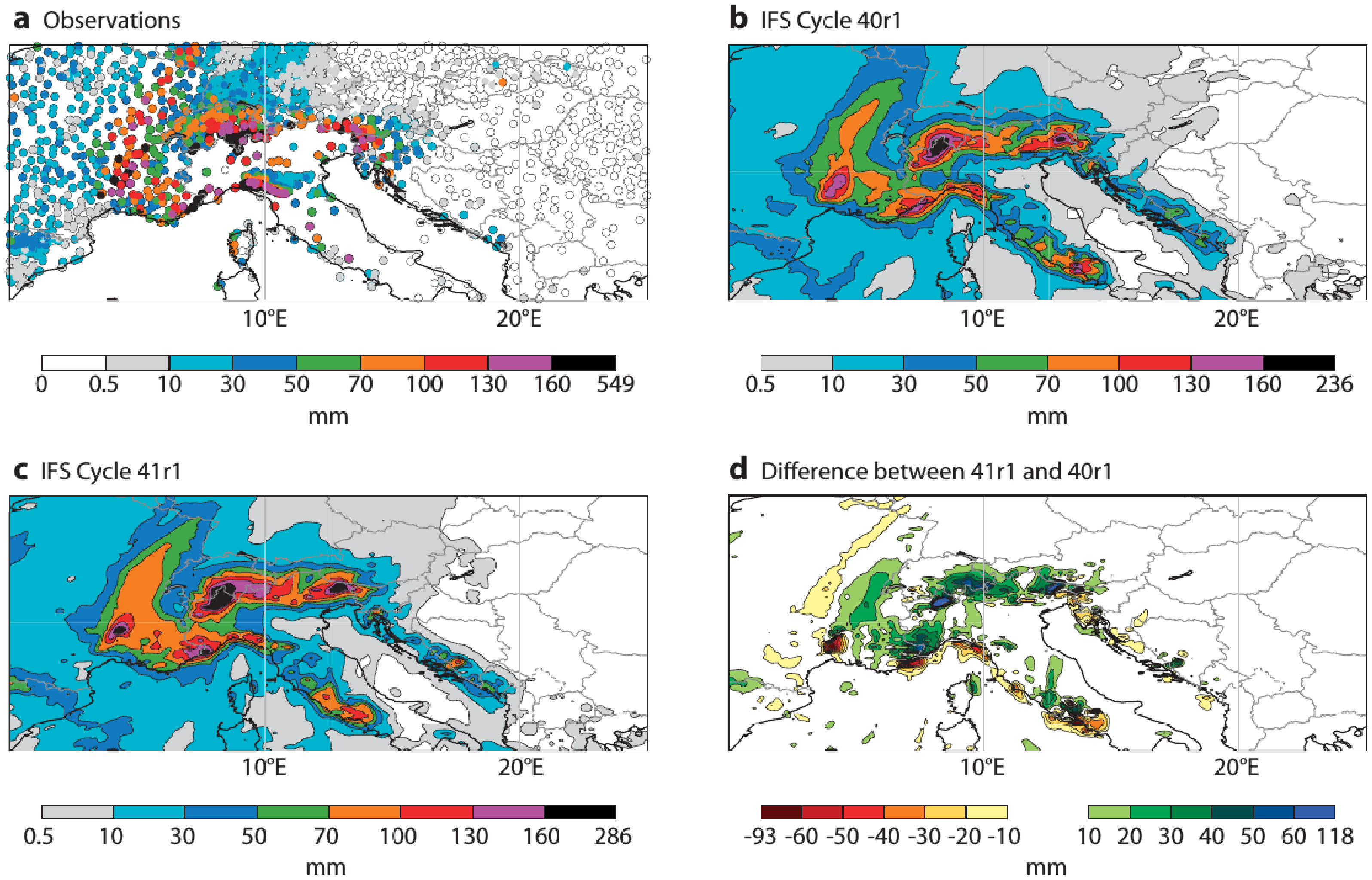
T 20N to 90N 1000hPa: Performance improved (2-3% in summer; 1% in winter)

Balsamo et al, ECMWF Newsletter 137, Tellus-A, 2012

Microphysics upgrade – orographic precipitation

Case study – Floods in Italy 3-5 Nov 2014

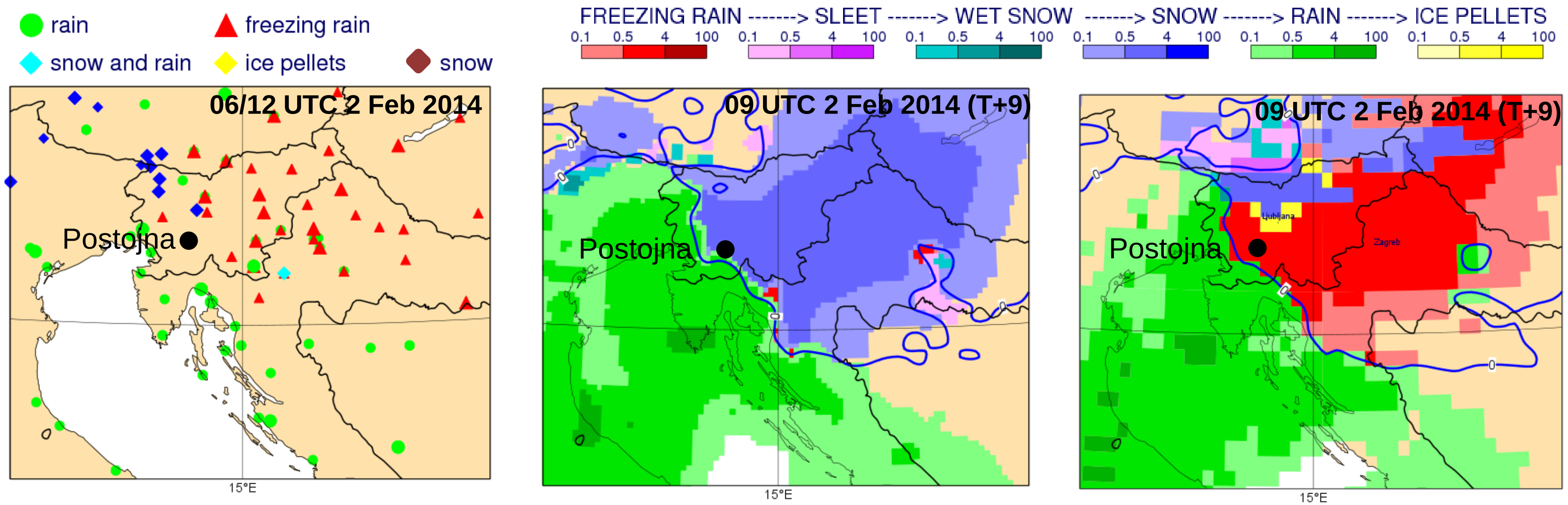
Precipitation accumulation 3-5 Nov 2014



Forbes et al., 2015, ECMWF Newsletter 144

Microphysics upgrade & new diagnostics for precipitation types – predicting high-impact freezing rain events

- Case Study: Slovenia/Croatia 02 Feb 2014
- Freezing rain caused severe disruption and damage, tranports/power/forests…
- IFS physics at the time (40r1) not able to predict
- New physics in 41r1 allows prediction of freezing rain events
- Evaluation in HRES/ENS shows potential for useful forecasts

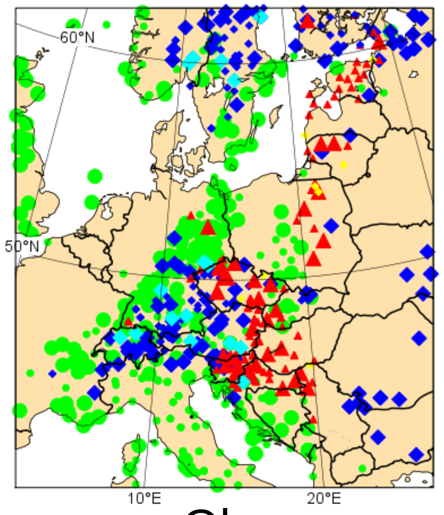


SYNOP Observations **IFS HRES 40r1** **IFS HRES 41r1**

ECMWF Newsletter 141

Probability of freezing rain accumulation from the IFS ensemble

Case Study: 02 Feb 2014



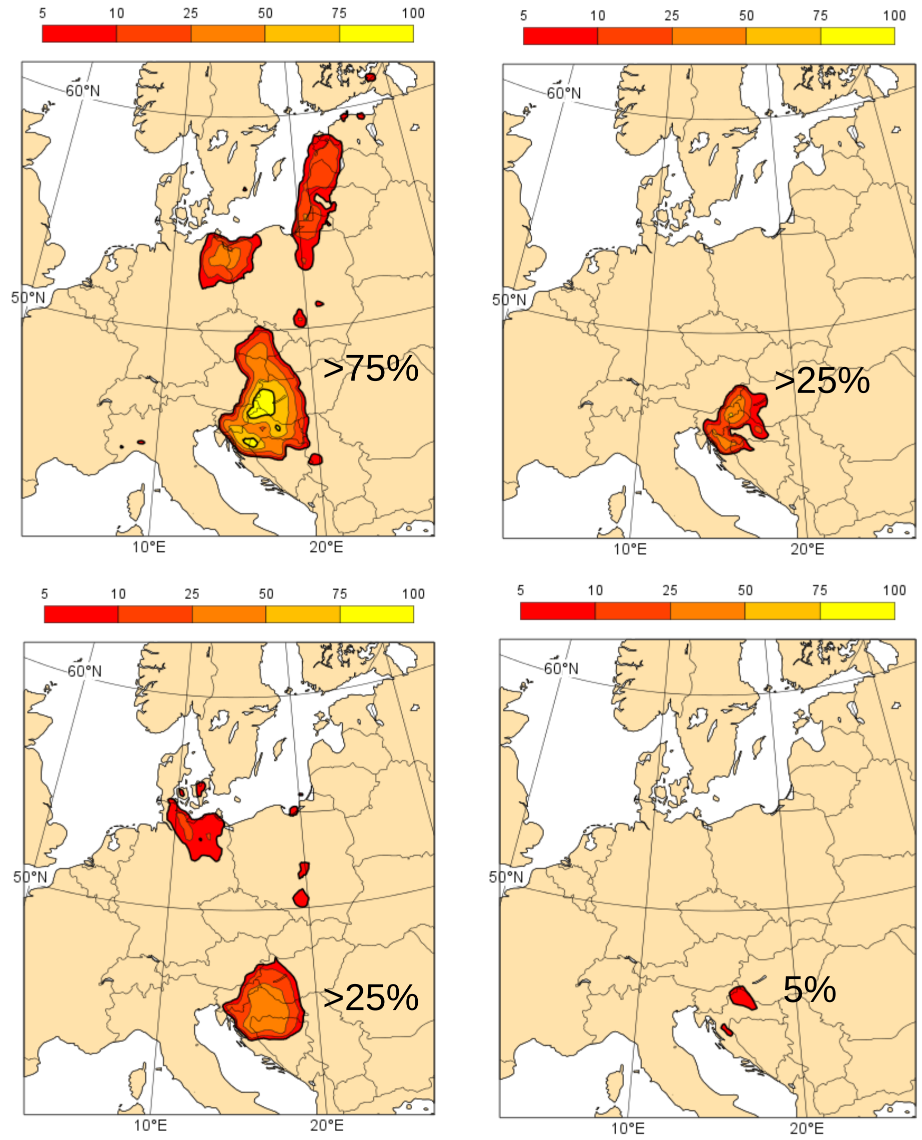
Obs

- rain
- snow
- freezing rain
- snow and rain
- ice pellets

Prob (fzra > 1mm) | Prob (fzra > 5mm)

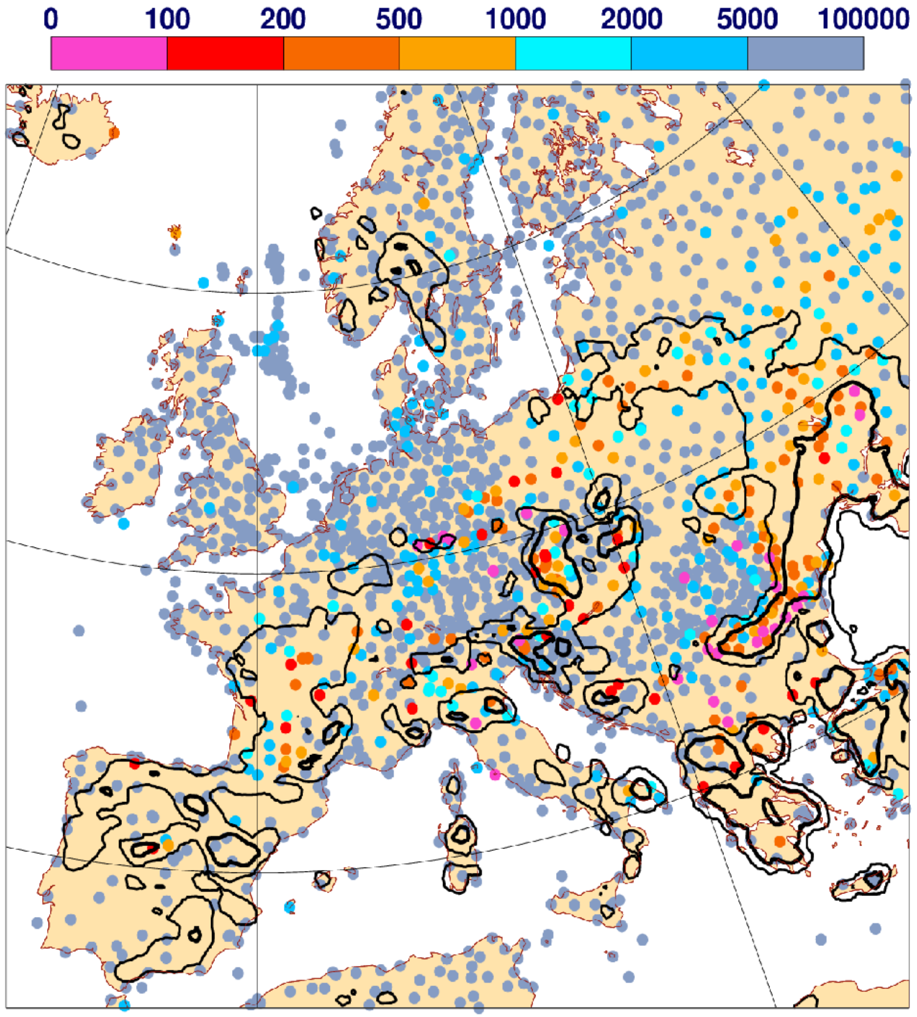
Day 3 forecast

Day 5 forecast



New diagnostic: Visibility/Fog

Case study: 15 Dec 2014, 3 day probability forecast from IFS ensemble



Observed visibility (m) at 06Z 15 Dec 2014 (dots)
ENS 3-day forecast probability of fog (<1000m) >10% (thin), **>50% (thick)**

ECMWF

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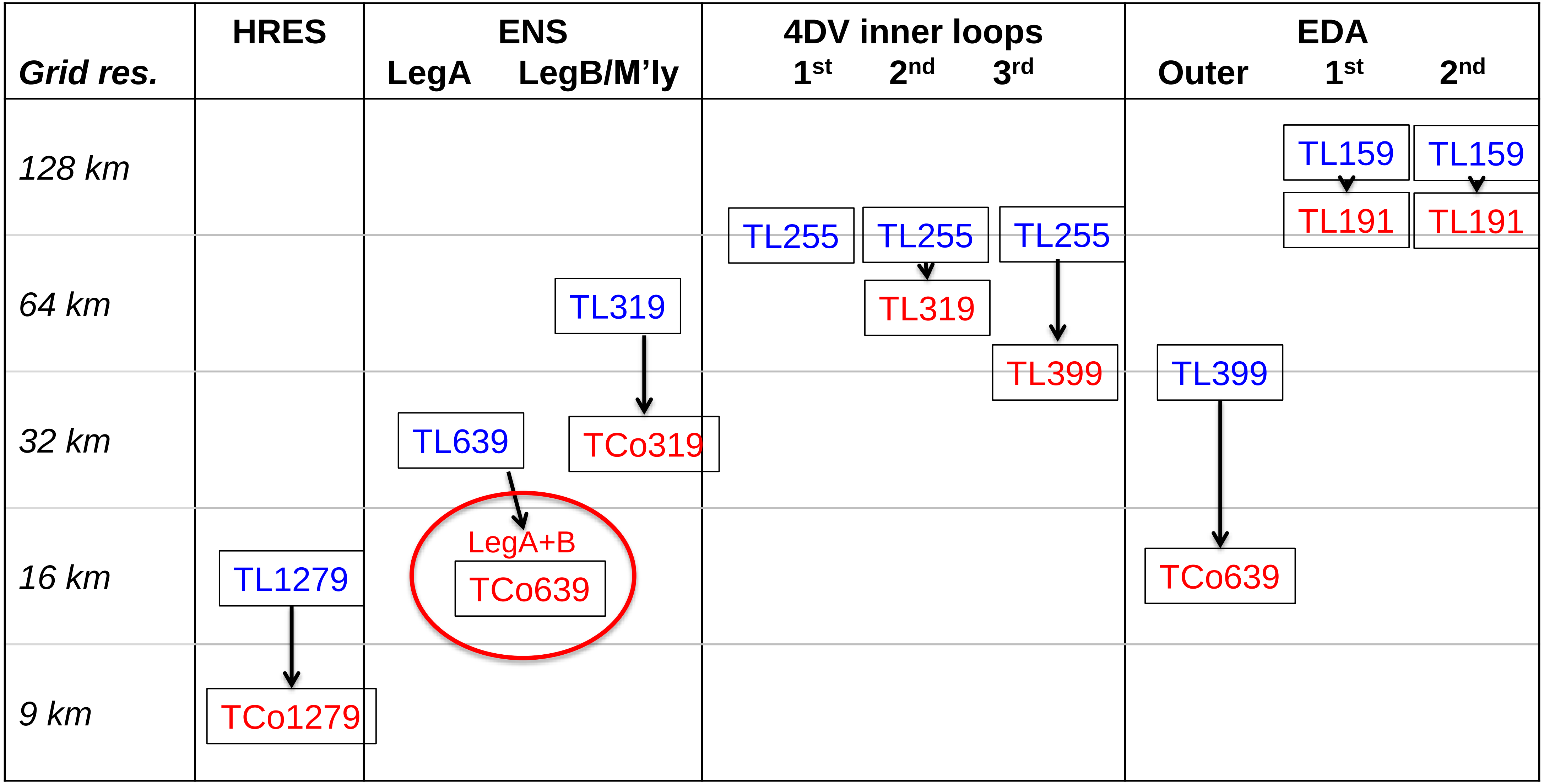
Resolution upgrade – 8 March 2016

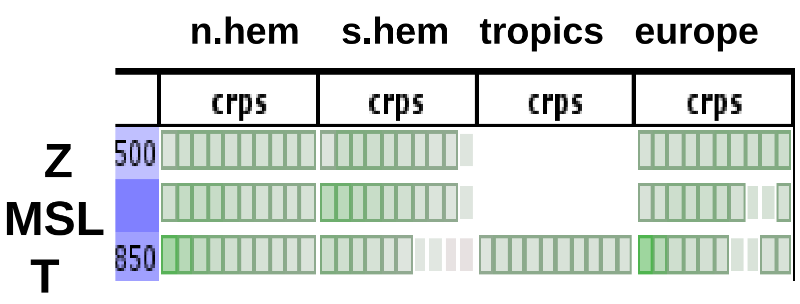
41r1 → 41r2



Performance summary: 41r2 (08.15-03.16)

HRES

ENS



T850 : 4-2%
Z500 : 3-2%

Z500 :7-4% AC
3-2% RMSE

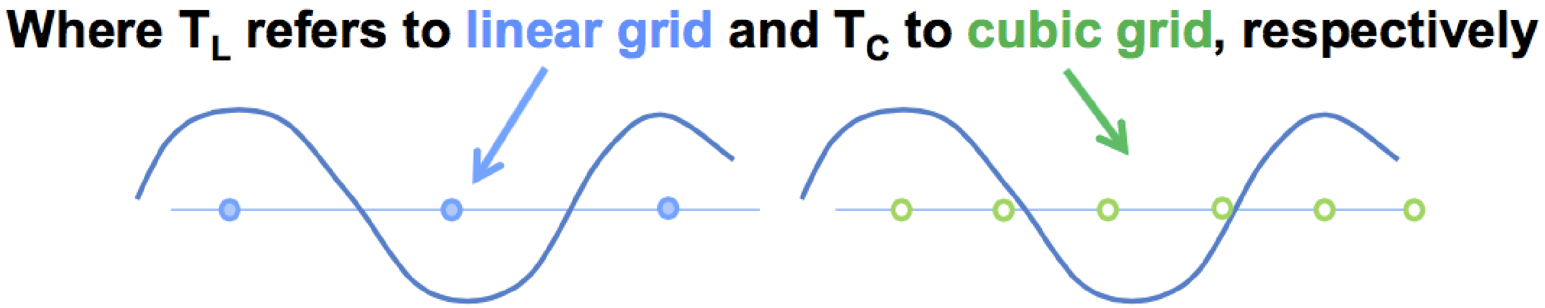
T2m, D2m, v10m 1-4% RMSE decrease

Cy41r2 (Highlights)

MOD	Higher resolution 8/16km, new cubic-octahedral reduced Gaussian grid Number of iterations in SL trajectory Radiation-surface LW/SW updating, radiation-surface LW tiling Improved physics for freezing rain TL/AD surface and VDF, non orographic drag
SAT	GPSRO observation error adjustment Improved data coverage (screening and obs error changes) Observation operator improvements
4DVAR	EDA resolution TCo639 fc/outer loop, TL191/T191 inner loops Same hybrid B both in EDA and HRES 4DVAR configuration TL255/TL319/TL399
ENS/WAV	Various technical changes preparing for the resolution upgrade
TECH	Efficiency gains, HugePages, vectorisation, optimisation, IOSERV

Resolution upgrade: cubic grids

2N+1 gridpoints to N waves : T_L linear grid
4N+1 gridpoints to N waves : T_c cubic grid



- Mathematically more correct in the presence of cubic non-linearities in the eqns
- Less numerical filtering – almost no numerical diffusion, no dealiasing
- Better mass conservation
- Less expensive than the equivalent linear grid (TC1023 cheaper than TL2047)

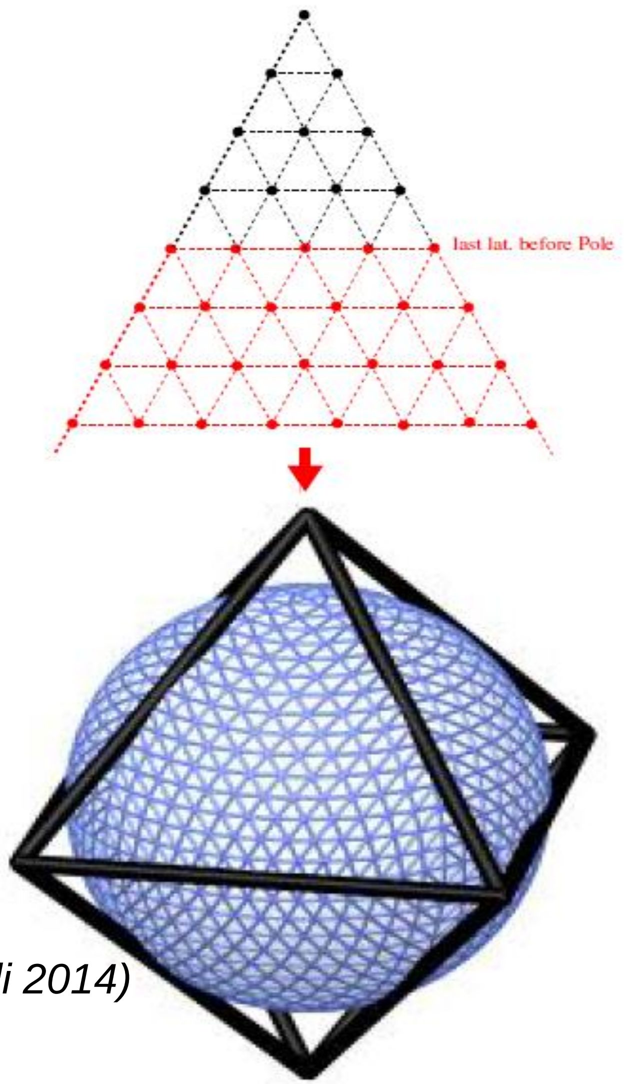
Resolution upgrade: octahedral reduced Gaussian grid

It is a reduced Gaussian grid with the same number of latitude circles (*NDGL*) than the standard Gaussian grid (↔ Gaussian weights) but with a new rule to compute the number of points per latitude circle.

Number of points per latitude

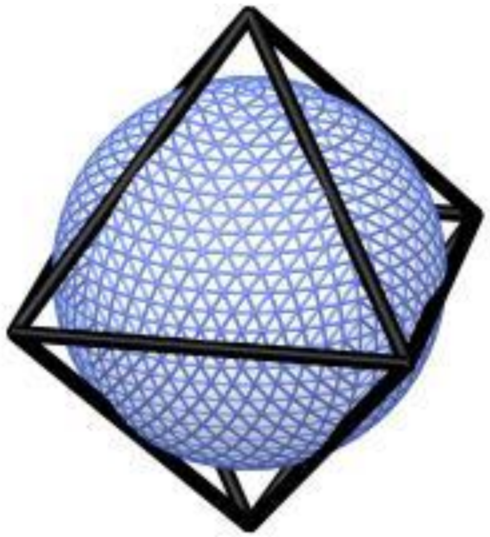
$NLOEN(lat_N)=20 \rightarrow$ Poles

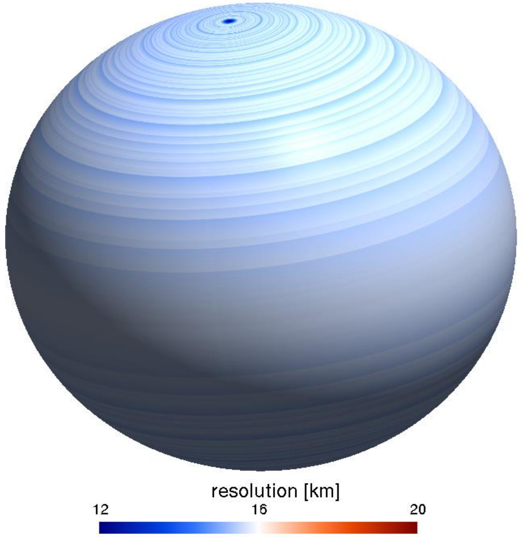
$NLOEN(lat_i)=NLOEN(lat_{i-1})+4$



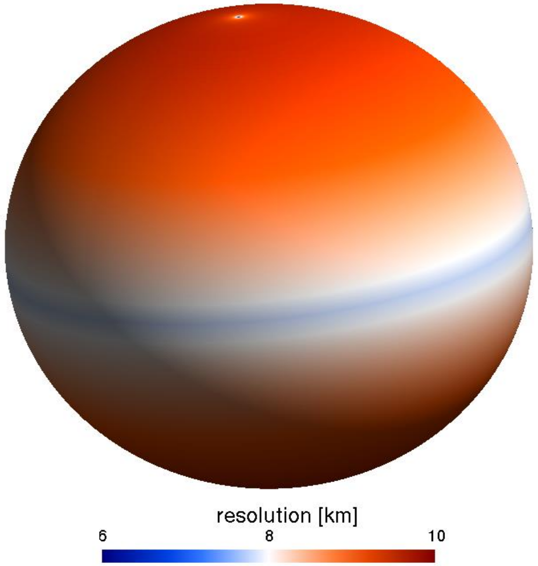
Re-think the spectral wave number truncation to gridpoint number ratio (Wedi 2014)
The cubic-octahedral grid (TCo1279) at ECMWF (Wedi et al 2015)
A new grid for the IFS (Malardel et al., ECMWF Newsletter 146)

Resolution upgrade: cubic-octahedral reduced Gaussian grid





T_L 1279: old reduced Gaussian Grid for HRES

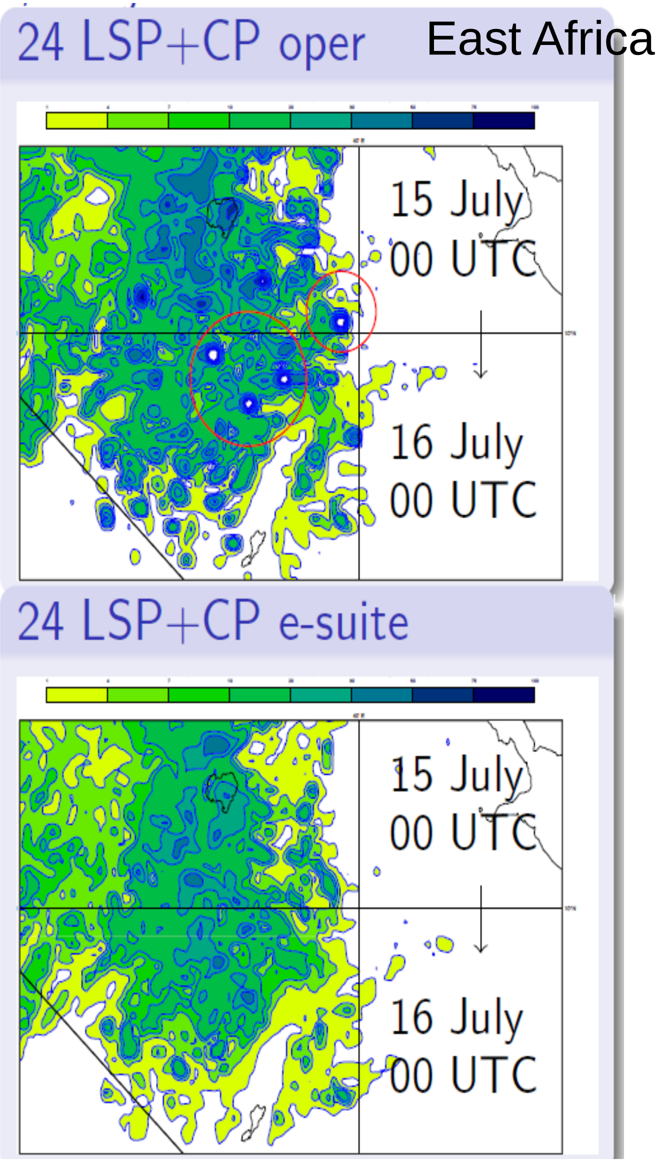


T_{co} 1279:New octahedral grid for HRES

Spectral truncation: T1279
but four points describing the shortest wave

Precipitation spectra: Oper TL1279 and TCo1279

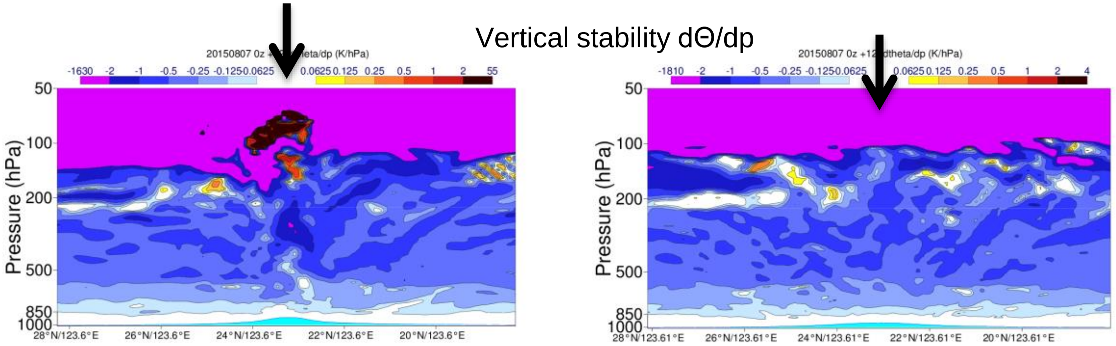
“Grid point storms” seen in resolved precipitation (LSP) in certain regions have gone in TCo1279



Improved semi-Lagrangian scheme

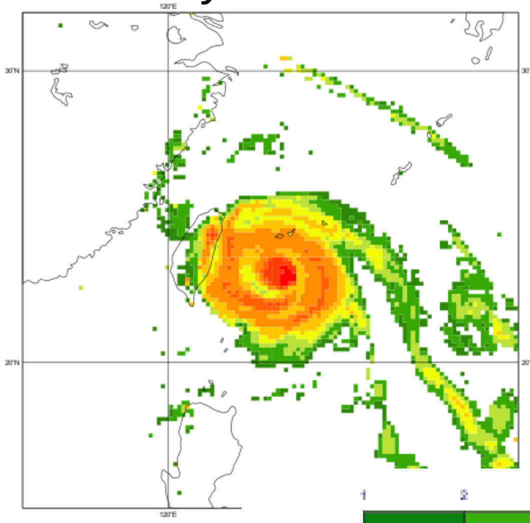
Instability with 3 iterations for semi-Lagrangian departure point in extreme situations (gravity waves above Himalayas, tropical cyclones); increasing to 5 iteration considerably improves the results

Vertical stability dΘ/dp

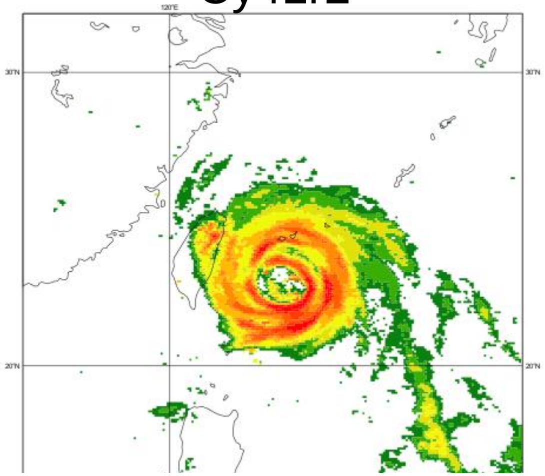


Tropical Cyclone Soudelor
Aug 2015

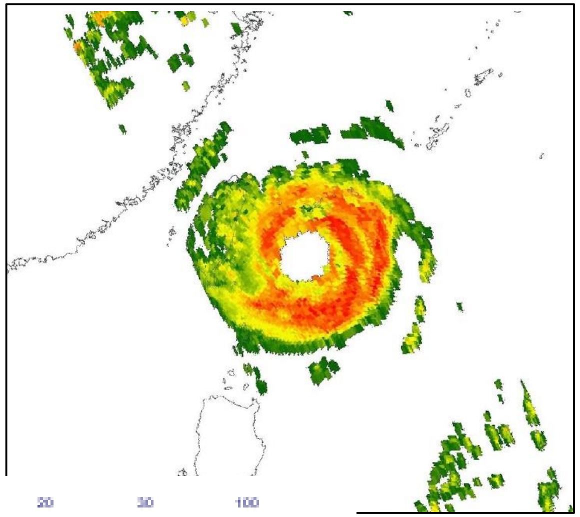
HRES TL1279
Cy41r1



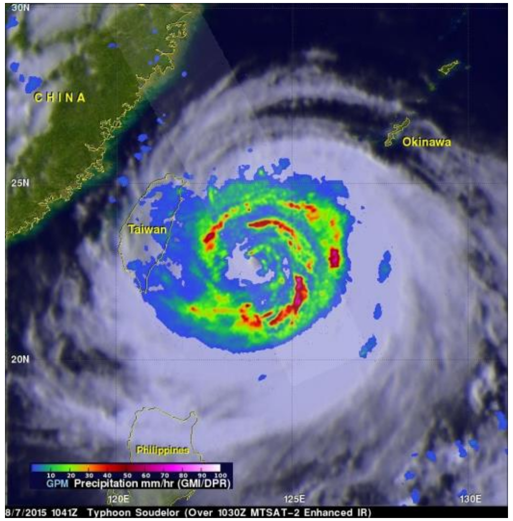
HRES TCo1279
Cy41r2

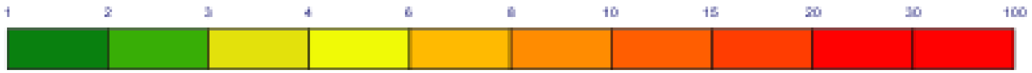


GPM observations



RADAR





Radiation approximate update: 41r2 T1279 (case 4 Jan 2014)

Control: radiation at T639/every 1h

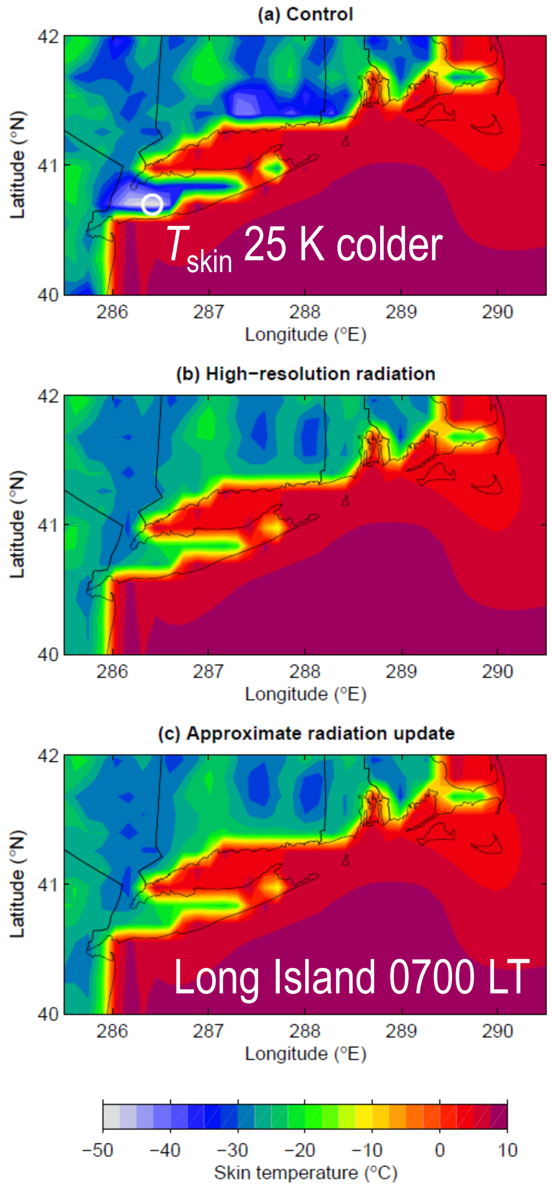
Radiation 12.5% of model time

Radiation every timestep/gridpt

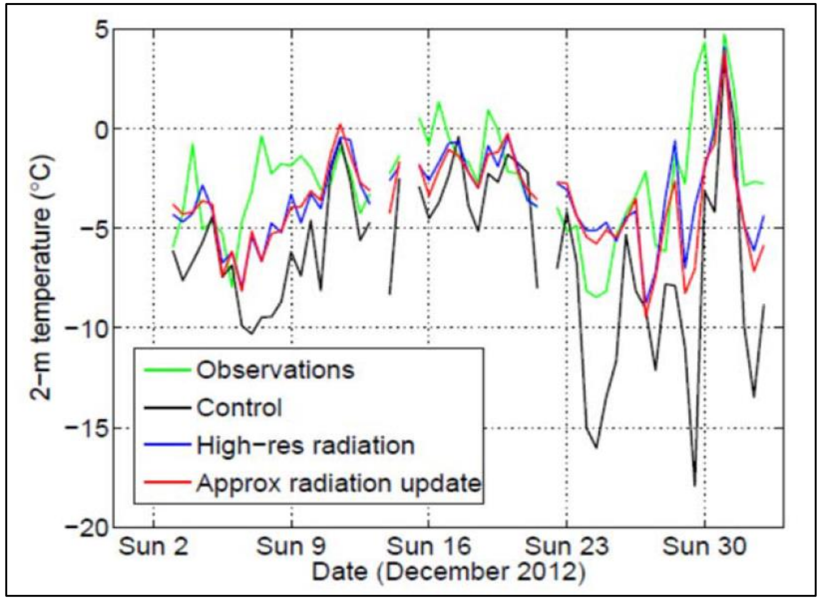
Radiation 12 times more expensive

New scheme

Radiation 2% more expensive



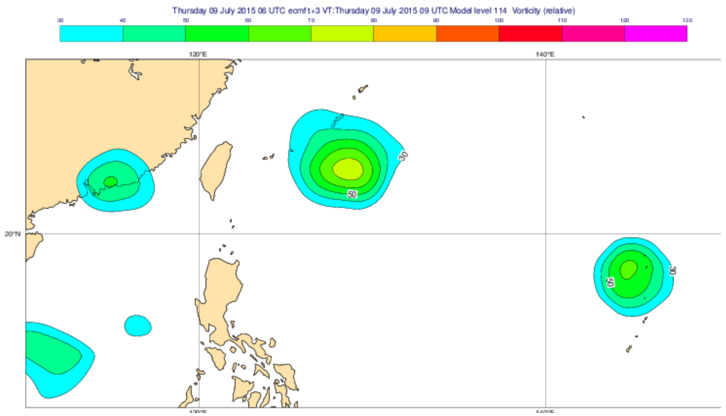
- Update surface LW&SW fluxes every timestep and gridpoint according to T_{skin} and albedo.
- Removes spurious cold/warm coastal T anomalies with minimal cost.



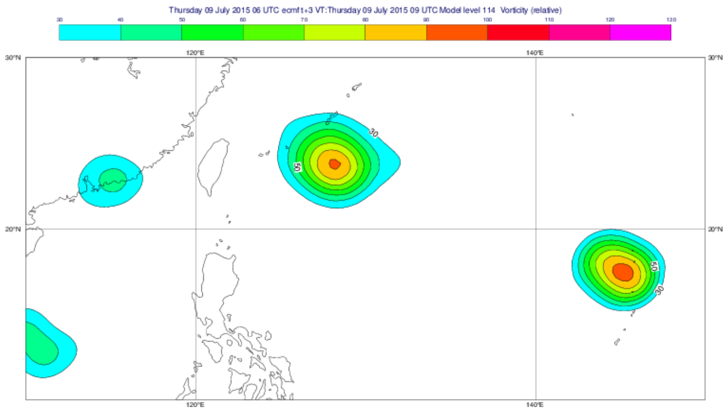
Hogan & Bozzo, ECMWF Newsletter 145

EDA improvements, TCo639 + B

Higher TCo639 resolution, smaller-scale variance and B heavily weighted towards the days errors at smaller scales gives more accurate analysis/forecasts—almost TL1279—and more spread where it matters.



41r1 TL399
20150709
0900z



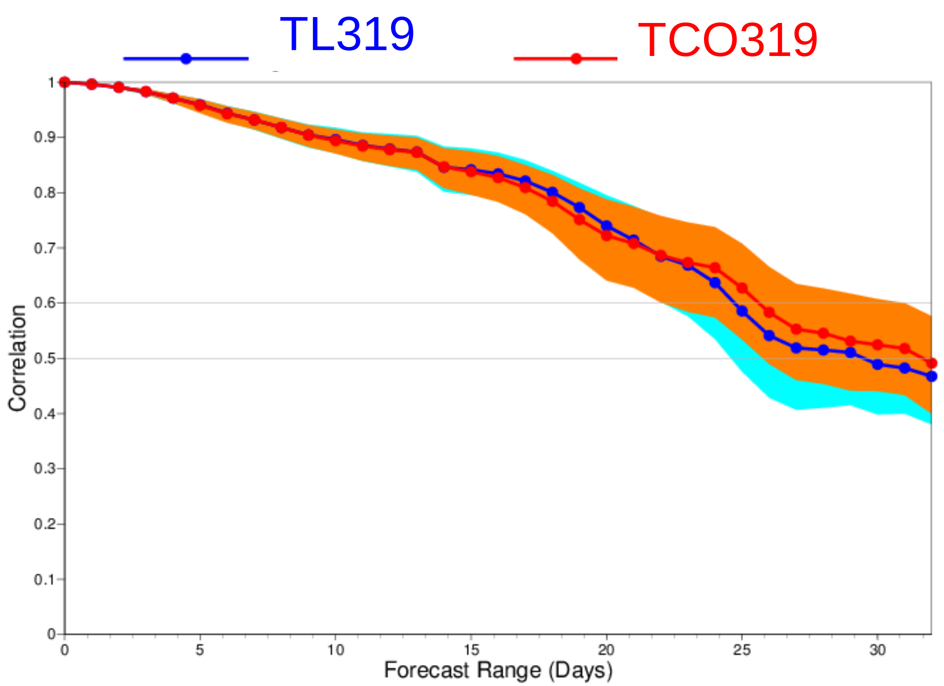
41r2 TCo639
20150709
0900z

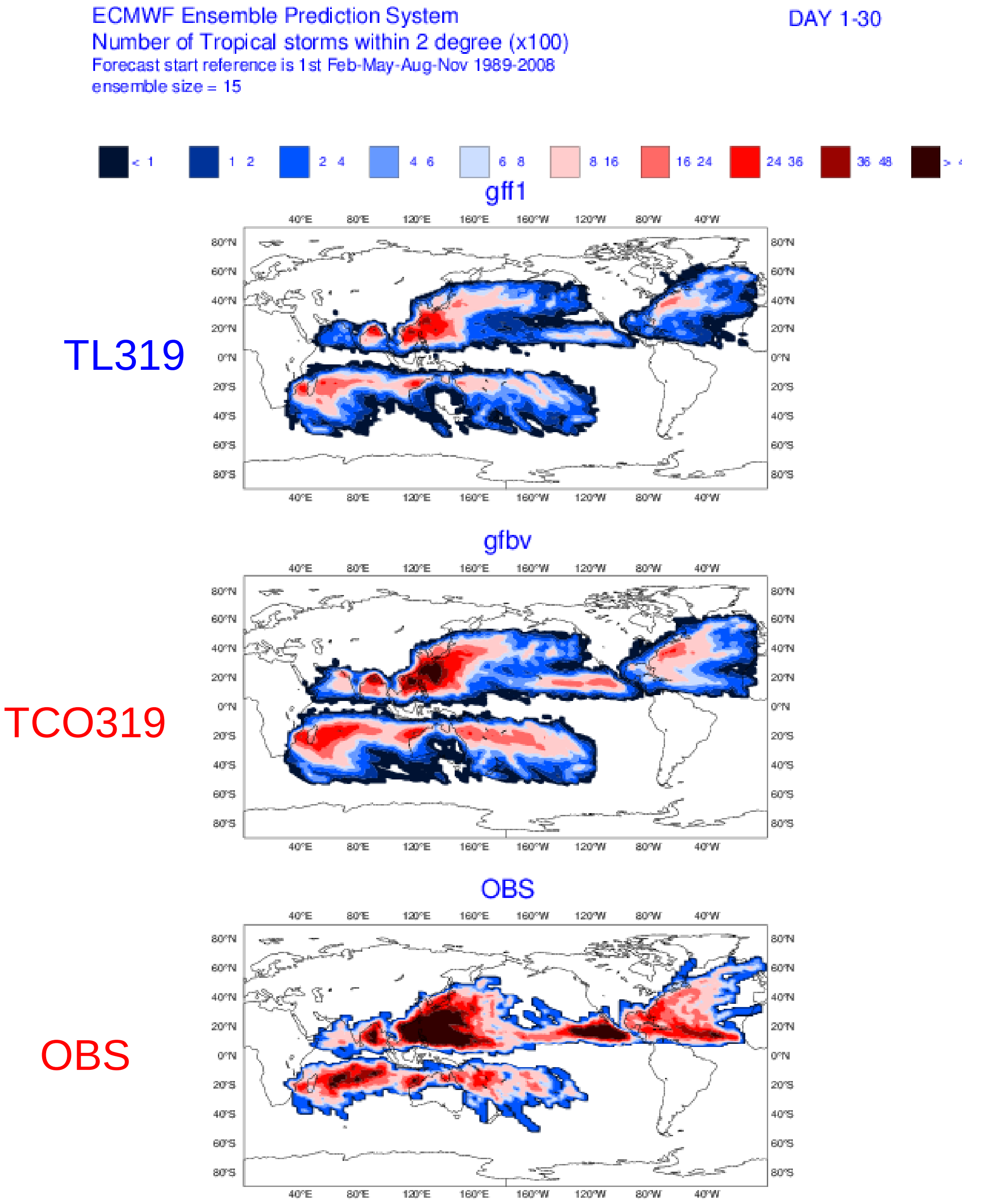
"Linfa, Chan-hom, and Nangka"

Monthly forecast: resolution upgrade

41r1: TL639 day 0-10, TL 319 day 10-46
41r2: Tco639 day 0-15, TCO 319 day 10-46

MJO Index bivariate correlation



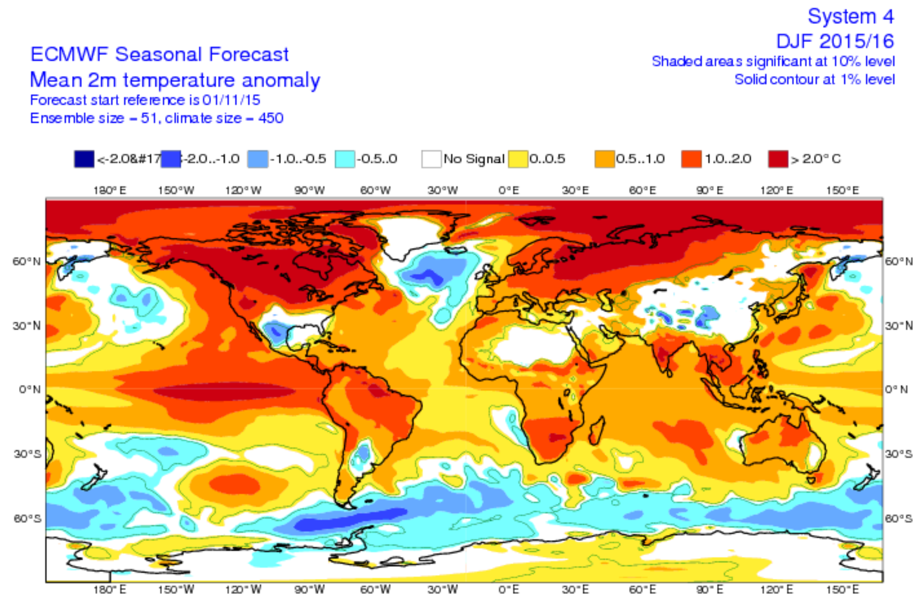


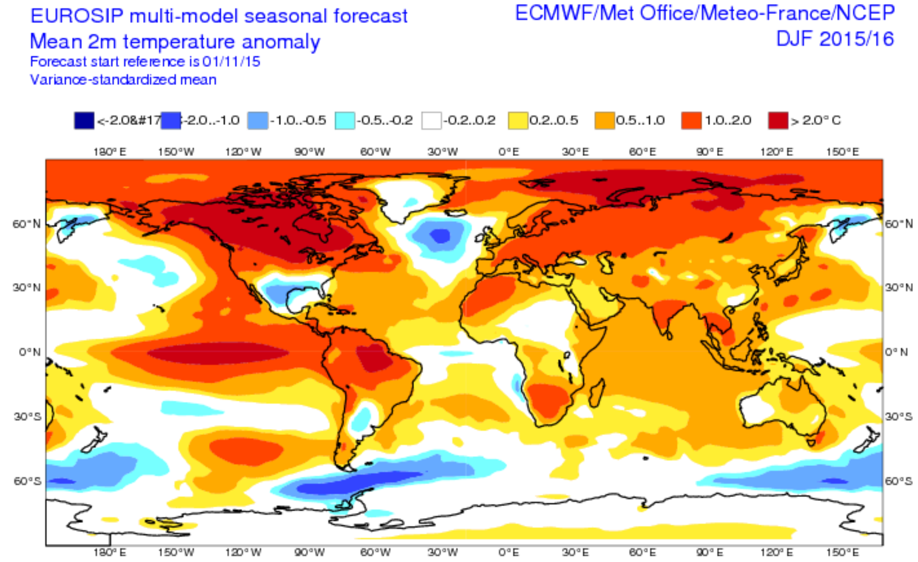
Monthly forecast – User oriented verification

2m temperature anomalies

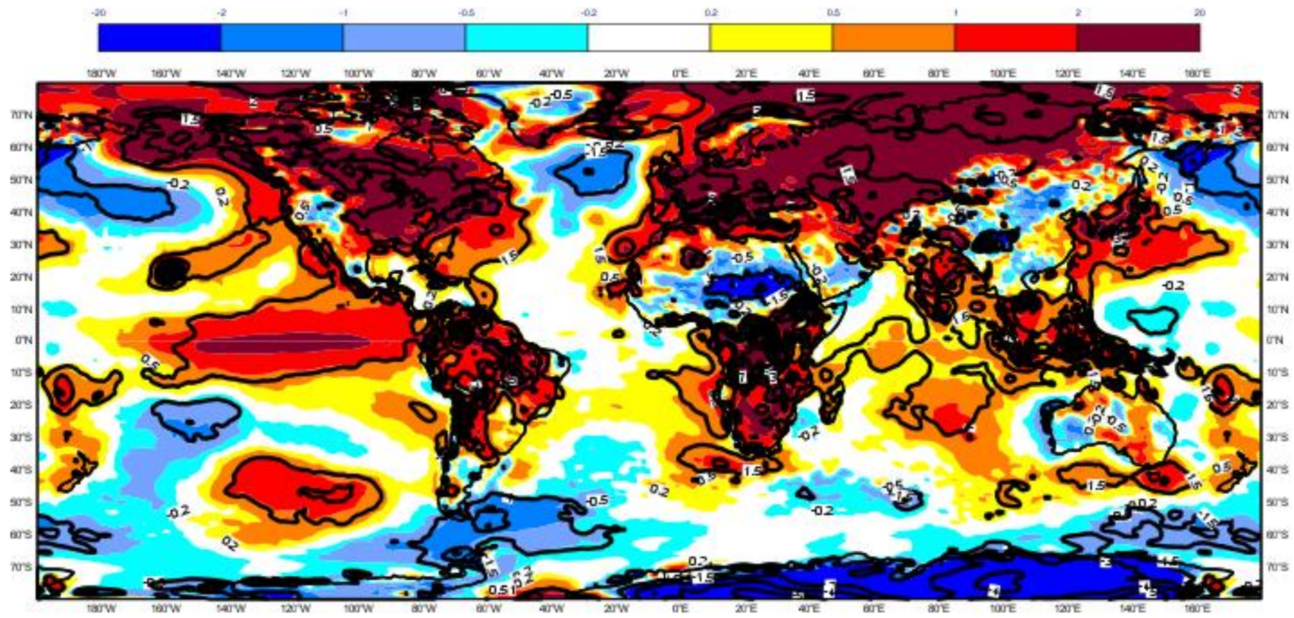
Verification metric: ROC area

Seasonal forecast





2mt anomalies for DJF 2016: analysis



Seasonal forecasts - System 5 configuration

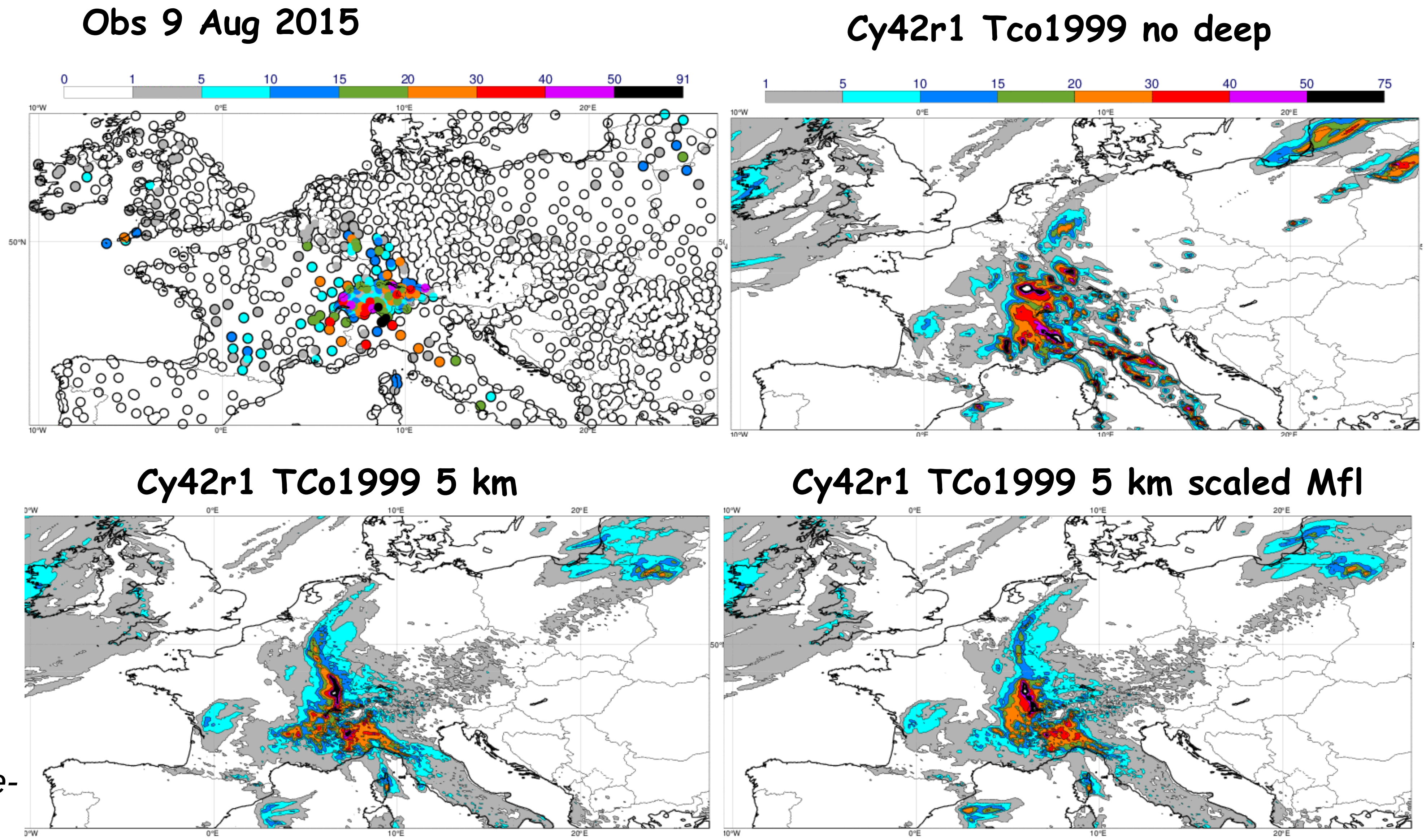
		S4	ERA-5	S5 Y1 (end '16)	S5 Y2 (end '17)
Atm	Cycle	36r4	41r2	43r1 (or 42r1)	
	Hor. resolution	T_L255	T_L639	TCo319 (or TL511)	
	Vert. resolution	L91	L137	L137 (or L91)	
	ICs forecast	Ope-an	--	Ope-an	
	ICs reforecast	ERA-I	--	ERA-I	
Land	ICs forecast	Ope-an	Ope-an	Nudging to Ope-an	
	IC reforecast	ERA-I/Land	--	Nudging to ERA-I/Land	
Ocean	Cycle	NEMO 3.0/3.1	--	NEMO 3.4	
	Resolution	ORCA100z42	--	ORCA025z75	
	ICs	ORAS4	--	ORAS5	
Sea Ice	Model	--	--	LIM2	
	ICs	--	--	ORAS5	
Config	Size forecast	51	--	51	
	Size reforecast	15	--	25	25 (51 every quarter)
	Forecast length	7m (13m)	--	7m (13m every quarter)	
	Reforecast years	1981-2010	--	1993-2015 (23y)	1981-2015 (35y) ?

Just some of the forthcoming challenges...

- Dynamical core
- 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

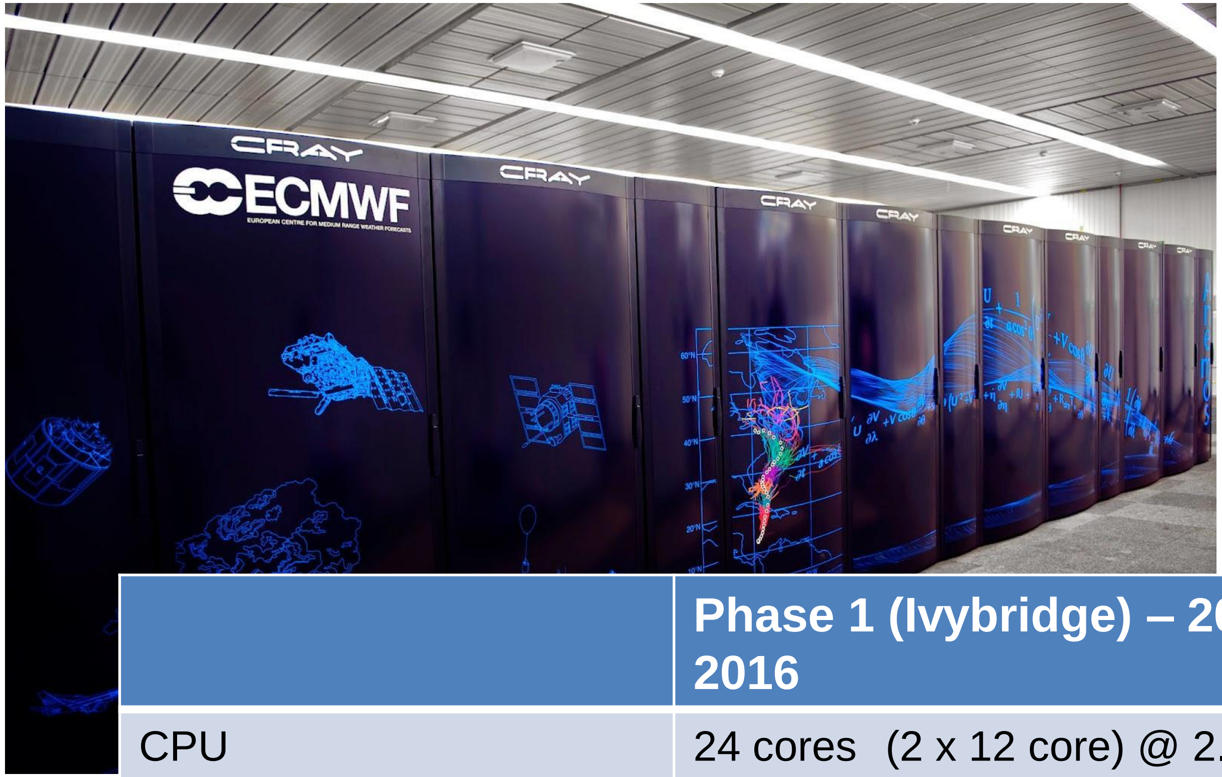
A bit of light in the grey-zone

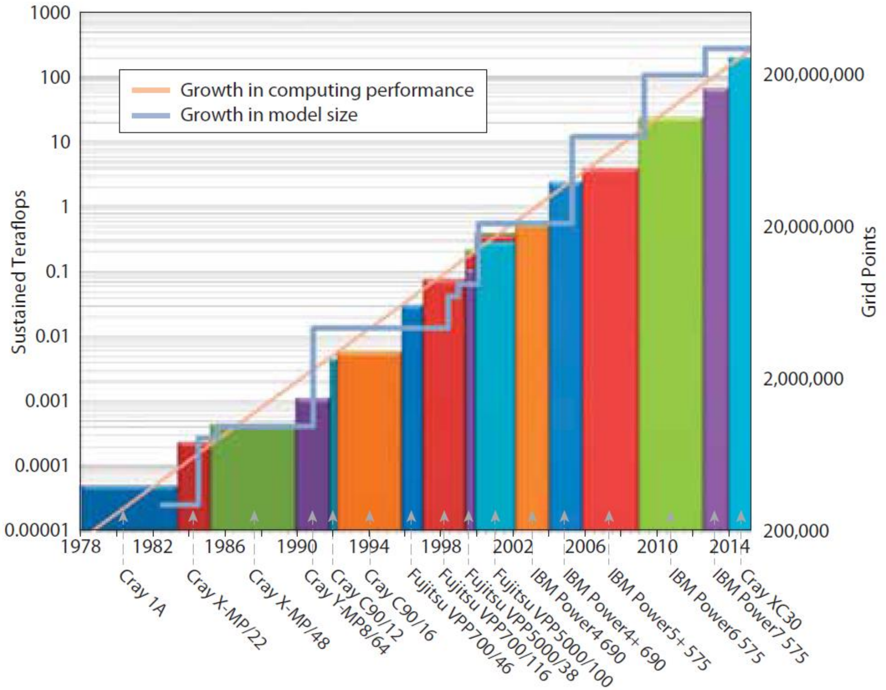
Convection parameterisation at 5km resolution



P. Bechtold in collaboration with DWD presented more examples in ECMWF's Annual Seminar on physical processes in present and future large-scale models, 2015

ECMWF HPC





	Phase 1 (Ivybridge) – 2014-2016	Phase 2 (Broadwell) – 2016-2020
CPU	24 cores (2 x 12 core) @ 2.7GHz	36 cores (2 x 18 core) @ 2.1 GHz
Memory/Node	64 Gb (1866 MHz DDR3)	128Gb (2400 MHz DDR4)
Memory/Core	2.6 Gb	3.5Gb (+35% cf Phase 1)
Parallel Nodes (per cluster)	3,400	3,513 (+3% cf Phase 1)
Total Cores (per cluster)	84,096	130,212 (+55% cf Phase 1)
Tf sustained (both clusters)	200	320 (+60% cf Phase 1)

Overall increase ~ 1.5

Four-year plan: Projected HPC cost

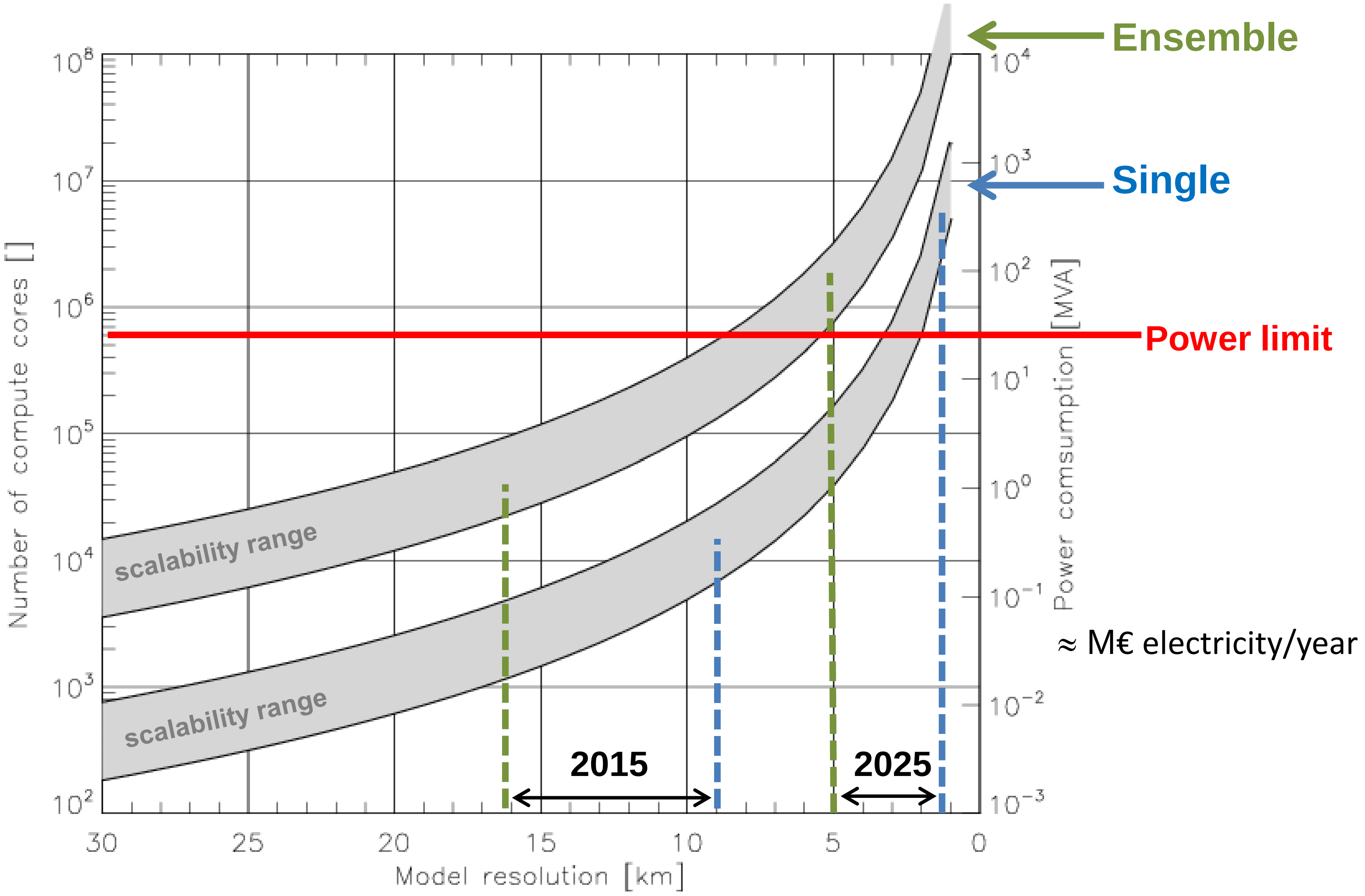
		2016		2017	2018	2019	2020
EDA:	H resolution o/l	TCo639					TCo1279
	H resolution i/l	TL191	TCo191				
	V resolution	L137					
	Coupling				orca025l75		
	Ensemble size	M25		M50			
	Window length	2x12h	4x6h				
	Efficiency gains						
	Nodes:	1600	2560	5120	5632	5632	28160
	Factor:	1	1.6	2.0	1.1	1.0	5.0
	Acc. factor:	1	1.6	3.2	3.5	**3.5**	**17.6**

Strategic target:
Global 5km,
seamless analysis-
forecast ensemble
in 2025

		2016		2017	2018	2019	2020
ENS/legA:	H resolution	TCo639					TCo1279
	V resolution	L91			L137		
	Coupling	orca100l42	orca025l75				
	Forecast range	d10		d15			
	Ensemble size	M51					
	Reforecast ensemble size	M11				M15	
	Efficiency gains						
	Nodes:	1530	1683	2525	3787	4355	21774
	Factor:	1	1.1	1.5	1.5	1.2	5.0
	Acc. factor:	1	1.1	1.7	2.5	**2.8**	**14.2**

ECMWF

Simple compute projection (only resolution)



[Bauer et al. 2015]

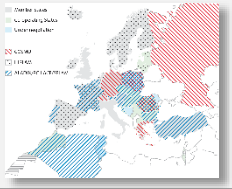
nature

ECMWF

ECMWF Scalability Programme

Governance:

ECMWF, Member states, Regional consortia



Projects:

Observation processing ↔ **Data assimilation** ↔ **Numerical methods** ↔ **Model output Processing**

Code adaptation

Computer architecture support

intel
NVIDIA
CRAY THE SUPERCOMPUTER COMPANY
IBM

ESCAPE

ESiWACE

NextGenIO

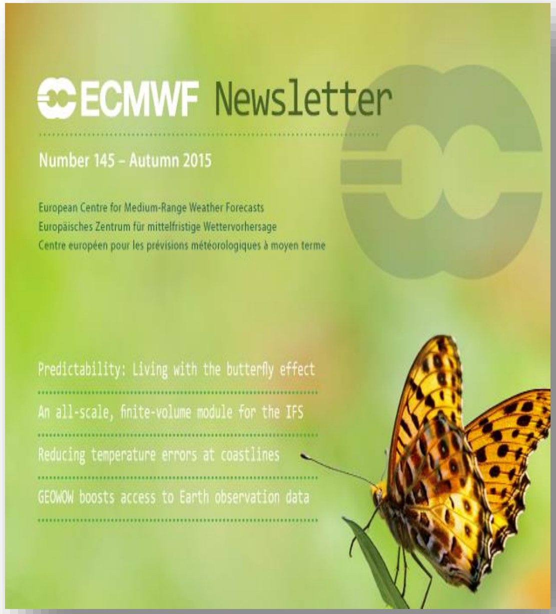
Earthserver 2

Liaisons with ECMWF data and services users

Member and Co-operating States visits: reviewed format to address needs of ECMWF data users.

Using ECMWF's Forecasts (UEF June 2015)

Quantifying and communicating uncertainty



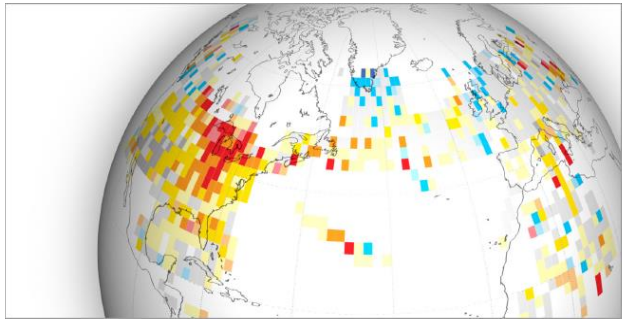
Using ECMWF's Forecasts (UEF 6th – 9th June 2016)

"Shaping future approaches to evaluating high impact weather forecasts"

- High impact weather forecasts: measuring long term improvement
- User-oriented
- Seamless verification across different time scales

Website: http://www.ecmwf.int/en/learning/workshops-and-seminars/n/using-ecmwf%27s-forecasts-uef2016

#uef2016



22 April 2016 - Abstract submission deadline
3 May 2016 - Acceptance notifications

Outreach and training

Training Catalogue

- Computing
- Meteorology
- Software packages and applications

http://www.ecmwf.int/en/learning/training/training-catalogue

Research annual seminar: 5th to 9th September 2016

Earth system modelling for seamless prediction: on which processes should we focus to further improve atmospheric predictive skill?

Workshops

Research and technical topics
http://www.ecmwf.int/en/learning/workshops-and-seminars

Thank you for your attention …

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