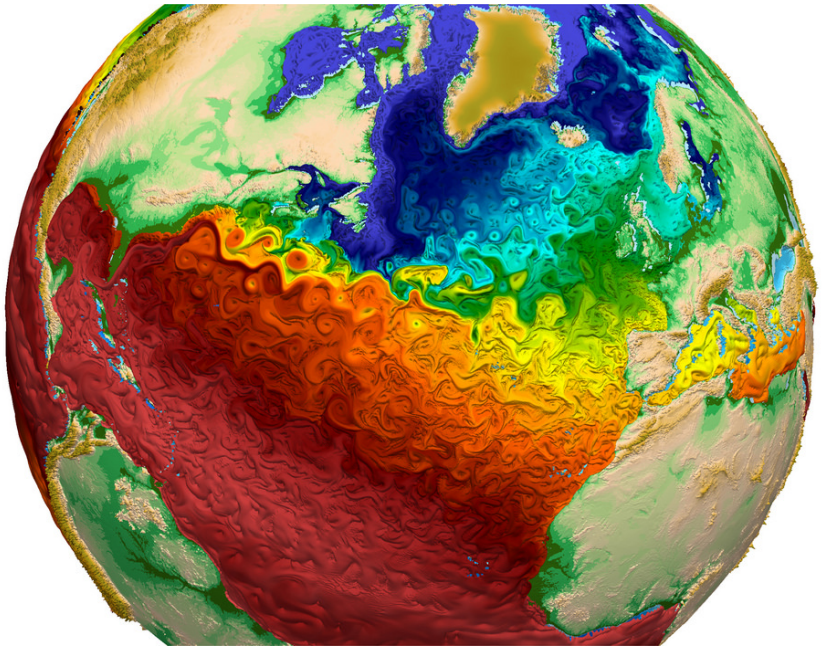
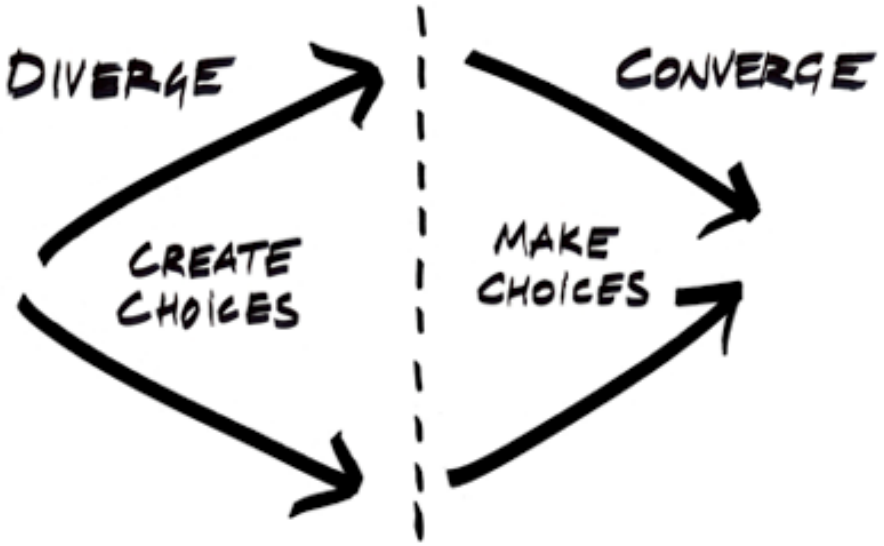
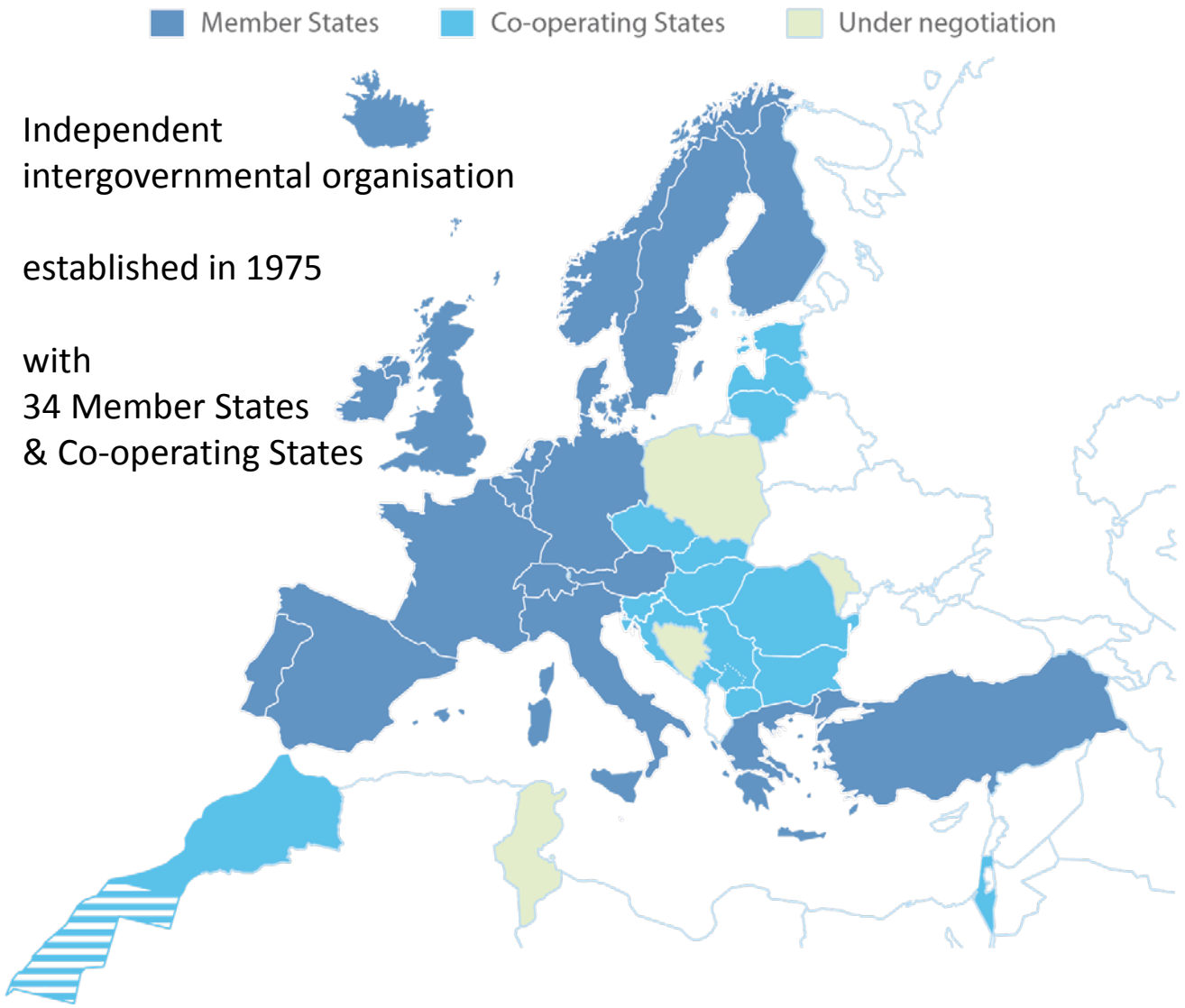
ECMWF and the roadmap to extreme-scale computing in weather and climate prediction



http://www.lanl.gov/newsroom/picture-of-the-week/pic-week-2.php



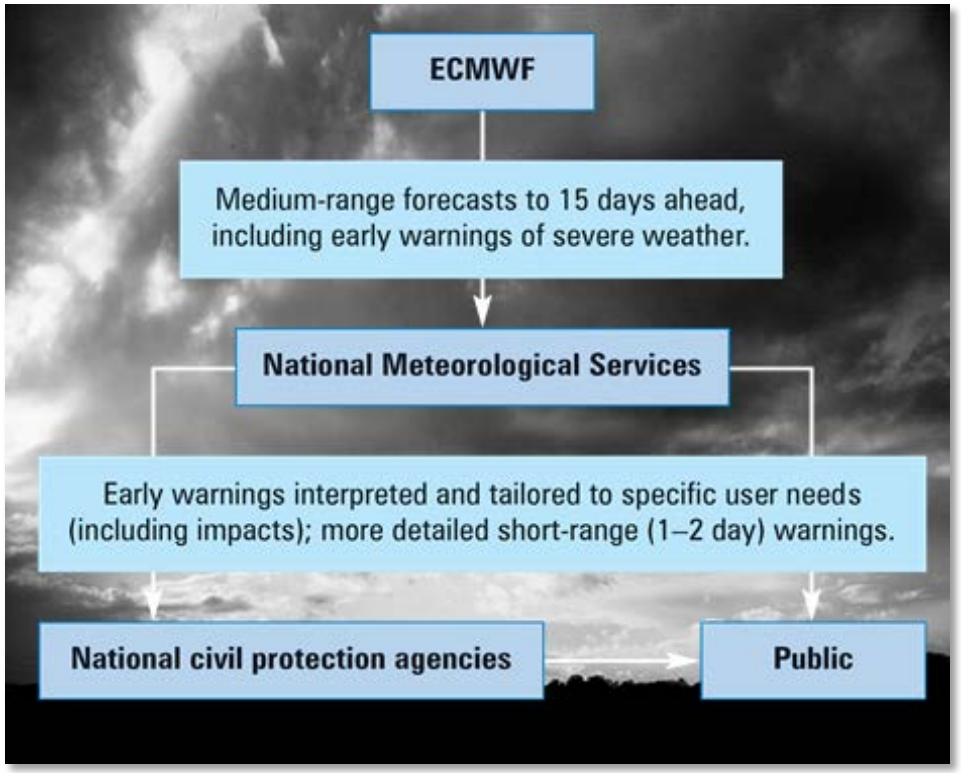
European Centre for Medium-Range Weather Forecasts



Independent intergovernmental organisation

established in 1975

with
34 Member States
& Co-operating States



ECMWF

EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

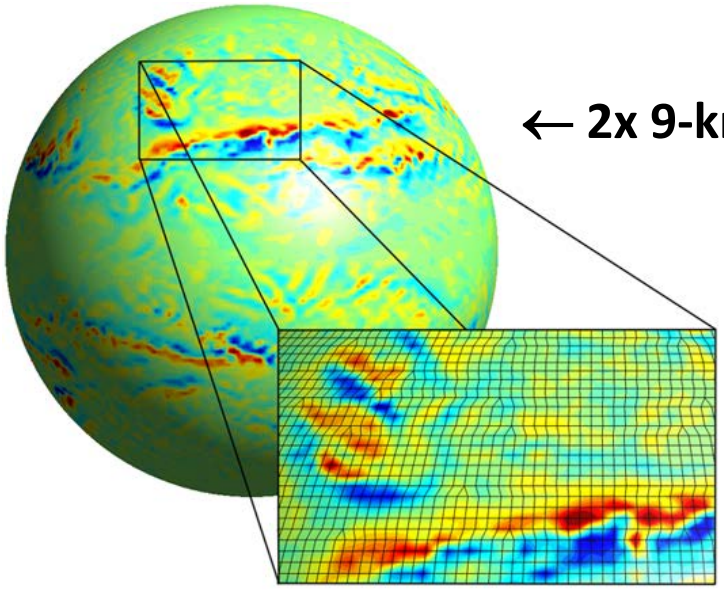
opernicus
Europe's eyes on Earth

European Commission

Climate Change Service

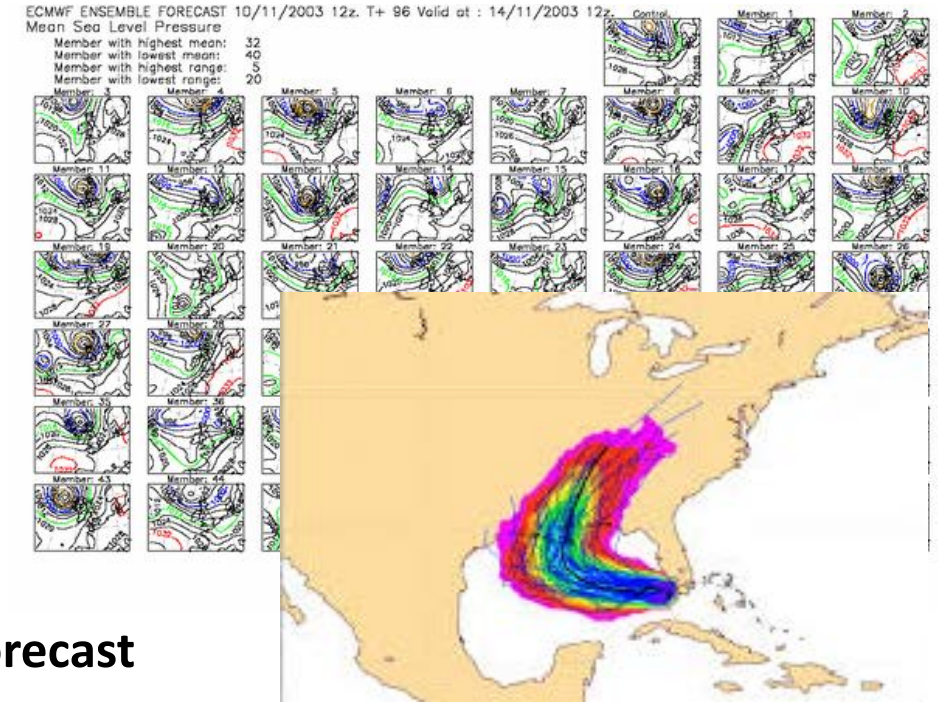
Atmosphere Monitoring Service

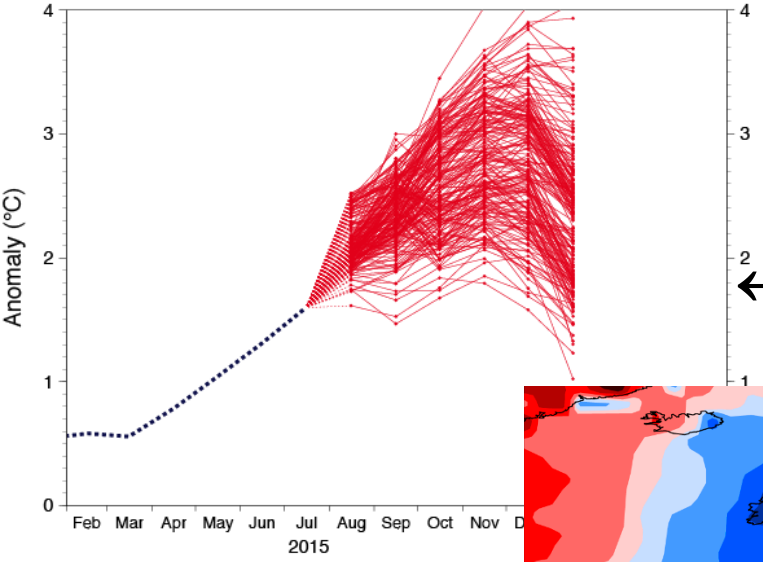
ECMWF Integrated Forecasting System (IFS)



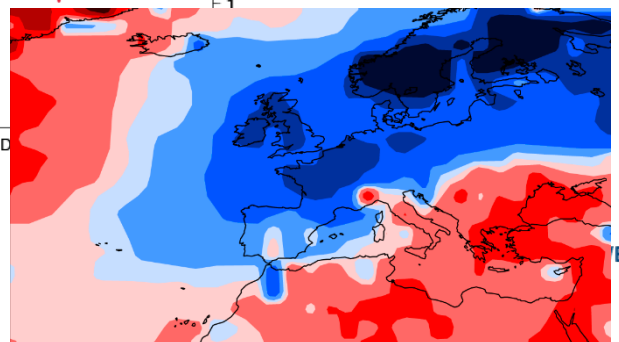
← 2x 9-km high-resolution 10-day forecasts per day

51x 18-km lower-resolution
15-day forecasts per day… →
… extended to 46 days
twice per week at 36 km





← 51x 64-km low resolution 7-month forecast per month

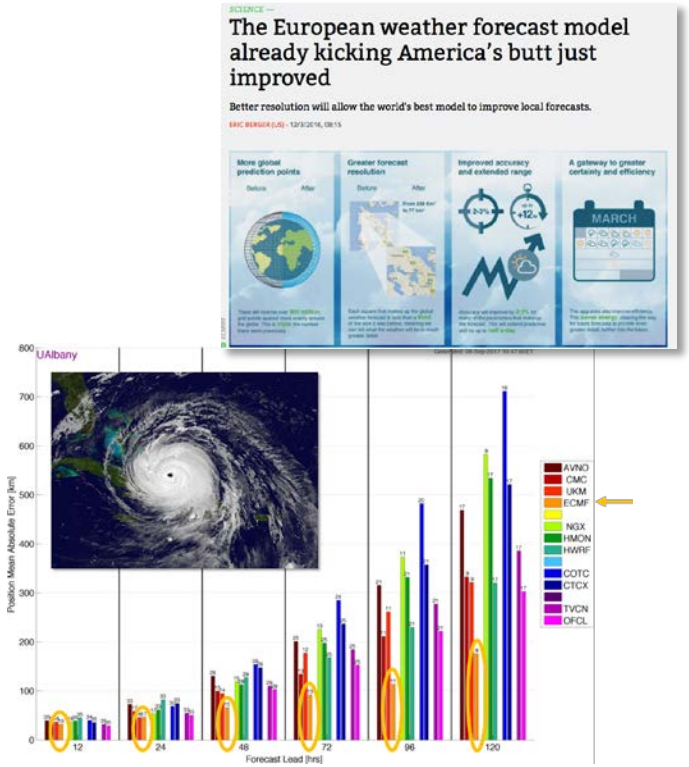


ECMWF

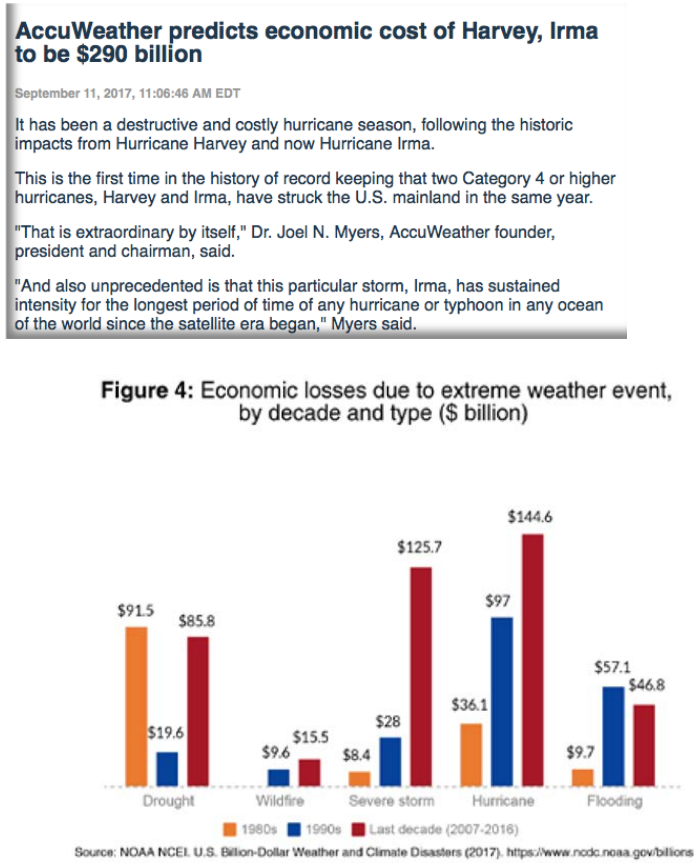
What is unique about weather & climate prediction?

(and why is it a perfect application for European technology leadership?)

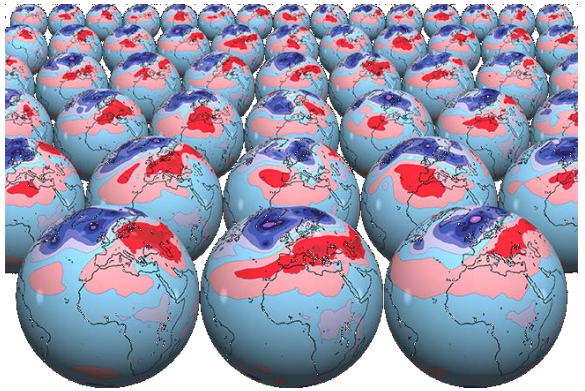
1. European science leadership:

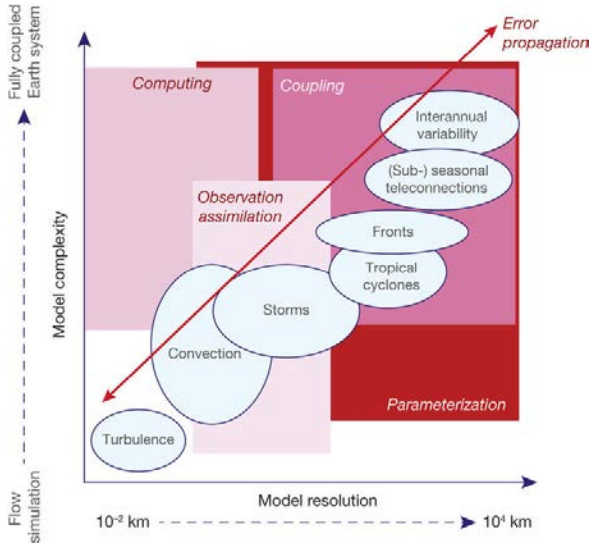


2. Outstanding socio-economic impact:



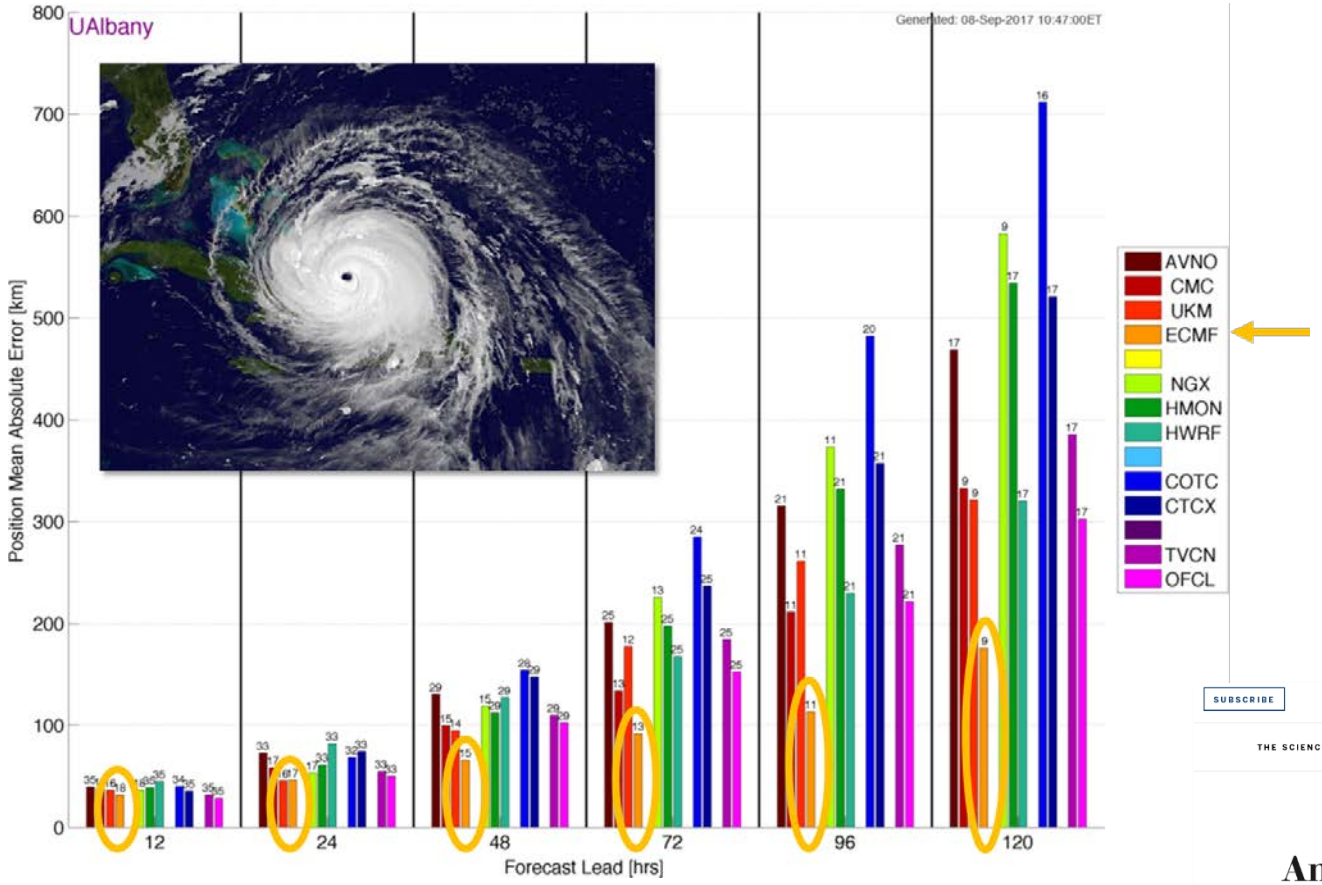
3. Limited by HPC & BD capabilities:





European leadership

World leadership in Europe – but still far away from sufficient accuracy and reliability!



ECMWF

EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECAST

SCIENCE —

The European weather forecast model already kicking America's butt just improved

Better resolution will allow the world's best model to improve local forecasts.

ERIC BERGER (US) - 12/3/2016, 08:15

NATIONAL GEOGRAPHIC | PHOTO OF THE DAY | TV | LATEST STORIES

GLOBAL POSITIVE FORUM PARIS SEPTEMBER 1ST 2017 — Let's Accelerate Together the Positive Revolution — globalpositiveforum.org — #ActForPositive

Why Are Europeans Better at Predicting Weather?

Wednesday's snow no-show in Washington was another misfire by U.S. forecasters.

By **Peter Miller**, for National Geographic News

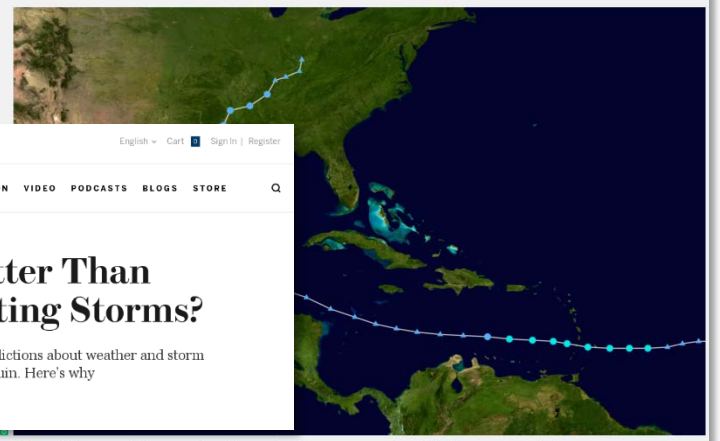
ars TECHNICA — BIZ & IT | TECH | SCIENCE | POLICY | CARS | GAMING & CULTURE | FORUMS

SCIENCE —

At times during Harvey, the European model outperformed humans

NOAA's new hurricane model, the HMON, performed terribly.

ERIC BERGER - 9/5/2017, 2:30 PM



Enlarge / Which model did the best job of forecasting Harvey has a hurricane? The European model, of course.

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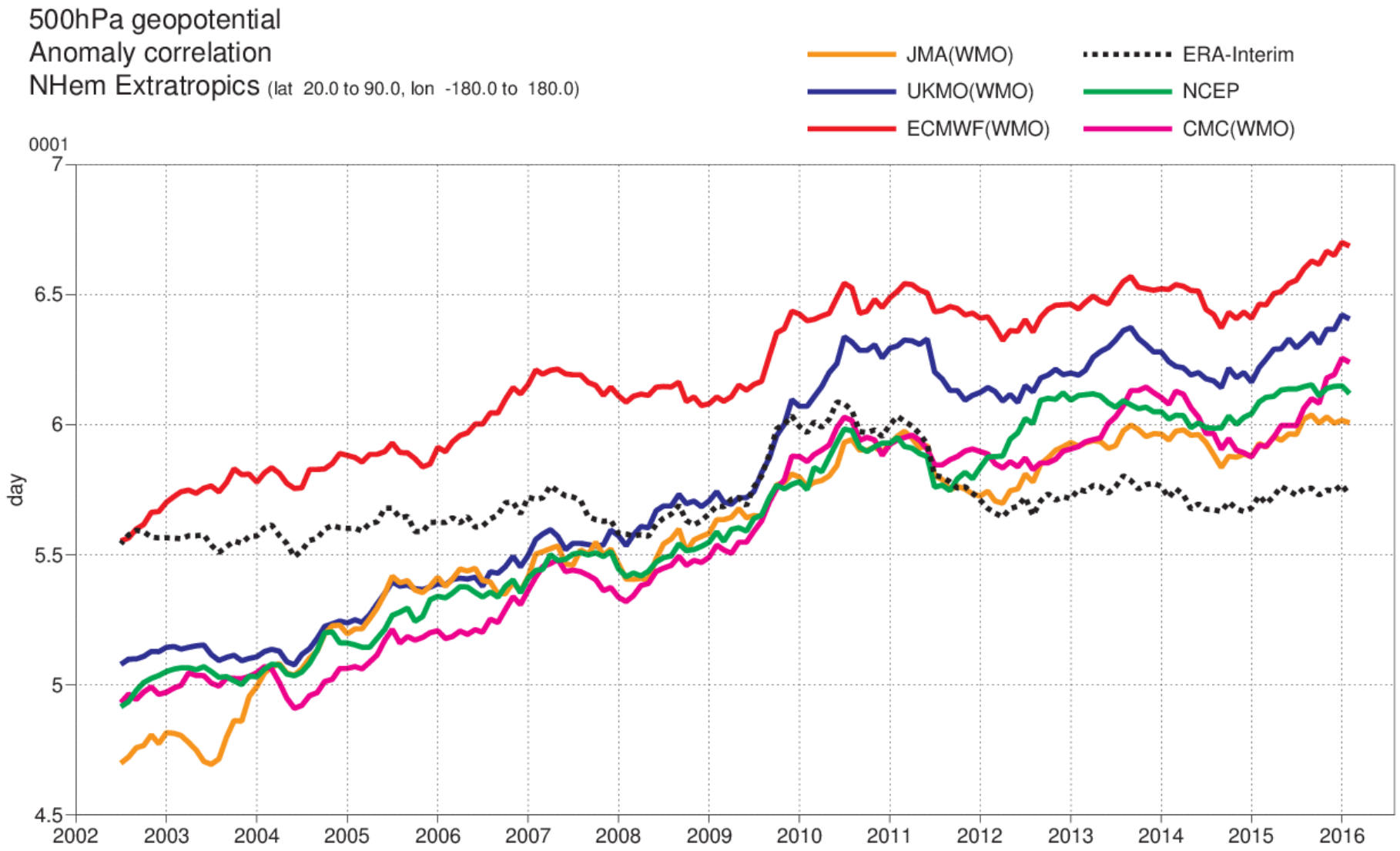
SUSTAINABILITY

Are Europeans Better Than Americans at Forecasting Storms?

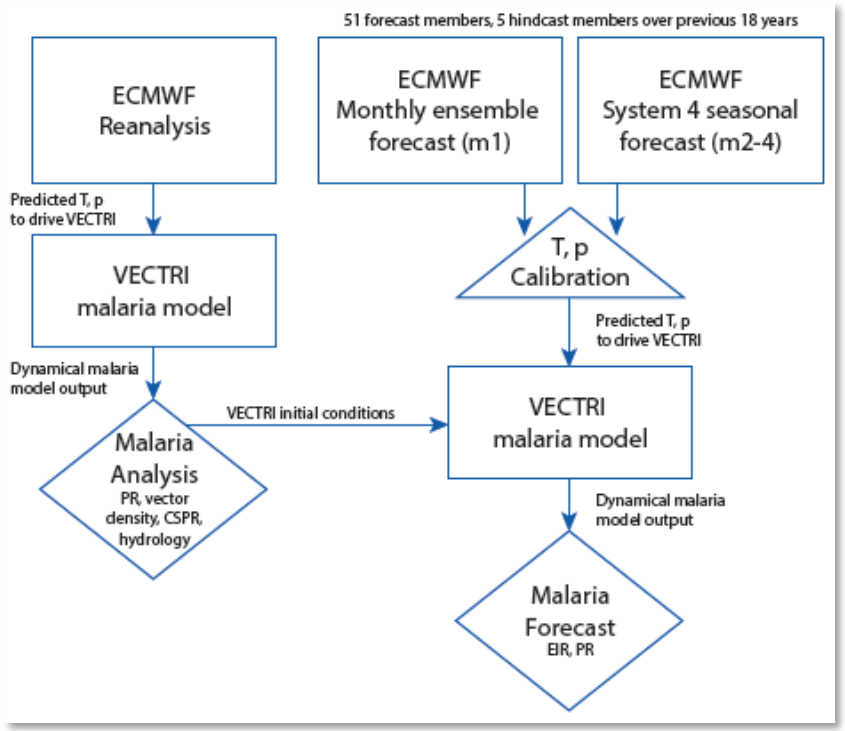
European and U.S. models frequently make different predictions about weather and storm tracks, including that of Hurricane Joaquin. Here's why

European leadership

Day at which anomaly correlation (= correlation between forecast-climate and verifying analysis-climate) drops below 80%



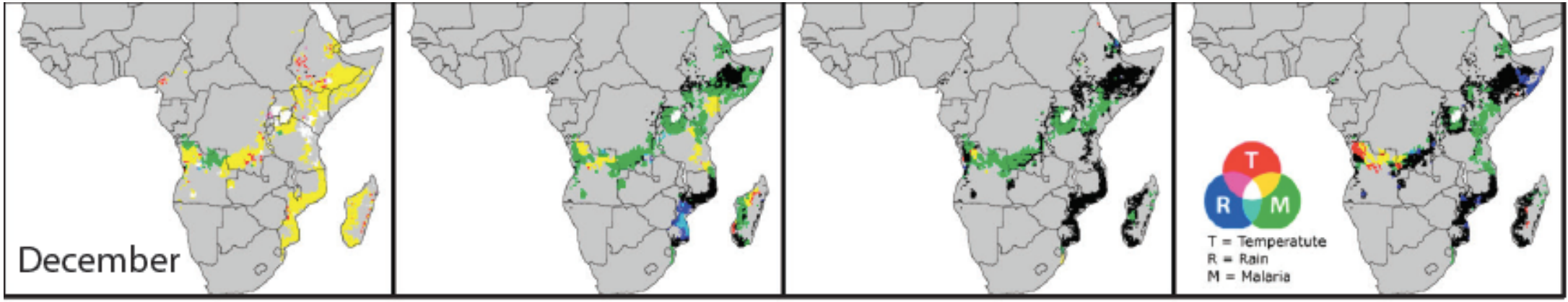
Weather extremes → health extremes



Di Giuseppe and Tompkins 2014:

"… integrating climate forecast information into the decision-making process will require extensive country-level evaluation of the system's past performance, including cost–loss analysis of potential intervention actions taken on the basis of the information. To carry out such an analysis adequately, improvements in the representation of model uncertainty and increased ensemble sizes will be necessary…"

Predictive skill for anomalies of rainfall (blue), temperature (red), malaria (green); no skill: black



ECMW

Advance warning 1 month lead time

Advance warning 2 months lead time

Advance warning 3 months lead time

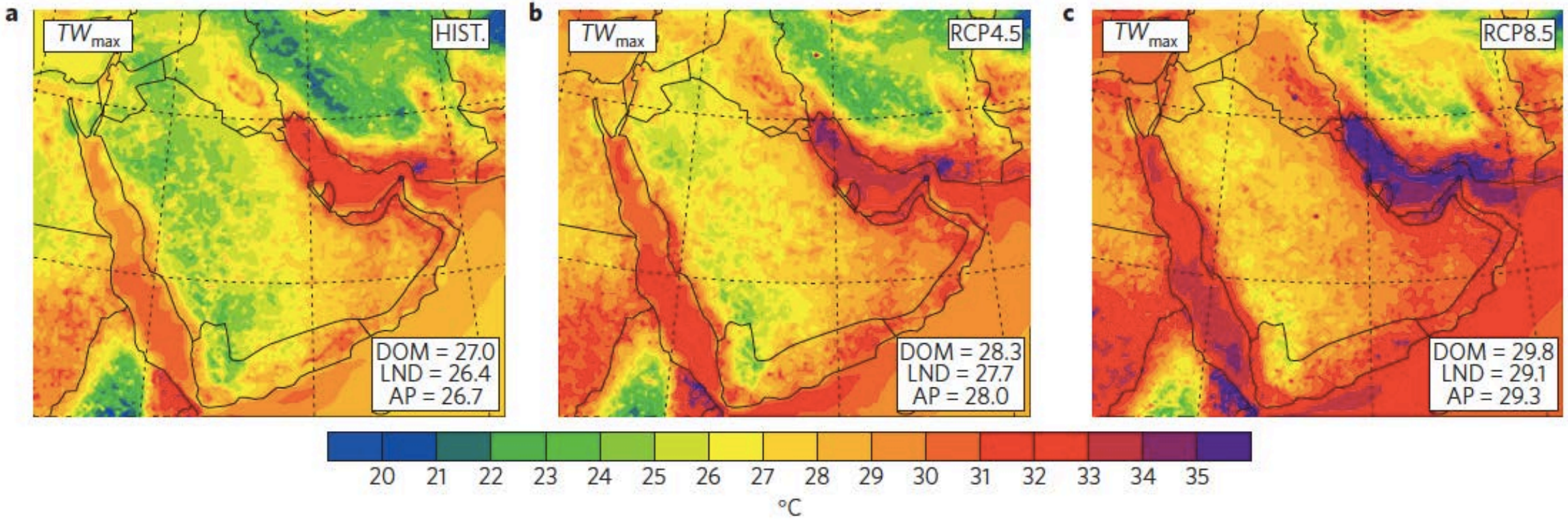
Advance warning 4 months lead time

Weather extremes → health extremes

Future temperature in southwest Asia projected to exceed a threshold for human adaptability

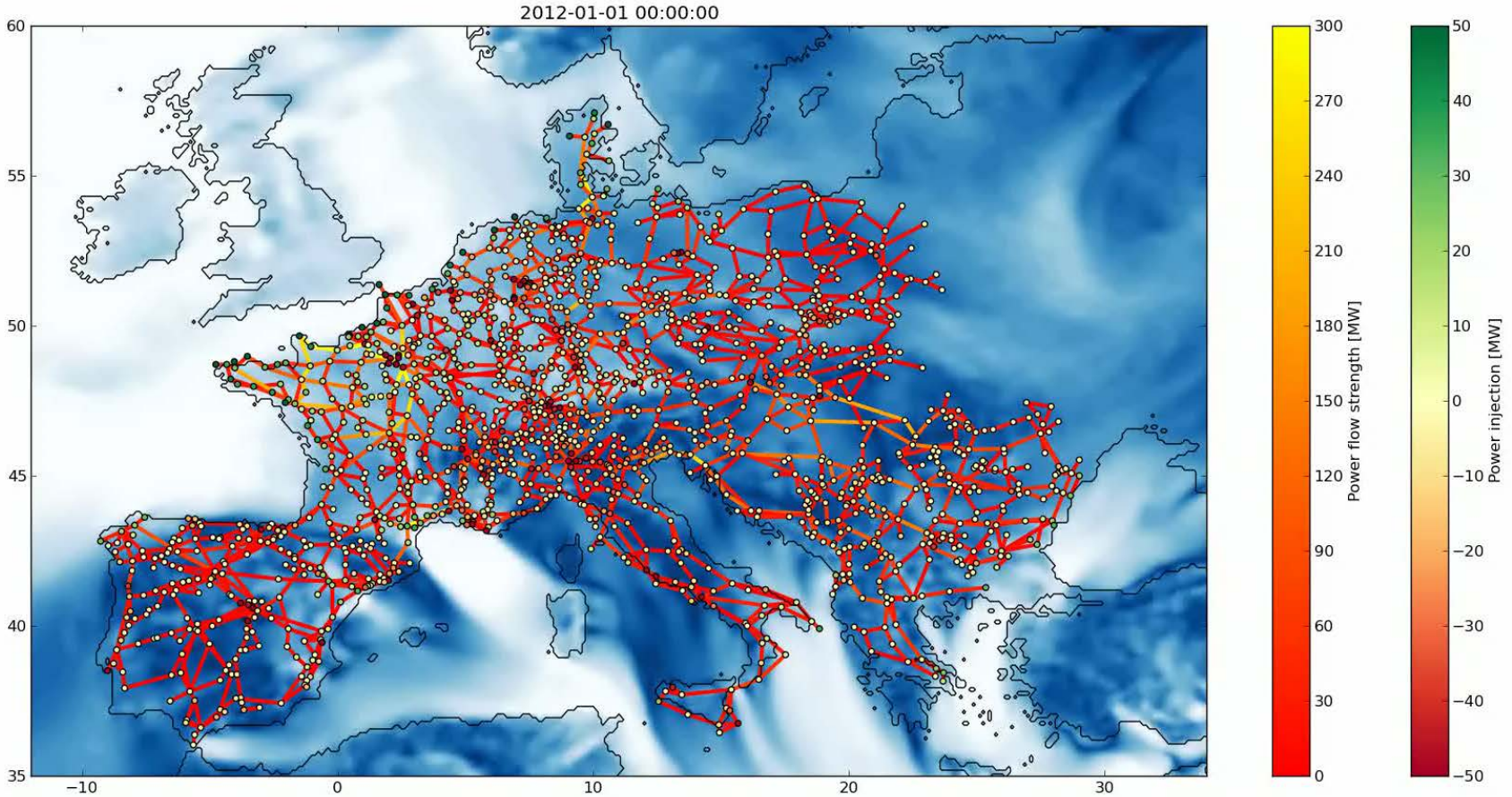
Jeremy S. Pal[1,2] and Elfatih A. B. Eltahir[2]*

nature climate change
LETTERS
PUBLISHED ONLINE: 26 OCTOBER 2015 | DOI: 10.1038/NCLIMATE2833



RCP8.5 ensemble predictions cause life threatening wet bulb temperature regimes

Weather extremes → energy extremes



[Courtesy Pierre Pinson DTU]

The grand forecasting challenge:

Predict renewable power generation, dynamic uncertainties, and space-time dependencies at once for Europe

(…with a changing climate)

Better predictions from growth in multiple dimensions

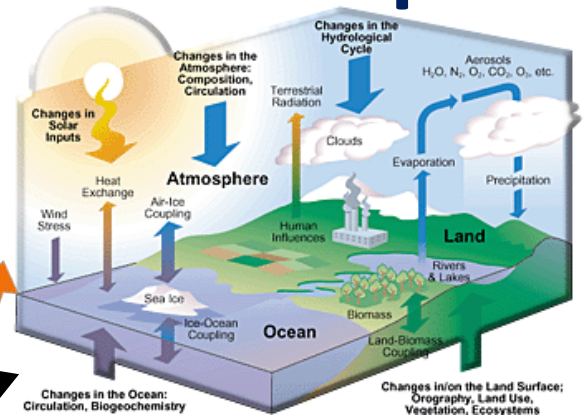
Computer power

Model complexity

Model resolution

Today

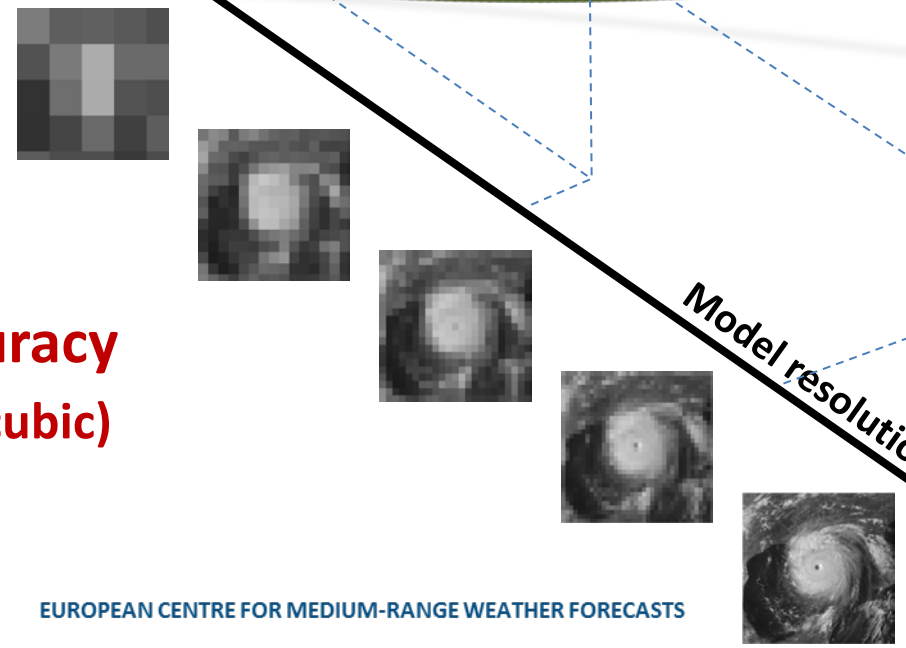
Tomorrow



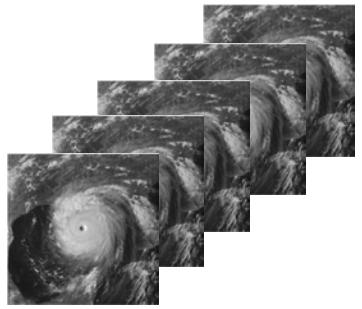
→ Range
(cost: linear-quadratic)

→ Reliability
(cost: linear)

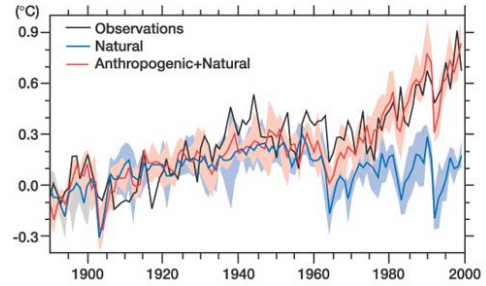
→ Accuracy
(cost: cubic)



Ensembles



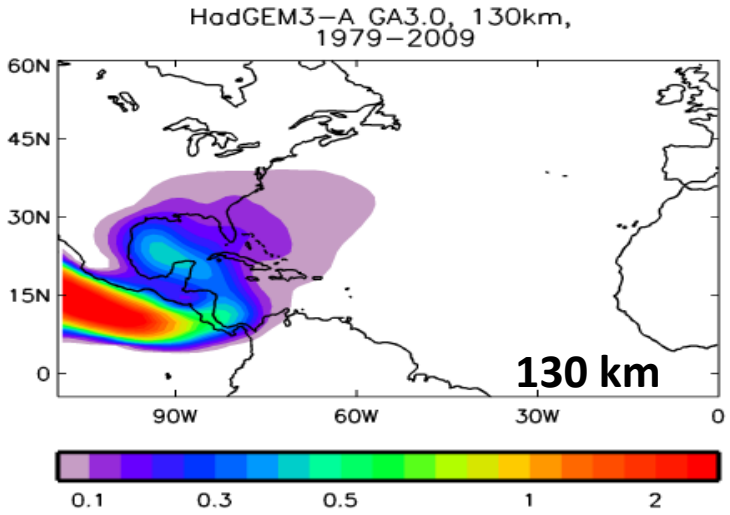
Long climate runs

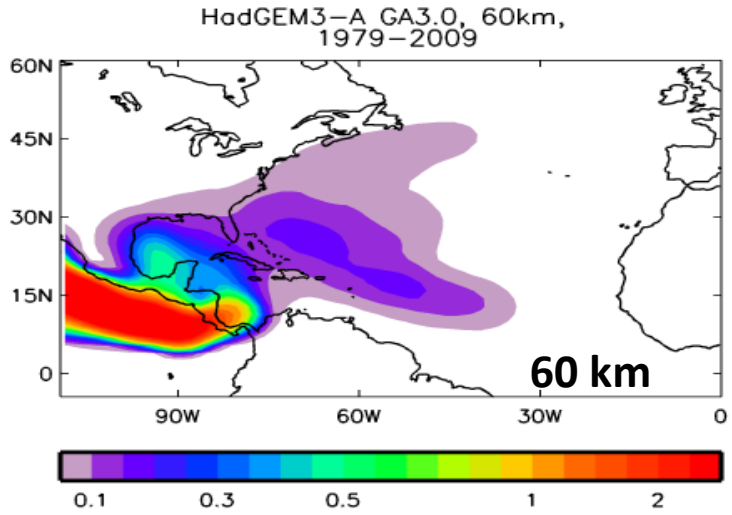


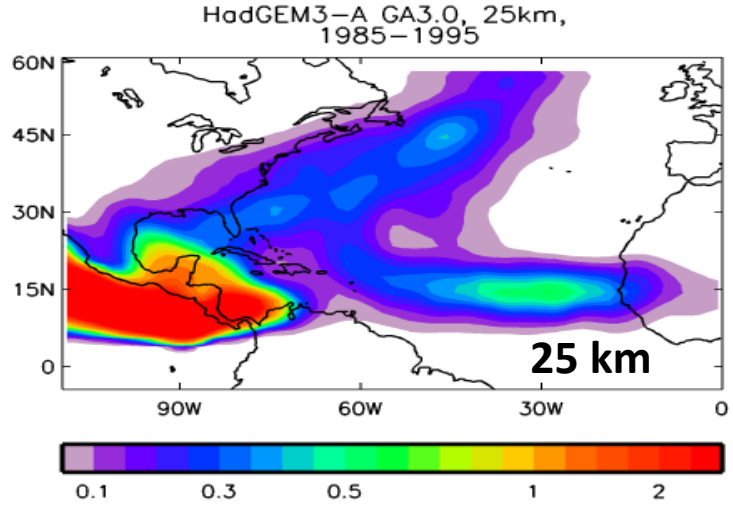
The importance of resolution

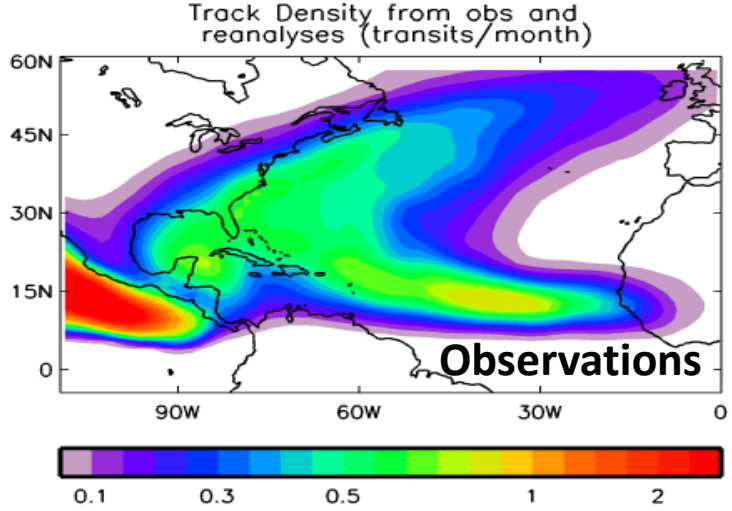
Impact on simulated tropical cyclones

HADGEM3
PRACE UPSCALE
PL Vidale (NCAS)
M Roberts (MO/HC)

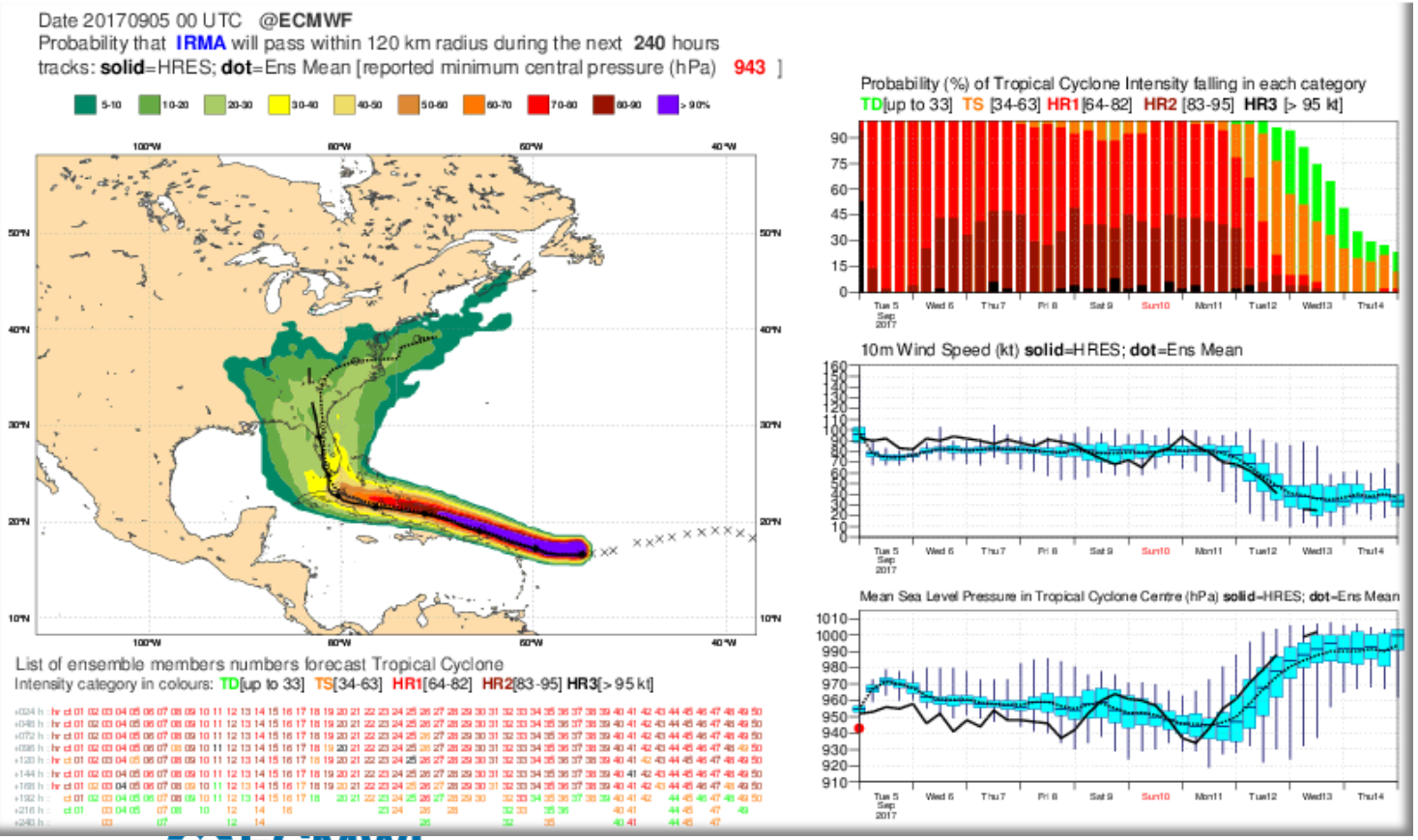


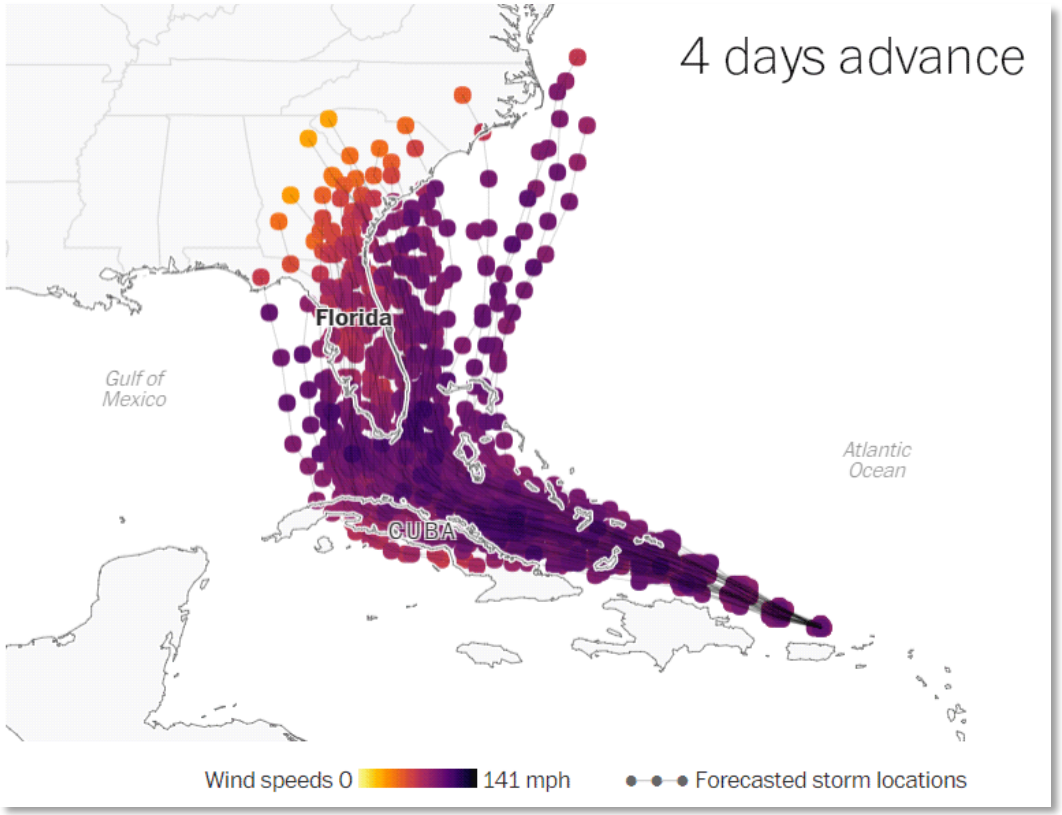




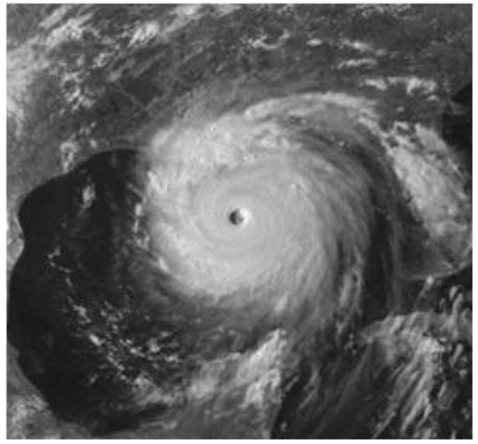


The importance of ensembles



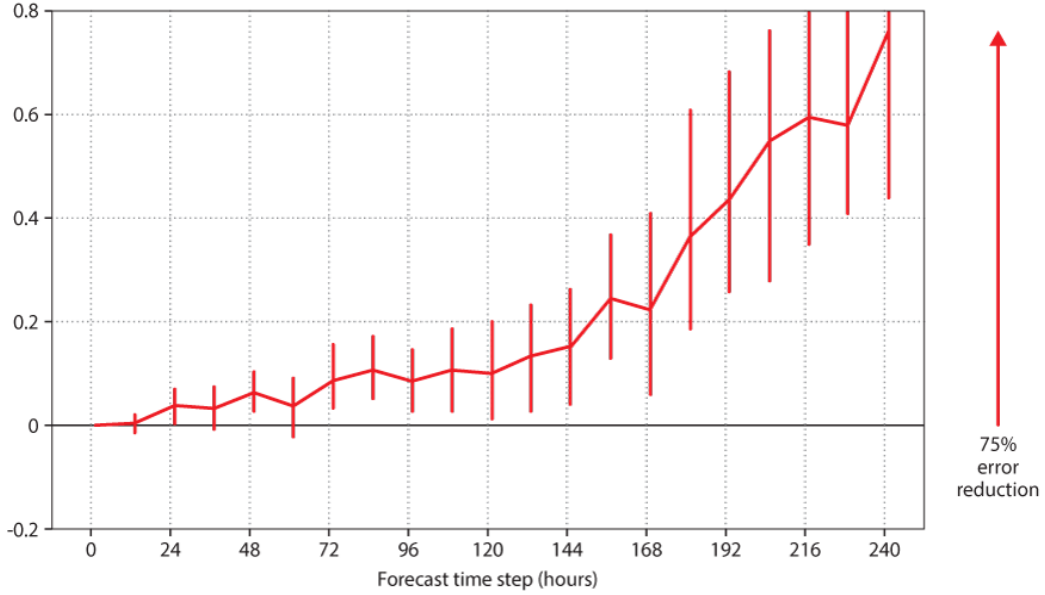


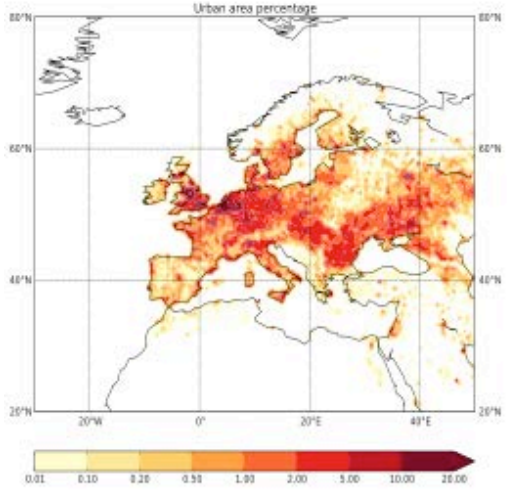
The importance of Earth-system complexity



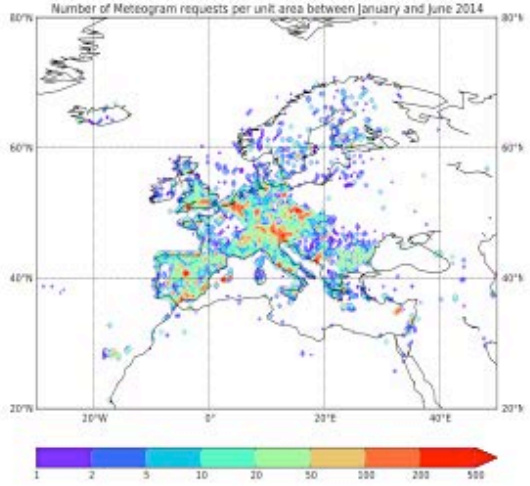
Mean absolute error reduction of forecasts of tropical cyclones intensity when ocean coupling is activated.

Period May 2016 – January 2017. Bars indicate 95% confidence intervals.

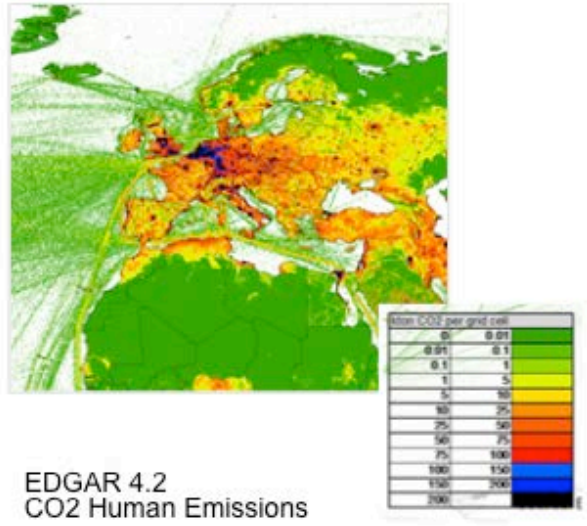




Urban area (in %, from ECOCLIMAP, Masson et al., 2003)



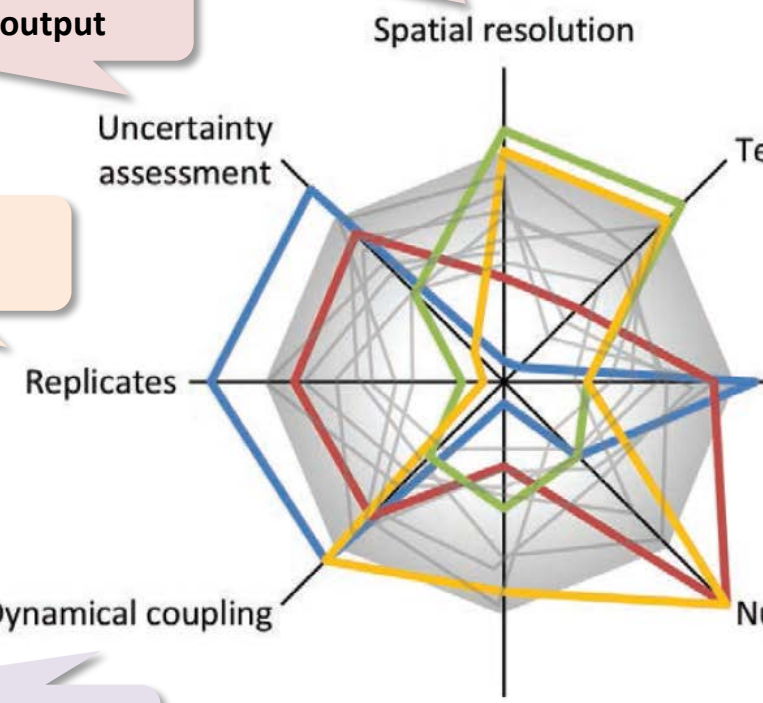
Number of ECMWF Meteograms product requests from Member-States



EDGAR 4.2
CO2 Human Emissions

Need to include urban areas for weather forecasting and emission monitoring

Can’t have it all?



- quadratic # grid points
- **global communication**
- **memory limited**

- depends on spatial resolution
- **strictly sequential**
- different for atmosphere, ocean

- **strictly sequential**
- **time to solution** (weather vs climate)

- number of prognostic variables
- **memory limited**

- number of prognostic variables
- **memory limited**

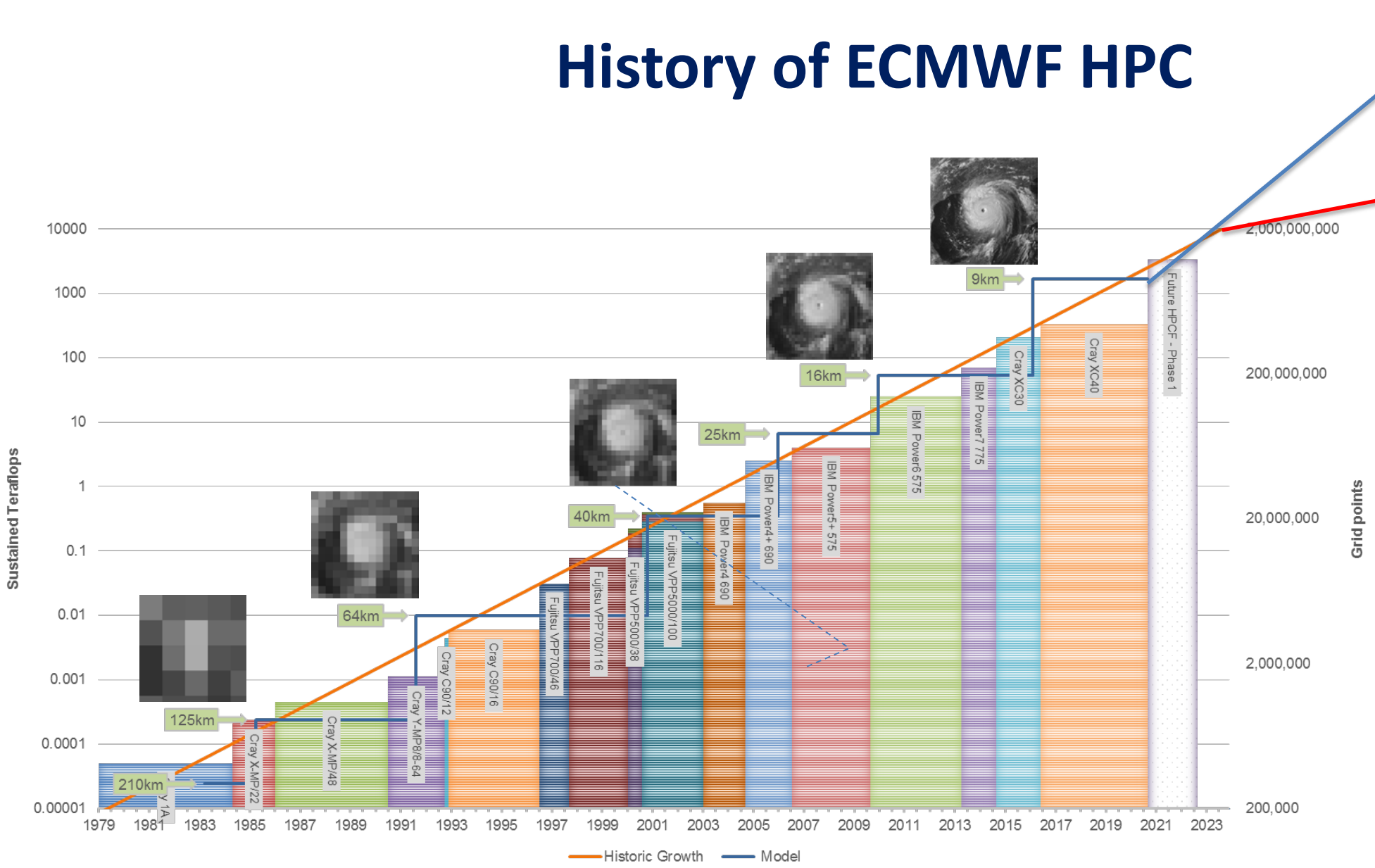
- communication of data between models
- **latency between models**

- multiplies entire model compute
- multiplies entire model output

- **multiplies entire model compute**
- **multiplies entire model output**

[Smith et al. 2014]

History of ECMWF HPC



Divergence no.1: Sustained – peak performance

Divergence no.2: Earth-system model degrees of freedom – Moore's law

Machine	Sustained/Peak %
Cray 1A	31%
Cray X-MP/22	50%
Cray X-MP/48	48%
Cray Y-MP8/8-64	42%
Cray C90/12	39%
Cray C90/16	39%
Fujitsu VPP700/46	31%
Fujitsu VPP700/116	30%
Fujitsu VPP700E/48	31%
Fujitsu VPP5000/38	30%
Fujitsu VPP5000/100	30%
IBM Power4 690	6%
IBM Power4+ 690	8%
IBM Power5+ 575	11%
IBM Power6 575	8%
IBM Power7 775	5%
Cray XC30	6%
Cray XC40	4%

Expected data growth

Data acquisition

50x more observational data per day

Forecast run

Product generation

2000x more model data per time step

25x more forecast product data per day in critical path

30x more data sent to customers per day in critical path

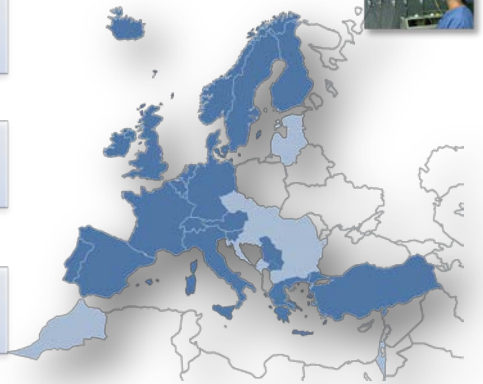
Dissemination

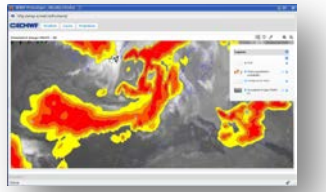
RMDCN

Internet

Web services

Internet





100x more data archived per day

Archive

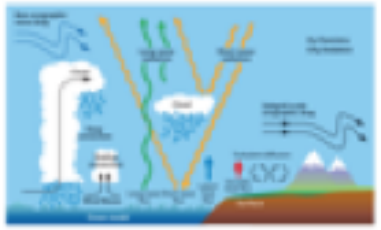
Data Handling System

Today: ~2 Pbyte per week!

Total archive: ~ 250 Pbyte

Future models

Domain science

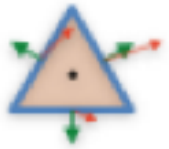


Physics

$$\rho\dot{\mathbf{u}} = -\nabla p + \rho g - 2\Omega \times (\rho \mathbf{u}) + f$$
$$\dot{p} = -\left(\frac{c_{pd}}{c_{vd}}\right) p \nabla \cdot \mathbf{u} + \left(\frac{c_{pd}}{c_{vd}} - 1\right) Q_h$$
$$\rho c_{pd} \dot{T} = \dot{p} + Q_h$$

Mathematical description

$$\nabla \cdot \mathbf{v} := \frac{1}{A} \sum_{k \in \mathcal{E}} \mathbf{v}_k \cdot \mathbf{l}_k$$

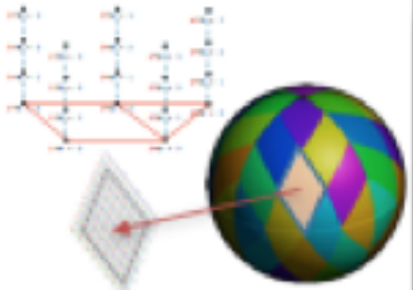


Algorithm development

```
on_edges( sum_reduction, v(), l() ) / A()
```

Domain specific language (GridTools)

Multidisciplinary Abstractions



memory layout, parallelisation, & data structures

OpenACC

OpenMP

NVIDIA CUDA

MPI

Programming models & libraries

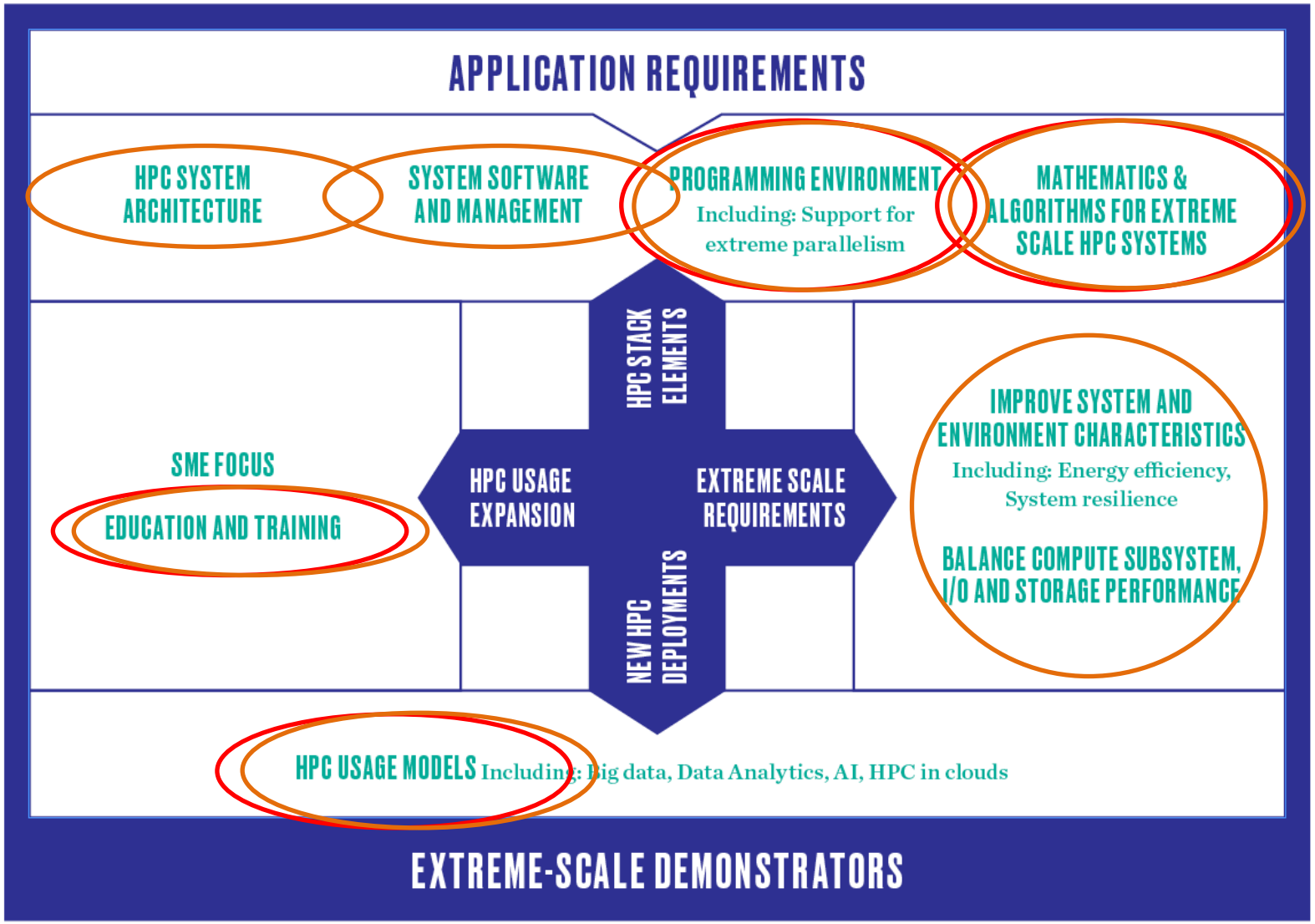
Hardware specific instructions

← Better methodology: Algorithmic flexibility

← Better computing: Hardware flexibility

Forecasting system redesign: exaFLOPS or extreme-scale?

ETP4HPC SRA-3

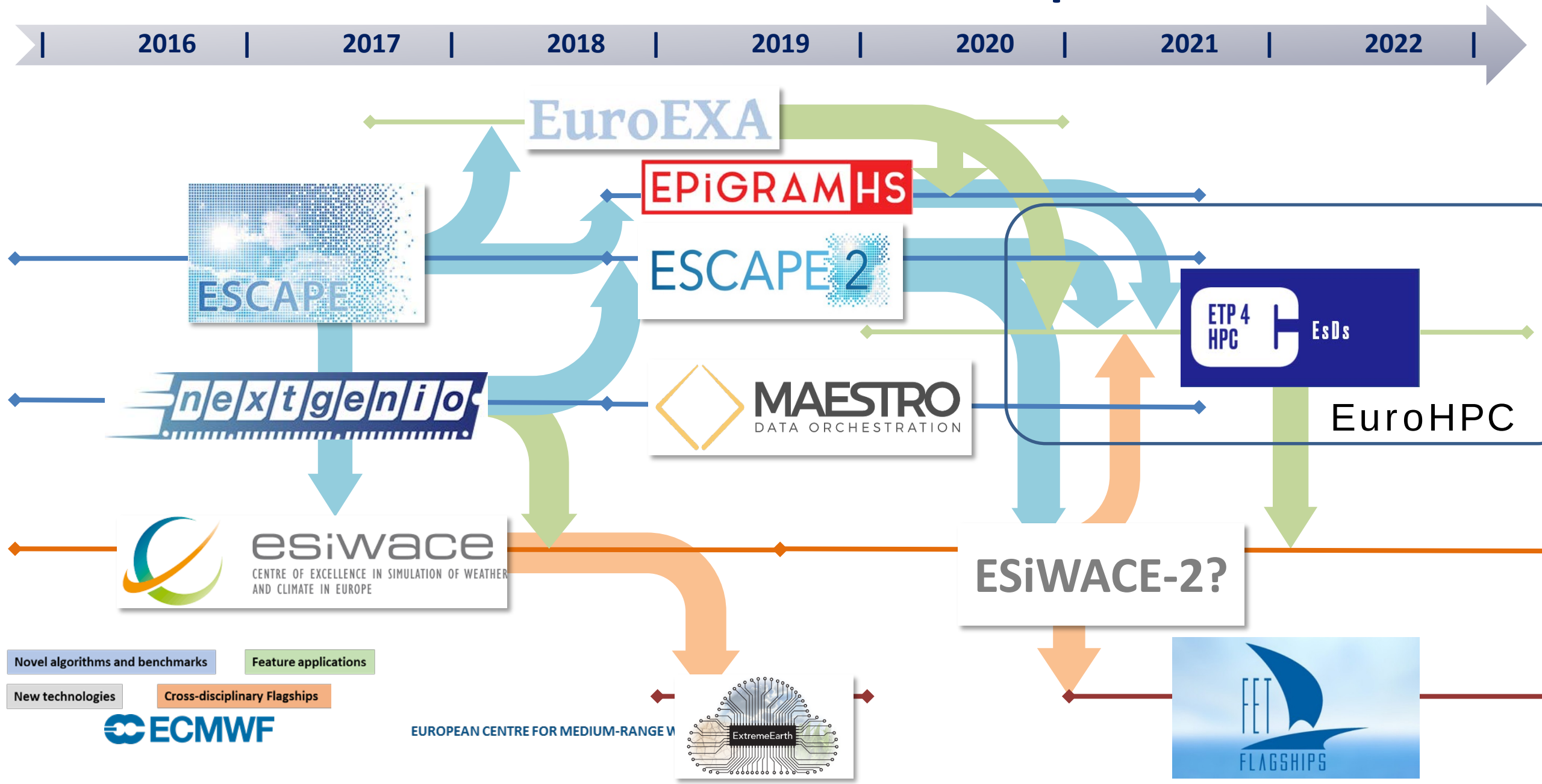


No.1 focus areas of weather&climate community for enhancing sustained performance on <u>exaFLOPS</u> machines

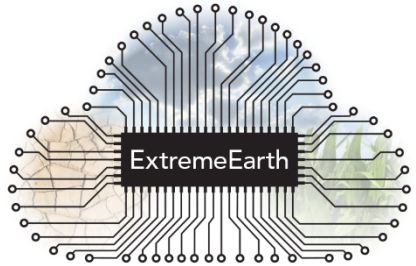
No. 1 focus areas of weather&climate community for achieving true <u>extreme-scale</u> performance

ECMWF

Weather and Climate roadmap in H2020



Future forecasting systems



Science

Weather & climate

Hydrology & water

Energy

Food & agriculture

Disasters & risks

Health

Solid Earth

Co-Design

Advanced mathematics & algorithms

Multi-scale/multi-physics models

Separation of concerns methods: science & technology

Software stack & hardware components

End-to-end demonstrators

Technology

Numerical modelling

Data assimilation & fusion

Deep learning

Programming models

Extreme computing & storage

Edge and cloud computing

Workflows & data handling

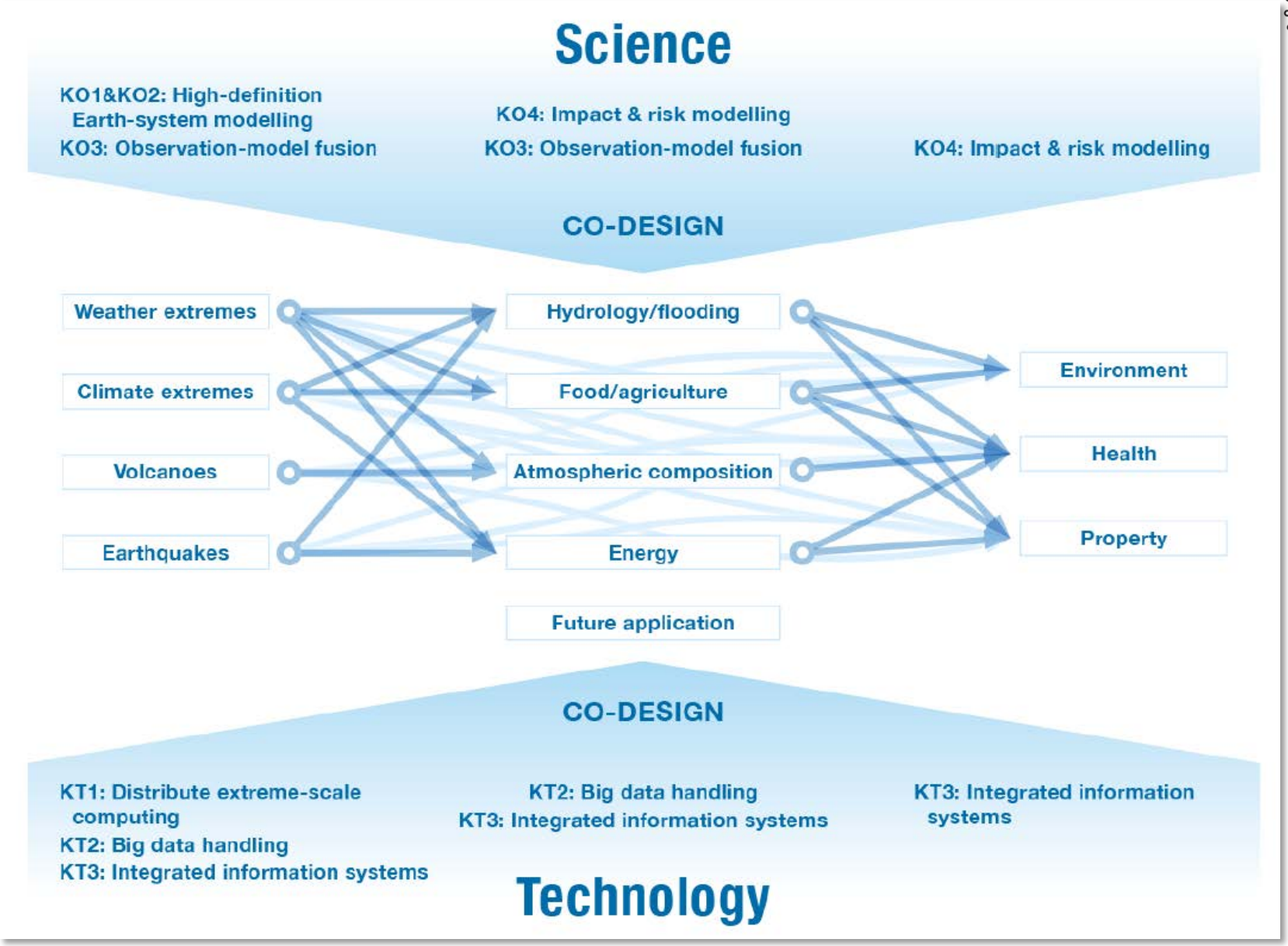
Ultra high-resolution, integrated Earth-system & impact modelling capability

Integrated exascale Earth-system data analytics & management capability

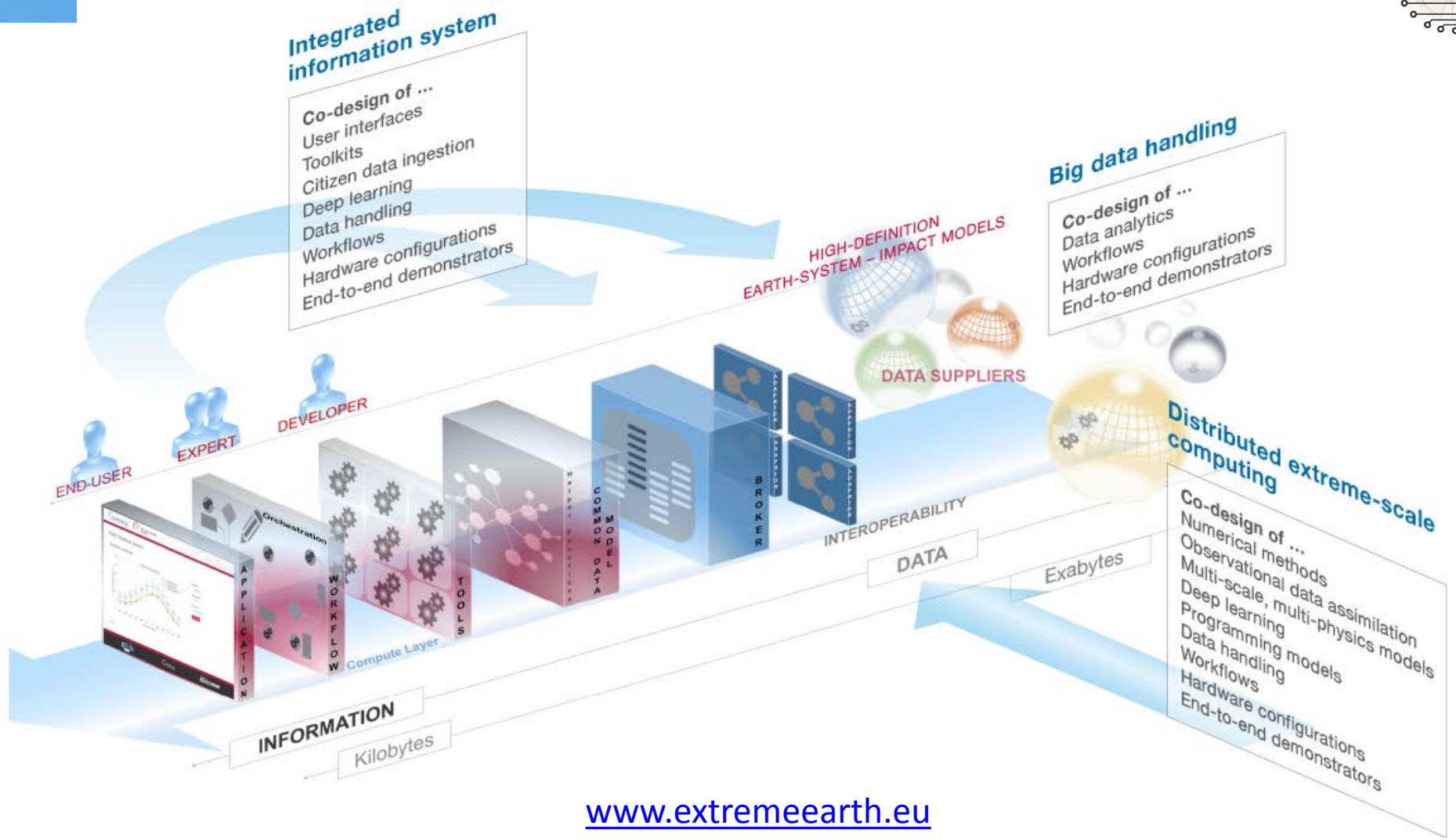
Earth-system HPC technology and exascale capability

Integrated Earth-system information system capability

ExtremeEarth Flagship proposal



ExtremeEarth Flagship proposal

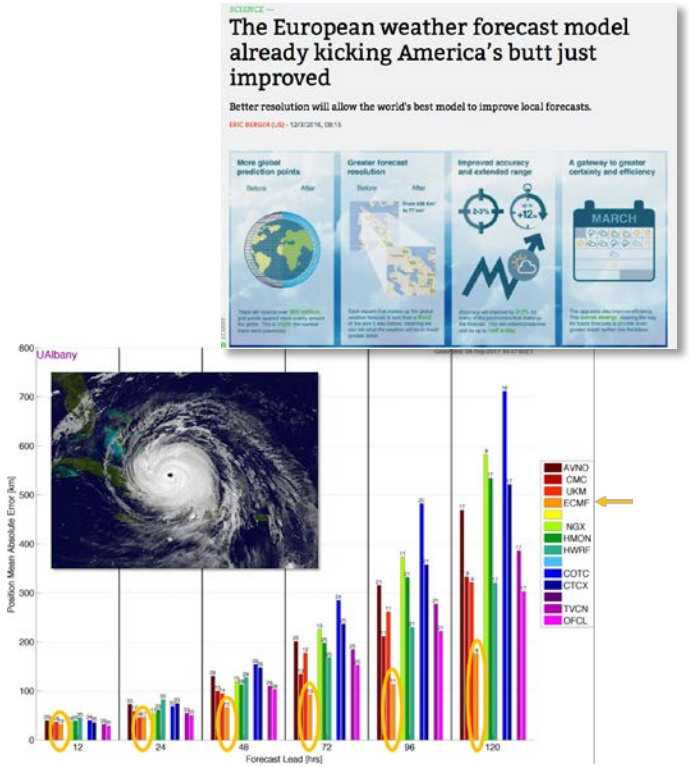


www.extremeearth.eu

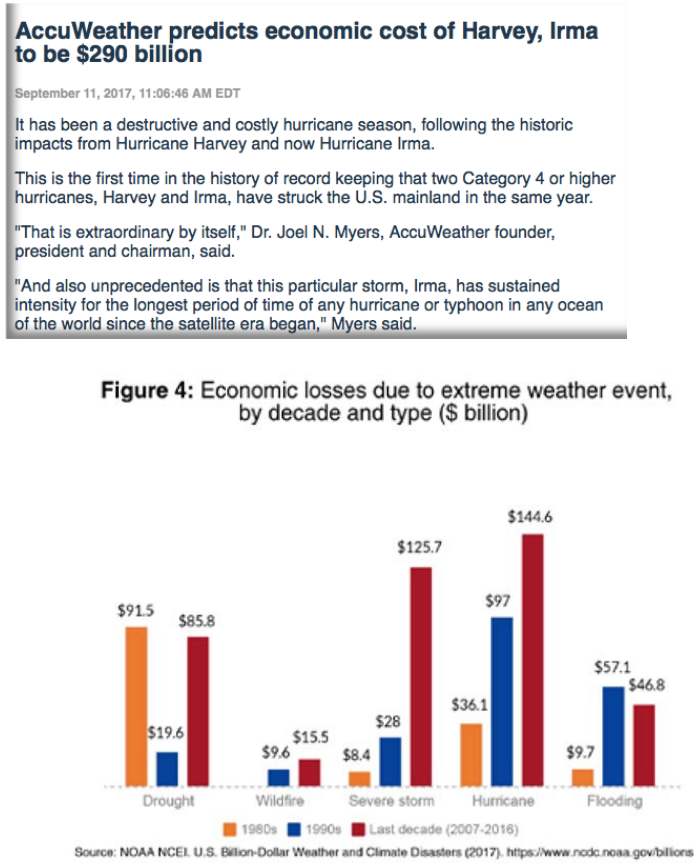
What is unique about weather & climate prediction?

(and why is it a perfect application for European technology leadership?)

1. European science leadership:



2. Outstanding socio-economic impact:



3. Limited by HPC & BD capabilities: