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

European Centre for Medium-Range Weather Forecasts

Independent intergovernmental organisation
established in 1975
with
34 Member States & Co-operating States
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
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!

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.

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

At times during Harvey, the European model outperformed humans

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

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 Dorian. 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...”
Weather extremes $\rightarrow$ 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$^2$

RCP8.5 ensemble predictions cause life threatening wet bulb temperature regimes
Weather extremes → energy extremes

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

- **Accuracy** (cost: cubic)
- **Range** (cost: linear-quadratic)
- **Reliability** (cost: linear)

Model resolution

Model complexity

Computer power

Ensembles

→ Long climate runs

Observations
Natural
Anthropogenic-Natural
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.

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
- Time to solution (weather vs climate)
- Number of prognostic variables
- Memory limited
- Communication of data between models
- Latency between models
- 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

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</table>
Expected data growth

Today: ~2 Pbyte per week!
Total archive: ~ 250 Pbyte
Future models

← Better methodology: Algorithmic flexibility

← Better computing: Hardware flexibility
No. 1 focus areas of weather&climate community for achieving true extreme-scale performance

No. 1 focus areas of weather&climate community for enhancing sustained performance on exaFLOPS machines
Weather and Climate roadmap in H2020


EuroEXA

ESCAPE

EPiGRAM HS

ESCAPE 2

nextgenio

MAESTRO

Data Orchestration

MAESTRO

ESiWACE 2?

ESiWACE

ESoEs

ETP 4 HPC

EuroHPC

ESoEs

Novel algorithms and benchmarks

Feature applications

New technologies

Cross-disciplinary Flagships

ECMWF

EUROPEAN CENTRE FOR MEDIUM-RANGE V

ExtremeEarth
**ExtremeEarth Flagship proposal**

**Science**

KO1&KO2: High-definition Earth-system modelling  
KO3: Observation-model fusion  
KO4: Impact & risk modelling

**CO-DESIGN**

- Weather extremes  
- Climate extremes  
- Volcanoes  
- Earthquakes  
- Hydrology/flooding  
- Food/agriculture  
- Atmospheric composition  
- Energy  
- Environment  
- Health  
- Property  
- Future application

**Technology**

KT1: Distribute extreme-scale computing  
KT2: Big data handling  
KT3: Integrated information systems
ExtremeEarth Flagship proposal

www.extremeeearth.eu
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