The future of climate modelling

An artist's impression of Richardson's forecast factory
(thanks to Francois Schuiten for permission to reproduce image)
http://www.ucd.ie/news/dec06/121506_weather_forecast.htm

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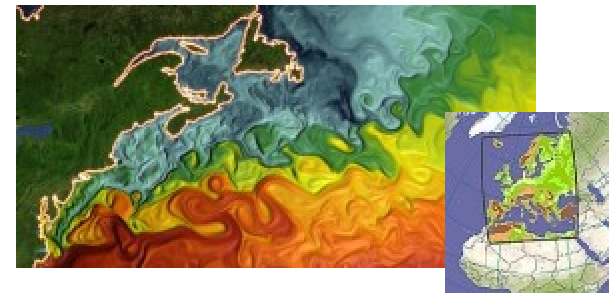
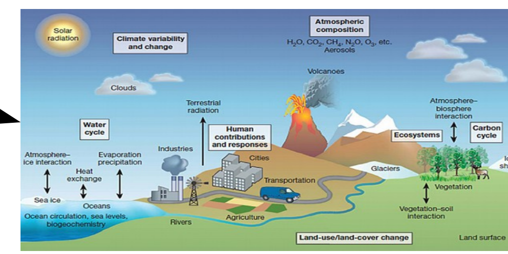
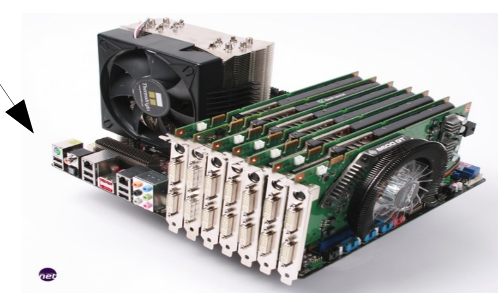




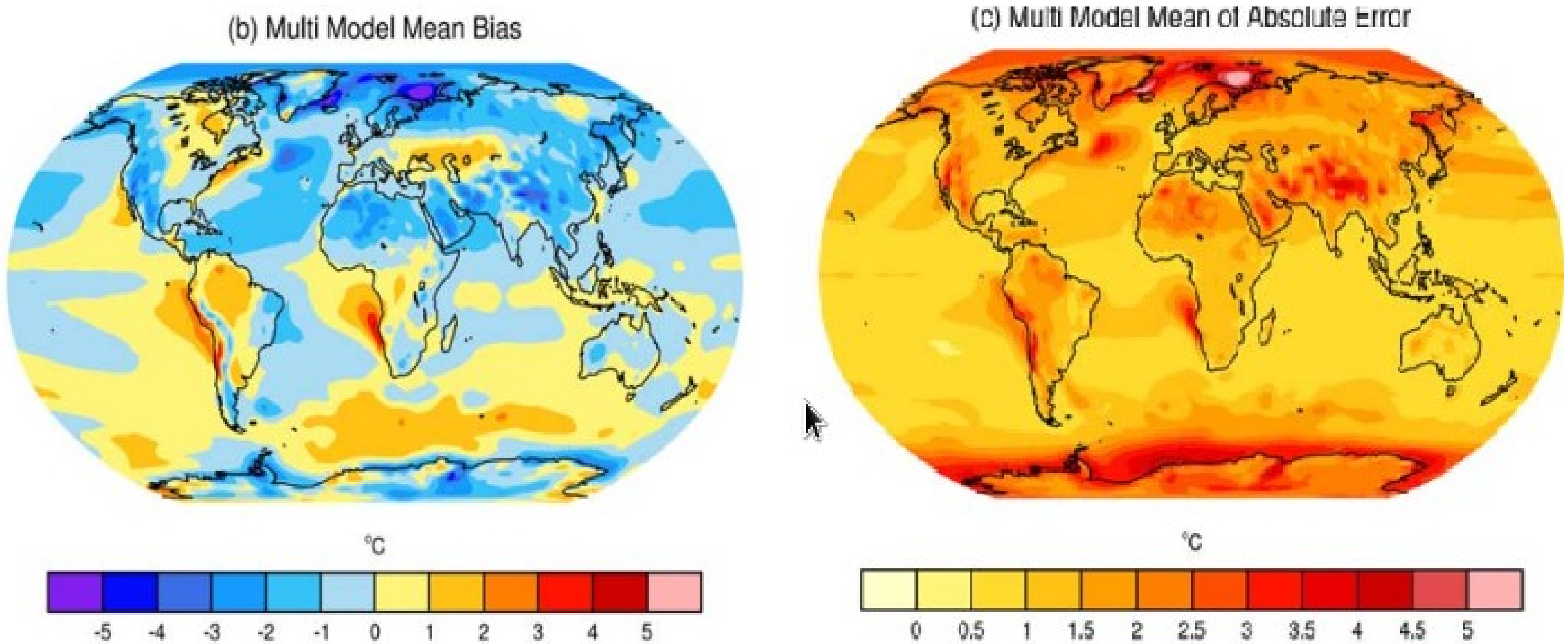


Where are we today?

- GCMs, ESMs, RCMs
- Model uncertainty range is estimated in comparison with other models, without any systematic selection scheme for models
- Model output is utilized until better version are available.
- Processes: most severe challenges in clouds, radiation, sea ice, … with impact on large scale patterns and variability
- Resolution:
  - ESMs: 100 – 200 km (atm)
  - GCMs: down to 20 km
- Well organized internationally (CMIP, CORDEX)
- User communities interested in a large range of scales from global – local
- Major political ambitions are formulated based on scientific knowledge informed by climate models (COP-21 Paris treaty)

SMHI

Climate models have biases

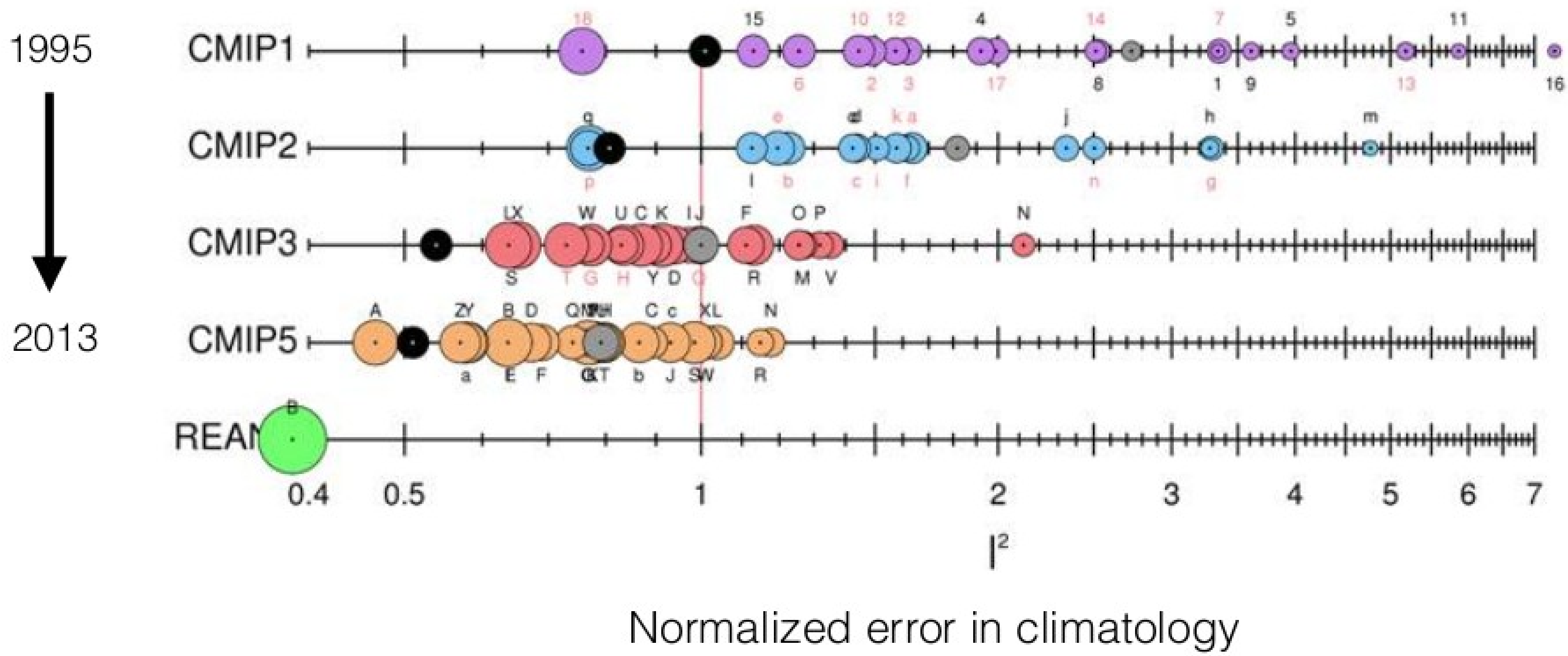


IPCC: “With few exceptions, the absolute error (outside polar regions and other data-poor regions) is less than 2°C. Individual models typically have larger errors, but in most cases still less than 3°C, except at high latitudes … . Some of the larger errors ... may result simply from mismatches between the model topography and the actual topography. There is also a tendency for a slight, but general, cold bias. Outside the polar regions, relatively large errors are evident in the eastern parts of the tropical ocean basins, a likely symptom of problems in the simulation of low clouds. The extent to which these systematic model errors affect a model’s response to external perturbations is unknown, but may be significant (see Section 8.6). In spite of the discrepancies discussed here, the fact is that models account for a very large fraction of the global temperature pattern: the correlation coefficient between the simulated and observed spatial patterns of annual mean temperature is typically about 0.98 for individual models. This supports the view that **major processes governing surface temperature climatology are represented with a reasonable degree of fidelity** by the models.”

SMHI

Model biases decrease over time

Thomas Reichler



- Multi-model mean scores better: model errors average out

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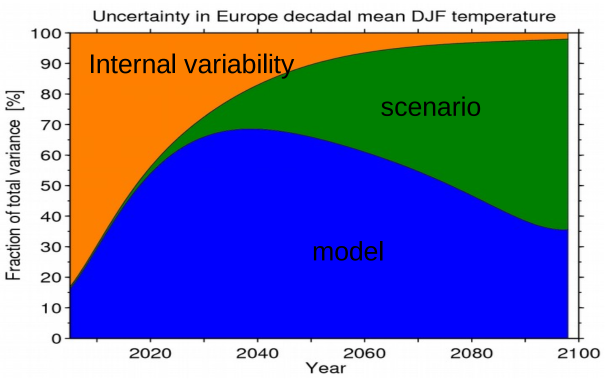
The motivation for further development

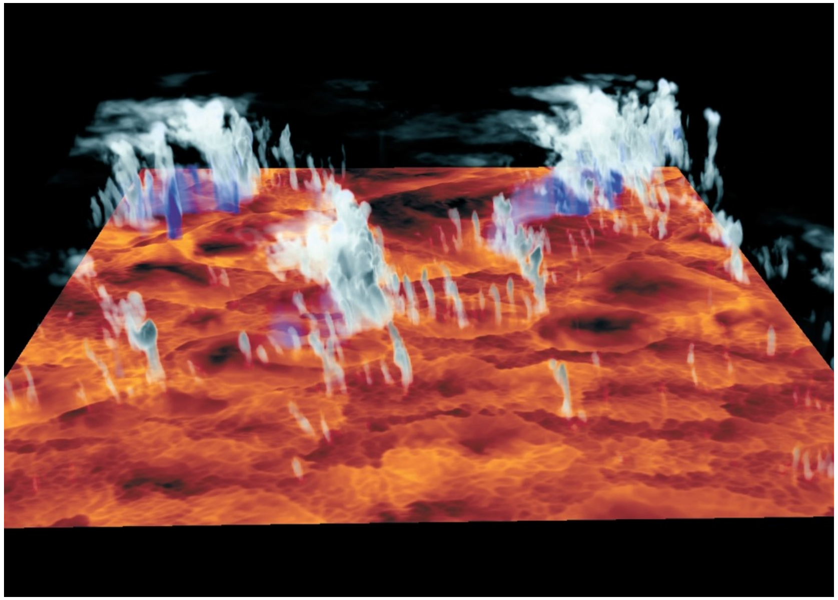


Hawkins and Sutton (2009)

- Reduce model errors and biases (processes, teleconnections, numerics, etc)
- Better map the overall projection uncertainty
- Better tools to explore climate and earth system processes
- More relevant regional and local information for impact research and climate services
- Better tools for exploring consequences of alternative emission and land use pathways
- Better climate prediction (“reliability”, “predictability”)

Extreme global resolution?

- Better by definition
- Resolve ocean eddies and individual cloud systems to become represented explicily, as a regime shift towards reduced biases
- Better ability to describe and understand the origins of extremes and how they may change.
- Requires new forms of collaboration in the community
- Remote drivers of regional climate change requires global models
- Combining with global downscaling
-

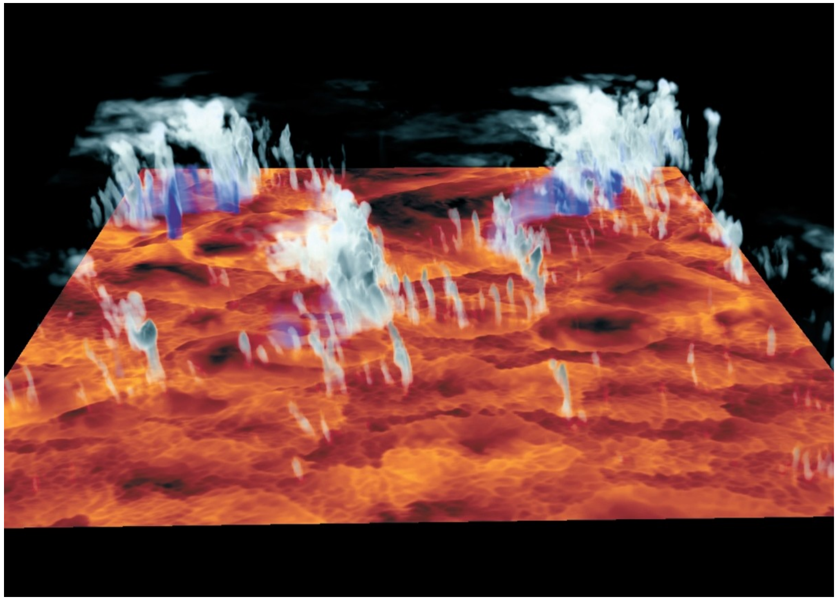


Simulation of convective cloud systems in a limited-area high-resolution climate model, Schlemmer, MPI, 2014

Limits of extreme global resolution

- Convection-resolving models need exascale supercomputing, anticipated in the 2020's.
- Limited to short time scales due to limited HPC resources
- Careful coupled tuning is a challenge

  (if not impossible by 2020's)
  - Questions remain if the potential for more accurate projections/preditions actually can be achieved
- Resources, at the expense of other climate modelling efforts?
- Risk for reduced diversity,
  - limited possibilities to assess uncertainty
- When? used for actual climate services
- Do we benefit more from higher resolution or from standard resolution ensemble?



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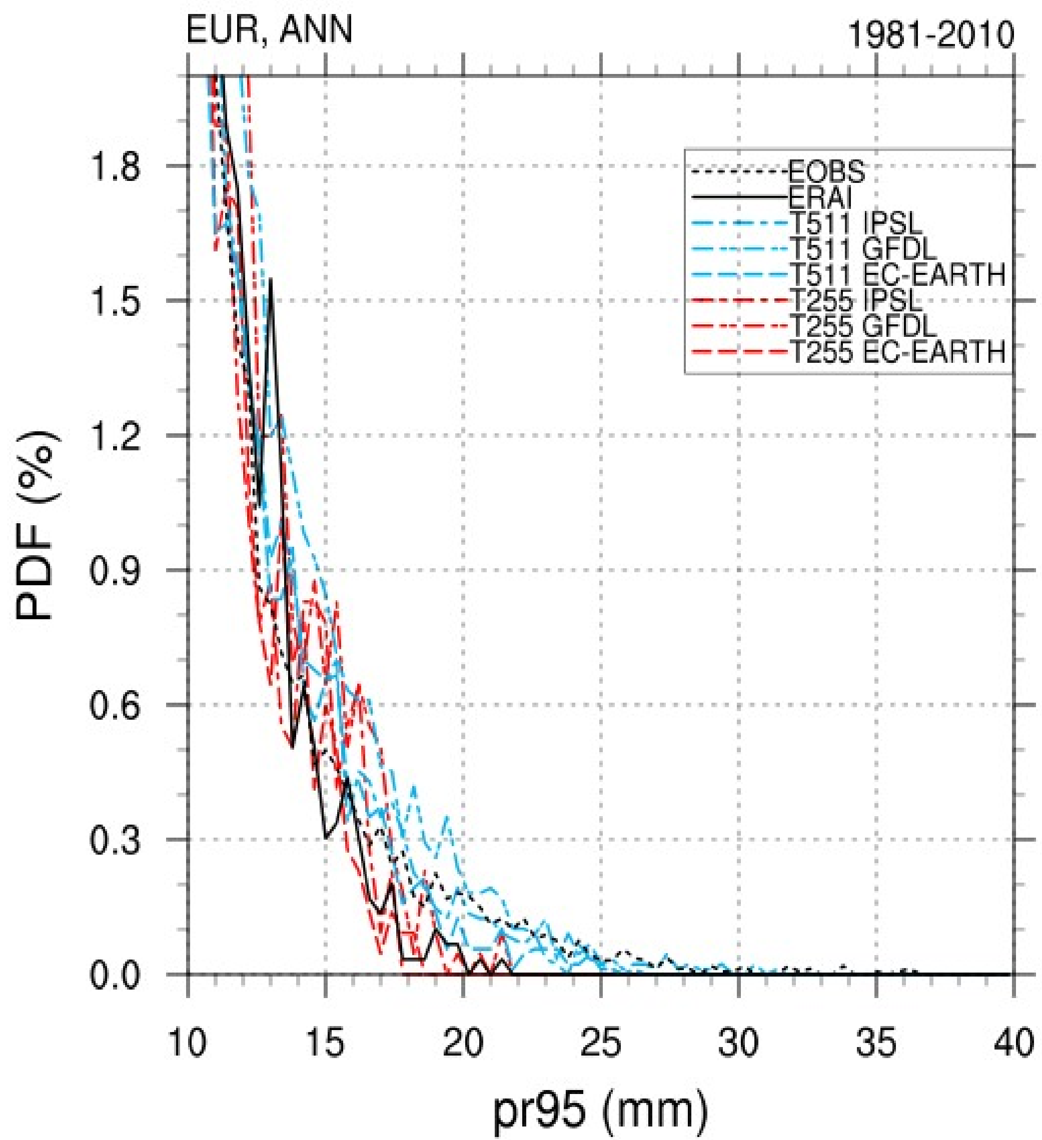
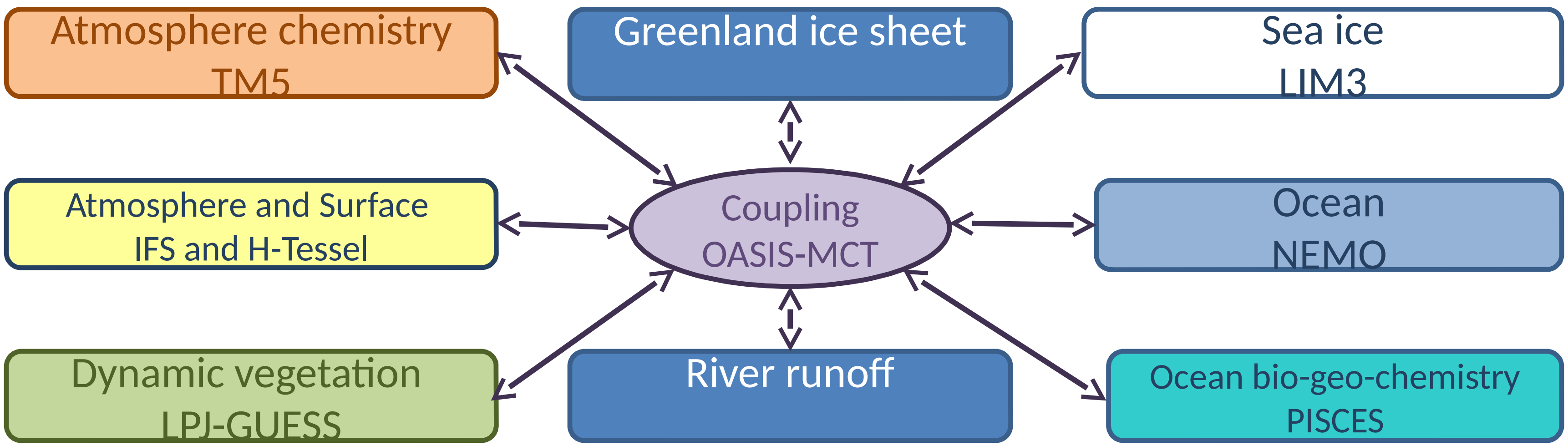
Recent example: increased resolution gives more realistic precipitation globally



Wyser and Strandberg, SMHI, HELIX

More ESM complexity



- For more complete feedbacks (e.g. carbon cycle) and additional user-relevant information
- A flexible framework for coupling many ESM components
- Moderate resolution

More ESM complexity

- Responses to a warming climate and increasing CO2 concentrations, some of which may feedback onto global climate change itself. Examples include:
  - ocean acidification, and impacts on marine ecosystems and carbon uptake
  - permafrost melt and it's socio-economic impacts and effects on methane/carbon release
  - wetland methane (CH4) emissions and
  - changing wildfire risk, associated effects on land cover, carbon uptake and emission of chemical constituents
- ESMs provide a more direct link between climate change and human activities, e.g. for near-term mitigation of aerosols, methane and black carbon, and long-term emission pathways
  - require detailed insights in biogeochemical processes and feedbacks which only ESMs can provide.
- Policy-relevant questions can be addressed by ESMs, such as; the level of CO2 emissions compatible with a given climate stabilization target (e.g. 2 deg)

Hierarchy approach

- A range of models of different complexity and resolution with a focus on
  - understanding processes
  - tracing effects through levels of complexity and resolution, rather than adding processes based on availability and without understanding interactions with existing processes.
- Much less HPC demanding than extreme resolution
- Challenges
  - Unclear if full traceability actually is possible
  - Misses the potential benefits of very high resolution

Better processes

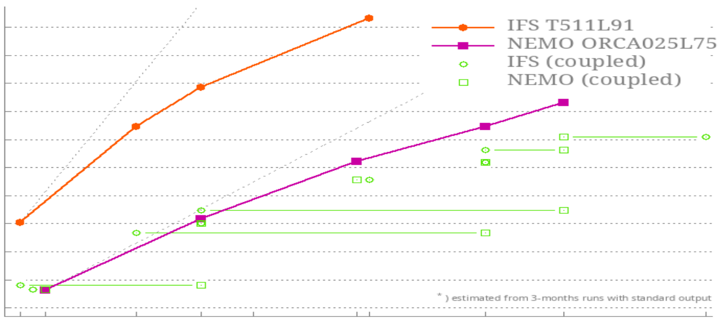
- Clouds/radiation/aerosol direct and indirect effects
- Teleconnections
  - Tropics – Europe
  - Mid-latitudes - Arctic
  - Monsoon - Arctic
- sea ice
- ESM related processes

- Stochastic parameterizations

Better numerics and codes

- Discretization should be of high order to most efficiently using computer resources (for a given accuracy)
- Apply principles of proven accuracy and stability, even for boundary conditions and interfaces (e.g. Method of Manufactured Solutions, MMS)
- Better optimization of parameterizations (tuning)
- Higher standards for model documentation, model verification and tuning
- Open code (for transparency and more efficient community engagement)
- Modular code
- Irregular grids

Efficiency



- New dynamical cores from scratch
  - MPI (ICON), MeteoFrance, ECMWF, SMHI (RCA5), ...
- Current efforts: ECMWF Scalability project, EU-ESCAPE, ...
- How many ESMs do we need?
  - Genealogy vs. model diversity is needed (and will be needed)
  - More advanced open coupling frameworks
    - Coupler, interfaces, modularity, scripting standards

Summary

- Very high resolution (1 km)
  - Is tempting and needed, but the practical potential is a challenge
  - We need to ensure that huge resource requests can co-exist with other approaches (ESMs)
- ESMs are necessary for more complete climate feedbacks, and for pressing questions on emission and mitigation pathways.
- Diversity of complementary approaches is needed. No single focus.
- Numerics need to be improved for accuracy and efficiency on upcoming computers
- Community frameworks for coupling models, to allow model diversity with limited resources

The End