



FP7 Support Action - European Exascale Software Initiative

DG Information Society and the unit e-Infrastructures

IESP Meeting - Cologne

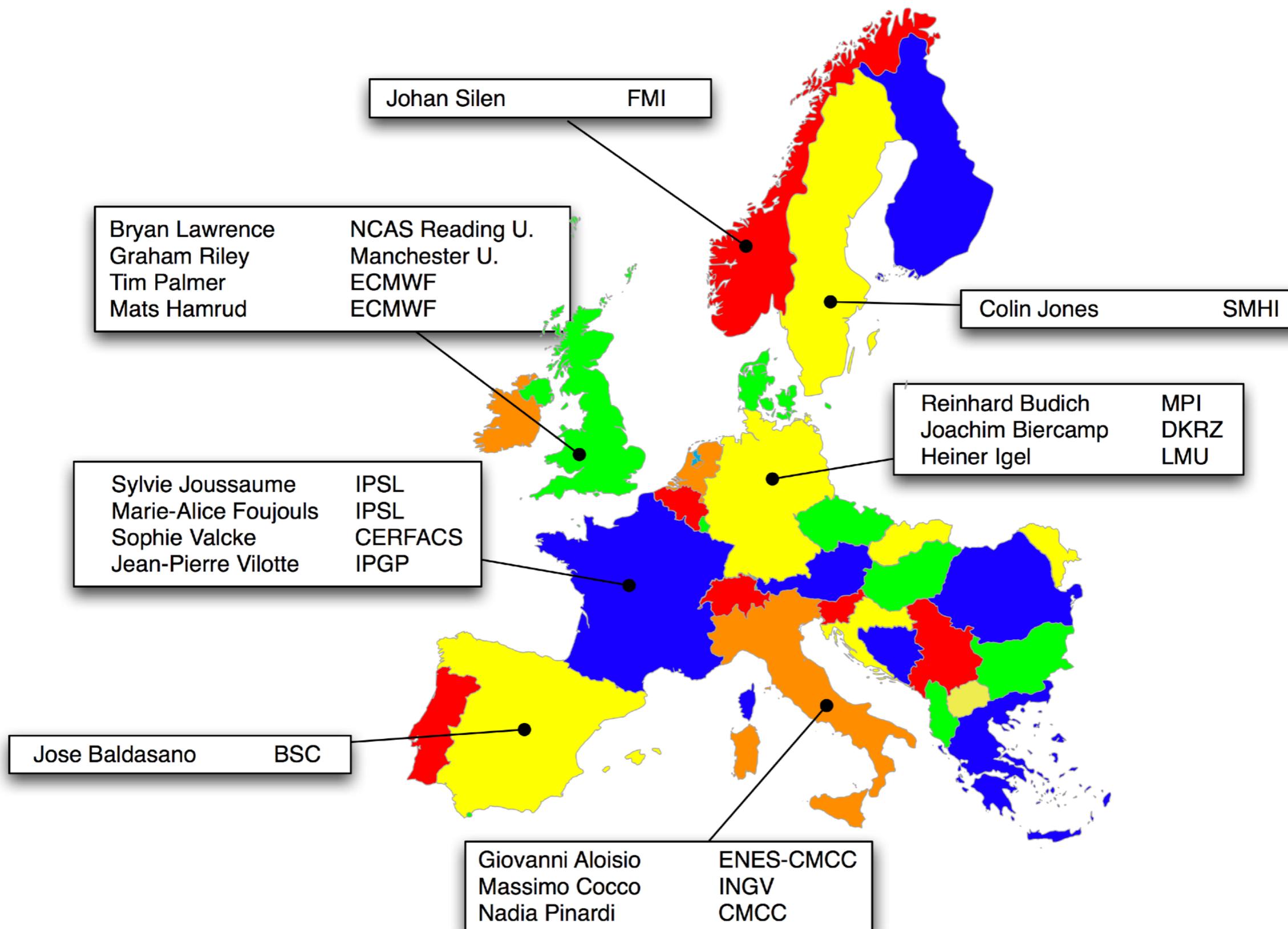
EESI WG3.2 on
Weather, Climatology & solid Earth Sciences

Speaker: prof. Giovanni Aloisio
CMCC & University of Salento
Lecce - Italy



Centro Euro-Mediterraneo
per i Cambiamenti Climatici

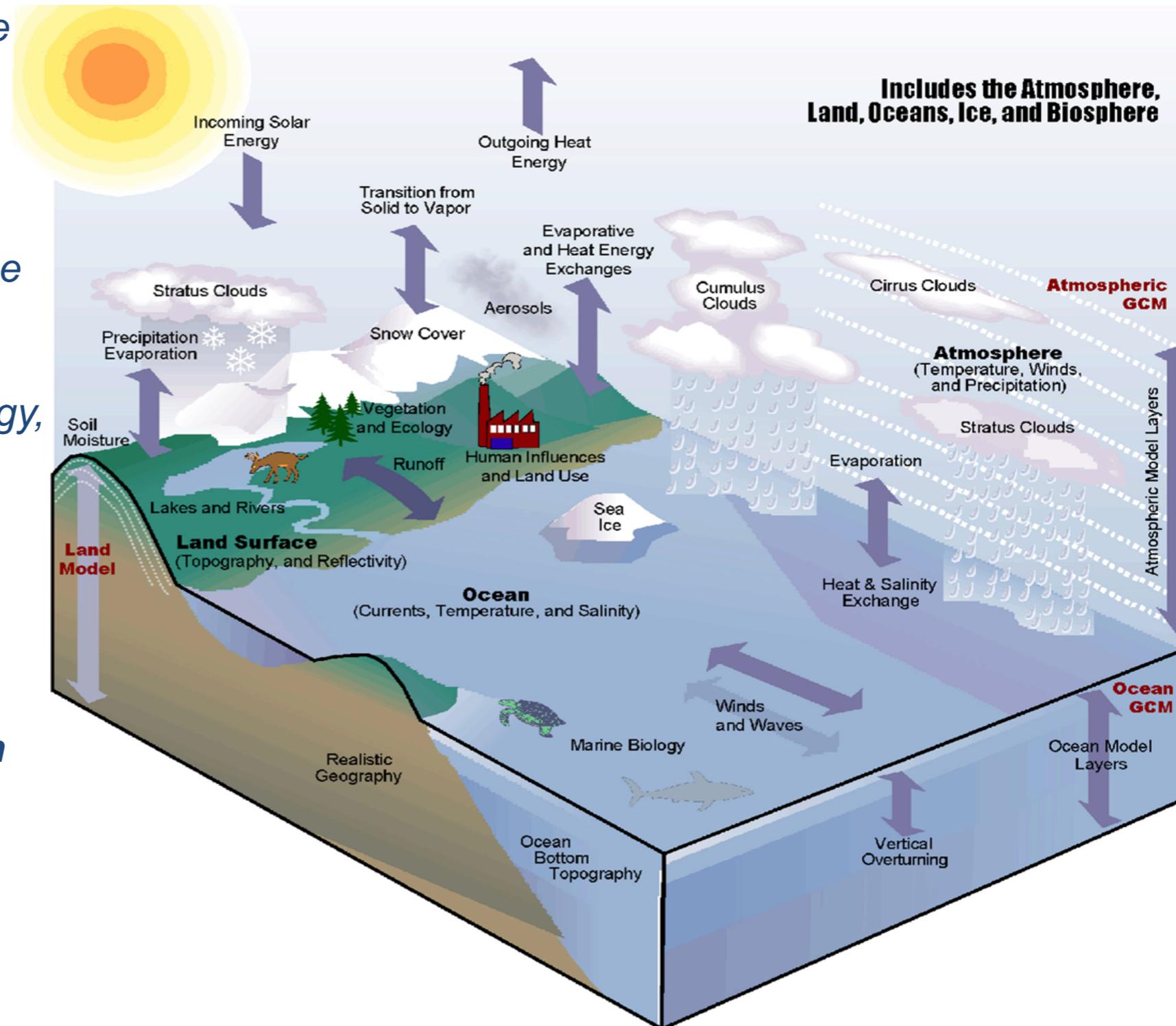
The conclusions of the WCES panel



- The **main goal** of the WCES Working Group is:
“to provide a coherent and integrated vision/roadmap towards Exascale, focusing on the main issues, requirements and expectations coming from the Weather, Climate and solid Earth Sciences communities.
- *To achieve this goal the working group composition has taken into account the multifaceted and heterogeneous aspects connected with the WCES domains*

The Earth System complexity – a big challenge

- Several **complex processes** to be simulated
- Several **interacting processes**
- Great range of **time scales** to be analyzed
- Great range of **spatial scales** to be considered
- Need **interdisciplinary sciences** (physics, chemistry, biology, geology, seismology...)
- Inherently **non-linear governing equations**
- Need **sophisticated numerics**
- Need **huge computational resources**
- ...and large volumes of data can be produced



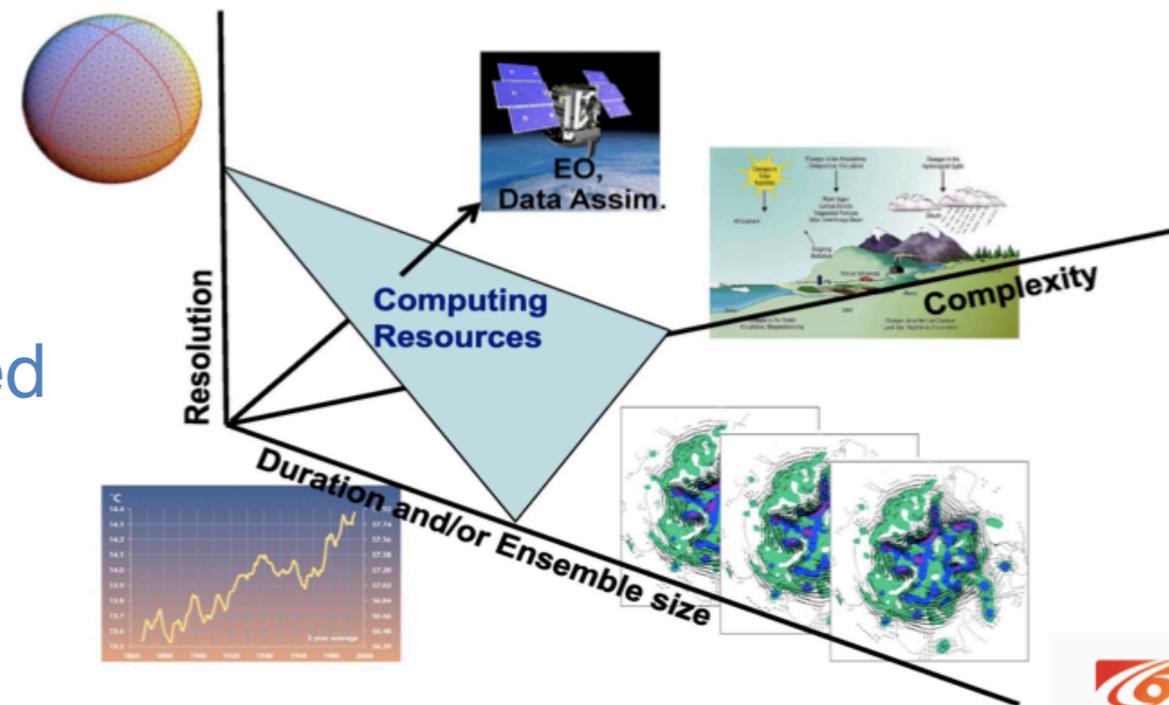
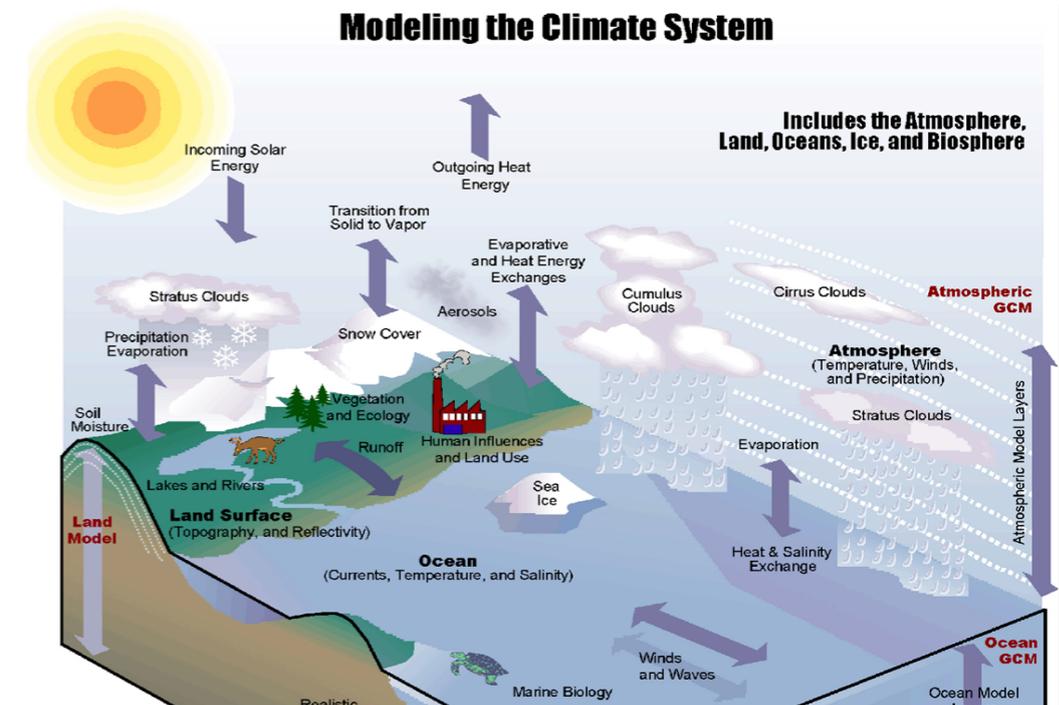
Grand challenges: computing complexity

HPC: the only way

- Accurate models are needed
- Complex systems to be studied
- Long run simulations
- I/O is a major issue

Climate Simulations

- Climate models run on current machines tens of weeks to simulate one century
- PBs of data are currently produced in the CMIP5 context
- Hundreds of exabytes of data are expected by 2020

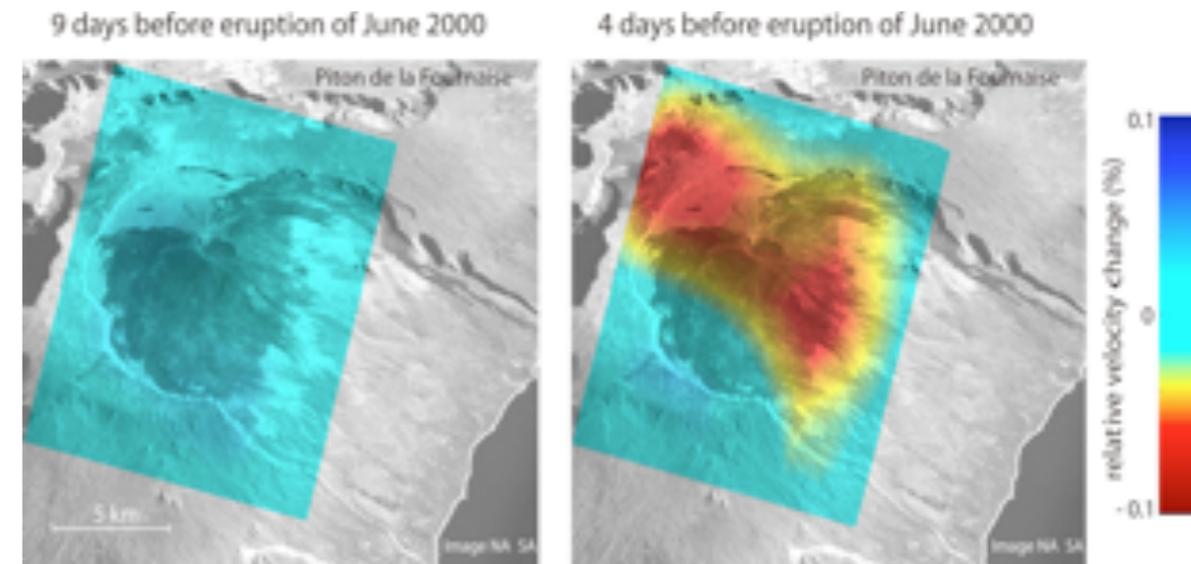


Grand challenges: computing complexity



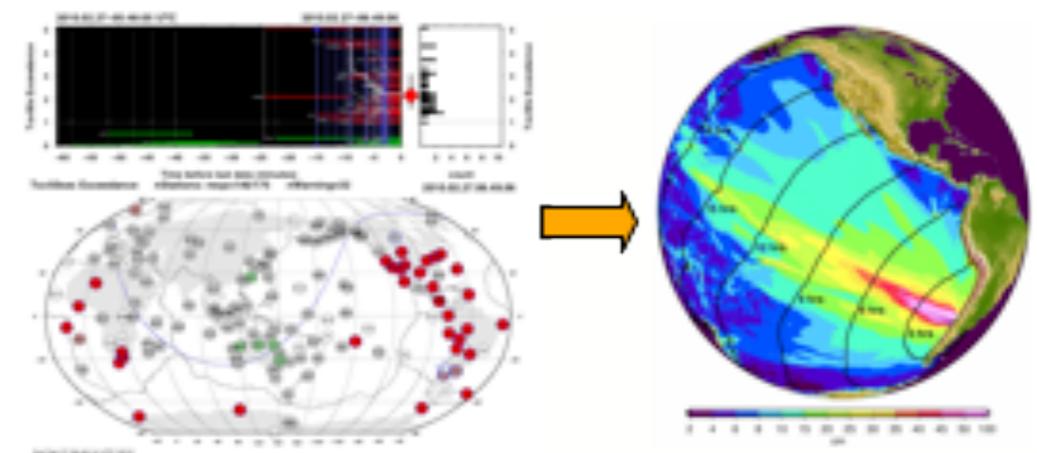
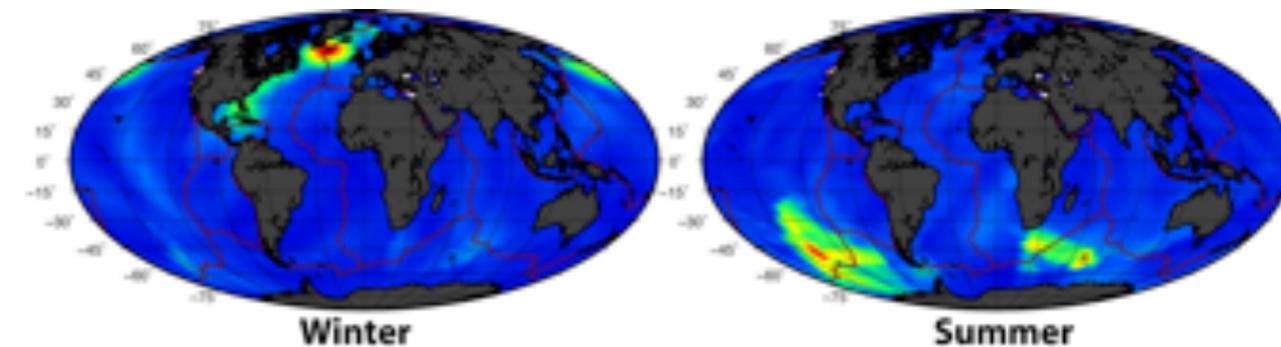
HPC: from data driven to data intensive research

- Data intensive applications
- Large volume data analysis
- Orchestrated workflows of HPC applications



Solid Earth Simulations

- Continuous data flow analyses (seismic noise correlations, precursors to volcanic eruptions, seasonal coupling between solid Earth, atmosphere & oceans)
- Real time forecasting of earthquake production rates (detection and location)
- Predicting earthquake and tsunami impact



International joint efforts

Hundreds of agencies spread around the globe for worldwide observations

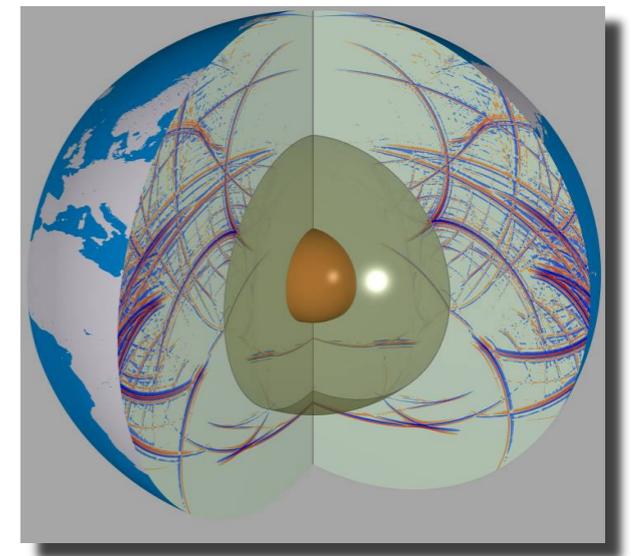
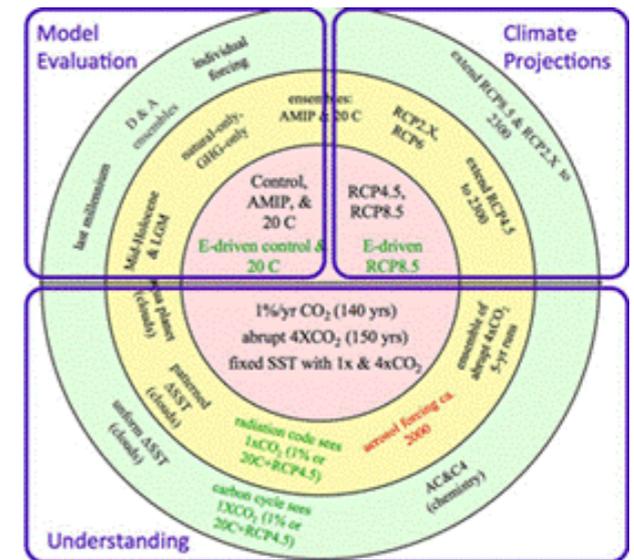
130 countries, including Europe, 2500 experts contribute to The Intergovernmental Panel on Climate Change (IPCC) . Nobel Prize 2007

20 modelling meteorological centres cooperate on Couple Model Intercomparison Project (CMIP5)

20 partners from 18 EU countries involved in the EPOS infrastructure for Solid Earth

US and Japan investing strongly in the domain

Ageing workforce





ENES gathers the European community developing and applying climate models of the Earth system

***48 Partners
15 EU Countries***

It was established in 2001

- to foster a better integration of the European modelling efforts with respect to human potential, hardware and software
- to develop tight collaborations among EU research & computing centers working on weather & climatology
- to establish a European Climate Computing Facility
- to enhance the exchange of software and model results

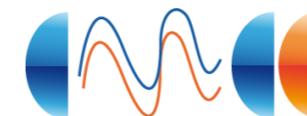
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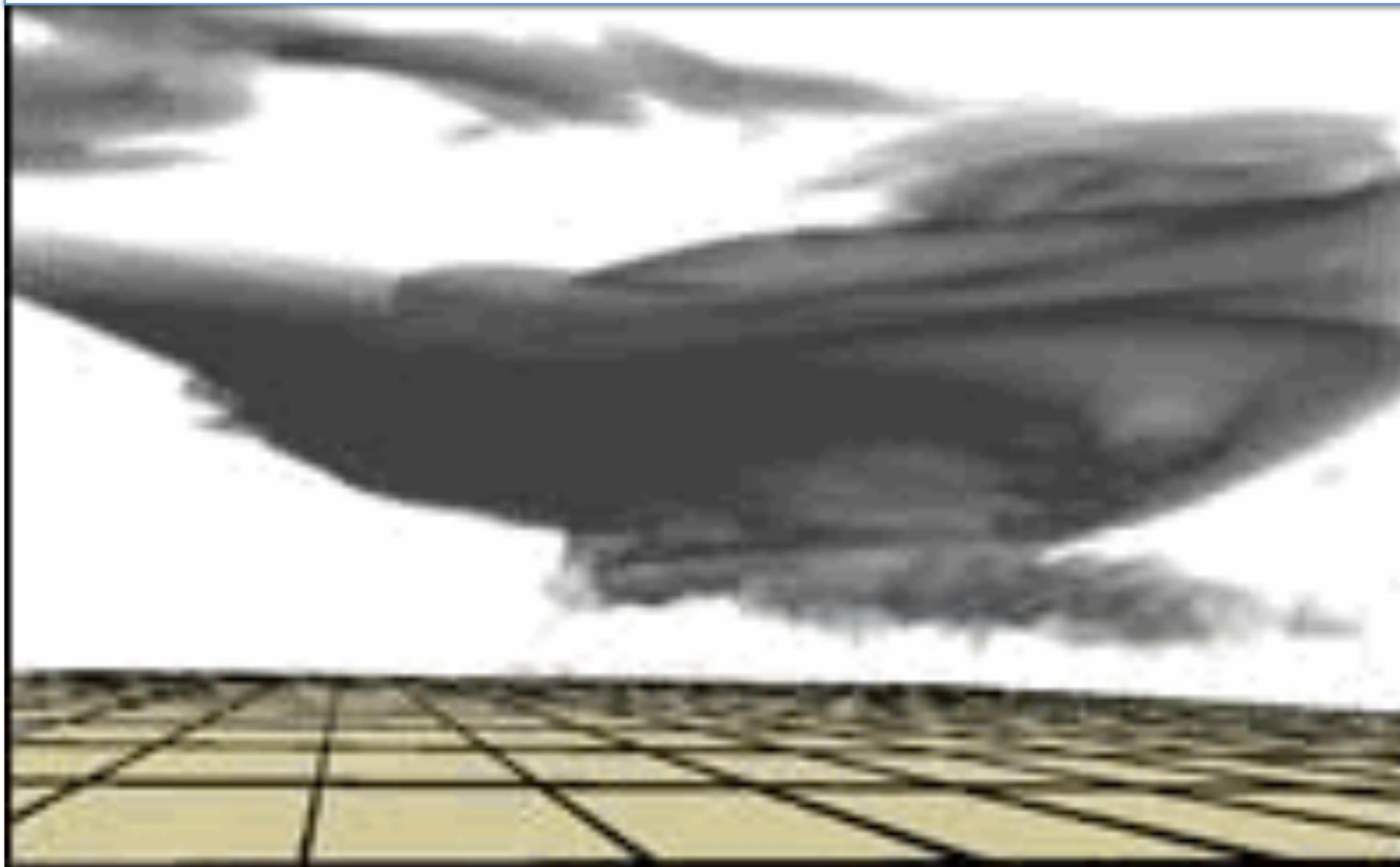


- Access to increased computational capabilities for climate modelling is in particular required to meet the need for **higher spatial and temporal resolution**, better physical process representation, explicit modelling or more biogeochemical processes, much **longer runs** and **larger ensembles**.

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The dream of future global climate models

Tornado simulation obtained by a **very high resolution**
“regional” atmospheric model
 (WRF-Weather Research & Forecast Model)



WRF



Resolution
 25 m * 20 m

Domain size
 50*40 Km

Computing Resources



Le Mieux Computer
 2048 procs @PSC

Current Global Models



Resolution
 100 Km -200 km

Current Regional Models



Resolution
 10 Km -20 km

Simulations performed at the University of Pittsburgh (From Droegemeier and Xu of the University of Oklahoma’s Center for Analysis and Prediction of Storms (CAPS))

Understanding complex natural events

- Stronger research activities in the WCES domains are still needed to understand natural events
- High-end Computing can provide the proper ICT basis to simulate and forecast such complex systems and their impacts on society, health and economy



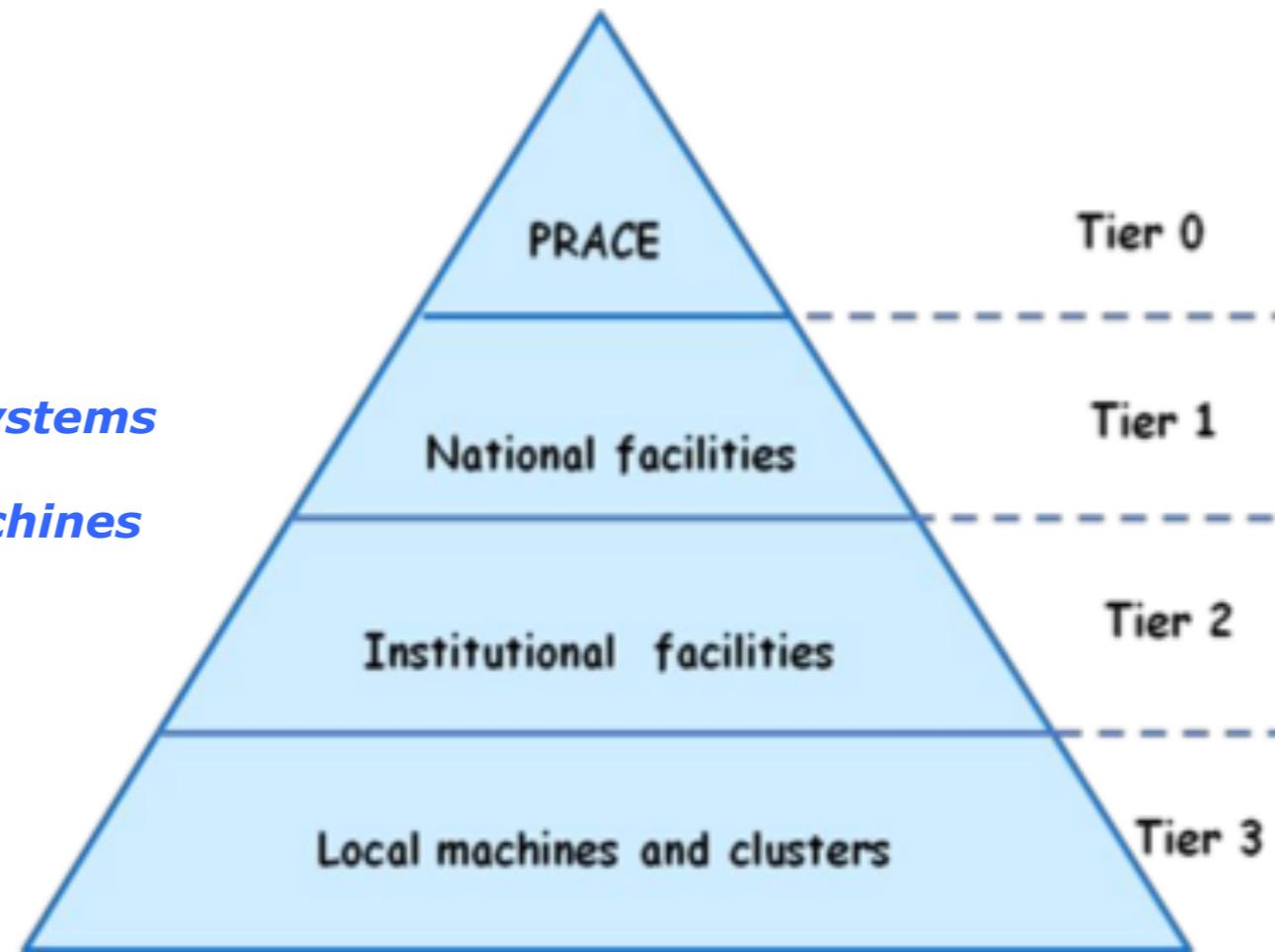
Katrina Hurricane, August 2005

The available European HPC ecosystem

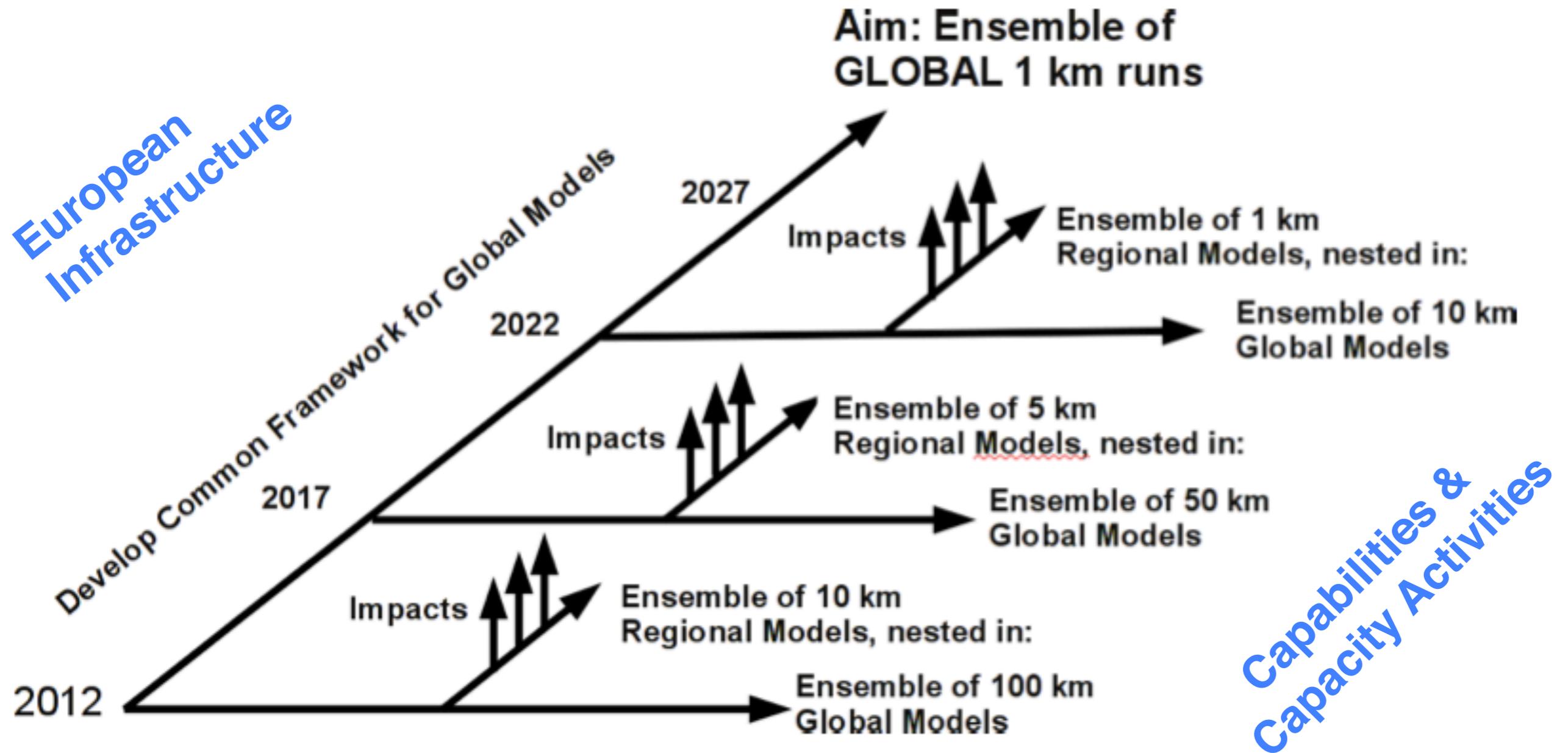
Global Models



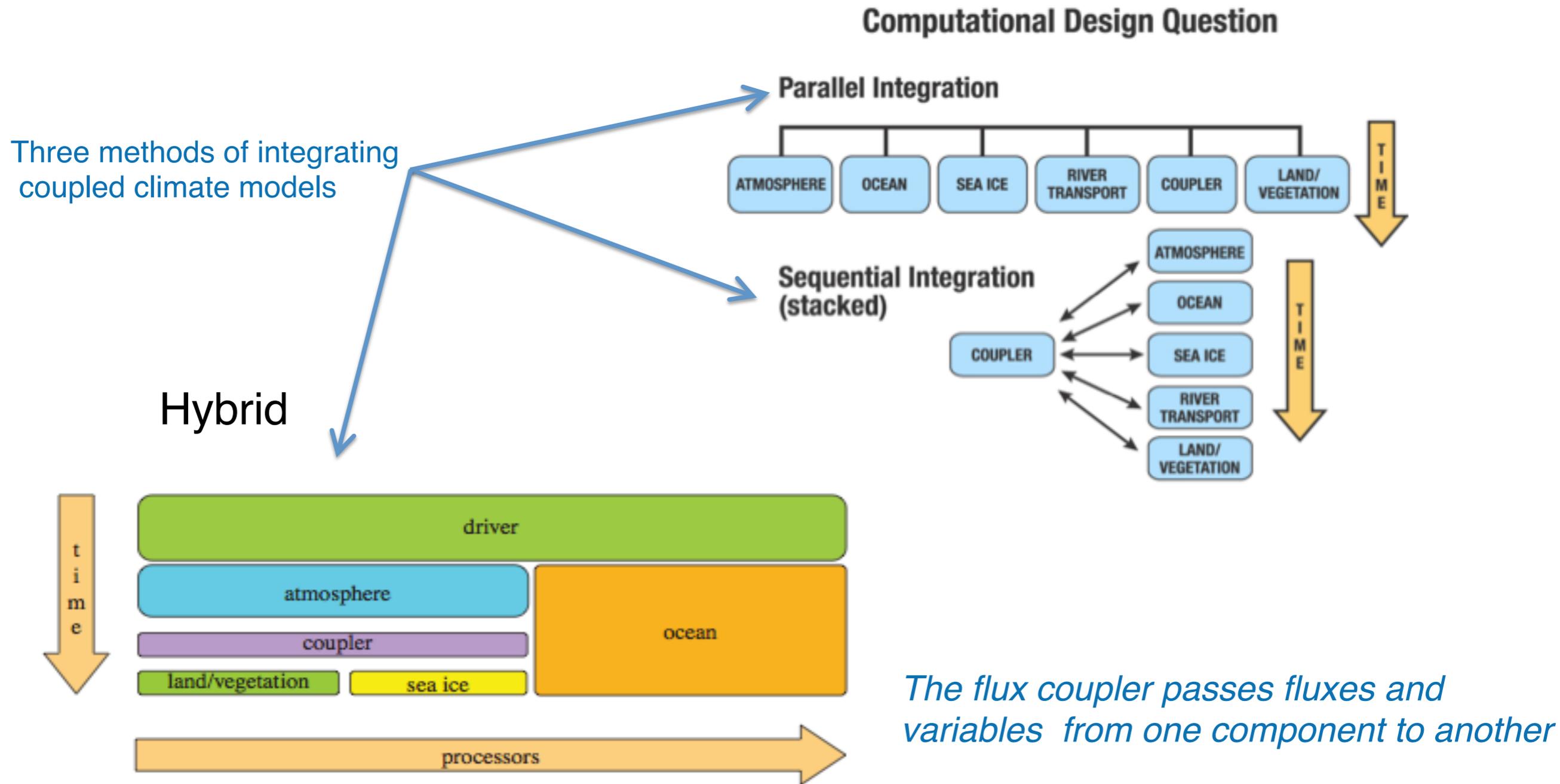
*Tier1 and above computing systems
can be used as
“Capability” & “Capacity” machines*



Ecosystems of models, data transfer & data interpretation



Coupling components in a climate model



- Efficient scaling of **individual component** models to, at least, tens of thousands of cores
 - Overlap communication with computation, ‘loosening’ of synchronization between processes
 - Exploitation of data parallelism in the vertical dimension and functional parallelism during the updates to the prognostic variables
 - Hybrid programming concepts like PGAS or usage of accelerators.

- Scalable **coupling** of the individual component models
 - Need for a common software framework allowing combination and coupling of component models with minimal intrusion into the existing legacy codes

- Direct coupling using a fully concurrent multiple executable approach (a la **OASIS**) is relatively straight-forward to implement
 - The main advantage of this approach is that it requires minimal intrusion into, or restructuring of, existing legacy codes.
 - The drawback is that it is less flexible, and in some cases, less efficient as the coupling exchanges necessarily imply some data transfer.
- Coupling framework via top-level interfaces within one integrated application (a la **ESMF**)
 - More flexible, but needs a code-decomposition into init, run and finalize units

Earth Science Models - Numerical Issues

- Formulation of new dynamical cores to resolve hydrostatic and **non-hydrostatic** regimes
 - non-hydrostatic dynamical cores for global cloud resolving atmospheric models (1km)

Newton's Law, applied to the atmosphere

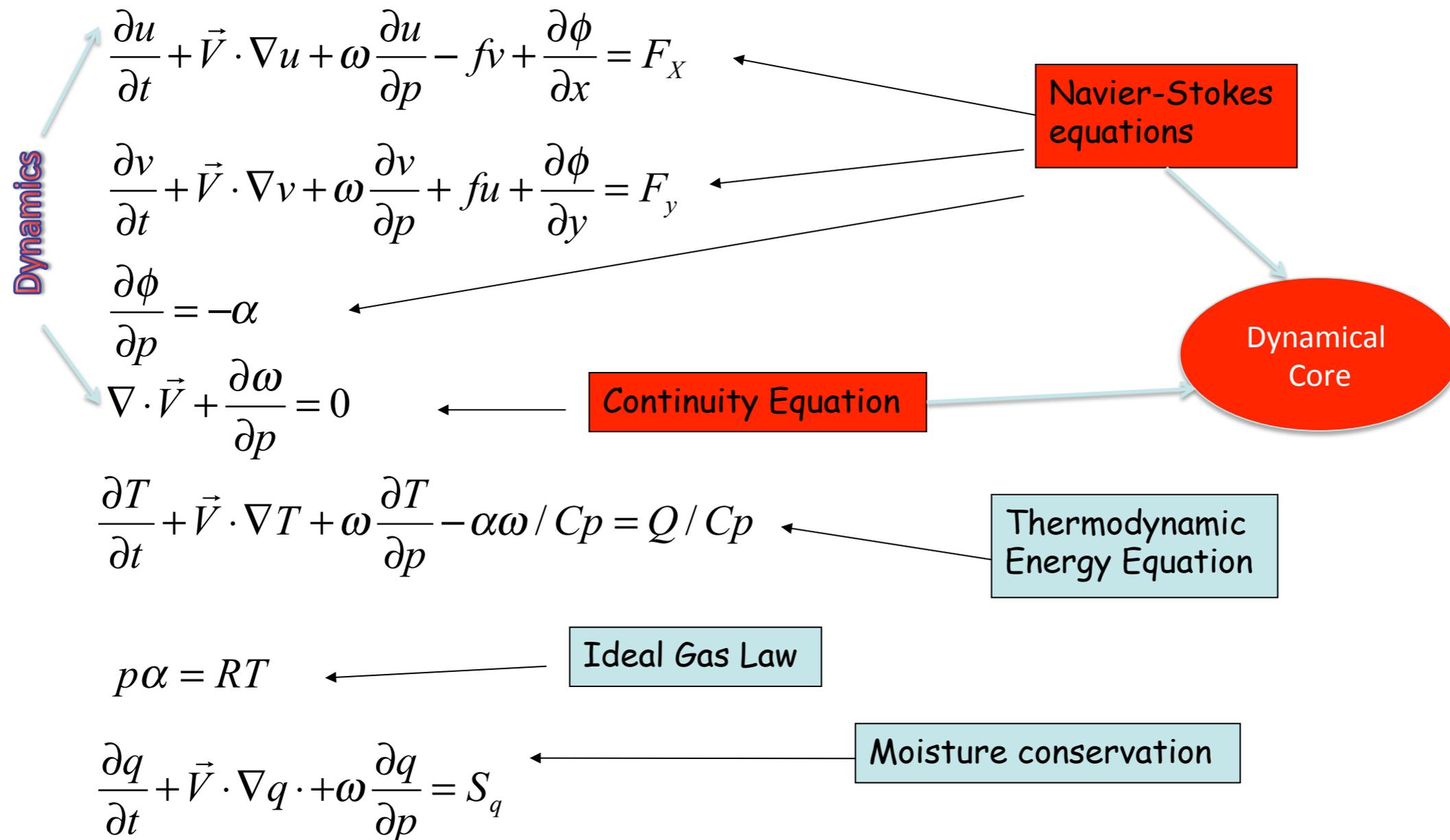
$$\rho \mathbf{g} - \nabla p + \nu \nabla^2 \mathbf{u} = \rho \left(\frac{\partial}{\partial t} + \mathbf{u} \cdot \nabla \right) \mathbf{u}$$



$$\rho \mathbf{g} - \nabla p + \nu \nabla^2 \mathbf{u} = \rho \left(\frac{\partial}{\partial t} + \mathbf{u} \cdot \nabla \right) \mathbf{u} \leftarrow \text{nonlinear}$$

Unpacks into billions of individual equations, describing scales of motion from planetary scales to microscopic scales.

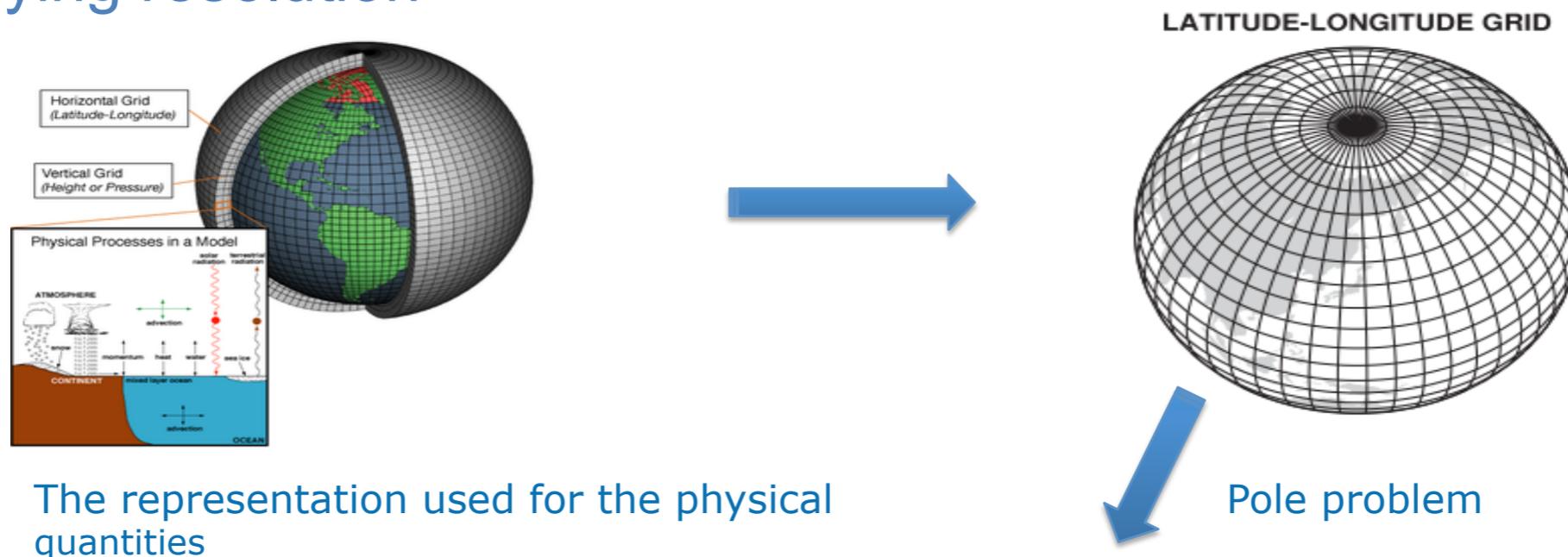
The atmosphere in "Primitive Equations"



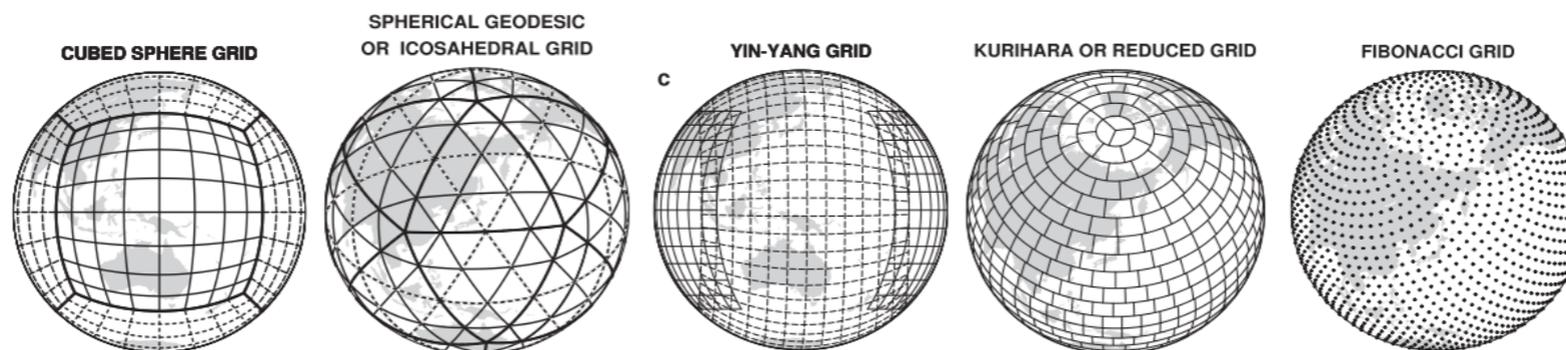
- In principle: possible to solve (#unknowns = #equations).
- In practice: analytical solutions not possible (e.g. non-linearity)
- (Various filtered forms of the equations of motion...)

Earth Science Models - Numerical issues

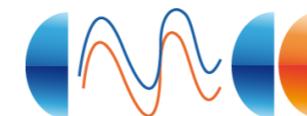
- Different grid systems need to be exploited:
 - More promising seem the quasi-uniform grids i.e. cubed sphere, icosahedral, Yin-Yang, Fibonacci
 - An approach to meet high-spatial resolution and long integration times is to develop model on non-uniform grids, i.e. use locally varying resolution



The representation used for the physical quantities



Different grid systems



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Data Intensive applications in Earth Science

- **Exploration, analysis and manipulation of large datasets** plays an important role in the WCES domains. Data intensive applications allow to query, analyze and manipulate very large datasets in order to have a **deeper understanding of complex phenomena**
- A stronger work (“community-based”) on **standardization** of data formats, metadata conventions, standard products and work flows across disciplines is needed.
- New and **parallel strategies** with respect to the scalability of **data reduction**, filtering, post-processing, and (interactive) **visualization** are needed to support data analysis of large volume of data.

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Cross-cutting dimensions - Data Management: Input/Output

- Need to work with the hardware providers to develop **efficient I/O libraries** which can cope with the demands of the user communities
- **Quality control** on the output of numerical simulations should be moved at an earlier stage to reduce the burden of unnecessary I/O traffic
- A stronger adoption of **data compression mechanisms** is needed to reduce data movement.

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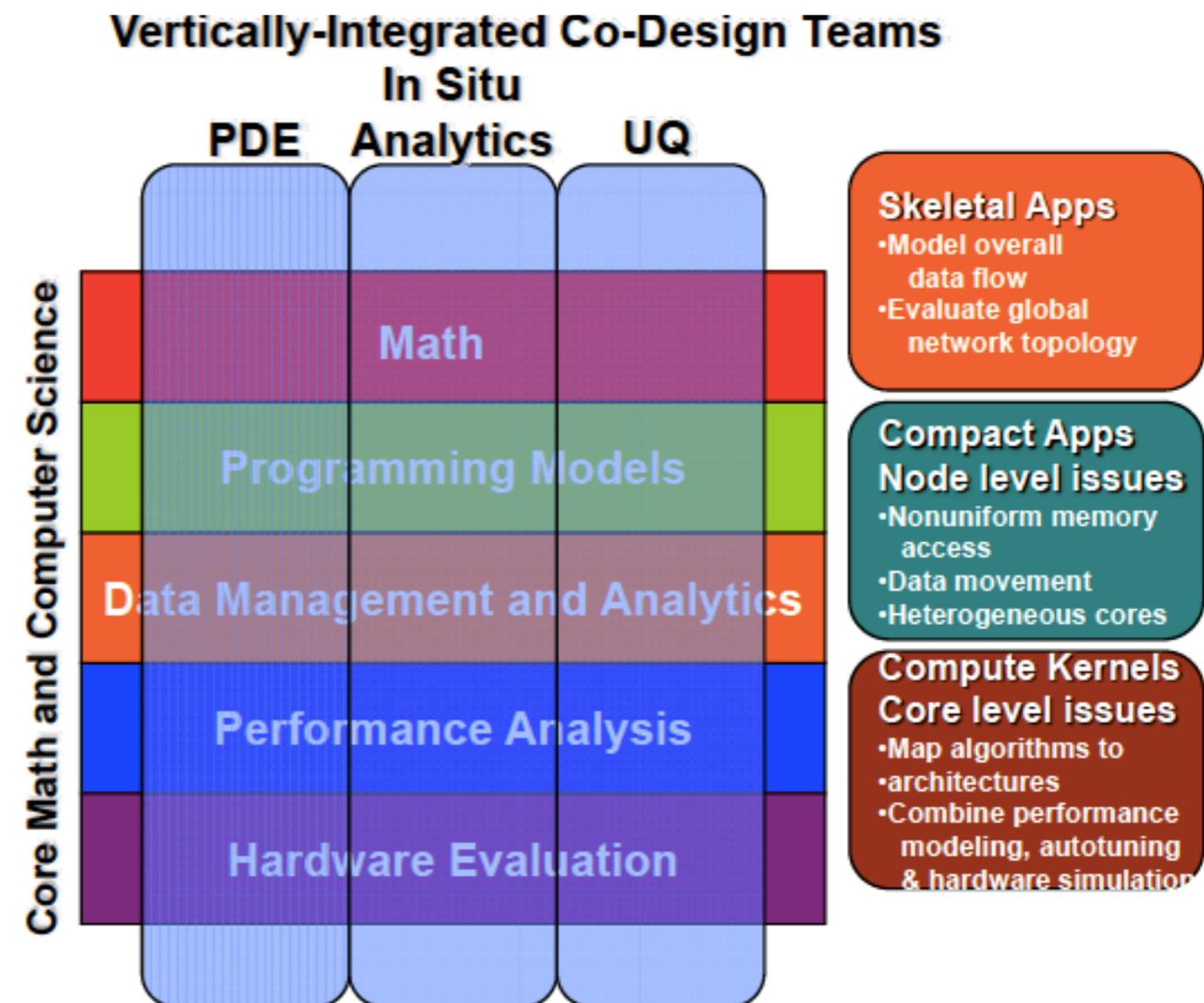
How to progress in WCES domains

- 2012-2020 timeframe
 - 300 Meuro (700 FTEs) as min
 - 400 Meuro (900 FTEs) as max

- Exascale facilities adoption

- Education & Training

- Co-Design Centres would be the “optimal solutions





University of
Reading



FMI



**British Atmospheric
Data Centre**

NATIONAL CENTRE FOR ATMOSPHERIC SCIENCE
NATURAL ENVIRONMENT RESEARCH COUNCIL



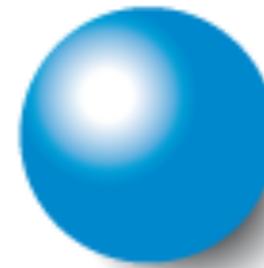
INGV

CERFACS



Max-Planck-Institut
für Meteorologie

ECMWF



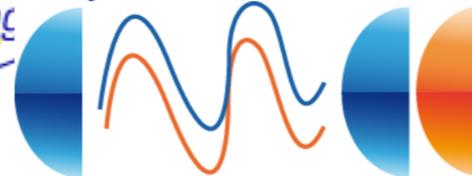
Institut
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DKRZ



enes



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SMHI



IPGP
INSTITUT DE PHYSIQUE
DU GLOBE DE PARIS



**National Centre for
Atmospheric Science**

NATURAL ENVIRONMENT RESEARCH COUNCIL



LMU

MANCHESTER
1824

Timeline, needs of HR, provisional costs

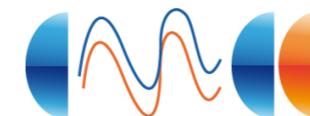
Roadmap issue	FTE/year → 2015		Integrated (4 years) Provisional Costs 2012 → 2015		FTE/year 2015 → 2020		Integrated (5 years) Provisional Cost 2015 → 2020	
	Min	Max	Min	Max	Min	Max	Min	Max
Earth Science Models								
Earth System Models optimization	35	45	11200	14400	70	90	35000	45000
Dynamical cores	20	25	6400	8000	40	50	20000	25000
Flexible couplers and coupling frameworks	15	20	4800	6400	30	40	15000	20000
Multiscale Simulation	12	15	3840	4800	24	30	12000	15000
Data Assimilation	15	20	4800	6400	30	40	15000	20000
Uncertainty and predictability	12	15	3840	4800	24	30	12000	15000
Data Intensive appl. in Earth Science								
Scientific data management	25	30	8000	9600	50	60	25000	30000
Data analysis and visualization	20	25	6400	8000	40	50	20000	25000
Cross-cutting dimensions								
Performance	15	25	4800	8000	30	50	15000	25000
Programmability	10	15	3200	4800	20	30	10000	15000
Data Management - I/O	25	30	8000	9600	50	60	25000	30000
Data Management - Data Discovery	15	20	4800	6400	30	40	15000	20000
Others	10	15	3200	4800	20	30	10000	15000
Total	229	300	73280	96000	458	600	229000	300000

Cost for 1 FTE/year (KEuro) - 2012-2015	80
Cost for 1 FTE/year (KEuro) - 2016-2020	100

Thanks

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