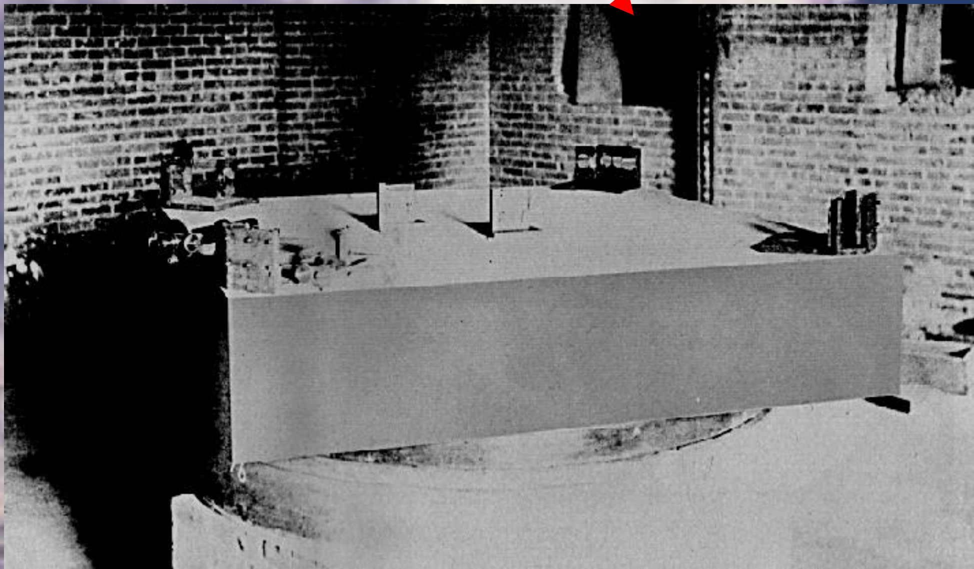
Climate Research Directions

A scientific consideration of climate (I)

Crucial experiments like the famous experiment of Michelson e Morley are not possible in climate science

How is it possible a scientific investigation of climate ?



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A scientific consideration of climate (II)

We can male experiments if we represent the climate system via a set of mathematical relations: the equation of climate.

The equation of climate are very difficult, but they can be solved by numerical methods.

We can then treat very complex mathematical equations, paying the price of a enormous number of elementary operations.

The next generation of numerical models will be like new, more powerful, telescopes or particle accelerators and they will allow us to look further into the working of the Earth climate more accurately, extensively and reliably.

Euro Mediterranean
Center
for Climate Change

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The Mission

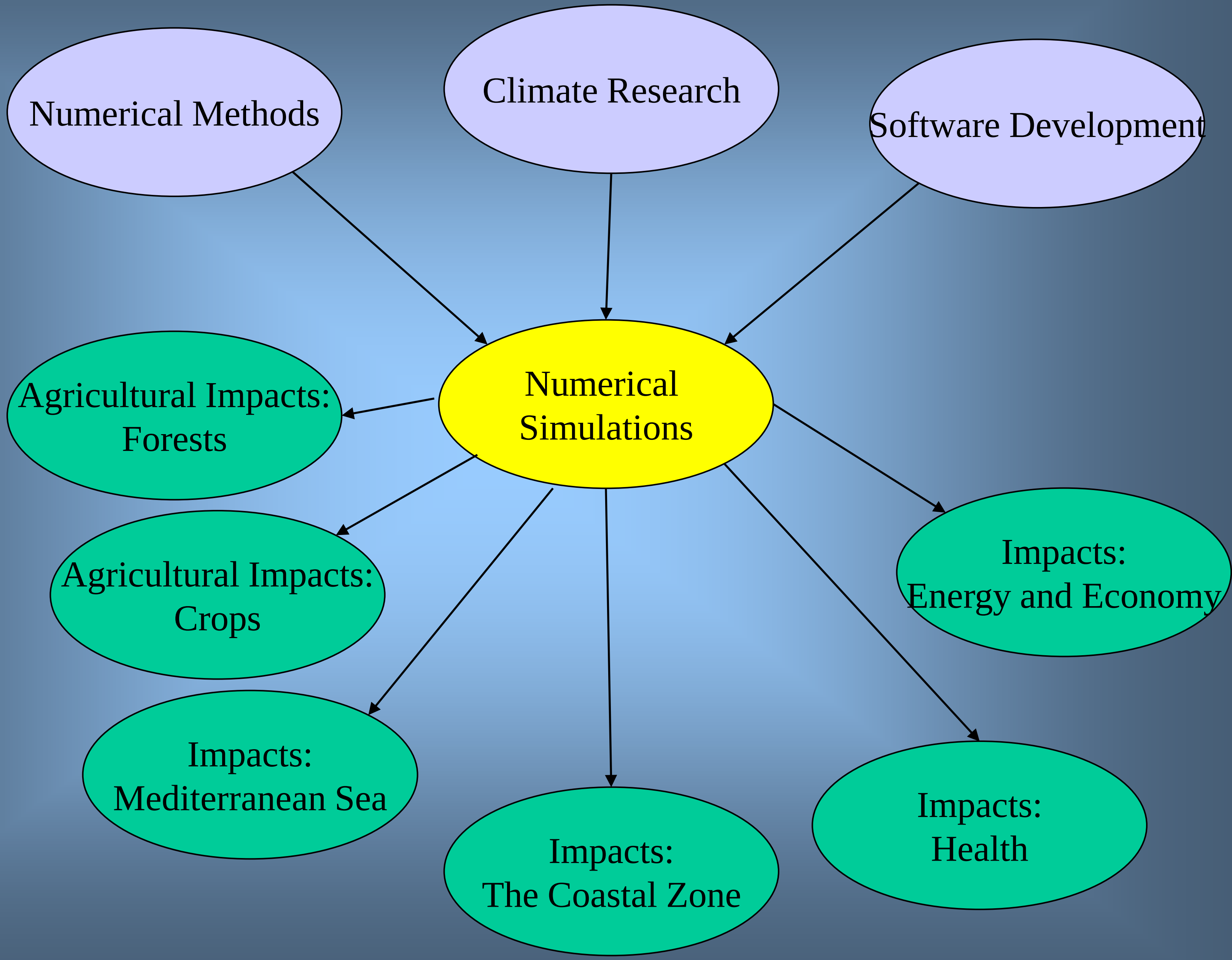
Improve our understanding of the nature and mechanisms of climate variability, its causes and its impacts, with a special emphasis on the Mediterranean Area and its interactions with the global climate. Major research themes will include tropical-extratropical teleconnections, decadal and interdecadal cliate variability and the issues linked to the general circulation.

Develop high quality products that will be made available to the scientific community, with an adequate user support, documentation and training. Research will support the improvement of the CMCC products and guarantee a continous high quality level.

Establish a significant computational facility to support italian climate numerical simulation research and contribute to capacity building in the Mediterranean region

Produce numerical models, simulations, applications and assessments. CMCC will also perform high level training in the areas of climate dynamics and its impacts.

The Structure of the CMCC



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CMCC-INGV planned scenario simulations:

- High-resolution, short-term (decadal) prediction experiments
- Long scenario simulations with the Carbon Cycle

High-resolution, short-term (decadal) prediction experiments

- Ensemble of integrations of the period 1965-2035 with start dates every 5 years (1965, 1970, …, 2005) and 3 member for each start date;
- Oceanic initial conditions: Ocean Analysis (CMCC-INGV) with observed anomalies on top of model climatology;
- Atmospheric ini. cond.: AMIP run;
- Sea-Ice ini. cond.: Ocean Analysis for the sea-ice cover distribution and model climatology for the sea-ice thickness;
- Prescribed GHGs and aerosols from observations for 1965-2005 and from scenarios (according to CMIP5) for 2005-2035;

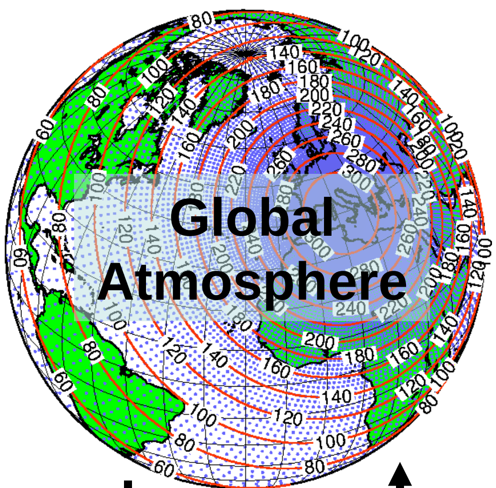
(Start by the end of 2009)

Long-term (centennial) projection experiments with the Carbon Cycle Earth System Model

- Past Control Run and Historical (1850-2005) experiment
- Idealized 1% year experiment
- Prescribed GHGs and aerosols from observations for 1965-2005 and from scenarios (according to CMIP5, RCP4.5 and RCP8.5) for 2005-2100;.
- Hibbard et al (2007) design: Specified CO2 concentration, save the land and ocean carbon fluxes to compute implied emission;.

High-resolution, short-term (decadal) prediction experiments

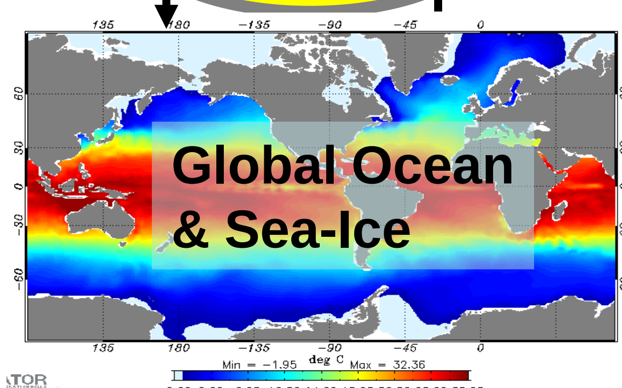
The high resolution CMCC-MODEL



Heat Flux
Water Flux
Momentum Flux

COUPLER

SST
Sea-ice



ATMOSPHERE *(dynamics, physics, prescribed gases and aerosols)*

ECHAM5 T159 - L31
Roeckner et al. (2006)

(T63-L95 stratosphere resolving)
(Manzini et al. 2006)

COUPLER Oasis 3
Valcke et al. (2004)

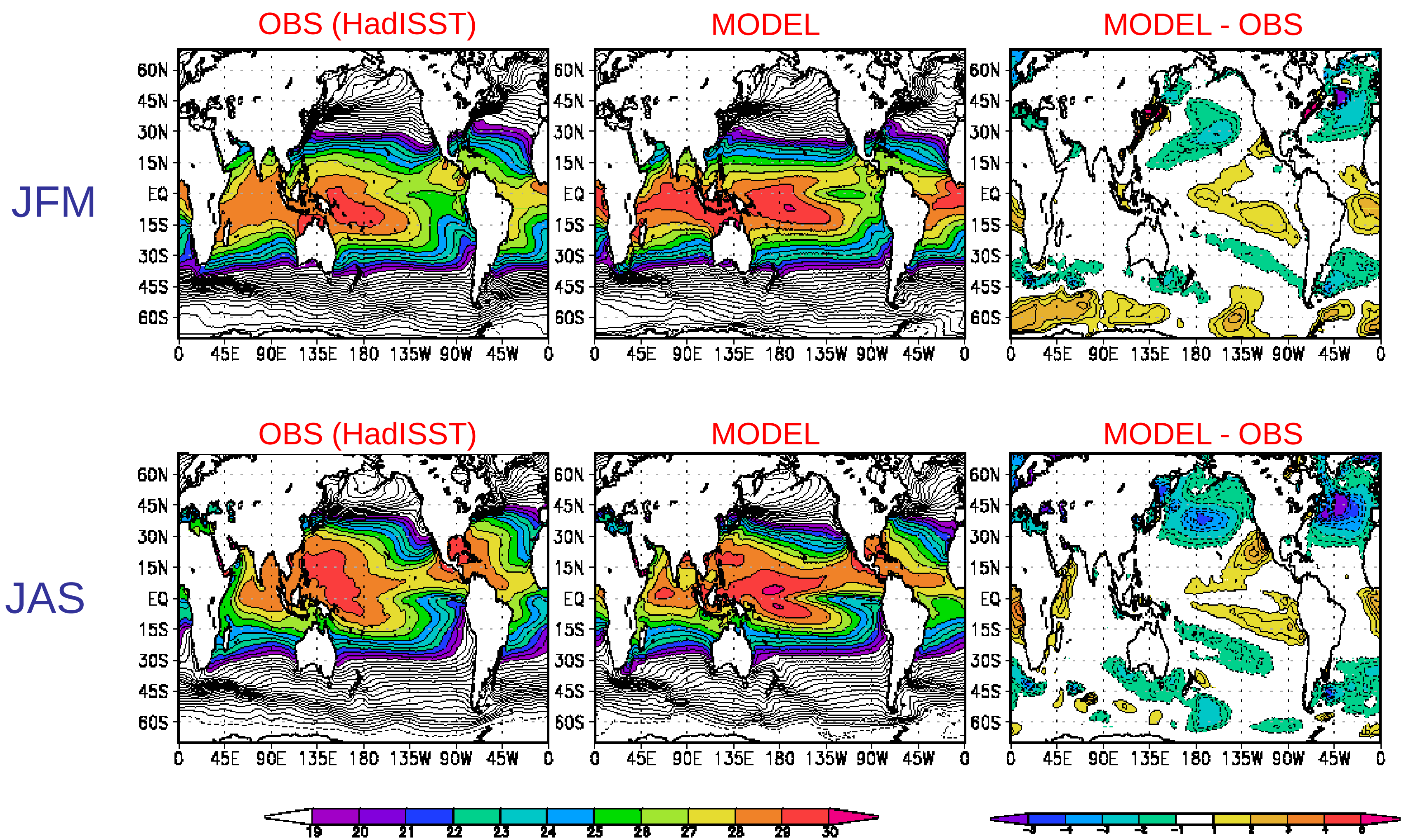
OCEAN (dynamics and physics)
NEMO/ORCA2 (Barnier et al. 2006)

SEA-ICE: LIM (Timmermann et al. 2005)

High-resolution, short-term (decadal) prediction experiments

Preliminary results from a 20th Century simulation

Mean SST 1951-2000



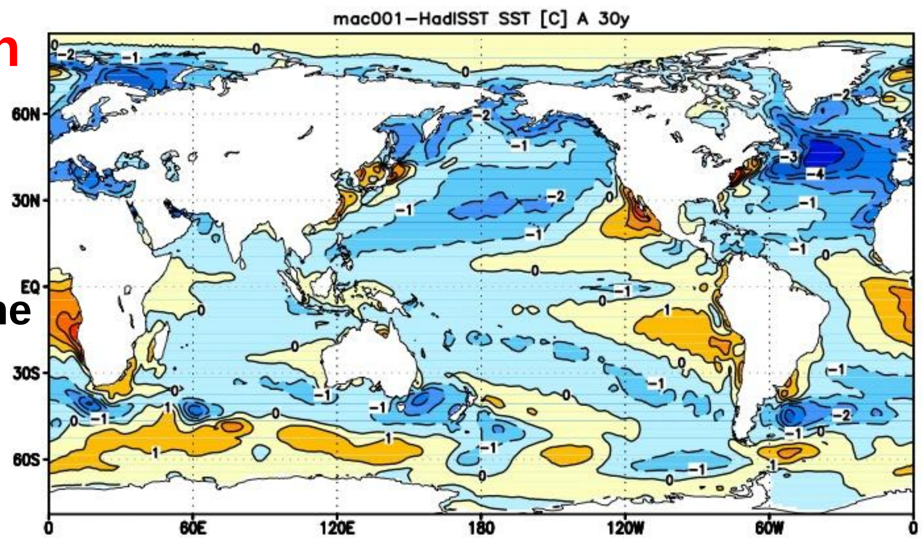
CMCC Atmosphere Ocean Model + Stratosphere

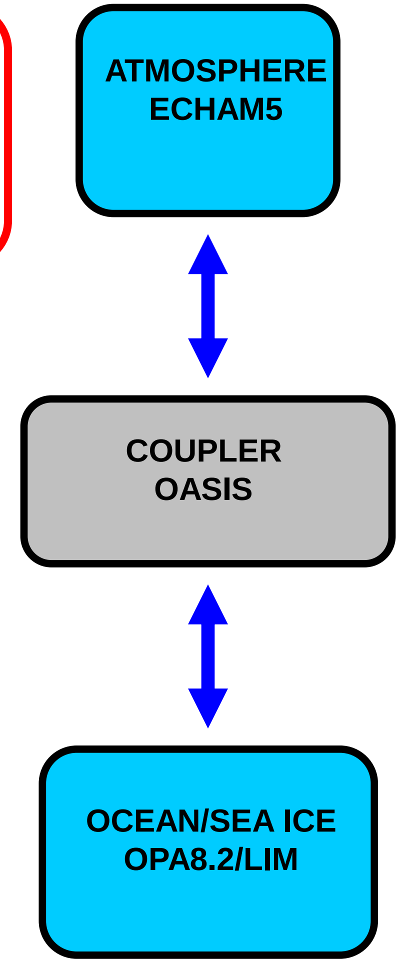
ECHAM5@T63L95, top at 80 km (Manzini et al 2006, Giorgetta et 2006, Cagnazzo et al 2007)

Present Control: 130-year Simulations

Annual Mean SST [K]
Model-OBS

(Model: 30-yr average from the 130 year run; OBS: 30-yr HadSST)

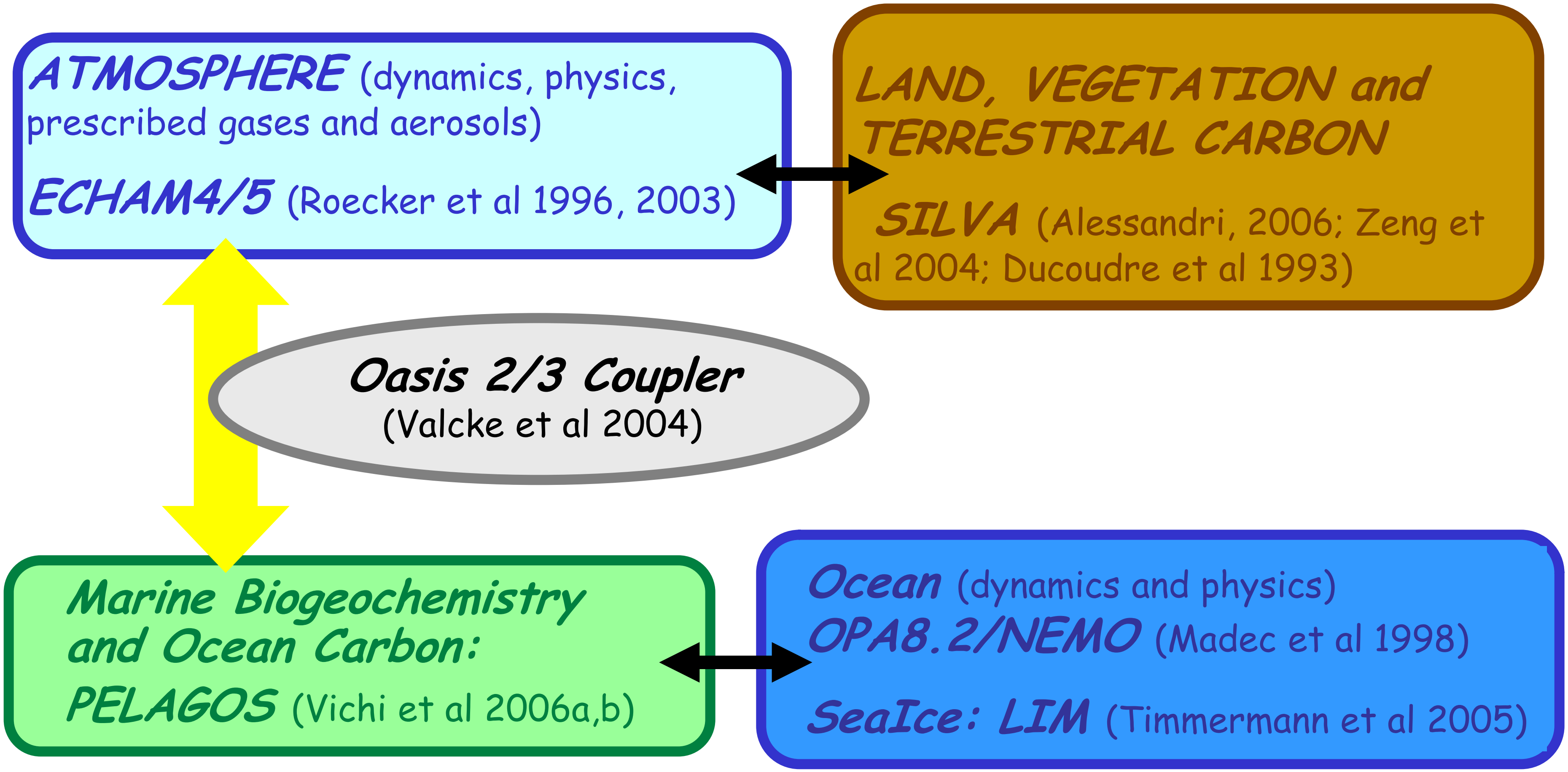




Planned (part of the COMBINE EC project):

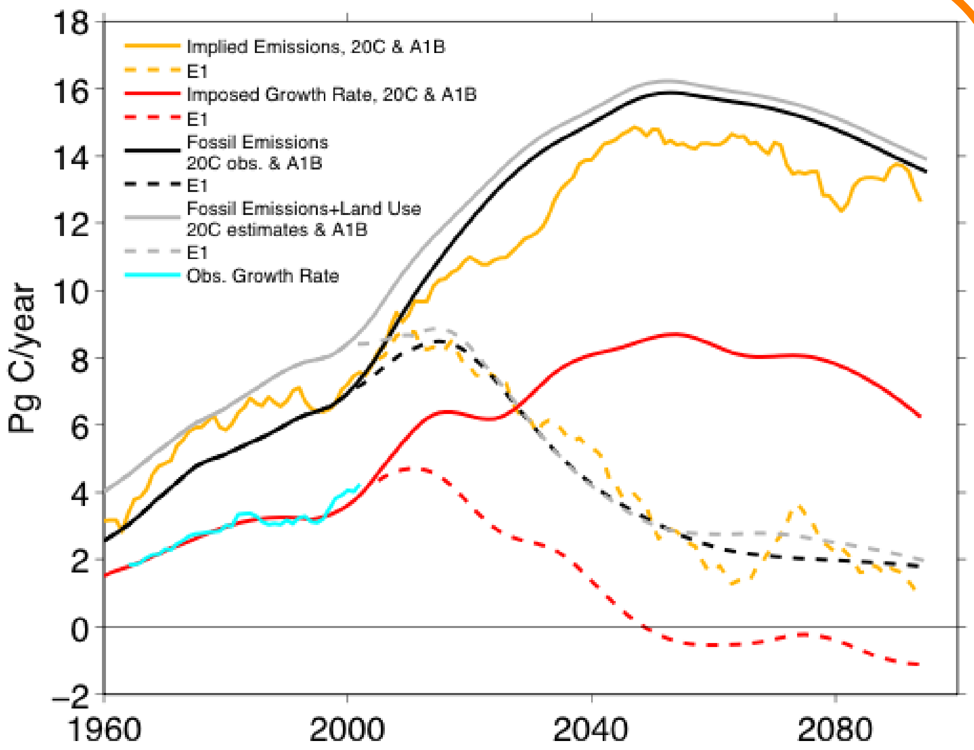
- *Past Control Run and 3 Ensembles of 10-year Hindcasts Runs*
- *Near-Term Potential Predictability Runs (3x10; RCP4.5)*

CMCC/INGV Carbon Earth System Model



The CMCC/INGV Carbon ESM has been used in the ENSEMBLES exploratory runs (Johns et al, in preparation), with the Hibbard et al (2007) design applied to the A1B and E1 scenarios .

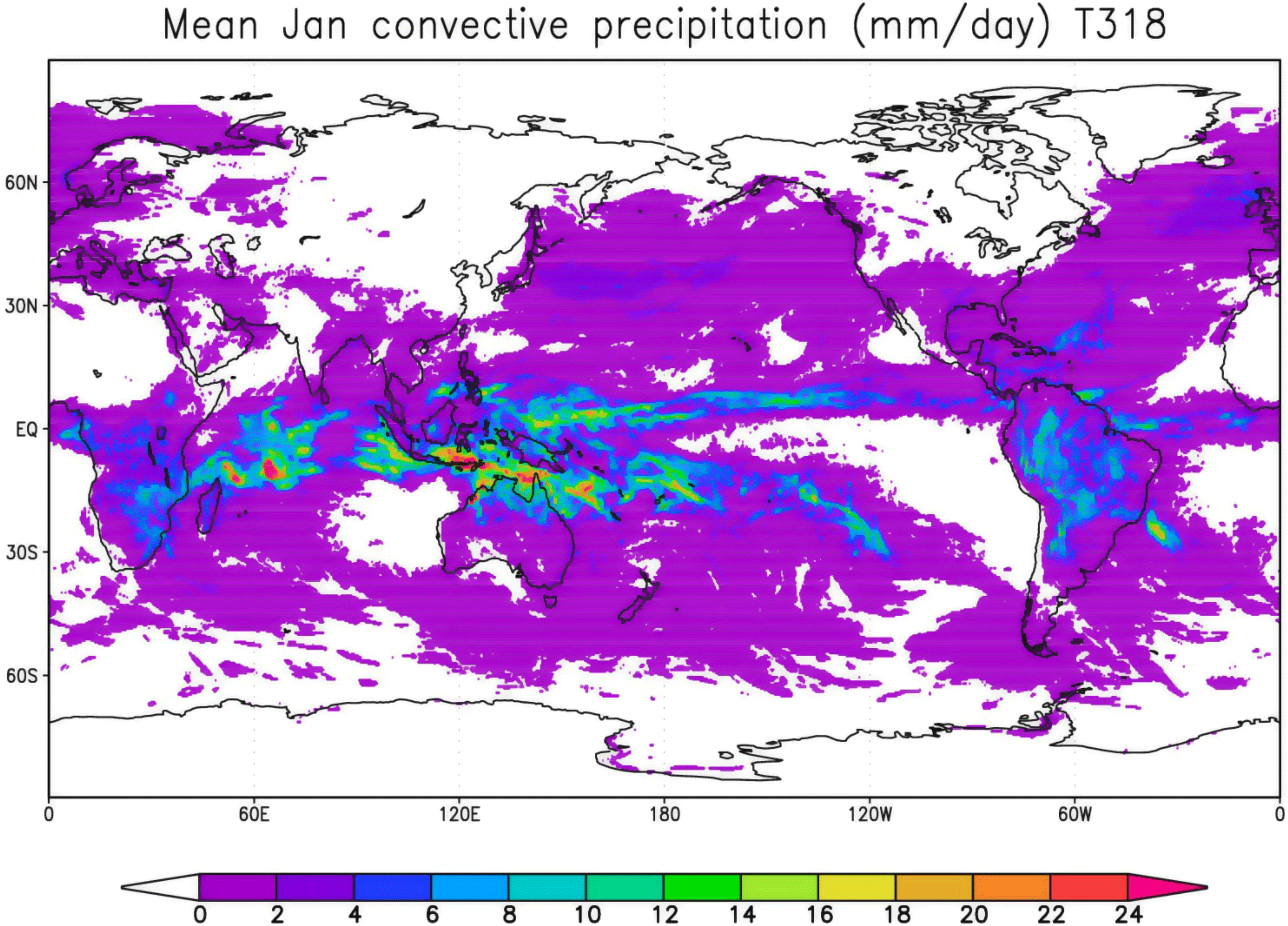
Implied Emissions from the CMCC/INGV Carbon ESM



Planned (part of the COMBINE EC project):

- *Past Control Run and Historical (1850-2005) Run*
- *Idealized 1%/yr simulation*
- *RCP4.5 and RCP8.5 simulations*

Mean JAN Precipitation Global 30km Resolution



CIRCE

Climate Change and Impact ResearCh: the Mediterranean Environment

An FP6 Project of the European Union

INGV - Istituto Nazio ofisica e Vulcanologia - Italy

Chair: Antonio Navarra and Laurence Tubiana
www.circeproject.eu

Evolution of Computational Resources

Grid Spacing	Effective Resolution (km)	Cost relative to 2005 models
630	1350	0.015
~1975 Climate Models		
320	670	0.12
160	330	1
~2005 Climate Models		
110	220	3.3
50	110	27
26	60	220
17	40	830
~2005 Numerical Weather Prediction Models		
10	20	3800
4	8.5	60,000
1	2.1	3,800,600
0.5	1	37,000,000

A new paradigm for numerical simulations

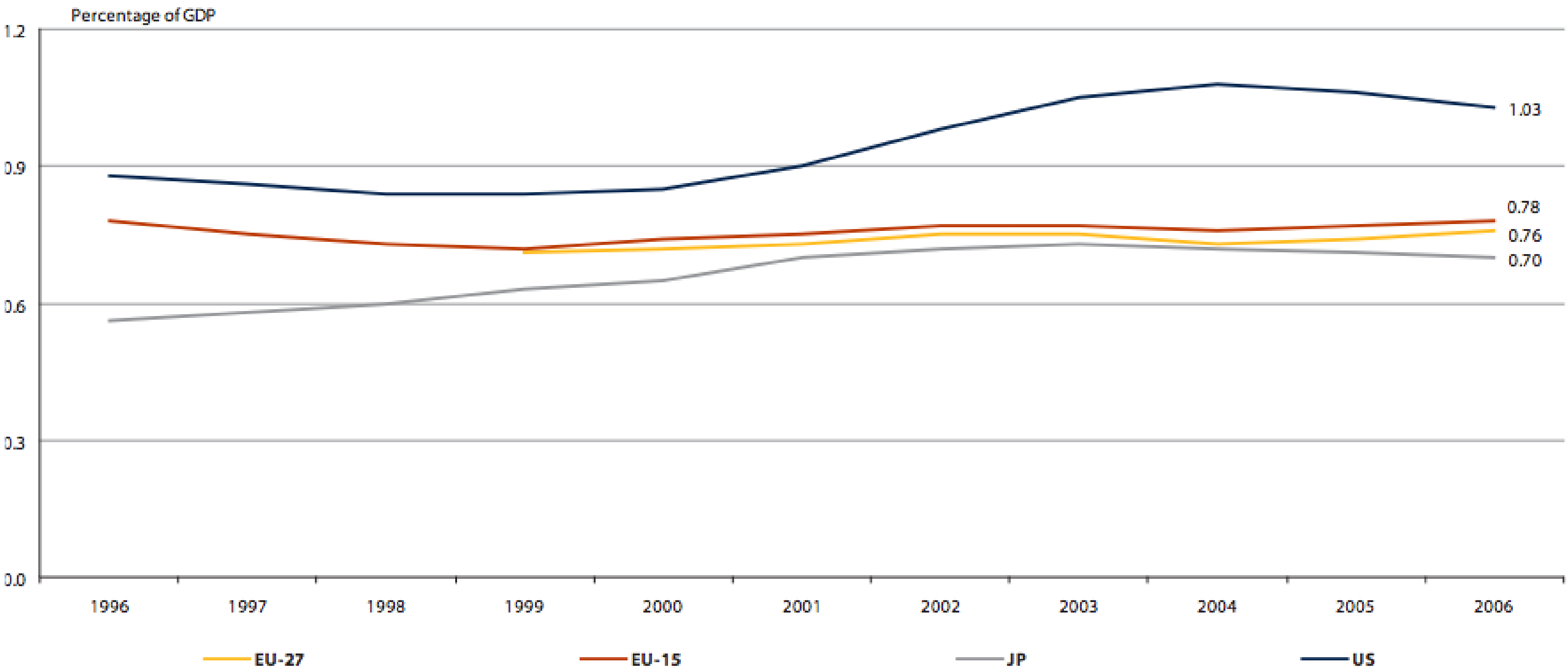
Numerical experiments will be complex multi-institutional, transnational enterprises

- **Concept Stage** – Definition of idea and objective, analysis of existing skills and resources
- **Scientific Case** – Definition of scientific objectives and goals, arguments for priority in terms of scientific values, relevance and impact
- **Technical Case** – Definition of methods and experimental planning, organization and governance of the consortium, exploitation strategy
- **Detailed Multiyear Planning** – Detailed definition of targets and responsabilities in the consortium, phasing of experimental and analysis systems and archiving, decommissioning strategy

Welcome to the era of Industrial Computing

R&D Trends

Figure 1.1: Total GBAORD as a percentage of GDP, EU-15, EU-27, Japan and the United States, 1996–2006



INGV - Is

GBAORD:
government budget appropriations or outlays on research and development

R&D

fisica e Vulcanologia - Italy

Figure 1.2: Total GBAORD as a percentage of GDP, EU-27 and selected countries, 2006

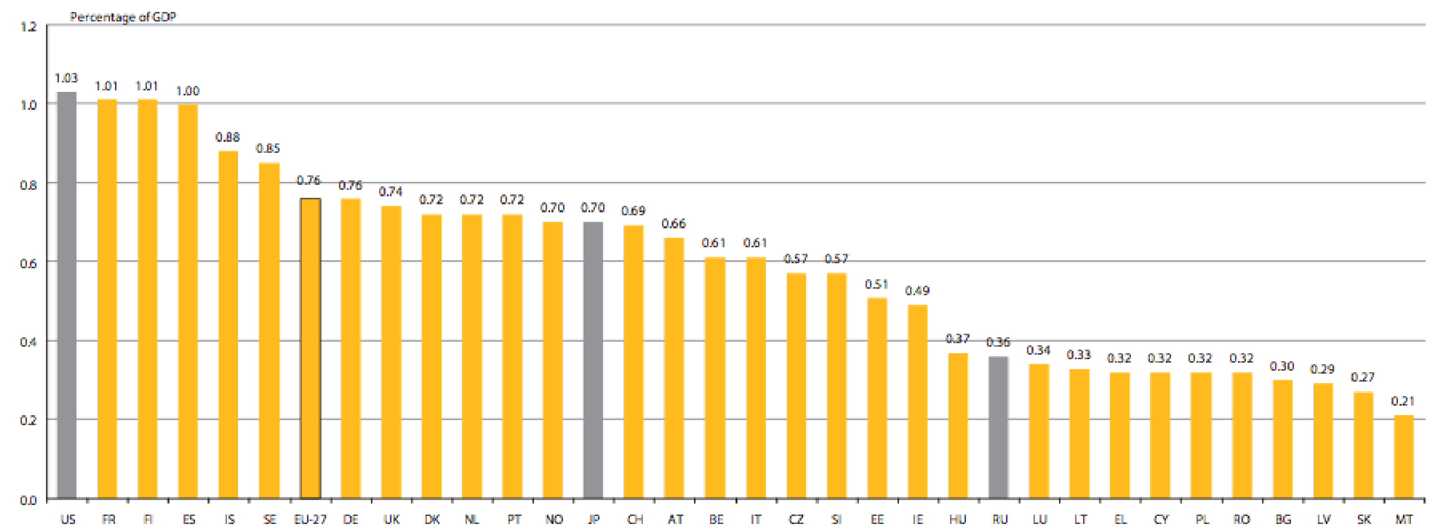
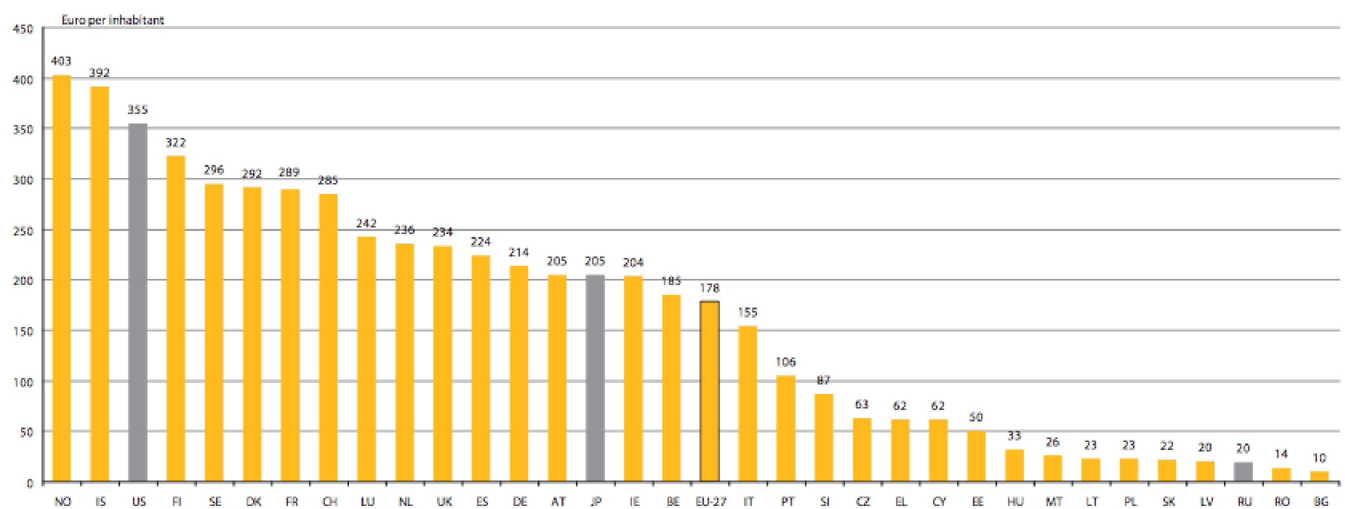


Figure 1.4: Total GBAORD in EUR per inhabitant, EU-27 and selected countries, 2006



Evolution of R&D Expenditure

Figure 2.2: R&D expenditure as a percebtage of GDP in 2006 and average annual growth rate (AAGR) 2001–2006(1), all sectors, EU-27 and selected countries

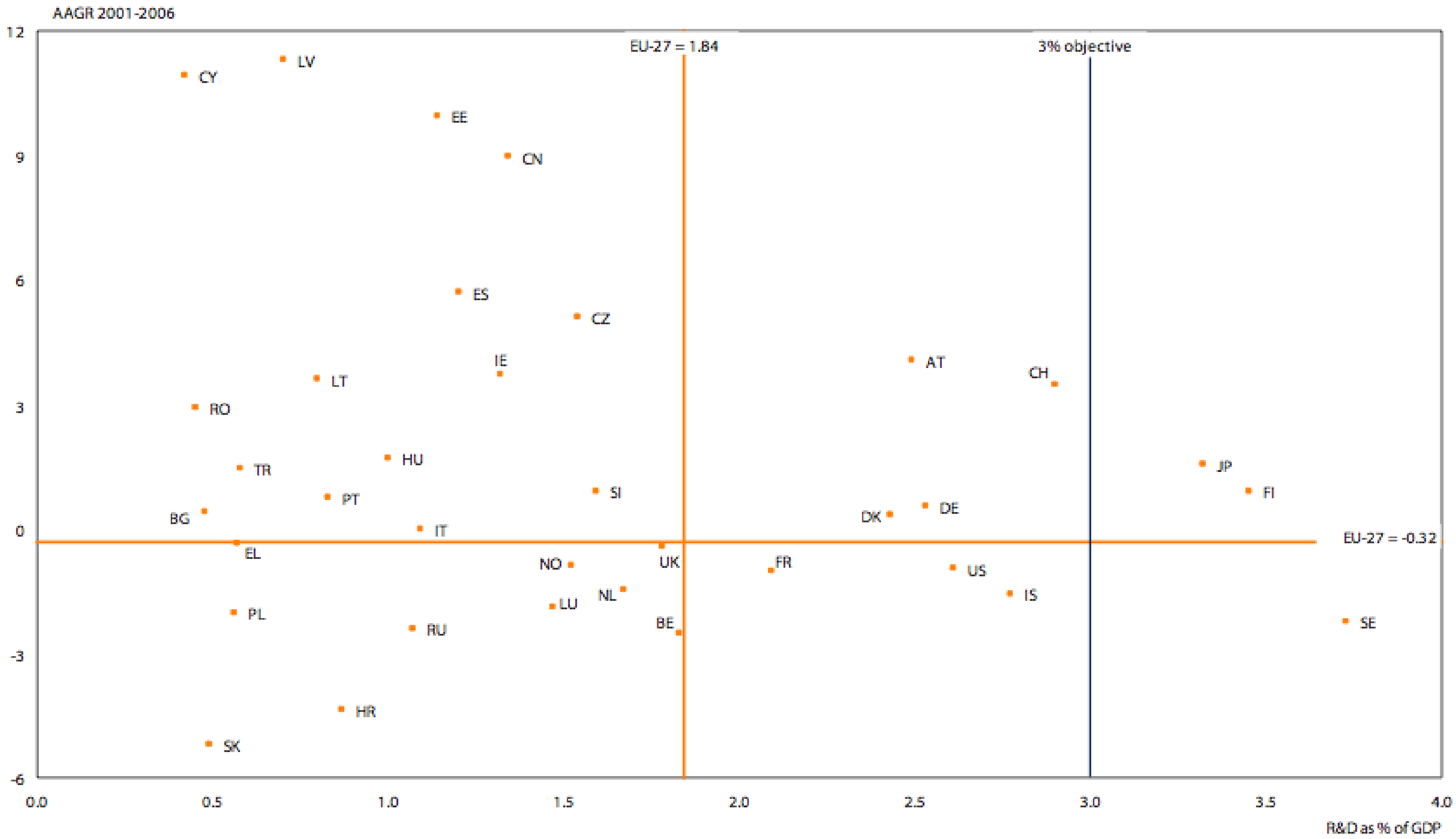


Table 1.6: Total GBAORD in EUR million and by socio-economic objectives as a percentage of total GBAORD, EU-27 and selected countries, 2006

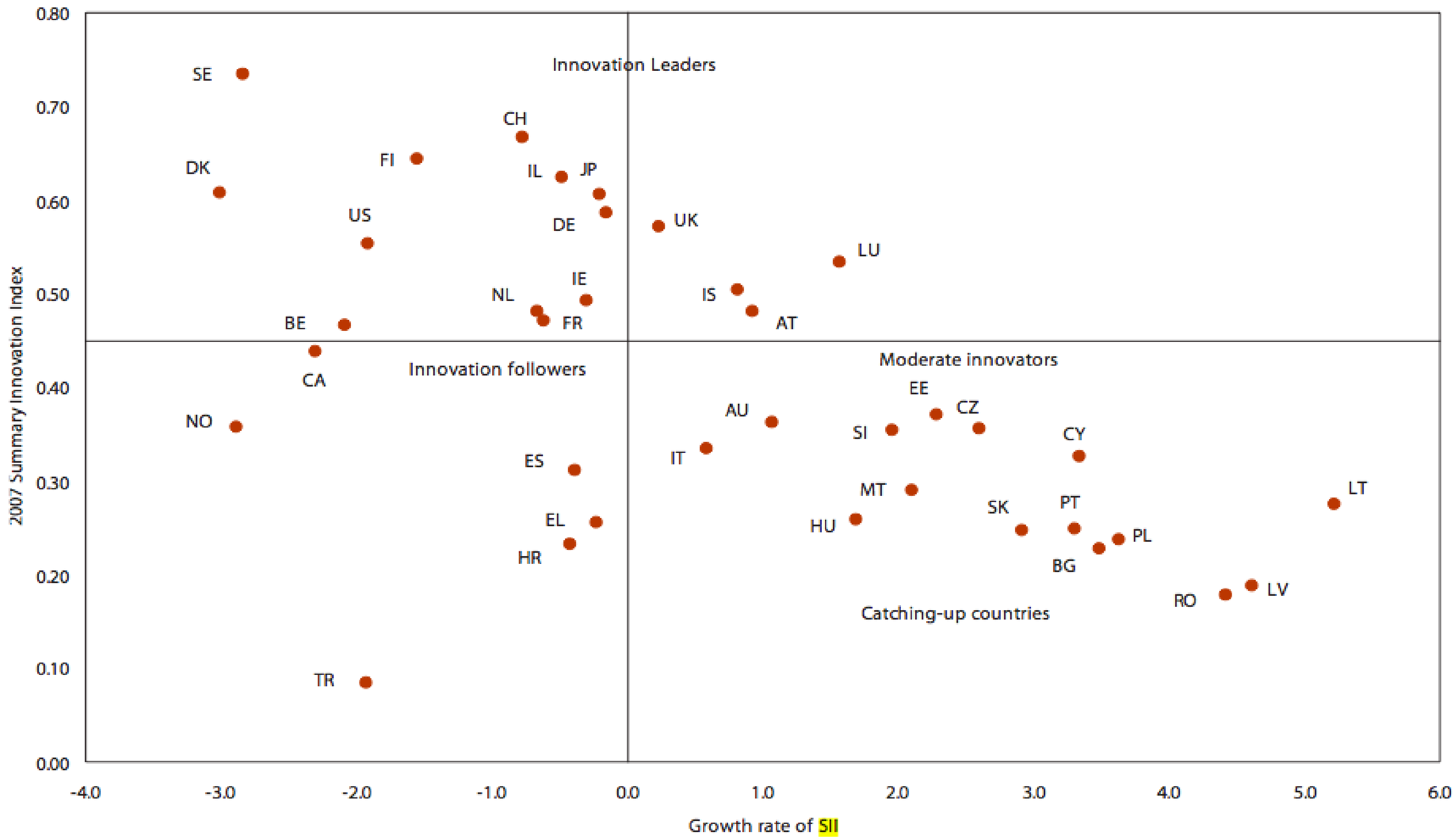
	Exploration and exploitation of the earth	Infrastructure and general planning of land-use	Control and care of the environment	Protection and improvement of human health	Production, distribution and rational utilization of energy	Agricultural production and technology	Industrial production and technology	Social structures and relationships	Exploration and exploitation of space	Research financed from GUF	Non-oriented research	Other civil research	Defence	Total civil GBAORD	Total GBAORD in mio eur
EU-27	1.6 s	1.8 s	2.5 s	7.4 s	2.6 s	3.3 s	10.4 s	3.5 s	4.6 s	30.3 s	17.1 s	1.8 s	13.2 s	86.8 s	87 840 s
BE	0.6	0.8	2.2	1.9	1.9	1.3	33.3	4.1	10.1	17.1	23.9	2.6	0.3	99.7	1 946
BG	:	:	:	:	:	:	:	:	:	:	:	:	:		75
CZ	2.1	3.8	2.6	6.8	2.4	4.9	11.8	2.5	0.7	26.4	26.8	6.0	3.1	96.9	646
DK	0.7	0.7	1.7	8.5	2.1	5.9	6.4	6.5	1.9	44.3	19.2	1.5	0.7	99.3	1 587
DE	1.8 i	1.8 i	3.1 i	4.5 i	2.9 i	2.3 i	12.6 i	3.5 i	4.9 i	39.2 i	16.9 i	0.6 i	6.5 i	93.5 i	17 608
EE	1.5 e	7.0 e	5.8 e	9.3 e	3.1 e	10.3 e	5.2 e	7.6 e	0.0 e	0.0 e	44.7 e	4.4 e	1.0 e	99.0 e	67 e
IE	2.6	0.5	0.8	5.5	0.0	9.8	9.3	11.1	0.0	57.4	2.9	0.0	0.0	100	858
EL	3.4	2.0	3.1	7.1	2.1	6.0	10.3	4.7	2.0	47.9	9.3	1.7	0.5	99.5	685
ES	1.2	4.3	3.7	10.5	2.7	6.2	19.5	3.1	2.9	18.4	7.3	4.0	16.2	83.8	9 799
FR	0.7 p	0.7 p	2.2 p	4.8 p	3.6 p	1.2 p	5.9 p	0.5 p	7.1 p	21.7 p	26.6 p	2.6 p	22.4 p	77.6 p	18 225 p
IT	2.3	1.0	2.6	10.3	4.0	4.0	11.7	5.2	9.5	41.8	6.2	0.0	1.4	98.6	9 099
CY	1.6	1.3	1.1	6.1	0.4	21.0	2.7	7.9	0.0	27.0	31.0	0.0	0.0	100	47
LV	0.6	1.6	2.8	6.9	3.4	18.7	16.2	8.1	0.3	:	41.1	:	0.3	99.7	46
LT	2.6	4.2	9.3	9.9	3.2	8.4	12.2	32.3	:	:	:	17.0	0.9	99.1	78
LU	0.4	3.2	4.0	8.4	0.6	2.6	22.1	15.8	0.4	18.8	20.4	3.1	0.0	100.0	114
HU	2.9	2.1	9.7	13.1	10.4	16.4	19.6	9.1	2.3	9.1	5.0	0.3	0.1	99.9	329
MT	0.0	0.8	0.0	0.0	0.0	6.3	0.0	4.2	0.0	86.1	1.3	1.3	0.0	100	10.5
NL	0.3	3.8	1.9	4.5	2.1	5.3	10.9	1.8	3.1	47.1	10.0	7.1	2.1	97.9	3 858
AT	2.0 i	1.4 i	1.6 i	3.8 i	0.7 i	1.9 i	12.6 i	1.9 i	0.2 i	60.7 i	13.2 i	0.0 i	0.0 i	100 i	1 692 i
PL	0.9	0.7	1.3	1.5	0.7	0.7	10.8	0.5	0.1	4.8	76.9	0.2	0.9	99.1	858
PT	1.2 p	6.6 p	3.8 p	7.0 p	0.9 p	8.1 p	16.9 p	3.7 p	0.3 p	38.5 p	9.2 p	3.2 p	0.6 p	99.4 p	1 116 p
RO	2.3	3.0	5.1	5.7	2.3	9.4	22.1	11.9	1.4	:	13.8	19.8	3.2	96.8	309
SI	0.0	1.6	1.6	3.7	0.9	2.3	22.8	2.3	0.0	4.5	49.6	9.2	1.6	98.4	173
SK	1.0	7.3	0.0	5.0	0.1	8.1	8.9	2.5	:	26.0	32.6 i	1.7	6.6 i	93.4 i	120
FI	1.2	2.0	1.6	6.2	4.4	5.8	27.2	5.5	1.7	25.6	16.2	:	2.8	97.2	1 694
SE	0.7 p	4.0 p	1.8 p	1.2 p	3.6 p	2.2 p	5.7 p	4.5 p	0.9 p	45.1 p	13.6 p	:	16.8	83.2	2 675
UK	2.7 p	0.8 p	1.8 p	14.1 p	0.2 p	3.1 p	1.1 p	5.3 p	2.2 p	21.6 p	18.6 p	0.4 p	28.3 p	71.7 p	14 124 p
IS	:	4.7	0.4	10.9	1.5	21.1	0.9	7.6	:	40.4	12.5	0.0	0.0	100	117
NO	2.5	2.4	1.9	11.3	3.3	8.5	7.9	6.3	2.1	34.9	12.9	:	5.9	94.1	1 869
CH	0.1 i	0.3 i	0.1 i	1.3 i	1.0 i	2.2 i	1.0 i	2.2 i	4.5 i	59.6 p	9.1 i	17.7 i	0.6 i	99.4 i	2 123
JP	1.8 i	4.1 i	0.8 i	3.9 i	15.2 i	3.4 i	7.3 i	0.7 i	6.8 i	34.2 i	16.7 i	:	5.1 i	94.9 i	24 478 i
RU	:	:	:	:	:	:	:	:	:	:	:	:	:	:	2 854
US	0.8 i	1.3 i	0.5 i	21.8 i	0.9 i	2.0 i	0.3 i	1.3 i	7.6 i	:	5.5 i	0.0	57.9 i	42.1 i	108 330 i

Table 2.3: R&D expenditure in EUR million and average annual growth rate (AAGR), by sector of performance, EU-27 and selected countries, 2001–2006

	All sectors			Business enterprise sector			Government sector			Higher education sector		
	2001	2006	AAGR 2001-2006	2001	2006	AAGR 2001-2006	2001	2006	AAGR 2001-2006	2001	2006	AAGR 2001-2006
EU-27	178 549 s	213 127 s	3.6 s	115 689 s	135 716 s	3.2 s	23 570 s	28 777 s	4.1 s	37 914 s	46666 s	4.2 s
BE	5 373	5 798 p	1.5 p	3 921	3 934 p	0.1 p	331	500 p	8.6 p	1 059	1 291 p	4.0 p
BG	71	121	11.3	15	31	16.2	48	78	10.2	9	12	5.9
CZ	832	1 761	16.2	501	1 165	18.4	197	309	9.4	130	279	16.5
DK	4 278	5 349 p	4.6 p	2 934	3 560 p	3.9 p	503	360 p	-6.5 p	809	1 396 p	11.5 p
DE	52 002	58 848 p	2.5 p	36 332	41 148	2.5	7 146 i	8 100 p	2.5 p	8 524	9 600 p	2.4 p
EE	49	151 p	25.3 p	16	67 p	32.5 p	7	20	23.6	25	61	20.0
IE	1 284	2 311 p	12.5 p	900	1 560 p	11.6 p	104	150	7.6	280	601	16.5
EL	852	1 223 e	7.5 e	278	367 e	5.7 e	188	254 e	6.3 e	383	585 e	8.9 e
ES	6 227	11 815	13.7	3 261	6 558	15.0	989	1 971	14.8	1 925 e	3 266	11.1
FR	32 887	37 844 p	2.8 p	20 782 b	23 942 p	2.9 p	5 432	6 546 p	3.8 p	6 217	6 875 p	2.0 p
IT	13 572	15 599	3.5	6 661	7 856	4.2	2 493	2 701	2.0	4 418	4 712 b	1.6 b
CY	27	62 p	17.6 p	5	14 p	21.0 p	12	18 p	7.0 p	7	26 p	29.1 p
LV	38	112	24.4	14	57	32.7	8	17	15.9	16	39	19.5
LT	91	191	15.9	27	53	14.9	36	44	3.8	29	94	26.8
LU	364	497 pe	5.3 pe	337	422 e	3.8 e	26	63 p	15.8 p	1	12 p	54.0 p
HU	548 i	900	10.4	220 i	435 i	14.6 i	142 i	228 i	10.0 i	141 i	219 i	9.2 i
MT	12	28 p	23.5 p	3	17 p	55.2 p	2	1	-9.3	7	9	7.2
NL	8 075	8 910 pe	2.0 pe	4 712	5 134 p	1.7 p	1 114	1 260 i	2.5 i	2 184	:	:
AT	4 684	6 423 e	8.2 e	3 131	4 284 e	8.2 e	266	325 e	5.1 e	1 266	1 689 e	7.5 e
PL	1 323	1 513	2.7	474	477	0.1	414	560	6.2	433	469	1.6
PT	1 038	1 201	3.7	330	462	8.8	216	176	-5.0	381	425	2.8
RO	177	444	20.2	109	215	14.6	48	144	24.6	20	79	31.5
SI	341	484	7.2	197	291	8.1	83	119	7.4	55	73	5.7
SK	149	217	7.7	101	93	-1.5	35 i	71 i	14.9 i	13	52	31.2
FI	4 619	5 761	4.5	3 284	4 108	4.6	471	539	2.7	834	1 079	5.3
SE	10 511 i	11 691	2.2	8 118 i	8 754	1.5	297 i	525	12.1	2 085	2 387	2.7
UK	29 403	34 037	3.0	19 260 b	20 985	1.7	2 949 b	3 401	2.9	6 671	8 892	5.9
IS	261	364	8.7	153	187	5.1	52	86	13.1	49	80	13.0
NO	3 037	4 071	6.0	1 814	2 204	4.0	444	637	7.5	780	1 229	9.5
CH	6 852	8 486	5.5	5 065	6 257	5.4	90 bi	91 i	0.2 i	1 566	1 943	5.5
HR	271	297	2.4	115	109	-1.4	60	79	7.0	95	109	3.5
TR	1 172	2 432	15.7	395	901	17.9	86	284	26.9	690	1 248	12.6
CN	14 063	30 002	16.4	8 499	21 325	20.2	4 183	5 912	7.2	1 381	2 765	14.9
JP	143 015	121 831	-3.9	105 364	93 137	-3.0	13 637	10 100	-7.2	20 687	16 330	-5.7
RU	4 025	8 466	16.0	2 829	5 643	14.8	978	2 285	18.5	210	517	19.8
US	310 205 i	273 772 pi	-2.5 pi	225 566 i	192 584 pi	-3.1 pi	35 013 i	30 462 pi	-2.7 pi	37 642 i	39 098 pi	0.8 pi

Summary Innovation Index

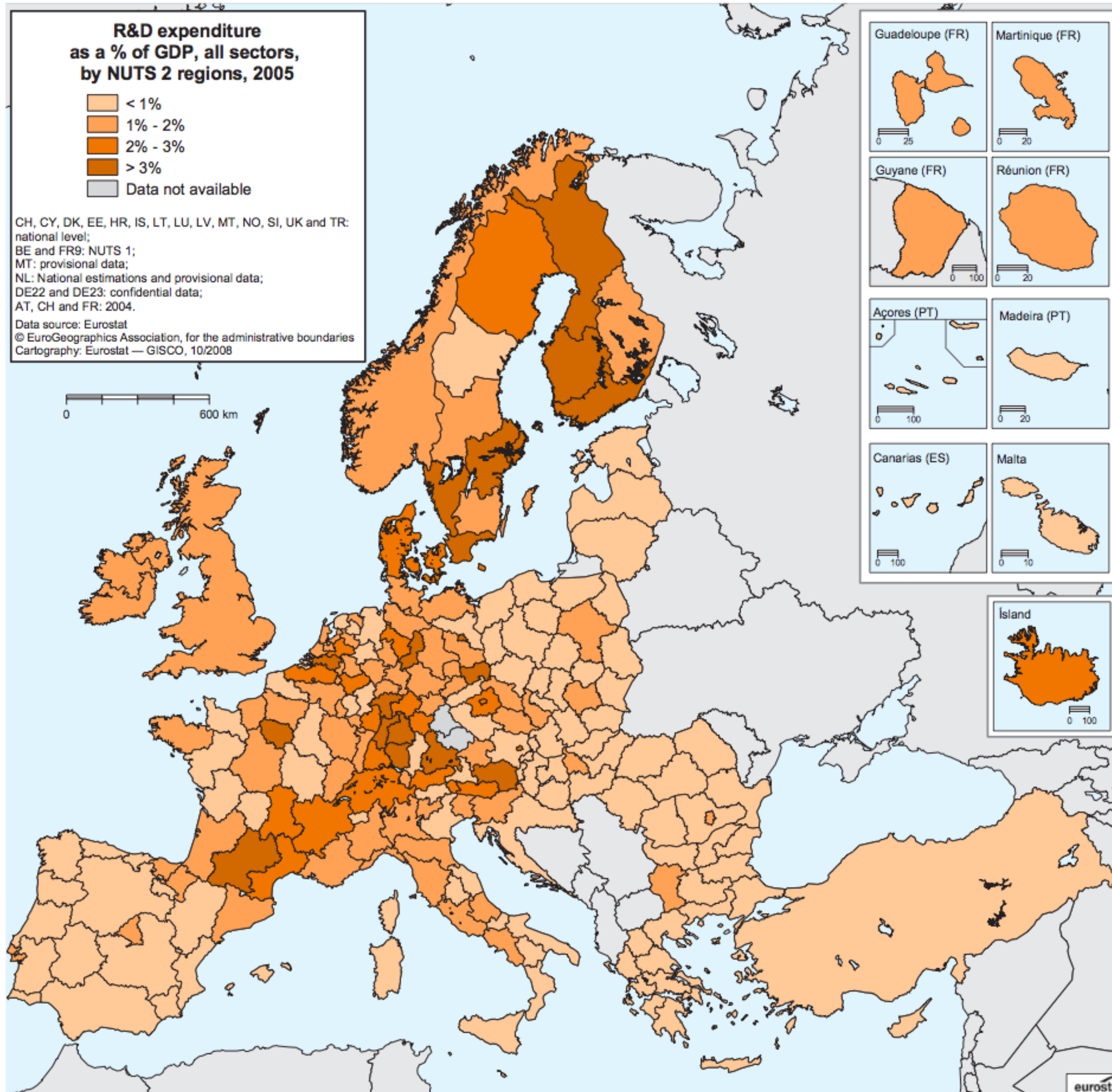
Figure 5.1: Summary Innovation Index (SII) in 2007 and growth rate of SII, EU-27 and selected countries



Regional R&D

INGV - Istituto Nazionale di Geofisica e Vulcanologia - Italy

Map 2.12: R&D expenditure as a percentage of GDP, all sectors, 2005 - NUTS 2



Sustaining and directing the research effort

Funding for Earth Systems research is stationary or decreasing.

Single investigator programs (NSF or ERC)are too small to engage global issues.

Research spending from defense budgets and private sector entities – is still not keyed to climate and low carbon research.

Investments in climate research and low carbon technologies are not growing

A new international research paradigm

We need to identify the new questions. What are the big scientific and technological questions that will make a real difference to policy and investment decisions in the coming decade, and that can drive the research agenda of the next generation of researchers and scientists?

We need to mobilize new sources of funding. We need to be able to articulate the scale of funding needed. What is the scale of that funding? How does it compare to other efforts to accomplish other advancements in knowledge and technology?

We need new global institutional solutions to deliver the support this research deserves. What forms of global public-private partnerships do we need to ensure the private sector invests for the long term? What institutional arrangement should we set in place?