A suite of global circulation models

Klaus Fraedrich, Meteorologisches Institut, KlimaCampus, Hamburg

1. Introduction	KlimaCampus	
2. On models	PUMA – SAM – SOM – PlaSim	
3. Applications	diagnostics uncertainty	entropy – snowball earth stochastic forcing stoch. parameterization

DKRZ

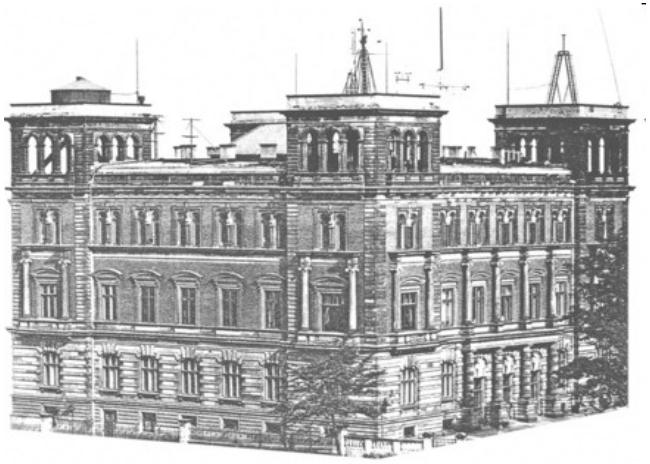
GKSS FORSCHUNGSZENTRUM

KlimaCampus

UH

Historic roots of climate research in Hamburg

Georg von Neumayer



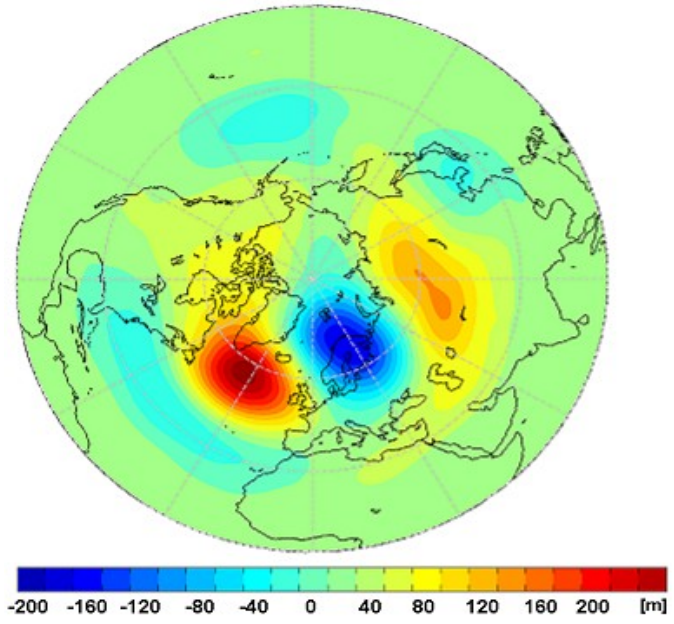
www.wissenschaft.hamburg.de

Seewarte Hamburg
(Naval Observatory)

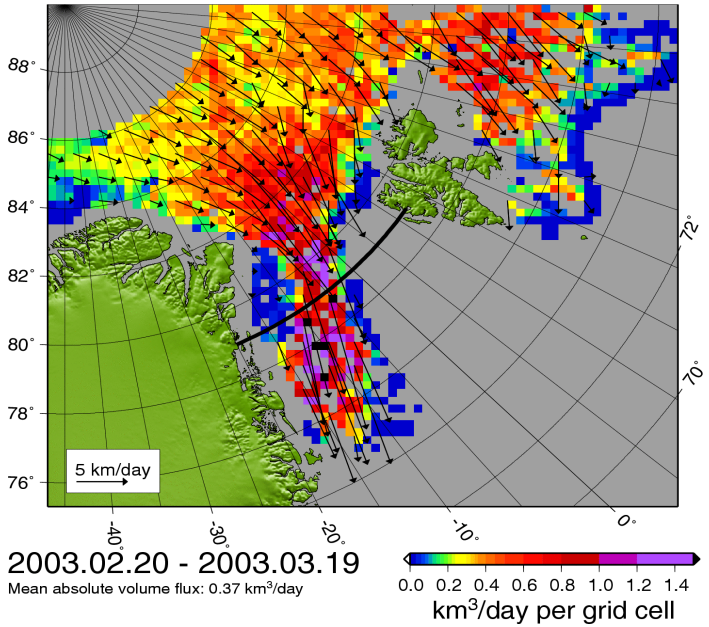
Wladimir Köppen

Existing expertise in marine and atmospheric sciences

Example: North Atlantic climate system



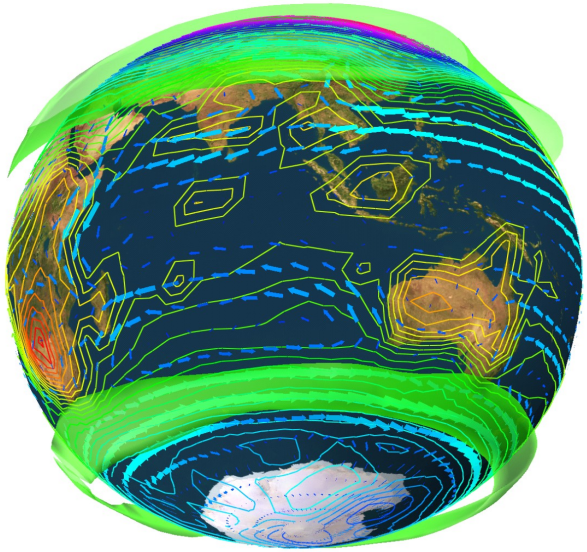
Pressure pattern over the Nordic Seas



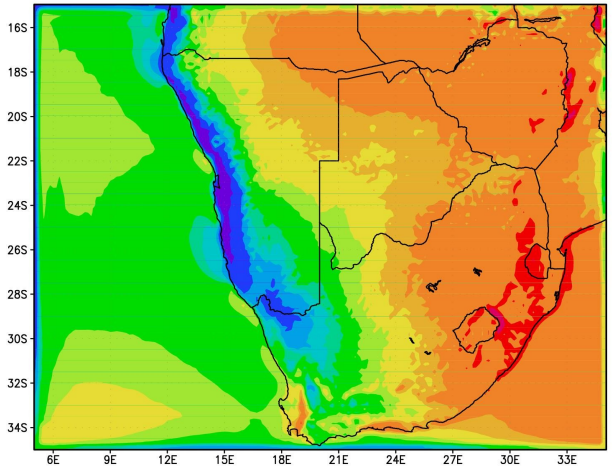
Freshwater export from the Arctic

Existing expertise in marine and atmospheric sciences

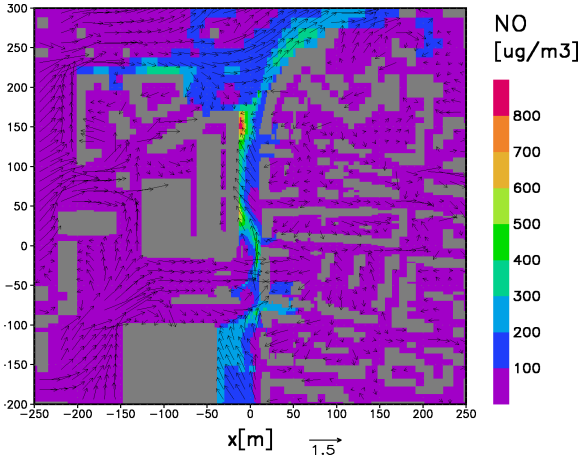
Example: Modelling climate and ecosystem at all scales



Global climate system modelling
Model spectrum:: MPG-UNI
ECHAM-family
SAM – PUMA – PlanetSimulator



Regional climate modelling
(Example: Rainfall over
South Africa)

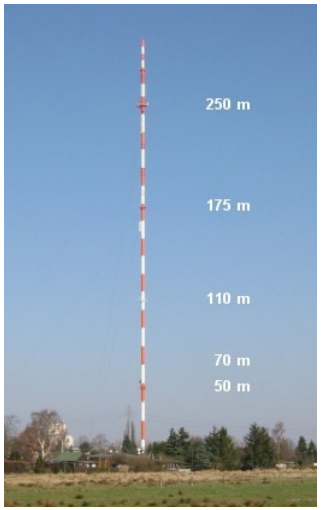


Urban scale modelling

Infrastructure for climate research

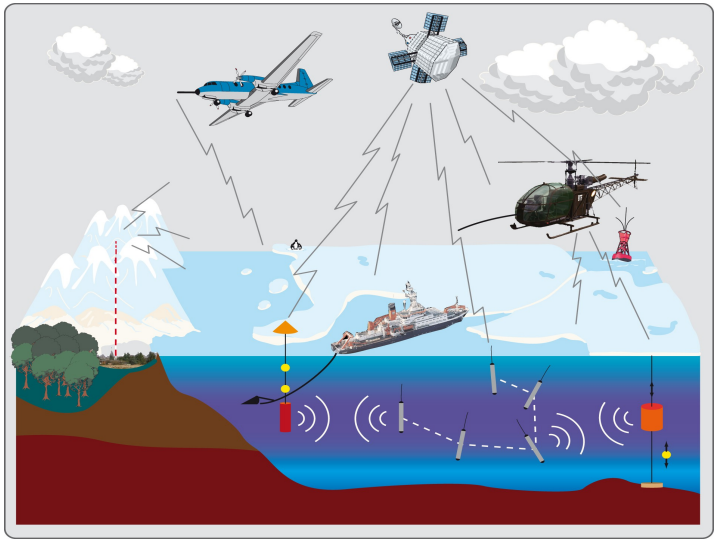
Research Platforms

DKRZ

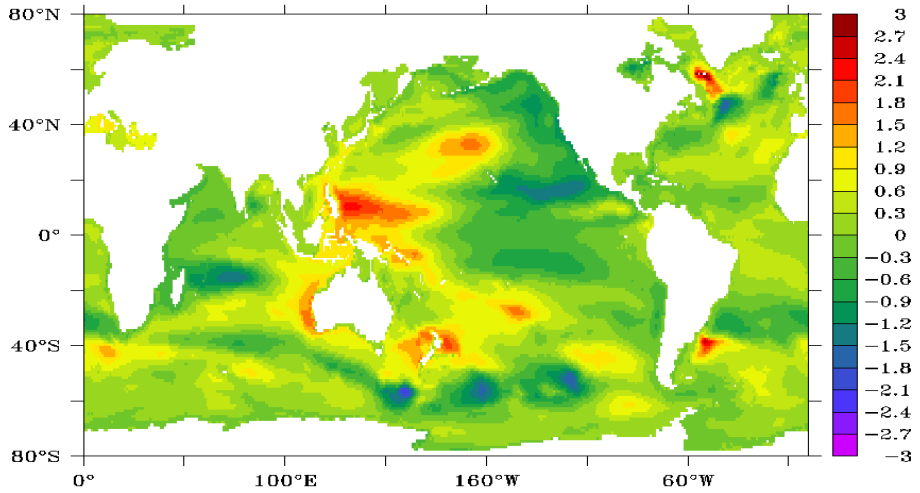


New challenges and research questions

A. Analysis of past and present climate system components



comprehensive data base, measurements



data assimilation, sea level

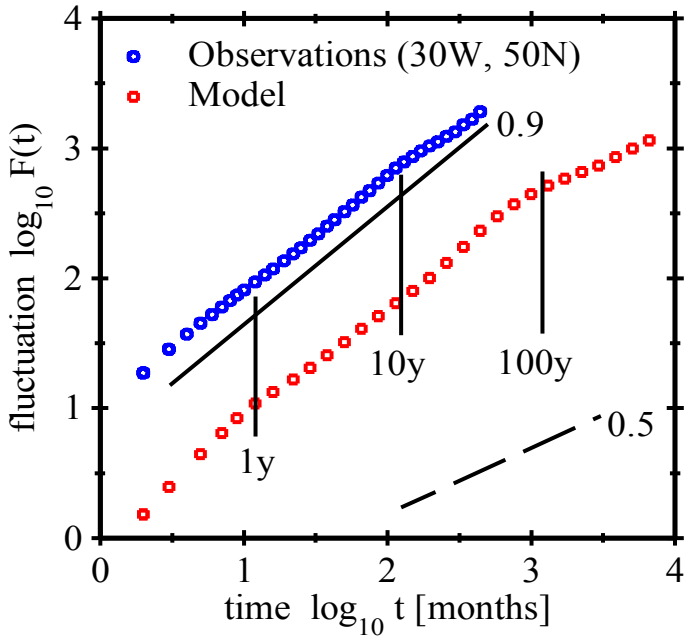
Aim: ERA-data but for A+O

New challenges and research questions

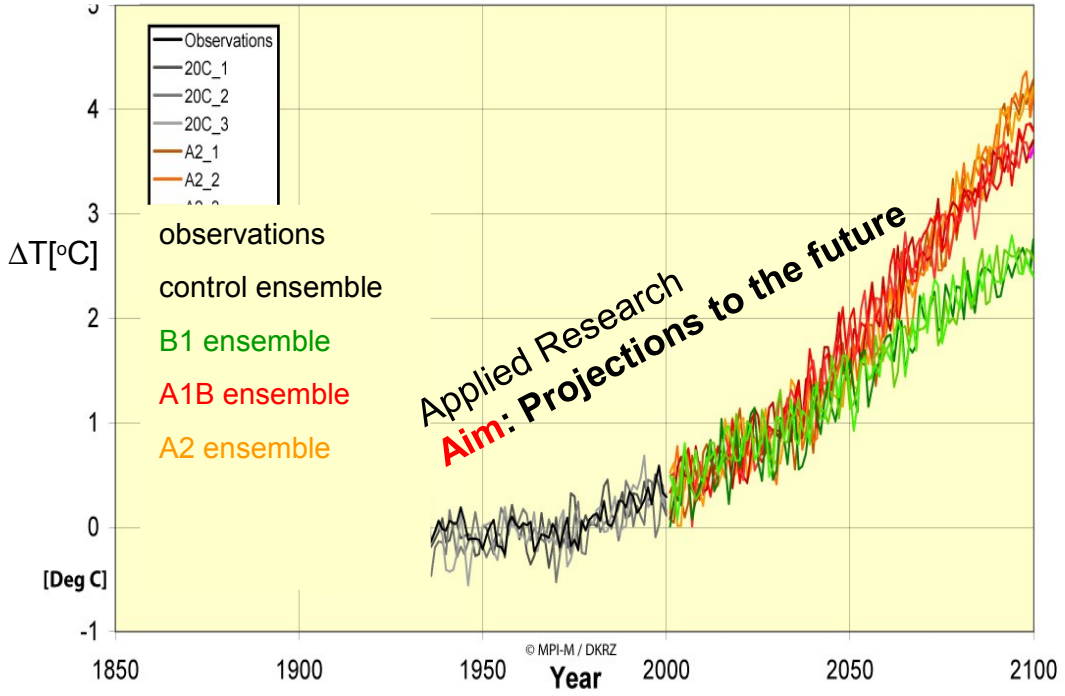
A. Analysis of past and present climate system components

B. Climate dynamics, variability and predictions

Temperature variability



Temperature projections



Basic Research

Aim: Cause and use of long term memory?

Practical: extending predictability limits

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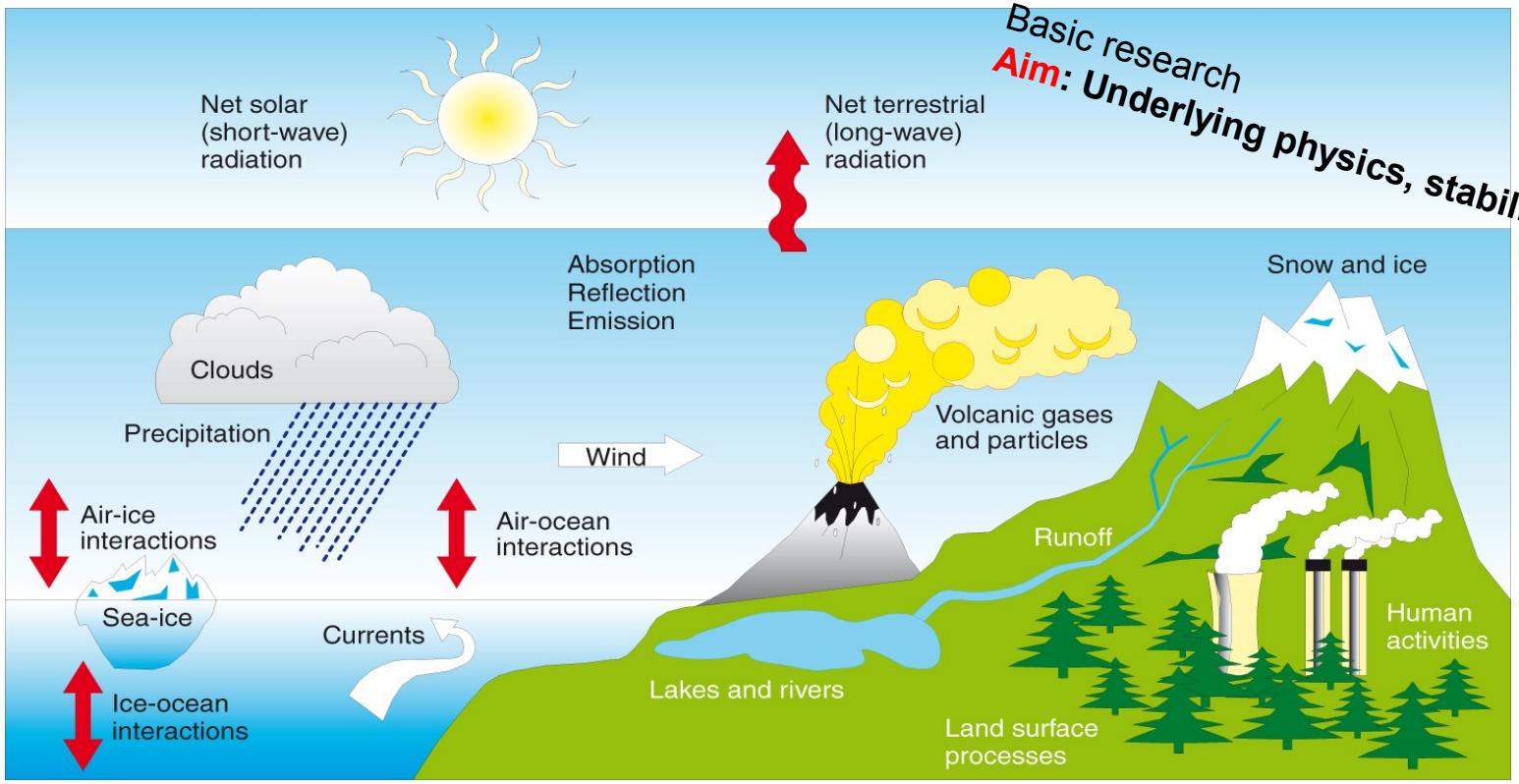
New challenges and research questions

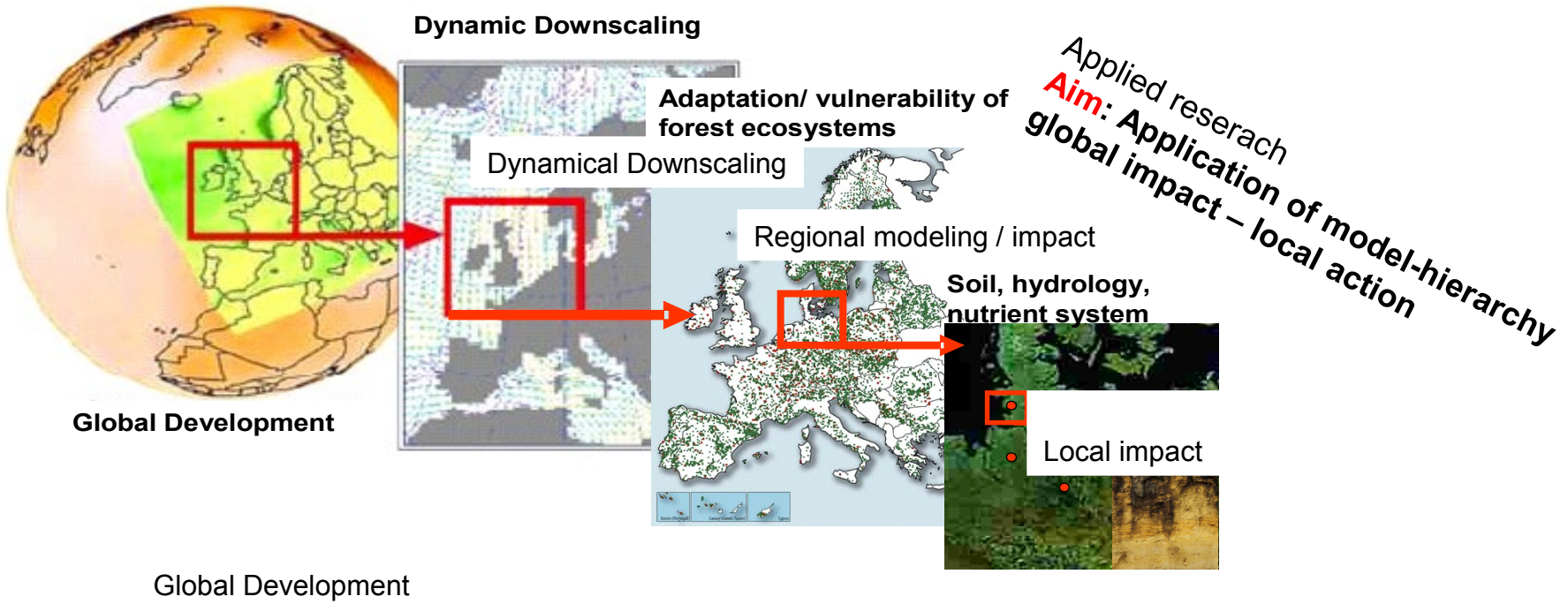
A. Analysis of past and present climate system components
B. Climate dynamics, variability and predictions
C. Feedbacks in the climate system, interactions humans - climate



Basic research
Aim: Underlying physics, stability/sensitivity

New challenges and research questions

A. Analysis of past and present climate system components
B. Climate dynamics, variability and predictions
C. Feedbacks in the climate system, interactions humans – climate
D. Impacts of climate variability and change on regional system



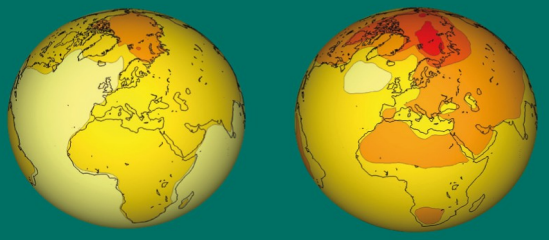
Global Development

Graduate education at the KlimaCampus

SICSS
(School of Integrated Climate System Scienes)

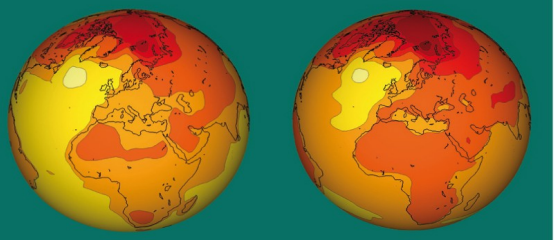
MSc program
Integrated Climate System Sciences

2 years

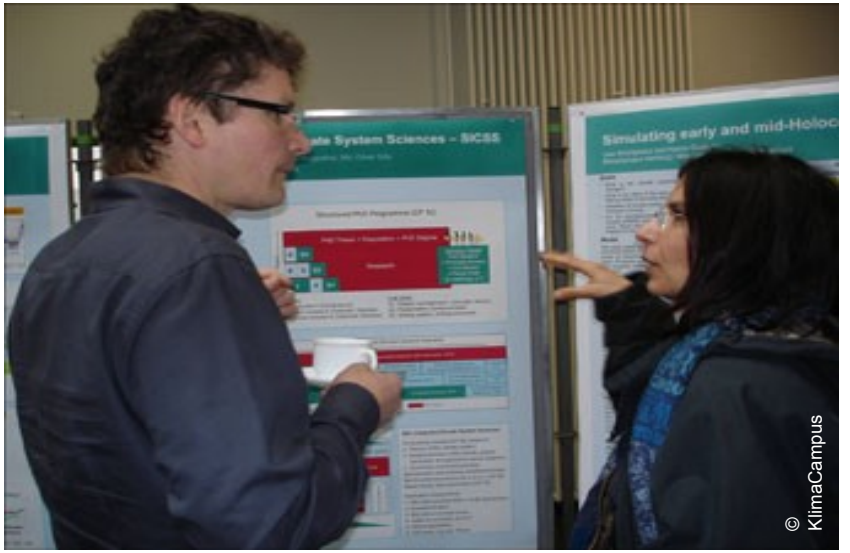


Doctoral program
Integrated Climate System Sciences

3 years



Dialoque and discourse with the public



- sharing the fascination of climate science
- stake holder discourse

CSC
Climate Service Center
Germany

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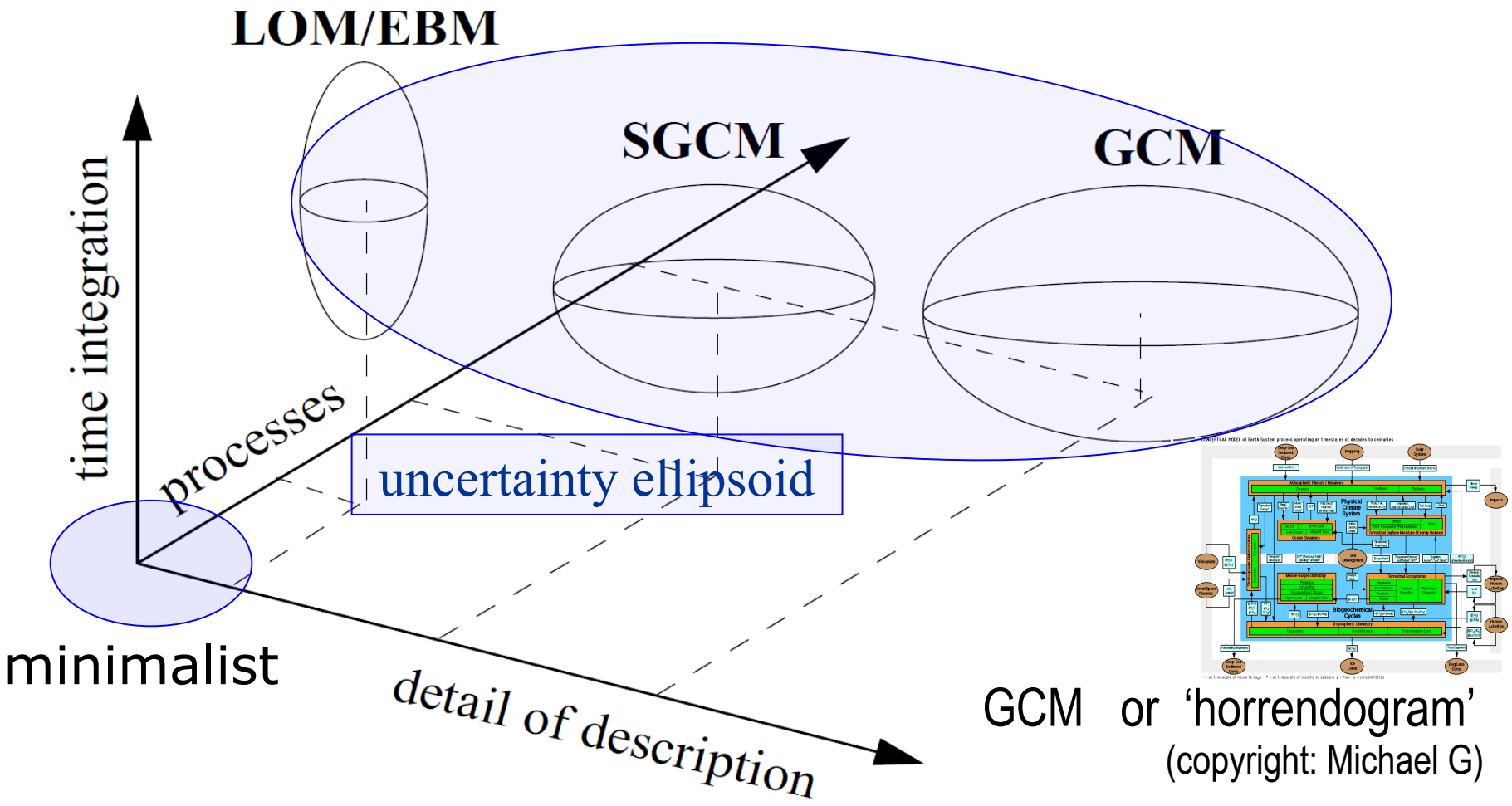
on models ....

Hierarchy of Global Circulation Models

... in an uncertainty environment



GCM or 'horrendogram'

(copyright: Michael G)

Source:
General Circulation Models of the Atmosphere
in Encyclopedia of Nonlinear Science (2005)

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A Suite of Global Circulation Models (GCM)

Suite of Global Circulation Models

University of Hamburg KF, T.Frisius, E.Kirk, F.Lunkeit

Atmosphere (spectral)

- **S**hallow **A**tmosphere **M**odel*
- **P**ortable **U**niv. **M**odel of the **A**tmosphere*: dynamical core
- **Pla**net **Sim**ulator: General Circulation Model

* **with adjoint version**

Ocean

- **M**ixed **L**ayer, Diffusion
- **S**pectral **O**cean **M**odel: shallow water
- **L**arge **S**cale **G**eostrophic

AO-Coupled

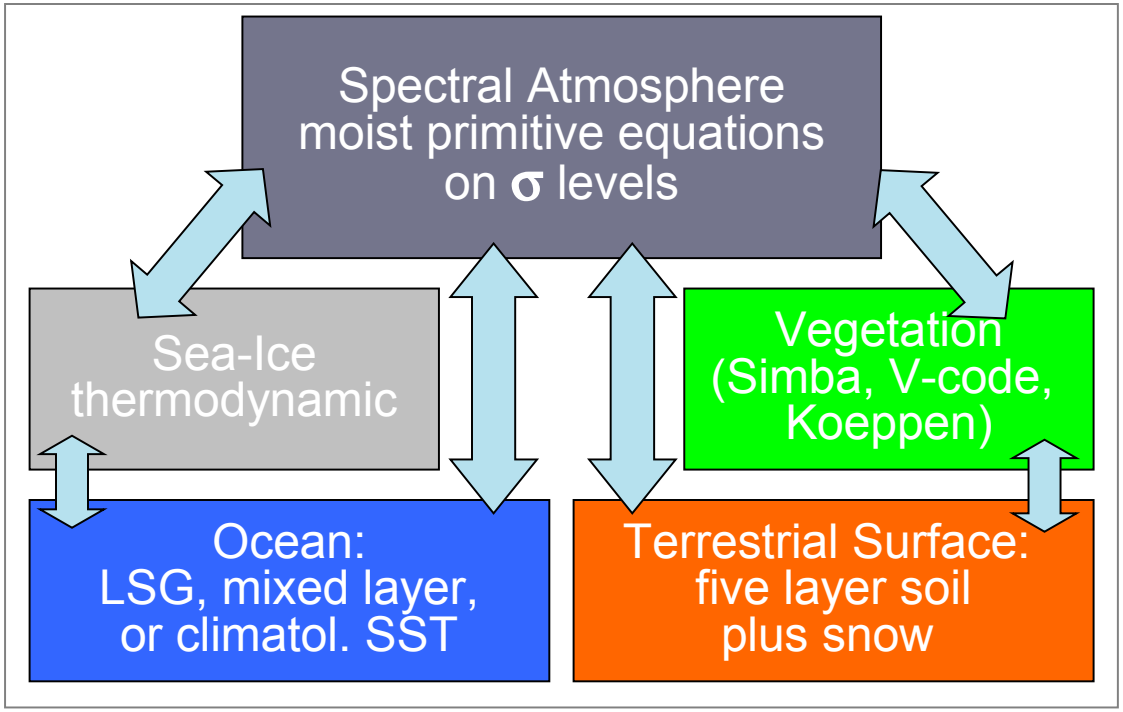
PlaSim–ML, PlaSim–SOM, PlaSim–LSG

Laboratory

- **D**irect **N**umerical **S**imulation: Rotating Tank

PlaSim: Planet Simulator

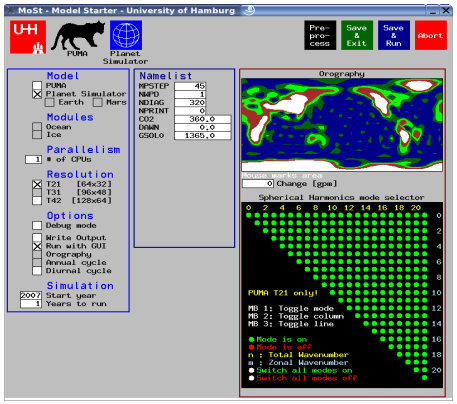
University of Hamburg KF, E.Kirk, F.Lunkeit

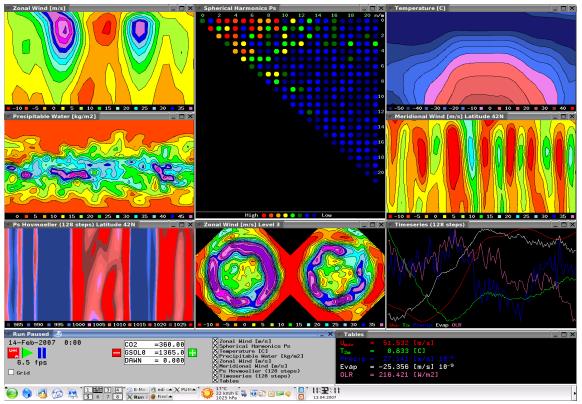


Key features

- portable
- fast
- open source
- parallel
- modular
- easy to use
- documented
- compatible

Model **St**arter
and
Graphic **U**ser **I**nterface





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http://www.mi.uni-hamburg.de/plasim

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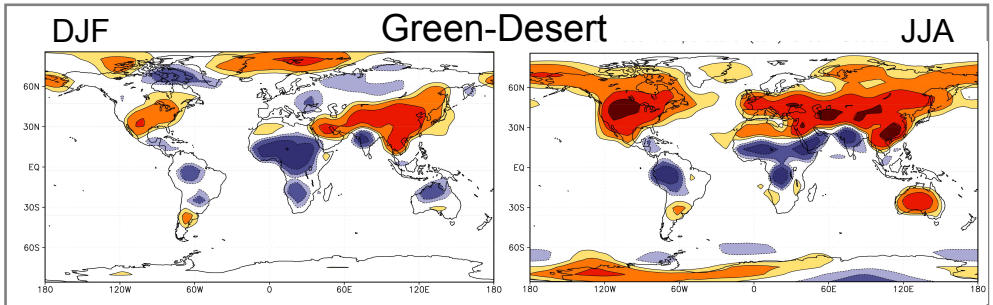
PlaSim: Planet Simulator

University of Hamburg KF, E.Kirk, F.Lunkeit



Components

- Spectral model on σ levels
- Moist Primitive Equations
- Radiation
- Clouds and convection
- Land surface and soil
- Vegetation
- Ocean: LSG, Mixed Layer
- Thermodynamic sea ice

Applications

- Aqua-planet: double ITCZ, convective schemes
- Strato/troposphere: double jets, wave breaking
- Vegetation extremes
- Global entropy diagnostics
- Maximum entropy production (MEP)
- Ultra-long runs: long term memory
- Paleo modeling
- Earth climates idealized: snowball, mud, desert vs green world
- Mars climates: orbital parameters, role of ice

Information and downloads at: http://www.mi.uni-hamburg.de/plasim

Universität Hamburg

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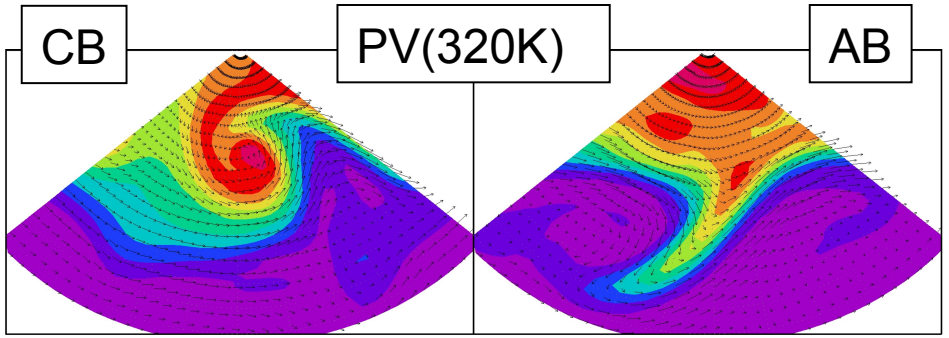
PUMA: Portable University Model of the Atmosphere

University of Hamburg KF, E.Kirk, F.Lunkeit



Components

- Primitive Equations on σ levels
- Spectral model: dynamical core
- Rayleigh friction, Newtonian cooling,
- Hyperdiffusion, stochastic forcing
- Scalable resolution
- Configurable forcings

Applications

- Storm tracks: teleconnections and spatial resonance
- Synchronisation
- Tracer dynamics
- Stochastic parameterisation
- Stoch. forcing: coherence resonance
- Parameter optimisation
- Maximum entropy production (MEP)
- Strato/troposphere: double jets
- Wave breaking
- Adjoint modeling: a diagnostic tool

Information and downloads at: http://www.mi.uni-hamburg.de/puma

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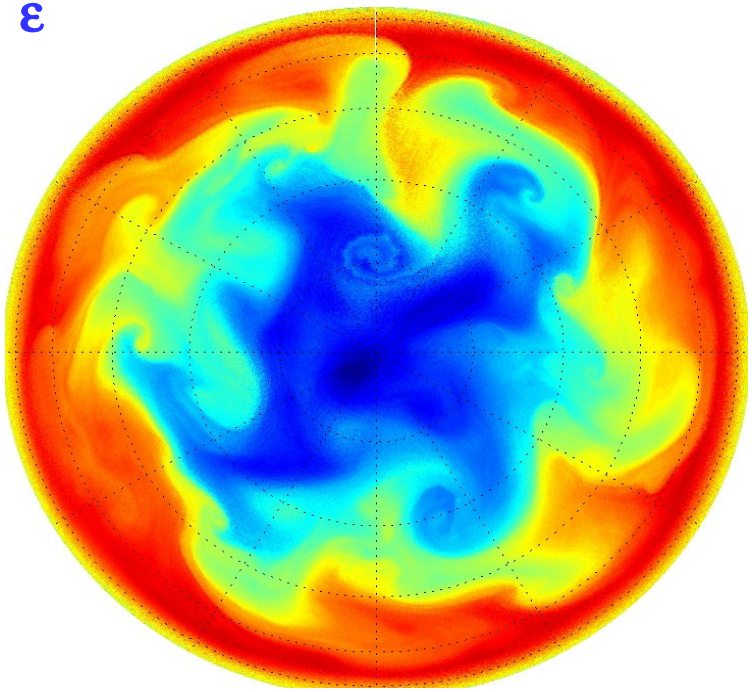
Bridging models synchronisation

$dX1/dt = PUMA(X1) + (X2-X1) / \varepsilon$

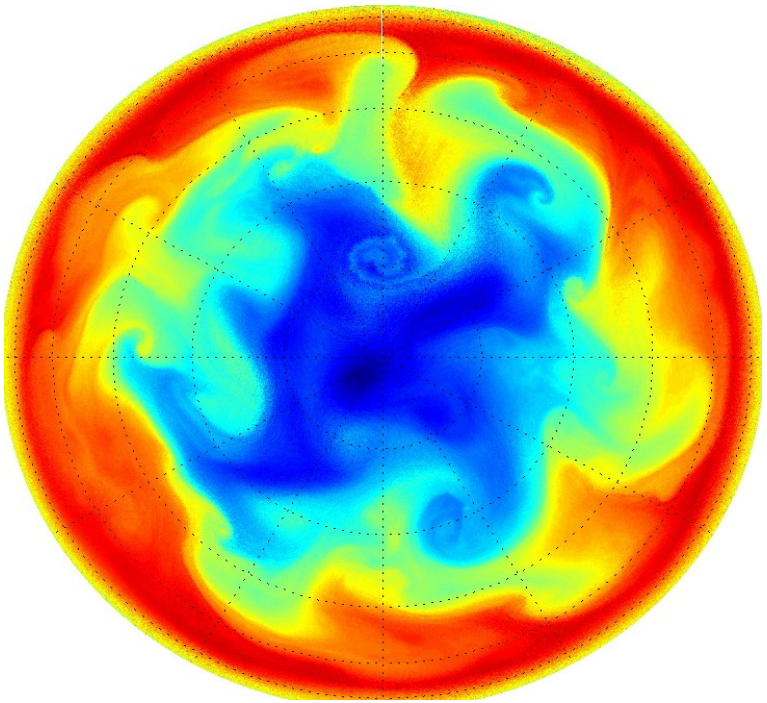
$dX2/dt = PUMA(X2) + (X1-X2) / \varepsilon$



PUMA-1

$(X1-X2) / \varepsilon$

$(X2-X1) / \varepsilon$

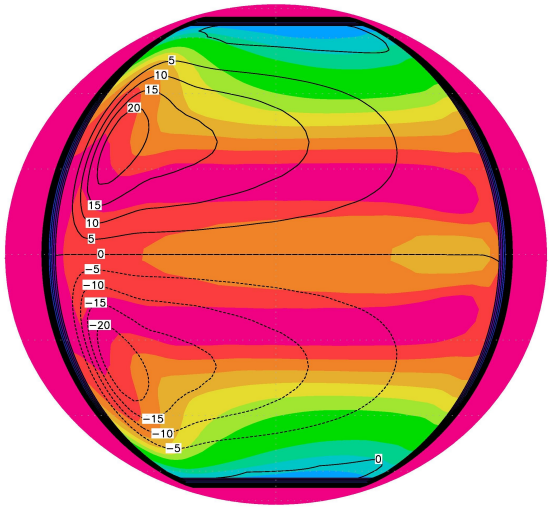


PUMA-2

figures: resolution T-1385 (~10km)

SOM: Spectral Ocean Model

University of Hamburg T.Frisius, KF, X. Zhu, W. Wang (Ocean Modelling)



Components

- Bousinesq equations plus salinity
- Continents: nearly infinite drag
- Interface to atmosphere:mixed layer
- Convective adjustment

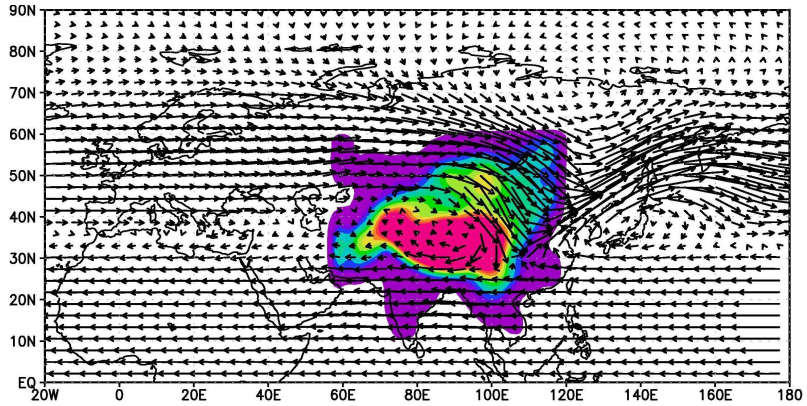
Applications

- MOC: Long term climate variability
- Large scale geostrophic (LSG) effects
- Paleo ocean
- Stochastic parameterization
- Eddy resolving simulation:
  ocean currents
- Ocean heat transports and
  entropy production

SAM: Shallow Atmosphere Model

University of Hamburg T. Frisius, KF, X. Zhu

Flow over the Tibetan Plateau:
Zonally symmetric forcing



Components

- Shallow water equations
- Vorticity forcing
- Stochastic forcing

Applications

- Flow over topography: Bridging Eurasia
- Decay of two-dim. turbulence
- Eddy-resolving: barotropic ocean
- Stability of barotropic flow
- Rotating tank experiment (DNS)

Information at: http://www.mi.uni-hamburg.de/sam.6074.0.html

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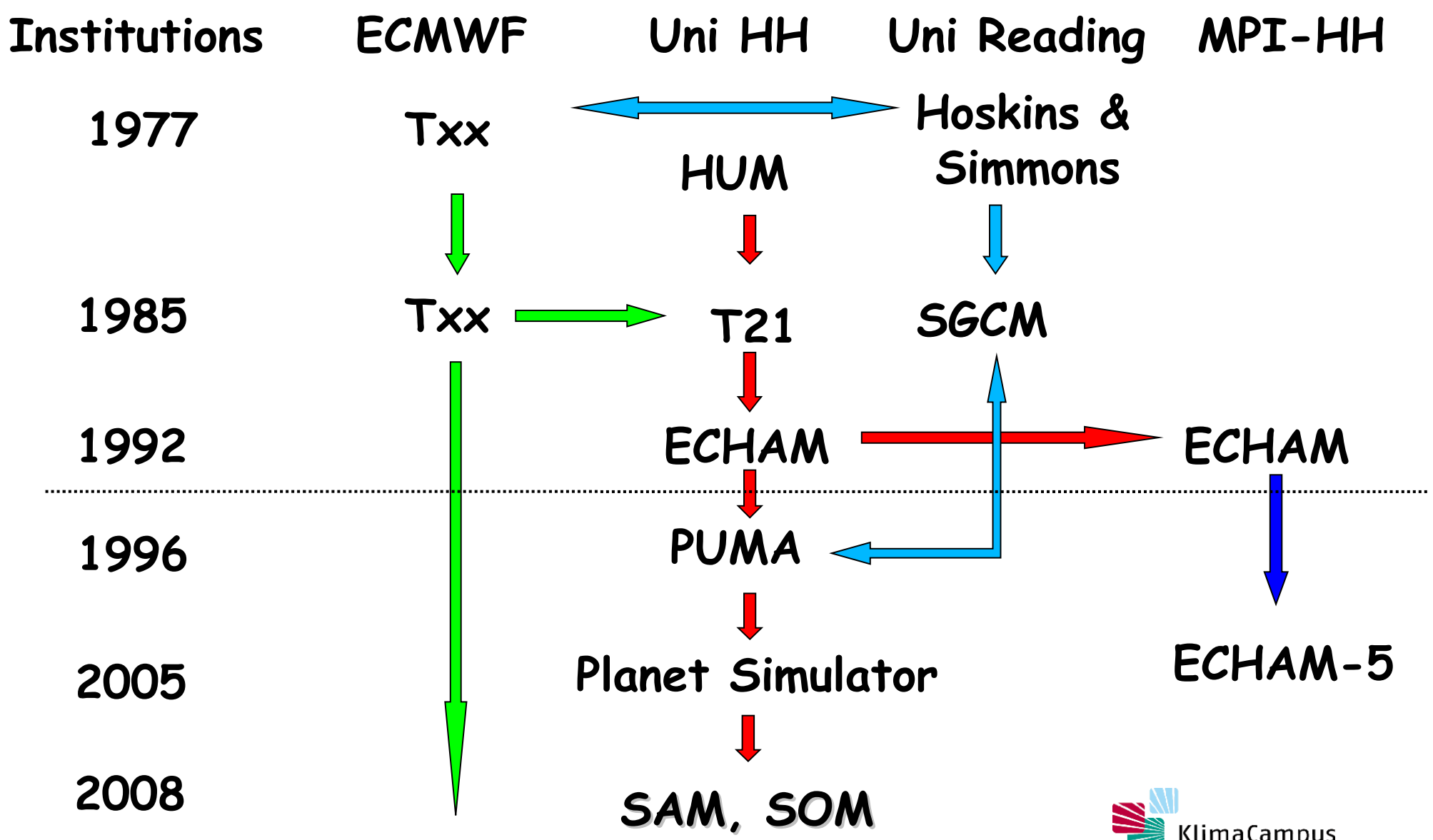
PUMA - Planet Simulator – SAM – SOM: ‚Family Tree'



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PUMA – PLASIM – SAM – SOM users

BELGIUM
Universite de Liege, Laboratoire de Physique Atmospherique et Planetaire
Universite Libre de Bruxelles, Centre for Nonlinear Phenomena and Complex Systems

CANADA
Memorial University, St. John's, Newfoundland, Dept of Physics & Physical Oceanography

CHINA
Nanjing University of Information Science and Technology, Nanjing
Ocean University of China, Qingdao, Department of Meteorology

ENGLAND
University of Oxford, Department of Physics
University of Reading, Department of Meteorology

FRANCE
Universite de La Reunion, Department of Physics
Laboratoire de Meteorologie Dynamique, Paris
Ecole Normale Superieur, Department Terre-Atmosphere-Ocean (TAO), Paris
Laboratoire de Physique des Oceans, Universite de Bretagne Occidentale, Brest

GERMANY
Freie Universität Berlin, Meteorologisches Institut
Universität Kiel, Institut für Meereskunde
Universität Bonn, Meteorologisches Institut
Bergakademie Freiberg, Institut für Geophysik
GKSS Geesthacht, HGF, Institut für Küstenforschung
Senckenberg Forschungsinstitut und Naturmuseum, HGF, Frankfurt
MPI-Biogeochemie, Jena
MPI-Sonnensystemforschung, Katlenburg
Potsdam Institute for Climate Impact Research, Potsdam

INDIA
Indian Institute of Tropical Meteorology, Poona/Pune, Climate and Global Modeling Division

ISRAEL
Bar Ilan University, Ramat Gan, Department of Geography and Environment

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PUMA – PLASIM – SAM – SOM users cont‘d

ITALY
Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Rome
University of Rome "La Sapienza", Rome, Physics Department
Inst. of Atmospheric Sciences and Climate, ISAC, Italian National Research Council,Torino
European Academy Bozen/Bolzano (EURAC)
University of Genova, ISAC, Lecce

THE NETHERLANDS
Utrecht University, Department of Environmental Sciences
Wageningen University and Research Centre, Department of Environmental Sciences

NEW ZEALAND
National Institute of Water & Atmospheric Research, Wellington

NORWAY
Bjerknes Centre for Climate Research, Bergen
Department of Meteorology, University of Oslo,

RUSSIA
Institute of Computational Mathematics and Mathematical Geophysics, Russian Academy of Sciences, Novosibirsk
Institute of Numerical Mathematics, Russian Academy of Sciences, Moscow
Space Research Institute, Russian Academy of Sciences, Moscow

SINGAPORE
National University of Singapore, Centre for Remote Imaging, Sensing and Processing

SPAIN
Campus de Ourense, Sciencias, Edeficio de Fisicas, Physica de la Atmosfera y el Oceano
University of Santiago de Compostela, Faculty of Physics, Nonlinear Physics

SWEDEN
Stockholm University, Department of Meteorology

USA
University at Albany, Department of Atmospheric and Environmental Sciences
University of Colorado, Boulder, Atmospheric and Oceanic Sciences
National Oceanic Atmospheric Administration (NOAA), Earth System Res. Lab., Phys. Sci. Div., CIRES, Boulder
Princeton University, Geophysical Fluid Dynamics Laboratory
Oregon State University, College of Oceanic and Atmospheric Sciences
New York University, Courant Institute of Mathematical Sciences

KlimaCampus

Theoretical Meteorology: research areas

Fundamental properties of atmospheric and climate dynamics

Atmospheric circulation	waves, wave breaking, jets, cyclones
Hydrological cycle	precipitation, runoff, environmental impacts
Climate variability	long term memory, trends, extremes
Dynamics and predictability	stochastic dynamics, thermodynamics (entropy) predictions, concepts
Model development	global spectral AO-model, direct numerical simulation atmosphere, ocean, land