Interactive Visualization in Climate Science

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Wien

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Hamburg

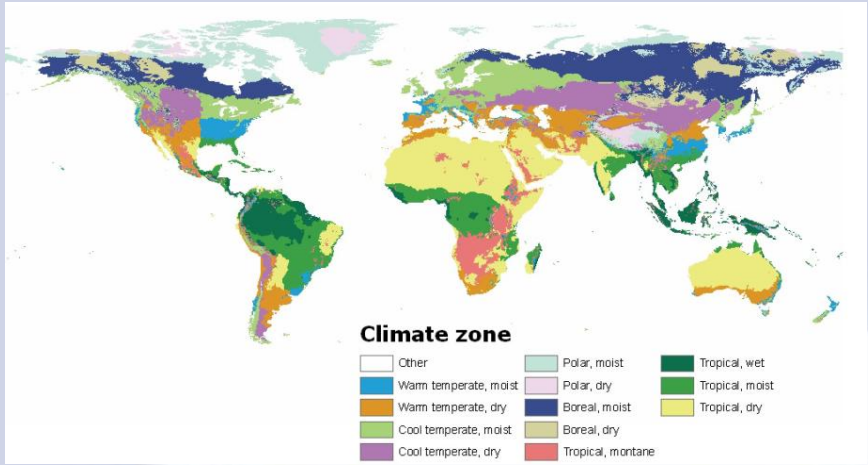
Outline

- Weather and climate science
- The German Climate Computing Center (DKRZ)
- Visualization at DKRZ

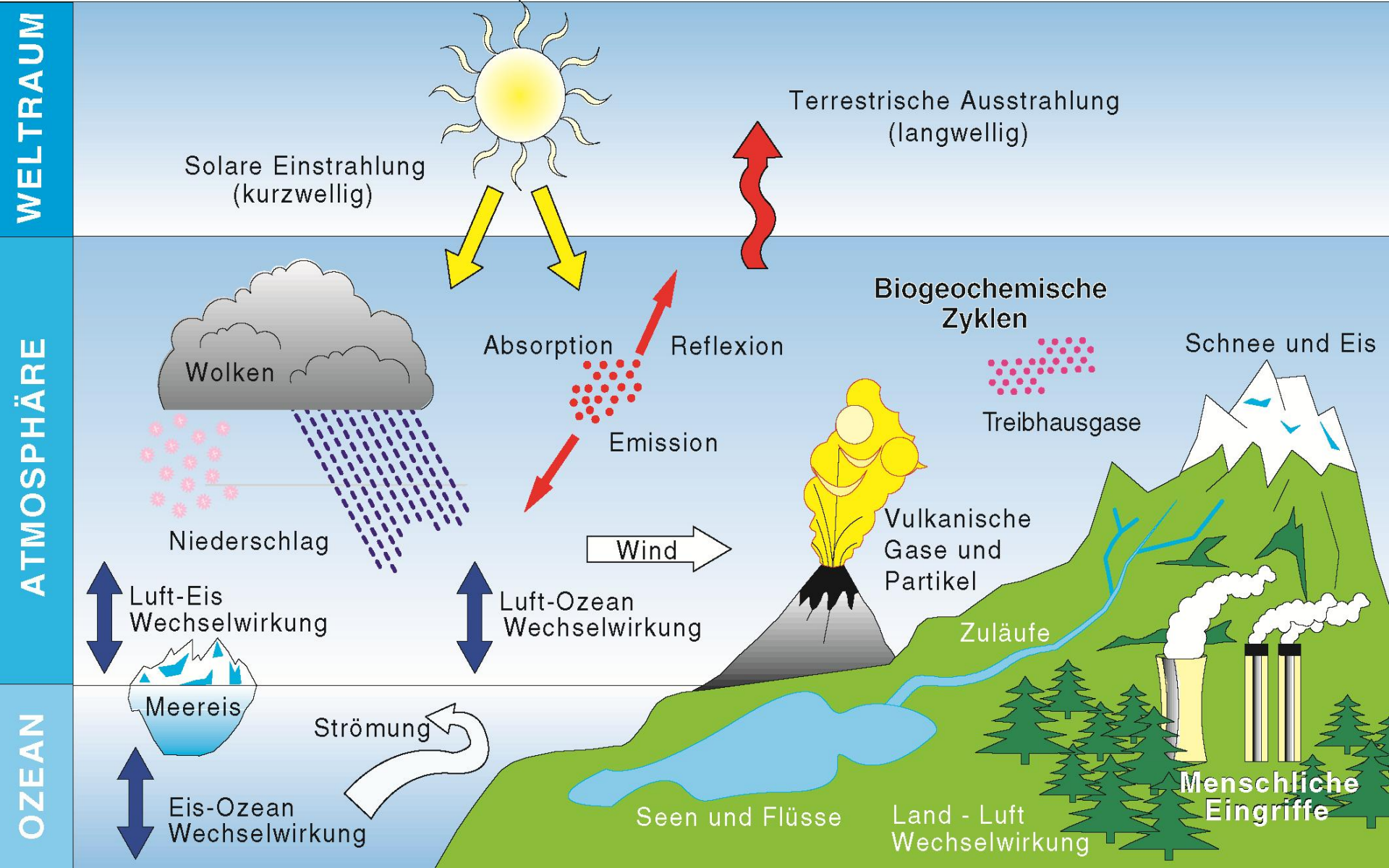
DKRZ

Weather and Climate

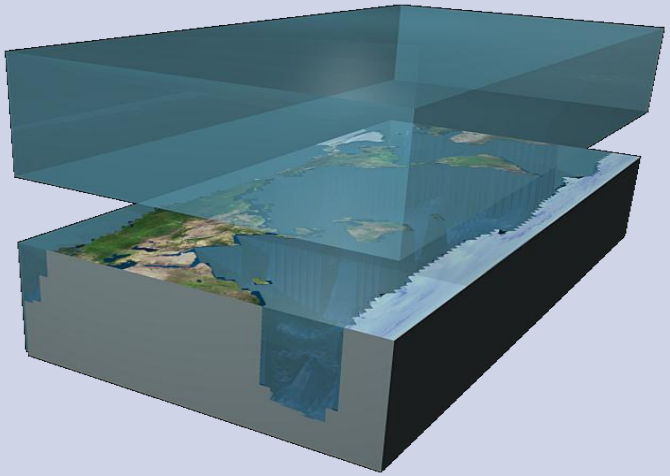
- **Weather**: Atmospheric conditions over a short period of time.
- **Climate**: Behavior over a long period of time (> 30 years).
- Climate is the *statistical* weather, that describes weather variations for a certain location and time of year.

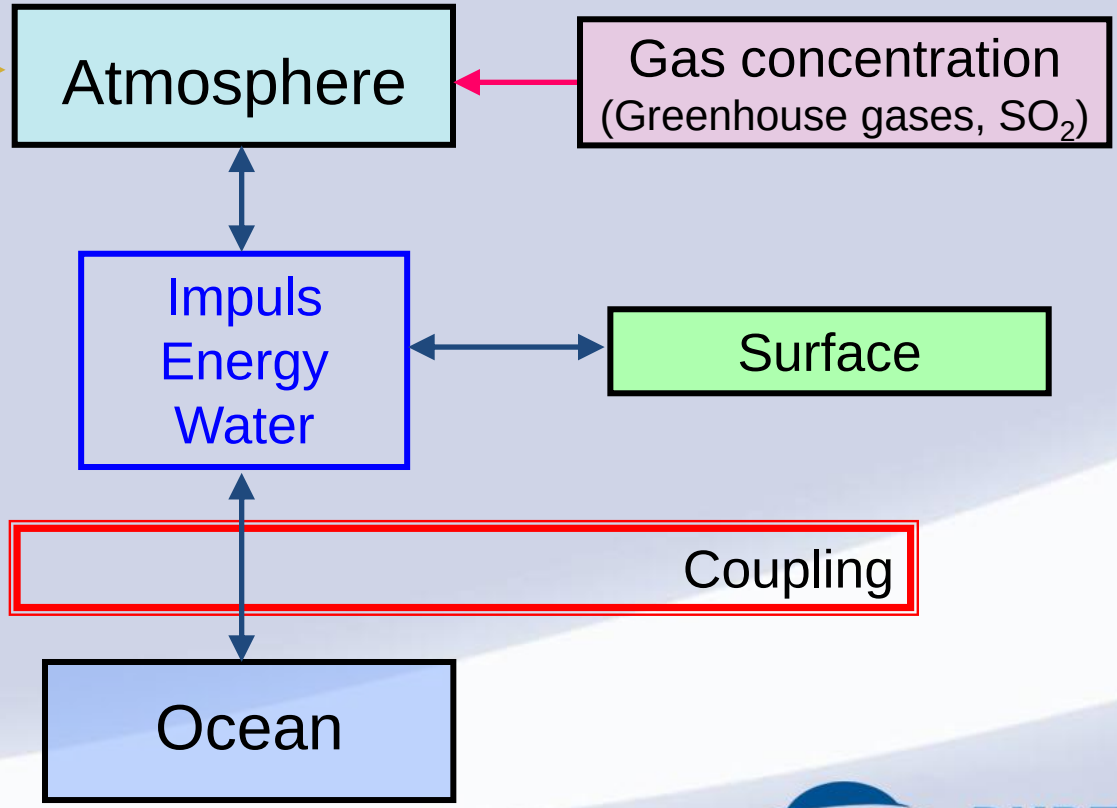


DKRZ

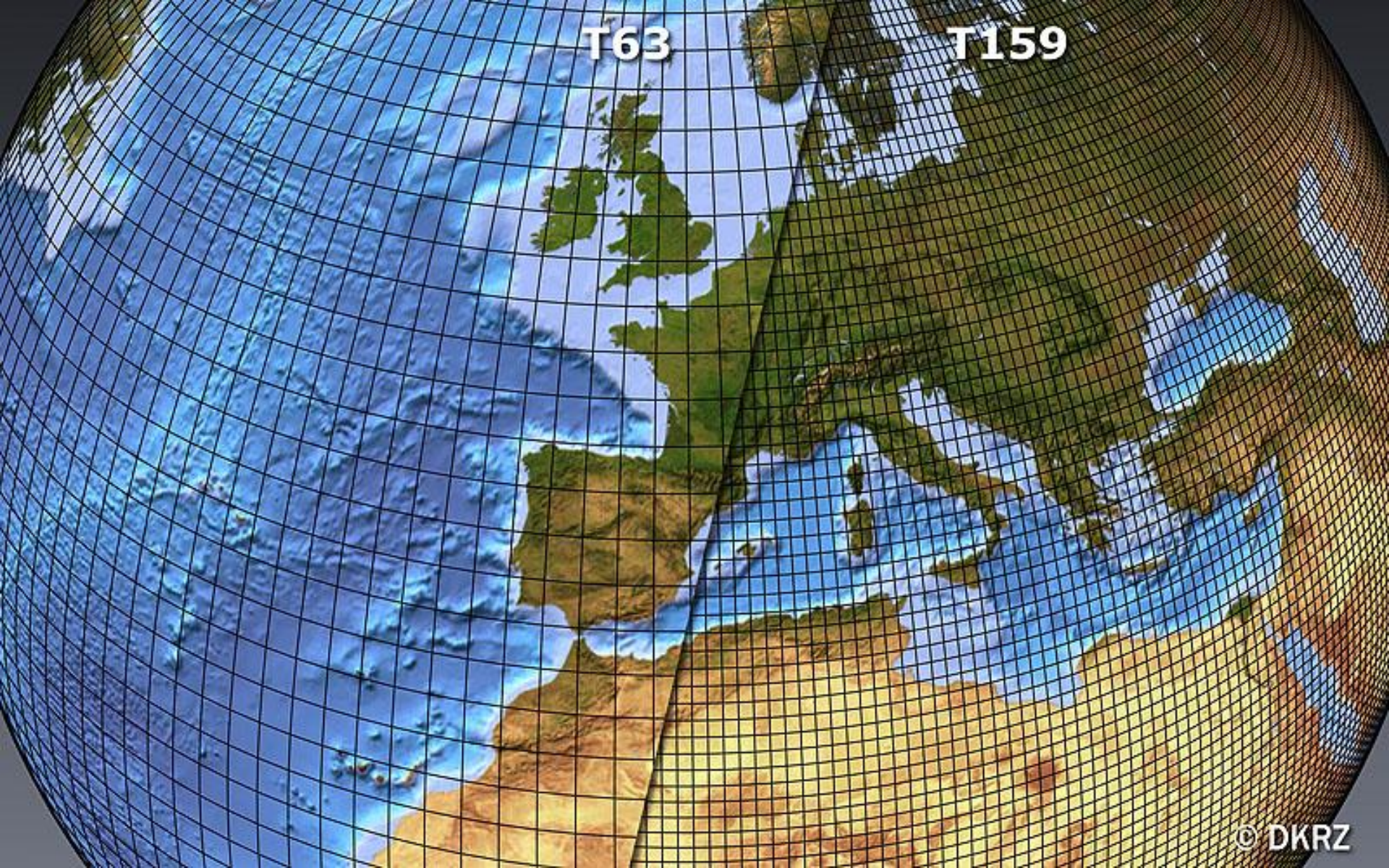

WELTRAUM
ATMOSPHÄRE
OZEAN
Solare Einstrahlung
(kurzwellig)
Terrestrische Ausstrahlung
(langwellig)
Wolken
Absorption
Reflexion
Emission
Biogeochemische
Zyklen
Schnee und Eis
Treibhausgase
Niederschlag
Wind
Vulkanische
Gase und
Partikel
Luft-Eis
Wechselwirkung
Luft-Ozean
Wechselwirkung
Zuläufe
Meereis
Strömung
Eis-Ozean
Wechselwirkung
Seen und Flüsse
Land - Luft
Wechselwirkung
Menschliche
Eingriffe

Physical climate model





DKRZ

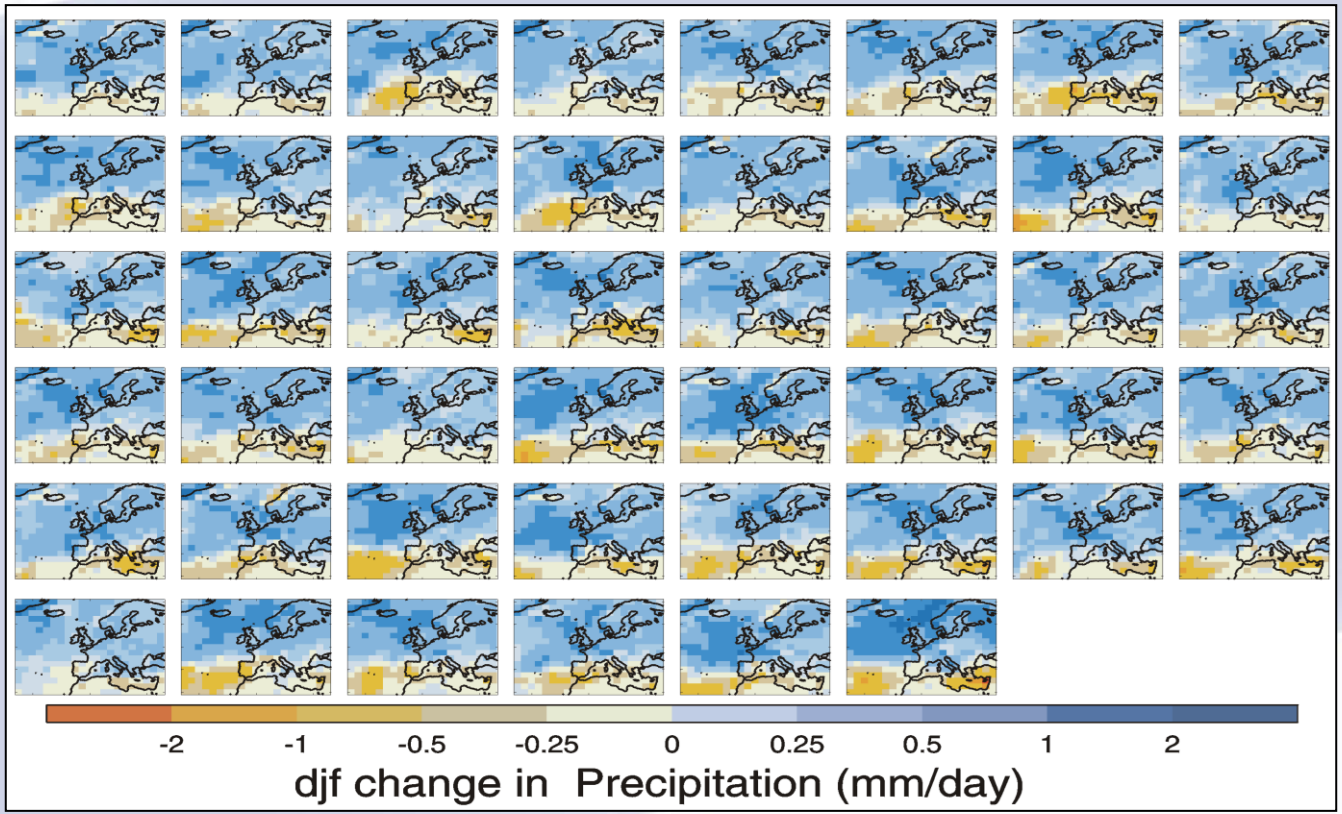

T63
T159
© DKRZ

Models

- MPI-OM (ocean)
  - HAMOCC (ocean carbon cycling)
- ECHAM (atmosphere)
  - JSBACH (biosphere)
- REMO (regional atmospheric model)
- MITRAS / METRAS (micro- and mesoscale atmospheric models)
- ICON (atmosphere, ocean, new grid)

DKRZ

Ensembles



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CMIP5 Experiments

- 3D coupled systems (ocean, atmosphere)
- Full carbon cycle including biosphere and oceanbiogeo-chemistry
- Simulated time: 10.000 years
- Horizontal resolution: ≈ 50 – 200 km
- 340 experiments with result data ≈ 650 TB
- Base experiments (e.g. the recent history historical 1850 to 2005)
- Projections (2005 to 2100, and 2005 to 2300, 3 different scenarios)

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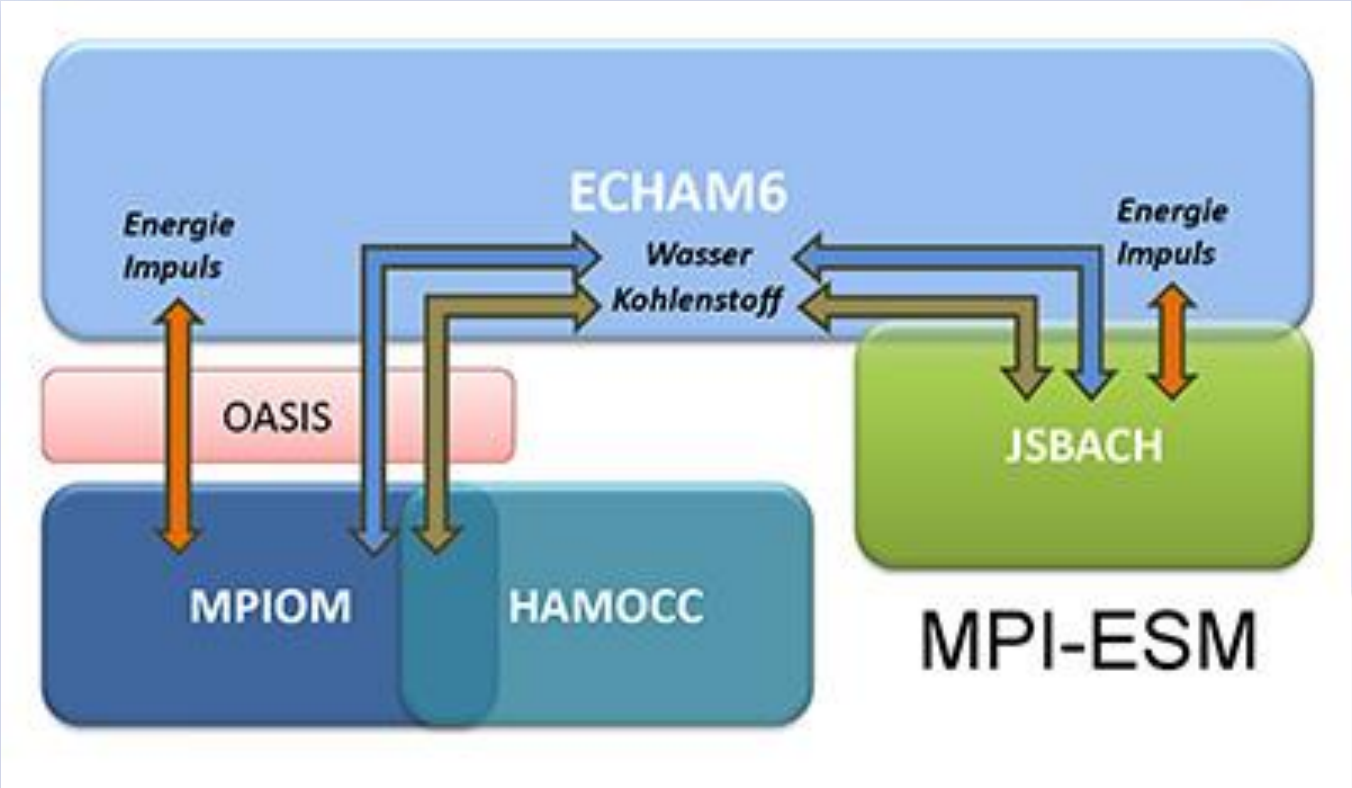
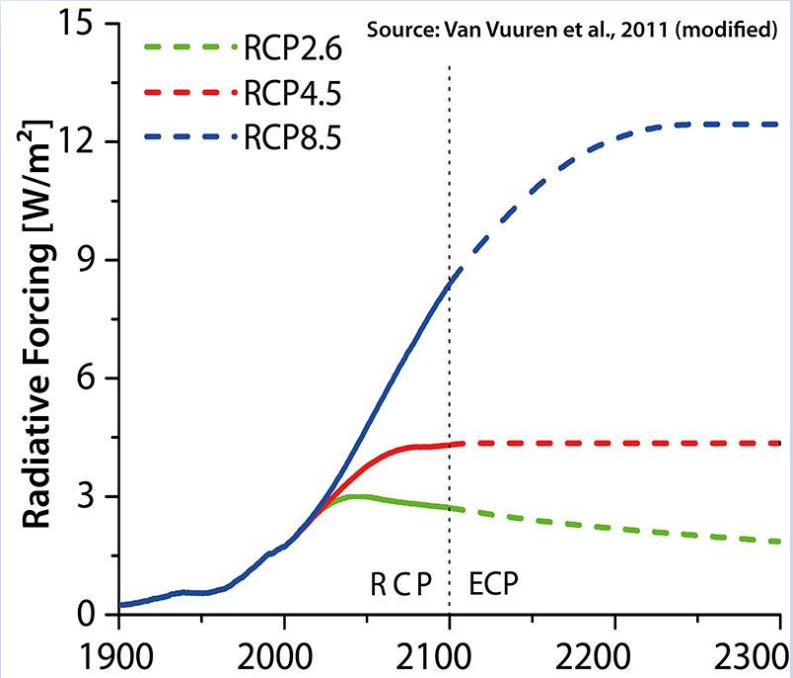
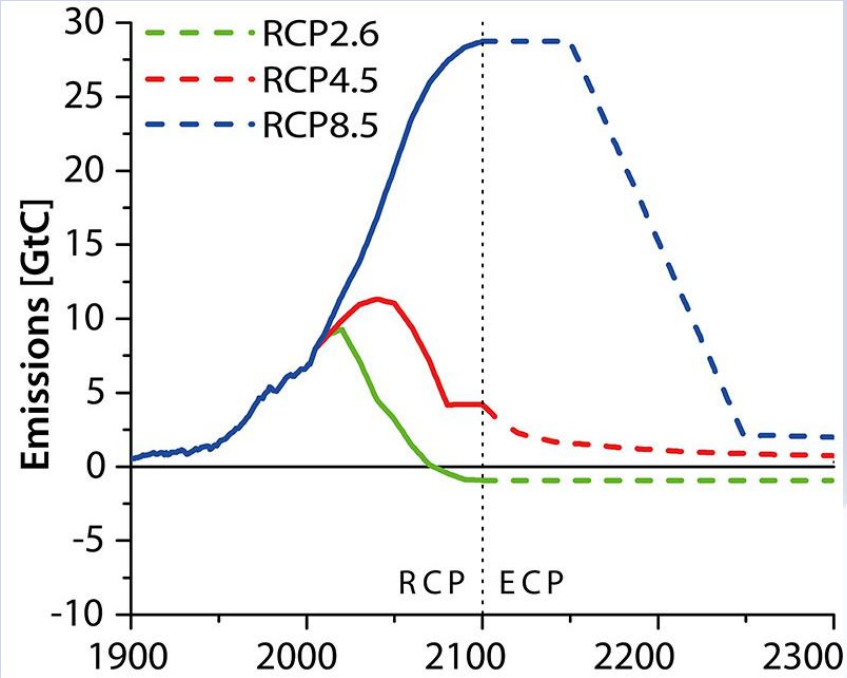
MPI ESM


ECHAM6
Energie
Impuls
Wasser
Kohlenstoff
Energie
Impuls
OASIS
JSBACH
MPIOM
HAMOCC
MPI-ESM

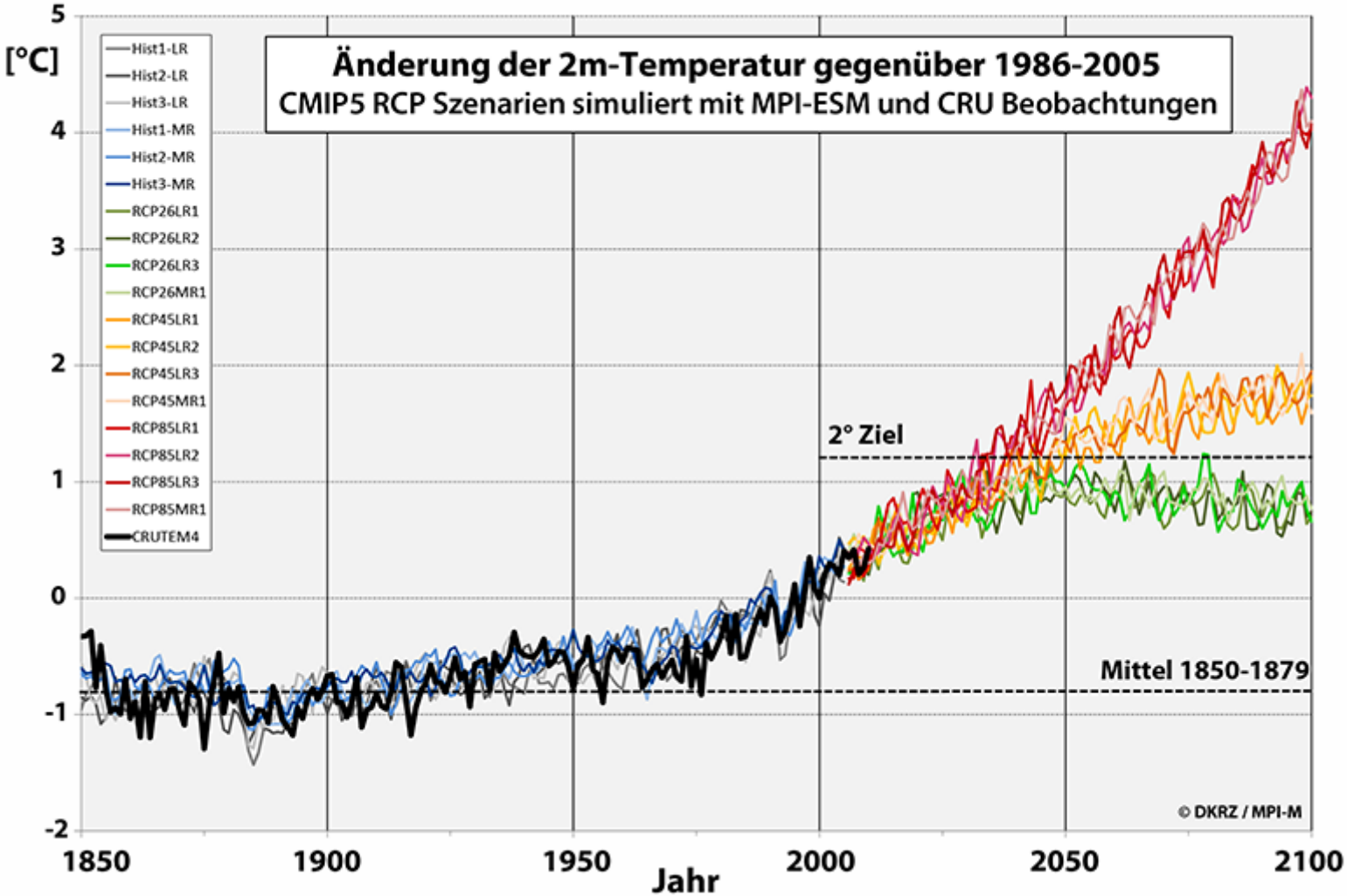
DKRZ

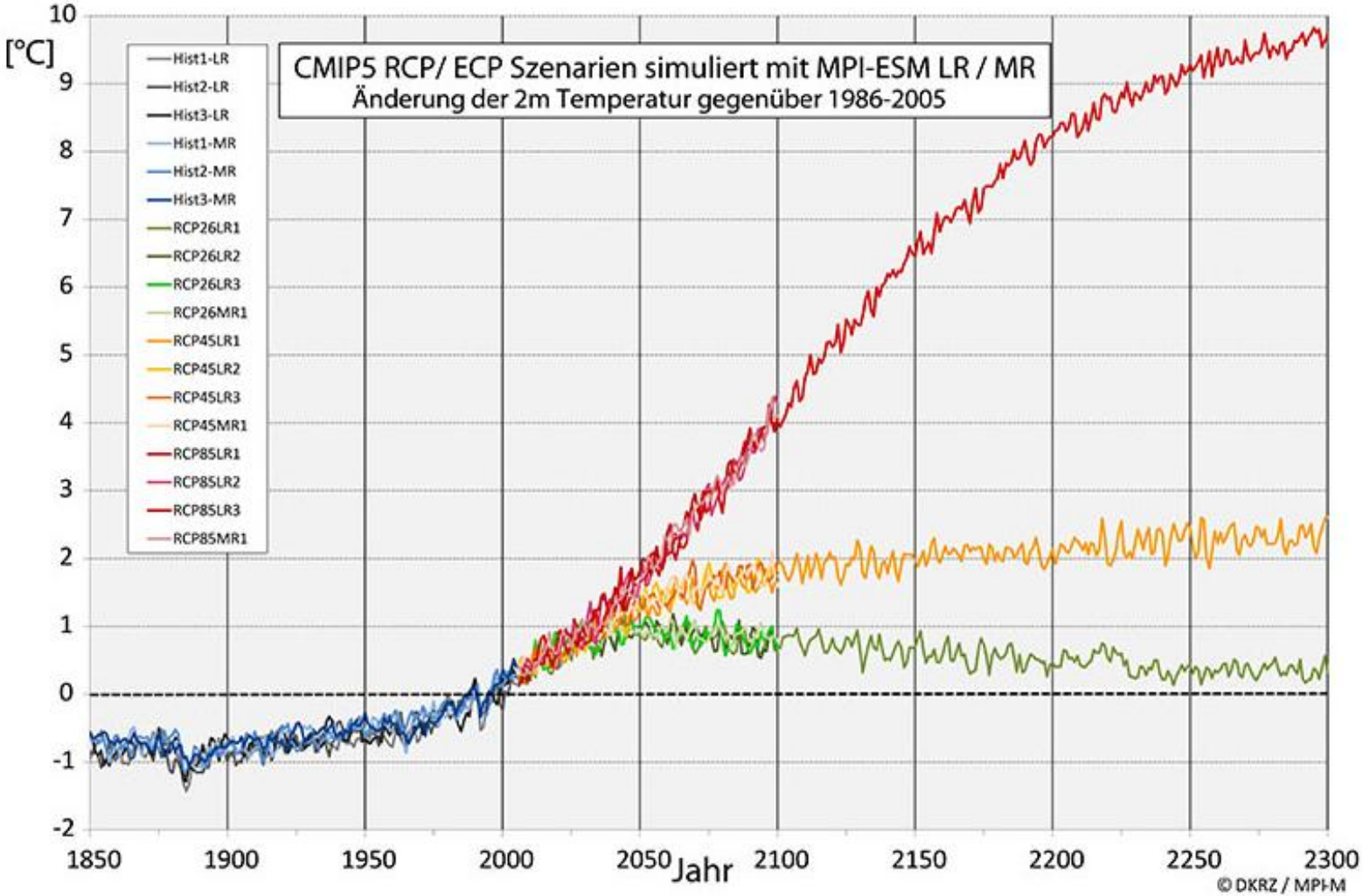
CMIP5 Scenarios

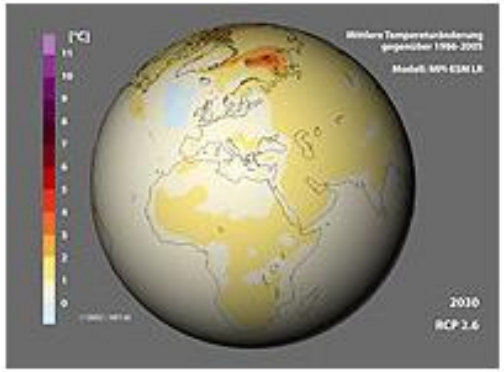
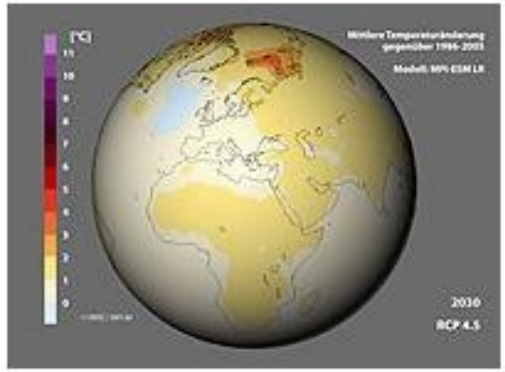
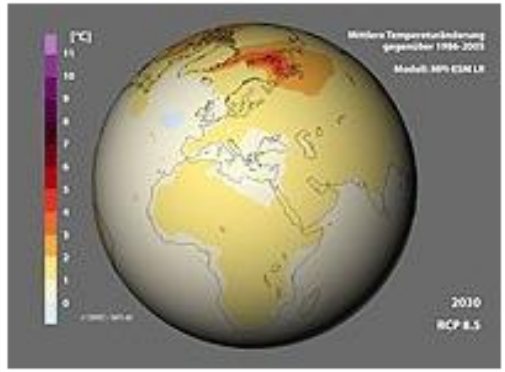
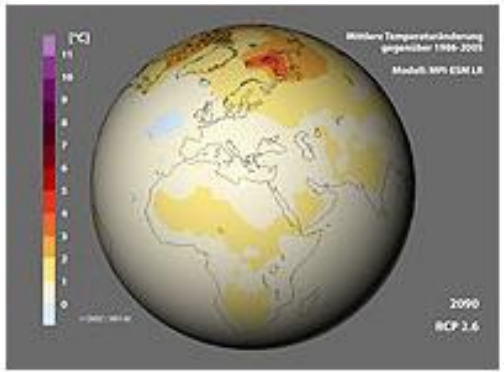
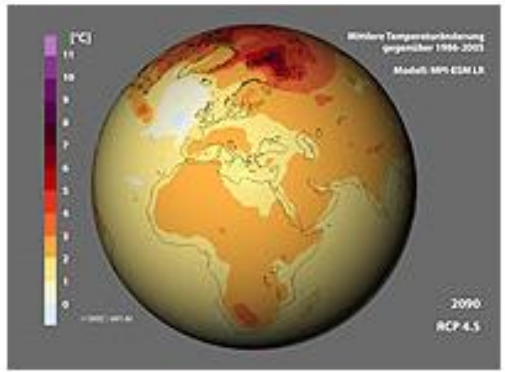
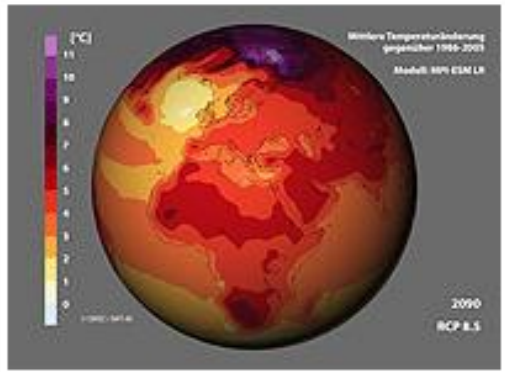


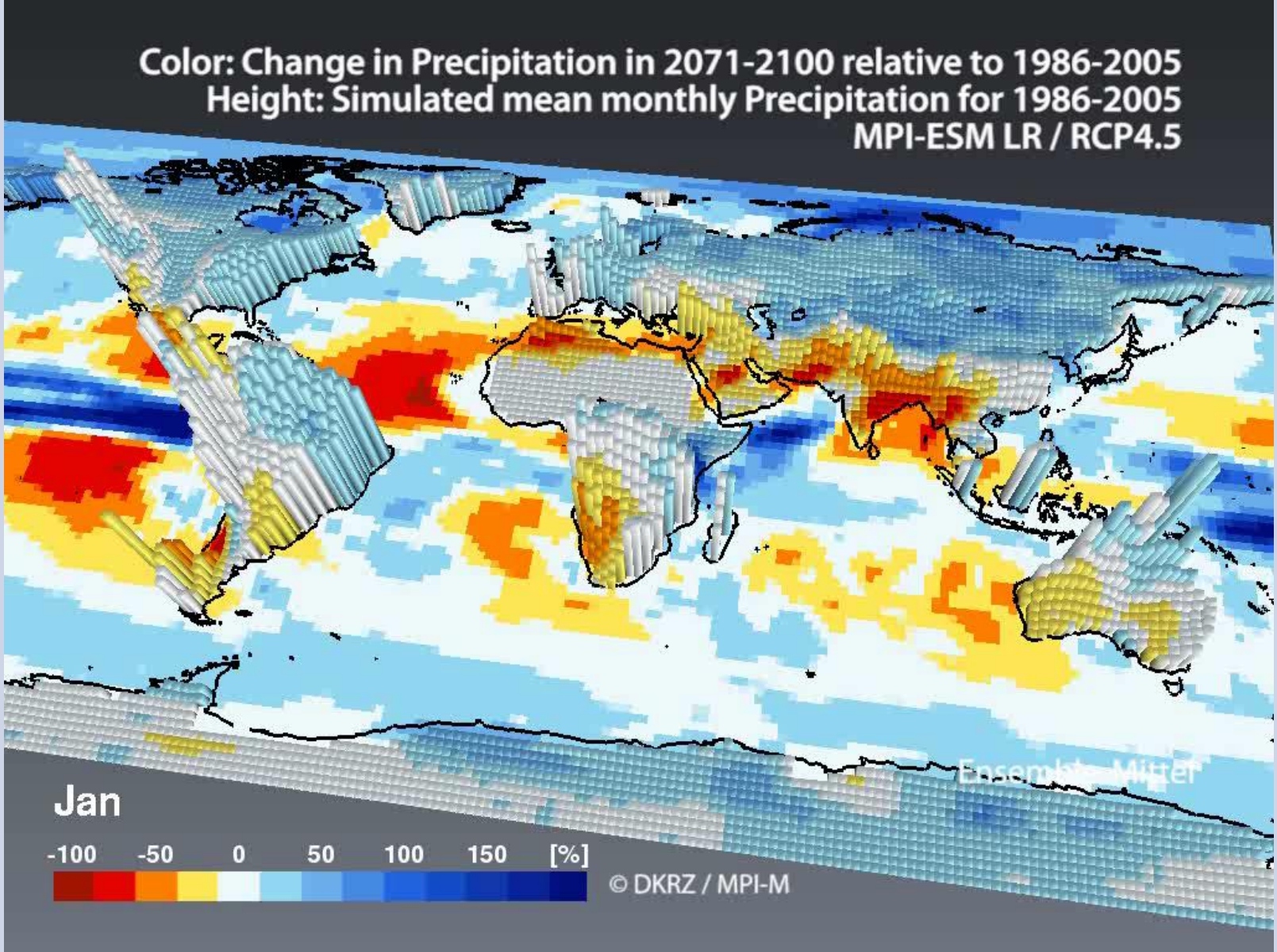


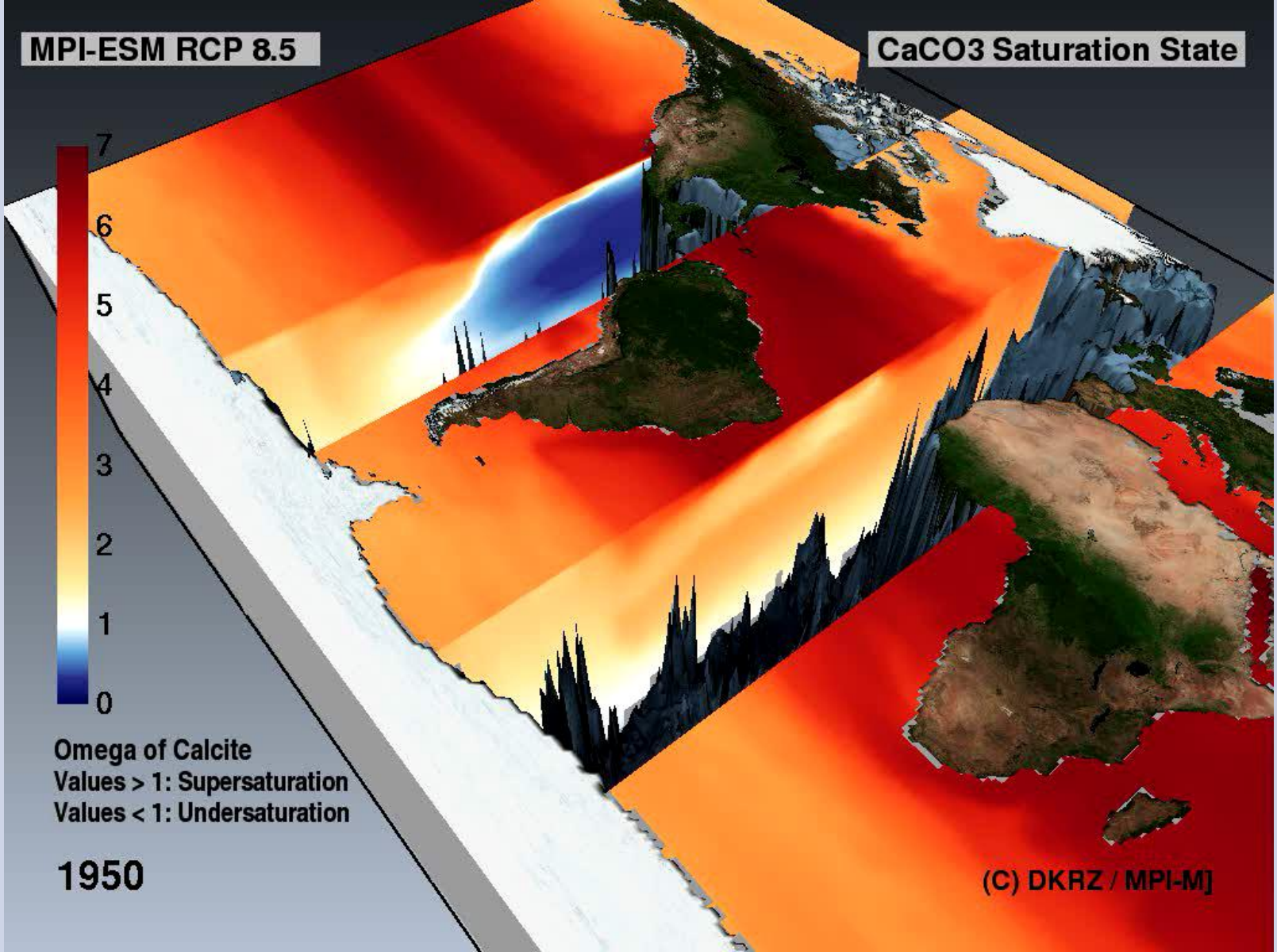
RCP = Representative Concentration Pathways

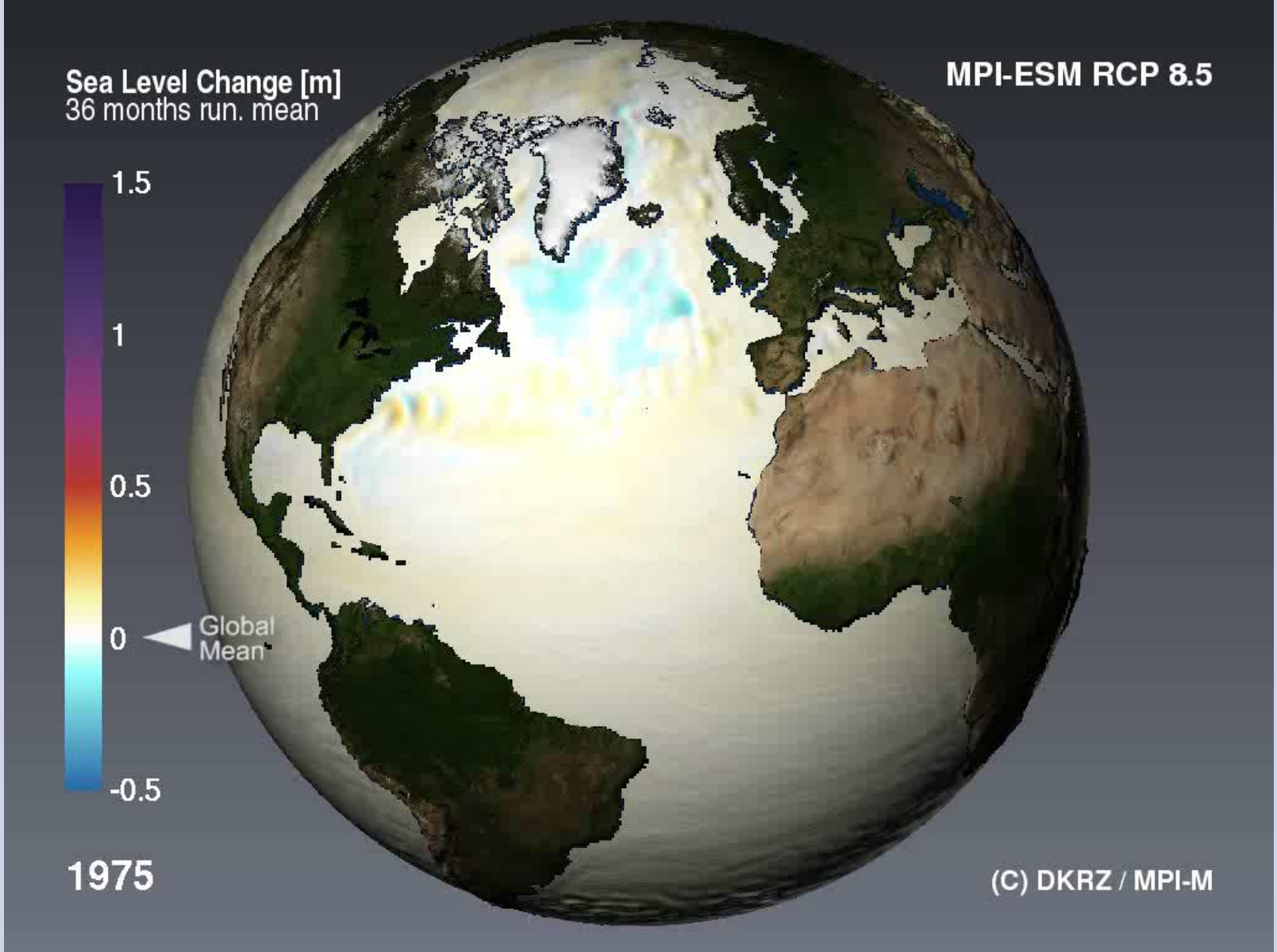

Änderung der 2m-Temperatur gegenüber 1986-2005
CMIP5 RCP Szenarien simuliert mit MPI-ESM und CRU Beobachtungen
[°C]
5
4
3
2
1
0
-1
-2
Hist1-LR
Hist2-LR
Hist3-LR
Hist1-MR
Hist2-MR
Hist3-MR
RCP26LR1
RCP26LR2
RCP26LR3
RCP26MR1
RCP45LR1
RCP45LR2
RCP45LR3
RCP45MR1
RCP85LR1
RCP85LR2
RCP85LR3
RCP85MR1
CRUTEM4
2° Ziel
Mittel 1850-1879
© DKRZ / MPI-M
1850
1900
1950
2000
2050
2100
Jahr


CMIP5 RCP/ ECP Szenarien simuliert mit MPI-ESM LR / MR
Änderung der 2m Temperatur gegenüber 1986-2005
[°C]
Hist1-LR
Hist2-LR
Hist3-LR
Hist1-MR
Hist2-MR
Hist3-MR
RCP26LR1
RCP26LR2
RCP26LR3
RCP26MR1
RCP45LR1
RCP45LR2
RCP45LR3
RCP45MR1
RCP85LR1
RCP85LR2
RCP85LR3
RCP85MR1
10
9
8
7
6
5
4
3
2
1
0
-1
-2
1850
1900
1950
2000
2050
2100
2150
2200
2250
2300
Jahr
© DKRZ / MPI-M

	RCP2.6	RCP4.5	RCP8.5
2030			
2090			


Color: Change in Precipitation in 2071-2100 relative to 1986-2005
Height: Simulated mean monthly Precipitation for 1986-2005
MPI-ESM LR / RCP4.5
Ensemble-Mittel
Jan
-100
-50
0
50
100
150
[%]
© DKRZ / MPI-M


MPI-ESM RCP 8.5
CaCO3 Saturation State
7
6
5
4
3
2
1
0
Omega of Calcite
Values > 1: Supersaturation
Values < 1: Undersaturation
1950
(C) DKRZ / MPI-M]


Sea Level Change [m]
36 months run. mean
MPI-ESM RCP 8.5
1.5
1
0.5
0
Global Mean
-0.5
1975
(C) DKRZ / MPI-M

Work at DKRZ

- Administration
- Scientific Computing (University of Hamburg)
- Applications
- Data Management
- Systems

Max-Planck-Institut für Meteorologie

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

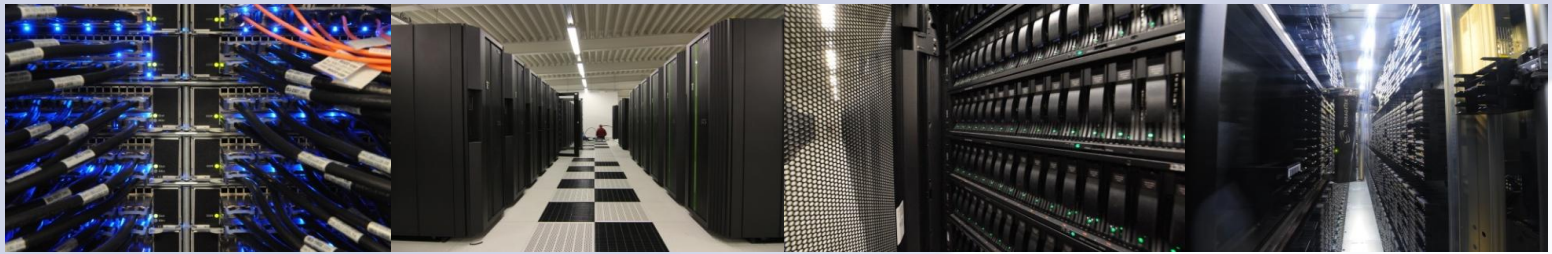
Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

AWI Alfred-Wegener-Institut für Polar- und Meeresforschung

DKRZ

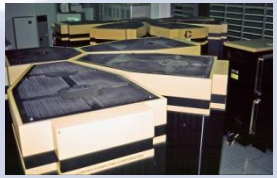
Systems at DKRZ

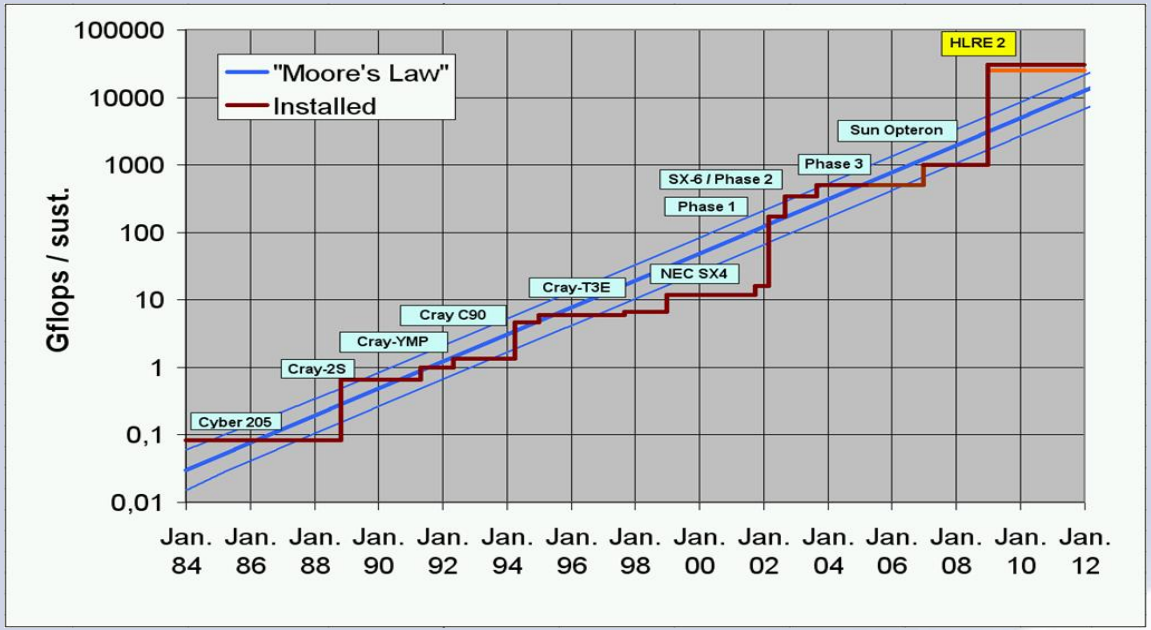
- IBM p575 Power 6 cluster (8448 cores)
- Sun AMD Opteron cluster (2048 cores)
- HP SVA cluster (10 graphics nodes)
- Sun StorageTek SL8500 tape library (7 libs)
- Dell Blade Center (10 Dell M605, 6 Dell M610, …)



DKRZ

Supercomputing at DKRZ



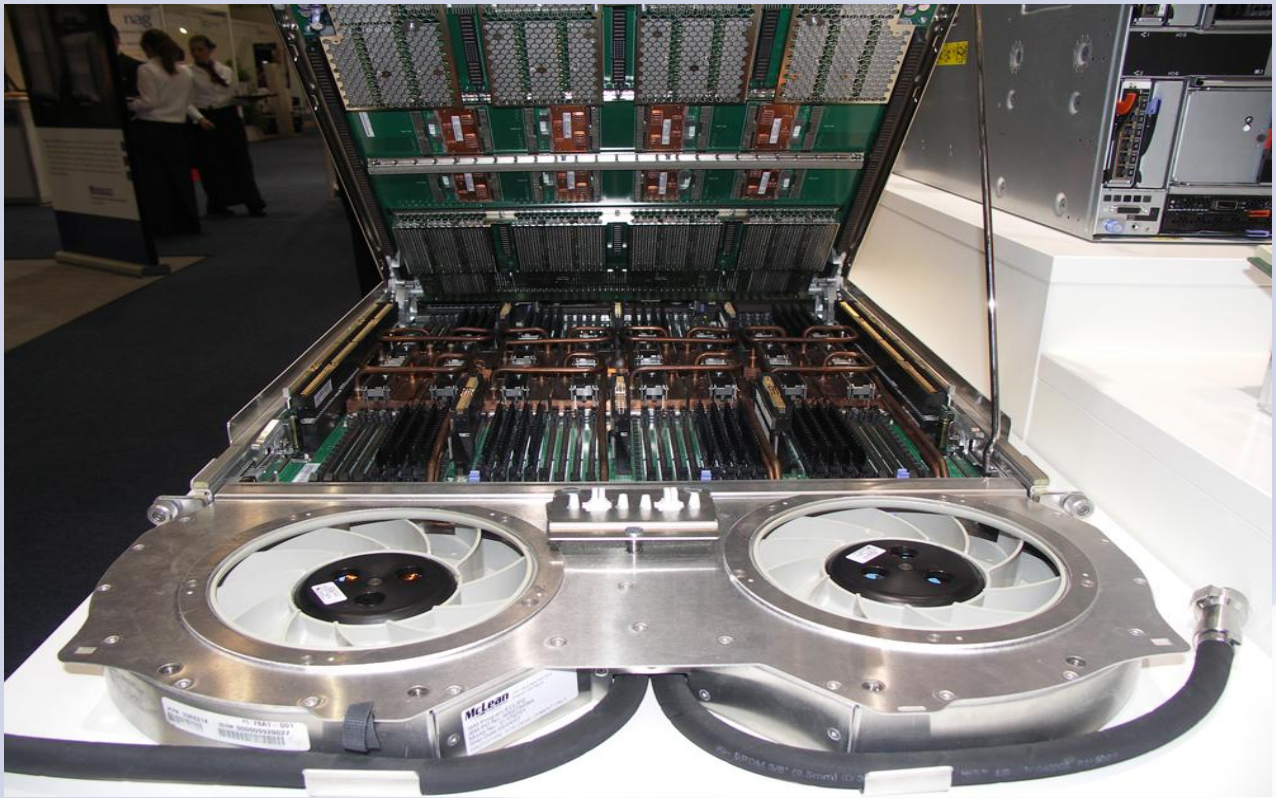



POWER6
BUILT ON
Power
ENDDO
!$OMP END DO
!$OMP DO
DO i3 = 1, snsp
it = ssps-1+i3
DO i2 = 1, 2
DO i1 = 1, SIZE(ls2,1)
ls_sp(k)%send_buffer(i1
ENDDO
ENDDO
ENDDO
!$OMP END DO
!$OMP DO
DO i3 = 1, snsp
it = ssps-1+i3
DO i2 = 1, 2
DO i1 = 1, SIZE(ls3,1)
ls_sp(k)%send_buffer(i1
ENDDO
ENDDO
ENDDO
!$OMP END DO
IF (lm0s(k)) THEN
!$OMP DO
DO i2 = 1, nsnm0
it = snn0+i2
DO i1 = 1, SIZE(ls0,1)
ls_sp(k)%send_buffer0 (
ENDDO
ENDDO
!$OMP END DO
ENDIF
!$OMP END PARALLEL
#else
!$OMP PARALLEL
!$OMP WORKSHARE
ls_sp(k)%send_buffer (:SIZE(
ls_sp(k)%send_buffer (:SIZE(
ls_sp(k)%send_buffer (:SIZE(
!$OMP END WORKSHARE

Blizzard

- Peak performance: 158 TeraFlop/s
- 264 IBM Power6 nodes
- 16 dual core CPUs per node (8,448 cores)
- 20 TB of main memory and 7 PB of disk space
- Infiniband network: 7.6 TB/s (aggregated)

Compute node IBM Power6



DKRZ

Beneath the Floor

Data

Electricity

Water
(cooling)

DKRZ

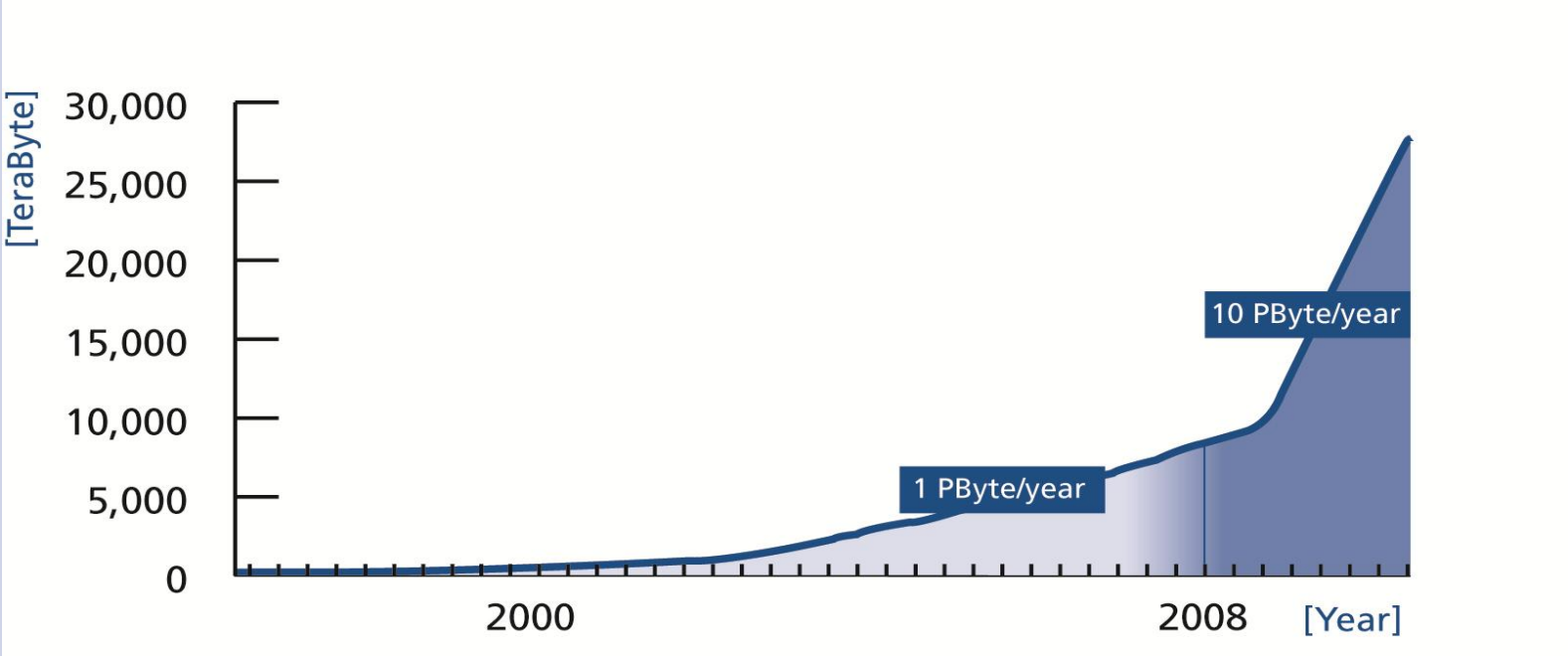
HPSS

- 7 Sun StorageTek SL8500 tape libraries
- 8 robots per library
- More than 60,000 magnetic cartridges
- Over 80 tape drives
- Capacity around 100 PB
- Bandwidth 5 GB/s (bidirectional)

DKRZ

STORAGETEK
STORAGETEK
STORAGETEK

Data growth at DKRZ



Visualization at DKRZ

- Michael Böttinger (Geophysics, since 1990)
- Niklas Röber (Computer Science, since 2009)

- Manage VIS systems (hardware/software)
- Assistance in VIS problems / teaching
- Development (Avizo)
- Public relations

DKRZ

Halo

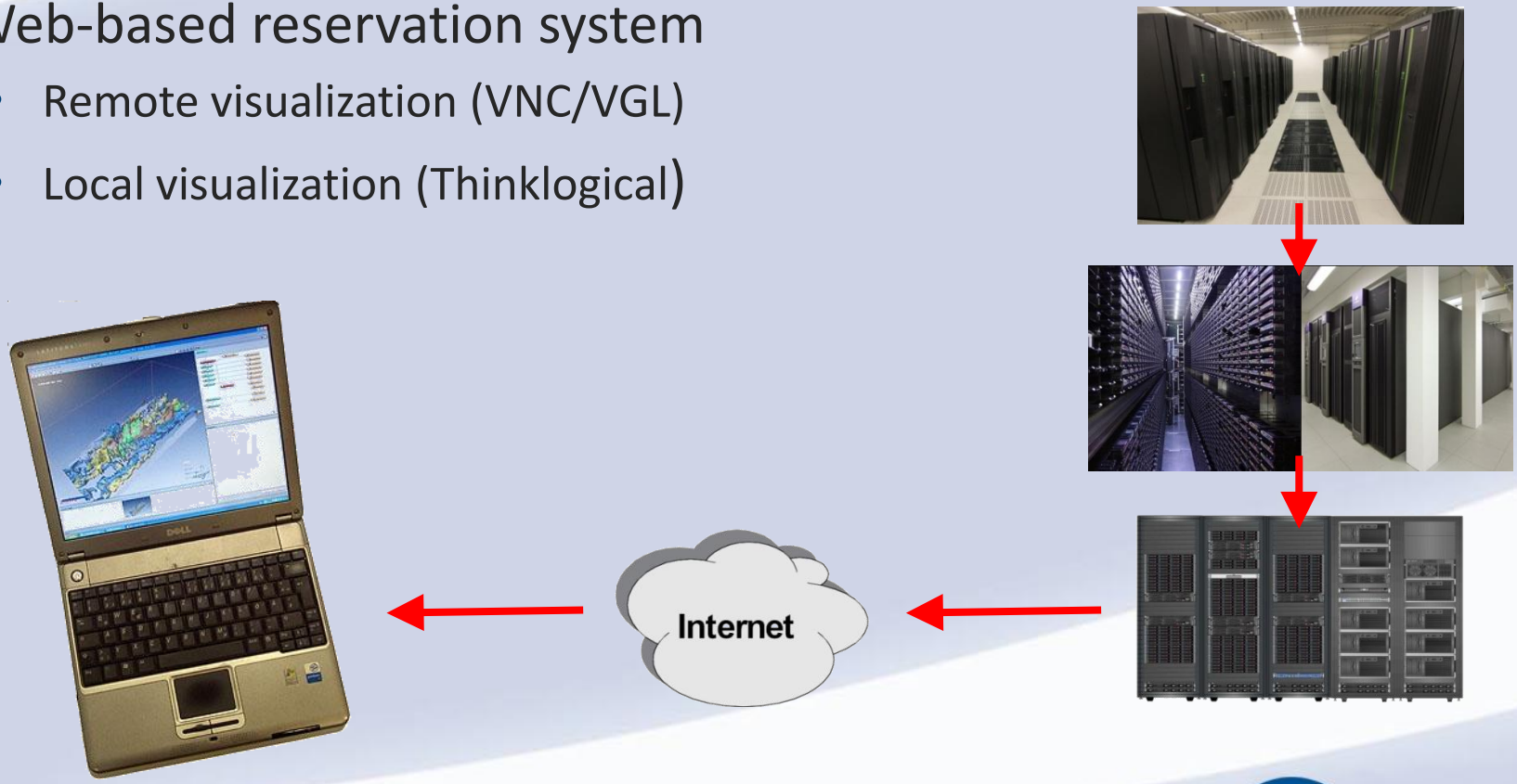
- 5 x Dell Blade M610x (2 Intel Xeon 2.5 GHz (Hexa Core), 96 GB RAM, Nvidia Tesla M2070Q)
- 2 x HP ProLiant DL370 G6 (2 Intel Xeon X5680 3.33 GHz (Hexa Core), 96 GB RAM, 2 Nvidia Quadro 6000)
- 1 x Dell Precision R5400 (2 Intel Xeon 3 GHz (Dual Core), 32 GB RAM, Nvidia Quadro 5000)
- 1 x HP ProLiant DL585 (4 Opteron64 2.4 GHz (Dual Core), 128 GB RAM, 2 Nvidia Quadro FX 5500 als QuadroPlex)
- 5 x HP XW 9400 (2 Opteron64 2.6 GHz (Dual Core), 32 GB RAM, Nvidia Quadro FX 5500)

- CentOS 5.x, 10 GE uplink (gpfs), head node

DKRZ

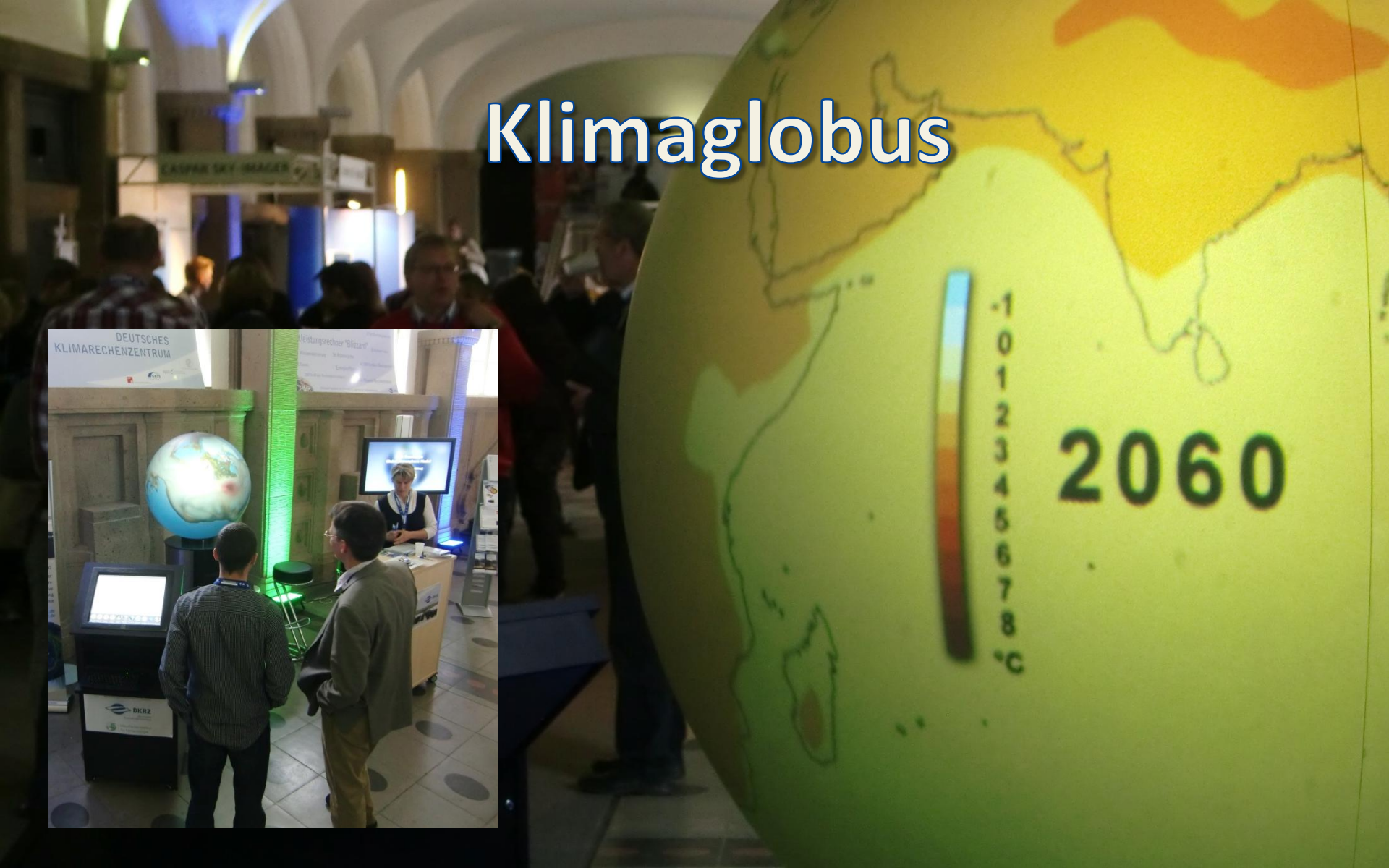
Remote Visualization

- Web-based reservation system
  - Remote visualization (VNC/VGL)
  - Local visualization (Thinklogical)



DKRZ

Klimaglobus



Software

- Processing and preview: cdo, nco, ncview
- 2D visualization: grads, ferret, ncl, idl, matlab
- 3D visualization: Avizo Green, Simvis

DKRZ

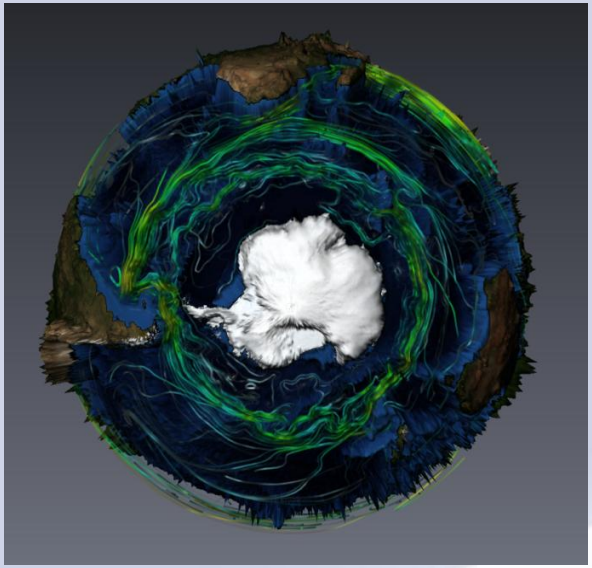
Avizo Green

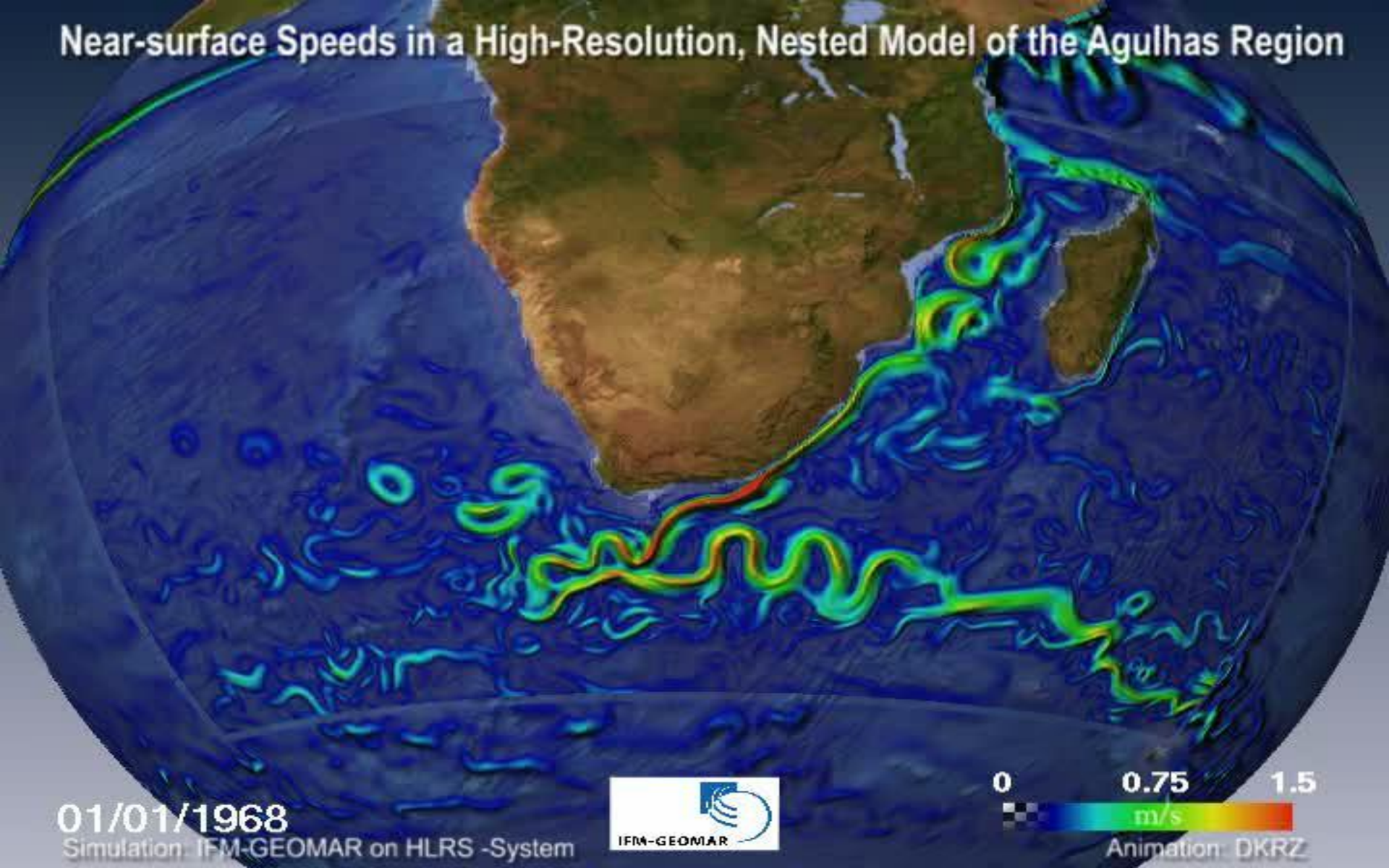
- **Avizo:** Commercial General Purpose Visualization System
- Domain specific enhancements (development within DKRZ viz-server procurement)
- NetCDF CF-1.0 reader
  - Supports regular, rectilinear, rotated and curvilinear grids
  - Support for large data:
    - „Streaming“ of time dependent data
    - Utilization of main memory for caching of NetCDF-Data
- Geographical projections (cylindric equidistant, spherical, mollweide …)

DKRZ

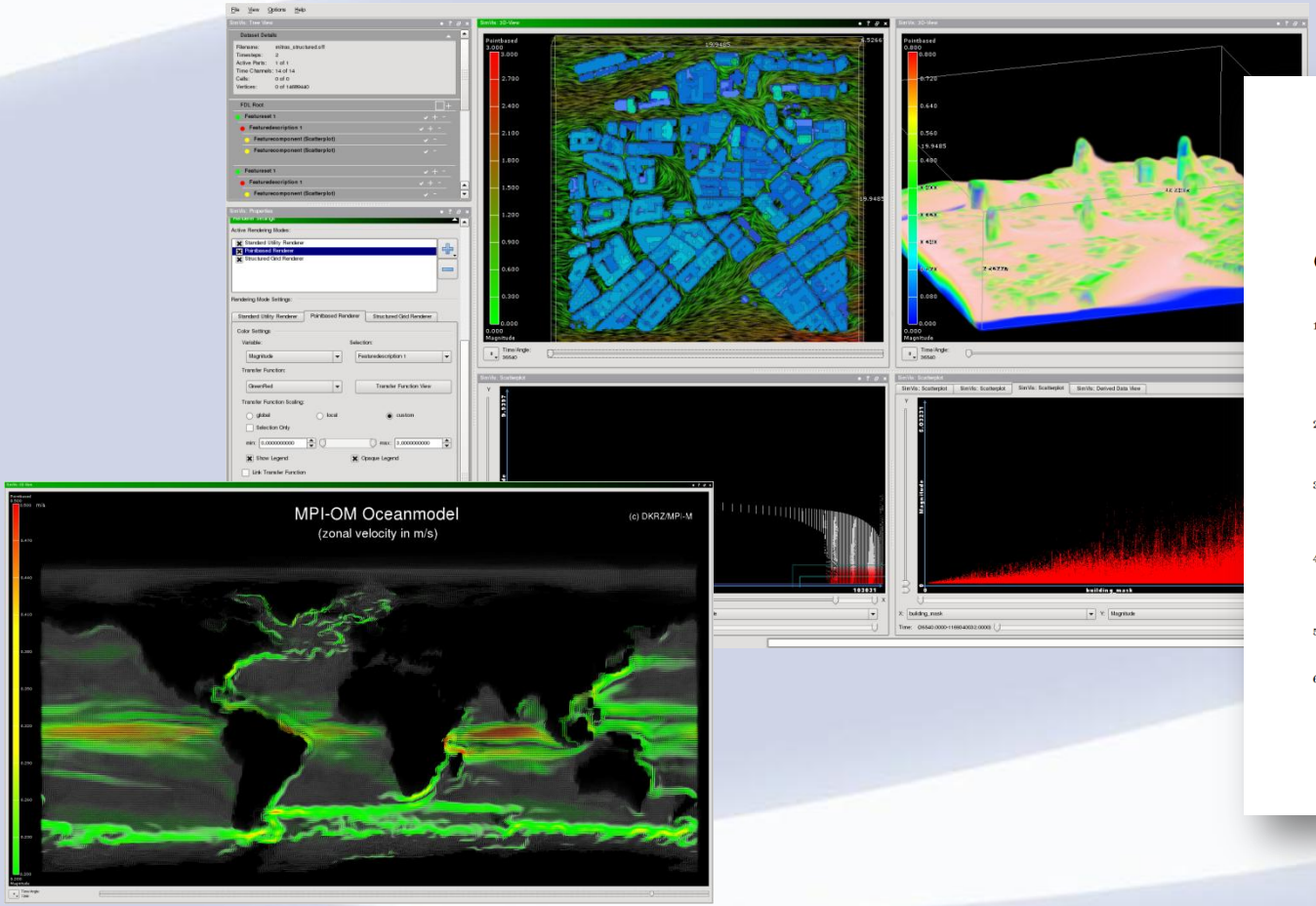
Avizo Green

- „Earth“ module
  - Textures, 3 levels of detail
  - Elevation and bathymetry
  - Continental outlines and country borders
- Fast HW based bump shading for 2D slices
- Particle advection & trajectories
- Volume rendering for rectilinear grids
- Avizo XPand – development of own compute and display modules




Near-surface Speeds in a High-Resolution, Nested Model of the Agulhas Region
01/01/1968
Simulation: IFM-GEOMAR on HLRS -System
IFM-GEOMAR
0
0.75
1.5
m/s
Animation: DKRZ

Simvis



Contents

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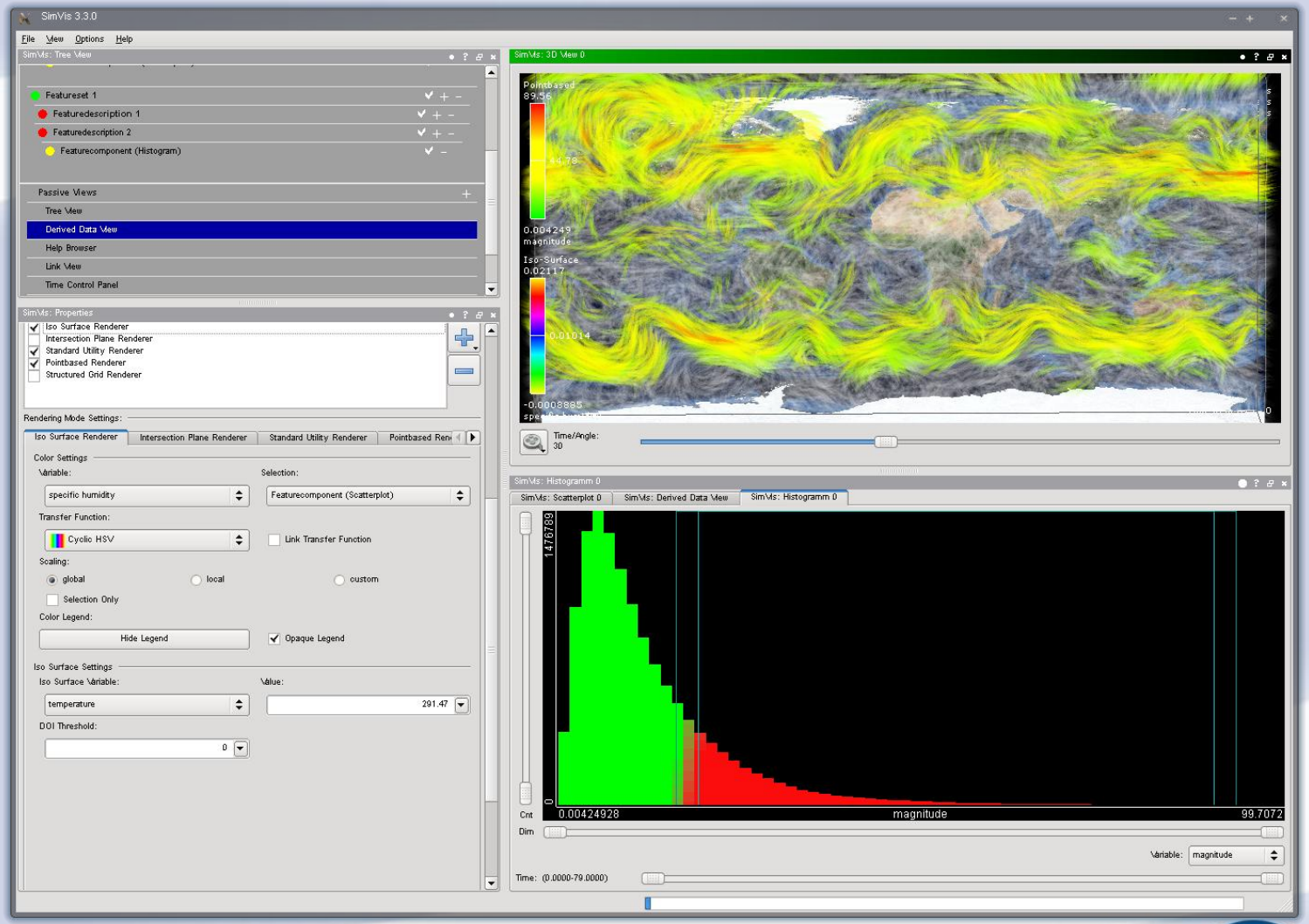
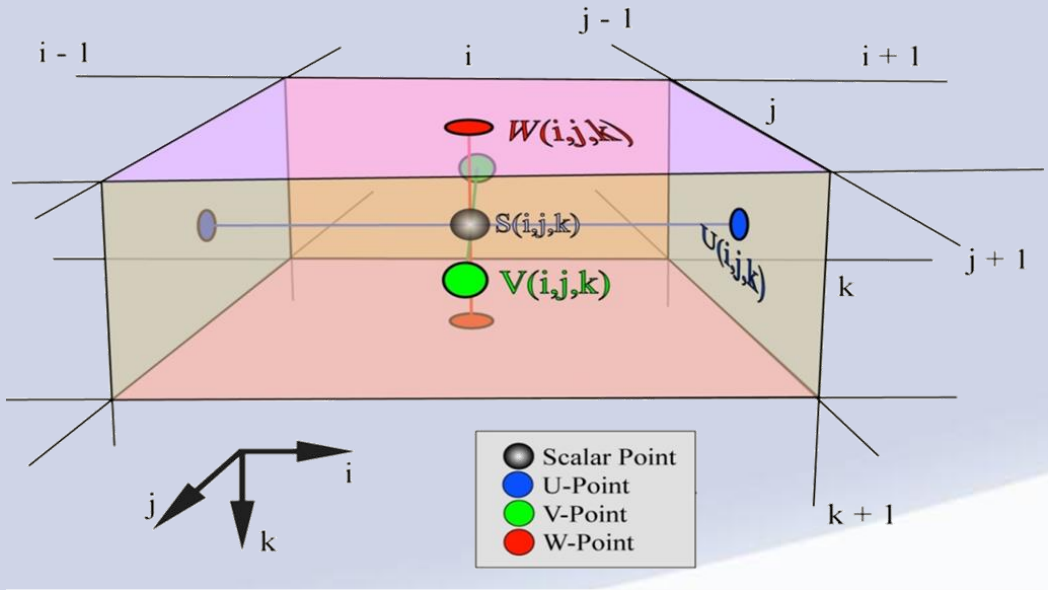
DKRZ

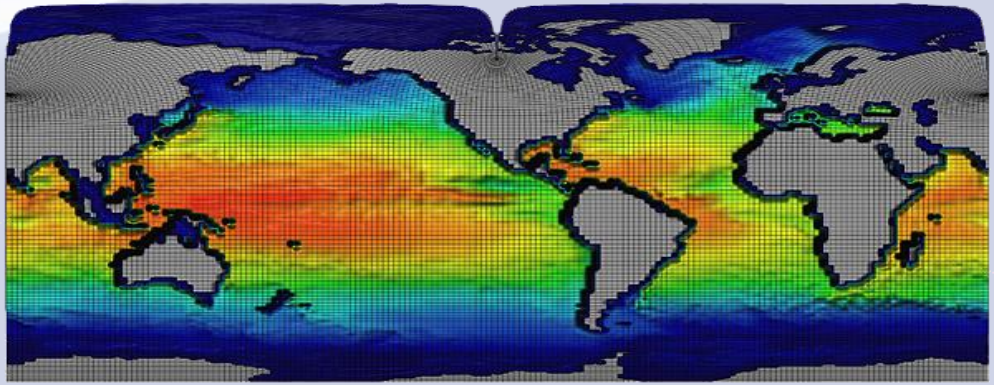

SimVis 3.3.0
File View Options Help
SimVis: Tree View
Featureset 1
Featuredescription 1
Featuredescription 2
Featurecomponent (Histogram)
Passive Views
Tree View
Derived Data View
Help Browser
Link View
Time Control Panel
SimVis: Properties
Iso Surface Renderer
Intersection Plane Renderer
Standard Utility Renderer
Pointbased Renderer
Structured Grid Renderer
Rendering Mode Settings:
Iso Surface Renderer
Intersection Plane Renderer
Standard Utility Renderer
Color Settings
Variable:
specific humidity
Selection:
Featurecomponent (Scatterplot)
Transfer Function:
Cyclic HSV
Link Transfer Function
Scaling:
global
local
custom
Selection Only
Color Legend:
Hide Legend
Opaque Legend
Iso Surface Settings
Iso Surface Variable:
temperature
Value:
291.47
DOI Threshold:
0
SimVis: 3D View 0
Pointbased
89.56
44.78
0.004249
magnitude
Iso-Surface
0.02117
0.01014
-0.0008885
Time/Angle:
30
SimVis: Histogramm 0
SimVis: Scatterplot 0
SimVis: Derived Data View
SimVis: Histogramm 0
1476789
0
Cnt
0.00424928
magnitude
99.7072
Dim
Variable:
magnitude
Time: (0.0000-79.0000)

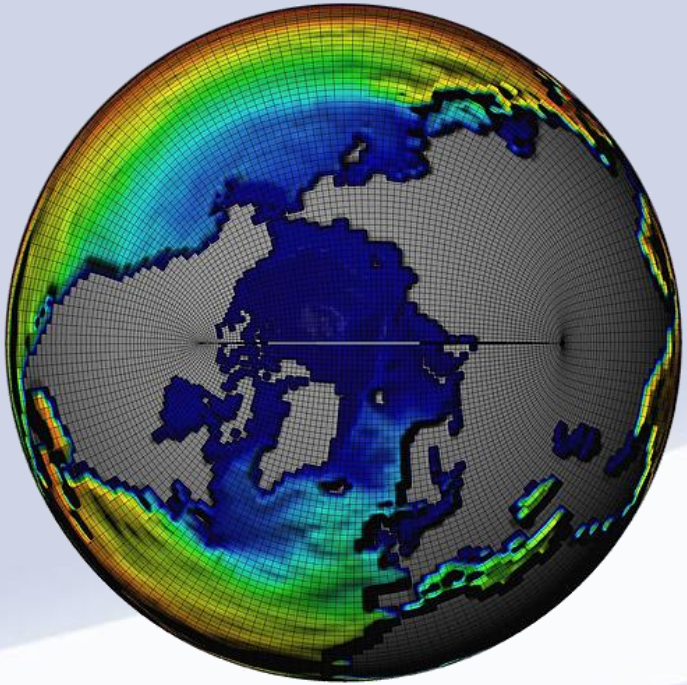
Data Variables

Atmosphere: k points upwards (pressure or height)
Ocean: k points downwards (depth)



Grids

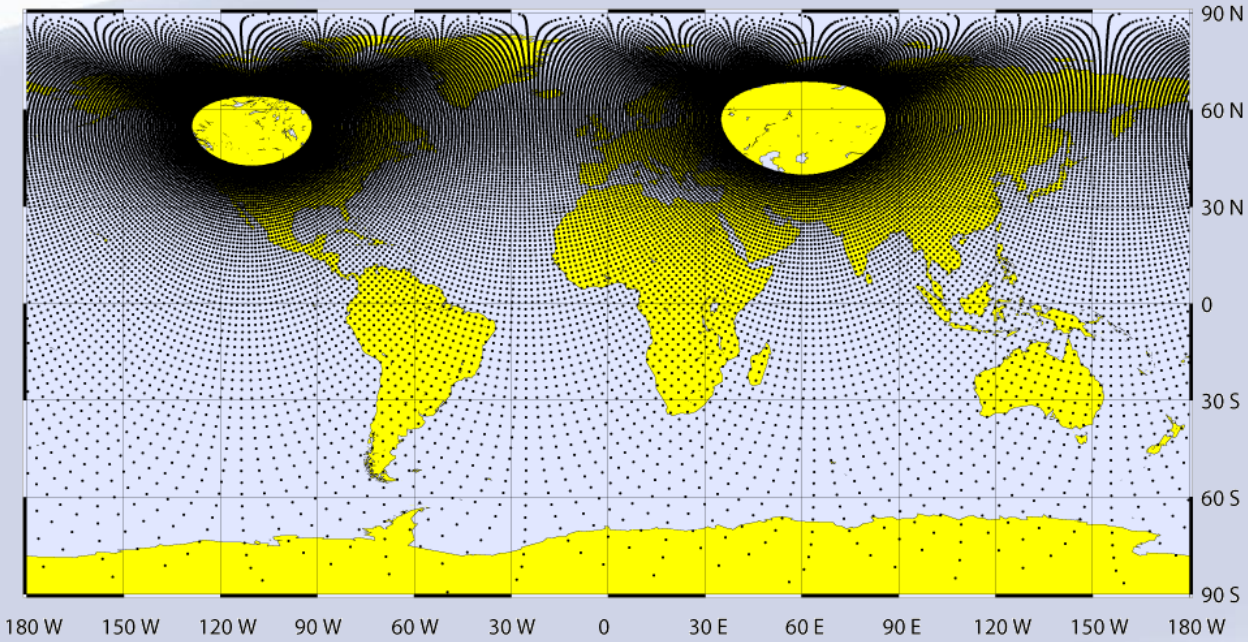


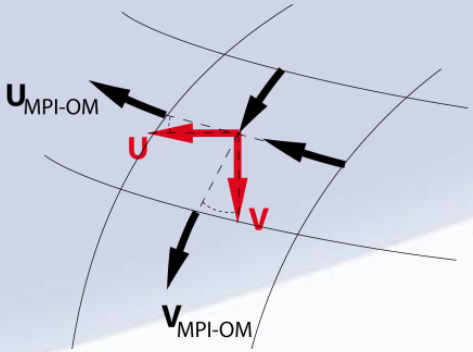


- Regular, rectilinear, rotated and curvilinear grids using NetCDF CF-1.0
- Example: tripolar curvilinear grid (OPA, IFM-GEOMAR Kiel)

DKRZ

Rotated Grids



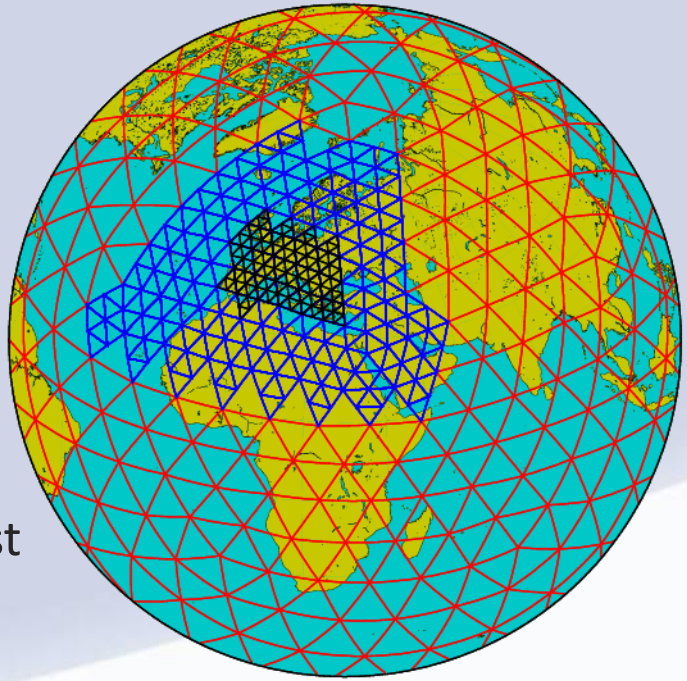


REMO, MPI-OM

DKRZ

ICON

- ICON: ICOsahedral Non-hydrostatic
- No poles, allows refinements
- Developed jointly by:
  - MPI-M (development of an atmospheric and ocean component)
  - DWD (high resolution atmospheric forecast model for Europe with nesting)



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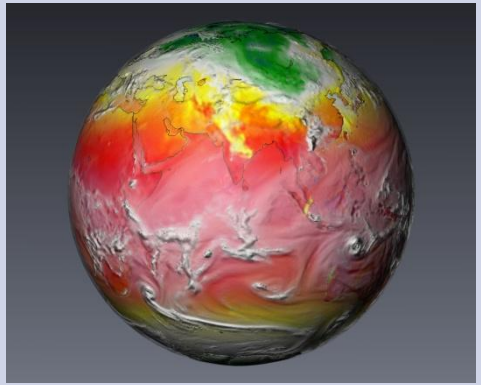
Data Sizes

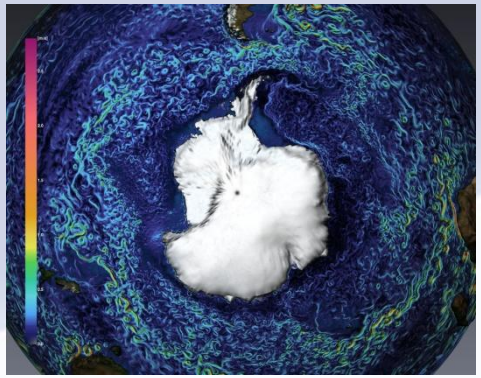
- Project STORM:
  - Atmosphere (768 x 394 x 199)

    (*u,v,w,t,p,q,ws,sn, …*)
  - Ocean (3002 x 2394 x 80)

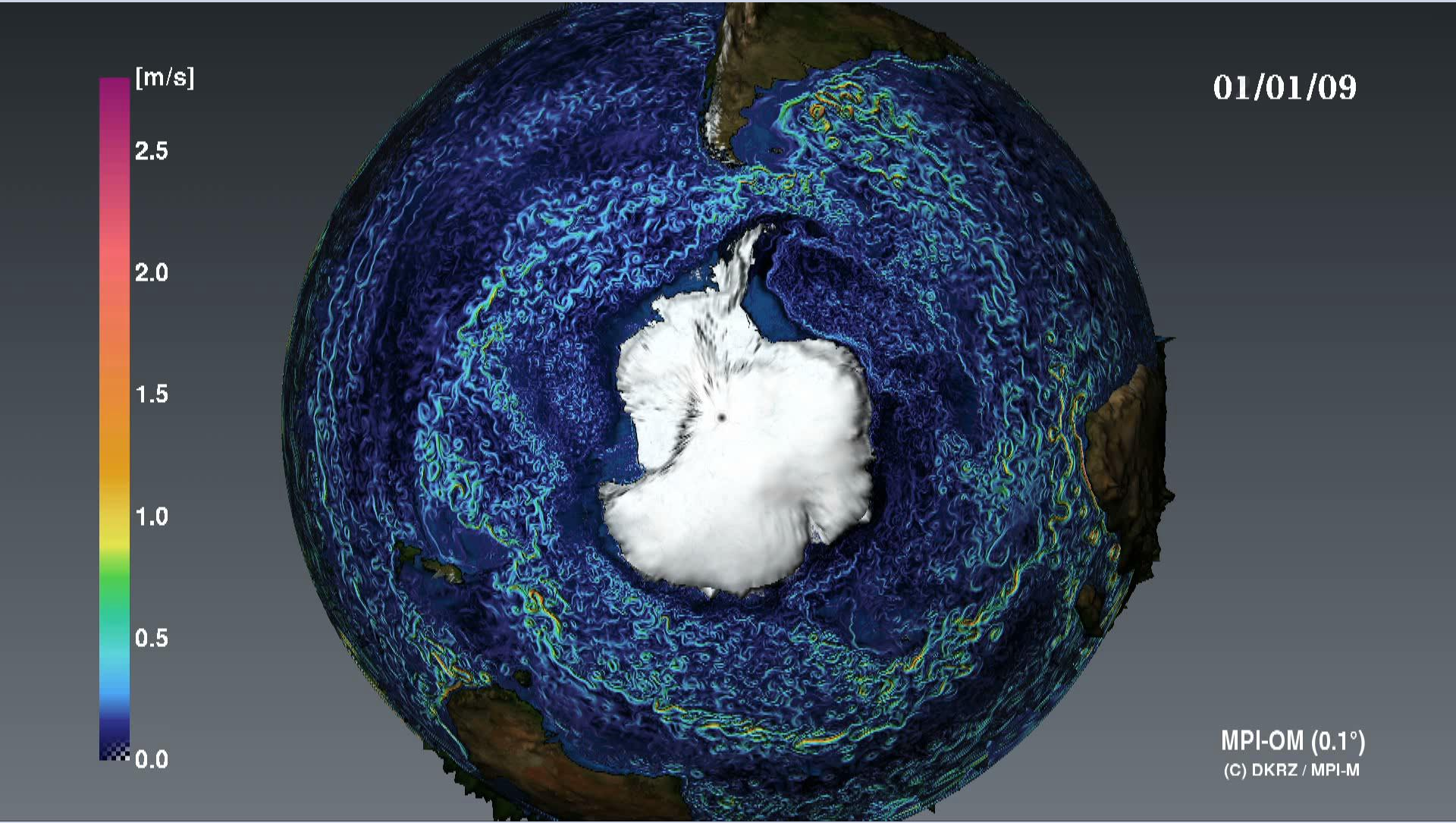
    (*uko,vke,wo,tho,sao, …*)
  - Long time simulations

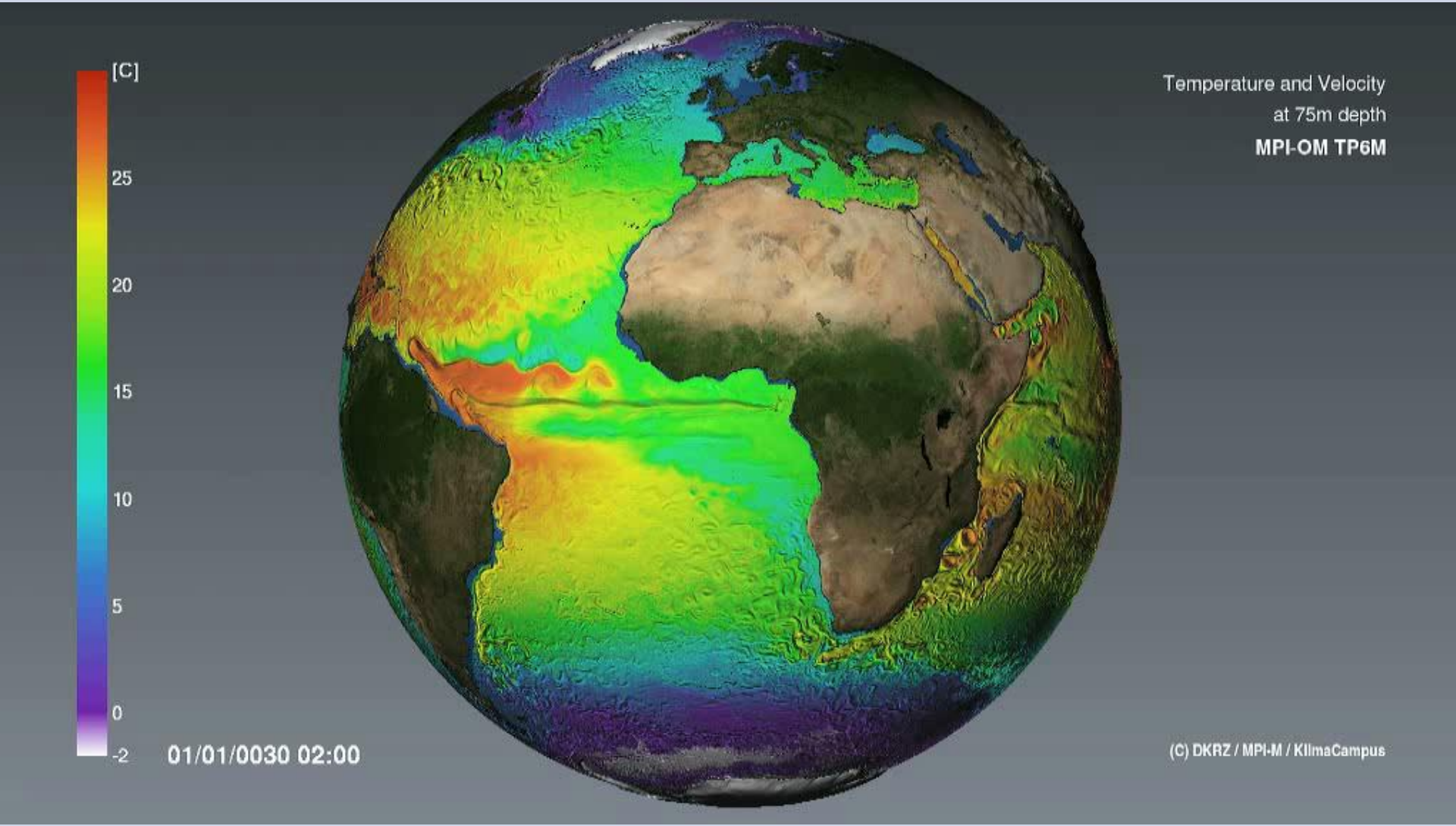
    (> 10,000 time steps)

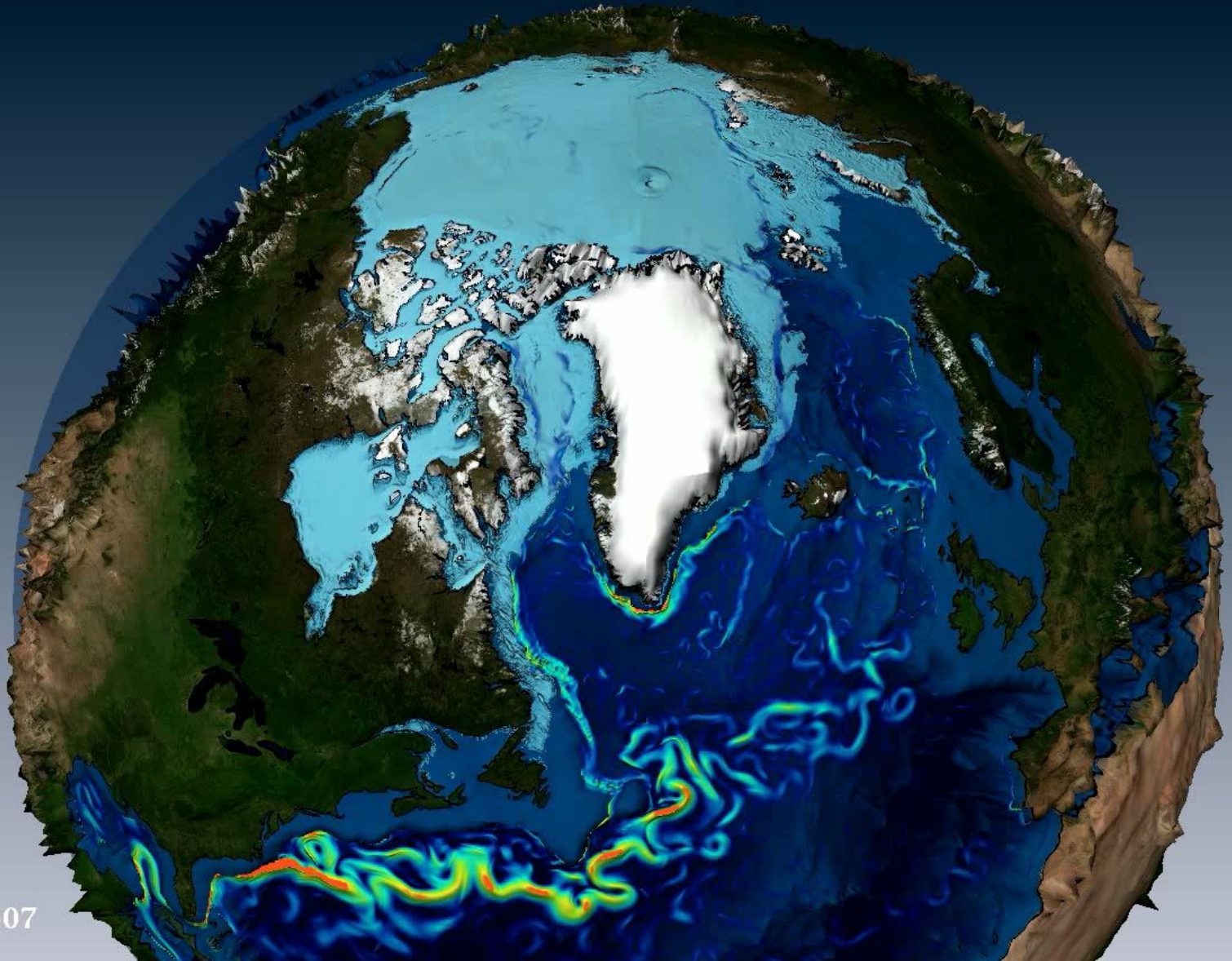


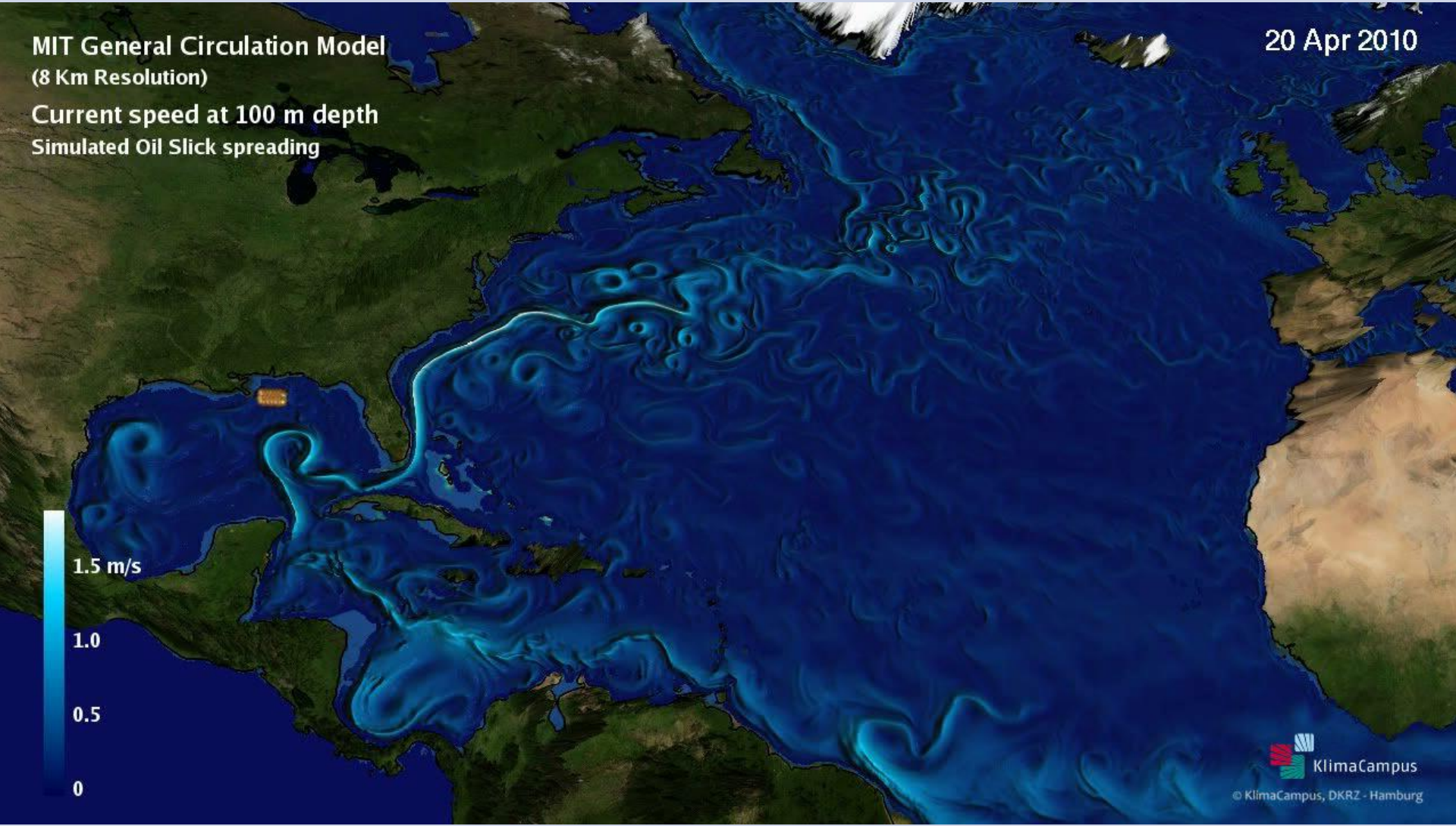


DKRZ

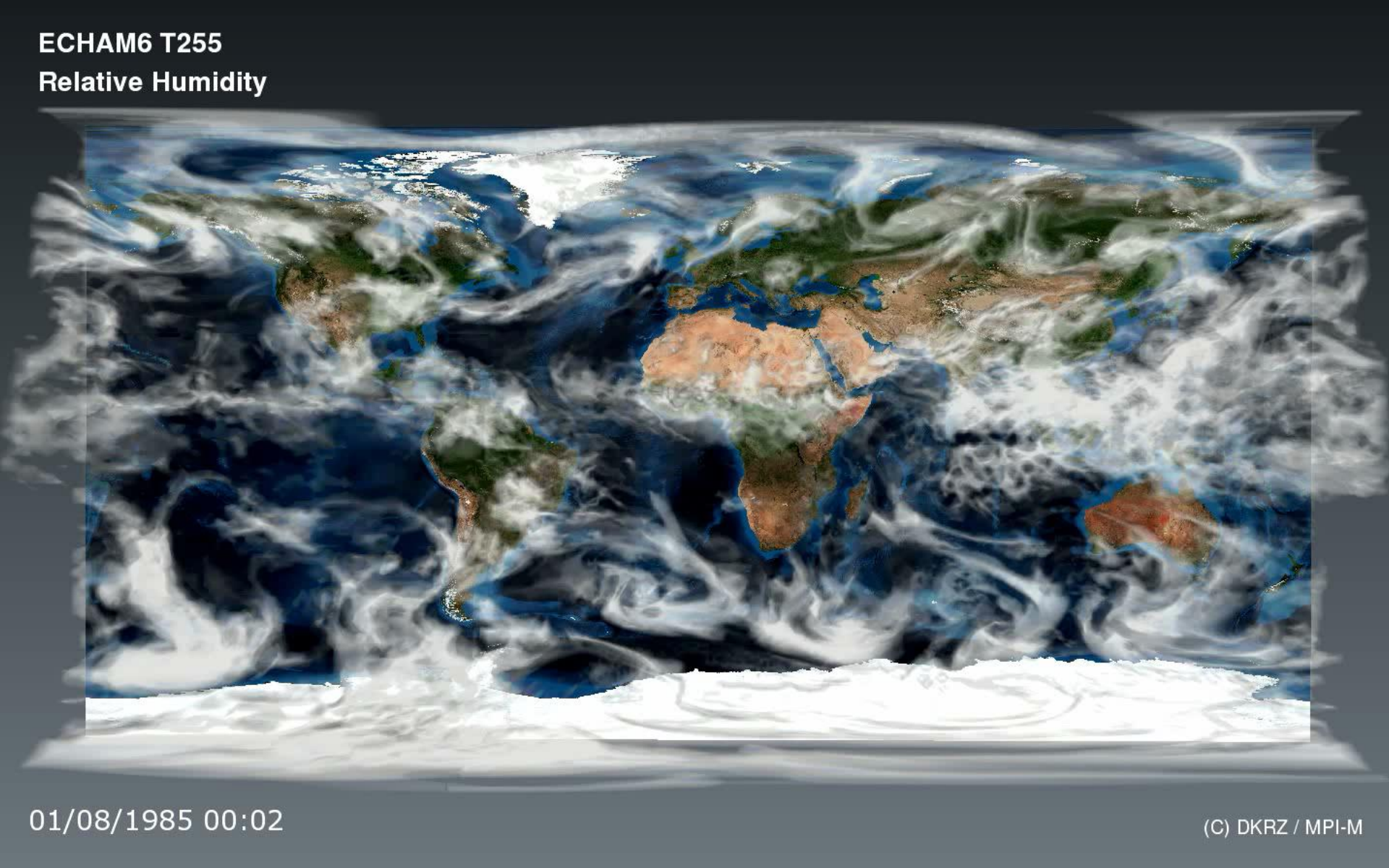

[m/s]
2.5
2.0
1.5
1.0
0.5
0.0
01/01/09
MPI-OM (0.1°)
(C) DKRZ / MPI-M

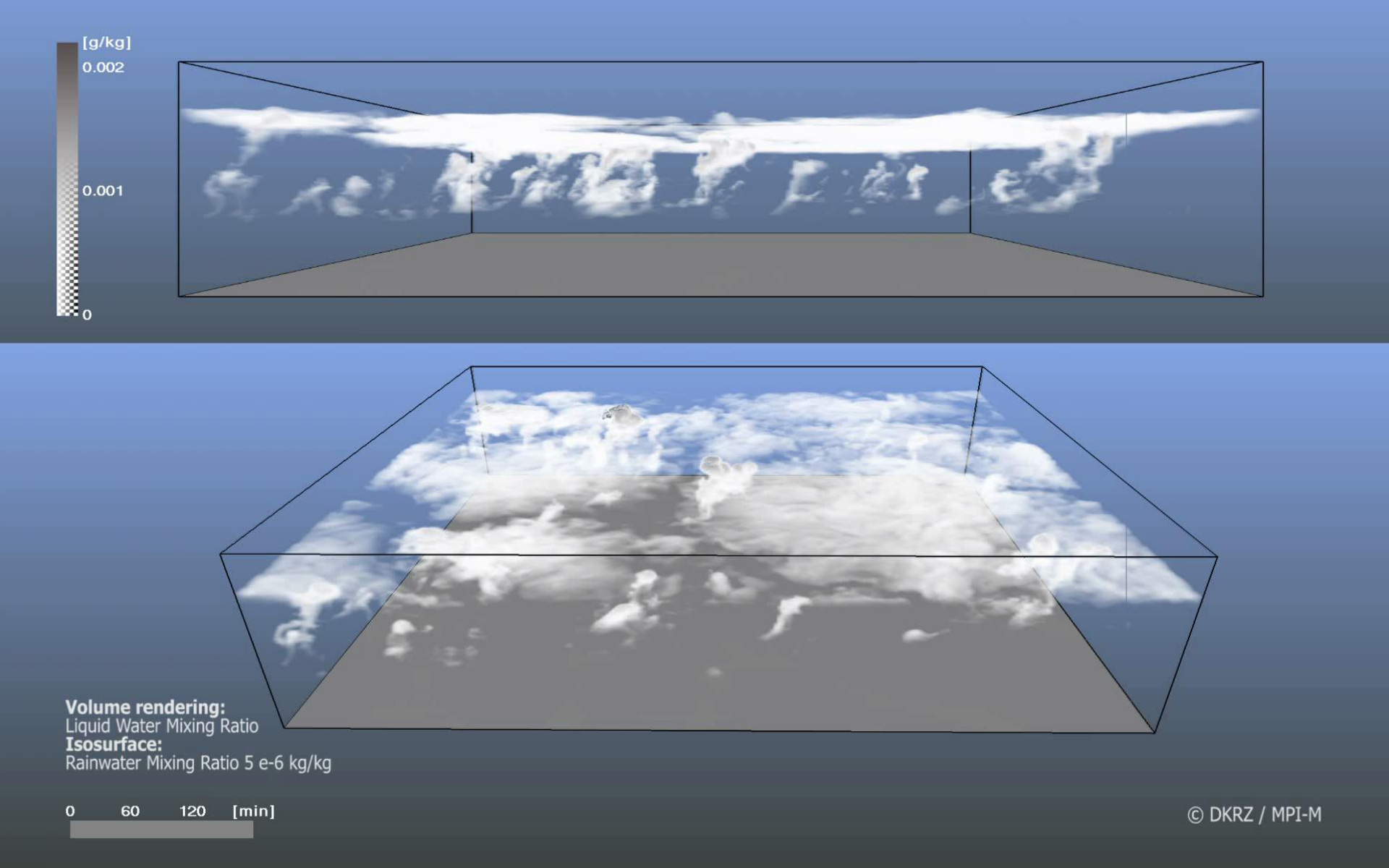

[C]
25
20
15
10
5
0
-2
01/01/0030 02:00
Temperature and Velocity
at 75m depth
MPI-OM TP6M
(C) DKRZ / MPI-M / KlimaCampus


2002-01-07


MIT General Circulation Model
(8 Km Resolution)
Current speed at 100 m depth
Simulated Oil Slick spreading
20 Apr 2010
1.5 m/s
1.0
0.5
0
KlimaCampus
© KlimaCampus, DKRZ - Hamburg


Tracer Isosurface: 1.e-6
1.0
1e-01
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-08
1e-09
1e-10
1e-11
1e-12
1e-13
1e-14
1e-15
01/02/1998
(C) DKRZ & MPI-M


ECHAM6 T255
Relative Humidity
01/08/1985 00:02
(C) DKRZ / MPI-M


[g/kg]
0.002
0.001
0
Volume rendering:
Liquid Water Mixing Ratio
Isosurface:
Rainwater Mixing Ratio 5 e-6 kg/kg
0
60
120
[min]
© DKRZ / MPI-M

Open Questions

- I/O problems (data sizes are getting bigger and bigger)
  - Distributed and/or in-situ visualization?
  - Interactivity?
- Uncertainty visualization (through ensembles)
- (Multivariate data sets)
- New computing architectures (heterogeneous systems for simulation **AND** visualization)

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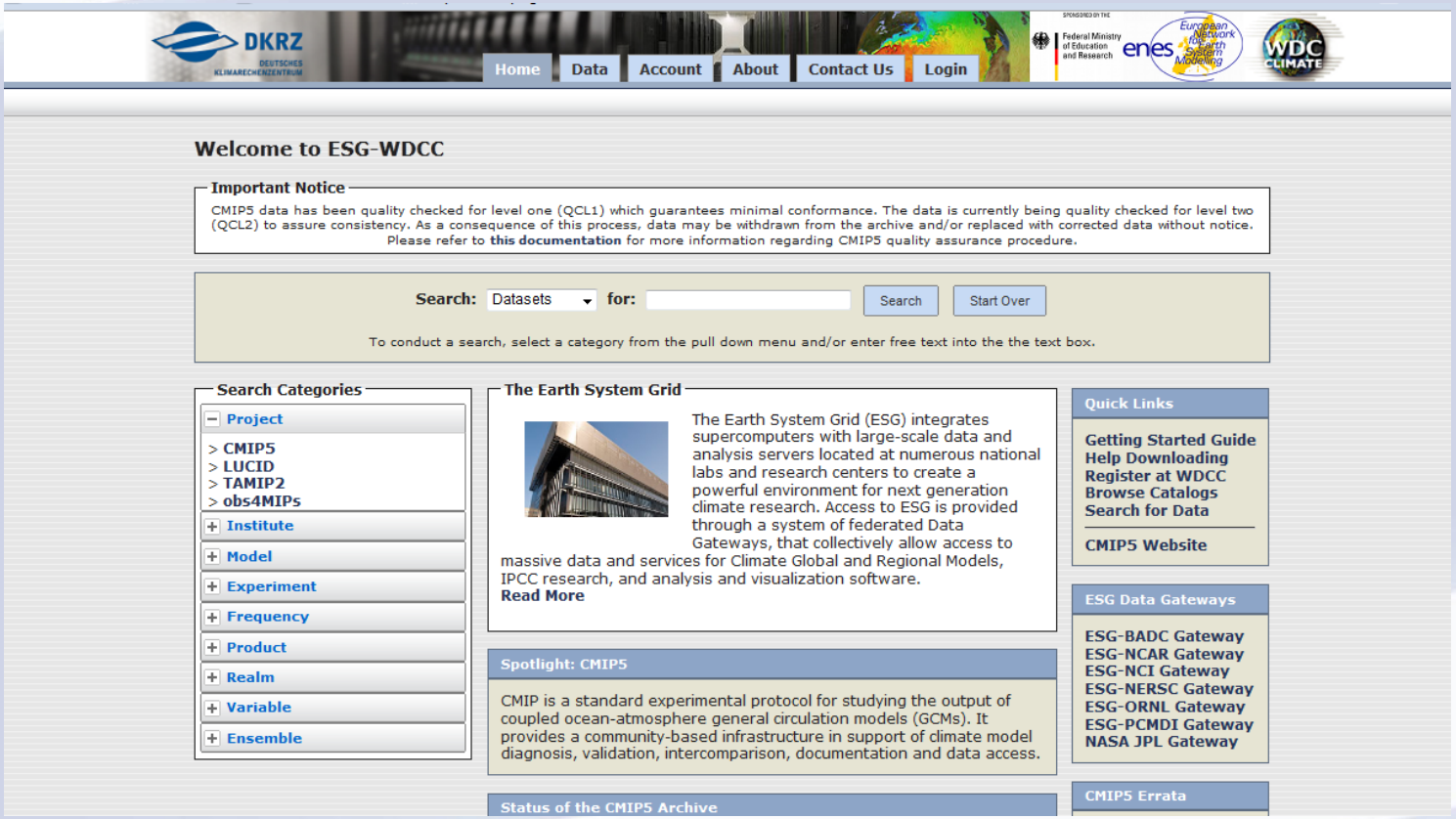
Getting the Data …



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Working Together?

- Interesting data
- Challenging visualization / data analysis problems
- Little background in data sonification

Visit us!

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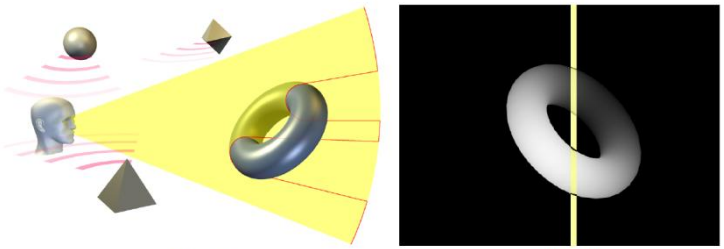
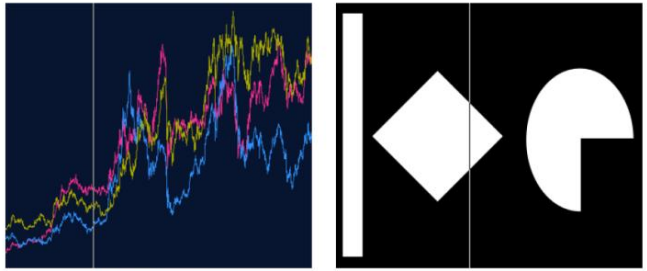
Data Sonification



(a) 3D Scanline. (b) Depth Buffer.

Figure 28: Scanline Sonification for 3D Objects.



(a) Stock Market Data Sonification. (b) 2D Shapes Sonification.

Figure 71: 1D/2D Data Sonification.

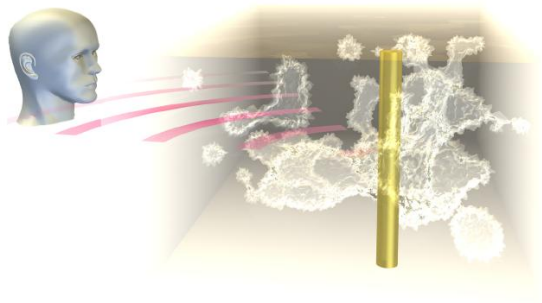
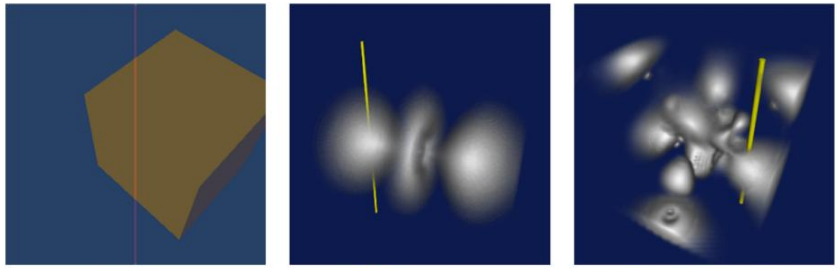


Figure 29: 3D Volume Sonification using an interactive Chimes.



(a) Cube. (b) Hydrogen Atom. (c) Protein Molecule.

Figure 72: Sonification of 3D Objects and Data Volumes.

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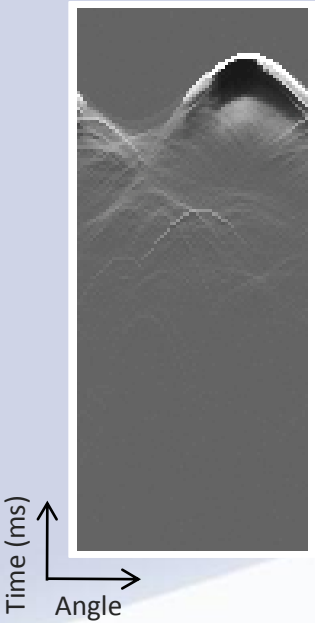
Sound Rendering

- 3D waveguide meshes
  - Improved efficiency (20x – 60x)
  - Improved simulation results for BCC lattice
- Ray acoustic simulation
  - Real-time simulation up to 30k models (incl. auralization)
  - Integration of wave-based effects (diffraction)
  - Frequency-based material modeling
- Promising virtual HRIR simulations
  - Simulations exhibit all important features
  - On the way to personalized HRTFs



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Applications I

- Audio-only computer games

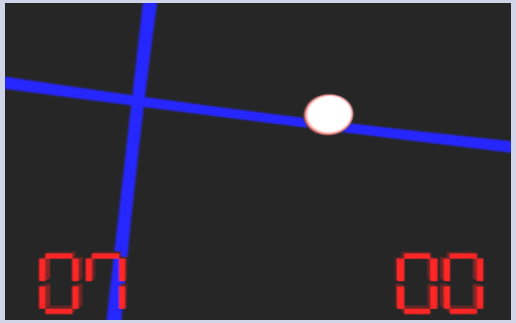
  Development of games that are played solely through listening.

  - Three action, one auditory adventure game
  - Usability test

- Augmented audio reality (AAR)

  Enhancing a real environment with additional auditory information.

  - Self developed AAR system
  - Usability test



Audiogame *Mosquito*

AAR Game *The hidden Secret*

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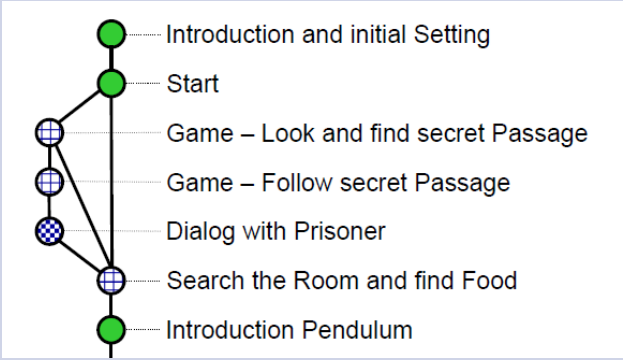
Applications II

- Interactive audiobooks

  Combining audiobooks with interactive elements from computer games.

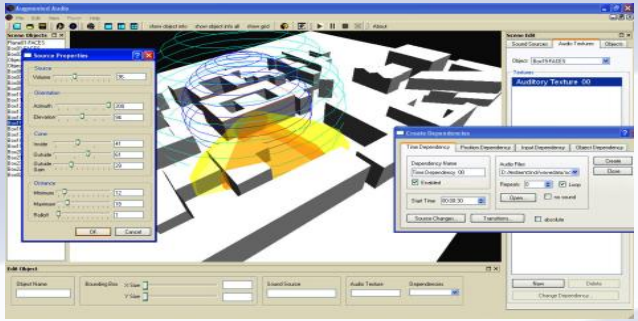
  - Non-linear story graph with variable degree of interaction
  - Usability tests



Storytree *The Pit and the Pendulum*

- Scene authoring environment

  - Extension of audio framework
  - Authoring of 3D sound sources, acoustics, auditory textures and ring menu systems



Authoring Environment

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