Interactive Data Visualization with Focus on Climate Research

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German Climate Computing Center (DKRZ)

Agenda

- Visualization in HPC Environments
- Climate System, Climate Models and Climate Data
- Visualization: Domain specific Tools and Systems
- Application Examples
- Future Perspectives

Data Production at DKRZ

6 PByte
GPFS

Hard Disks

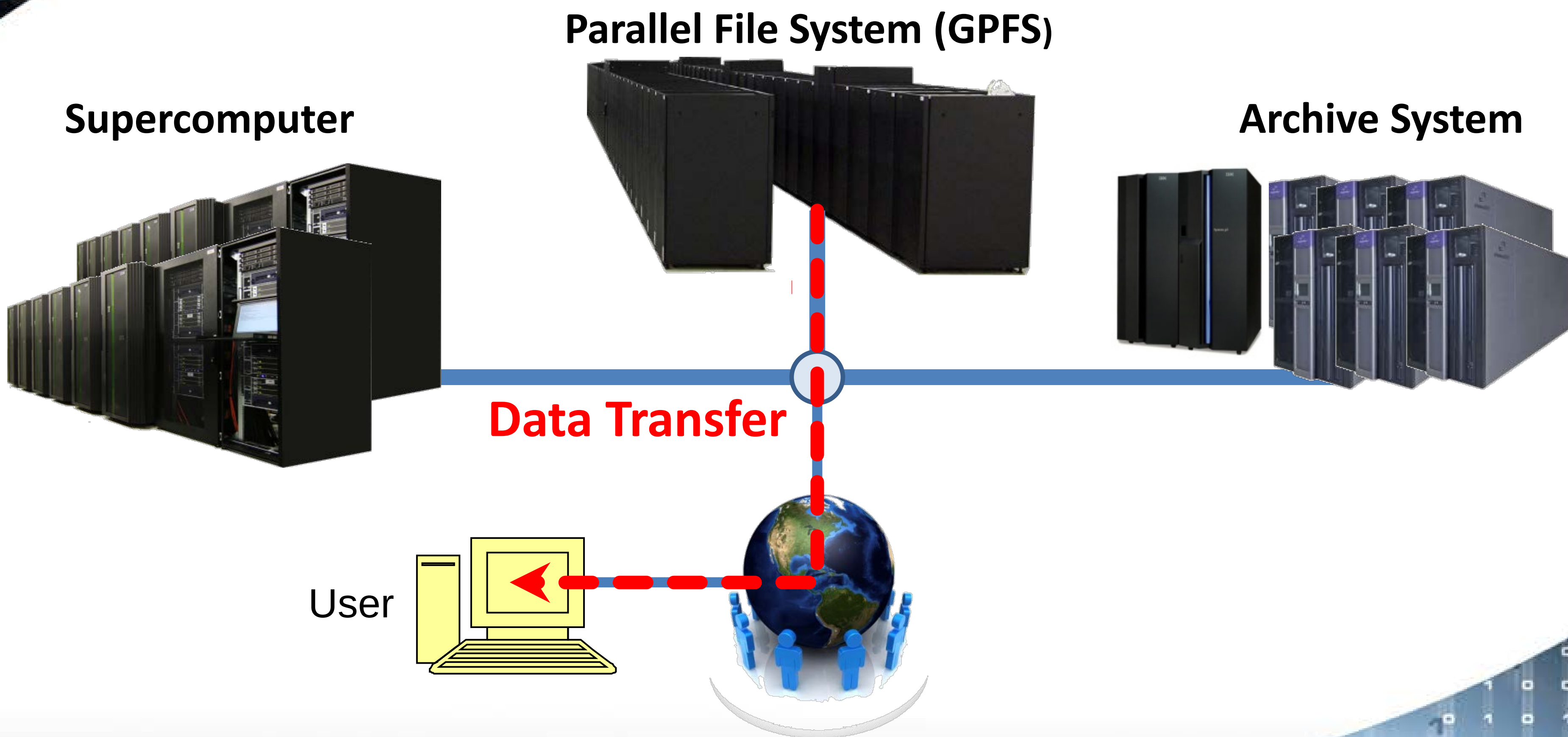
Supercomputer

158 TFlops
20 TByte Mem.

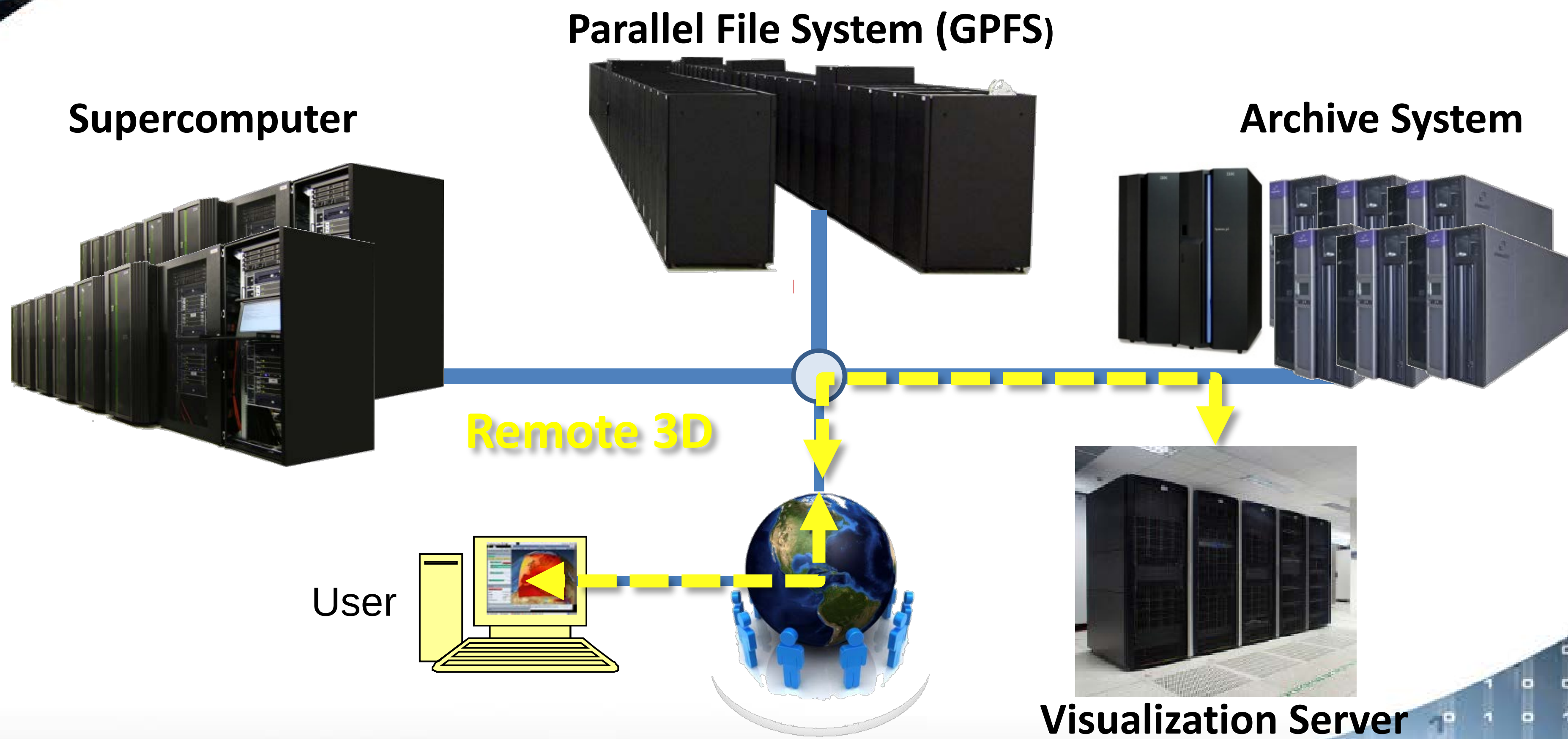
7 Silos
88 Drives
100 PByte

Archive System

Visualization in HPC Environments



Visualization in HPC Environments

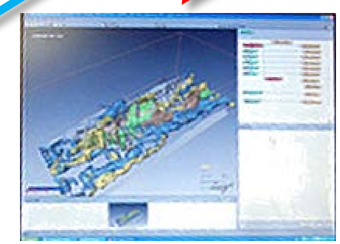


Remote-3D-Rendering

Local Computer:
- *Keyboard / Mouse*
- *Display*
- *Remote-3D Client*

Visualization Server:
- *3-D-Software (OpenGL)*
- *Remote 3D-Server*
- *Data*

Software Solution:
TurboVNC / Virtual GL



Keyboard / Mouse

Capture Keyboard / Mouse

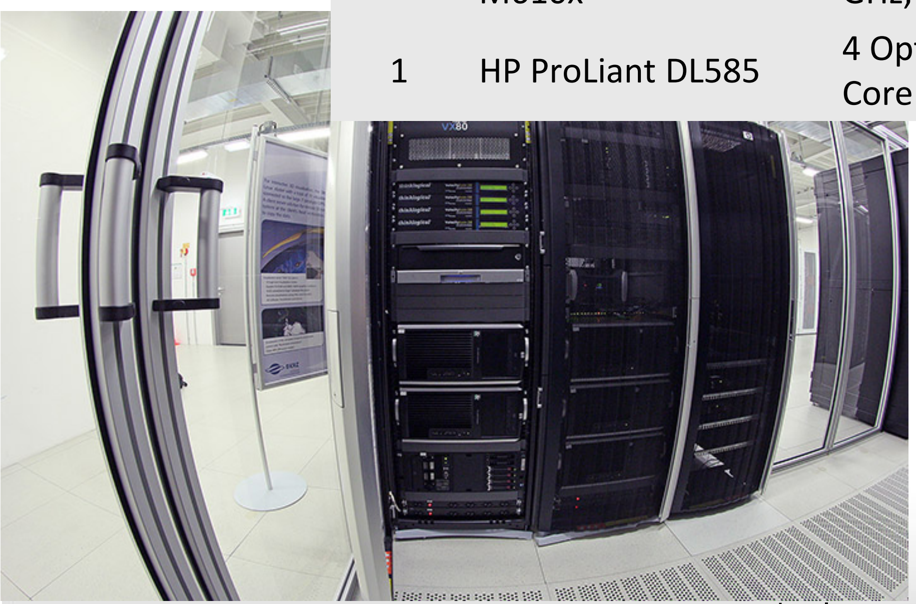
Internet

Uncompress Image
Display Image

Capture Framebuffer
Compress Image
Send Image to Client

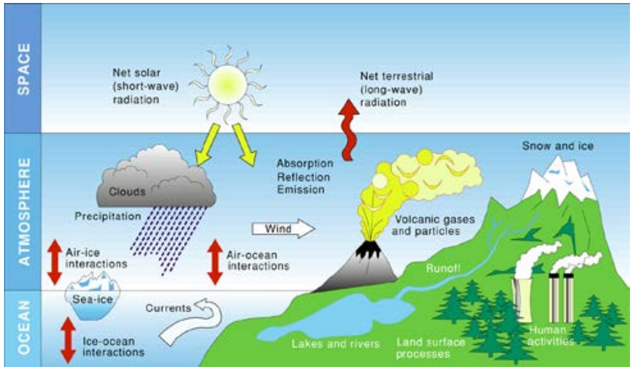
Visualization Cluster

Nodes	Type	CPUs	RAM	Gfx Cards
1	Transtec Lynx 2610R	2 Intel Xeon E5-2690 2.9 GHz, 8-core	256 GB	2 Nvidia Quadro K5000, 4 GB
2	HP ProLiant DL370 G6	2 Intel Xeon X5680 3.33 GHz, 6-Core	96 GB	2 NVidia Quadro 6000, 6 GB
1	Dell Precision R5400	2 Intel Xeon 3 GHz (2-Core)	32 GB	NVidia Quadro 5000, 2.5 GB
4	Dell PowerEdge M610x	2 Intel Xeon E5649 2.53 GHz, 6-Core	96 GB	NVidia Tesla M2070Q, 6GB
1	HP ProLiant DL585	4 Opteron64 2.4 GHz, 2-Core	128 GB	2 Nvidia Quadro FX 5500, 1 GB

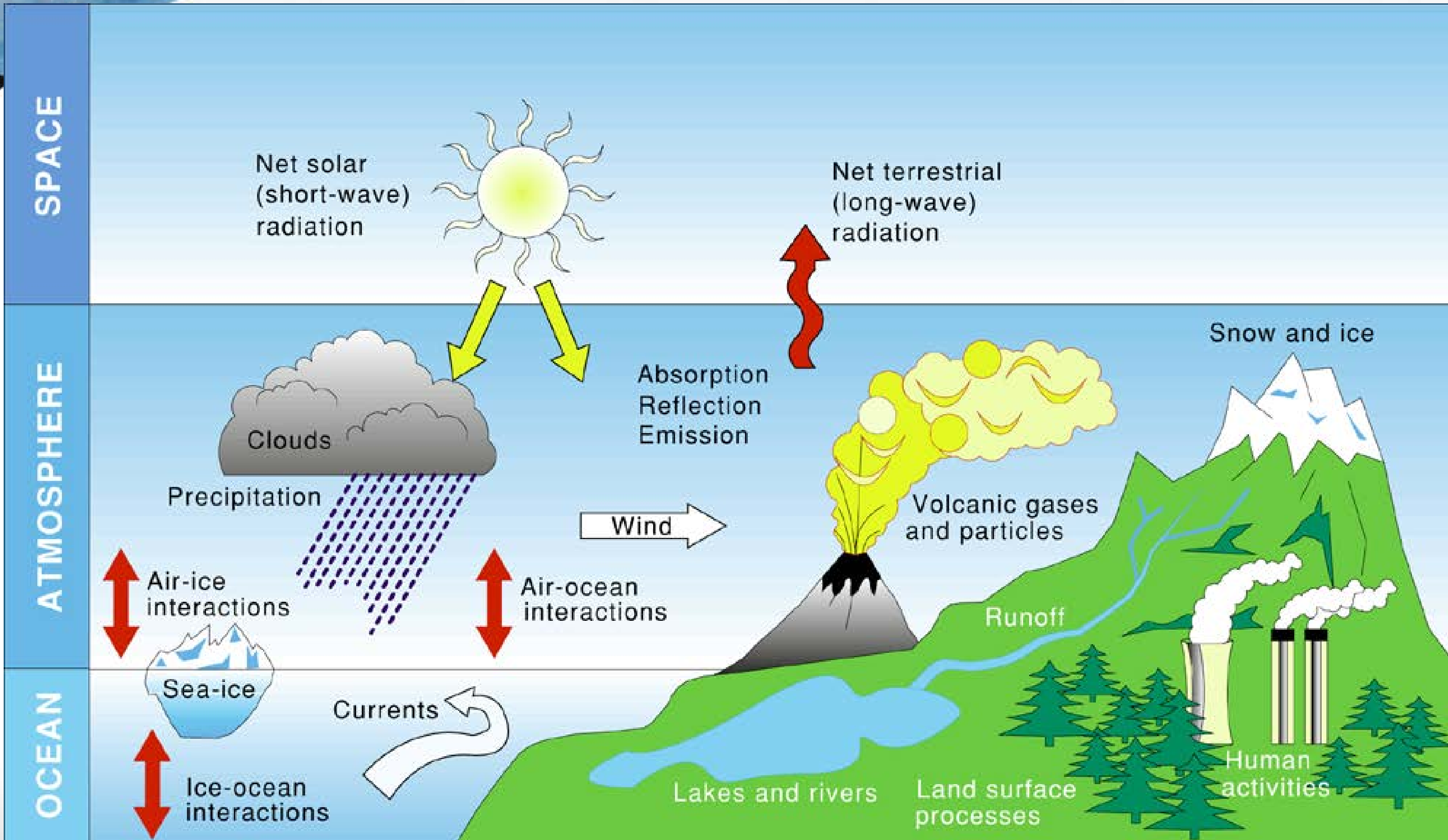


- 9 Nodes (HP), heterogenous
- 10 GE Network
- GPFS directly mounted
- CentOS (RH5)

Climate System, Climate Models and Climate Data



The Climate System



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Atmosphere Model

- Conservation Laws (Momentum, Energy, Mass)
- State Equations
- Radiation
- Boundary Conditions (Earth Geometry, Astronomical Parameters, Distribution of Land and Sea
- Differential Equations

$$\frac{\partial U}{\partial t} - (f+\xi) \cdot V + \dot{\eta}\frac{\partial U}{\partial \eta} + \frac{R_d T_v}{a}\frac{\partial}{\partial \lambda} ln p + \frac{1}{a}\frac{\partial}{\partial \lambda}(\phi + E) = P_U + K_U \tag{2.2.1}$$

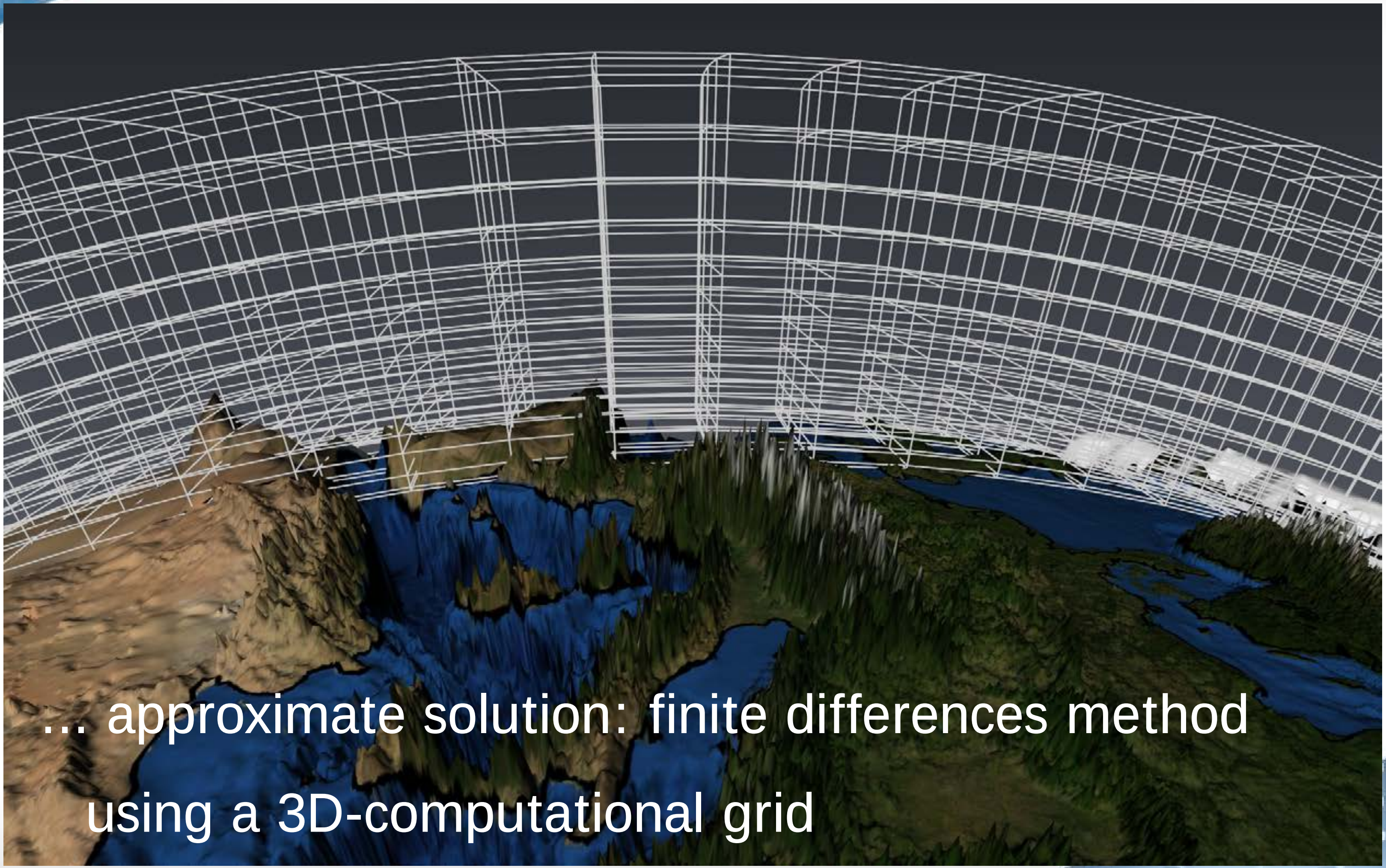
$$\frac{\partial V}{\partial t} + (f+\xi) \cdot U + \dot{\eta}\frac{\partial V}{\partial \eta} + \frac{R_d T_v}{a}(1-\mu^2)\frac{\partial}{\partial \mu} ln p + \frac{(1-\mu^2)}{a}\frac{\partial}{\partial \mu}(\phi + E) = P_V + K_V \tag{2.2.2}$$

$$\frac{\partial T}{\partial t} + \frac{U}{a(1-\mu^2)}\frac{\partial T}{\partial \lambda} + \frac{V}{a}\frac{\partial T}{\partial \mu} + \dot{\eta}\frac{\partial T}{\partial \eta} - \frac{\kappa T_v \omega}{(1+(\delta-1)q_v)p} = P_T + K_T \tag{2.2.3}$$

$$\frac{\partial q_v}{\partial t} + \frac{U}{a(1-\mu^2)}\frac{\partial q_v}{\partial \lambda} + \frac{V}{a}\frac{\partial q_v}{\partial \mu} + \dot{\eta}\frac{\partial q_v}{\partial \eta} = P_{q_v} + K_{q_v} \tag{2.2.4}$$

$$\frac{\partial q_w}{\partial t} + \frac{U}{a(1-\mu^2)}\frac{\partial q_w}{\partial \lambda} + \frac{V}{a}\frac{\partial q_w}{\partial \mu} + \dot{\eta}\frac{\partial q_w}{\partial \eta} = P_{q_w} + K_{q_w} \tag{2.2.5}$$

Atmosphere Models



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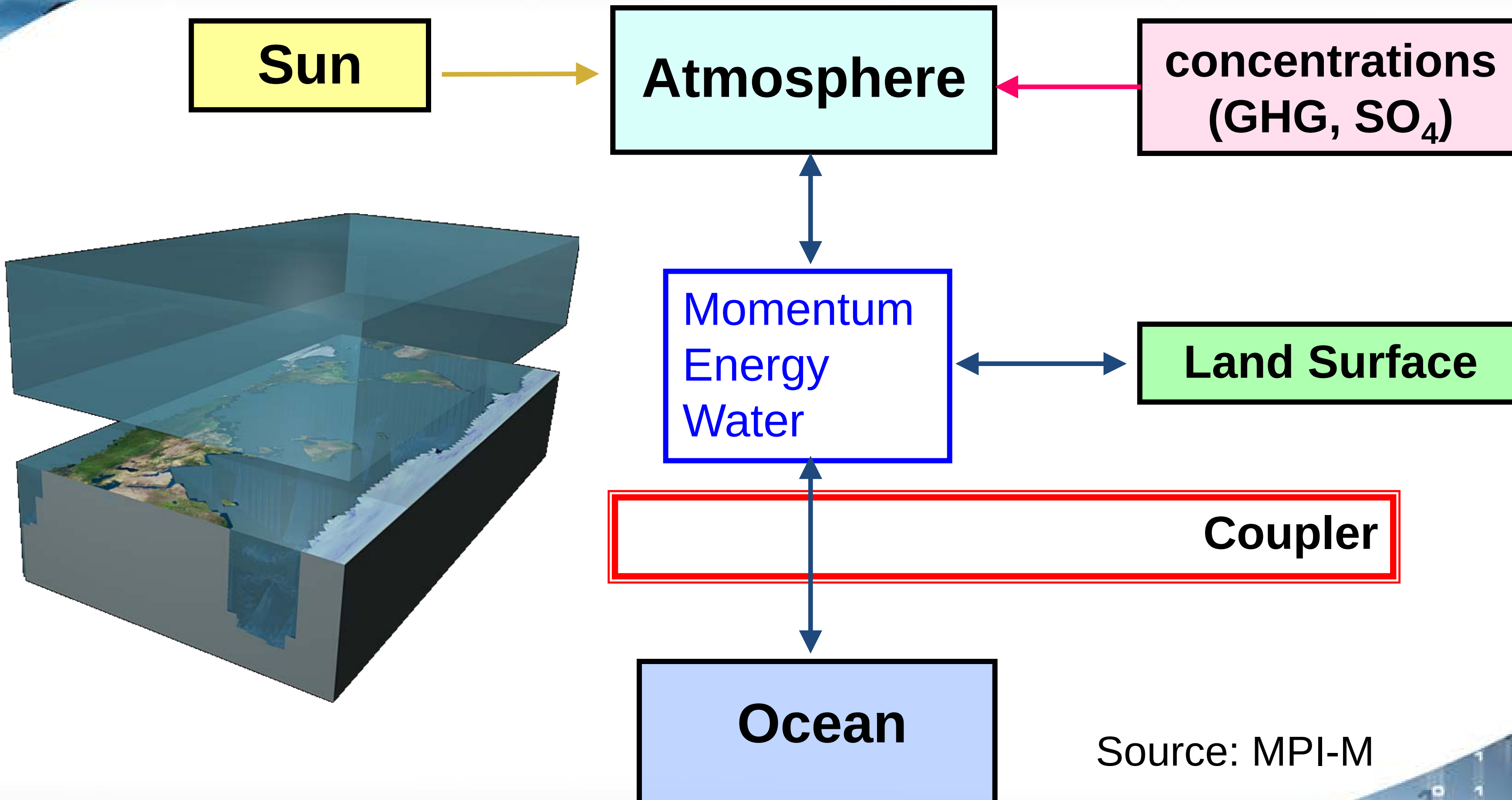
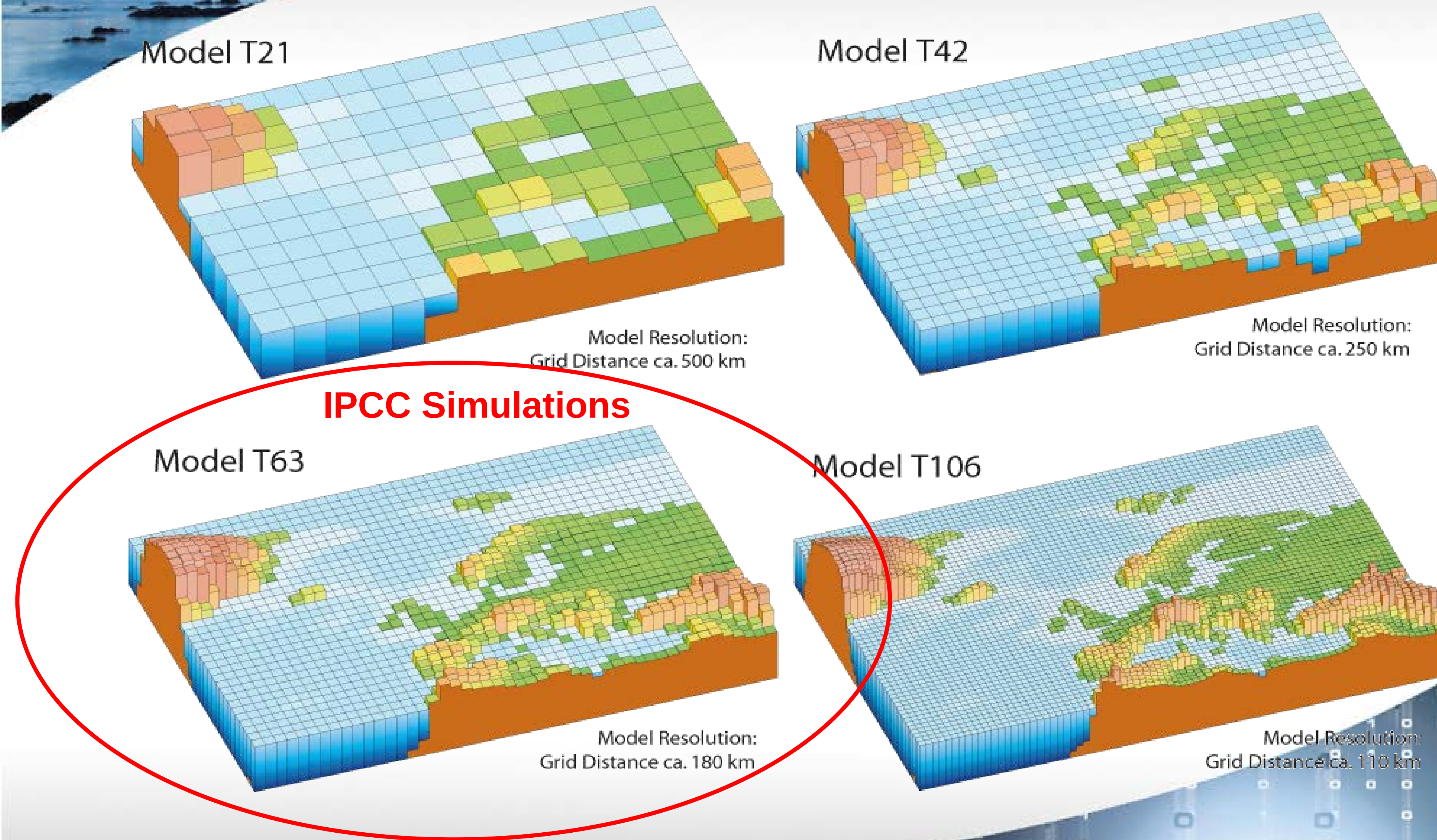
A coupled climate model



Source: MPI-M

Grid Resolution



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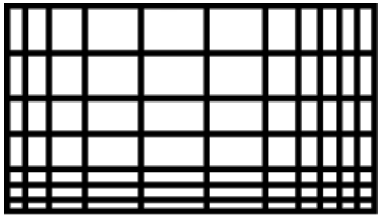
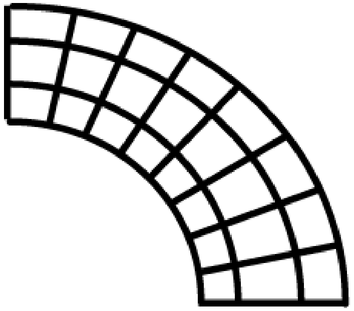
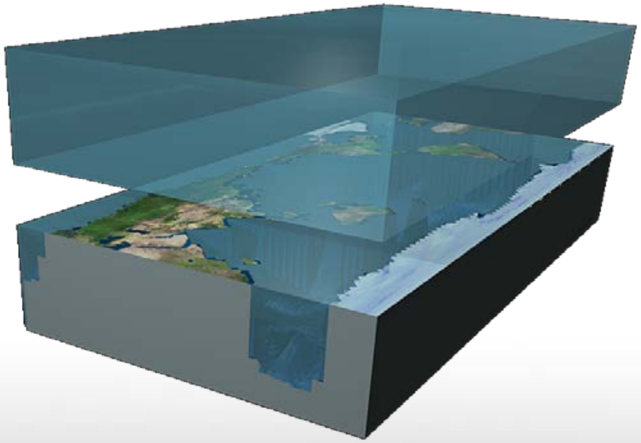
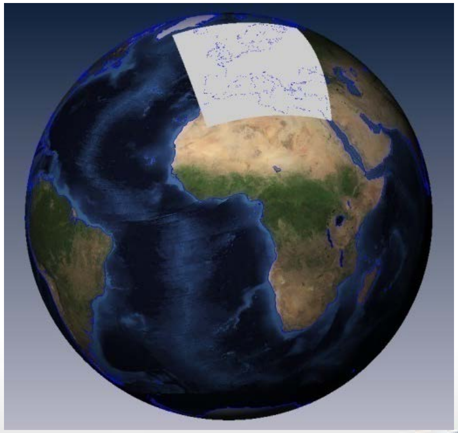
Climate Models – Data Structures

- Relatively coarse 3D grids, some quantities only 2D
- Grids: rectilinear, curvilinear, rotated, irregular ...
- Multivariate / scalar and vector fields
- Time dependence: very long time series
- Coupled models: distinct grids
- Multi run experiments (ensembles)









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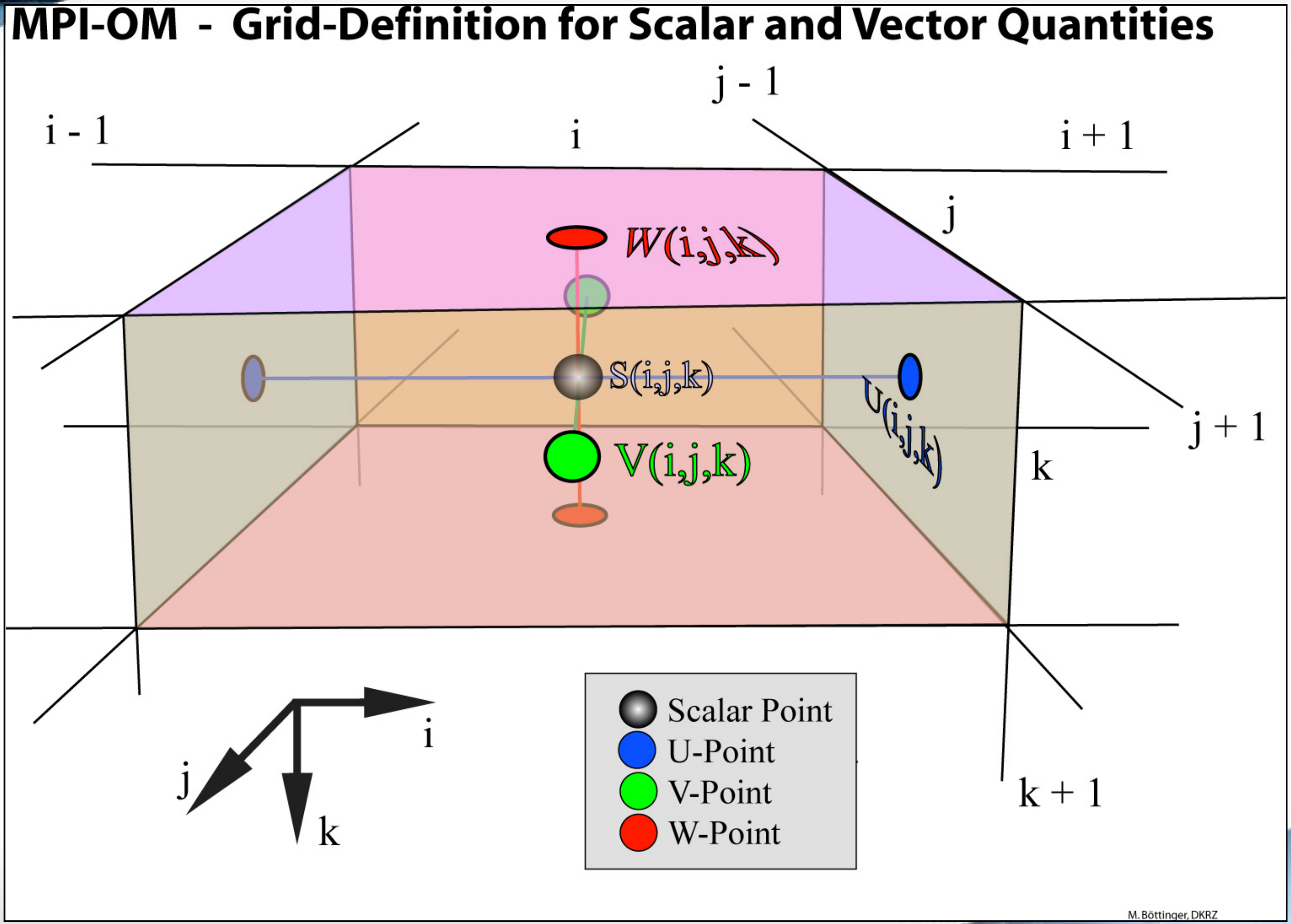
Staggered Grids



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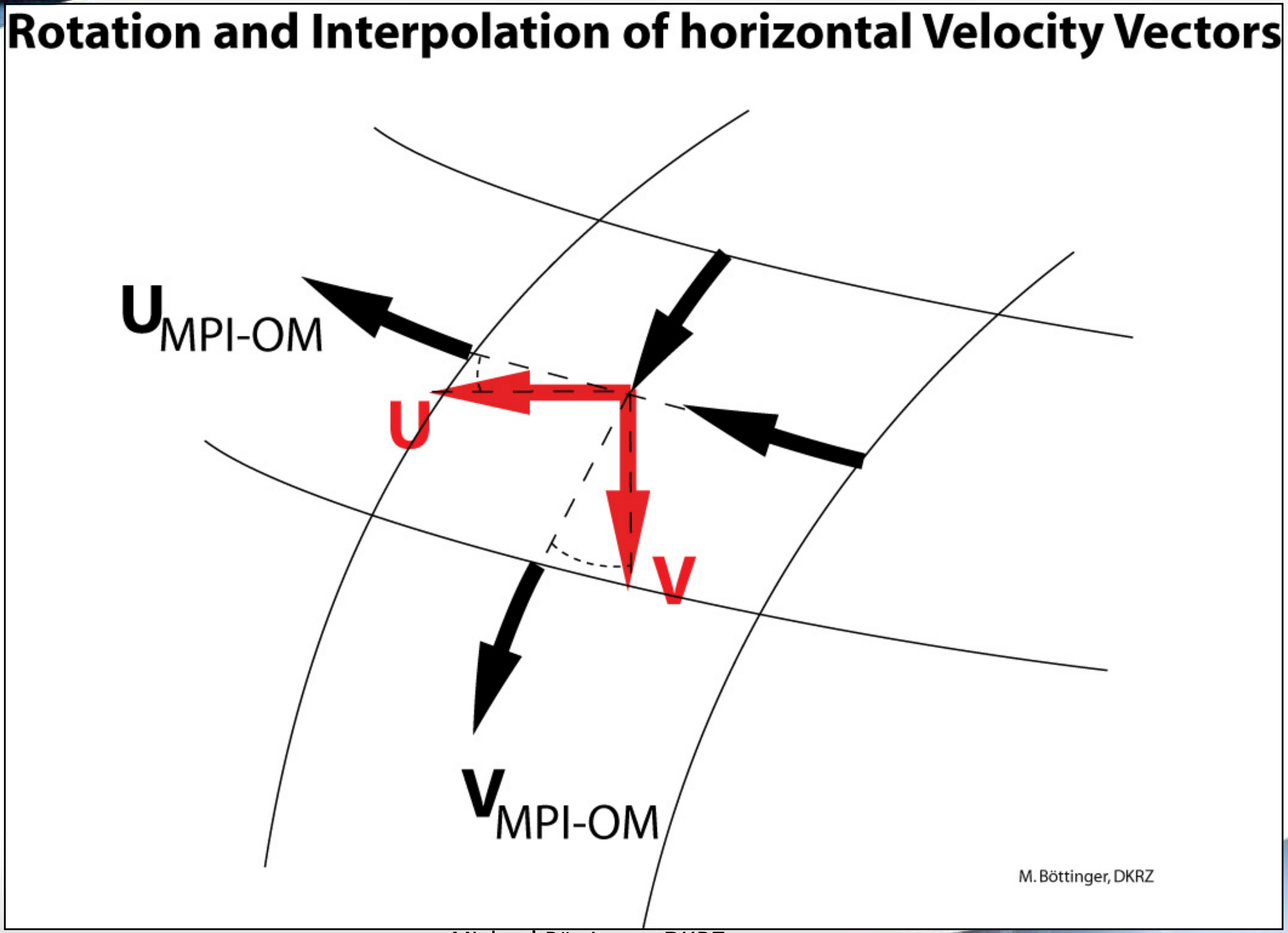
Curvilinear Grids



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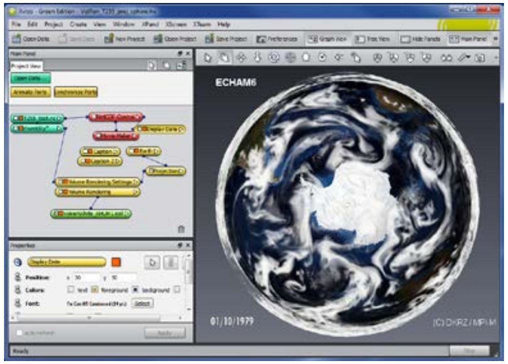
File Formats and other requirements

- Formats: GRIB and NetCDF
  - *Conventions* for Metadata (NetCDF/CF-1.0)
- Other domain specific features
  - Geographical mapping of data
  - *Special Values* (masking of grid cells with “no data”)

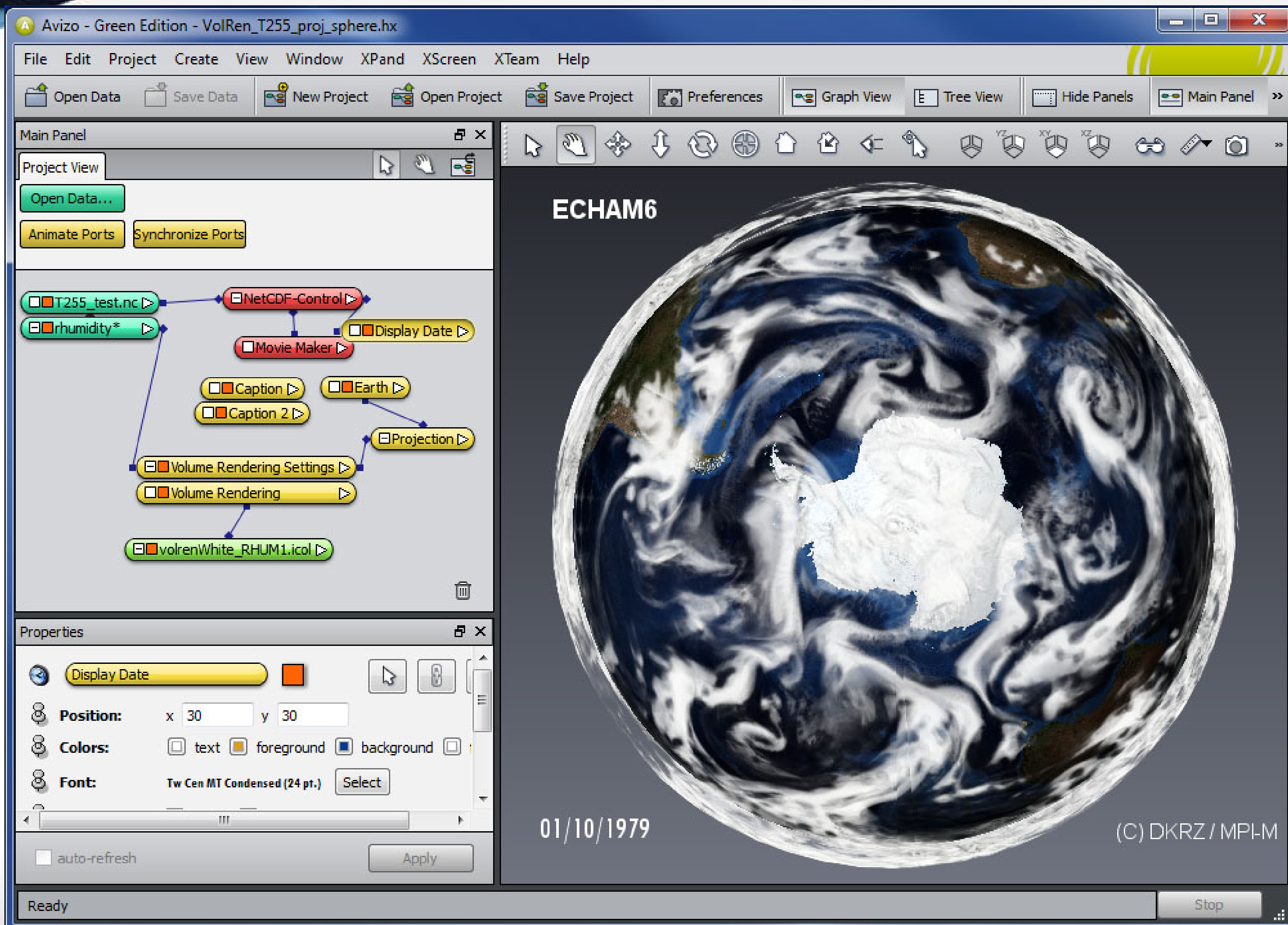
Visualization: Domain specific Tools and Systems



Visualization Software

Categorie	Typ	Name	URL	Features
Programming- and Scripting languages for analysis	$$ $$ $$ free	Matlab IDL Mathematica R	www.mathworks.de/products/matlab www.exelisvis.com www.wolfram.com/mathematica www.r-project.org	Simulation + Gfx 2D+ scripting Simulation + Gfx Statistik, 2D script
Domain specific Visualization Software	frei frei frei frei frei frei frei	Ferret GrADs Vis5D+ GMT ODV IDV NCL	ferret.wrc.noaa.gov/Ferret www.iges.org/grads vis5d.sourceforge.net gmt.soest.hawaii.edu odv.awi-bremerhaven.de/ www.unidata.ucar.edu/software/idv www.ncl.ucar.edu/	2D script based 2D script based 3D interactive (old) 2D script based 2D script based 3D interactive 2D script based
3D Visualization Systems	$$ frei $$ frei $$ frei	Avizo OpenDX AVS/Express Paraview SimVis VisIt	www.vsg3d.com/products/avizo.asp www.opendx.org www.avs.com www.paraview.org http://www.simvis.at wci.llnl.gov/codes/visit	Climate Extensions 3D, alt climate features 3D GUI, parallel 3D/2D -> multivariate 3D, parallel

3D Visualization Software: Avizo Green

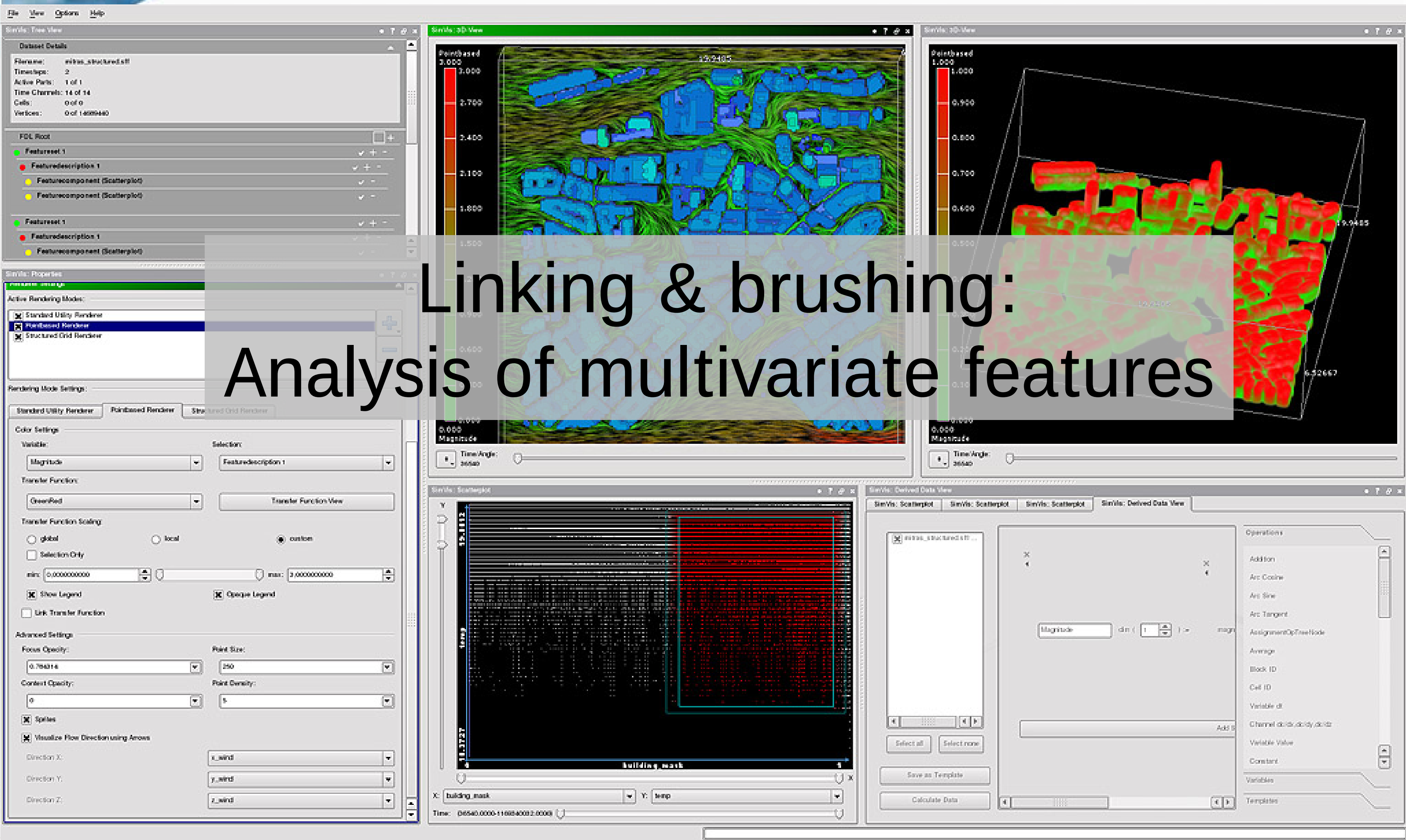


3D Vis-Software: Avizo Green

Avizo with domain specific extensions

- NetCDF CF-1.0 Reader
  - supports regular, rectilinear, rotated, curvilinear and irregular grids
  - “larger” data: streaming for time dependent data
  - Caching in memory
- Map Projections
  - Cylindric Equidistant, Spherical, Mollweide etc.
- „Earth“ Module
  - Textures, LOD techniques
  - Topography / Bathymetry
  - Continental and political Outlines
- HW-based Bump Shading for 2D Slices
- Vector Vis Methods
- Volume Rendering (rectilinear grids)

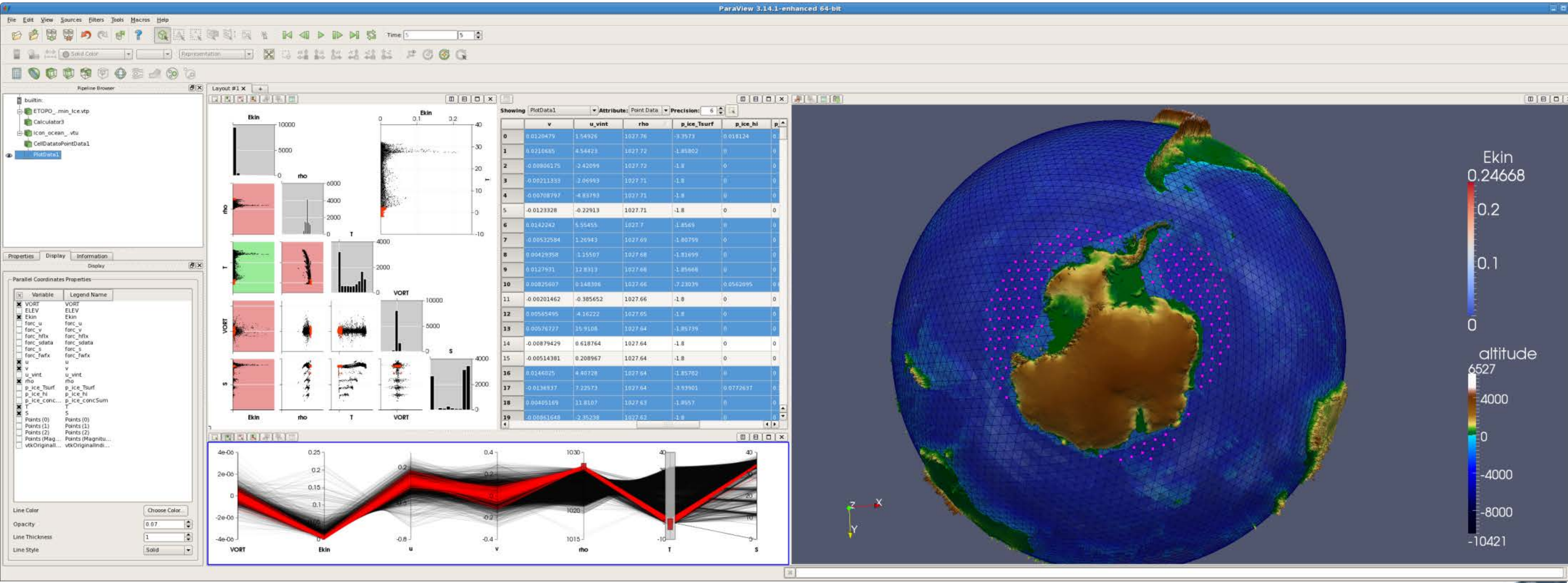
Another 3D-Visualization Paradigm: SimVis



Linking & brushing:

Analysis of multivariate features

Paraview



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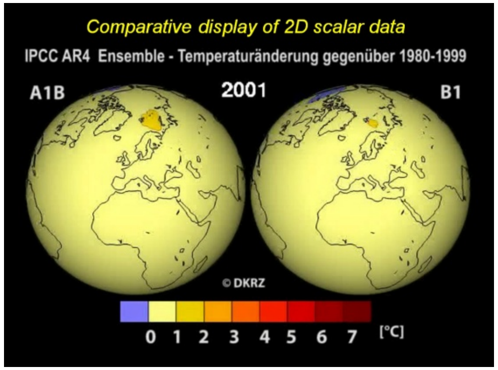
Application Examples



Simulations for CMIP5 / IPCC AR5

- Simulations 2010/2011
- Earth System: Biosphere, Ocean Biogeochemistry
- Computational effort: factor 60 compared to that of IPCC AR4
- 13 000 simulated model years
- Results: 650 TeraBytes -> 60 Terabytes ESG

Max-Planck-Institut für Meteorologie

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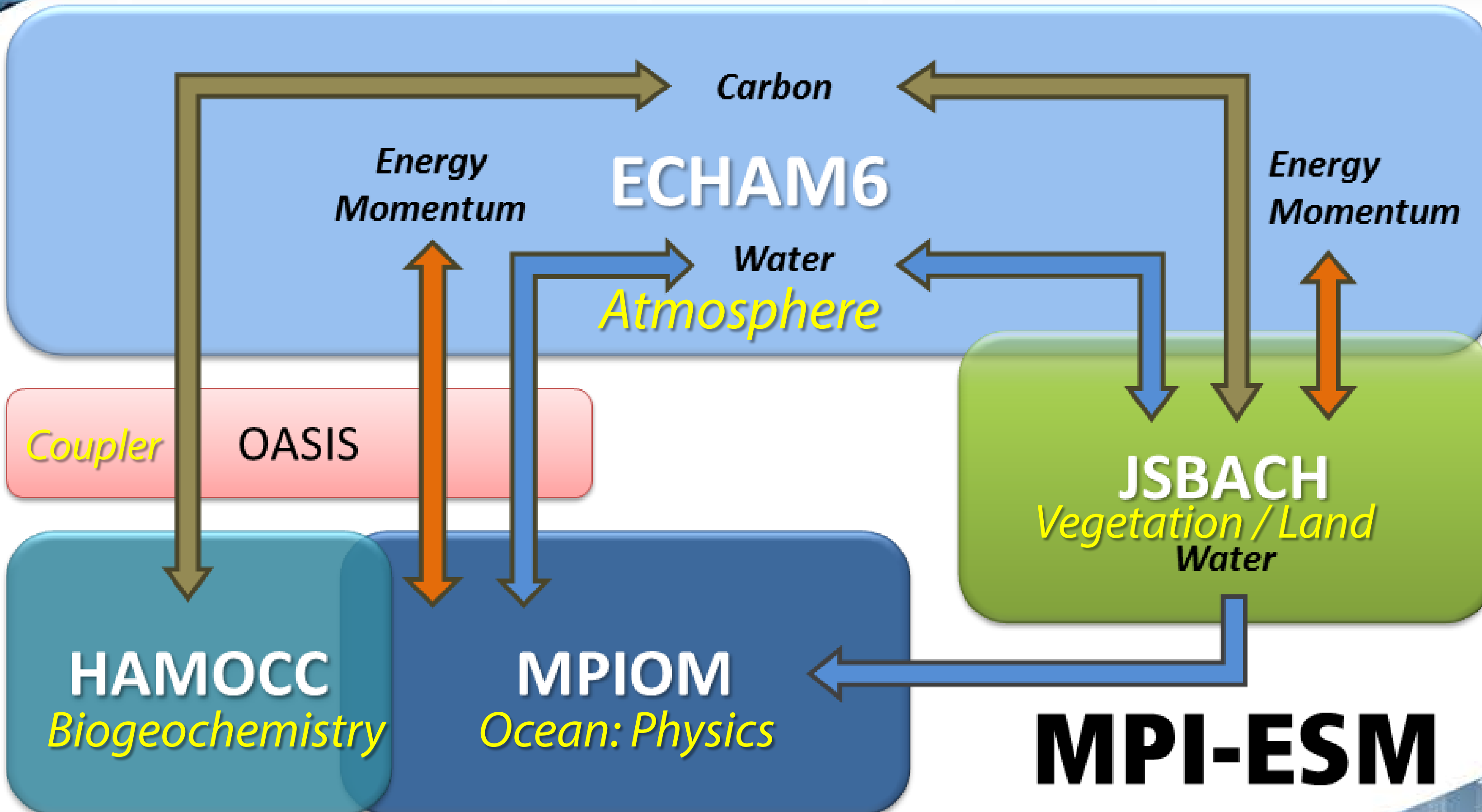
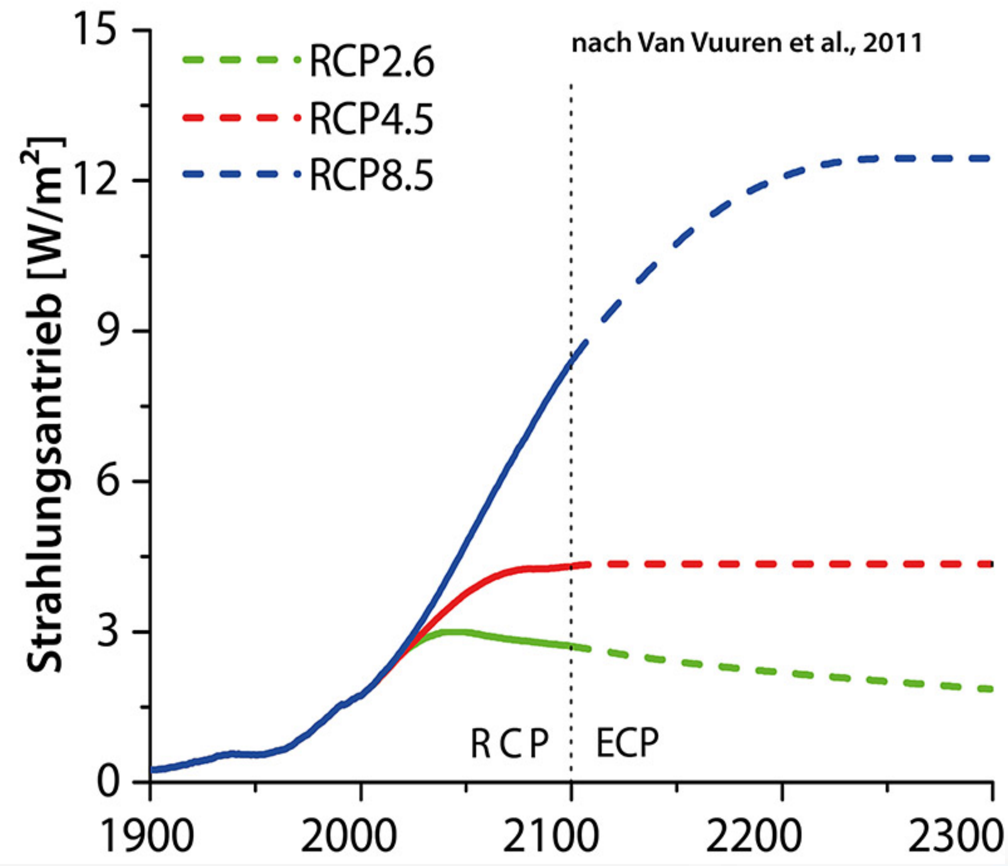
Earth System Model



IPCC-AR5 Simulations
RCP-Scenarios

RCP = Representative Concentration Pathways



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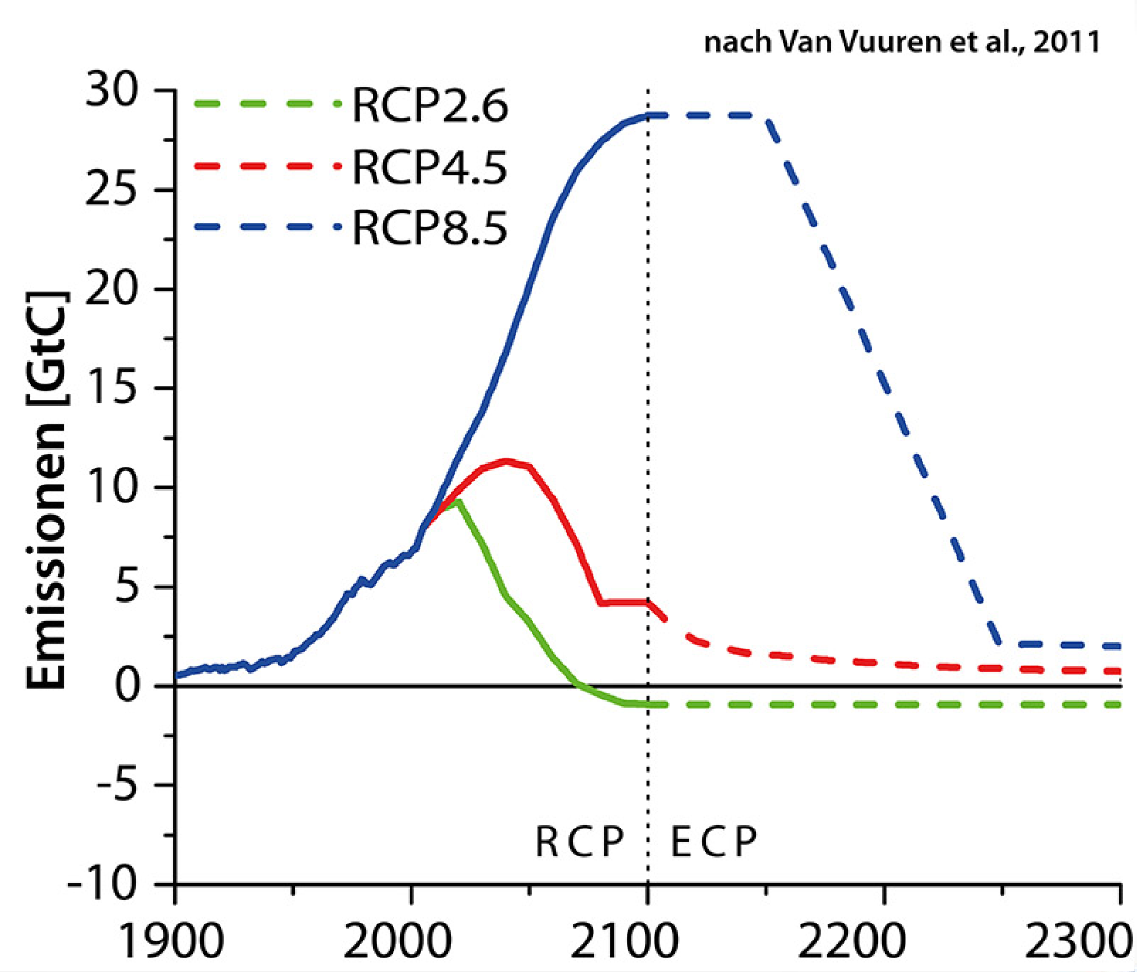
IPCC-AR5 Simulations
RCP-Scenarios



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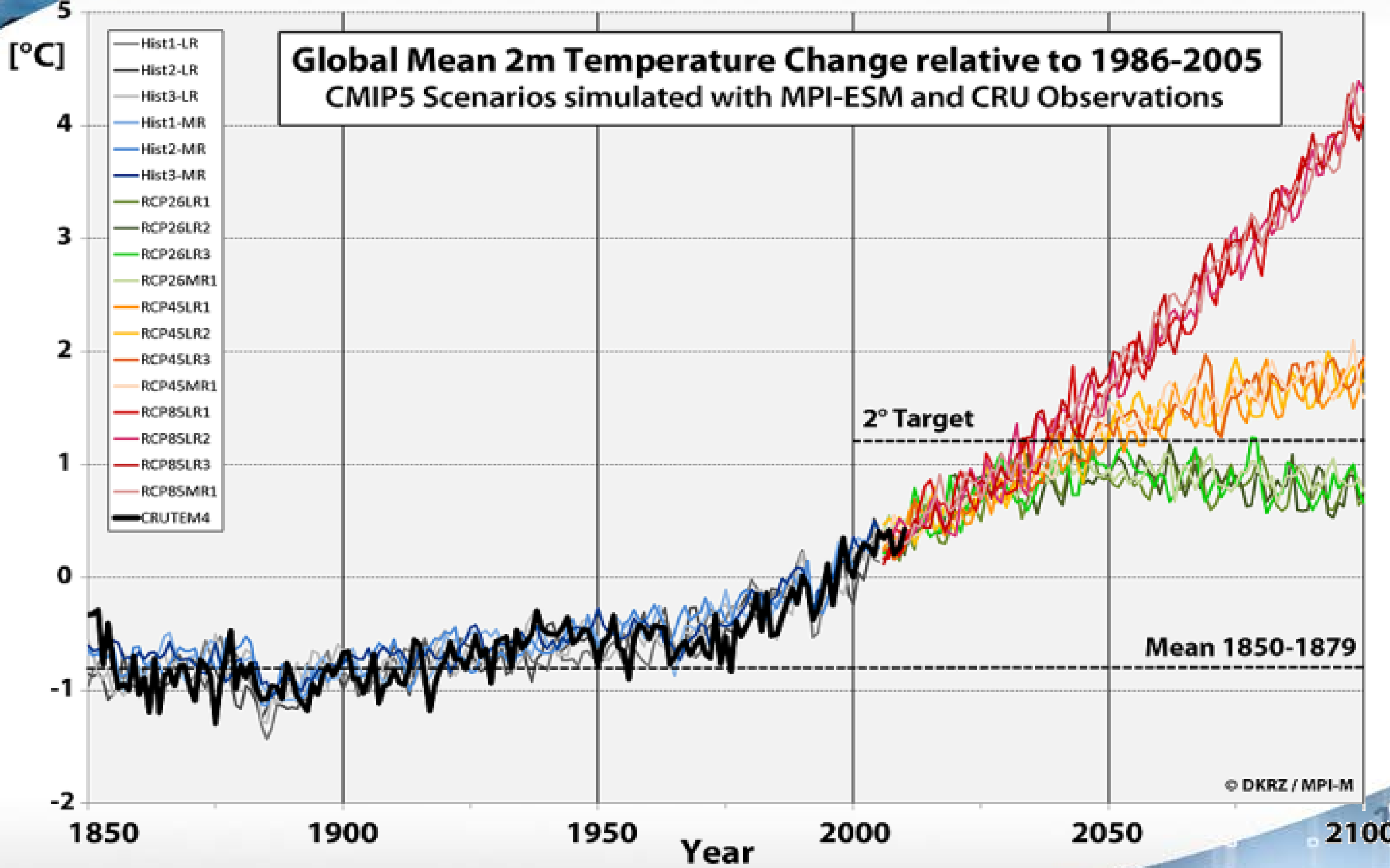
IPCC-AR5 Simulations Temperature Change



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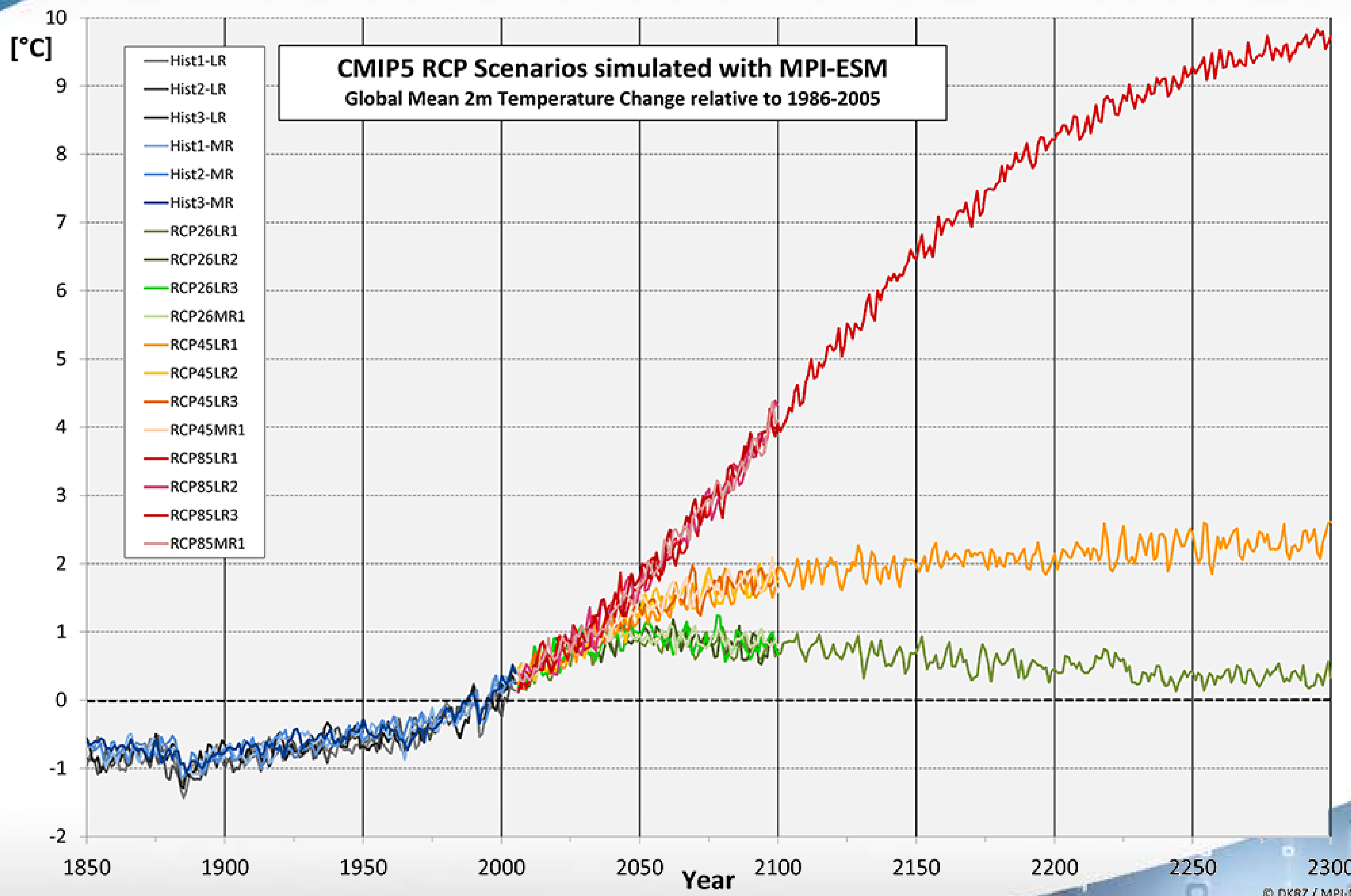
IPCC-AR5 Simulations Temperature Change



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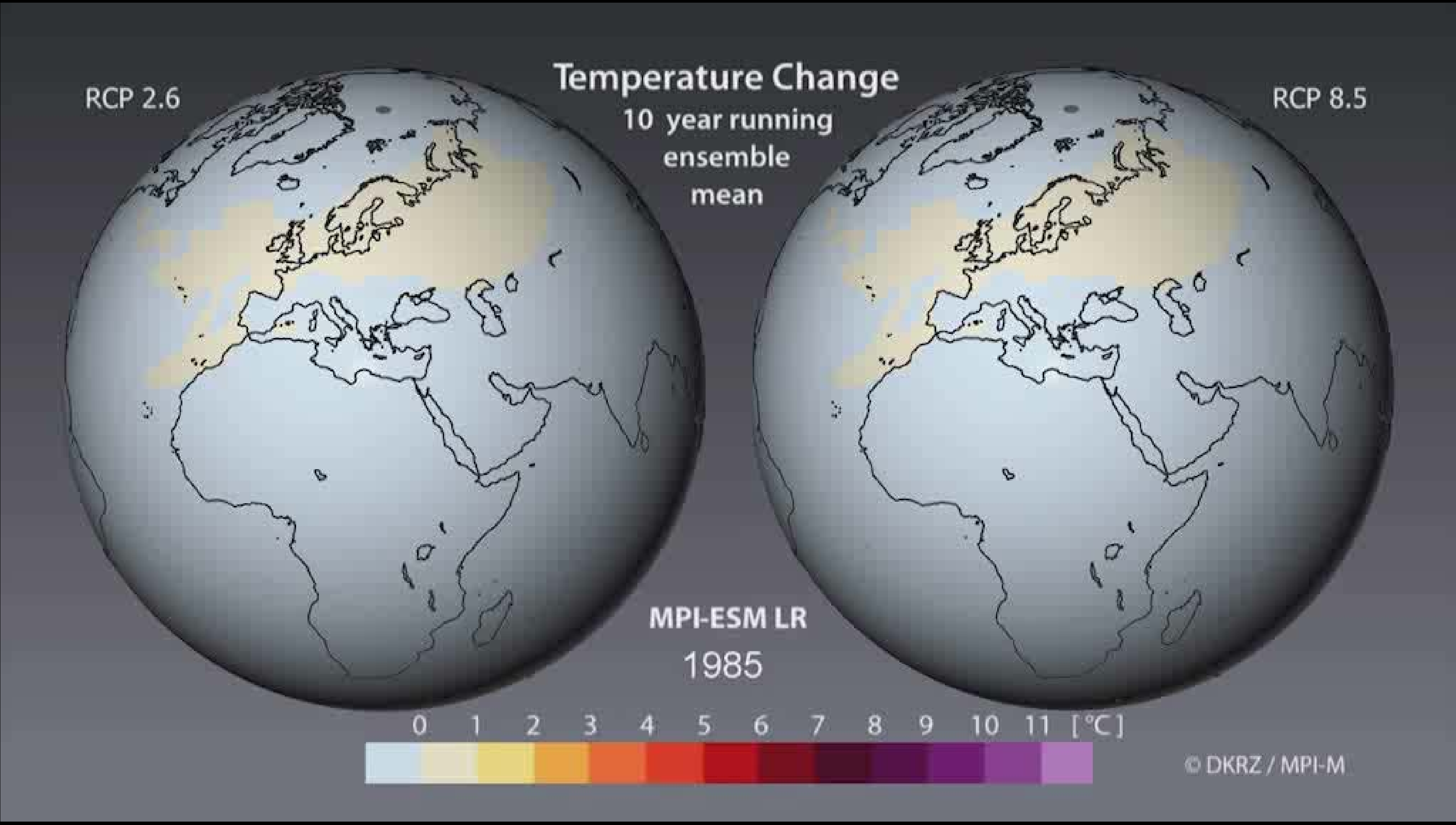
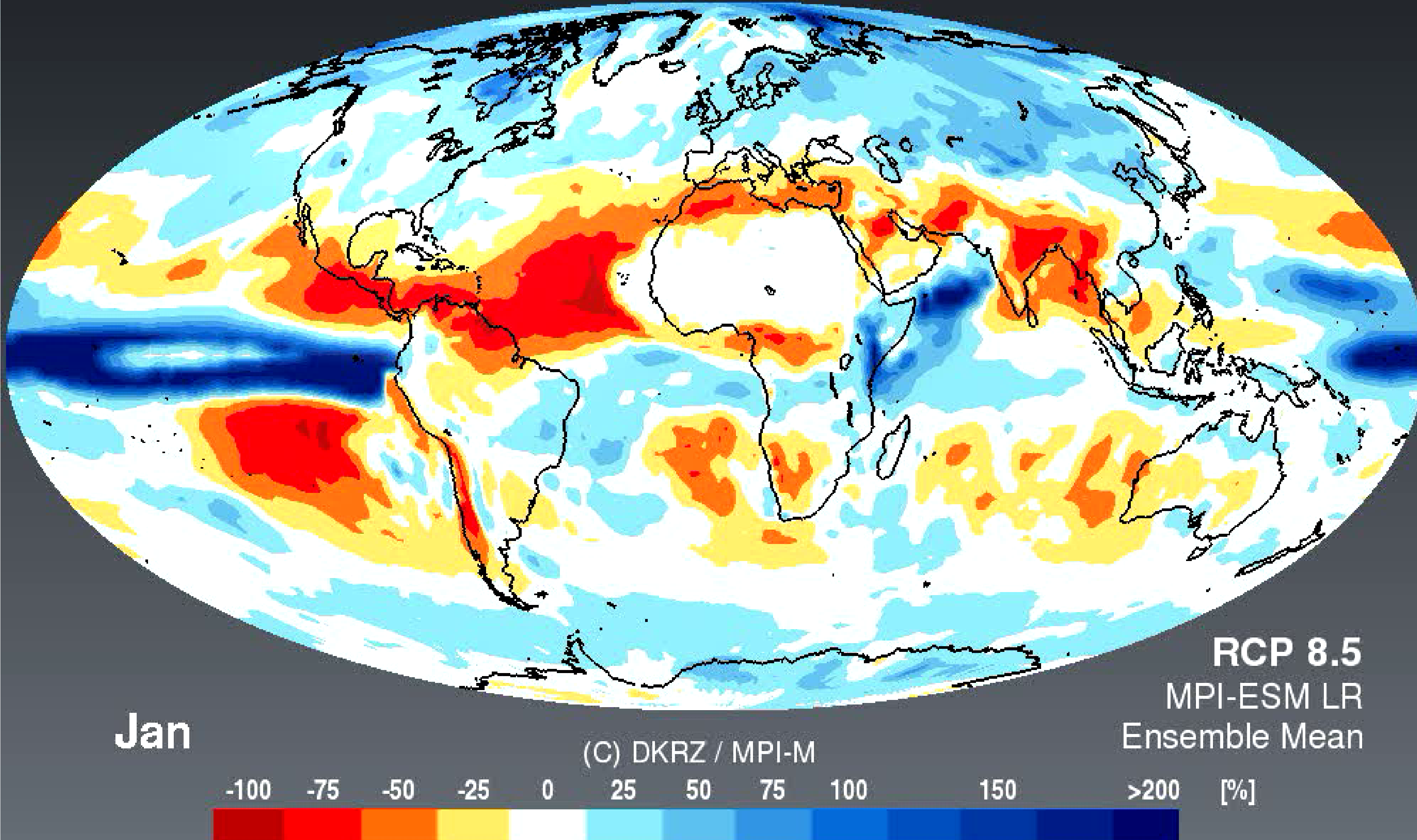
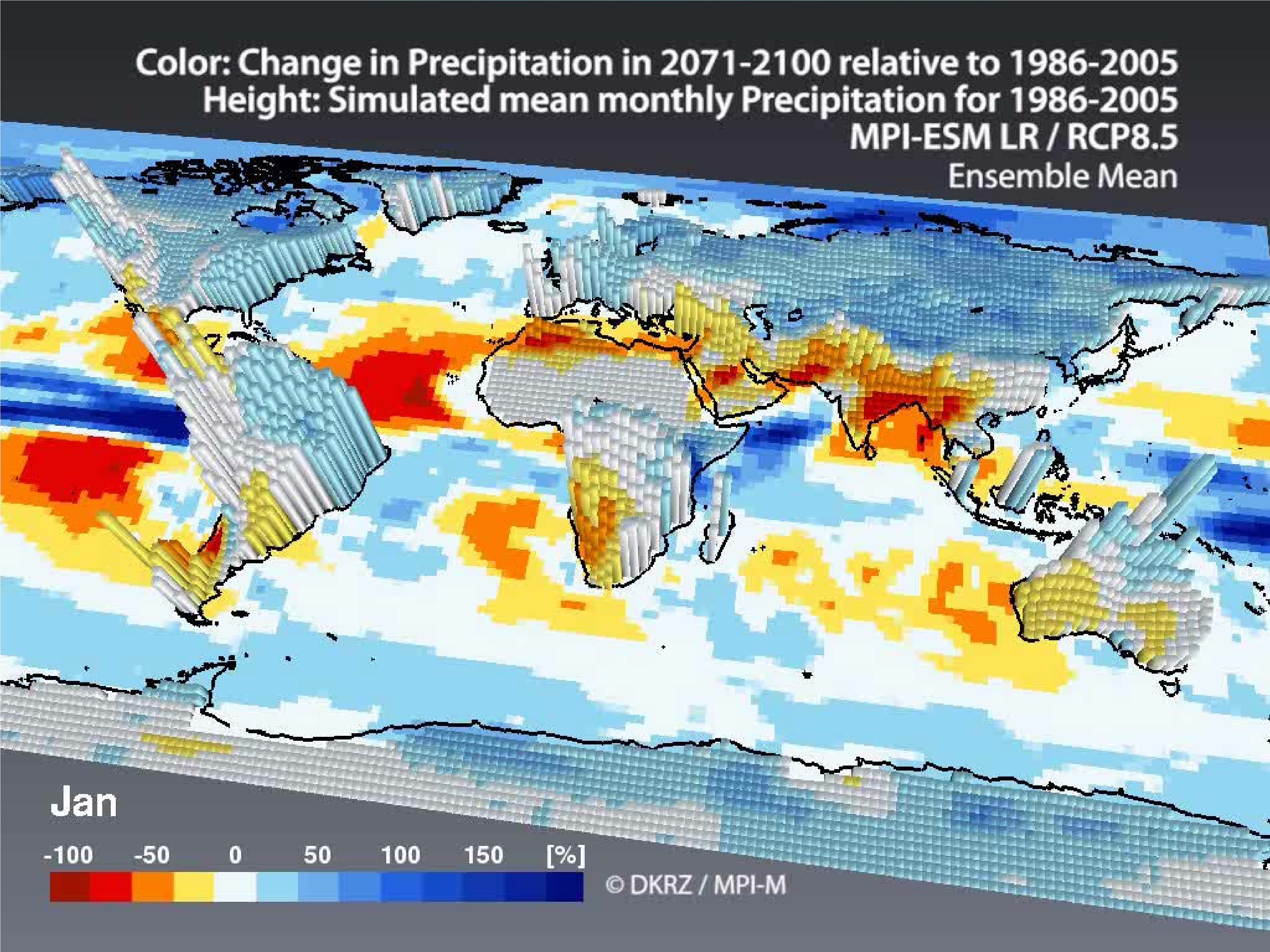
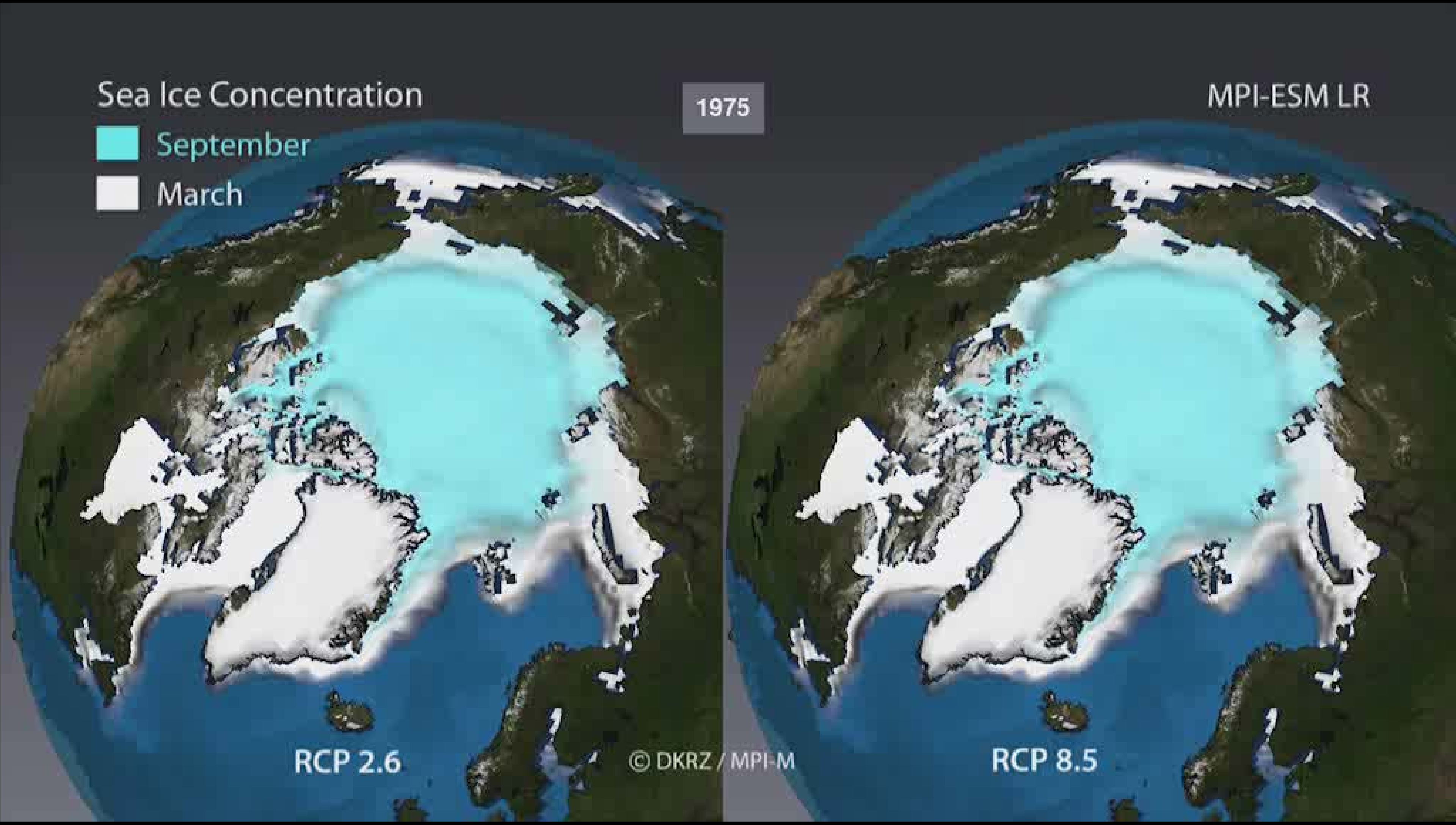


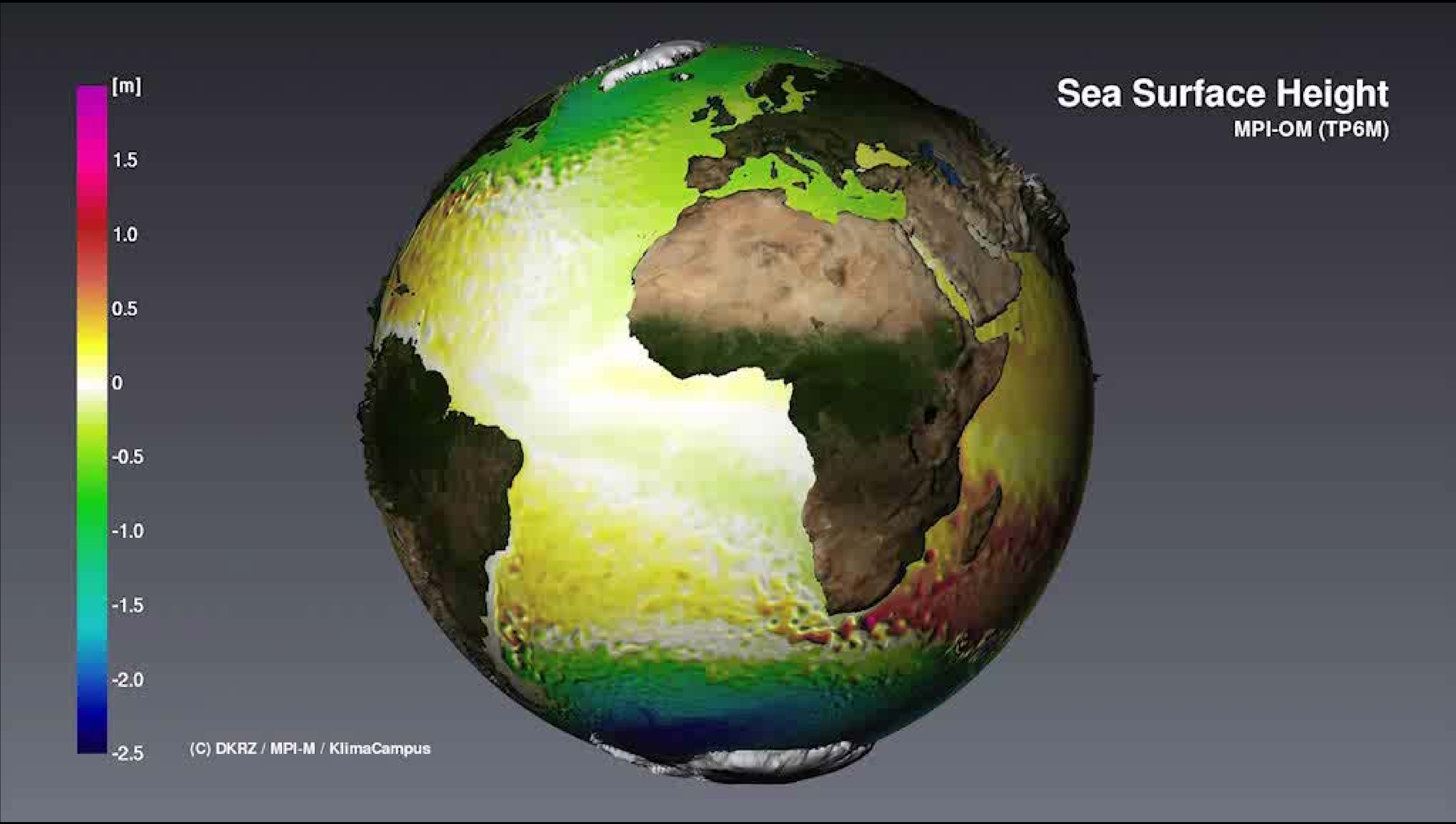
Temperature Change
10 year running ensemble mean
RCP 2.6
RCP 8.5
MPI-ESM LR
1985
0 1 2 3 4 5 6 7 8 9 10 11 [°C]
© DKRZ / MPI-M

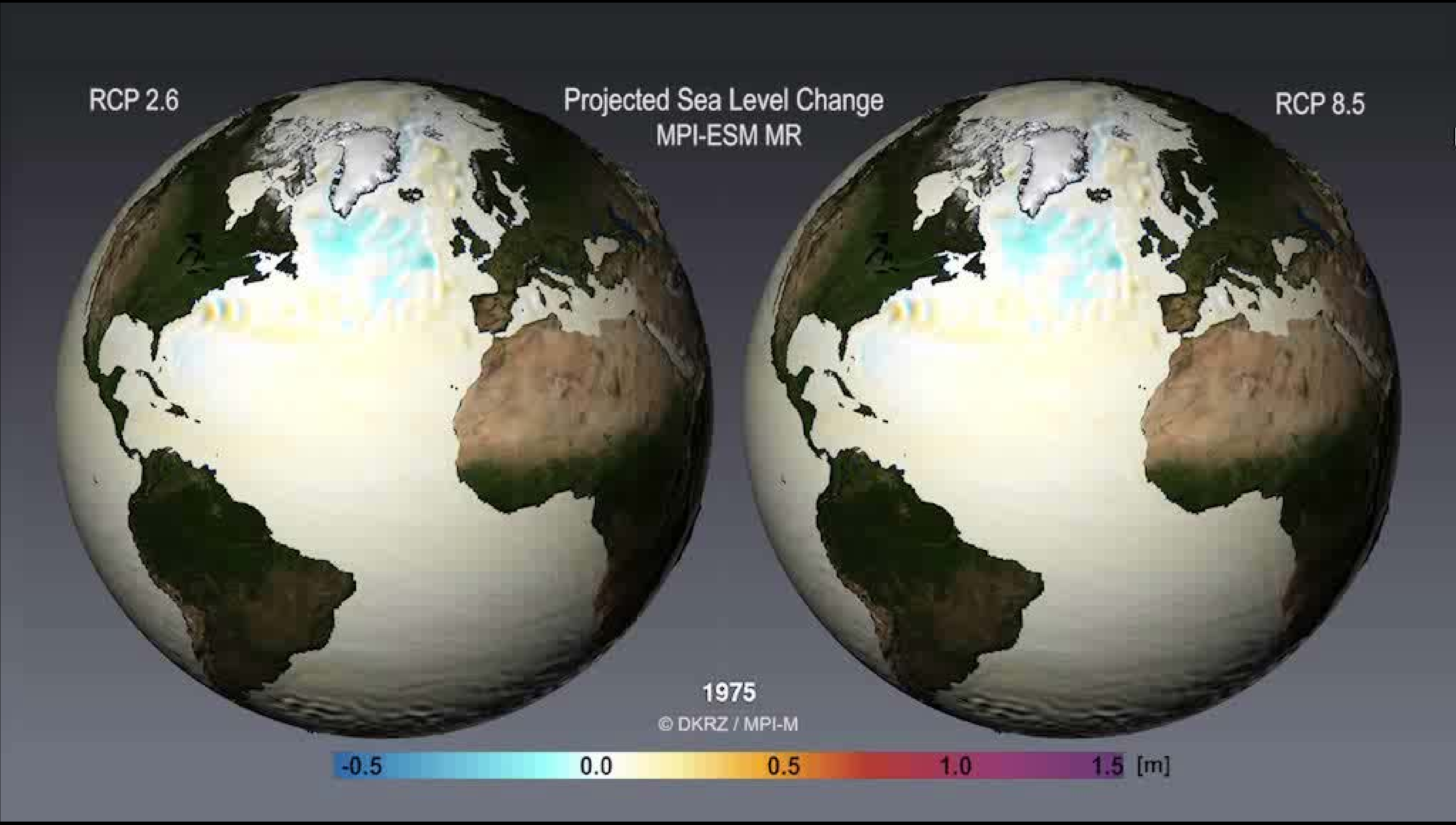
Change in Precipitation for 2071-2100 relative to 1986-2005

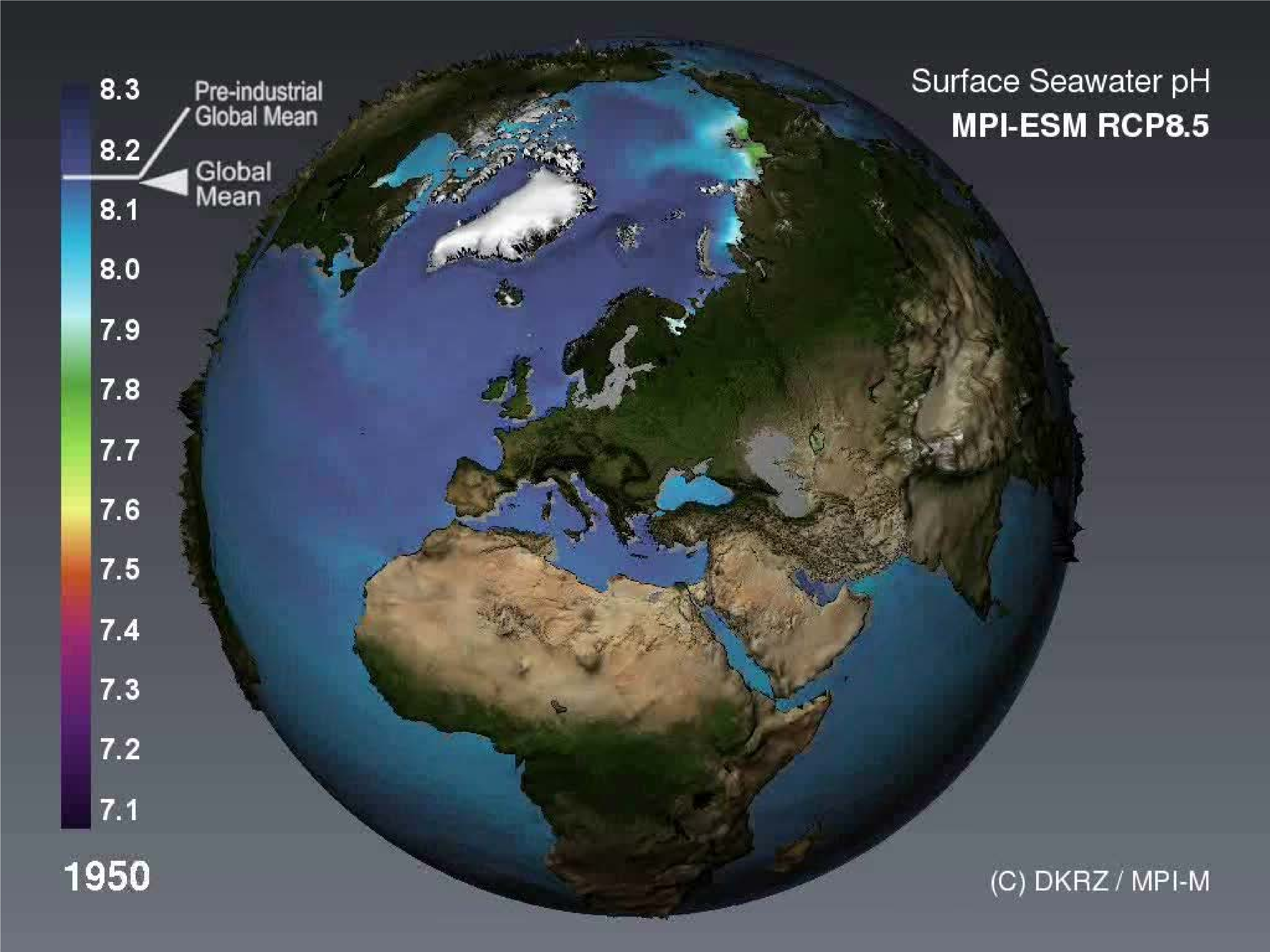


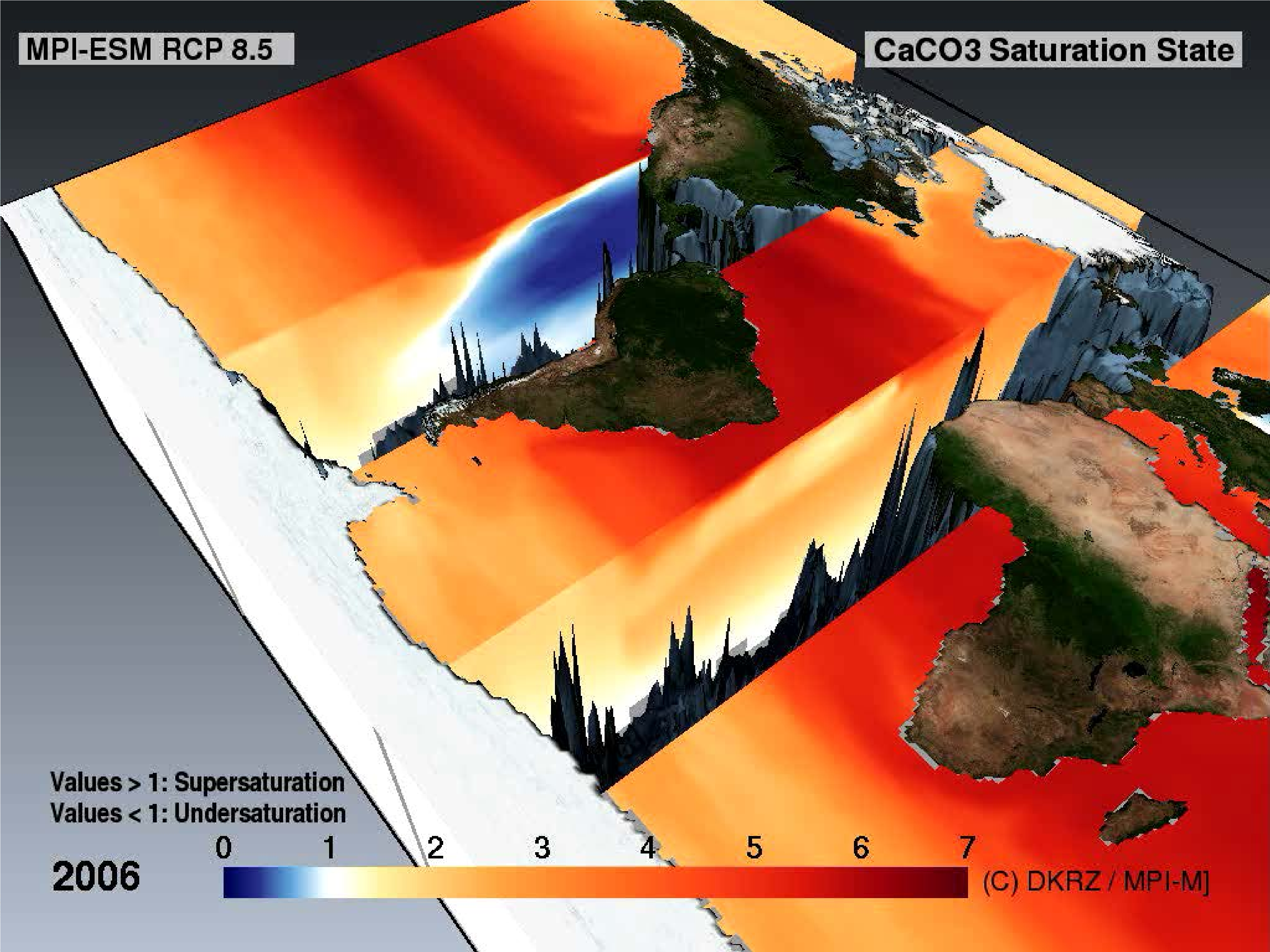

Color: Change in Precipitation in 2071-2100 relative to 1986-2005
Height: Simulated mean monthly Precipitation for 1986-2005
MPI-ESM LR / RCP8.5
Ensemble Mean
Jan
-100 -50 0 50 100 150 [%]
© DKRZ / MPI-M

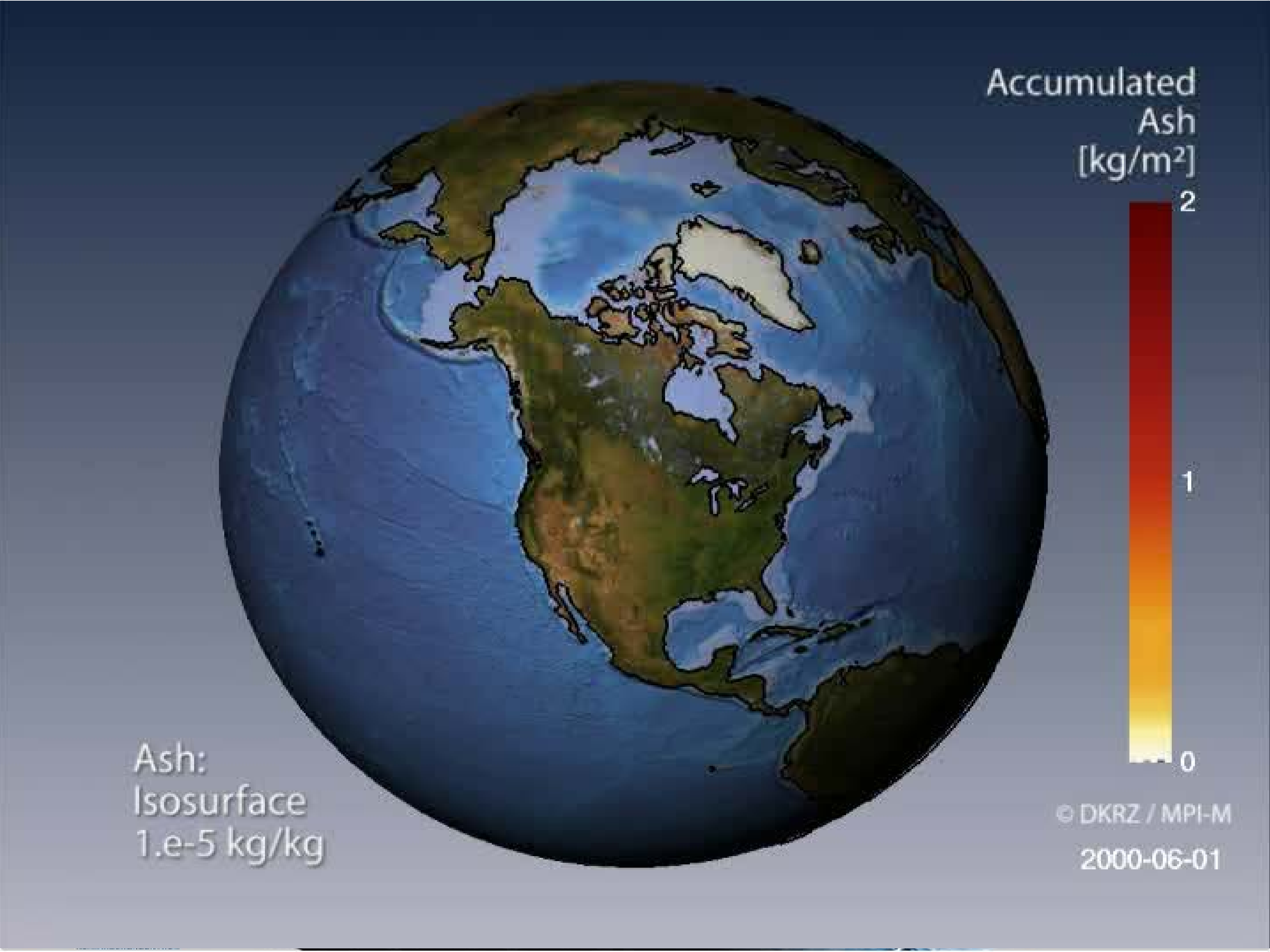

Sea Ice Concentration
September
March
1975
MPI-ESM LR
RCP 2.6
© DKRZ / MPI-M
RCP 8.5

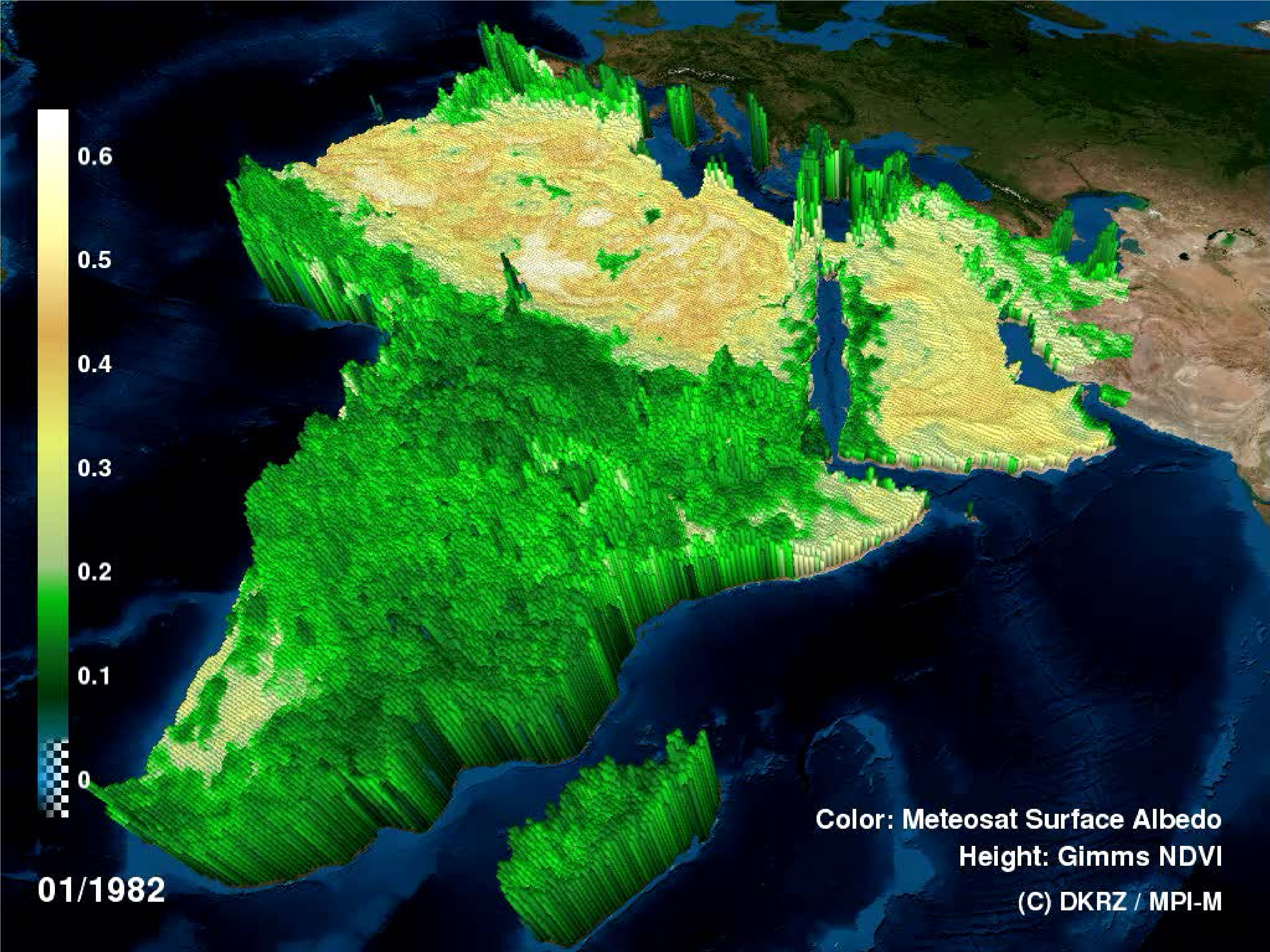

Sea Surface Height
MPI-OM (TP6M)
[m]
1.5
1.0
0.5
0
-0.5
-1.0
-1.5
-2.0
-2.5
(C) DKRZ / MPI-M / KlimaCampus


RCP 2.6
Projected Sea Level Change
MPI-ESM MR
RCP 8.5
1975
© DKRZ / MPI-M
-0.5
0.0
0.5
1.0
1.5
[m]


Surface Seawater pH
MPI-ESM RCP8.5
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
Pre-industrial
Global Mean
Global
Mean
1950
(C) DKRZ / MPI-M


MPI-ESM RCP 8.5
CaCO3 Saturation State
Values > 1: Supersaturation
Values < 1: Undersaturation
0 1 2 3 4 5 6 7
2006
(C) DKRZ / MPI-M]


Accumulated
Ash
[kg/m²]
2
1
0
Ash:
Isosurface
1.e-5 kg/kg
© DKRZ / MPI-M
2000-06-01

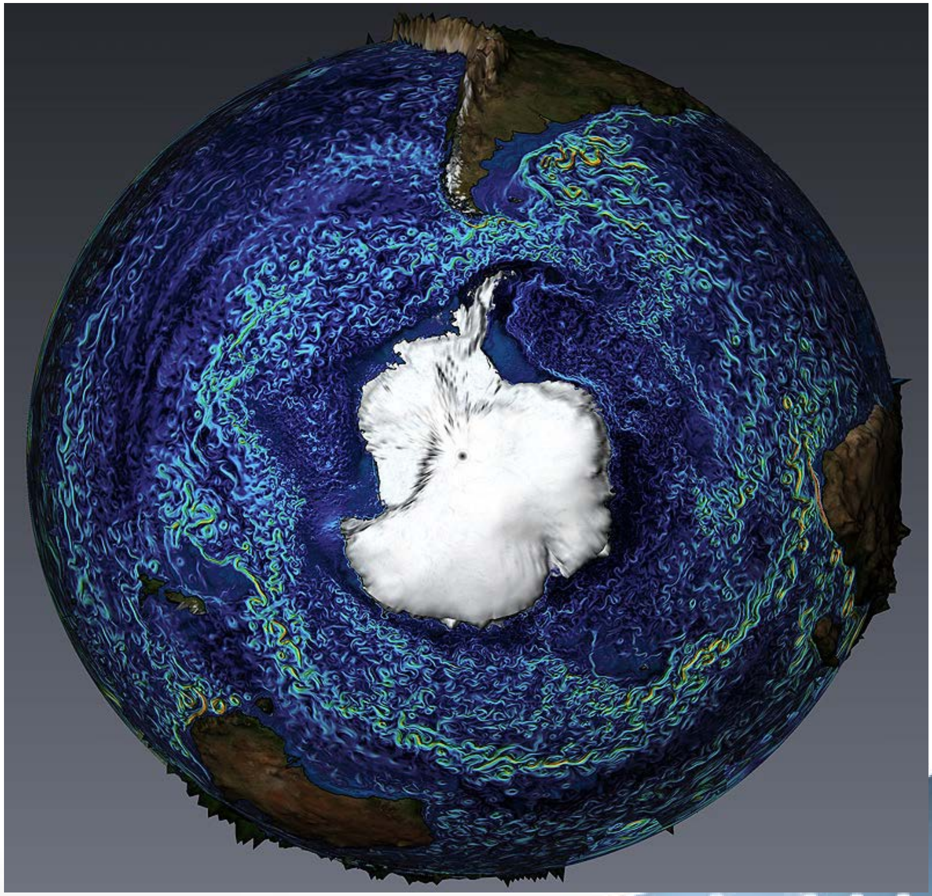

0.6
0.5
0.4
0.3
0.2
0.1
0
01/1982
Color: Meteosat Surface Albedo
Height: Gimms NDVI
(C) DKRZ / MPI-M

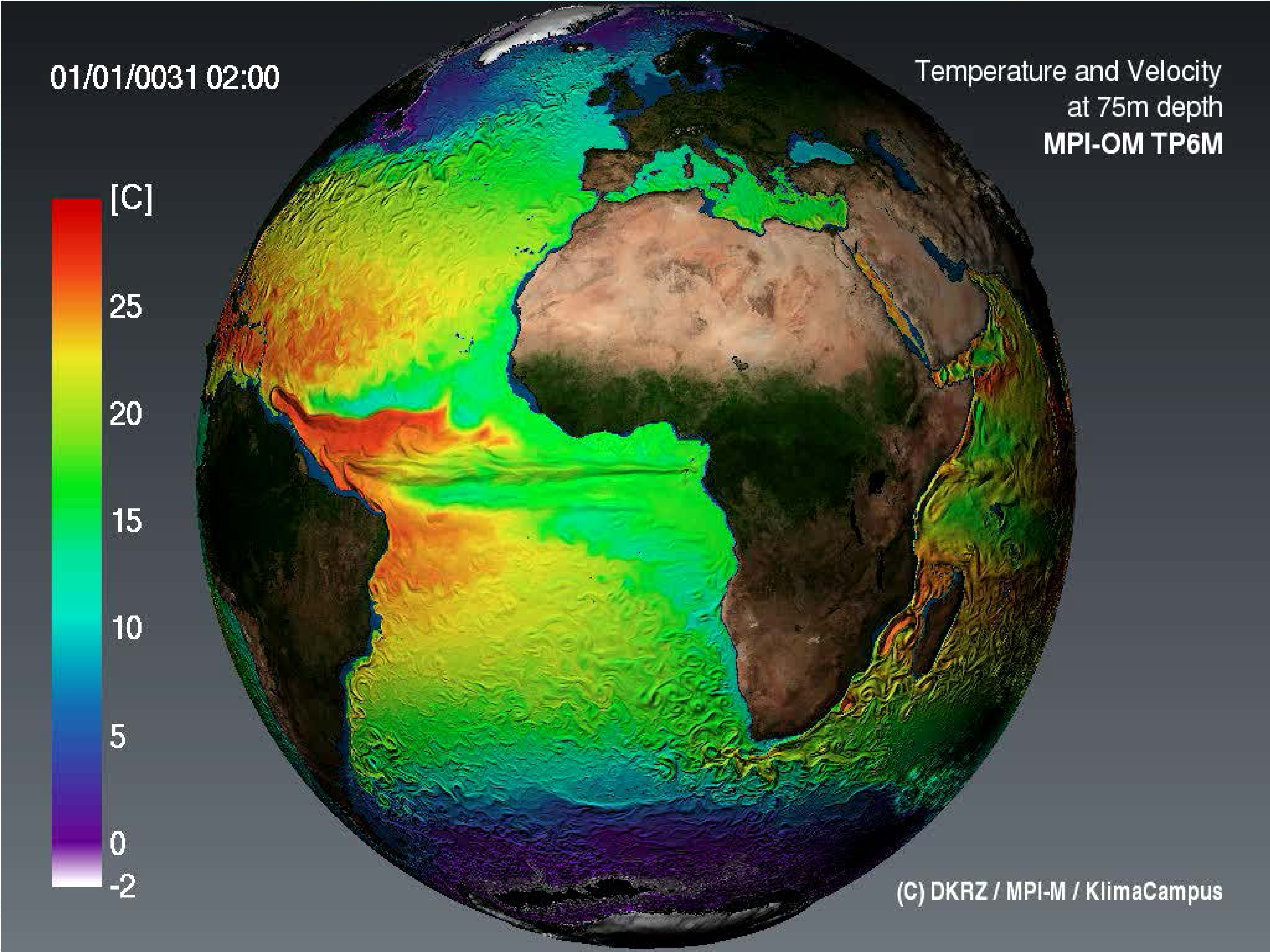
MITRAS - Wilhelmsburg BSU Building - Difference

Towards Exascale Models

STORM: development of a high resolution coupled climate model

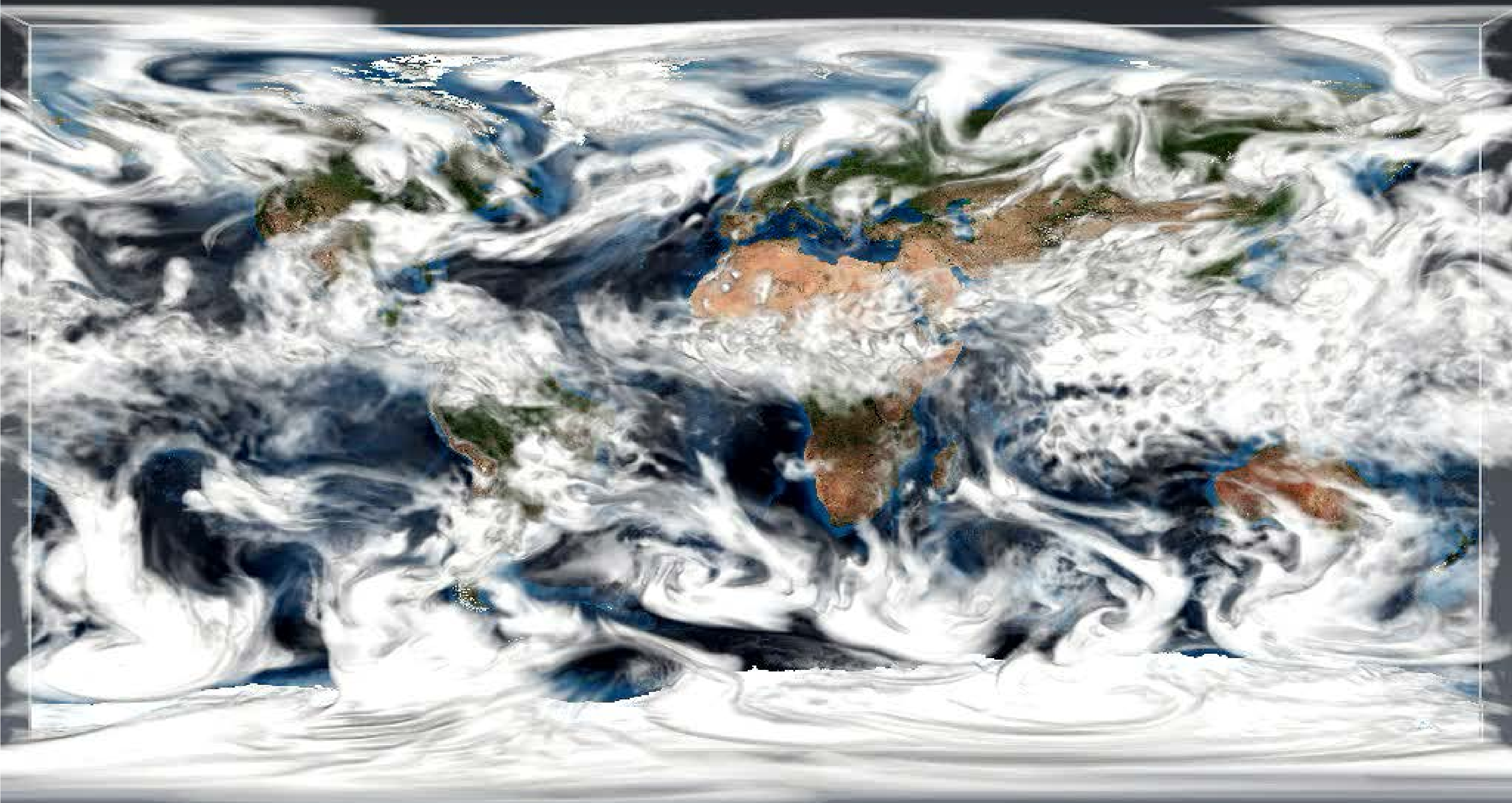
- Joint project: MPI-M, KlimaCampus, DKRZ
- Atmosphere: ca. 40 km, 768 x 384 x 95
- Ocean: ca. 10 km, 3600 x 2394 x 80
- High storage frequency: data storage expensive
- Vis-SW /HW not prepared for data size




01/01/0031 02:00
Temperature and Velocity
at 75m depth
MPI-OM TP6M
[C]
25
20
15
10
5
0
-2
(C) DKRZ / MPI-M / KlimaCampus

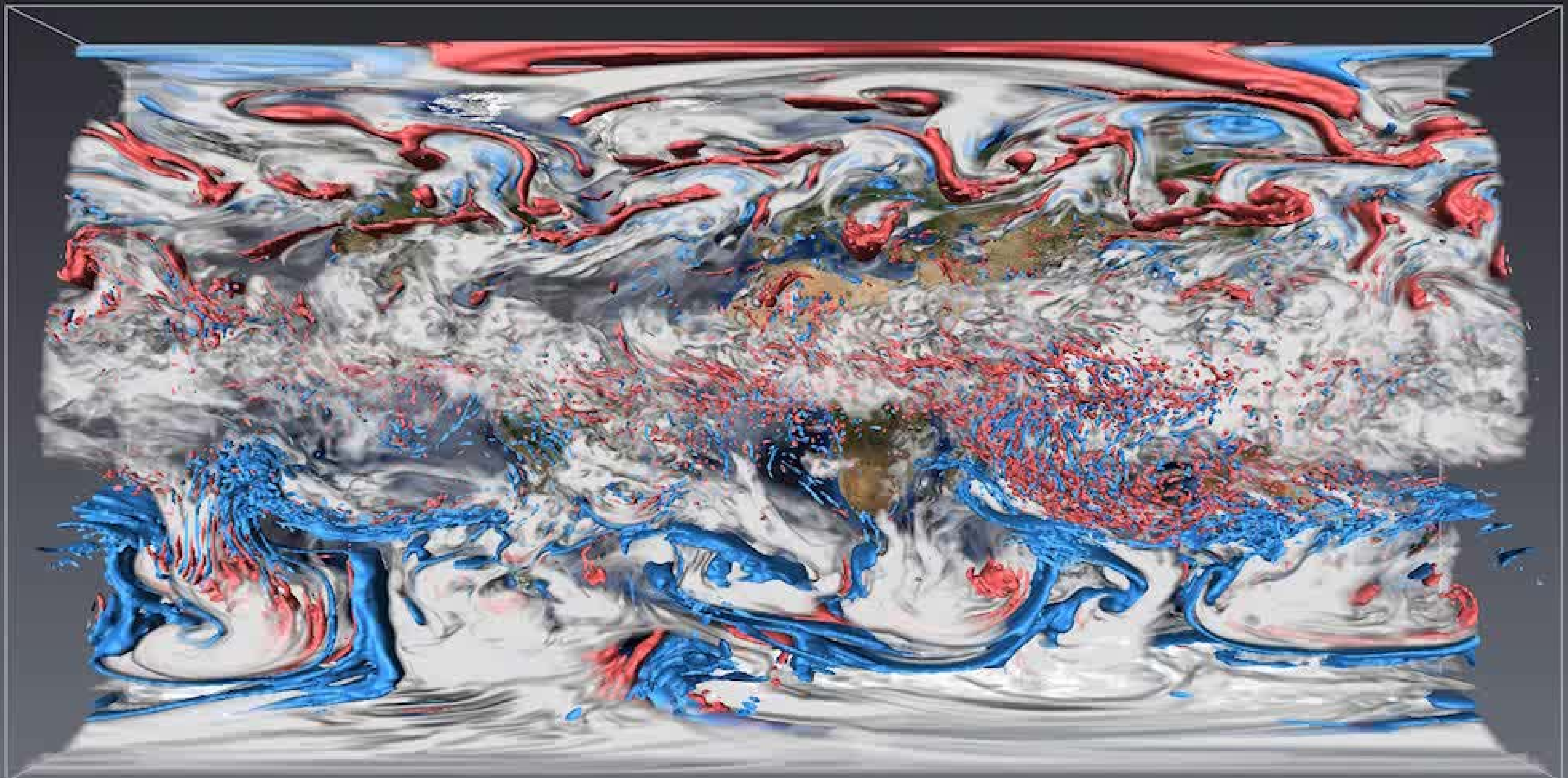
ECHAM6 T255

Relative Humidity

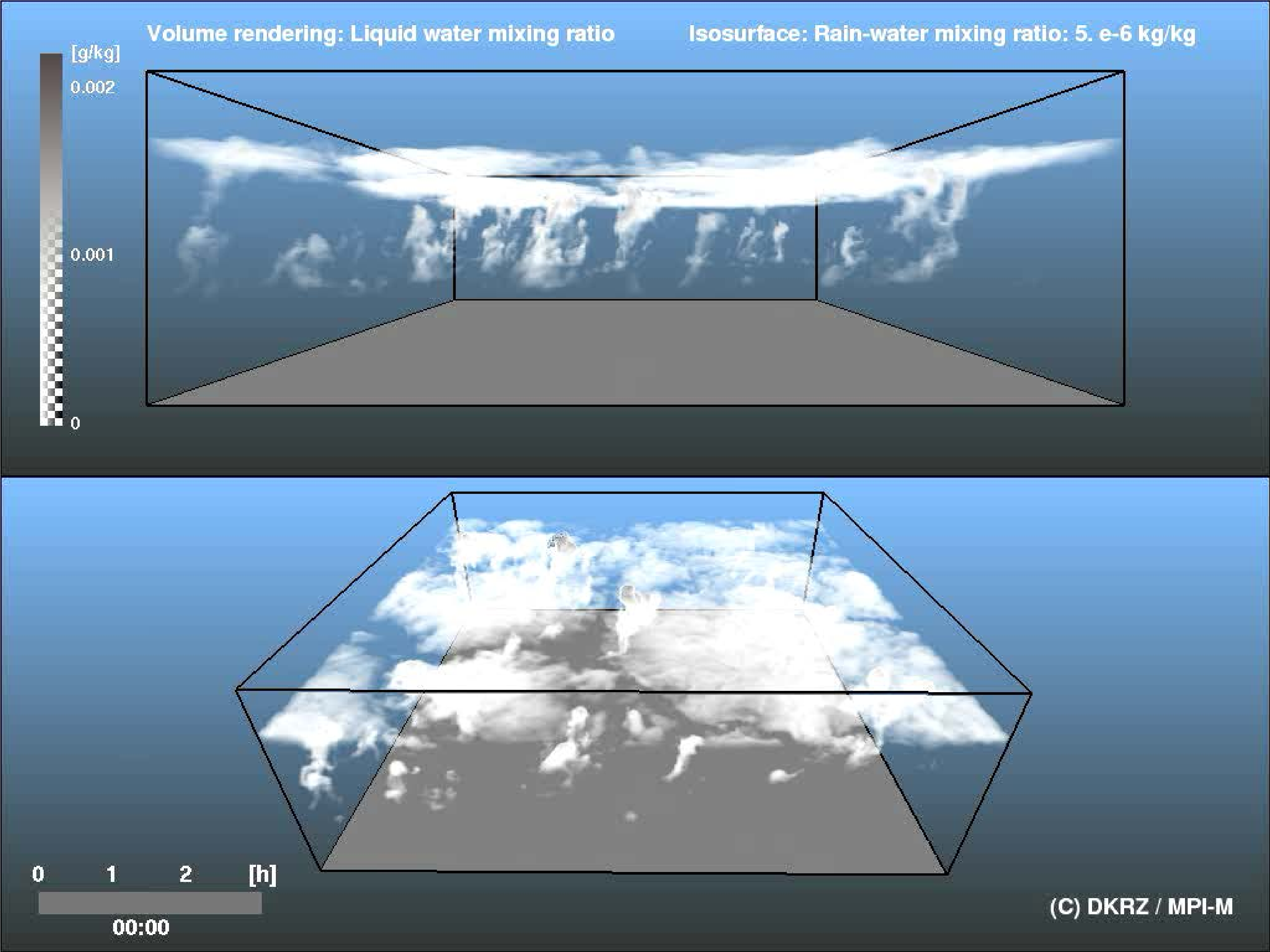


01/08/1985
00:00

ECHAM6 T255 Volume Rendering: Relative Humidity Vorticity Isosurfaces: Blue: -0.0001 , Red: 0.0001



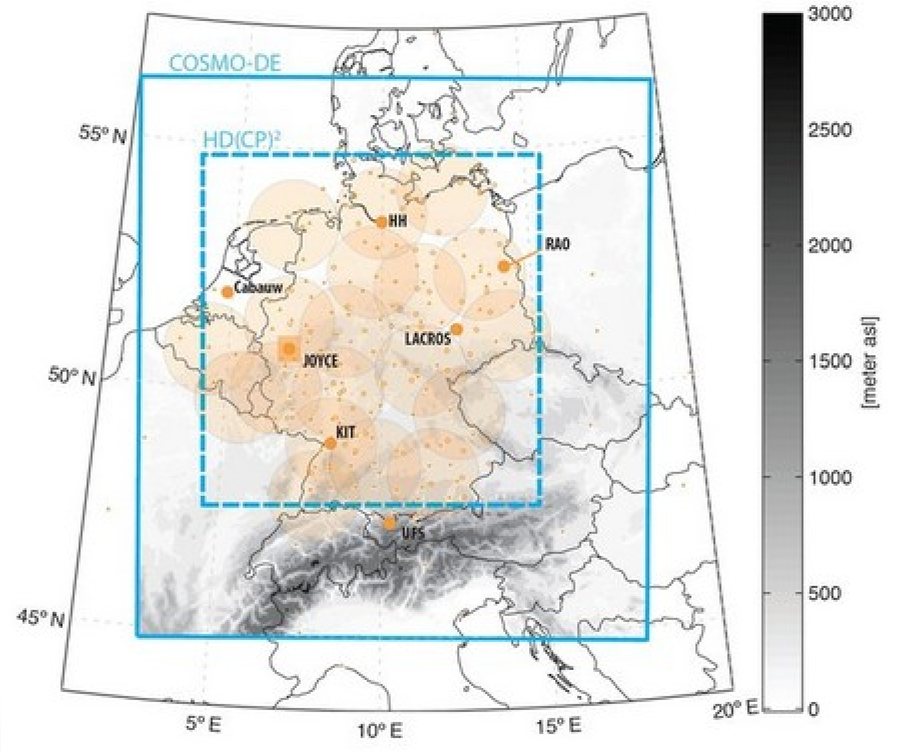
01/08/1985 00:00


Volume rendering: Liquid water mixing ratio
Isosurface: Rain-water mixing ratio: 5. e-6 kg/kg
[g/kg]
0.002
0.001
0
0
1
2
[h]
00:00
(C) DKRZ / MPI-M

Future Challenges

HD(CP)²

High definition clouds and precipitation
for advancing climate prediction



- BMBF funded project
- Cloud resolving model
- ICON-Grid (unstructured)
- Horizontal grid spacings of 100 m
- Vertically: e.g. 250 layers
- Domains of 1000 km x 1000 km

http://hdcp2.zmaw.de/

Summary and Outlook

- Visualization of Climate Model Data (with Avizo)
  - Data interface supports native model data formats
  - Many domain specific requirements met (mapping, map projections, geographical context, time dependence)
  - New: irregular grids via NetCDF
  - Extendability (DKRZ: source code agreement with VSG)
- Challenges: towards Exascale Vis
  - High spatial resolution
  - -> for visualization high *temporal* resolution required
  - -> High cost of data output/storage/access
  - Scalability of Data transfer / access / processing
  - Scalability of Visualization Software
  - Paradigm change?

Questions?

boettinger@dkrz.de

http://www.dkrz.de

DKRZ
DEUTSCHES
KLIMARECHENZENTRUM

Many of the animations shown can be found here:
http://www.dkrz.de/Klimaforschung-en/konsortial-en/ipcc-ar5/ergebnisse
or here:
http://www.dkrz.de/about-en/media/galerie/Vis