



# Visualisierung in der Klimaforschung

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Michael Böttinger, DKRZ

# Datenvisualisierung – Anwendungen

Visualisierung als **Analyse-Werkzeug**  
("Interaktive visuelle Datenanalyse")

- ▶ Explorieren (unbekannter) Daten
- ▶ Qualitative Analyse

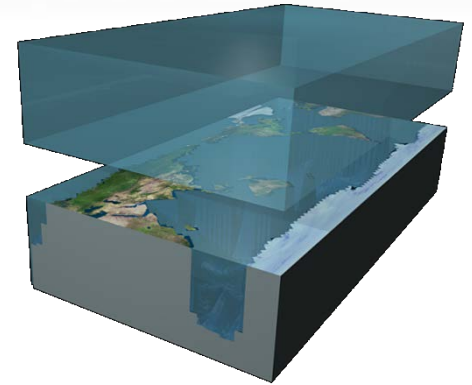
Visualisierung für **Präsentationen**

- ▶ Visualisierung schon bekannter Vorgänge
- ▶ Medien für Kommunikationszwecke

# Visualisierung – Status Quo

- Daten

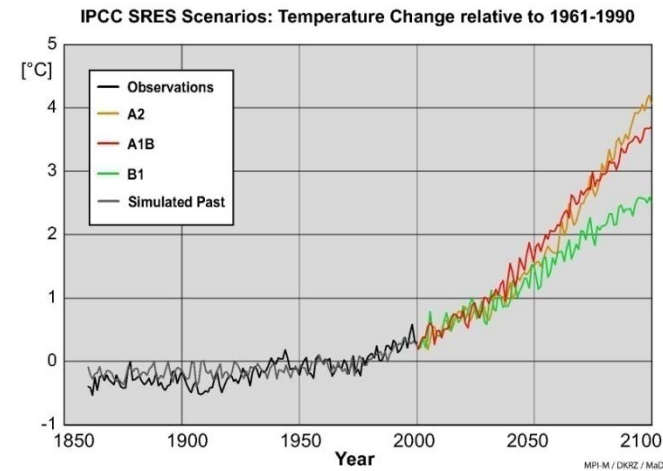
- zunehmend groß
- 3D + zeitabhängig + multivariat (+ Ensembles)



- Visualisierung (üblich)

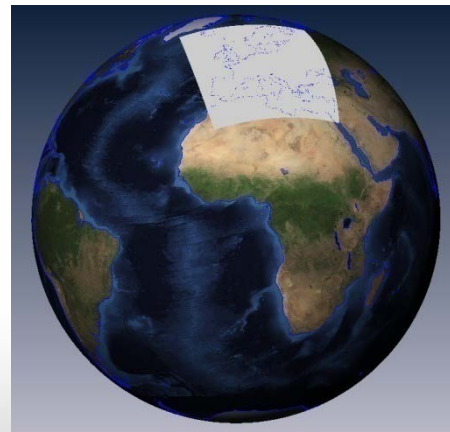
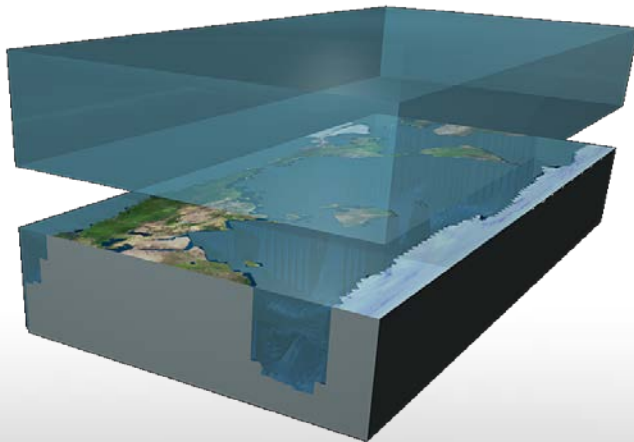
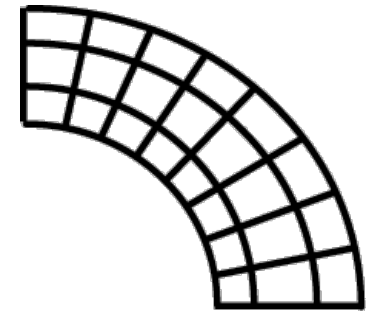
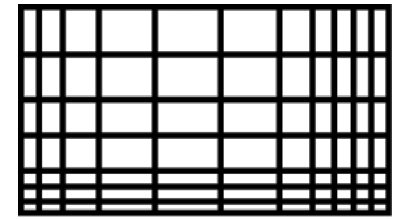
- 1D oder 2D-Methoden
- Batch oder Script basiert
- lokale Workstation oder über X11
- -> angemessen für viele Fragestellungen

- Interaktive 3D Visualisierung



# Klimadaten

- Georeferenzierte Daten -> Mapping
- Relativ grobe 3D Gitter, auch 2D
- Gitter: rektilinear, kurvilinear, rotatiert, irregulär ...
- Multivariate / Skalar- und Vektorfelder
- "Special values"
- Zeitachse: lang ...
- Gekoppelte Modelle: unterschiedliche Gitter
- Multi-Run-Experimente (Ensembles)

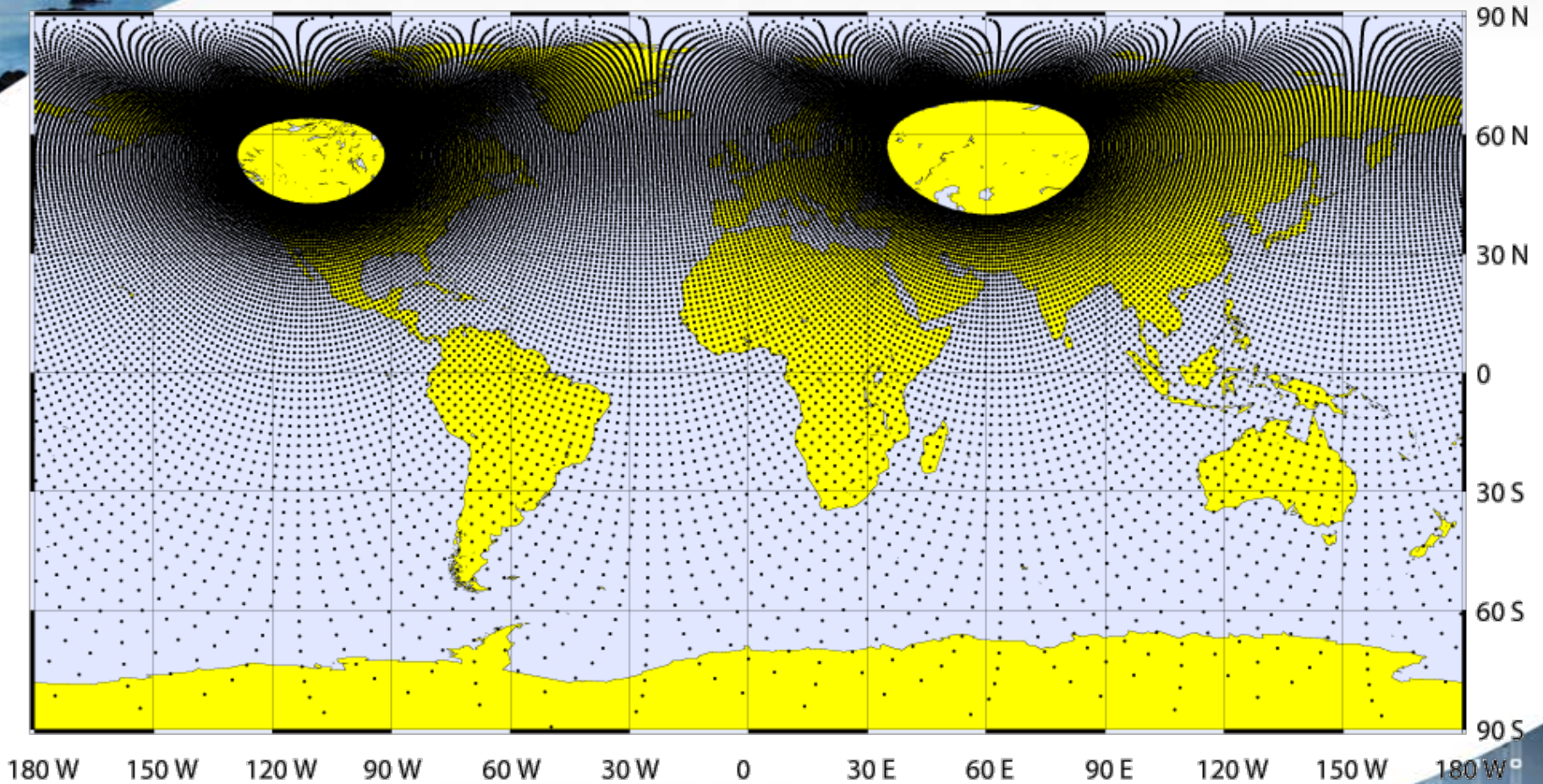


# Datenstrukturen und Formate

- ▶ Formate: GRIB, netCDF, IEEE binary
  - *Konventionen* für Metadaten (z.B. NetCDF/CF-1.0)
  - (NetCDF3 → NetCDF4/HDF )
- ▶ Andere spezifische Eigenschaften
  - Geographisches Mapping
  - *Special Values* (Ausmaskieren von Gitterelementen ohne gültige Werte)



# Modellgitter

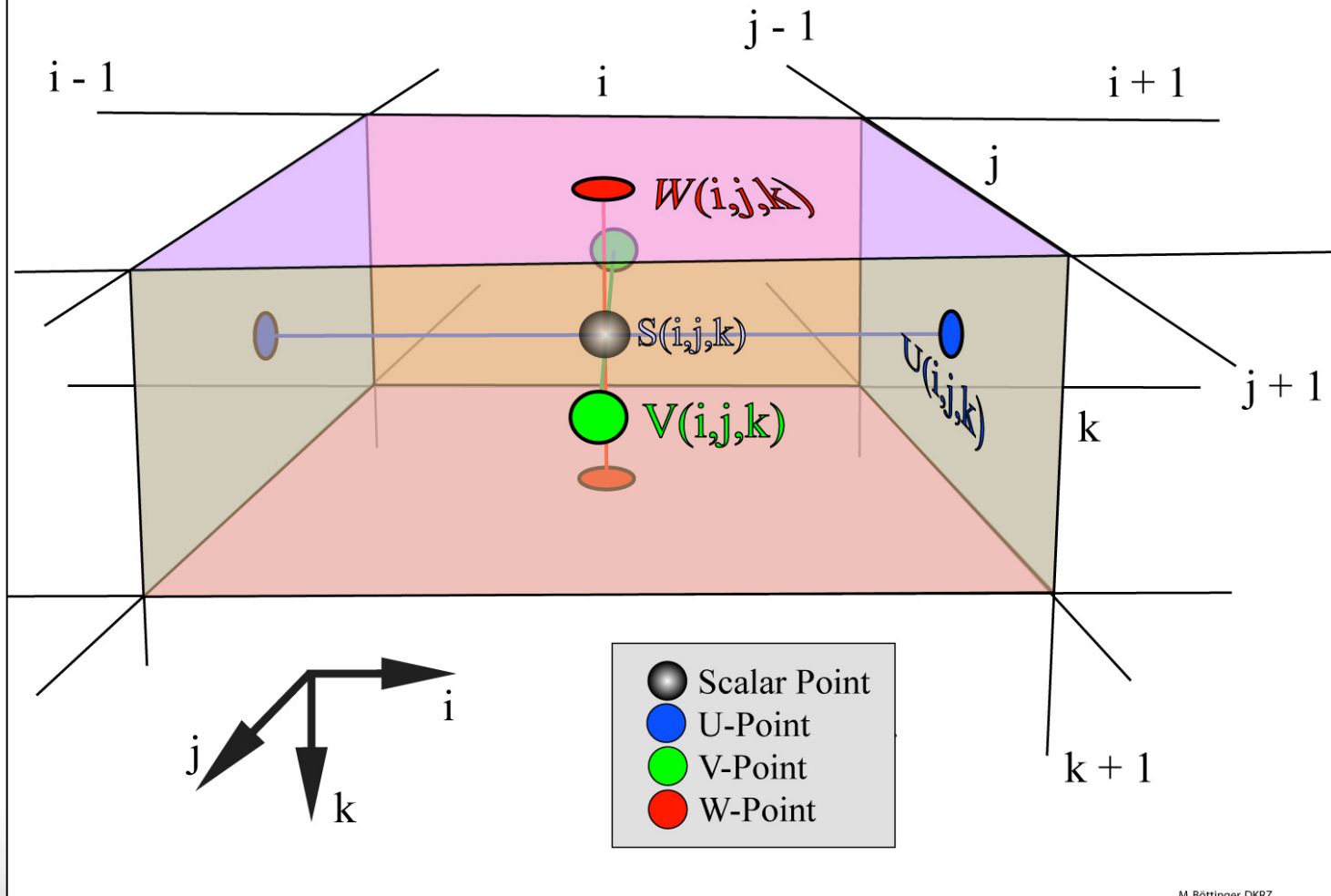


Beispiel: krummliniges 302x132 Gitter des HOPE-C Ozeanmodelles.

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# Krummlinige Modellgitter

## MPI-OM - Grid-Definition for Scalar and Vector Quantities

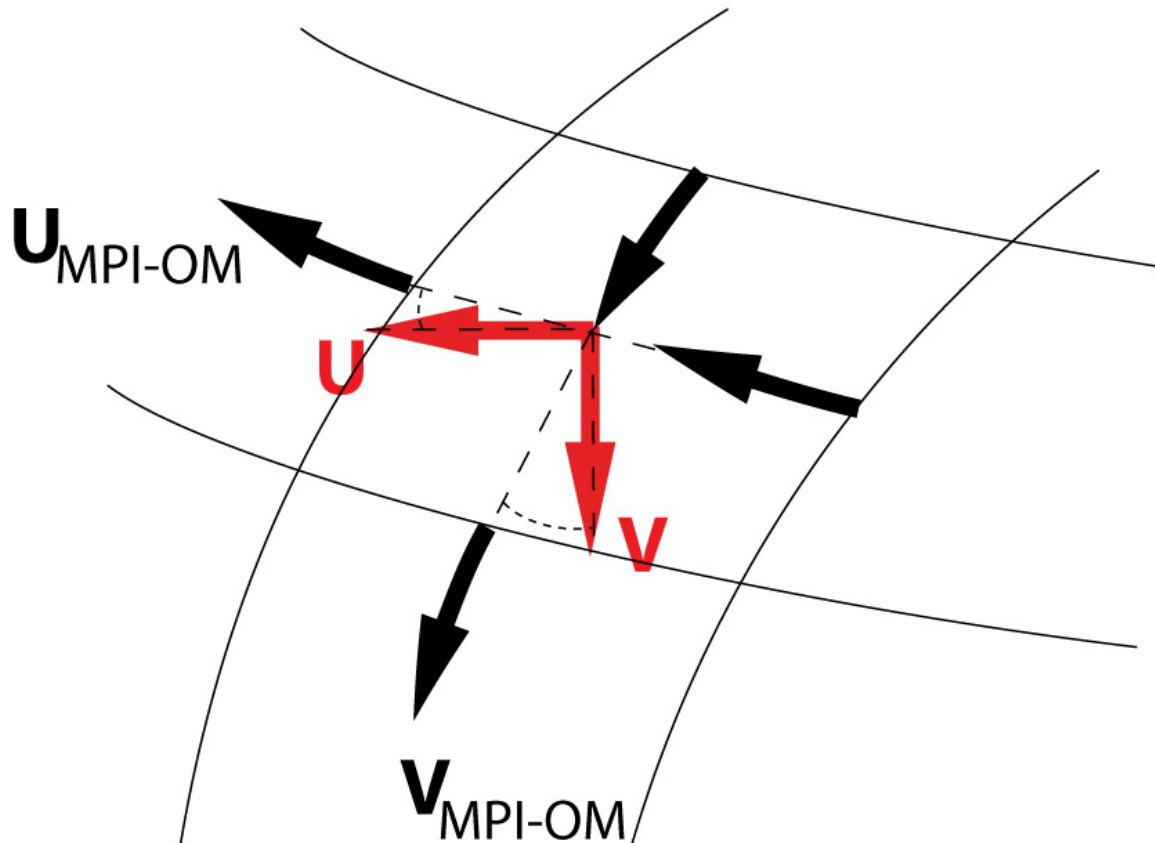


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# Krummlinige Modellgitter

## Rotation and Interpolation of horizontal Velocity Vectors



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# Datenproduktion am DKRZ

6 PByte  
GPFS



Festplatten

158 TFlops  
20 TByte Mem.



Supercomputer

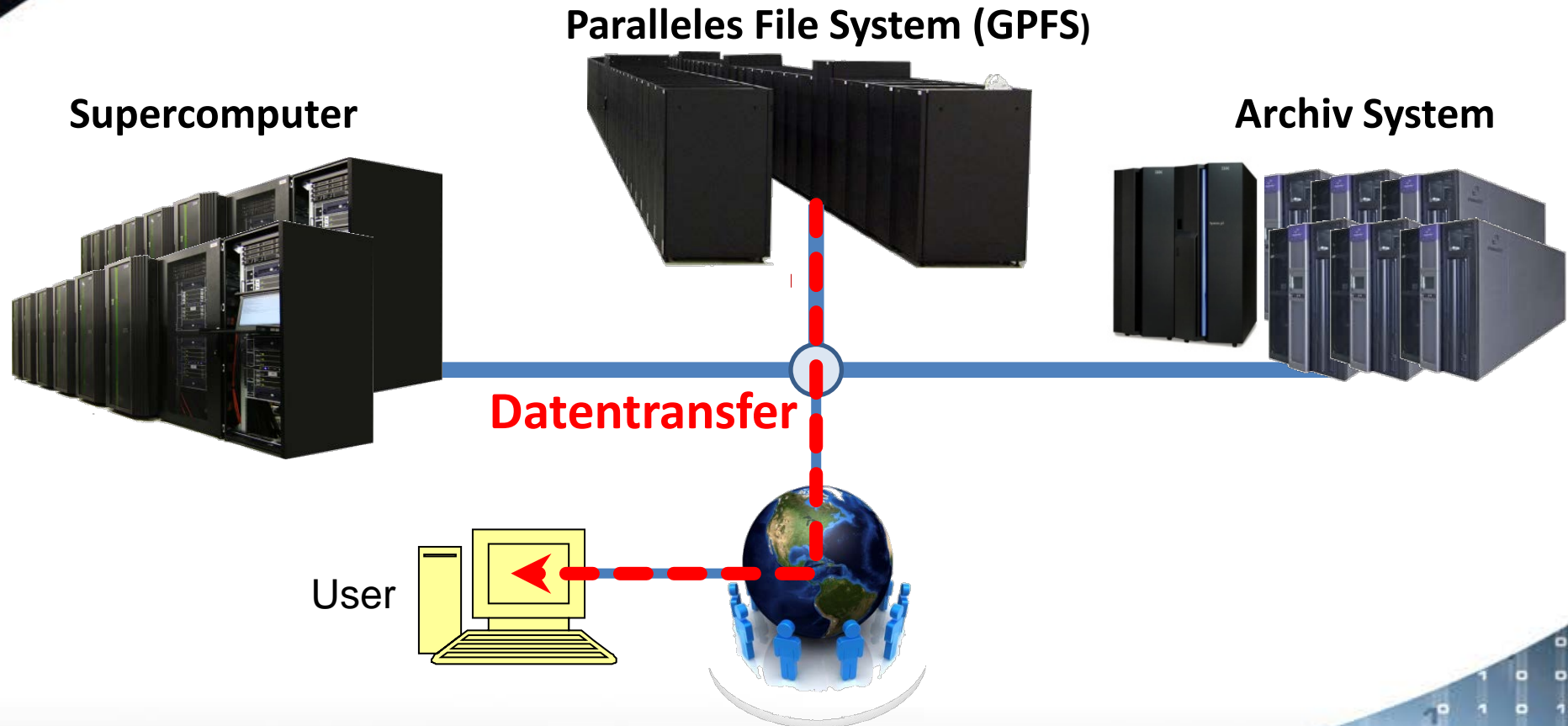
7 Silos  
70 Laufwerke  
100 PByte



Archivsystem

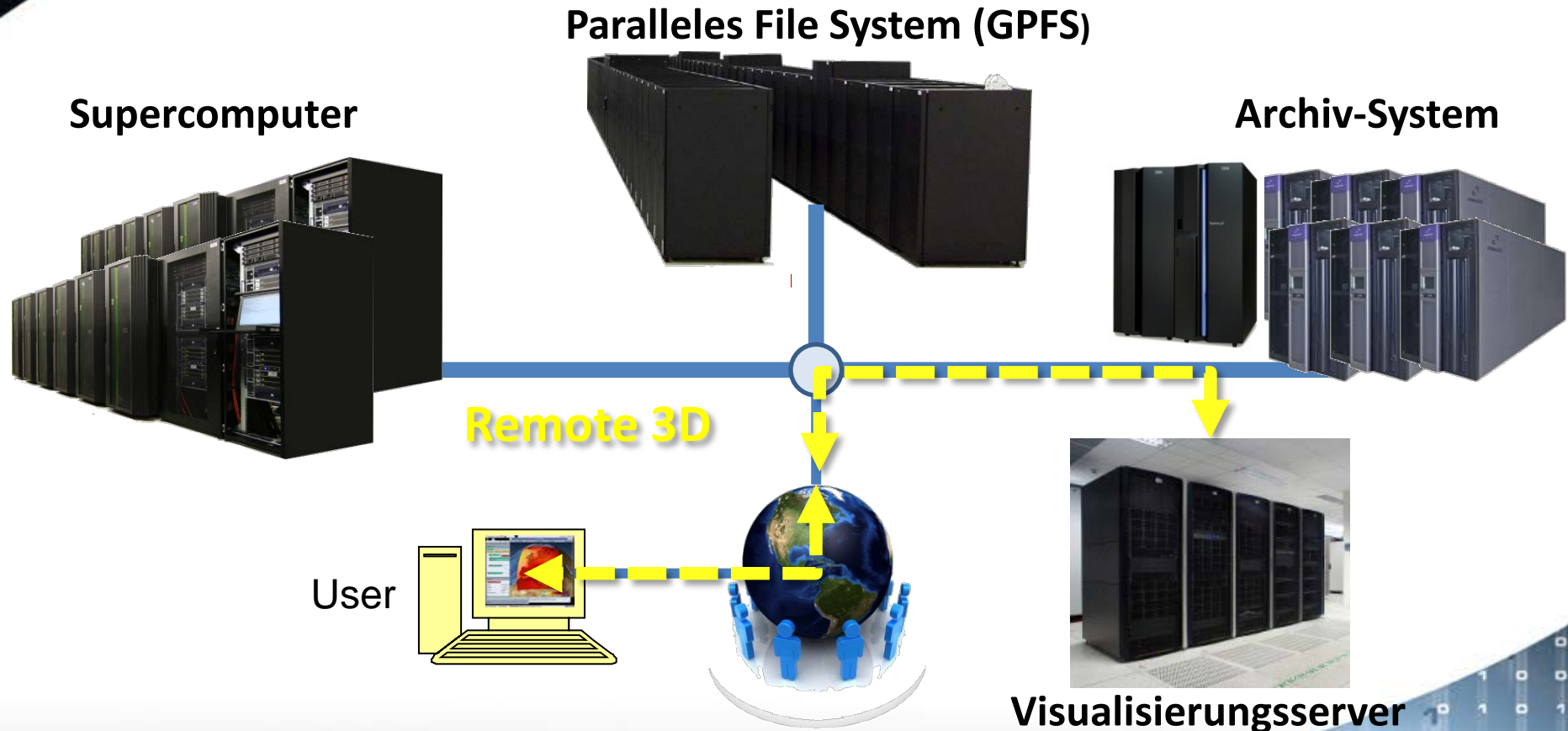
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# Visualisierung in einer HPC Umgebung



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# Visualisierung in einer HPC Umgebung



Michael Böttinger & Niklas Röber,  
DKRZ



# Visualisierungs-Server

## ▶ 9 Knoten

HP, Transtec, Dell

- 2 CPUs, 2 – 8 Core
- 32 GB – 256 GB Main Memory
- Nvidia GPUs: Quadro K5000  
Quadro 6000, Quadro 5000,  
Tesla M2070Q

## • 10 GE Netzwerk

## • Remote 3 D-Rendering: TurboVNC/VirtualGL



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# Remote-3D-Rendering

## Lokaler Computer:

- Keyboard / Mouse
- Display
- Remote 3D Client



Uncompress Image  
Display Image

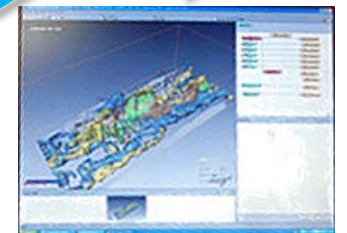
Software:  
Turbo VNC / VirtualGL

## Visualisierungsserver:

- 3-D-Software (OpenGL)
- Remote 3D-Server
- Data



Keyboard / Mouse



Capture Keyboard / Mouse

Internet

Capture Framebuffer  
Compress Image  
Send Image to Client

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# Lokale Nutzung: Stereo + VR

## Barco „VR-Workroom“

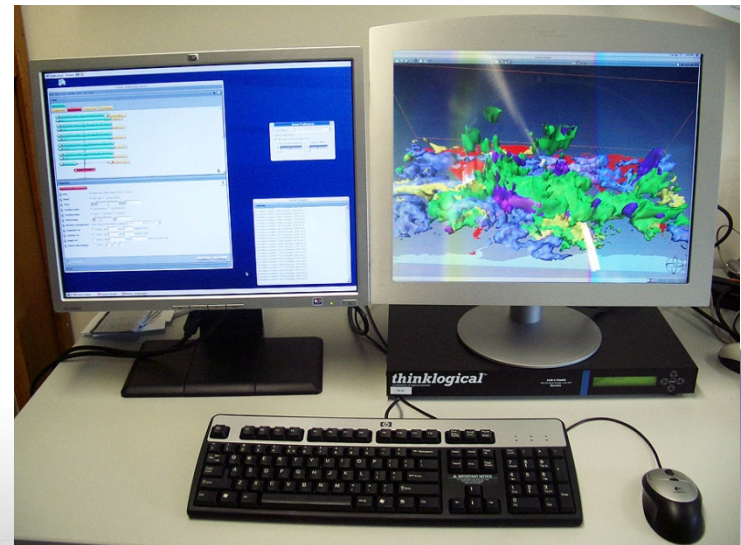
- ▶ 2,90 x 1,63 (16:9)
- ▶ Passives Stereo (Zirkular)
- ▶ 2 Barco ICON H600 (1920x1080, jew. bis 6000 Lumen)
- ▶ ARTtrack 2 optical IR Tracking

## SeeReal CN20 Autostereo Displays

- ▶ Vertical Interlacing
- ▶ Setup: Cinerama Desktop  
2 Displays mit 20", 1600x1200

## Thinklogical DVI/USB Vernetzung

- ▶ Transmitter/Receiver/Martrix
- ▶ LWL



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# Visualisierung: Domänenspezifische Software

Systems



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# Visualisierungssoftware

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



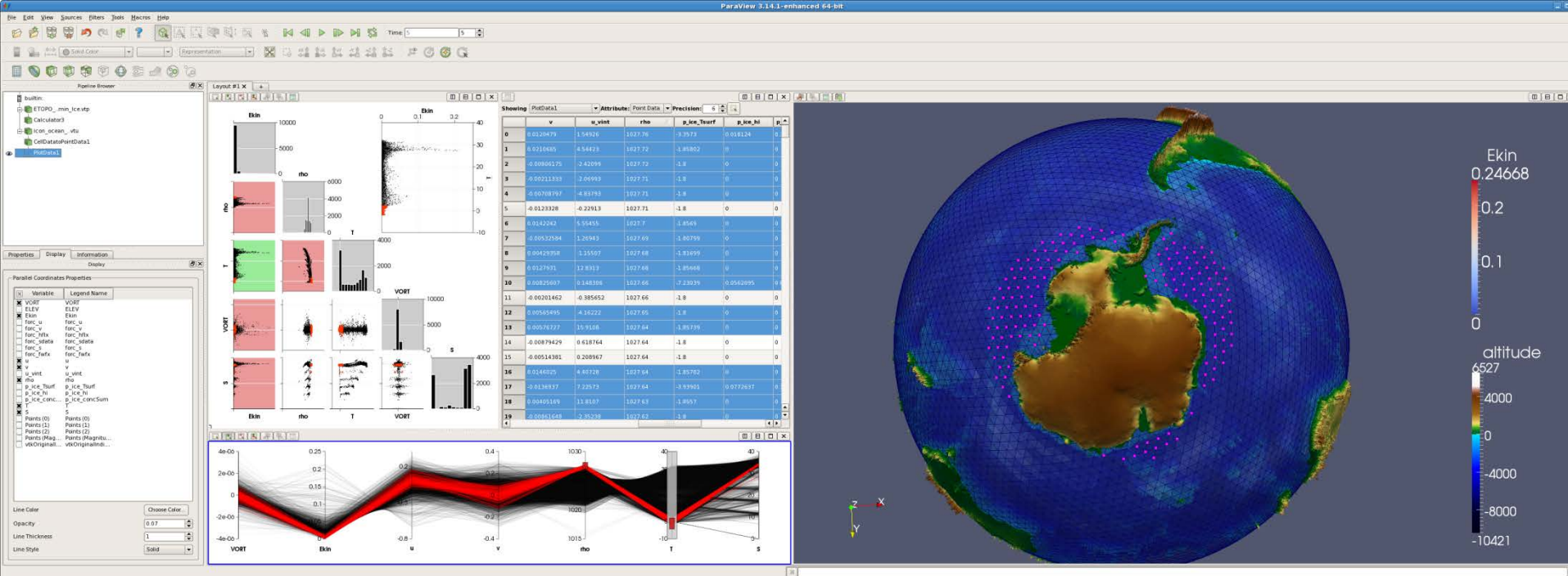
# SimVis

The screenshot displays the SimVis software interface with several panels:

- SimVis: Tree View:** Shows dataset details for 'mblas\_structuredE11', including filename, timesteps, active parts, time channels, cells, and vertices.
- SimVis: 3D View (Left):** A 3D visualization of a building structure with a color scale for 'Painted based' ranging from 1.000 to 3.000.
- SimVis: 3D View (Right):** A 3D visualization of a building structure with a color scale for 'Painted based' ranging from 0.600 to 1.000.
- SimVis: Properties:** A panel for 'Active Rendering Mode' with options for 'Standard Utility Render', 'Painted Render', and 'Structured Grid Render'.
- Color Settings:** A panel for 'Variable: Magnitude' with a 'Selection: Featuredescription 1' dropdown. It includes a 'Transfer Function' section with a 'Green/Red' color map and a 'Transfer Function Scaling' section with 'global', 'selection only', and 'custom' options.
- Advanced Settings:** A panel for 'Focus Opacity' (0.78434), 'Context Opacity' (0), 'Point Size' (250), and 'Point Density' (5). It also includes 'Spikes' and 'Visualize Flow Direction using Arrows' options.
- SimVis: Scatterplot:** A scatterplot showing 'building\_mask' on the X-axis and 'temp' on the Y-axis. The plot shows a dense distribution of points, with a red rectangular region highlighted.
- SimVis: Derived Data View:** A panel for 'SimVis: Derived Data View' showing a list of variables and a 'Calculate Data' button.

Linking & brushing:  
Analyse von multivariaten Eigenschaften

# Paraview 4



Soon: Tutorial on Paraview

<http://www.dkrz.de/Nutzerportal-en/doku/halo/sw/paraview>

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# 3D Visualization Software: Avizo Green

The screenshot displays the Avizo Green Edition software interface. The main window is titled "Avizo - Green Edition - VolRen\_T255\_proj\_sphere.hx". The menu bar includes File, Edit, Project, Create, View, Window, XPand, XScreen, XTeam, and Help. The toolbar contains icons for Open Data, Save Data, New Project, Open Project, Save Project, Preferences, Graph View, Tree View, Hide Panels, and Main Panel. The Project View panel on the left shows a hierarchical tree structure with nodes such as T255\_test.nc, rhumidity\*, NetCDF-Control, Movie Maker, Display Date, Caption, Earth, Projection, Volume Rendering Settings, Volume Rendering, and volrenWhite\_RHUM1.icol. The Properties panel at the bottom left shows settings for the selected "Display Date" node, including Position (x: 30, y: 30), Colors (text, foreground, background), and Font (Tw Cen MT Condensed (24 pt.)). The Main Panel on the right displays a 3D visualization of the Earth with a white, cloud-like structure over the North Pole. The text "ECHAM6" is visible in the top left of the visualization area, and "01/10/1979" is displayed at the bottom left. The copyright notice "(C) DKRZ / MPI-M" is visible at the bottom right. The status bar at the bottom shows "Ready" and a "Stop" button.

# Avizo Green

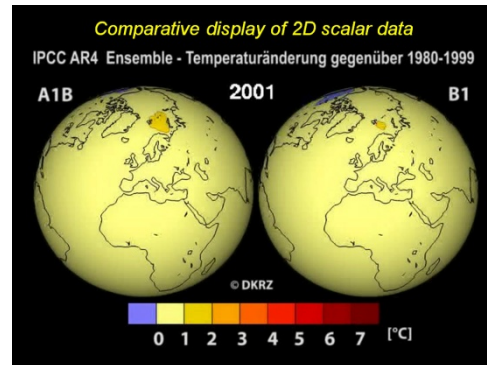
## Domänenspezifische Features in *Avizo*

- ▶ **NetCDF CF-1.0 Reader**
  - Unterstützt reguläre, rektilineare, rotierte und gekrümmte Gitter
  - Unterstützung "großer" Datensätze: Streaming für zeitabhängige Daten
  - Hauptspeicher-Caching
- ▶ **Geographische Projektionen**
  - Zylindrisch Äquidistant, Spherisch, Mollweide u.v.a.m.
- ▶ **„Earth“ Modul**
  - Texturen, 3 Detaillierungsgrade
  - Topographie / Bathymetrie
  - Kontinente und politische Grenzen

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# Anwendungsbeispiele



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# Rechnungen für CMIP5 / IPCC AR5

- ▶ Simulationen 2010/2011
- ▶ Erdsystem: Landbiosphäre, Ozean-Biogeochemie
- ▶ Rechenaufwand Faktor 60 gegenüber IPCC AR4
- ▶ 13 000 simulierte Modelljahre
- ▶ Ergebnisse: 650 TeraByte -> 60 Terabyte ESG



Max-Planck-Institut  
für Meteorologie

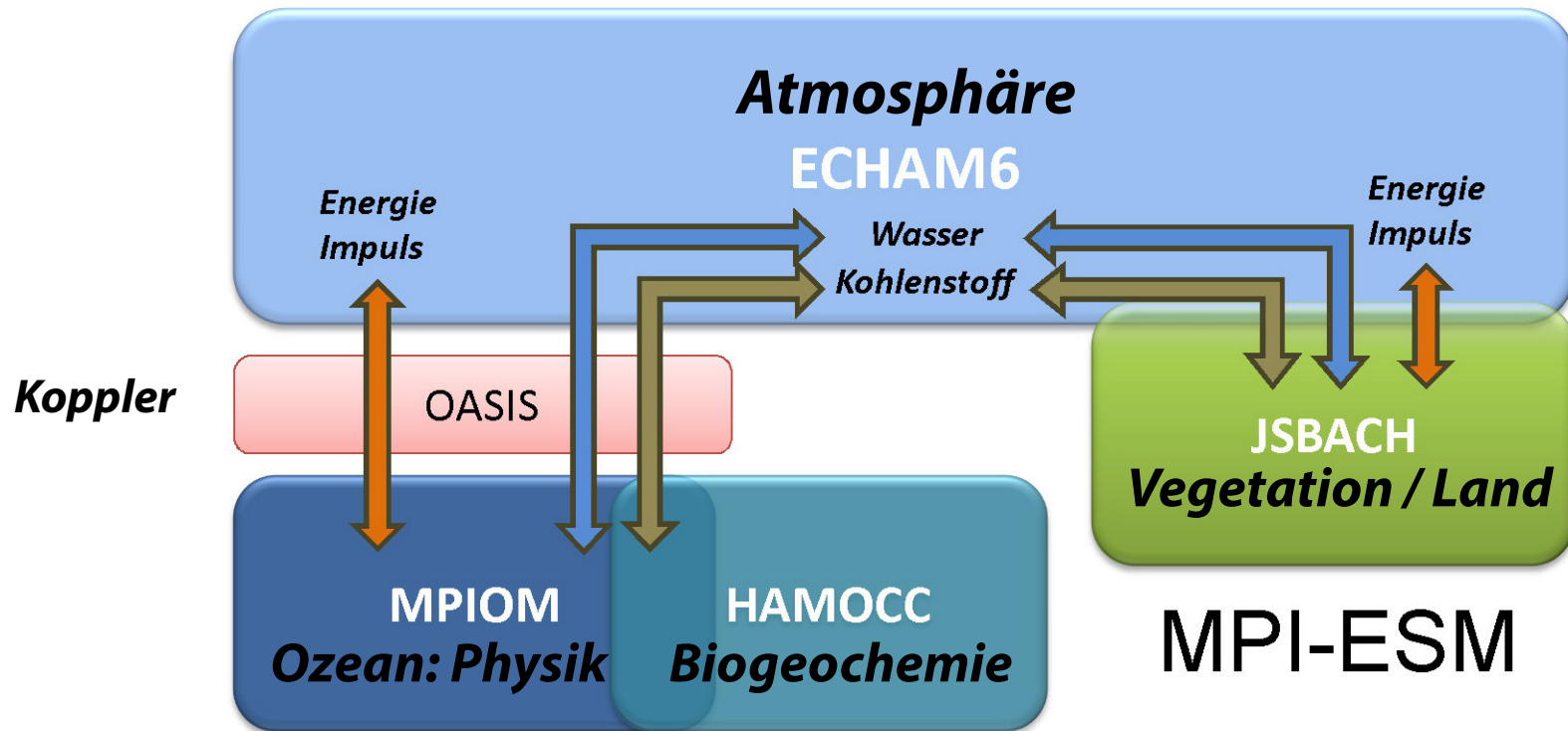


**DKRZ**

DEUTSCHES  
KLIMARECHENZENTRUM

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# Erdsystem-Modell



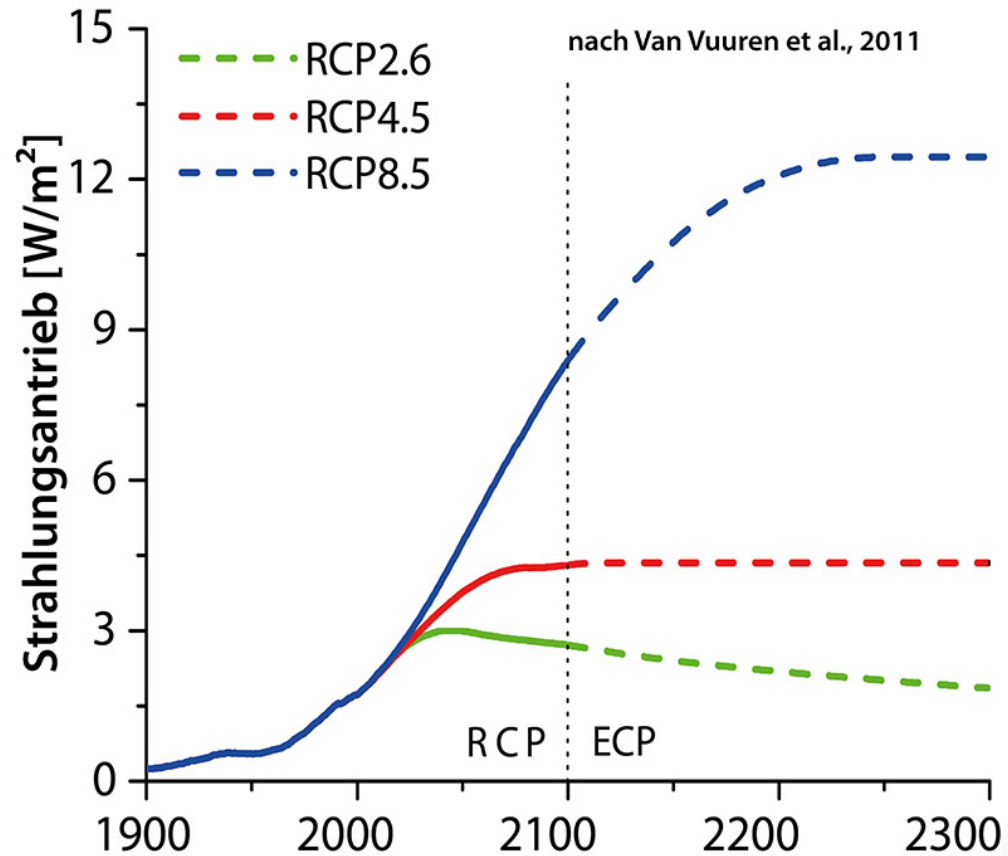
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# IPCC-AR5 Rechnungen

## Einführung: RCP-Szenarien

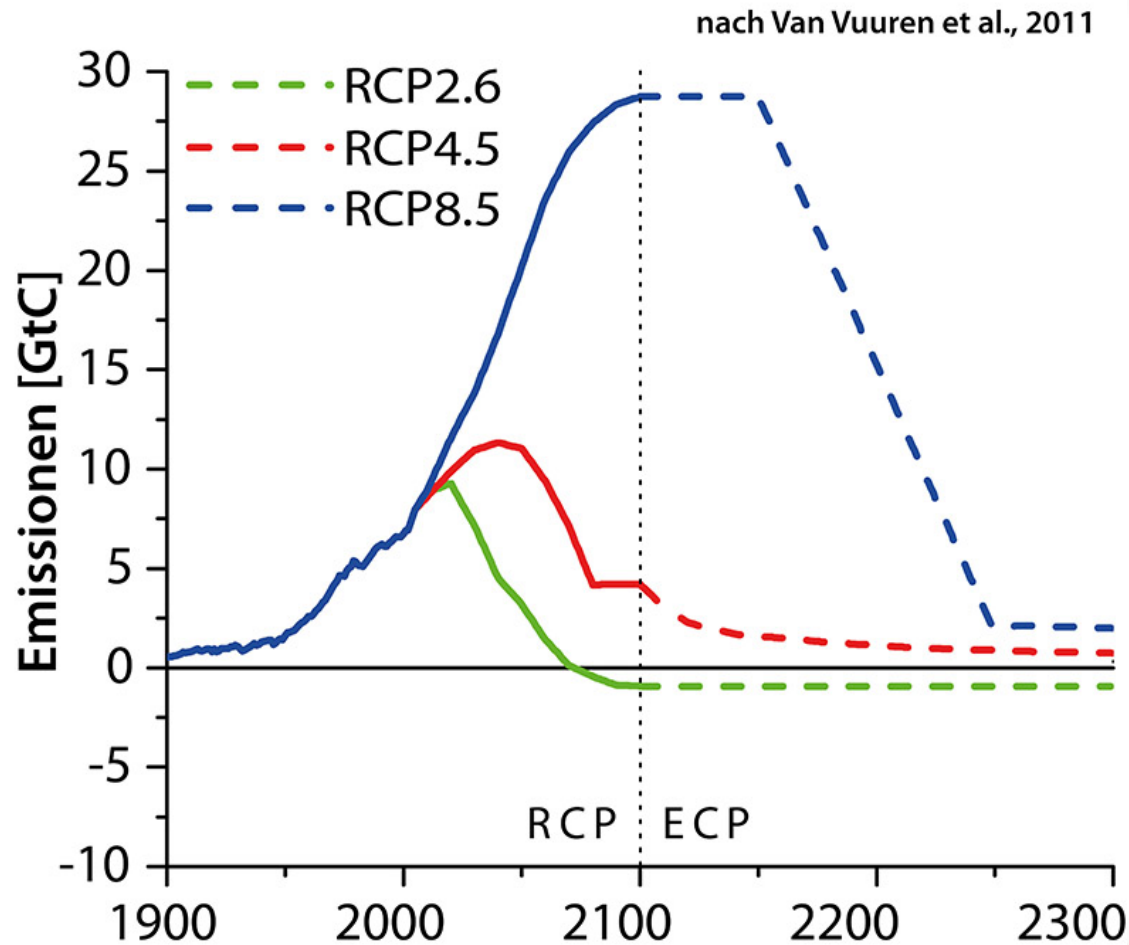
RCP = Representative Concentration Pathways



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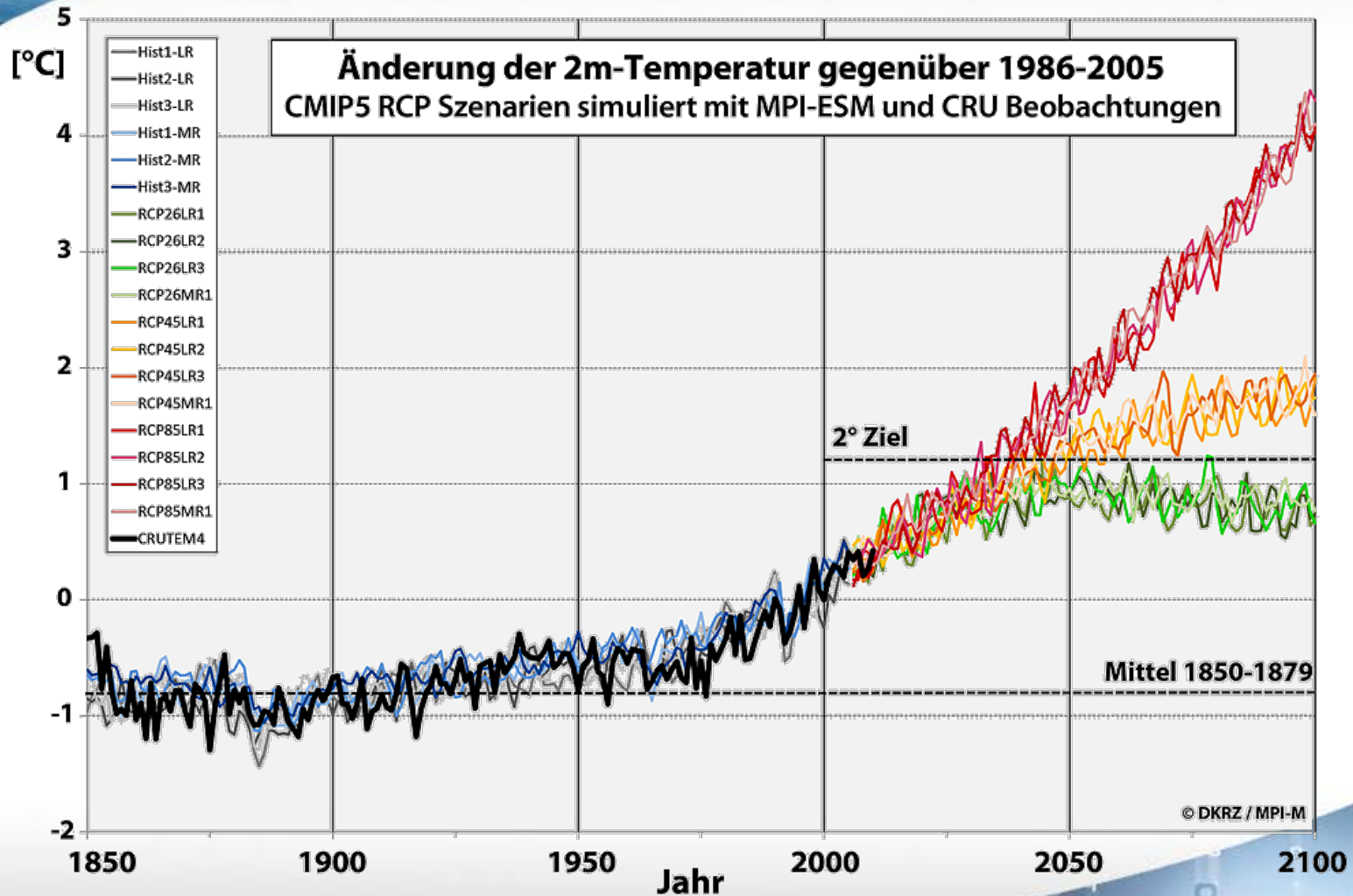
# IPCC-AR5 Rechnungen

## Einführung: RCP-Szenarien



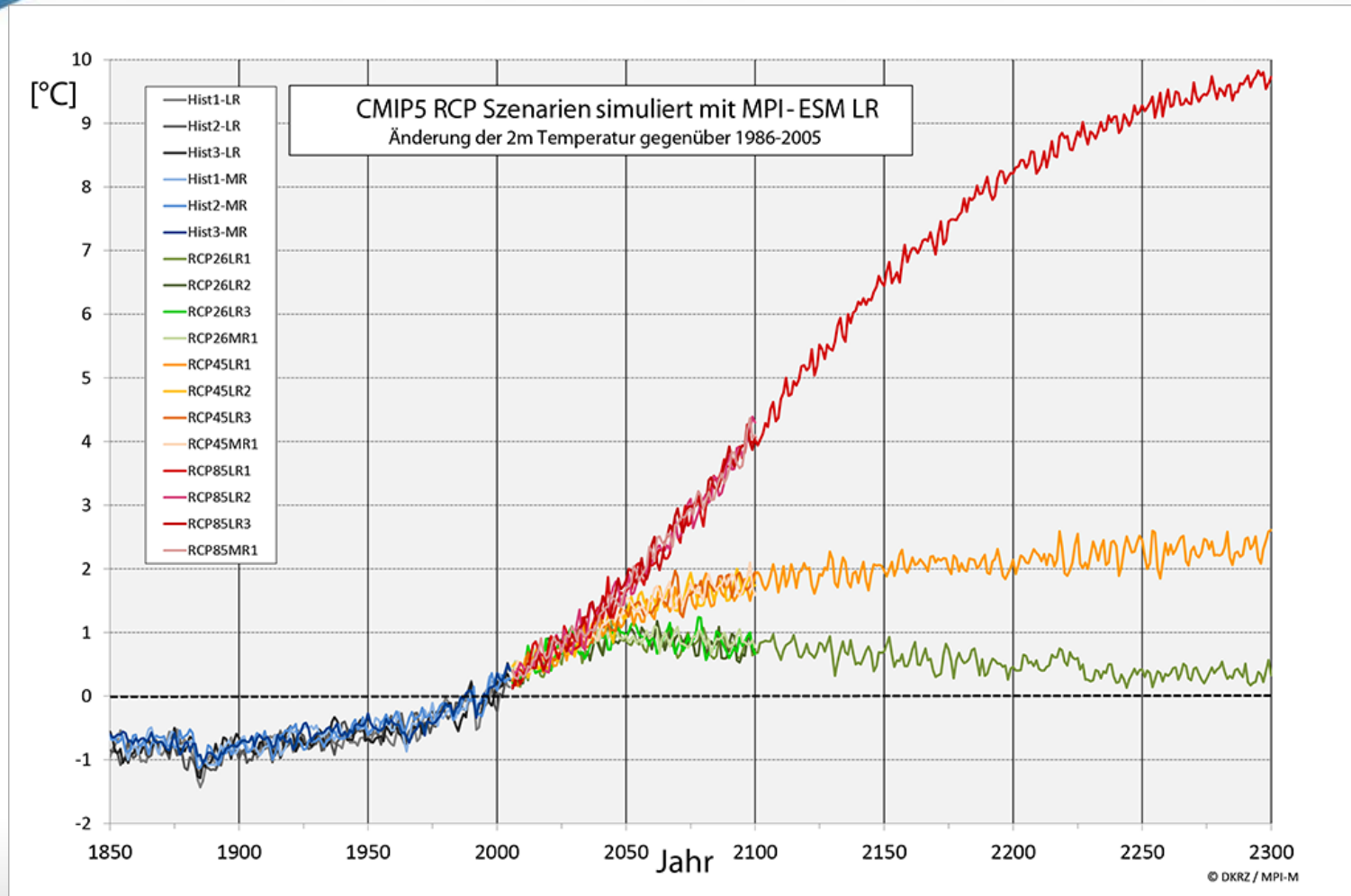
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# IPCC-AR5 Rechnungen Temperatur-Änderungen





# IPCC-AR5 Rechnungen Temperatur-Änderungen



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RCP 2.6

# Temperature Change

10 year running  
ensemble  
mean

RCP 8.5

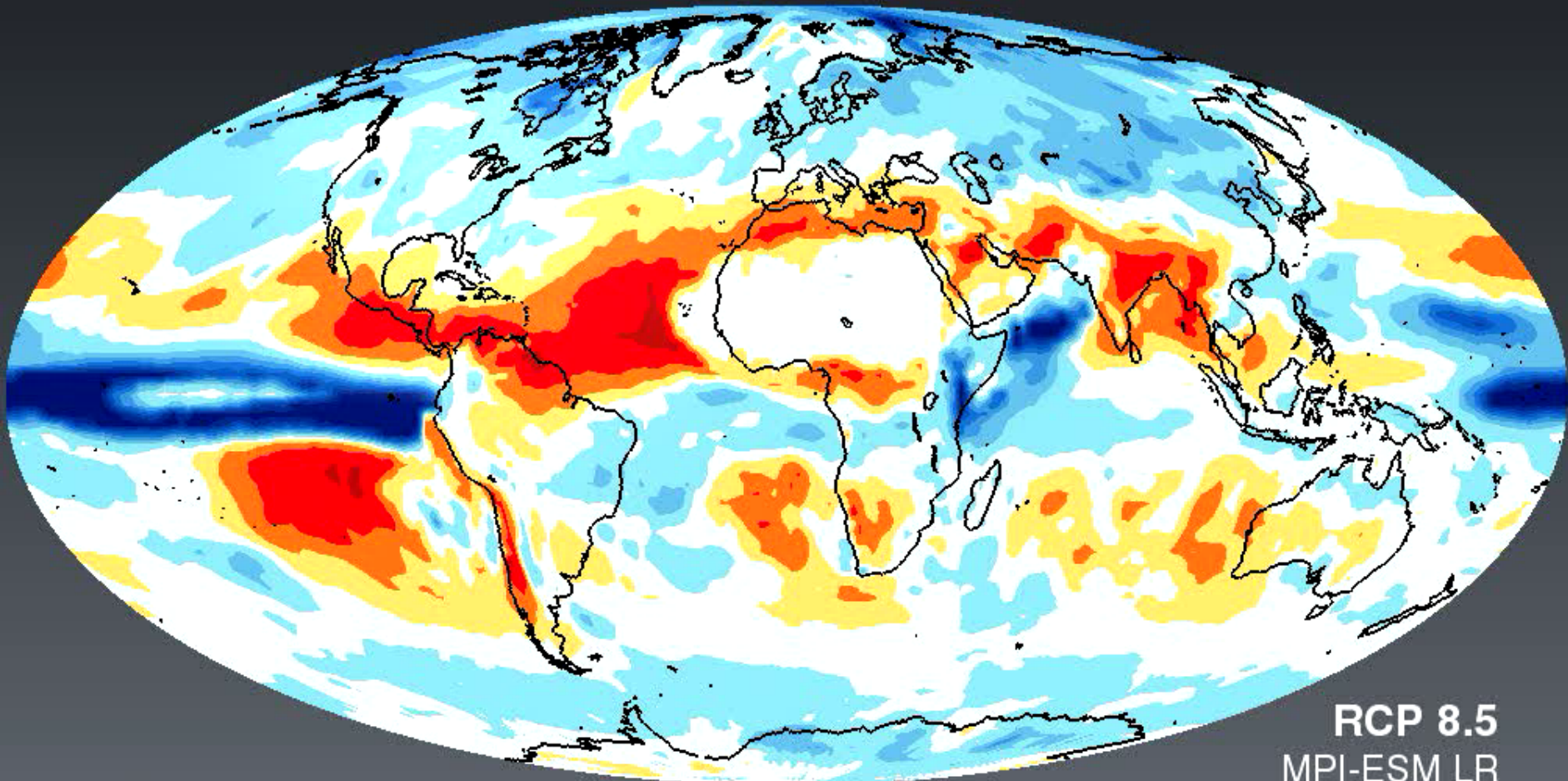
MPI-ESM LR  
1985



© DKRZ / MPI-M

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



Jan

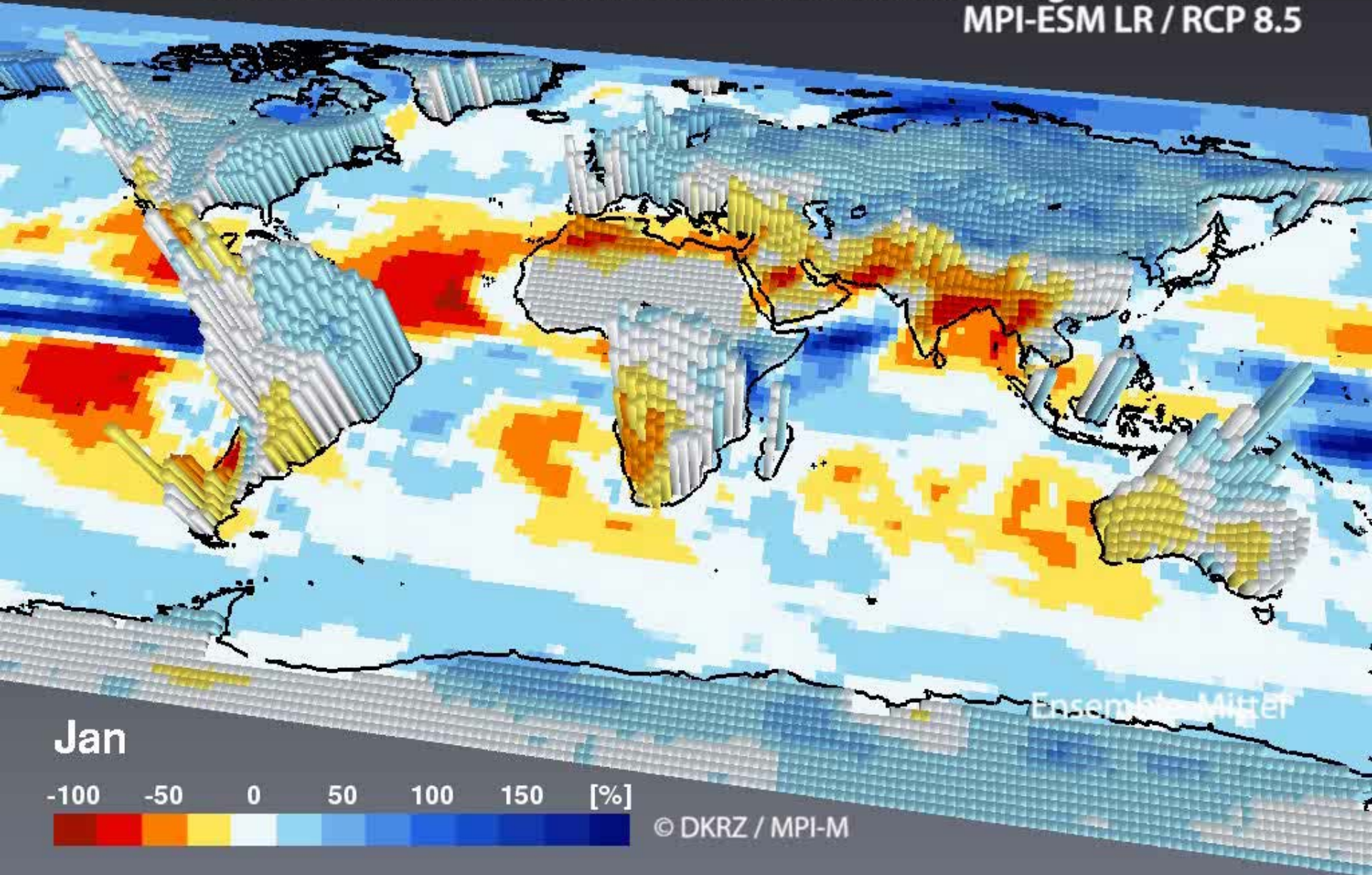
(C) DKRZ / MPI-M

RCP 8.5  
MPI-ESM LR  
Ensemble Mean



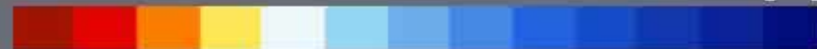


Farbe: Prozentuale Niederschlagsänderung 2071-2100 gegenüber 1986-2005  
Höhe: Simulierter mittlerer monatlicher Niederschlag für 1986-2005  
MPI-ESM LR / RCP 8.5



Jan

-100 -50 0 50 100 150 [%]



© DKRZ / MPI-M



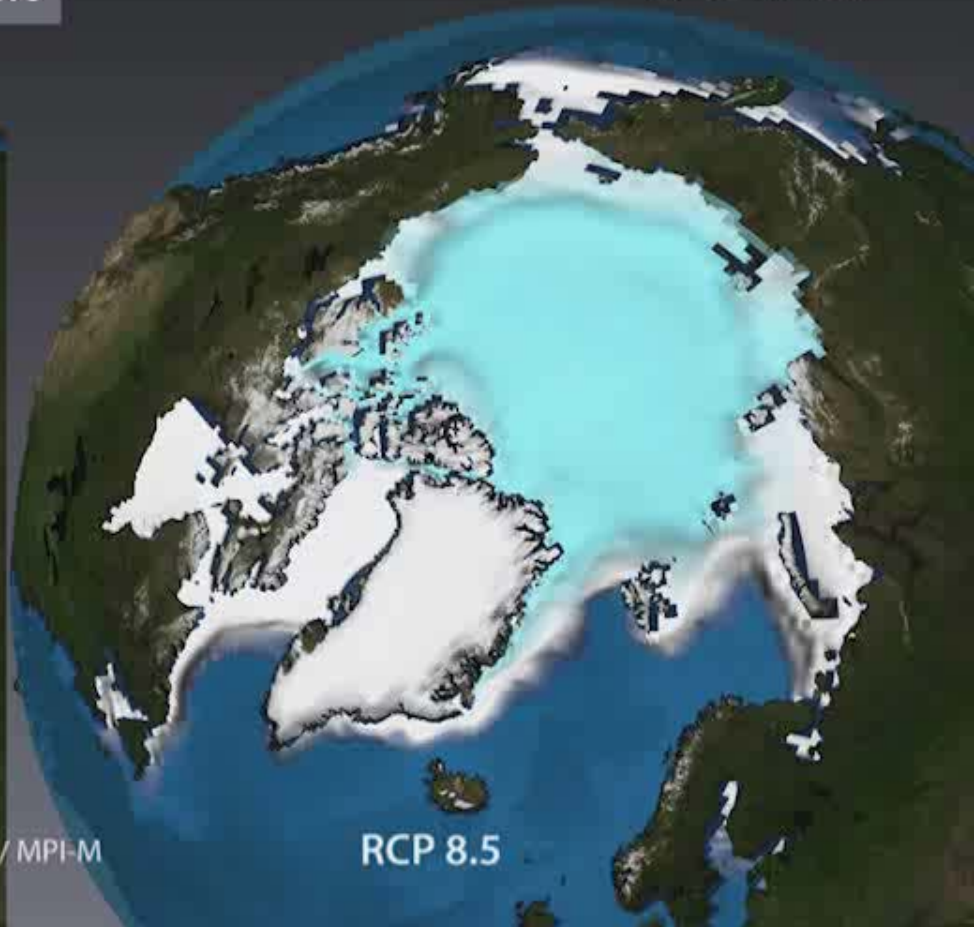
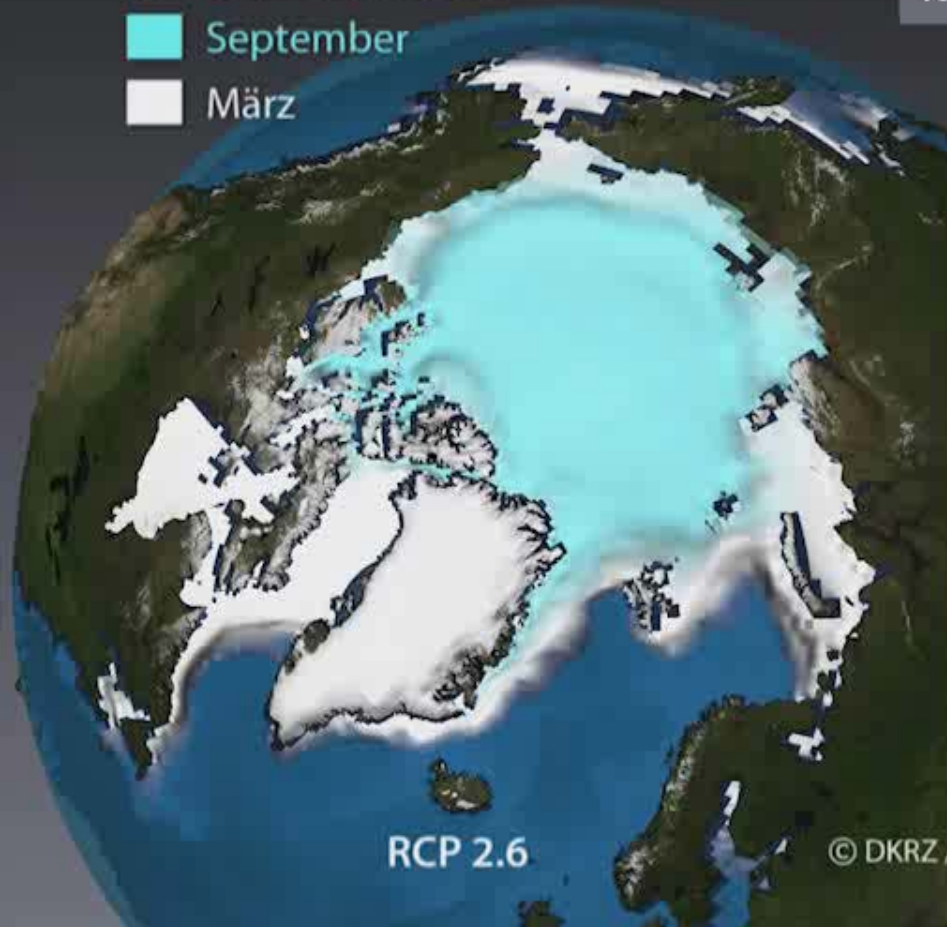
# Meereis-Konzentration

■ September

■ März

1975

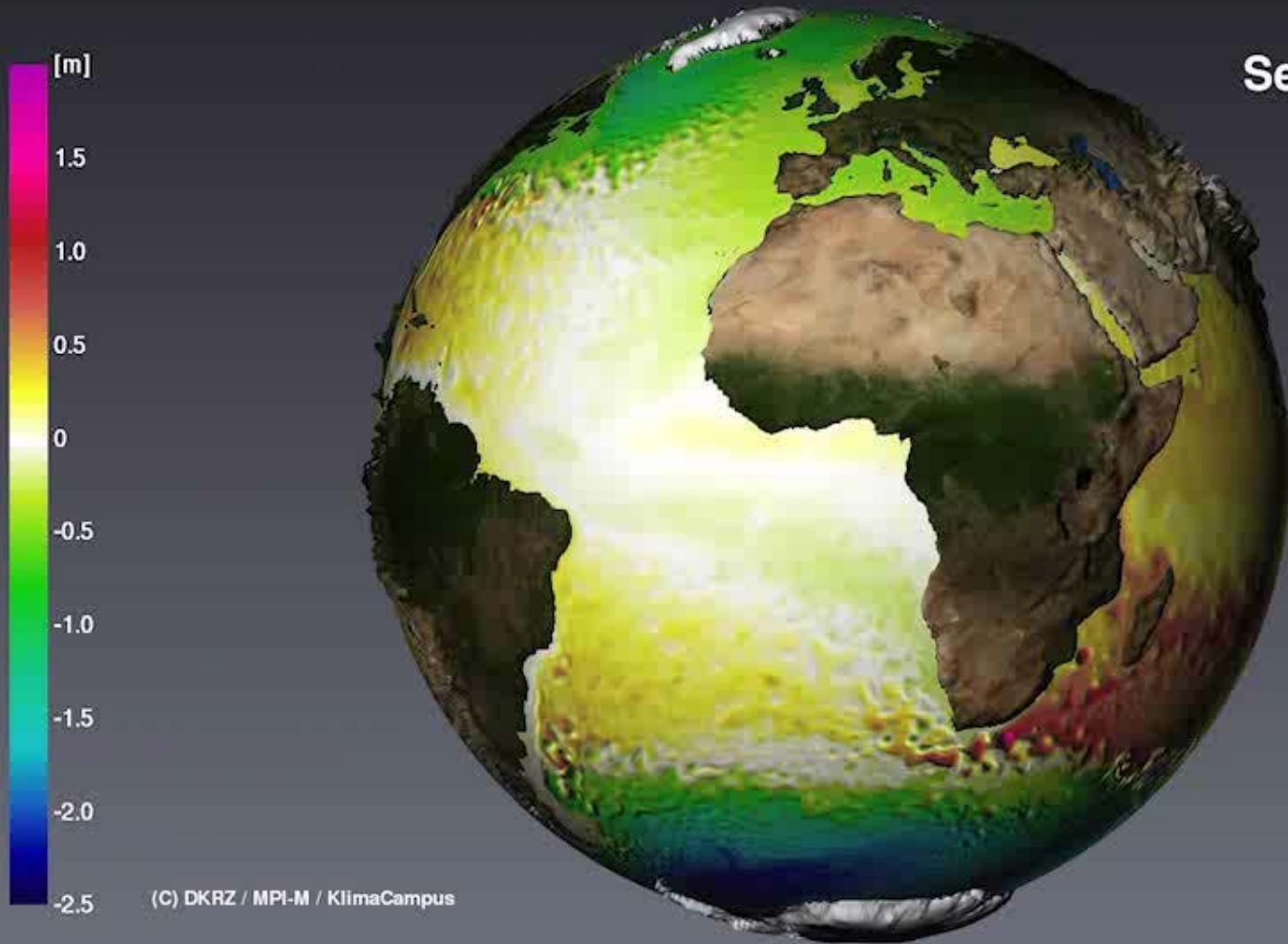
MPI-ESM LR



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# Sea Surface Height

MPI-OM (TP6M)

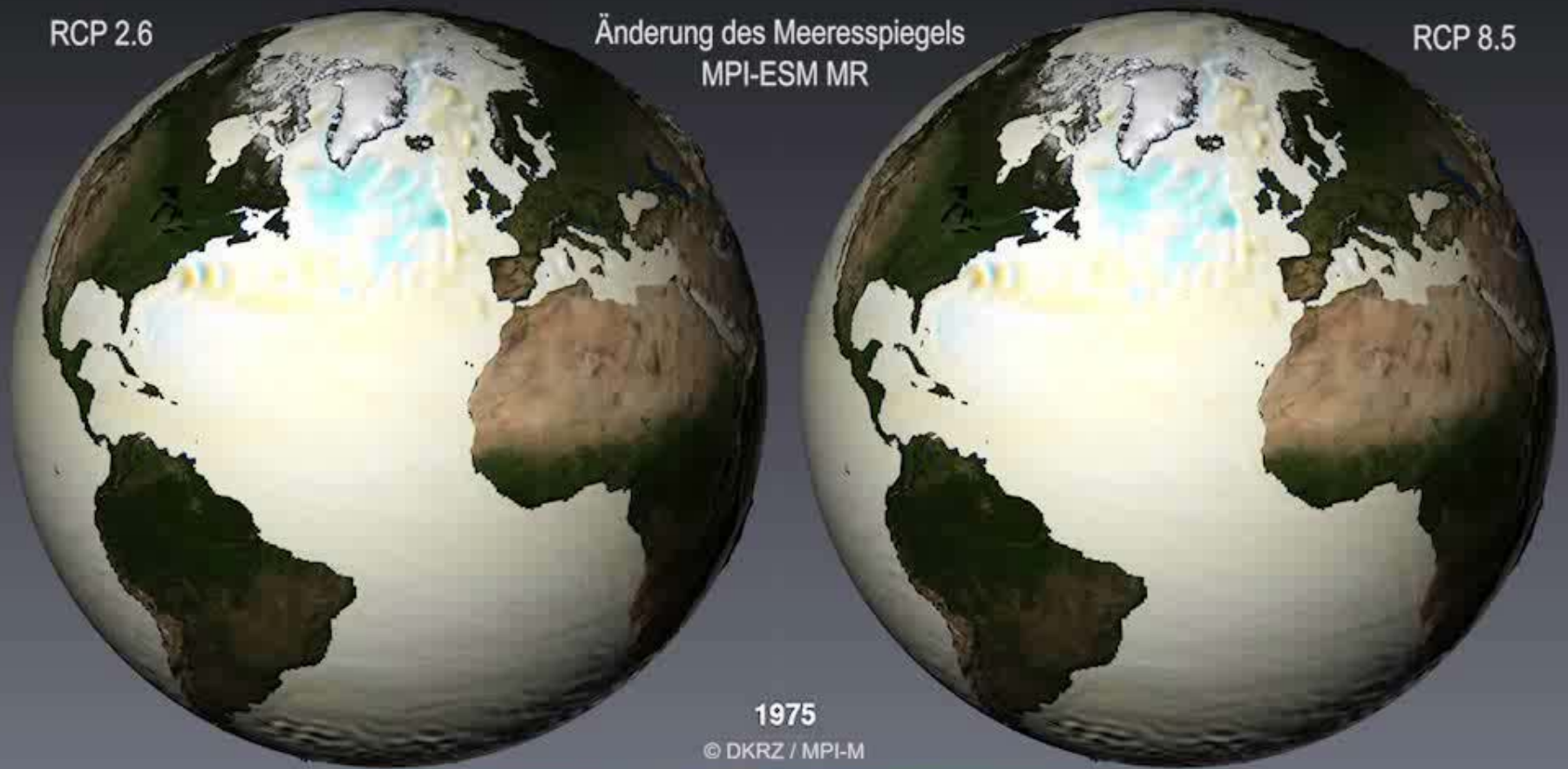




RCP 2.6

Änderung des Meeresspiegels  
MPI-ESM MR

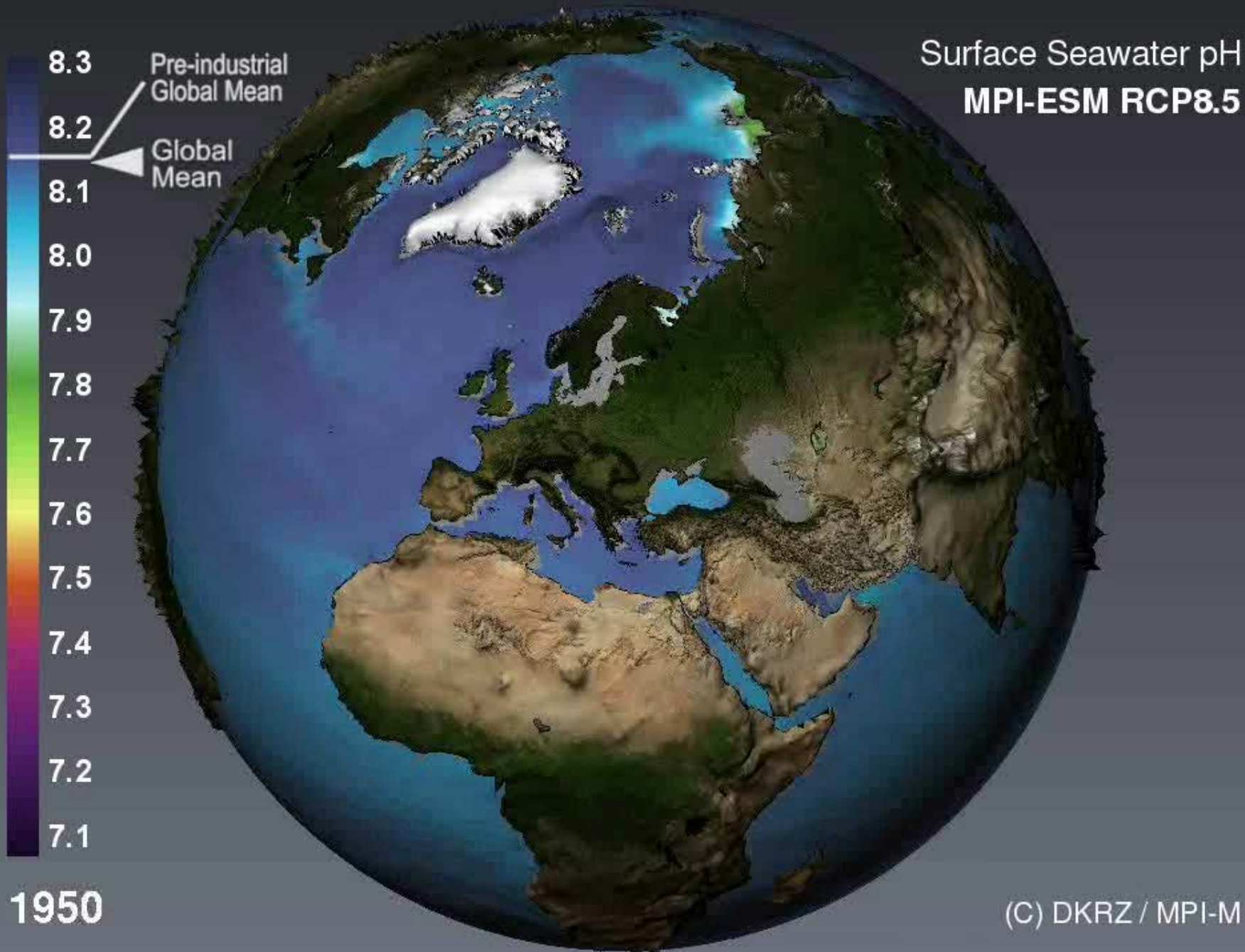
RCP 8.5



1975

© DKRZ / MPI-M







**MPI-ESM RCP 8.5**

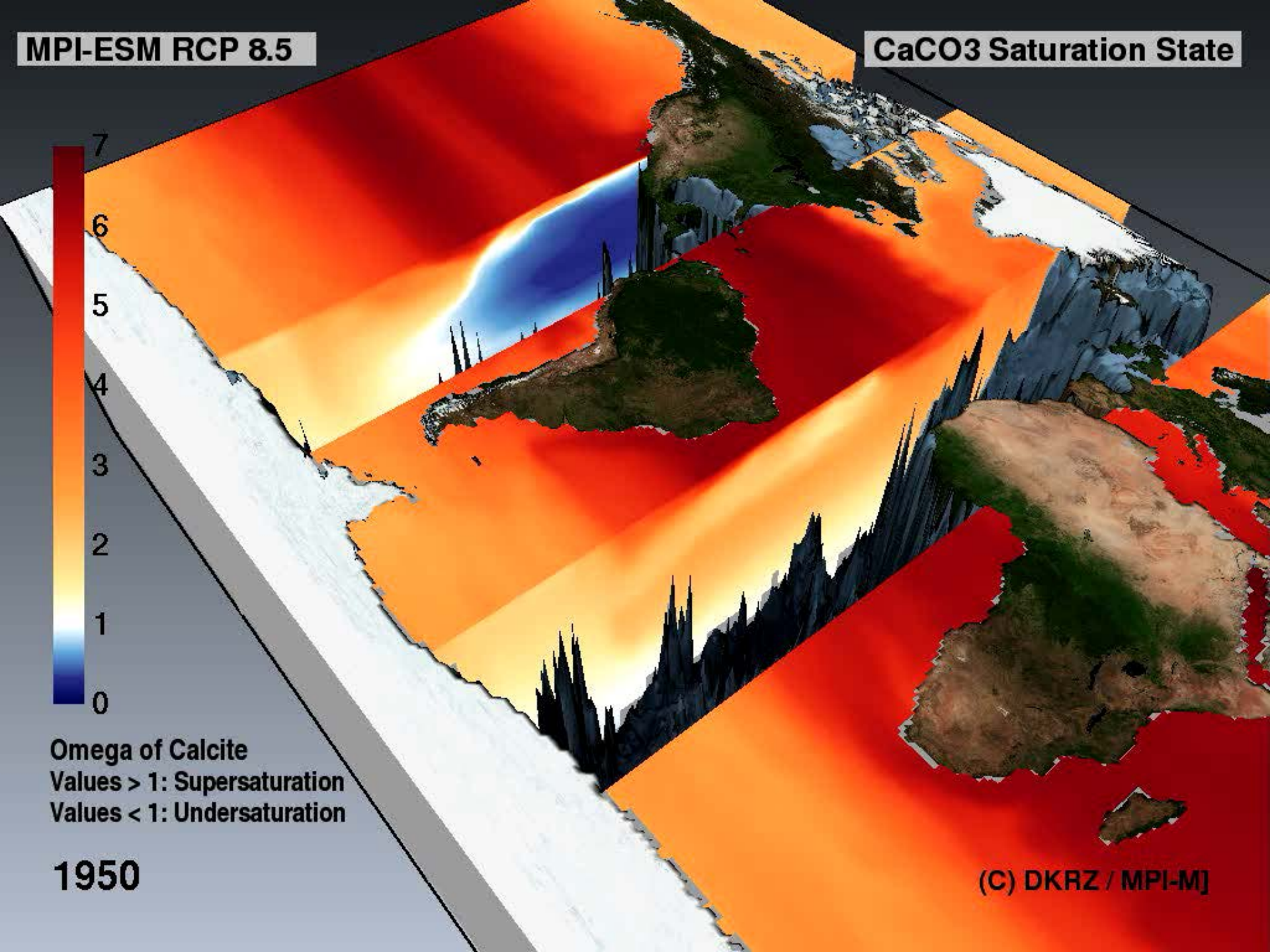
**CaCO<sub>3</sub> Saturation State**



**Omega of Calcite**  
Values > 1: Supersaturation  
Values < 1: Undersaturation

**1950**

(C) DKRZ / MPI-MJ







Accumulated  
Ash  
[kg/m<sup>2</sup>]

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

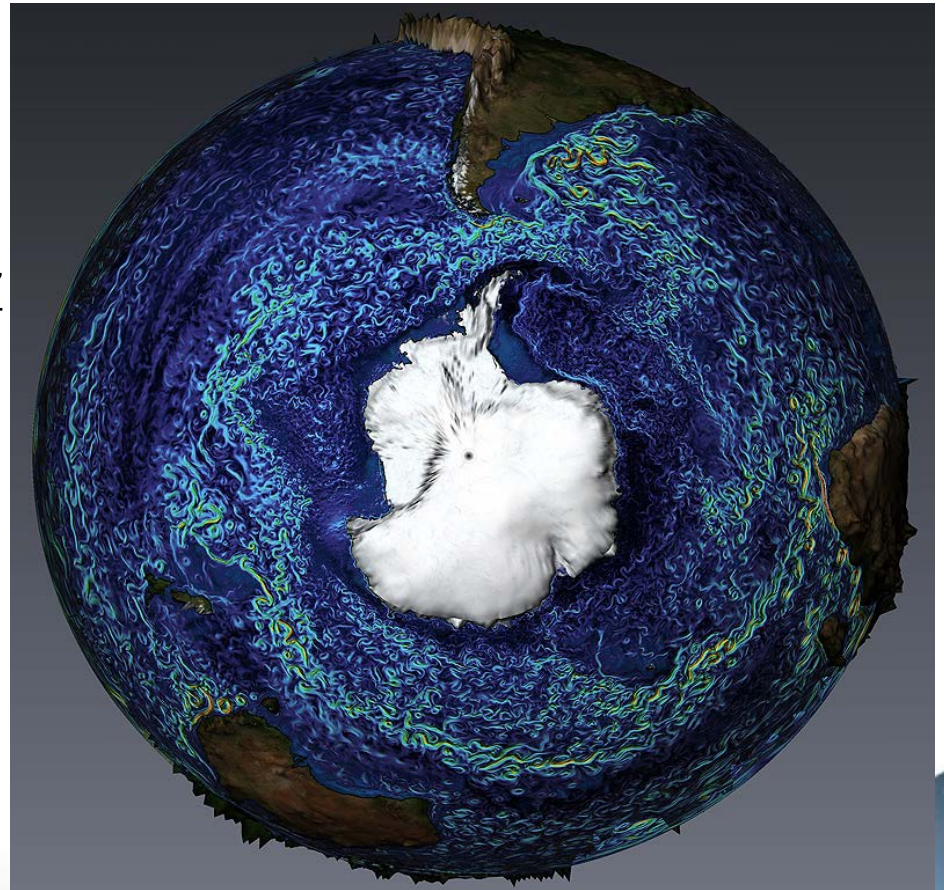
(C) DKRZ / MPI-M



# In Richtung Exascale

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

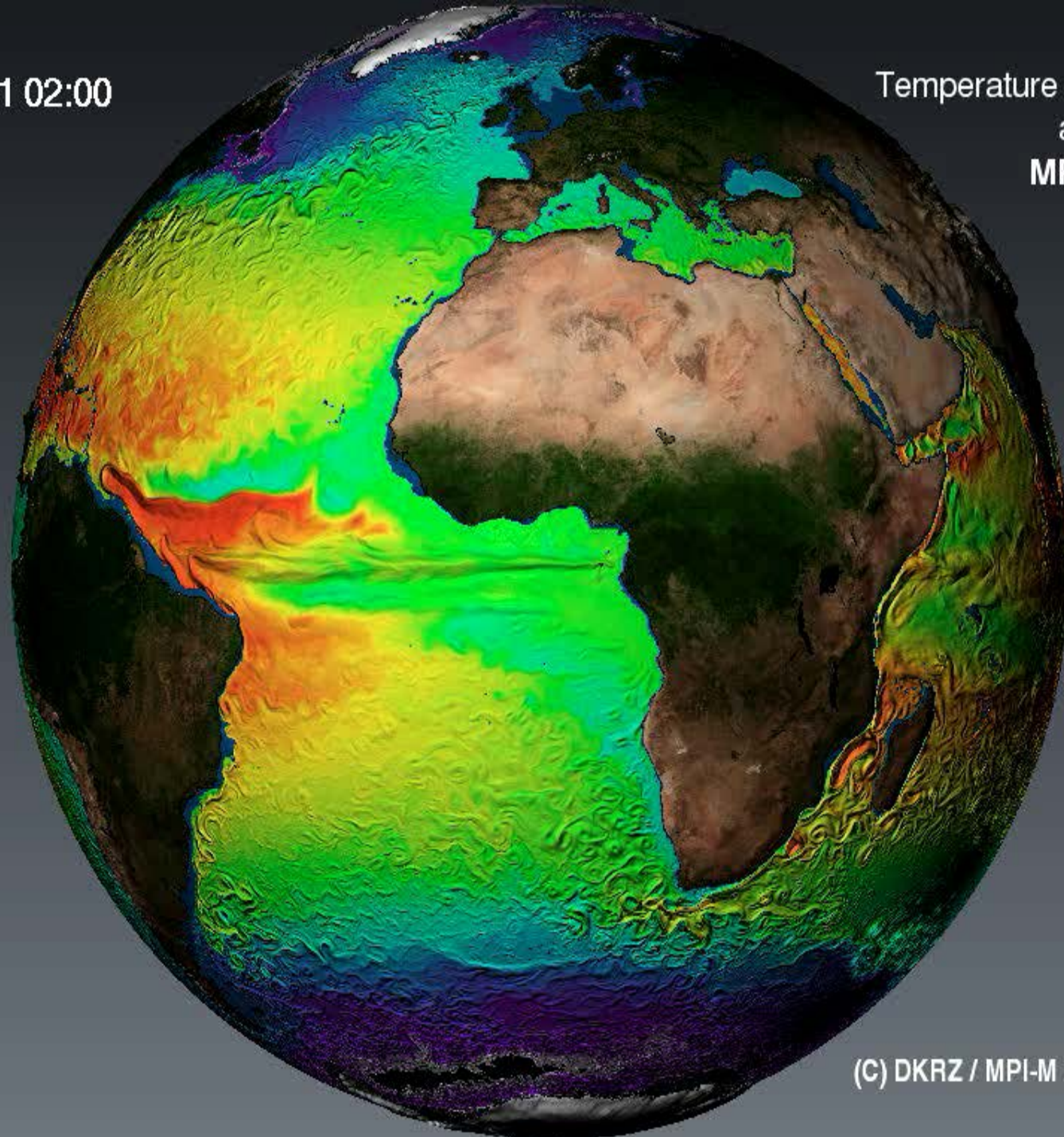


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01/01/0031 02:00

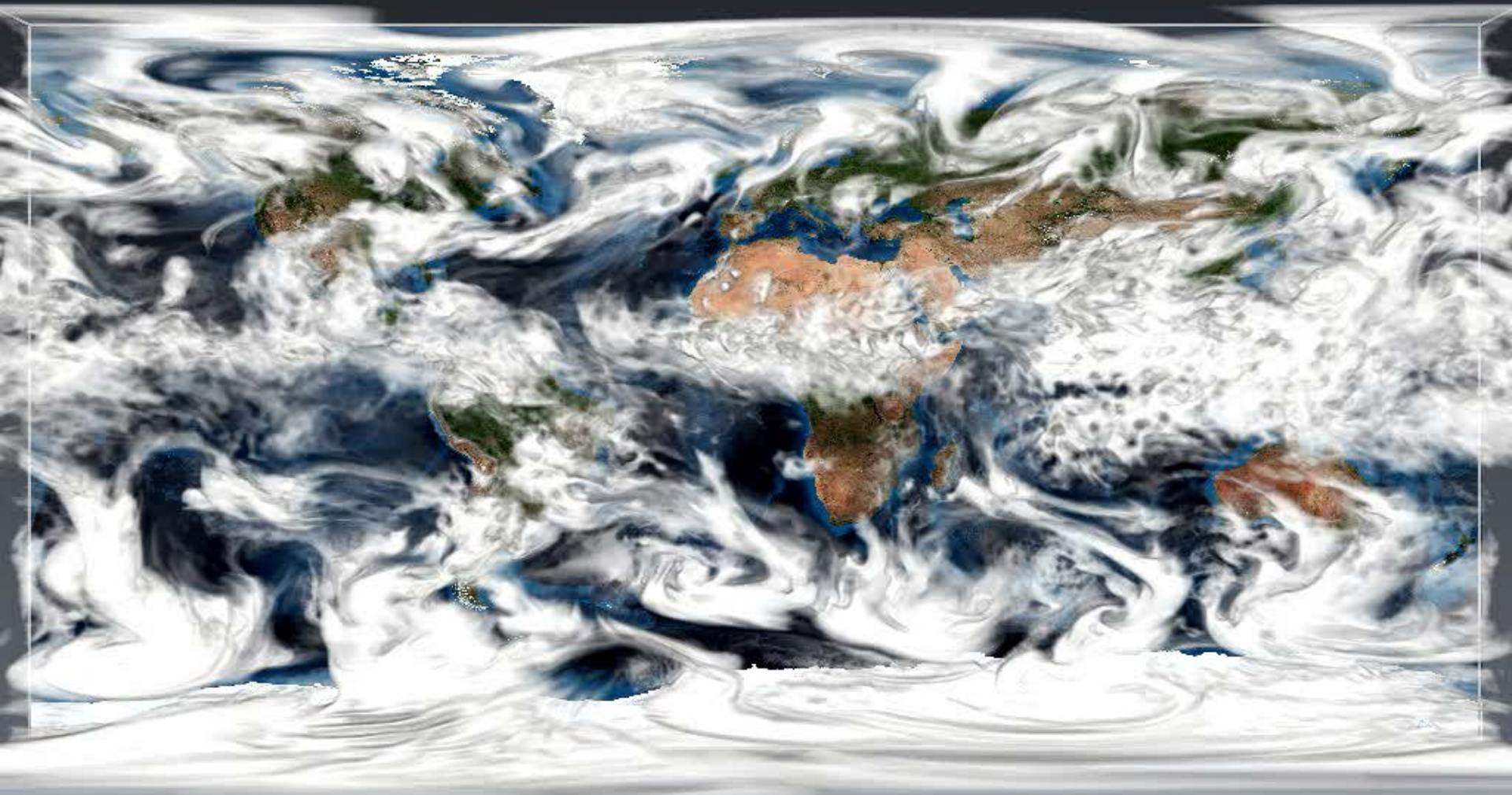
Temperature and Velocity  
at 75m depth  
MPI-OM TP6M



(C) DKRZ / MPI-M / KlimaCampus



**ECHAM6 T255**  
**Relative Humidity**



**01/08/1985**  
**00:00**

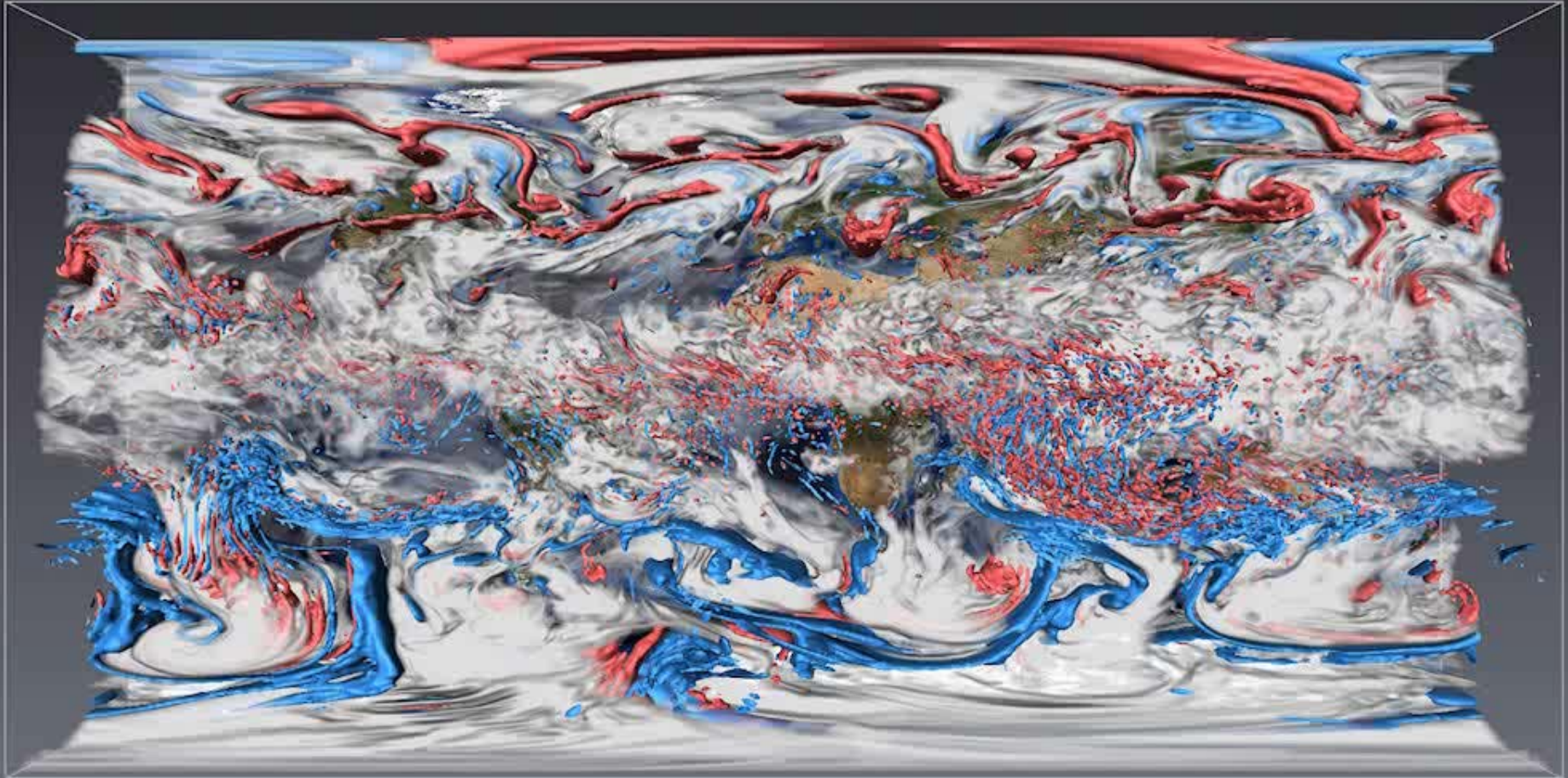
(C) DKRZ / MPI-M



ECHAM6 T255

Volume Rendering: Relative Humidity

Vorticity Isosurfaces: Blue: -0.0001, Red: 0.0001



01/08/1985 00:00

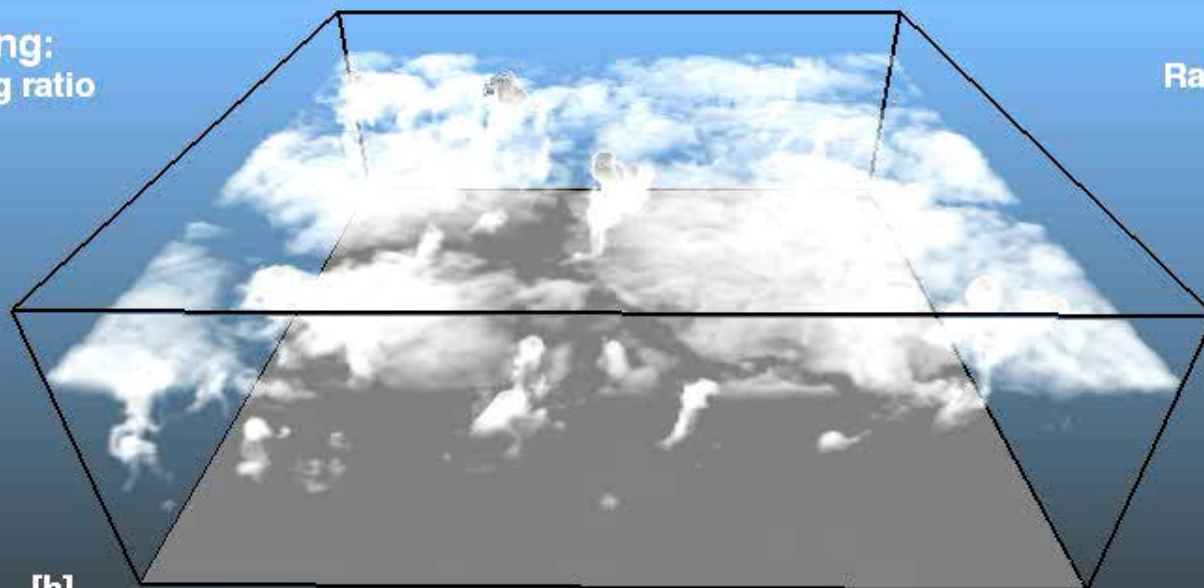
(C) DKRZ / MPI-M

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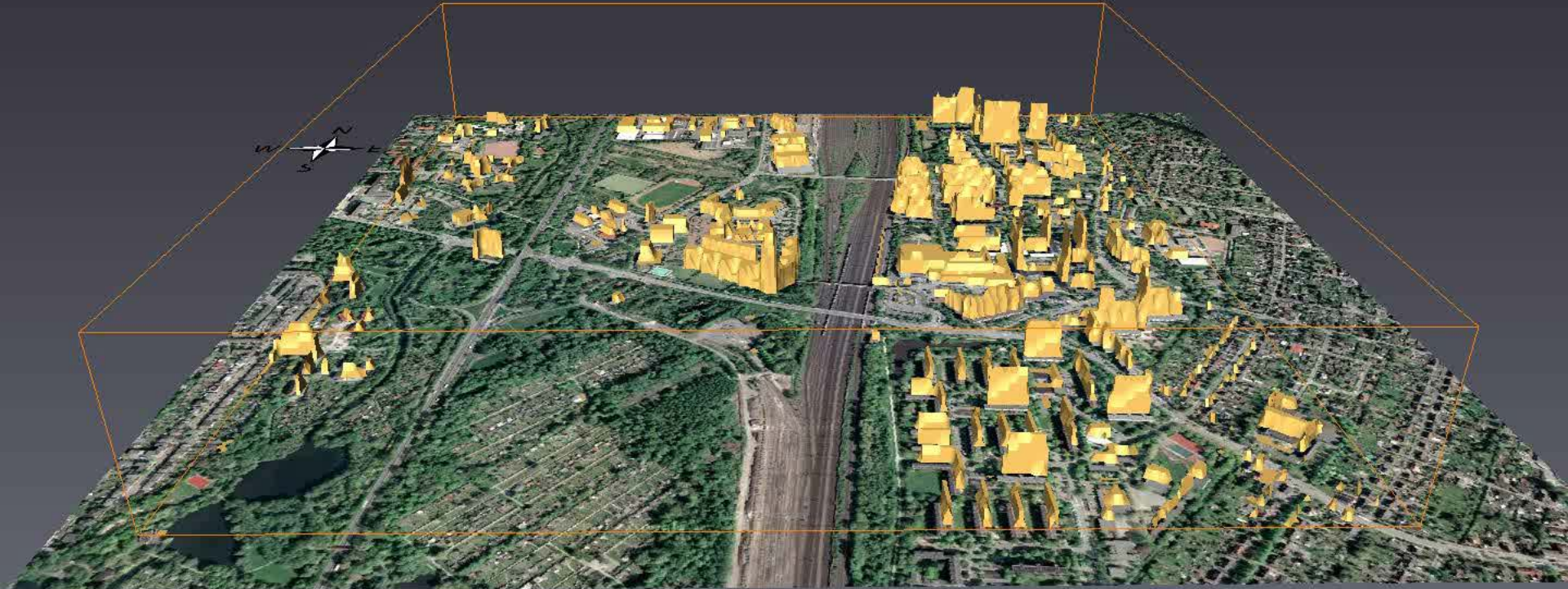
**Volume rendering:**  
Liquid water mixing ratio



**Isosurface:**  
Rain-water mixing ratio  
 $5. \text{e-}6 \text{ kg/kg}$



MITRAS - Wilhelmsburg BSU Building - Difference



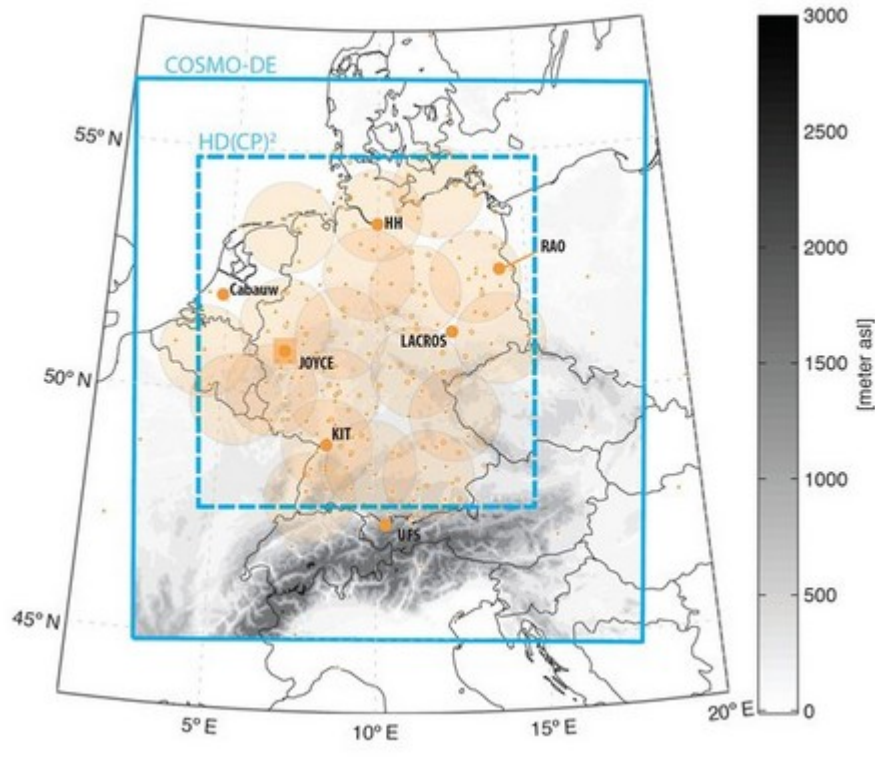


# Herausforderungen



## HD(CP)<sup>2</sup>

High definition clouds and precipitation  
for advancing climate prediction



- ▶ BMBF -Projekt (ab 2013)
- ▶ Wolkenauflösendes Modell
- ▶ ICON-Gitter (unstrukturiert)
- ▶ Horizontales Gitter : 100 m Aufl.
- ▶ Vertikal: 250 Schichten
- ▶ Modellgebiet 1000 km \* 1000 km

<http://hdcp2.zmaw.de/>

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# Zusammenfassung und Ausblick

- ▶ Visualisierung von Klimamodelldaten (mit Avizo)
  - Direkte Unterstützung nativer Datenformate
  - Viele domänenspezifische Forderungen erfüllt (Mapping, Kartenprojektionen, geographischer Kontext, Zeitabhängigkeit)
  - Neu: irreguläre Gitter via NetCDF
  - Erweiterbarkeit (DKRZ: Source Code Agreement mit VSG)
- ▶ Herausforderungen: Richtung Exascale-Visualisierung
  - Hohe räumliche Auflösung
  - -> für Visualisierung hohe *zeitliche* Auflösung notwendig
  - -> Hohe Kosten für output/storage/access
  - Skalierbarkeit von Datentransfer / -zugriff / -bearbeitung
  - Skalierbarkeit der Visualisierungssoftware
  - Paradigmenwechsel?

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<http://www.dkrz.de>

**ENDE**



**DKRZ**

DEUTSCHES  
KLIMARECHENZENTRUM

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