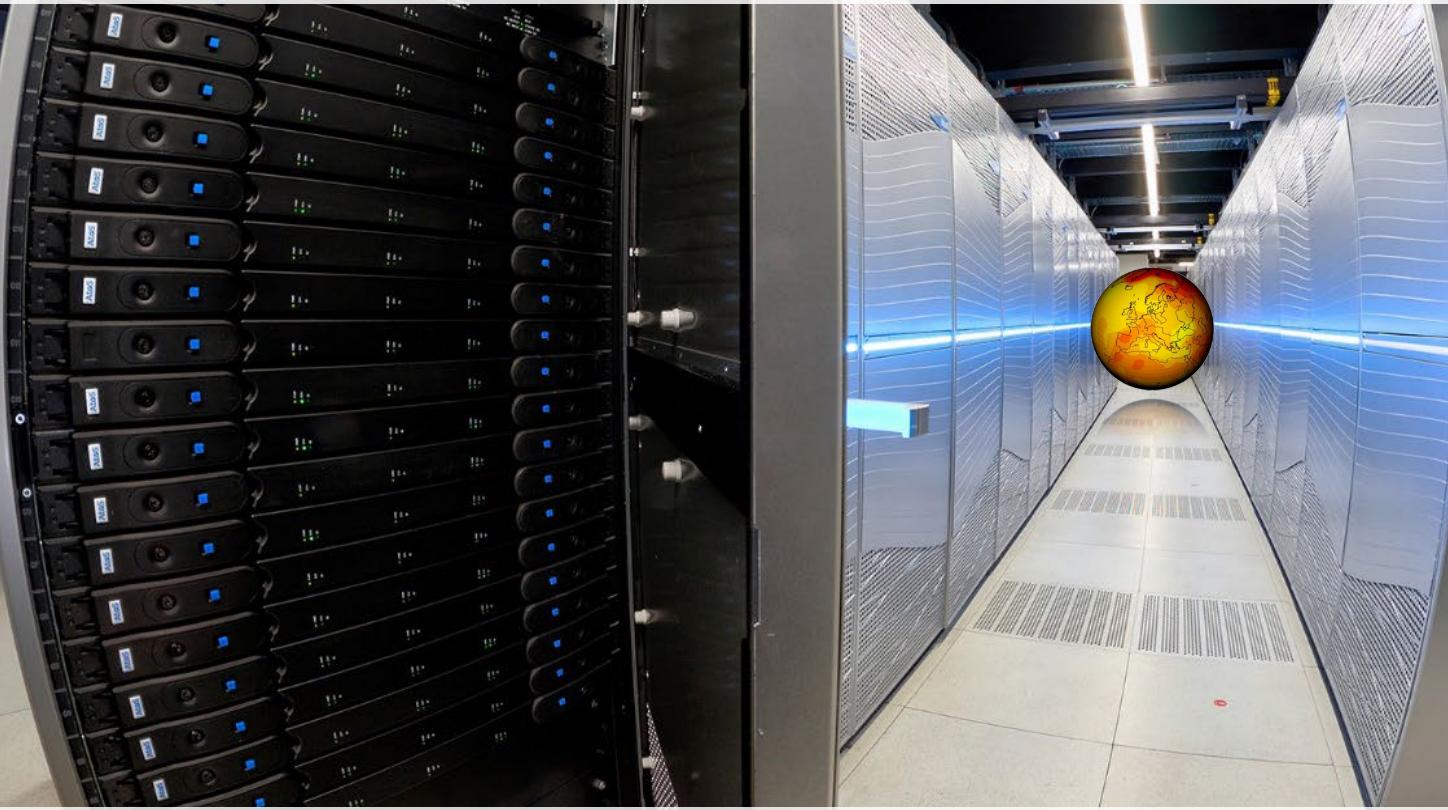


Deutsches Klimarechenzentrum - Das Weltklima im Hochleistungsrechner



Michael Böttinger Deutsches Klimarechenzentrum (DKRZ)

Klima- und Erdsystemforschung in Hamburg

Exzellenzcluster CLICCS

- Universitätsinstitute
 - Meteorologie
 - Ozeanographie
 - Geophysik
 - ...



EXZELLENZCLUSTER
CLIMATE, CLIMATIC CHANGE,
AND SOCIETY (CLICCS)



- Max-Planck-Institut für Meteorologie



- Helmholtz-Zentrum Hereon



- Climate Service Center Germany



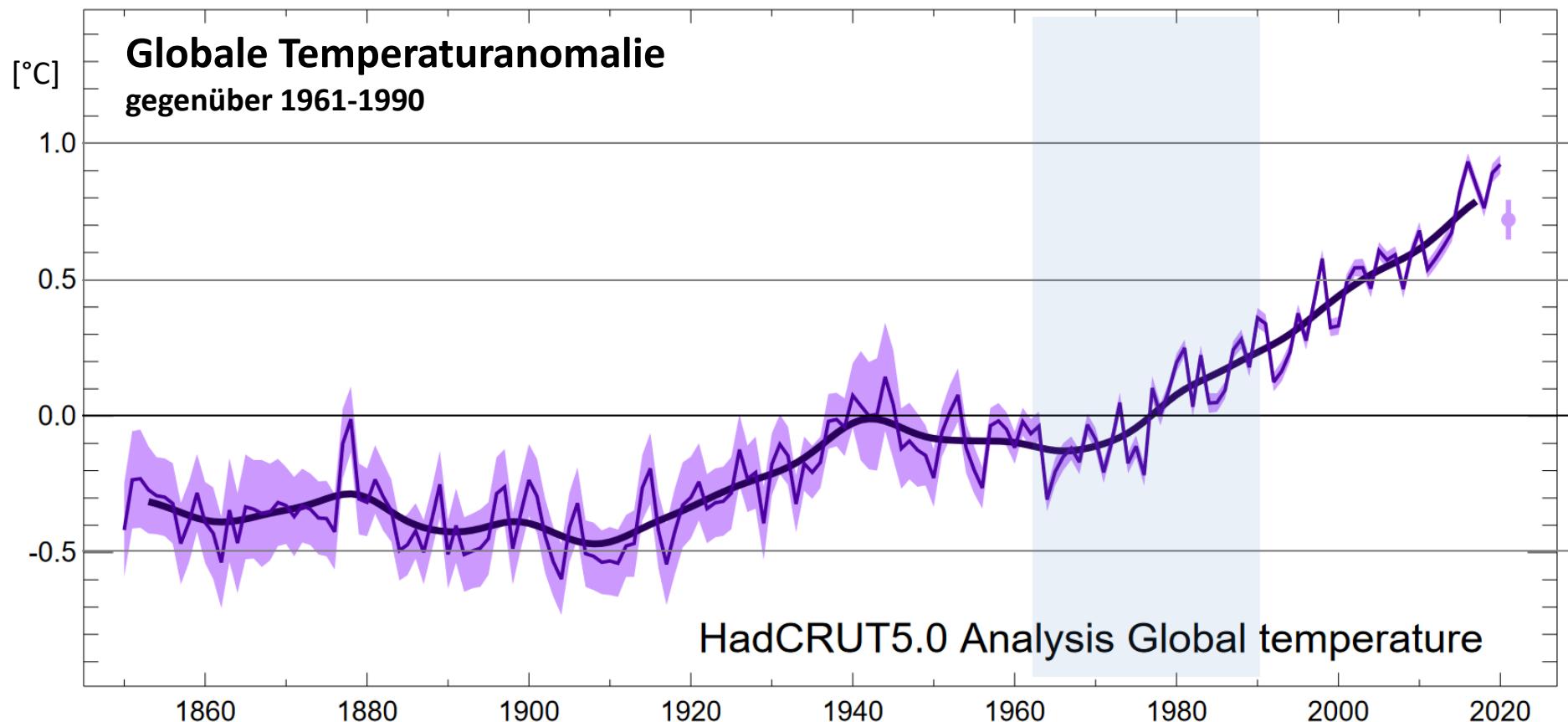
- **DKRZ (nationale Einrichtung)**



Wetter und Klima

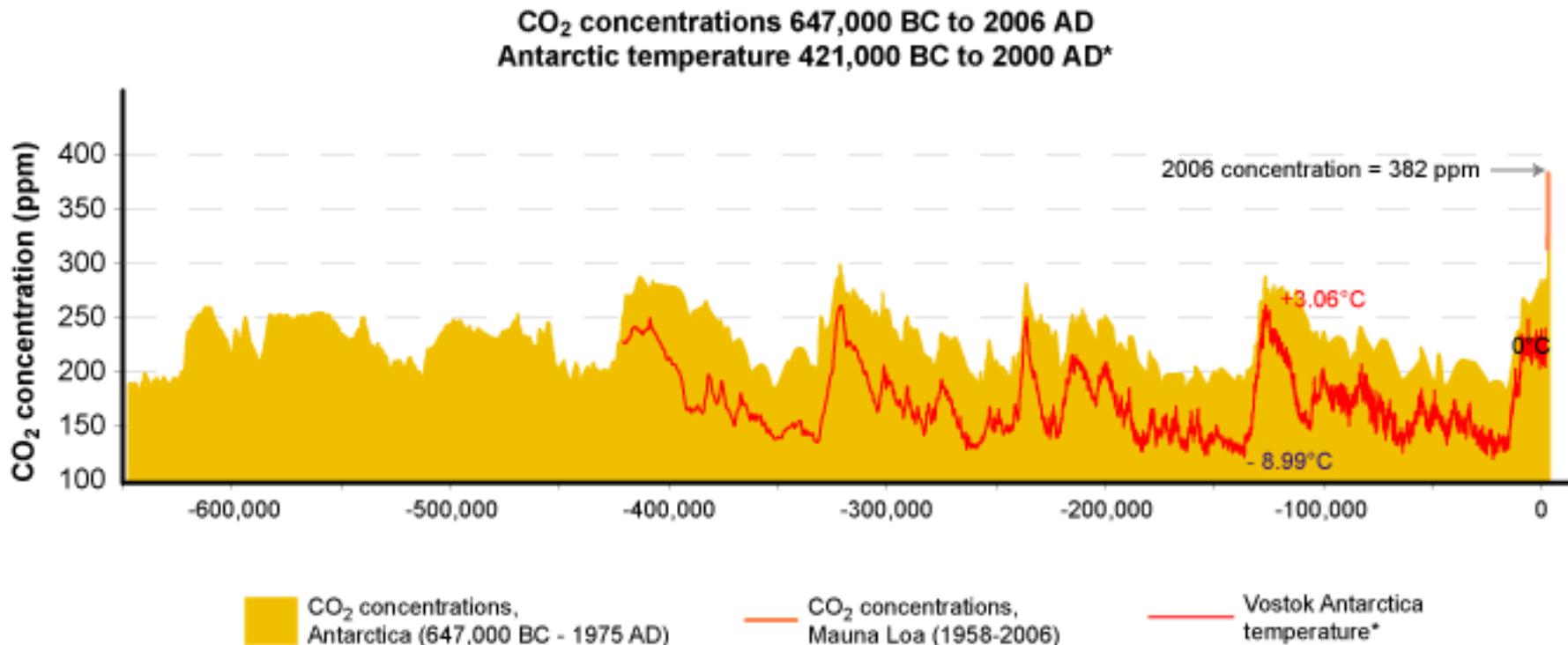


Klima auf Basis direkter Messungen



Quelle: HADCRUT5, Climatic Research Unit (University of East Anglia) and Met Office

Blick in die Vergangenheit



* Antarctic temperature is measured as the change from average conditions for the period 1850 AD - 2000 AD

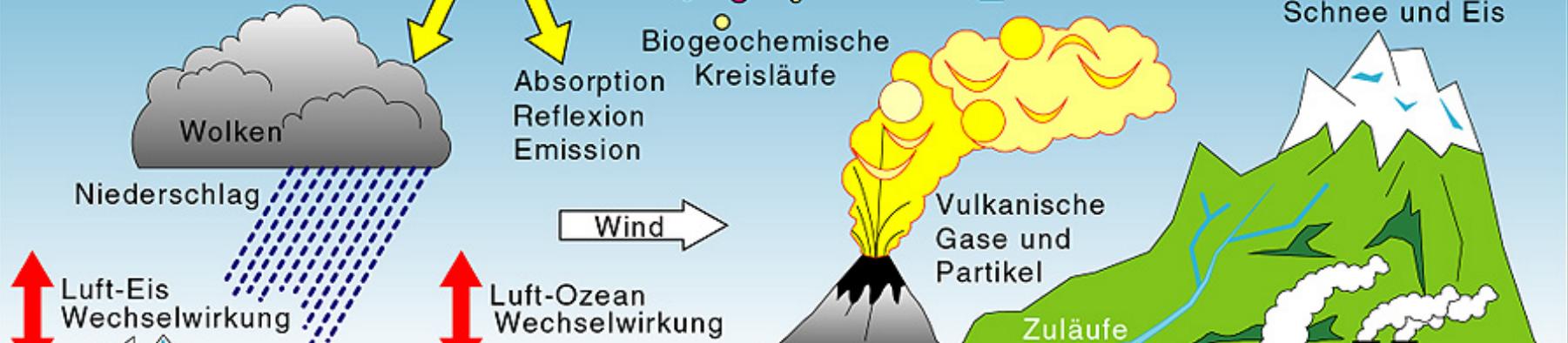
Quelle: UNEP

Das Klimasystem

WELTRAUM



ATMOSPHÄRE



OZEAN



Worauf basiert ein Modell der Atmosphäre?

- Naturgesetze und beobachtete Gesetzmäßigkeiten
 - Gleichungen, die das Verhalten von Flüssigkeiten und Gasen beschreiben
 - Erhaltungssätze (Impuls, Energie, Masse)
 - Strahlung
 - Randbedingungen (Erdgeometrie, Bahnparameter, Land-Meer-Verteilung,...)

Worauf basiert ein Modell der Atmosphäre?

Gleichungen nicht direkt lösbar ...

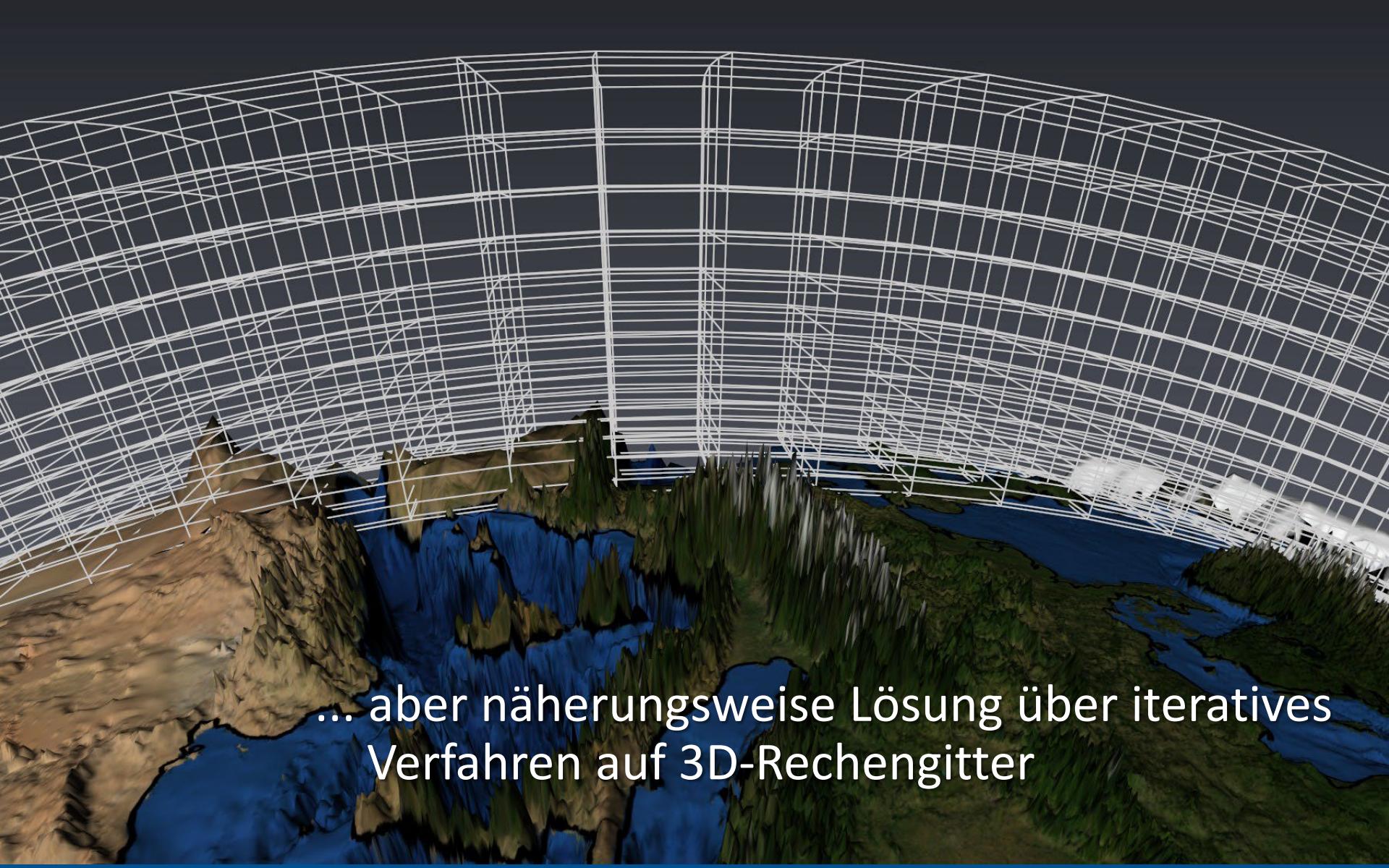
$$\frac{\partial U}{\partial t} - (f + \xi) \cdot V + \dot{\eta} \frac{\partial U}{\partial \eta} + \frac{R_d T_v}{a} \frac{\partial}{\partial \lambda} \ln p + \frac{1}{a} \frac{\partial}{\partial \lambda} (\phi + E) = P_U + K_U$$

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

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

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

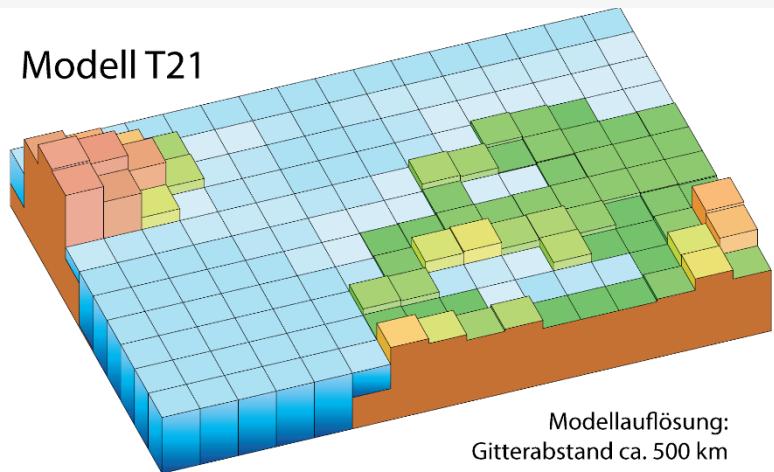
$$\frac{\partial q_w}{\partial t} + \frac{U}{a(1 - \mu^2)} \frac{\partial q_w}{\partial \lambda} + \frac{V}{a} \frac{\partial q_w}{\partial \mu} + \dot{\eta} \frac{\partial q_w}{\partial \eta} = P_{q_w} + K_{q_w}$$



... aber näherungsweise Lösung über iteratives
Verfahren auf 3D-Rechengitter

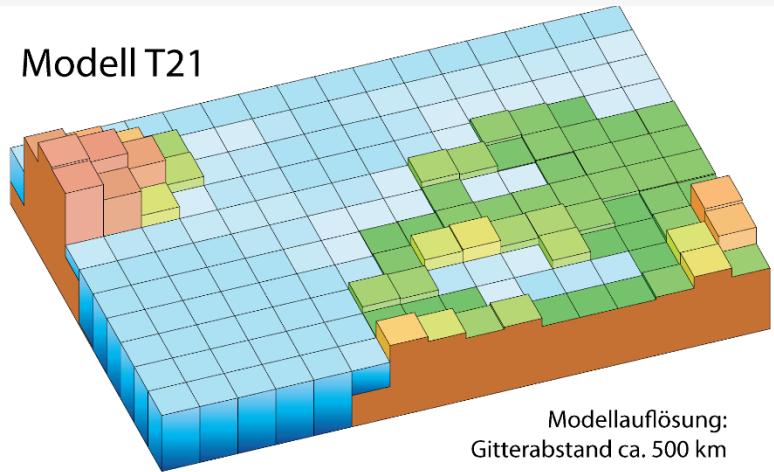
Modell-Auflösung

Modell T21

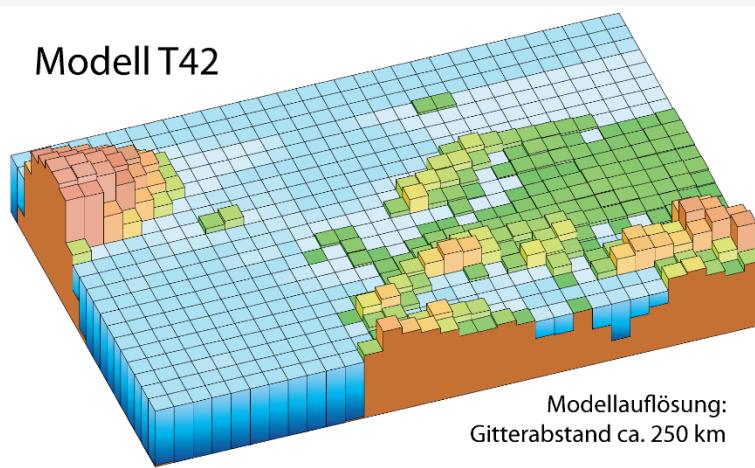


Modell-Auflösung

Modell T21



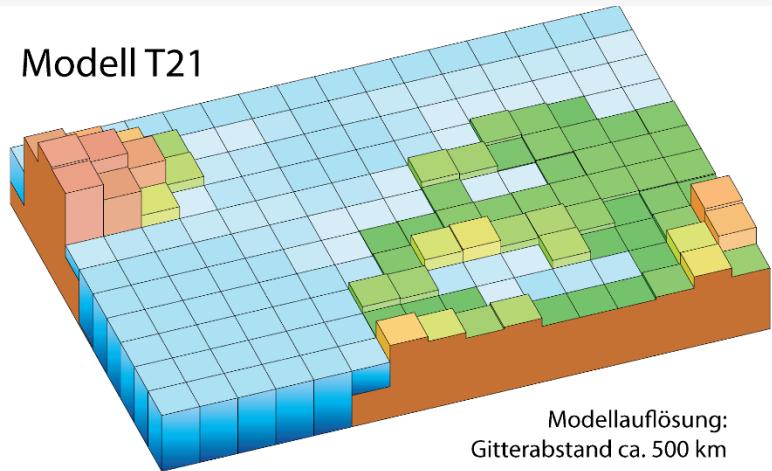
Modell T42



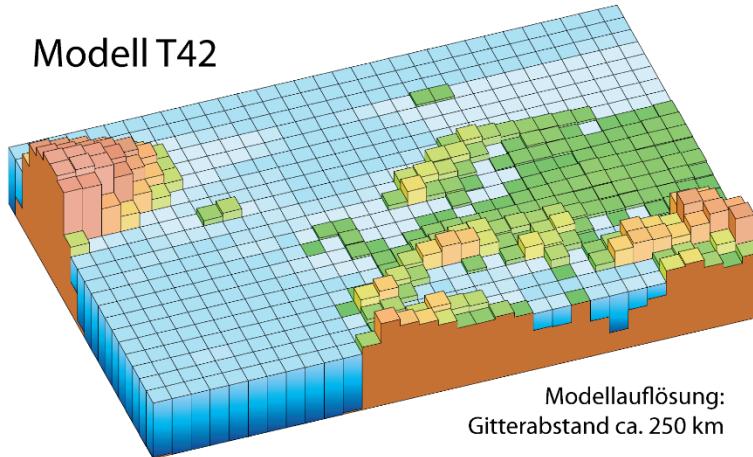
10-fache Rechenzeit!

Modell-Auflösung

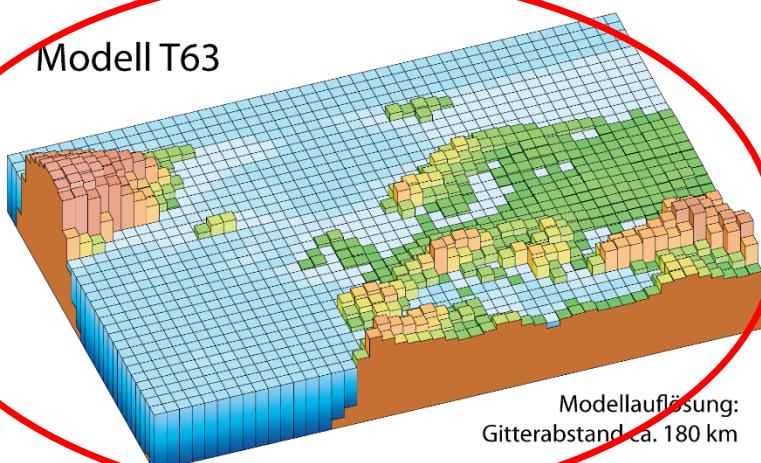
Modell T21



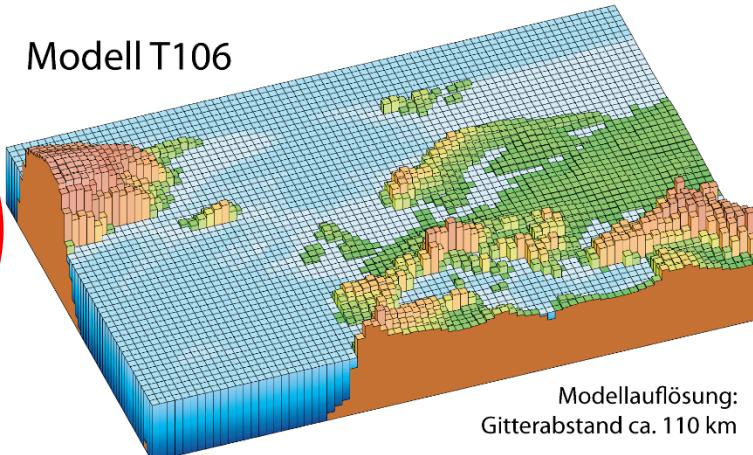
Modell T42



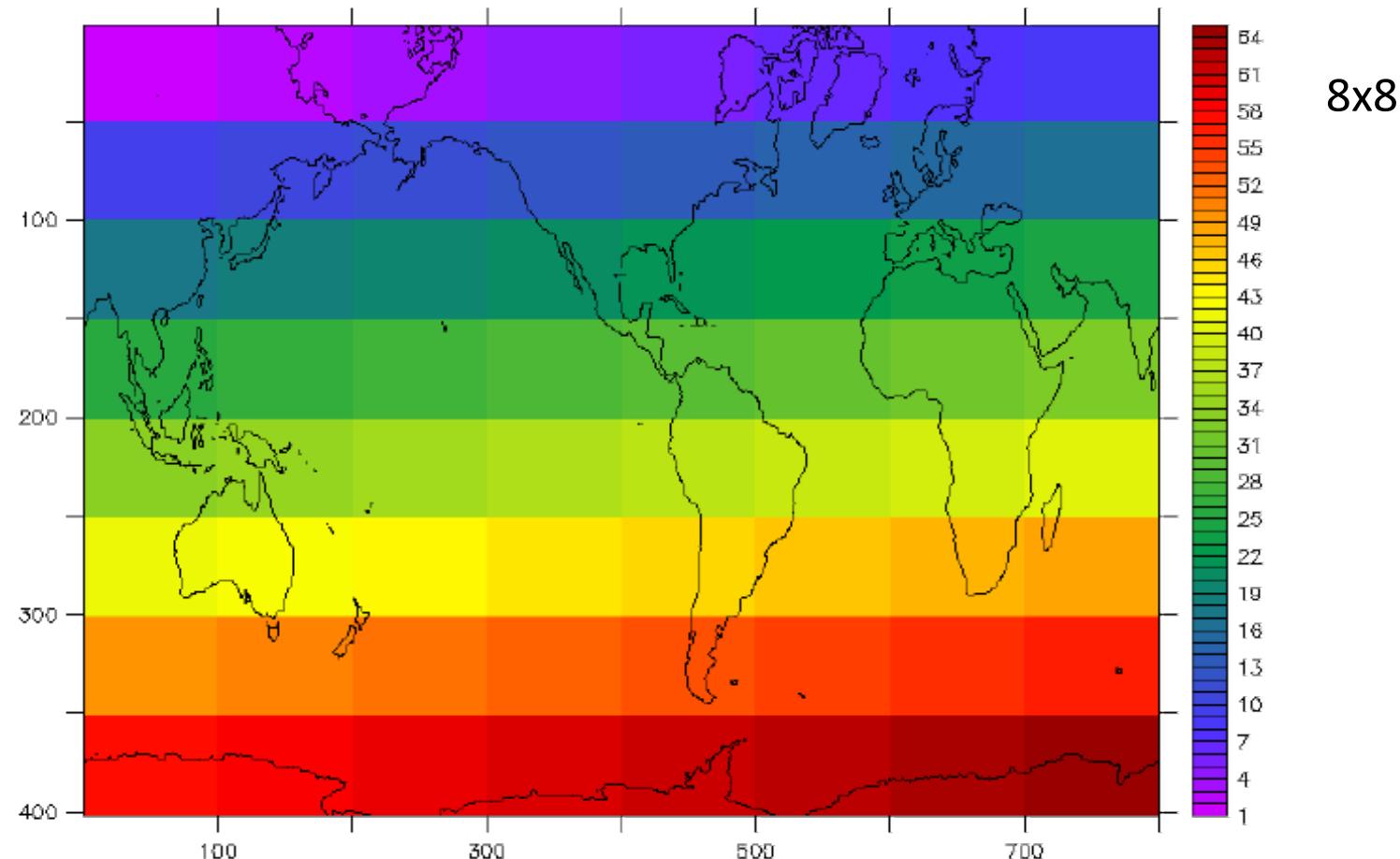
Modell T63



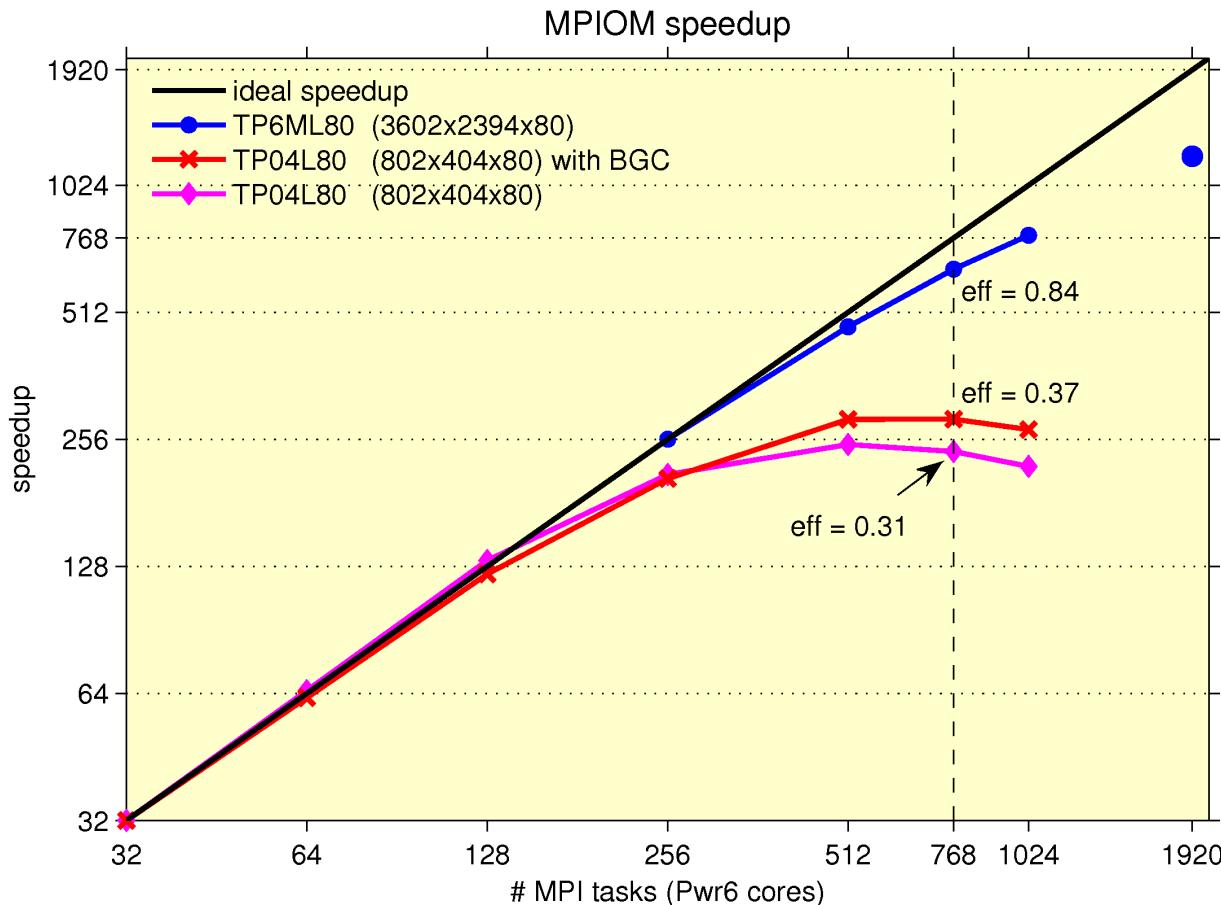
Modell T106



Parallelisierung



Skalierung



Das Deutsche Klimarechenzentrum



Organisation

Gesellschafter der DKRZ GmbH:

- MPG: 53% Uni-HH: 27% AWI: 10% Hereon: 10%

Kostenverteilung

- Investitionskosten: HGF 45%, MPG 40%, Hamburg 15%
- Betriebskosten: DKRZ-Gesellschafter

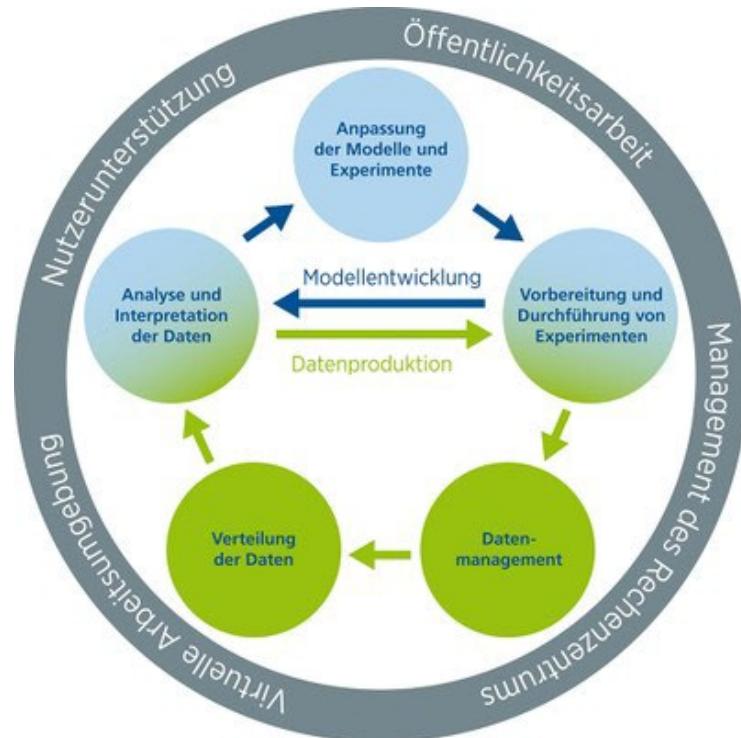
Nutzung

- Gesellschafter: 50 % insgesamt, aufgeteilt in
MPG: 27% Uni-HH: 13% AWI: 5% Hereon: 5%
- Erdsystemforschungs-Community 50 % insgesamt, WLA

DKRZ-Struktur

Etwa 100 Mitarbeiter:innen

- Systeme
- Anwendungen
 - Beratung
 - Programmoptimierung
 - Parallelisierung
 - Visualisierung
- Datenmanagement
 - CERA Klimadatenbank
 - Langzeitarchivierung
 - Datenverteilung: WDCC, ESGF
 - Datenpublikation
 - Machine Learning
- Verwaltung
- Uni Forschungsgruppe: Parallel E/A, Energieeffizienz im Hochleistungsrechnen





HLRE-4: Hochleistungsrechnersystem für die Erdsystemforschung 4 „Levante“
Platz 53 in der weltweiten TOP500-Liste (11/2022)

HLRE-4 „Levante“

Levante (aktuell)

- Atos BullSequana XH2000
 - CPU-Knoten: 2.832
 - Prozessorkerne: 370.000
 - Rechenleistung: 14 PFLOPS
 - Hauptspeicher: 815 Terabyte
 - Festplattenspeicher: 132 Petabyte
- sowie
- GPU-Knoten: 60
 - Nvidia A100 GPUs: 240
 - Rechenleistung: 2,8 PFLOPS



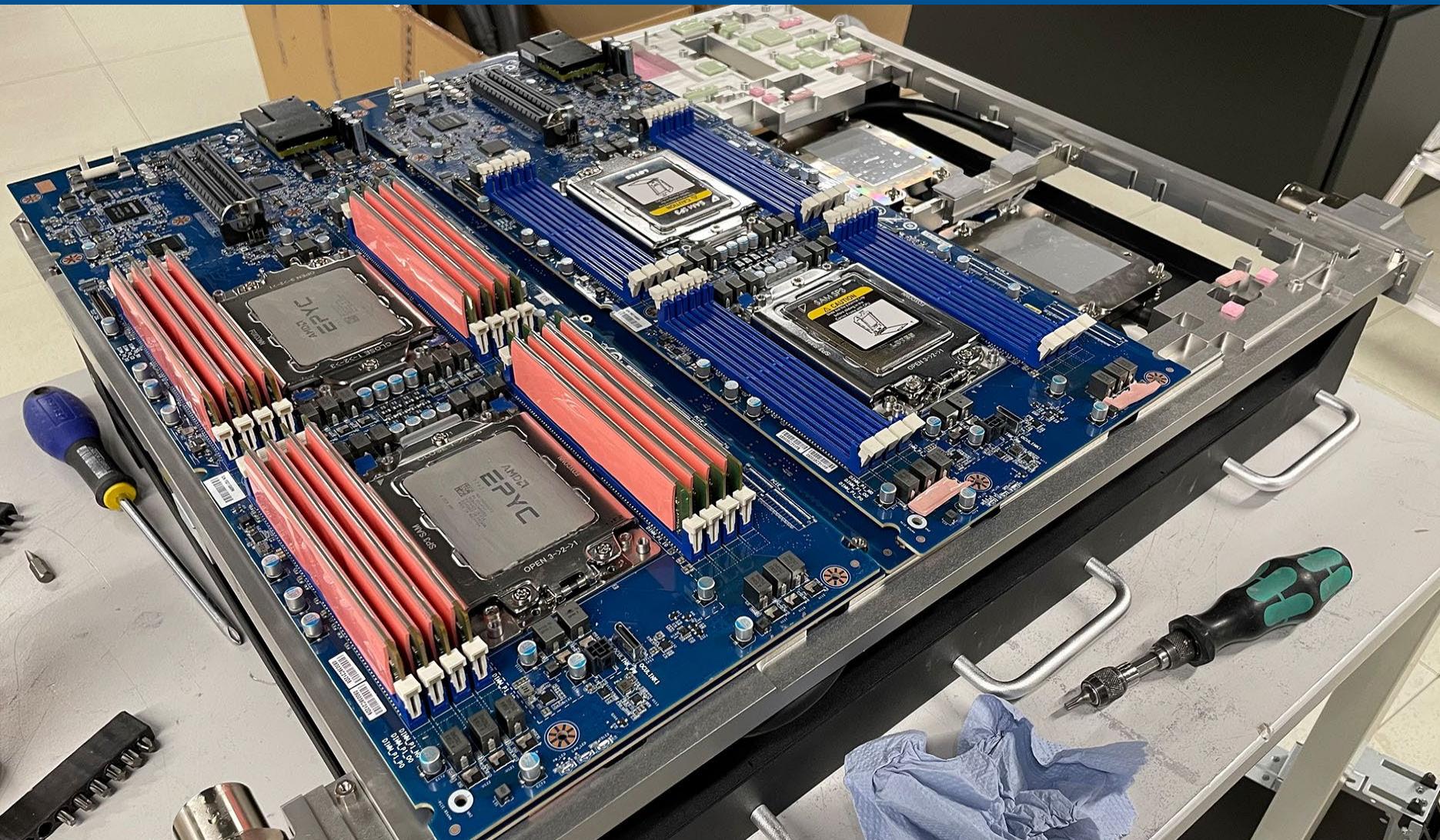
HLRE-4 „Levante“

3 CPU-Knoten pro Blade

32 Blades pro Rack

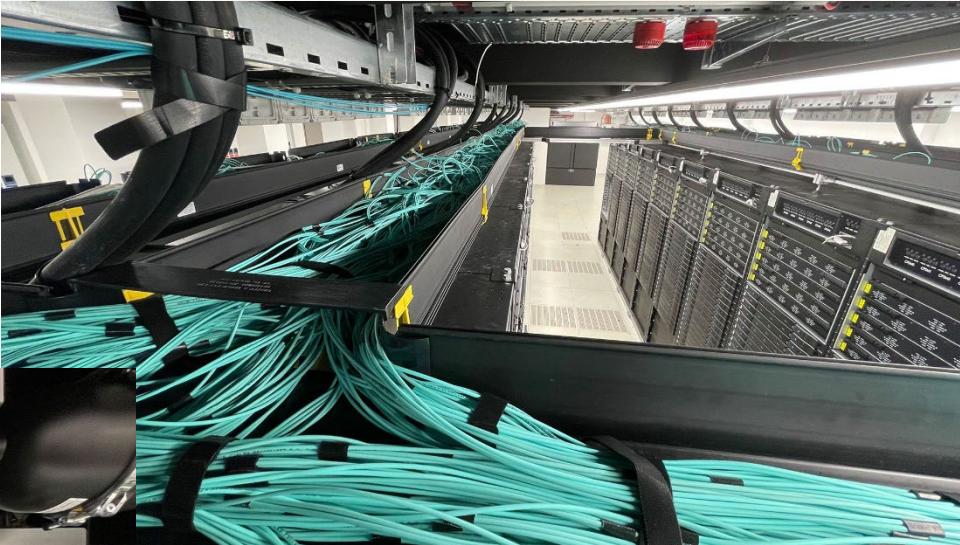
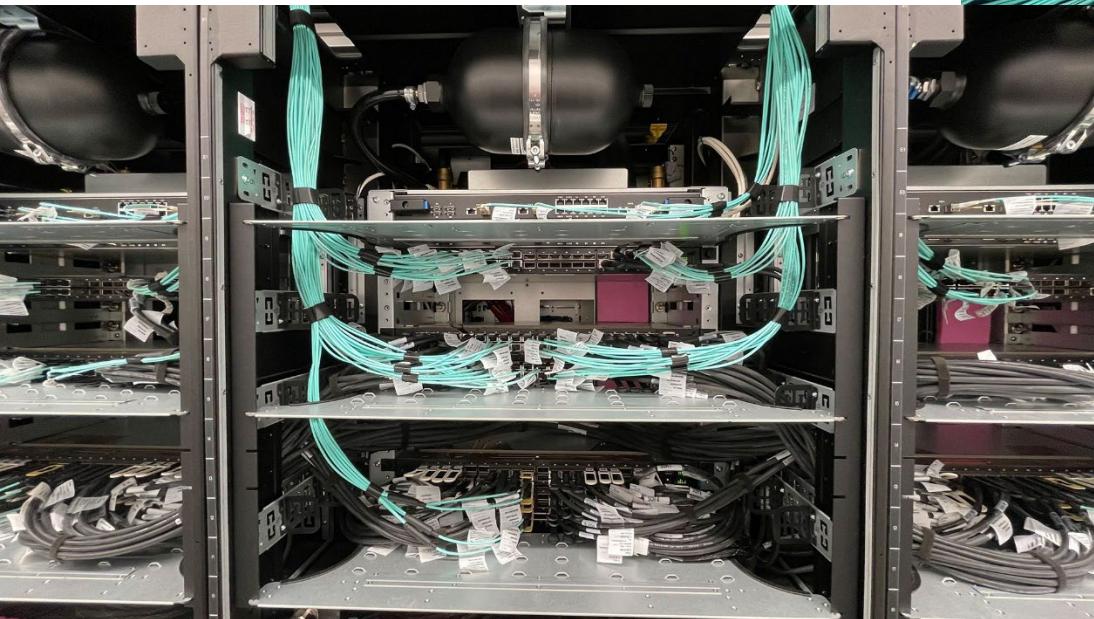
= 96 CPU-Knoten pro Rack





Hochgeschwindigkeitsnetzwerk

- NVIDIA Mellanox InfiniBand HDR 100G/200G
- Anbindung der Rechnerknoten mit 100 Gbit/s



Festplattenspeichersystem



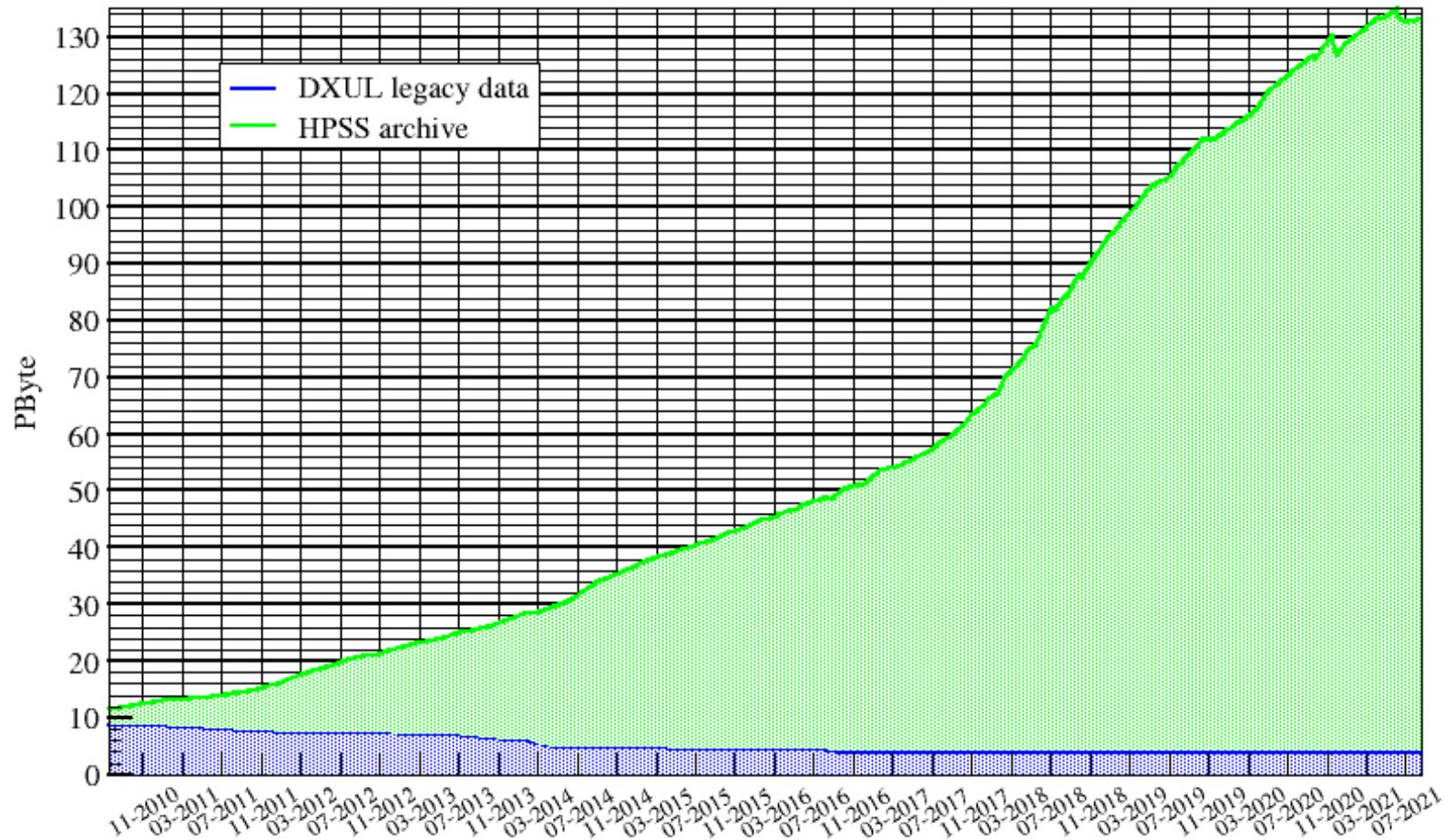
Hersteller: DDN

Paralleles Dateisystem: 132 Petabyte

Magnetbandsilo



Das Datenarchiv am DKRZ



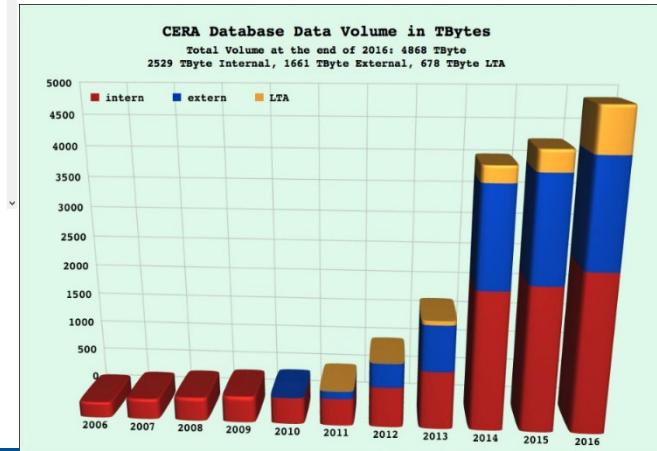
Das World Data Centre for Climate am DKRZ

The screenshot shows a web browser window with three tabs: "HRE-3 'Mistral' — DKRZ", "World Data Center for Clim...", and "CERA - WDCC". The main content is a search results page for "IPCC AR5". The header includes the WDC CLIMATE logo and the DKRZ logo. On the left, there's a map of the world and a sidebar with filters like "Citation-DOI" (793), "Bounding box", "Temporal coverage", "Project" (15), "Topic Name" (722), "Keywords" (229), "Aggregation" (13), "Type" (5), "Code Type" (10), "Institutes" (71), "Persons" (330), and "Format" (12). The search results list several items under "IPCC-DDC_AR5 (IPCC Data Distribution Centre : Assessment Report Five data sets)":

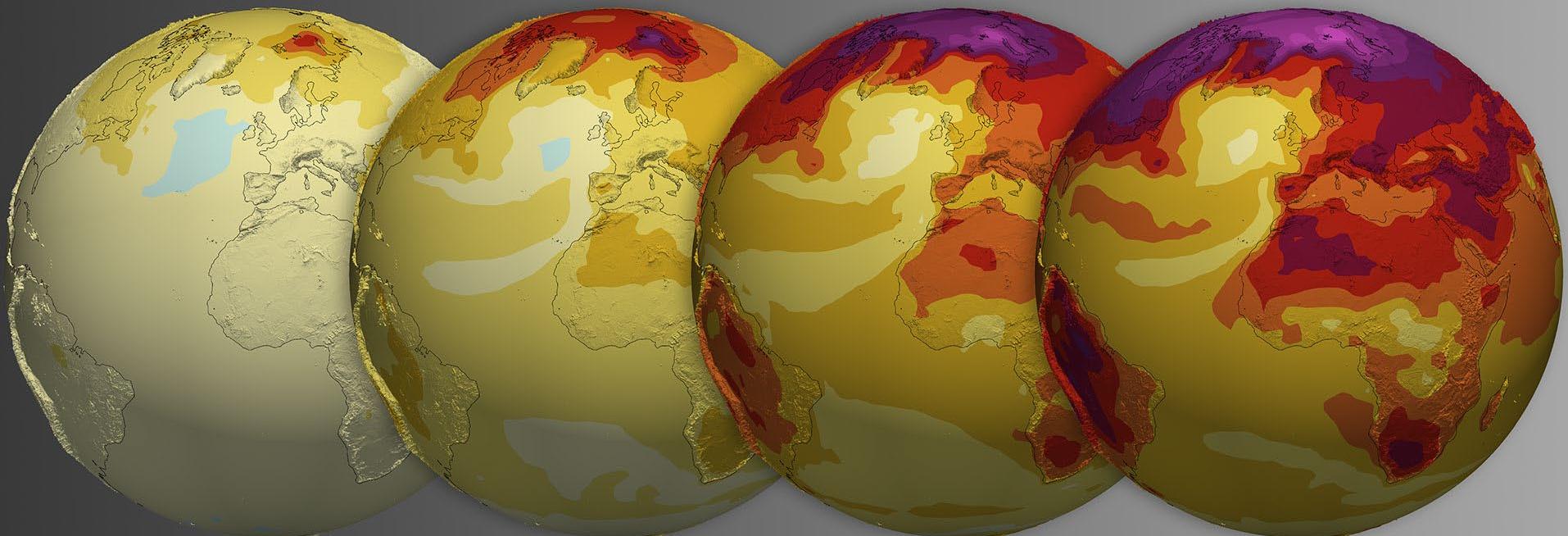
- IPCC DDC AR5 ETH Zurich/IPCC AR5 WGI additional historical experiments
- IPCC DDC AR5 ETH Zurich/IPCC AR5 WGI decadal experiments
- IPCC DDC AR5 ETH Zurich/IPCC AR5 WGI esm experiments
- IPCC DDC AR5 ETH Zurich/IPCC AR5 WGI noVole experiments
- IPCC-AR5_CMIP5 (IPCC Assessment Report 5 and Coupled Model Intercomparison Project data sets)
- IPCC DDC AR5 ETH Zurich/IPCC AR5 WGI main long-term experiments
- IPCC-DDC AR5 storage media subset
- IPCC-DDC AR5 storage media subset for Africa
- IPCC-DDC AR5 storage media subset for Asia
- IPCC-DDC AR5 storage media subset for Australia

Each item has a "DOI" or "experiment" button.

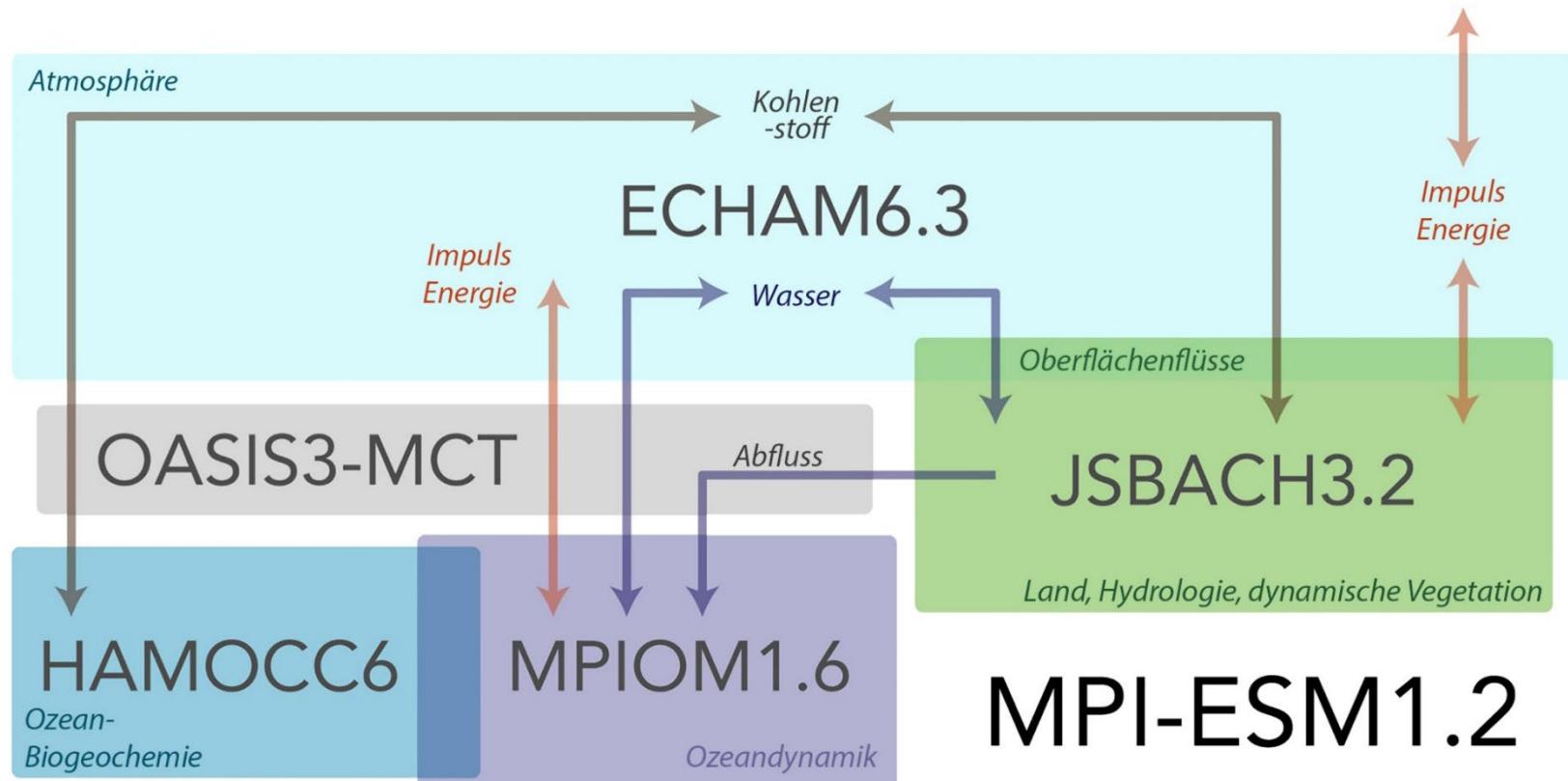
- ▶ Langzeitspeicherung
- ▶ Datenbankgröße 5 PB
- ▶ Freier Datendownload
cera-www.dkrz.de
- ▶ Stichwortsuche



Klimaprojektionen



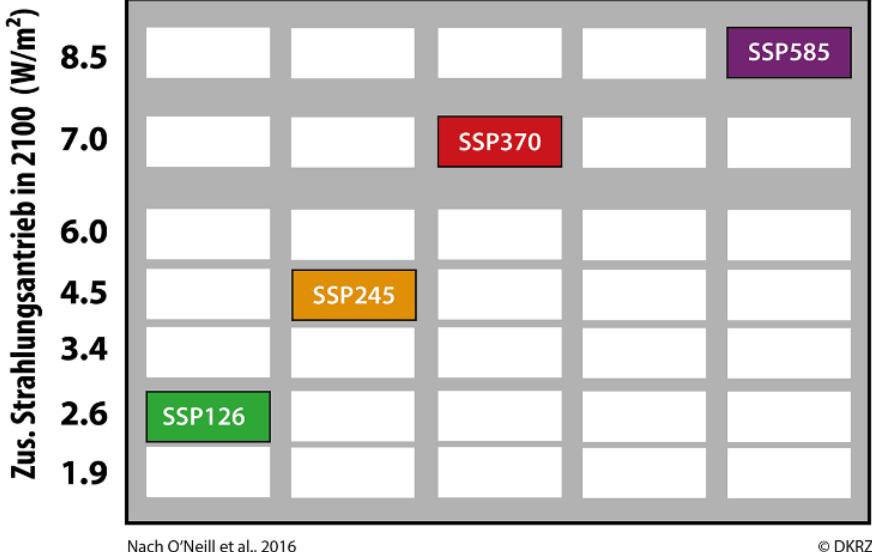
Erdsystem-Modell



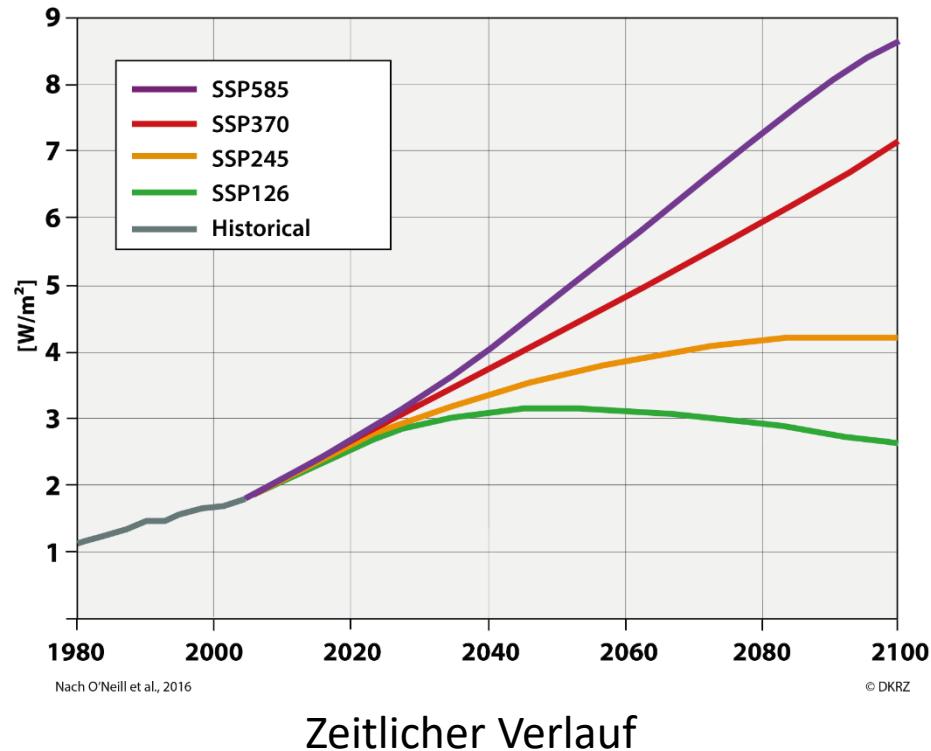
(übersetzt, Quelle: Mauritsen et al., 2019)

CMIP6-Rechnungen - Einführung: SSP-Szenarien

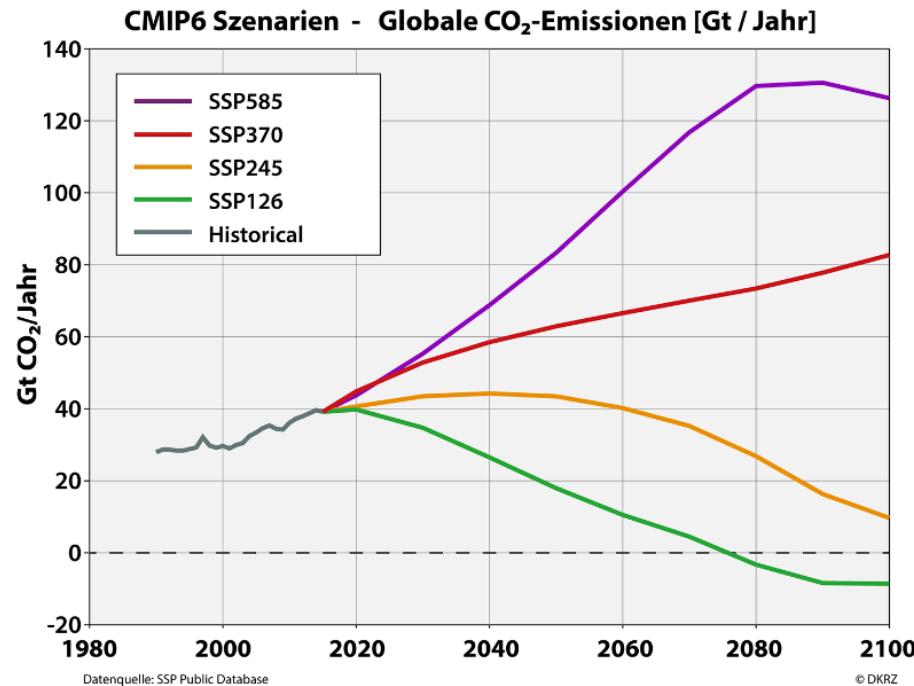
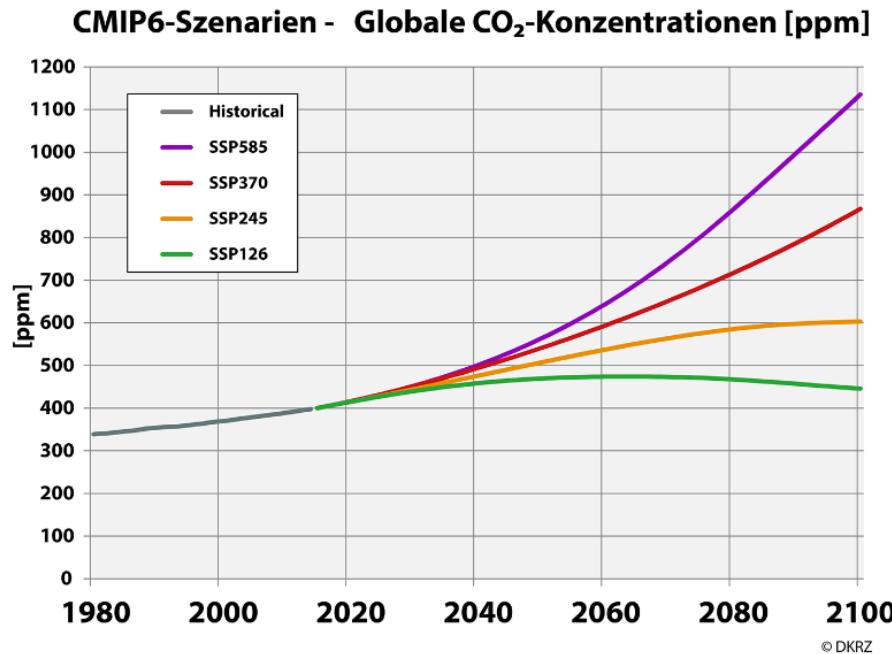
Gemeinsame sozioökonomische Entwicklungspfade (SSPs)



CMIP6 Szenarien - zusätzlicher Strahlungsantrieb [W/m^2]

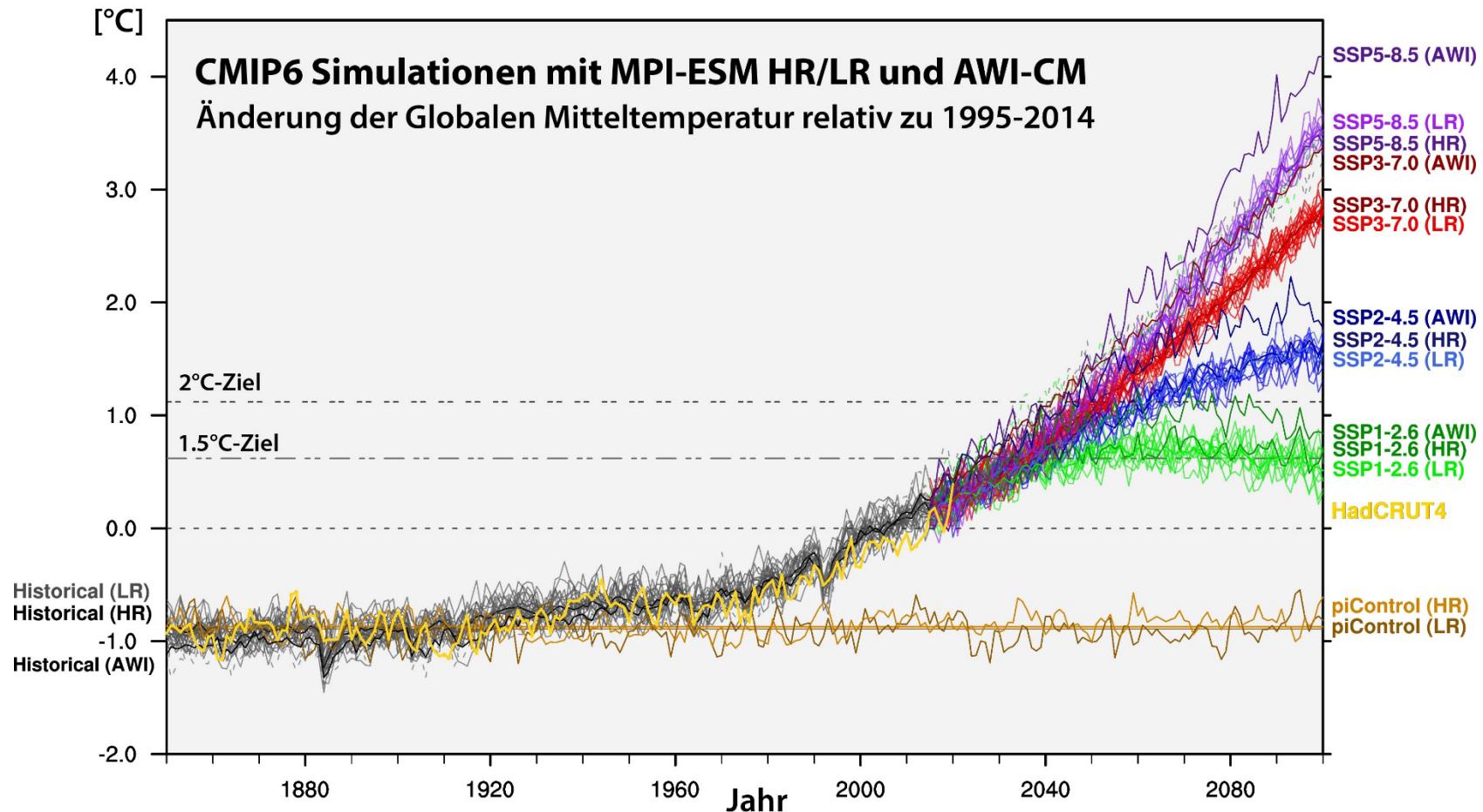


CMIP6-Rechnungen - Einführung: SSP-Szenarien



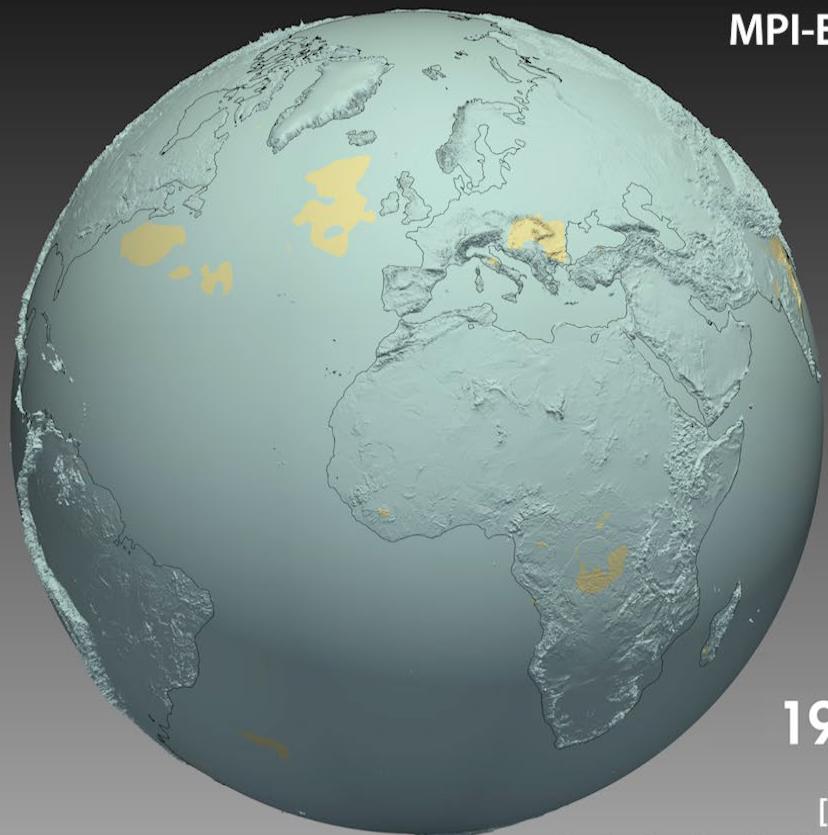
Welche Emissionen sind „erlaubt“?

Deutsche CMIP6-Rechnungen - Übersicht



Temperaturänderung gegenüber 1995-2014

MPI-ESM HR



1999

[°C]

SSP126



SSP585

© DKRZ /MPI-M

Euro-Cordex

Änderung der Anzahl von Hitzetagen gegenüber 1971-2000



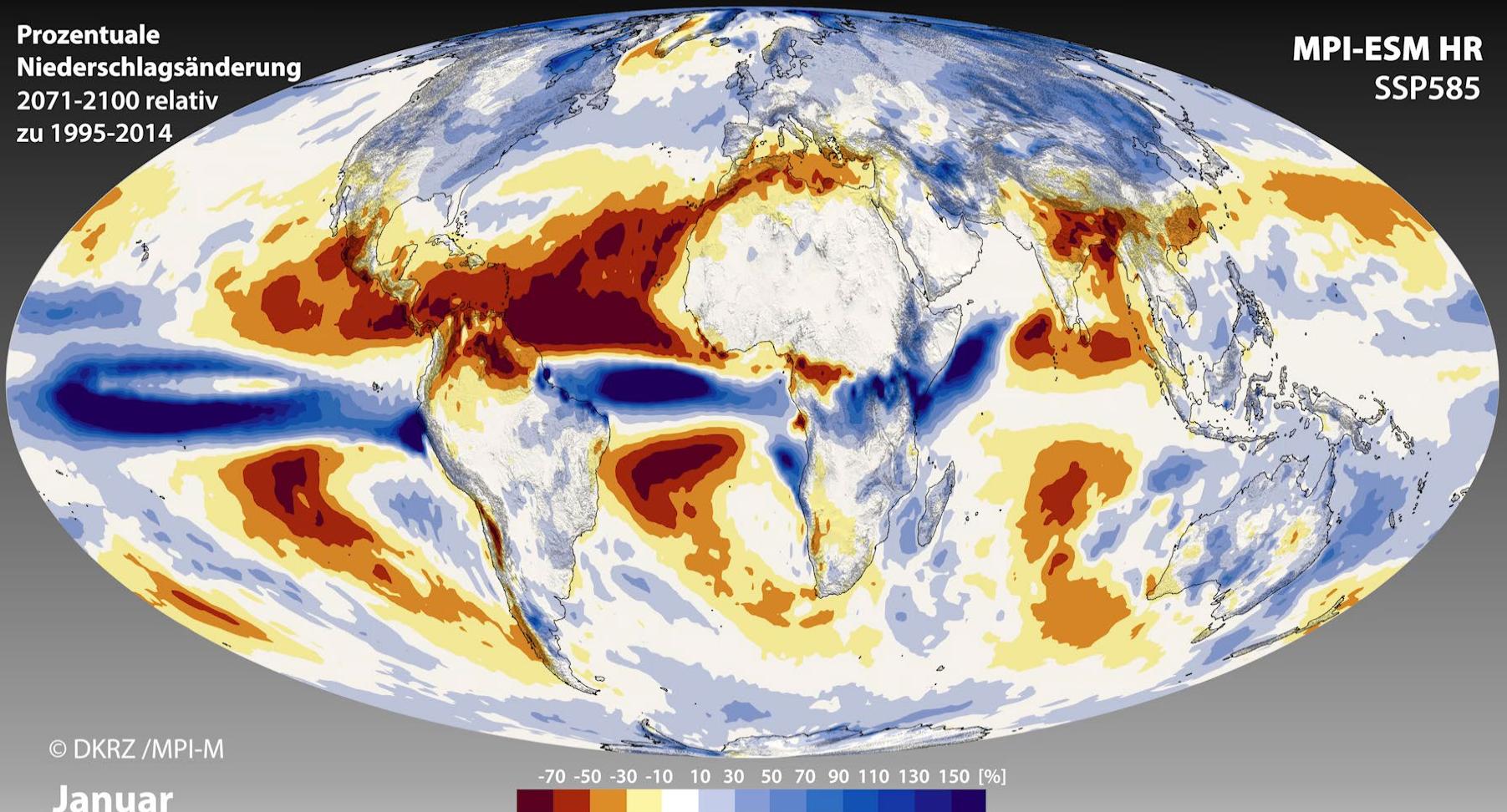
1986

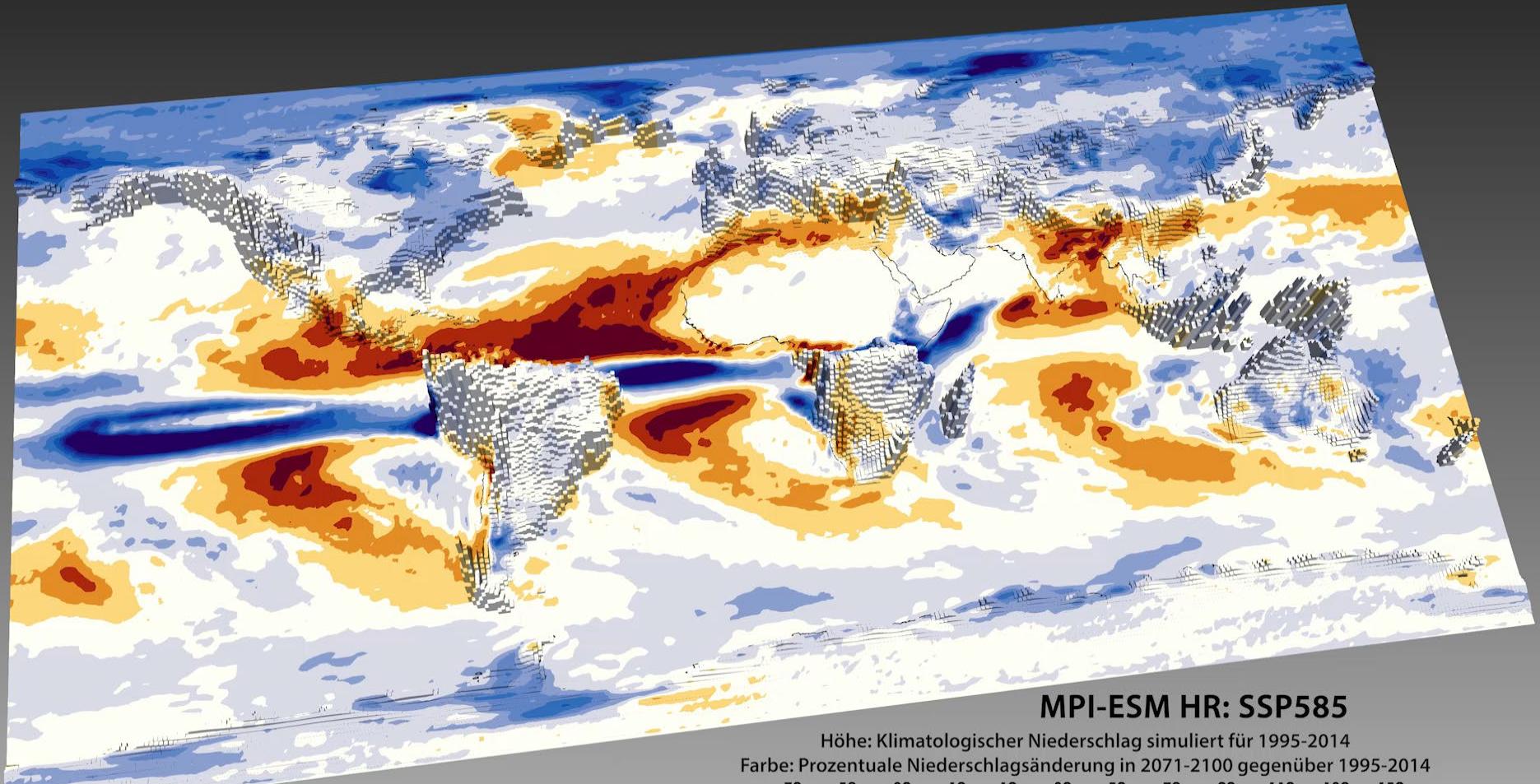


© DKRZ / GERICS

Prozentuale
Niederschlagsänderung
2071-2100 relativ
zu 1995-2014

MPI-ESM HR
SSP585





MPI-ESM HR: SSP585

Höhe: Klimatologischer Niederschlag simuliert für 1995-2014
Farbe: Prozentuale Niederschlagsänderung in 2071-2100 gegenüber 1995-2014

-70 -50 -30 -10 10 30 50 70 90 110 130 150



Januar

© DKRZ /MPI-M

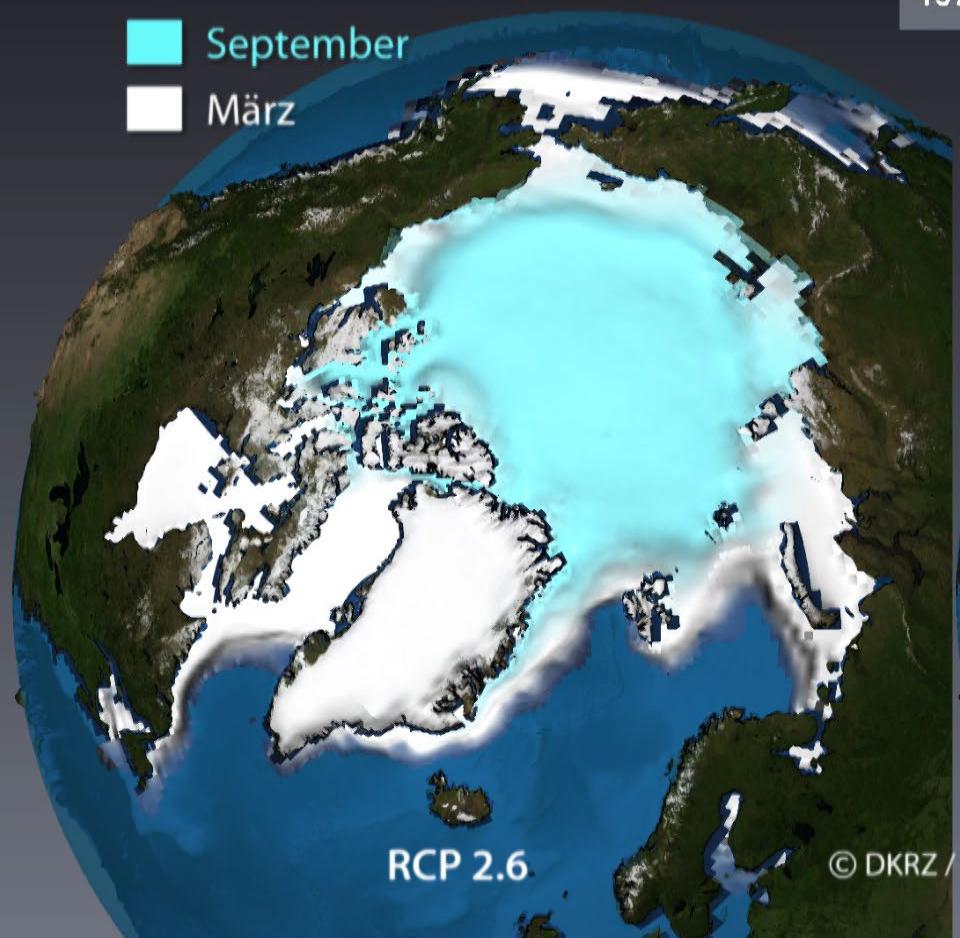
Meereis-Konzentration

September

März

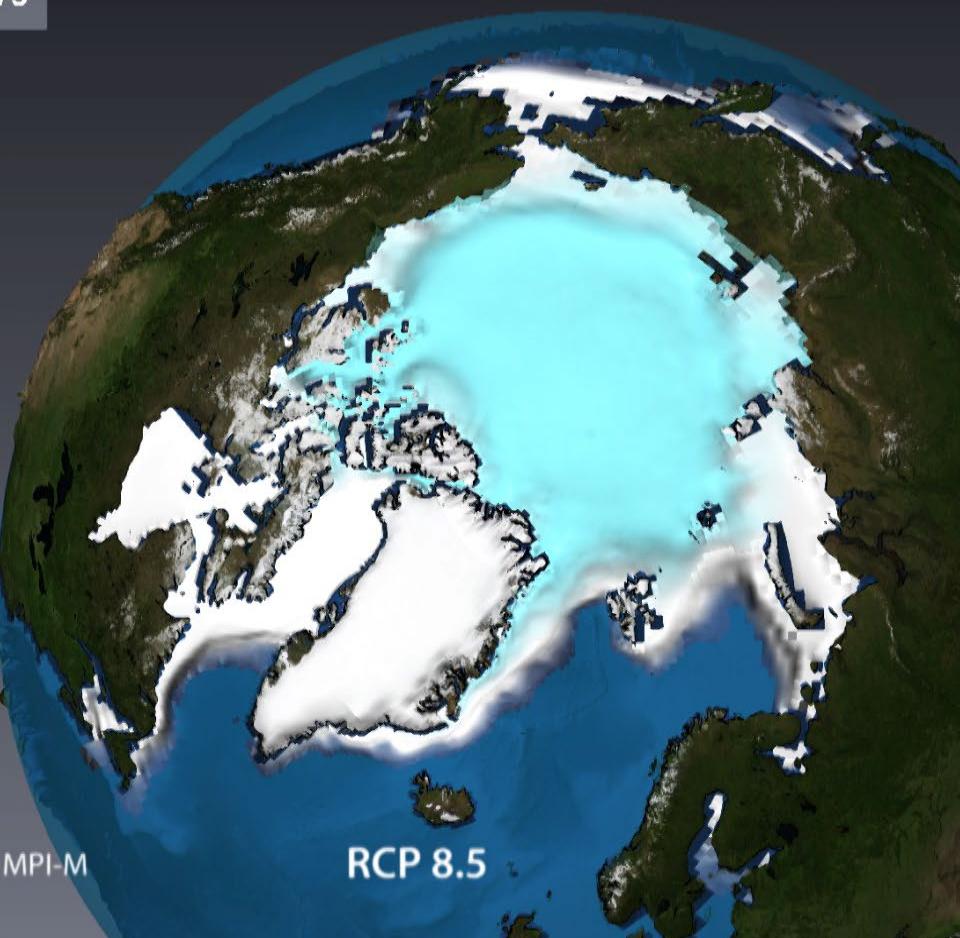
1975

MPI-ESM LR



RCP 2.6

© DKRZ / MPI-M



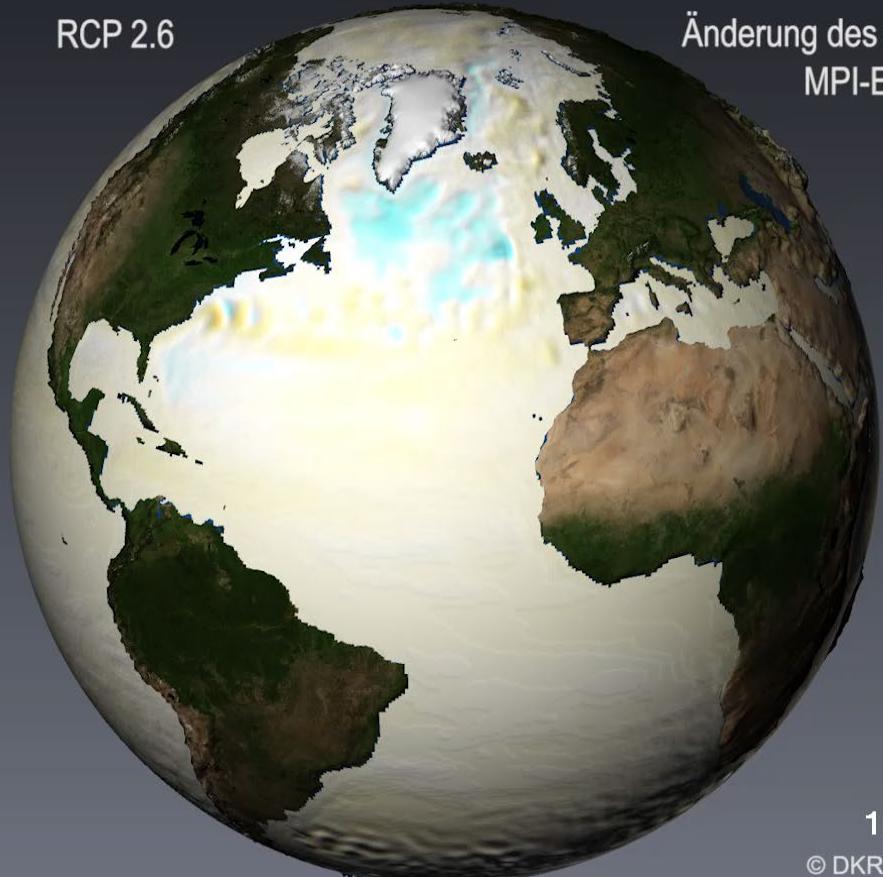
RCP 8.5



RCP 2.6

Änderung des Meeresspiegels
MPI-ESM MR

RCP 8.5



1975

© DKRZ / MPI-M

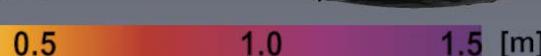
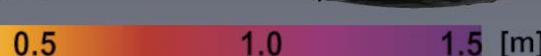
-0.5

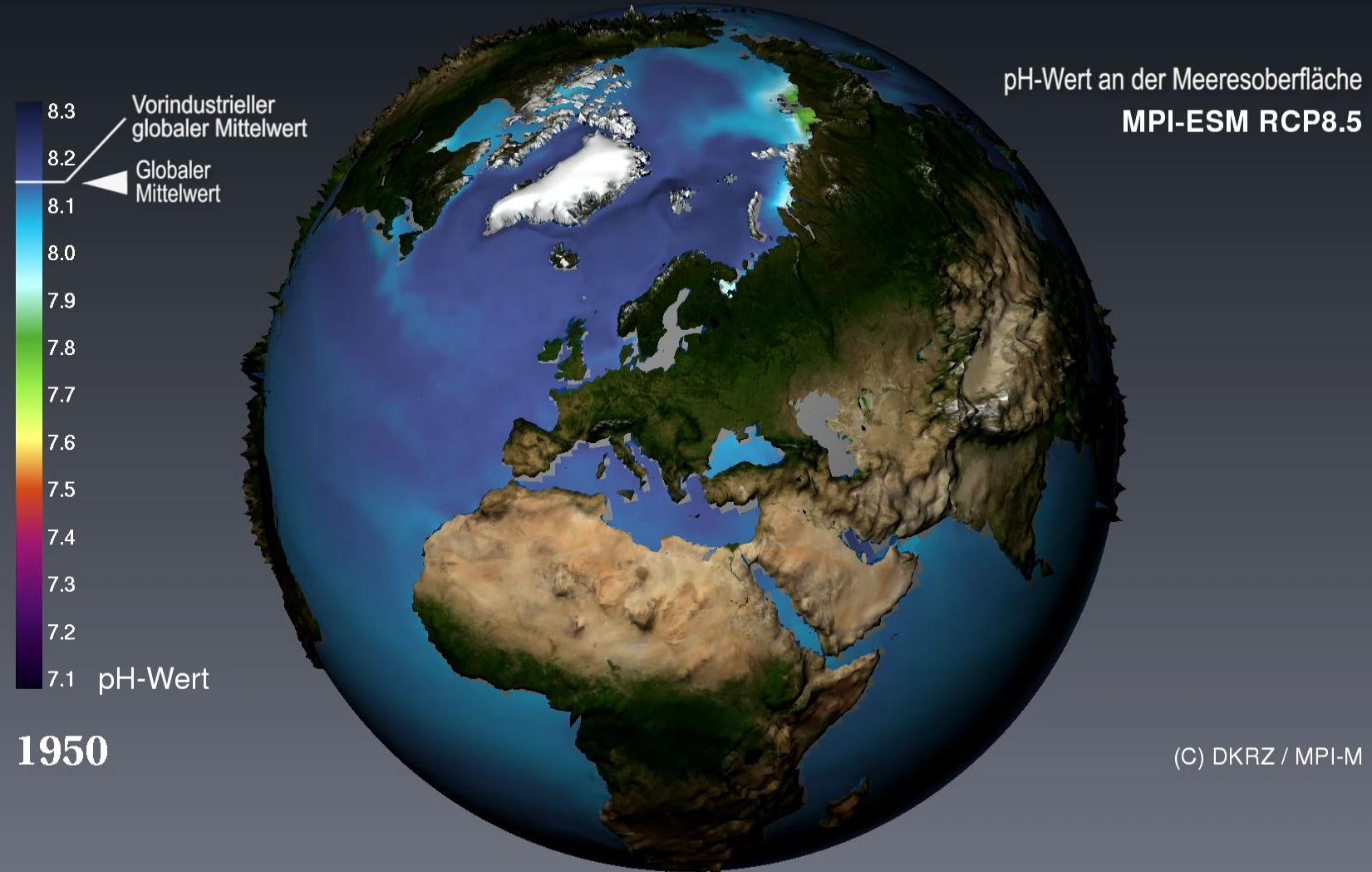
0.0

0.5

1.0

1.5 [m]

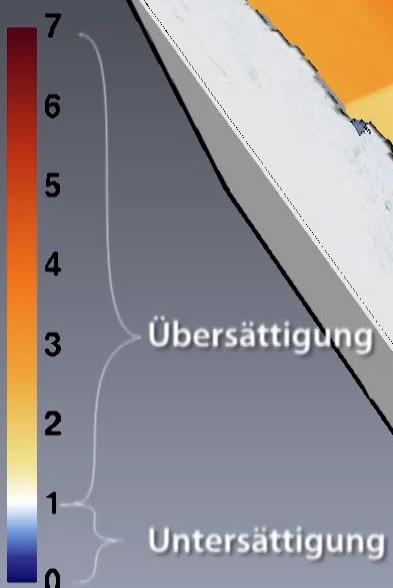




(C) DKRZ / MPI-M

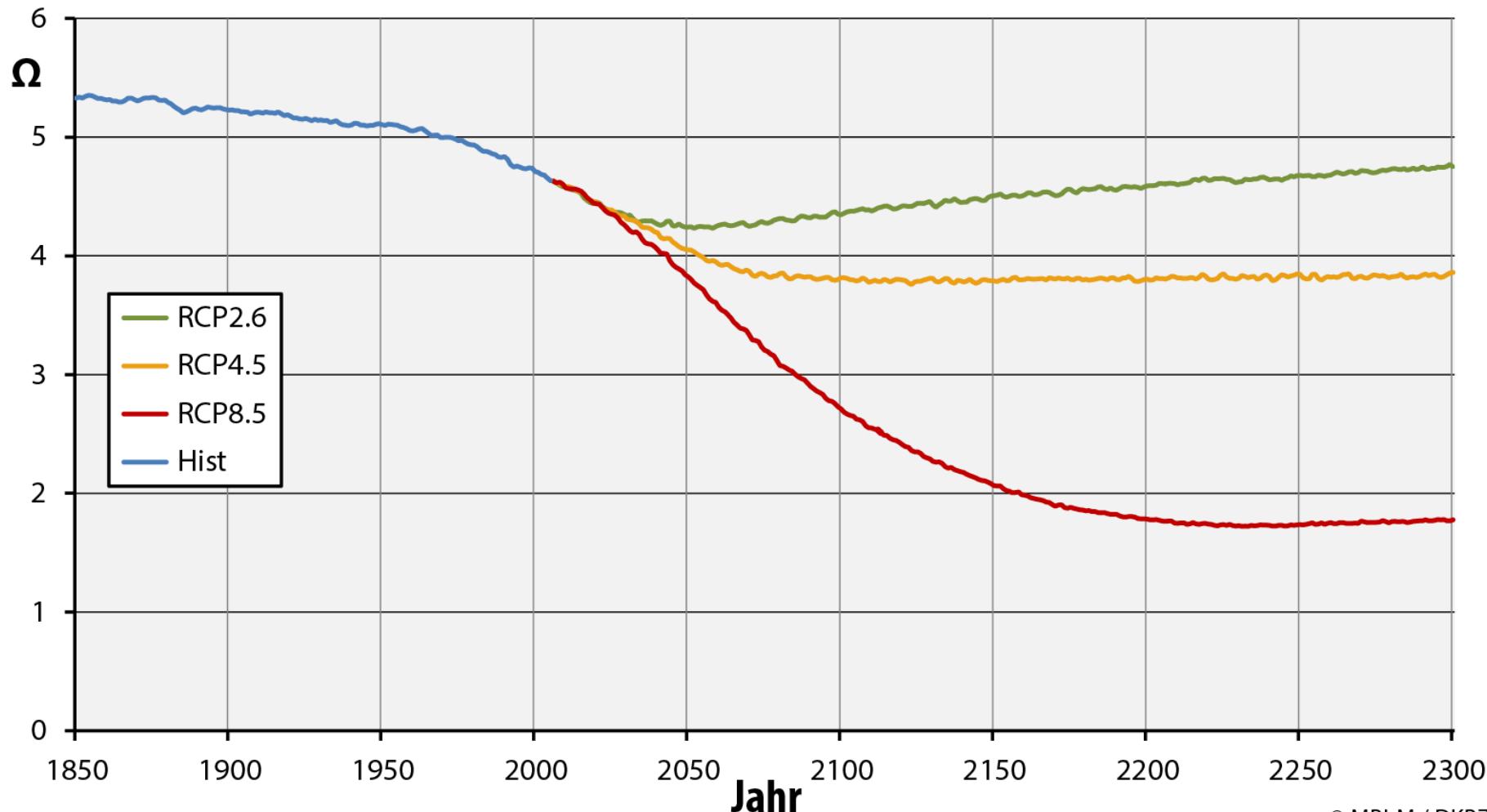
Karbonat-Sättigung
(Kalzit)

MPI-ESM RCP 8.5



1950 © DKRZ / MPI-M

MPI-ESM: global gemittelte Kalzit-Sättigung an der Meeresoberfläche



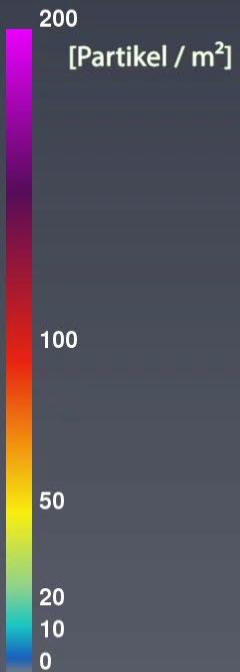


(C) DKRZ / MPI-M

Plastikmüll im Ozean

Partikelquelle: Ozeanoberfläche

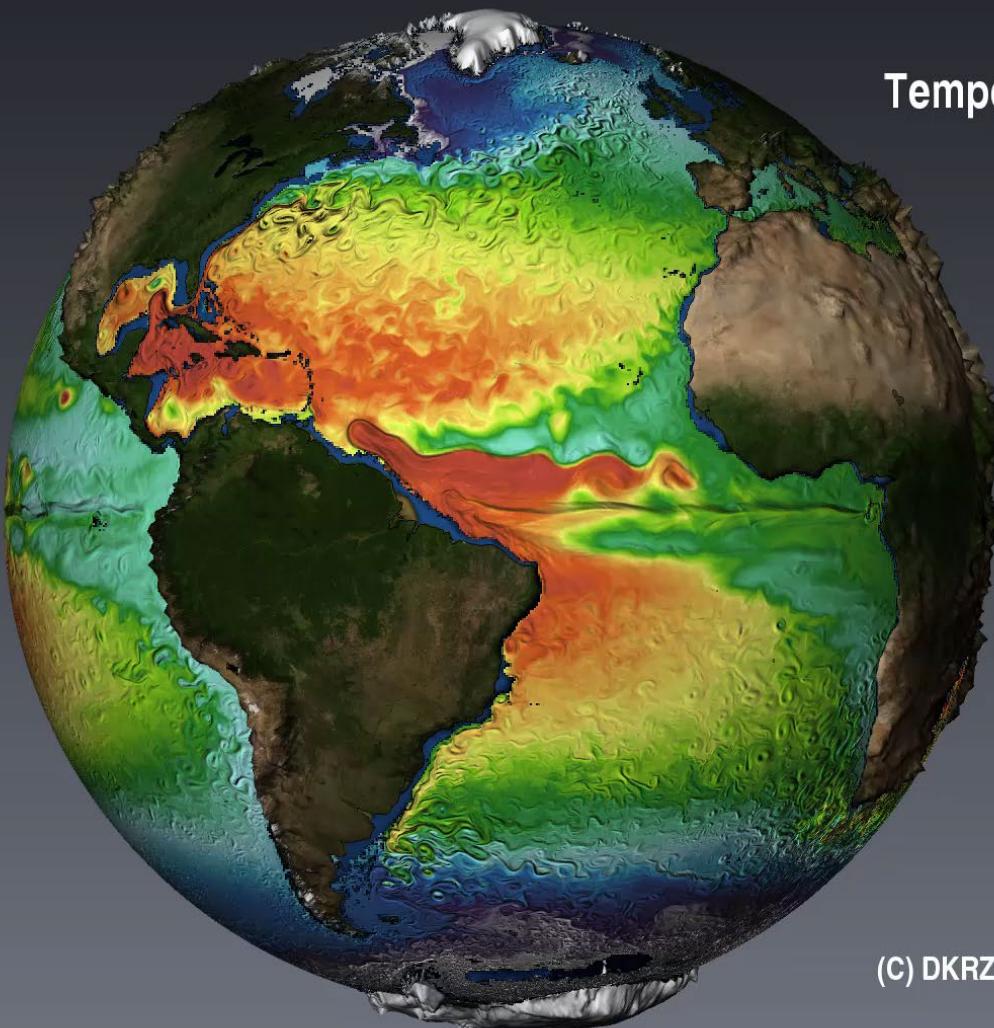
Modell: MPI-OM TP04



01/01/0001

(C) DKRZ / MPI-M

Temperature and Velocity
at 75m depth
MPI-OM TP6M



01.01.

(C) DKRZ / MPI-M / STORM-Consortium

Phytoplankton

50 [mg Chl / m³]

-32

16

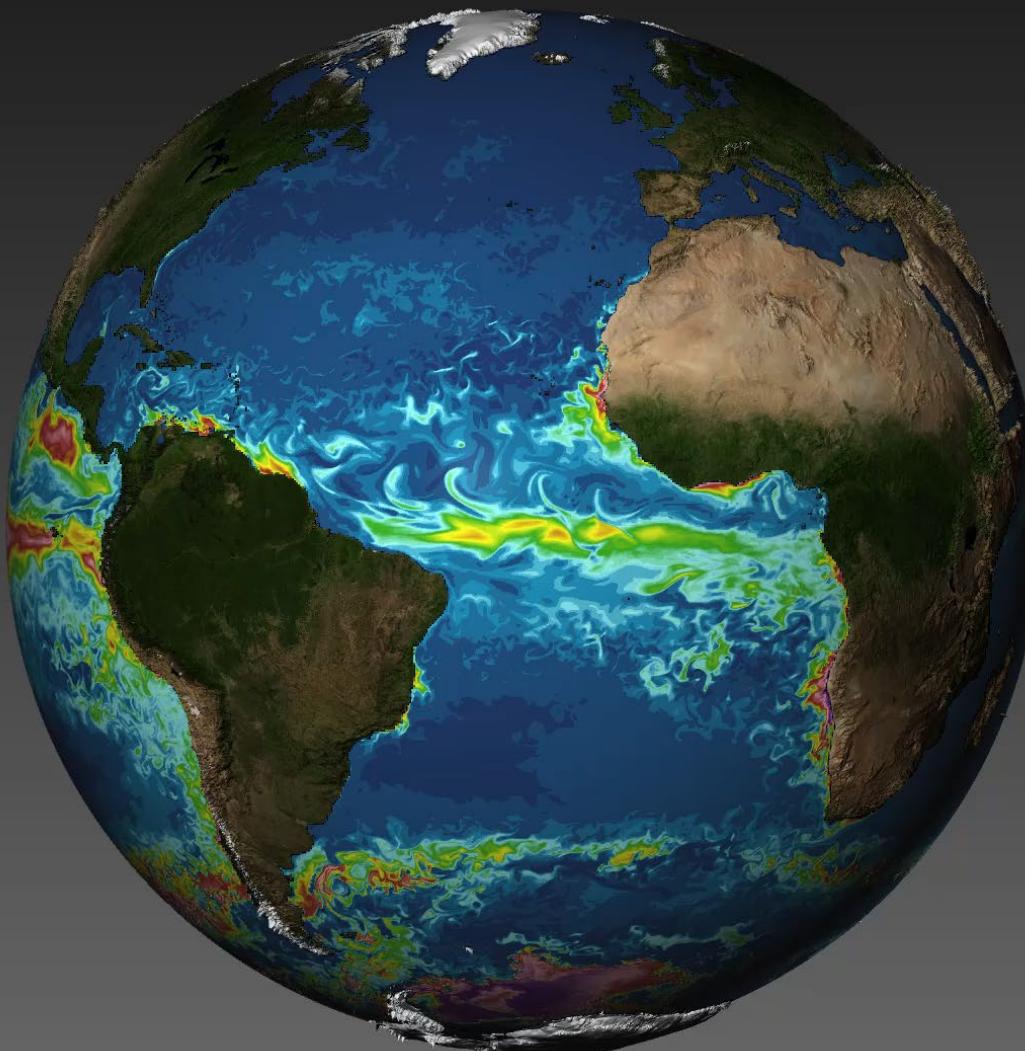
-8

4

1

0

2001/01/01



HAMOCC/MPIOM TP6M

(C) DKRZ/MPI-M

**Sea Ice
Concentration (Opacity)
and Thickness (Height)**

FESOM



01/01/2005

(C) DKRZ / AWI

Surface Elevation and Velocity

[m/s]

1.4

1.2

1.0

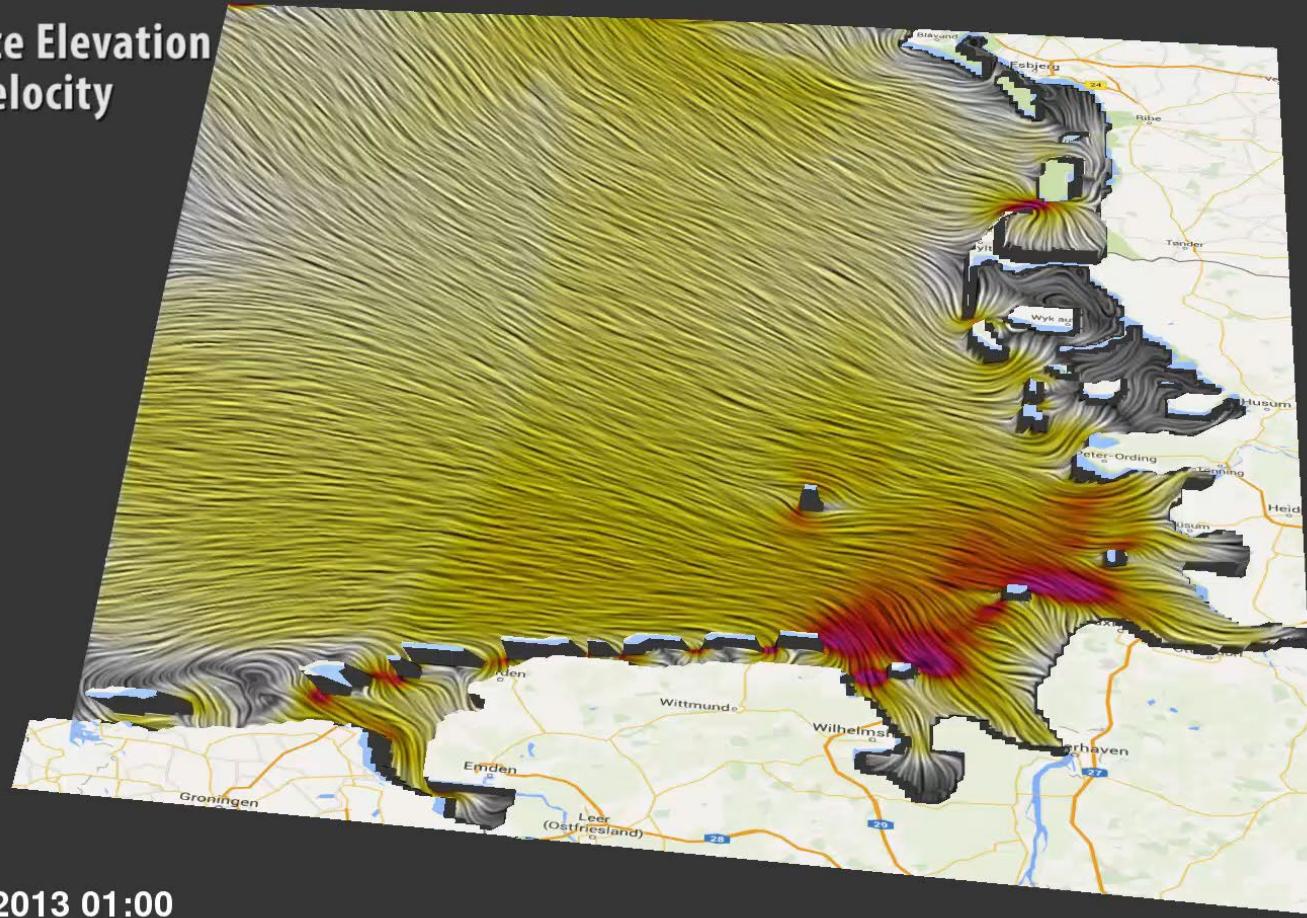
0.8

0.6

0.4

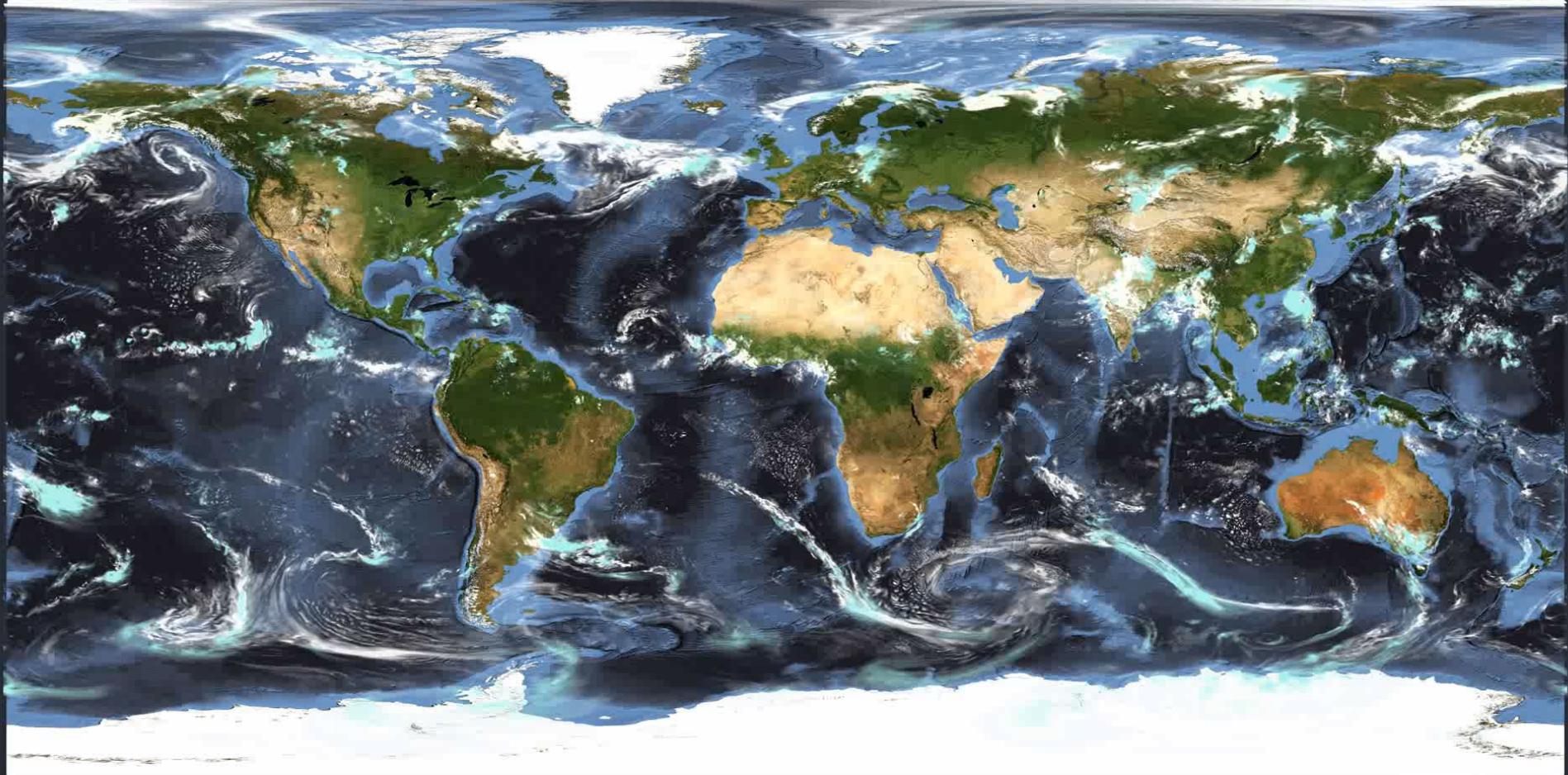
0.2

0

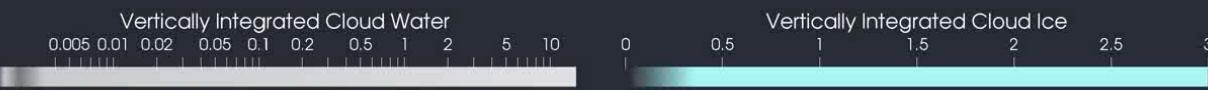


25.11.2013 01:00

(C) DKRZ / HZG



ICON DYAMOND R2B10 2.5km Resolution
01.08.2016 at 00:00





$\text{HD}(\text{CP})^2$

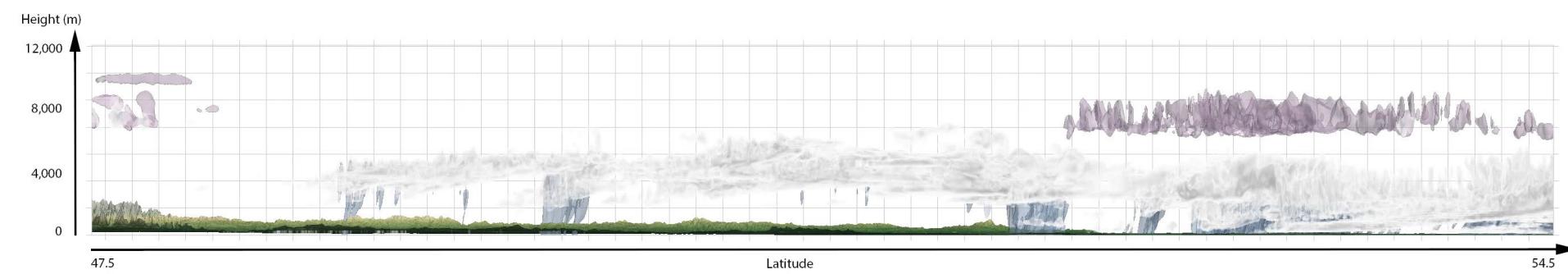
Blue Isosurface: Rain Water 0.0001 kg/kg Purple Isosurface: Cloud Ice 0.0001 kg/kg

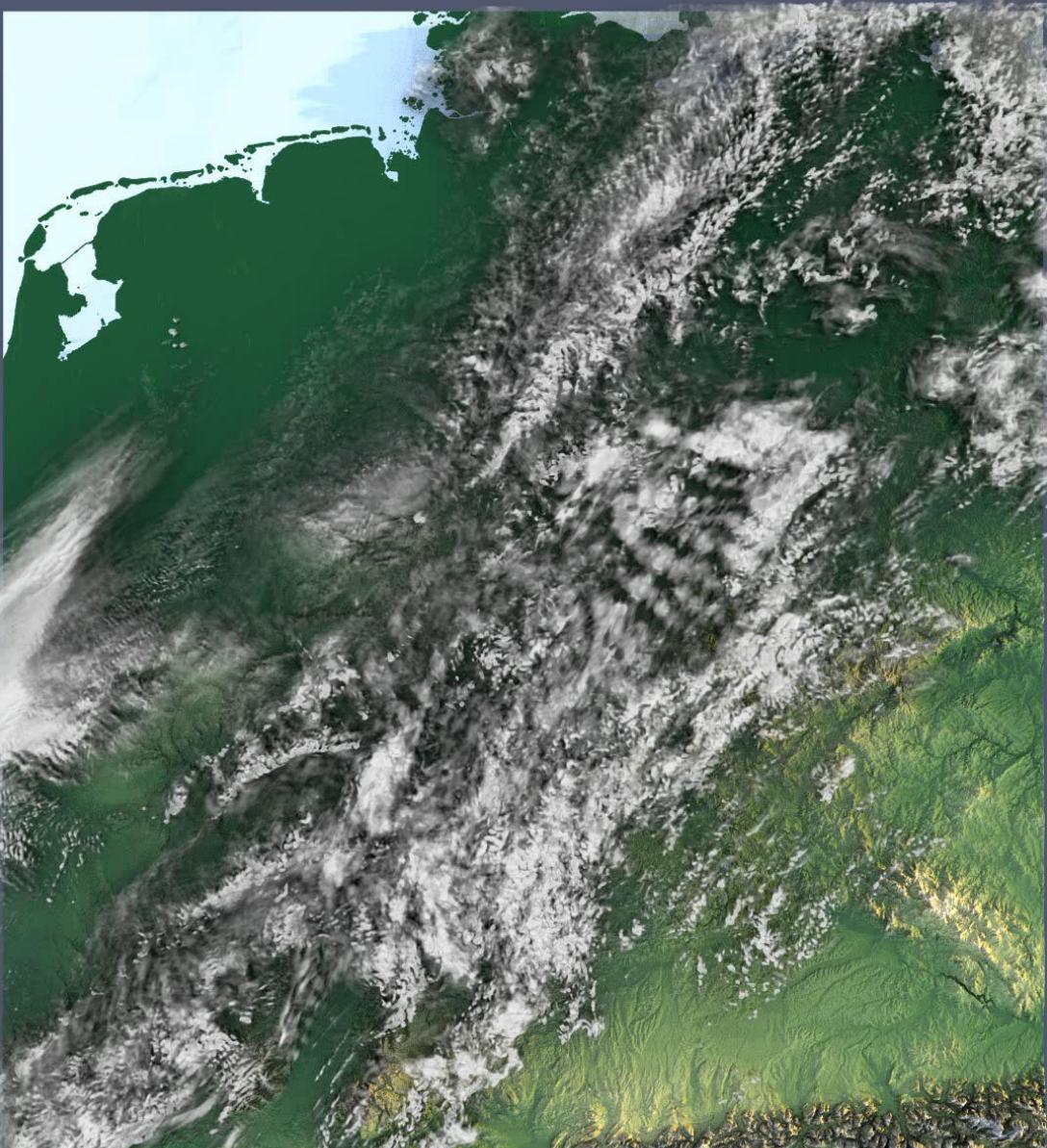
26/04/2013 00:00

0 0.001 0.002 0.003 0.004 [kg/kg]

Specific Cloud Water Content

(C) DKRZ / MPI-M





www.dkrz.de
boettinger@dkrz.de