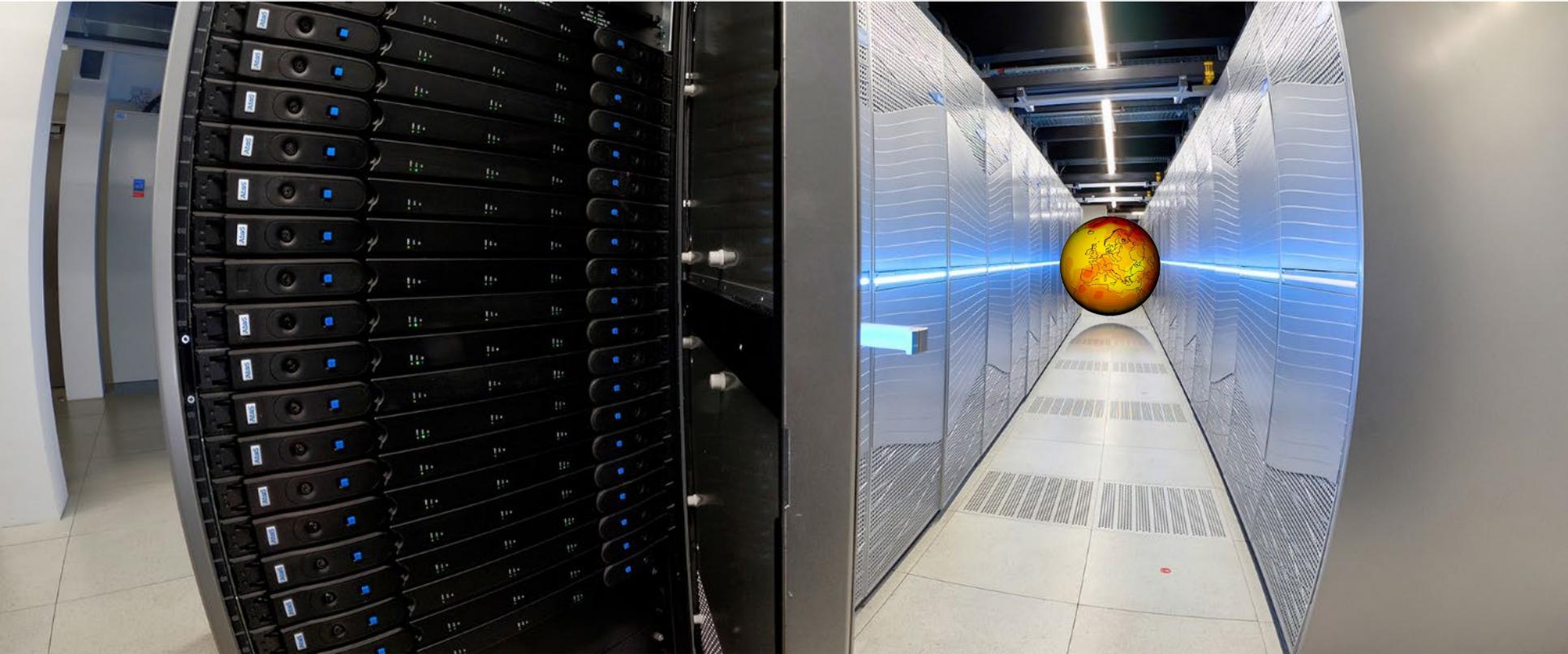


Deutsches Klimarechenzentrum - Das Weltklima im Hochleistungsrechner



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



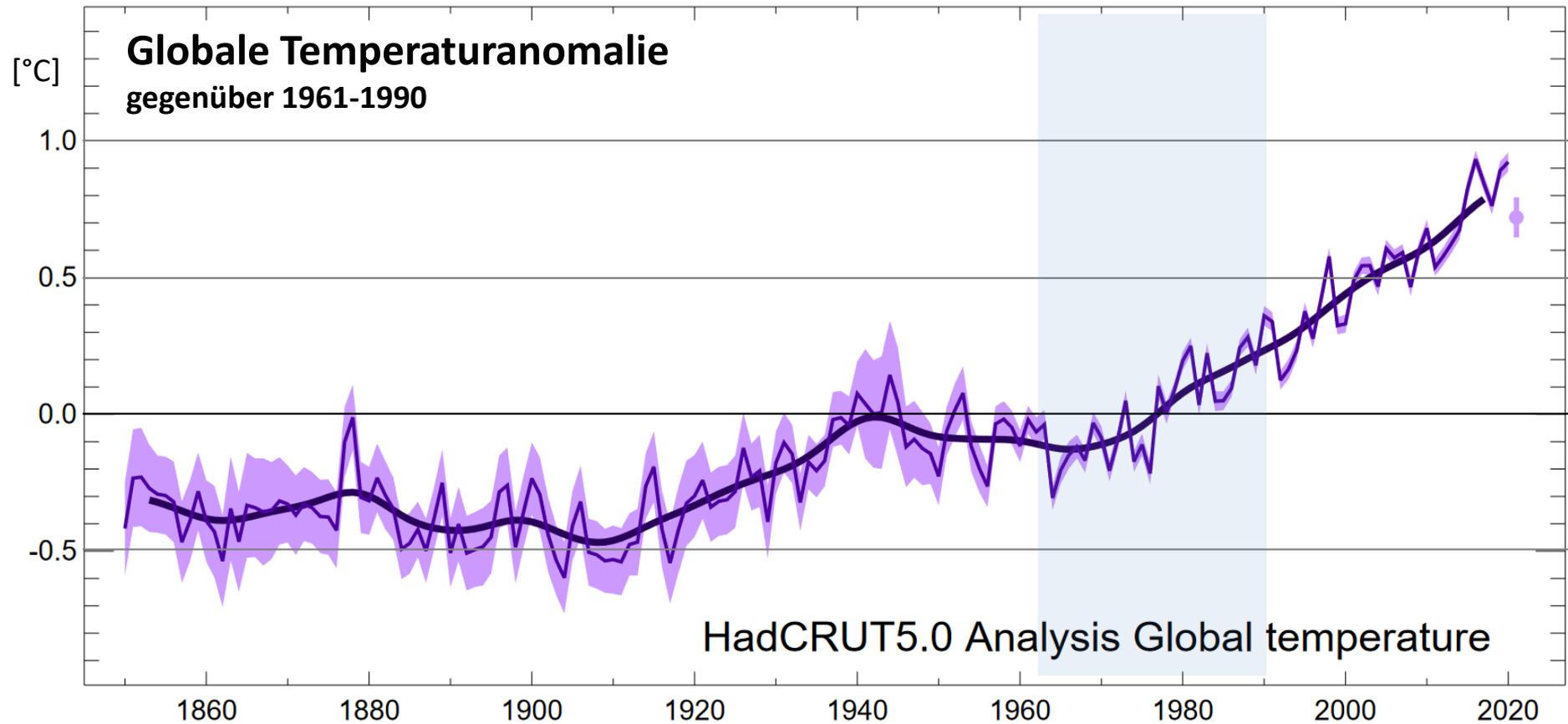
- **DKRZ (nationale Einrichtung)**



Wetter und Klima

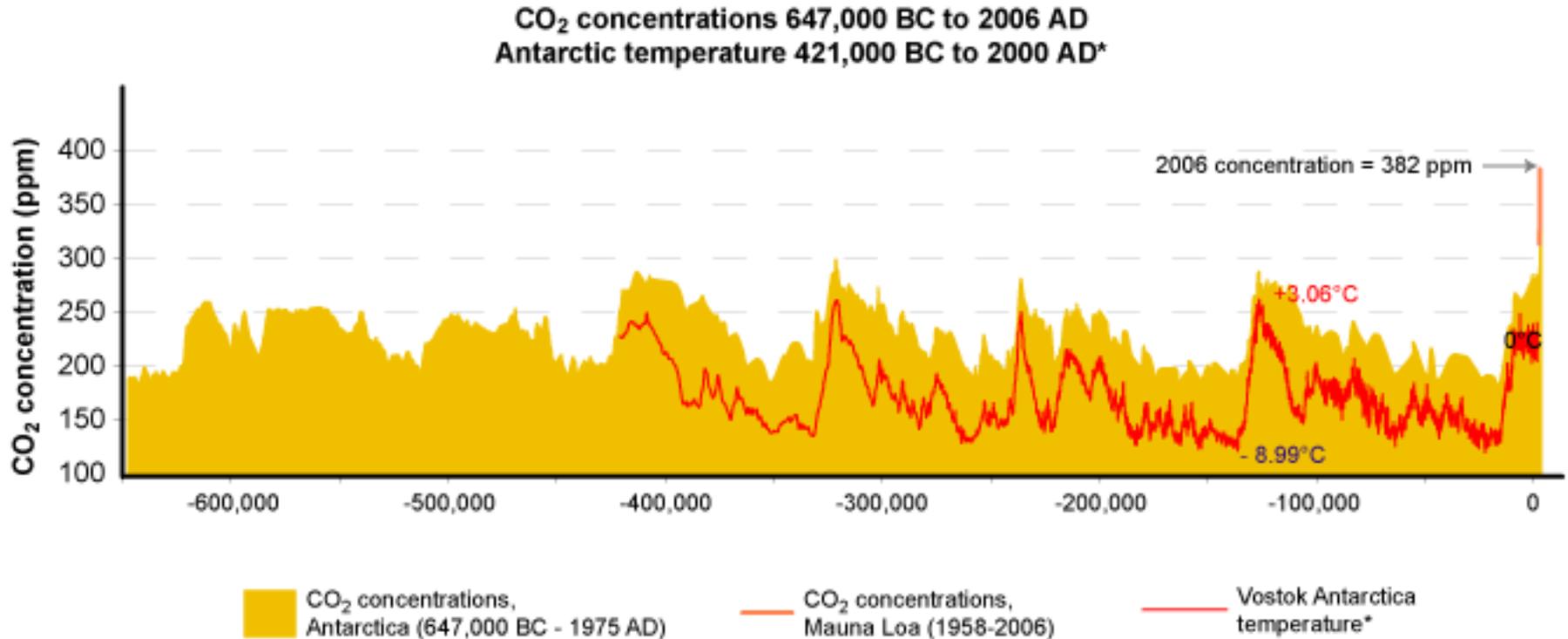


Klima auf Basis direkter Messungen



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

Blick in die Vergangenheit

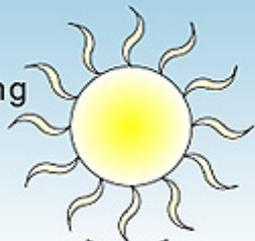


* Antarctic temperature is measured as the change from average conditions for the period 1850 AD - 2000 AD

Quelle: UNEP

Das Klimasystem

Solare Einstrahlung
(kurzwellig)



Terrestrische Ausstrahlung
(langwellig)



Wolken



Niederschlag



Luft-Eis
Wechselwirkung



Luft-Ozean
Wechselwirkung



Biogeochemische
Kreisläufe

Absorption
Reflexion
Emission



Wind



Vulkanische
Gase und
Partikel



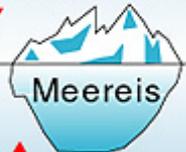
Schnee und Eis



Zuläufe



Meereis



Eis-Ozean
Wechselwirkung



Strömung



Seen und Flüsse



Land - Luft
Wechselwirkung



Menschliche
Eingriffe

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 (Erdsgeometrie, Bahnparameter, Land-
Meer-Verteilung,...)

Worauf basiert ein Modell der Atmosphäre?

Gleichungen nicht direkt lösbar ...

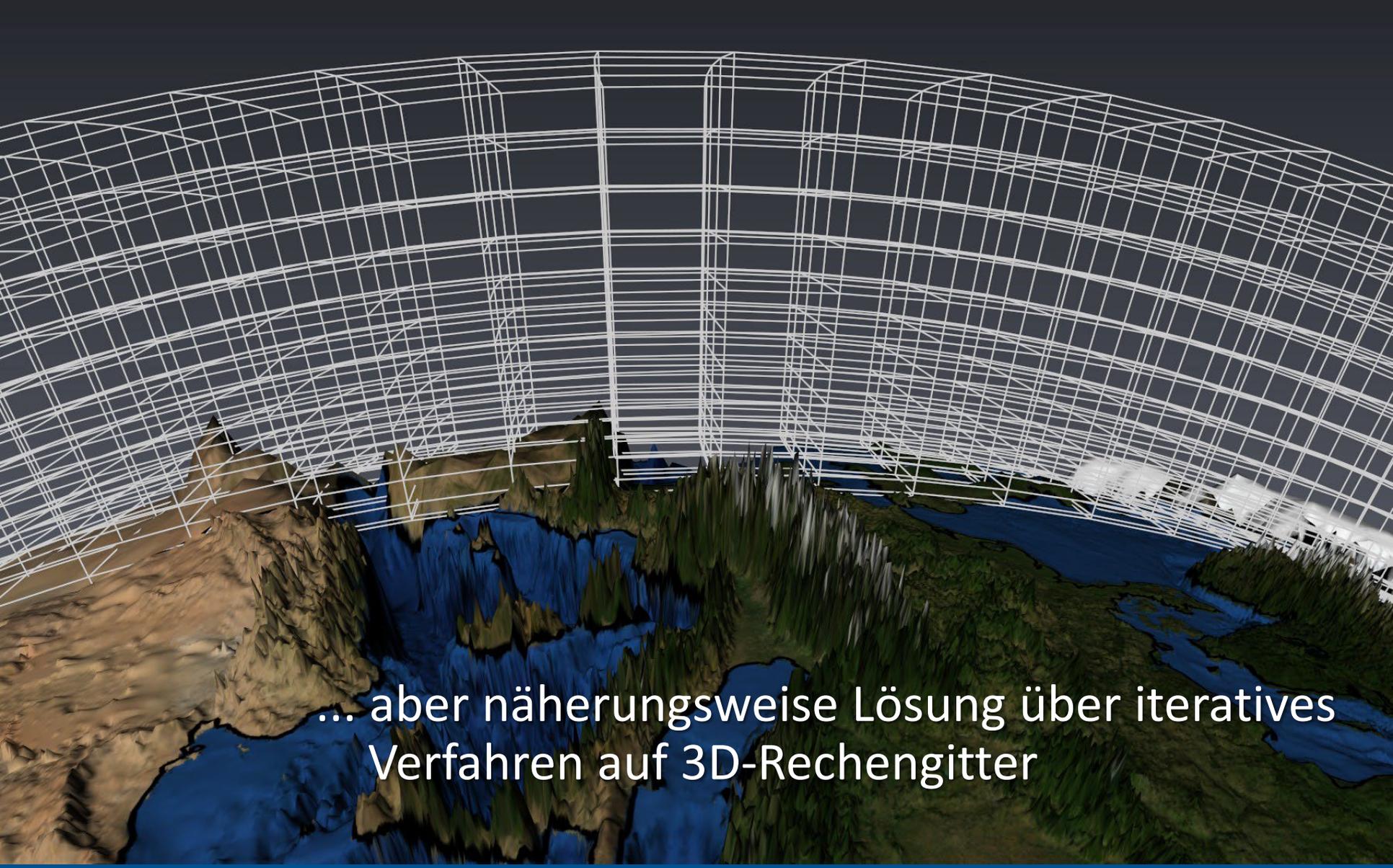
$$\frac{\partial U}{\partial t} - (f + \xi) \cdot V + \dot{\eta} \frac{\partial U}{\partial \eta} + \frac{R_d T_v}{a} \frac{\partial}{\partial \lambda} \ln p + \frac{1}{a} \frac{\partial}{\partial \lambda} (\phi + E) = P_U + K_U$$

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

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

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

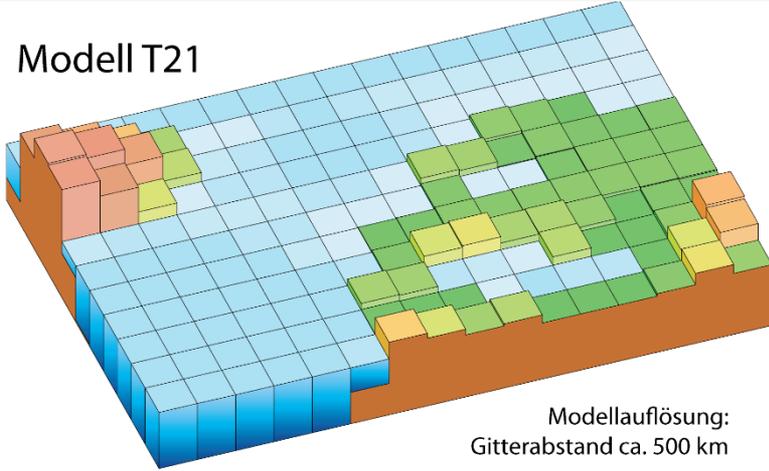
$$\frac{\partial q_w}{\partial t} + \frac{U}{a(1 - \mu^2)} \frac{\partial q_w}{\partial \lambda} + \frac{V}{a} \frac{\partial q_w}{\partial \mu} + \dot{\eta} \frac{\partial q_w}{\partial \eta} = P_{q_w} + K_{q_w}$$



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

Modell-Auflösung

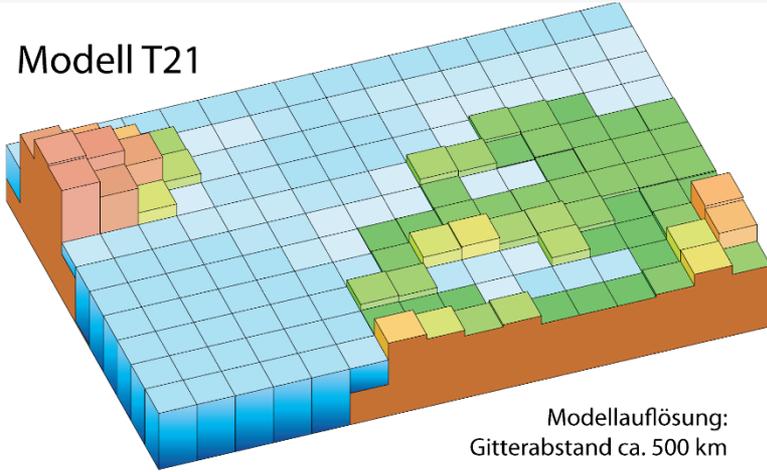
Modell T21



Modellauflösung:
Gitterabstand ca. 500 km

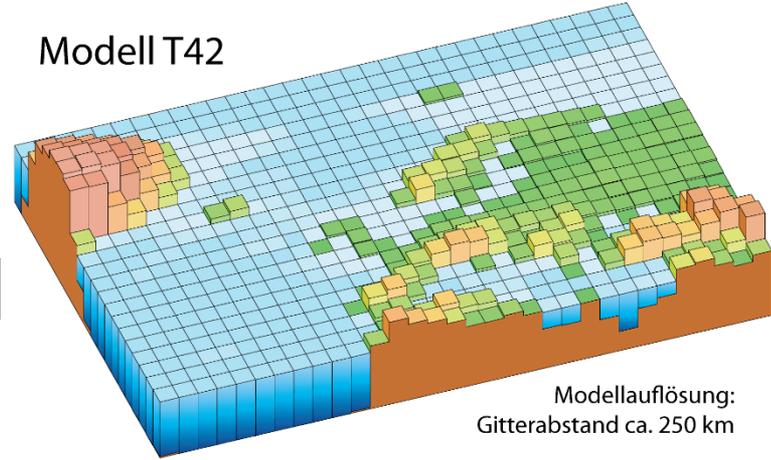
Modell-Auflösung

Modell T21



Modellauflösung:
Gitterabstand ca. 500 km

Modell T42



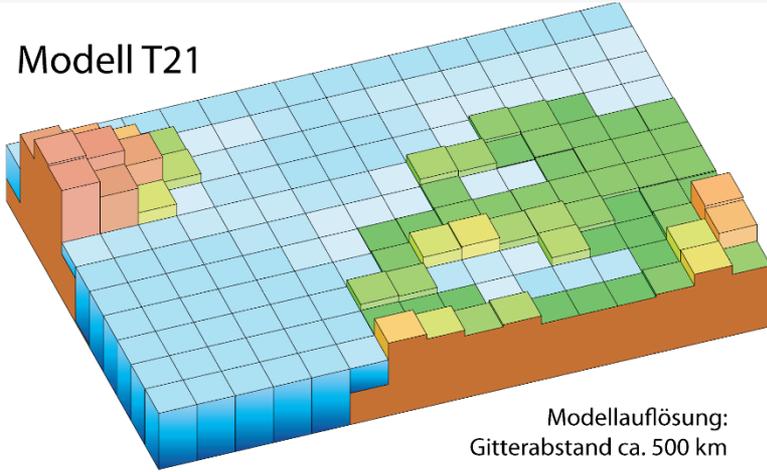
Modellauflösung:
Gitterabstand ca. 250 km



10-fache Rechenzeit!

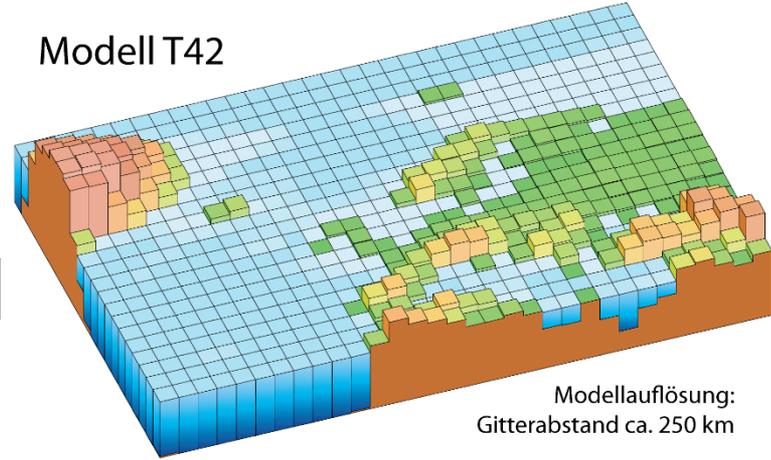
Modell-Auflösung

Modell T21



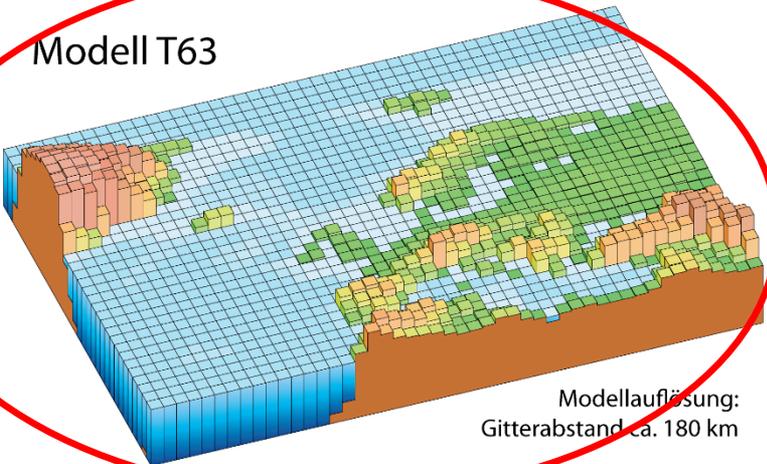
Modellauflösung:
Gitterabstand ca. 500 km

Modell T42



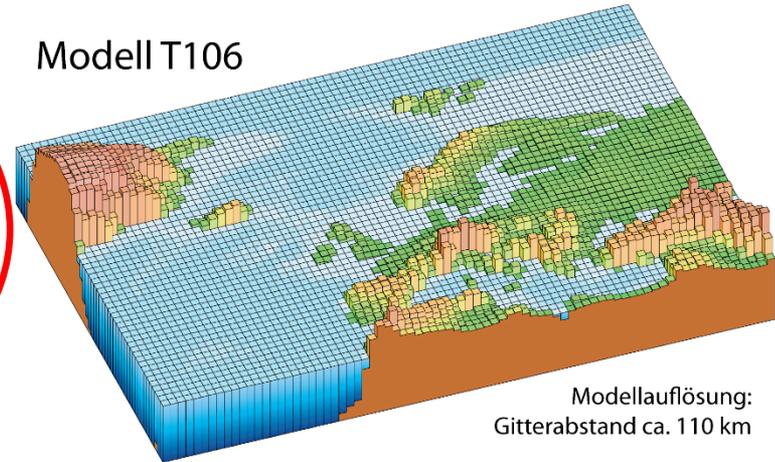
Modellauflösung:
Gitterabstand ca. 250 km

Modell T63



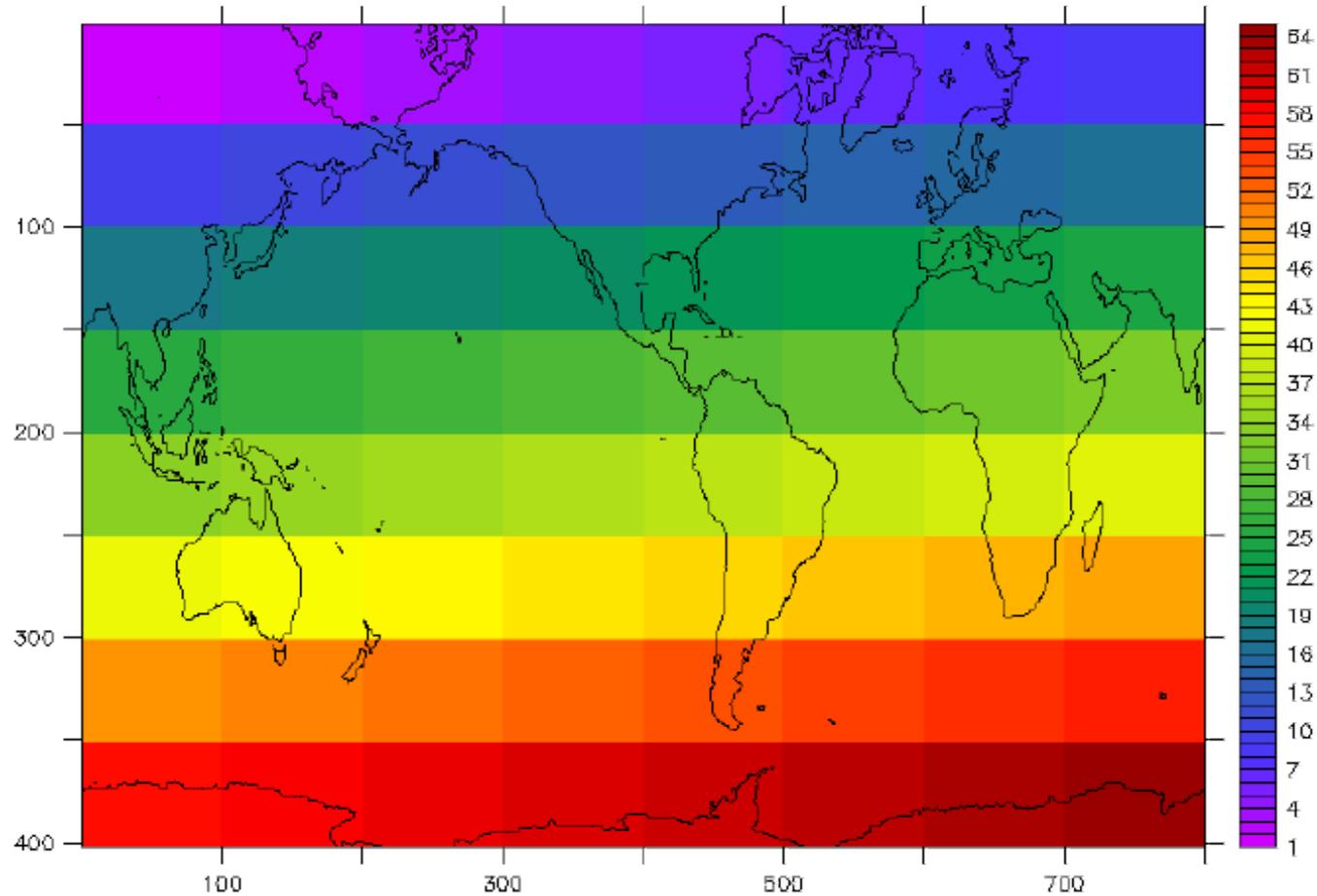
Modellauflösung:
Gitterabstand ca. 180 km

Modell T106



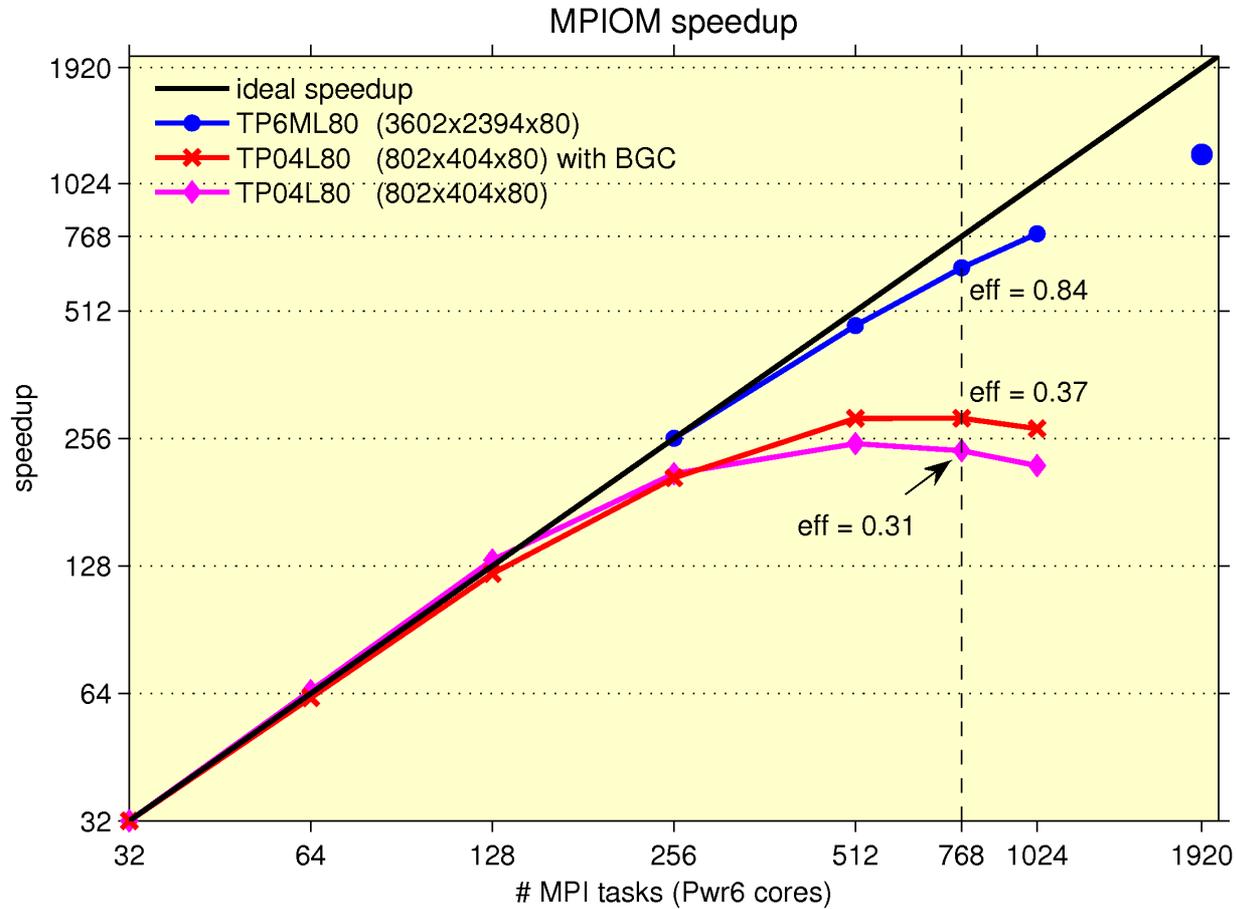
Modellauflösung:
Gitterabstand ca. 110 km

Parallelisierung



8x8

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

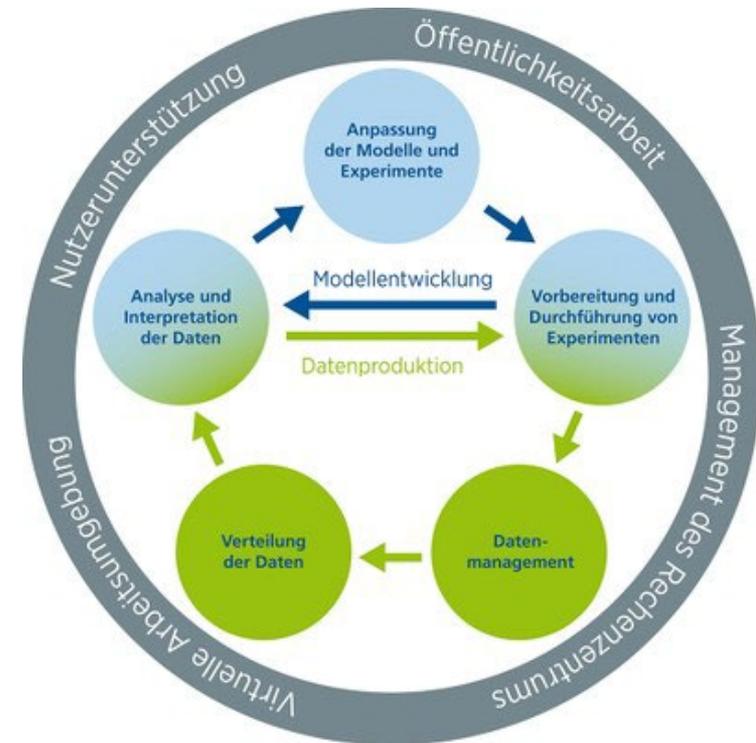
Nutzung

- 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
 - Programoptimierung
 - 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

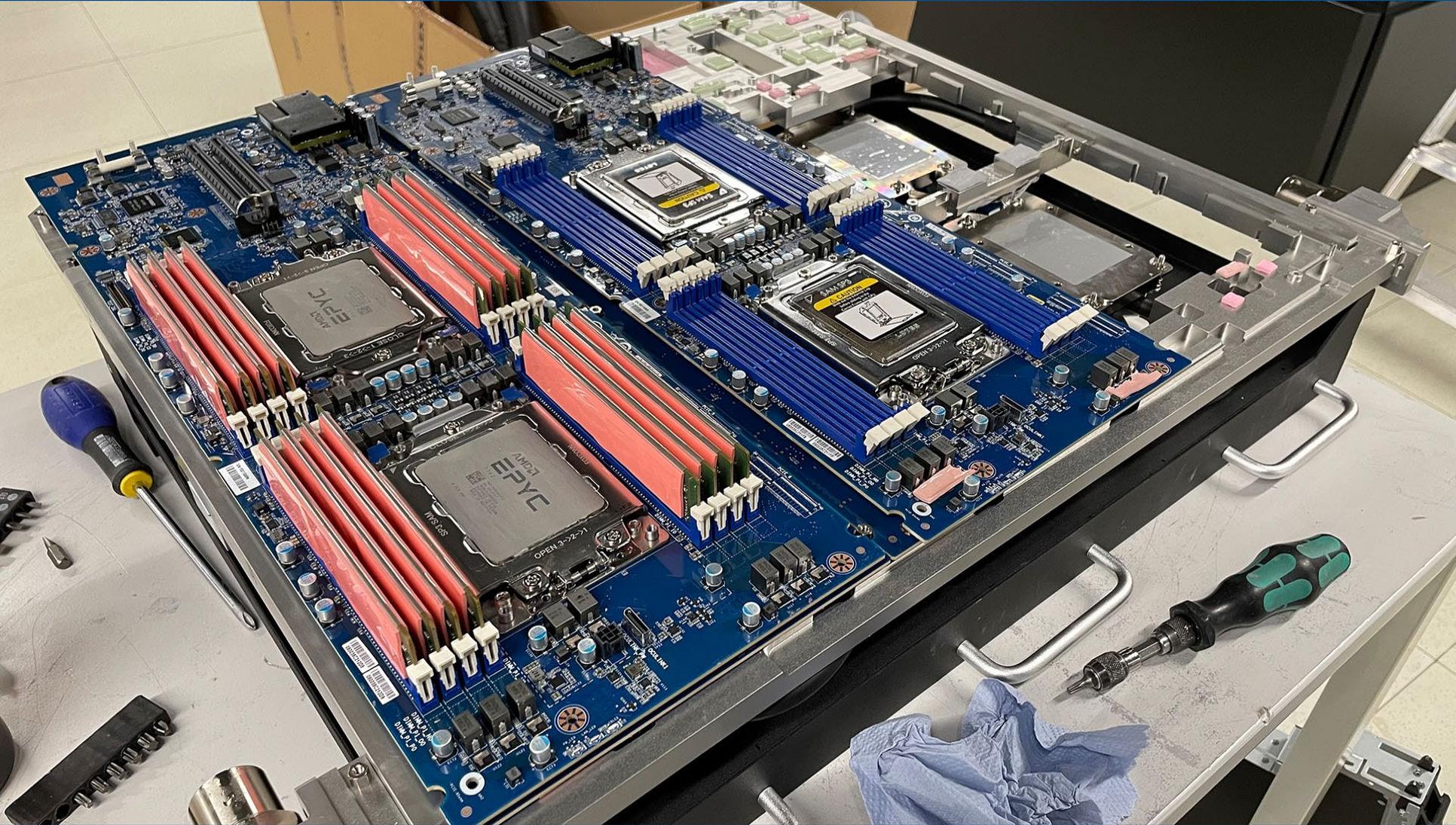
- GPU-Knoten: 60
- Nvidia A100 GPUs: 240
- Rechenleistung: 2,8 PFLOPS



HLRE-4 „Levante“

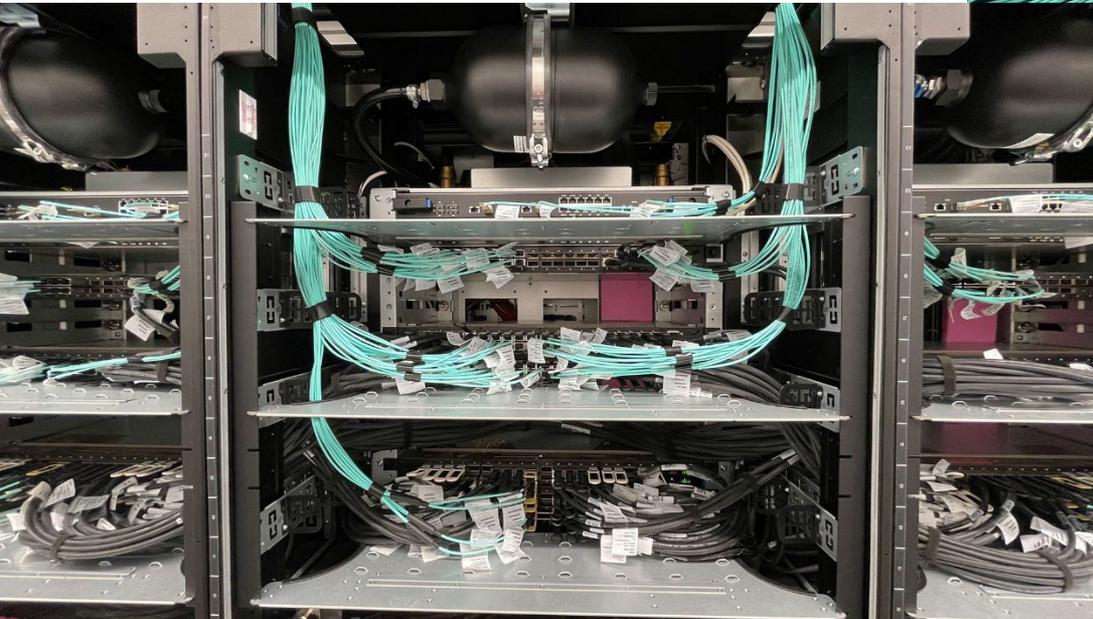
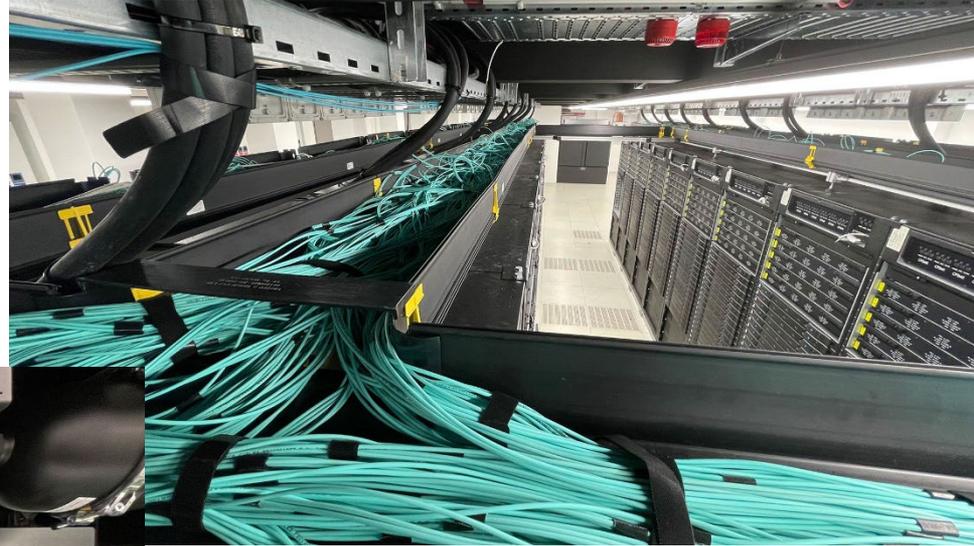
3 CPU-Knoten pro Blade
32 Blades pro Rack
= 96 CPU-Knoten pro Rack





Hochgeschwindigkeitsnetzwerk

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



Festplattenspeichersystem



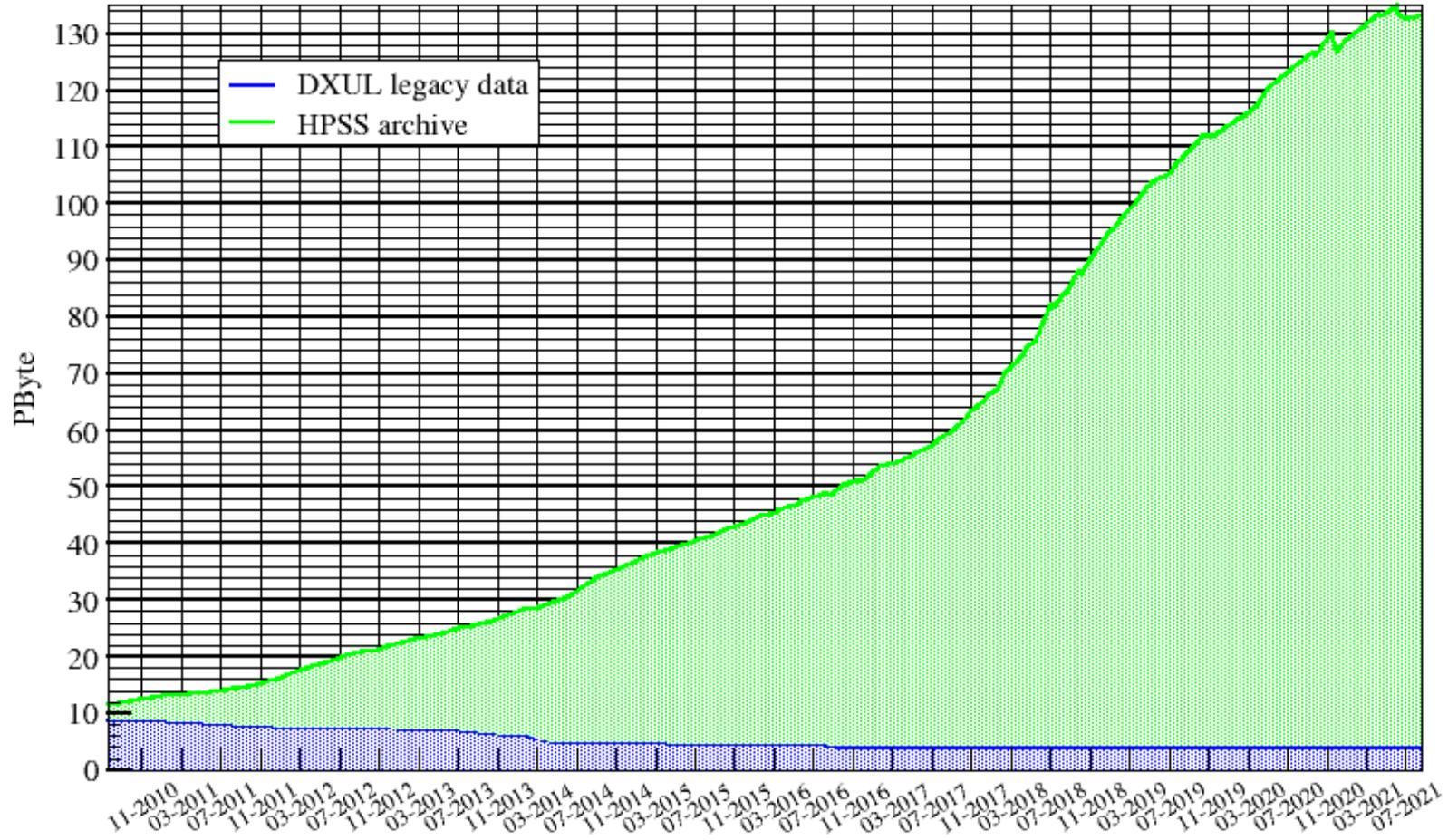
Hersteller: DDN

Paralleles Dateisystem: 132 Petabyte

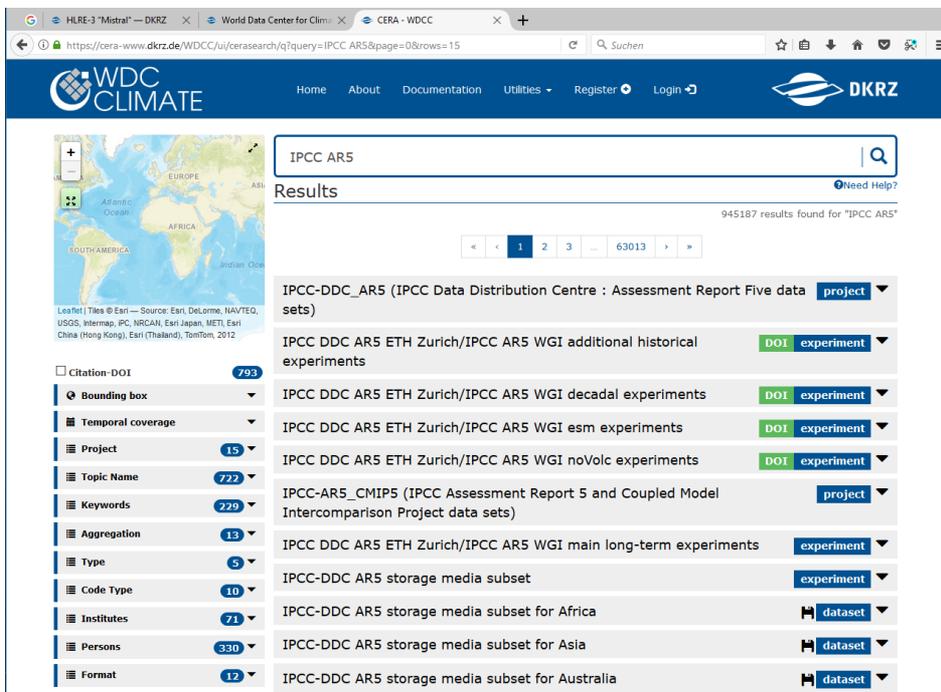
Magnetbandsilo



Das Datenarchiv am DKRZ

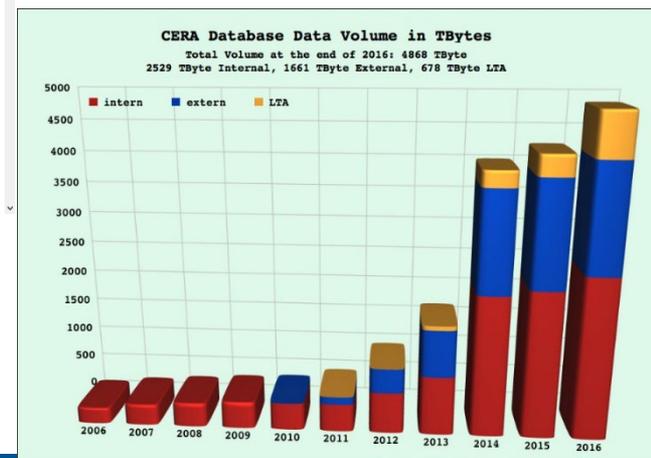


Das World Data Centre for Climate am DKRZ

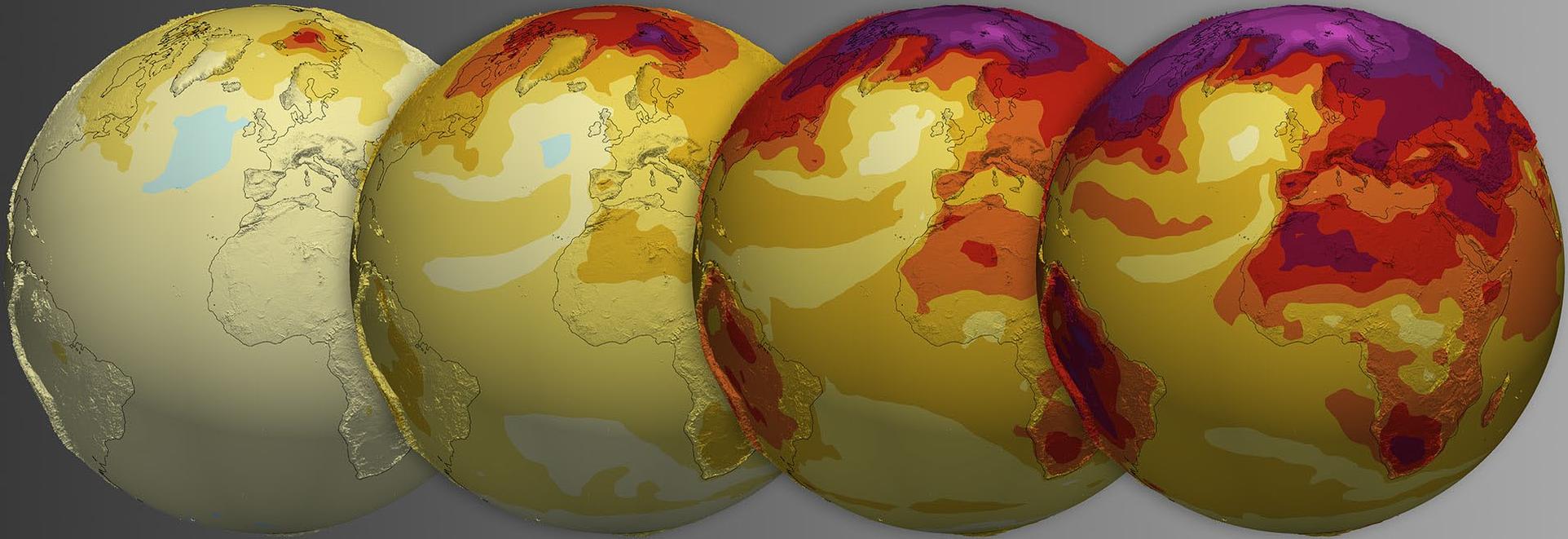


The screenshot shows the WDC Climate website interface. At the top, there is a search bar containing 'IPCC AR5' and a search button. Below the search bar, it indicates 'Results' and '945187 results found for "IPCC AR5"'. A navigation bar on the left lists various filters such as 'Bounding box', 'Temporal coverage', 'Project', 'Topic Name', 'Keywords', 'Aggregation', 'Type', 'Code Type', 'Institutes', 'Persons', and 'Format', each with a corresponding count. The main content area displays a list of search results, including 'IPCC-DDC_AR5 (IPCC Data Distribution Centre : Assessment Report Five data sets)', 'IPCC DDC AR5 ETH Zurich/IPCC AR5 WGI additional historical experiments', and 'IPCC DDC AR5 ETH Zurich/IPCC AR5 WGI decadal experiments', among others. Each result has a dropdown menu with labels like 'project', 'experiment', or 'dataset'.

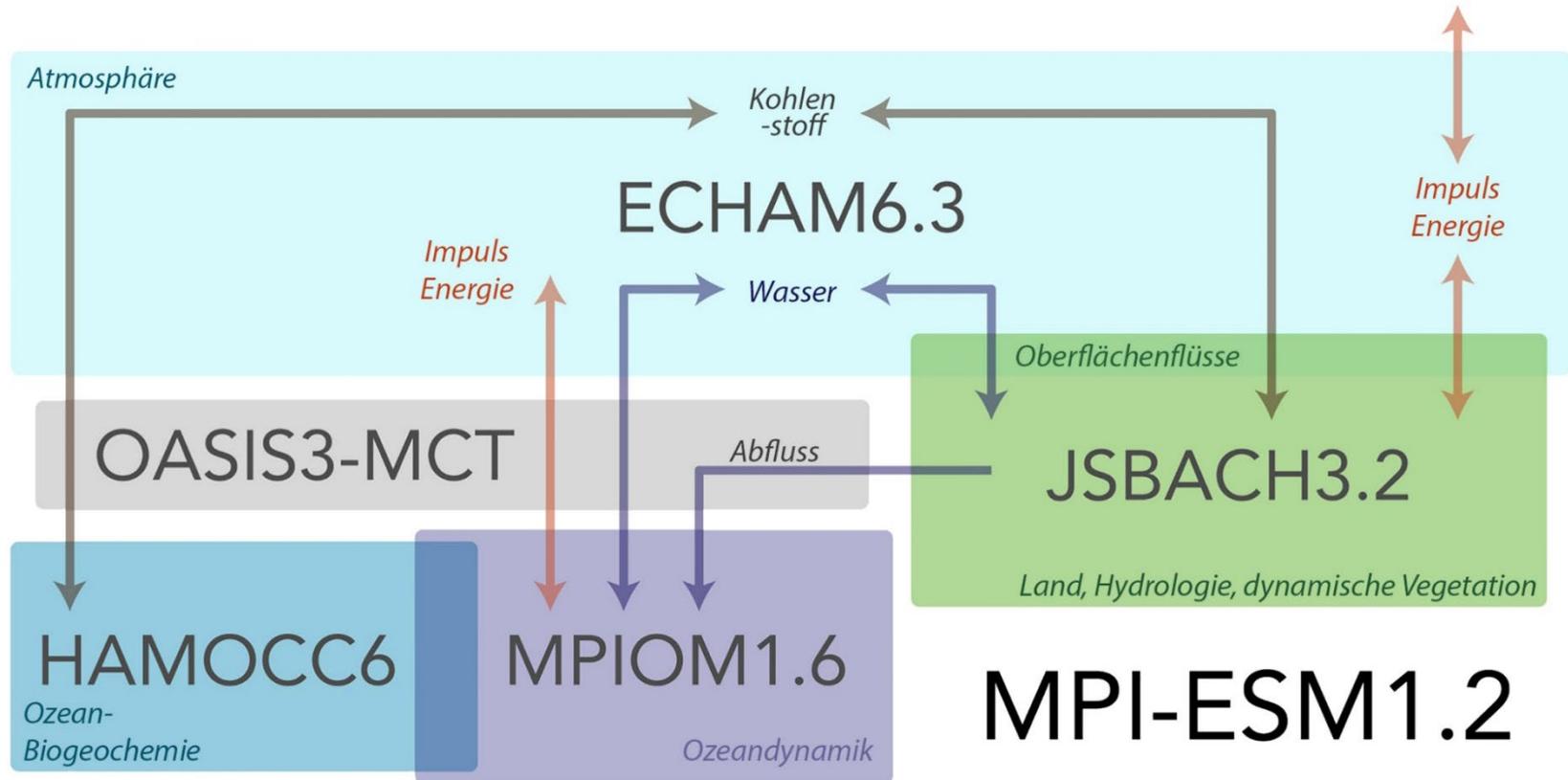
- ▶ Langzeitspeicherung
- ▶ Datenbankgröße 5 PB
- ▶ Freier Datendownload
- cera-www.dkrz.de**
- ▶ Stichwortsuche



Klimaprojektionen



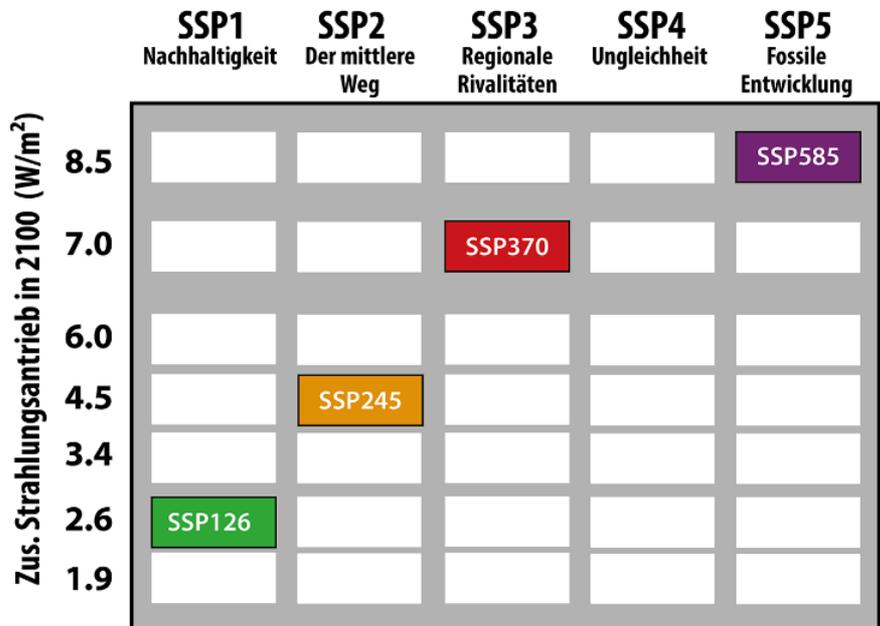
Erdsystem-Modell



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

CMIP6-Rechnungen - Einführung: SSP-Szenarien

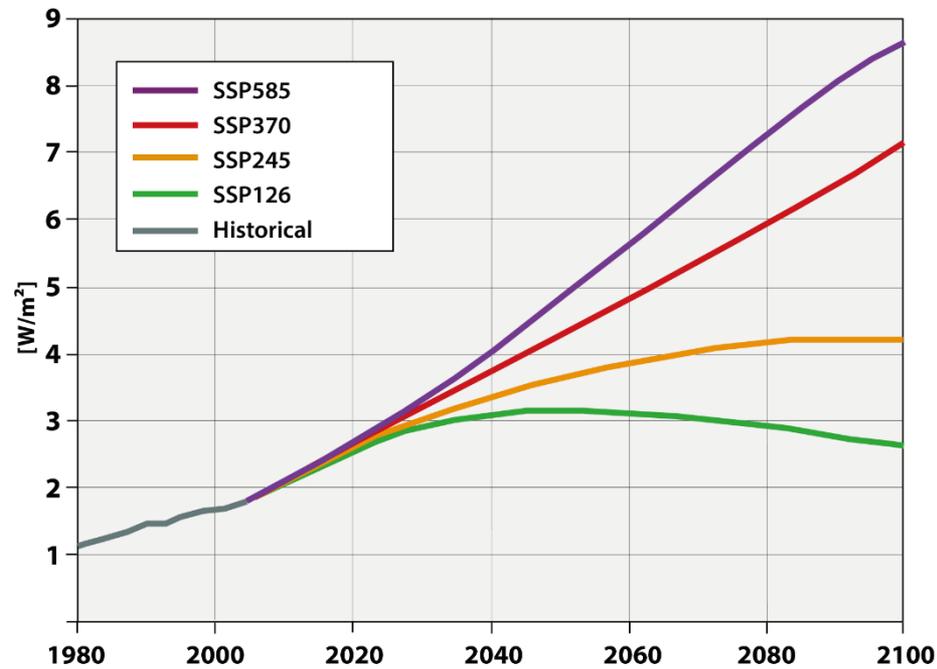
Gemeinsame sozioökonomische Entwicklungspfade (SSPs)



Nach O'Neill et al., 2016

© DKRZ

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



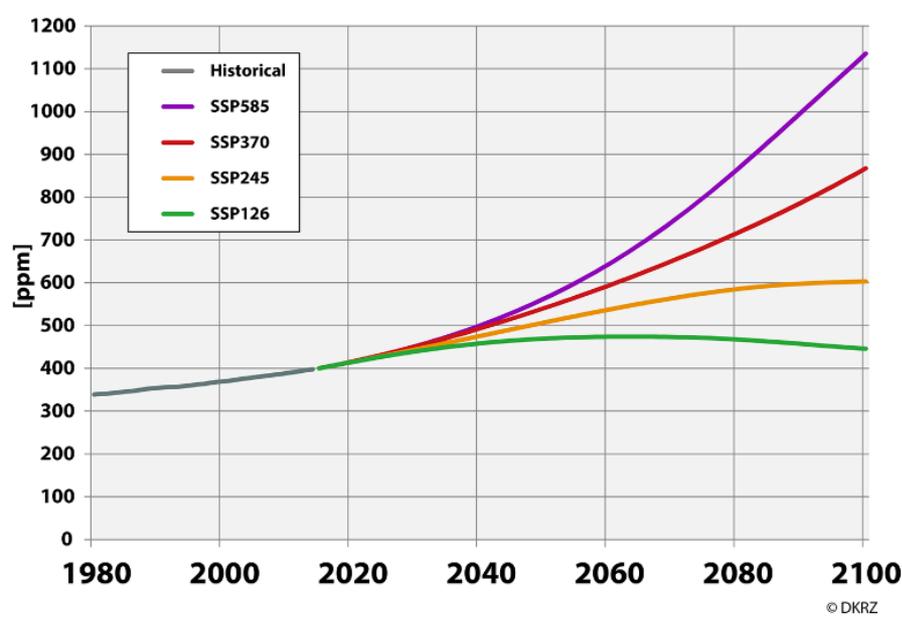
Nach O'Neill et al., 2016

© DKRZ

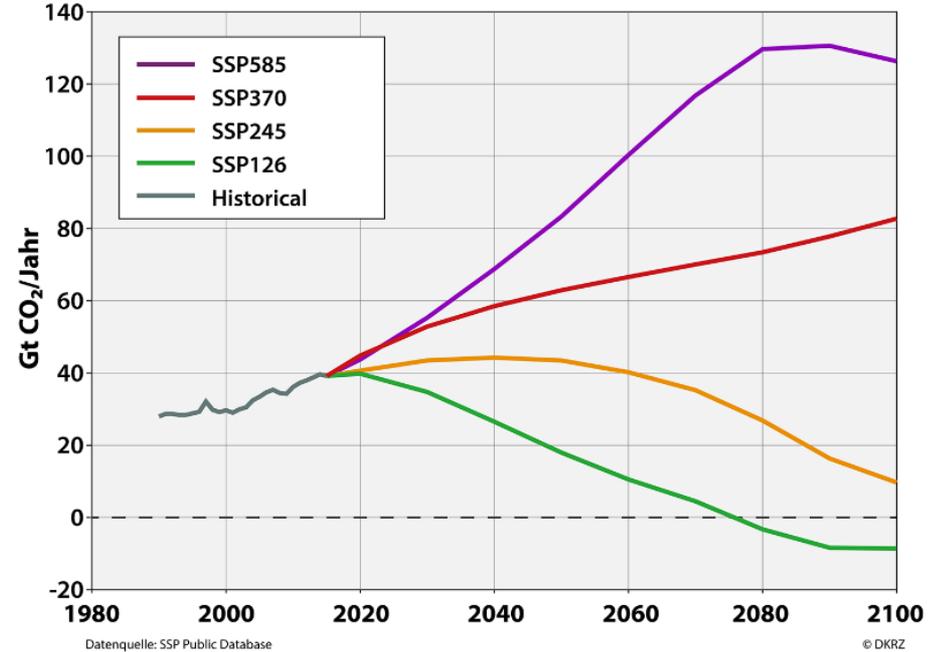
Zeitlicher Verlauf

CMIP6-Rechnungen - Einführung: SSP-Szenarien

CMIP6-Szenarien - Globale CO₂-Konzentrationen [ppm]

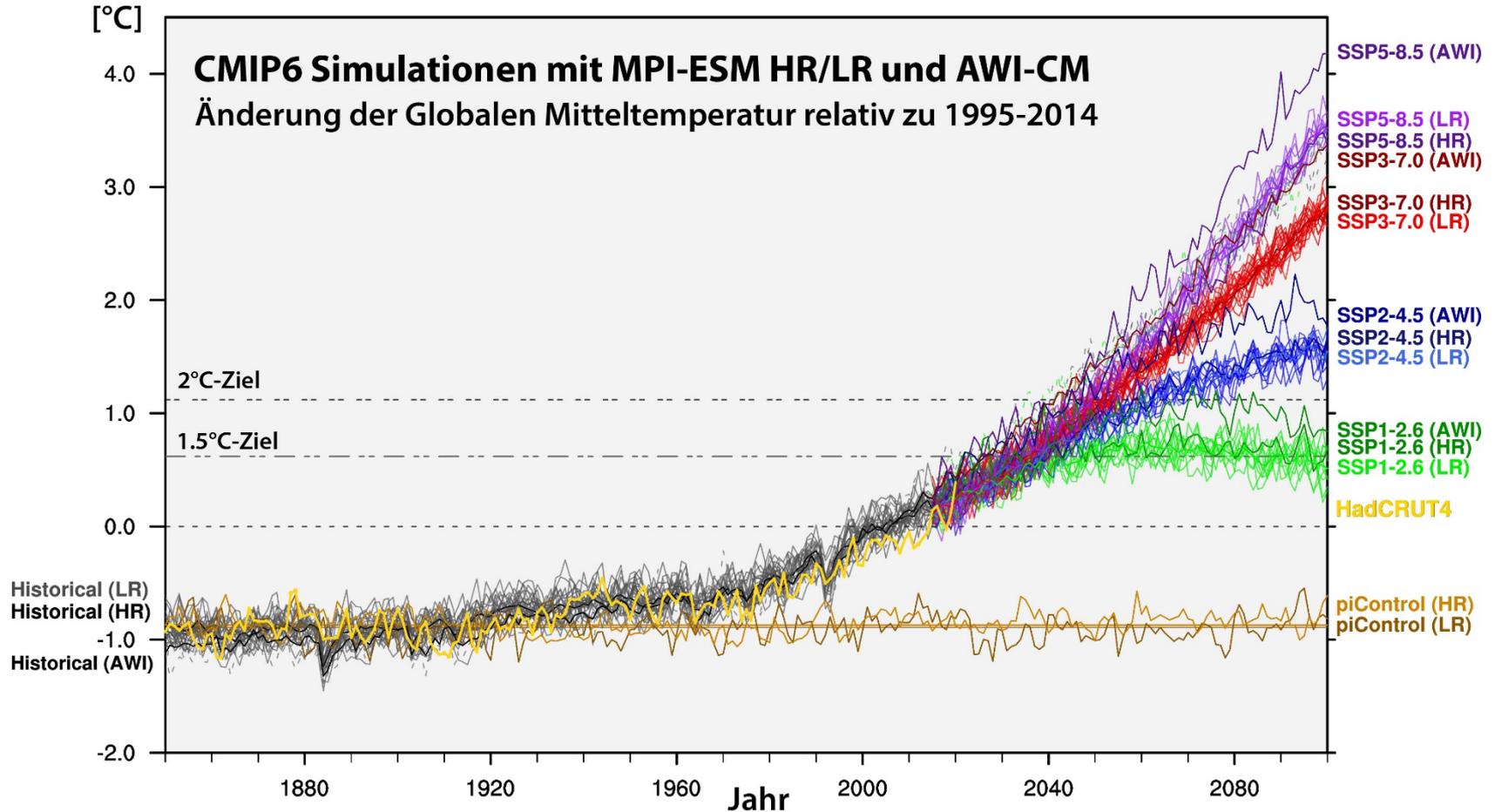


CMIP6 Szenarien - Globale CO₂-Emissionen [Gt / Jahr]



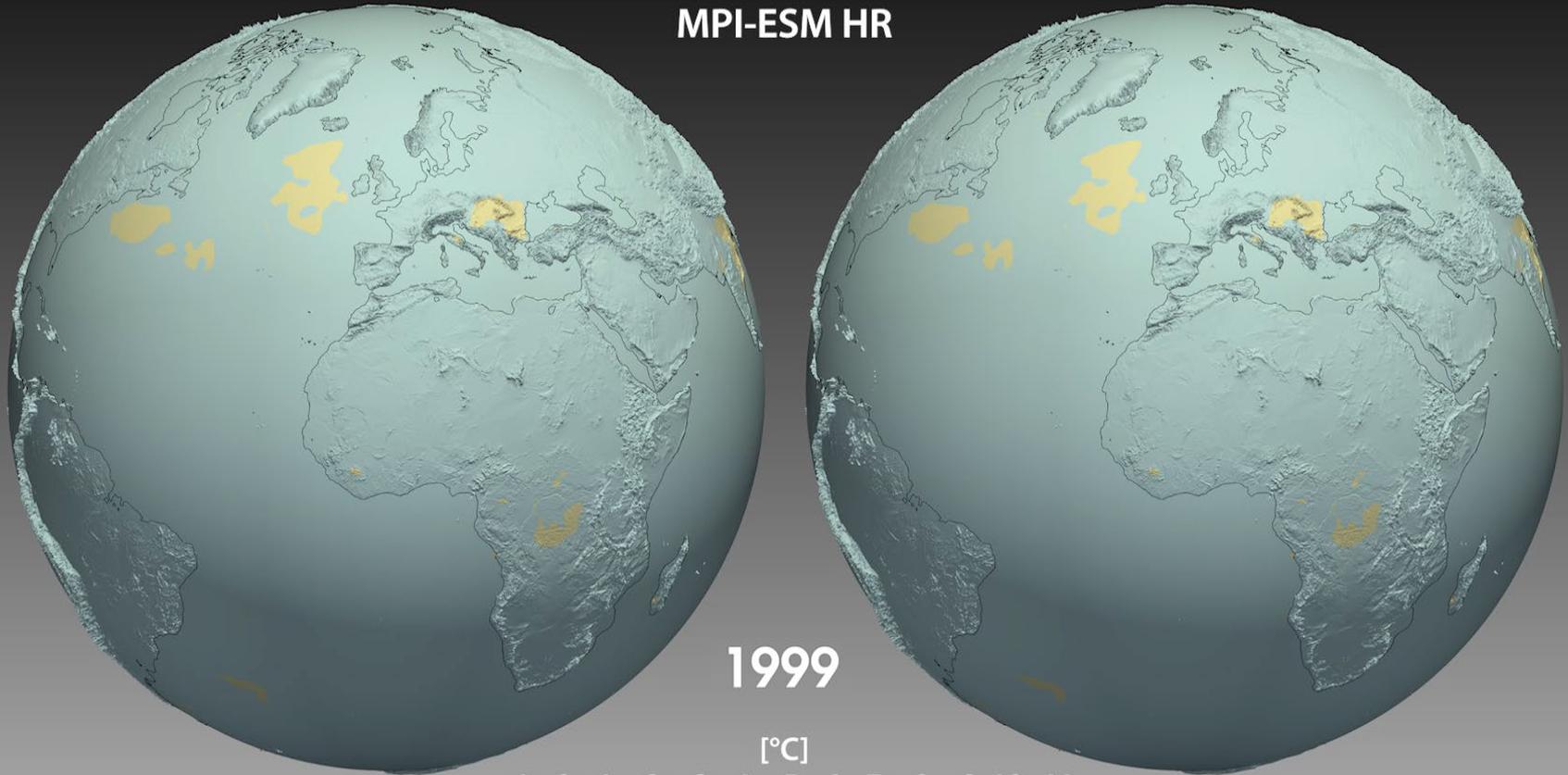
Welche Emissionen sind „erlaubt“?

Deutsche CMIP6-Rechnungen - Übersicht



Temperaturänderung gegenüber 1995-2014

MPI-ESM HR



1999

[°C]

-1 0 1 2 3 4 5 6 7 8 9 10 11

SSP126

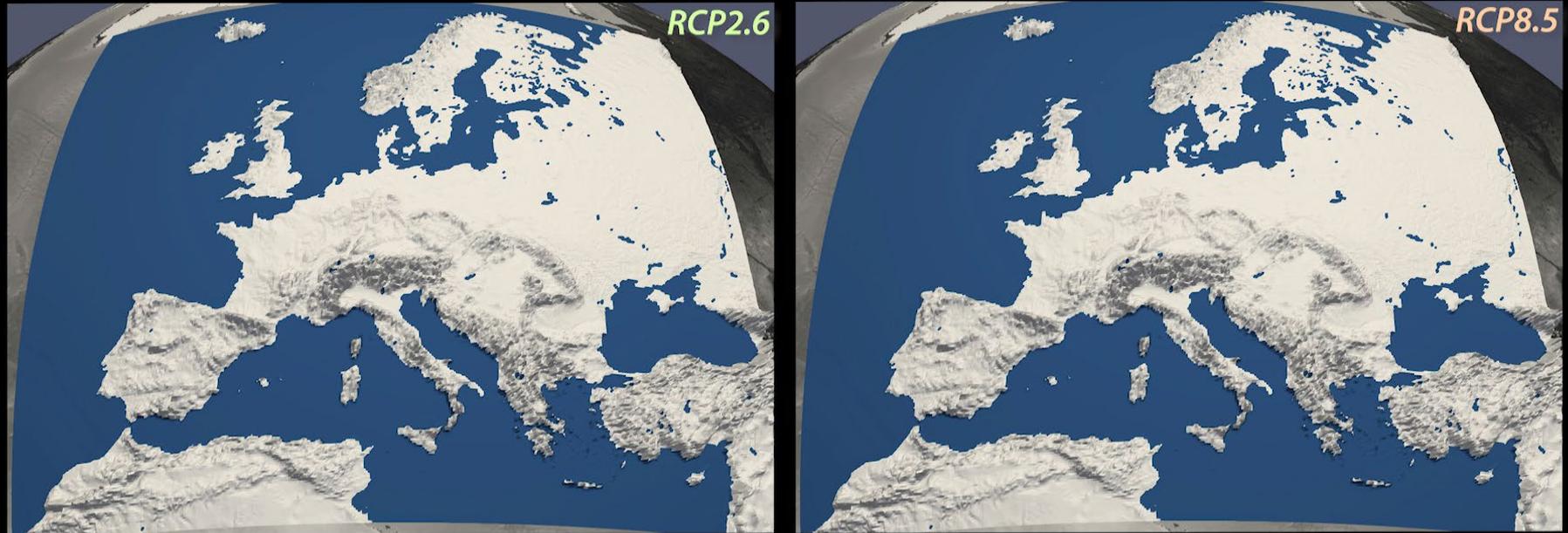


SSP585

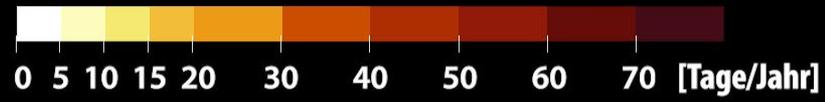
© DKRZ /MPI-M

Euro-Cordex

Änderung der Anzahl von Hitzetagen gegenüber 1971-2000



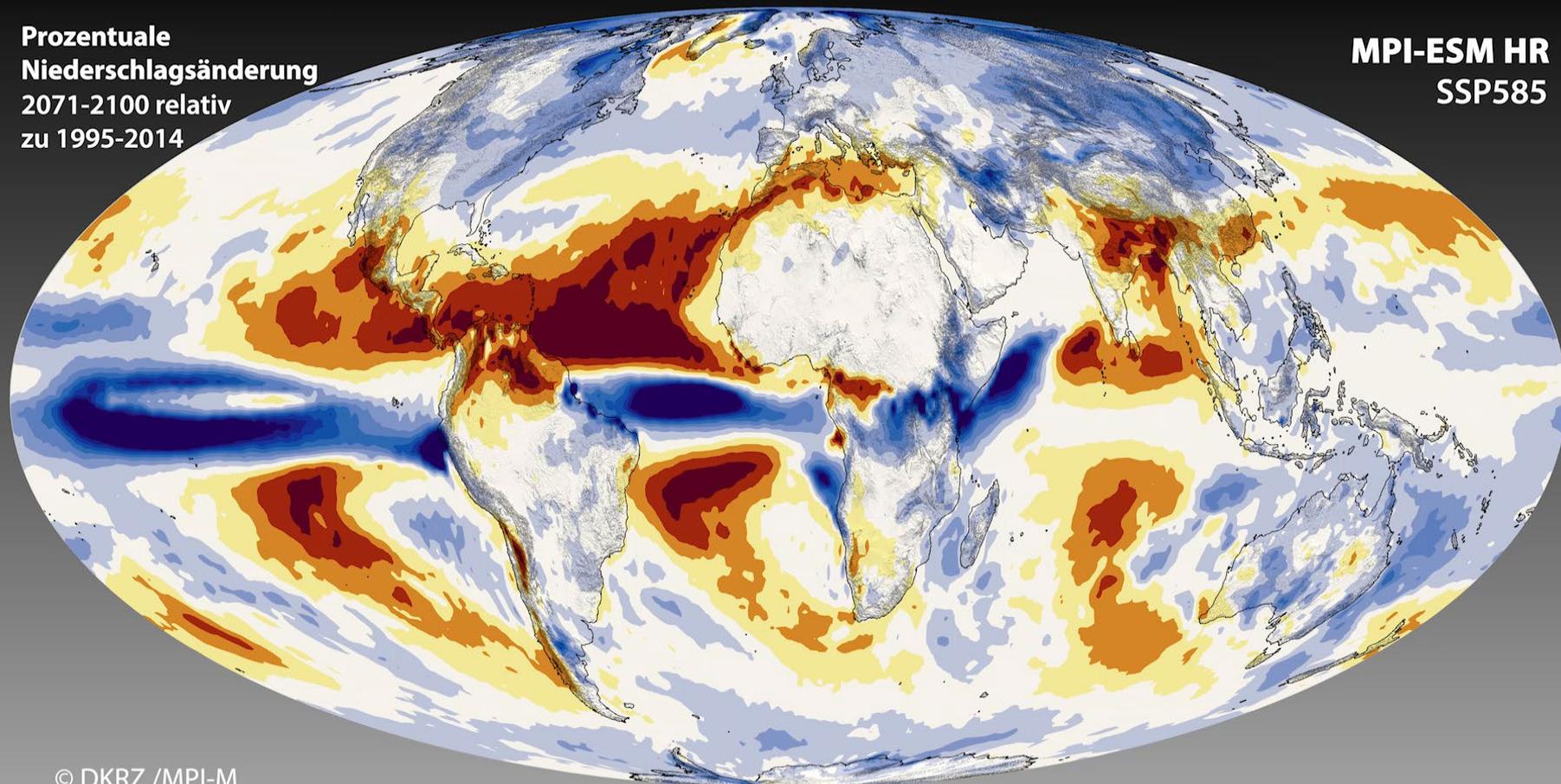
1986



© DKRZ / GERICS

Prozentuale
Niederschlagsänderung
2071-2100 relativ
zu 1995-2014

MPI-ESM HR
SSP585

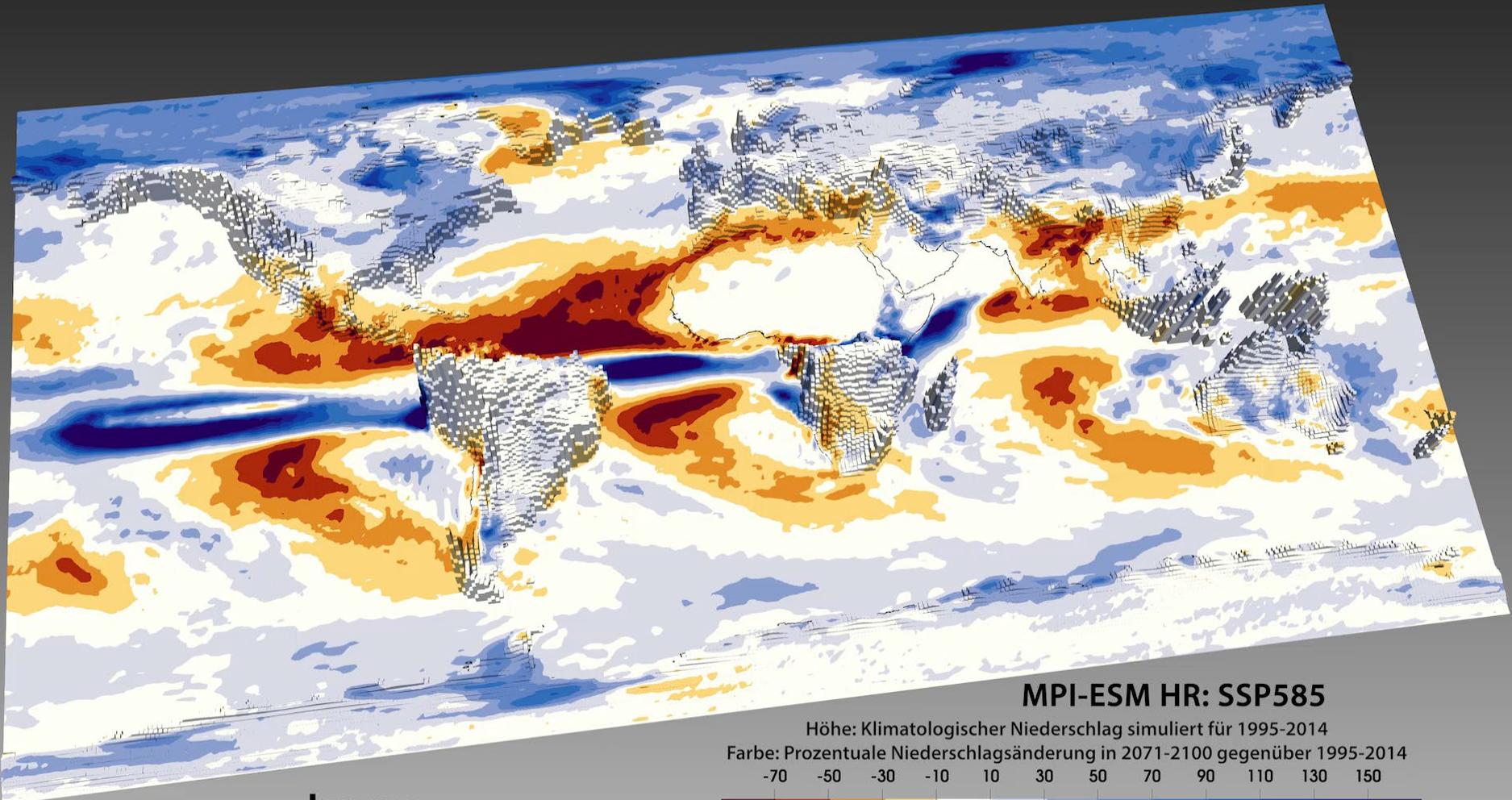


© DKRZ /MPI-M

Januar

-70 -50 -30 -10 10 30 50 70 90 110 130 150 [%]





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

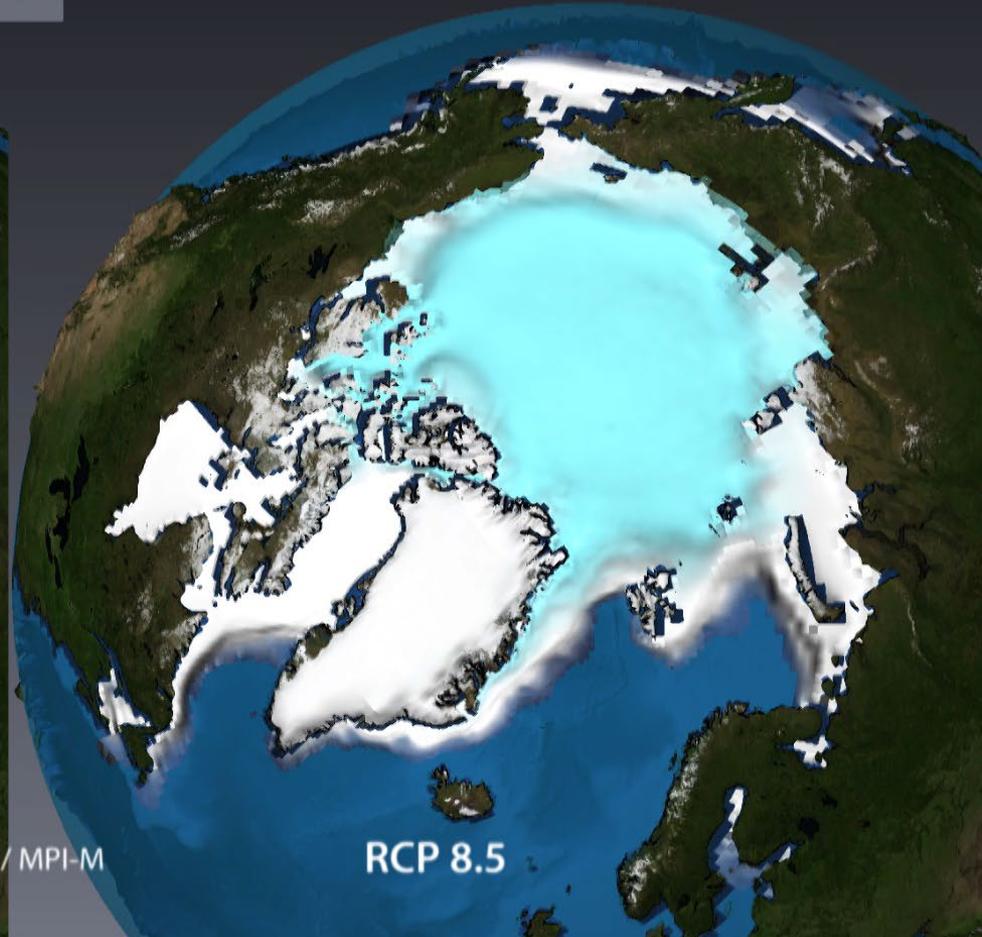
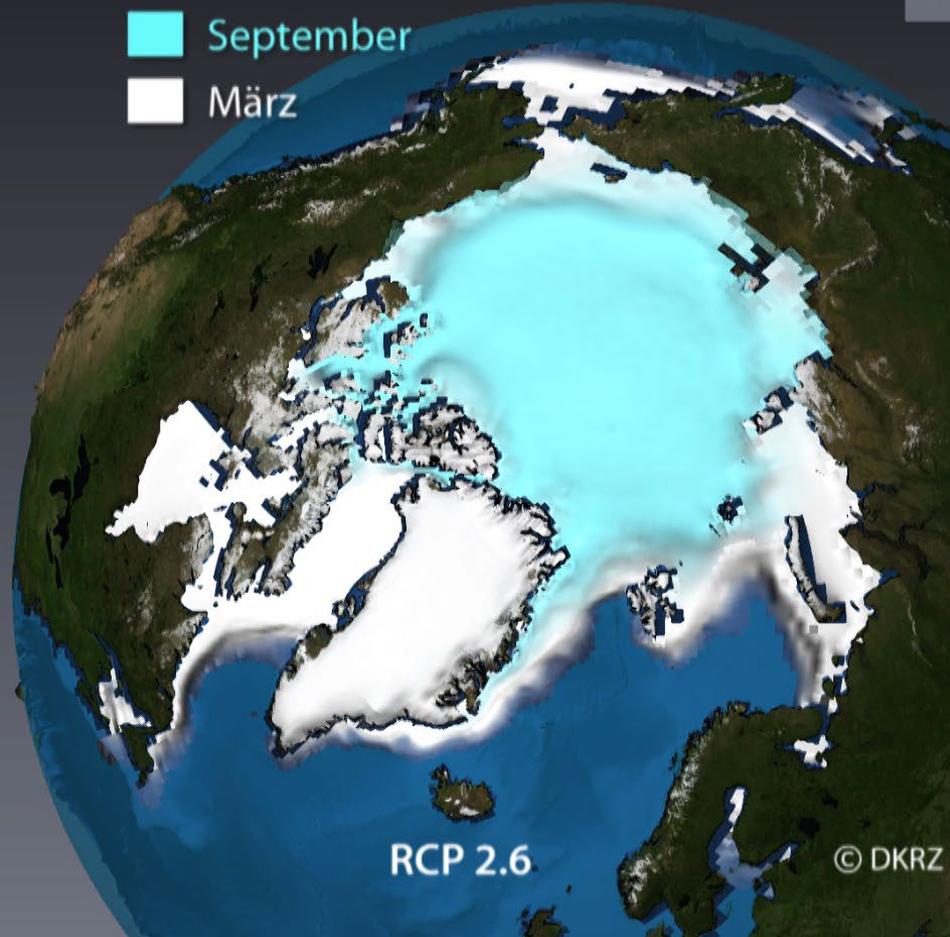
Meereis-Konzentration

 September

 März

1975

MPI-ESM LR



- Ice free area
- Additional ice free area

RCP8.5 / 4xCo2: Ice Sheet Thickness (Height) and Change in Ice Sheet Thickness (Color)

200
[m]
0
-200
-400
-600
-800

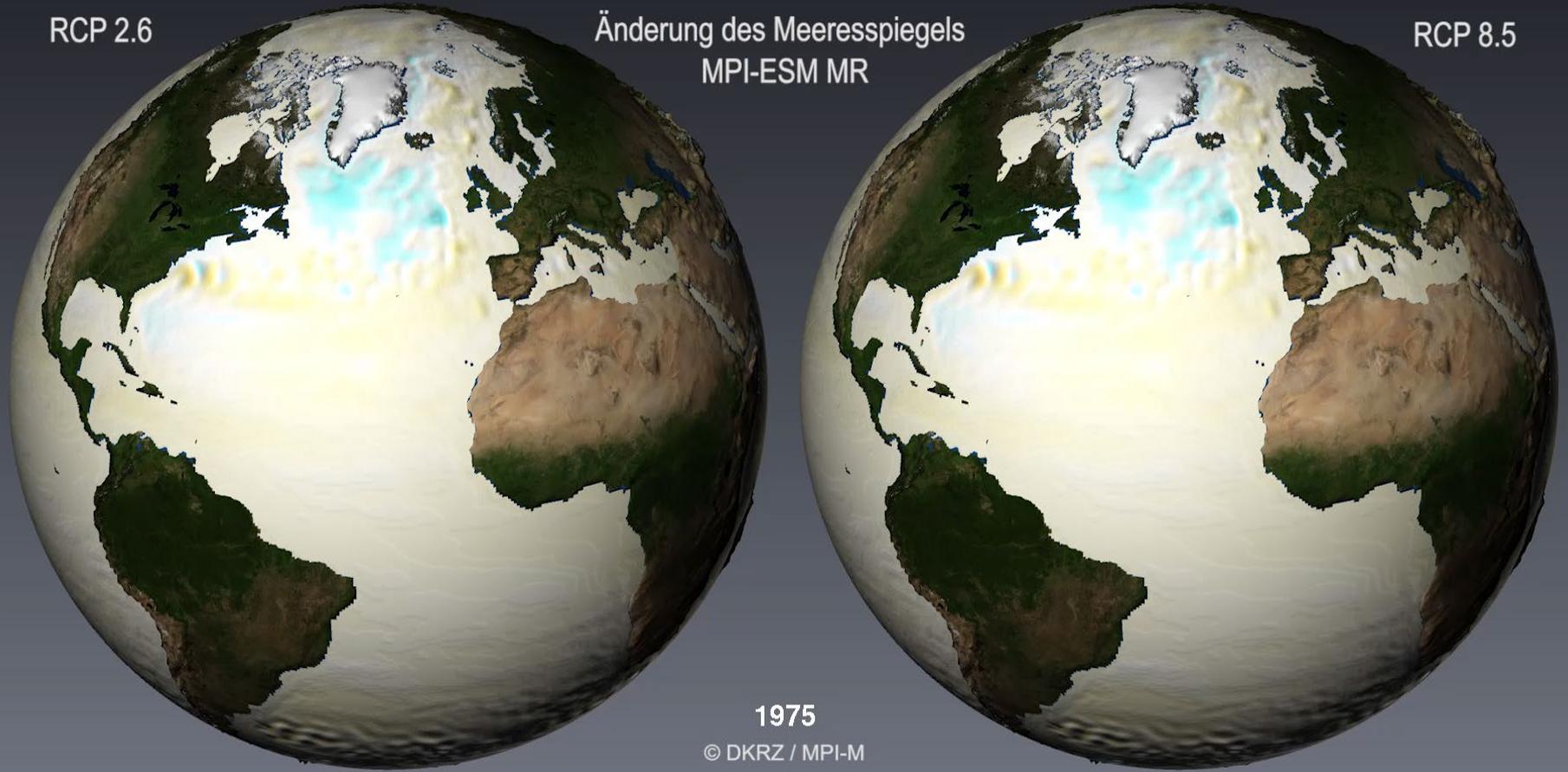
1850

© DKRZ / MPI-M
EU-Project THOR

RCP 2.6

Änderung des Meeresspiegels
MPI-ESM MR

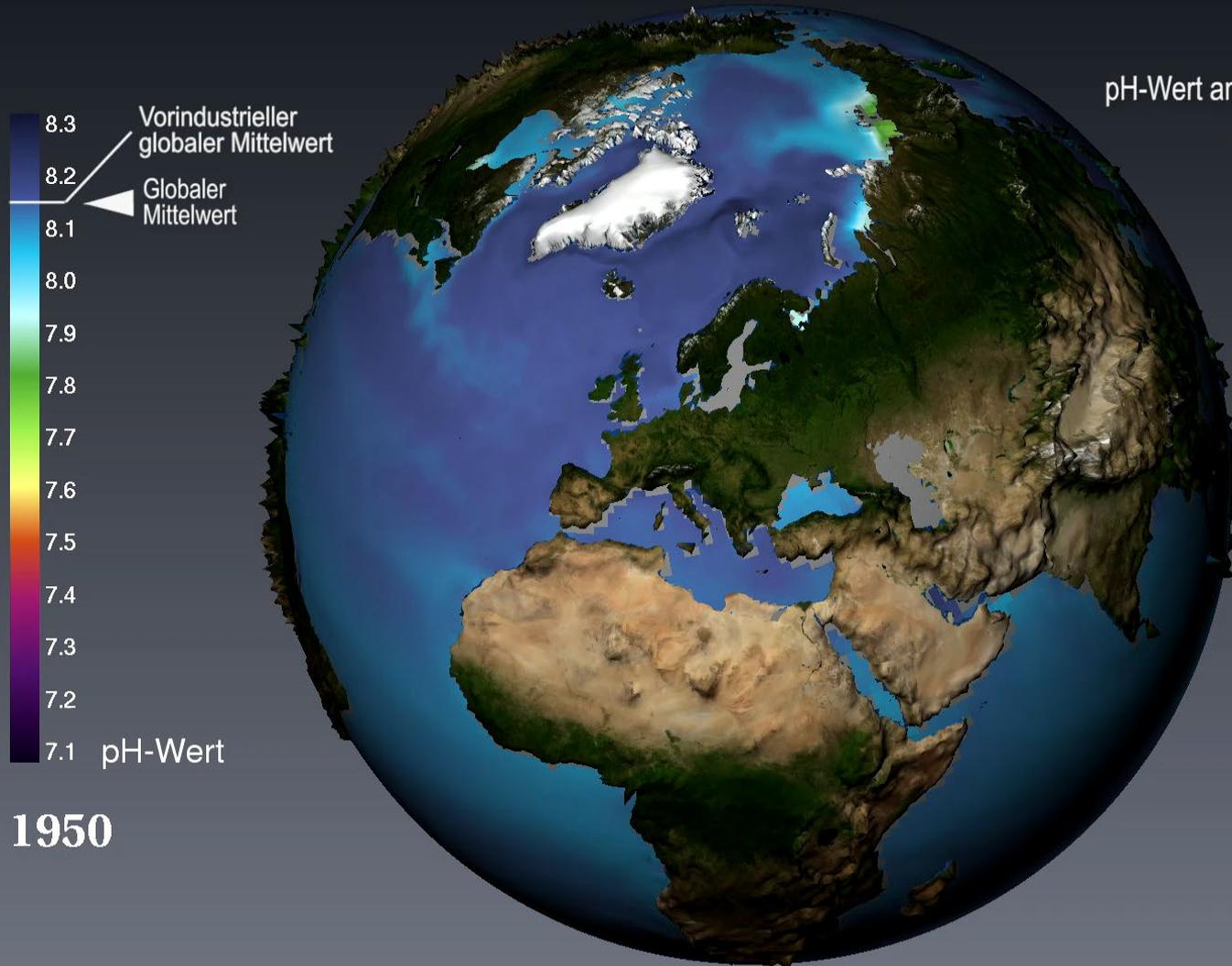
RCP 8.5



1975

© DKRZ / MPI-M

-0.5 0.0 0.5 1.0 1.5 [m]



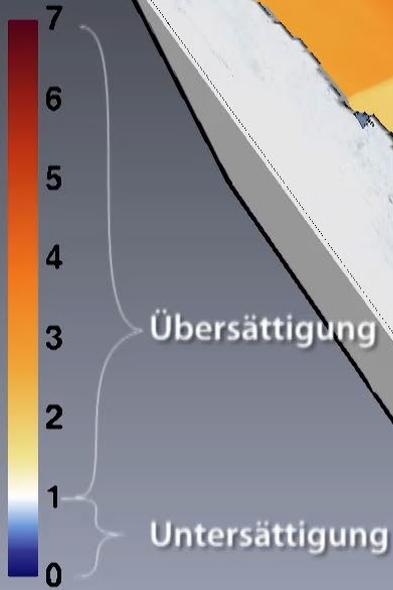
pH-Wert an der Meeresoberfläche
MPI-ESM RCP8.5

1950

(C) DKRZ / MPI-M

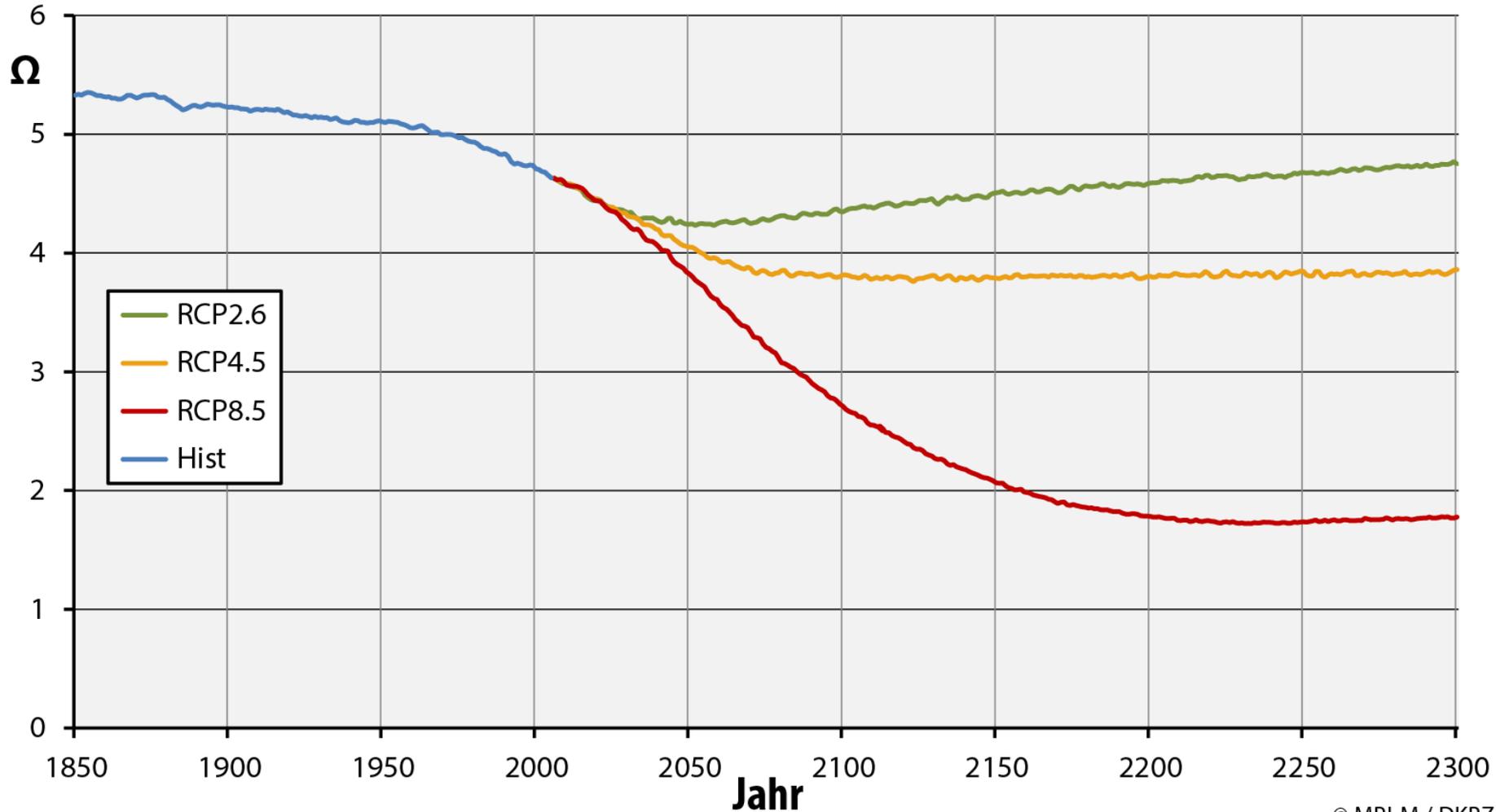
Karbonat-Sättigung
(Kalzit)

MPI-ESM RCP 8.5



1950 © DKRZ / MPI-M

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



[kg/m²]



1.e-5 kg/kg SO_x
1.e-5 kg/kg Asche

Tag: 01

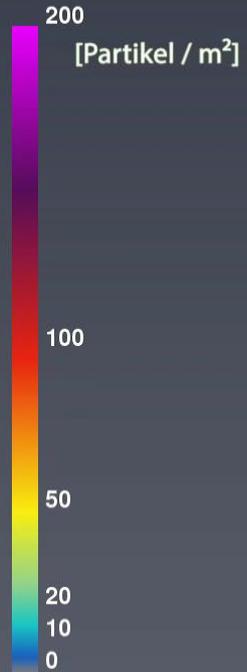


(C) DKRZ / MPI-M

Plastikmüll im Ozean

Partikelquelle: Ozeanoberfläche

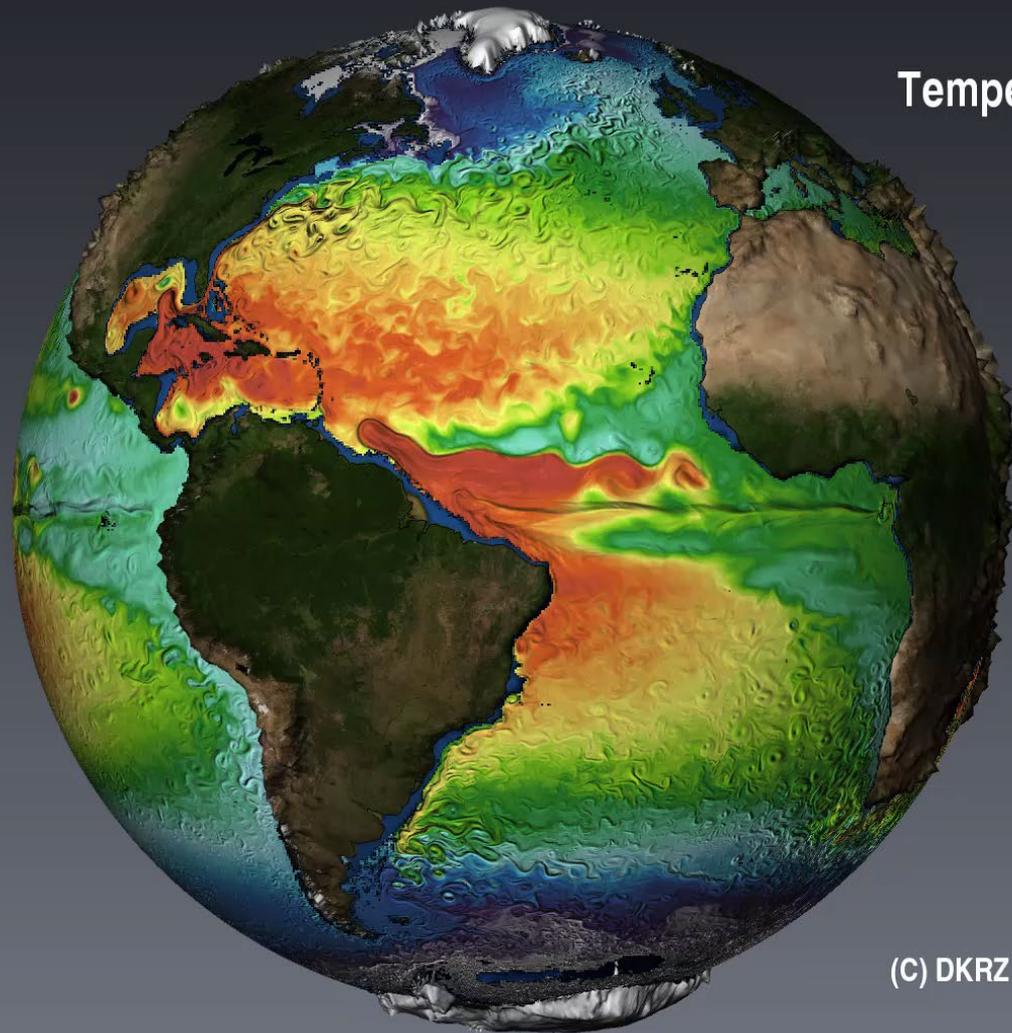
Modell: MPI-OM TP04



01/01/0001

(C) DKRZ / MPI-M

Temperature and Velocity
at 75m depth
MPI-OM TP6M



01.01.

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

HAMOC/MPIOM TP6M

Phytoplankton

50 [mg Chl / m³]

32

16

8

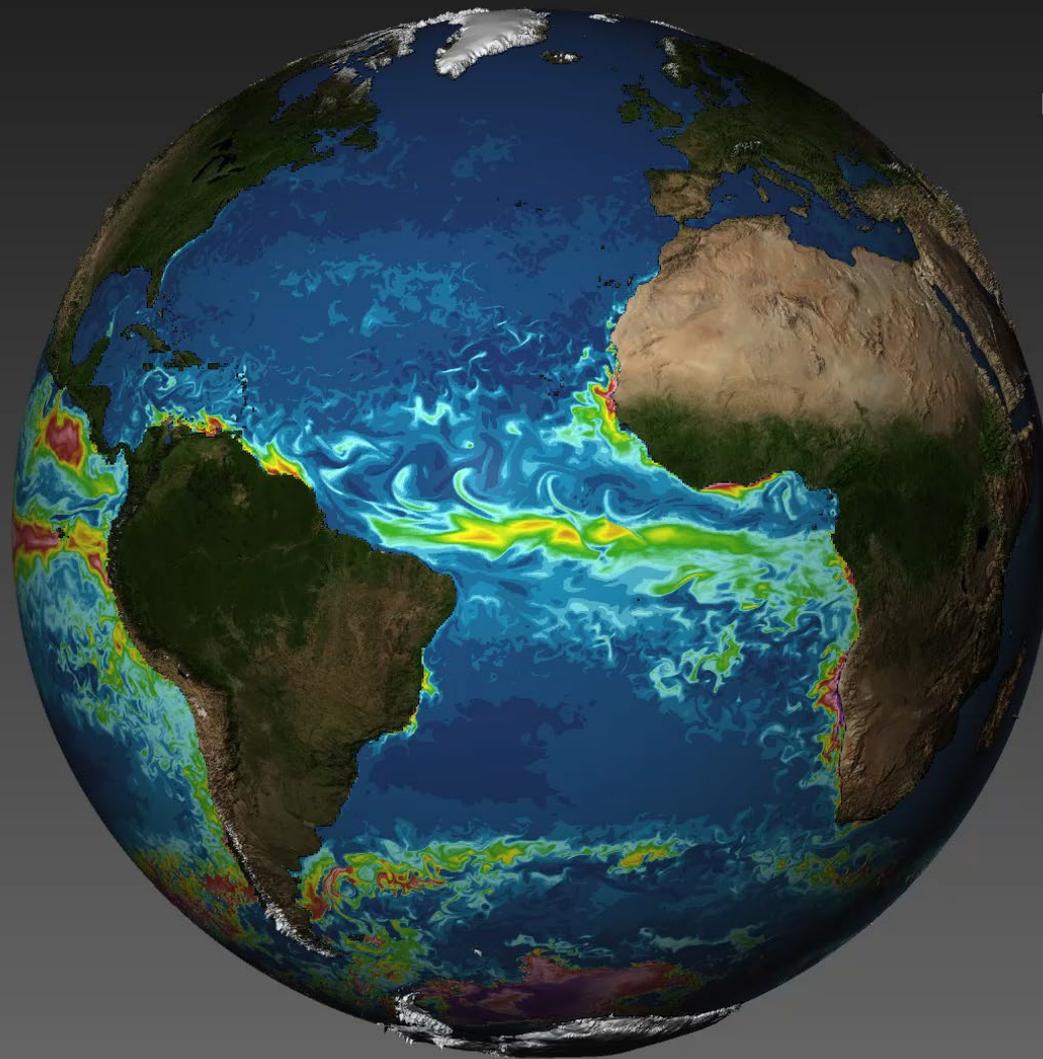
4

2

1

0

2001/01/01



(C) DKRZ/MPI-M

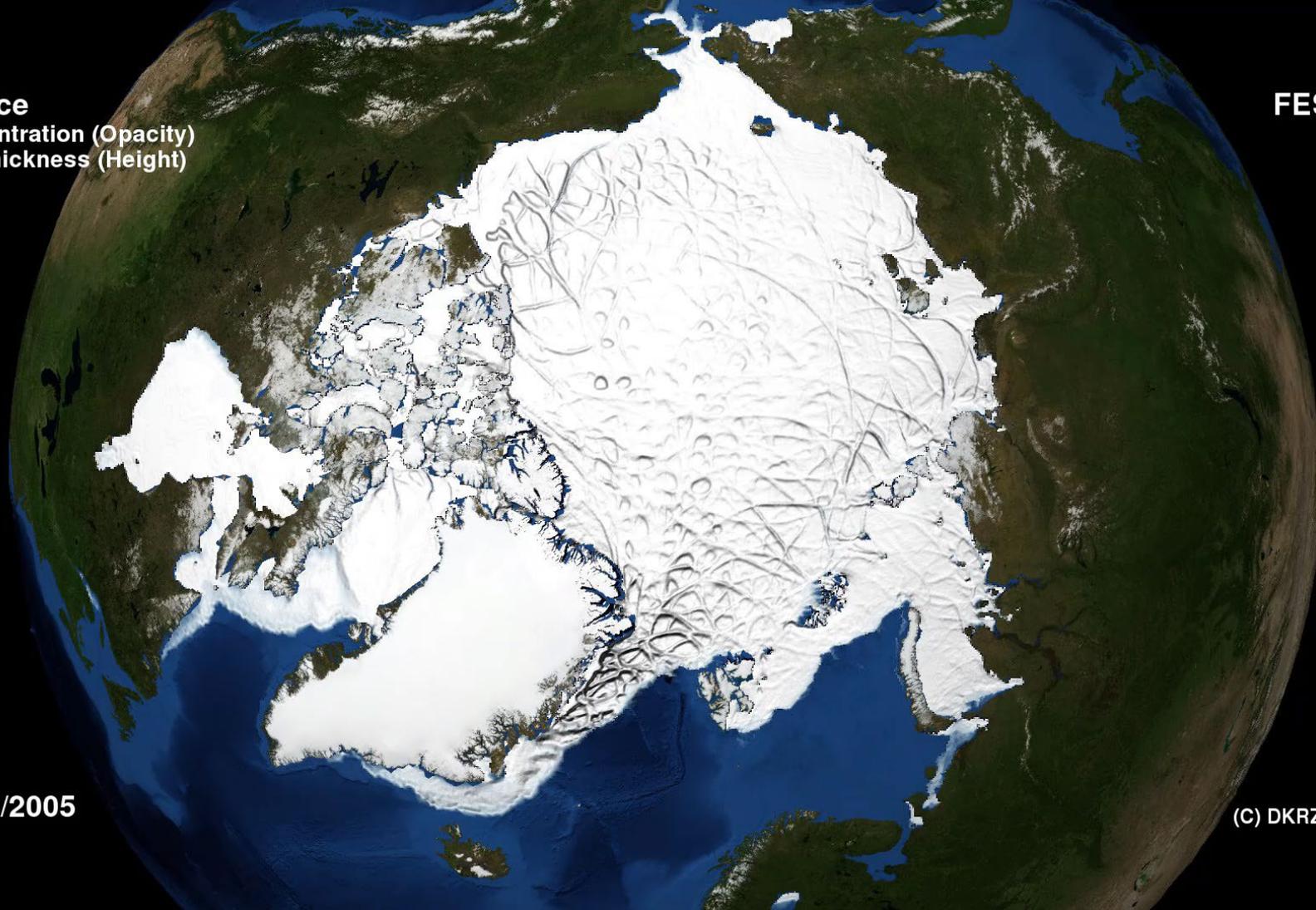
Sea Ice
Concentration (Opacity)
and Thickness (Height)

FESOM

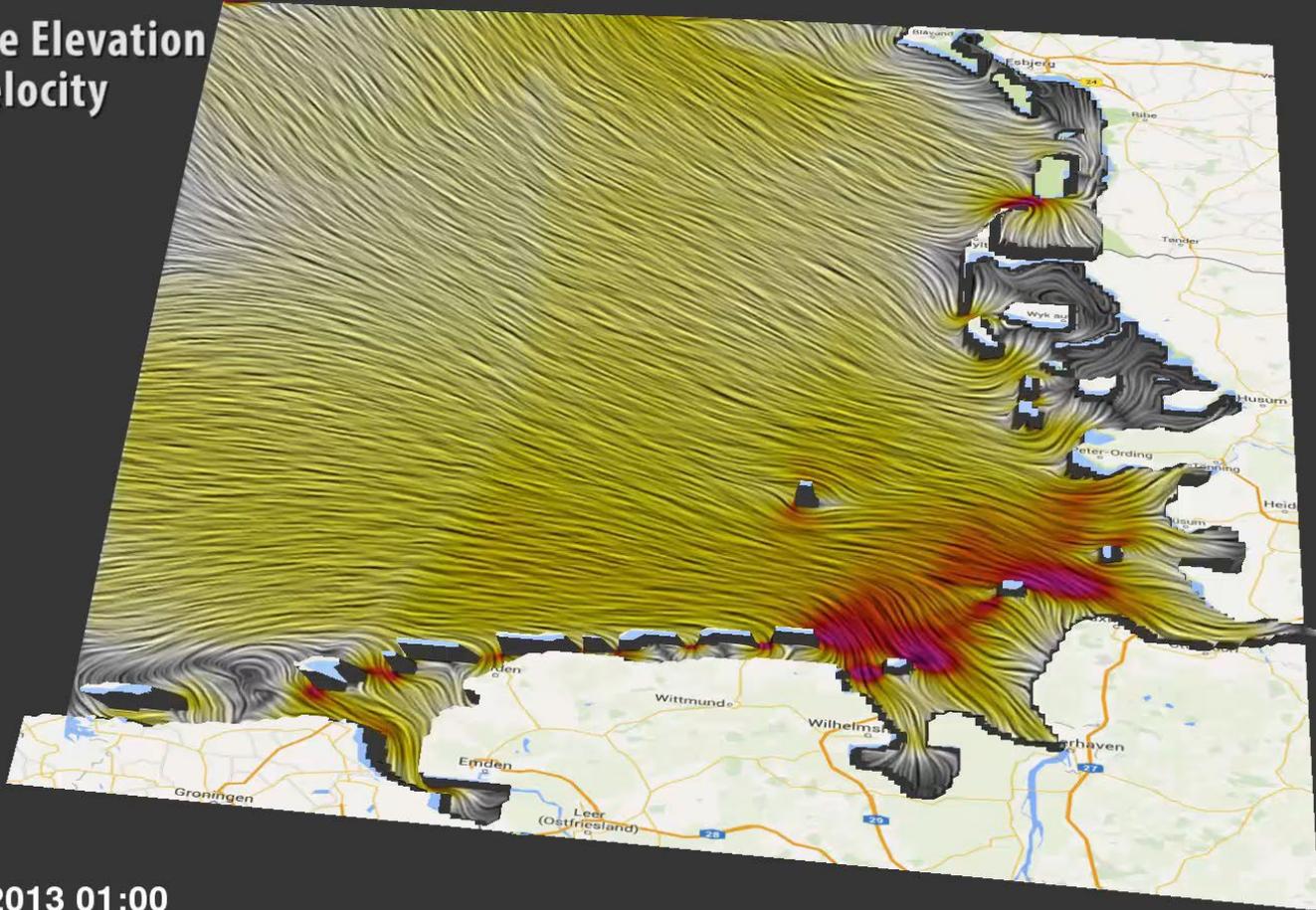


01/01/2005

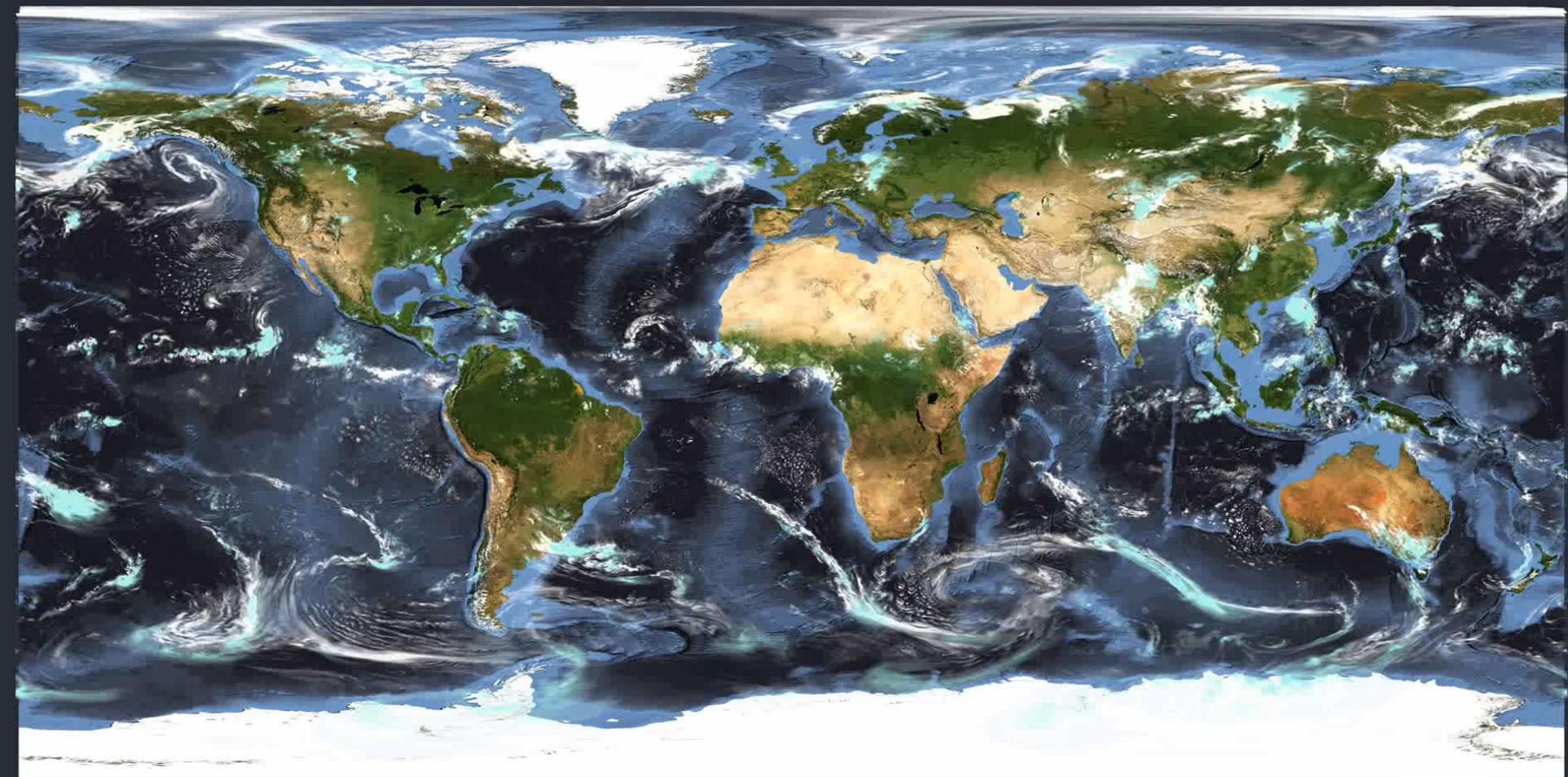
(C) DKRZ / AWI



Surface Elevation and Velocity

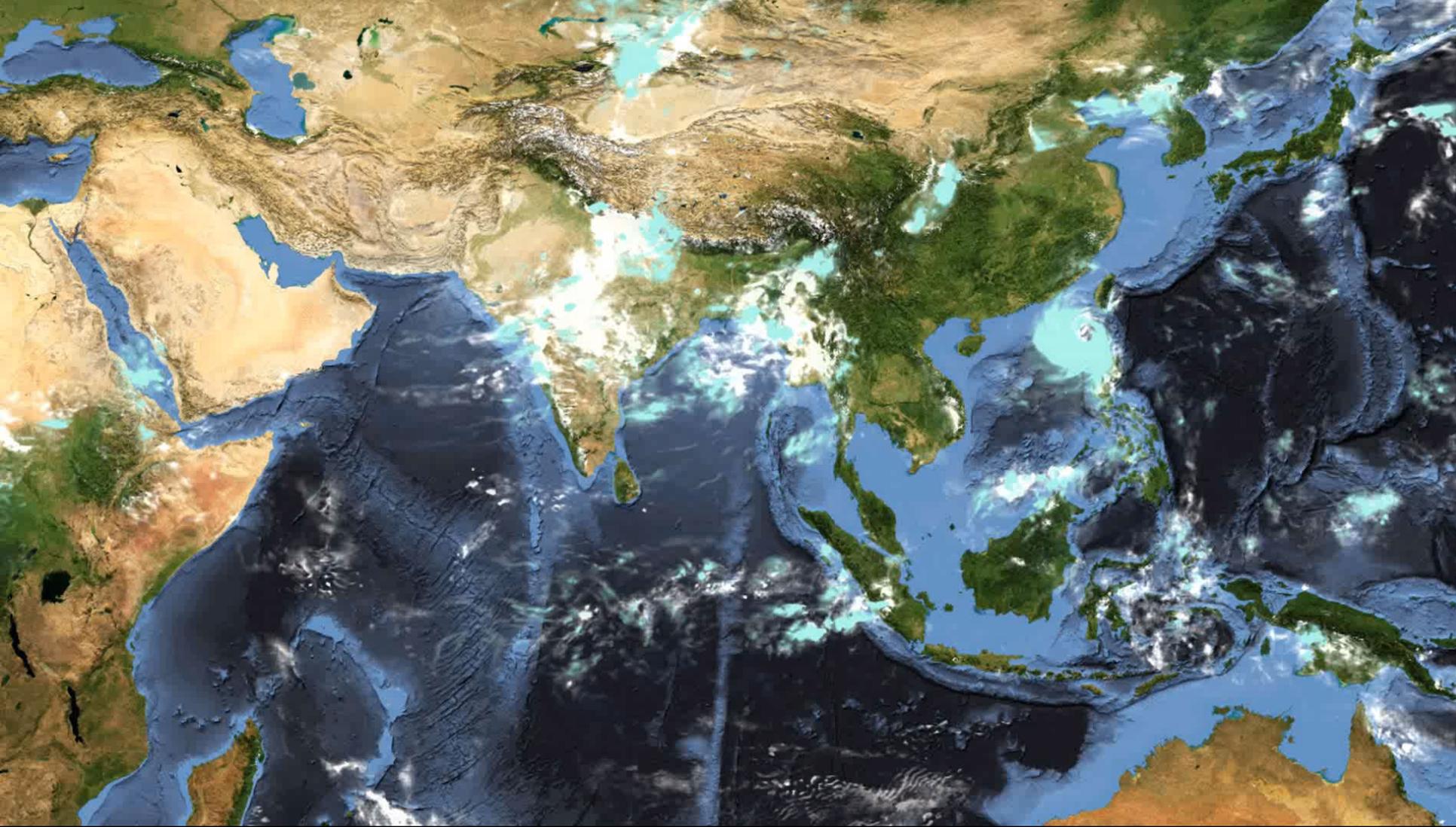


25.11.2013 01:00



ICON DYAMOND R2B10 2.5km Resolution
01.08.2016 at 00:00





HD(CP)²

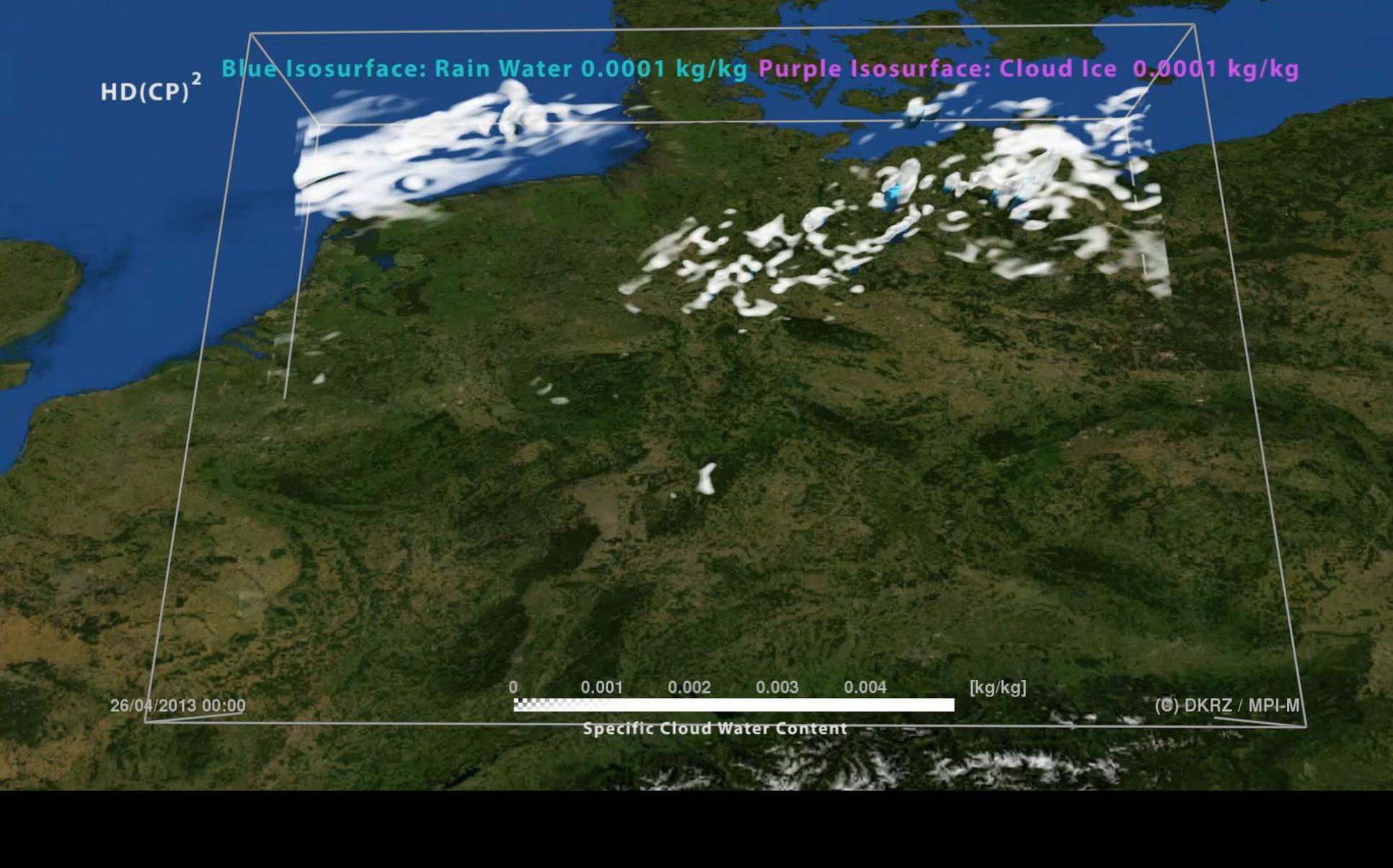
Blue Isosurface: Rain Water 0.0001 kg/kg Purple Isosurface: Cloud Ice 0.0001 kg/kg

26/04/2013 00:00

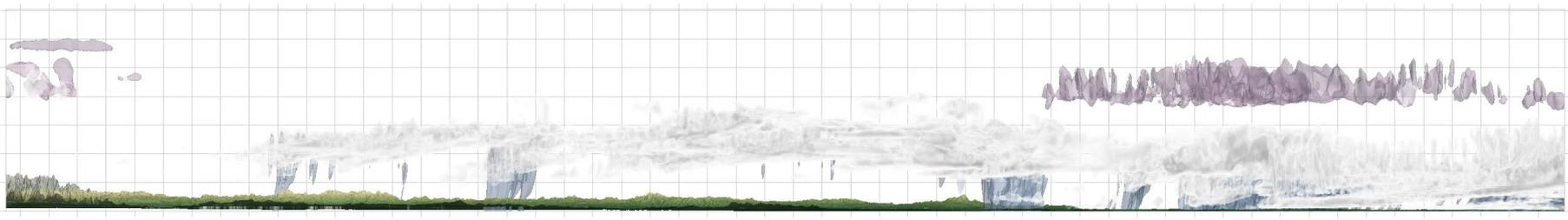
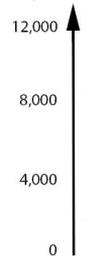
0 0.001 0.002 0.003 0.004 [kg/kg]

Specific Cloud Water Content

(C) DKRZ / MPI-M



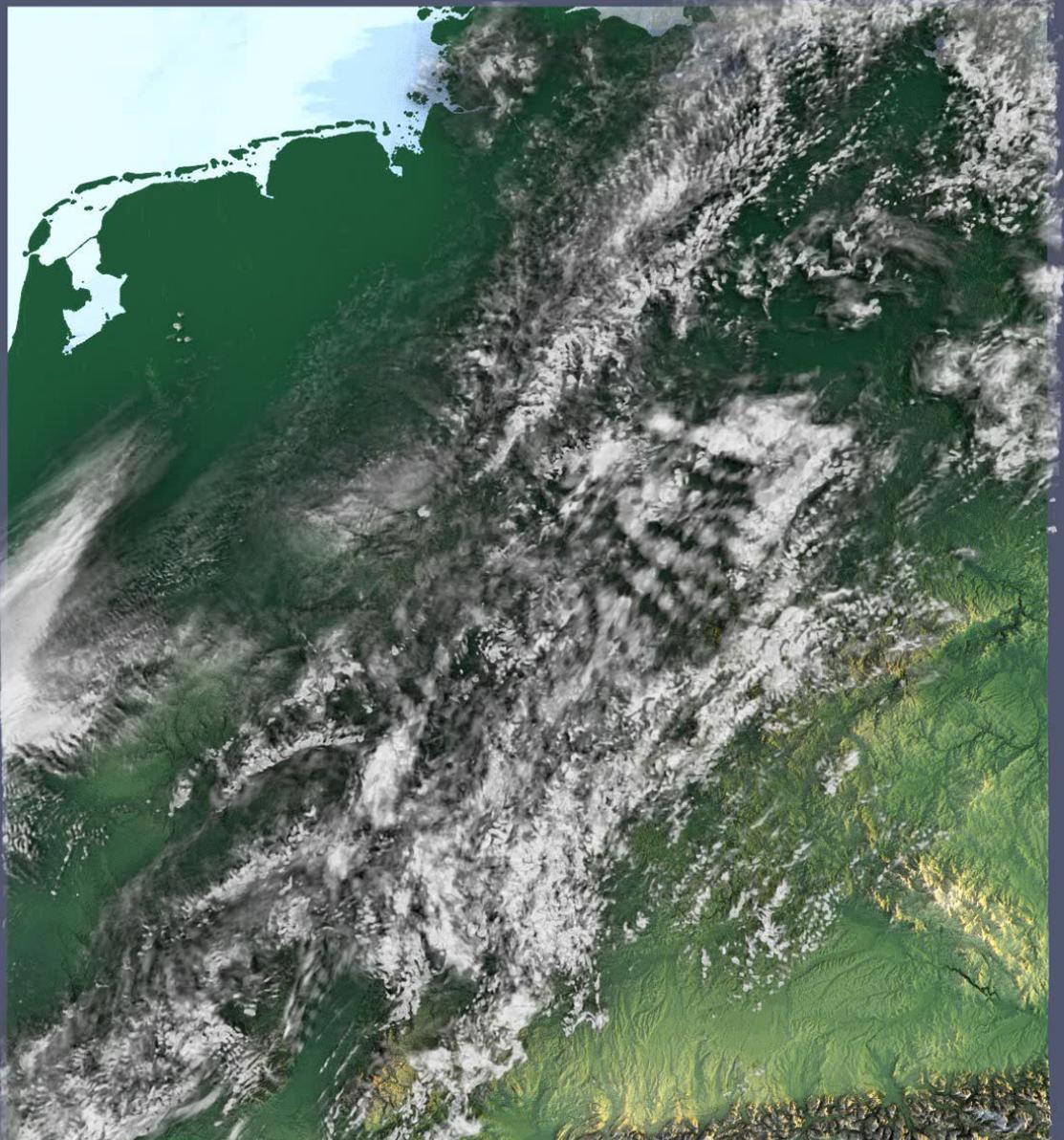
Height (m)



47.5

Latitude

54.5



www.dkrz.de
boettinger@dkrz.de