State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM



Show the state of the art to visualize scientific data at the DKRZ.

Different data and grid types need different visualization types and programs.

State of the Art in Earth Science Data Visualization

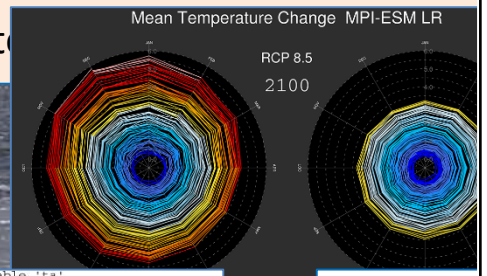
Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

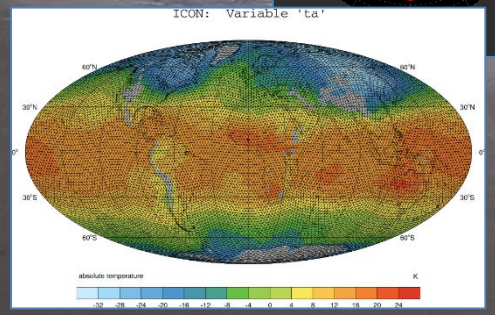
DKRZ
DEUTSCHES KLIMARECHENZENTRUM

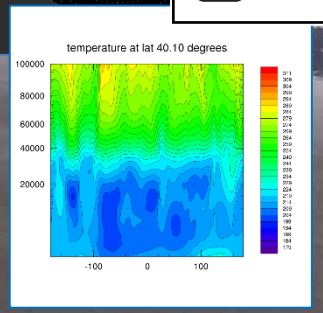
What are we talking about?

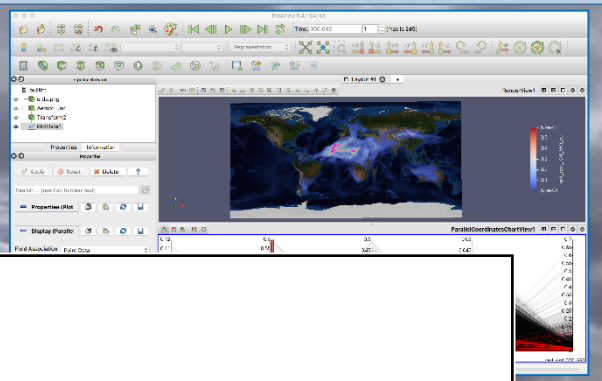
Earth Science Data

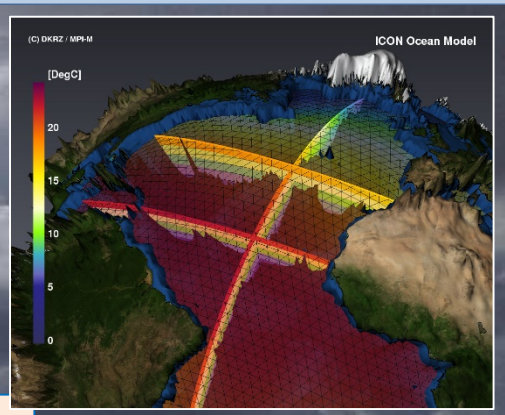
- Increasing data file size
- Various formats of scientific data se
- Different kinds of grids underlying t
- Common used visualization types
- Support









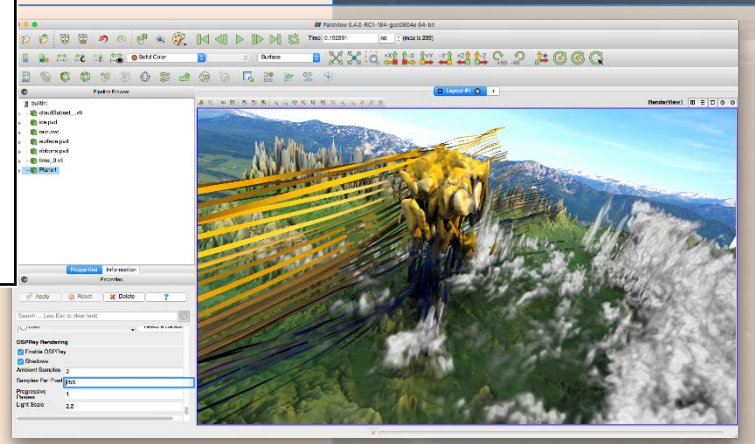


Software

- Avizo ✝

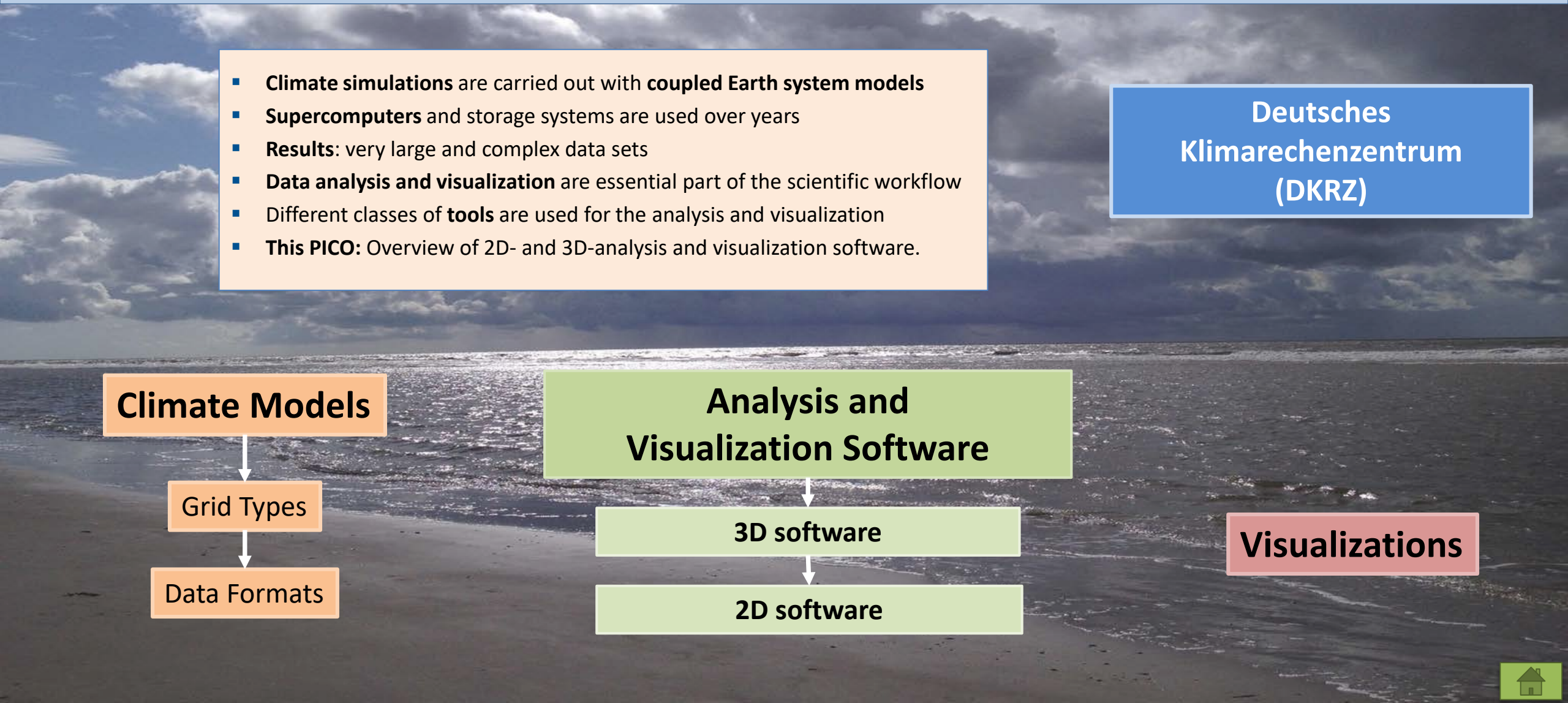
2D software

- NCL
- Python: matplotlib/basemap, PyNGL/PyNIO



State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany



- **Climate simulations** are carried out with **coupled Earth system models**
- **Supercomputers** and storage systems are used over years
- **Results**: very large and complex data sets
- **Data analysis and visualization** are essential part of the scientific workflow
- Different classes of **tools** are used for the analysis and visualization
- **This PICO:** Overview of 2D- and 3D-analysis and visualization software.

Deutsches Klimarechenzentrum (DKRZ)

Climate Models

- Grid Types
- Data Formats

Analysis and Visualization Software

- 3D software
- 2D software

Visualizations

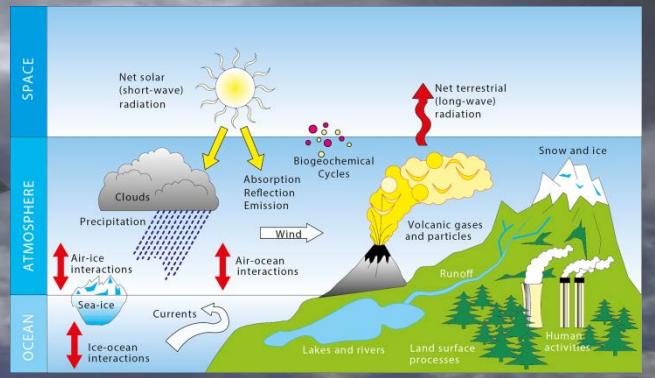
State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

Climate Models

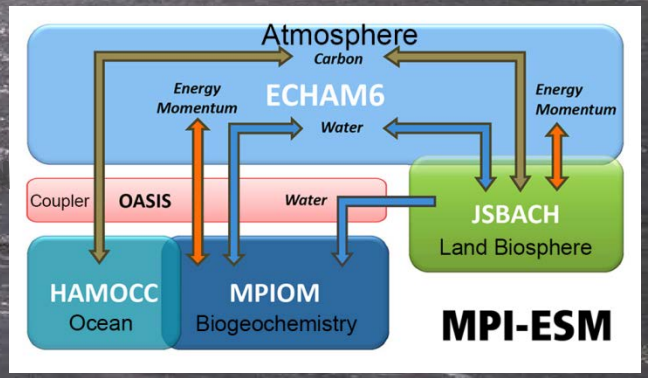
To understand the **climate system,** the different **physical** and **bio-geochemical processes and interactions** in atmosphere, ocean and on the land surface need to be taken into account.

To facilitate simulations of the whole Earth system, **coupled numerical models** of the different subsystems are used. Due to the model complexity, the spatial model resolution, the long simulation periods and the use of ensemble techniques to reduce the model uncertainty, powerful **supercomputers and storage systems** are needed for this research.









State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

Grid Types

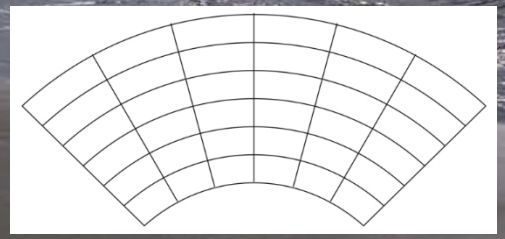
Numerical climate models require atmosphere and ocean to be divided into **grid cells**. Depending on the **discretization** and **numerical scheme** used, we have to deal with different **grid types** of the 3D time-dependent data. The algorithms used for the visualization are usually computationally less expensive for simpler grid types.

Simple grid type: **regular**, **rectilinear**

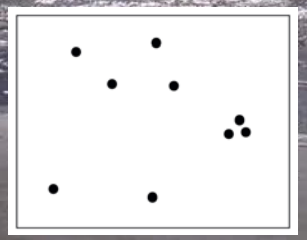
Complex grid types: **curvilinear**, **unstructured**

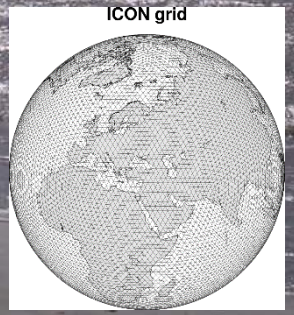


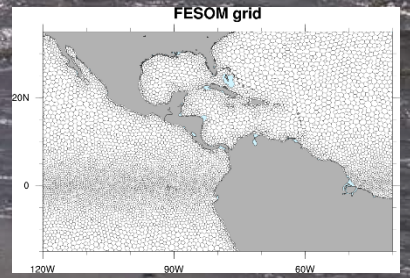
Rectilinear



Curvilinear







Unstructured

State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM







The new High Performance Computer System for Earth System Research (HLRE-3):

- 3.300 compute nodes (> 100.000 cores)
- 266 TB main memory
- 20 PB parallel file system

- 3.6 PetaFlops peak performance
- 54 PB parallel file system
- 21 visualization nodes with 2 Nividia GPUs

State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

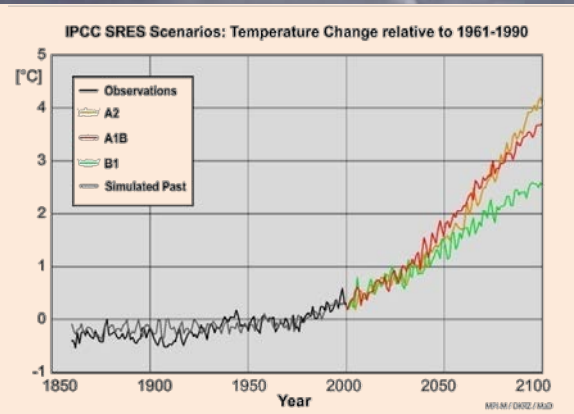
DKRZ's Visualization Services

Visualization by the user

1D oder 2D-methods

Batch or script-based

local workstations or server-based



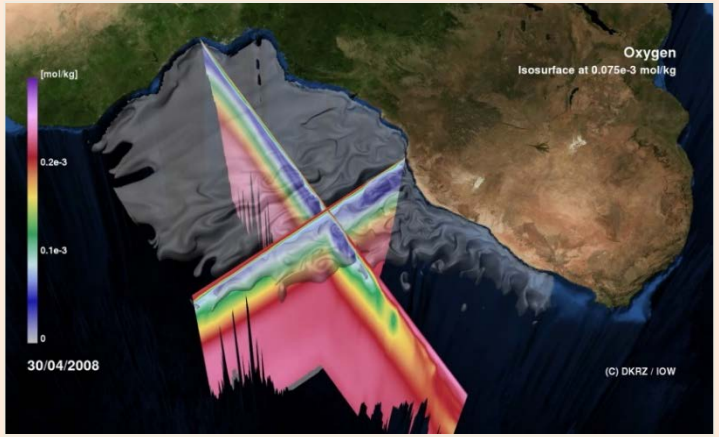
Services by DKRZ

Software, Hardware & Remote Vis

Tutorials, Documentation

Interactive 3D Visualization

- Application Projects
- In-House Developments



State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

Presentation Devices



Climate Globe



4K Touch Table



VR-Powerwall

State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Visualization and Analysis Software

Type	Name	URL	Properties	
Domain-specific	NCL	http://www.ncl.ucar.edu/	2D script-based	free
	IDV	http://www.unidata.ucar.edu/software/idv/	2D/3D interactive GUI	free
	Vapor	https://www.vapor.ucar.edu/	3D interactive GUI	free
	UV-CDAT	http://uvcdat.llnl.gov/	Collection: 2D /3D tools	free
	GrADS	http://cola.gmu.edu/grads/	2D script-based	free
	Ferret	http://www.ferret.noaa.gov/Ferret/	2D script-based	free
	GMT	http://gmt.soest.hawaii.edu/	2D script-based	free
General-purpose	ParaView	http://www.paraview.org/	3D interactive GUI	free
	Avizo	https://www.fei.com/software/avizo3d/	3D interactive GUI	$$ †
	IDL	http://www.harrisgeospatial.com/	2D script-based	$$
	Python / matplotlib	http://matplotlib.org/	2D script-based	free

State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ's supported Visualization and Analysis Software

3D software

- ParaView
- Vapor
- Avizo †

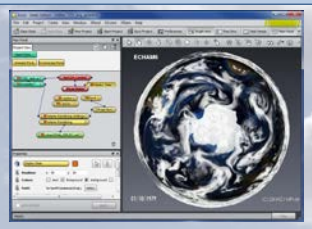
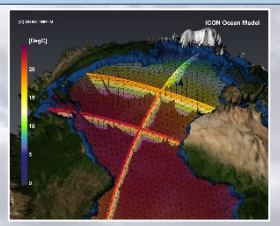
2D software

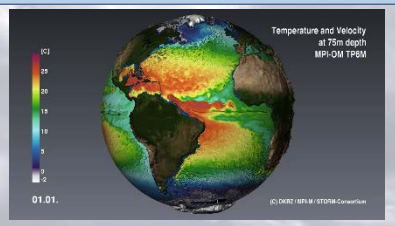
- NCL
- Python: matplotlib/basemap, PyNGL/PyNIO

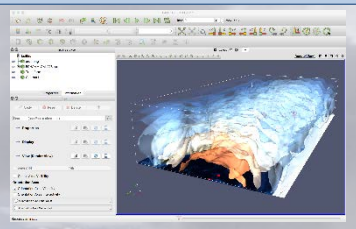
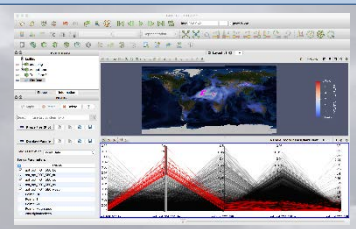
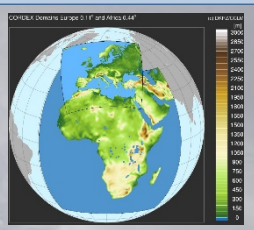
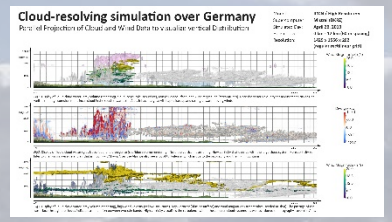
State of the Art in Earth Science Data Visualization

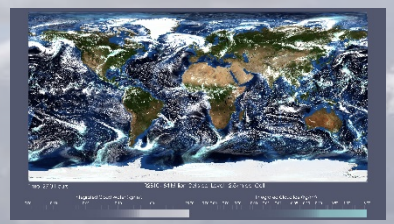
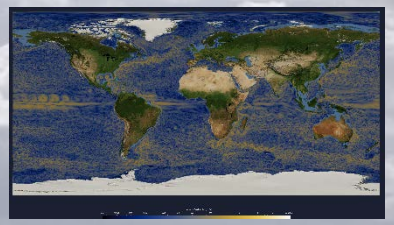
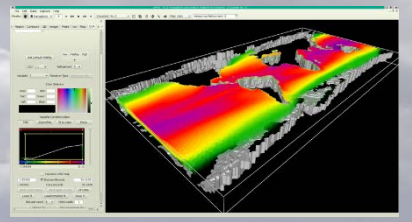
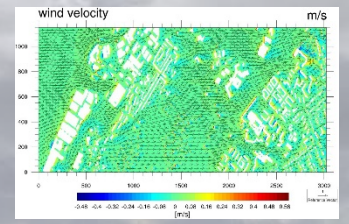
Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

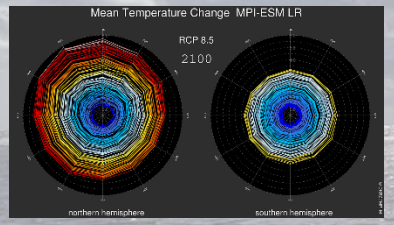
DKRZ
DEUTSCHES
KLIMARECHENZENTRUM

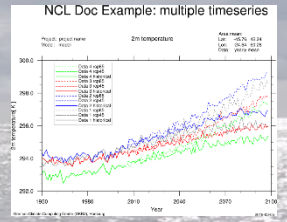



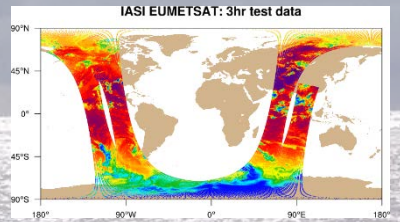


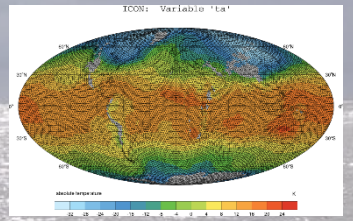
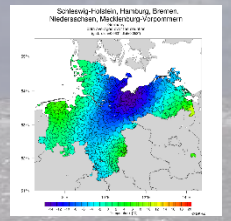
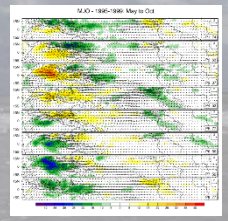
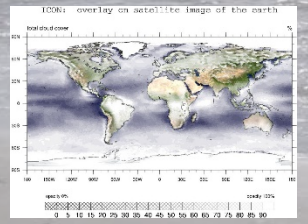





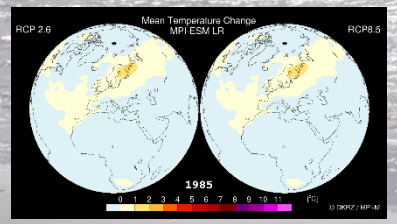





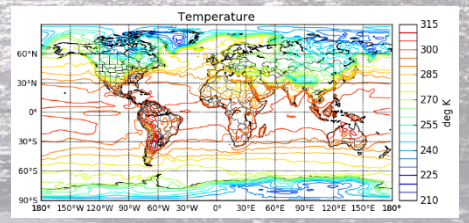


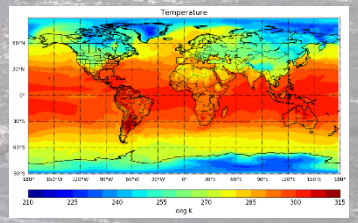


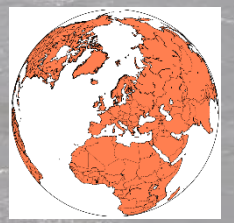
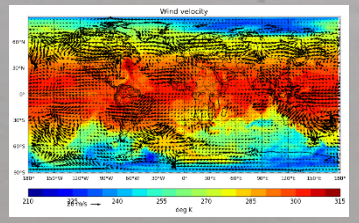


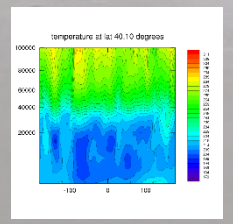





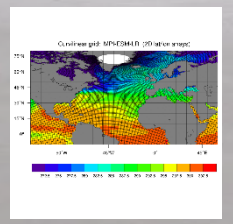
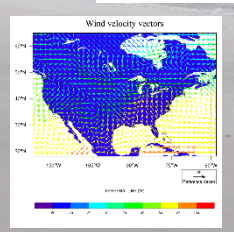


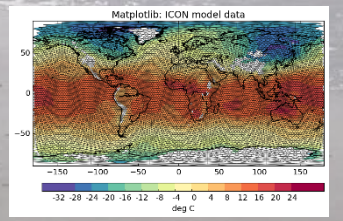


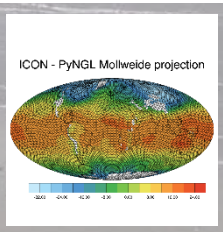


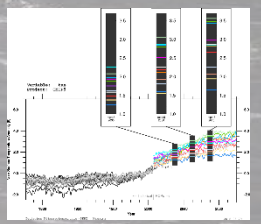





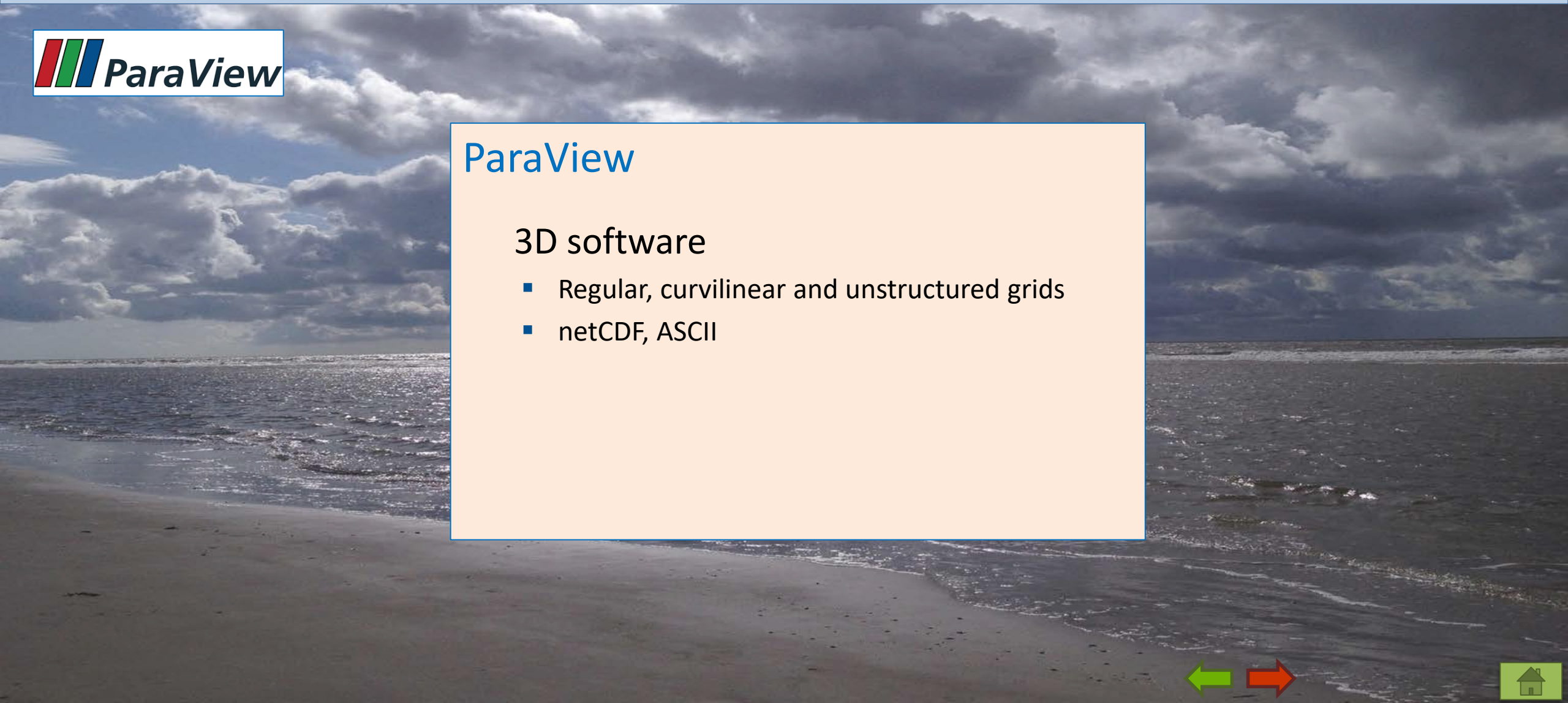






State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany



ParaView

3D software

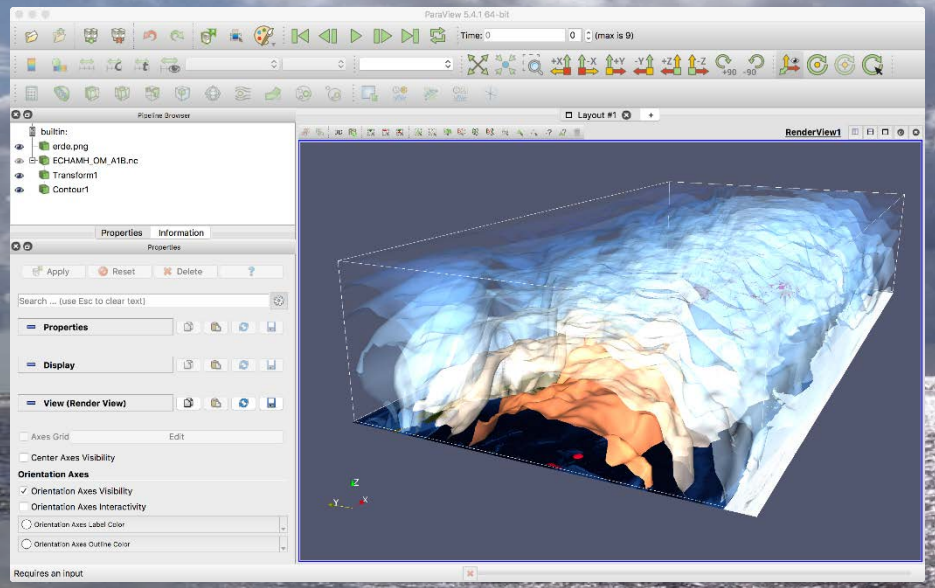
- Regular, curvilinear and unstructured grids
- netCDF, ASCII

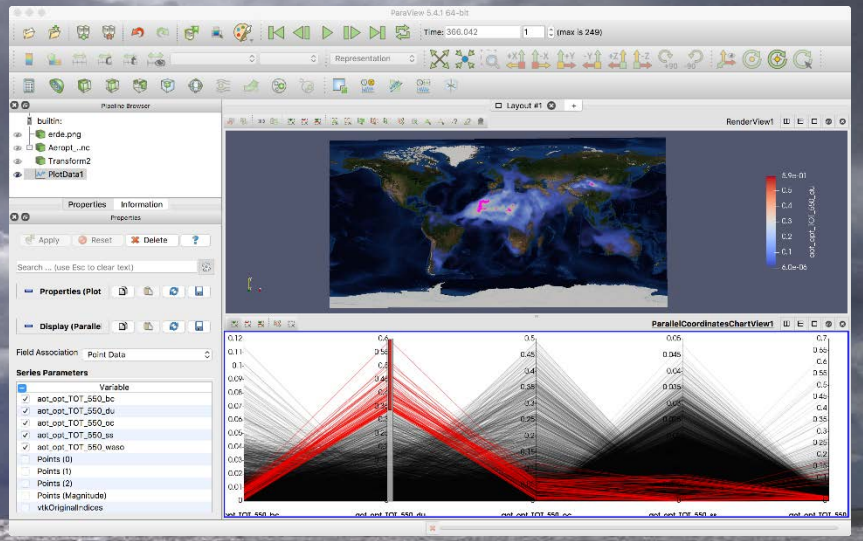
State of the Art in Earth Science Data Visualization

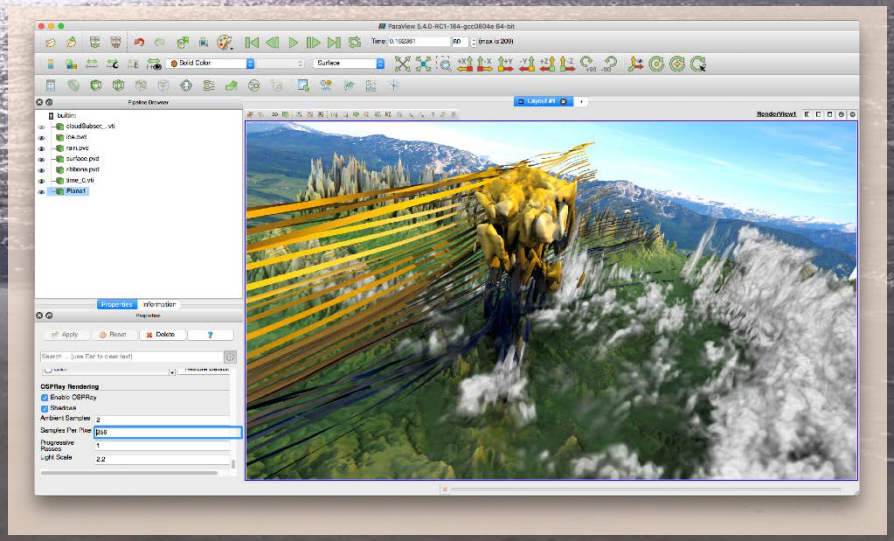
Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

ParaView





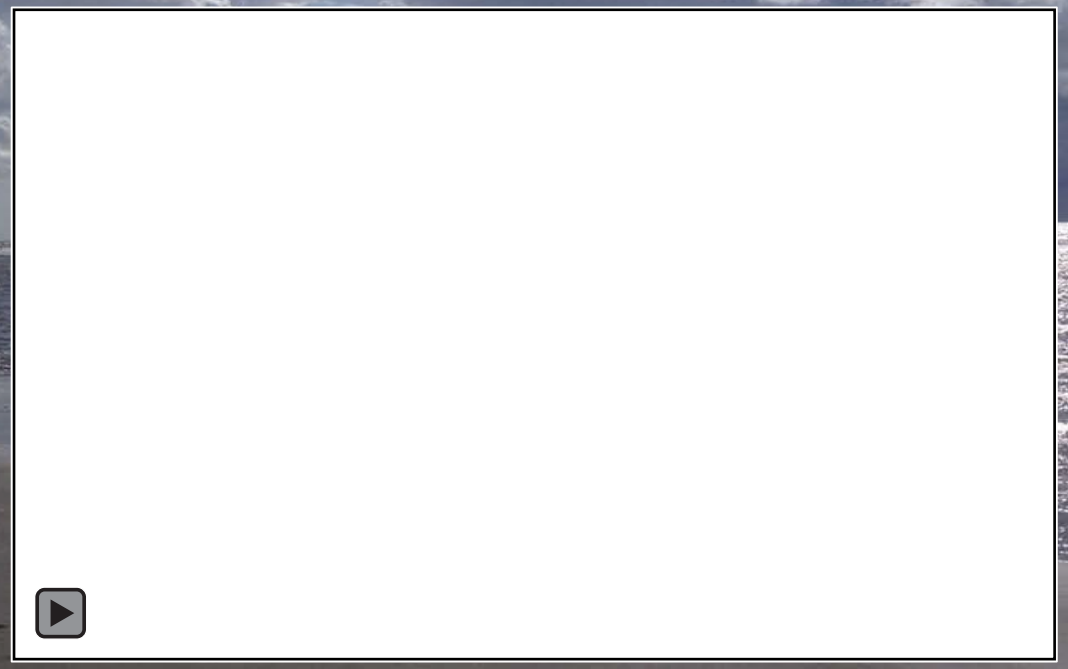


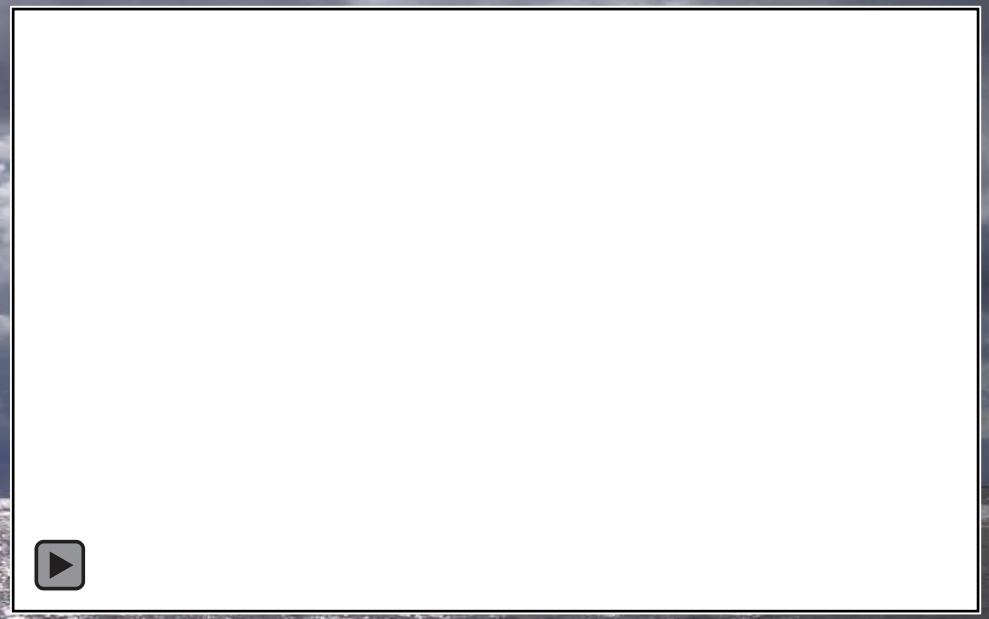
State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

ParaView





State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

Vapor

3D software

- Read regular grids
- netCDF, ASCII

Plot types

- Contours
- Cross Sections
- Isosurface
- Flow Visualization
- World Map

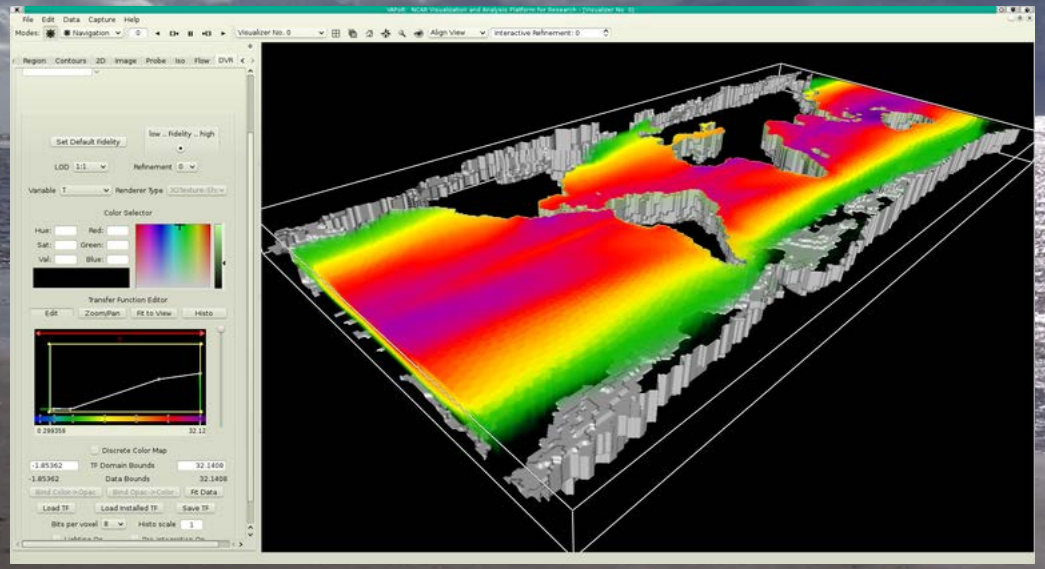
https://www.vapor.ucar.edu/

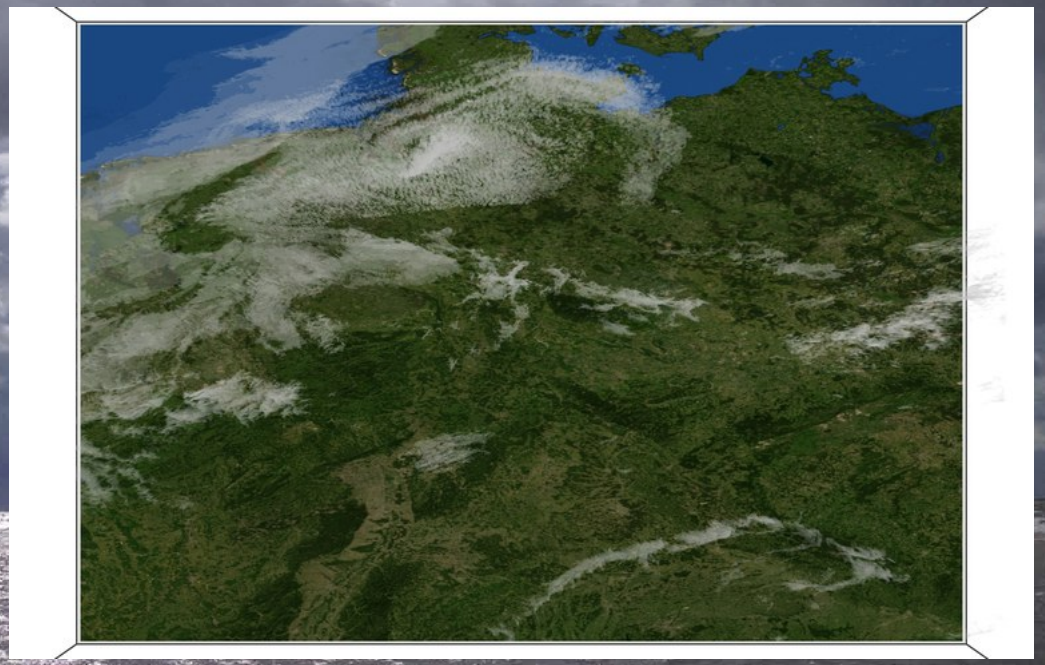
State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Vapor





State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ DEUTSCHES KLIMARECHENZENTRUM

Avizo | Amira-Avizo Software

Avizo (Climatology and Geophysics Profile)

3D software

- Read regular grids
- netCDF, ASCII

Plot types

- Slice
- Bar Chart
- Iso-Surface
- Glyphs
- Streamlines
- Volume Rendering

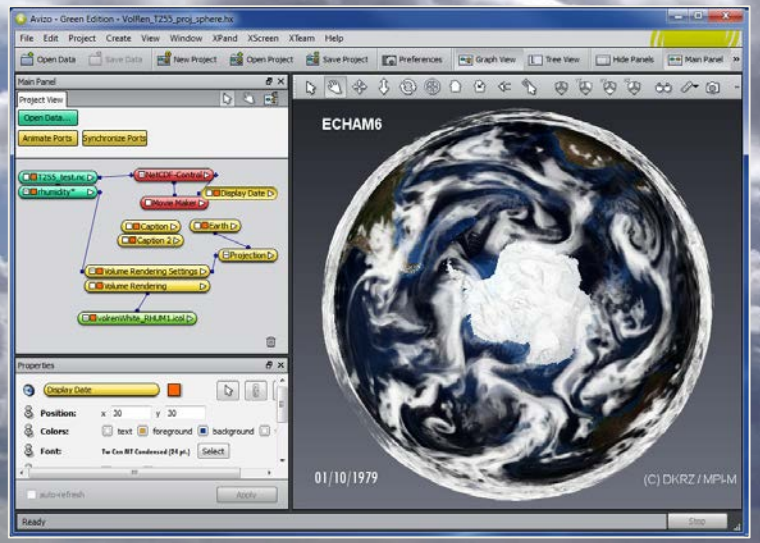
http://www.fei.com/software/avizo-3d/

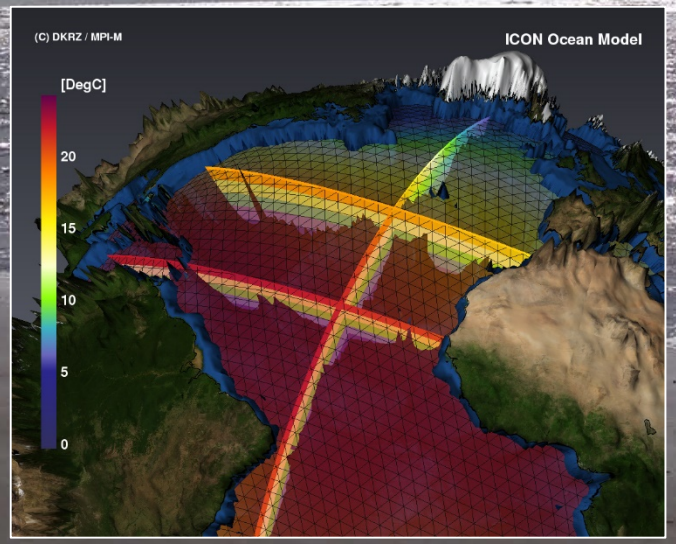
State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Avizo



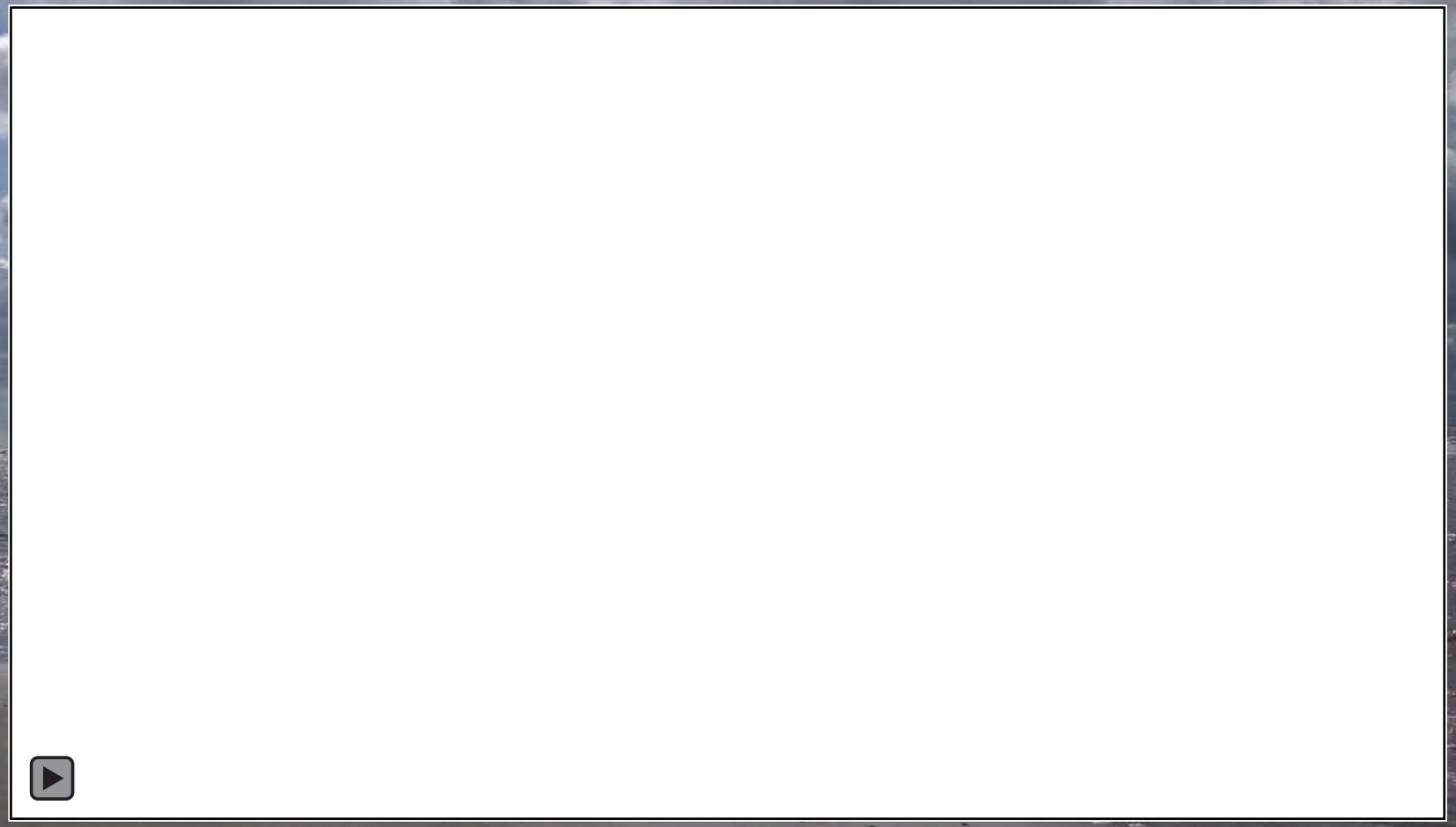


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Avizo

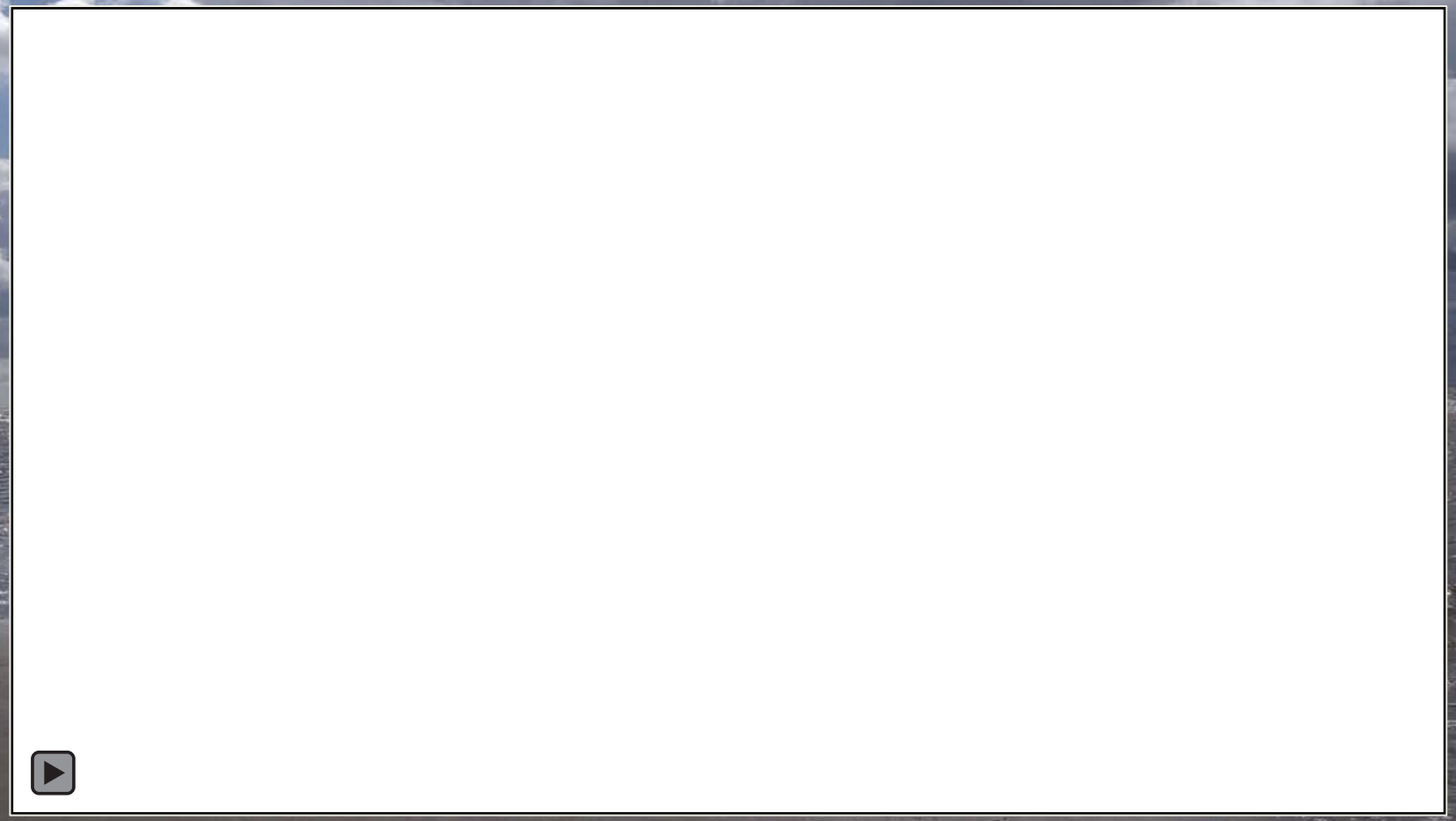


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Avizo



Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

NCL – NCAR Command Line Language

2D software

- Read regular, curvilinear and unstructured grids
- Data formats: netCDF, GRIB, ASCII
- Data analysis functions library

Plot types:

- XY
- Contour
- Vector
- Bar Charts
- Overlay
- Panel
- Animation

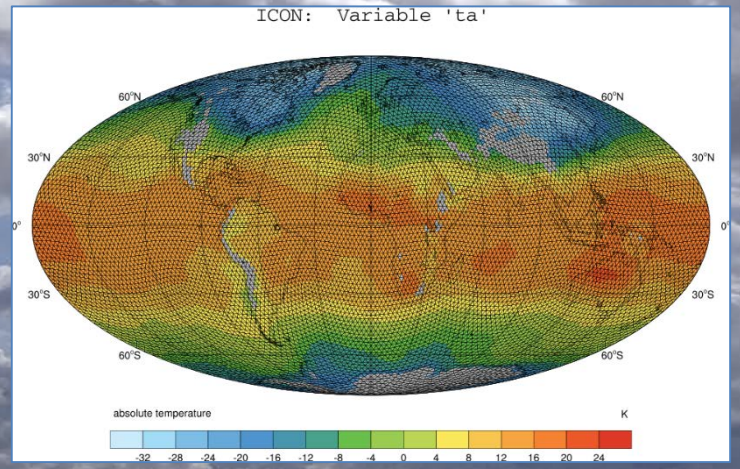
http://ncl.ucar.edu

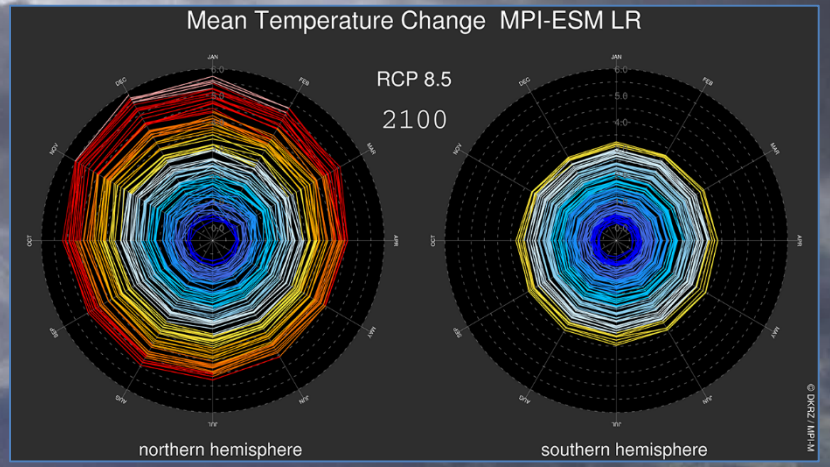
State of the Art in Earth Science Data Visualization

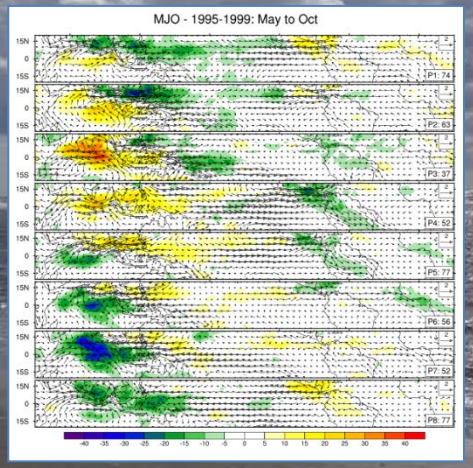
Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

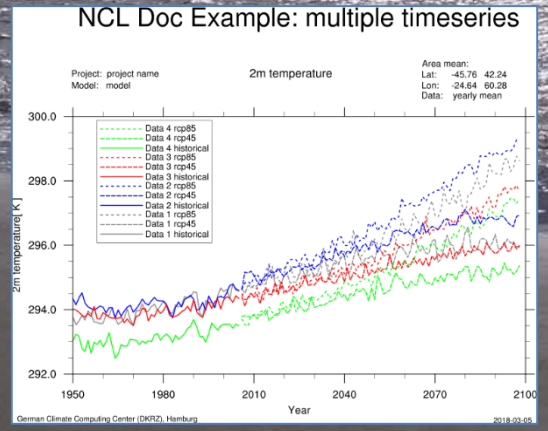
DKRZ
DEUTSCHES KLIMARECHENZENTRUM

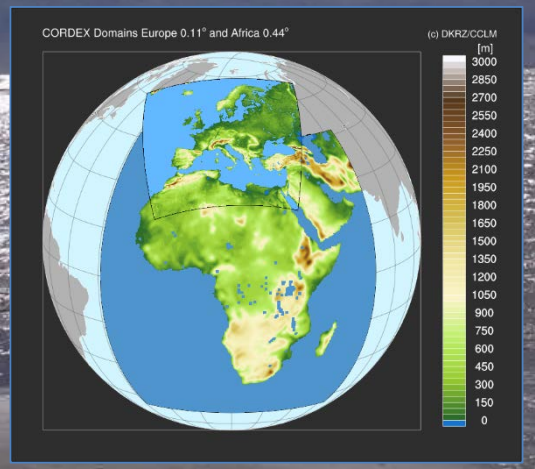
NCL

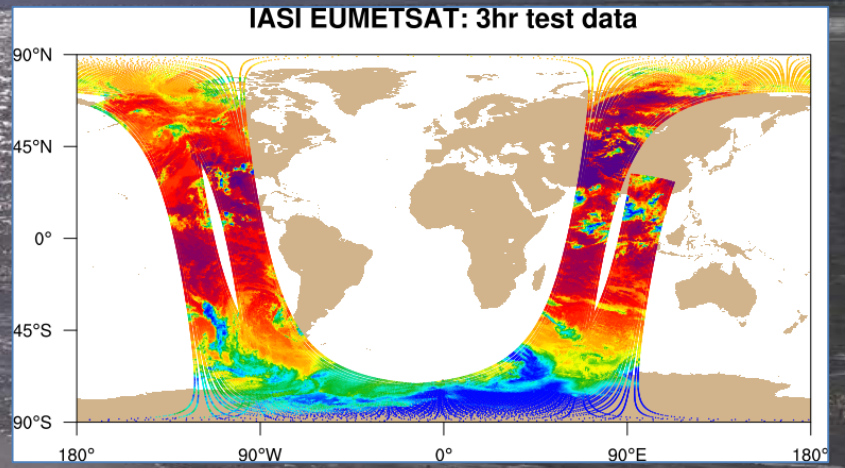










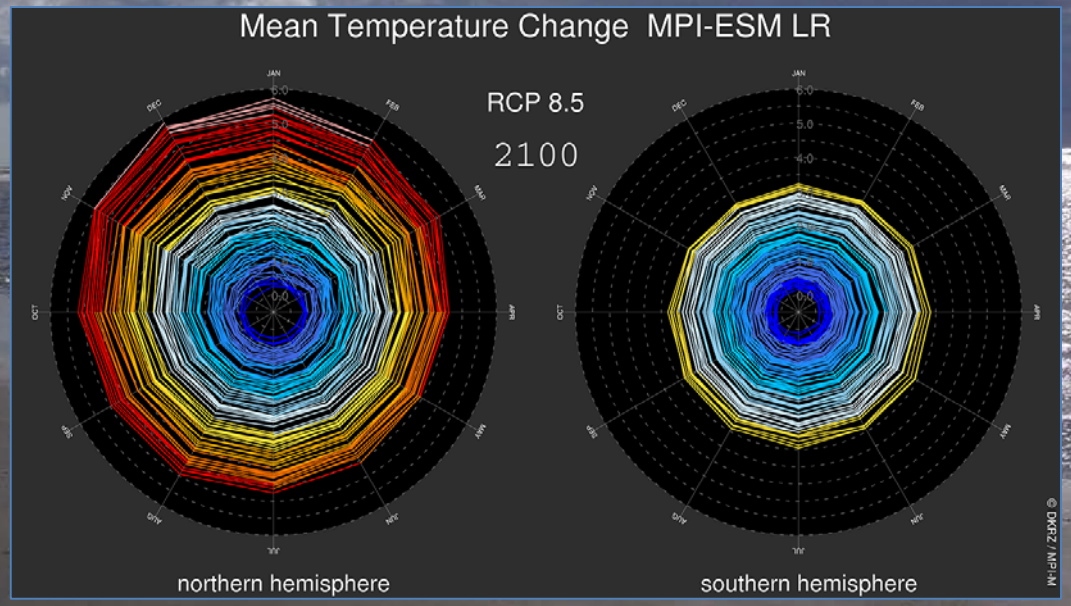


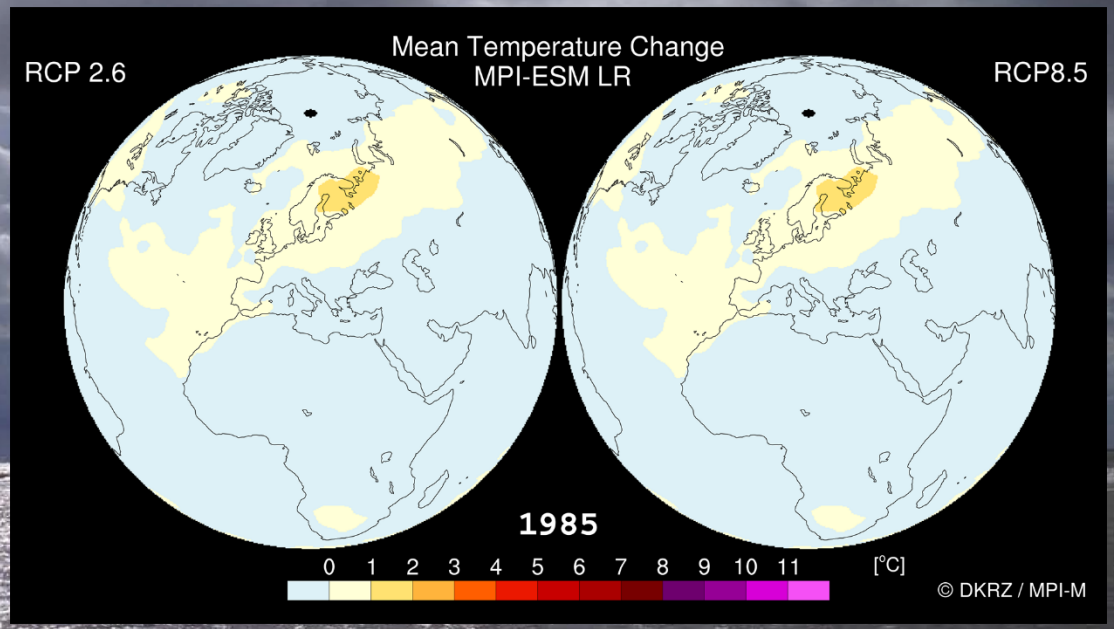
State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

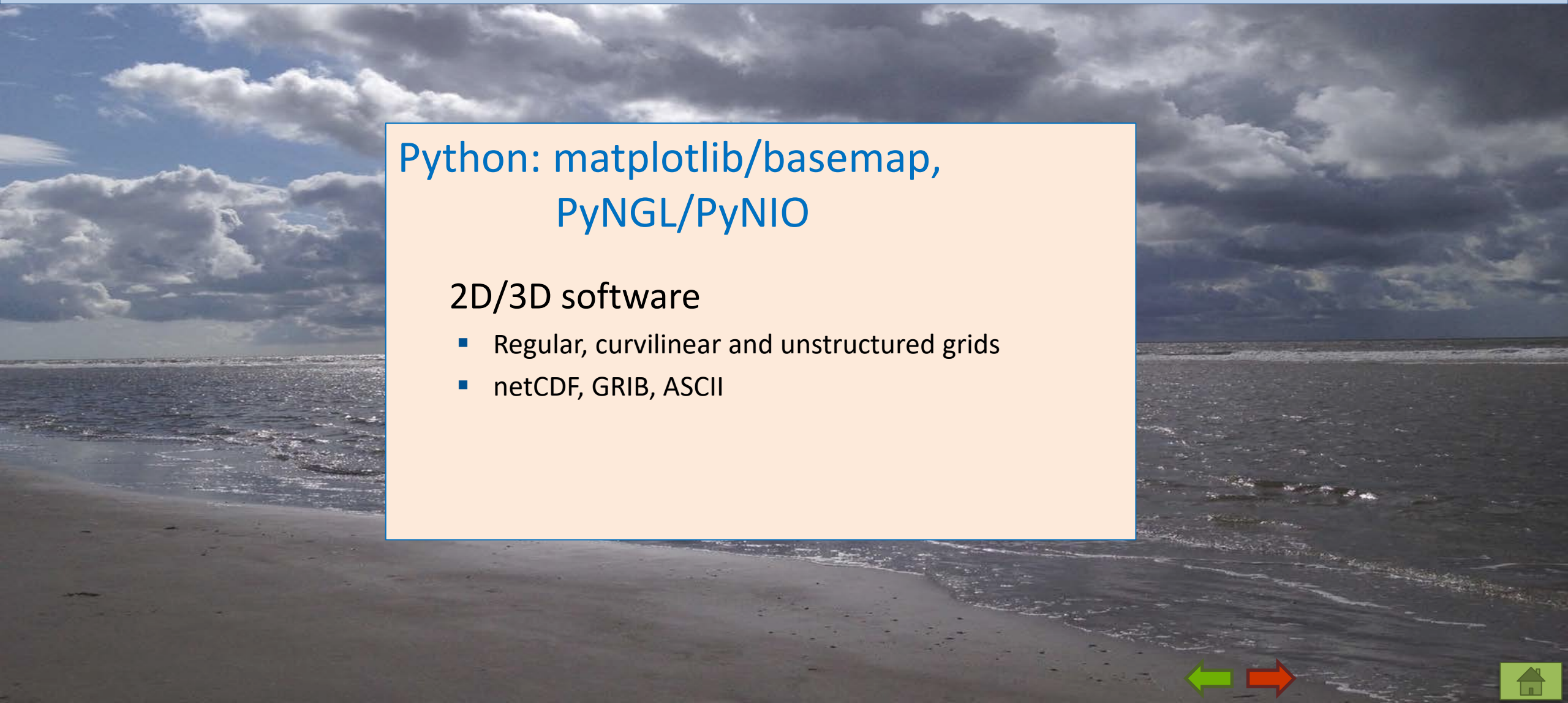
NCL Animations





State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany



Python: matplotlib/basemap, PyNGL/PyNIO

2D/3D software

- Regular, curvilinear and unstructured grids
- netCDF, GRIB, ASCII

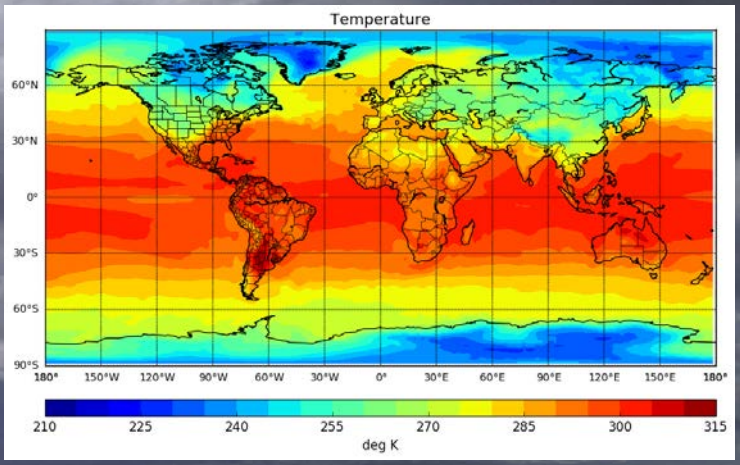
State of the Art in Earth Science Data Visualization

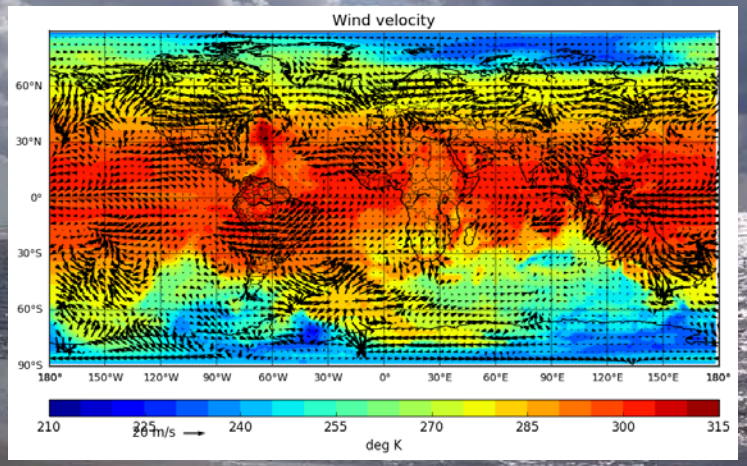
Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

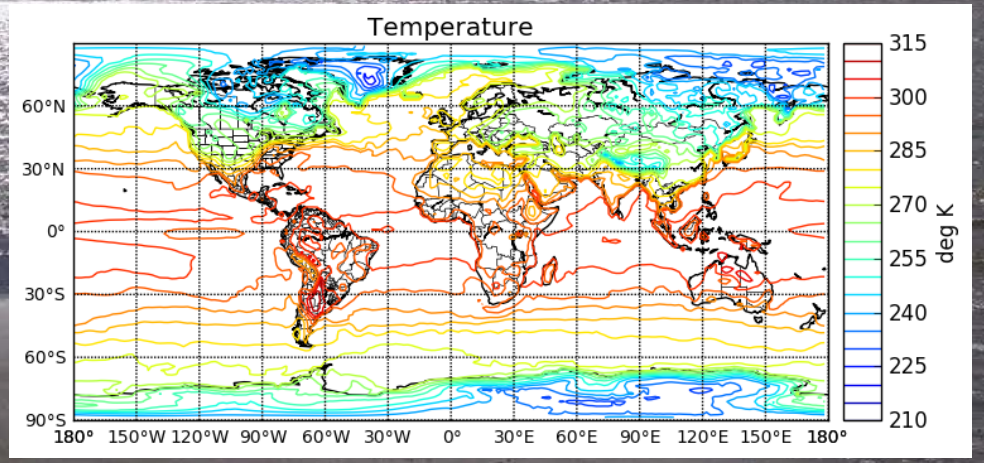
DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Python matplotlib/basemap







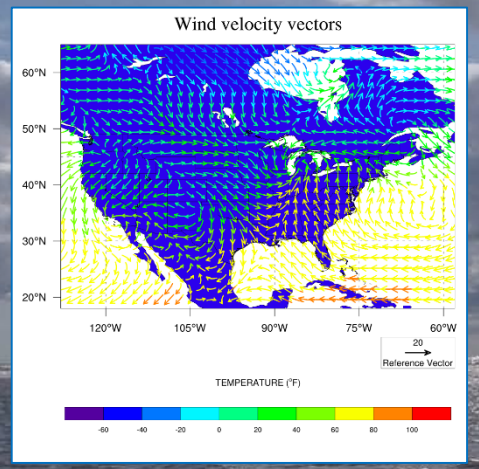


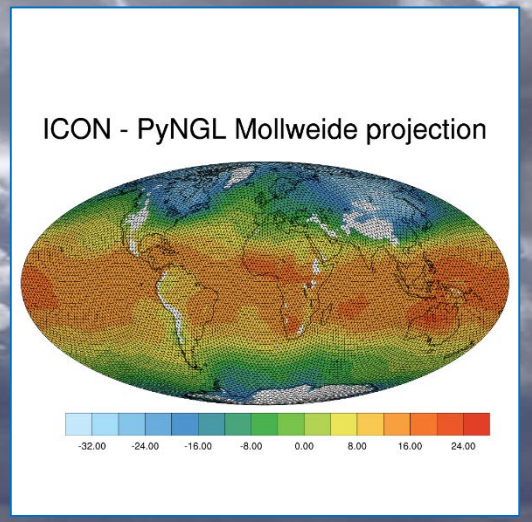
State of the Art in Earth Science Data Visualization

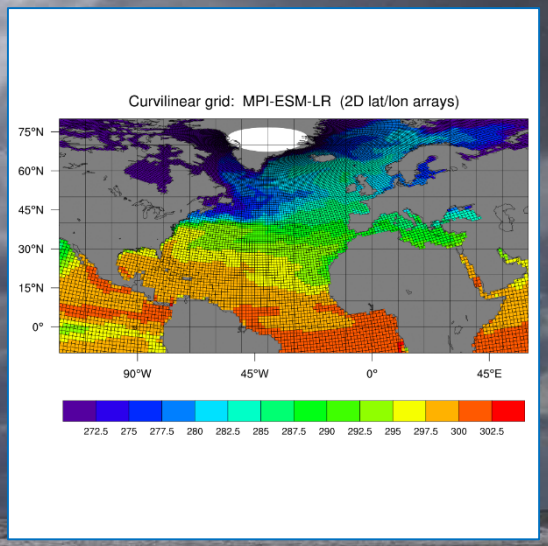
Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

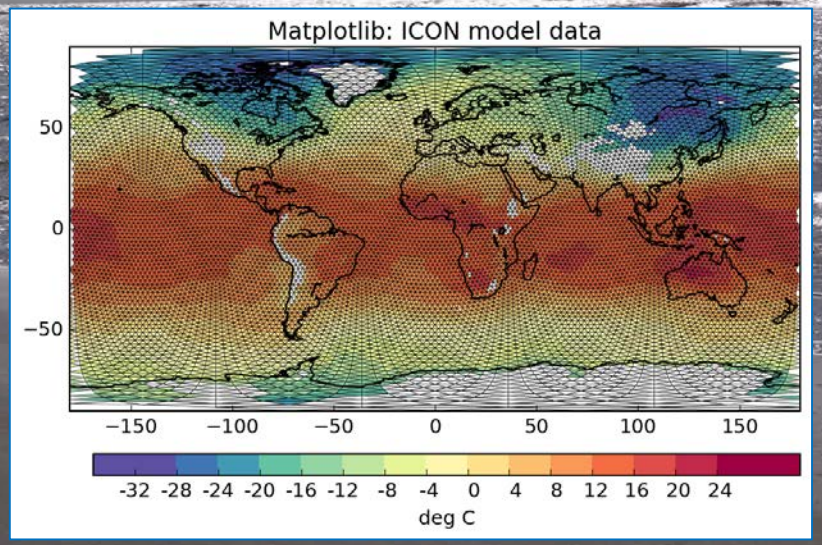
DKRZ
DEUTSCHES KLIMARECHENZENTRUM

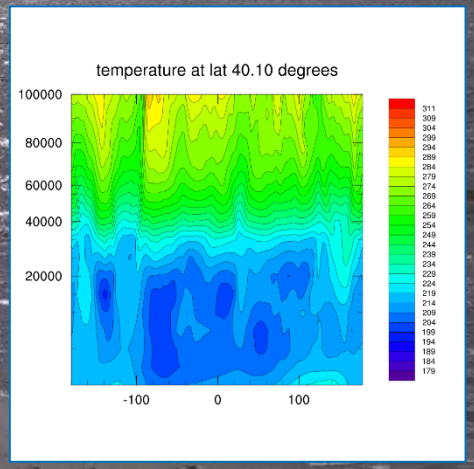
Python PyNGL/PyNIO









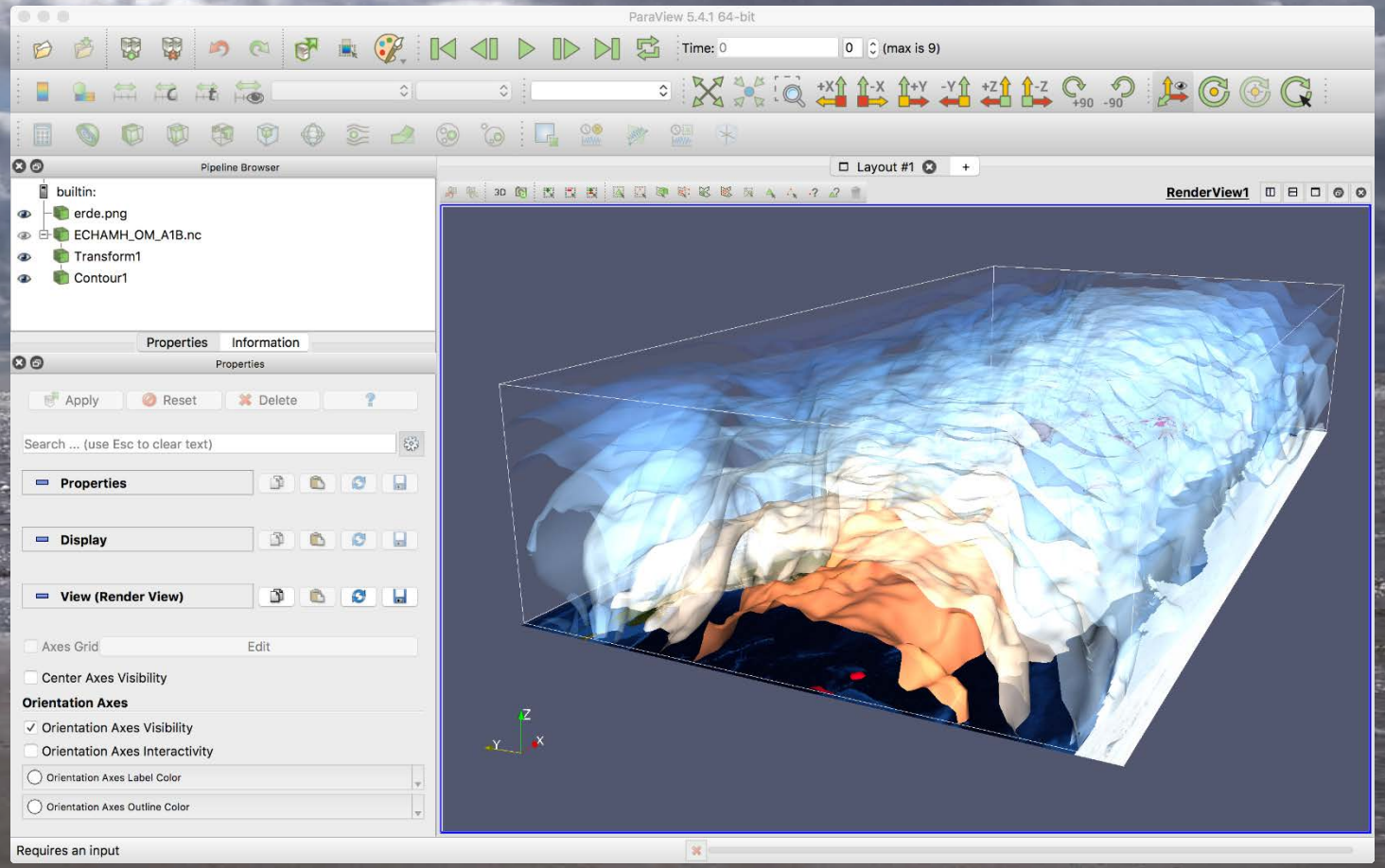


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

ParaView - Isosurfaces

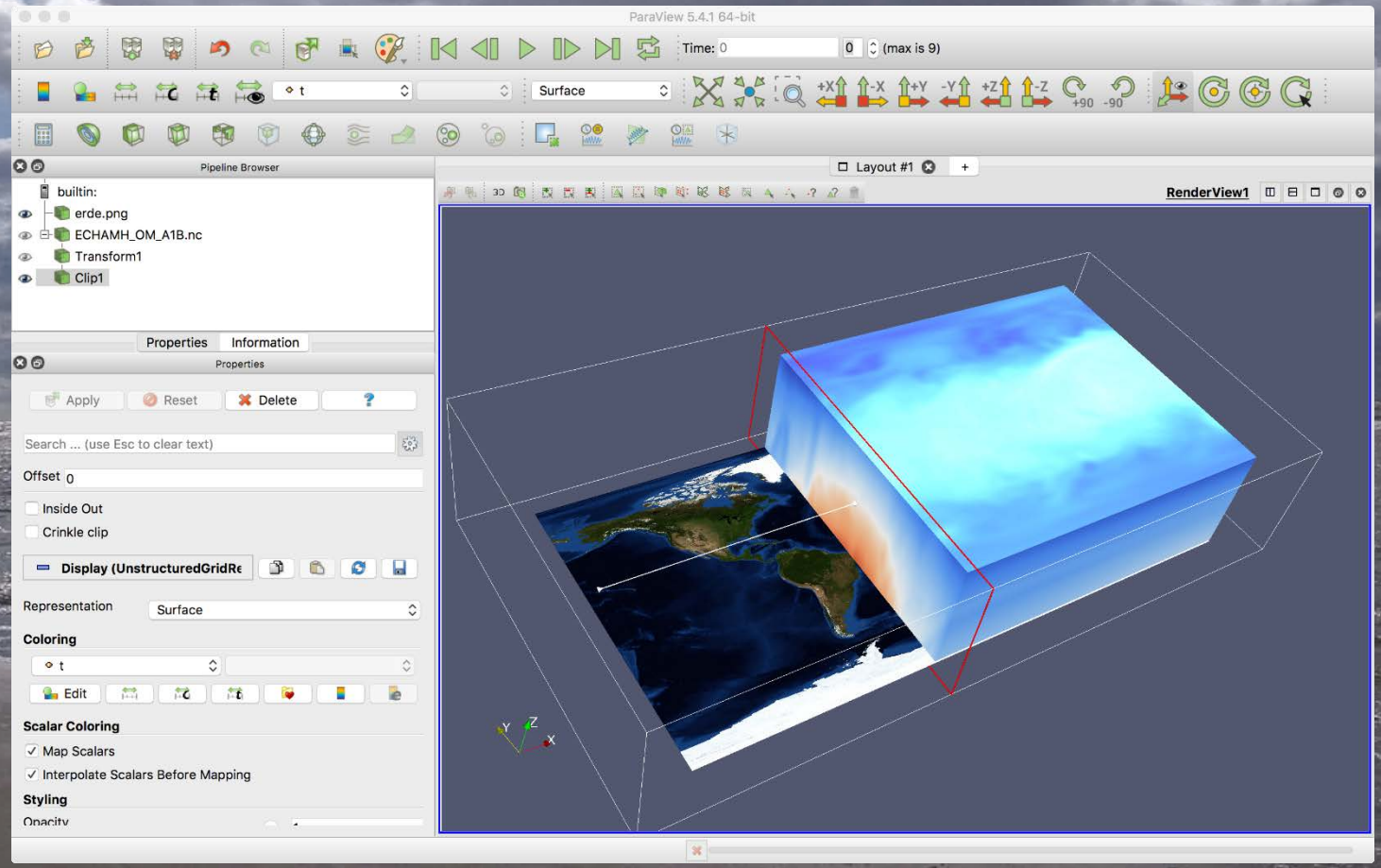


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

ParaView - clipping

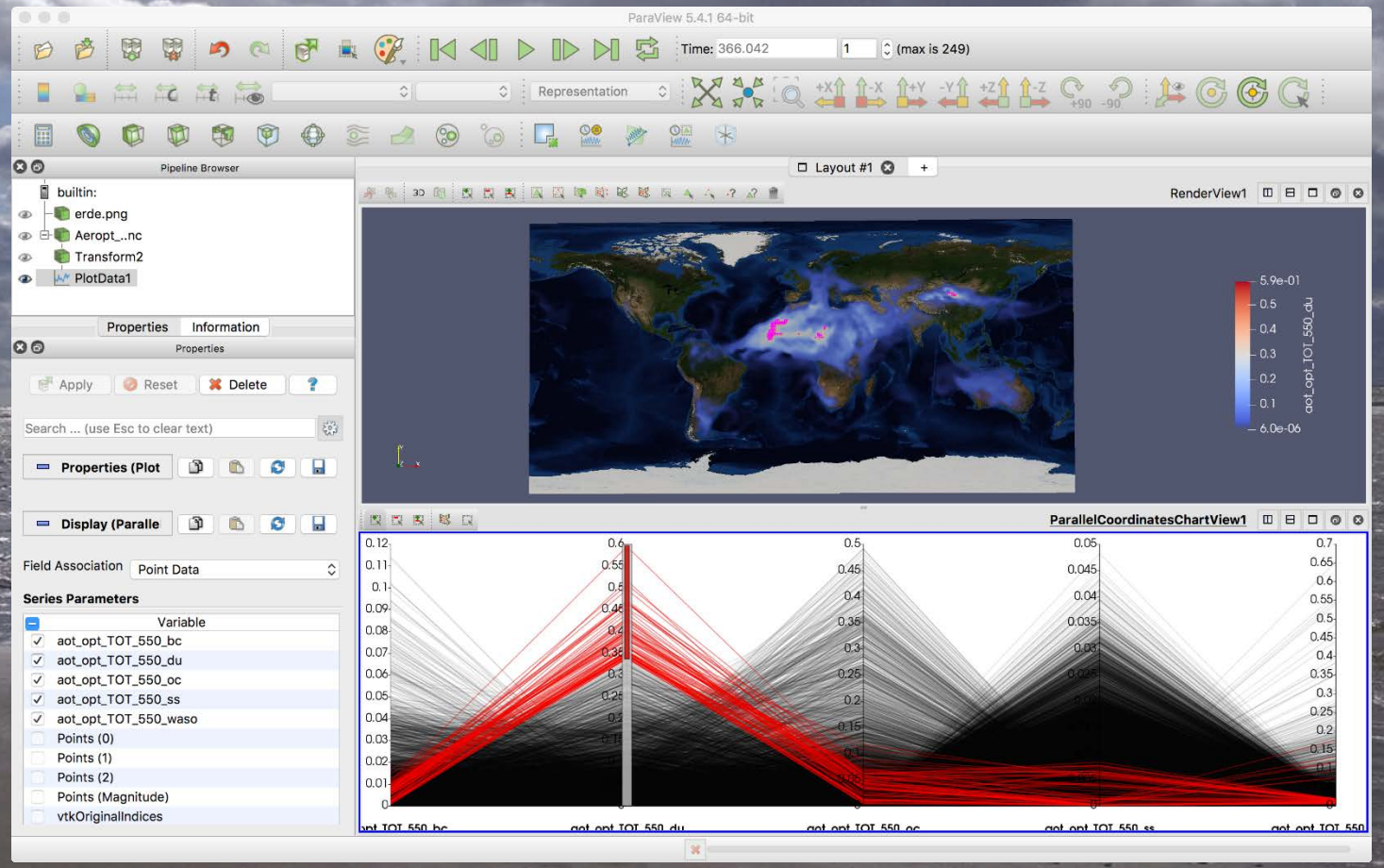


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES
KLIMARECHENZENTRUM

ParaView – lining & brushing



State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES
KLIMARECHENZENTRUM

ParaView

Cloud-resolving simulation over Germany

Parallel Projection of Cloud and Wind Data to visualize vertical Distribution

Model:	**ICON / High Resolution**
Supercomputer:	**Mistral (DKRZ)**
Simulated Day:	**April 26, 2013**
Height Level:	**0 km - 12 km (60 m spacing)**
Resolution:	**1429 x 1556 x 202 (regular rectilinear grid)**

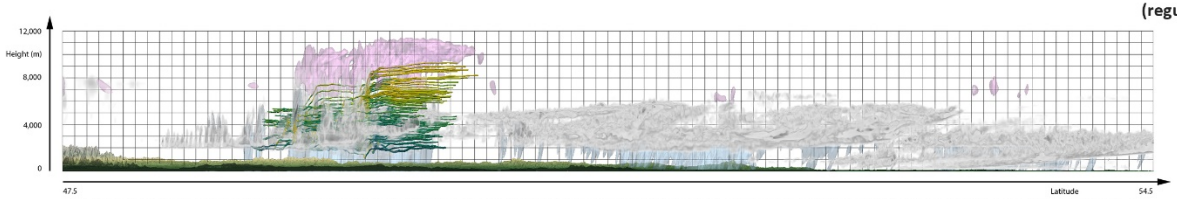


Fig1. Display of liquid cloud water (gray volume rendering), cloud ice (purple isosurface), rain (blue isosurface) and wind magnitude (streamtubes). Note the various cloud types at different altitudes, as well as the huge cumulonimbus incus cloud in the south towards the Alps. It has a large anvil shaped ice cap and strong upward moving winds.

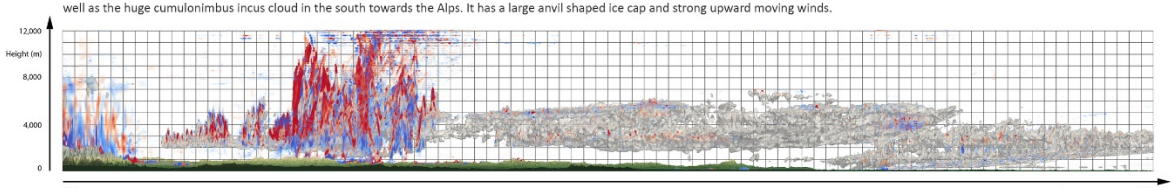


Fig2. Display of liquid cloud water (gray isosurface) and divergence (red/blue volume rendering). Note the vertical hoses of high/low vorticity that overlap with the large cloud system. Here vorticity relates to changes in pressure and air that is moving up/down. Over the Alps we also see a lot of turbulence, which is due to the orography and the high mountains.

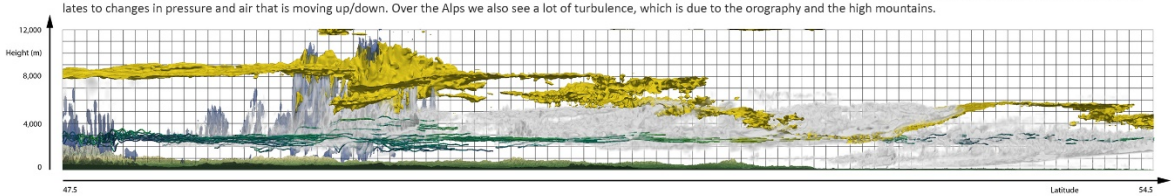


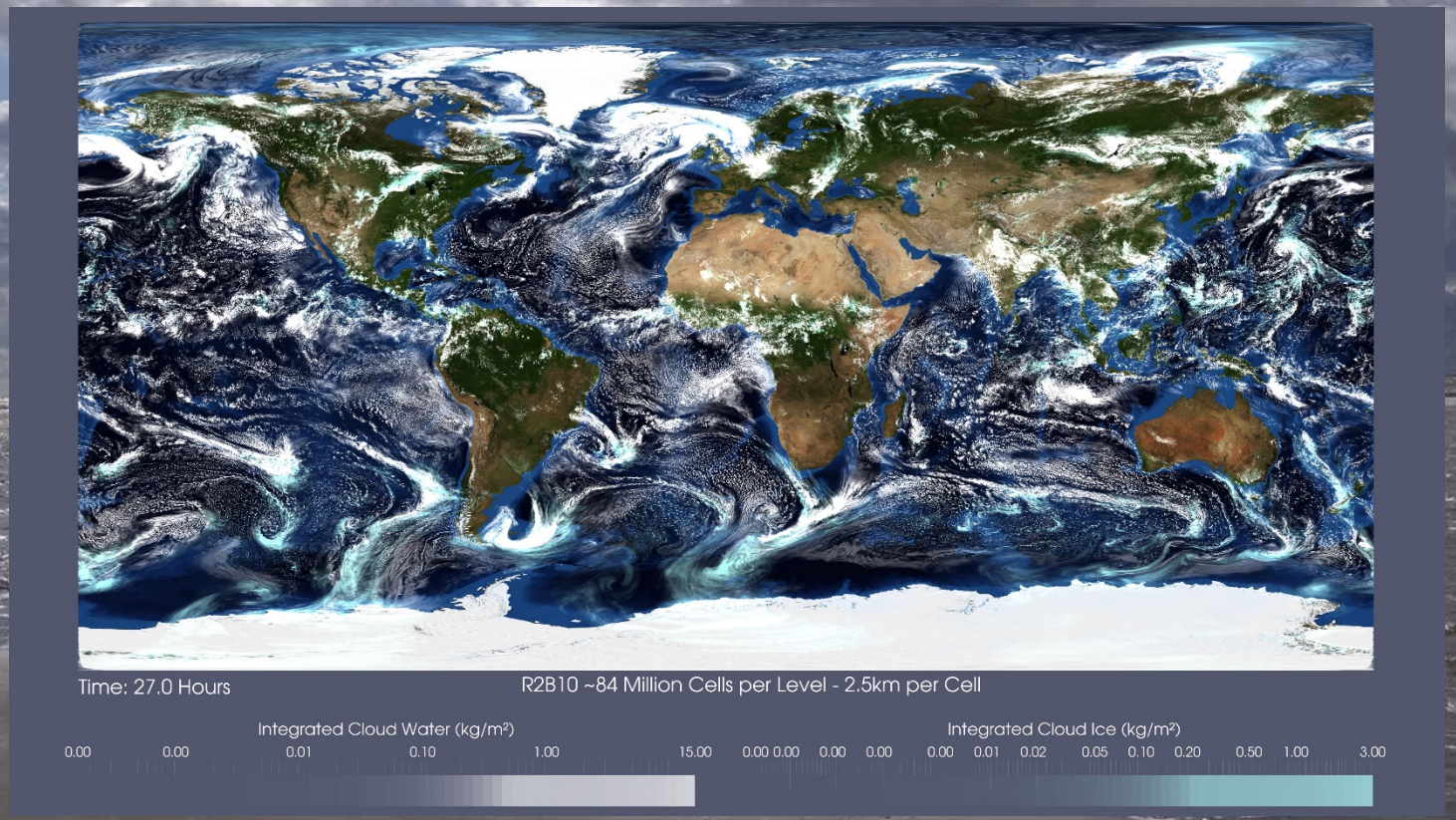
Fig3. Display of liquid cloud water (gray volume rendering), high wind velocity (yellow isosurface), high vorticity (blue isosurface) and wind magnitude (streamtubes, seeded at 3km). The passage of the isosurface through the clouds indicates a separation between two rain bands. High vorticity visualizes the turbulence within the cumulus cloud systems, as well as - due to the orography - over the Alps.

State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

ParaView Clouds

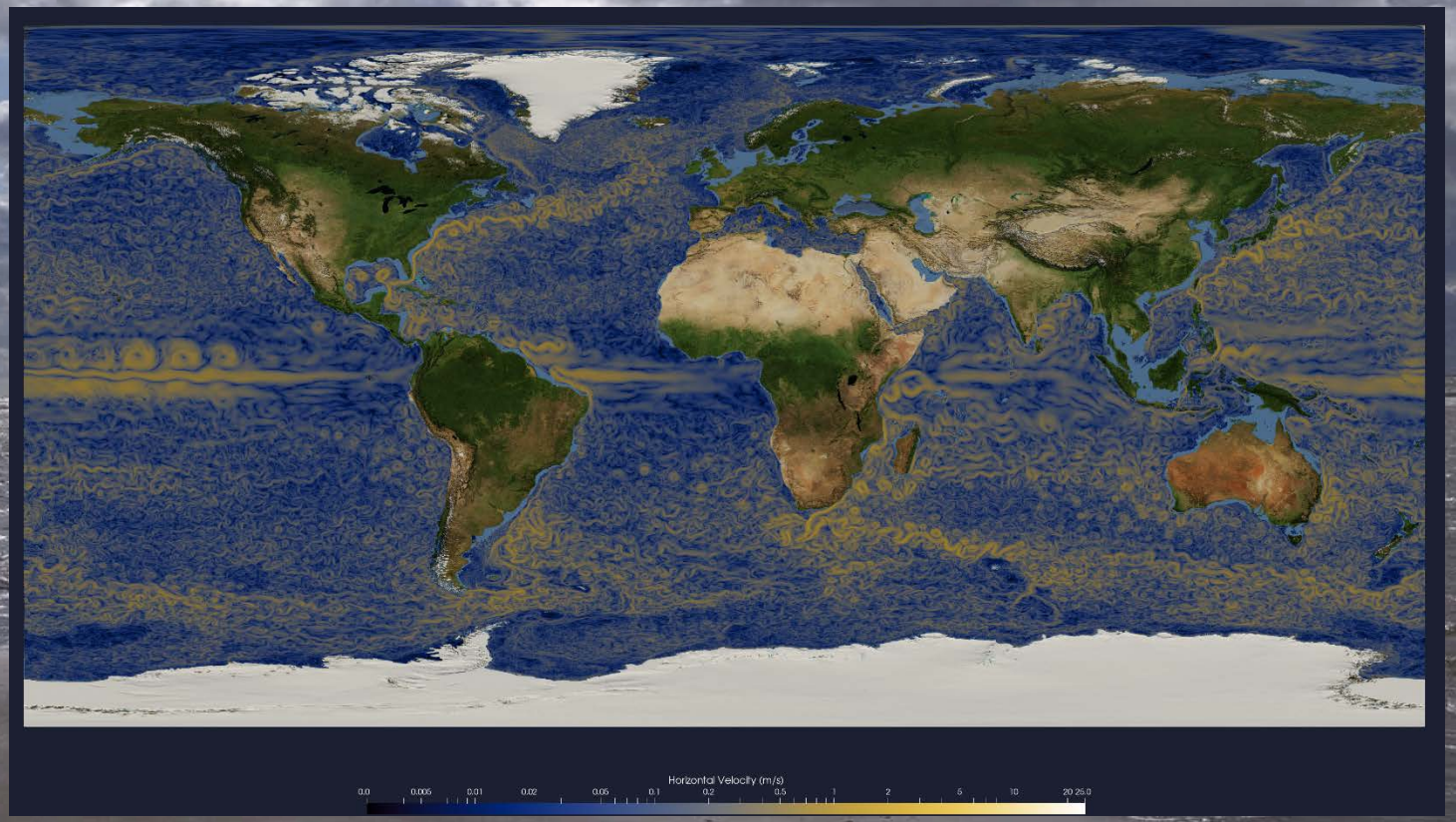


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES
KLIMARECHENZENTRUM

ParaView Velocity

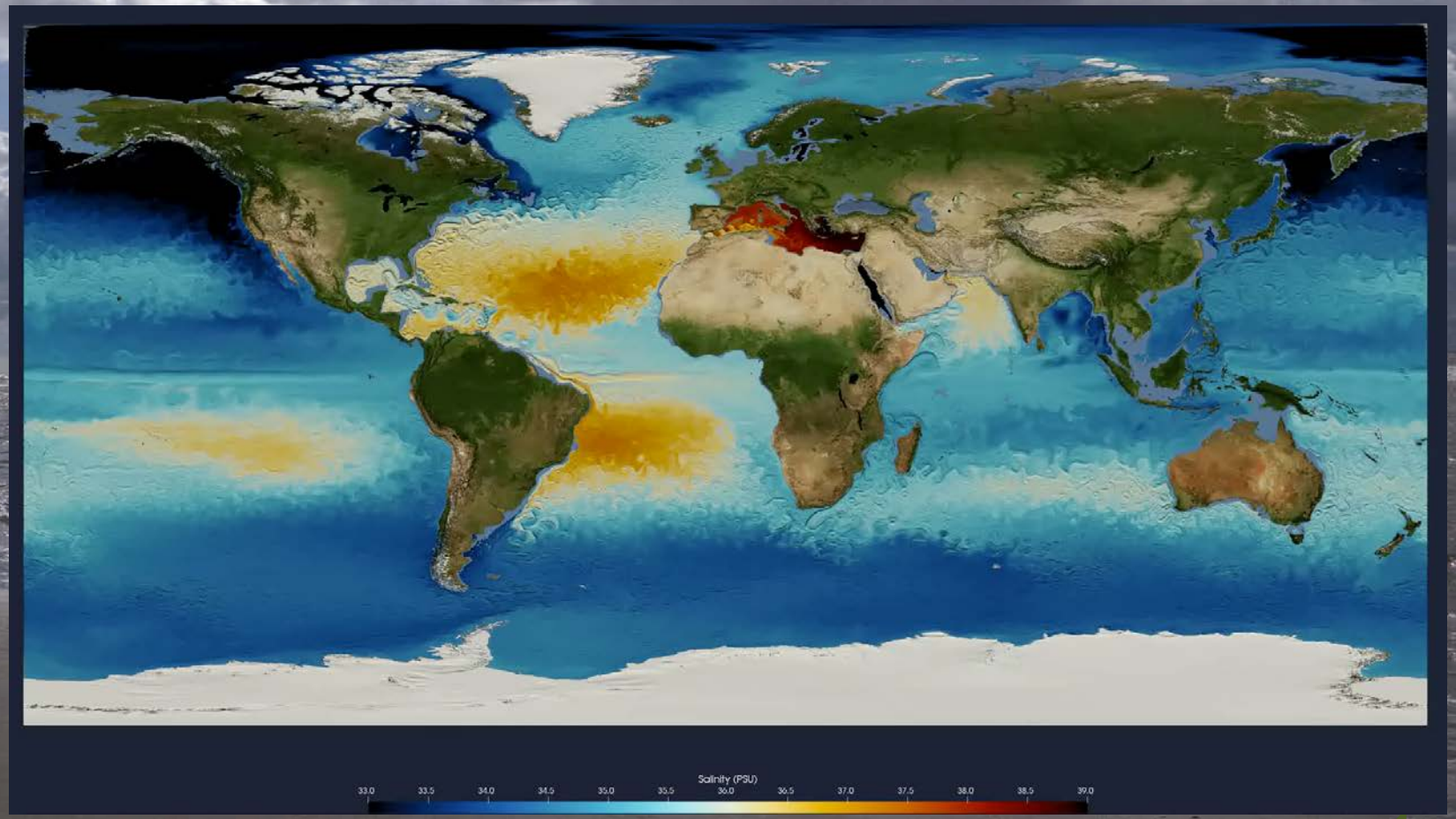


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES
KLIMARECHENZENTRUM

ParaView Salinity Animation

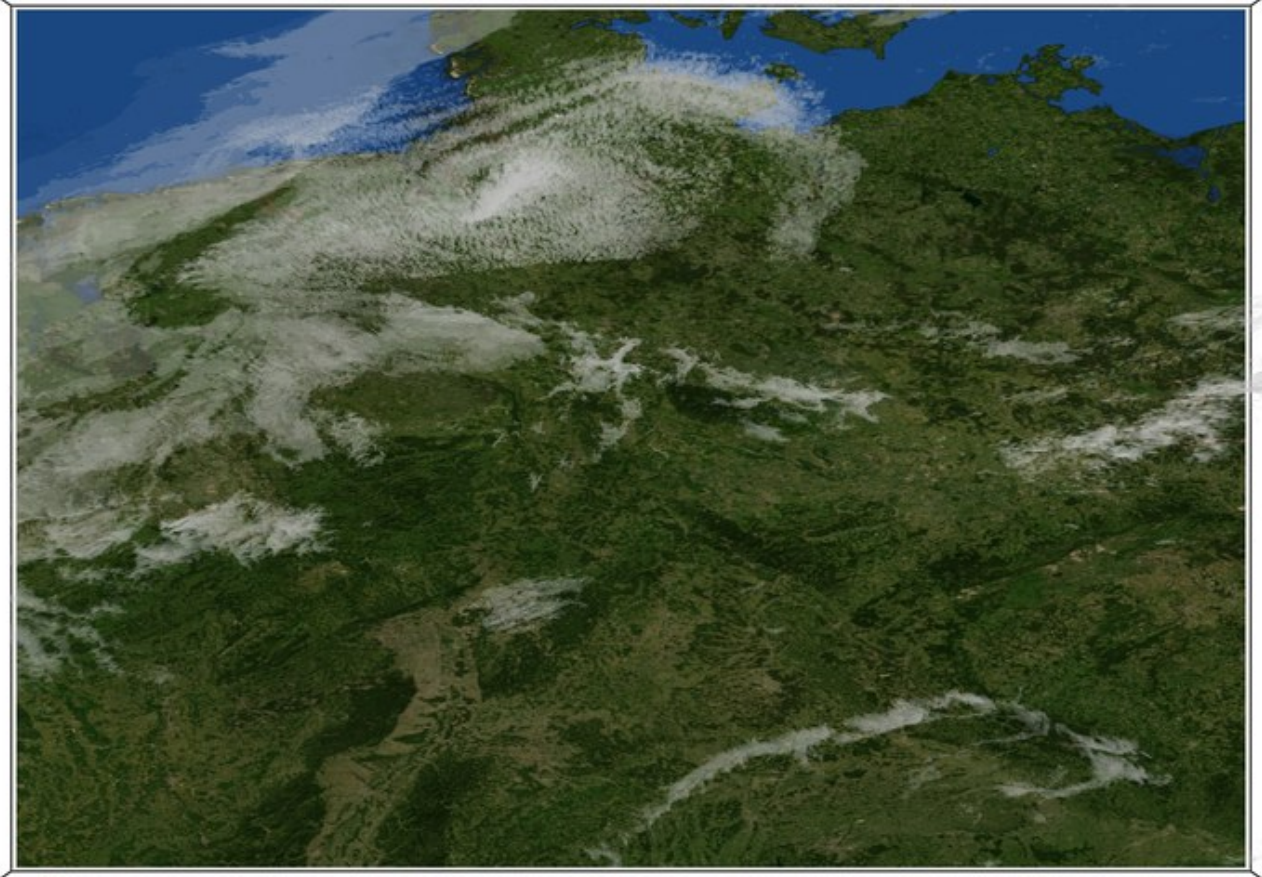


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Vapor – ICON cloud data

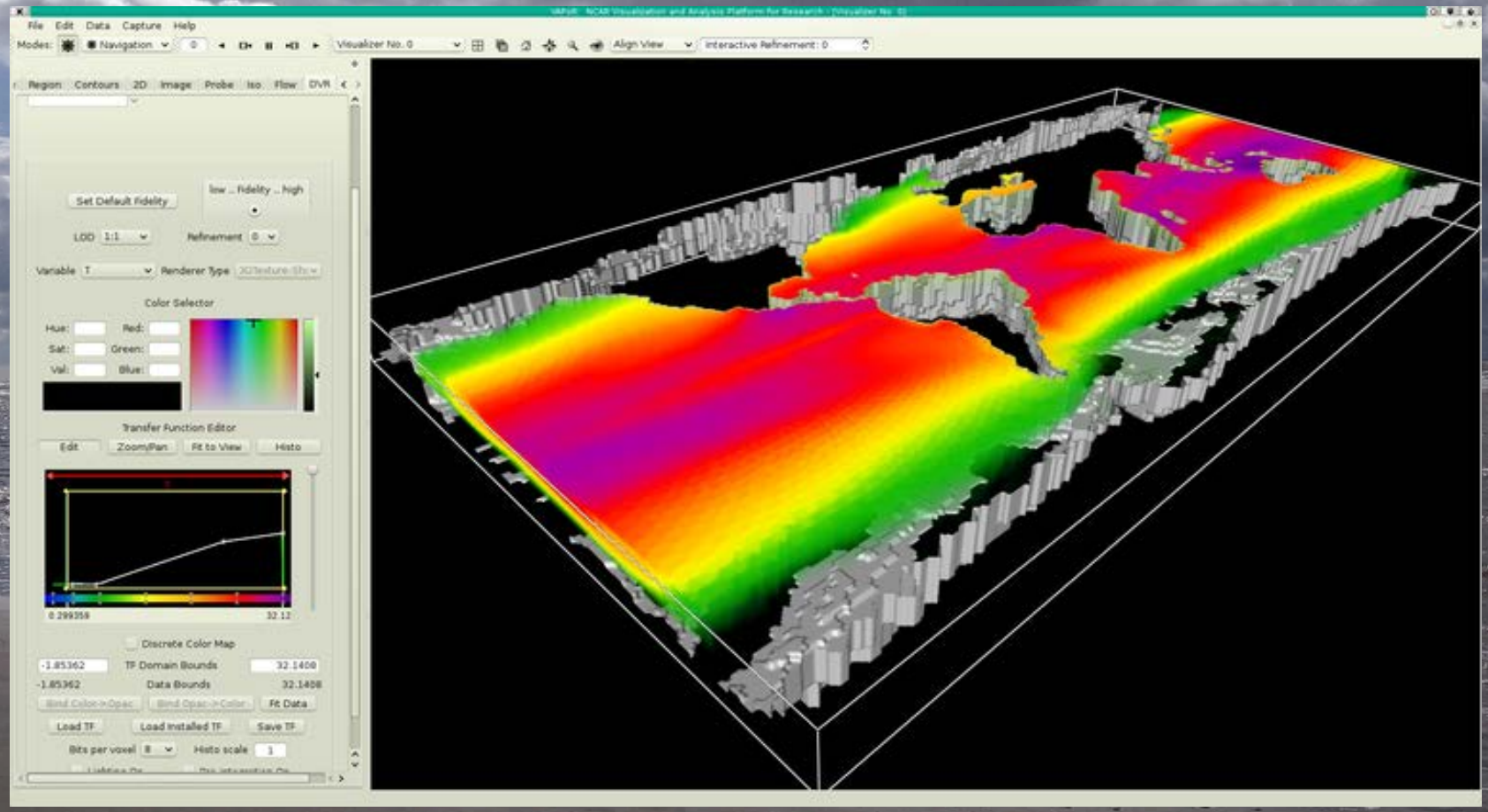


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Vapor – ICON ocean data

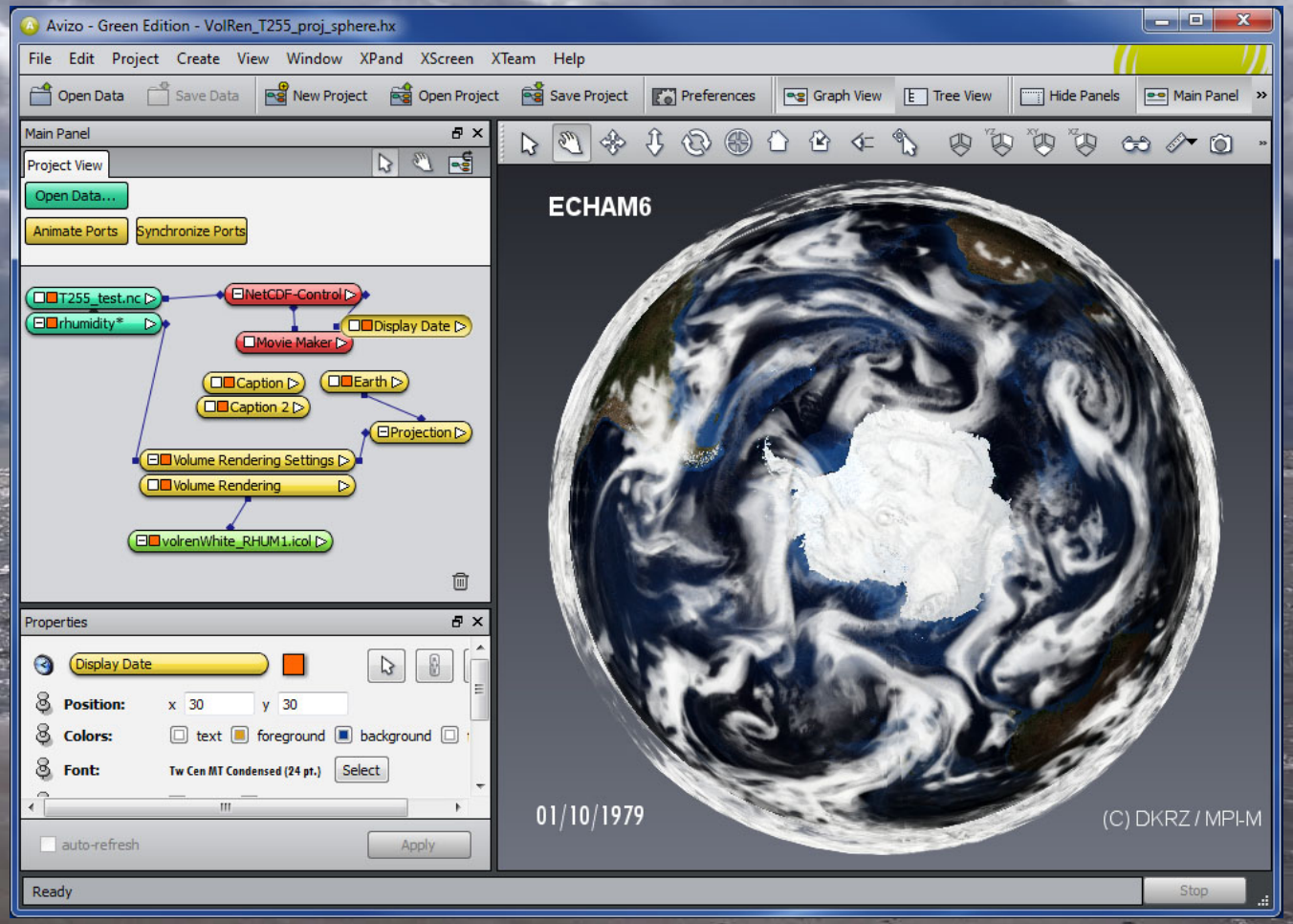


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Avizo GUI

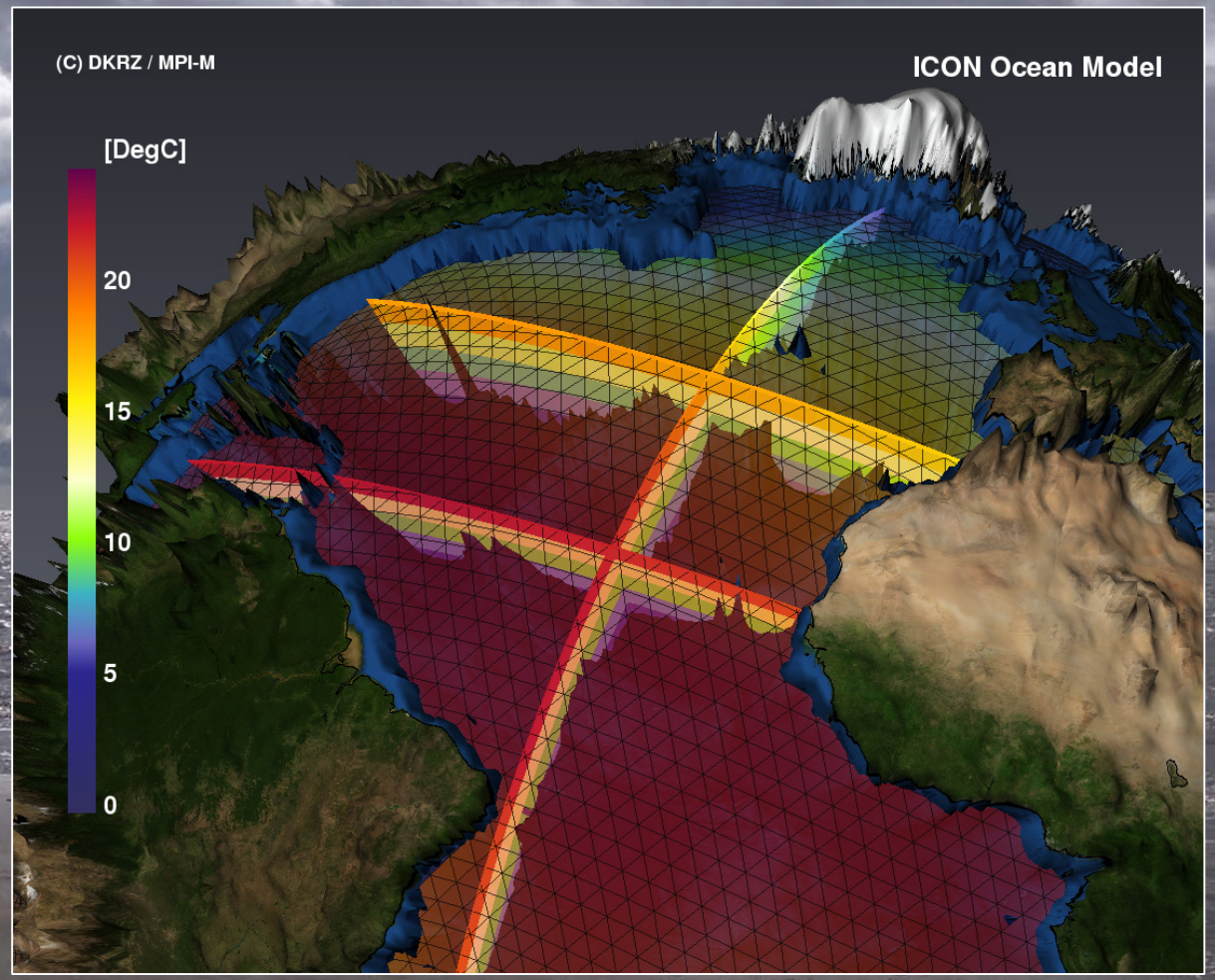


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Avizo ICON Ocean Model

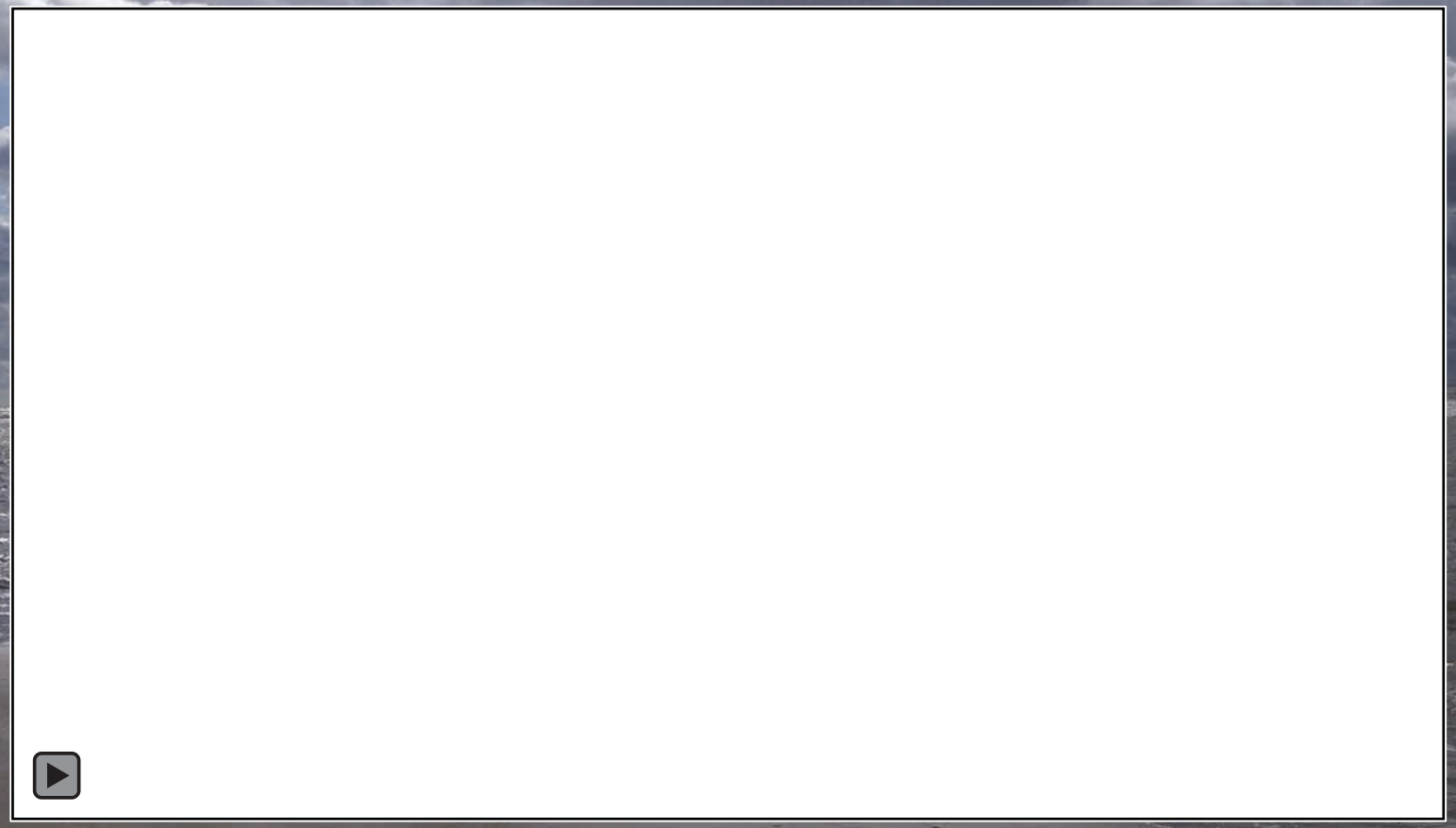


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Avizo Animation

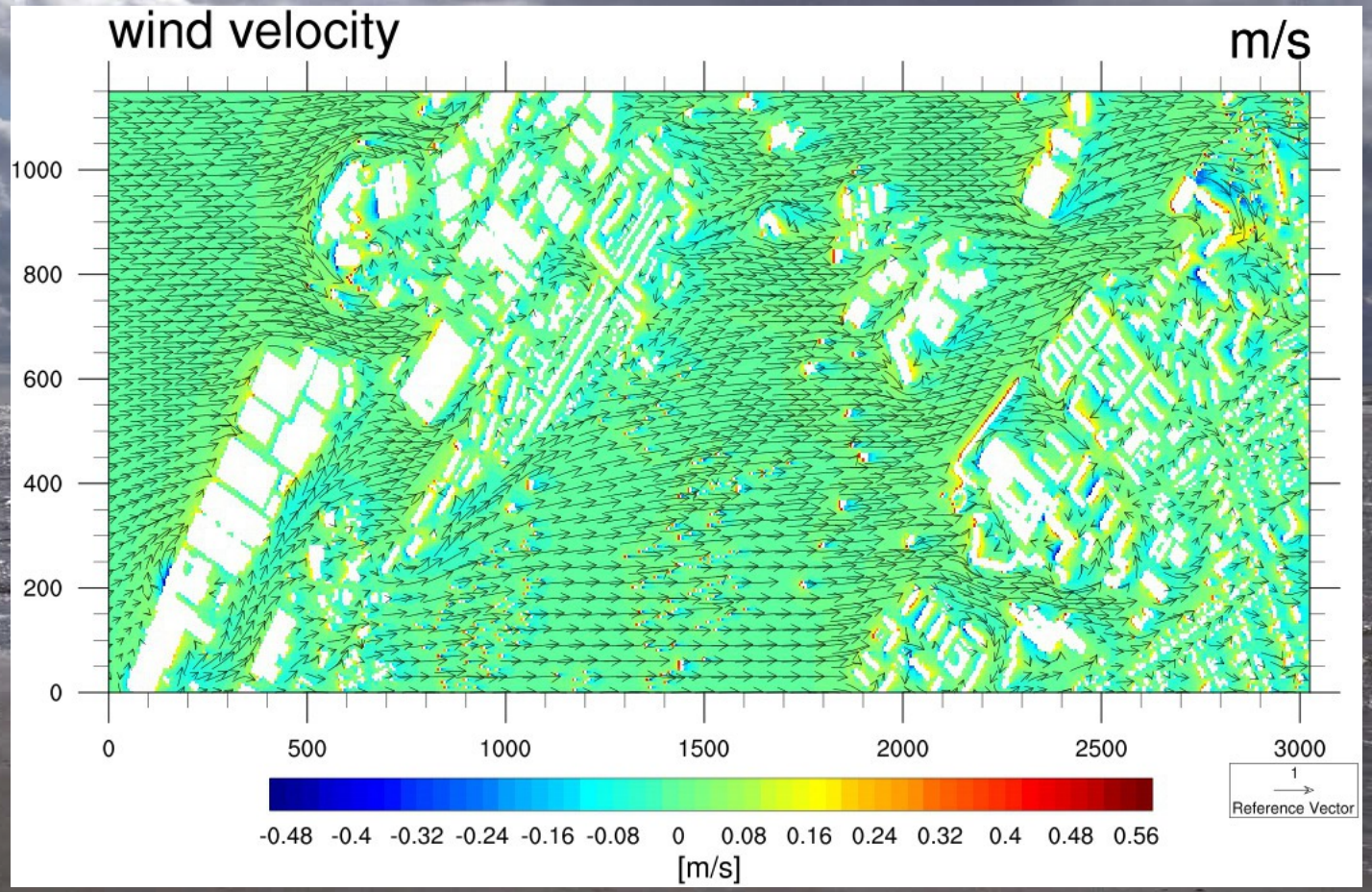


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

NCL - Monitoring web page for MPI-ESM

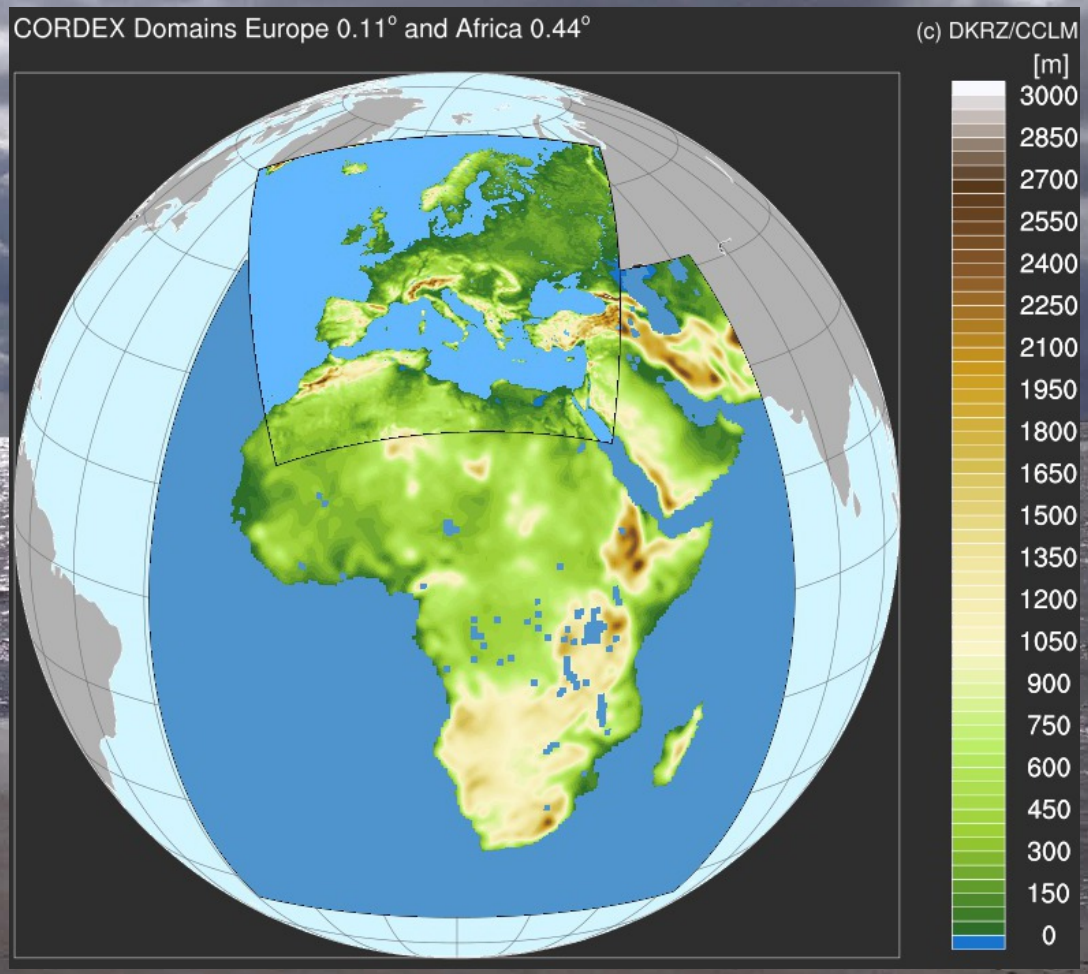


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

NCL - Display different domains and resolutions on Earth globe

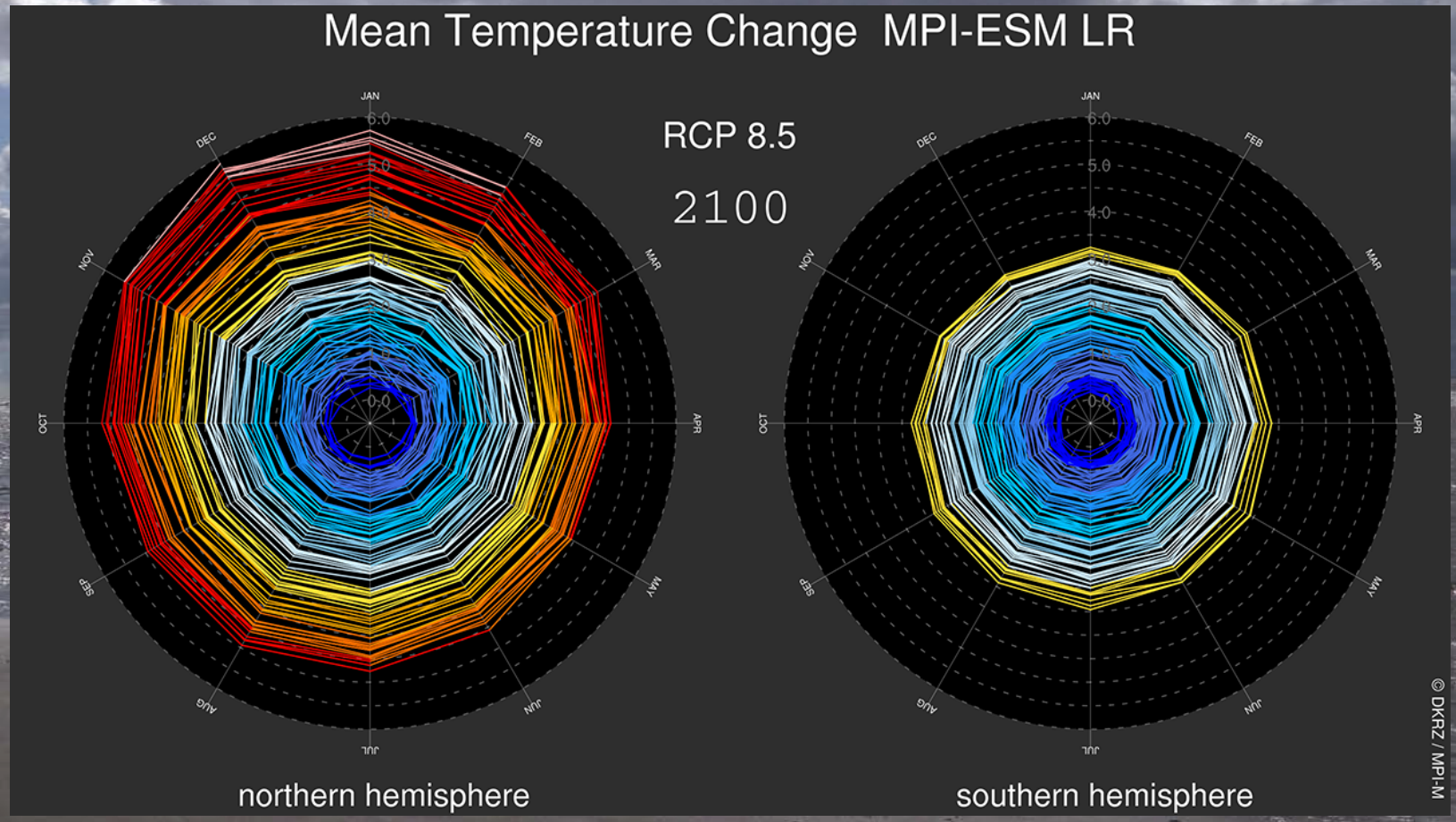


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

NCL - Spiral Plot similar to Ed Hawkins‘s spiral animation

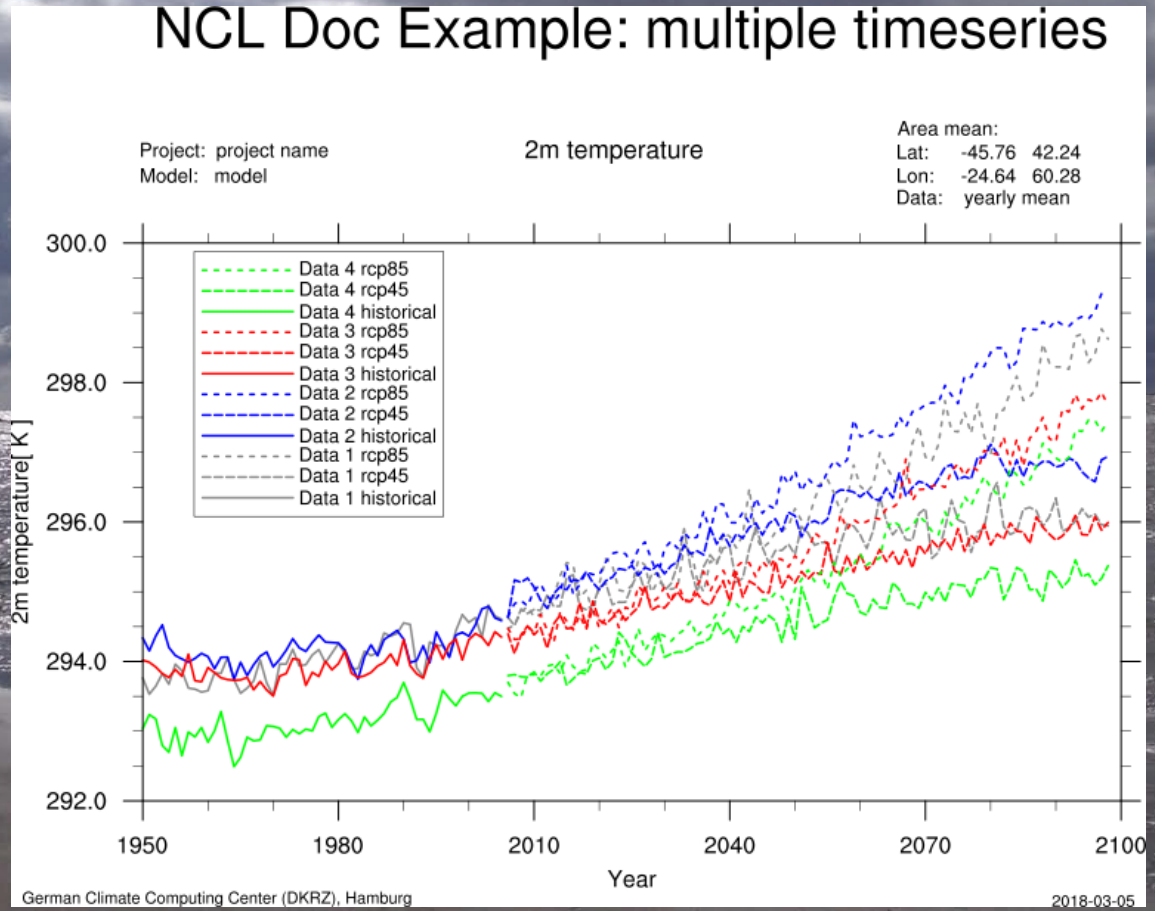


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

NCL - Multiple timeseries

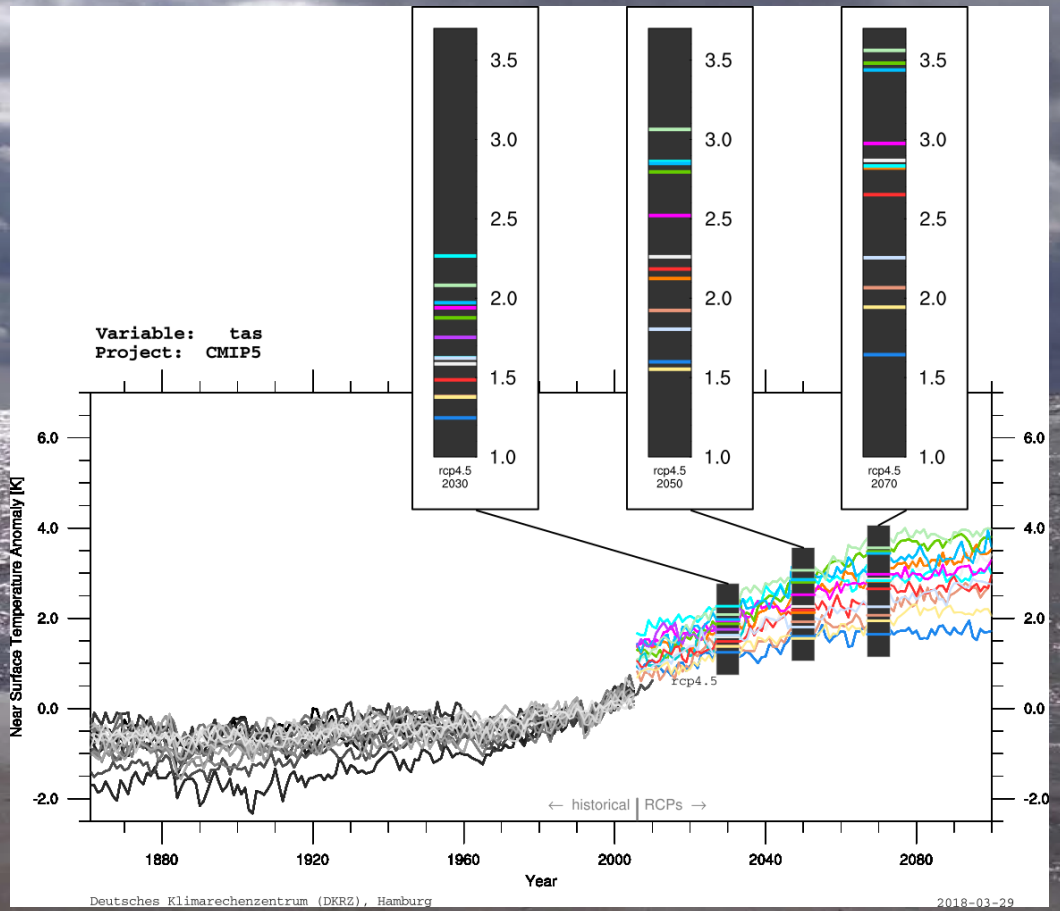


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

NCL - Multiple timeseries with bars

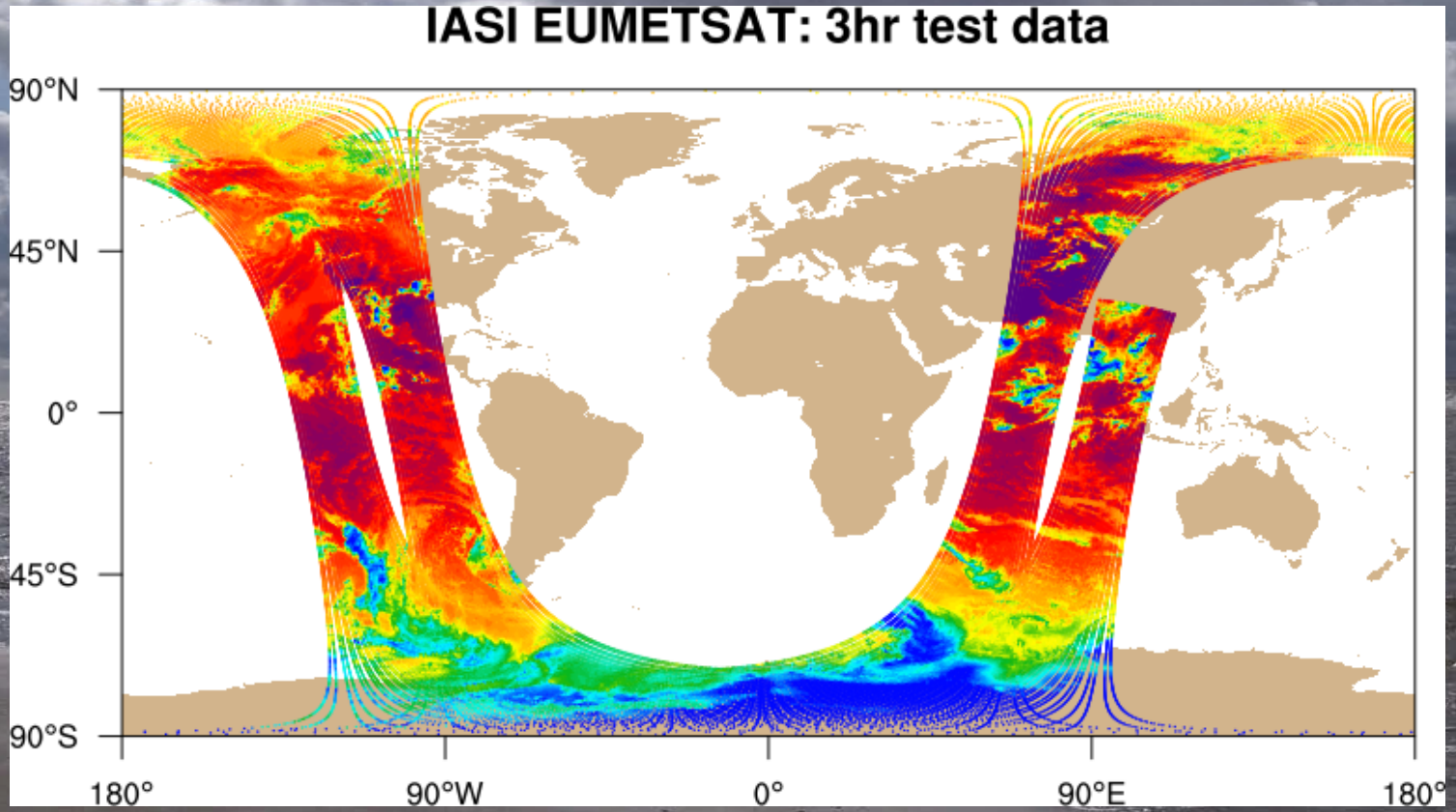


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

NCL – Satellite Data

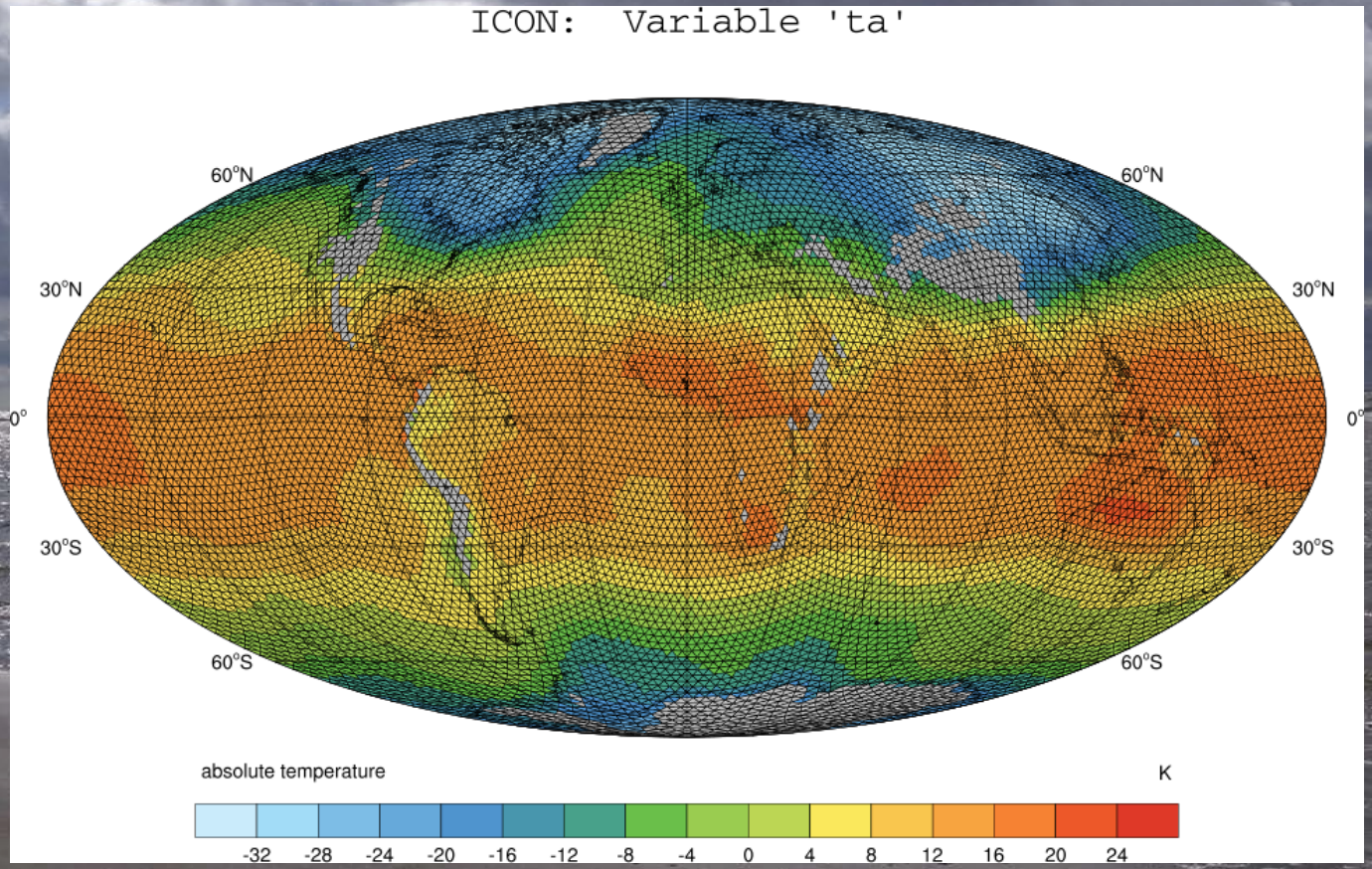


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

NCL – unstructured ICON model data

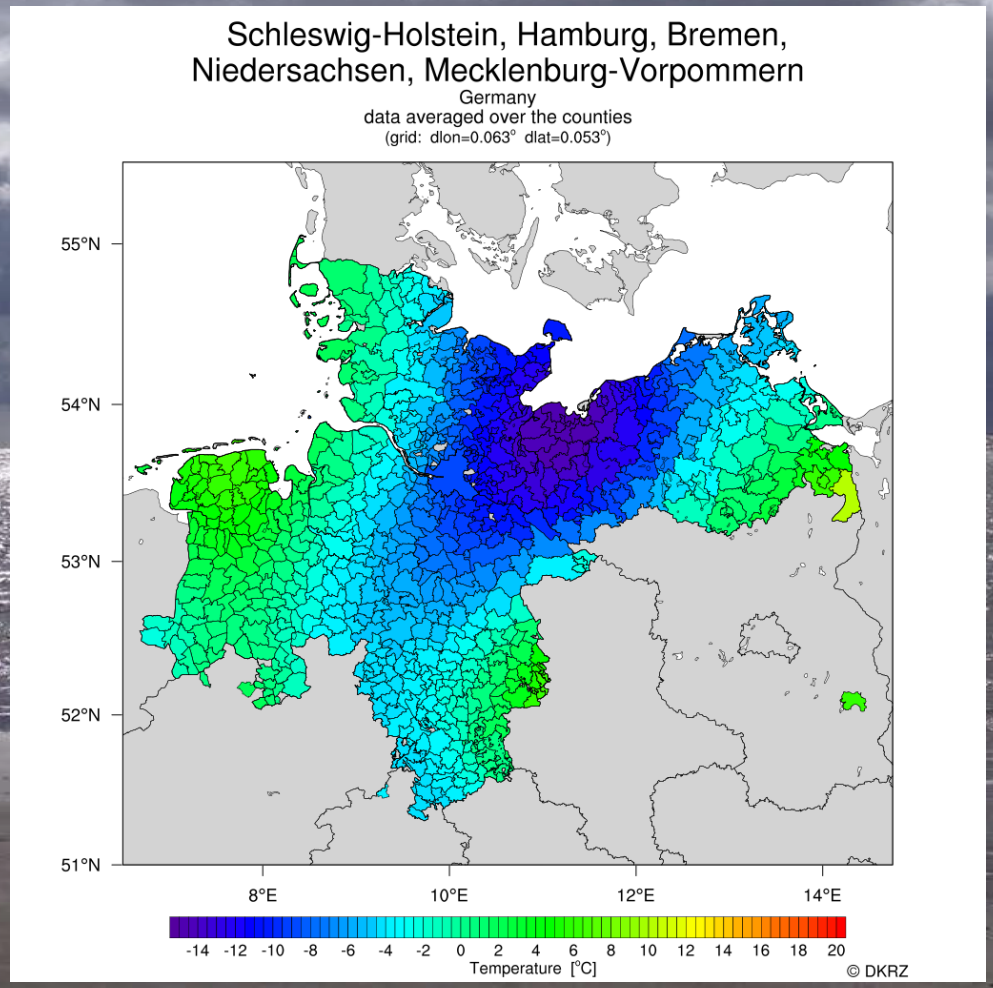


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

NCL – use of shapefiles

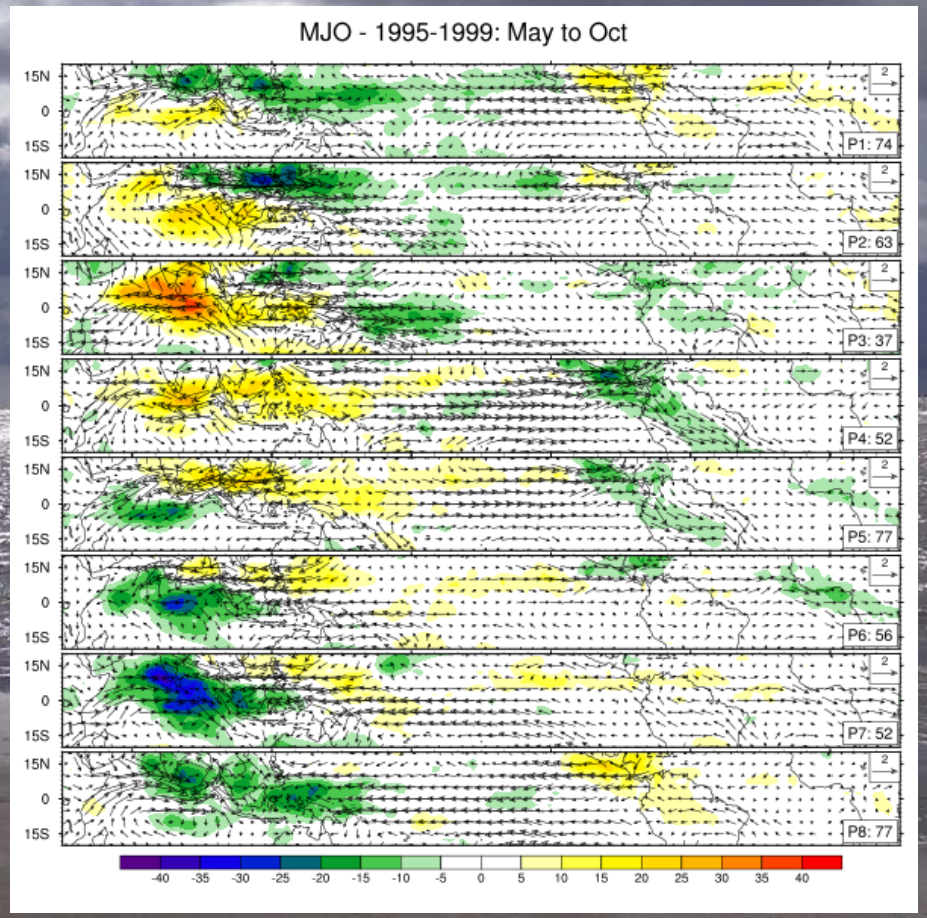


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

NCL – Madden-Julian Oscillation

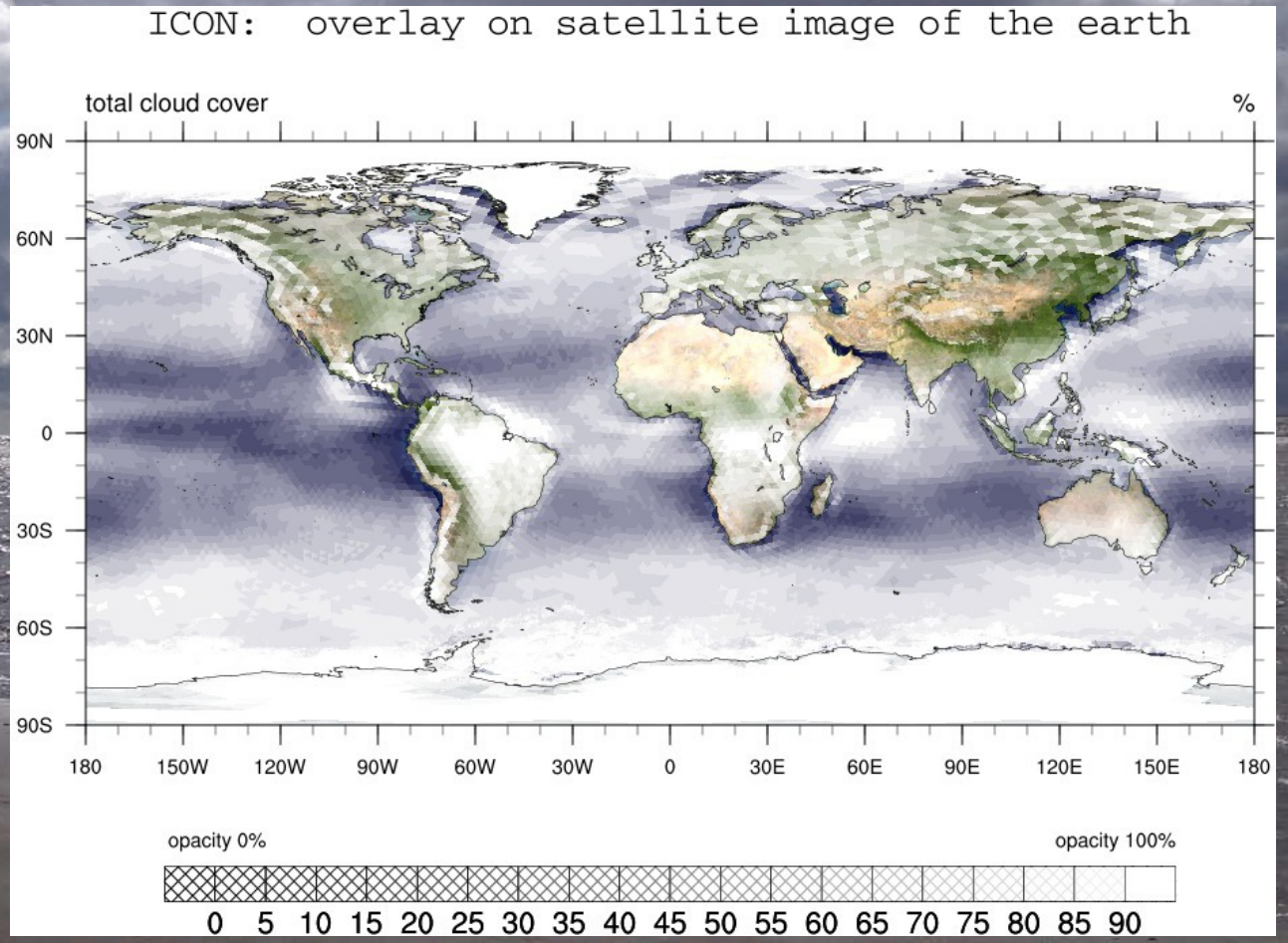


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Use transparency to overlay on Earth topography (JPEG file)



State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

NCL Animation: spiral plot

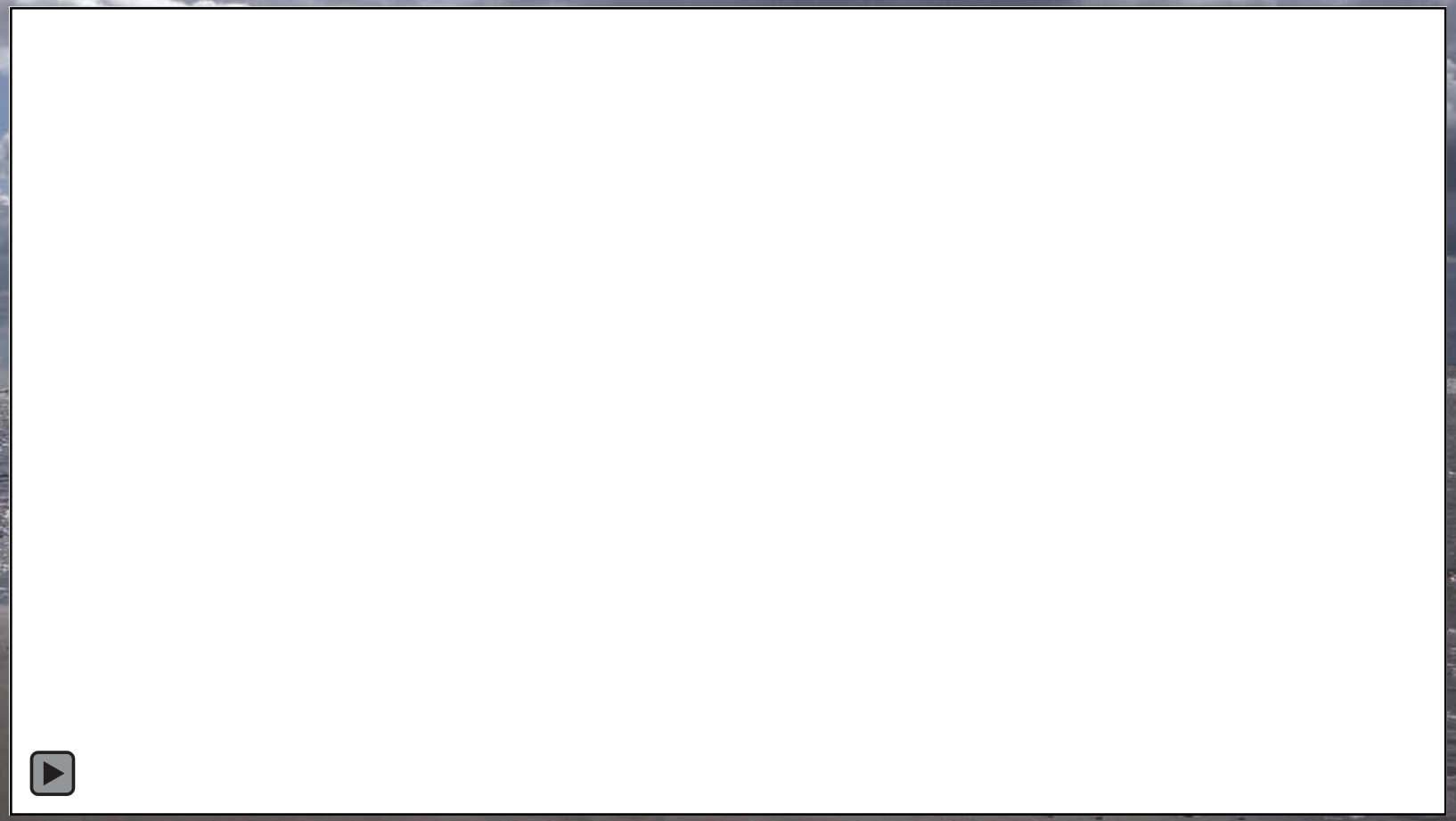


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

NCL Animation: spinning globes

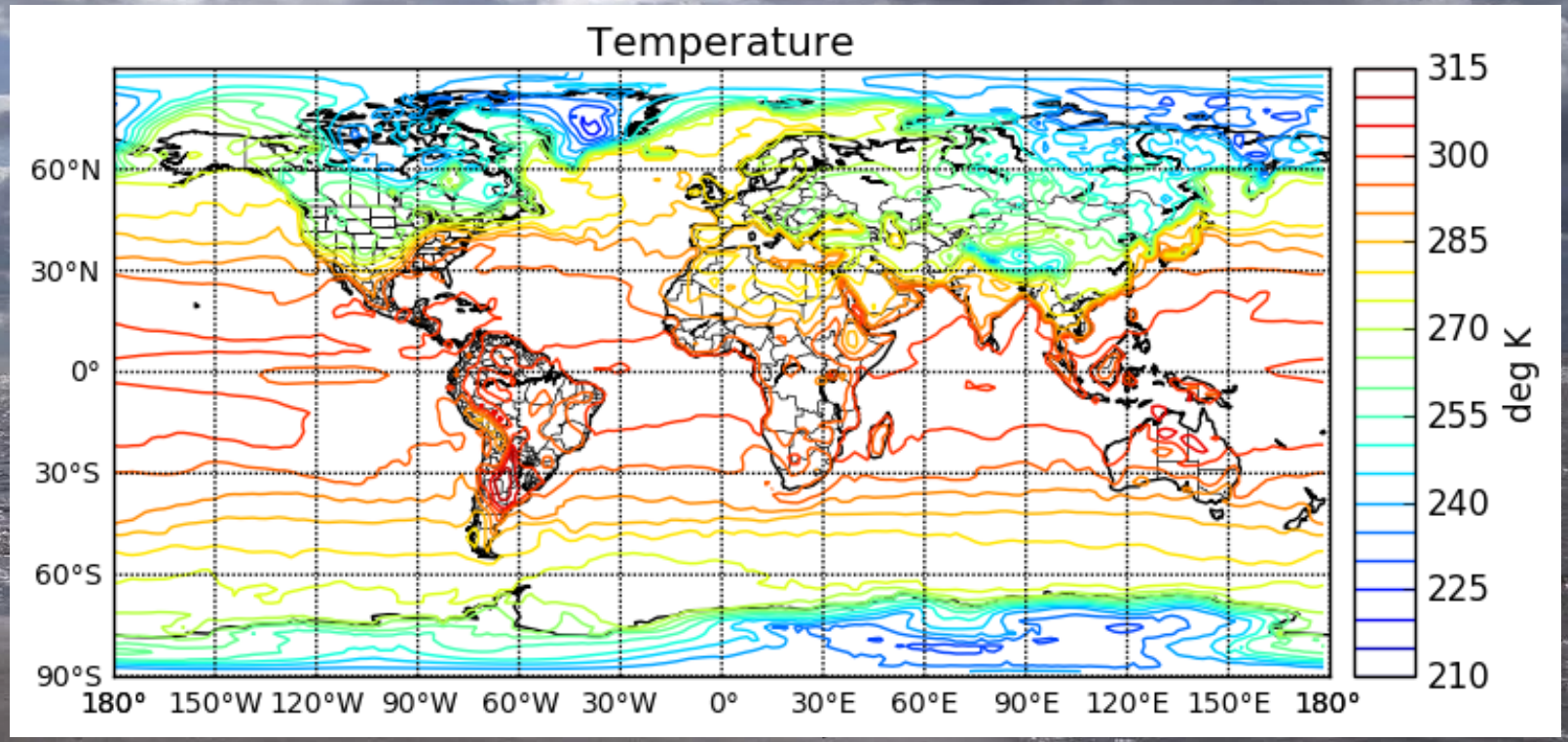


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Python – matplotlib/basemap: Contour Lines

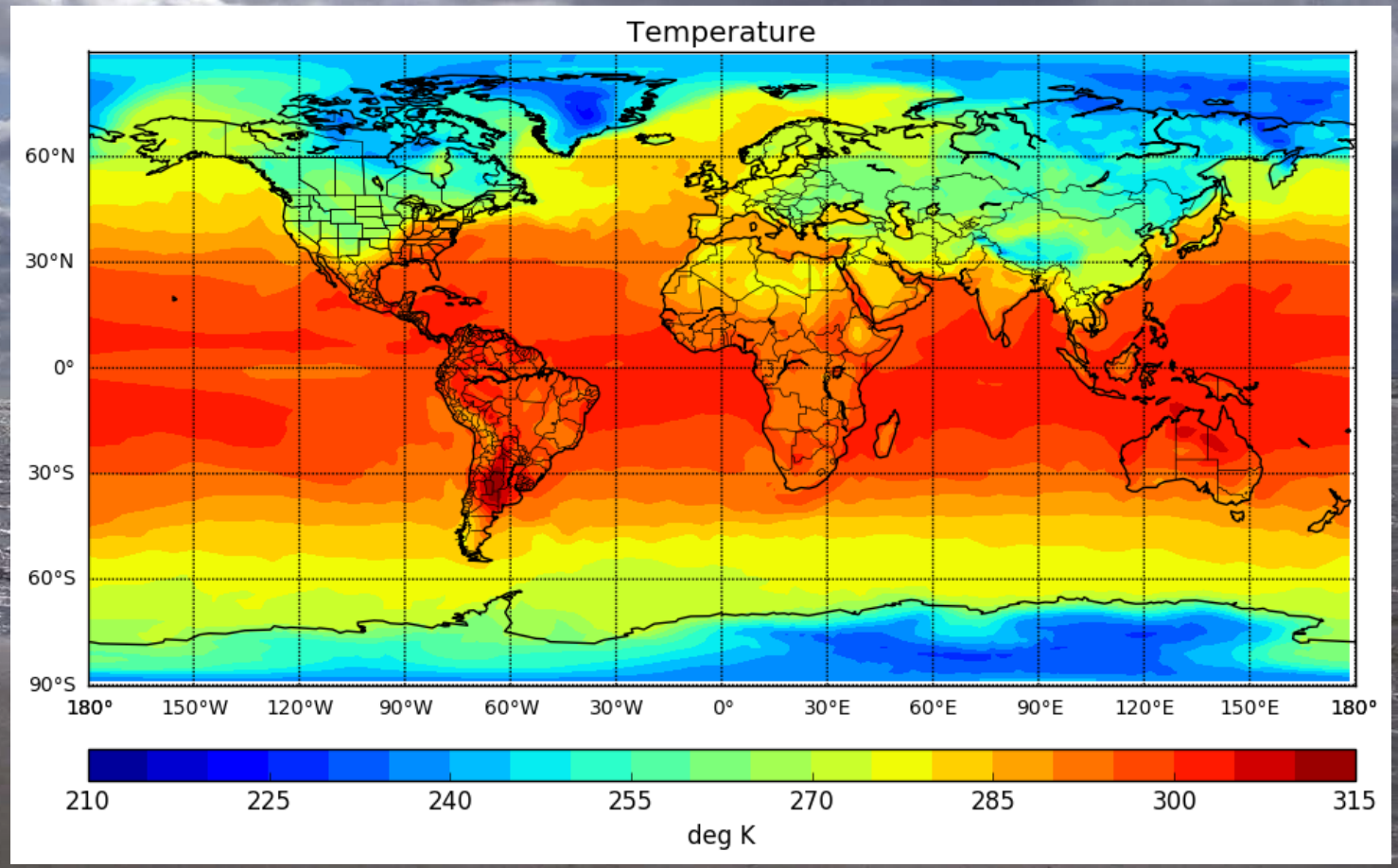


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Python – matplotlib/basemap: Contours filled



State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Python – matplotlib/basemap: Map Orthographic Projection

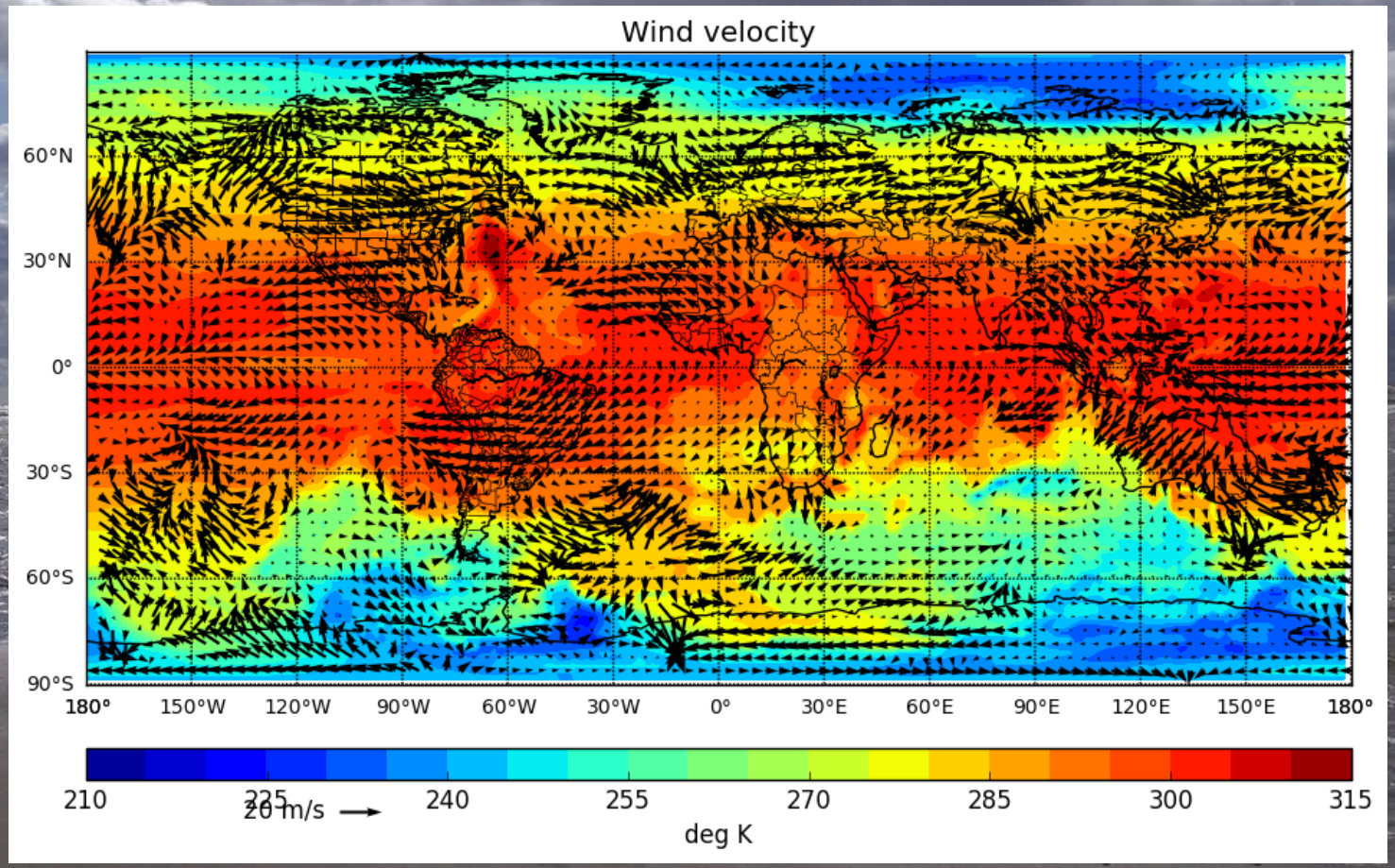


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Python – matplotlib/basemap: Vectors on contours

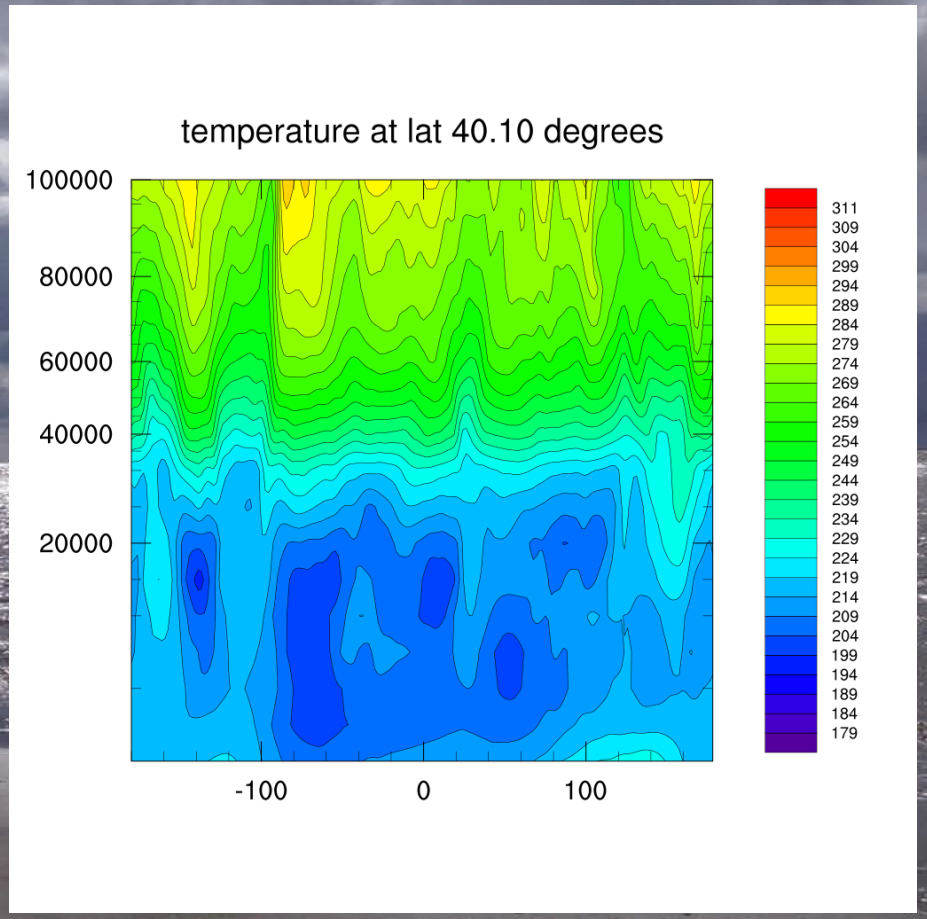


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

PyNGL/PyNIO: Slice plot

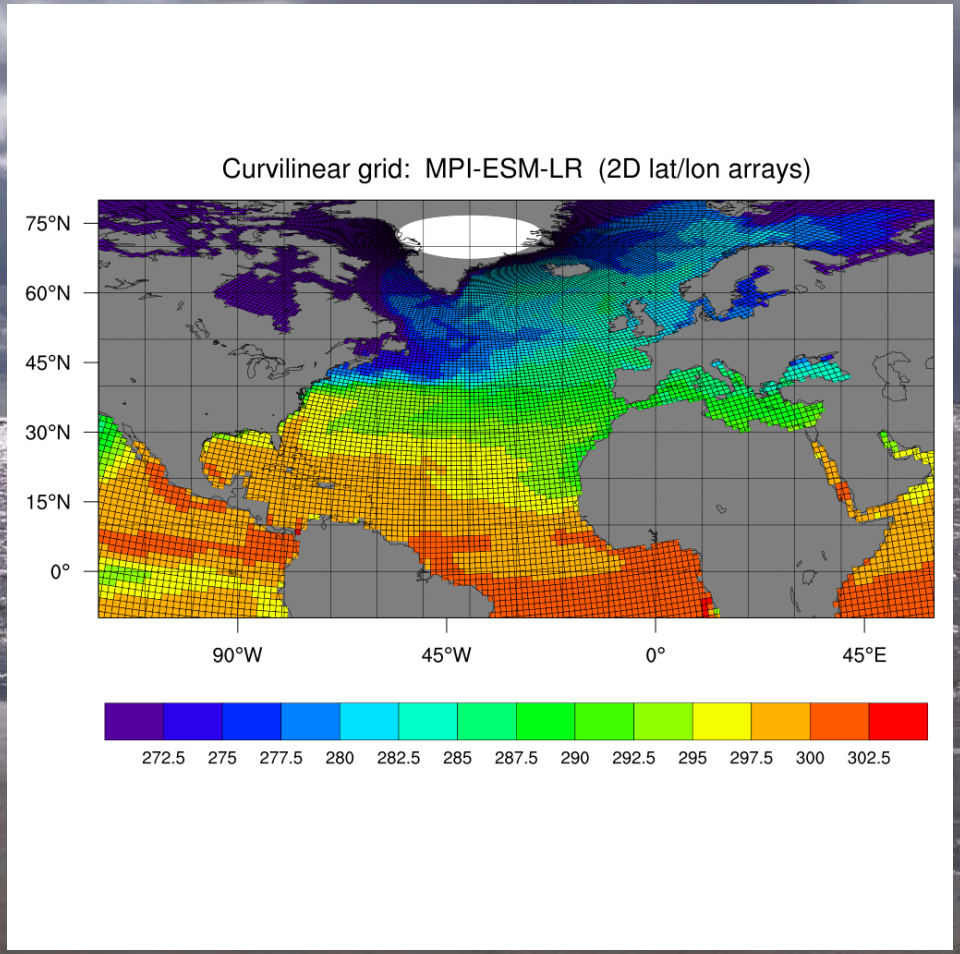


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

PyNGL/PyNIO: Contour plot of curvilinear data

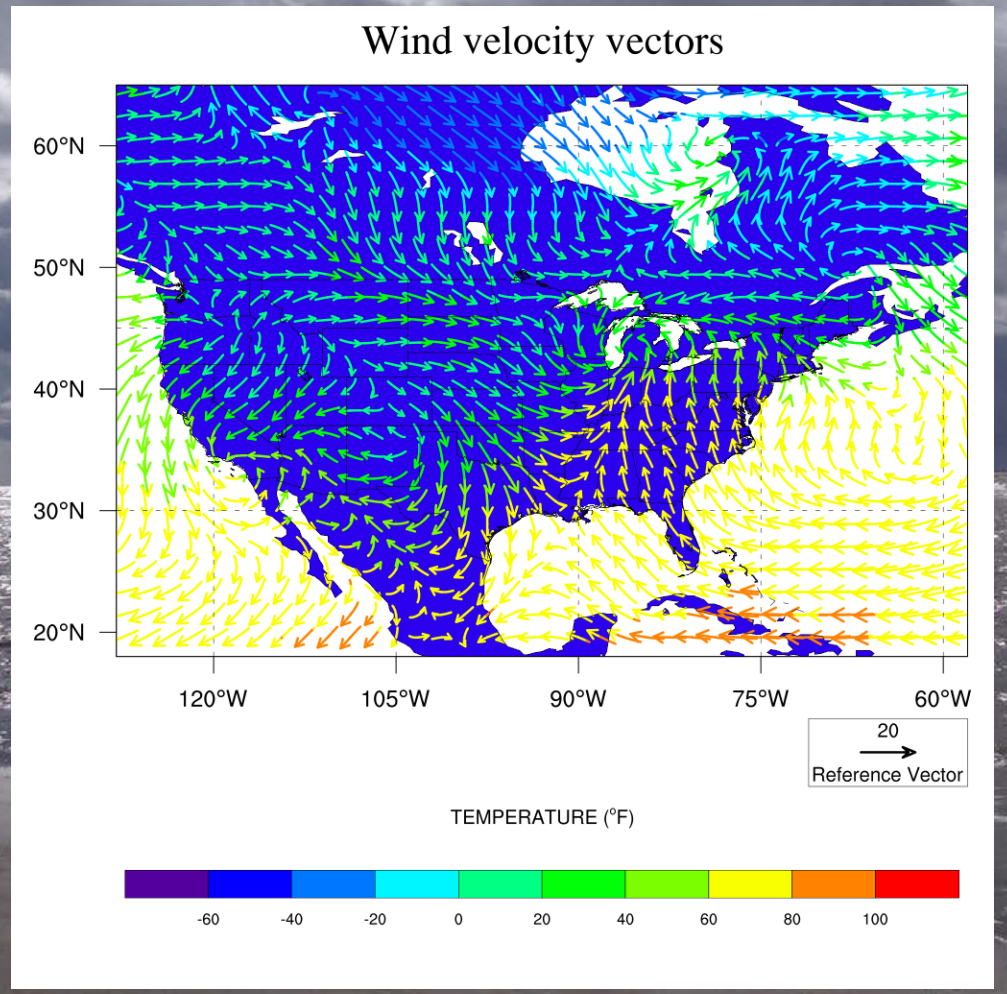


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

PyNGL/PyNIO: Vectors

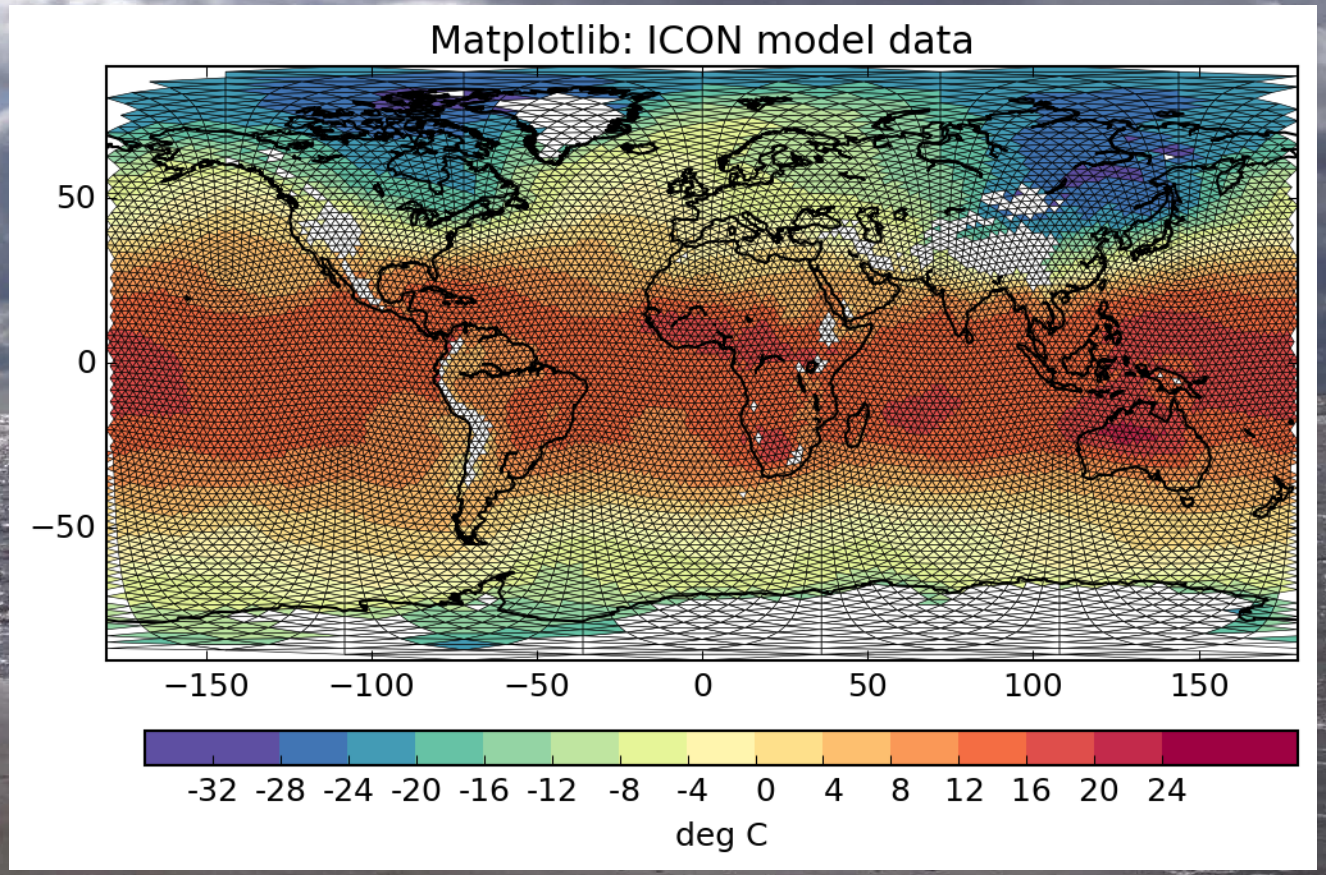


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

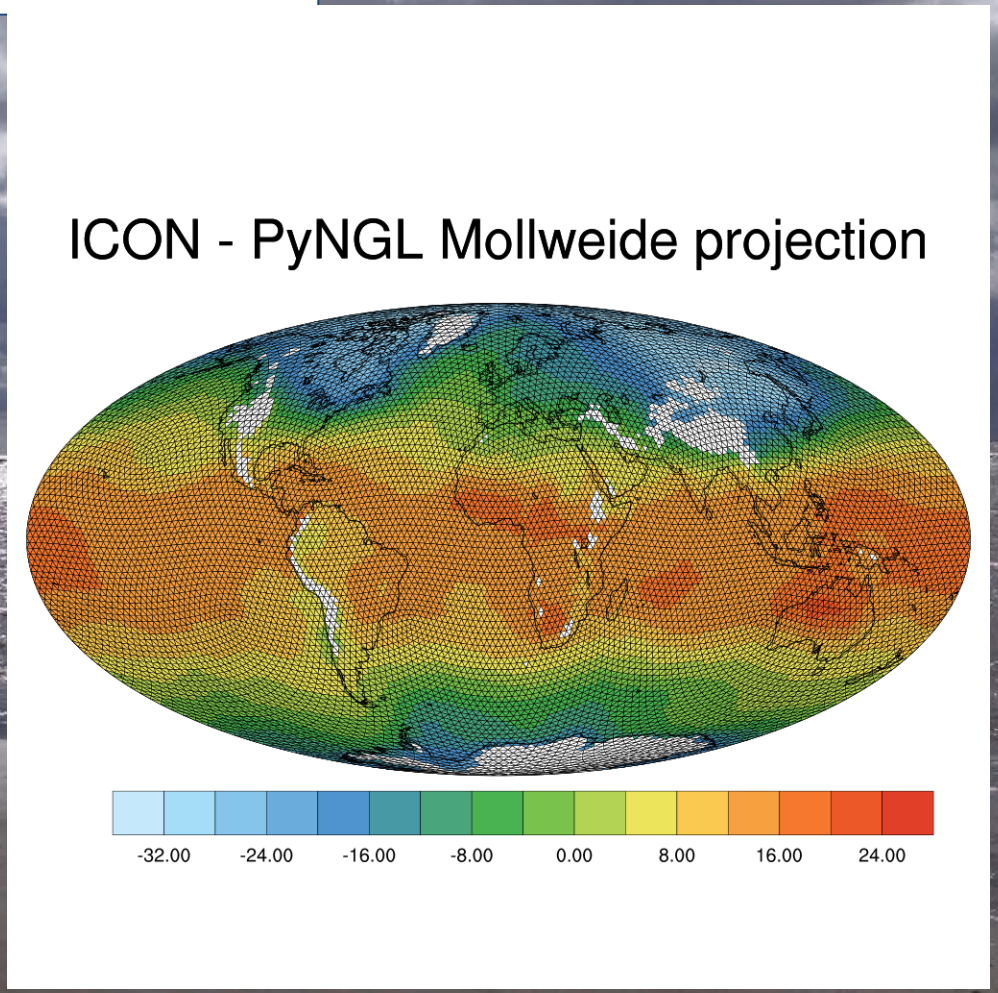
PyNGL/PyNIO: Unstructured data: ICON



State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

PyNGL/PyNIO: Mollweide projection: ICON data

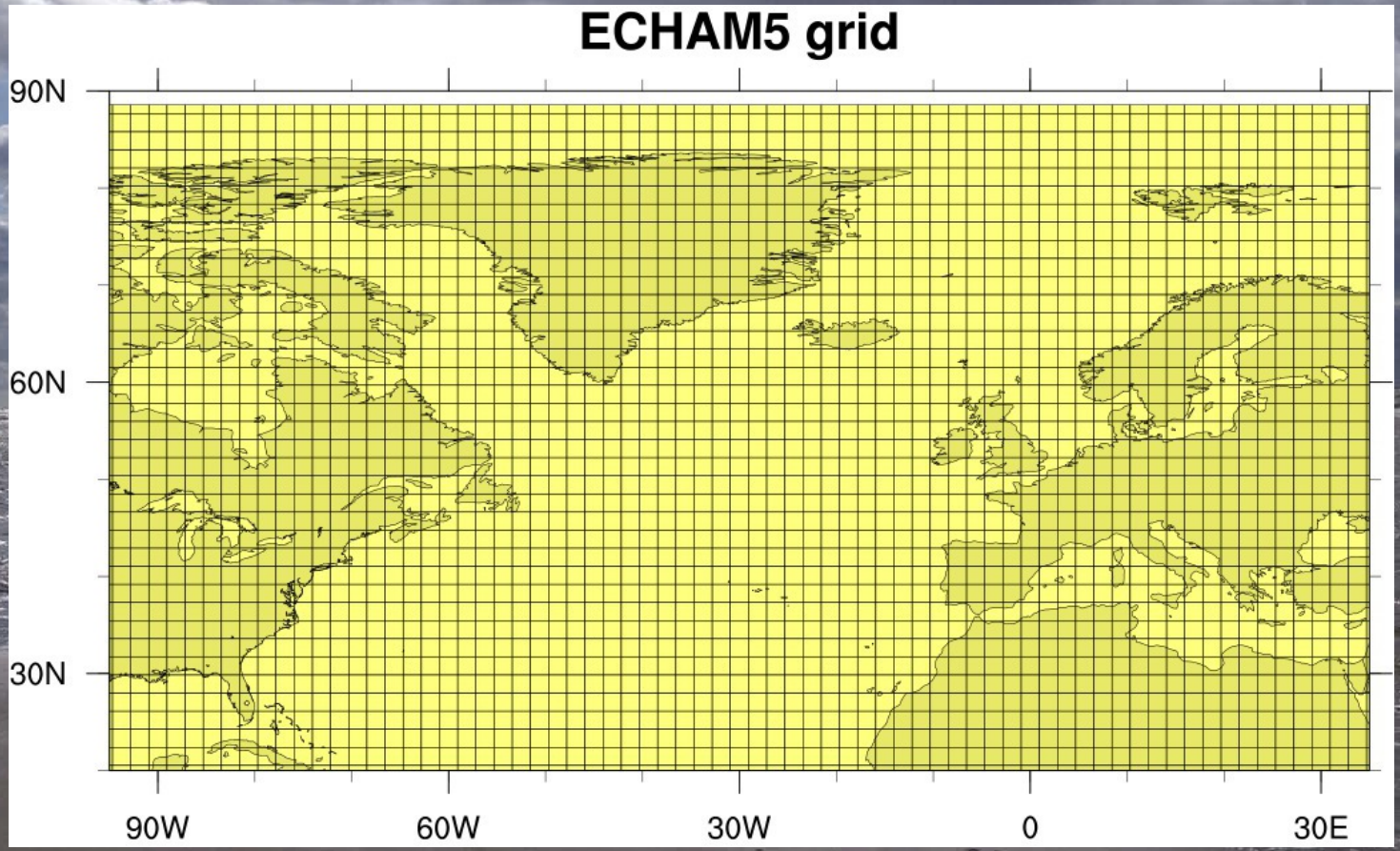


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

ECHAM5: rectilinear grid

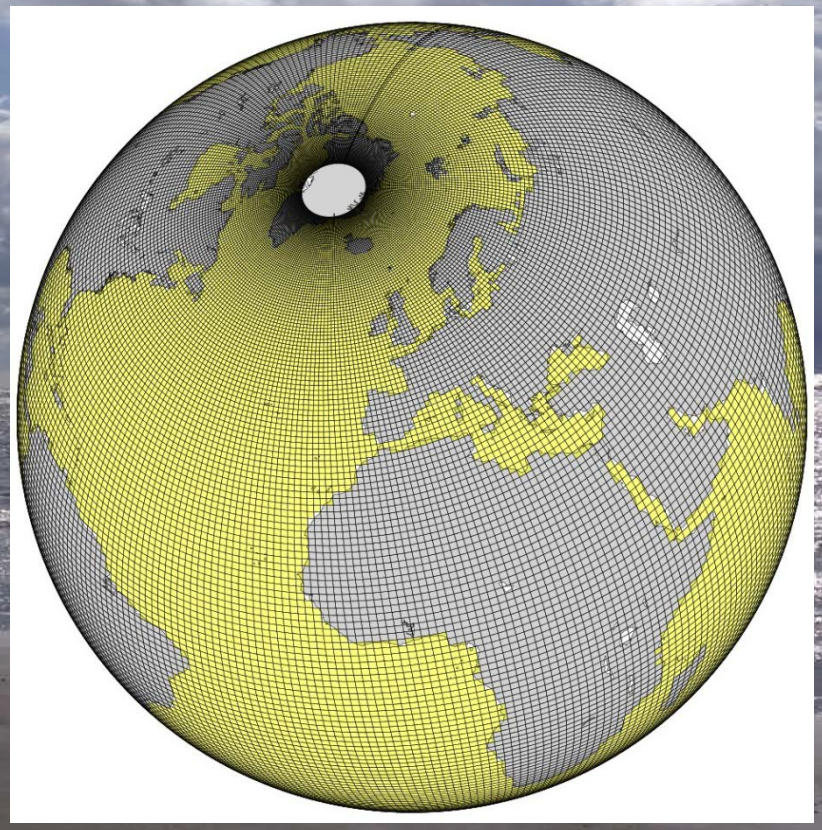


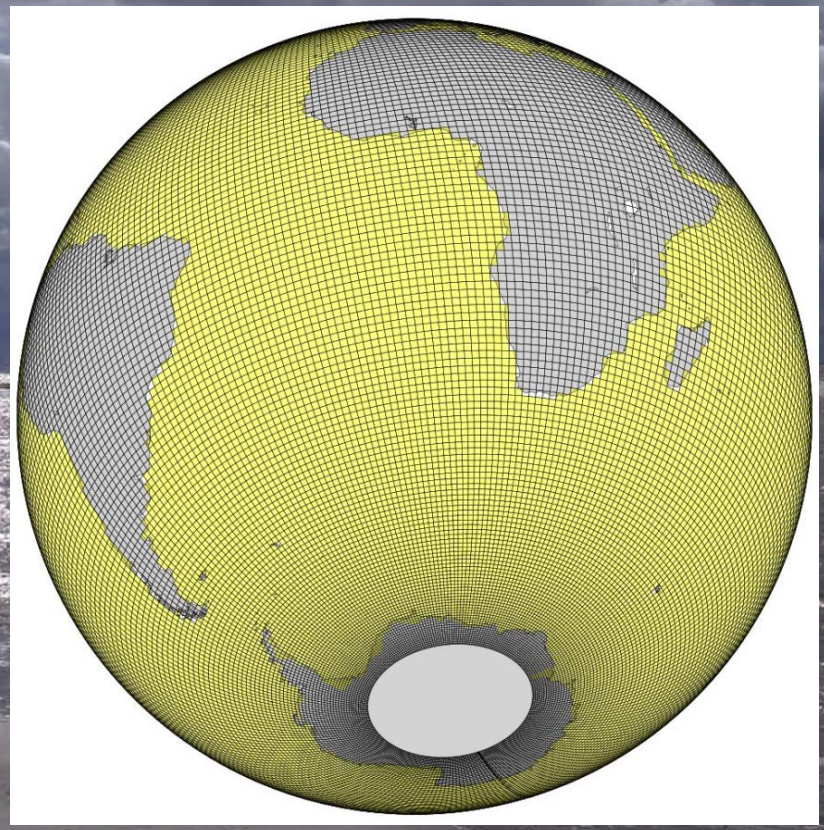
State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES
KLIMARECHENZENTRUM

MPIOM: curvilinear grid



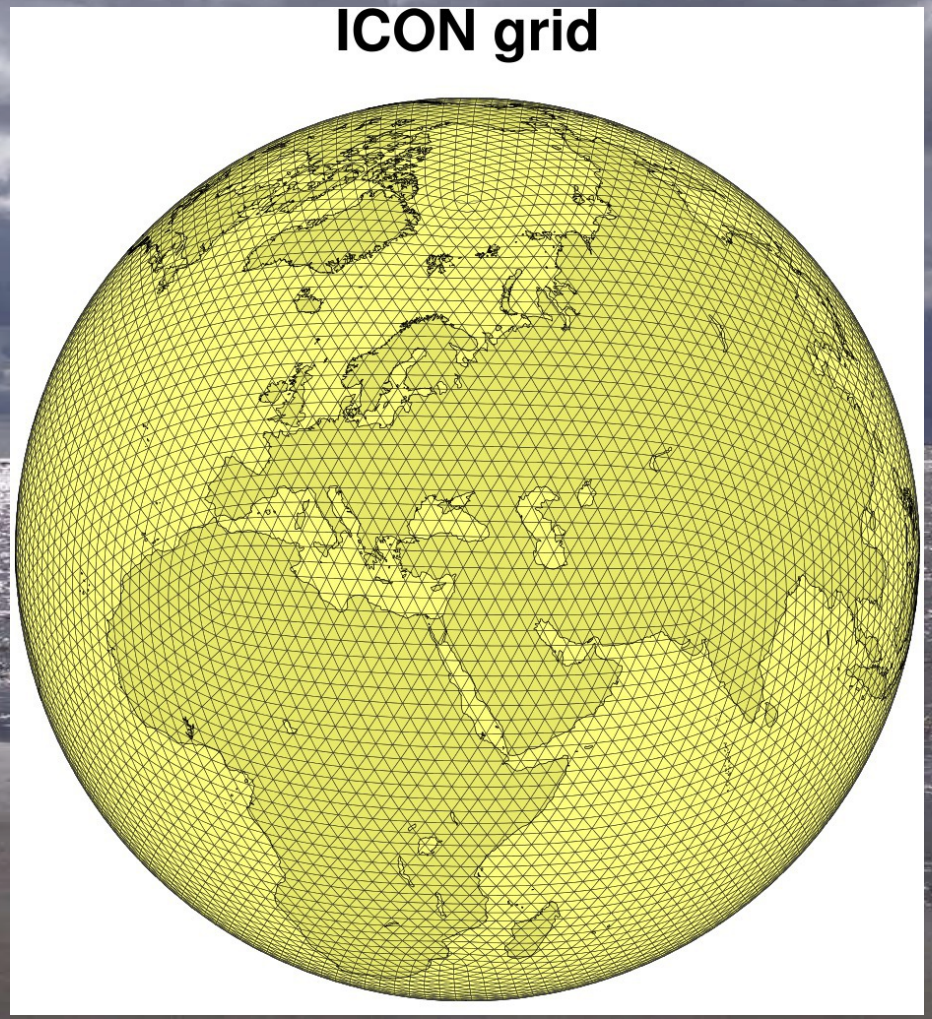


State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

ICON: unstructured grid



State of the Art in Earth Science Data Visualization

Karin Meier-Fleischer , Michael Böttinger , and Niklas Röber
Deutsches Klimarechenzentrum (DKRZ), Hamburg, Germany

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

FESOM: unstructured grid

