Climate Change and its Coastal Impacts in the Pacific Ocean

Shoshiro Minobe
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9:00-10:30:
Self Introduction, Lecture CMIP6.
10:45-12:00: Practice, Q&A:
Play with CMIP6 data via Interactive Atlas
14:00-15:30:
Some examples from our studies
and explanation of sample scripts
15:45-16:45: Practice, Q&A
Data analysis using python

Self Introduction

My research areas

- I am a professor of Hokkaido University in Sapporo, Japan,
  - and a tennis player.
- Our university is pretty strong in earth science, and the second strongest university for oceanography in Japan.
- I took my PhD for annual cycle of the tropical Pacific both for the ocean and the atmosphere.
- Then, I have been interested in decadal climate variability over and around the North Pacific.
- After that, I have shifted to frontal scale air-sea interaction.
- Now I am also working on ocean deoxygenation and marine ecosystems.

I welcome international students.

- I have many international students which have conducted high-level studies in my laboratory. My recent doctor course students are mostly international students.
  - Emi Yati (Indonesia) graduate in the last September (Emi Minobe et al. 2020 Frontiers in Marine Science (IF=4.4, referred IPCC-AR6 WG2), Emi Minobe 2021 J. Oceanography (IF=1.8))
  - Jiaxiang Gao (China, master from Chinese Academy of Science) will graduate this Sept. (Gao Minobe et al. 2020 Environmental Research Letters (IF=6.2))
  - Givo Alsepan (Indonesia) will graduate this Sept. (Alseapan Minobe et al. 2020 J. Climate (IF=5.1))
  - Jinyoung Son (Korea) (going to submit to J. Climate)
  - Yumi Abe (Japan)
  - Gong Zhanqiu (China, master from Beijing Normal University) will join from this October

Japanese scholarship

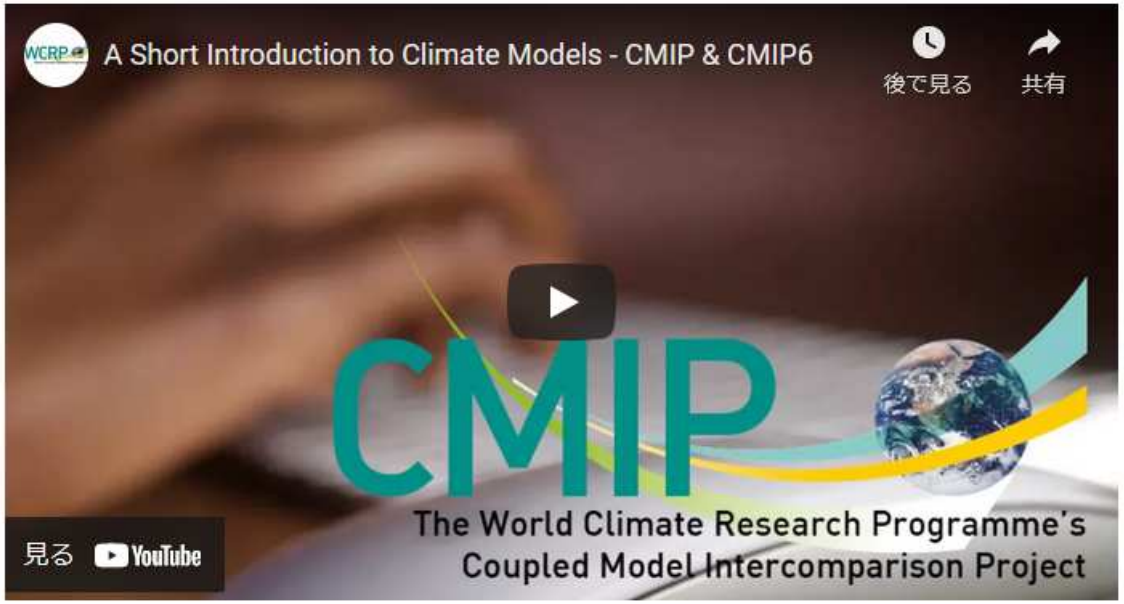
- Unfortunately, Japanese university do not pay for students, and thus students and their family need to pay tuition and living expense or to secure scholarship.
- In Japan, MEXT scholarship is very good, but of course very competitive. If you are interested in this, please prepare with a long enough time including studying Japanese, which can help a better evaluation.
- Please try so-called embassy recommendation, by which you will apply Japanese embassy in your country in the next year.

1. Introduction of CMIP6 data

What is CMIP?

- CMIP stands for “Coupled Model Intercomparison Project”, which is a project of WCRP.

WCRP Coupled Model Intercomparison Project (CMIP)



Models and tools are free!

- To conduct a large-size multi-model analysis, you need a high-speed internet connection, a powerful workstation, and a big storage. These might be beyond out of reach for most of students.
- However, to train your ability, several model outputs with limited year range is OK. The downloading data amount may be smaller than watching youtube!
- In addition to the model outputs are free, the analysis tools are also free. This is a recent big change. Ten years ago, most of professional researchers used Matlab, which is an expensive commercial software, but now we use python, which is free.

Relation with IPCC

- IPCC assess research papers, but do not conduct researches by themselves.
- CMIP models sometimes called IPCC-model, but this is wrong.
- Nevertheless, CMIP is organized with a focus for IPCC.

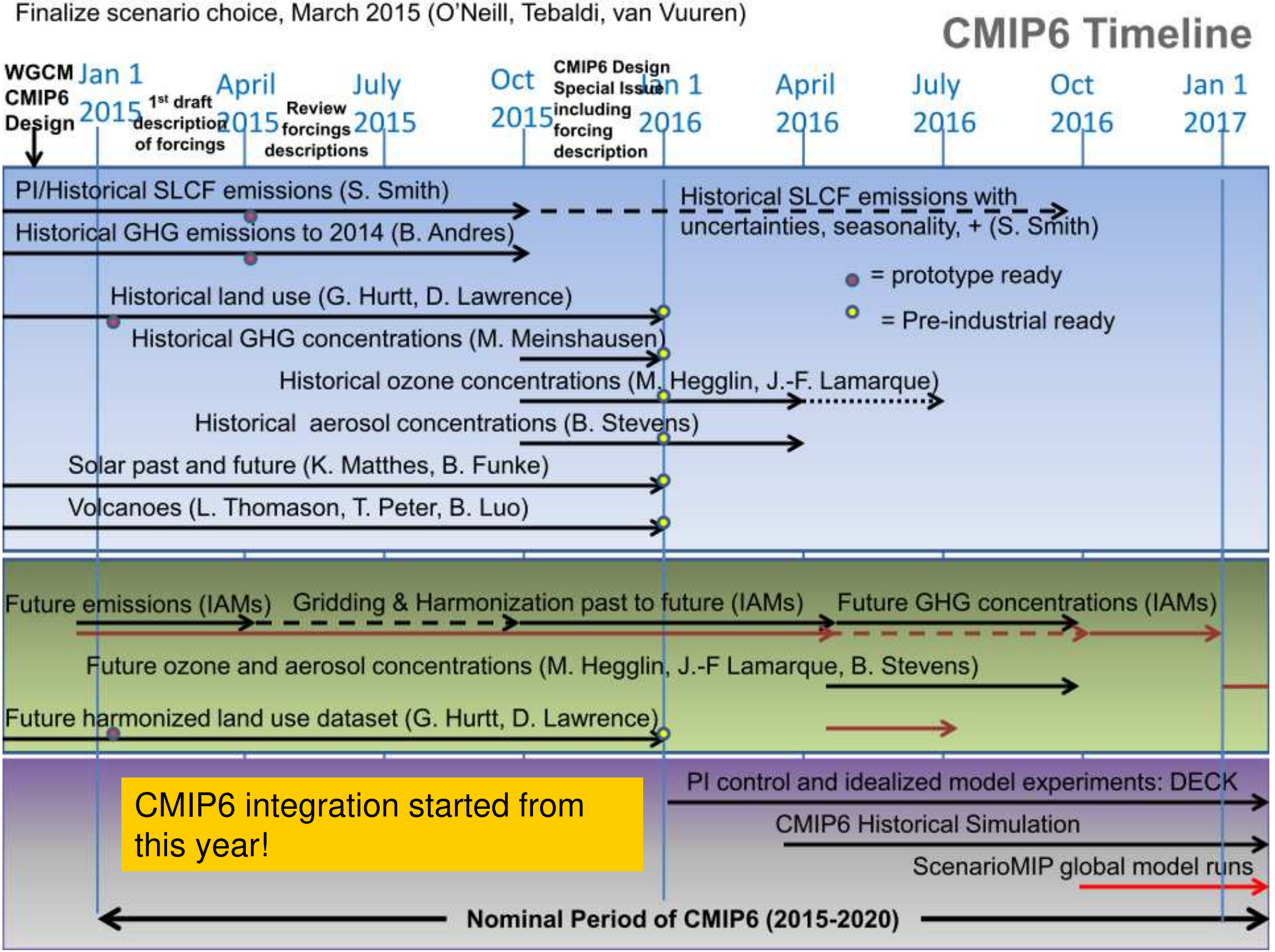
CMIP analysis as a young player's game

- I always suggest for a young researcher to choose a new research field, for which old researchers cannot work.
- By doing so, you can be a valuable talent.
- If you have a skill of multi-model analysis of CMIP in addition to other basic ability as a researcher, many institute will want you.

CMIP generations

- Climate Model Intercomparison Project
  - CMIP3 $\rightarrow$ IPCC-AR4 (2007)
  - CMIP5 $\rightarrow$ IPCC-AR5 (2013-14)
  - No CMIP4
  - CMIP6 (2015-) $\rightarrow$ IPCC-AR6 (2021-22)

Finalize scenario choice, March 2015 (O'Neill, Tebaldi, van Vuuren)

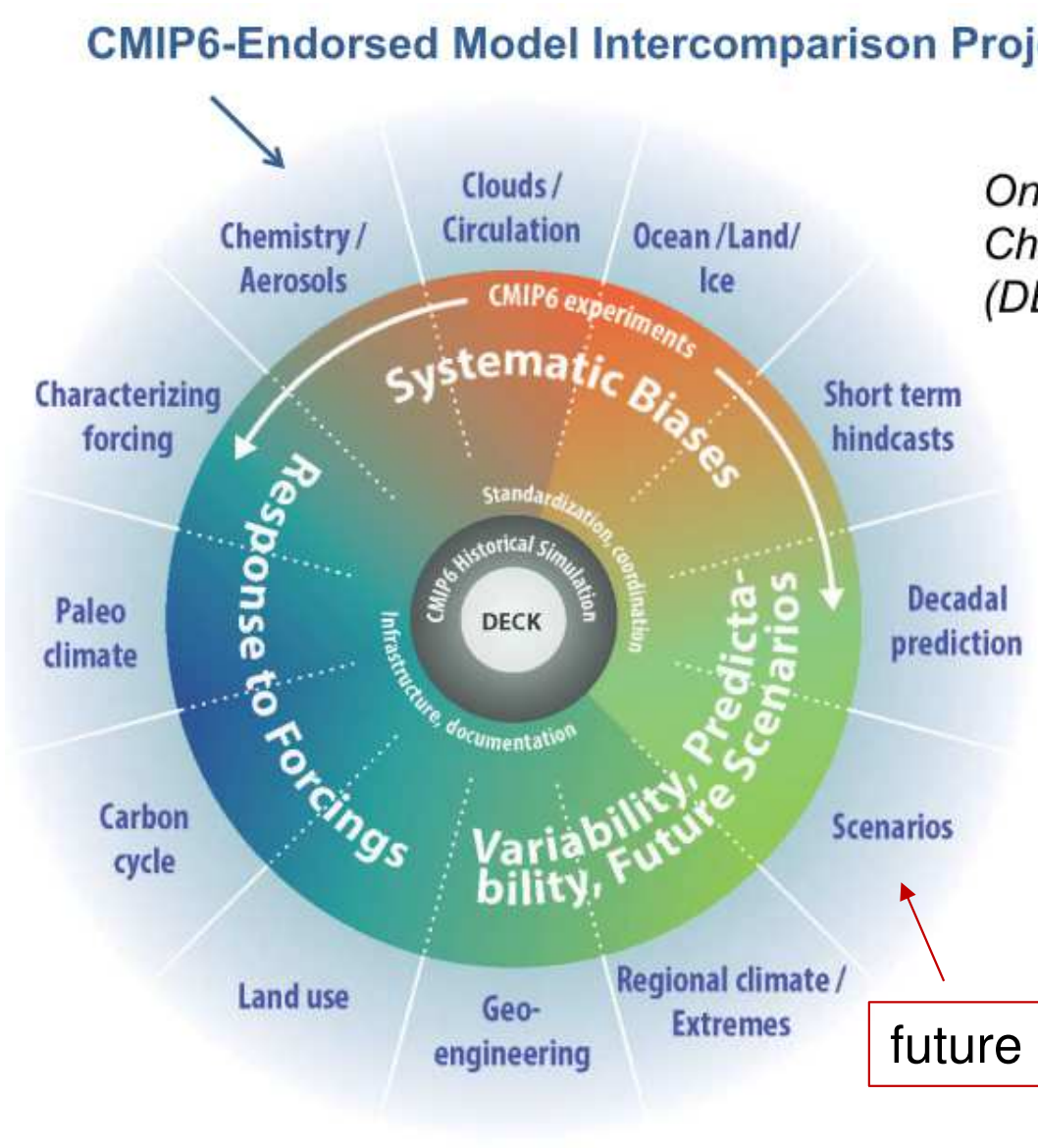


http://embracecmip2015.sciencesconf.org/conference/embracecmip2015/pages/Veronika_Eyring.pdf

CMIP6 structure

- Common experiments (entrance ticket for CMIP6)
  - Modelling teams of a model must provide data of these experiments.
- Endorsed MIPs
  - Modelling teams can join, but not necessary.

CMIP6: DECK + Historical + other MIPs



Ongoing Diagnosis, Evaluation, and Characterization of Klima (DECK) Experiments

DECK (entry card for CMIP)

i. AMIP simulation (~1979-2014)
ii. Pre-industrial control simulation
iii. 1%/yr CO_2 increase
iv. Abrupt 4xCO_2 run

CMIP6 Historical Simulation (entry card for CMIP6)

v. Historical simulation using CMIP6 forcings (1850-2014)

future runs

*(DECK & CMIP6 Historical Simulation to be run **for each model configuration** used in the subsequent CMIP6-Endorsed MIPs)*

***Note:** The themes in the outer circle of the figure might be slightly revised at the end of the MIP endorsement process*

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CMIP forcing

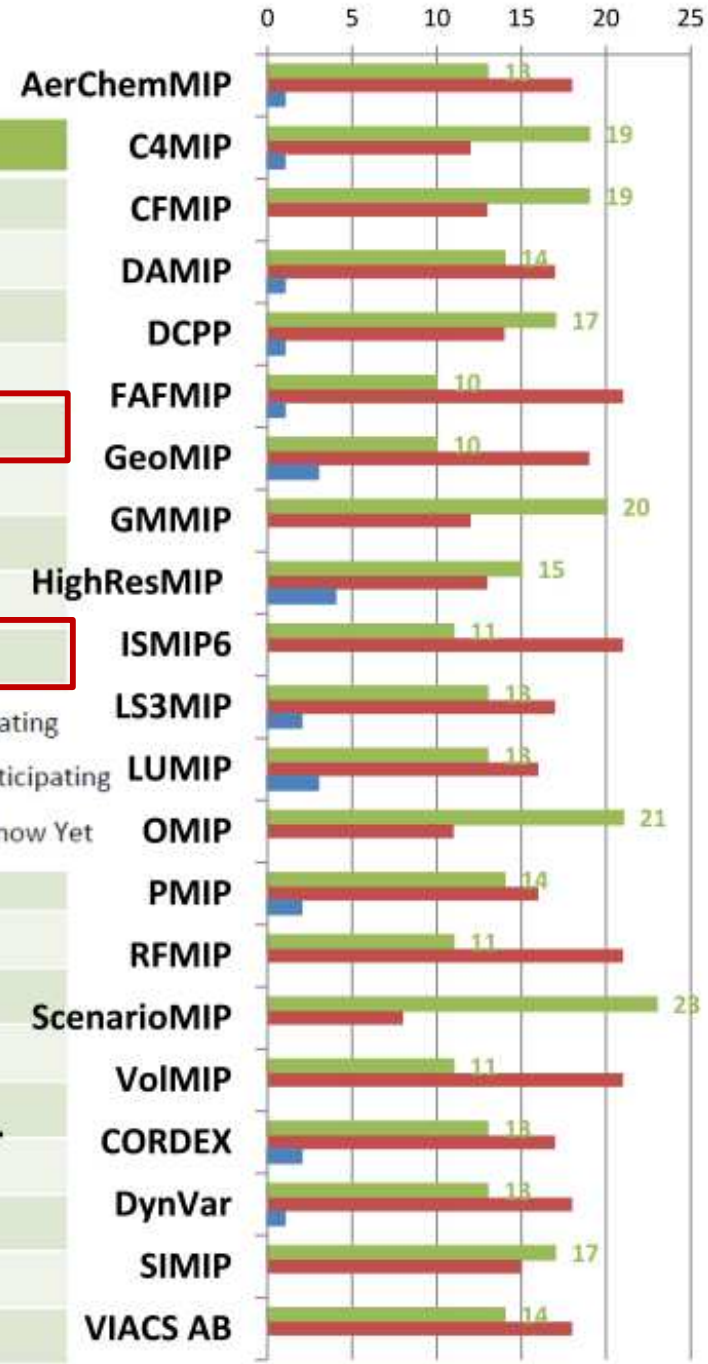
- CMIP models are coupled models, which contain ocean, atmosphere, land, ice models with coupling between those subsystem models.
- The forcings, which are given from the outside of the model system, are
  - greenhouse gas concentrations
  - aerosol concentrations (anthropogenic & natural)
  - solar radiation
  - earth's orbit factors
  - land use

Projection & Prediction

- Estimation of future conditions based on CMIP6 scenario runs is called “projection” (not prediction), because CMIP6 scenario runs do not contain predictable components associated with initial condition.
- For example, seasonal forecasting with typically used for 0.5-1 year prediction starts from the latst observation-based initial condition, which give the most of predictable component on this timescale.
- Unique exception in CMIP6 is Decadal Climate Prediction Project (DCPP), in numerical modelling runs start from observation-based initial condition.

CMIP6-Endorsed MIPs and Model Groups' Commitments to Participate in each MIP

	Long Name of MIP (Short Name of MIP)
1	Aerosols and Chemistry Model Intercomparison Project (AerChemMIP)
2	Coupled Climate Carbon Cycle Model Intercomparison Project (C4MIP)
3	Cloud Feedback Model Intercomparison Project (CFMIP)
4	Detection and Attribution Model Intercomparison Project (DAMIP)
5	Decadal Climate Prediction Project (DCPP)
6	Flux-Anomaly-Forced Model Intercomparison Project (FAFMIP)
7	Geoengineering Model Intercomparison Project (GeoMIP)
8	Global Monsoons Model Intercomparison Project (GMMIP)
9	High Resolution Model Intercomparison Project (HighResMIP)
10	Ice Sheet Model Intercomparison Project for CMIP6 (ISMIP6)
11	Land Surface, Snow and Soil Moisture MIP (LS3MIP)
12	Land-Use Model Intercomparison Project (LUMIP)
13	Ocean Model Intercomparison Project (OMIP)
14	Paleoclimate Modelling Intercomparison Project (PMIP)
15	Radiative Forcing Model Intercomparison Project (RFMIP)
16	Scenario Model Intercomparison Project (ScenarioMIP)
17	Volcanic Forcings Model Intercomparison Project (VolMIP)
18	Coordinated Regional Climate Downscaling Experiment (CORDEX)
19	Dynamics and Variability of the Stratosphere-Troposphere System (DynVar)
20	Sea-Ice Model Intercomparison Project (SIMIP)
21	Vulnerability, Impacts & Adaptation and Climate Services AB (VIACS AB)



http://embracecmip2015.sciencesconf.org/conference/embracecmip2015/pages/Veronika_Eyring.pdf

A common problem in the ocean models

- CMIP6 models generally do not resolve ocean mesoscale eddies and the narrow strong currents such as the Kuroshio and the Gulf Stream are heavily biased.
- CMIP6 ocean model resolution is typically 50-100 km.
  - 100 km or coarser: No ocean mesoscale eddies.
  - 25-50 km: eddy permitting models.
  - 10 km or finer: eddy resolving models.

HighResMIP (Haarsma et al. 2016, GMD)

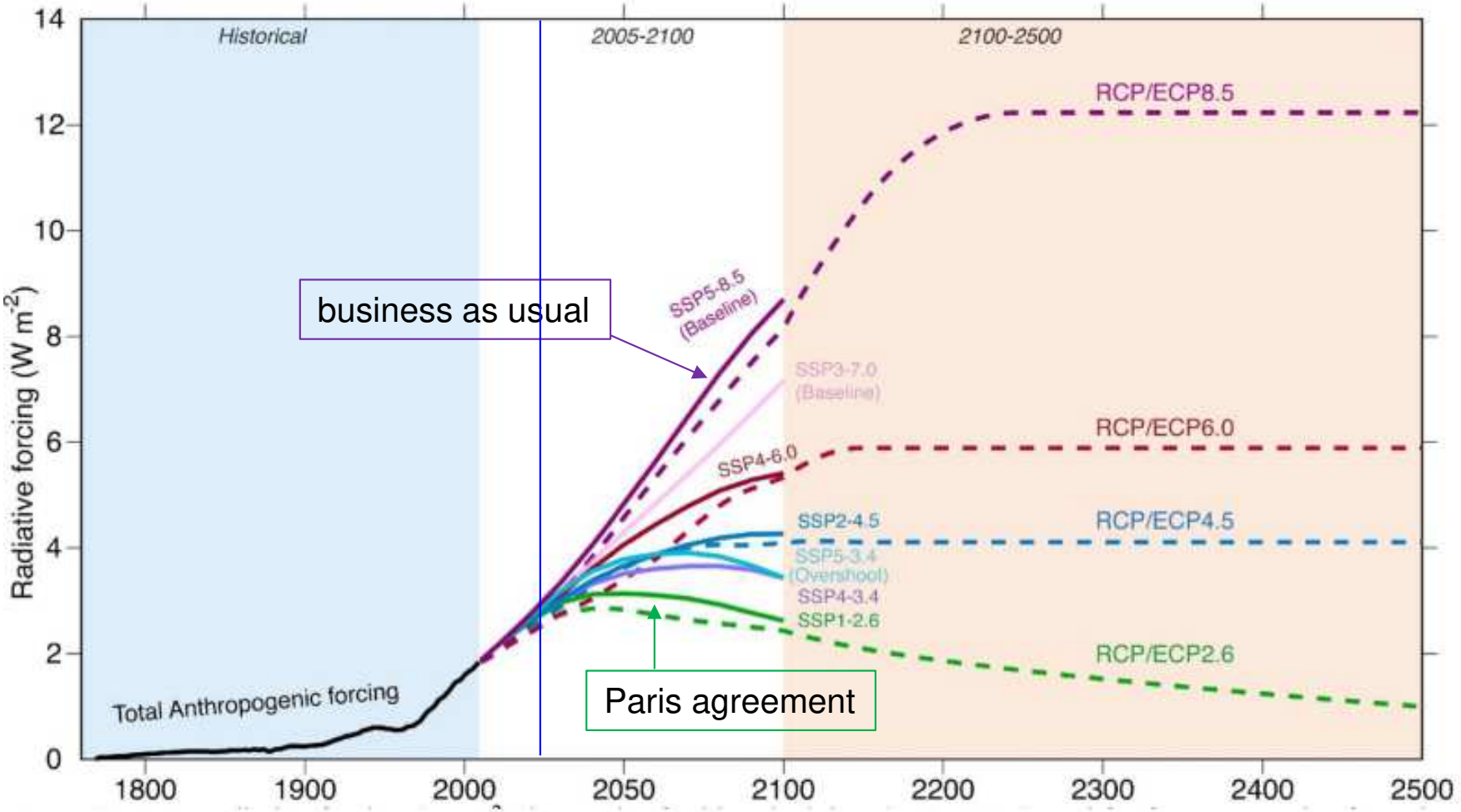
- High-Res.: 25-50 km AGCM (typically 150 km in CMIP5), 0.25-deg or higher (upto 0.1-deg) OGCM.
  - Close to necessary resolution of 20 km for proper latent heating suggested by Willison et al. (2013 JC).
- Tier 1: AGCM only run 1950-2014 (historical)
  - with 0.25-deg SST and ICE of HadISST2.
- Tier 2: Coupled run 1950-2050 (RCP8.5)
- Tier 3: AGCM only run 2015-2100 (or -2050) (future)
  - Observed SST and ICE + trend deduced from CMIP5 models for RCP8.5.

Scenarios

- A big uncertainty of future projection lies in uncertainty of forcings for future global warmings.
- Since one cannot know exactly future CO2 concentration, which is needed to give as a forcing, CMIP takes a scenario approach.
- A scenario is an integrated set of information for forcings including greenhouse gas concentration, aerosol concentration, land use etc.

CMIP6 scenarios

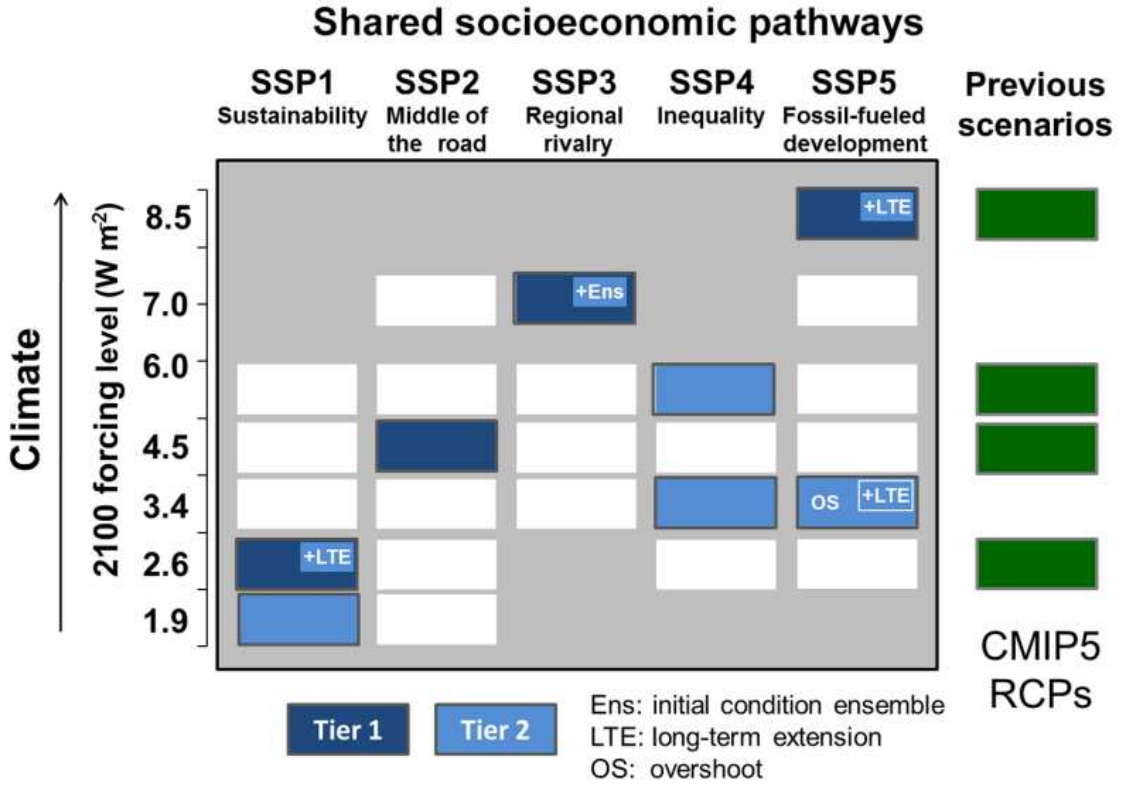
- Shared Socioeconomic Pathway (SSP) in CMIP6
  - Representative Concentration Pathways (RCP) in CMI5



IPCC SROCC, Chapter 1

What is the number in scenario?

- The last number of SSP5-8.5 or RCP8.5 (i.e., 8.5) means radiative forcing at 2100 in w/m^2.
- Radiative forcing is a measure of greenhouse warming forcing represented as a radiation.
- The major CMIP6 scenarios are
  - SSP1-2.6
  - SSP2-4.5
  - SSP3-7.0
  - SSP5-8.5

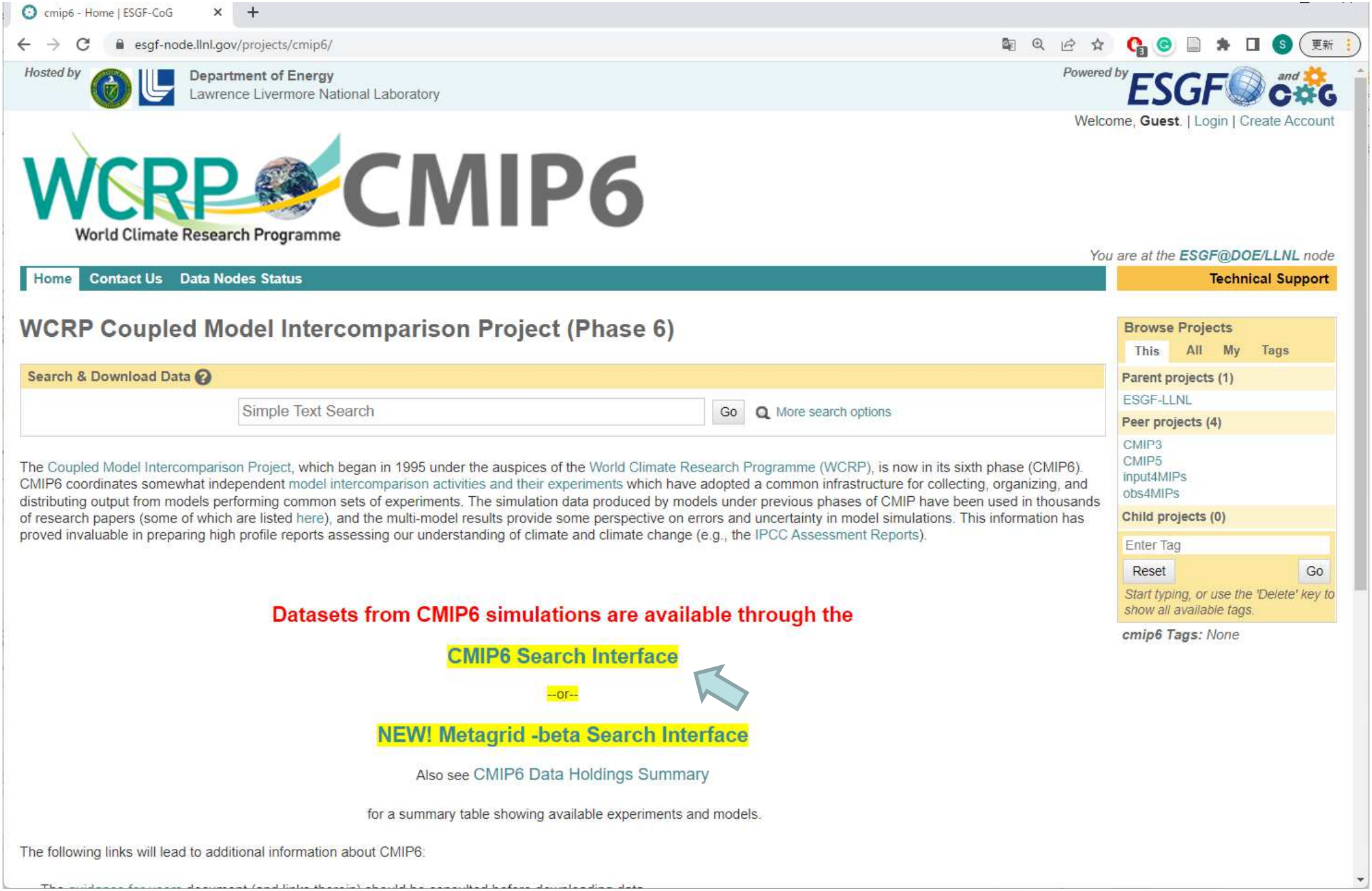


O'Neill et al. (2016 doi:10.5194/gmd-9-3461-2016)

2. CMIP6 Data Availability

ESGF

- Earth System Grid Federation provides interface by which users can search and download CMIP5/6 and some other data.
- The actual data are stored in each modelling centers or national data storage, but from ESGF interface you can find data of multiple institutes across nations.
- Each ESGF site is called as ESGF node.
- One downloads the data from the modelling centers or national data storage and not from ESGF node, thus the bandwidth between the former for you determines the download speed.
  - This is the reason why I choose Japanese model as materials, because I can download much faster than other countries' model data.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WCRP Coupled Model Intercomparison Project (Phase 6)
Search & Download Data
Simple Text Search
Go
More search options
The Coupled Model Intercomparison Project, which began in 1995 under the auspices of the World Climate Research Programme (WCRP), is now in its sixth phase (CMIP6). CMIP6 coordinates somewhat independent model intercomparison activities and their experiments which have adopted a common infrastructure for collecting, organizing, and distributing output from models performing common sets of experiments. The simulation data produced by models under previous phases of CMIP have been used in thousands of research papers (some of which are listed here), and the multi-model results provide some perspective on errors and uncertainty in model simulations. This information has proved invaluable in preparing high profile reports assessing our understanding of climate and climate change (e.g., the IPCC Assessment Reports).
Datasets from CMIP6 simulations are available through the
CMIP6 Search Interface
--or--
NEW! Metagrid -beta Search Interface
Also see CMIP6 Data Holdings Summary
for a summary table showing available experiments and models.
The following links will lead to additional information about CMIP6:
Browse Projects
This
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My
Tags
Parent projects (1)
ESGF-LLNL
Peer projects (4)
CMIP3
CMIP5
input4MIPs
obs4MIPs
Child projects (0)
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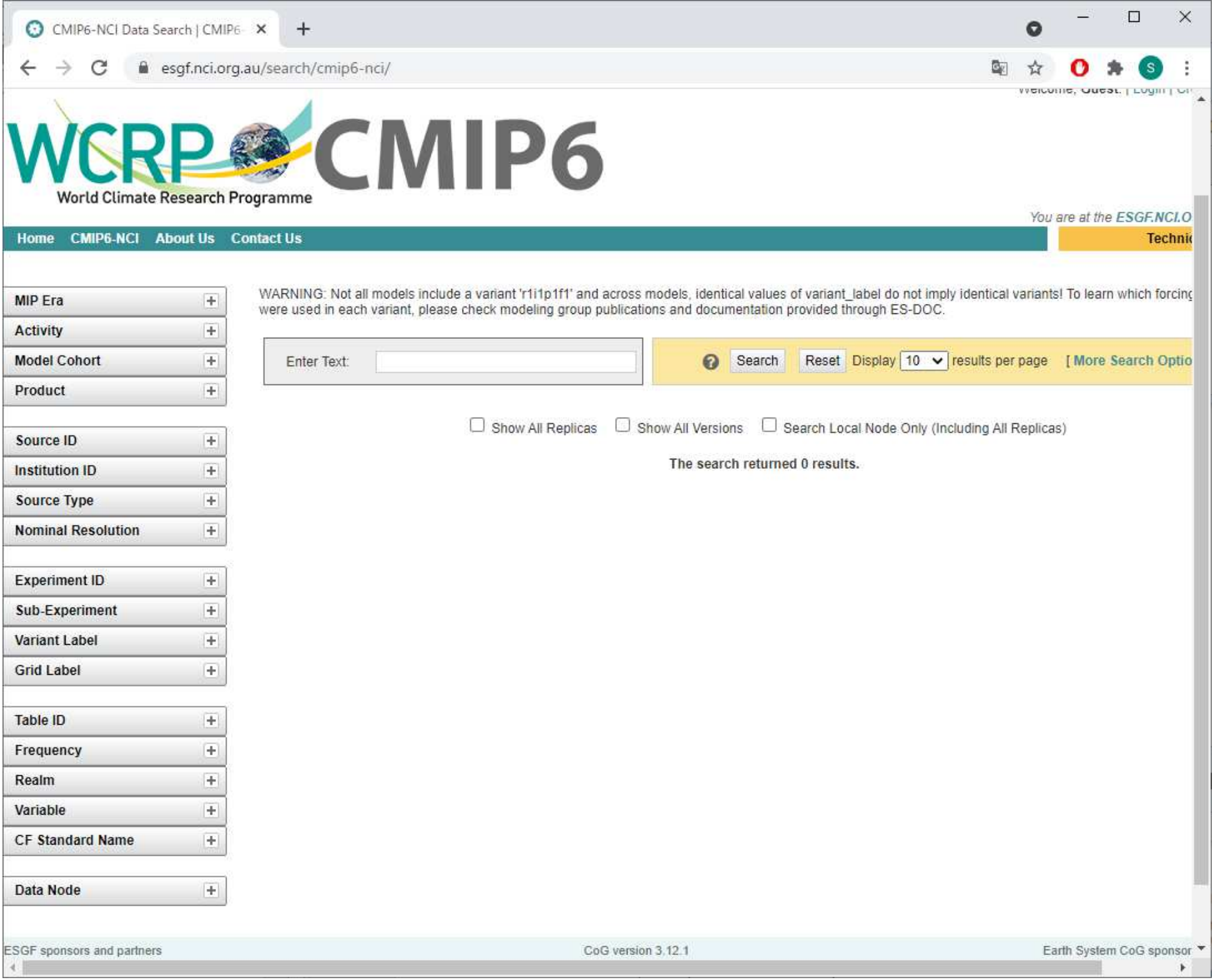
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MIP Era
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Enter Text:
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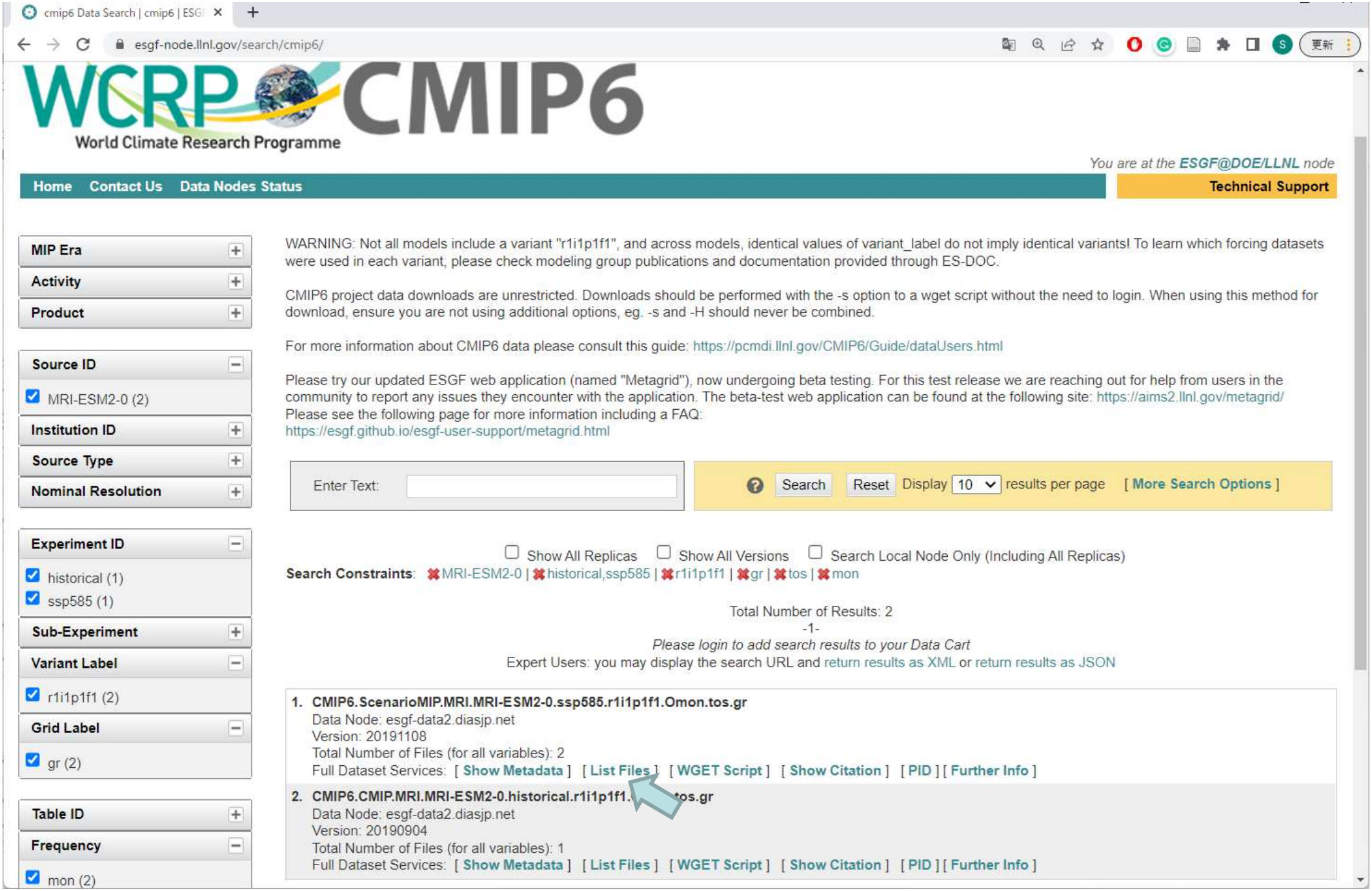
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Home Contact Us Data Nodes Status
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WARNING: Not all models include a variant "r1i1p1f1", and across models, identical values of variant_label do not imply identical variants! To learn which forcing datasets were used in each variant, please check modeling group publications and documentation provided through ES-DOC.
CMIP6 project data downloads are unrestricted. Downloads should be performed with the -s option to a wget script without the need to login. When using this method for download, ensure you are not using additional options, eg. -s and -H should never be combined.
For more information about CMIP6 data please consult this guide: https://pcmdi.llnl.gov/CMIP6/Guide/dataUsers.html
Please try our updated ESGF web application (named "Metagrid"), now undergoing beta testing. For this test release we are reaching out for help from users in the community to report any issues they encounter with the application. The beta-test web application can be found at the following site: https://aims2.llnl.gov/metagrid/
Please see the following page for more information including a FAQ:
https://esgf.github.io/esgf-user-support/metagrid.html
Enter Text:
Search Reset Display 10 results per page [More Search Options]
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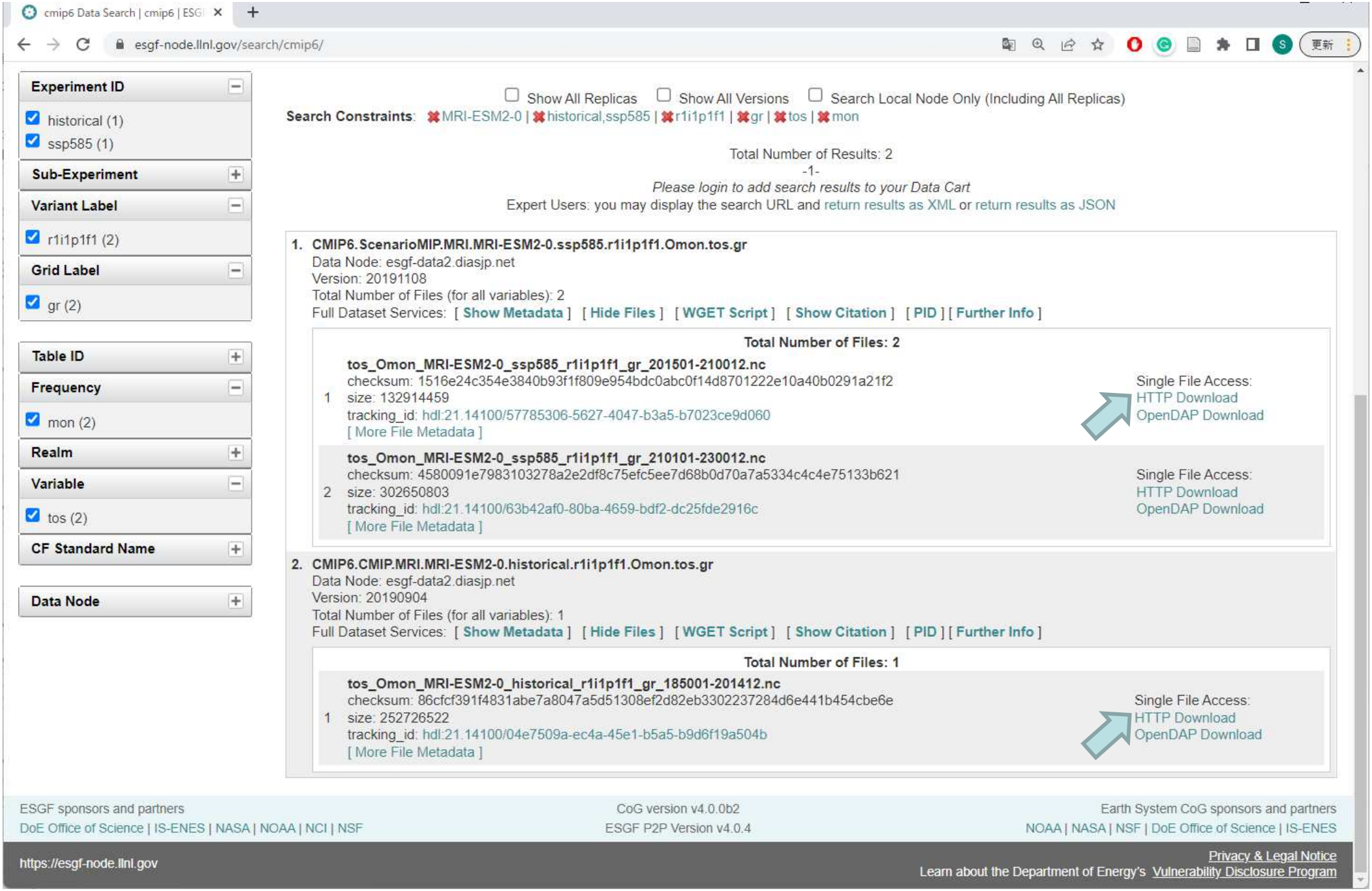
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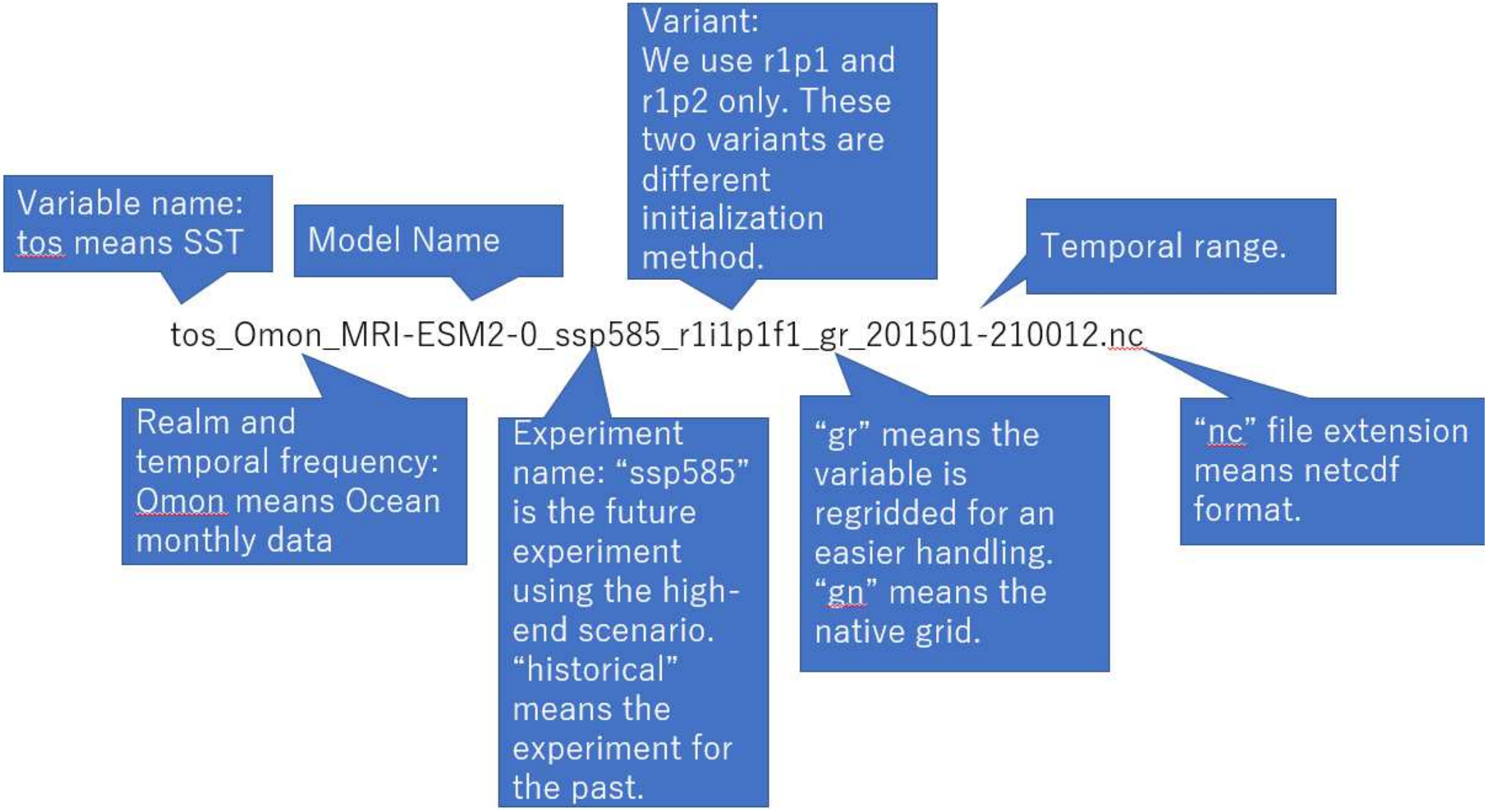
CMIP6 file name convention



CMIP6 data in C3S

- Copernicus Climate Change Service (C3S) provides CMIP6 historical and scenario simulations for many atmospheric data (including spatially 3D data) and surface ocean and sea-ice data (spatially 2D data only) with capability of downloading of selected-region.

https://cds.climate.copernicus.eu/cdsapp#!/dataset/projections-cmip6?tab=form

variables available at C3S

Variable

- Air temperature
- Daily maximum near-surface air temperature
- Eastward near-surface wind
- Evaporation including sublimation and transpiration
- Grid-cell area for atmospheric grid variables
- Land ice area percentage
- Near-surface air temperature
- Near-surface specific humidity
- Northward near-surface wind
- Percentage of the grid cell occupied by land including lakes
- Relative humidity
- Sea floor depth below geoid
- Sea level pressure
- Sea surface salinity
- Sea-ice area percentage on ocean grid
- Snow depth
- Specific humidity
- Surface altitude
- Surface downward northward wind stress
- Surface downwelling shortwave radiation
- Surface temperature
- Surface upward latent heat flux
- Surface upwelling longwave radiation
- TOA incident shortwave radiation
- TOA outgoing shortwave radiation
- Total runoff
- Capacity of soil to store water
- Daily minimum near-surface air temperature
- Eastward wind
- Geopotential height
- Grid-cell area for ocean variables
- Moisture in upper portion of soil column
- Near-surface relative humidity
- Near-surface wind speed
- Northward wind
- Precipitation
- Sea area percentage
- Sea ice thickness
- Sea surface height above geoid
- Sea surface temperature
- Sea-ice mass per area
- Snowfall flux
- Surface air pressure
- Surface downward eastward wind stress
- Surface downwelling longwave radiation
- Surface snow amount
- Surface temperature of sea ice
- Surface upward sensible heat flux
- Surface upwelling shortwave radiation
- TOA outgoing longwave radiation
- Total cloud cover percentage

Clear all

Size of the data

- It is important to have a feasible plan and feasibility of CMIP5/6 analysis largely depends on data size required for a specific research.
- 3D data are 40-70 times larger than 2D data.
- Daily data are 30 times larger than monthly data.

Some ocean variables

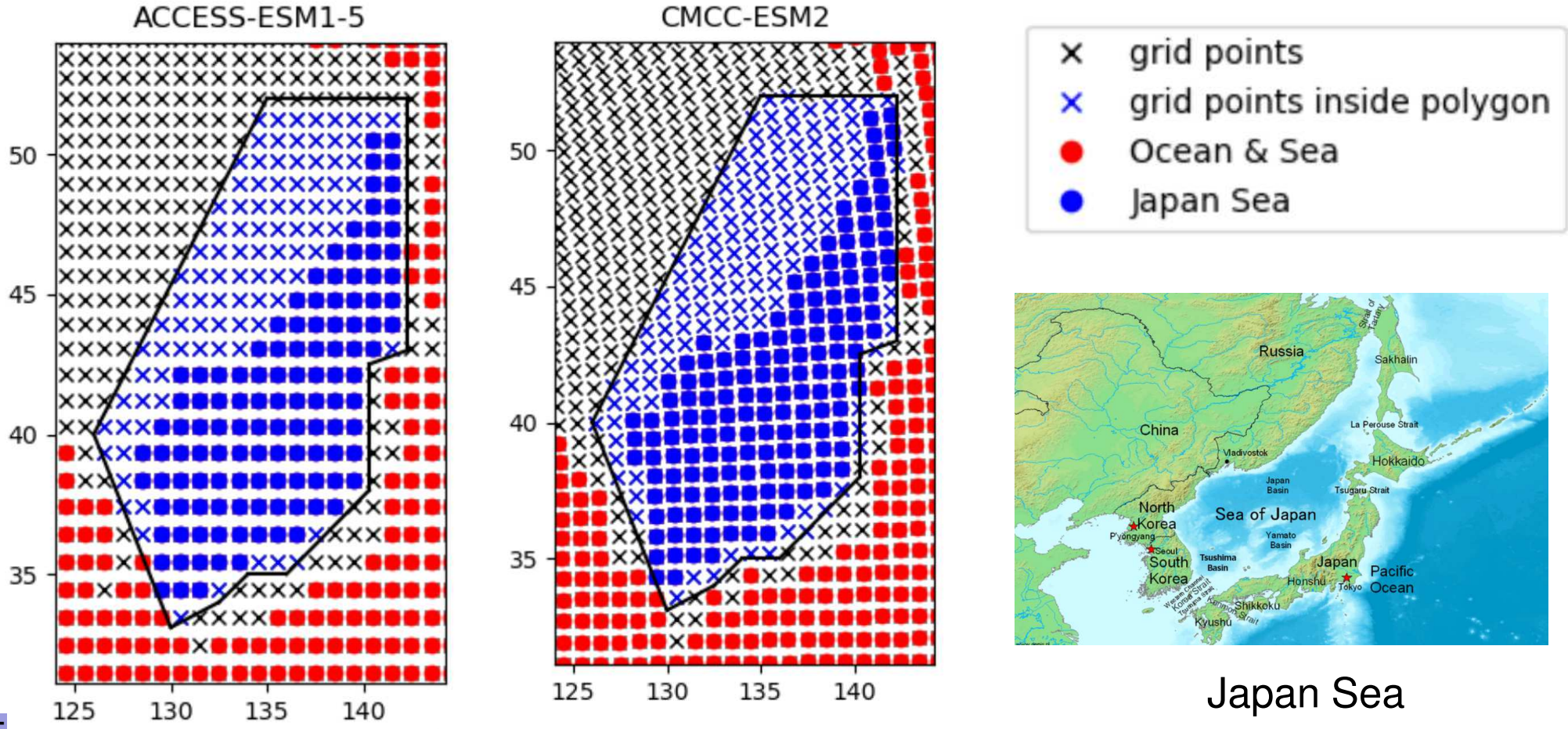
- 2D data
  - tos: SST
  - zg: sea-surface height
    - Note that coupled models do not sufficiently contain the land-ice melt effect.
- 3D data
  - to: potential temperature
  - so: salinity
  - uo: x-ward component of current
  - vo: y-ward component of current

Research purposes to use CMIP5/6 models

- To evaluate the future changes
- To understand the mechanisms of future changes
- To evaluate role of forcings in the past changes
- To evaluate the model ability to reproduce the past changes
  - If model cannot simulate the past, we cannot rely on them for future.
- To provide boundary conditions of regional models
- To understand the resolution dependency of some phenomena using HighResMIP

Original or remapped coordinate

- Most of ocean models do not have lat-lon grid, but have curvelinear grid or unstructured grid.



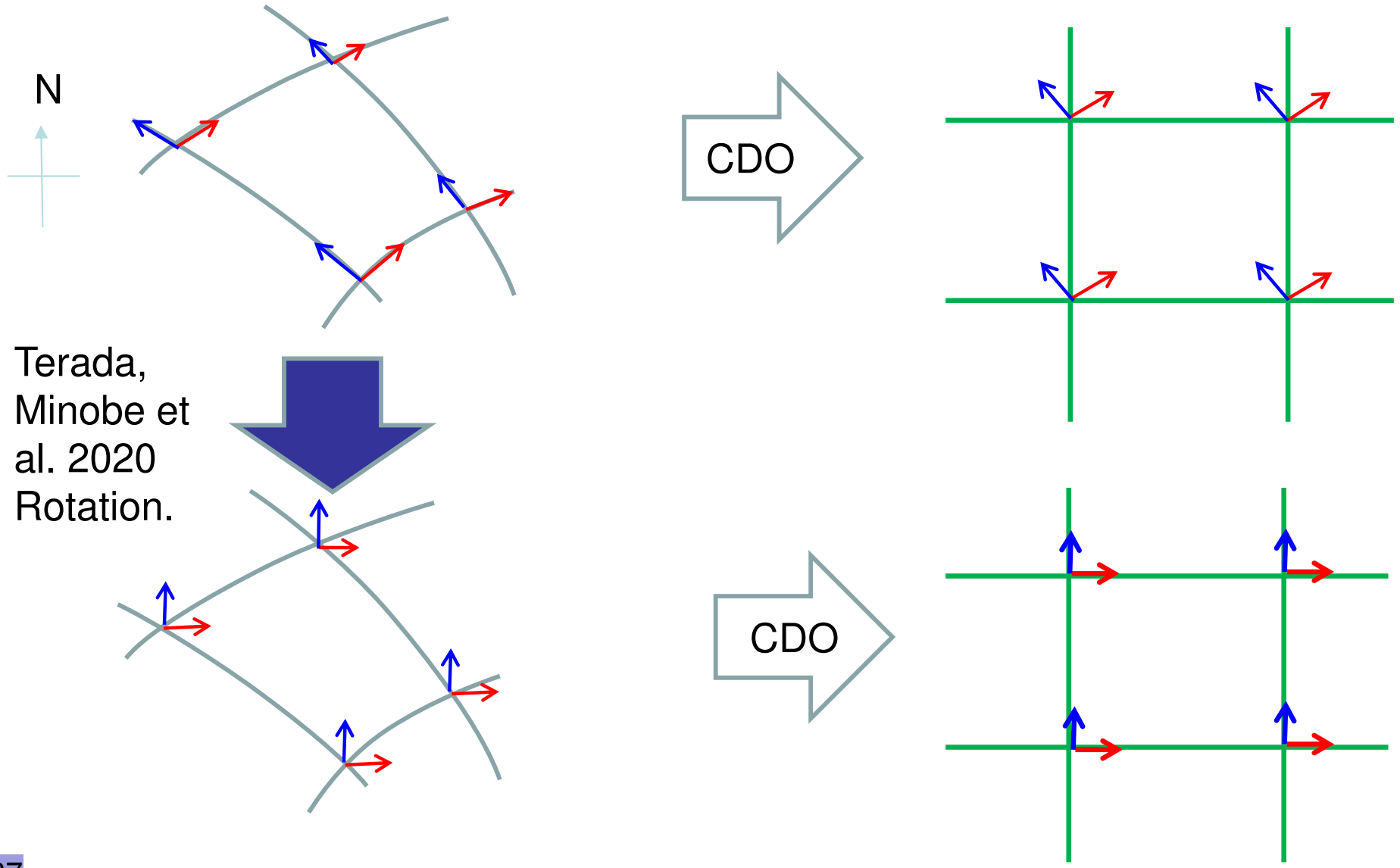
Japan Sea

Work on original coordinate or remapped coordinate

- When we draw a map figure of multi-model mean, we need to remap models on a common grid (e.g., 1x1 lat-lon).
  - Most users use Climate Data Operator (CDO), a free tool developed by Max Planck Institute in Germany.
- However, if we analyze near coastal data, sometimes it is better or even necessary to use original coordinate data.

Ocean velocities are problematic

- CMIP5's ocean velocities are x-ward and y-ward velocities of the ocean coordinate, and standard tool (CDO or NCL) can interpolate but cannot rotate velocities (except for Max Planck Ocean model).



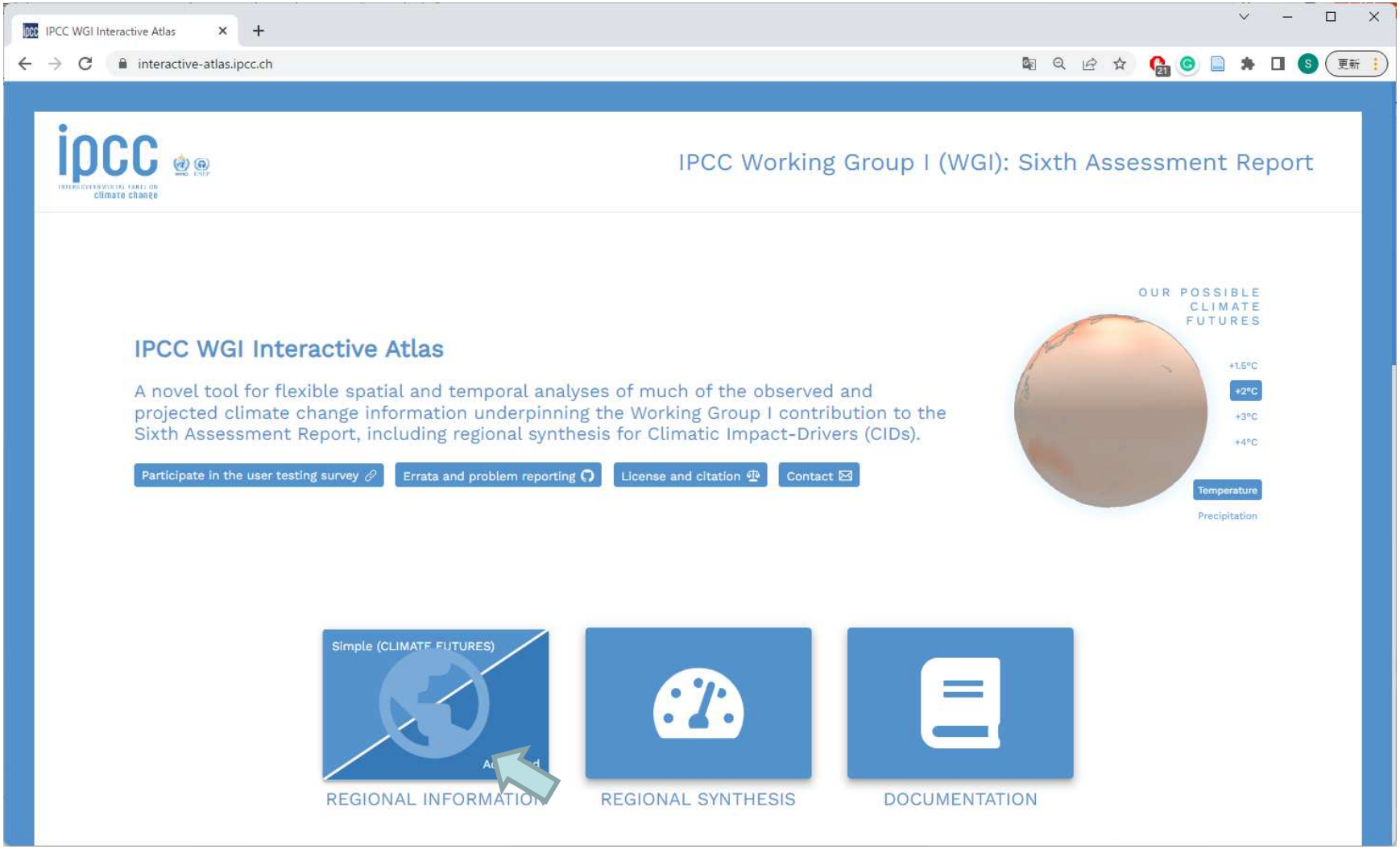
Emphasis on regionality

- WCRP now emphasizes regionality.
- Regional studies are mainly conducted by researchers in each region.
  - Future changes of Japan are mainly studied by Japanese.
  - There were so many studies in developed countries, but not in developing counties.
  - So, there are lots of opportunities in researchers in developing counties.

3. IPCC WG1 Interactive Atlas

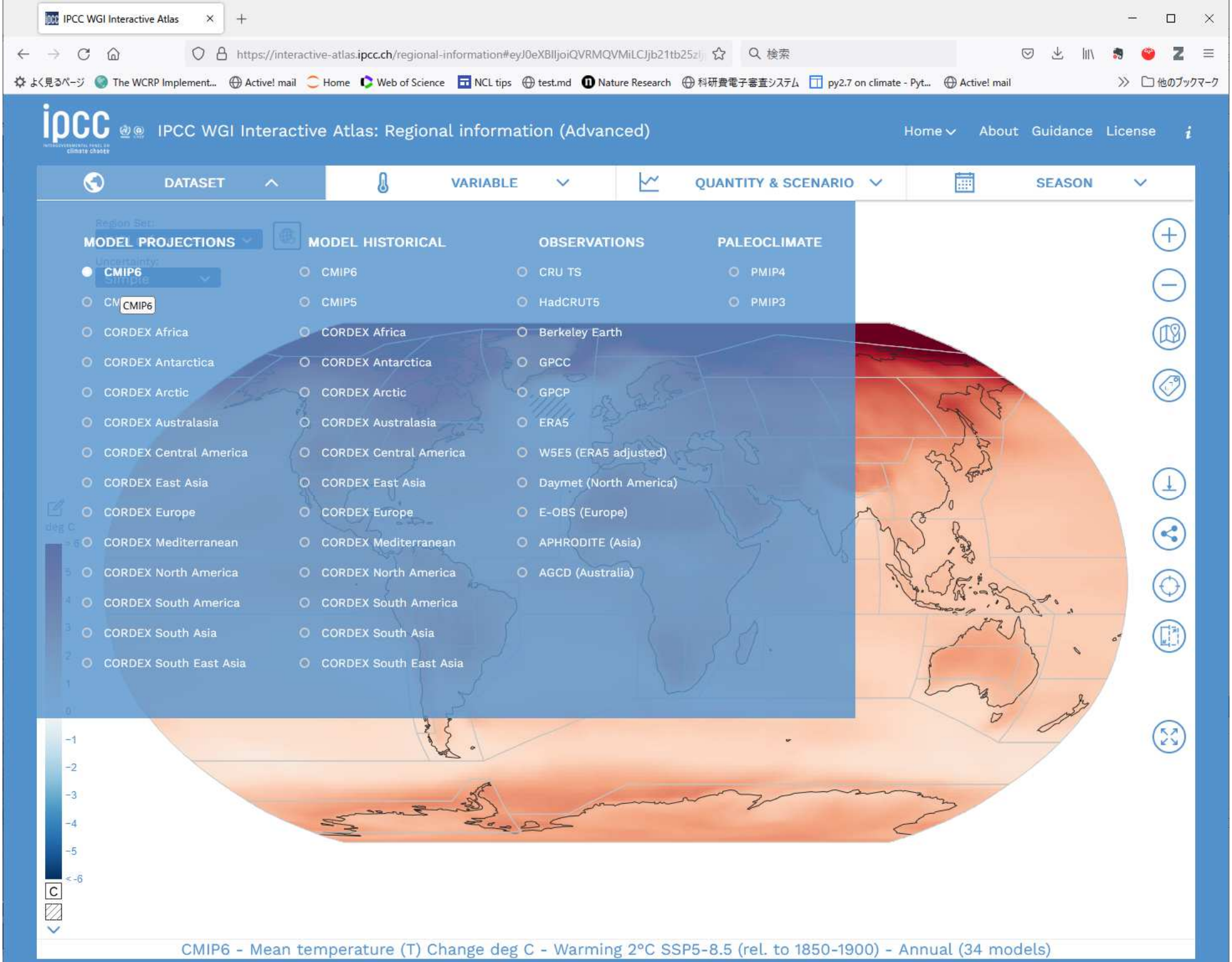
By using this Atlas, we can obtain multi-model mean information for SST, sea-surface height, etc.

IPCC WG1 Interactive Atlas



https://interactive-atlas.ipcc.ch/

How to know point information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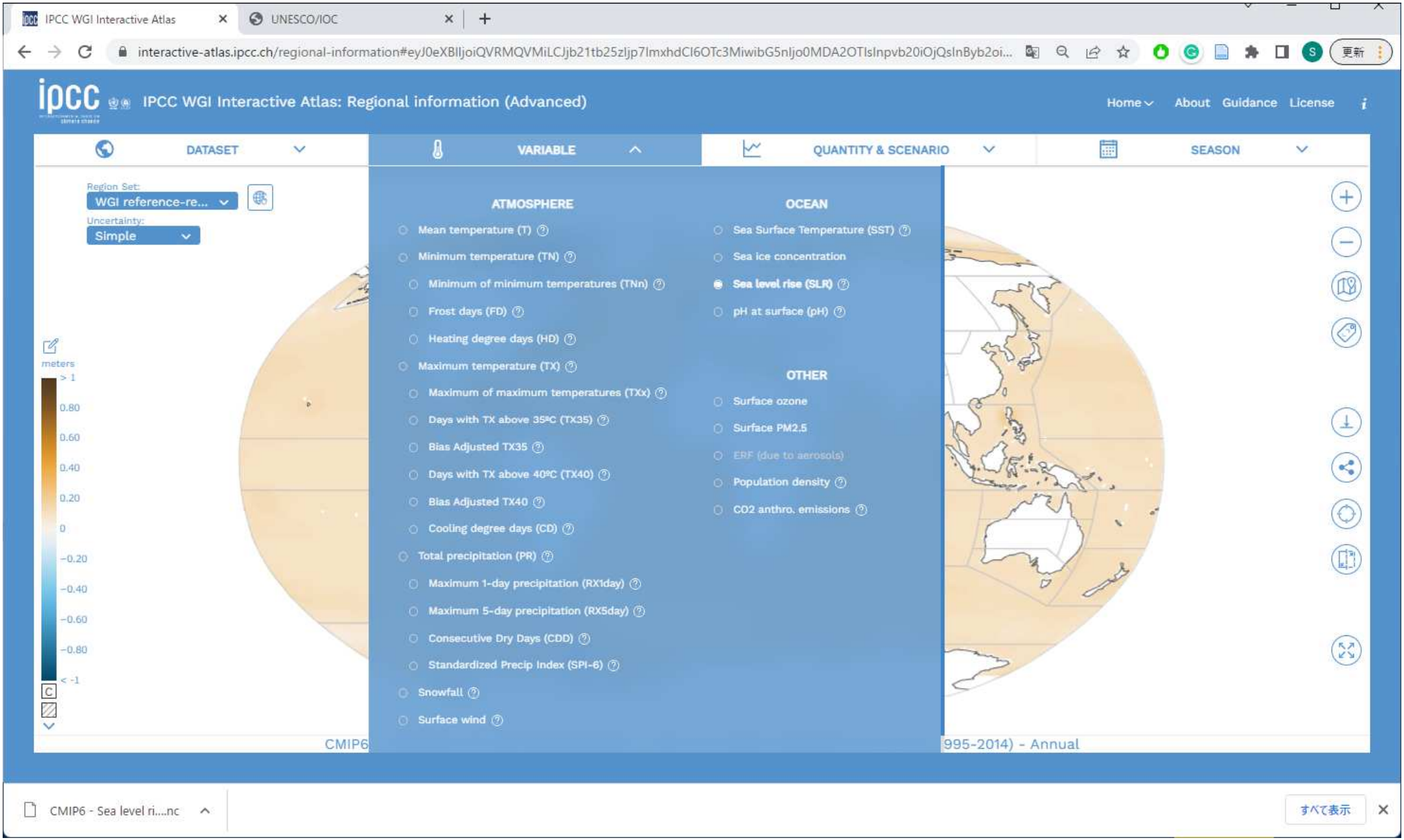
ERA5
W5E5 (ERA5 adjusted)
Daymet (North America)
E-OBS (Europe)
APHRODITE (Asia)
AGCD (Australia)
PMIP4
PMIP3
deg C
C
CMIP6 - Mean temperature (T) Change deg C - Warming 2°C SSP5-8.5 (rel. to 1850-1900) - Annual (34 models)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ATMOSPHERE
Mean temperature (T)
Minimum temperature (TN)
Minimum of minimum temperatures (TNn)
Frost days (FD)
Heating degree days (HD)
Maximum temperature (TX)
Maximum of maximum temperatures (TXx)
Days with TX above 35ºC (TX35)
Bias Adjusted TX35
Days with TX above 40ºC (TX40)
Bias Adjusted TX40
Cooling degree days (CD)
Total precipitation (PR)
Maximum 1-day precipitation (RX1day)
Maximum 5-day precipitation (RX5day)
Consecutive Dry Days (CDD)
Standardized Precip Index (SPI-6)
Snowfall
Surface wind
OCEAN
Sea Surface Temperature (SST)
Sea ice concentration
Sea level rise (SLR)
pH at surface (pH)
OTHER
Surface ozone
Surface PM2.5
ERF (due to aerosols)
Population density
CO2 anthro. emissions
meters
> 1
0.80
0.60
0.40
0.20
0
−0.20
−0.40
−0.60
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CMIP6
995-2014) - Annual
CMIP6 - Sea level ri....nc
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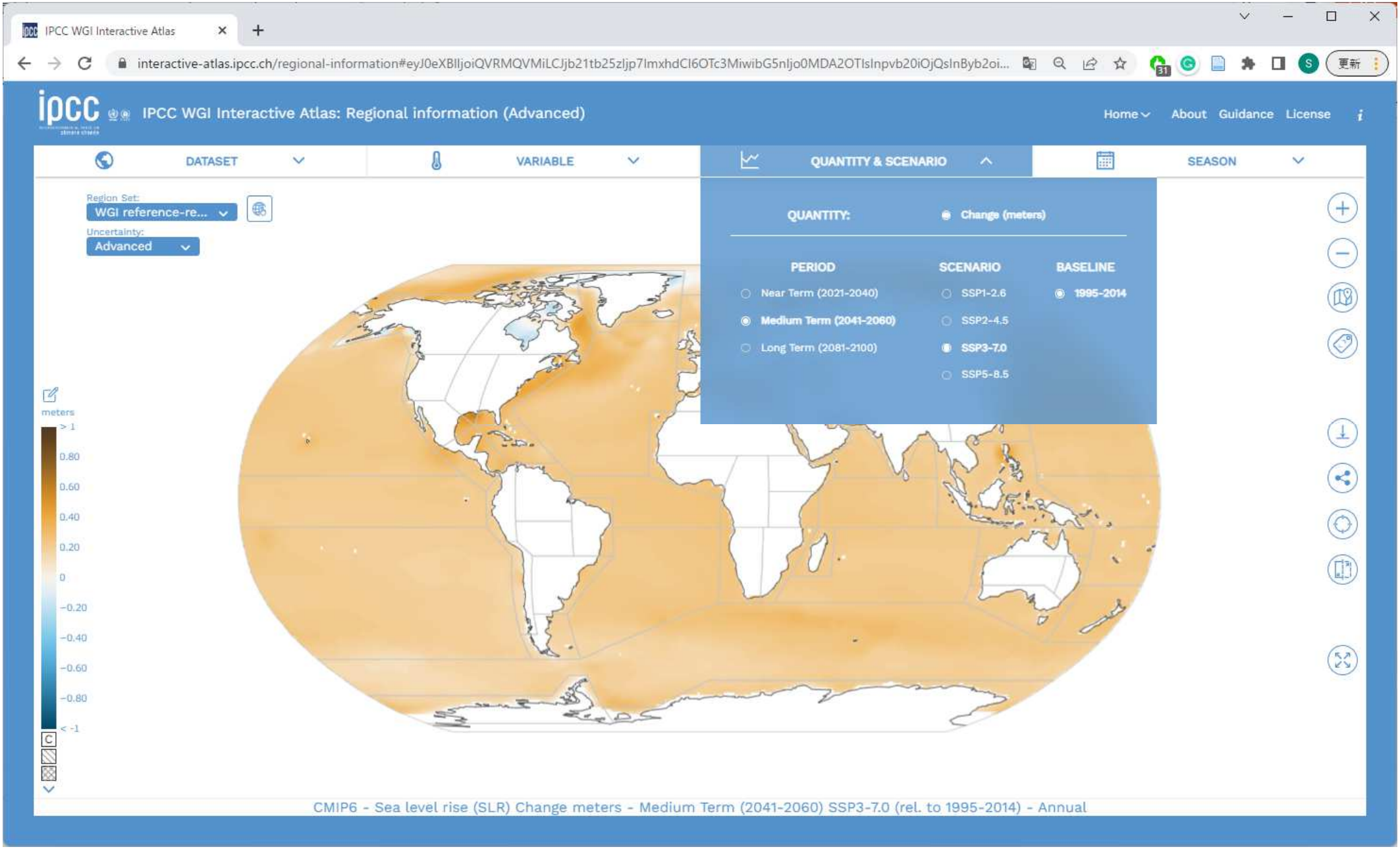
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QUANTITY:
Change (meters)
PERIOD
Near Term (2021-2040)
Medium Term (2041-2060)
Long Term (2081-2100)
SCENARIO
SSP1-2.6
SSP2-4.5
SSP3-7.0
SSP5-8.5
BASELINE
1995-2014
meters
> 1
0.80
0.60
0.40
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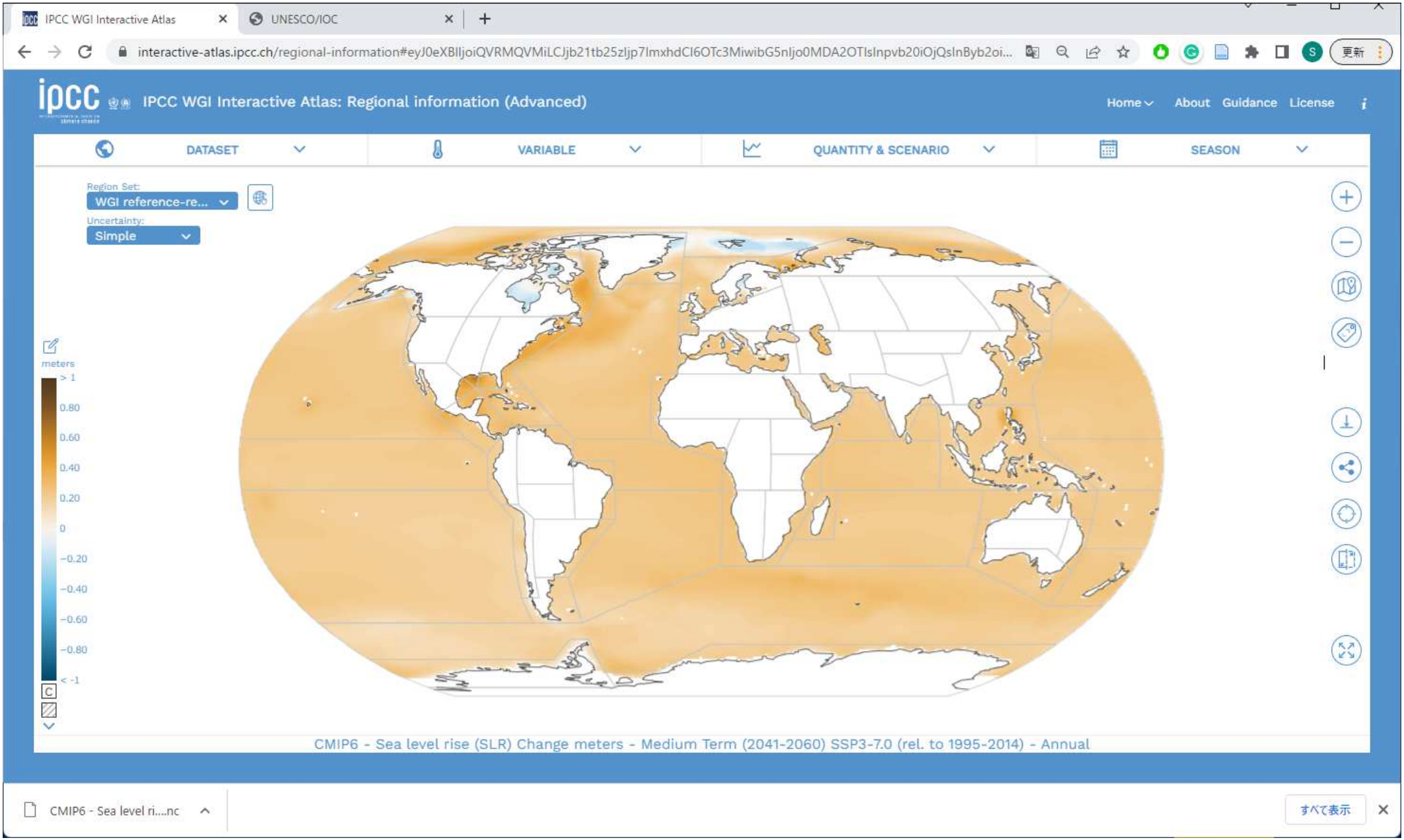
CMIP6 - Sea level rise (SLR) Change meters - Medium Term (2041-2060) SSP3-7.0 (rel. to 1995-2014) - Annual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< -1
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CMIP6 - Sea level rise (SLR) Change meters - Medium Term (2041-2060) SSP3-7.0 (rel. to 1995-2014) - Annual
CMIP6 - Sea level ri....nc
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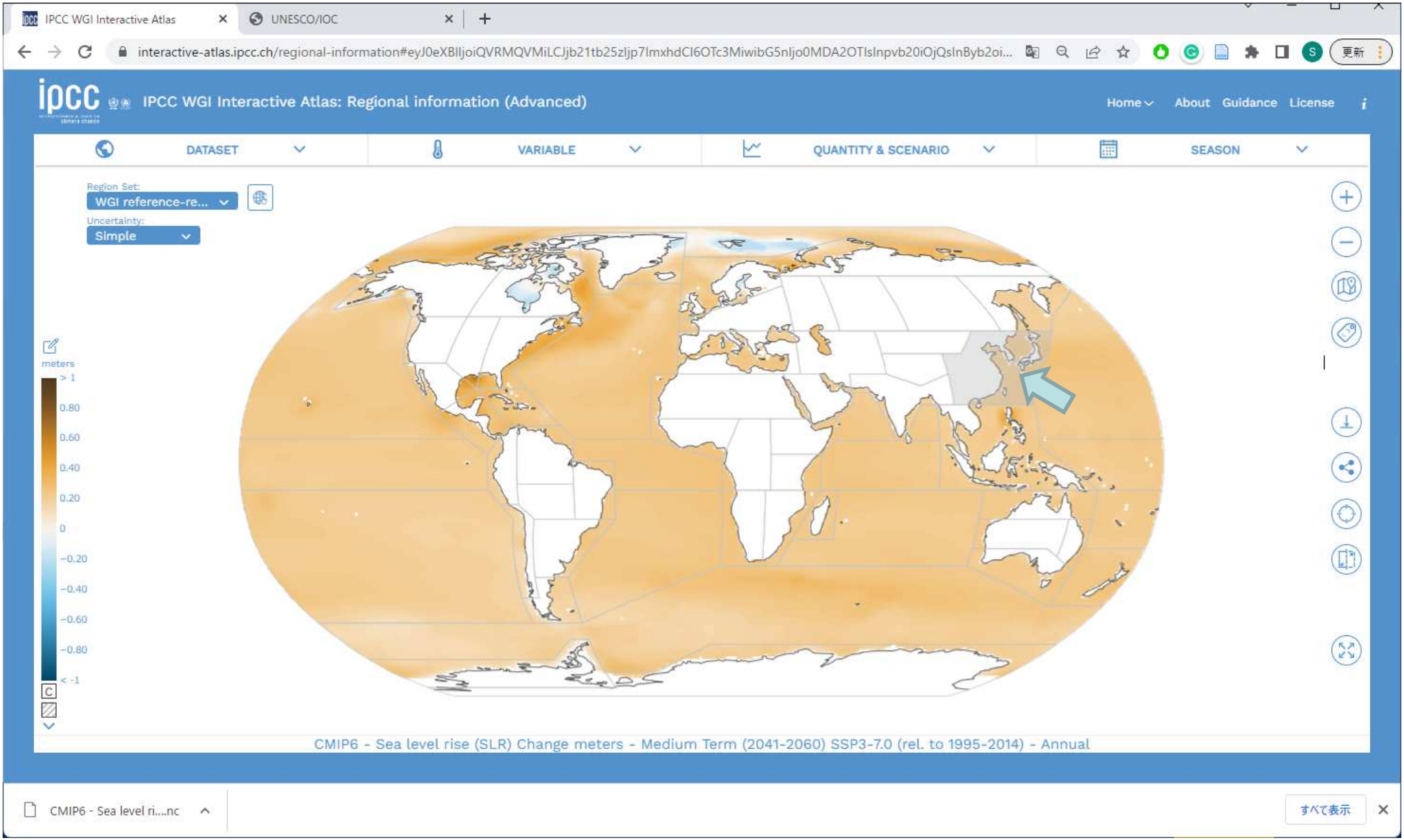
Regional Information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Uncertainty:
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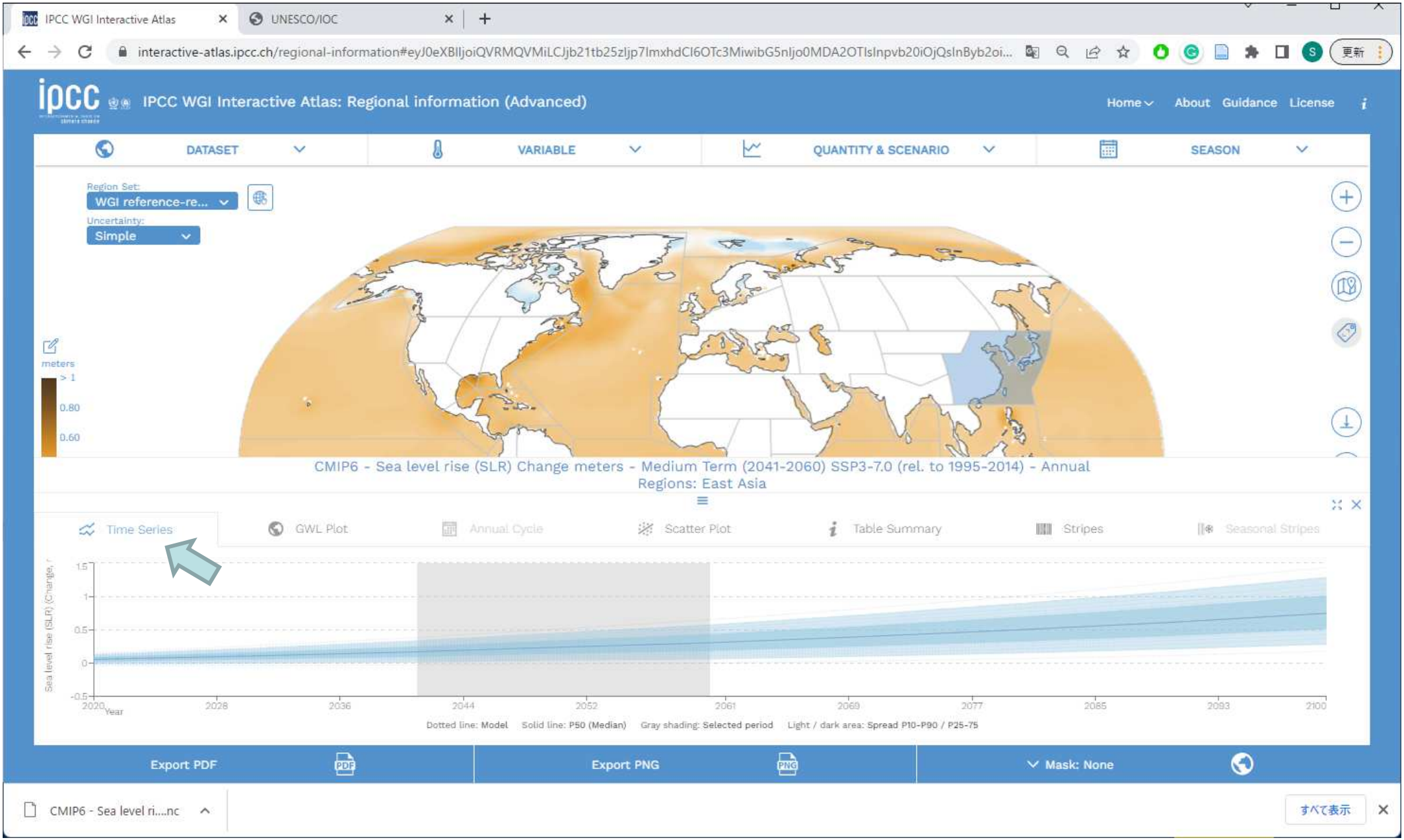
−0.60
−0.80
< -1
CMIP6 - Sea level rise (SLR) Change meters - Medium Term (2041-2060) SSP3-7.0 (rel. to 1995-2014) - Annual
CMIP6 - Sea level ri....nc
すべて表示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SEASON
Region Set:
WGI reference-re...
Uncertainty:
Simple
meters
> 1
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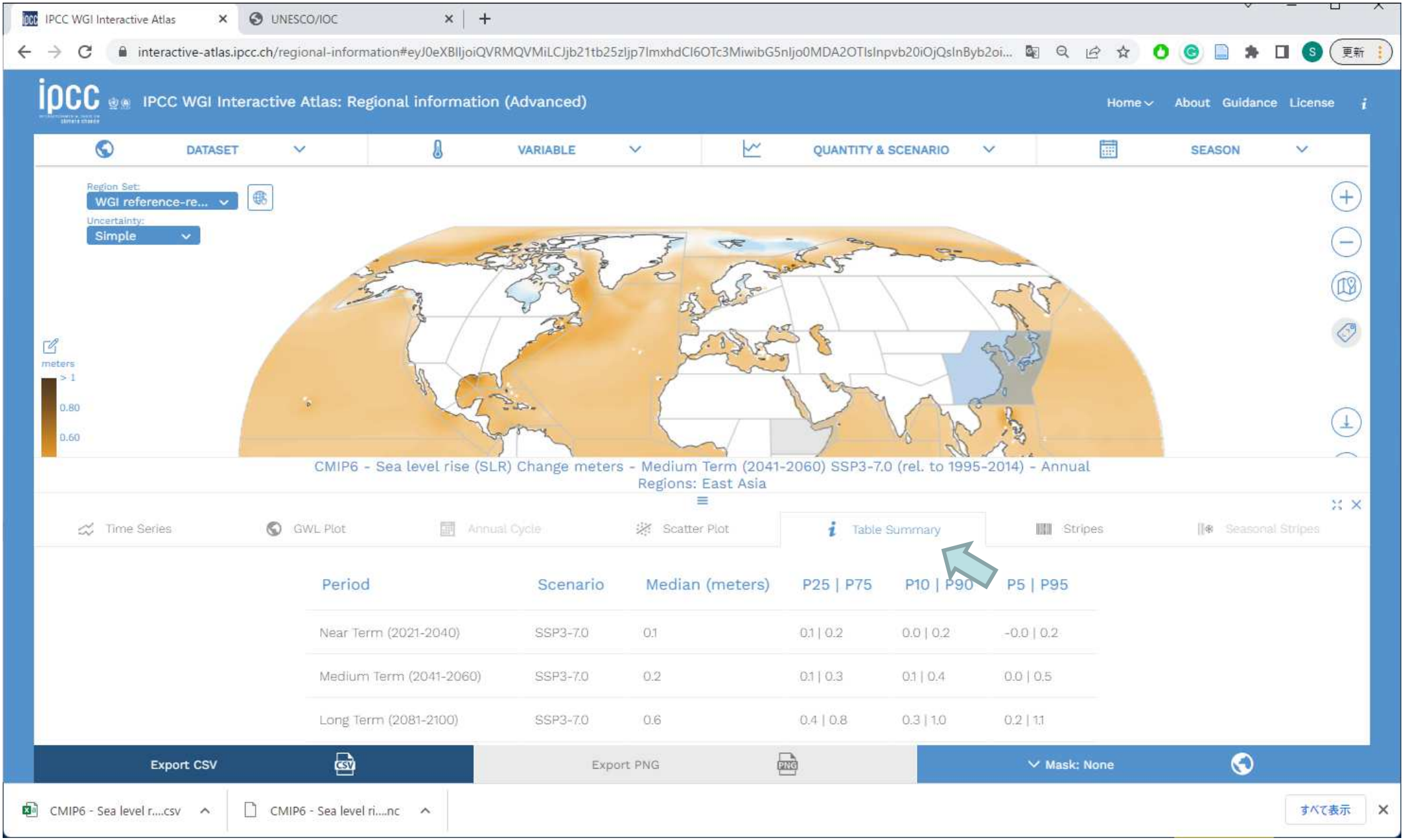
0.60
CMIP6 - Sea level rise (SLR) Change meters - Medium Term (2041-2060) SSP3-7.0 (rel. to 1995-2014) - Annual
Regions: East Asia
Time Series
GWL Plot
Annual Cycle
Scatter Plot
Table Summary
Stripes
Seasonal Stripes
Sea level rise (SLR) (Change, r
1.5
1
0.5
0
-0.5
2020
2028
2036
2044
2052
2061
2069
2077
2085
2093
2100
Year
Dotted line: Model
Solid line: P50 (Median)
Gray shading: Selected period
Light / dark area: Spread P10-P90 / P25-75
Export PDF
Export PNG
Mask: None
CMIP6 - Sea level ri....nc
すべて表示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Uncertainty:
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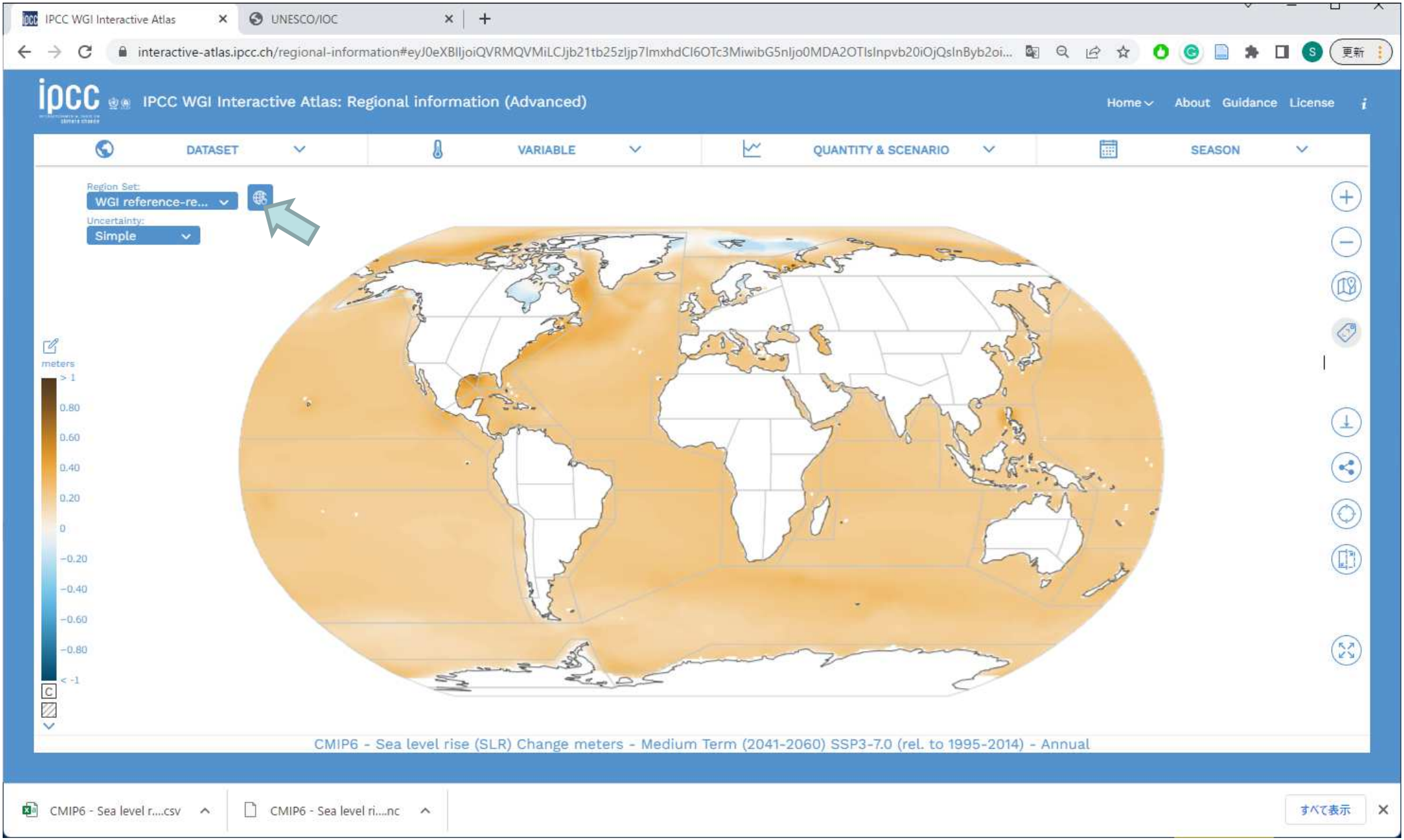
meters
> 1
0.80
0.60
CMIP6 - Sea level rise (SLR) Change meters - Medium Term (2041-2060) SSP3-7.0 (rel. to 1995-2014) - Annual
Regions: East Asia
Time Series
GWL Plot
Annual Cycle
Scatter Plot
Table Summary
Stripes
Seasonal Stripes
Period
Scenario
Median (meters)
P25 | P75
P10 | P90
P5 | P95
Near Term (2021-2040)
SSP3-7.0
0.1
0.1 | 0.2
0.0 | 0.2
-0.0 | 0.2
Medium Term (2041-2060)
SSP3-7.0
0.2
0.1 | 0.3
0.1 | 0.4
0.0 | 0.5
Long Term (2081-2100)
SSP3-7.0
0.6
0.4 | 0.8
0.3 | 1.0
0.2 | 1.1
Export CSV
Export PNG
Mask: None
CMIP6 - Sea level r....csv
CMIP6 - Sea level ri....nc
すべて表示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Uncertainty:
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meters
> 1
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−0.40
−0.60
−0.80
< -1
C
CMIP6 - Sea level rise (SLR) Change meters - Medium Term (2041-2060) SSP3-7.0 (rel. to 1995-2014) - Annual
CMIP6 - Sea level r....csv
CMIP6 - Sea level ri....nc
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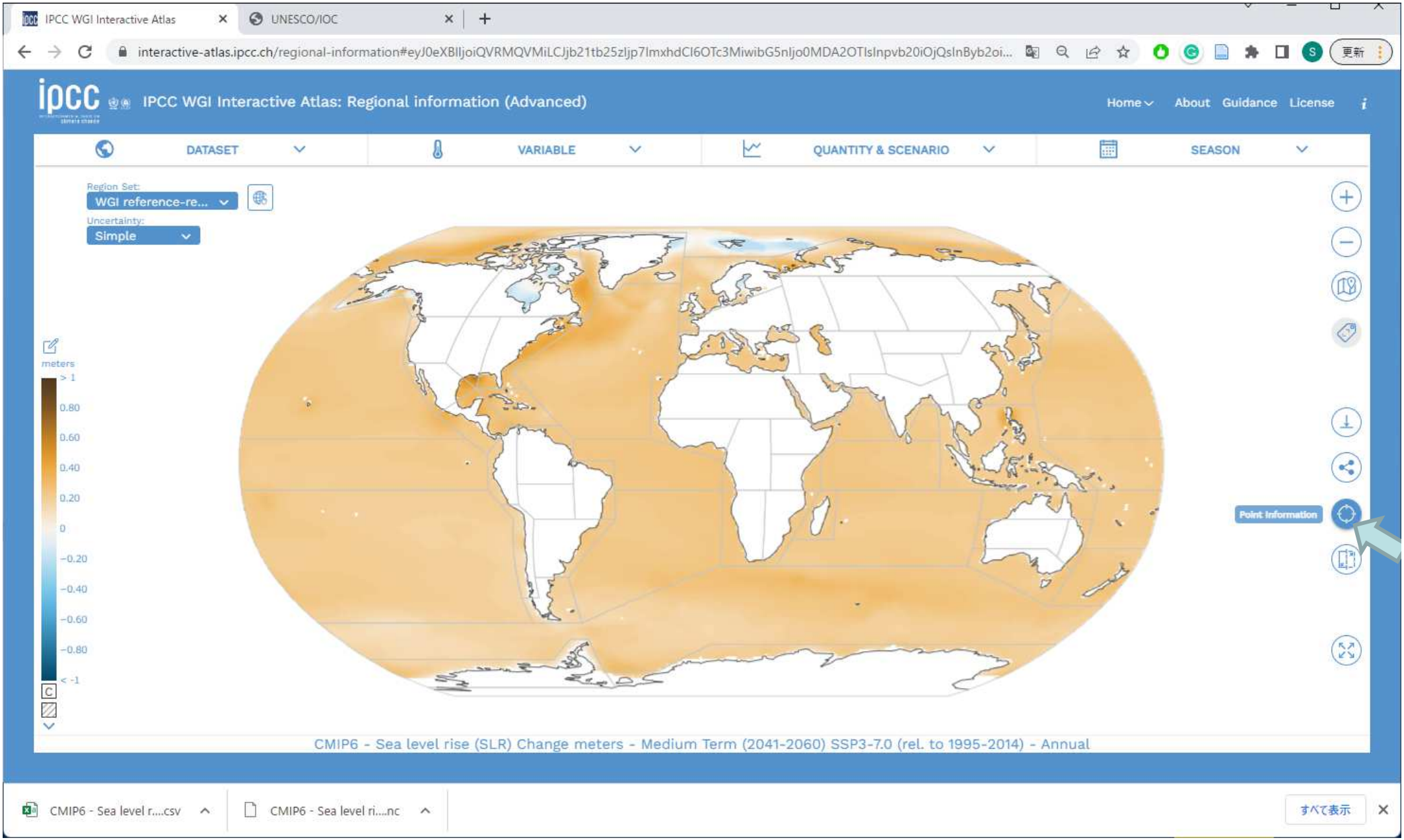
Point information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−0.20
−0.40
−0.60
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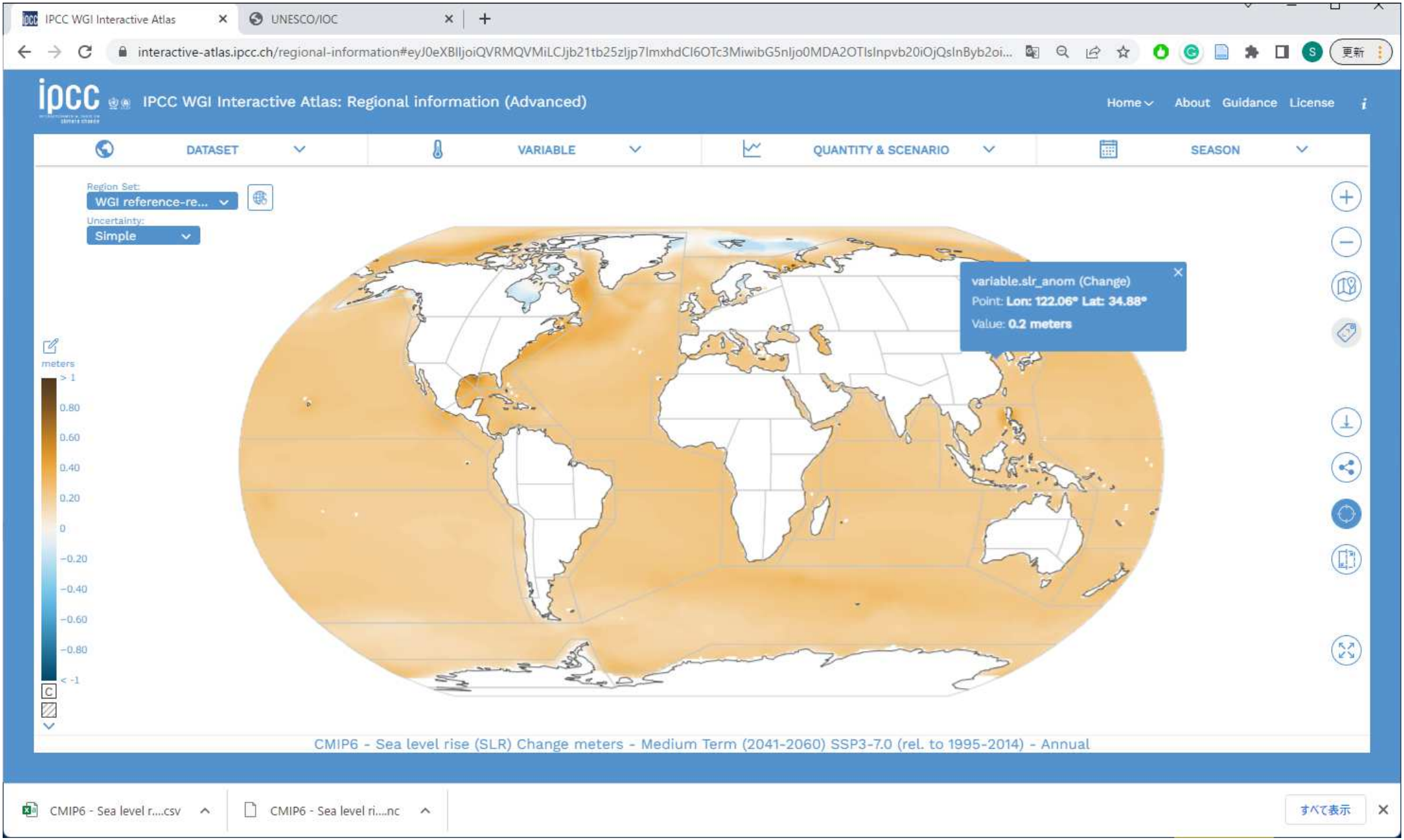
< -1
C
Point Information
CMIP6 - Sea level rise (SLR) Change meters - Medium Term (2041-2060) SSP3-7.0 (rel. to 1995-2014) - Annual
CMIP6 - Sea level r....csv
CMIP6 - Sea level ri....nc
すべて表示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Region Set:
WGI reference-re...
Uncertainty:
Simple
variable.slr_anom (Change)
Point: Lon: 122.06° Lat: 34.88°
Value: 0.2 meters
meters
> 1
0.80
0.60
0.40
0.20
0
−0.20
−0.40
−0.60
−0.80
< -1
C
CMIP6 - Sea level rise (SLR) Change meters - Medium Term (2041-2060) SSP3-7.0 (rel. to 1995-2014) - Annual
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CMIP6 - Sea level ri....nc
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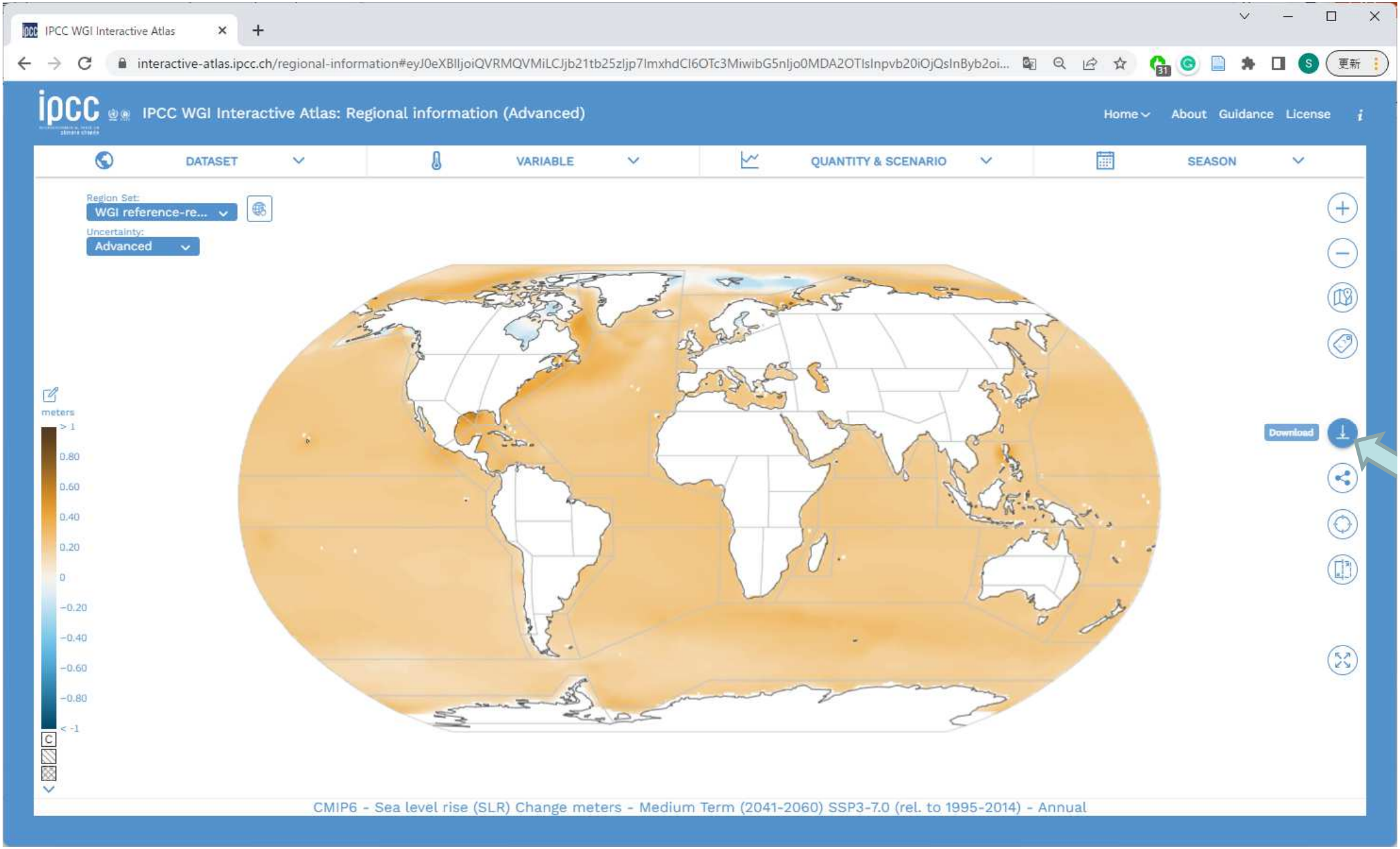
Downloading Map Data and Plotting by Yourself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SEASON
Region Set:
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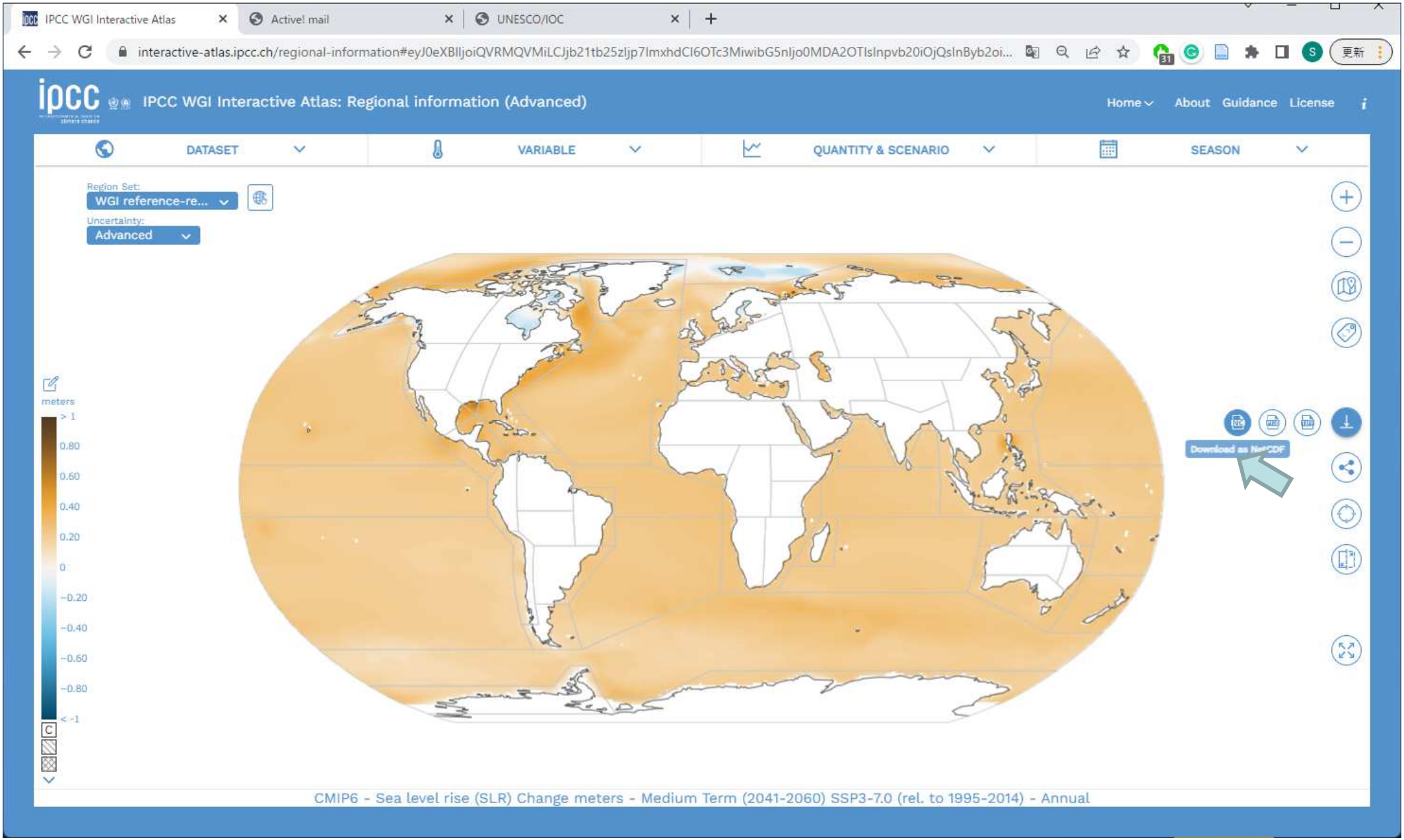
Uncertainty:
Advanced
meters
> 1
0.80
0.60
0.40
0.20
0
−0.20
−0.40
−0.60
−0.80
< -1
Download
CMIP6 - Sea level rise (SLR) Change meters - Medium Term (2041-2060) SSP3-7.0 (rel. to 1995-2014) - Annual



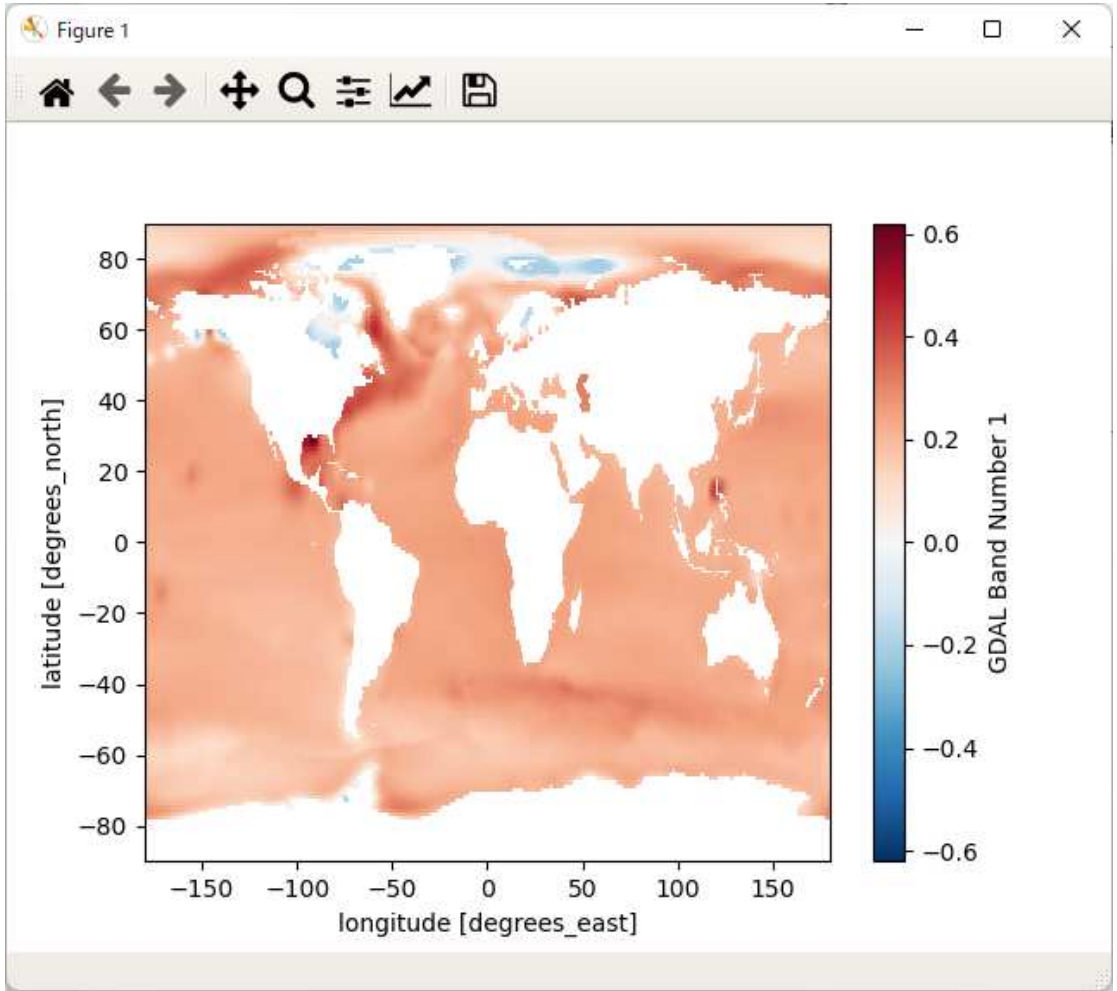
The file size is very small, just 133KB.

```
import xarray as xr

xs=xr.open_dataset('CMIP6 - Sea level rise (SLR) Change meters - Medium Term
(2041-2060) SSP3-7.0 (rel. to 1995-2014) - Annual).nc') #open file for xarray
xa=xs['total']                                  # generate xarray dataarray
print(xa.sel(lat=34.5,lon=122.5))               # print value at 34.5N, 122.5E
xa.plot()                                       # plot a map
plt.show()                                      # show figure
```

```
<xarray.DataArray 'total' ()>
array(0.221449, dtype=float32)
Coordinates:
    lat      float64 34.5
    lon      float64 122.5
Attributes:
    long_name:      GDAL Band Number 1
    grid_mapping:   crs
```

This value means the total sea-level rise around Qingdao will be 22.2 cm in 2041-2060 period relative to 1995-2014 under SSP3-7.0 scenario.



Pros and Cons of the Interactive Atlas

- IPCC Interactive Atlas is great to get CMIP6 information, but it has its own limitation.
- In particular, near the “coast” remapping on the same grid can cause a problem, because of differences of coastal topography between different models.
- If you want to know accurate information, you need to work with CMIP6 data of respective models.

Morning Practice

- Use IPCC interactive Atlas and try to summarize future change of a variable and region of your interest with respect to middle (2041-2060) and long terms (2081-2100) and low and low (SSP 1-2.6) and high (SSP 5-8.5) emission scenarios.