x4c: Xarray for efficient CESM postprocessing, analysis, and visualization

Motivation, Design, and Features

Feng Zhu
Paleoclimate Software Engineer II
PPC, CGD, NSF NCAR

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Self-Introduction

MS in AOS
(2016; UW-Madison)

PhD in Earth Sciences
(2021; USC)

Research Interests:

- Paleoclimate Modeling, Data Assimilation, and Machine Learning (led two NSF-funded proposals on ML-enhanced Earth system sciences)
- Scientific Programming for facilitating Scientific Discovery

Motivation

A typical workflow for a CESM-based research:

CESM Modeling

Postprocessing
(History to Timeseries)

- Analysis
- Visualization

CESM_postprocessing

- Out of maintenance
- Not very flexible to use and debug
- Small issues (e.g., timestamps, metadata/variable handling)

xarray

Motivation

Xarray is a great tool that has provided powerful, fundamental blocks for scientific analysis and visualization tasks. However, it still requires nontrivial programming skills and efforts.

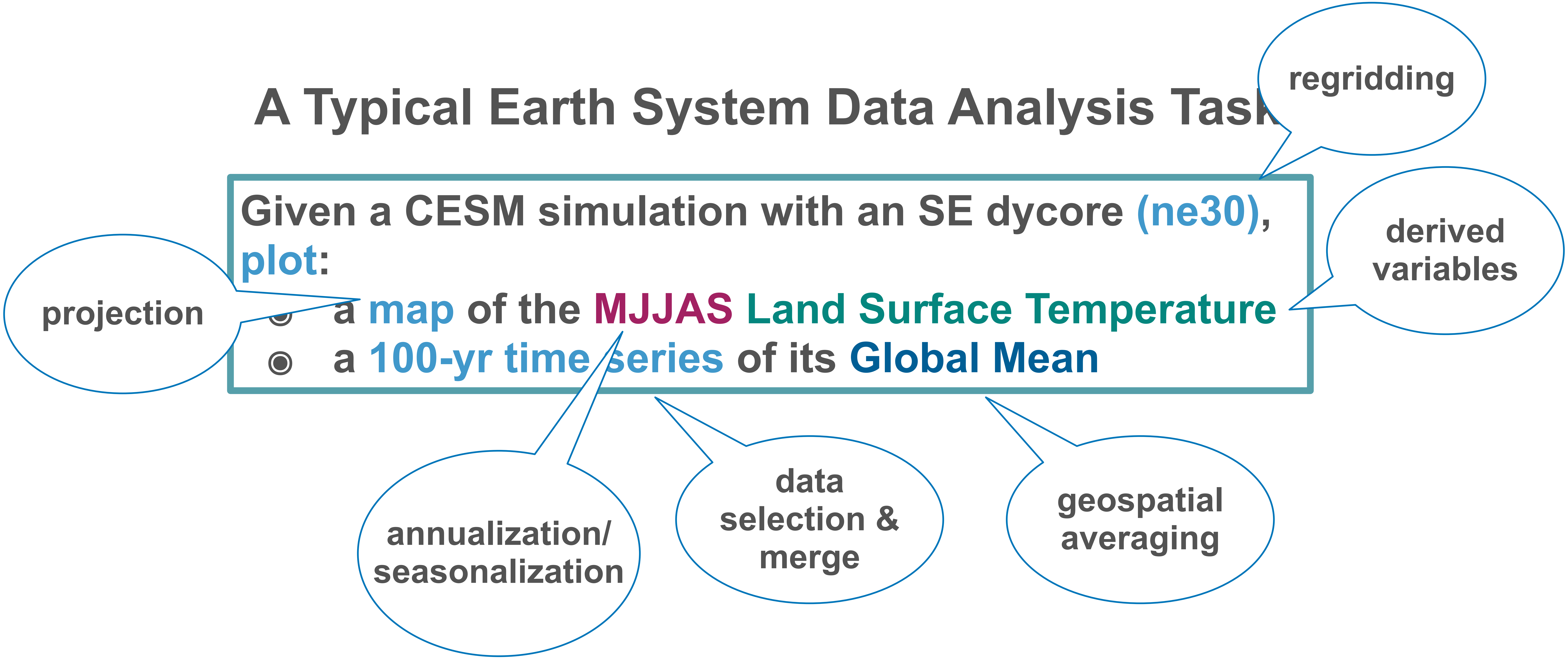
an **interruption** to the scientific mind flow

lengthy & **error-prone**

what scientists really need is a tool that works, but with minimal programming skills and efforts, and thus minimal interruption to the mind flow, so as to better focus on scientific thinking

Motivation

A Typical Earth System Data Analysis Task



Given a CESM simulation with an SE dycore (ne30), plot:

- **a map of the MJJAS Land Surface Temperature**
- **a 100-yr time series of its Global Mean**

Motivation

x4c

— Xarray for CESM —

x4c is an Xarray extension that features intuitive, flexible, concise, and easy-to-use workflows for CESM postprocessing, analysis, and visualization.

x4c aims to liberate scientists from technical details and facilitate scientific thinking.

Motivation

A typical workflow for a CESM-based research:

CESM Modeling

⇩

Postprocessing
(History to Timeseries)

⇩

- **Analysis**
- **Visualization**

CESM_postprocessing

xarray

}

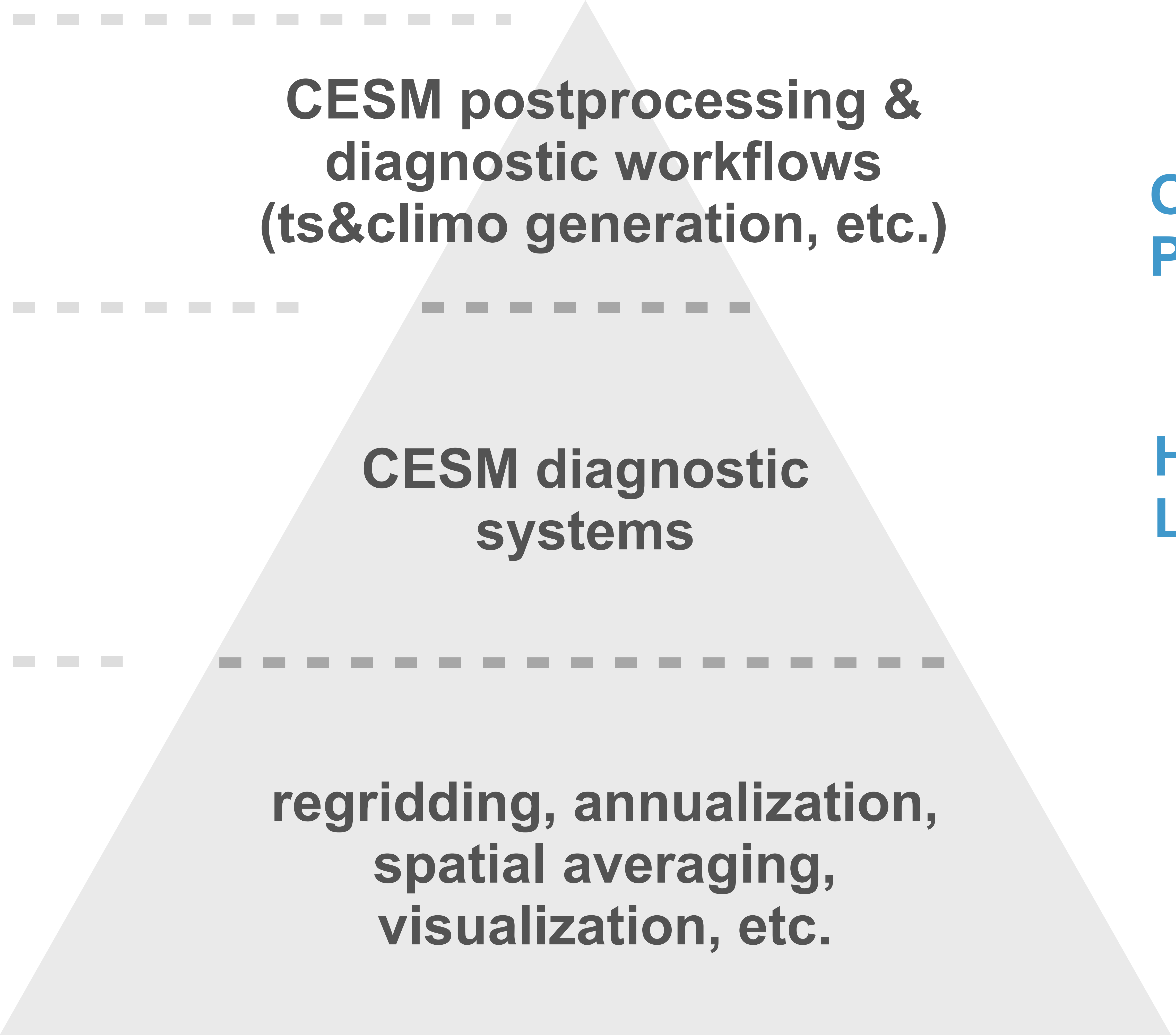
NCAR CGD

CGD-SIF Award on CESM Postprocessing (under the guidance of Michael Levy & Brian Dobins)

x4c

— Xarray for CESM —

Design



High-level Workflows (History, Timeseries)

CESM postprocessing & diagnostic workflows (ts&climo generation, etc.)

Object-Orient Programming (OOP)

Advanced Features (Timeseries)

CESM diagnostic systems

High Cohesion, Low Coupling

Fundamental Features (Xarray Extension)

regridding, annualization, spatial averaging, visualization, etc.

Intuitive, Concise, Flexible

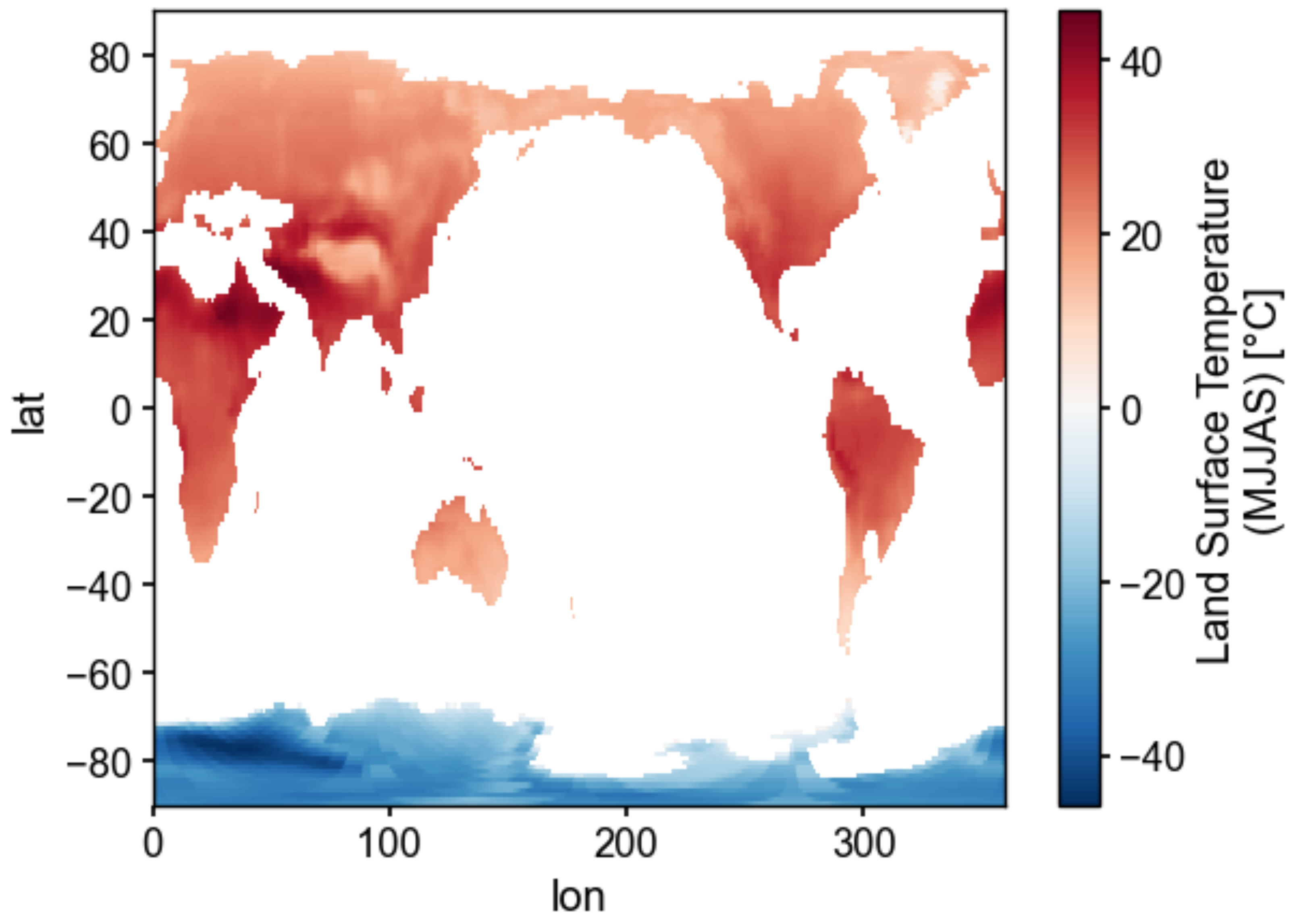
A Bottom-up Design

▣ Fundamental Features (Xarray Extension)

Given a CESM simulation with an SE dycore (ne30), plot:

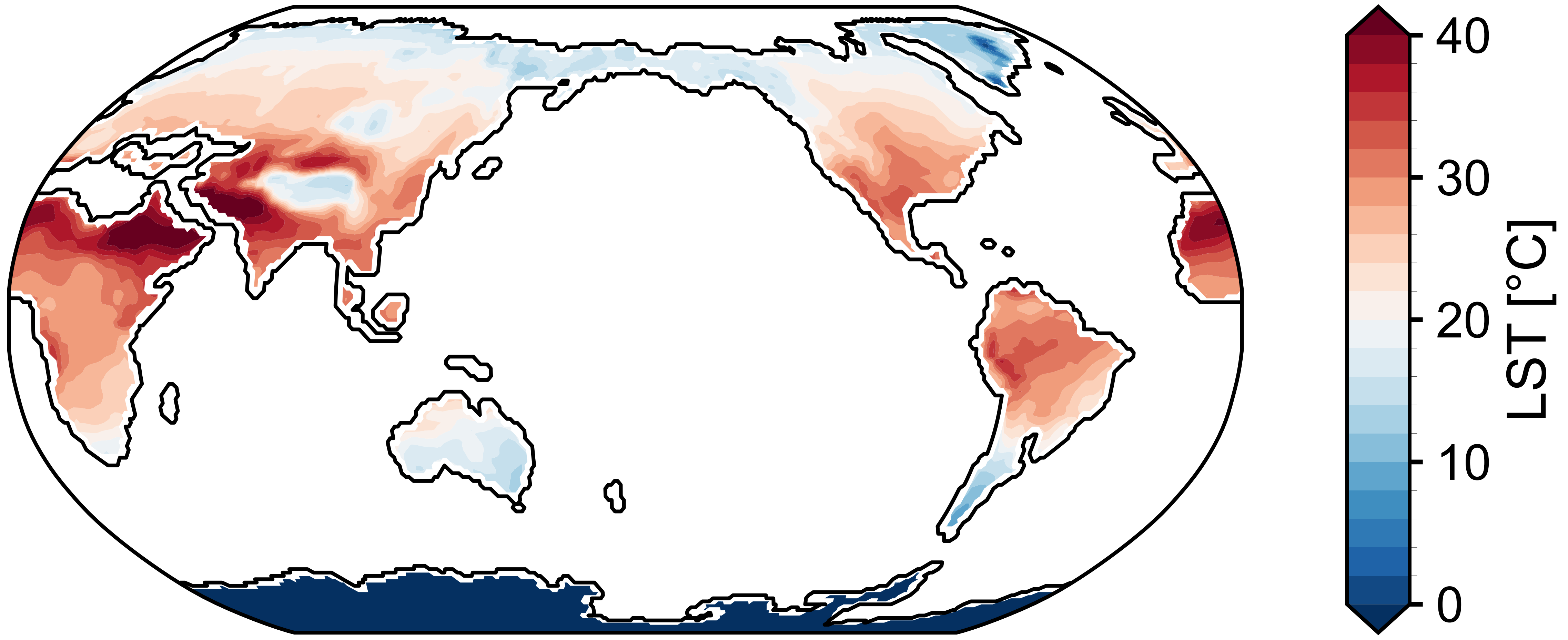
- a map of the MJJAS Land Surface Temperature

da.plot()



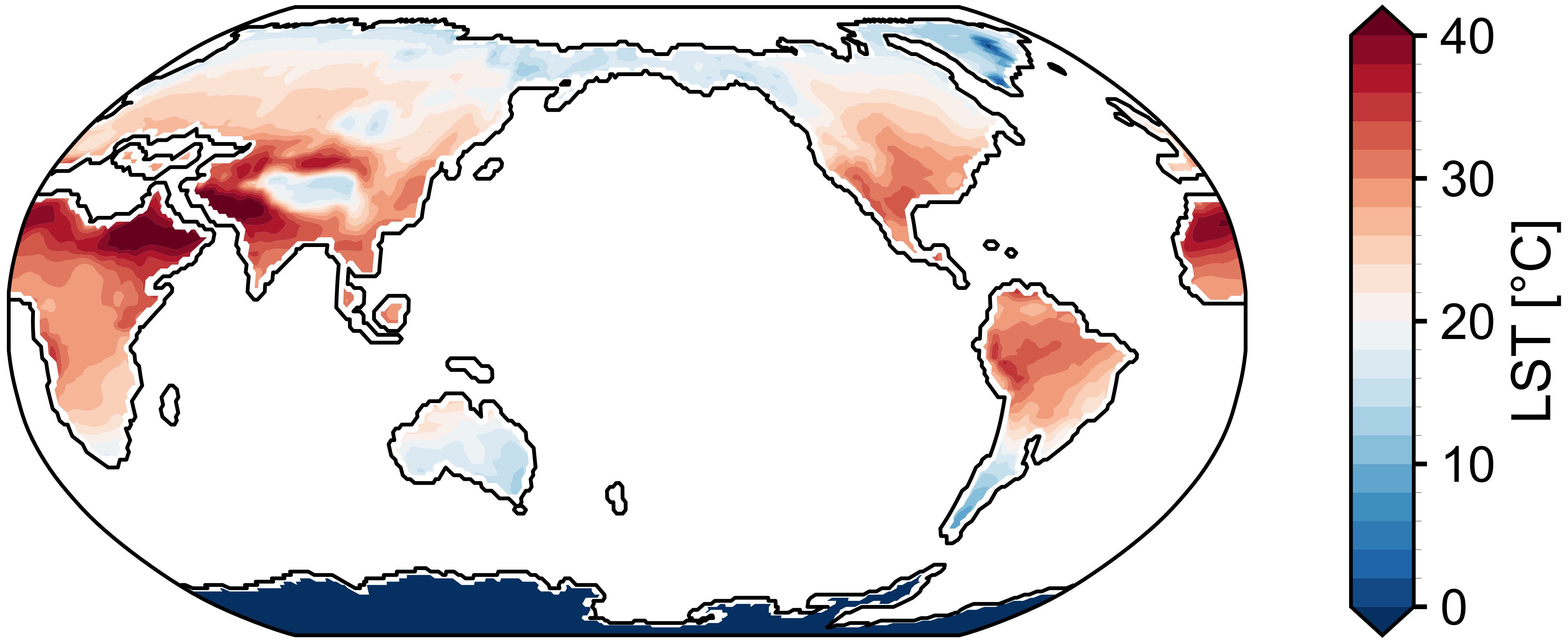
da.x.plot()

Land Surface Temperature (MJJAS)



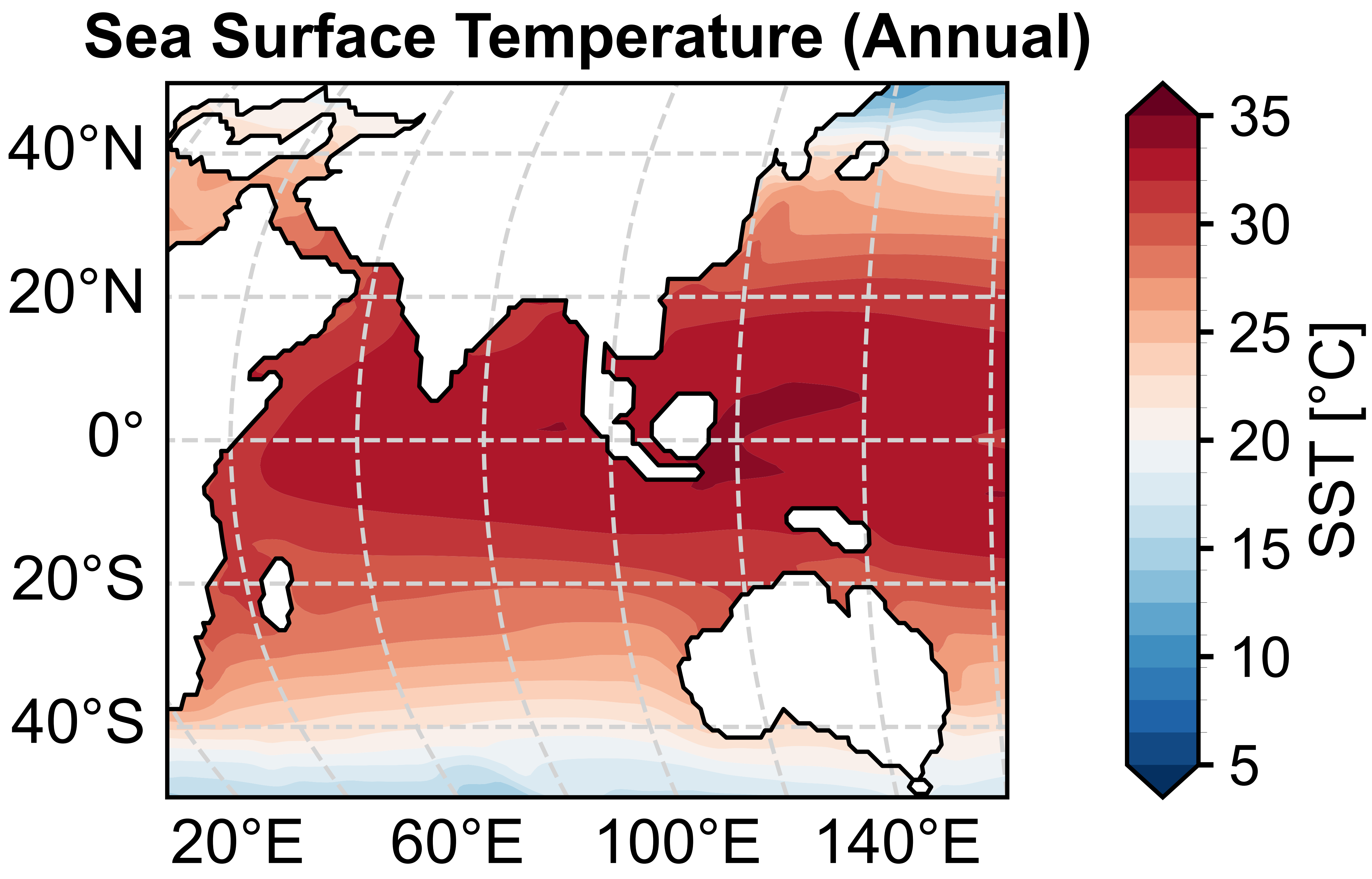
▣ Fundamental Features (Xarray Extension) Visualization

da.x.plot()


Land Surface Temperature (MJJAS)

```
x4c.set_style('journal_spines', font_scale=1.2)

fig, ax = da.x.plot()

x4c.showfig(fig)
x4c.savefig(fig, './figs/LST_MJJAS.pdf')
```

Fundamental Features (Xarray Extension) Visualization


Sea Surface Temperature (Annual)

```
x4c.set_style('journal_spines', font_scale=1.2)

fig, ax = da.x.plot(
    levels=np.linspace(5, 35, 21),
    cbar_kwargs={'ticks': np.linspace(5, 35, 7)},
    add_gridlines=True,
    latlon_range=(-50, 50, 30, 160),
)

x4c.showfig(fig)
x4c.savefig(fig, './figs/SST_ann_regional.pdf')
```

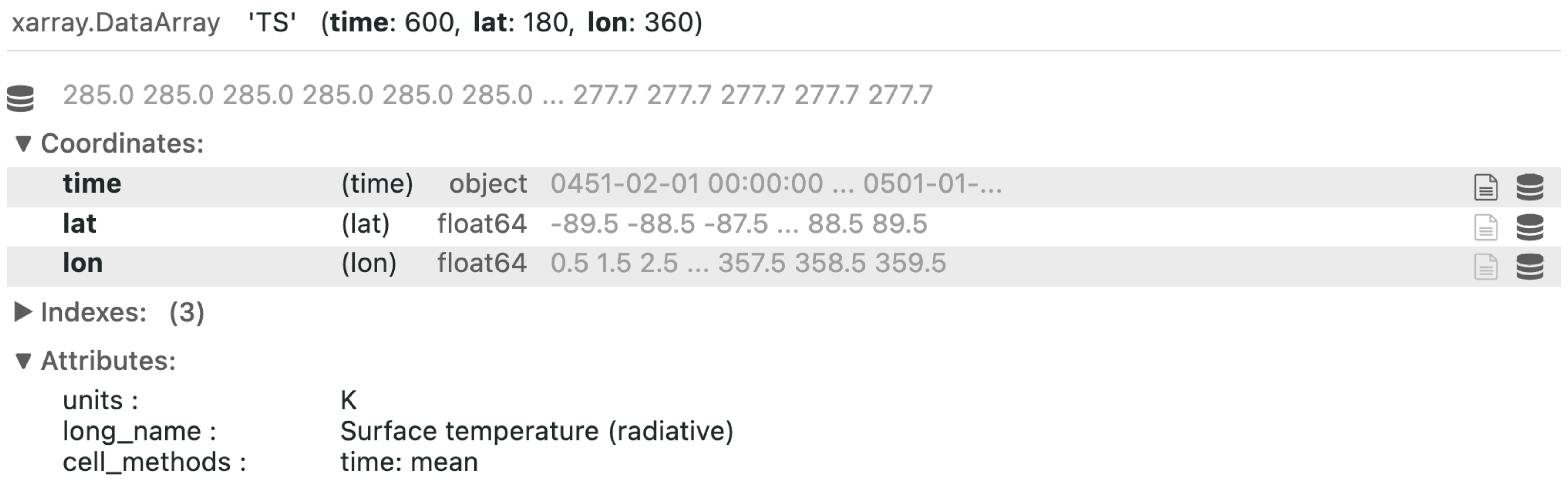
Fundamental Features (Xarray Extension) Regridding

ds.x.regrid([dlon=1, dlat=1, weight_file=...])

- **dlon**: the longitude spacing
- **dlat**: the latitude spacing
- **weight_file**: the path to a user-provided ESMF weighting file for other regridding cases

Leveraging xESMF
- atm: ne16/30/120np4/pg3 to 1x1 / 2x2
- ocn: gXX to any regular grid

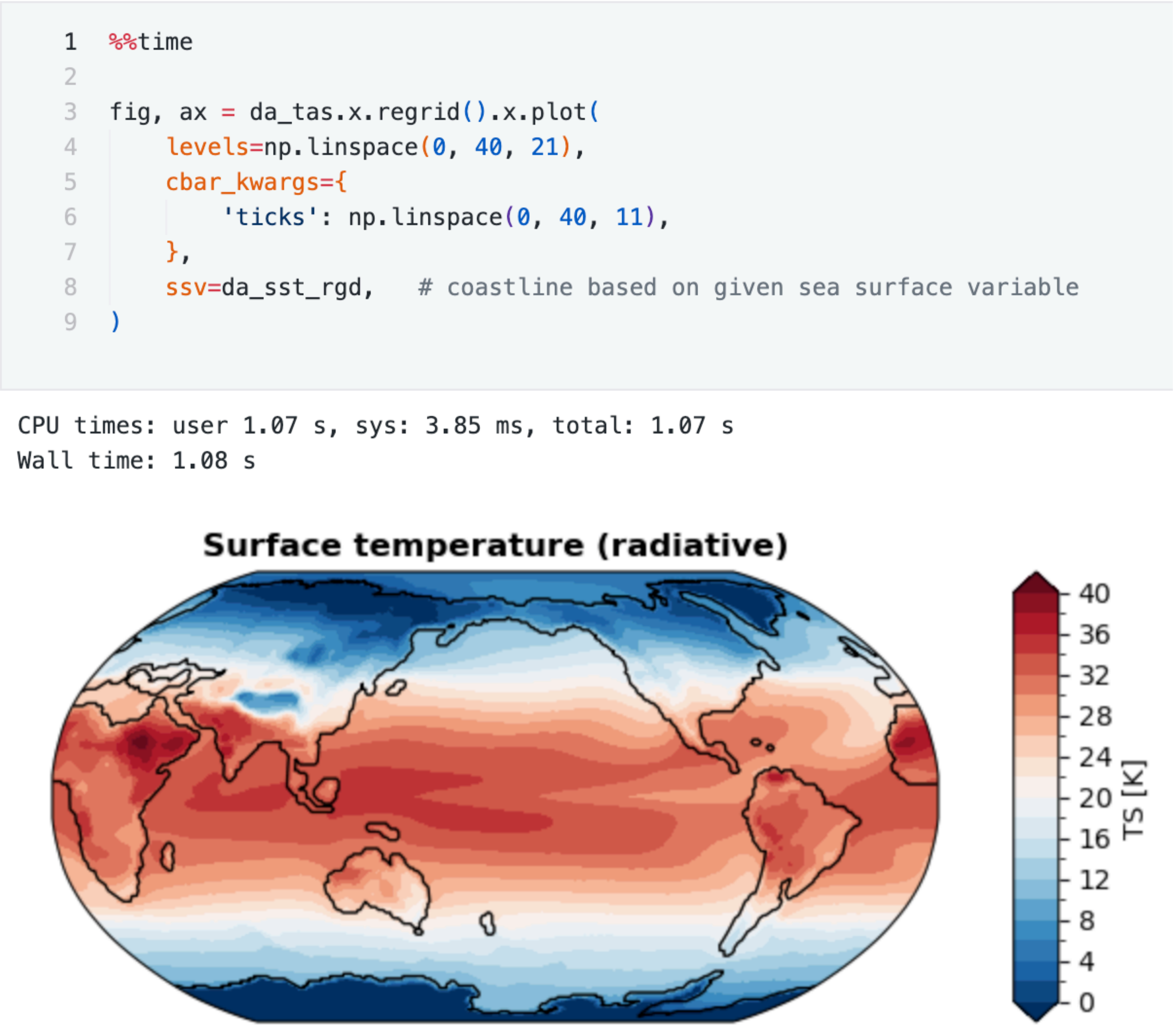
```
ds = x4c.open_dataset(fpath, comp='atm', grid='ne30np4')
ds_rgd = ds.x.regrid()
ds_rgd['TS']
```



```
xarray.DataArray   'TS'   (time: 600,  lat: 180,  lon: 360)

285.0 285.0 285.0 285.0 285.0 285.0 ... 277.7 277.7 277.7 277.7 277.7
▼ Coordinates:
    time          (time)    object   0451-02-01 00:00:00 ... 0501-01-...
    lat           (lat)     float64  -89.5 -88.5 -87.5 ... 88.5 89.5
    lon           (lon)     float64  0.5 1.5 2.5 ... 357.5 358.5 359.5
▶ Indexes:   (3)
▼ Attributes:
    units :           K
    long_name :       Surface temperature (radiative)
    cell_methods :    time: mean
```

Fundamental Features (Xarray Extension)

1. x4c w/ regridding



```
%%time

fig, ax = da_tas.x.regrid().x.plot(
    levels=np.linspace(0, 40, 21),
    cbar_kwargs={
        'ticks': np.linspace(0, 40, 11),
    },
    ssv=da_sst_rgd,    # coastline based on given sea surface variable
)
```

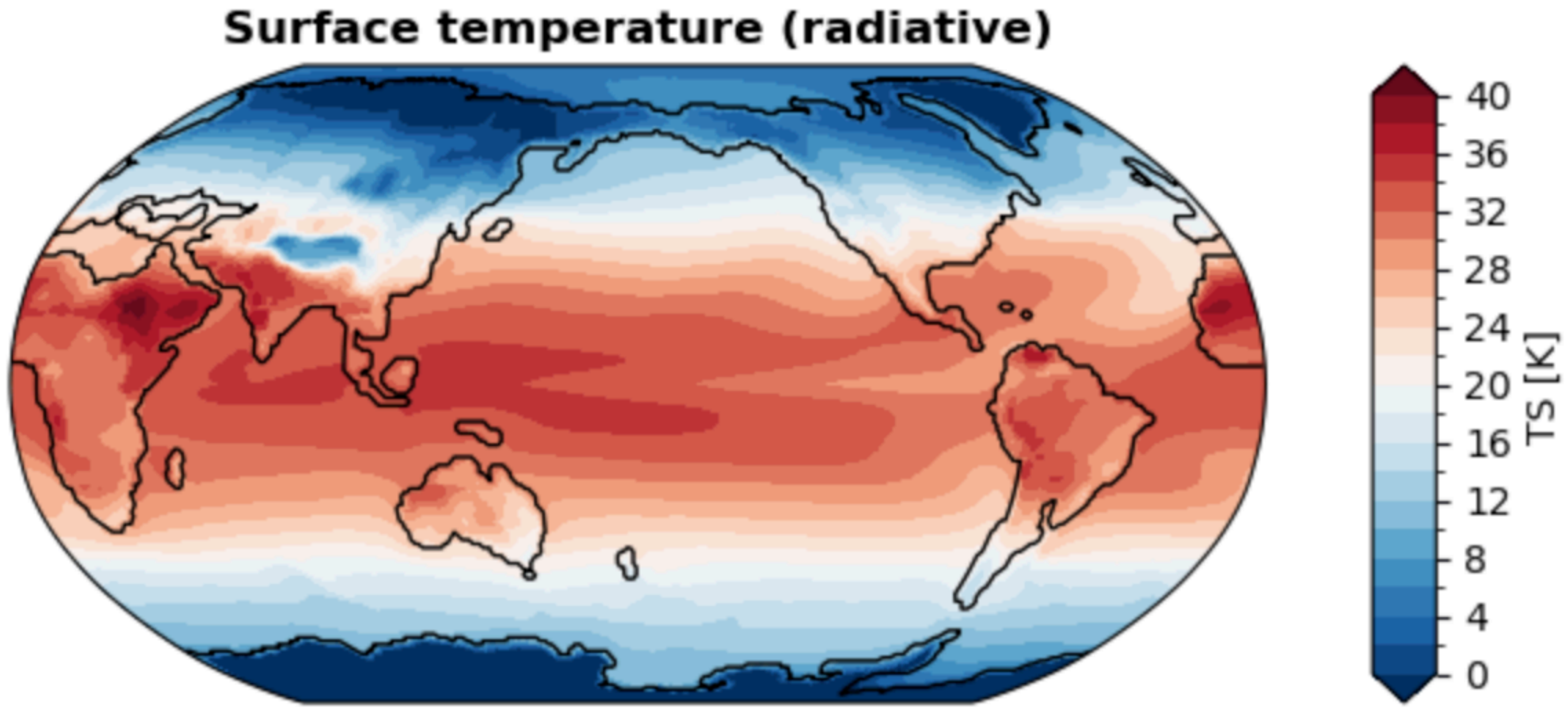
```
CPU times: user 1.07 s, sys: 3.85 ms, total: 1.07 s
Wall time: 1.08 s
```

Fundamental Features (Xarray Extension) Visualization (ne30)

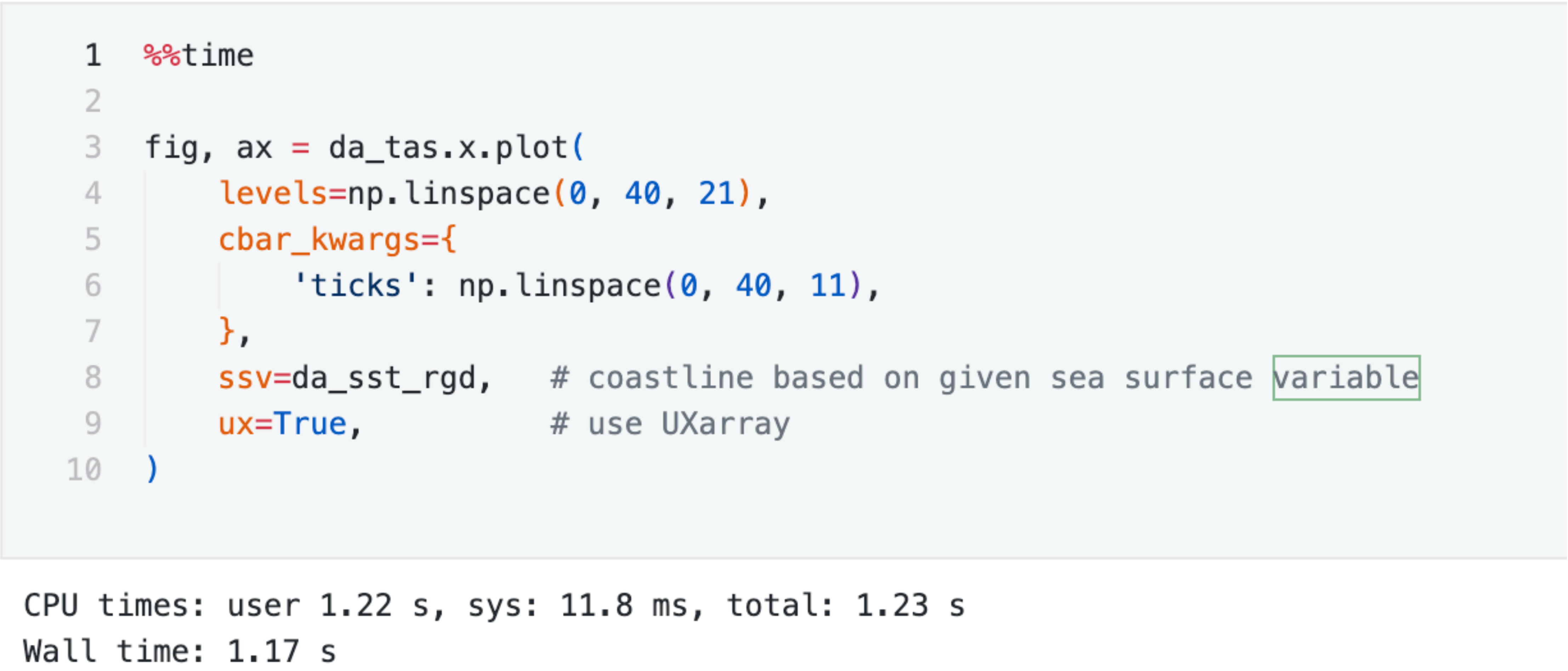
2.1 x4c w/o regridding

```
%%time
fig, ax = da_tas.x.plot(
    levels=np.linspace(0, 40, 21),
    cbar_kwargs={
        'ticks': np.linspace(0, 40, 11),
    },
    ssv=da_sst_rgd,   # coastline based on given sea surface variable
)
```

```
CPU times: user 287 ms, sys: 0 ns, total: 287 ms
Wall time: 286 ms
```

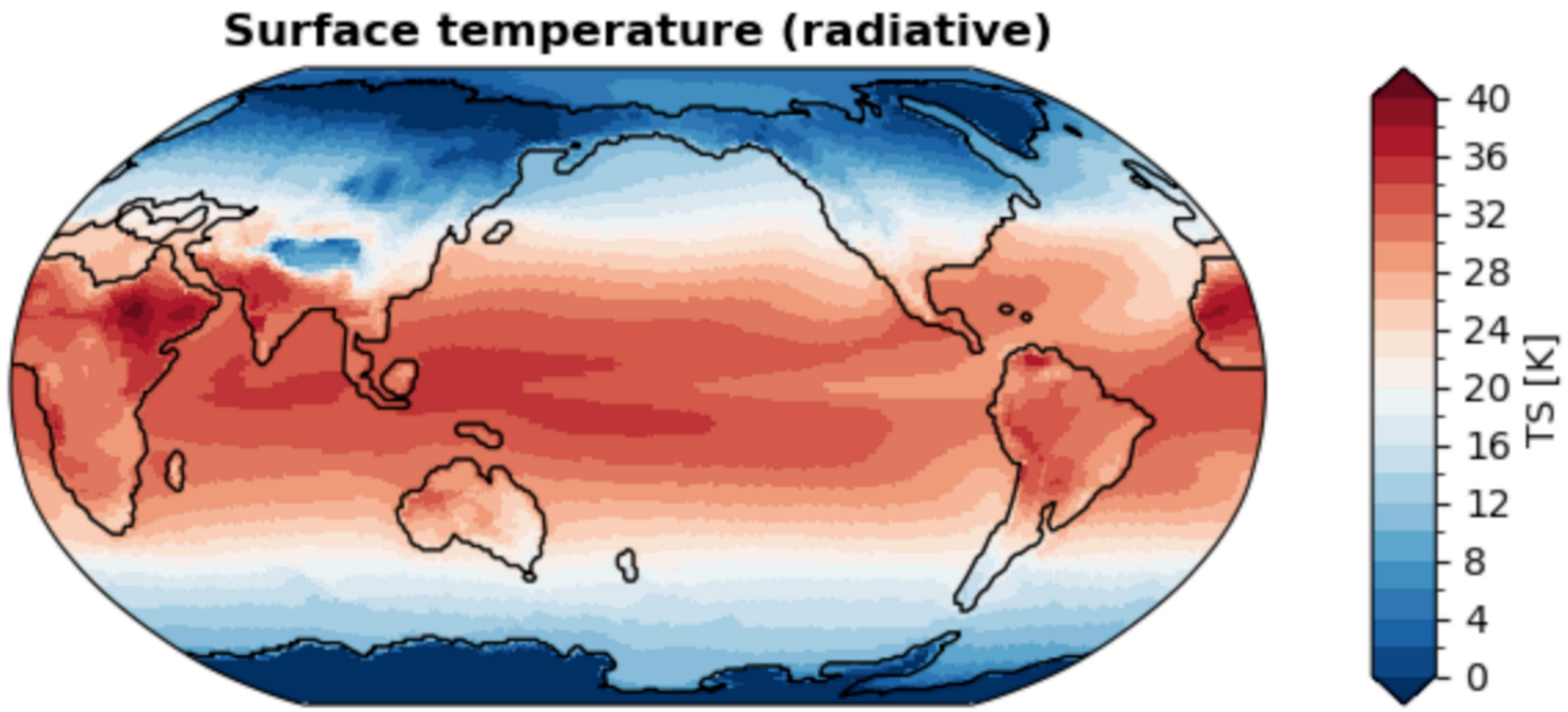


2.2 uxarray



```
%%time

fig, ax = da_tas.x.plot(
    levels=np.linspace(0, 40, 21),
    cbar_kwargs={
        'ticks': np.linspace(0, 40, 11),
    },
    ssv=da_sst_rgd,   # coastline based on given sea surface variable
    ux=True,          # use UXarray
)
```

```
CPU times: user 1.22 s, sys: 11.8 ms, total: 1.23 s
Wall time: 1.17 s
```

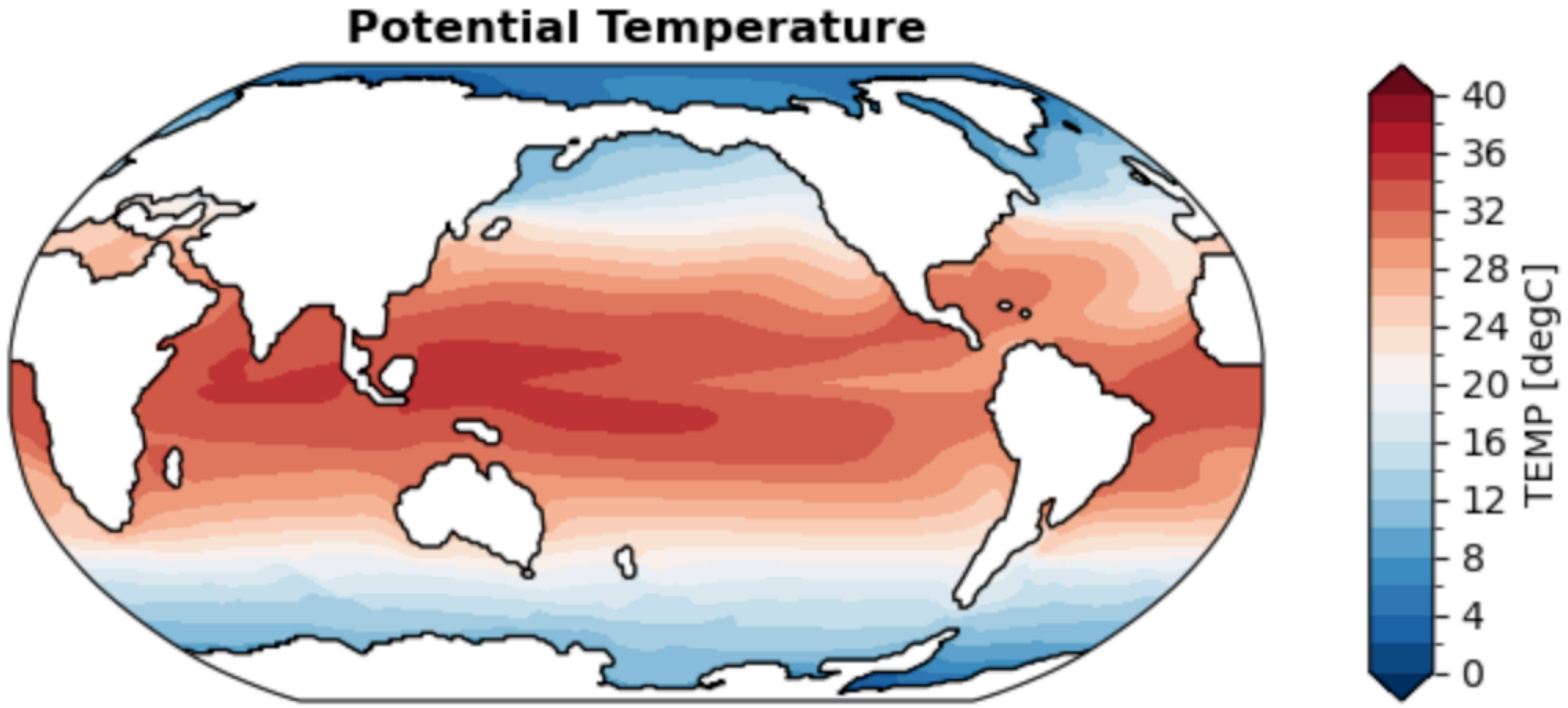


Fundamental Features (Xarray Extension) Visualization (g16)

1. x4c w/ regridding

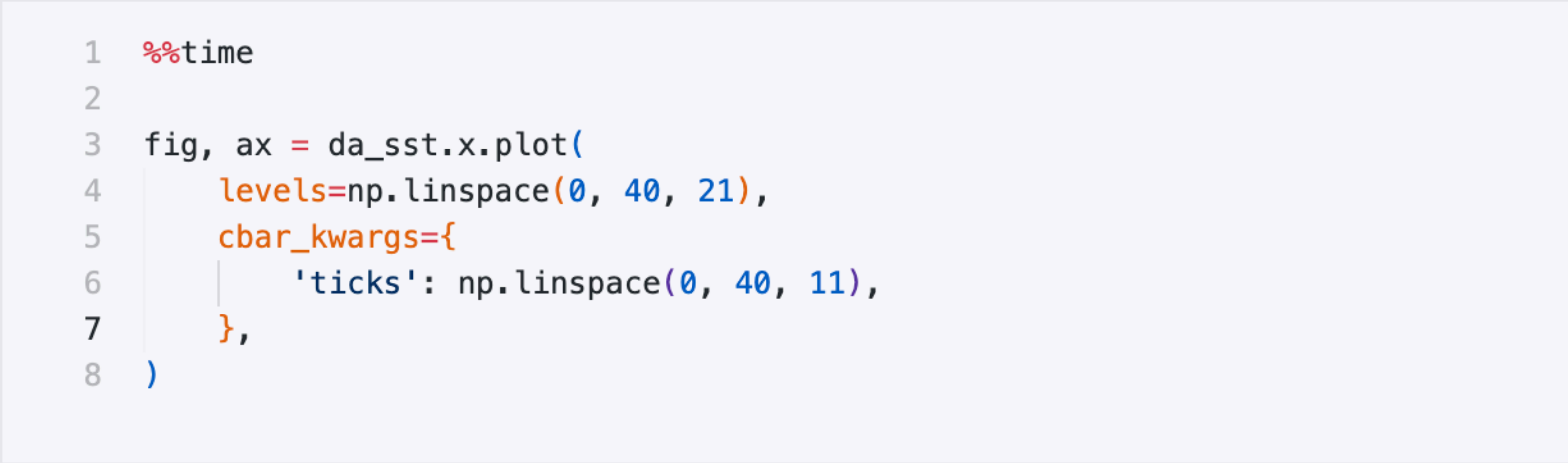
```
%%time

fig, ax = da_sst.x.regrid().x.plot(
    levels=np.linspace(0, 40, 21),
    cbar_kwargs={
        'ticks': np.linspace(0, 40, 11),
    },
)
```

```
CPU times: user 2.39 s, sys: 19.8 ms, total: 2.41 s
Wall time: 2.41 s
```



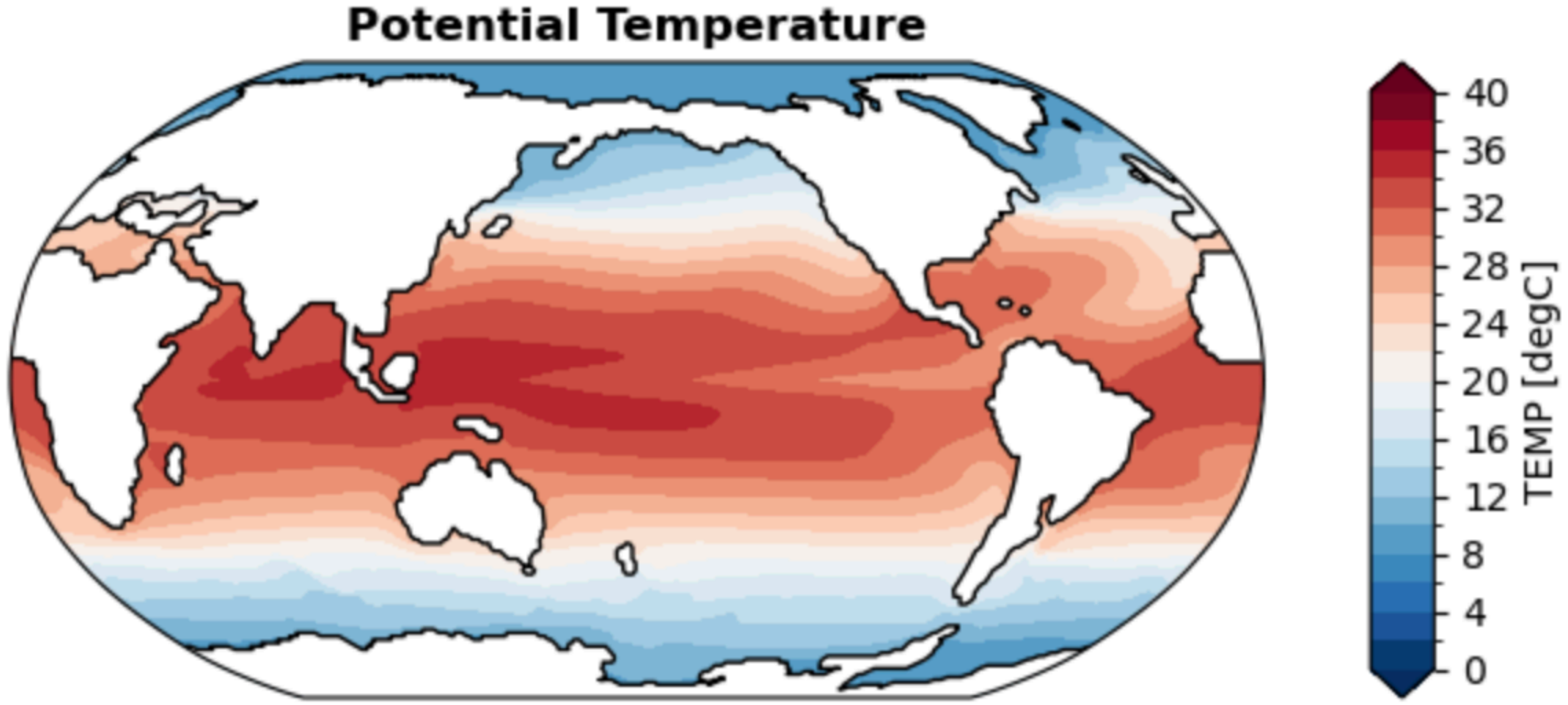
Potential Temperature

2. x4c w/o regridding



```
%%time

fig, ax = da_sst.x.plot(
    levels=np.linspace(0, 40, 21),
    cbar_kwargs={
        'ticks': np.linspace(0, 40, 11),
    },
)
```

```
CPU times: user 579 ms, sys: 183 µs, total: 579 ms
Wall time: 577 ms
```



Potential Temperature

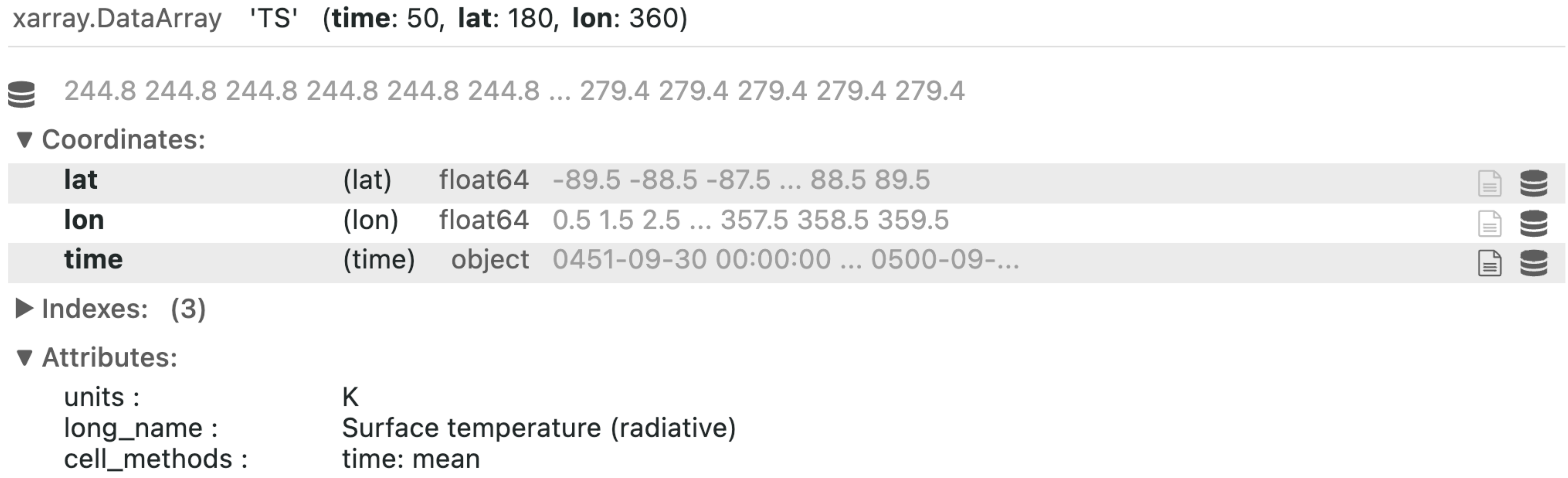
▣ Fundamental Features (Xarray Extension)

Annualization

ds.x.annualize([months=...])

- **months: a list of months over which to annualize; default: calendar year. Examples:**
  - **[6, 7, 8]: JJA seasonalization**
  - **[12, 1, 2]: DJF seasonalization**
  - **[3, 9, 10]: any arbitrary combination**

```
ds_ann = ds_rgd.x.annualize(months=[5, 6, 7, 8, 9], days_weighted=True)
ds_ann['TS']
```



```
xarray.DataArray   'TS'   (time: 50, lat: 180, lon: 360)

244.8 244.8 244.8 244.8 244.8 244.8 ... 279.4 279.4 279.4 279.4 279.4
▼ Coordinates:
    lat          (lat)    float64  -89.5 -88.5 -87.5 ... 88.5 89.5
    lon          (lon)    float64  0.5 1.5 2.5 ... 357.5 358.5 359.5
    time         (time)    object  0451-09-30 00:00:00 ... 0500-09-...
▶ Indexes:  (3)
▼ Attributes:
    units :            K
    long_name :        Surface temperature (radiative)
    cell_methods :     time: mean
```

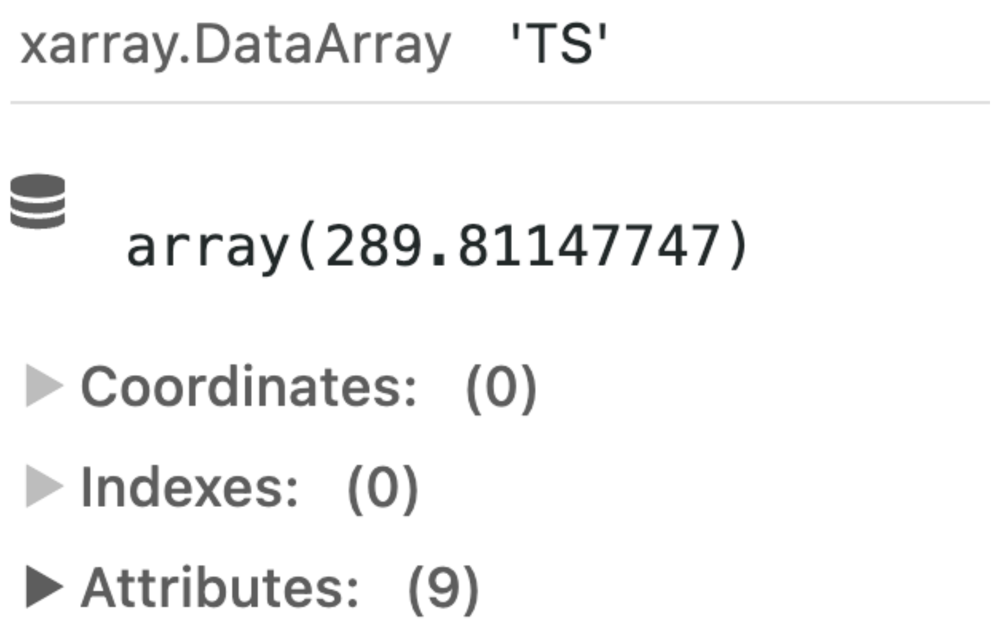
▣ Fundamental Features (Xarray Extension) Spatial Averaging

da.x.geo_mean([latlon_range=..., ind=...])

- latlon_range: a square range in [lat_min, lat_max, lon_min, lon_max] to perform an arbitrary geo-spatial averaging; default: global mean
- ind: a climate index; 'nino3.4', 'nino1+2', 'nino3', 'nino4', 'tpi', 'wp', 'dmi', 'iobw'

da.x.gm; da.x.nhm; da.x.shm; da.x.zm

```
da_gm = ds_ann['TS'].x.geo_mean()
da_gm
```



```
xarray.DataArray   'TS'

array(289.81147747)

▶ Coordinates:  (0)
▶ Indexes:  (0)
▶ Attributes:  (9)
```

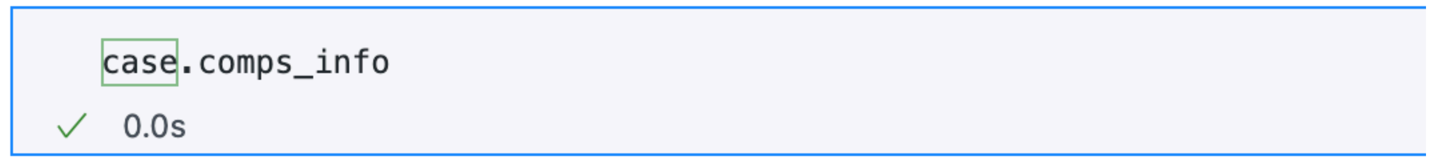
CESM Postprocessing (History)

A “Case” System

```
dirpath = '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104'
case = x4c.History(dirpath)
```

✓ 4.0s

```
>>> case.root_dir: /glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104
>>> case.casename: b.e30_beta02.BLT1850.ne30_t232.104
>>> case.paths["atm"]["cam.h0a"] created
>>> case.paths["atm"]["cam.h0i"] created
>>> case.paths["atm"]["cam.h2a"] created
>>> case.paths["atm"]["cam.h2i"] created
>>> case.paths["atm"]["cam.h3a"] created
>>> case.paths["atm"]["cam.h3i"] created
>>> case.paths["atm"]["cam.h4a"] created
>>> case.paths["atm"]["cam.h4i"] created
>>> case.paths["ocn"]["mom6.h.native"] created
>>> case.paths["ocn"]["mom6.h.rho2"] created
>>> case.paths["ocn"]["mom6.h.sfc"] created
>>> case.paths["ocn"]["mom6.h.z"] created
>>> case.paths["lnd"]["clm2.h0"] created
>>> case.paths["ice"]["cice.h"] created
>>> case.paths["rof"]["mosart.h0"] created
>>> case.vns["atm"]["cam.h0a"] created
>>> case.vns["atm"]["cam.h0i"] created
>>> case.vns["atm"]["cam.h2a"] created
>>> case.vns["atm"]["cam.h2i"] created
>>> case.vns["atm"]["cam.h3a"] created
>>> case.vns["atm"]["cam.h3i"] created
>>> case.vns["atm"]["cam.h4a"] created
>>> case.vns["atm"]["cam.h4i"] created
...
>>> case.vns["ocn"]["mom6.h.z"] created
>>> case.vns["lnd"]["clm2.h0"] created
>>> case.vns["ice"]["cice.h"] created
>>> case.vns["rof"]["mosart.h0"] created
```



```
case.comps_info
```

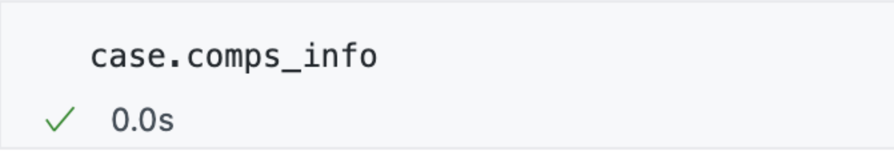
✓ 0.0s

```
{'atm': ['cam.h0a',
  'cam.h0i',
  'cam.h2a',
  'cam.h2i',
  'cam.h3a',
  'cam.h3i',
  'cam.h4a',
  'cam.h4i'],
 'ocn': ['mom6.h.native', 'mom6.h.rho2', 'mom6.h.sfc', 'mom6.h.z'],
 'lnd': ['clm2.h0'],
 'ice': ['cice.h'],
 'rof': ['mosart.h0']}
```

```
dirpath = '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104'
case = x4c.History(
    dirpath,
    comps=['atm', 'ocn'],
    comps_info={
        'atm': ['cam.h0a'],
        'ocn': ['mom6.h.sfc'],
    }
)
```

✓ 0.3s

```
>>> case.root_dir: /glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104
>>> case.casename: b.e30_beta02.BLT1850.ne30_t232.104
>>> case.paths["atm"]["cam.h0a"] created
>>> case.paths["ocn"]["mom6.h.sfc"] created
>>> case.vns["atm"]["cam.h0a"] created
>>> case.vns["ocn"]["mom6.h.sfc"] created
```



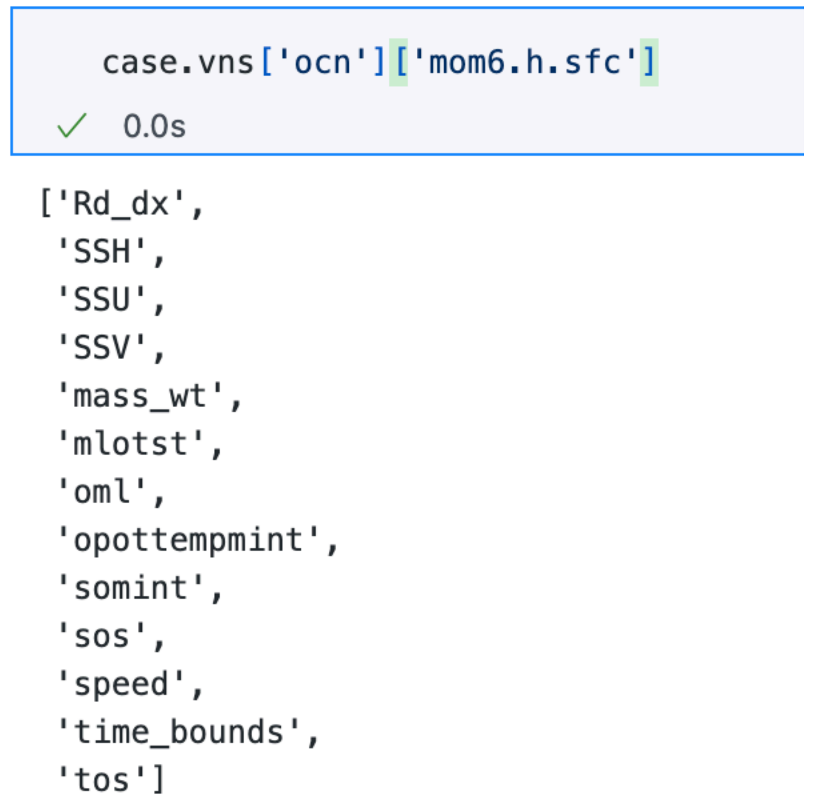
```
case.comps_info
```

✓ 0.0s

```
{'atm': ['cam.h0a'], 'ocn': ['mom6.h.sfc']}
```

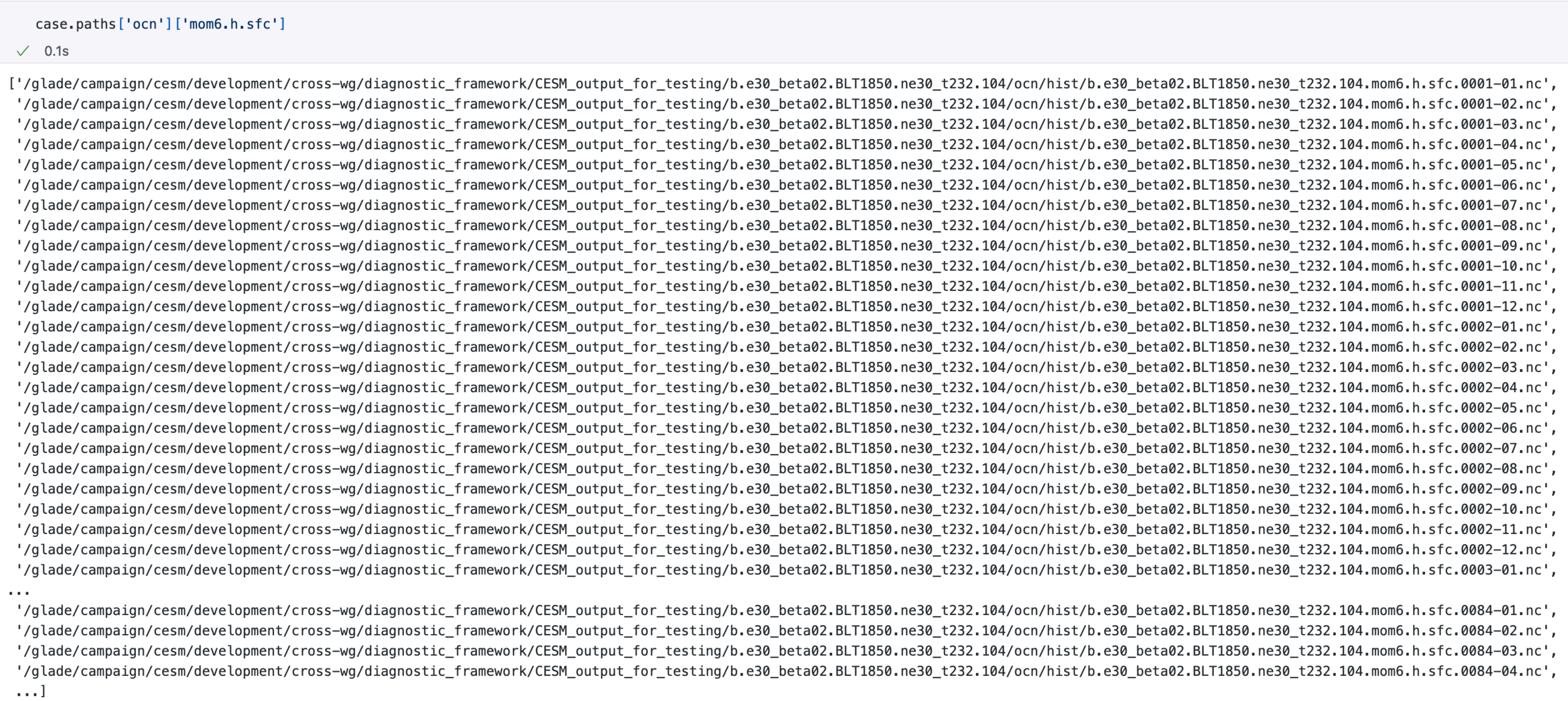
CESM Postprocessing (History)

A “Case” System



```
case.vns['ocn']['mom6.h.sfc']
✓ 0.0s
```

```
['Rd_dx',
 'SSH',
 'SSU',
 'SSV',
 'mass_wt',
 'mlotst',
 'oml',
 'opottempmint',
 'somint',
 'sos',
 'speed',
 'time_bounds',
 'tos']
```



```
case.paths['ocn']['mom6.h.sfc']
✓ 0.1s
```

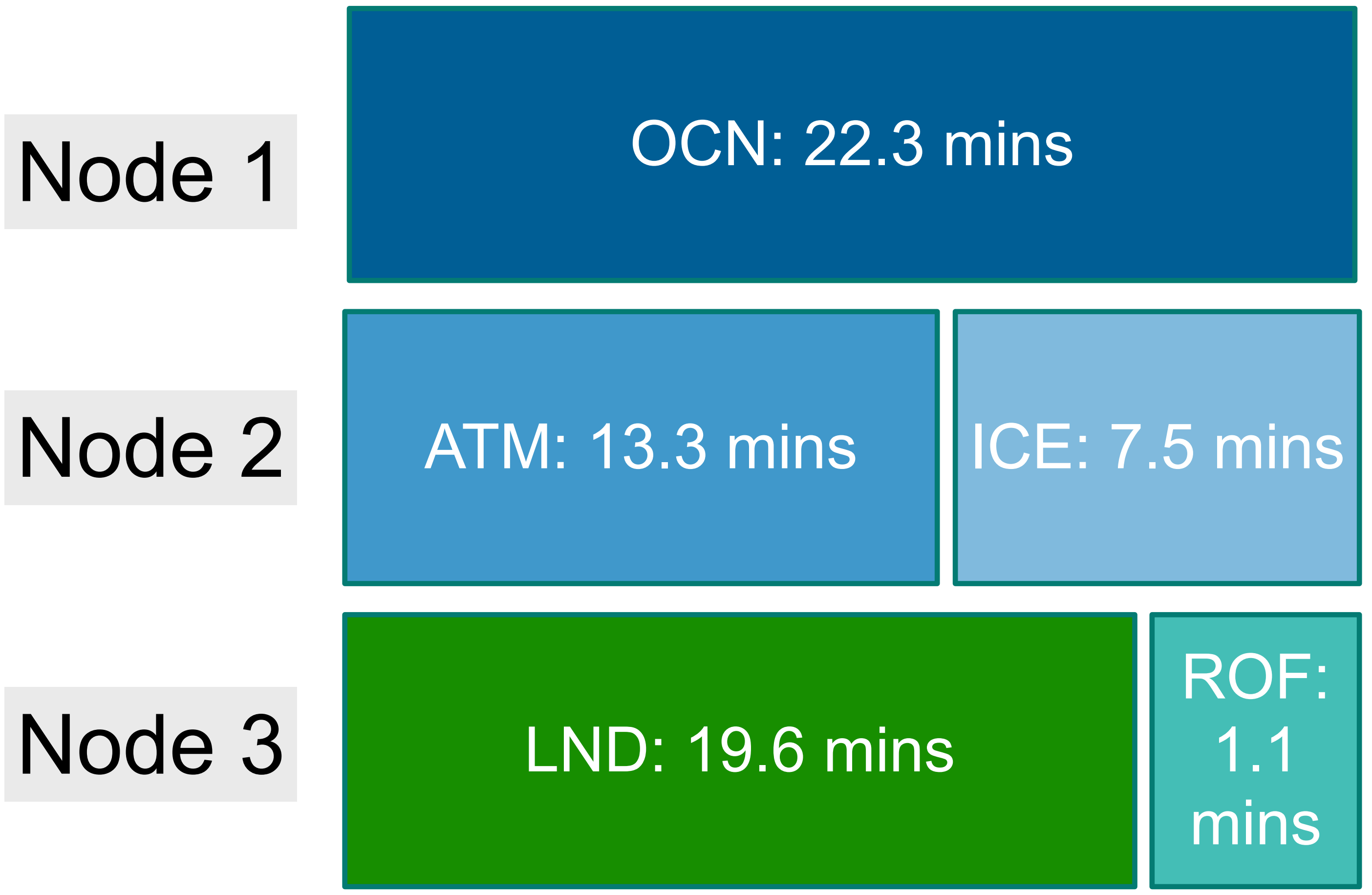
```
['/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0001-01.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0001-02.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0001-03.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0001-04.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0001-05.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0001-06.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0001-07.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0001-08.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0001-09.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0001-10.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0001-11.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0001-12.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0002-01.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0002-02.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0002-03.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0002-04.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0002-05.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0002-06.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0002-07.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0002-08.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0002-09.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0002-10.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0002-11.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0002-12.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0003-01.nc',
...
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0084-01.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0084-02.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0084-03.nc',
 '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/CESM_output_for_testing/b.e30_beta02.BLT1850.ne30_t232.104/ocn/hist/b.e30_beta02.BLT1850.ne30_t232.104.mom6.h.sfc.0084-04.nc',
 ...]
```

CESM Postprocessing (History)

History.gen_ts()

```
case.gen_ts(
    comps={'atm': ['PRECC']},
    output_dirpath=os.path.join('/glade/campaign/cgd/ppc/fengzhu/x4c/gen_ts/test', case.casename),
    staging_dirpath=os.path.join('/glade/derecho/scratch/fengzhu/x4c/gen_ts/test', case.casename),
    timespan=(1, 100),
    timestep=10,
    timestep_unit='year',
    nproc=4,
    overwrite=True,
)
```

```
● ➜  b.e30_beta02.BLT1850.ne30_t232.104 ll atm/proc/tseries/cam.h3a
  total 17G
  -rw-r--r-- 1 fengzhu ncar 1.7G Aug 21 11:07 b.e30_beta02.BLT1850.ne30_t232.104.cam.h3a.PRECC.0001010110800-0010122710800.nc
  -rw-r--r-- 1 fengzhu ncar 1.7G Aug 21 11:08 b.e30_beta02.BLT1850.ne30_t232.104.cam.h3a.PRECC.0011010110800-0020122710800.nc
  -rw-r--r-- 1 fengzhu ncar 1.7G Aug 21 11:10 b.e30_beta02.BLT1850.ne30_t232.104.cam.h3a.PRECC.0021010110800-0030122710800.nc
  -rw-r--r-- 1 fengzhu ncar 1.7G Aug 21 11:11 b.e30_beta02.BLT1850.ne30_t232.104.cam.h3a.PRECC.0031010110800-0040122710800.nc
  -rw-r--r-- 1 fengzhu ncar 1.7G Aug 21 11:12 b.e30_beta02.BLT1850.ne30_t232.104.cam.h3a.PRECC.0041010110800-0050122710800.nc
  -rw-r--r-- 1 fengzhu ncar 1.7G Aug 21 11:14 b.e30_beta02.BLT1850.ne30_t232.104.cam.h3a.PRECC.0051010110800-0060122710800.nc
  -rw-r--r-- 1 fengzhu ncar 1.7G Aug 21 11:15 b.e30_beta02.BLT1850.ne30_t232.104.cam.h3a.PRECC.0061010110800-0070122710800.nc
  -rw-r--r-- 1 fengzhu ncar 1.7G Aug 21 11:16 b.e30_beta02.BLT1850.ne30_t232.104.cam.h3a.PRECC.0071010110800-0080122710800.nc
  -rw-r--r-- 1 fengzhu ncar 1.7G Aug 21 11:17 b.e30_beta02.BLT1850.ne30_t232.104.cam.h3a.PRECC.0081010110800-0090122710800.nc
  -rw-r--r-- 1 fengzhu ncar 1.7G Aug 21 11:19 b.e30_beta02.BLT1850.ne30_t232.104.cam.h3a.PRECC.0091010110800-0100122710800.nc
```



Node 1

OCN: 22.3 mins

Node 2

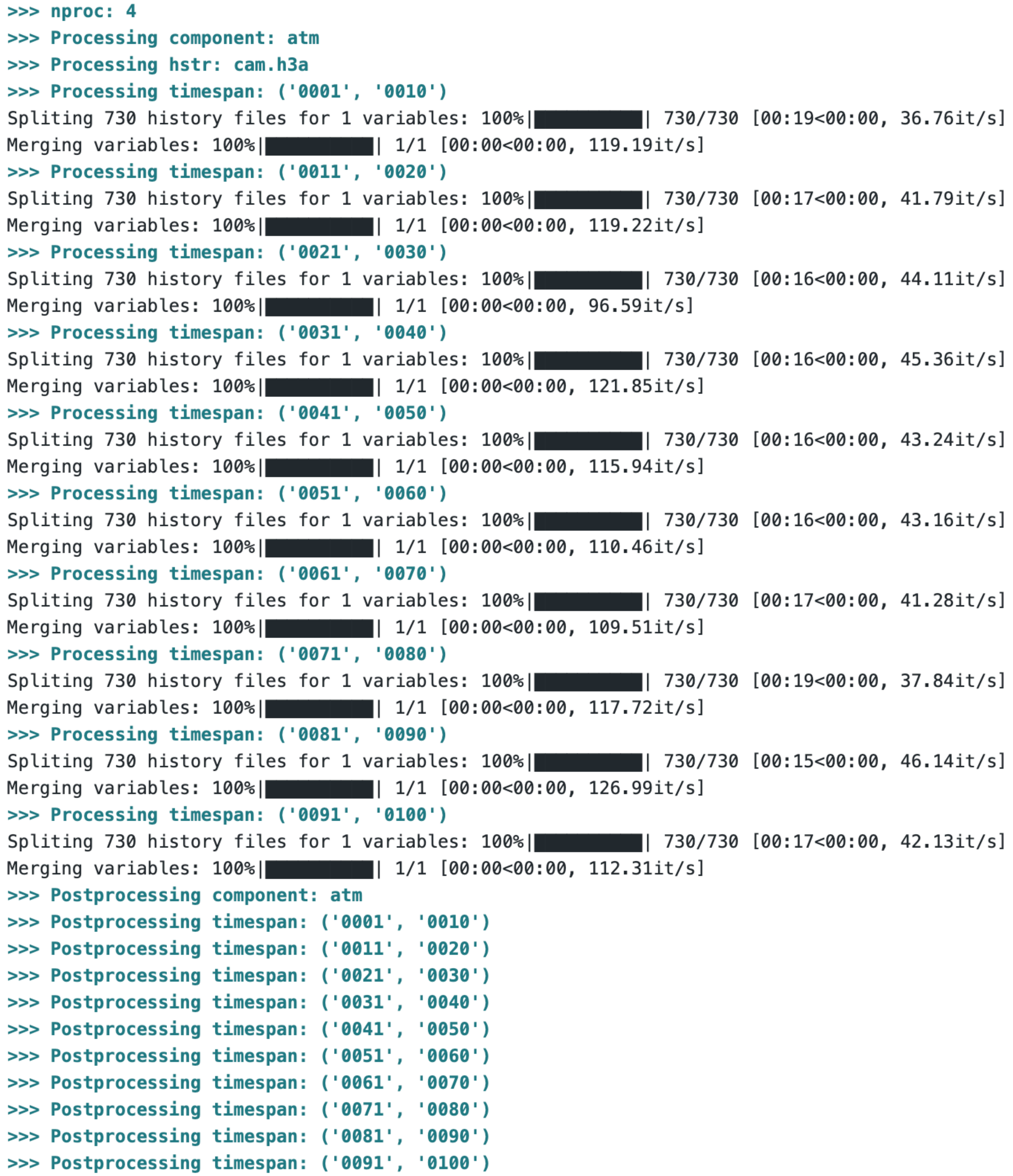
ATM: 13.3 mins

ICE: 7.5 mins

Node 3

LND: 19.6 mins

ROF: 1.1 mins



```
>>> nproc: 4
>>> Processing component: atm
>>> Processing hstr: cam.h3a
>>> Processing timespan: ('0001', '0010')
Spliting 730 history files for 1 variables: 100%|██████████| 730/730 [00:19<00:00, 36.76it/s]
Merging variables: 100%|██████████| 1/1 [00:00<00:00, 119.19it/s]
>>> Processing timespan: ('0011', '0020')
Spliting 730 history files for 1 variables: 100%|██████████| 730/730 [00:17<00:00, 41.79it/s]
Merging variables: 100%|██████████| 1/1 [00:00<00:00, 119.22it/s]
>>> Processing timespan: ('0021', '0030')
Spliting 730 history files for 1 variables: 100%|██████████| 730/730 [00:16<00:00, 44.11it/s]
Merging variables: 100%|██████████| 1/1 [00:00<00:00, 96.59it/s]
>>> Processing timespan: ('0031', '0040')
Spliting 730 history files for 1 variables: 100%|██████████| 730/730 [00:16<00:00, 45.36it/s]
Merging variables: 100%|██████████| 1/1 [00:00<00:00, 121.85it/s]
>>> Processing timespan: ('0041', '0050')
Spliting 730 history files for 1 variables: 100%|██████████| 730/730 [00:16<00:00, 43.24it/s]
Merging variables: 100%|██████████| 1/1 [00:00<00:00, 115.94it/s]
>>> Processing timespan: ('0051', '0060')
Spliting 730 history files for 1 variables: 100%|██████████| 730/730 [00:16<00:00, 43.16it/s]
Merging variables: 100%|██████████| 1/1 [00:00<00:00, 110.46it/s]
>>> Processing timespan: ('0061', '0070')
Spliting 730 history files for 1 variables: 100%|██████████| 730/730 [00:17<00:00, 41.28it/s]
Merging variables: 100%|██████████| 1/1 [00:00<00:00, 109.51it/s]
>>> Processing timespan: ('0071', '0080')
Spliting 730 history files for 1 variables: 100%|██████████| 730/730 [00:19<00:00, 37.84it/s]
Merging variables: 100%|██████████| 1/1 [00:00<00:00, 117.72it/s]
>>> Processing timespan: ('0081', '0090')
Spliting 730 history files for 1 variables: 100%|██████████| 730/730 [00:15<00:00, 46.14it/s]
Merging variables: 100%|██████████| 1/1 [00:00<00:00, 126.99it/s]
>>> Processing timespan: ('0091', '0100')
Spliting 730 history files for 1 variables: 100%|██████████| 730/730 [00:17<00:00, 42.13it/s]
Merging variables: 100%|██████████| 1/1 [00:00<00:00, 112.31it/s]
>>> Postprocessing component: atm
>>> Postprocessing timespan: ('0001', '0010')
>>> Postprocessing timespan: ('0011', '0020')
>>> Postprocessing timespan: ('0021', '0030')
>>> Postprocessing timespan: ('0031', '0040')
>>> Postprocessing timespan: ('0041', '0050')
>>> Postprocessing timespan: ('0051', '0060')
>>> Postprocessing timespan: ('0061', '0070')
>>> Postprocessing timespan: ('0071', '0080')
>>> Postprocessing timespan: ('0081', '0090')
>>> Postprocessing timespan: ('0091', '0100')
```

CESM Postprocessing (History)

History.gen_ts()

netCDF Operators (NCO) Software Stack

For production run, x4c supports multiple nodes leveraging MPI.
See *https://ncar.github.io/x4c/notebooks/post-pbs.html#CESM3-Example*

```
History: /glade/derecho/scratch/cmip7/archive/b.e30_beta06.B1850C_LTso.ne30_t232_wgx3.192.wrkflw.1
x4c Timeseries: /glade/campaign/cesm/development/cross-wg/diagnostic_framework/x4c/timeseries/b.e30_beta06.B1850C_LTso.ne30_t232_wgx3.192.wrkflw.1
Model years: 1 - 10
```

x4c

Task	Nodes	NCPUs	Mem	CPU	Elap
mom6.h.sfc+z	1	128	129.26	17.23	0.22
mom6.h.native +rho2+mosart	1	128	134.22	23.63	0.20
cam+cice.h+clm2	1	128	138	56.10	0.22
cice.h1	13	13*128	1655.82	34.93	0.25

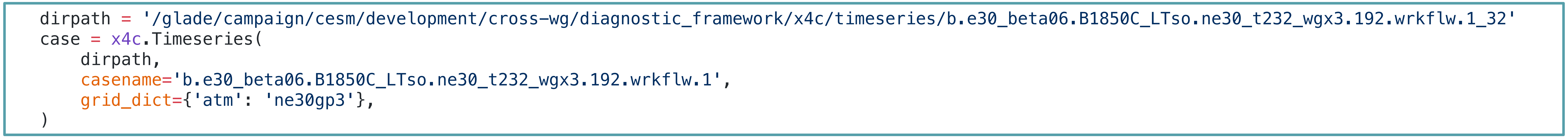
Baseline: CESM_postprocessing

Task	Nodes	NCPUs	Mem	CPU	Elap
all	16	1024	1952.26	24.66	0.21

▣ Diagnostic Features (Timeseries)   A “Case” System

case = x4c.Timeseries(dirpath, [grid_dict=…, casename=…, cesm_ver=…])

- **dirpath**: the History.gen_ts() generated timeseries directory
- **grid_dict**: the grid info; default: {'atm': 'ne30pg3', 'ocn': 'g16'}



```
dirpath = '/glade/campaign/cesm/development/cross-wg/diagnostic_framework/x4c/timeseries/b.e30_beta06.B1850C_LTso.ne30_t232_wgx3.192.wrkflw.1_32'
case = x4c.Timeseries(
    dirpath,
    casename='b.e30_beta06.B1850C_LTso.ne30_t232_wgx3.192.wrkflw.1',
    grid_dict={'atm': 'ne30gp3'},
)
```

```
>>> case.root_dir: /glade/campaign/cesm/development/cross-wg/diagnostic_framework/x4c/timeseries/b.e30_beta06.B1850C_LTso.ne30_t232_wgx3.192.wrkflw.1_32
>>> case.path_pattern: comp/proc/tseries/*/casename.hstr.vn.timespan.nc
>>> case.grid_dict: {'atm': 'ne30gp3', 'ocn': 'g16', 'lnd': 'ne30gp3', 'rof': 'ne30gp3', 'ice': 'g16'}
>>> case.casename: b.e30_beta06.B1850C_LTso.ne30_t232_wgx3.192.wrkflw.1
>>> case.paths["atm"]["cam.h0a"] created
>>> case.paths["atm"]["cam.h2a"] created
>>> case.paths["atm"]["cam.h1a"] created
>>> case.paths["ocn"]["mom6.h.sfc"] created
>>> case.paths["ocn"]["mom6.h.z"] created
>>> case.paths["ocn"]["mom6"] created
>>> case.paths["ocn"]["mom6.h.rho2"] created
>>> case.paths["ocn"]["mom6.h.native"] created
>>> case.paths["lnd"]["clm2.h0"] created
>>> case.paths["rof"]["mosart.h0"] created
>>> case.paths["ice"]["cice.h"] created
>>> case.paths["ice"]["cice.h1"] created
>>> case.vns["atm"]["cam.h0a"] created
>>> case.vns["atm"]["cam.h2a"] created
>>> case.vns["atm"]["cam.h1a"] created
>>> case.vns["ocn"]["mom6.h.sfc"] created
>>> case.vns["ocn"]["mom6.h.z"] created
>>> case.vns["ocn"]["mom6"] created
>>> case.vns["ocn"]["mom6.h.rho2"] created
>>> case.vns["ocn"]["mom6.h.native"] created
>>> case.vns["lnd"]["clm2.h0"] created
>>> case.vns["rof"]["mosart.h0"] created
>>> case.vns["ice"]["cice.h"] created
>>> case.vns["ice"]["cice.h1"] created
```

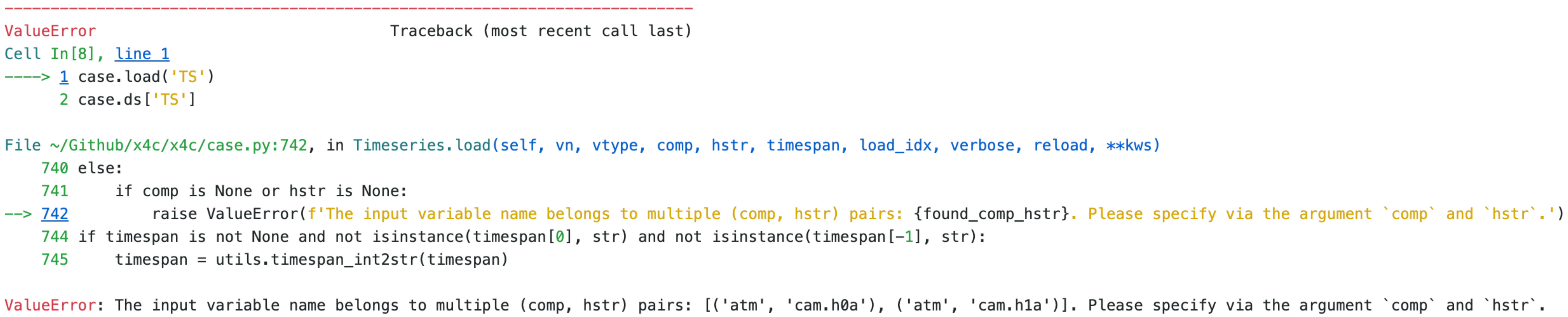
▣ Diagnostic Features (Timeseries)

Timeseries.load(raw)

case.load(vn, [timespan=..., load_idx=-1])

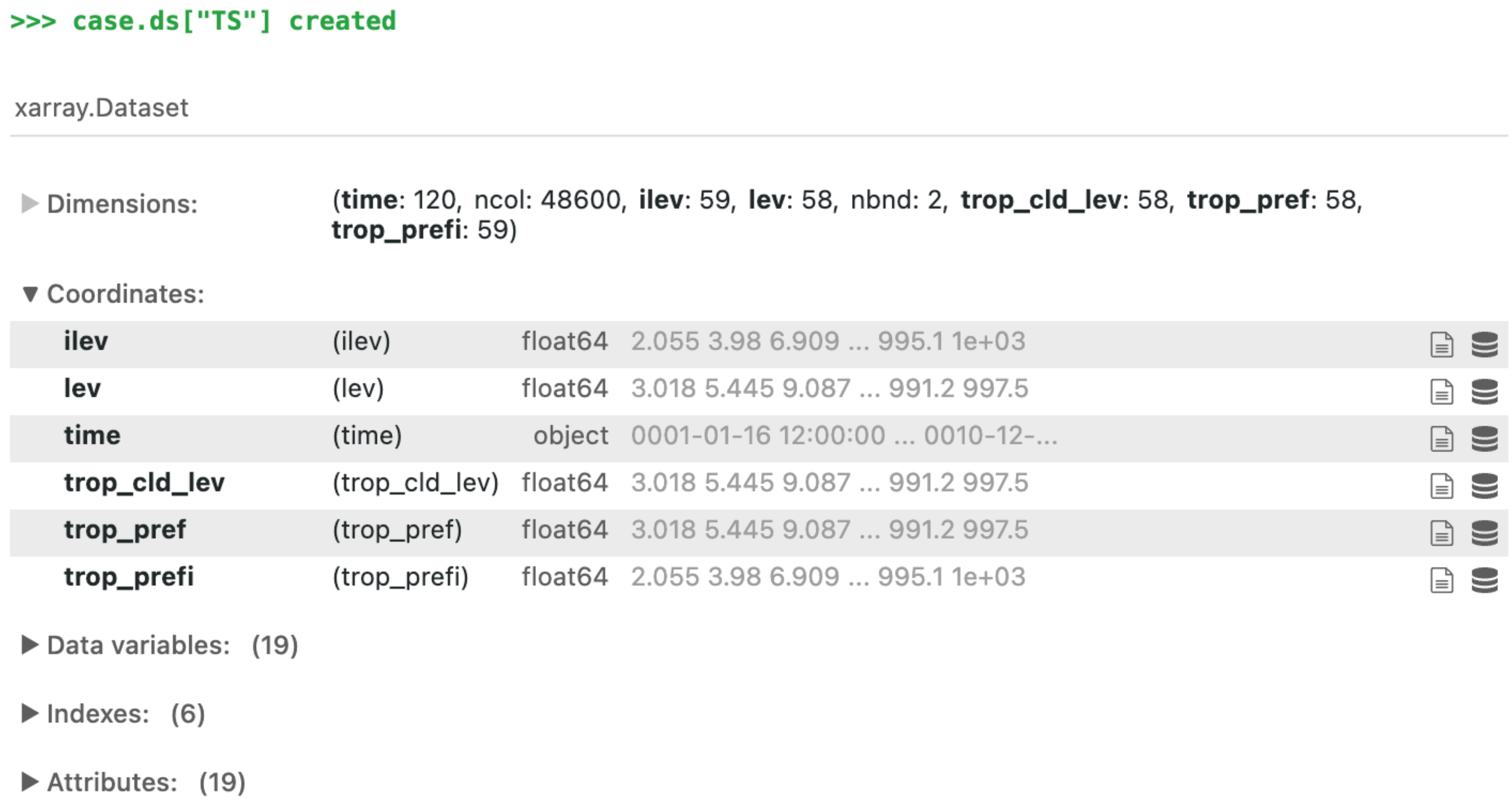
- vn: an existing variable name under the timeseries directory
- timespan: a timespan in (start, end) pointing to a single or multiple files
- load_idx: the file index to load; default: -1 (the last file)

```
case.load('TS')
case.ds['TS']
```



```
---------------------------------------------------------------------------
ValueError                                Traceback (most recent call last)
Cell In[8], line 1
----> 1 case.load('TS')
      2 case.ds['TS']

File ~/Github/x4c/x4c/case.py:742, in Timeseries.load(self, vn, vtype, comp, hstr, timespan, load_idx, verbose, reload, **kws)
    740 else:
    741     if comp is None or hstr is None:
--> 742         raise ValueError(f'The input variable name belongs to multiple (comp, hstr) pairs: {found_comp_hstr}. Please specify via the argument `comp` and `hstr`.')
    744 if timespan is not None and not isinstance(timespan[0], str) and not isinstance(timespan[-1], str):
    745     timespan = utils.timespan_int2str(timespan)

ValueError: The input variable name belongs to multiple (comp, hstr) pairs: [('atm', 'cam.h0a'), ('atm', 'cam.h1a')]. Please specify via the argument `comp` and `hstr`.
```

```
case.load('TS', comp='atm', hstr='cam.h0a')
case.ds['TS']
```



```
>>> case.ds["TS"] created

xarray.Dataset

▶ Dimensions:      (time: 120, ncol: 48600, ilev: 59, lev: 58, nbnd: 2, trop_cld_lev: 58, trop_pref: 58,
                   trop_prefi: 59)

▼ Coordinates:
    ilev           (ilev)          float64  2.055 3.98 6.909 ... 995.1 1e+03
    lev            (lev)           float64  3.018 5.445 9.087 ... 991.2 997.5
    time           (time)           object  0001-01-16 12:00:00 ... 0010-12-...
    trop_cld_lev   (trop_cld_lev)  float64  3.018 5.445 9.087 ... 991.2 997.5
    trop_pref      (trop_pref)     float64  3.018 5.445 9.087 ... 991.2 997.5
    trop_prefi     (trop_prefi)    float64  2.055 3.98 6.909 ... 995.1 1e+03

▶ Data variables:  (19)

▶ Indexes:  (6)

▶ Attributes:  (19)
```

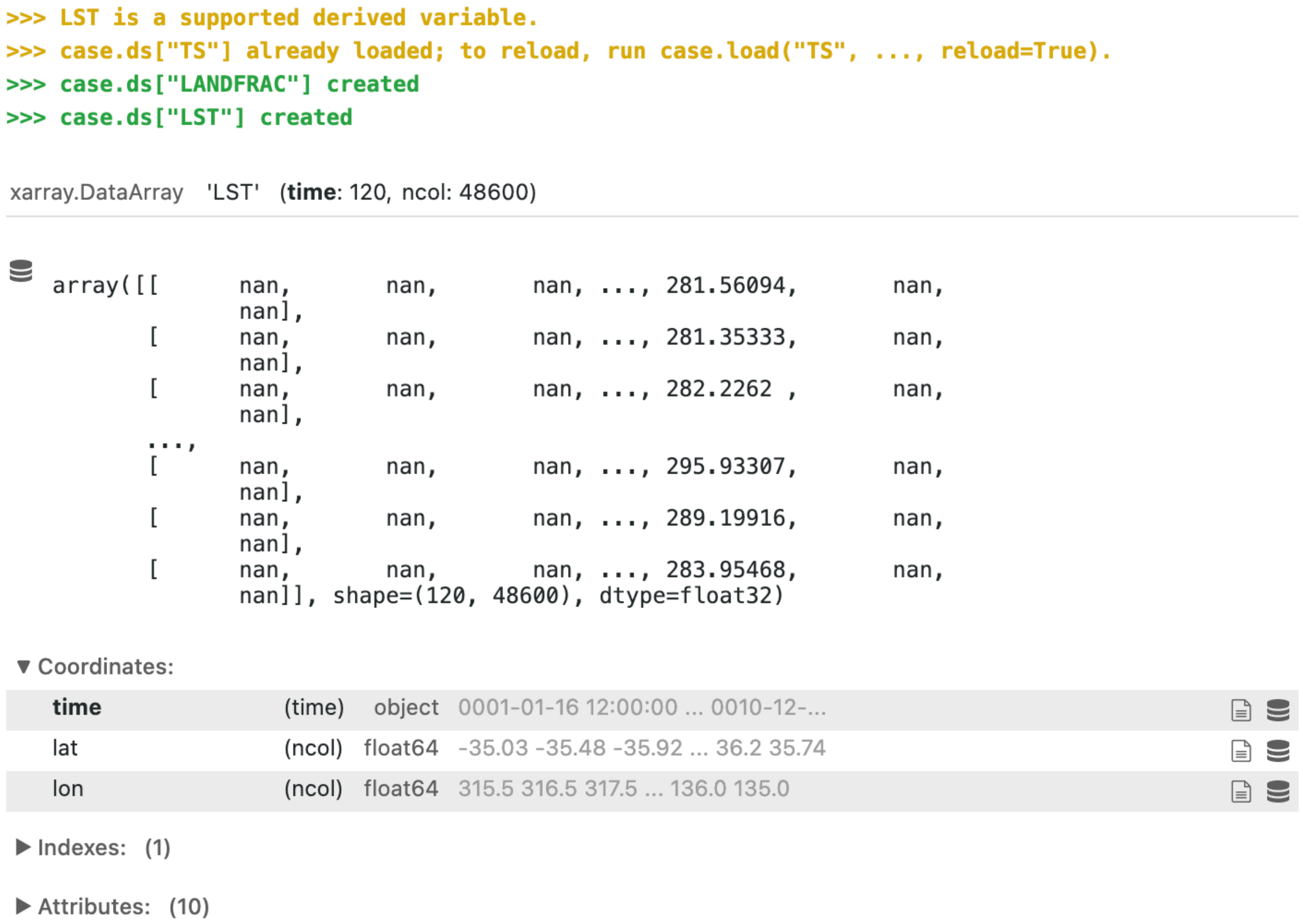
▣ Diagnostic Features (Timeseries)

Timeseries.load(derived)

case.load(vn, [timespan=..., load_idx=-1])

- vn: an existing variable name under the timeseries directory
- timespan: a timespan in (start, end) pointing to a single or multiple files
- load_idx: the file index to load; default: -1 (the last file)

```
case.load('LST', comp='atm', hstr='cam.h0a')
case.ds['LST']
```



```
>>> LST is a supported derived variable.
>>> case.ds["TS"] already loaded; to reload, run case.load("TS", ..., reload=True).
>>> case.ds["LANDFRAC"] created
>>> case.ds["LST"] created
```

xarray.DataArray 'LST' (**time**: 120, ncol: 48600)

```
array([[        nan,         nan,         nan, ..., 281.56094,         nan,
                nan],
       [        nan,         nan,         nan, ..., 281.35333,         nan,
                nan],
       [        nan,         nan,         nan, ..., 282.2262 ,         nan,
                nan],
       ...,
       [        nan,         nan,         nan, ..., 295.93307,         nan,
                nan],
       [        nan,         nan,         nan, ..., 289.19916,         nan,
                nan],
       [        nan,         nan,         nan, ..., 283.95468,         nan,
                nan]], shape=(120, 48600), dtype=float32)
```

▼ Coordinates:

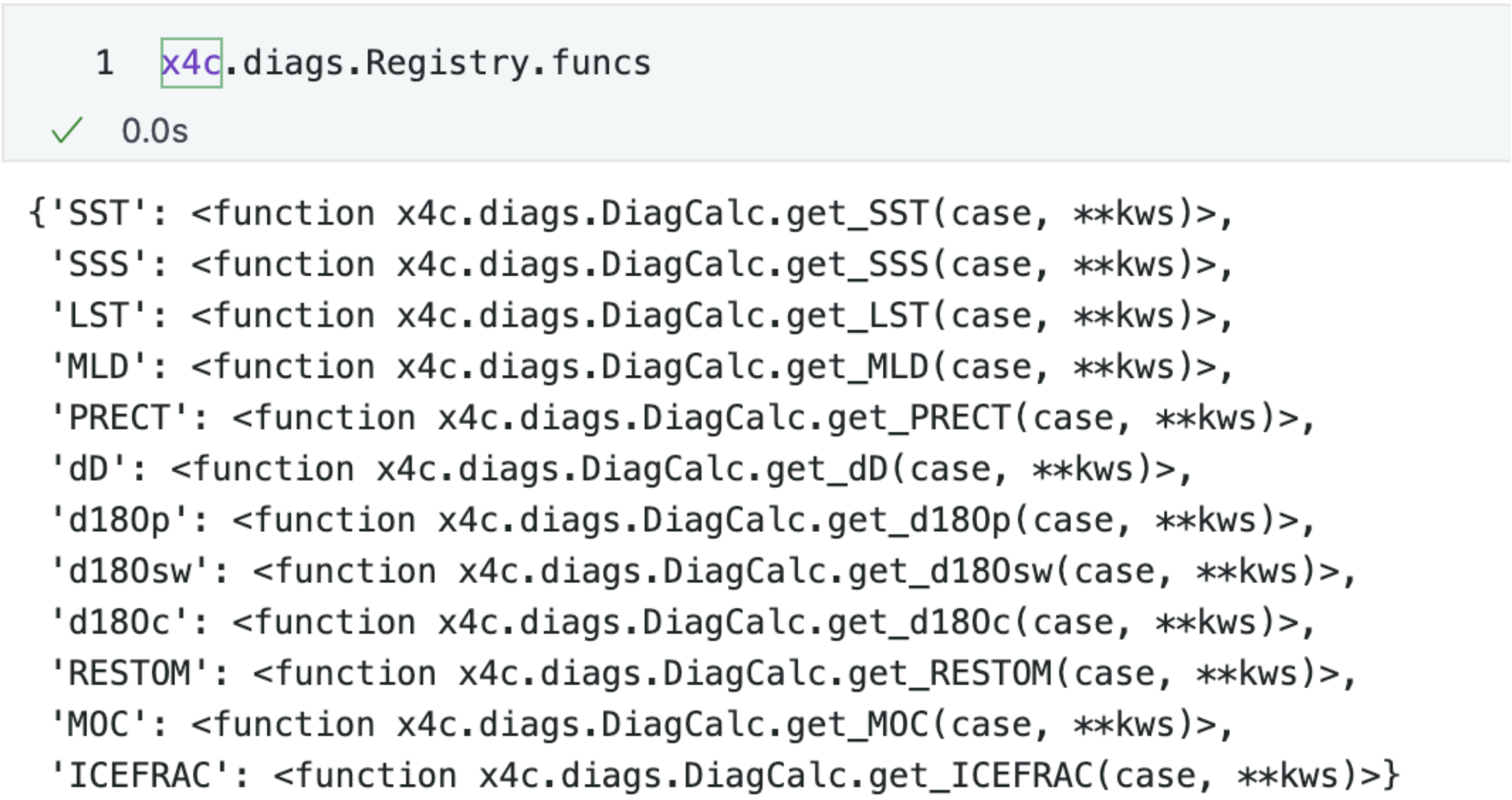
time	(time)	object	0001-01-16 12:00:00 ... 0010-12-...
lat	(ncol)	float64	-35.03 -35.48 -35.92 ... 36.2 35.74
lon	(ncol)	float64	315.5 316.5 317.5 ... 136.0 135.0

▶ Indexes: (1)

▶ Attributes: (10)

Diagnostic Features (Timeseries)

Timeseries.load(derived)

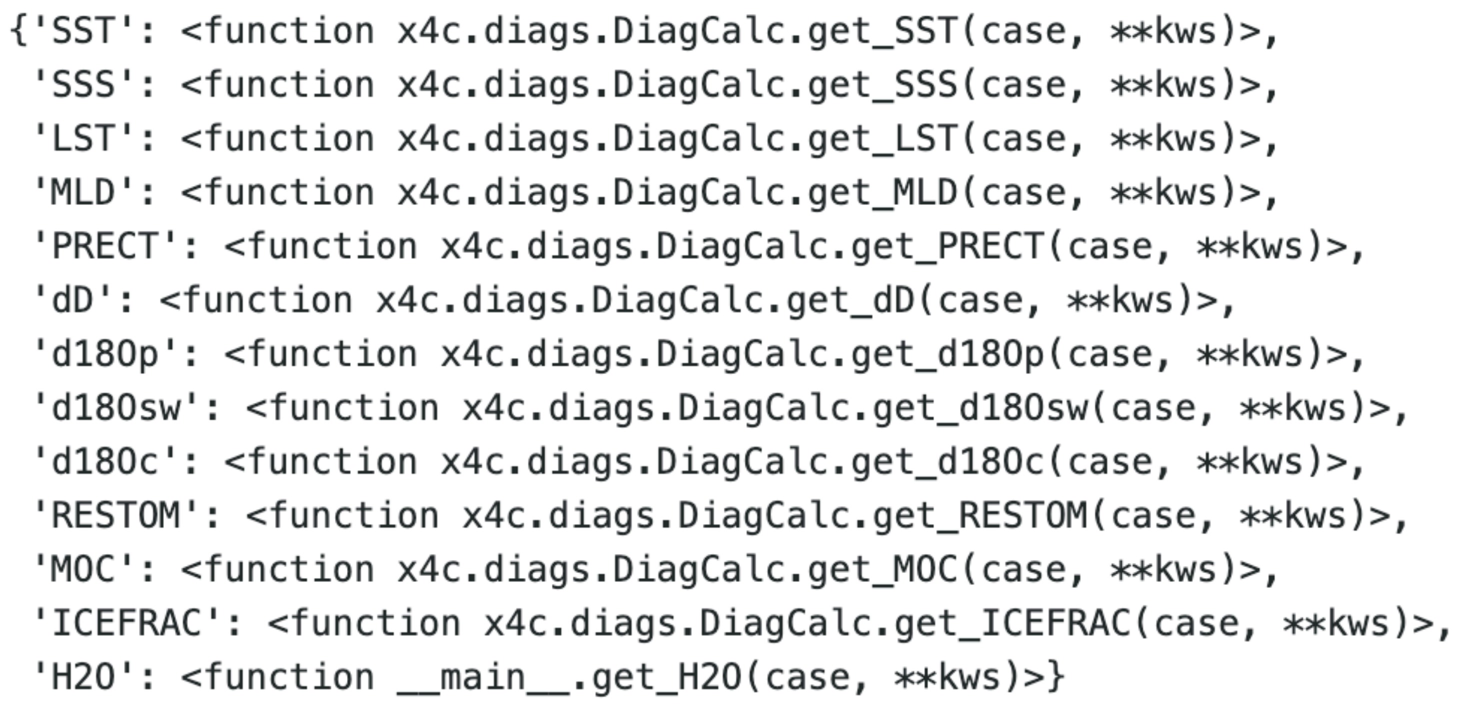


```python
x4c.diags.Registry.funcs
```

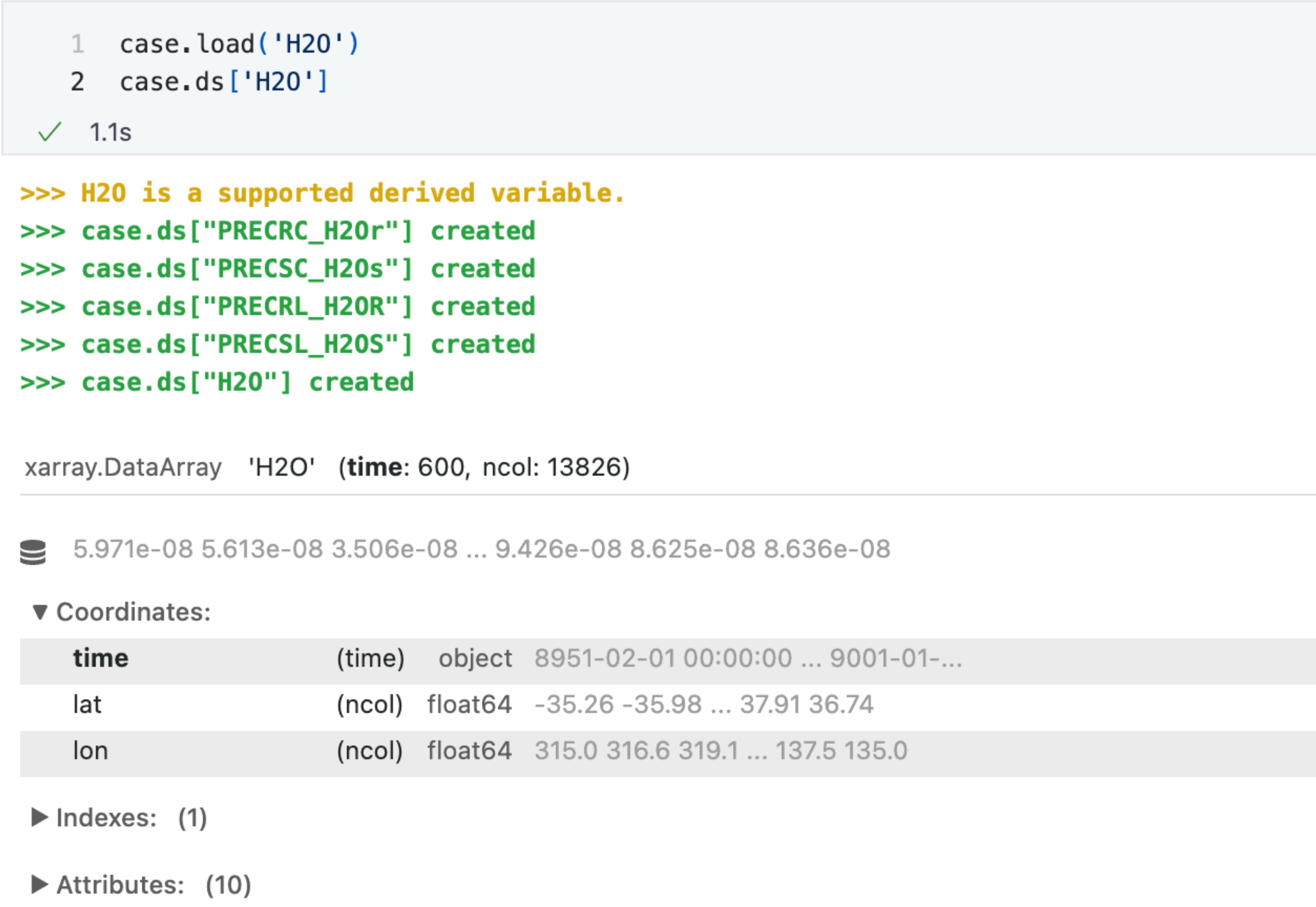
✓ 0.0s

```
{'SST': <function x4c.diags.DiagCalc.get_SST(case, **kws)>,
 'SSS': <function x4c.diags.DiagCalc.get_SSS(case, **kws)>,
 'LST': <function x4c.diags.DiagCalc.get_LST(case, **kws)>,
 'MLD': <function x4c.diags.DiagCalc.get_MLD(case, **kws)>,
 'PRECT': <function x4c.diags.DiagCalc.get_PRECT(case, **kws)>,
 'dD': <function x4c.diags.DiagCalc.get_dD(case, **kws)>,
 'd18Op': <function x4c.diags.DiagCalc.get_d18Op(case, **kws)>,
 'd18Osw': <function x4c.diags.DiagCalc.get_d18Osw(case, **kws)>,
 'd18Oc': <function x4c.diags.DiagCalc.get_d18Oc(case, **kws)>,
 'RESTOM': <function x4c.diags.DiagCalc.get_RESTOM(case, **kws)>,
 'MOC': <function x4c.diags.DiagCalc.get_MOC(case, **kws)>,
 'ICEFRAC': <function x4c.diags.DiagCalc.get_ICEFRAC(case, **kws)>}
```

```python
@x4c.diags.F
def get_H2O(case, **kws):
    case.load('PRECRC_H2Or', **kws)
    case.load('PRECSC_H2Os', **kws)
    case.load('PRECRL_H2OR', **kws)
    case.load('PRECSL_H2OS', **kws)
    h2o = case.ds['PRECRC_H2Or'].x.da + case.ds['PRECSC_H2Os'].x.da + case.ds['PRECRL_H2OR'].x.da + case.ds['PRECSL_H2OS'].x.da
    h2o = h2o.where(h2o > 1e-18, 1e-18)
    h2o.name = 'H2O'
    h2o.attrs['long_name'] = 'H2O'
    h2o.attrs['units'] = 'kg m-2 s-1'
    return h2o

x4c.diags.Registry.funcs
```



```
{'SST': <function x4c.diags.DiagCalc.get_SST(case, **kws)>,
 'SSS': <function x4c.diags.DiagCalc.get_SSS(case, **kws)>,
 'LST': <function x4c.diags.DiagCalc.get_LST(case, **kws)>,
 'MLD': <function x4c.diags.DiagCalc.get_MLD(case, **kws)>,
 'PRECT': <function x4c.diags.DiagCalc.get_PRECT(case, **kws)>,
 'dD': <function x4c.diags.DiagCalc.get_dD(case, **kws)>,
 'd18Op': <function x4c.diags.DiagCalc.get_d18Op(case, **kws)>,
 'd18Osw': <function x4c.diags.DiagCalc.get_d18Osw(case, **kws)>,
 'd18Oc': <function x4c.diags.DiagCalc.get_d18Oc(case, **kws)>,
 'RESTOM': <function x4c.diags.DiagCalc.get_RESTOM(case, **kws)>,
 'MOC': <function x4c.diags.DiagCalc.get_MOC(case, **kws)>,
 'ICEFRAC': <function x4c.diags.DiagCalc.get_ICEFRAC(case, **kws)>,
 'H2O': <function __main__.get_H2O(case, **kws)>}
```



```python
case.load('H2O')
case.ds['H2O']
```

✓ 1.1s

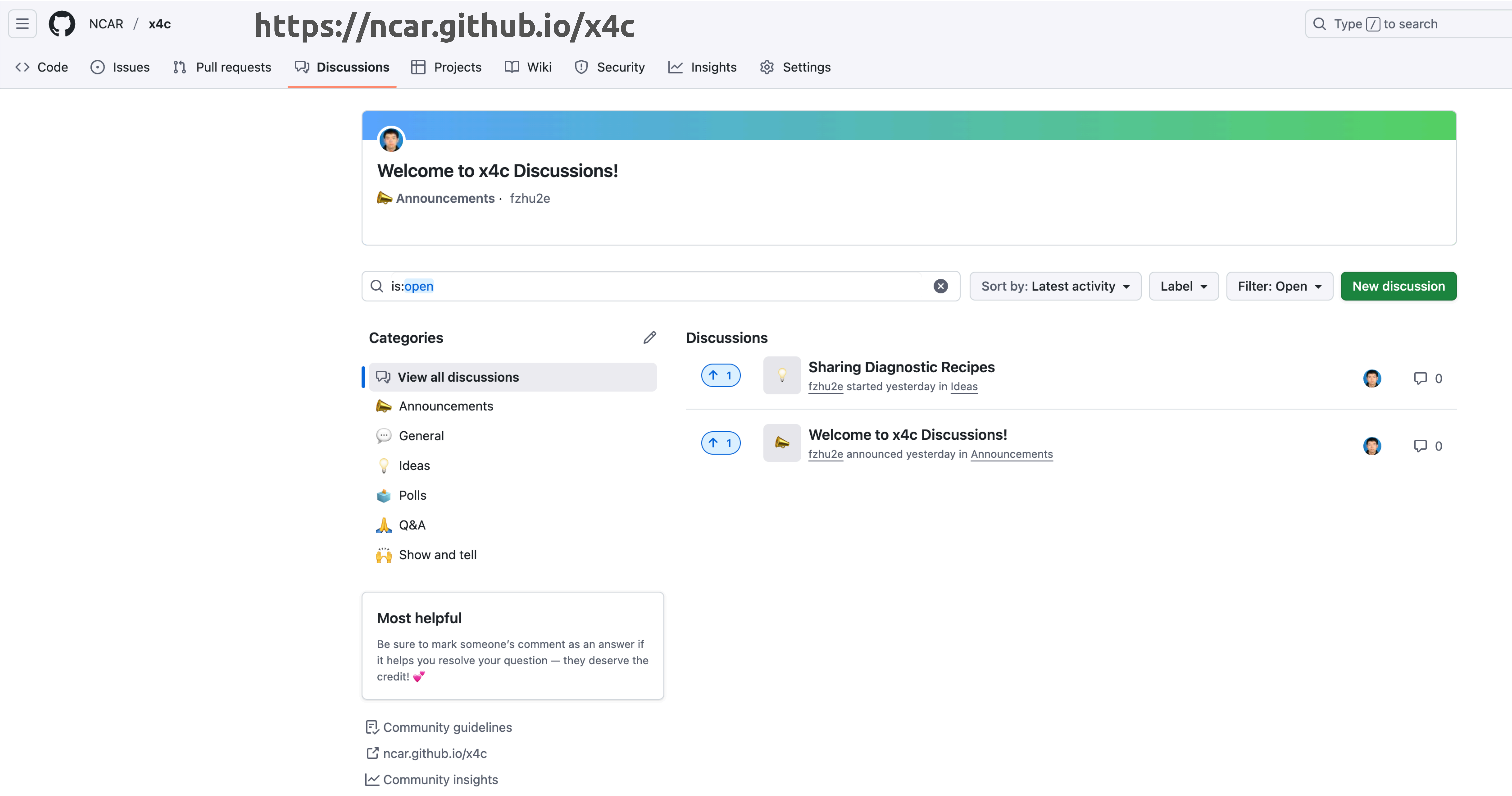
```
>>> H2O is a supported derived variable.
>>> case.ds["PRECRC_H2Or"] created
>>> case.ds["PRECSC_H2Os"] created
>>> case.ds["PRECRL_H2OR"] created
>>> case.ds["PRECSL_H2OS"] created
>>> case.ds["H2O"] created
```

```
xarray.DataArray  'H2O'  (time: 600, ncol: 13826)

5.971e-08 5.613e-08 3.506e-08 ... 9.426e-08 8.625e-08 8.636e-08

▼ Coordinates:
   time      (time)  object   8951-02-01 00:00:00 ... 9001-01-...
   lat       (ncol)  float64  -35.26 -35.98 ... 37.91 36.74
   lon       (ncol)  float64  315.0 316.6 319.1 ... 137.5 135.0

▶ Indexes:  (1)

▶ Attributes:  (10)
```

Diagnostic Features (Timeseries)

Contribution from the Community

https://ncar.github.io/x4c



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Welcome to x4c Discussions!

📣 Announcements · fzhu2e

is:open

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Categories

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Discussions

↑ 1	**Sharing Diagnostic Recipes** fzhu2e started yesterday in Ideas	0
↑ 1	**Welcome to x4c Discussions!** fzhu2e announced yesterday in Announcements	0

Most helpful

Be sure to mark someone's comment as an answer if it helps you resolve your question — they deserve the credit! 💕

Community guidelines

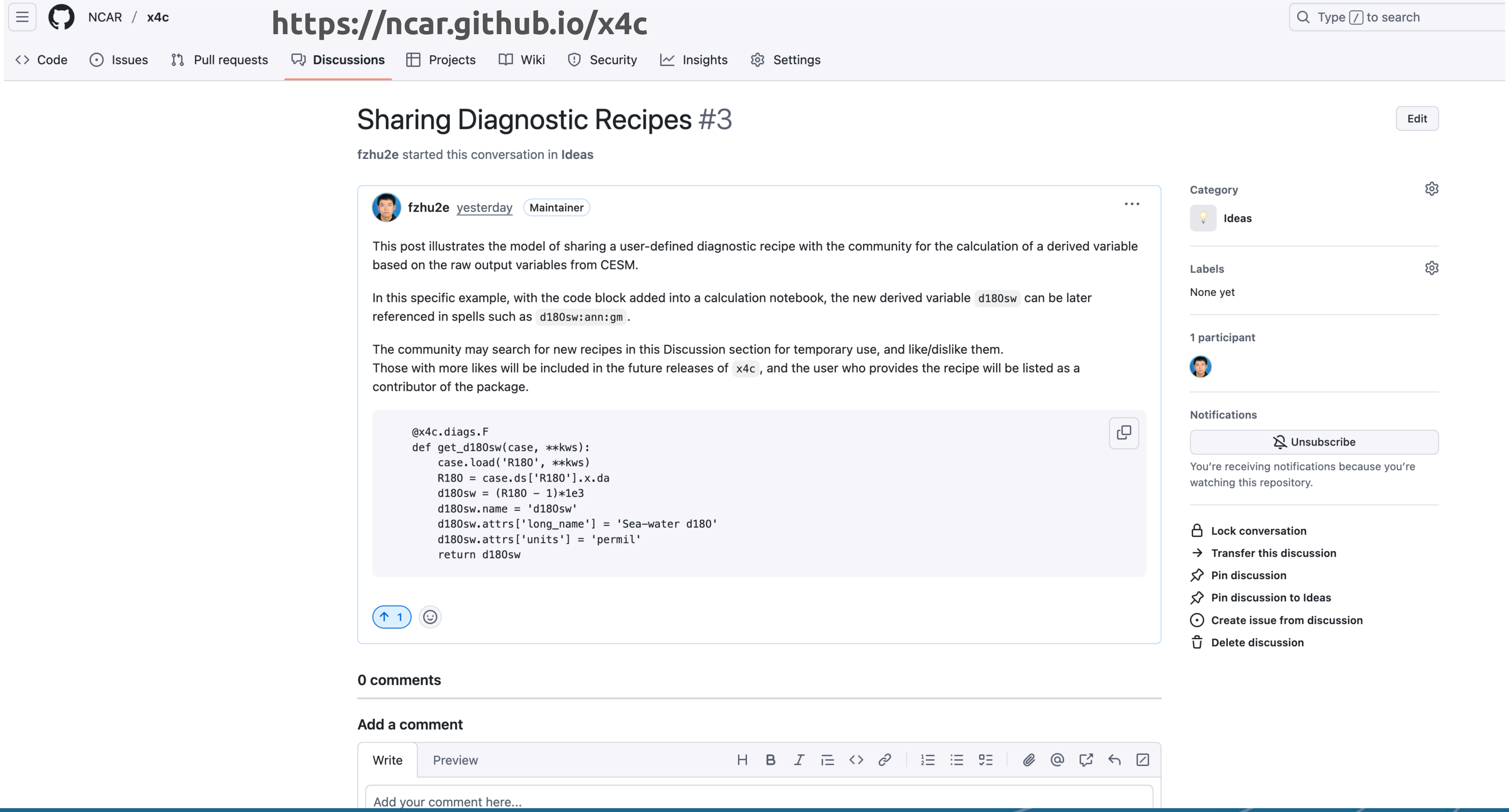
ncar.github.io/x4c

Community insights

Diagnostic Features (Timeseries)

Contribution from the Community

https://ncar.github.io/x4c



Sharing Diagnostic Recipes #3

fzhu2e started this conversation in **Ideas**

fzhu2e yesterday Maintainer

This post illustrates the model of sharing a user-defined diagnostic recipe with the community for the calculation of a derived variable based on the raw output variables from CESM.

In this specific example, with the code block added into a calculation notebook, the new derived variable `d18Osw` can be later referenced in spells such as `d18Osw:ann:gm`.

The community may search for new recipes in this Discussion section for temporary use, and like/dislike them.
Those with more likes will be included in the future releases of `x4c`, and the user who provides the recipe will be listed as a contributor of the package.

```
@x4c.diags.F
def get_d18Osw(case, **kws):
    case.load('R18O', **kws)
    R18O = case.ds['R18O'].x.da
    d18Osw = (R18O - 1)*1e3
    d18Osw.name = 'd18Osw'
    d18Osw.attrs['long_name'] = 'Sea-water d18O'
    d18Osw.attrs['units'] = 'permil'
    return d18Osw
```

0 comments

Add a comment

Add your comment here...

Category

Ideas

Labels

None yet

1 participant

Notifications

You're receiving notifications because you're watching this repository.

▣ Diagnostic Features (Timeseries)

A “Spell” System

Idea: to summarize a series of data processing steps with a spell that can be calculated and plotted

```
spell = 'vn:[:ann:sa]'
case.calc(spell)
case.plot(spell)
```

- vn: diagnostic variable name
- ann: annualization method
- sa: spatial averaging method

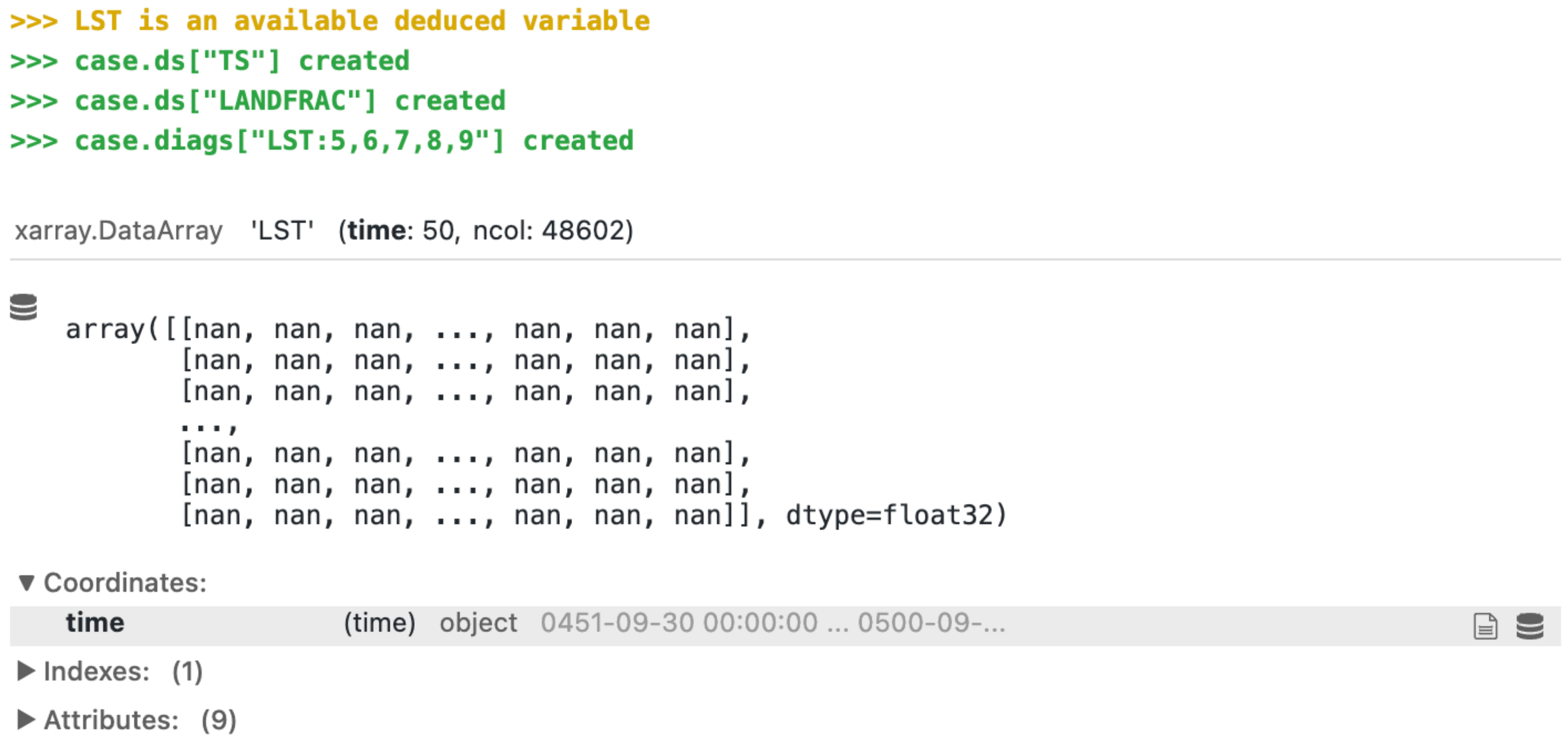
▣ Diagnostic Features (Timeseries)

A “Spell” System

Given a CESM simulation with an SE dycore (ne30), plot:

- **a map of the MJJAS Land Surface Temperature**

```
spell = 'LST:5,6,7,8,9'
case.calc(spell)
case.diags[spell]
```

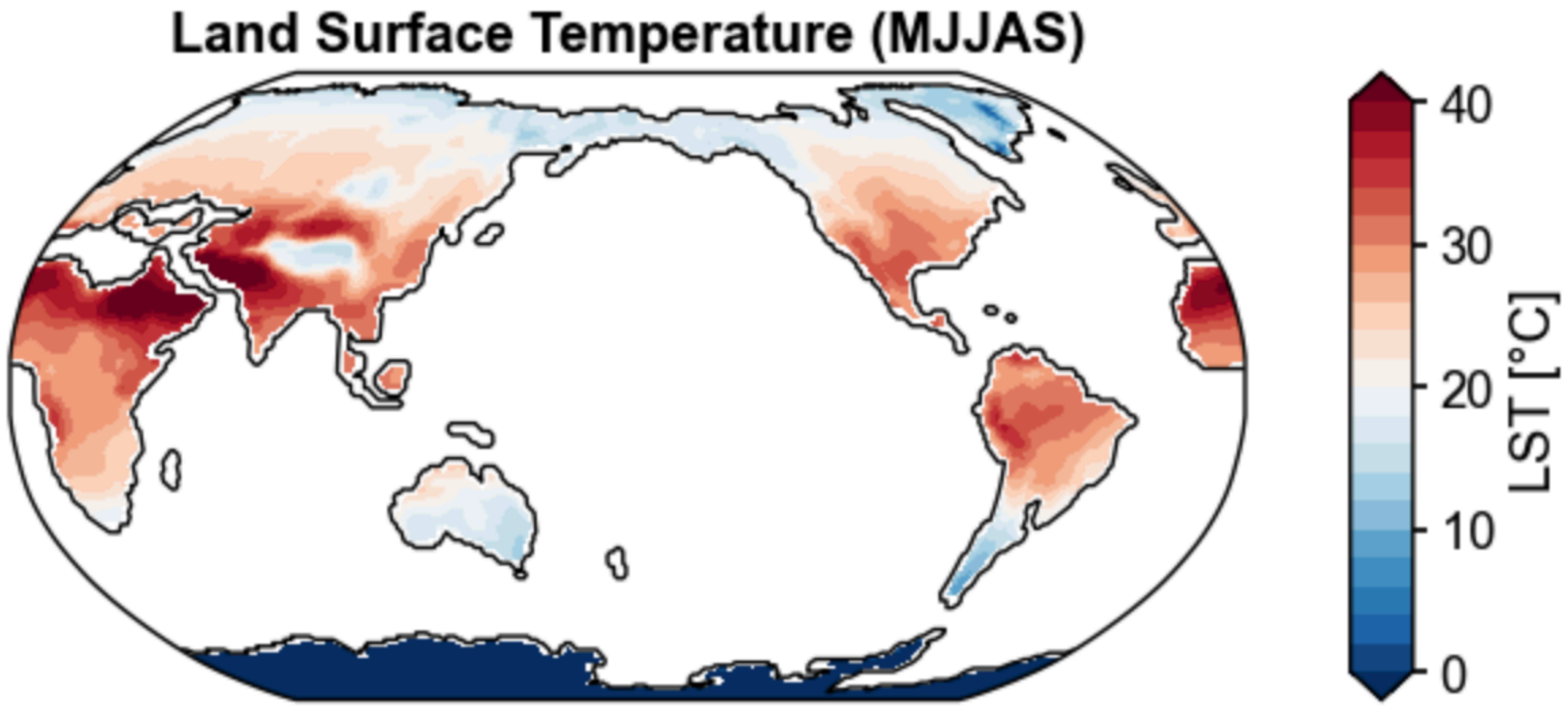


```
>>> LST is an available deduced variable
>>> case.ds["TS"] created
>>> case.ds["LANDFRAC"] created
>>> case.diags["LST:5,6,7,8,9"] created
```

```
xarray.DataArray   'LST'   (time: 50, ncol: 48602)

array([[nan, nan, nan, ..., nan, nan, nan],
       [nan, nan, nan, ..., nan, nan, nan],
       [nan, nan, nan, ..., nan, nan, nan],
       ...,
       [nan, nan, nan, ..., nan, nan, nan],
       [nan, nan, nan, ..., nan, nan, nan],
       [nan, nan, nan, ..., nan, nan, nan]], dtype=float32)

▼ Coordinates:
   time            (time)  object  0451-09-30 00:00:00 ... 0500-09-...
▶ Indexes:  (1)
▶ Attributes:  (9)
```

```
fig, ax = case.plot(spell)
```

```
>>> case.ds["SSH"] created
```



Land Surface Temperature (MJJAS)

▣ Diagnostic Features (Timeseries)

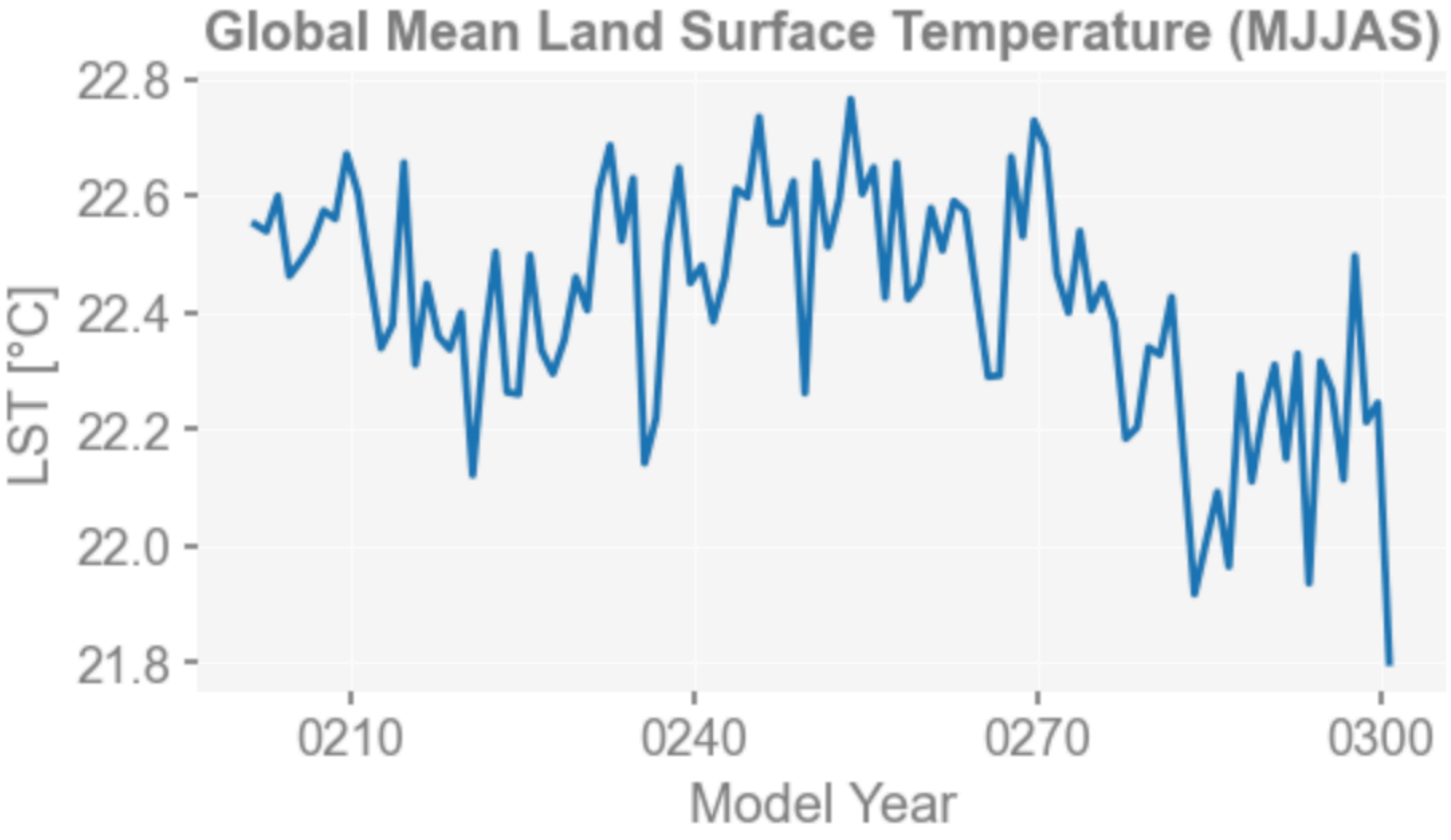
A “Spell” System

Given a CESM simulation with an SE dycore (ne30), plot:

- a **100-yr time series** of its **Global Mean**

```
x4c.set_style('web', font_scale=1.2)

spell = 'LST:5,6,7,8,9:gm'
fig, ax = case.plot(spell, timespan=(201, 300))
```

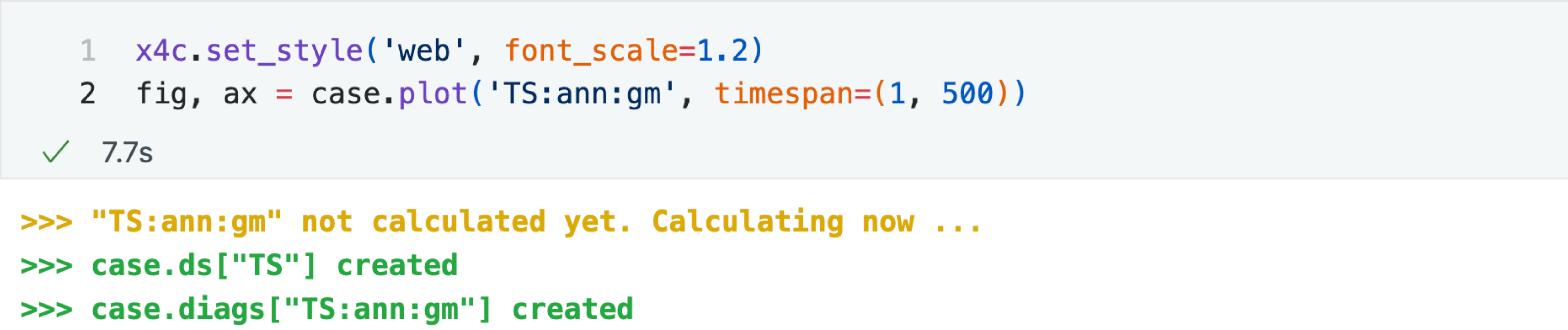
```
>>> "LST:5,6,7,8,9:gm" not calculated yet. Calculating now ...
>>> LST is an available deduced variable
>>> case.ds["TS"] created
>>> case.ds["LANDFRAC"] created
>>> case.diags["LST:5,6,7,8,9:gm"] created
```



Diagnostic Features (Timeseries)

A “Spell” System

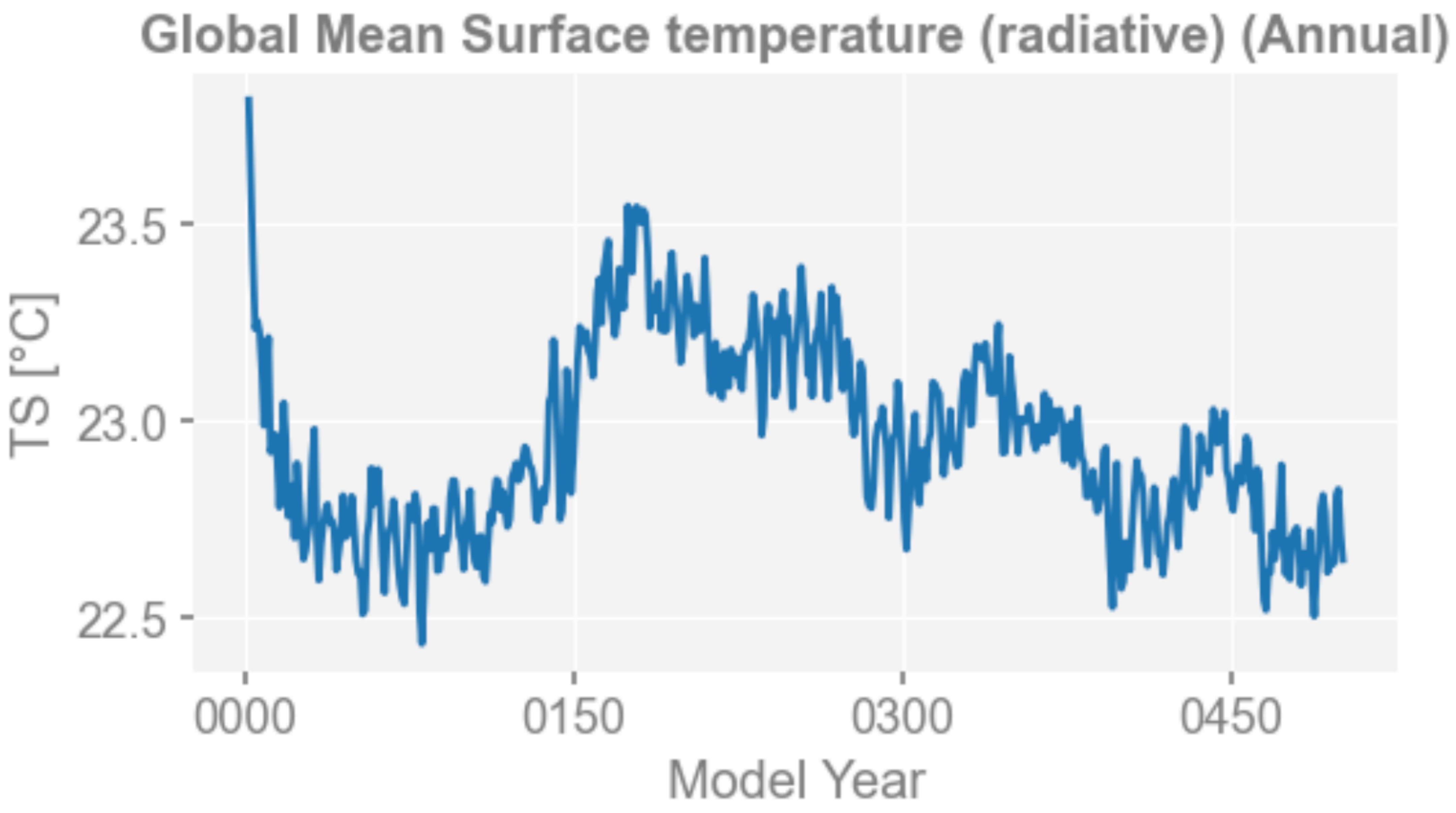
GMST 'TS:ann:gm'



```
x4c.set_style('web', font_scale=1.2)
fig, ax = case.plot('TS:ann:gm', timespan=(1, 500))
```

✓ 7.7s

```
>>> "TS:ann:gm" not calculated yet. Calculating now ...
>>> case.ds["TS"] created
>>> case.diags["TS:ann:gm"] created
```

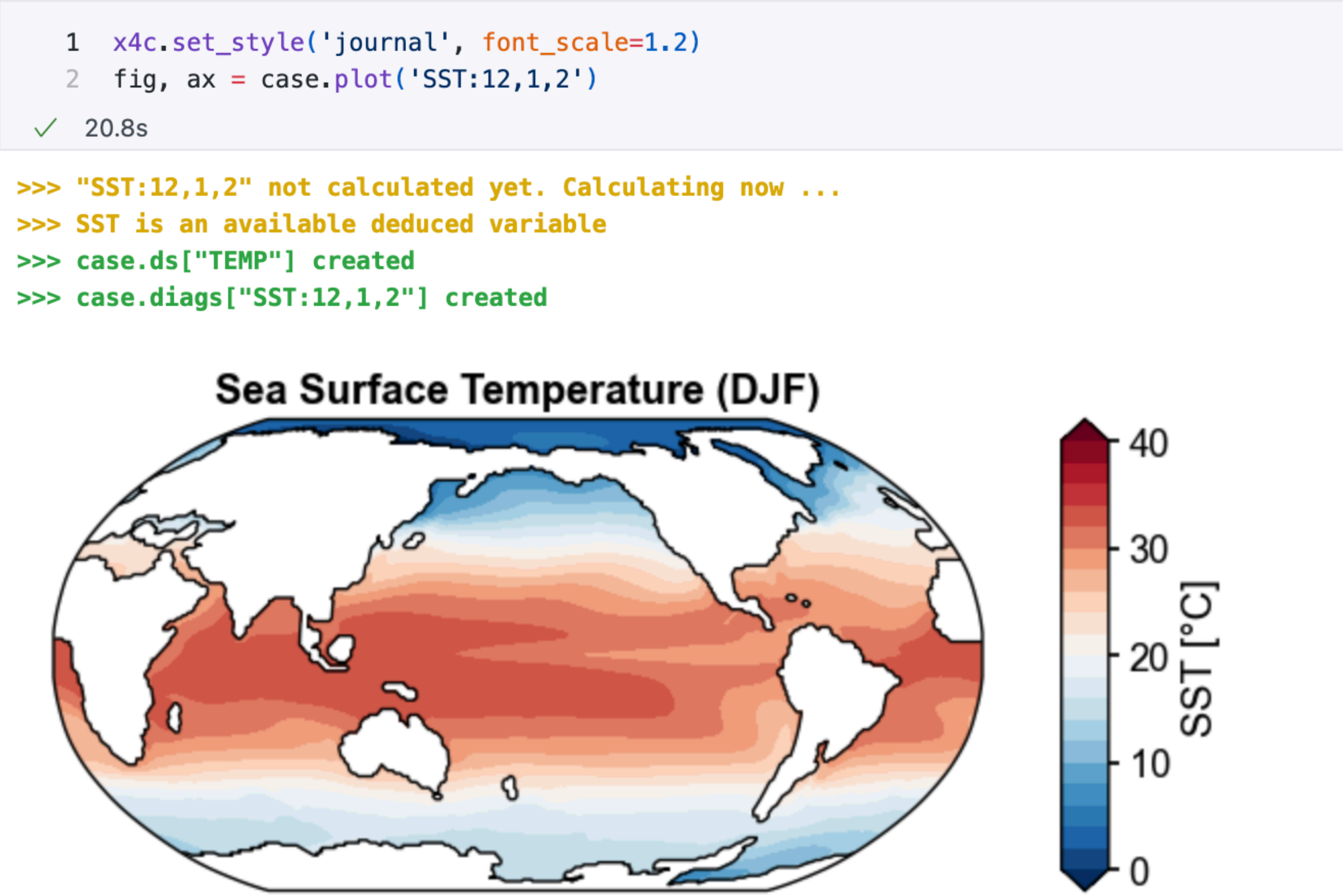


▣ Diagnostic Features (Timeseries)

A “Spell” System

A map of DJF SST

'SST:12,1,2'



```
x4c.set_style('journal', font_scale=1.2)
fig, ax = case.plot('SST:12,1,2')
✓ 20.8s
```

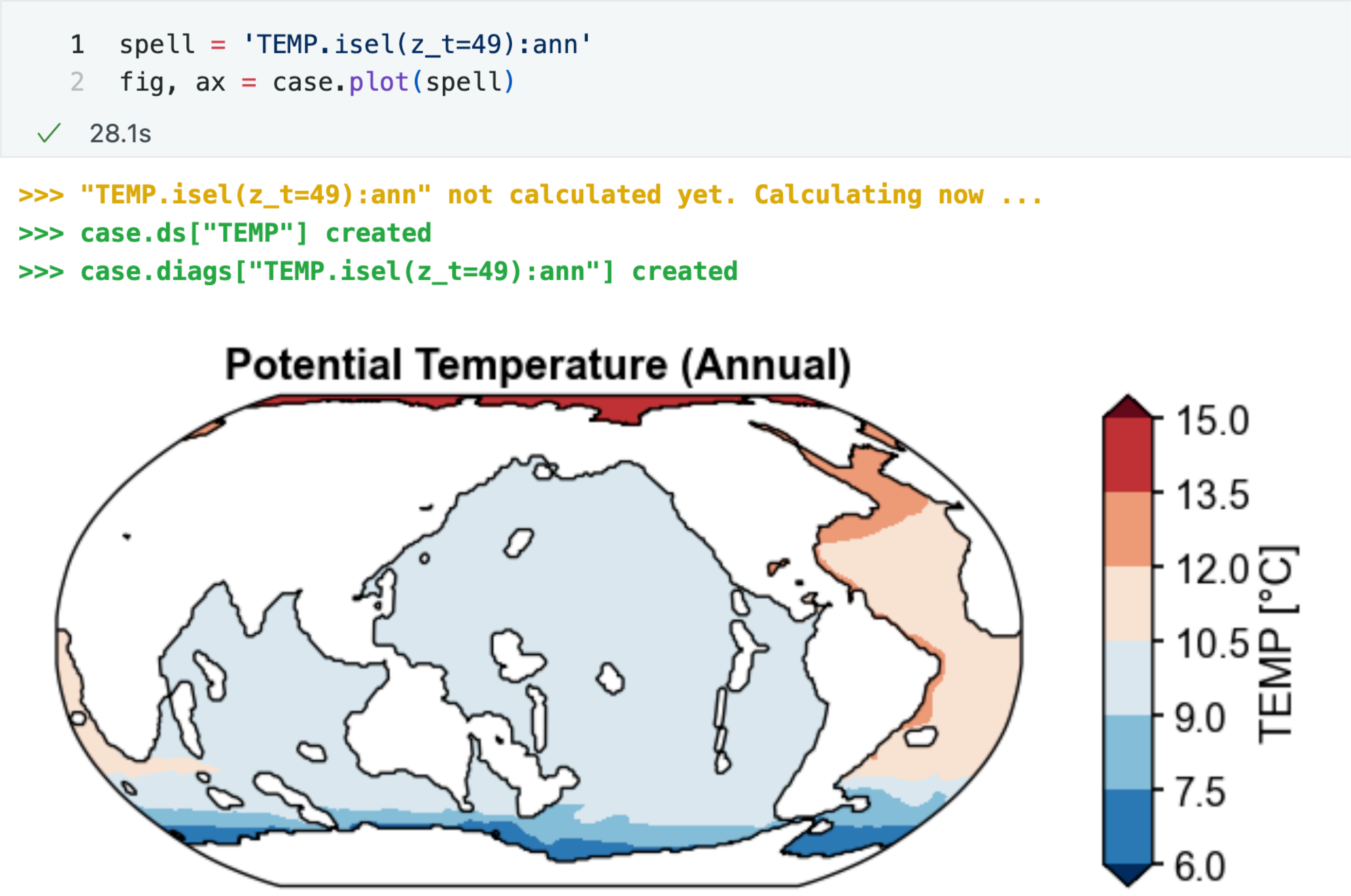
```
>>> "SST:12,1,2" not calculated yet. Calculating now ...
>>> SST is an available deduced variable
>>> case.ds["TEMP"] created
>>> case.diags["SST:12,1,2"] created
```

Diagnostic Features (Timeseries)

A “Spell” System

A map of annual Bottom Water Temperature (z_t=49)

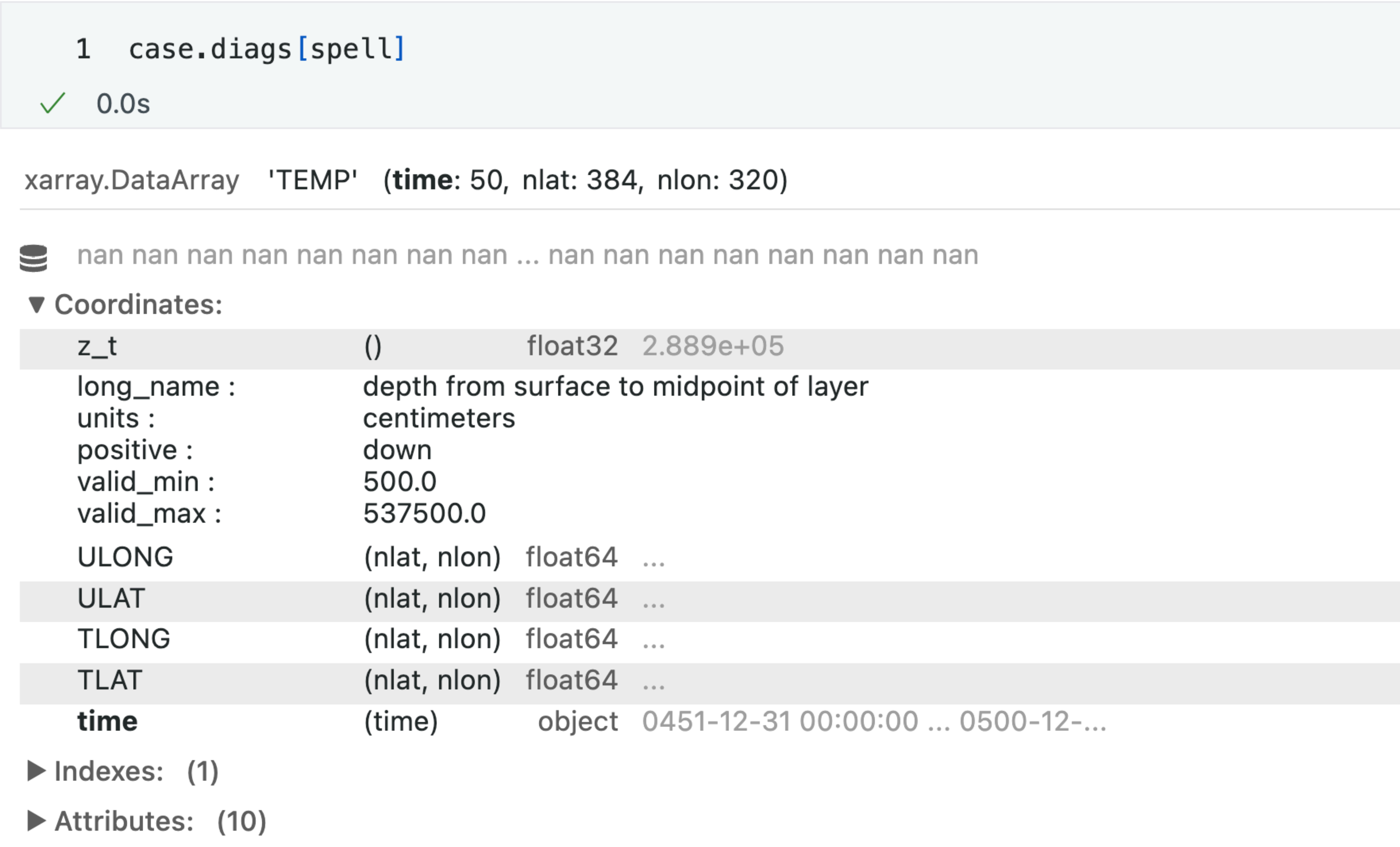
'TEMP.isel(z_t=49):ann'



```
spell = 'TEMP.isel(z_t=49):ann'
fig, ax = case.plot(spell)
```

✓ 28.1s

```
>>> "TEMP.isel(z_t=49):ann" not calculated yet. Calculating now ...
>>> case.ds["TEMP"] created
>>> case.diags["TEMP.isel(z_t=49):ann"] created
```



```
case.diags[spell]
```

✓ 0.0s

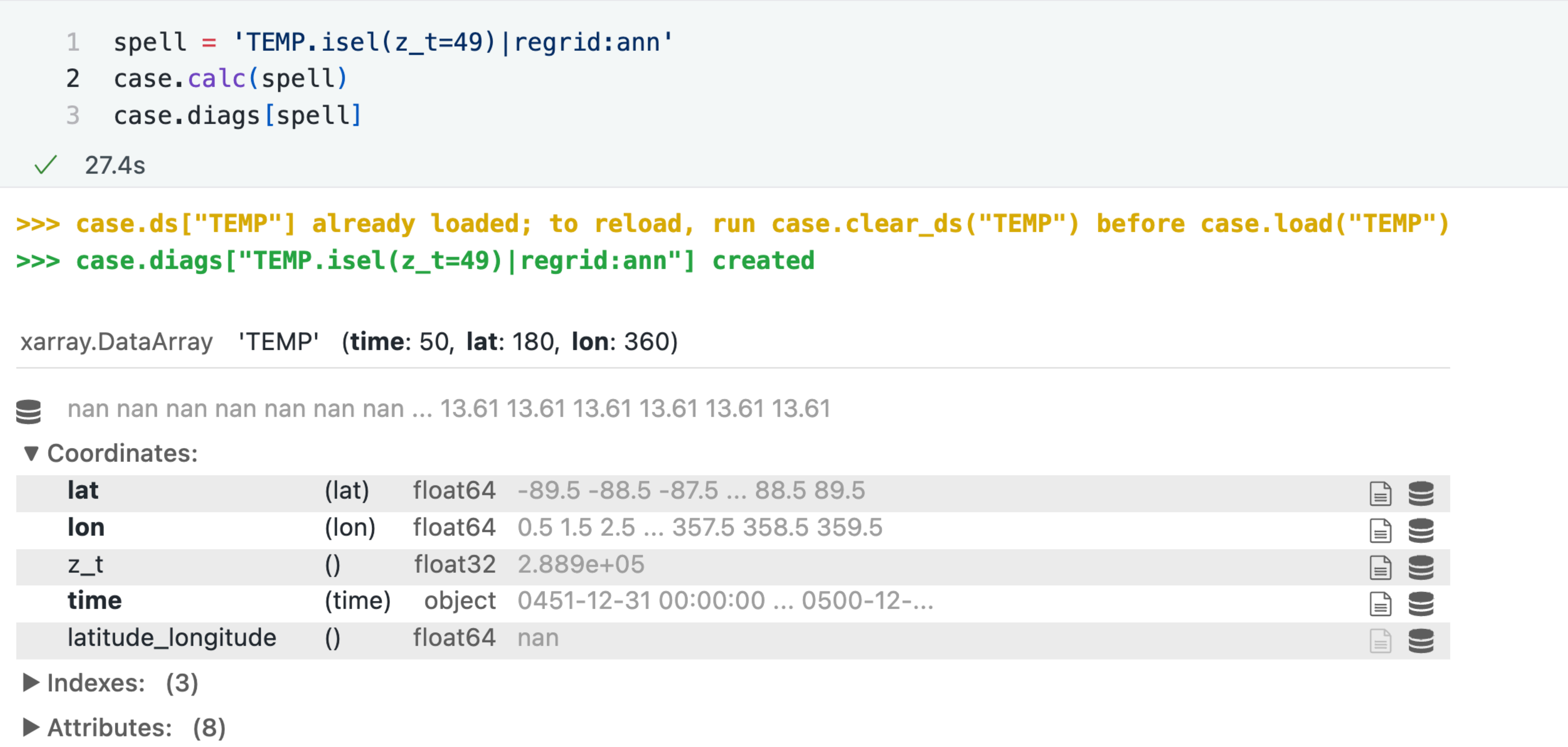
```
xarray.DataArray 'TEMP' (time: 50, nlat: 384, nlon: 320)

nan nan nan nan nan nan nan nan ... nan nan nan nan nan nan nan nan

▼ Coordinates:
   z_t            ()             float32  2.889e+05
   long_name :    depth from surface to midpoint of layer
   units :        centimeters
   positive :     down
   valid_min :    500.0
   valid_max :    537500.0
   ULONG          (nlat, nlon)   float64  ...
   ULAT           (nlat, nlon)   float64  ...
   TLONG          (nlat, nlon)   float64  ...
   TLAT           (nlat, nlon)   float64  ...
   time           (time)         object   0451-12-31 00:00:00 ... 0500-12-...
▶ Indexes: (1)
▶ Attributes: (10)
```

▣ Diagnostic Features (Timeseries)

A “Spell” System

A map of annual Bottom Water Temperature (z_t=49)

'TEMP.isel(z_t=49)|regrid:ann'



```python
spell = 'TEMP.isel(z_t=49)|regrid:ann'
case.calc(spell)
case.diags[spell]
```

✓ 27.4s

```
>>> case.ds["TEMP"] already loaded; to reload, run case.clear_ds("TEMP") before case.load("TEMP")
>>> case.diags["TEMP.isel(z_t=49)|regrid:ann"] created
```

xarray.DataArray 'TEMP' (**time**: 50, **lat**: 180, **lon**: 360)

nan nan nan nan nan nan nan ... 13.61 13.61 13.61 13.61 13.61 13.61

▼ Coordinates:

lat	(lat)	float64	-89.5 -88.5 -87.5 ... 88.5 89.5
lon	(lon)	float64	0.5 1.5 2.5 ... 357.5 358.5 359.5
z_t	()	float32	2.889e+05
time	(time)	object	0451-12-31 00:00:00 ... 0500-12-...
latitude_longitude	()	float64	nan

▶ Indexes: (3)

▶ Attributes: (8)

Diagnostic Features (Timeseries)

A “Spell” System

A map of annual Bottom Water Temperature (z_t=49)

'TEMP.isel(z_t=49)|regrid(dlon=2, dlat=2):ann'

```
spell = 'TEMP.isel(z_t=49)|regrid(dlon=2,dlat=2):ann'
case.calc(spell)
case.diags[spell]
```

✓ 26.4s

```
>>> case.ds["TEMP"] already loaded; to reload, run case.clear_ds("TEMP") before case.load("TEMP")
>>> case.diags["TEMP.isel(z_t=49)|regrid(dlon=2,dlat=2):ann"] created
```

```
xarray.DataArray   'TEMP'   (time: 50, lat: 90, lon: 180)

nan nan nan nan nan nan nan ... 13.61 13.61 13.61 13.61 13.61 13.61

▼ Coordinates:
    lat                  (lat)    float64   -89.0 -87.0 -85.0 ... 87.0 89.0
    lon                  (lon)    float64   1.0 3.0 5.0 ... 355.0 357.0 359.0
    z_t                  ()       float32   2.889e+05
    time                 (time)   object    0451-12-31 00:00:00 ... 0500-12-...
    latitude_longitude   ()       float64   nan
▶ Indexes:   (3)
▶ Attributes:   (8)
```

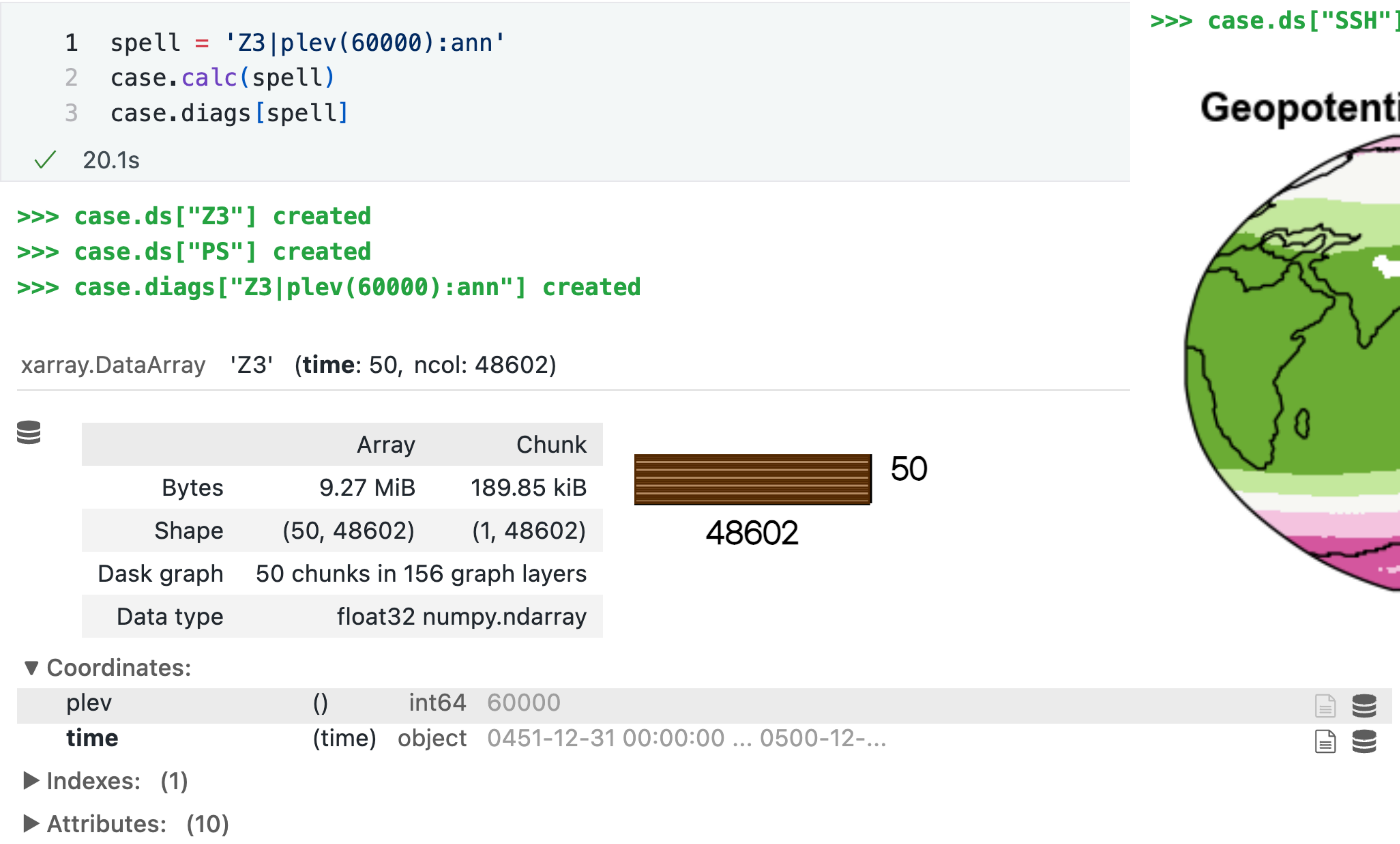
Diagnostic Features (Timeseries)

A “Spell” System

A map of annual 600 hPa Geopotential Height

GeoCAT

'Z3|plev(60000):ann'



```
spell = 'Z3|plev(60000):ann'
case.calc(spell)
case.diags[spell]
```

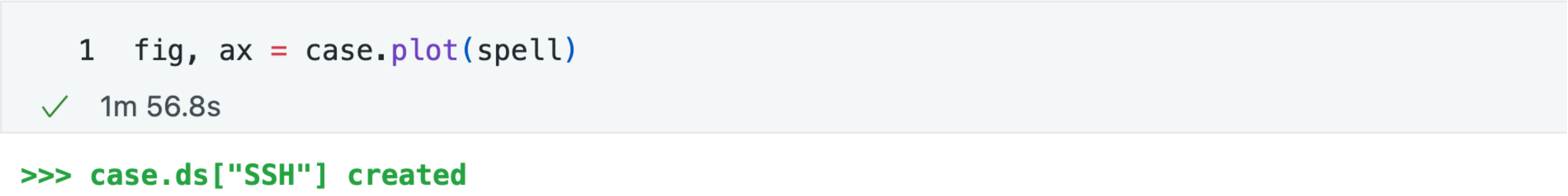
✓ 20.1s

```
>>> case.ds["Z3"] created
>>> case.ds["PS"] created
>>> case.diags["Z3|plev(60000):ann"] created
```

xarray.DataArray 'Z3' (**time**: 50, ncol: 48602)

	Array	Chunk
Bytes	9.27 MiB	189.85 kiB
Shape	(50, 48602)	(1, 48602)
Dask graph	50 chunks in 156 graph layers	
Data type	float32 numpy.ndarray	

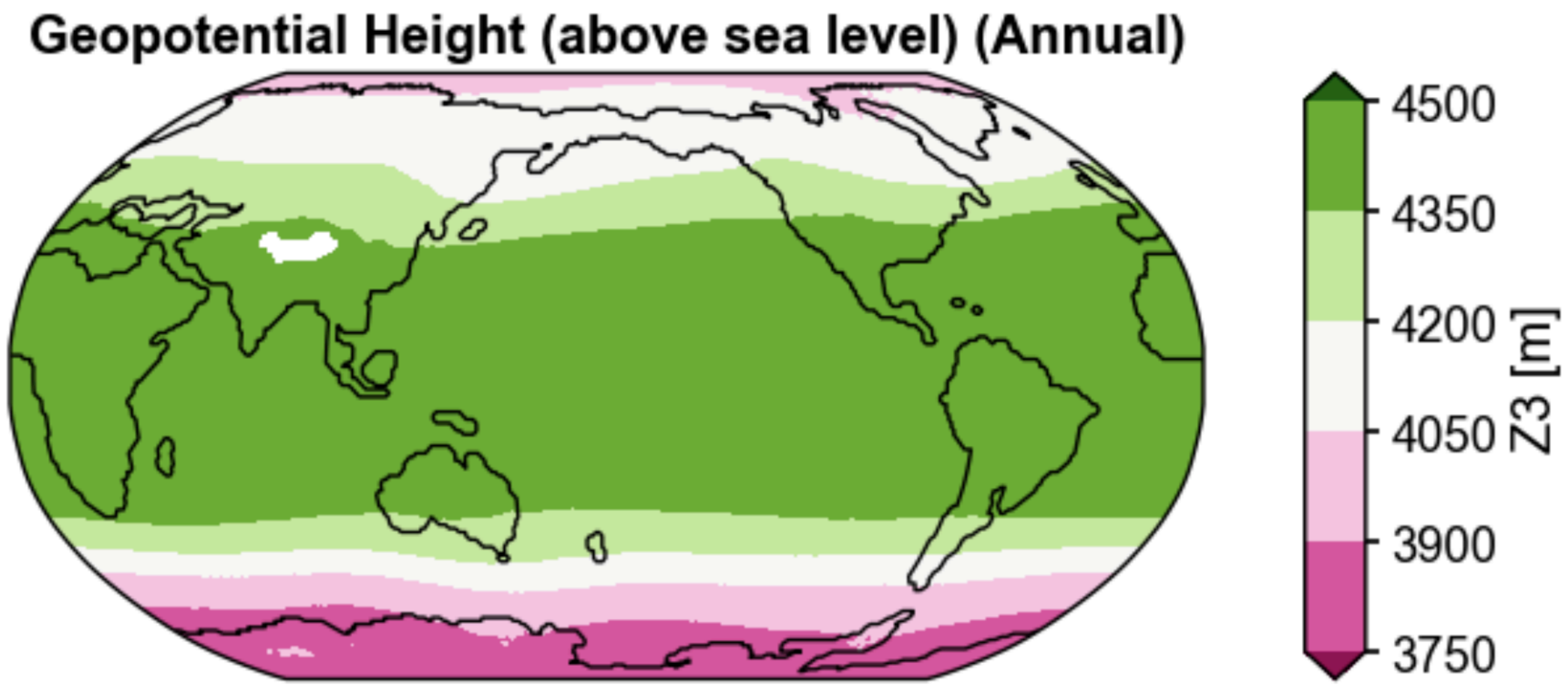
```
▼ Coordinates:
  plev      ()      int64   60000
  time      (time)  object  0451-12-31 00:00:00 ... 0500-12-...
▶ Indexes: (1)
▶ Attributes: (10)
```



```
fig, ax = case.plot(spell)
```

✓ 1m 56.8s

```
>>> case.ds["SSH"] created
```



Geopotential Height (above sea level) (Annual)

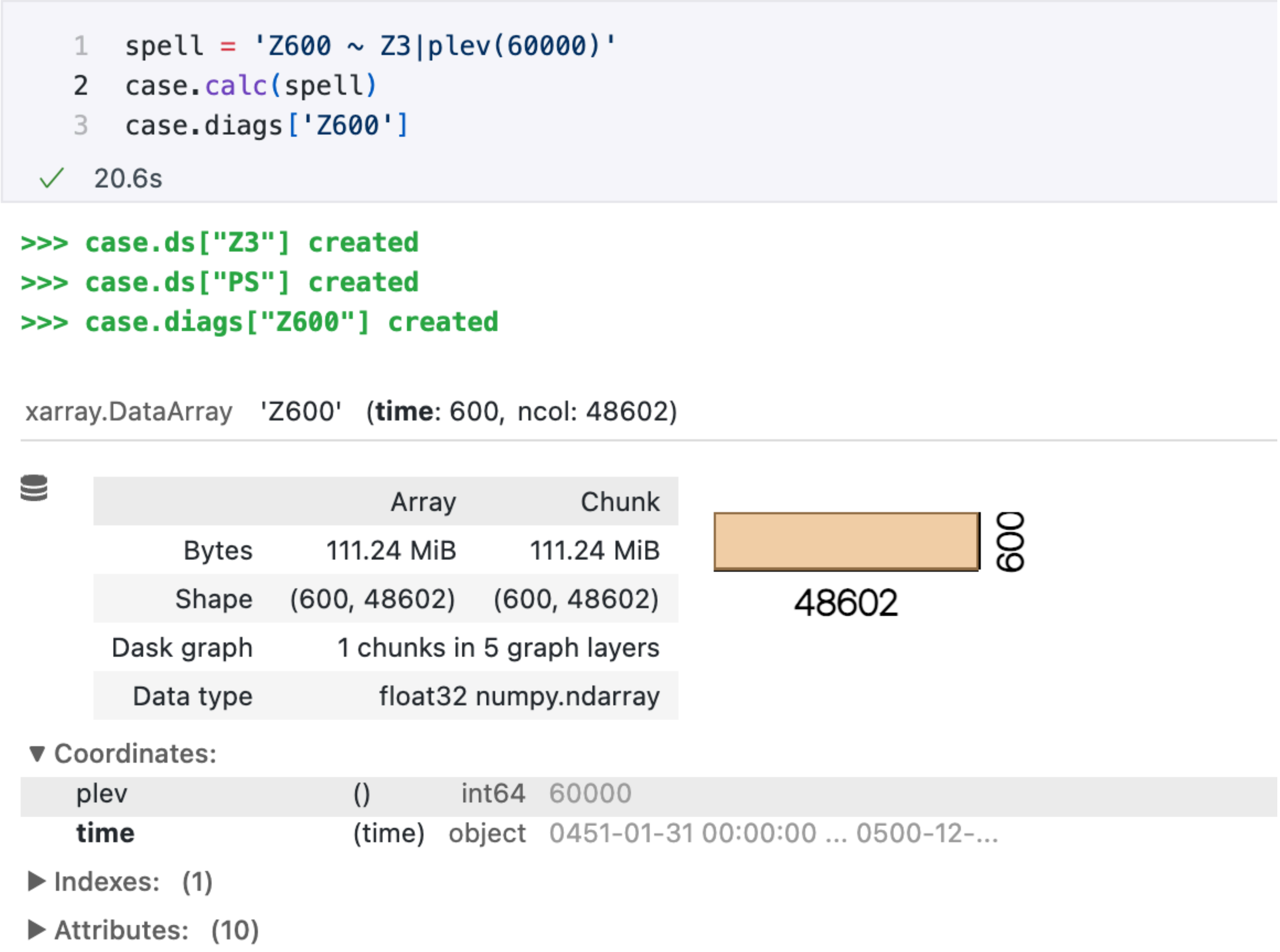
Diagnostic Features (Timeseries)

A “Spell” System

A map of annual 600 hPa Geopotential Height

'Z600 ~ Z3|plev(60000)'

'Z600:ann'



```
spell = 'Z600 ~ Z3|plev(60000)'
case.calc(spell)
case.diags['Z600']
```

✓ 20.6s

```
>>> case.ds["Z3"] created
>>> case.ds["PS"] created
>>> case.diags["Z600"] created
```

xarray.DataArray 'Z600' (**time**: 600, ncol: 48602)

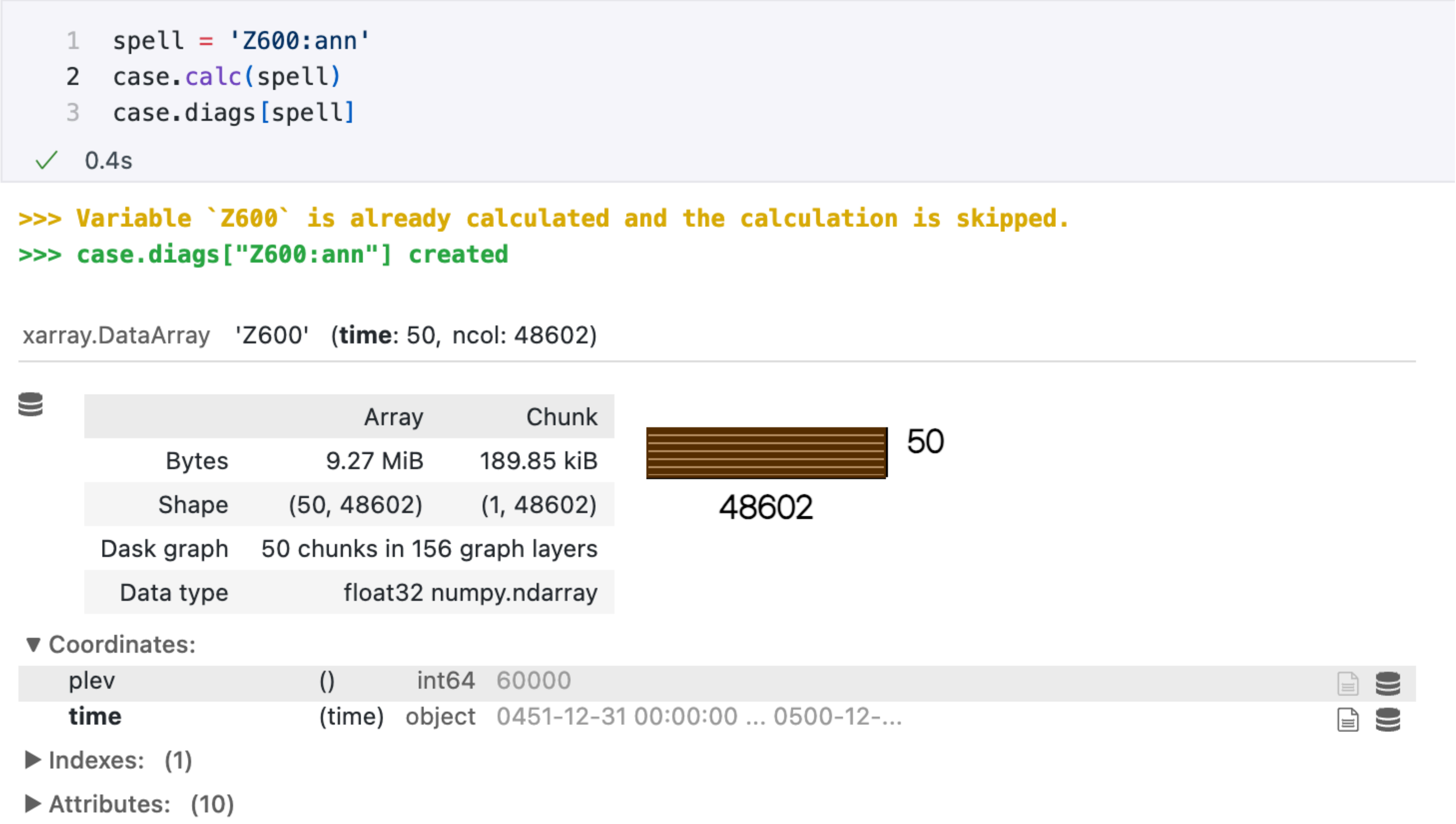
	Array	Chunk
Bytes	111.24 MiB	111.24 MiB
Shape	(600, 48602)	(600, 48602)
Dask graph	1 chunks in 5 graph layers	
Data type	float32 numpy.ndarray	

▼ Coordinates:

plev	()	int64	60000
time	(time)	object	0451-01-31 00:00:00 ... 0500-12-...

▶ Indexes: (1)

▶ Attributes: (10)



```
spell = 'Z600:ann'
case.calc(spell)
case.diags[spell]
```

✓ 0.4s

```
>>> Variable `Z600` is already calculated and the calculation is skipped.
>>> case.diags["Z600:ann"] created
```

xarray.DataArray 'Z600' (**time**: 50, ncol: 48602)

	Array	Chunk
Bytes	9.27 MiB	189.85 kiB
Shape	(50, 48602)	(1, 48602)
Dask graph	50 chunks in 156 graph layers	
Data type	float32 numpy.ndarray	

▼ Coordinates:

plev	()	int64	60000
time	(time)	object	0451-12-31 00:00:00 ... 0500-12-...

▶ Indexes: (1)

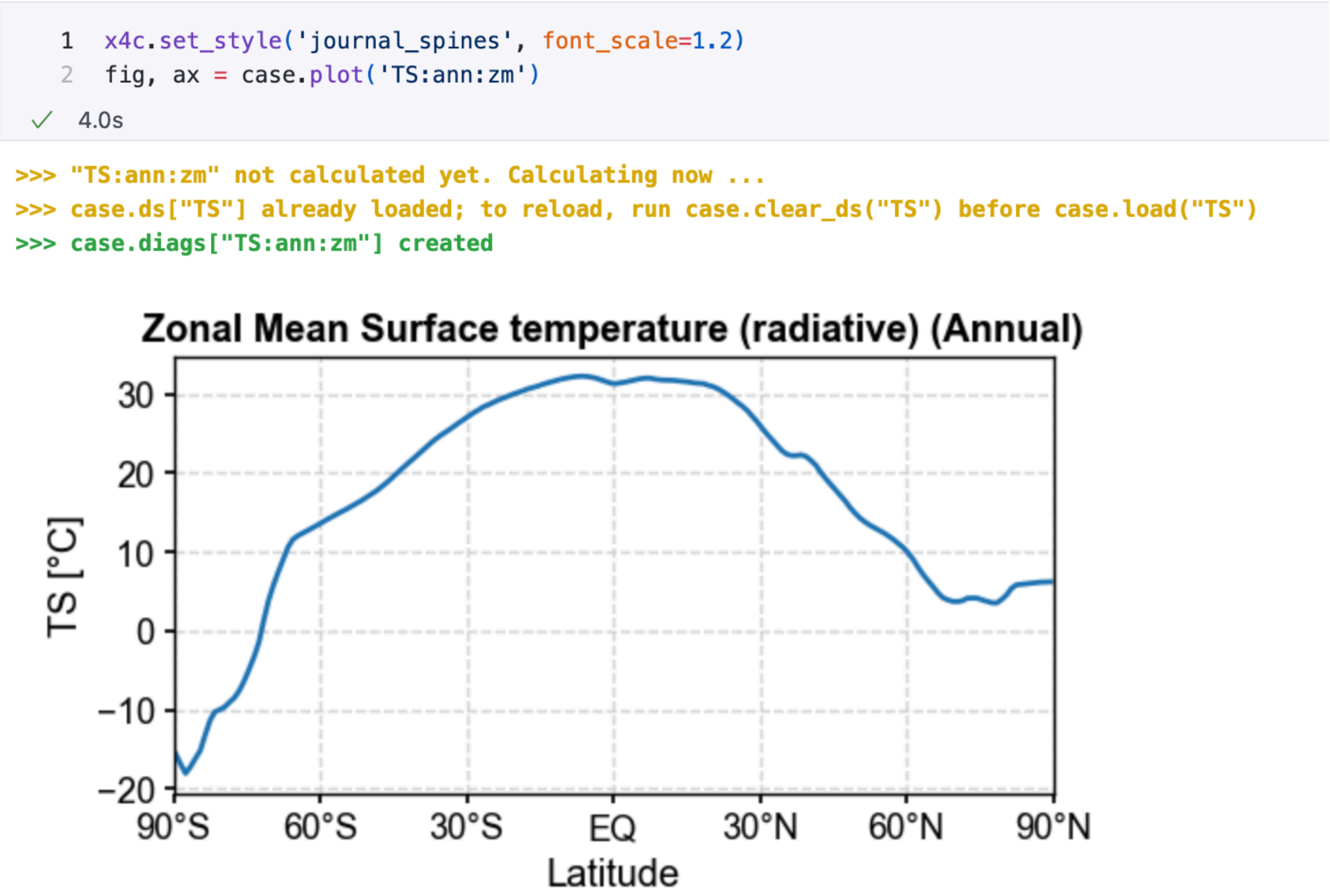
▶ Attributes: (10)

▣ Diagnostic Features (Timeseries)

A “Spell” System

Zonal mean of annual Surface Temperature

'TS:ann:zm'



```
x4c.set_style('journal_spines', font_scale=1.2)
fig, ax = case.plot('TS:ann:zm')
```

✓ 4.0s

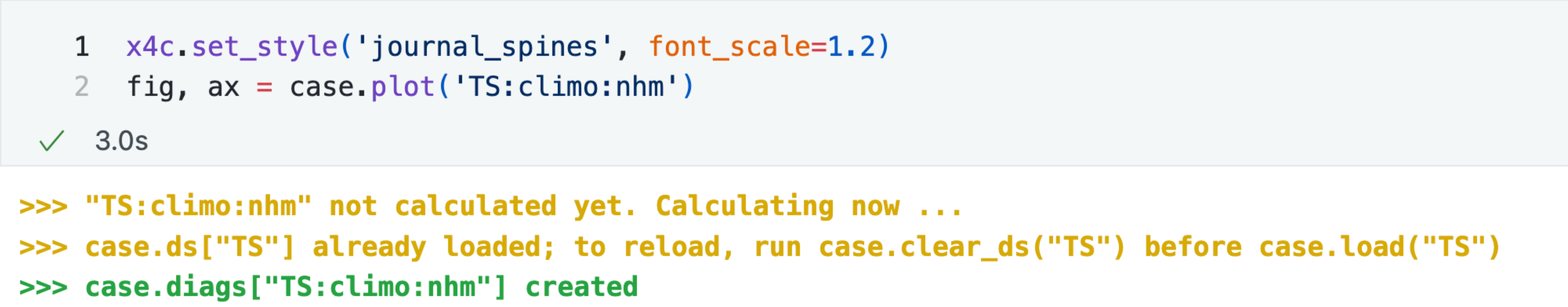
```
>>> "TS:ann:zm" not calculated yet. Calculating now ...
>>> case.ds["TS"] already loaded; to reload, run case.clear_ds("TS") before case.load("TS")
>>> case.diags["TS:ann:zm"] created
```

Diagnostic Features (Timeseries)

A “Spell” System

Seasonal cycle of Northern Hemisphere Surface Temperature

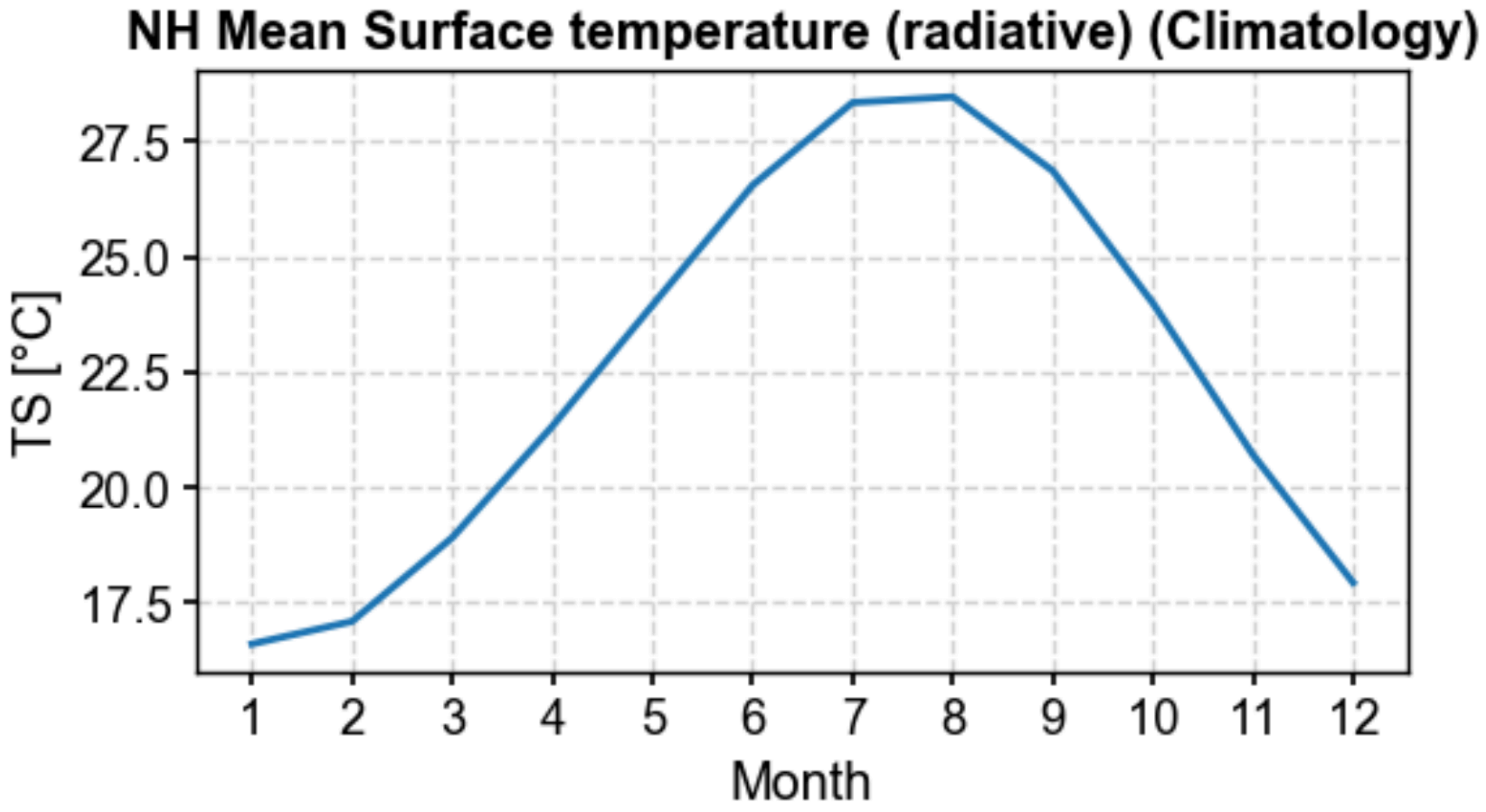
'TS:climo:nhm'



```
x4c.set_style('journal_spines', font_scale=1.2)
fig, ax = case.plot('TS:climo:nhm')
```

✓ 3.0s

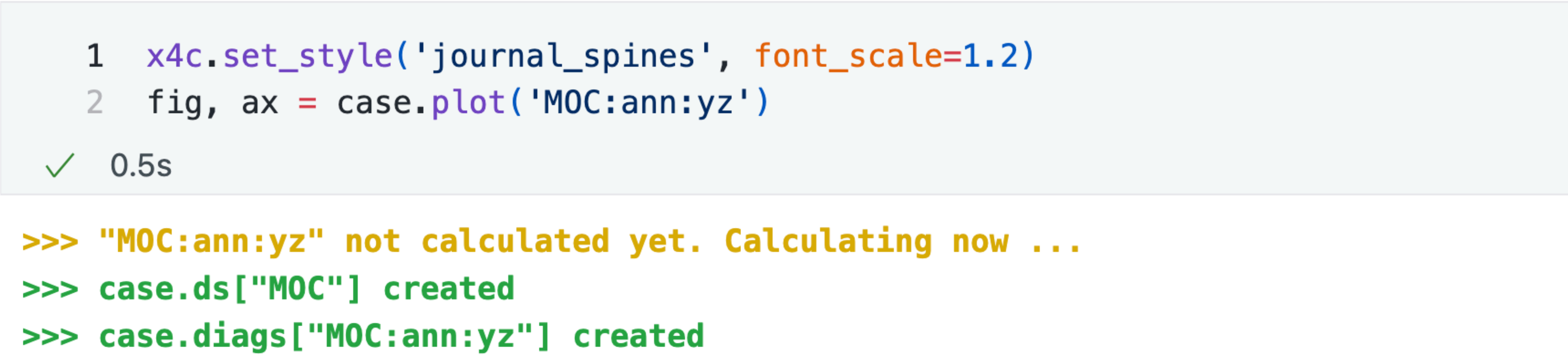
```
>>> "TS:climo:nhm" not calculated yet. Calculating now ...
>>> case.ds["TS"] already loaded; to reload, run case.clear_ds("TS") before case.load("TS")
>>> case.diags["TS:climo:nhm"] created
```



Diagnostic Features (Timeseries)

Zonal mean of annual Meridional Ocean Circulation (MOC)

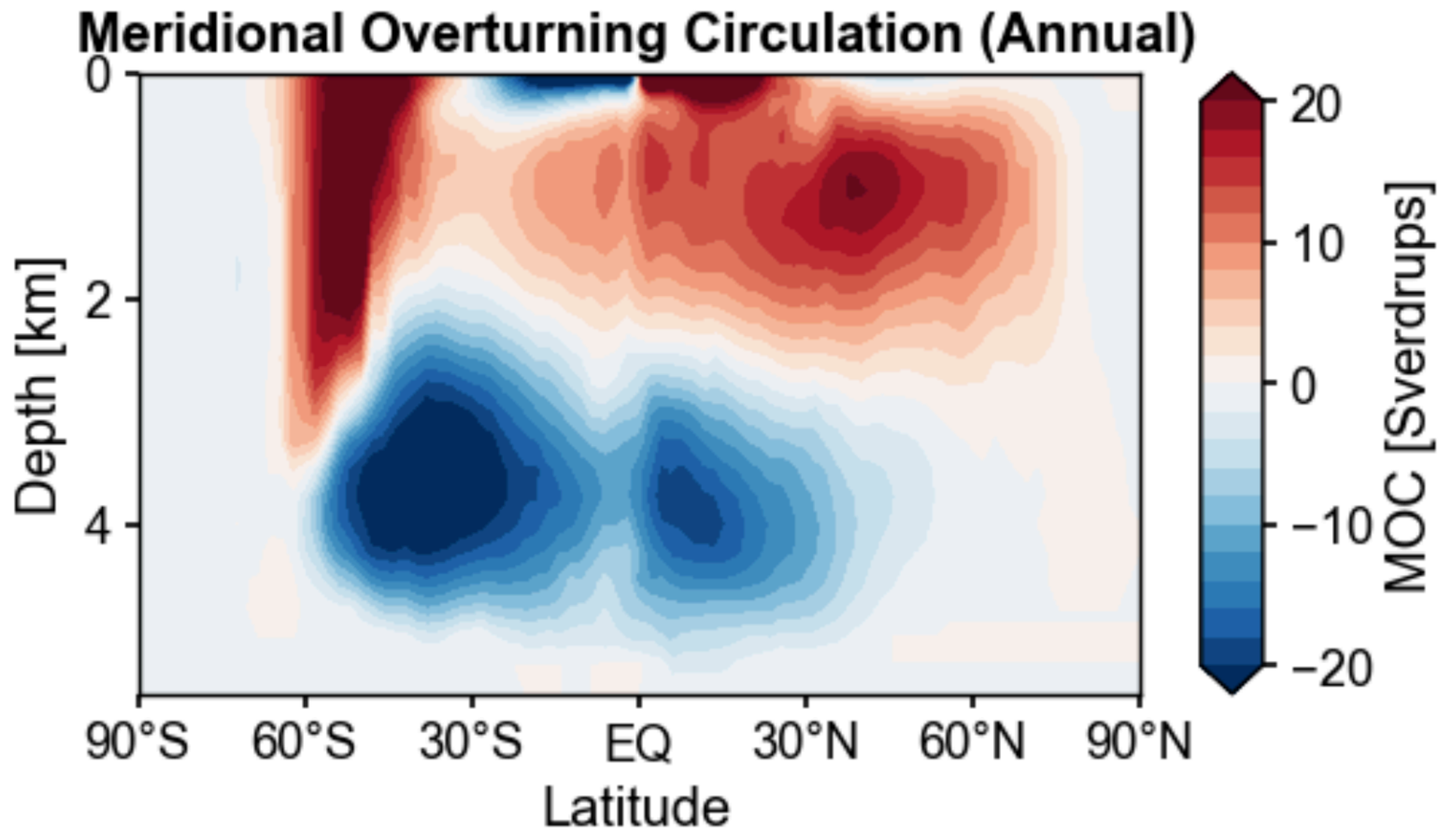
'MOC:ann:yz'



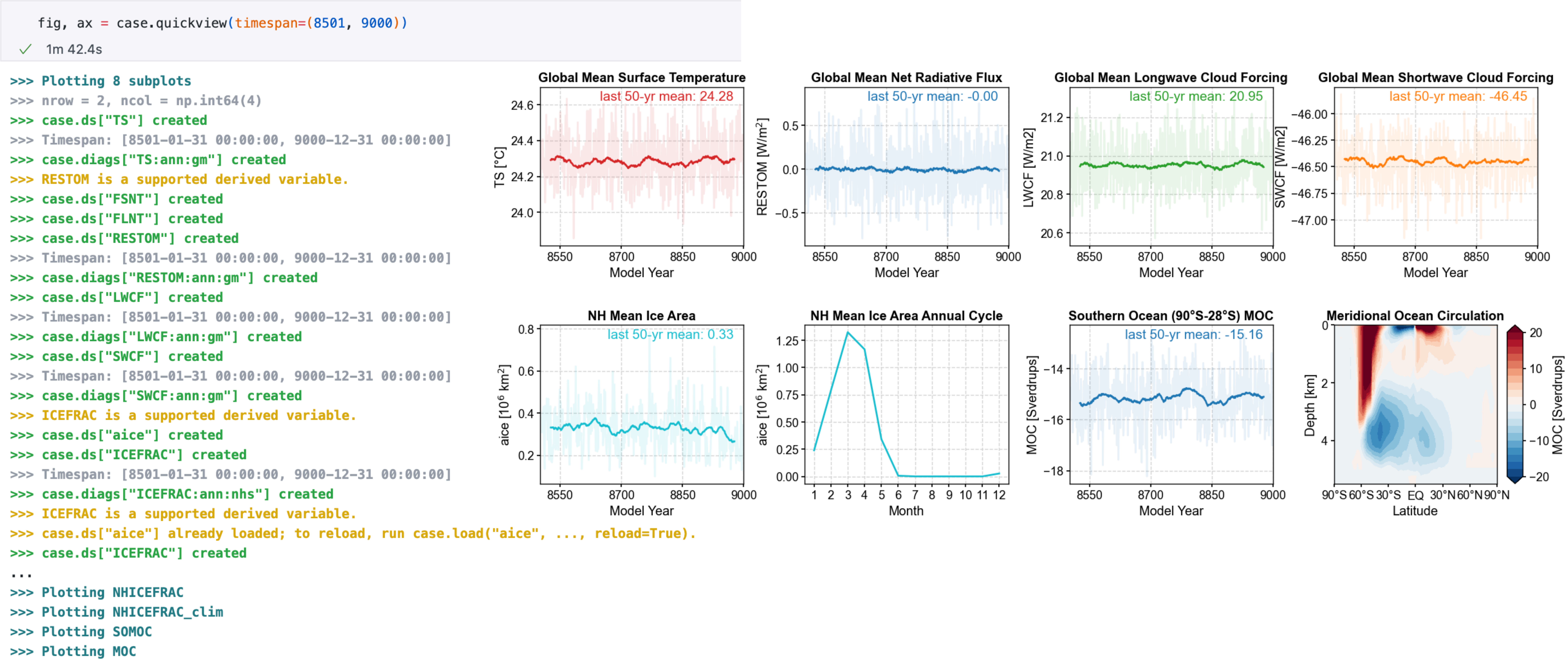
```
x4c.set_style('journal_spines', font_scale=1.2)
fig, ax = case.plot('MOC:ann:yz')
```

✓ 0.5s

```
>>> "MOC:ann:yz" not calculated yet. Calculating now ...
>>> case.ds["MOC"] created
>>> case.diags["MOC:ann:yz"] created
```



Diagnostic Features (Timeseries)



```
fig, ax = case.quickview(timespan=(8501, 9000))
```

✓ 1m 42.4s

```
>>> Plotting 8 subplots
>>> nrow = 2, ncol = np.int64(4)
>>> case.ds["TS"] created
>>> Timespan: [8501-01-31 00:00:00, 9000-12-31 00:00:00]
>>> case.diags["TS:ann:gm"] created
>>> RESTOM is a supported derived variable.
>>> case.ds["FSNT"] created
>>> case.ds["FLNT"] created
>>> case.ds["RESTOM"] created
>>> Timespan: [8501-01-31 00:00:00, 9000-12-31 00:00:00]
>>> case.diags["RESTOM:ann:gm"] created
>>> case.ds["LWCF"] created
>>> Timespan: [8501-01-31 00:00:00, 9000-12-31 00:00:00]
>>> case.diags["LWCF:ann:gm"] created
>>> case.ds["SWCF"] created
>>> Timespan: [8501-01-31 00:00:00, 9000-12-31 00:00:00]
>>> case.diags["SWCF:ann:gm"] created
>>> ICEFRAC is a supported derived variable.
>>> case.ds["aice"] created
>>> case.ds["ICEFRAC"] created
>>> Timespan: [8501-01-31 00:00:00, 9000-12-31 00:00:00]
>>> case.diags["ICEFRAC:ann:nhs"] created
>>> ICEFRAC is a supported derived variable.
>>> case.ds["aice"] already loaded; to reload, run case.load("aice", ..., reload=True).
>>> case.ds["ICEFRAC"] created
...
>>> Plotting NHICEFRAC
>>> Plotting NHICEFRAC_clim
>>> Plotting SOMOC
>>> Plotting MOC
```

Summary

- x4c aims to liberate scientists from technical details, facilitating scientific thinking.
- x4c enables concise gridded data analysis and publication-ready visualization with the .x command.
- x4c.History() makes CESM postprocessing (hist2ts) flexible and transparent.
- x4c.Timeseries(), along with the “spell” system, makes CESM diagnostic and visualization intuitive and efficient.
- x4c could serve as a foundational framework for diagnostic systems such as CUPiD.
- **Next Step:** *AI-enhanced Data Analysis and Visualization*

Porting LLMs to the “spell” system.

<u>Welcome funding support to expand this work!</u>

x4c

— Xarray for CESM —

Installation

- `conda install -c conda-forge xesmf cartopy geocat-comp pop-tools`
- `pip install x4c`

Documentation

- https://ncar.github.io/x4c

Thank you!

(fengzhu@ucar.edu)

Feng Zhu

Paleoclimate Software Engineer II

PPC, CGD, NSF NCAR

Nov 10, 2025

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