RF_model

November 26, 2024

[1]:
```python
import os

os.environ['HDF5_DISABLE_VERSION_CHECK'] = "1"

import datetime as dt
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import netCDF4 as nc
import xarray as xr

from sklearn import metrics
from sklearn.model_selection import GridSearchCV
from sklearn.ensemble import RandomForestRegressor

from eofs.xarray import Eof
from esem import rf_model
from glob import glob

from matplotlib import colors


import matplotlib.pyplot as plt
import cartopy.crs as ccrs

from utils_rf import *
```

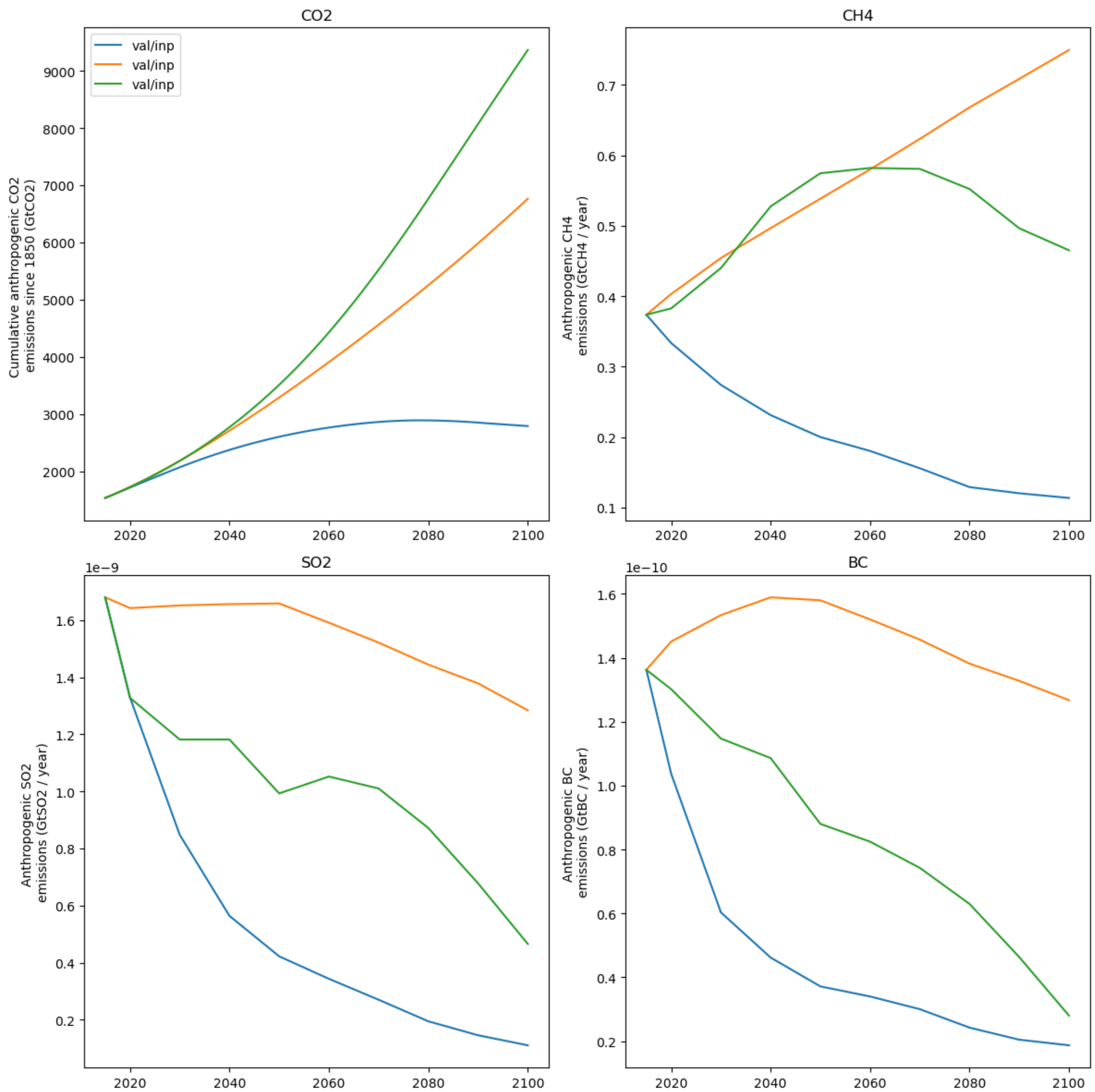
```
2024-11-26 21:35:30.263076: E
external/local_xla/xla/stream_executor/cuda/cuda_fft.cc:477] Unable to register
cuFFT factory: Attempting to register factory for plugin cuFFT when one has
already been registered
WARNING: All log messages before absl::InitializeLog() is called are written to
STDERR
E0000 00:00:1732682130.282512   52358 cuda_dnn.cc:8310] Unable to register cuDNN
factory: Attempting to register factory for plugin cuDNN when one has already
been registered
E0000 00:00:1732682130.288266   52358 cuda_blas.cc:1418] Unable to register
cuBLAS factory: Attempting to register factory for plugin cuBLAS when one has
```

```
already been registered
2024-11-26 21:35:30.347514: I tensorflow/core/platform/cpu_feature_guard.cc:210]
This TensorFlow binary is optimized to use available CPU instructions in
performance-critical operations.
To enable the following instructions: AVX2 AVX512F FMA, in other operations,
rebuild TensorFlow with the appropriate compiler flags.
```

[2]:
```
# path to save the net-cdf file
path_output ='outputs_ssp245_prediction_ESEm.nc'
```

0.0.1 Initial EDA to look at variables

[3]:
```
inputs = ["./train_val/inputs_ssp126.nc", "./train_val/inputs_ssp370.nc","./
 ↪train_val/inputs_ssp585.nc"]
SECONDS_IN_YEAR = 60*60*24*365

fig, axes = plt.subplots(2, 2, figsize=(12,12))

for input in inputs:
    label=input.split('_')[1][:-3]
    X = xr.open_dataset(input)
    x = range(2015, 2101)

    weights = np.cos(np.deg2rad(X.latitude))

    axes[0, 0].plot(x, X['CO2'].data, label=label)
    axes[0, 0].set_ylabel("Cumulative anthropogenic CO2 \nemissions since 1850␣
 ↪(GtCO2)")
    axes[0, 1].plot(x, X['CH4'].data, label=label)
    axes[0, 1].set_ylabel("Anthropogenic CH4 \nemissions (GtCH4 / year)")
    # FIXME: Not sure where this factor of 1000 comes from...! Maybe the CEDS␣
 ↪data is really g/m-2/s?
    axes[1, 0].plot(x, X['SO2'].weighted(weights).sum(['latitude',␣
 ↪'longitude']).data*SECONDS_IN_YEAR*1e-9, label=label)
    axes[1, 0].set_ylabel("Anthropogenic SO2 \nemissions (GtSO2 / year)")
    axes[1, 1].plot(x, X['BC'].weighted(weights).sum(['latitude', 'longitude']).
 ↪data*SECONDS_IN_YEAR*1e-9, label=label)
    axes[1, 1].set_ylabel("Anthropogenic BC \nemissions (GtBC / year)")

axes[0, 0].set_title('CO2')
axes[0, 1].set_title('CH4')
axes[1, 0].set_title('SO2')
axes[1, 1].set_title('BC')
axes[0, 0].legend()
plt.tight_layout()

test_data_path= "./test"+'inputs_ssp245.nc'
```



0.0.2 Random Forest Regressor Model Building

[4]:
```
train_files = [ "historical", "ssp585", "ssp126", "ssp370", ]
# Create training and testing arrays
X, solvers = create_predictor_data(train_files)
Y = create_predictdand_data(train_files)
```

[5]:
```
#parameters dictionary
param_dict_tas = {
    'n_estimators': 250,
    'min_samples_split': 5,
    'min_samples_leaf': 7,
```

```
    'max_depth': 5
}

param_dict_pr = {
    'n_estimators': 150,
    'min_samples_split': 15,
    'min_samples_leaf': 8,
    'max_depth': 40
}

param_dict_pr90 = {
    'n_estimators': 250,
    'min_samples_split': 15,
    'min_samples_leaf': 12,
    'max_depth': 25
}

param_dict_dtr = {
    'n_estimators': 300,
    'min_samples_split': 10,
    'min_samples_leaf': 12,
    'max_depth': 20
}
```

[6]:
```
rf_tas = rf_model(X, Y['tas'], random_state=0, bootstrap=True,␣
 ↪max_features='sqrt', **param_dict_tas)
rf_pr = rf_model(X, Y['pr'], random_state=0, bootstrap=True,␣
 ↪max_features='sqrt', **param_dict_pr)
rf_pr90 = rf_model(X, Y['pr90'], random_state=0, bootstrap=True,␣
 ↪max_features='sqrt',**param_dict_pr90)
rf_dtr = rf_model(X, Y["diurnal_temperature_range"], random_state=0,␣
 ↪bootstrap=True, max_features='sqrt',**param_dict_dtr)

rf_tas.train()
rf_pr.train()
rf_pr90.train()
rf_dtr.train()
```

```
2024-11-26 21:35:36.893152: E
external/local_xla/xla/stream_executor/cuda/cuda_driver.cc:152] failed call to
cuInit: INTERNAL: CUDA error: Failed call to cuInit: CUDA_ERROR_NO_DEVICE: no
CUDA-capable device is detected
```

[7]:
```
## Test on SSP245 pathway

X_test = get_test_data('ssp245', solvers)
Y_test = create_predictdand_data_test(['ssp245'])
```

```
tas_truth = Y_test["tas"]
pr_truth = Y_test["pr"]
pr90_truth = Y_test["pr90"]
dtr_truth = Y_test["diurnal_temperature_range"]
```

[8]:
```
m_out_tas, _ = rf_tas.predict(X_test)
m_out_pr, _ = rf_pr.predict(X_test)
m_out_pr90, _ = rf_pr90.predict(X_test)
m_out_dtr, _ = rf_dtr.predict(X_test)
```

[9]:
```
xr_output = xr.Dataset(dict(tas=m_out_tas, pr=m_out_pr, pr90=m_out_pr90,␣
 ↪diurnal_temperature_range=m_out_dtr)).assign_coords(time=m_out_tas.sample +␣
 ↪2014)
#save output to net-cdf file
xr_output.to_netcdf(path_output,'w')
```

0.0.3 Testing out predictions with test set

[10]:
```
print(f"RMSE: {get_rmse(tas_truth[35:], m_out_tas[35:]).mean()}")
print("\n")

print(f"RMSE: {get_rmse(dtr_truth[35:], m_out_dtr[35:]).mean()}")
print("\n")

print(f"RMSE: {get_rmse(pr_truth[35:], m_out_pr[35:]).mean()}")
print("\n")

print(f"RMSE: {get_rmse(pr90_truth[35:], m_out_pr90[35:]).mean()}")
```

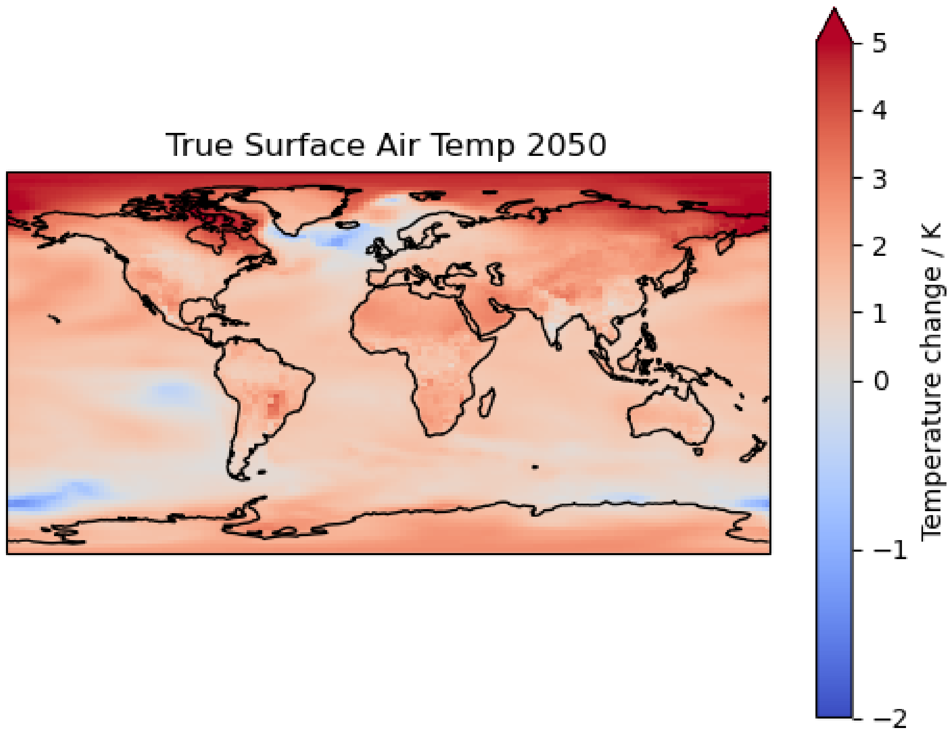
```
RMSE: 0.6823172244093356


RMSE: 0.16537489851670092


RMSE: 0.5578336782743653


RMSE: 1.5880423328622344
```

0.0.4 Comparing emulated results of RF model to True Results Graphically (Year 2050)

True vs Emulated Surface Air Temperature

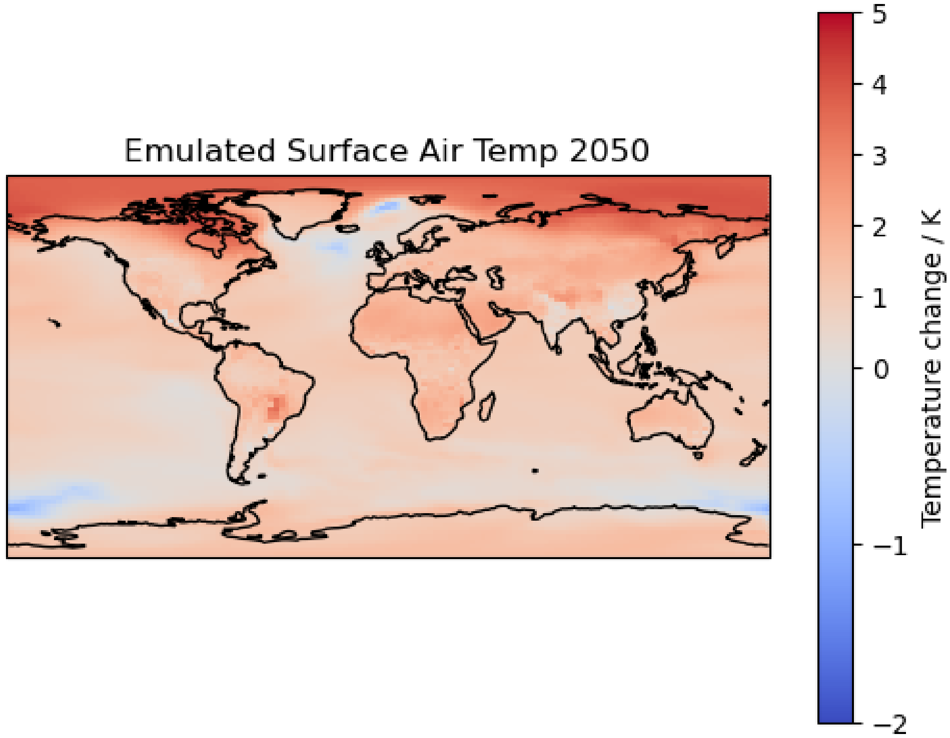
[11]:
```
divnorm=colors.TwoSlopeNorm(vmin=-2., vcenter=0., vmax=5)

ax = plt.axes(projection=ccrs.PlateCarree())
tas_truth.sel(time=2050).plot(cmap="coolwarm", norm=divnorm,
                              cbar_kwargs={"label":"Temperature change / K"})
ax.set_title("True Surface Air Temp 2050")
ax.coastlines()
# plt.show()
```

[11]:
```
<cartopy.mpl.feature_artist.FeatureArtist at 0x15396cf6fd00>
```



[12]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
m_out_tas.sel(sample=35).plot(cmap="coolwarm", norm=divnorm,
                              cbar_kwargs={"label":"Temperature change / K"})
ax.set_title("Emulated Surface Air Temp 2050")
ax.coastlines()
# plt.show()
```

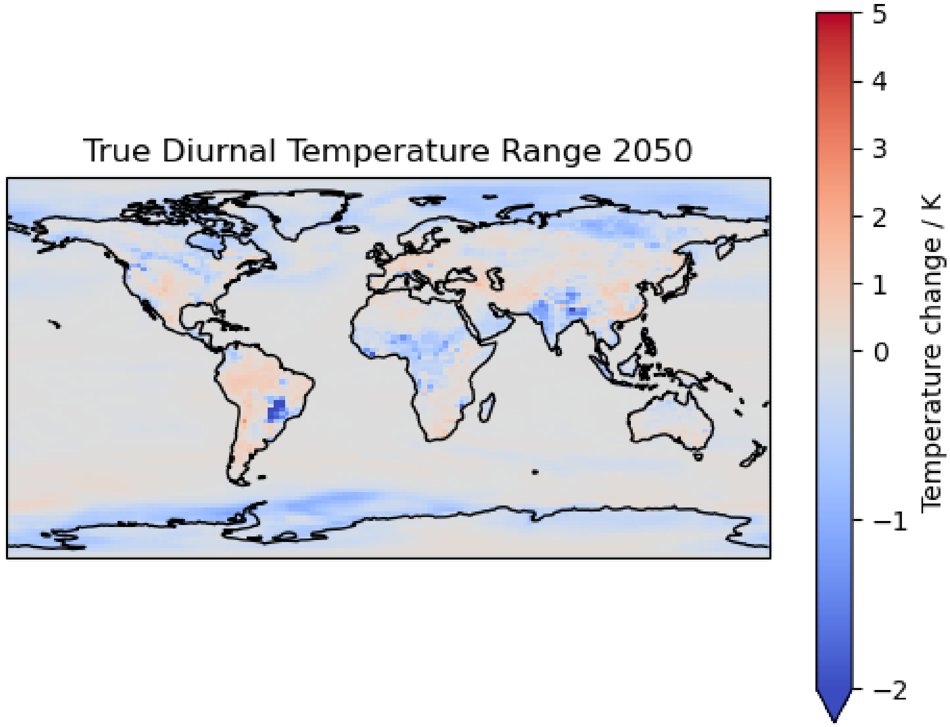
[12]:
```
<cartopy.mpl.feature_artist.FeatureArtist at 0x15396c671420>
```



True vs Emulated Diurnal Temperature Range

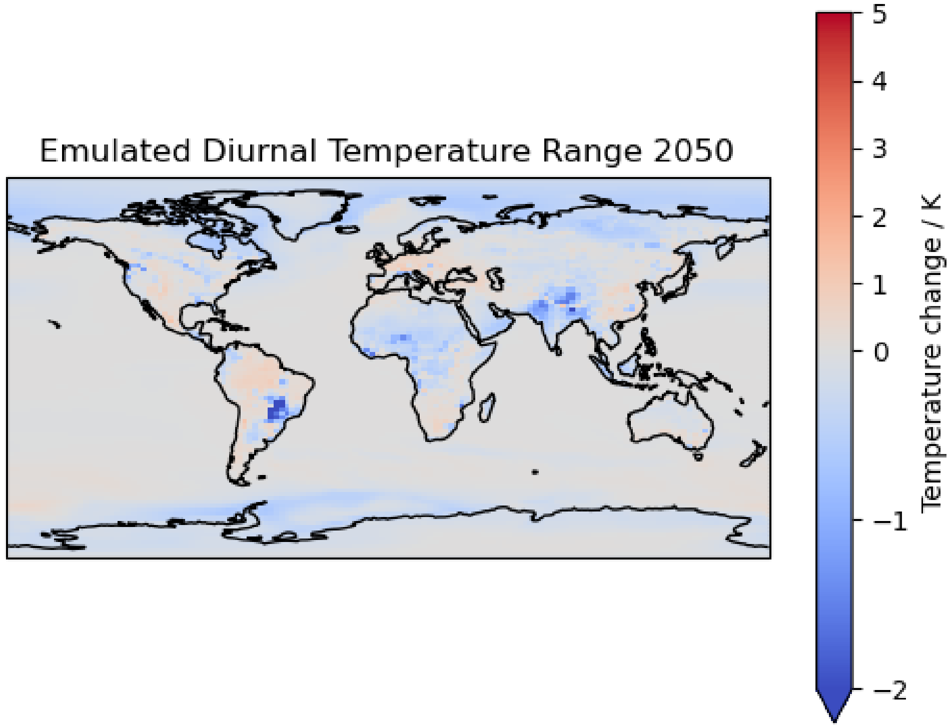
[13]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
dtr_truth.sel(time=2050).plot(cmap="coolwarm", norm=divnorm,
                              cbar_kwargs={"label":"Temperature change / K"})
ax.set_title("True Diurnal Temperature Range 2050")
ax.coastlines()
```

[13]: <cartopy.mpl.feature_artist.FeatureArtist at 0x15396c52a380>



[14]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
m_out_dtr.sel(sample=35).plot(cmap="coolwarm", norm=divnorm,
                              cbar_kwargs={"label":"Temperature change / K"})
ax.set_title("Emulated Diurnal Temperature Range 2050")
ax.coastlines()
```

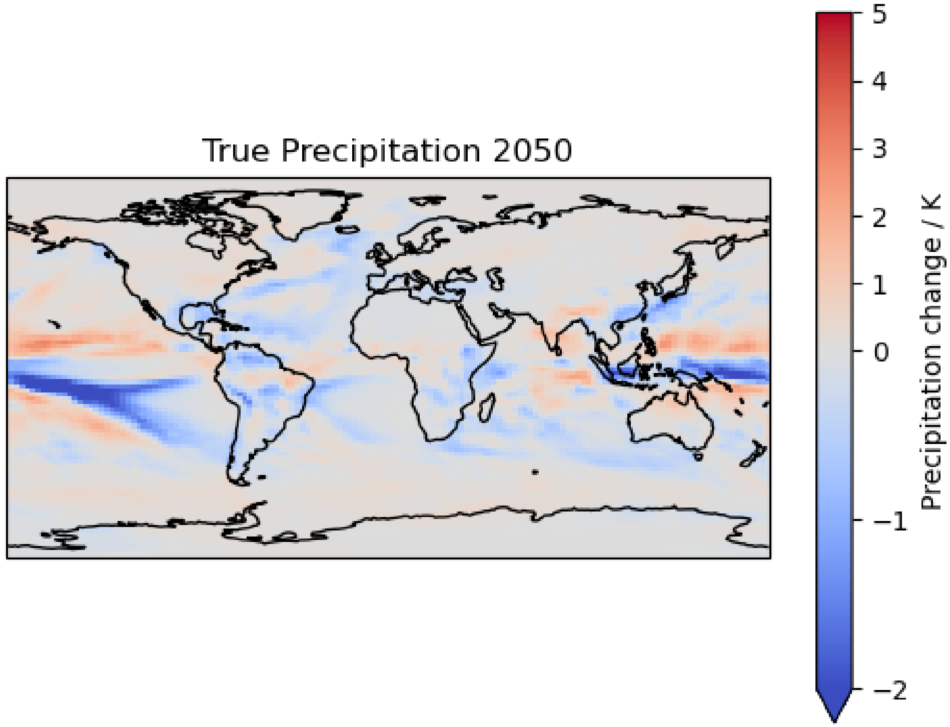
[14]: <cartopy.mpl.feature_artist.FeatureArtist at 0x15396c5e39d0>



True vs Emulated Percipitation

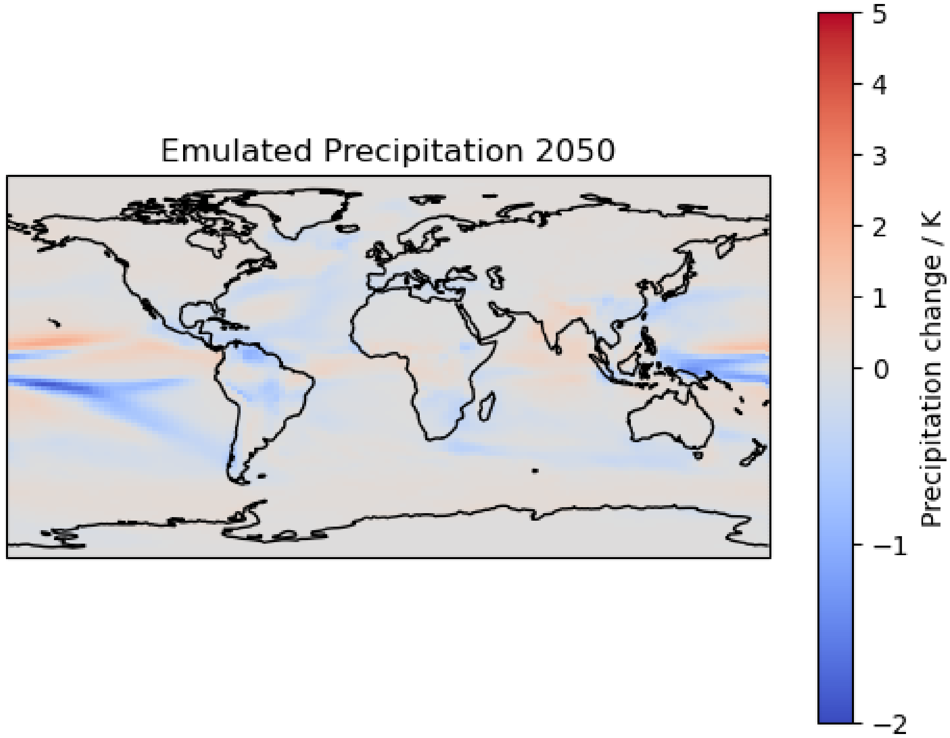
[15]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
pr_truth.sel(time=2050).plot(cmap="coolwarm", norm=divnorm,
                              cbar_kwargs={"label":"Precipitation change / K"})
ax.set_title("True Precipitation 2050")
ax.coastlines()
```

[15]: <cartopy.mpl.feature_artist.FeatureArtist at 0x15396c39e980>



[16]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
m_out_pr.sel(sample=35).plot(cmap="coolwarm", norm=divnorm,
                             cbar_kwargs={"label":"Precipitation change / K"})
ax.set_title("Emulated Precipitation 2050")
ax.coastlines()
```

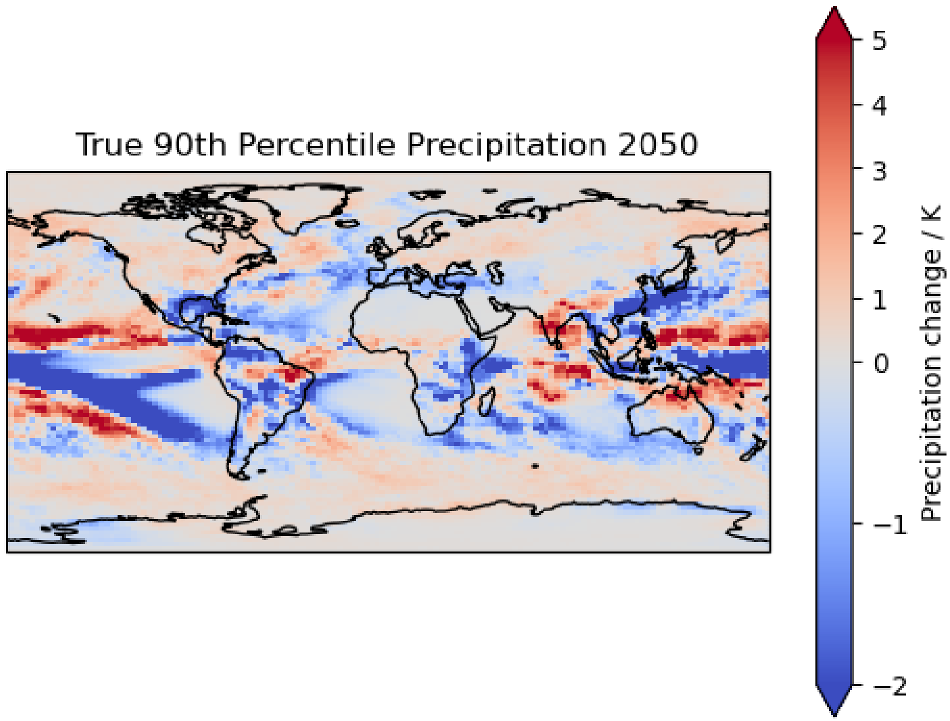
[16]: <cartopy.mpl.feature_artist.FeatureArtist at 0x15396c4a0f70>



True vs Emulated 90th Percentile Percipitation

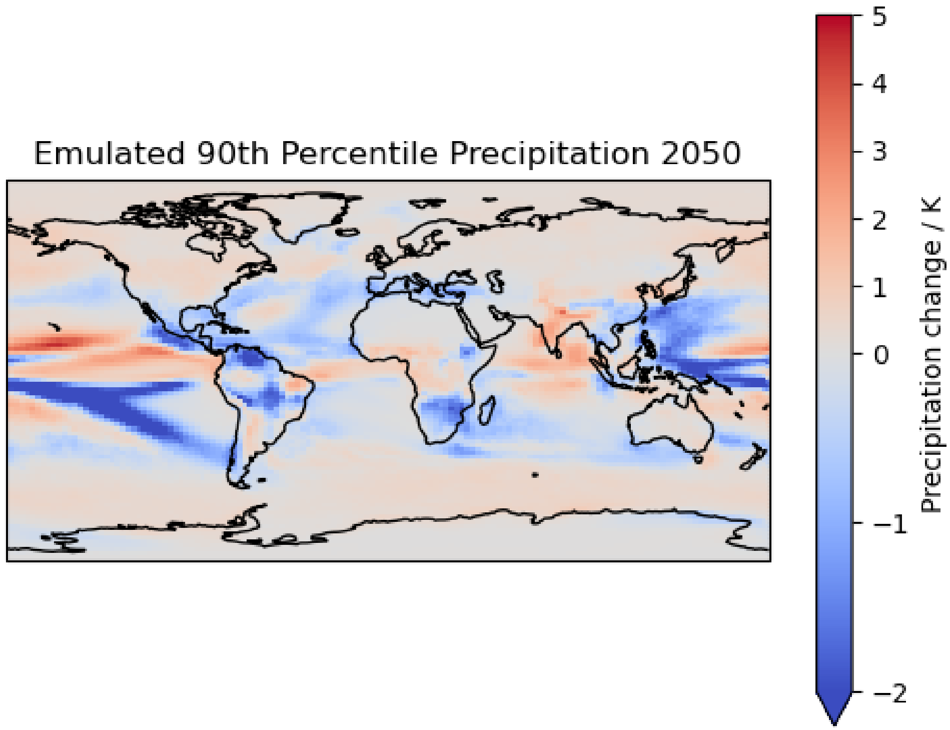
[17]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
pr90_truth.sel(time=2050).plot(cmap="coolwarm", norm=divnorm,
                               cbar_kwargs={"label":"Precipitation change / K"})
ax.set_title("True 90th Percentile Precipitation 2050")
ax.coastlines()
```

[17]: <cartopy.mpl.feature_artist.FeatureArtist at 0x15396c5071c0>



[18]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
m_out_pr90.sel(sample=35).plot(cmap="coolwarm", norm=divnorm,
                              cbar_kwargs={"label":"Precipitation change / K"})
ax.set_title("Emulated 90th Percentile Precipitation 2050")
ax.coastlines()
```

[18]: <cartopy.mpl.feature_artist.FeatureArtist at 0x15396c2de2c0>



0.0.5 Running models again with more optimized hyperparameter inputs

[19]:
```
X, solvers = create_predictor_data(train_files)
Y = create_predictdand_data(train_files)
```

[20]:
```
# only changed tas and pr parameters as others got worse
param_dict_tas_opt = {
    'n_estimators': 250,
    'min_samples_split': 15,
    'min_samples_leaf': 10,
    'max_depth': 10
}

param_dict_pr_opt = {
    'n_estimators': 250,
    'min_samples_split': 20,
    'min_samples_leaf': 10,
    'max_depth': 45
}

param_dict_pr90_opt = {
    'n_estimators': 250,
    'min_samples_split': 15,
```

```
    'min_samples_leaf': 12,
    'max_depth': 25
}

param_dict_dtr_opt = {
    'n_estimators': 300,
    'min_samples_split': 10,
    'min_samples_leaf': 12,
    'max_depth': 20
}
```

[21]:
```
# Used log2 instead of sqrt for max_features

rf_tas = rf_model(X, Y['tas'], random_state=0, bootstrap=True,␣
 ↪max_features='log2', **param_dict_tas_opt)
rf_pr = rf_model(X, Y['pr'], random_state=0, bootstrap=True,␣
 ↪max_features='log2', **param_dict_pr_opt)
rf_pr90 = rf_model(X, Y['pr90'], random_state=0, bootstrap=True,␣
 ↪max_features='log2',**param_dict_pr90_opt)
rf_dtr = rf_model(X, Y["diurnal_temperature_range"], random_state=0,␣
 ↪bootstrap=True, max_features='log2',**param_dict_dtr_opt)

rf_tas.train()
rf_pr.train()
rf_pr90.train()
rf_dtr.train()
```

[22]:
```
## Test on SSP245

X_test = get_test_data('ssp245', solvers)
Y_test = create_predictdand_data_test(['ssp245'])

tas_truth = Y_test["tas"]
pr_truth = Y_test["pr"]
pr90_truth = Y_test["pr90"]
dtr_truth = Y_test["diurnal_temperature_range"]
```

[23]:
```
# predictions for each variable
m_out_tas, _ = rf_tas.predict(X_test)
m_out_pr, _ = rf_pr.predict(X_test)
m_out_pr90, _ = rf_pr90.predict(X_test)
m_out_dtr, _ = rf_dtr.predict(X_test)
```

[24]:
```
path_output = "outputs_ssp245_prediction_hyper_change.nc"
xr_output = xr.Dataset(dict(tas=m_out_tas, pr=m_out_pr, pr90=m_out_pr90,␣
 ↪diurnal_temperature_range=m_out_dtr)).assign_coords(time=m_out_tas.sample +␣
 ↪2014)
```

```
#save output to net-cdf file
xr_output.to_netcdf(path_output,'w')
```

0.0.6 Testing out predictions with test set

[25]:
```
print(f"RMSE: {get_rmse(tas_truth[35:], m_out_tas[35:]).mean()}")
print("\n")

print(f"RMSE: {get_rmse(dtr_truth[35:], m_out_dtr[35:]).mean()}")
print("\n")

print(f"RMSE: {get_rmse(pr_truth[35:], m_out_pr[35:]).mean()}")
print("\n")

print(f"RMSE: {get_rmse(pr90_truth[35:], m_out_pr90[35:]).mean()}")
```

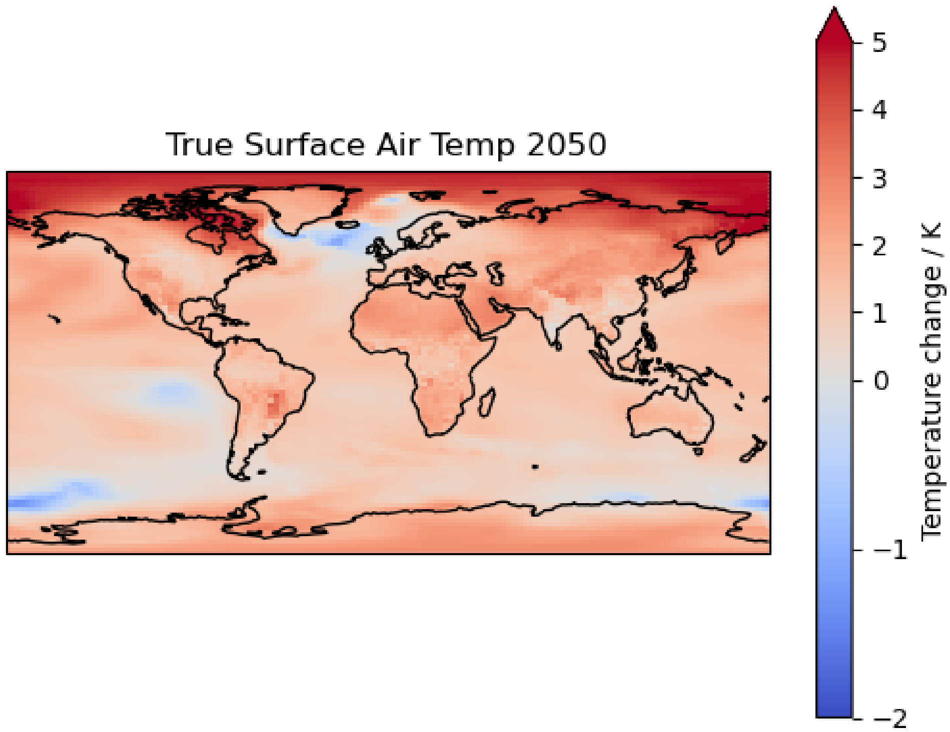
```
RMSE: 0.6602302805441683


RMSE: 0.16537489851670092


RMSE: 0.5494657322063173


RMSE: 1.5880423328622344
```

0.0.7 Comparing emulated results of New RF model to True Results Graphically (Year 2050)

True vs Emulated Surface Air Temperature

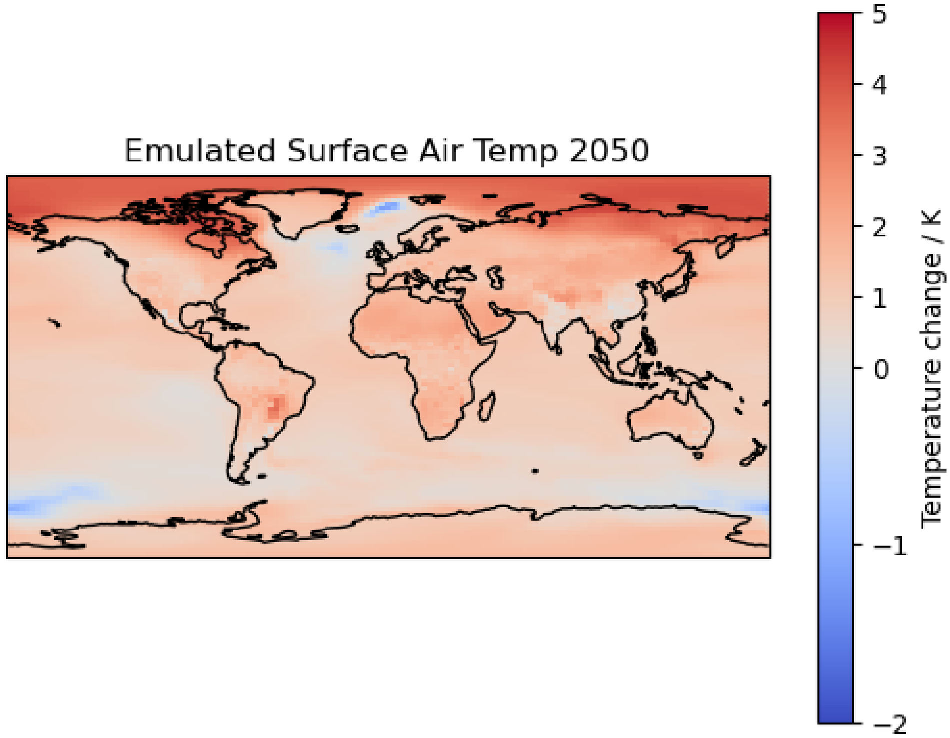
[26]:
```
divnorm=colors.TwoSlopeNorm(vmin=-2., vcenter=0., vmax=5)

ax = plt.axes(projection=ccrs.PlateCarree())
tas_truth.sel(time=2050).plot(cmap="coolwarm", norm=divnorm,
                              cbar_kwargs={"label":"Temperature change / K"})
ax.set_title("True Surface Air Temp 2050")
ax.coastlines()
# plt.show()
```

[26]:
```
<cartopy.mpl.feature_artist.FeatureArtist at 0x15396cf13970>
```



[27]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
m_out_tas.sel(sample=35).plot(cmap="coolwarm", norm=divnorm,
                              cbar_kwargs={"label":"Temperature change / K"})
ax.set_title("Emulated Surface Air Temp 2050")
ax.coastlines()
# plt.show()
```

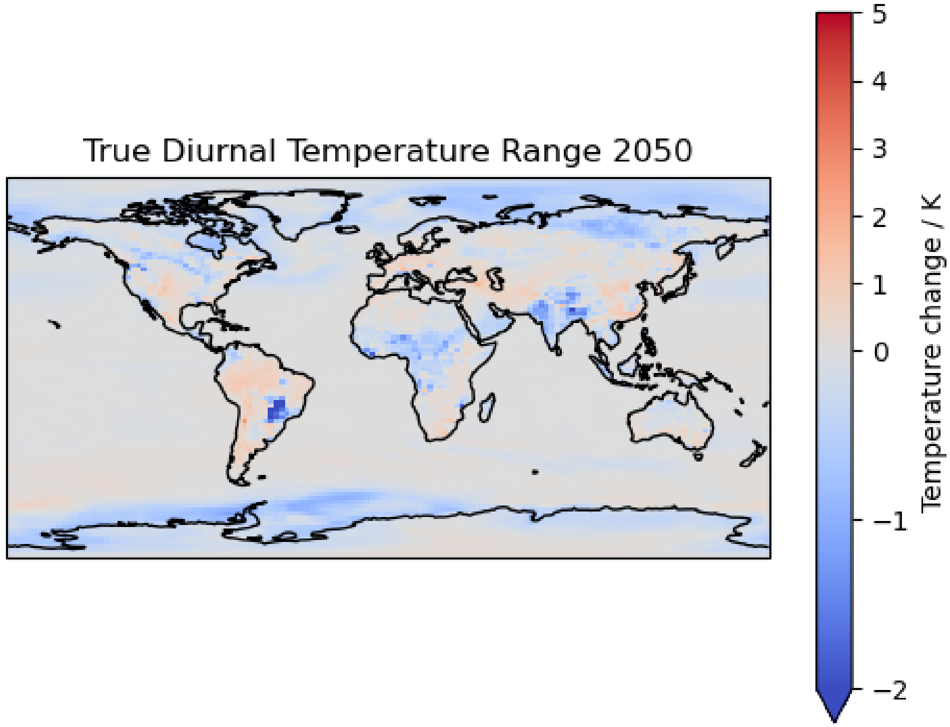
[27]: <cartopy.mpl.feature_artist.FeatureArtist at 0x15396c0b54b0>



True vs Emulated Diurnal Temperature Range

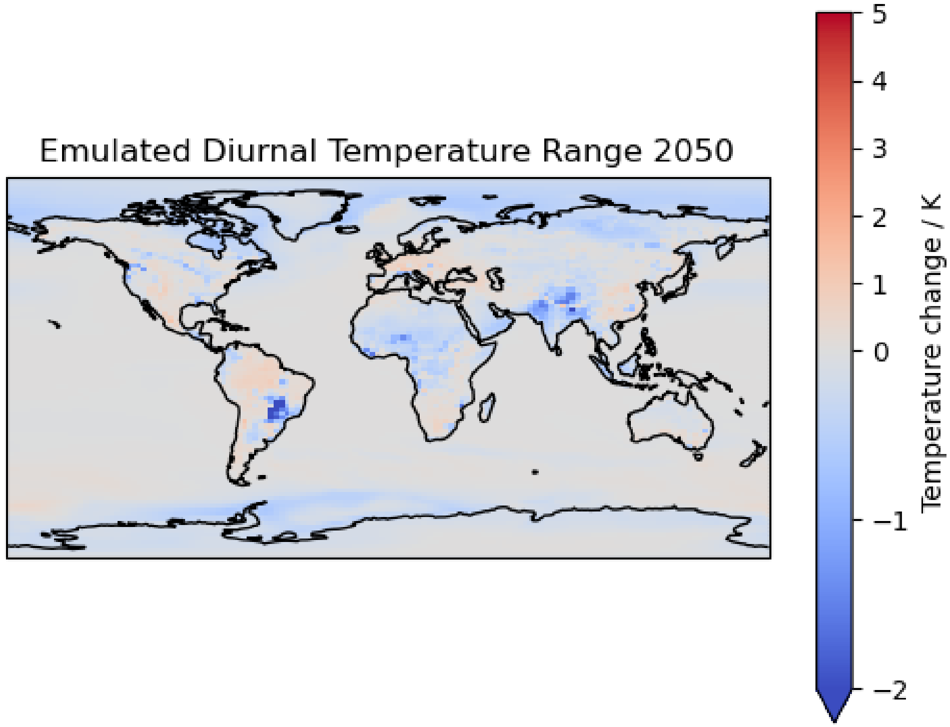
[28]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
dtr_truth.sel(time=2050).plot(cmap="coolwarm", norm=divnorm,
                              cbar_kwargs={"label":"Temperature change / K"})
ax.set_title("True Diurnal Temperature Range 2050")
ax.coastlines()
```

[28]:
```
<cartopy.mpl.feature_artist.FeatureArtist at 0x15396c3761a0>
```



[29]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
m_out_dtr.sel(sample=35).plot(cmap="coolwarm", norm=divnorm,
                              cbar_kwargs={"label":"Temperature change / K"})
ax.set_title("Emulated Diurnal Temperature Range 2050")
ax.coastlines()
```

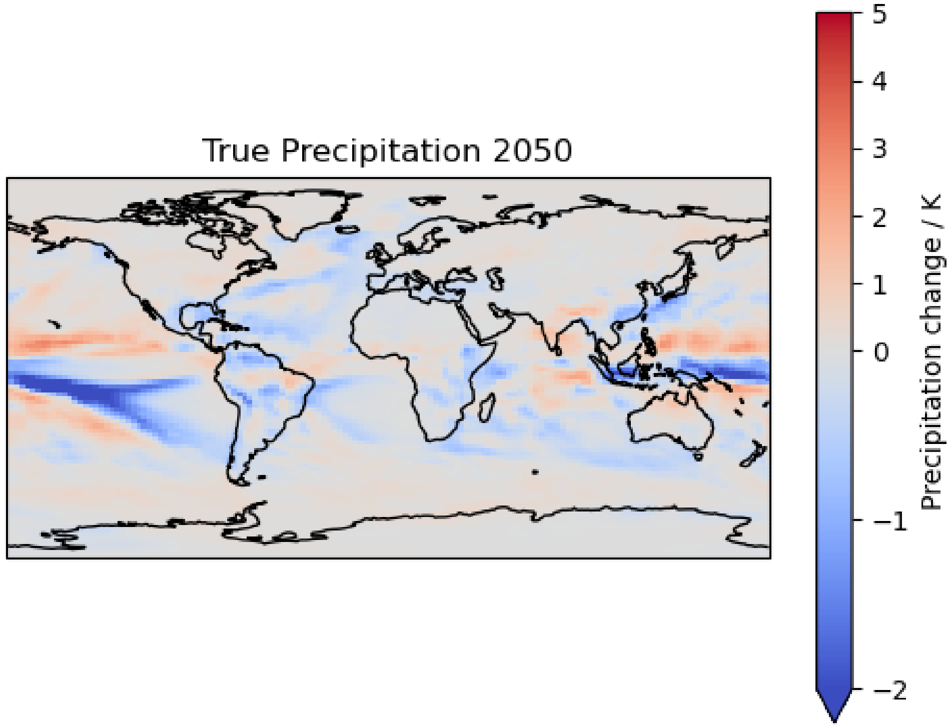
[29]: <cartopy.mpl.feature_artist.FeatureArtist at 0x15396cf3e170>



True vs Emulated Precipitation

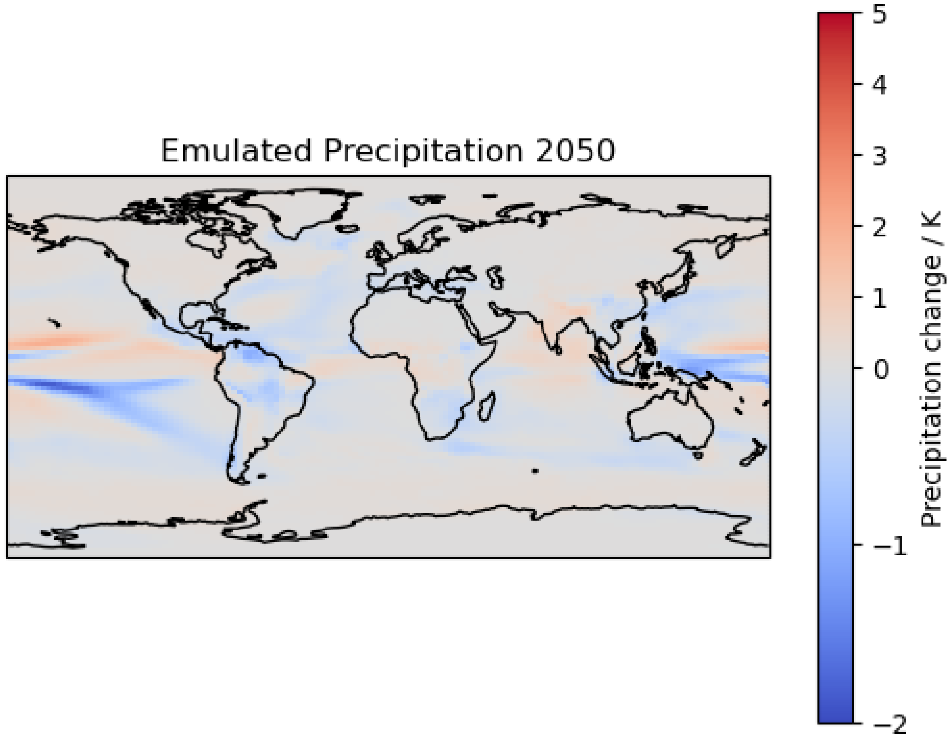
[30]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
pr_truth.sel(time=2050).plot(cmap="coolwarm", norm=divnorm,
                              cbar_kwargs={"label":"Precipitation change / K"})
ax.set_title("True Precipitation 2050")
ax.coastlines()
```

[30]: <cartopy.mpl.feature_artist.FeatureArtist at 0x15396cf6c760>



[31]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
m_out_pr.sel(sample=35).plot(cmap="coolwarm", norm=divnorm,
                             cbar_kwargs={"label":"Precipitation change / K"})
ax.set_title("Emulated Precipitation 2050")
ax.coastlines()
```

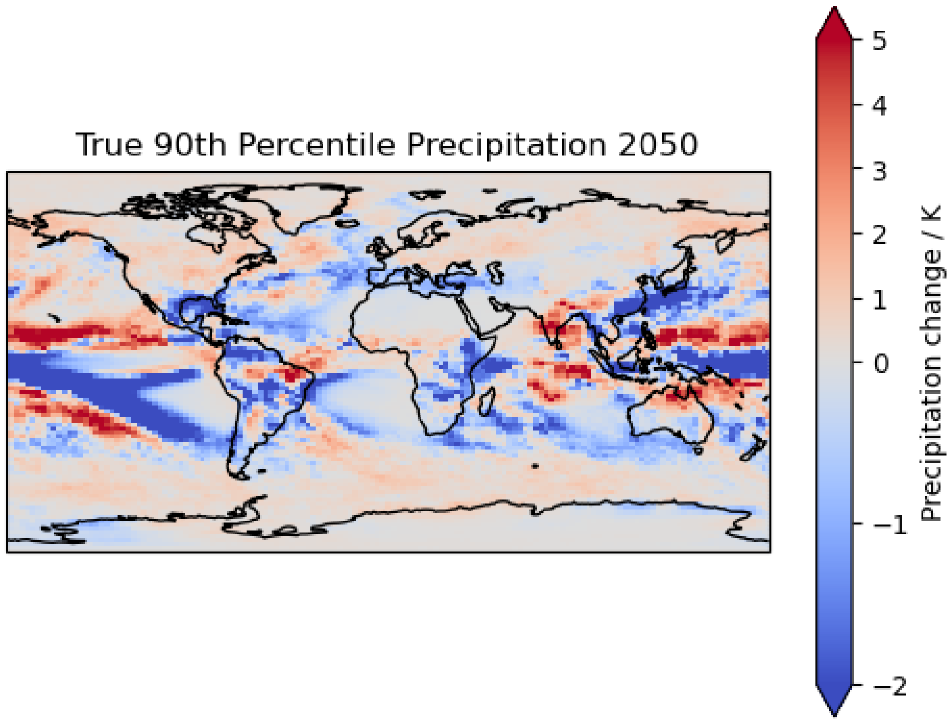
[31]: <cartopy.mpl.feature_artist.FeatureArtist at 0x153965c05360>



True vs Emulated 90th Percentile Precipitation

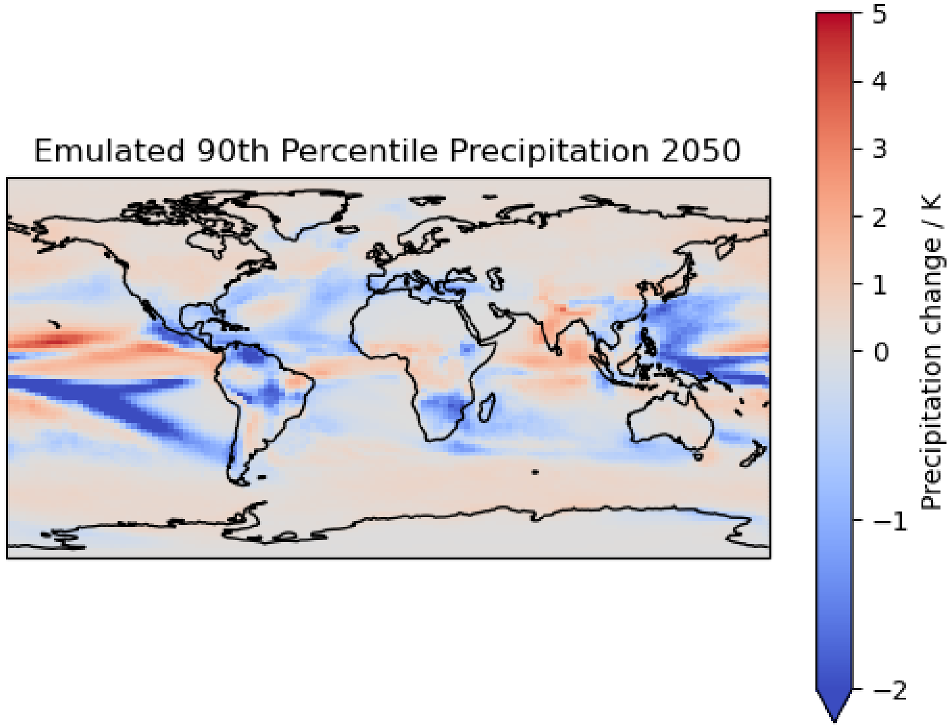
[32]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
pr90_truth.sel(time=2050).plot(cmap="coolwarm", norm=divnorm,
                               cbar_kwargs={"label":"Precipitation change / K"})
ax.set_title("True 90th Percentile Precipitation 2050")
ax.coastlines()
```

[32]: <cartopy.mpl.feature_artist.FeatureArtist at 0x15396597ea10>



[33]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
m_out_pr90.sel(sample=35).plot(cmap="coolwarm", norm=divnorm,
                                cbar_kwargs={"label":"Precipitation change / K"})
ax.set_title("Emulated 90th Percentile Precipitation 2050")
ax.coastlines()
```

[33]:
```
<cartopy.mpl.feature_artist.FeatureArtist at 0x1539659a0460>
```


Emulated 90th Percentile Precipitation 2050
Precipitation change / K
5
4
3
2
1
0
−1
−2