RF_model

November 28, 2024

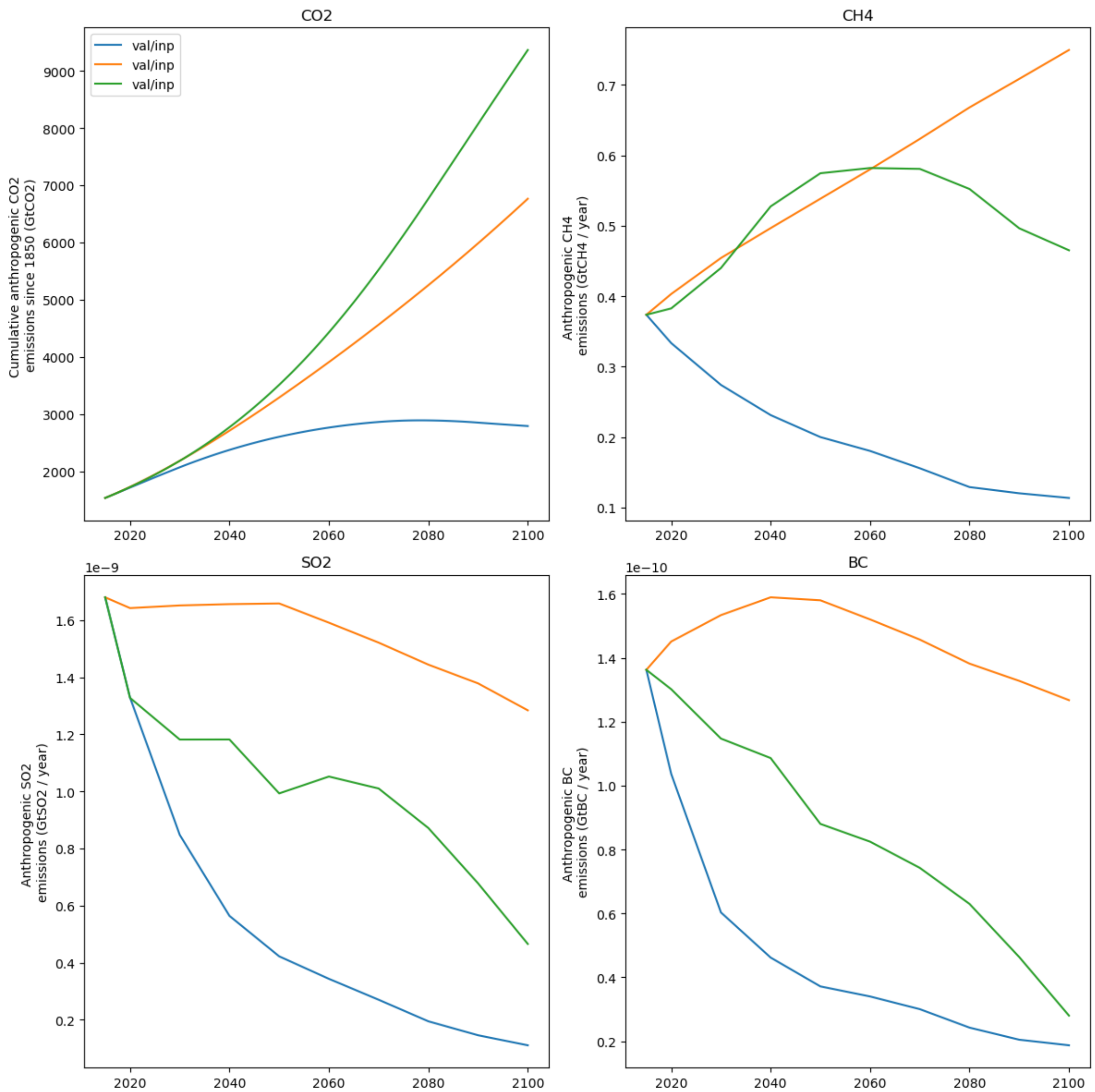
[38]:
```
import os

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 *
```

[39]:
```
# path to save the net-cdf file
path_output ='outputs_ssp245_prediction_ESEm.nc'
```

0.0.1 Initial EDA to look at variables

[40]:
```
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

[41]:
```
train_files = [ "historical", "ssp585", "ssp126", "ssp370", ]
# Create training and testing arrays
X, solvers = create_predictor_data(train_files)
Y = create_predictdand_data(train_files)
```

[42]:
```
#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
}
```

[43]:
```
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()
```

[44]:
```
## 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"]
```

[45]:
```
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)
```

[46]:
```
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

[47]:
```
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()}")
```

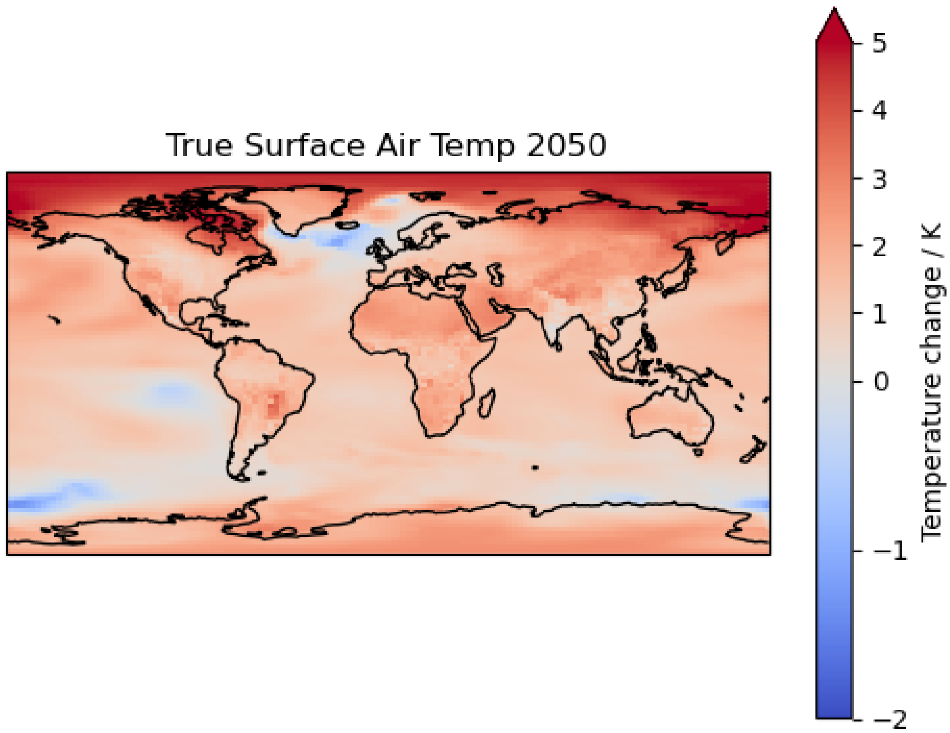
```
RMSE: 0.6823172244093356


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

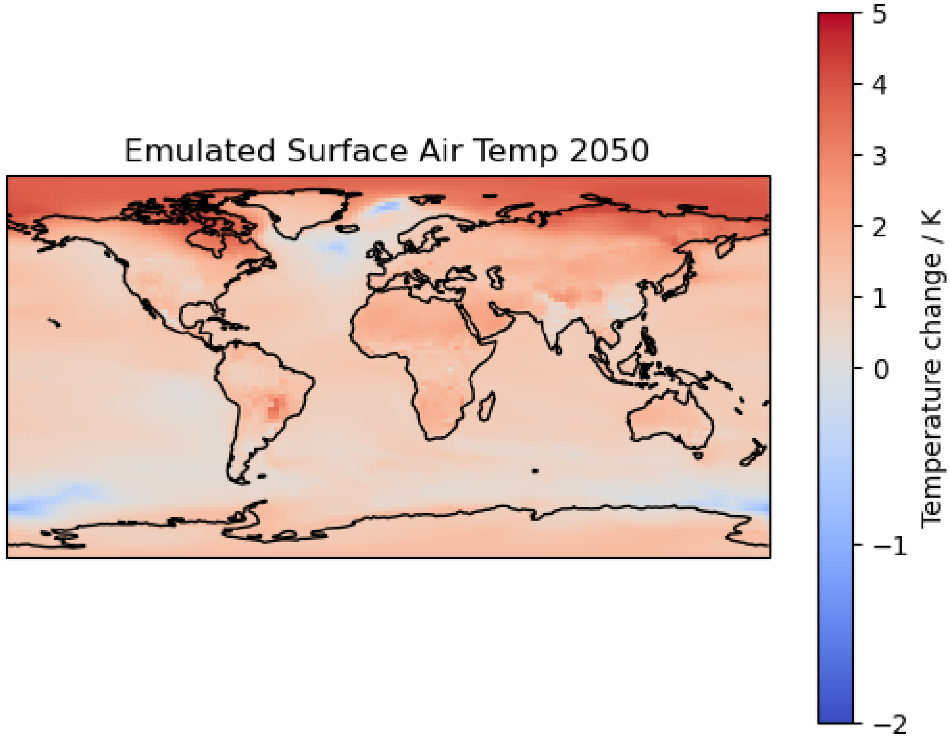
[48]:
```
divnorm=colors.TwoSlopeNorm(vmin=-2., vcenter=0., vmax=5)

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()
```

[48]: <cartopy.mpl.feature_artist.FeatureArtist at 0x15396cf6d420>



[49]:
```
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()
```

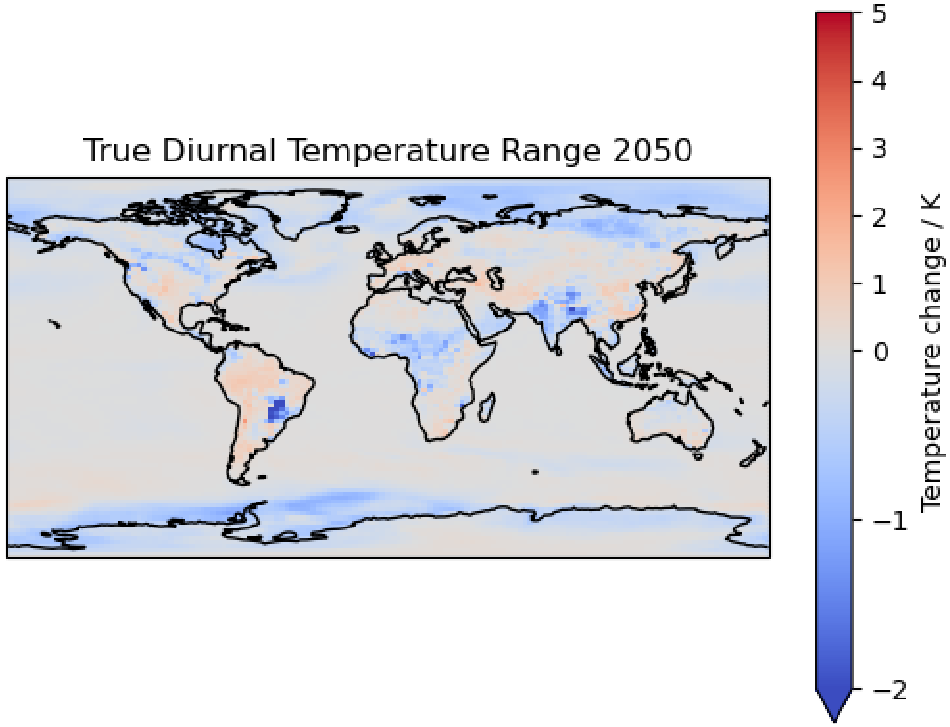
[49]: <cartopy.mpl.feature_artist.FeatureArtist at 0x15396484faf0>



True vs Emulated Diurnal Temperature Range

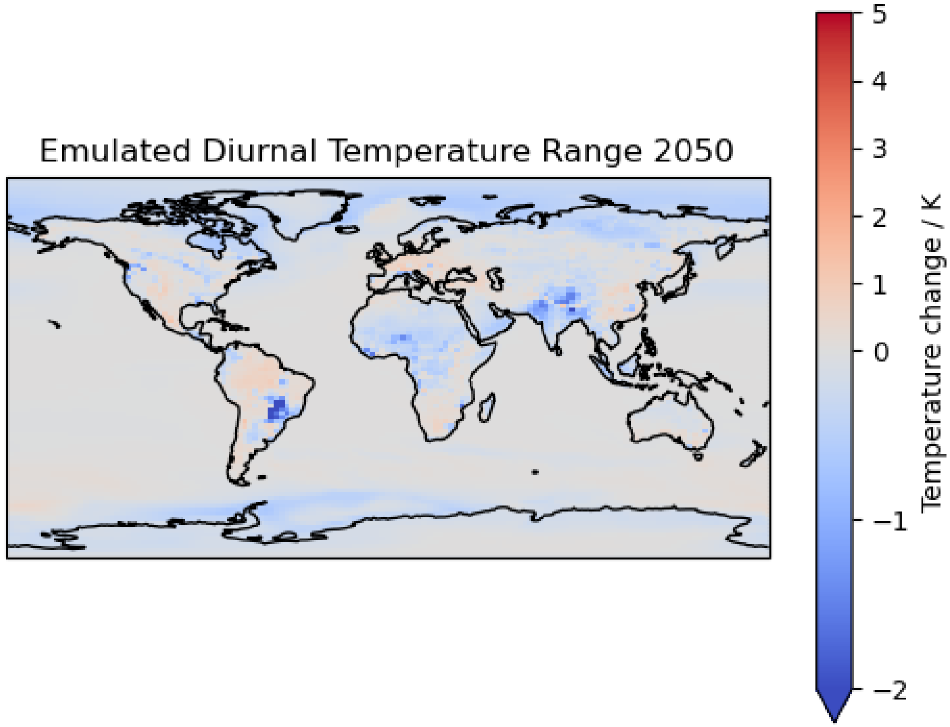
[50]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
dtr_truth.sel(time=2050).plot(cmap="coolwarm", norm=divnorm,
                              cbar_kwargs={"label":"Temperature change / K"})
ax.set_title("True Diurnal Temperature Range 2050")
ax.coastlines()
```

[50]:
```
<cartopy.mpl.feature_artist.FeatureArtist at 0x15396467b0a0>
```



[51]:
```
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()
```

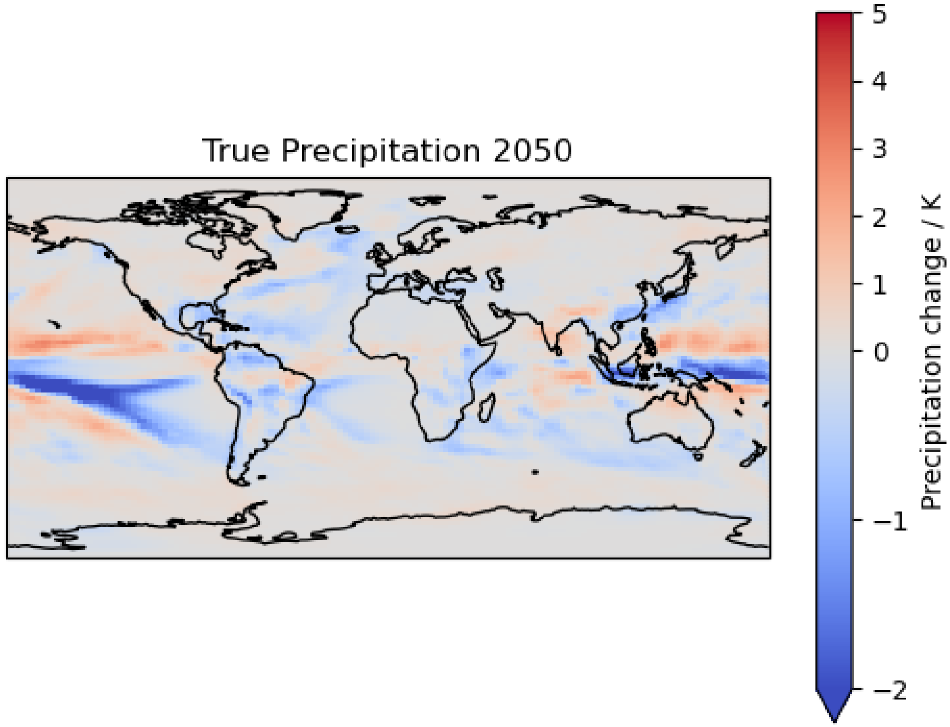
[51]: <cartopy.mpl.feature_artist.FeatureArtist at 0x153964727970>



True vs Emulated Percipitation

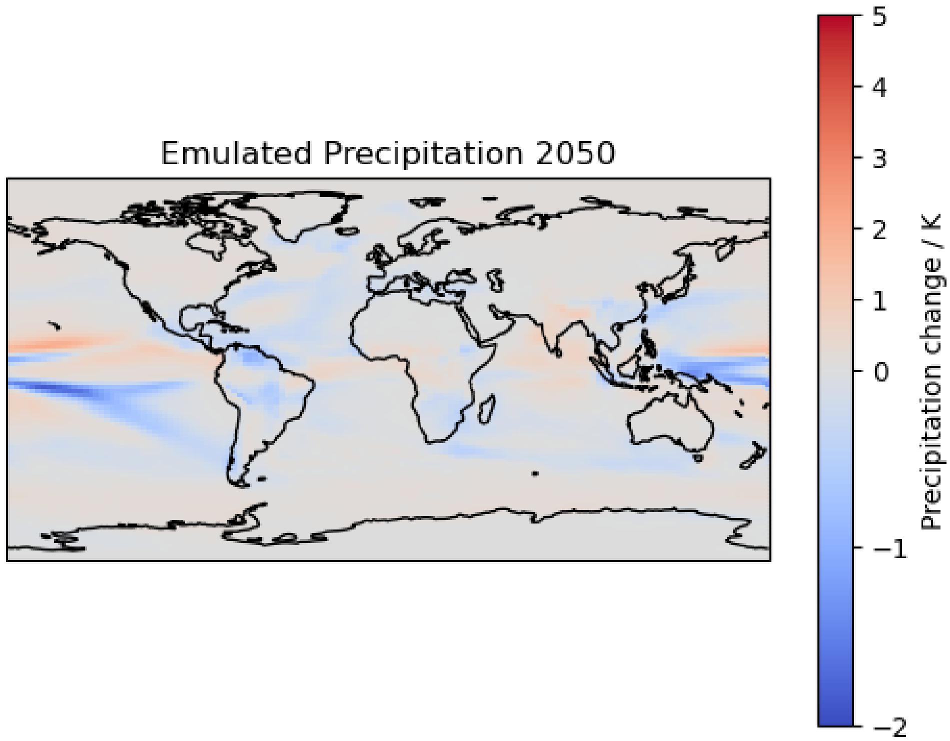
[52]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
pr_truth.sel(time=2050).plot(cmap="coolwarm", norm=divnorm,
                             cbar_kwargs={"label":"Precipitation change / K"})
ax.set_title("True Precipitation 2050")
ax.coastlines()
```

[52]: <cartopy.mpl.feature_artist.FeatureArtist at 0x1539645de4d0>



[53]:
```
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()
```

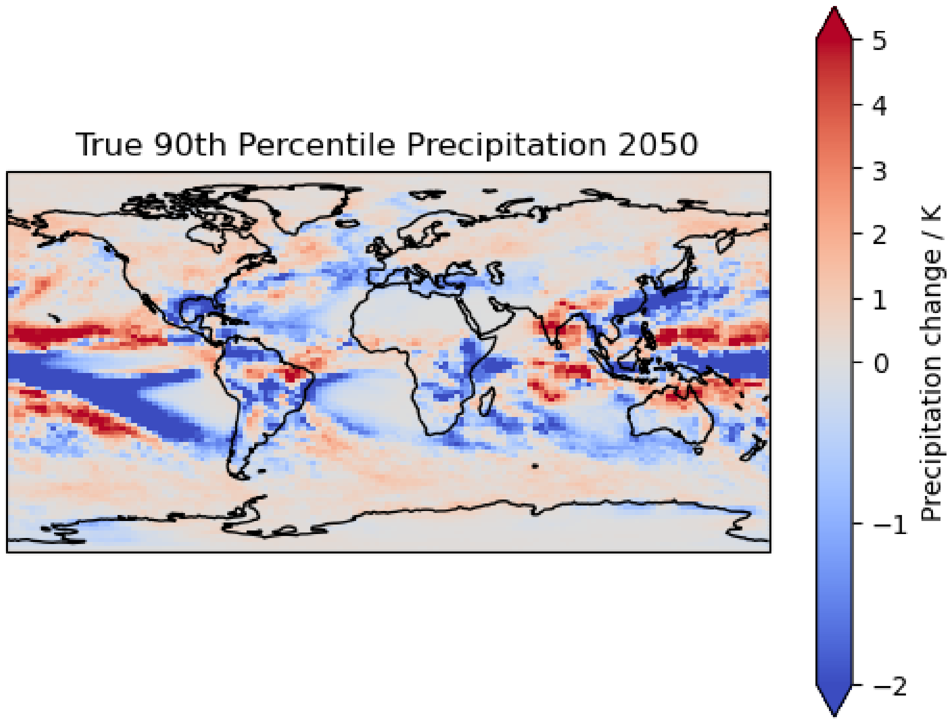
[53]: <cartopy.mpl.feature_artist.FeatureArtist at 0x15396460bcd0>



True vs Emulated 90th Percentile Percipitation

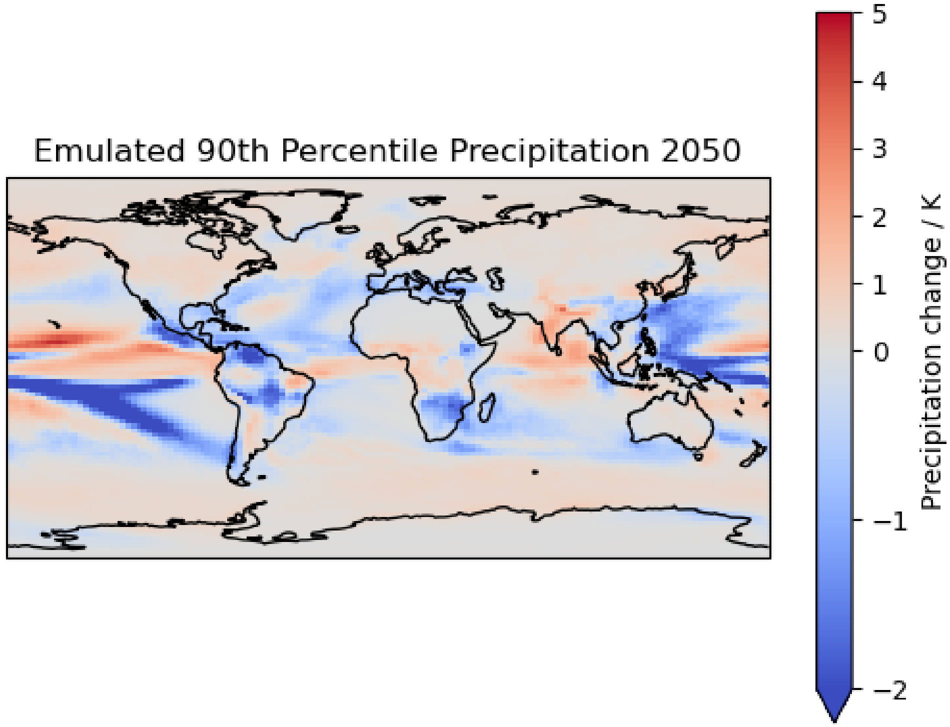
[54]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
pr90_truth.sel(time=2050).plot(cmap="coolwarm", norm=divnorm,
                               cbar_kwargs={"label":"Precipitation change / K"})
ax.set_title("True 90th Percentile Precipitation 2050")
ax.coastlines()
```

[54]:
```
<cartopy.mpl.feature_artist.FeatureArtist at 0x153964366fb0>
```




```
[55]: 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()
```

```
[55]: <cartopy.mpl.feature_artist.FeatureArtist at 0x153964422f20>
```



0.0.5 Running models Again After Grid Search

[64]:
```
X, solvers = create_predictor_data(train_files)
Y = create_predictdand_data(train_files)
```

[82]:
```
# hyperparameter grid
param_grid = {
    'n_estimators': [200,250,300,350],
    'max_depth': [10, 20,30,40,50],
    'min_samples_split': [10,15,20],
    'min_samples_leaf': [5, 10,15,20]
}

base_model = RandomForestRegressor(random_state=0, bootstrap=True,␣
 ↪max_features='log2')

best_params = {}
best_scores = {}

# List of target variables
targets = ['tas', 'diurnal_temperature_range', 'pr', 'pr90']
```

```python
# Loop over each target variable


# Uncomment out everything under this to run grid search
# Commented for now to reduce # of pages in pdf output of file




# for target in targets:
#     print(f"Running GridSearchCV for {target}...")

#     # Get training data
#     Y_train = Y[target].mean(dim=["lat", "lon"]).values
#     X_train = X

#     # GridSearchCV
#     grid_search = GridSearchCV(
#         estimator=base_model,
#         param_grid=param_grid,
#         cv=3,
#         scoring='neg_root_mean_squared_error',
#         verbose=2,
#         n_jobs=-1
#     )

#     # Fit the model
#     grid_search.fit(X_train, Y_train)

#     # results
#     best_params[target] = grid_search.best_params_
#     best_scores[target] = -grid_search.best_score_
#     print(f"Best parameters for {target}: {grid_search.best_params_}")
#     print(f"Best score for {target} (neg MSE): {grid_search.best_score_}")


# results_df = pd.DataFrame({
#     'Variable': targets,
#     'Best Parameters': [best_params[target] for target in targets],
#     'Best Negative MSE': [best_scores[target] for target in targets]
# })

# print("\nGrid Search Summary:")
# print(results_df)
```

[82]:

```
'\nUncomment out everything under this to run grid search \nCommented for now to
reduce # of pages in pdf output of file \n'
```

[67]:

```python
# new parameter values based on grid search
param_dict_tas_opt = {
    'n_estimators': 250,
    'min_samples_split': 15,
    'min_samples_leaf': 5,
    'max_depth': 10
}

param_dict_pr_opt = {
    'n_estimators': 250,
    'min_samples_split': 15,
    'min_samples_leaf': 5,
    'max_depth': 20
}

param_dict_pr90_opt = {
    'n_estimators': 200,
    'min_samples_split': 15,
    'min_samples_leaf': 5,
    'max_depth': 10
}

param_dict_dtr_opt = {
    'n_estimators': 250,
    'min_samples_split': 10,
    'min_samples_leaf': 5,
    'max_depth': 20
}
```

[68]:

```python
# Used log2 instead of sqrt for max_features, training on grid search parameter␣
↪tuning

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()
```

[69]:
```
## 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"]
```

[70]:
```
# 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)
```

[71]:
```
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

[72]:
```
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()}")
```

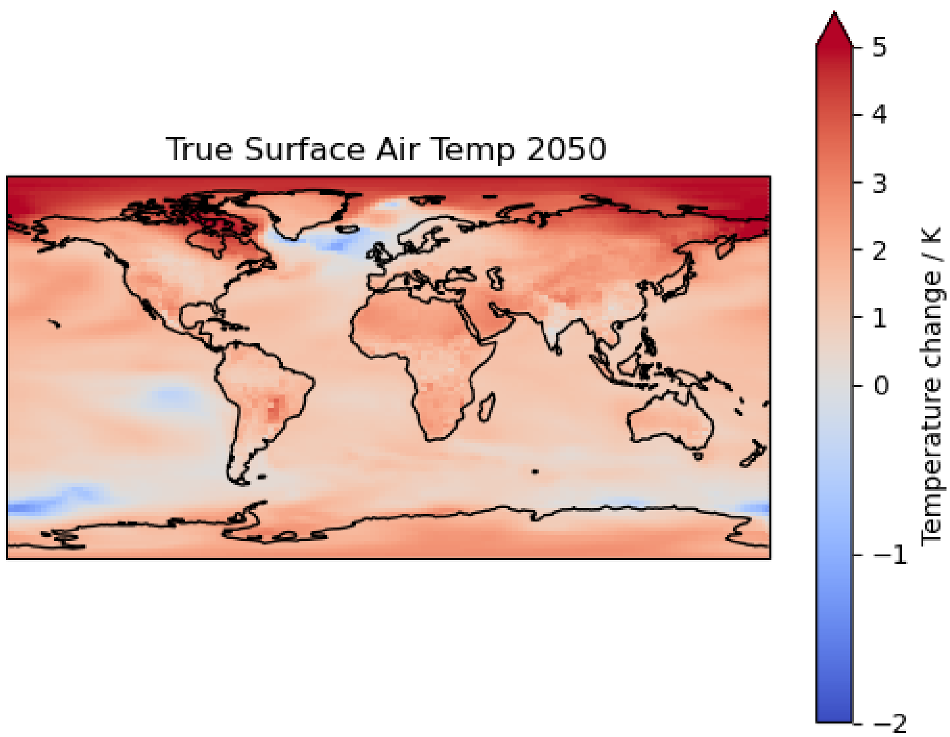
```
RMSE: 0.6614993057851092


RMSE: 0.16673128377739266


RMSE: 0.5548657390705033


RMSE: 1.5955868266285376
```

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

True vs Emulated Surface Air Temperature

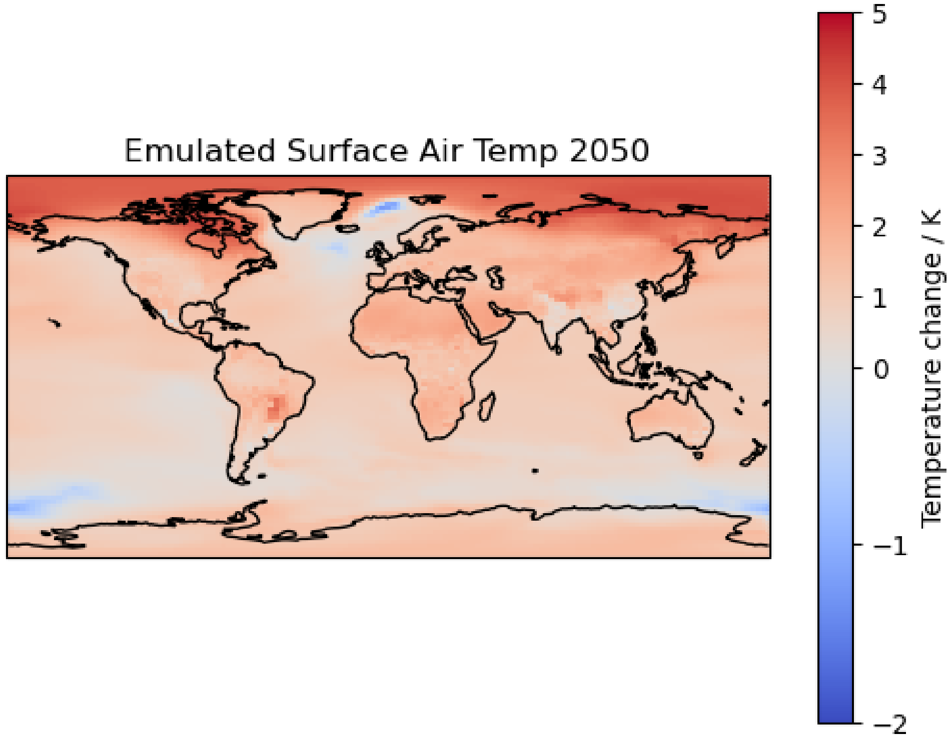
[73]:
```
divnorm=colors.TwoSlopeNorm(vmin=-2., vcenter=0., vmax=5)

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()
```

[73]: <cartopy.mpl.feature_artist.FeatureArtist at 0x1539647c9b70>



[74]:
```
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()
```

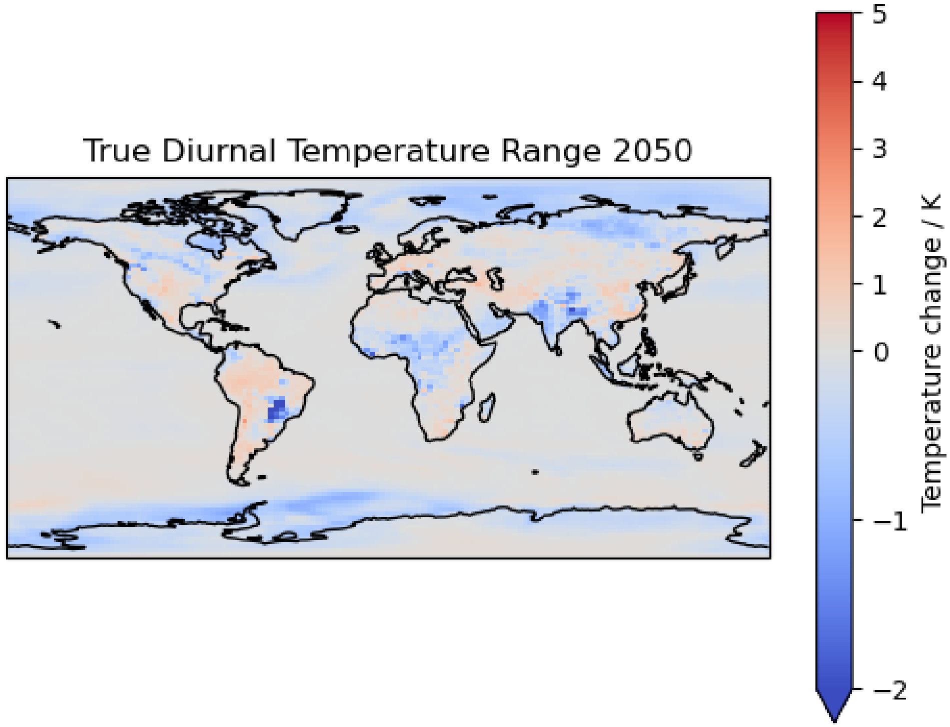
[74]: <cartopy.mpl.feature_artist.FeatureArtist at 0x153964cdfd30>



True vs Emulated Diurnal Temperature Range

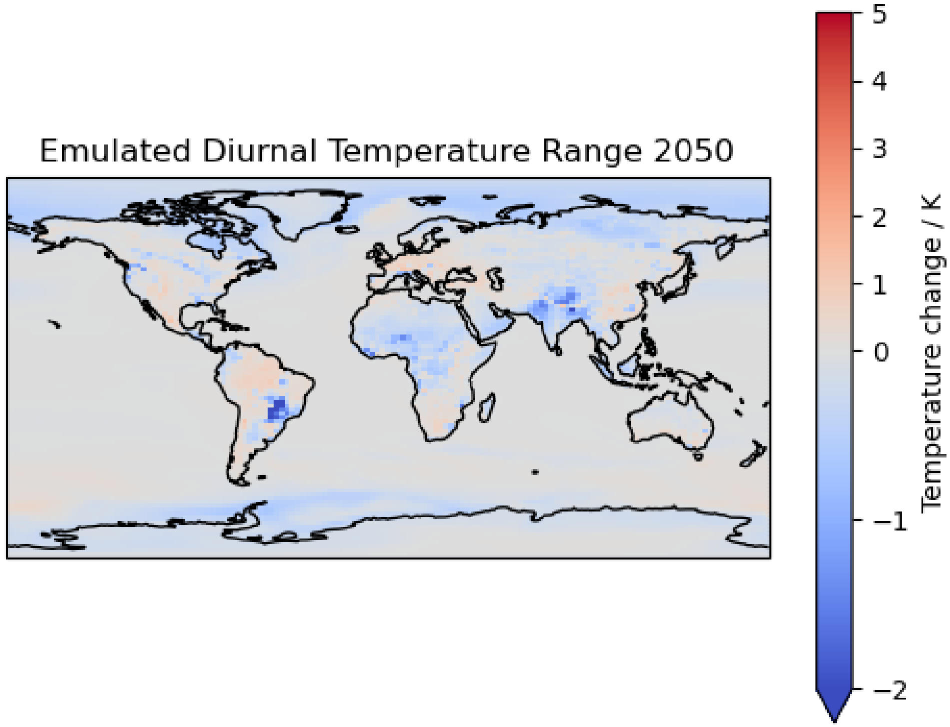
[75]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
dtr_truth.sel(time=2050).plot(cmap="coolwarm", norm=divnorm,
                              cbar_kwargs={"label":"Temperature change / K"})
ax.set_title("True Diurnal Temperature Range 2050")
ax.coastlines()
```

[75]: <cartopy.mpl.feature_artist.FeatureArtist at 0x15396df89990>



[76]:
```
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()
```

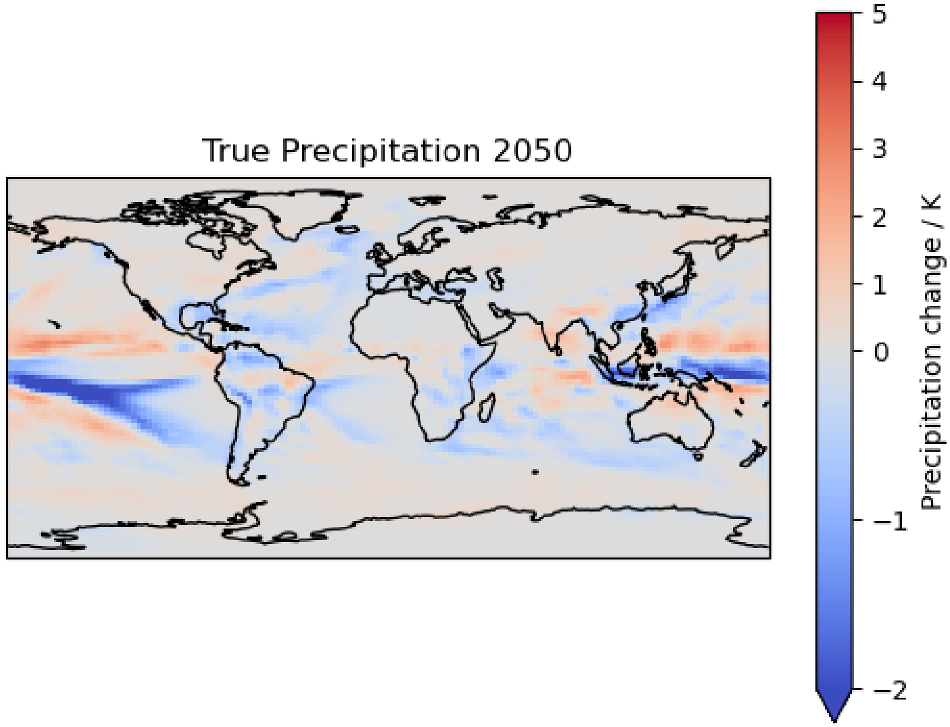
[76]:
```
<cartopy.mpl.feature_artist.FeatureArtist at 0x1539763aada0>
```



True vs Emulated Precipitation

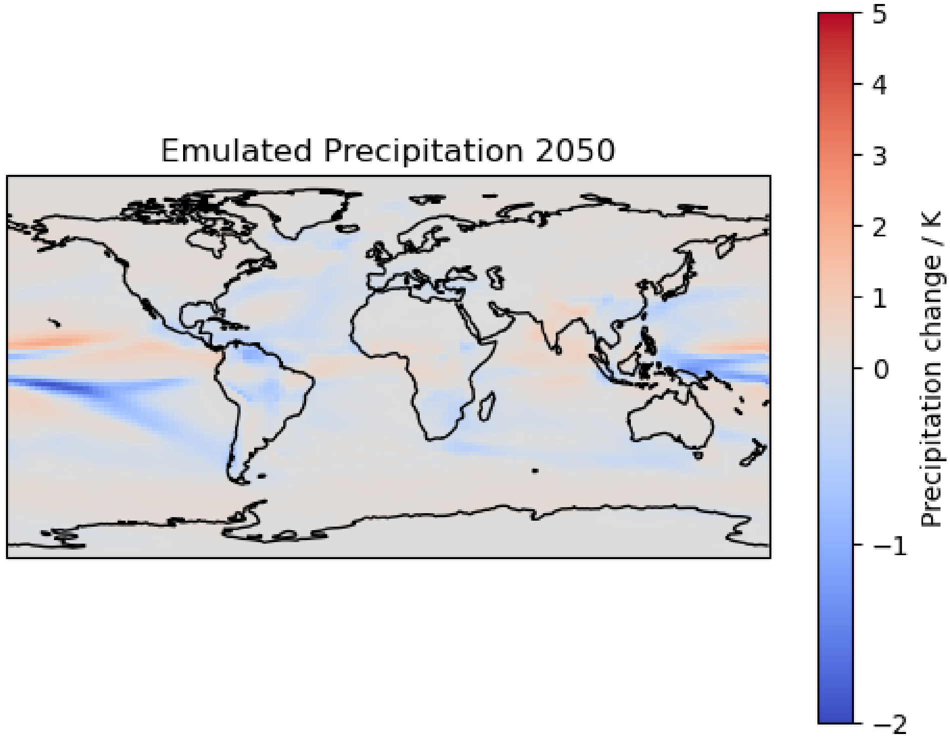
[77]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
pr_truth.sel(time=2050).plot(cmap="coolwarm", norm=divnorm,
                             cbar_kwargs={"label":"Precipitation change / K"})
ax.set_title("True Precipitation 2050")
ax.coastlines()
```

[77]:
```
<cartopy.mpl.feature_artist.FeatureArtist at 0x1539641dded0>
```



[78]:
```
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()
```

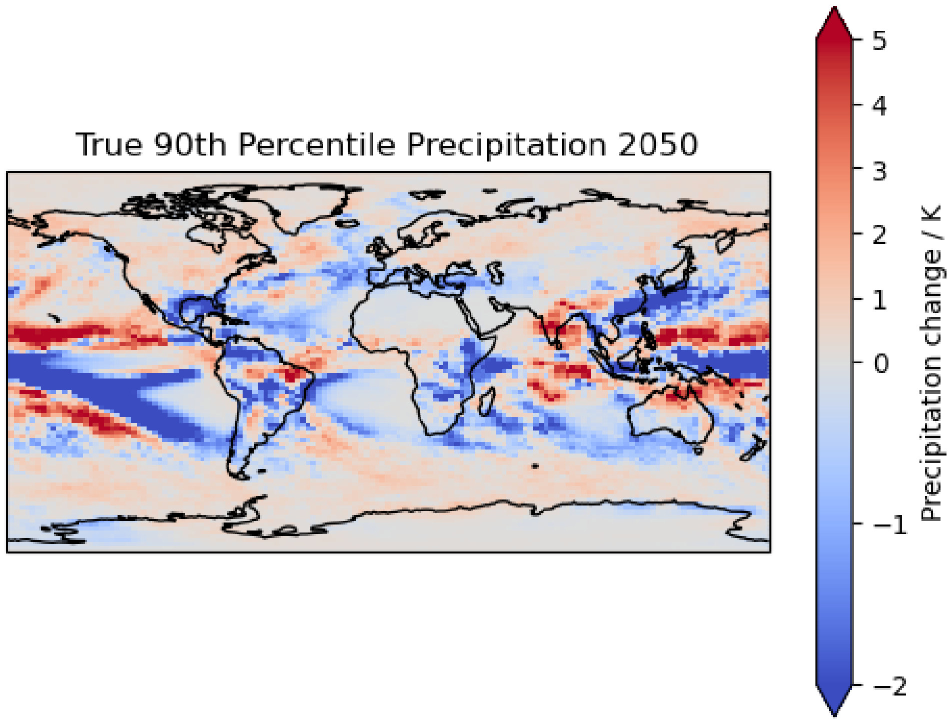
[78]: <cartopy.mpl.feature_artist.FeatureArtist at 0x1539763a88b0>



True vs Emulated 90th Percentile Precipitation

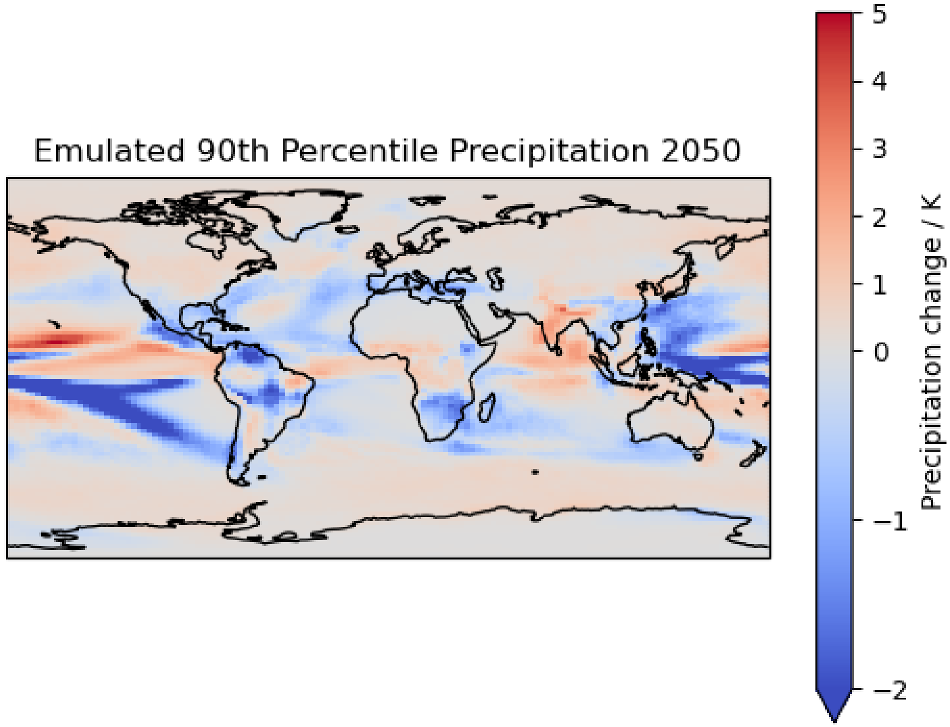
[79]:
```
ax = plt.axes(projection=ccrs.PlateCarree())
pr90_truth.sel(time=2050).plot(cmap="coolwarm", norm=divnorm,
                               cbar_kwargs={"label":"Precipitation change / K"})
ax.set_title("True 90th Percentile Precipitation 2050")
ax.coastlines()
```

[79]: <cartopy.mpl.feature_artist.FeatureArtist at 0x1539763a93f0>



[80]:
```
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()
```

[80]: <cartopy.mpl.feature_artist.FeatureArtist at 0x153963e72ad0>


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