Ppgp Monthly Meeting

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June 13, 2019

1 Summary of last meeting and Admin Stuffs

- Updates for TFR paper.
- Climate Project updates.

2 Paper Revision

We have finished up the revision and re-submitted it to AOAS.

3 Climate Project

3.1 CO_2 Forecast

3.1.1 Data Change

We have updated the CO_2 forecast with new data set. Now the data set are:

- WORLD POPULATION PROSPECT 2015 REVISION. We have considered 2017 revision. Because we are making forecast from 2015, we decided to use 2015 Revision.
- Maddison project 2018 Release for GDP data. (From Maddison Project 2010 Release.)
- National Carbon Emissions from Global Carbon Budget (2017).(From 2014 Version)

It may cause problems when transfering data from 2010 version of the data to 2015 version, mainly because the Maddison Project. From 2010 Release to 2018 Release of Maddison Project, the GDP estimates of past, based on Purchasing Power Parities, is differen across versions. In order to show this, we could show some plots for GDP data across two versions:

3.1.2 Bug in Model

We are doing modeling for correlation of GDP and intensities, by adding correlation ρ on the GDP gap and intensity. However, for the United States, the correlation was modeled with the same ρ, but was added on the raw GDP and its intensity. This will make the interpretation of ρ to be confusing. Therefore, we changed the sign specifically for the United States.

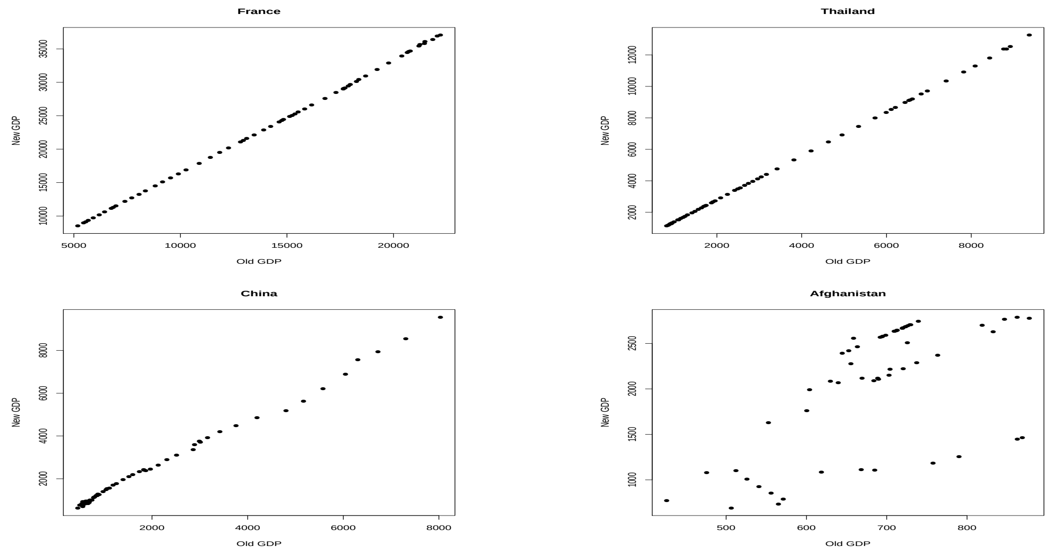

Figure 1: GDP data with 2010 and 2018 Maddison Comparison. GDP of France and Thailand are consistent for two versions (on the top left), but the statistics for China (Bottom Left) is changing slightly. To the worst, the data for Afghanistan don't match at all.

3.1.3 Change in Forecast

We use the new data to train and forecast the model with Kaya's (or IPAT) identity, which will train the GDP and Carbon Intensity model together and train the population model separately. Then the joint model will be forecasted to CO_2 emissions for most countries.

We could compare directly to the change of CO_2 emission forecast, and the yearly emissions around the world are projected in Figure 2 and 3:

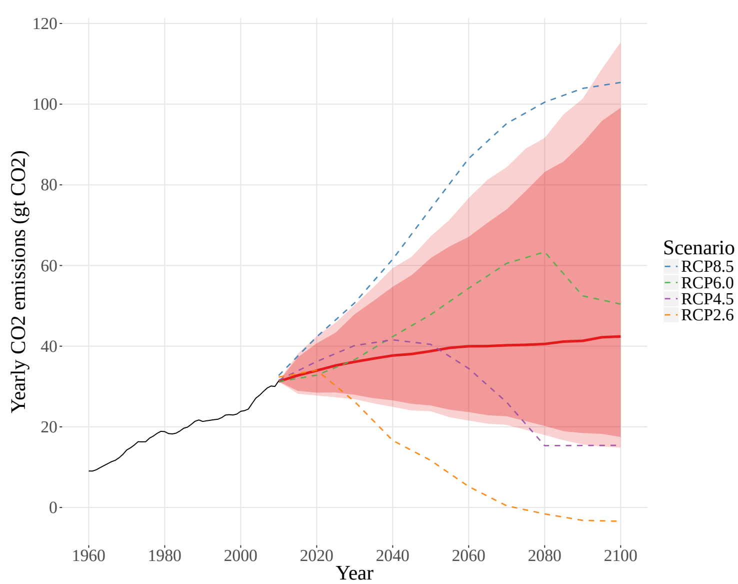

Figure 2: CO_2 Emissions forecasts with 2010 data. The forecast median of yearly emission at 2100 is 42 Giga tons around the world

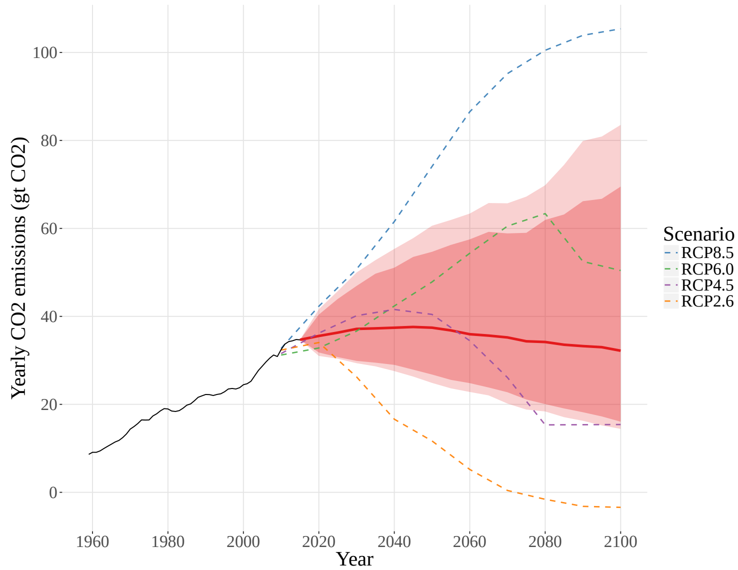

Figure 3: CO_2 Emissions are forecasted differently, based on the new data. The forecast median of yearly emission at 2100 is now 34 Giga tons around the world

We could figure out that this is quite different, and is mainly because of the major countries. We are digging into the fact why this is happening, by using the data before 2010 in 2015 version for doing forecast. The result are in progress.

3.2 Global Mean Temperature Forecast

3.2.1 Underlying Assumption

We considered changing the model for forecasting global mean temperature based on new CO_2 emission forecast. The underlying assumptions for this model is that the global mean temperature forecasts based on physics models will leads to linear relationship between cumulative carbon emissions and the global temperature increases. In order to show that, I collected the RCP forecasts for both carbon emissions as well as mean temperature. Results are in Figure 4:

Thus, we could easily argue that global mean temperature could be forecasted by cumulative CO_2 emissions with a linear relationship, this laid the foundation of our method in doing forecast by linear interpolation across RCP scenarios.

3.2.2 Data

- CMIP5: each data set is named like global_ tas_Amon_ACCESS1-0_ rcp45_r1i1p1.dat, where Global = global mean, Tas = surface air temperature, Amon = Atmospheric field, monthly average, ACCESS1-0 = the name of a particular model, rcp45 = the RCP4.5 emission scenario (It looks like these files include the response to historical forcing over years 1850-2005), and r1i1p1 = one particular simulation of this model.

  For a particular model, historical fits are the same for same particular simulation even if the emission scenarios are different.

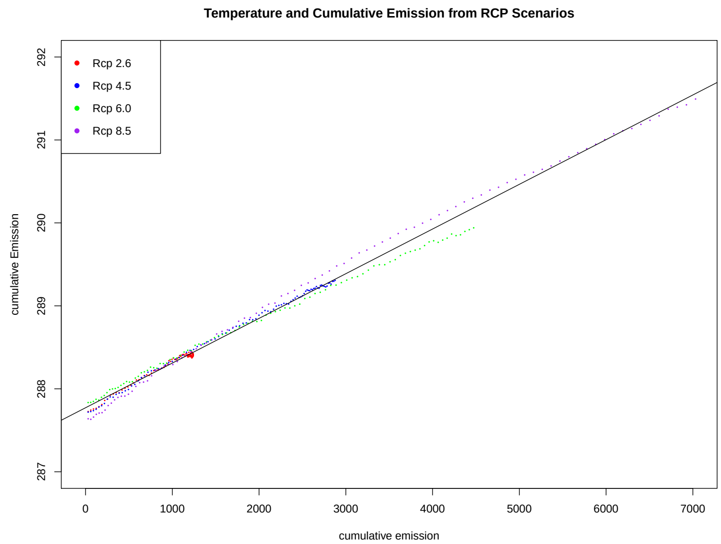

Figure 4: Relationship between global mean temperature and cumulative emissions in RCP forecasts. The overall R^2 is 0.9921.

CMIP5 models are the collections of models for past and future forecasts of global mean temperature anomaly (relative to 1861-1880), under different scenarios with deterministic methods. We use them as references of physics models, and denoted the mean of them (grouped by scenarios) as x_t. Note that for past observations, the global mean temperature are the same for different scenarios with the same model.

- HadCRUT4: It includes observations from 1850 to 2016 of the temperature difference to a certain level. To use that: we match the difference with the temperature observations in year 2005 (14.7 Celsius).

  We treat HadCRUT4 observations of past global mean anomaly (relative to 1861-1880) as our past observations. The differences between past model means (from CMIP5 models) and HadCRUT4 observations are denoted as y_t.

3.2.3 Models

Assume that z_t are difference between true (unobserved) anomaly relative to 1861-1880 and x_t. According to the ACF and PACF diagnosis, AR(1) model is suggested, and the Bayesian model is built as:

$$
\begin{aligned}
y_t &= z_t + \delta_t \\
z_t &= \rho z_{t-1} + \varepsilon_t \\
\delta_t &\sim \mathcal{N}(0, V_t) \\
\varepsilon_t &\sim \mathcal{N}(0, W)
\end{aligned}
$$

Model is trained with MCMC process, and to make forecast, we follow the steps:

1. Sample one trajectory of future CO_2 emissions from 2005 to 2100 from the posterior distribution of model in the first part.

2. Given that trajectory of future emissions, find the model mean forecast x_t for each year by interpolating between the forecasts for the different RCP(Representative Concentration Pathway) scenarios. Interpolation is based on **cumulative CO_2 emissions**. (RCP scenarios contain both CO_2 emissions, and CMIP5 models forecast of temperature are based on RCP scenarios)
3. Sample one trajectory of (ρ, W) in the model above.
4. Simulate forecast of z_t given the sampled ρ, W.
5. Final forecast $H_t = x_t + z_t$.
6. Repeat Steps 1 to 5 for many times.

3.2.4 Results

The global mean temperature forecasts is now summarized in Figure

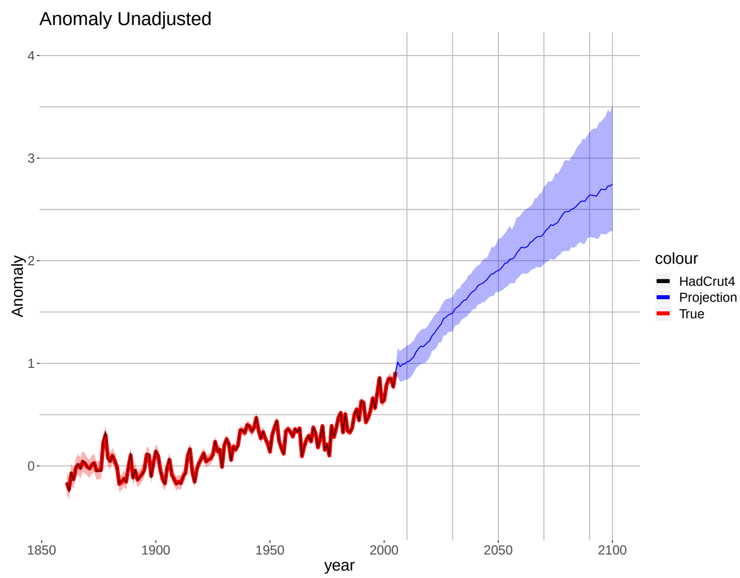

Figure 5: Global mean temperature forecasts with new data. The median forecast of global warming will be at 2.8 degree (in Celcius), and the 90% predictive interval is from 2.3 to 3.5 degree

There are other plots, including forecast until 2300, and 20 year average forecast. I didn't put them here but are stored in my computer.

3.3 Effect of Paris Agreement

3.3.1 Background

Countries are making promises on the Paris Agreement to commit reduction in carbon emissions. Different countries have made different types of commitments. Official files of these commitments are called *Intended Nationally Determined Contributions, or INDCs*. Many countries have ratified their commitments, and these documents will then be called as

Nationally Determined Contributions, or NDCs. All documents could be found here, which includes 180 countries in total.

We classify different types of commitments into four categories:

- Countries which have made the commitments directly on emission reduction (compared to level of some past years before). For example, Europe Union has made the commitment by cutting 40% of the emission by 2030 compared to the level of 1990.
- Countries which have made commitments on carbon intensity. For example, China has made the commitment of 60% reduction in emission per unit of GDP.
- Some countries have made commitments of emission reduction **compared with Business-as-Usual Scenario**. Actually, this is something that was called 'reduction' but actually not. For example, according to the report of Afghanistan, their current yearly emission is 35.5 million tons of CO2, and the BAU scenario will forecast their CO2 emissions to 48.9 million tons up to year 2030. They made the commitments of 13.6% reduction compared to BAU scenario, which means that their annual emission at 2030 will be 42.7 million tons.

  For these countries, we tried to find a referenced year emissions according to their INDCs or NDCs. Then, we assume the proportion ratio between the referenced year and the target year are their actual commitments (which could be increases in emissions).

  For countries without referenced year data, we assume the percentage reduction in emission compared with BAU levels are simply on their intensity.
- The other countries have made commitments with other things, such as proportion of renewable energies. These are hard to be relected directly on the carbon emissions, and most of these countries are African, which contribute little to global emissions. Thus, we decided to skip them.

3.3.2 Probability of Achieving the Goal

The first question of interest is that: What is the probability that these countries could achieve their commitments.

For doing this, we simply forecast the CO_2 emissions up to the target year, and calculate the proportion of trajectories below the target. The calculated probability are summarized in the map in Figure 6:

It is more interesting if we focus on Europe. If we zoom in, the results are in Figure 7:

It seems like Europe countries, China, India, the United States are all too optimistic about their work in carbon emission reduction, based on the recent data.

3.3.3 What if All Countries could Achieve Their Commitments

We conducted the analysis for projecting Global mean temperature with (1) current trend, (2) assuming countries could achieve their goal in Paris agreement and the policy will **NOT** continue (3) assuming countries could achieve their goal in Paris agreement and the policy will **BE** continuing.

The way we calculate the adjusted trajectores are based on the following rules:

For each country:

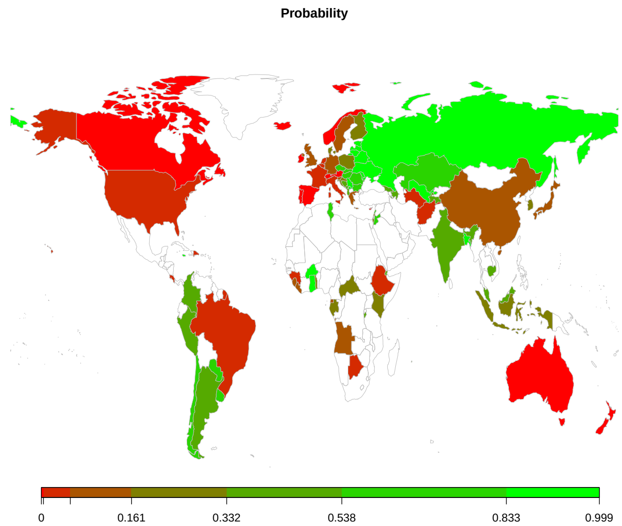

Figure 6: Probability that countries could achieve their goal according to their INDCs or NDCs.

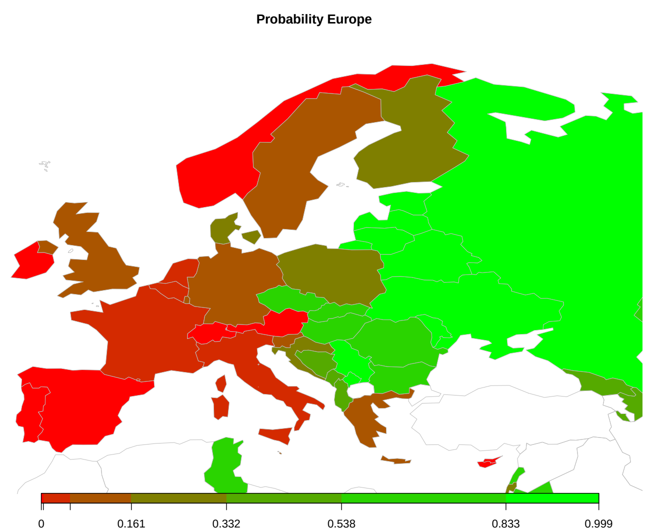

Figure 7: Probability that countries could achieve their goal according to their INDCs or NDCs, zoomed in for Europe.

- If the posterior trajectory shows lower emission (or intensity) than promised, keep it unchanged.
- If the posterior trajectory shows higher emission (or intensity) than promised:
  - If the country makes commitments in intensity, assume their goal of carbon intensity (in logarithm) is τ at year T, while the forecasted intensity (in logarithm) is τ_t

for $t = 1, 2, \ldots, T, T+1, \ldots, 2100$. Then, τ_t will be adjusted to:

$$\tilde{\tau}_t = \tau_t - \frac{t}{T}(\tau_T - \tau) \qquad\qquad \text{For } t \leq T$$

Based on our model assumption, the logarithm of GDP and intensity are correlated with correlation ρ. Thus, the logarithm of GDP g_t will change by:

$$\tilde{g}_t = g_t - \frac{\rho t \mathrm{sd}(\varepsilon_g)}{T \mathrm{sd}(\varepsilon_\tau)}(\tau_T - \tau)$$

If we consider the scenario that policies will not be continued, the most realistic assumption of future τ_t will just follow the patterns without the extra changes. Thus,

$$\tilde{\tau}_t = \tau_t - (\tau_T - \tau) \qquad\qquad \text{For } t > T$$

If we consider scenario that policies will be continued, then:

$$\tilde{\tau}_t = \tau_t - \frac{t}{T}(\tau_T - \tau) \qquad\qquad \text{For } t > T$$

The GDP will change accordingly.

- If the country makes commitments in total emission, assume their goal of yearly emission is c at year T, while the forecasted emissions is c_t for $t = 1, 2, \ldots, T, \ldots, 2100$. Then assume the required reduction in logarithm of intensity at year T is x, then we will get:

$$\begin{aligned}
&\tilde{g}_T = g_T - \frac{\rho \mathrm{sd}(\varepsilon_g)}{\varepsilon_\tau} x \\
&\tilde{\tau}_T = \tau_T - x \\
\Rightarrow &\tilde{g}_T + \tilde{\tau}_T = g_T + \tau_T - \left(1 + \frac{\rho \mathrm{sd}(\varepsilon_g)}{\varepsilon_\tau}\right) x \\
\Rightarrow &\log\left(\frac{c_T}{c}\right) = \left(1 + \frac{\rho \mathrm{sd}(\varepsilon_g)}{\varepsilon_\tau}\right) x \\
\Rightarrow &x = \log\left(\frac{c_T}{c}\right) \Bigg/ \left(1 + \frac{\rho \mathrm{sd}(\varepsilon_g)}{\varepsilon_\tau}\right)
\end{aligned}$$

Then, this x will work as the $\tau_T - \tau$ in the previous case and the rest part are the same.

I would like to show two examples, USA and China. The United States CO_2 emissions are the top among country making commitments in cutting total emissions, while China is the top among countries making commitments in intensity. They are summarized in Figure 8 and 9

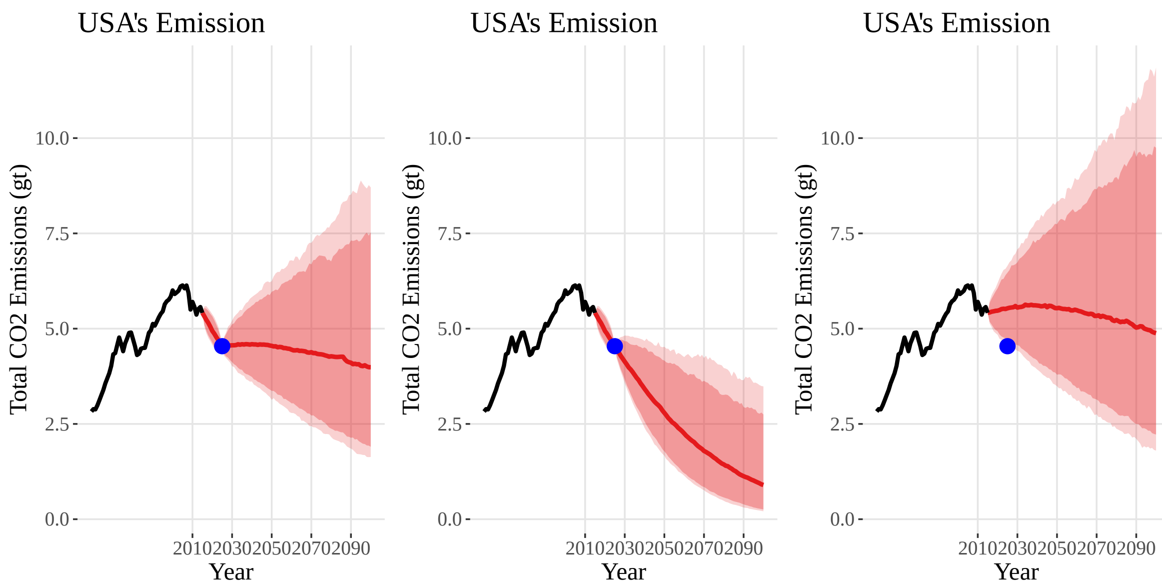

Figure 8: Emission forecast of the United States, assuming promises on Paris agreement is achieved and policies will not be continued (left), policies will be continued (middle), and without assuming promises are achieved (right).

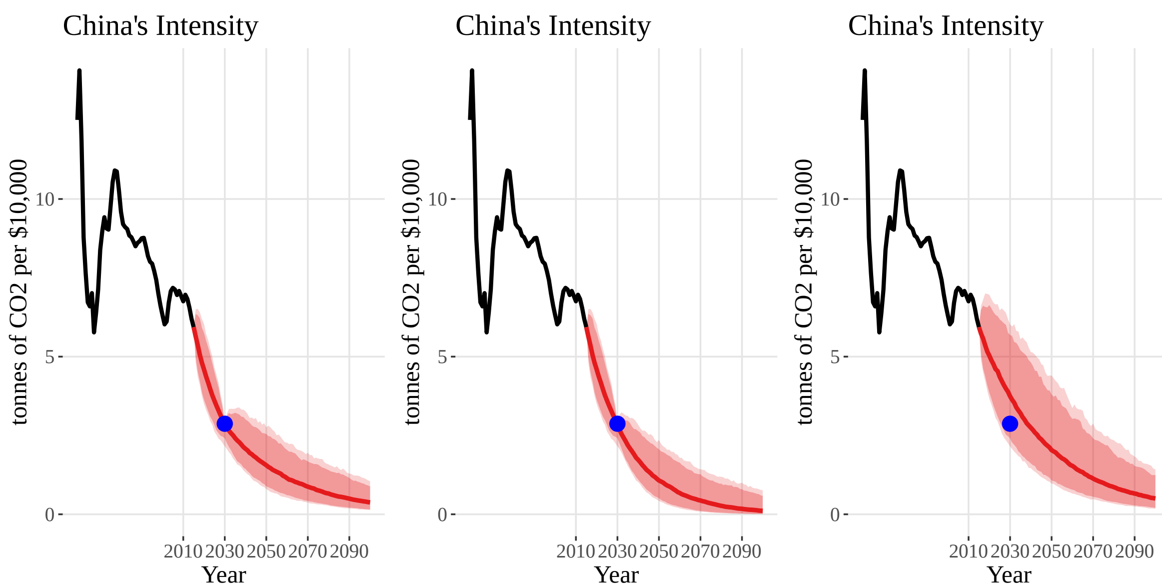

Figure 9: Intensity forecast of the China, assuming promises on Paris agreement is achieved and policies will not be continued (left), policies will be continued (middle), and without assuming promises are achieved (right).

In order to make forecast of global mean temperature under different scenarios, we shoud calculate the cumulative emission changes. We still use the example of the United States and China. Results are in Figure 10 and 11

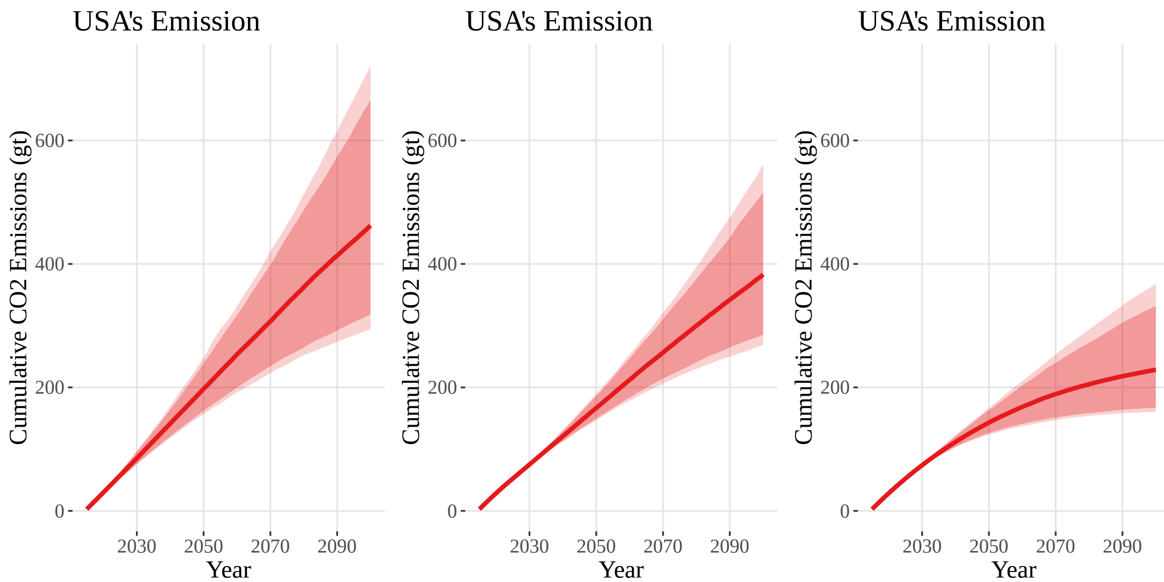

Figure 10: Cumulative emission forecast of the United States, assuming promises on Paris agreement is achieved and policies will not be continued (middle), policies will be continued (right), and without assuming promises are achieved (left).

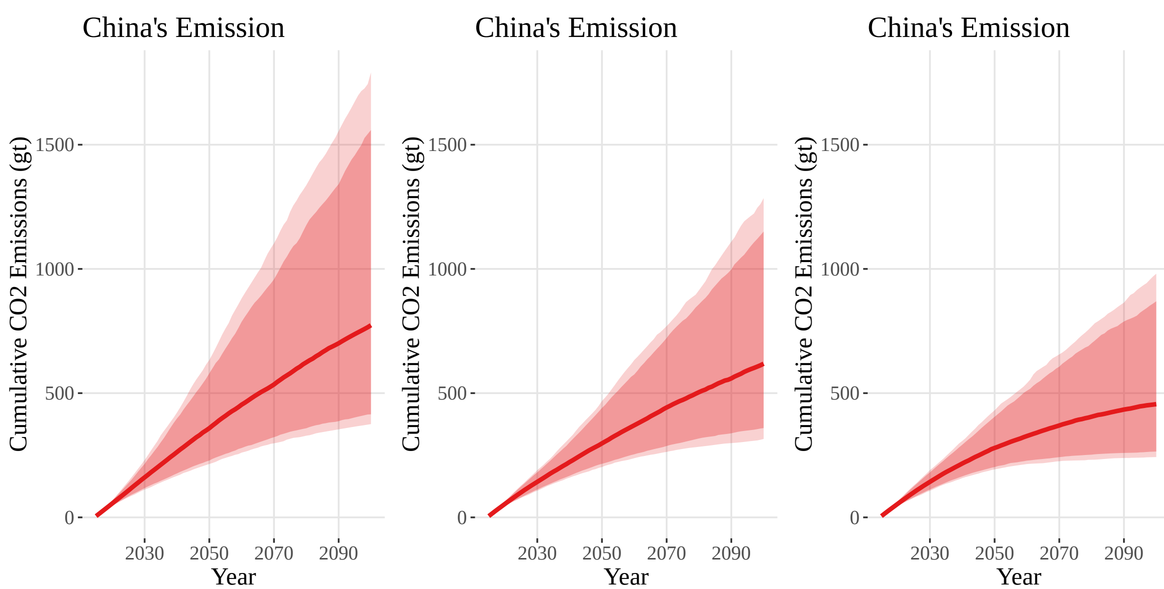

Figure 11: Cumulative emission forecast of the China, assuming promises on Paris agreement is achieved and policies will not be continued (middle), policies will be continued (right), and without assuming promises are achieved (left).

Finally, we want to show the changes in forecasting global mean temperature under three scenarios, Figure 12, 13 and 14

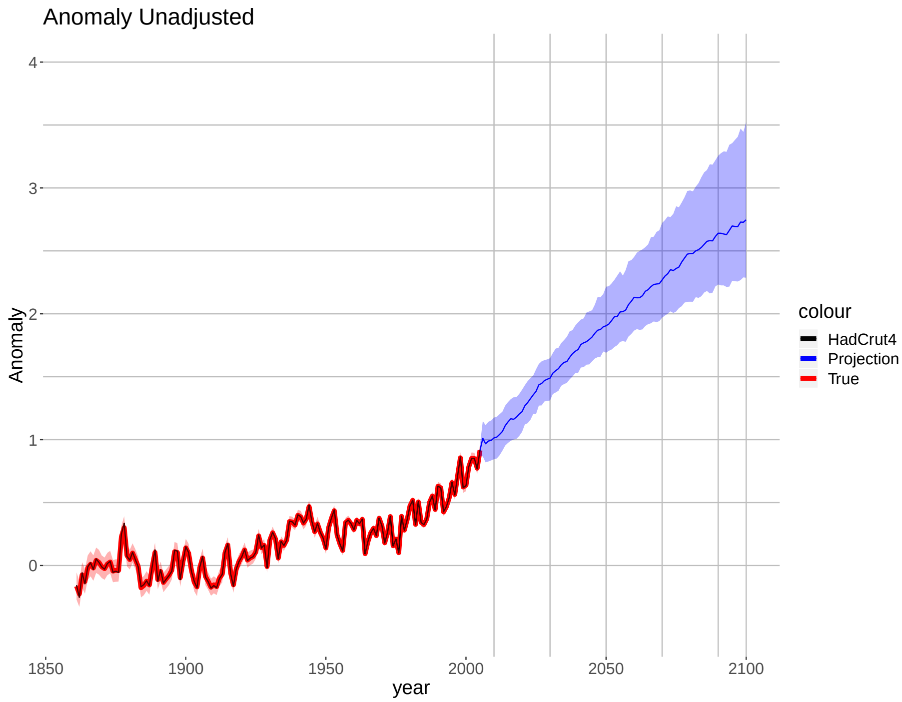

Figure 12: Global Mean Temperature

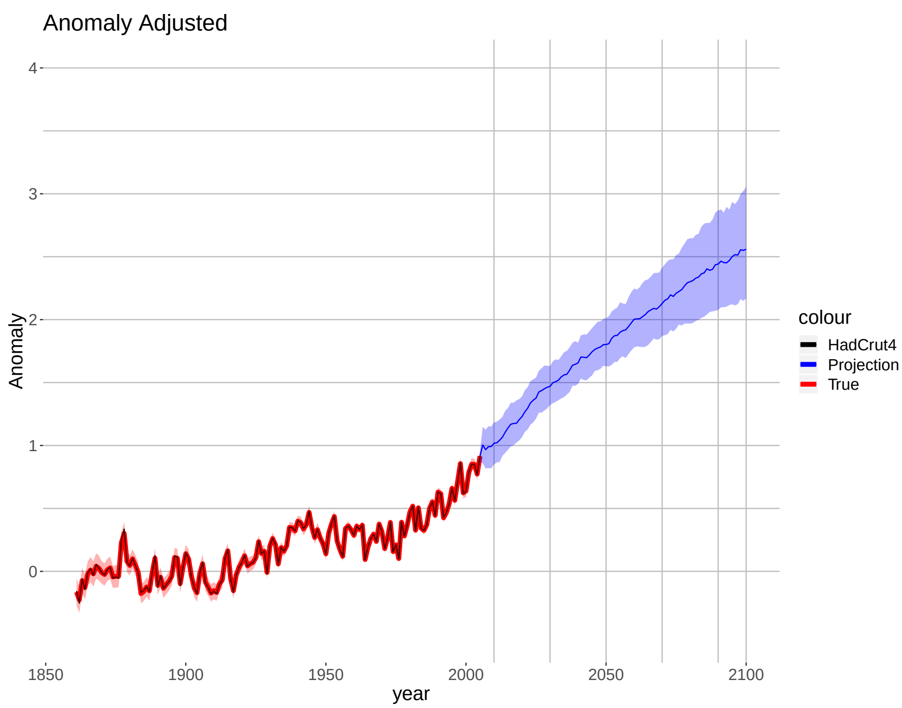

Figure 13: Global Mean Temperature with Paris Agreement Commitments Achieved

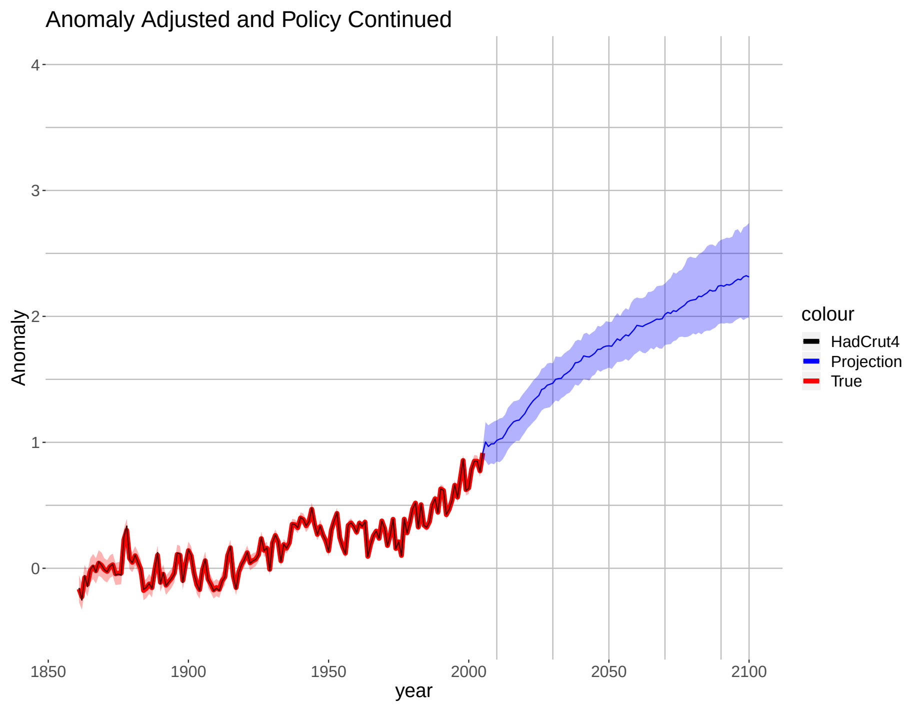

Figure 14: Global Mean Temperature with Paris Agreement Commitments Achieved and Policy Continued

Median forecasts for three scenarios are 2.8, 2.6 and 2.3 degrees respectively, and the 90% predictive intervals are $[2.3, 3.5]$, $[2.2, 3]$ and $[2, 2.7]$ degrees respectively. These results gave us the idea that it seems not infeasible to achieve the goal of 2 celcius of global warming.

3.3.4 Amount of Extra Effort to Achieve the Goal of 2 Celcius of Global Warming

The last question of interest is how much extra effort countries have to make to achieve the goal of 2 celcius global warming by the end of this century (could also be 1.5). This is a not well-defined problem, and we could define it rigorously by setting the objective to be achieving less than 2 celcius of lobal warming in **median** or **95% quantile**. To quantify this, we consider bi-section optimization method. Take **median** as an example, the steps are as follows:

- Assume the current median anomaly forecast at 2100 is $W(>2)$, and the objective ratio is x_0 and it is initialized as 1 within interval $[L, R] = [0.1, 1]$ (arbitrary, large enough);
- Take $x_1 = (L + R)/2$.
- For each posterior CO_2 emission trajectory c_t, find r, such that:

$$\sum_{t=2015}^{2100} c_t r^{t-2015} = x_1 \sum_{t=2015}^{2100} c_t$$

  (This step is allocate reductions of the total emissions into yearly emission evenly, and with this step, unreasonable trajectories will disappear.)

- Adjust c_t to $\tilde{c}_t = c_t r^{t-2015}$.
- Forecast global mean temperature to year 2100 and obtain the median forecast W_1. If W_1 is close enough to 2, then output x_1. Otherwise
  - If $W_1 > 2$, set $L = x_1$,
  - if $W_1 < 2$, set $R = x_1$.
- Repeat Steps 2-5 until W_1 is close enough to 2.

With this method, we have got:

- Additional **60.3%** of cumulative emission reduction will be needed (compared with the Policy Continued Scenario, same below) for 2 degree of global warming in **median**.
- Additional **114.7%** of cumulative emission reduction will be needed (compared with the Policy Continued Scenario) for 2 degree of global warming in **95% quantile**.
- Additional **157.4%** of cumulative emission reduction will be needed (compared with the Policy Continued Scenario) for 2 degree of global warming in **median**.

Here addition reduction means that, assuming the current forecasted cumulative emission is X_1, while the forecast emission assuming all countries fulfilling their promises is X_2, then assuming the reported ratio is r, the required cumulative emission is then be $X_1 - (1+r)(X_1 - X_2)$.

4 Plan

- We will spend some time in the question that what has been changed from 2010 data to 2015 data. We will do that by re-training the model with data before 2010 in 2015 version of the data.
- We will draft a paper for all the works of the climate project.
- We will wait for next steps of TFR paper reviews.
- We will keep updated and I will be in Sunnyvale during the summer.