

論文の内容の要旨

論文題目 Reconstruction of Historical Weather with Data Assimilation
Using Old Diaries (古日記データ同化による歴史天候の復元)

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Climate can control not only human life style but also other living beings. It is important to investigate historical climate to understand the current and future climates. Information about daily weather can give a better understanding of past life on earth. Long-term weather influences crop calendar as well as the development of civilizations. Unfortunately, existing reconstructed daily weather data are limited after 1850s due to the availability of instrumental data. The climate data prior to that are derived from proxy materials (e.g., tree-ring width, ice core isotopes, etc.) which are either in annual or decadal scale. However, there are many historical documents which contain information about weather such as personal diaries. In Japan, around 20 diaries in average during the 16th – 19th centuries have been collected and converted into a digitized form. As such, diary data exist in many other countries. This study aims to reconstruct historical daily weather during the 18th and 19th centuries using personal daily diaries which have qualitative weather descriptions such as ‘cloudy’ or ‘sunny’ by incorporating this information to a Climate model using a data assimilation scheme.

To reproduce climate a numerical weather prediction model can be used. In this study, Global Spectral Model by Scripps Experimental Climate Prediction Center based on Global Seasonal forecast system in National Centers for Environmental Prediction’s is used. This model was used as the operational forecast model there until 2004, and as the basis for several model development projects. However, these models are not perfect and the results can be improved if observations available in the past can be incorporated to model results. Data Assimilation is useful to get the best estimate from a model and observations considering the model errors and the observation uncertainties. There are attempts to reconstruct past climate using other proxies such as tree ring, coral, ice core and sediment. The merit of these climate reconstructions are that they cover several thousand years sometimes beyond last millennium.

However, limitation of these proxy reconstruction is that they are either annual or seasonal and not available in all the regions. On the other hand, the personal diary information provides more frequent information allowing to reconstruct climate in high resolution using online data assimilation techniques. In this study we used Local Ensemble Kalman Filter which uses ensemble forecast to calculate error covariances. And it has localization ability that can do assimilation grid wise to each state vector parallelly considering all the observation in the local area which makes the computation more efficient. Chapter 2 discussed about the assimilation system in detail and characteristics of diary data. Japan has a digitized database of old personal diaries from 17th century. There are around 20 diaries in 19th century. Even though personal diaries have valuable information about daily weather, they are limited to qualitative information such as descriptions like ‘sunny’ and ‘cloudy’ and it was a challenge to convert them to usable quantitative format to be used in the climate model. This qualitative information was converted to probabilistic representative quantitative values of total column cloud content (TCC) and downward shortwave radiation (SR).

Chapter 3 further investigated the possibility of assimilating uncertain weather information. It was not clear about suitable model settings and sensitivity of the number of observation and observation uncertainty for uncertain weather assimilation up to now. This chapter found solution to them with several experiments. When TCC data is assimilated, the correlation improved to 0.47 from -0.01 in average over Japan. In particular, the correlation of TCC improved to 0.64 from -0.13 at Choshi station. There are no significant contributions to other variables (i.e., correlation change in: Temperature 0.3 to 0.2, Precipitation -0.95 to 0.1 and Surface Pressure 0.18 to 0.3). Experiments with different number of observation stations showed improvement in correlation coefficient and RMSE around the observations sites even with 18 number of stations. This indicate even the fewer number of weather records are available local improvement can be achieved over those regions. Further, the simulation using data from 418 stations improved the results on not only the exact areas near the stations, but also remote areas. For instance, correlation coefficients of TCC, Temperature, Precipitation and Specific humidity in a non-assimilated site (i.e., Choshi station) improved from -0.13 to 0.38, 0.30 to 0.57, -0.10 to 0.53, -0.13 to 0.61 respectively. Simulations with different observations uncertainties were carried out to investigate the sensitivity to observation uncertainty and found that if a small observation uncertainty is given, assimilation scheme neglects the observations because ensemble spread is away from the observations. This was clear in results where an observation error with 1% achieved only 0.17 correlation while observations with error of 50% correlation improved correlation coefficient to 0.42. Impact from the initial conditions was analyzed by doing simulations with perturbed simulations instead of initial conditions created from time shift method as in previous experiments. Correlation was better in time shift method

(e.g., correlation decreased to 0.45 with perturbed initial condition method in comparisons to 0.64 in Choshi station using time shift method and RMSE increased to 39.9% in comparison to 32.6% in time shift method). Thus, it was decided to use time shift method to create ensembles.

Real weather diary data is quite different from the regular observations or synthesized observations used in Chapter 3 because they do not have any numbers. Lack of boundary data such as SST and Sea-ice fraction are other main challenges for simulation of forecast model during the 19th century. Currently there is no study which has overcome these challenges to assimilate qualitative description data. Hence in Chapter 4 we evaluated the impact from poor boundary condition. Assimilation system's skill was found to reduce mainly in precipitation when low frequency Sea surface temperature and Sea-ice fraction data are used. Correlation of all station average in Precipitation in 1995 April reduced from 0.58 to 0.32 even though correlation in SR and TCC changed only slightly (i.e., 0.79 to 0.81 and 0.76 to 0.65 respectively). Another challenge is the sensitivity of assimilation time, diary data information is mostly available in daily scale and impact on assimilating at particular time step has not been investigated earlier. Separate experiments showed that assimilation results in morning and evening has only a slight difference. In spring the correlation coefficient of average of all the stations change from 0.54 to 0.43 in Precipitation, 0.66 to 0.72 in SR, 0.66 to 0.73 in TCC and 0.81 to 0.8 in Temperature when assimilation time changed to 3 pm from 9 am. Further, Impact to model performance by assimilating only three weather classes data was evaluated in comparison to assimilating TCC from JMA observations with added 30% uncertainty, and it was found that the model could still capture the temporal variation even though correlation of TCC reduced to 0.47 to 0.57 and 0.32 from 0.54 in precipitation in comparison to direct TCC observation assimilation with 30% uncertainty at Choshi station.

Chapter 5 evaluated the skill of the model in assimilating document weather data. Main limitation was lack of instrumental data in the past. Hence an alternative approach was followed by assimilating weather classes data derived from recent description data. All these experiments were carried out with real data keeping the consistency with 19th Century data quality. This is the first study to carry out such realistic experiments to investigate the performance of assimilating weather class data into a climate model. Several simulations were done in the recent period where observations data available for validation. Twentieth century weather classes, data derived from JMA descriptions was utilized. SR assimilation could improve correlation of TCC average in all the stations from 0.19 to 0.68 in spring while reducing RMSE by 8 %. Improvements in other seasons and fields such as precipitation could be achieved as well. Further, we investigated opportunities to improve the accuracy of the model by incorporating other information such as absence of precipitation and found correlation of precipitation in all the station average could be improved to 0.67 from 0.45 in spring.

Monthly anomaly values over 1995-1999 showed good correlation in precipitation, TCC and SR. By analyzing pressure fields, it could be shown that the model could capture the synoptic scale weather patterns such as extra tropical cyclones. Bootstrap experiments were done using only half observations to check model performance when some diaries are absence. Even though the model performance was reduced to some extend satisfying correlation could be achieved. Correlation of all the stations average in TCC was 0.57, in SR was 0.72 and in precipitation was 0.45.

Chapter 6 assimilated weather information from weather diaries in 19th century into the climate model for the first time in the historical data assimilation field using the settings and parameters identified from Chapter 2 and Chapter 3 with weather classes from other studies for 1830s and weather classes directly from derived from Historical Weather Data Base for 1860s as explained in Chapter 2. The model could capture weather types such as ‘cloudy’ and ‘sunny’ after data assimilation in 1830s similar to conditions of weather classes. Similar skill was observed in 1860s experiments. Due to lack of instrumental data for daily comparison, monthly temperature from early instruments in Yokahama was used to check the model performance. Correlation coefficient in temperature without data assimilation and with assimilation were 0.96 and 0.94 respectively which are evenly high because the model can capture the seasonality. The model could produce extra tropical cyclones similar to 1995 when several diaries indicate rainy (weather class 3) during the spring period. By investigating precipitation anomaly from 1861 to 1864, 1861 May shown to be a wet (19.0 mm/month higher) and 1864 relatively dry year (13.5 mm/month less).

The last chapter makes the conclusions and discusses recommendation for future studies. In this study, weather categories from qualitative description data could be converted to weather classes and assimilate into a general circulation model using a data assimilation scheme. The results showed that assimilation of weather classes using SR improved the correlation of non-assimilated variables as well, and it was revealed that the resulted atmospheric distributions could capture the actual synoptic weather events. To further expand this research, more information from diaries such as wind direction and snow information can be utilized. This study used only the diary data in Japan. In future, this methodology can be applied globally when more digitized diaries are available in different regions.