PAPER ID: 380

Prediction of Future Temperature and Precipitation Changes in Bhola District of Bangladesh Using SDSM

Md. Masud Rana[1],*, Sajal Kumar Adhikary[2] and Md. Bashirul Islam[3]

[1]Lecturer, Department of Civil Engineering, Northern University of Business and Technology Khulna (NUBTK)-9100, Bangladesh, email: masudrana2k14@gmail.com

[2]Professor, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET) Khulna-9203, Bangladesh, email: sajal@ce.kuet.ac.bd

[3]Lecturer, Department of Civil Engineering, Bangladesh University Business and Technology (BUBT), Dhaka1216, Bangladesh, email: islam1901566@stud.kuet.ac.bd

*Corresponding author [Md. Masud Rana]

Keywords:

- Coastal area;
- Climate change;
- Statistical downscaling;
- RCP;
- GCM;
- CanESM2;

Abstract: The largest delta basin Bangladesh over the world has been experiencing the adverse effects of climate change which is almost similar to other countries. Natural disasters with irregular precipitation and temperature patterns have all severely impacted the human health and water resource sectors across the country (particularly in coastal areas). The southeast coastal region of this country has already been facing serious floods, cyclones, and saline water intrusion problems due to the potential climate change impacts, which are anticipated to be intensified in the future years. This study aimed to analyze the potential climate change over the southern coastal region of Bangladesh using a downscaling approach under different Representative Concentration Pathway i.e RCP (RCP 2.6, RCP 4.5, and RCP 8.5) scenarios. One climate station (Bhola) was considered in this study for the analysis and subsequent future period of (near future period: 2022-2050; mid-future period: 2051-2080; and far future period: 2081-2100) climate change predictions of precipitation, maximum temperature (Tmax), and minimum temperature (Tmin). A Statistical Downscaling Model (SDSM) was adopted to downscale a widely used General Circulation Model i.e GCM (e.g., the Canadian Earth System Model) for future projections. A quantitative approach was used for selecting suitable predictors, calibration, and validation with and without bias correction of monthly sub-models, where the results indicated the suitability of SDSM for downscaling daily precipitation, Tmax, and Tmin under different RCP scenarios for future periods. Compared to the baseline period of 1975–2005, the projected annual precipitation, Tmax, Tmin in Bhola climatic station indicated an increase of 2.75% to 11.49%, 5.19% to 12.45%, and 8.74% to 13.79%; +0.26 to +0.47°C, 0.27°C to 0.64°C and 0.30°C to 0.75°C; and 0.53°C to 0.62°C, 0.65°C to 0.88°C and 0.62°C to 1.36°C, in near, mid and the far future period, under the RCP2.6 to RCP8.5 respectively. Overall, the results showed that the future climate is expected to be warmer and rainy in those southern areas, which should be considered for the adaptive management of water resources in the study regions.

1. Introduction

In recent years, climate change is a major concerning issue in the world. Burning of fossil fuels, and anthropogenic activities on lands surface are the main causes of increasing greenhouse gases responsible for global warming (Mahmood & Babel, 2013). Global warming can make a significant change in water resources, agriculture, the environment, industries, human health, and coastal and terrestrial ecosystems (Shahriar et. al., 2021).

Temperature and precipitation are the most important climatic factors which have already been changed due to global climate change. The climatic factors are increasing runoff unavailability, inadequate water supply in irrigation and industries, crop destruction, damage to agriculture and livestock, frequent flood, flash flood, soil erosion, drought, and damage ecosystem of hydrology every year (Qiu et al., 2016). Nowadays the prediction and variability of global climatic factors are investigated by Global Climate Models (GCMs). GCMs scale is converted to a regional scale through a statistical downscaling approach for predicting regional climate changes (Hao et. al., 2022).

Bangladesh is an agricultural country with more than 80% of the people directly dependent on agriculture or work related to agriculture. Most precipitation (70-85% of annual precipitation) occurs in this country during the monsoon season from June to October. The distribution of precipitation in this country is heterogeneous. This country is also regarded as the most climate-vulnerable country in the world. The coastal part of this country is facing climate-induced impacts-rising sea levels, heightening storm surges, increasing saline water intrusion, and loss of wetlands. Bhola district is located in the southern coastal part of the country which is the most affected area by climate change (e.g., flooding, river erosion, storms, etc.) in Bangladesh. In the dry season, this region is subjected to salinity intrusion mainly due to decreasing freshwater flow in the Meghna River (Ahmmed et. al., 2020). Most of the land in the dry season is subjected to the availability of non-saline (fresh) water for Boro cultivation (Molla, 2019). About 35% of land in this region remains fallow during the Rabi season which severely damages the regional and national economy. This region also faces the minimum average temperature decreased, maximum average temperature, and precipitation increases (Rana & Adhikary, 2020). The overall objective of this study is to downscale climatic factors (temperature and precipitation) using GCM output for future climate change scenarios over the Bhola district which is the largest island of Bangladesh. The following specific objectives of this present study are to develop monthly sub-models in the SDSM platform for downscaling precipitation and temperature (Tmin, Tmax) for Bhola weather station by selecting an appropriate set of NCEP predictors and to check with satisfactory results, the model. The model is then used for evaluating the climate projection and also generate the trend of projection for all RCPs and compare from 2006 to 2100 future time period.

2. Materials and Methods

2.1 Study area and data description

Bhola district, the south-central part of Bangladesh, is located between 90º 40' and 91º 0' east longitudes and between 22º 0' and 22º 40' north latitudes. The total area of the district is about 3737.21 km^2 which is bounded by the Noakhali and Lakshmipur districts, Shahbazpur channel and Meghna (lower) river to the east, Barisal and Patuakhali districts and Tentulia River to the west, Barisal and Lakshmipur districts to the north, the Bay of Bengal to the south. This area is important for fisheries and agricultural activities which are significantly affected by climatic condition. The climatic condition of this area in terms of temperature and precipitation varied from year to year.

The daily observed climate data for temperature (Tmin and Tmax) and precipitation were collected from Bangladesh Meteorological Department (BMD) over thirty years (1975-2005). The mean and precipitation, maximum temperature, and minimum temperature were about 2408 mm, 30.3°C, and 21.52°C respectively. The whole time series data were categorized (i.e., calibration, validation, and bias correction) to check the model performance and minimize the downscaled error. Some missing data in observed values were handled by multi-linear regression coding.

The 26 predictors for NCEP/NCAR were downloaded with a grid resolution of 2.5º x 2.5º from the website: https://www.esrl.noaa.gov. Three emission scenarios: RCP8.5 (very high), RCP4.5 (intermediate), and RCP2.6 (very low) were obtained from the CMIP5 statistical downscaling predictors overview of a Canadian climate model with 2.8125° x 2.8125° grid resolution.

2.2 Description of SDSM

The statistical downscaling model (SDSM) is a hybrid linear regression-based model that utilizes stochastic weather generation and multivariate linear regression for generating future climate scenarios (Wilby et al., 1998). A multiple linear regression model incorporating the correlation matrix, partial correlation, p-value, histograms, and scatter plots is used to select a combination of some appropriate indicators from the predictors (Mahmood & Babel, 2013). During the selection of predictors, multicollinearity should be considered to avoid erroneous results. In this study, two optimized models: (i) Ordinary least square method (OLS) was selected for precipitation prediction, and (ii) Dual simplex method (DS) was selected for the Temperature prediction. Both methods are used to compare the results and any modifications to the existing methods should also be described (Huang et al., 2011).

In SDSM, monthly, annual, and seasonal sub-models are also available to establish statistical or empirical relationships between small- and large-scale variables. There are two types of sub-model related to local-scale variables: (i) one is a conditional sub-model used for the dependent variable (e.g., precipitation and evaporation), and (ii) another is unconditional sub-model used for the independent variable (e.g., temperature) calibration (Chu et al., 2010). In this study, daily historical and NCEP data for 30 years (1961-2005) is available for getting output. In major cases, data for temperature is disturbed (not precipitation) which is transformed in SDSM for regression analysis.

2.3 Model justification

The selection of suitable predictors is an important and challenging task in SDSM. Results of variance, correlation matrix, partial correlation, and p values among the observed temperature and precipitation with NCEP predictors are the main indicators that are used for the screening of predictors (Wilby & Dawson, 2007).

The performance of the statistical model has been accomplished by calculating the explained variance (EV), Coefficient of determination (R^2), Root Means Square Error (RMSE), and Nash-Sutcliffe Model efficiency (NSE) by comparing observed and simulated data of Precipitation, Maximum Temperature, and Minimum Temperature. The best fitting of EV values not less than 60% identifies between observed and simulated values. The value of R^2 and NSE denotes how much the observed and simulated values match. The range of R2 values varies from 0 to and at the same time, the NSE values fluctuate from $-\infty$ to 1. In both cases, 1 is the perfect matching prediction outcome. On the other hand, RMSE indicates how much apart the regression data point is from the best-fitting curve line. Bias correction is an approach that is adopted to minimize the biases of predicted values downscaled from daily time series data (Mahmud and Babel, 2012).

2.3.1 Future trend

The future climate scenario generation over three periods (e.g., near Future Period, FP-1 (2022-2050); Mid Future Period, FP-2 (2051-2080) and Far Future Period, FP-3 (2081-2100)) was performed after checking the model accuracy by using calibration performance. The CanESM2 model generated three RCP (2.6, 4.5, and 8.5) scenarios based on the baseline period (1975-2005) are considered. The monthly predicted results of precipitation and temperature were compared with the monthly observed data period for climate change analysis. A positive value indicates increasing and a negative value indicates decreasing the variance of the results to the baseline data period.

3. Result and Discussions

3.1 Assessment of model performance

The most challenging work is to identify the most suitable predictors list. In this study area, the lists of most suitable predictors are for precipitation (Mean sea level pressure (Pa), 850 hPa Relative vorticity of true and 850 hPa Specific humidity), for Tmax (500 hPa Relative vorticity of true, Total precipitation, 500 hPa Specific humidity,850 hPa Specific humidity, 1000 hPa Specific humidity, Air temperature at 2 m) for Tmin are (500 hPa Relative vorticity of true, 850 hPa Specific humidity, 1000 hPa Specific humidity). These predictors are most responsible for this area because of the geographic location.

Table 1: Predictors list and Model performance check during calibration and validation

Climatic Parameter	Predictors Name	Calibration		Validation			
				With bias		*Without bias*	
		EV	**R^2**	**RMSE**	**NSE**	**RMSE**	**NSE**
Precipitation	*mslp, p8_z, s850*	66.98	0.67	128.92	0.62	128.05	0.63
Tmax	*p5_z, prcp, s_500, s_850, shum, temp*	70.65	0.71	1.42	0.67	1.38	0.68
Tmin	*p5_z, s_850, shum*	79.26	0.79	0.83	0.97	0.78	0.97

The observed data (1975-2005) was divided into two categories where around 70% of data (1975-1995) are used for calibration and 30% of data (1996-2005) are validation of this model. For calibrating the model, EV and R^2 values are evaluated where the values vary from 66.98 to 79.26 and 0.67 to 0.79. This result indicates that the model for this station is suitable and satisfactory. It also declares that this model can be used for further validation checks. The validation performance is carried out by calculating RMSE and NSE. Before bias correction, the RMSE and NSE are 128.92 and 0.62 for precipitation, and after bias correction; they become 128.05 and 0.63 respectively. At the same time, the Tmax and Tmin show the same pattern improvement of model performance with respect to before and after bias correction. Table 1 indicates that this model can be used for future climate change projections.

3.2 Mean annual anomaly and trend of future projection

Using GCM with observed values evaluates future annual average anomaly of precipitation (mm) in percentage and change of temperature (Tmax and Tmin) for three individual periods considering RCP2.6, RCP4.5, and RCP8.5 scenarios. For precipitation, the change of anomaly in percentage is considered based on observed values whereas only anomaly/change based on observed values has been considered. Overall observation from Table 2 is that the precipitation and Temperature (Tmax and Tmin) show a positive trend line based on observed values. Maximum positive increments are found for RCP8.5 and least for RCP2.6 scenarios.

Table 2: Annual average changes of daily precipitation, Tmax, and Tmin under several RCPs

Climatic Parameter	FP-1 (2022-2050)			FP-2 (2051-2080)			FP-3 (2081-2100)		
	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Prec. (mm)	+2.75	+7.25	+11.49	+5.19	+7.66	+12.45	+8.74	+10.70	+13.79
Tmax (°C)	+0.26	+0.34	+0.47	+0.27	+0.40	+0.64	+0.30	+0.45	+0.75
Tmin (°C)	+0.53	+0.56	+0.62	+0.65	+0.69	+0.88	+0.62	+0.84	+1.36

For precipitation, the anomaly (%) change would be varies from +2.75% to +11.49%, +5.19% to +12.45% and +8.74% to +13.79% for FP-1, FP-2 and FP-3 respectively. At the same time, the change of Tmax was found +0.26°C, +0.34°C, and +0.47°C under RCP2.6, RCP4.5, and RCP8.5 scenarios respectively for FP-1. The Tmax gradually increased and maximum +0.64°C and +0.75°C temperatures would be maximized for FP-2 and FP-3 under RCP8.5 scenarios. For Tmin, this pattern is also similar to Tmax and it would be +0.62°C, +0.88°C, and +1.36°C temperature for FP-1, FP-2, and FP-3 respectively under the same RCP scenarios.

According to Figure 2, the R^2 value varies from 0.0140 to 0.3397 for precipitation, 0.1012 to 0.6291 for Tmax and 0.0354 to 0.8517 for Tmin. Its results also inform that RCP8.5 scenarios show the best fitting downscaling output among RCP2.6 and RCP4.5 scenarios. So, the best projection of the maximum upward trend is $y = 2.3162x + 2590.3$ for precipitation, $y = 0.0051 + 30.155$ for Tmax, and $y = 0.0167x + 21.233$ for Tmin respectively under RCP8.5 scenarios.

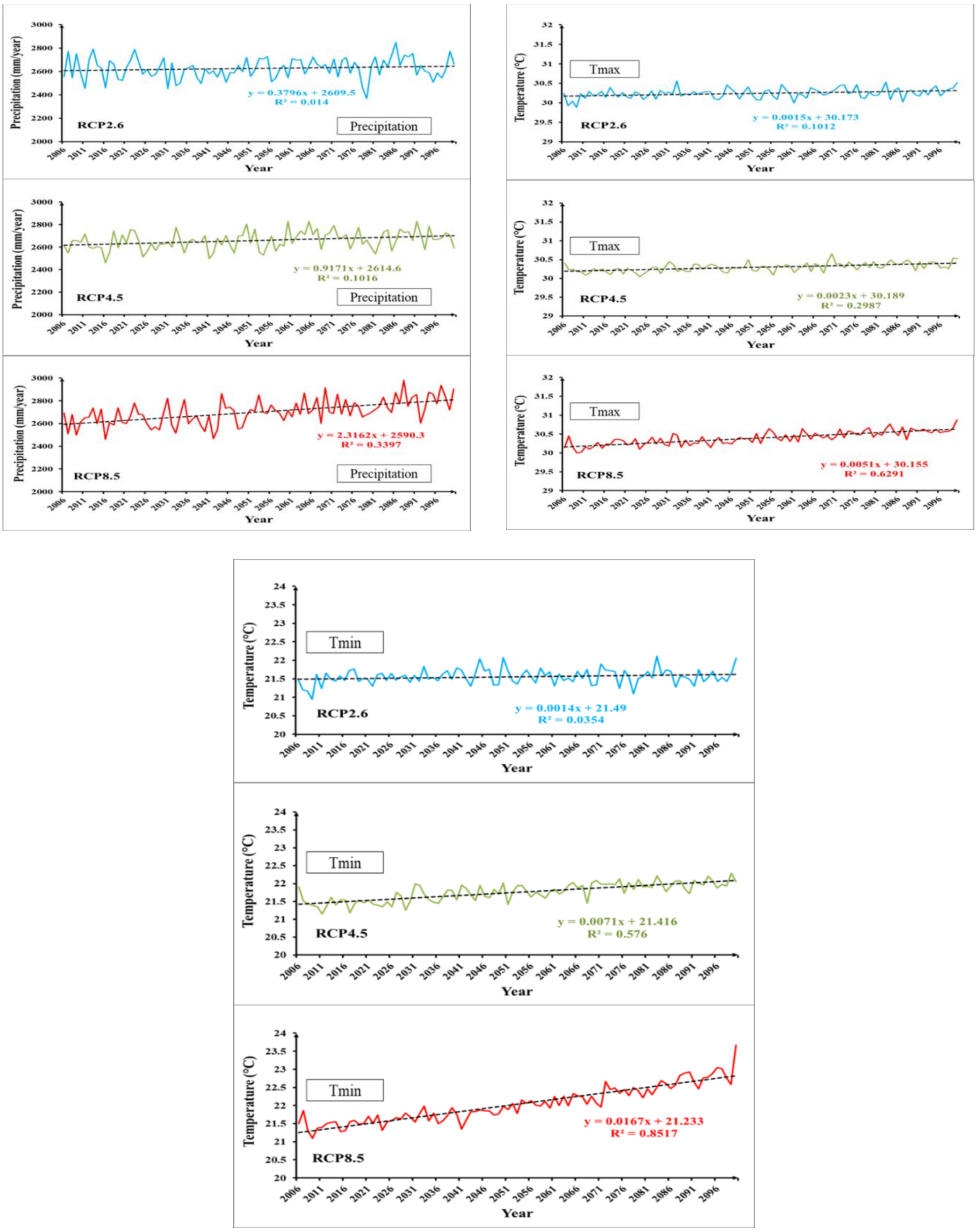

Figure 1: Mean annual Projection for Precipitation, Tmax, and Tmin from 2006-2100 under RCP scenarios

4. Conclusions

The annual mean precipitation and Temperature (Tmax and Tmin) are projected using a statistical downscaling model (SDSM) in Bhola weather station of Bangladesh considering CMIP5 GCMs data. The statistical approach performed is checked and illustrates the combination of the satisfactory results under the monthly sub-model. The conclusions and summary of this study area is outlined in the following:

- The projected precipitation, Tmax, and Tmin would be significantly increased under all RCPs consideration. The calculation of anomaly percentage is considered based on observed values for precipitation but only changes with respect to observed values are conducted for temperature.
- The change of all climatic projection is evaluated under RCP2.6, RCP4.5, and RCP8.5 where RCP2.6 (low carbon emission scenario) shows the least magnitude and RCP8.5 (high carbon emission scenario) exhibit the maximum.
- The maximum anomaly for precipitation, Tmax, and Tmin would be 13.79%, 0.75°C, and 1.36°C respectively at the end of this current century. Comparing only Tmax and Tmin, The change of Tmin would be greater than Tmax.
- According to the evaluation of the R^2 value, the best projection fits RCP8.5 scenarios for all parameters.
- All projected parameters (precipitation and temperature) would be linear trend lines for all RCPs and the RCP8.5 shows the higher tangential line with respect to other RCPs.
- The overall projection for this study area is that this area would be rainy and warm simultaneously day by day.

These projections of precipitation and temperature (Tmax and Tmin) can help the decision and policy maker of Bangladesh to minimize the loss of any natural hazards and migration for life.

Acknowledgment

The authors are very much grateful to Khulna University of Engineering and Technology for providing a funding opportunity. Special thanks to Bangladesh Meteorological Department who helped us by sharing their data.

References

Ahmmed, I., Shaibur, M. R., & Sarwar, S. (2020). Adaptation strategies with changing climatic conditions: a case study of coastal Bhola district, Bangladesh. Environ. Biol. Res., 2(2), 11-21.

Chu, J. T., Xia, J., Xu, C. Y., & Singh, V. P. (2010). Statistical downscaling of daily mean temperature, pan evaporation and precipitation for climate change scenarios in Haihe River, China. Theoretical and Applied Climatology, 99(1–2), 149–161.

Hao, W., Shao, Q., Wei, P., Zhu, C., Chen, X., & Chen, R. (2022). Evaluation and projection of the annual maximum streamflow in response to anthropogenic and climatic effects under nonstationary conditions in the Hanjiang River Basin, China. Journal of Water and Climate Change, 13(4), 1855-1877.

Huang, J., Zhang, J., Zhang, Z., Xu, C. Y., Wang, B., & Yao, J. (2011). Estimation of future precipitation change in the Yangtze River basin by using statistical downscaling method. Stochastic Environmental Research and Risk Assessment, 25(6), 781–792.

IPCC. (2022). IPCC Special Report 2022. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to Eradicate Poverty, 32. https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_FullReport.pdf

Mahmood, R.H., & Babel, M. S. (2013). Evaluation of SDSM developed by annual and monthly sub-models for downscaling temperature and precipitation in the Jhelum basin, Pakistan and India. Theoretical and Applied Climatology, 113(1–2), 27–44. https://doi.org/10.1007/s00704-012-0765-0

Molla, S.R. (2019). Effect of Climate Change and Salinity Intrusion on Agriculture and Socio-Economic Condition of Bhola District, Bangladesh. Project Selected by the Jashore University of Science and Technology, Jashore 7408, Fiscal Year: 20118-19 (Current Project). Jashore University of Science & Technology, just.edu.bd/research/item/5f423618c1d9b840d427d834. Accessed 16 Oct. 2022.

Qiu, L., Peng, D., Xu, Z., & Liu, W. (2016). Identification of the impacts of climate changes and human activities on runoff in the upper and middle reaches of the Heihe River basin, China. Journal of Water and Climate Change, 7(1), 251–262. https://doi.org/10.2166/wcc.2015.115

Rana, M. M., & Adhikary, S. K. (2020). A Demand-Driven Water Management Framework for Rajshahi City Corporation in Bangladesh. 5th International Conference on Civil Engineering for Sustainable Development (ICCESD 2020), KUET, Khulna, Bangladesh, February 7-9, 2020.

Shahriar, S. A., Siddique, M. A. M., & Rahman, S. M. A. (2021). Climate change projection using statistical downscaling model over Chittagong Division, Bangladesh. Meteorology and Atmospheric Physics, 133(4), 1409-1427. https://doi.org/10.1007/s00703-021-00817-x

Wilby, R. L., & Dawson, C. W. (2007). SDSM 4.2— A decision support tool for the assessment of regional climate change impacts, User Manual. Department of Geography, Lancaster University, UK, August, 1–94.

Wilby, R. L., Wigley, T. M. L., Conway, D., Jones, P. D., Hewitson, B. C., Main, J., & Wilks, D. S. (1998). Statistical downscaling of general circulation model output: A comparison of methods. Water Resources Research, 34(11), 2995–3008. https://doi.org/10.1029/98WR02577