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DA NANG'S EXTREME RAINFALL AND CLIMATE CHANGE BY THE 2020s & 2050s

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SYNOPSIS

EXPOSURE

This report provides a technical overview of the extreme event analysis conducted to investigate how climate change might alter the intensity of future extreme rainfall in Da Nang. This report is meant for hydrological engineers, water managers, and urban planners requiring more techincal information.

Climate change will alter the frequency and intensity of extreme rainfall events, which are currently caused either by typhoons or more localized storms, and increase sea levels leading to greater tidal flooding and higher storm surges. Taken together, this implies that climate change will intensify flood risk in the future. Coupled with continued development, it is possible that Da Nang could experience unprecedented levels of flooding in the future.

Introduction

Located in central Vietnam, the city of Da Nang, is experiencing rapid urbanization and development. Population is increasing around 11% a year, new construction continues to rise along the coastline, and nearly annual flooding disrupts livelihoods, commerce, and development. The flooding is due to a combination of rapid urbanization and land-use change, tidal flooding, and heavy rainfall both in the city and upstream. Climate change will alter the frequency and intensity of extreme rainfall events, which are currently caused either by typhoons or more localized storms, and increase sea levels leading to greater tidal flooding and higher storm surges. Taken together, this implies that climate change will intensify flood risk in the future. Coupled with continued development, it is possible that Da Nang could experience unprecedented levels of flooding in the future.

The purpose of this study was to investigate how climate change might alter the frequency and intensity of extreme rainfall events for two future periods, the 2020s and the 2050s. The Da Nang Department of Construction (DoC) and Da Nang University of Technology (DUT) constructed an urban flood model for Da Nang to test a variety of flooding scenarios, based upon three historical flood episodes—one each in 2007, 2009, and 2010. ISET–International conducted extreme rainfall event analysis to inform key stakeholders of potential future extreme rainfall events that could contribute to urban flooding. This technical report discusses plausible changes in extreme rainfall intensity and frequency for Da Nang by the 2020s and the 2050s. ISET-International did not investigate or develop scenarios related to population and land-use change for the urban flood model; these activities were conducted by DoC and DUT.

The analysis was conducted with support from the Rockefeller Foundation and the Climate Development and Knowledge Network. The rainfall analysis supports the overall objective of the two concurrent research projects underway. The first research project funded by the Climate Development and Knowledge Network hypothesizes that climate-adapted shelter has a positive benefit cost ratio accruing to vulnerable populations. The overall goal of the other research project's, funded by the Rockefeller Foundation, is to add substantive new insights on the economics and other returns to investment in climate resilience that go substantially beyond the costs and benefits of individual interventions. Both research programs are exploring the economic returns to key urban systems that alter development and land-use pathways in a manner that reduces vulnerability and increases resilience. Storm profiles were conditioned on projected changes in extreme rainfall between 2006–2065 in order to support the flood modeling for the economic analysis.

This technical report provides information of a more technical nature to individuals such as water managers, urban developers, or utilities managers who require more detailed information as to how projected changes in an area's extreme rainfall events can be calculated. The information provided uses the case study example of calculations for Da Nang, but the methodology presented and all of the datasets, except for the station-level data, are applicable for repeating similar types of analyses throughout Asia. The cautions and assumptions section is pertinent to all extreme event analysis applications. This brief does not provide extremely detailed information on the calculations; for this, we encourage readers to access the resources listed in the Further Reading/References section.

Methodology

DATA

No single climate model will ever be able to project the exact changes in rainfall, temperature, or other climate variables in any given year or period in the future for any part of the world. This is because no one knows exactly what emissions, populations, and land use changes might occur in the future, and due to the limitations of the models themselves. Global circulation models (GCMs) project how the climate might change, given changes to these human-controlled factors, which are accounted for as representative concentration pathways (RCPs) in the IPCC 5th Assessment models (van Vuuren et al., 2011). Because no single model can project exact changes to an area's climate, it is necessary to use projections from multiple GCMs, each driven by a couple of RCPs, to capture the possible range and trend of changes. Furthermore, climate is a description of an area's average weather over a period of time, typically 30 years. Climate change analysis involves comparing the statistics of an area's particular weather as projected for a period in the future that is at least 30 years long, with a period of historical climate of the same length.

With these two caveats, we downloaded daily precipitation data (simulated historical and projected future) from the CMIP5 Multi-Model Ensemble Database: http://pcmdi9.llnl.gov/esgf-web-fe/. The ensemble set of projected daily rainfall was formed using projections from 8 GCMs, each running the RCPs 4.5 and 8.5, for a total of 16 ensemble members against which to compare future rainfall with past rainfall. Simulated historical rainfall by the GCMs covered the period 1961–2005, whereas future projected rainfall for each RCP spanned 2006–2065. Historical daily rainfall covering the period of 1976–2011 for four stations in and surrounding Da Nang were purchased from Nha Trang Hydro-Meteorological Forecasting Station. Station data were cleaned

TABLE 1

DATASETS AND MODELS USED FOR ESTIMATING FUTURE CHANGES TO DA NANG'S EXTREME RAINFALL EVENTS

Dataset/Model	Data Provider	Description
APHRODITE	Research Institute for Humanity and Nature (RIHN), Meteorological Research Institute of Japan Meteorological Agency (MIR/JMA)	High-resolution daily precipitation datasets from rain-gauge observation (Yatagai et al., 2012)
Station-level: Cam Le, Cau Lau, Da Nang, Ai Nghai	Nha Trang Hydro-Meteorological Forecasting Station	Daily precipitation (1976-2011) from rain-gauge observation
CMIP5: BCC-CSM1.1(m)	Beijing Climate Center, China Met Administration	Simulated daily precipitation from the following experiments:
CanCM4, CanESM2	Canadian Centre for Climate Modelling & Analysis	
CSIRO-MK3.6.0	Commonwealth Scientific & Industrial Research Organization (CSIRO)/ Queensland Climate Change Centre of Excellence (Australia)	Historical (1960-2005) RCP 4.5 (2005-2065) RCP 8.5 (2005-2065)
HadGEM2	Met Office Hadley Centre (U.K.)	
MIROC-ESM	Japan Agency for Marine-Earth Science & Technology, Atmosphere & Ocean Research Institute (University of Tokyo), and National Institute for Environmental Studies	All downloaded from CMIP5 Multi-Model Ensemble Dataset:
MPI-ESM-MR	Max Planck Institute for Meteorology (MPI-M)	http://pcmdi9.llnl.gov/esgf-web-fe/
NCAR-CCSM4	National Center for Atmospheric Research (U.S.)	
Nor-ESM1-M	Norwegian Climate Centre	

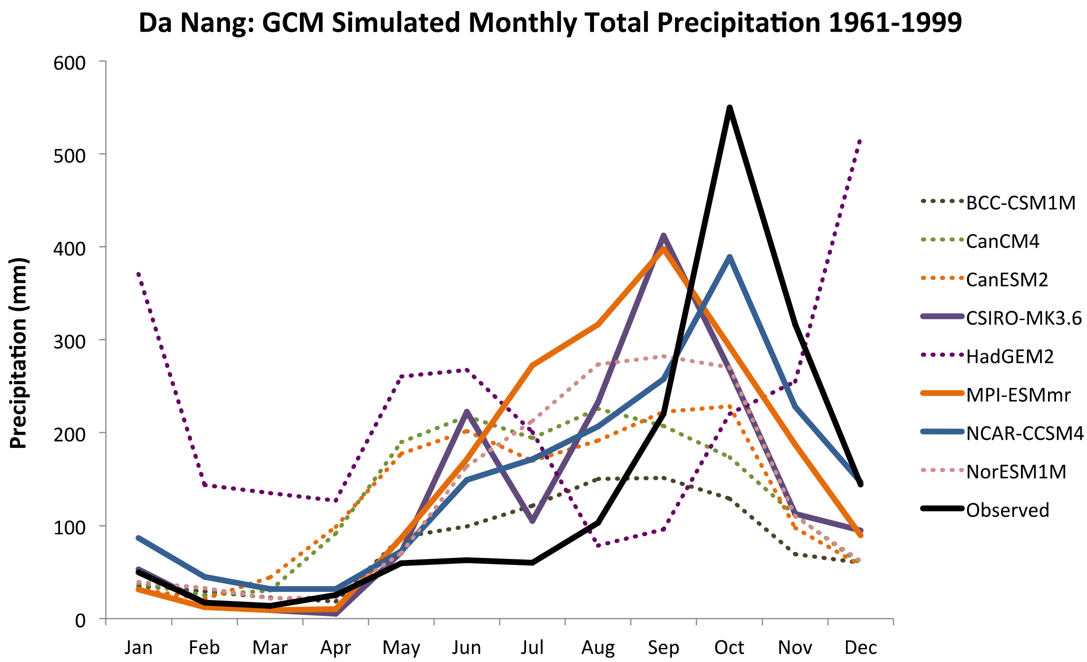
and underwent several quality control checks. Additional historical data covering the period of 1961–1975 were accessed from the APHRODITE project database (Yatagai et al., 2012), and used to extend the historical observation record for Da Nang and surrounding area. Table 1 displays the datasets and models used to estimate potential changes to Da Nang's extreme rainfall characteristics:

MODEL VALIDATION

While multiple models must be used in estimating potential changes to an area's rainfall, especially if for the near-term or out to the 2060s, it is necessary to use some validation tests to ensure that the selected models are able replicate key rainfall statistics for that area. The Cautions and Assumptions section details the reasons for selecting a subset of GCMs out of a broader group of possible models. We used a moments comparison test, comparing the area-averaged station rainfall data with the grid-scale simulated rainfall of each GCM over the period 1961–1999. Three models—CSIRO-MK3.6, MPI-ESMMR, and NCAR-CCSM4—were able to reasonably replicate the seasonality of Da Nang's rainfall, as well as the median and standard deviation (the first and second moments) of monthly rainfall totals. Given the outcome of the moments comparison test, we selected these three models to form the basis of estimating changes to the nature of extreme rainfall events in Da Nang. The remaining models were rejected for further extreme event analysis because of their inability to replicate Da Nang's rainfall characteristics, as shown in Figure 1.

FIGURE 1

GCM SIMULATED AND STATION-AVERAGED, OBSERVED HISTORICAL MONTHLY TOTAL PRECIPITATION. THE SOLID LINES CORRESPOND WITH GCMS THAT REPLICATED OBSERVED STATISTICS WELL; DOTTED LINES WITH MODELS THAT HAVE BEEN REJECTED.



EXTREME RAINFALL EVENT ANALYSIS

Extreme rainfall events are by statistical definition rare. A rainfall event that happens frequently, such as every year or every few years, is not considered an extreme event. Because extreme rainfall events happen so rarely, they do not follow normal statistics and different calculations must be used to ascertain how frequently they occur (return period), and their corresponding average intensity (mm/hr) over particular durations of time (hours). Therefore, when calculating how extreme events might change in the future, it is not possible to simply multiply historical rainfall amounts associated with flood events by projected changes in seasonal or monthly rainfall totals.

Extreme rainfall event analysis to support hydrological analysis (e.g. flood modeling) is often represented through intensity-duration-frequency (IDF) curves for an area, which are formed by fitting one of the extreme value distributions to a dataset formed from the maximum annual daily rainfall value, from at least 30 years of daily rainfall data. Generalized IDF curves follow the form:

$i = a(T) / b(d)$ (Eq. 1)

$a(T) = \mu + \sigma F^{-1}(1-1/T)$ (Eq. 2)

$b(d) = d^{\eta}$ (Eq. 3)

where *i* is the rainfall intensity of particular duration d and return period T, a(T) is a function determined through fitting an extreme value probability distribution, and b(d) is a scaling function for rainfall of different durations but the same return period. Mu (μ) and sigma (σ) are parameters of EVI distribution, while nu (η) is a scaling parameter (Menabde, Seed, & Pegram, 1999; Koutsoyiannis, Kozonis, & Manetas, 1998; Chow, Maidment, & Mays, 1988). The Further Reading section contains resources describing the formation and uses of IDF curves, including some IDF curves for other areas of Vietnam (see Daniells and Tabios, 2008).

Many locations within a given area, in this case Da Nang and the surrounding stations like Cau Lau, share similar rainfall characteristics and common IDF curves can be calculated for a single area (Daniells and Tabios, 2008). After comparing the statistics of each station-level daily precipitation dataset, we combined the data into a single, area-averaged dataset and calculated the historical IDF curves. Table 2 and Figure 2 display the IDF curves for Da Nang for select durations and return periods. To read the table or IDF curve, look at the duration of the event and then look at the corresponding intensity. The total precipitation of an event lasting a particular amount of time, with a given return period, can be determined from looking at an area's IDF curve/table. For example, the average total precipitation associated with an event of a 24-hour duration and a return period of 15 years is 316.8 mm (13.2 mm/h x 24 hours) as shown on the 15-year curve in Figure 2. The durations shown correspond with the durations of the extreme events modeled in DUT's urban flood model.

FIGURE 2

IDF CURVES FOR DA NANG FOR SELECT RETURN PERIODS AND DURATIONS OF 12 TO 108 HOURS. THE DURATIONS SHOWN CORRESPOND WITH THE DURATIONS OF THE EXTREME EVENTS MODELED IN DUT'S URBAN FLOOD MODEL.

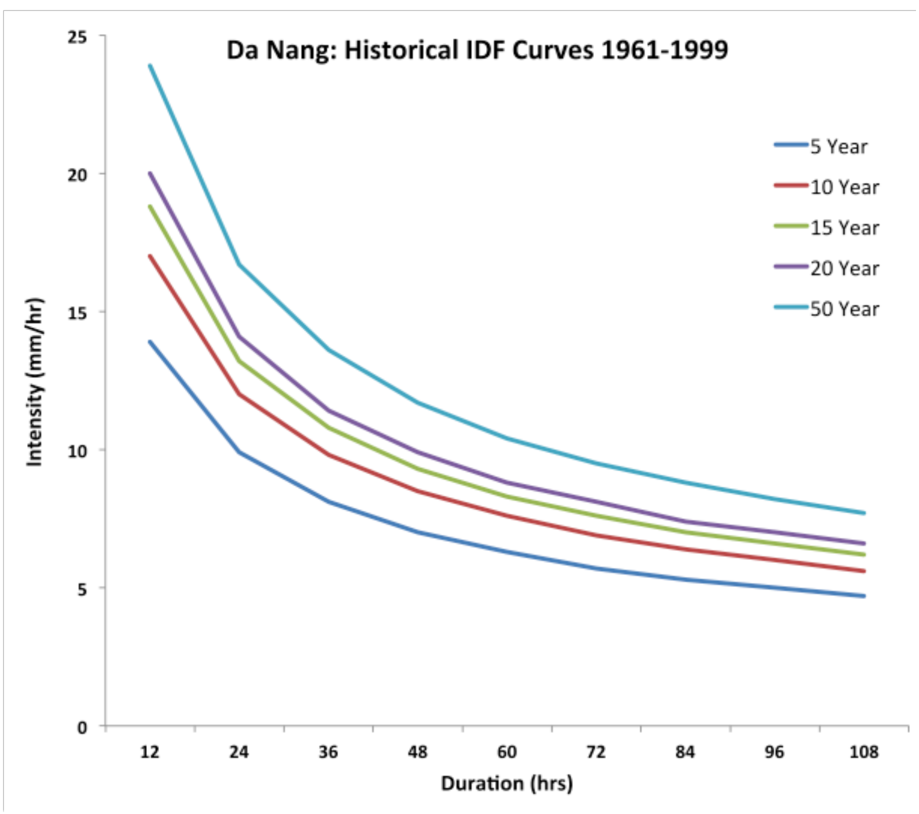


TABLE 2

IDF TABLE FOR DA NANG AND SURROUNDING AREA FOR SELECT DURATIONS AND RETURN PERIODS FROM THE HISTORICAL PERIOD 1961–1999. THE FULL IDF CURVES OUT TO 108-HOUR DURATION EVENTS FOR THESE RETURN VALUES ARE SHOWN ABOVE IN FIGURE 2. THE 100-YEAR RETURN PERIOD CURVE IS NOT SHOWN IN FIGURE 2.

	RETURN PERIOD (YEARS)		
Duration (Hrs)	**2 Years**	**15 Years**	**100 Years**
12	9.2 mm/hr	18.8 mm/hr	26.8 mm/hr
24	6.6 mm/hr	13.2 mm/hr	18.7 mm/hr
48	4.8 mm/hr	9.3 mm/hr	13.1 mm/hr
96	3.5 mm/hr	6.6 mm/hr	9.1 mm/hr

In Da Nang, the historical floods of 1999, 2007, 2009, and 2010 corresponded with rainfall events with characteristics shown in Table 3. The 1999 rainfall event corresponds to an extremely severe rainfall event in Da Nang's historical record, while the 2007 event is a moderately severe event. The 2009 and 2010 events were actually fairly common, small rainfall amount events. That flooding occurred in the city during these two years indicates that it is strongly influenced by factors other than rainfall, such as rapid urbanization, tidal influences, and lack of coordination in reservoir management between Da Nang and the upstream locations.

TABLE 3

INTENSITY, DURATION, AND FREQUENCY CHARACTERISTICS OF THE RAINFALL EVENTS ASSOCIATED WITH THE FLOOD EVENTS CHOSEN FOR THE URBAN FLOOD MODEL. THE TOTAL CUMULATIVE PRECIPITATION ASSOCIATED WITH THE FOUR DAYS OF MOST INTENSE RAINFALL (96 HOUR DURATION) OF THE 1999 EVENT IS 998.4 MM (10.4 MM/HR X 96 HRS).

Event	1999	2007	2009	2010
Intensity (mm/hr)	10.4	6.7	3.5	2.7
Duration (hrs)	96	96	120	96
Return Period (Years)	1 in 300	1 in 16	1 in 4	1 in 2

PROJECTED RAINFALL EXTREMES EVENT ANALYSIS

Estimating how climate change will impact the frequency and intensity of rainfall events for an area requires scaling between a GCM's IDF curves of simulated historical rainfall and the observed, station-scale IDF curves at a location (Mailhot, Duchesne, Caya, & Talbot, 2007). GCMs will usually underrepresent an area's rainfall if much of its extreme rainfall is due to thunderstorms, because the average grid cell of a GCM is between ~75–150km and thunderstorms are on a smaller scale of ~5–20km. The majority of Da Nang's extreme rainfall is associated with thunderstorms during the monsoon season or typhoons. As can be seen in Figure 1, all of the GCMs underrepresent Da Nang's rainfall during the rainy season of September–December, which is expected and quite normal. Thus, it is necessary to scale the simulated historical IDF curves from GCMs against the observed, station-scale curves, and apply these areal reduction factors to the future IDF curves. The areal reduction factors are calculated as:

$$ARF(T,d) = \frac{x_p^{(g)}(\boldsymbol{T}, \mathrm{d})}{x_p^{(s)}(\boldsymbol{T}, \boldsymbol{d})} \quad \text{(Eq. 4)}$$

where $x^{(s)}(T,d)$ and $x^{(g)}(T,d)$ are average rainfall depths of particular events of duration d and return periods T at the station scale (superscript ^{s}) and grid box scale (superscript ^{g}) in the control climate (subscript ^{p}) (Mailhot et al., 2007).

By comparing the 1961–1999 (past) IDF curves of each GCM with the observed, station-scale IDF curves for the same period, we developed separate areal reduction scaling factors for each GCM. We then calculated the IDF curves for the projected rainfalls from CSIRO-MK3.6, MPI-ESM-MR, and NCAR-CCSM4 from the RCPs 4.5 and 8.5, for two time periods. The first future time period calculated changes in extreme rainfall from 2006–2030, corresponding to changes by the end of the 2020s; the second future time period covered 2031–2065, corresponding to changes by the end of the 2050s. These six sets of IDF curves for each time period were compared with the historical, station-scale IDF curves to see how things changed between the future and the past.

Percentage scaling factors were produced for the three different flood events being modeled by DUT from the future IDF curves. The duration of each rainfall event associated with each flood was found, as well as its corresponding intensity and return period. We then calculated the percent differences between the historical intensities of each event, with the projected, future intensities with the same return period and duration. These percent differences formed the percentage scaling factors for DUT's urban flood model, e.g. if the particular intensity of an event was projected to increase between 9% and 29%, the scaling factors for that event would be 1.09 and 1.29. The scaling factors for this analysis assumed that hourly rainfall values were being used in the flood model; had the flood model used daily rainfall values, the scaling factors would have been different.

Possible Changes to Da Nang's Extreme Rainfall: 2020s and 2050s

In the future, according to a range of different climate model and emission scenarios, the intensity and frequency characteristics of rainfall events for Da Nang are likely to change. However, the types of changes are different between the 2020s and the 2050s and between events that are rare and common, as seen in Figure 3 and Figure 4. Rainfall events that are not that severe and that happen frequently (with a return period of 1 in 10 years or less) are not projected to change significantly by the end of the 2020s or 2050s when compared with 1961–1999, as shown in Figure 3.

FIGURE 3

RANGE IN PROJECTED CHANGES IN 2-YEAR RETURN PERIOD RAINFALL INTENSITIES (COMMON RAIN EVENTS) OVER THE 2020s (LEFT FIGURE) AND 2050s (RIGHT FIGURE) WHEN COMPARED WITH 1961–1999 (THE SOLID BLACK LINE).

Note that the intensity scales are different between the left and right figures.

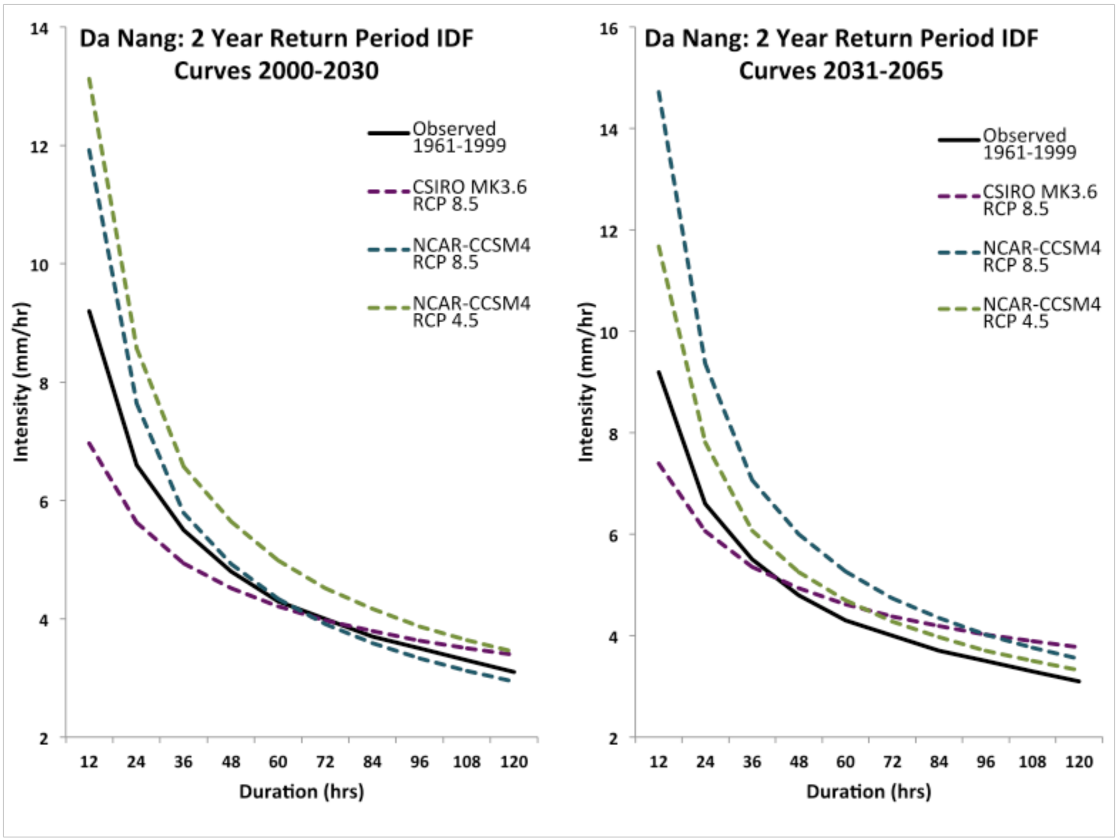


TABLE 4

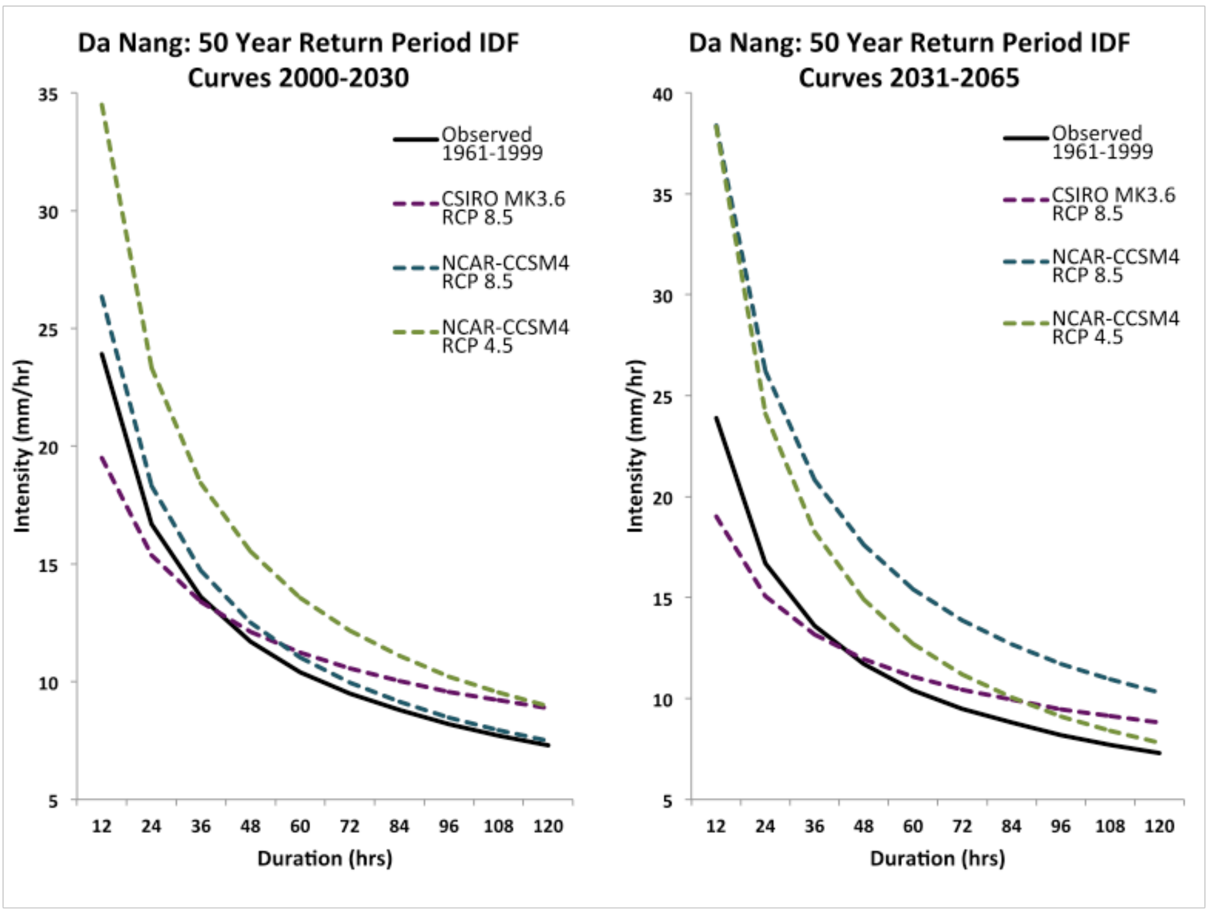
POSSIBLE CHANGES IN RAINFALL INTENSITIES BY THE 2020s AND 2050s, WHEN COMPARED WITH 1961–1999, FOR RAINFALL EVENTS THAT HAVE CAUSED FLOODING IN DA NANG AND WERE USED IN THE DUT FLOOD MODEL INVESTIGATION.

Rainfall Event	Intensity 1961-1999	Percent Change 2020s	Percent Change 2050s
1999	10.4 mm/hr	9.1 to 29.4%	13.1 to 48.1%
2007	6.7 mm/hr	3.0 to 23.6%	26.4 to 63.2%
2009	3.5 mm/hr	-4.9 to 13.8%	3.1 to 22.9%
2010	2.7 mm/hr	-10.6 to 4.0%	-0.6 to 14.9%

The possible changes in moderate to severe rainfall events are potentially greater than those for smaller, more common events as shown in Table 4. Figure 4 depicts the multi-model spread of projected IDF curves for 50-year return period rainfall intensities in the 2020s and 2050s, with the historical, observed IDF curve. The intensity of these moderate-to-severe rainfall events might increase more between the 2020s and the 2050s when compared with 1961–1999. However, there is more uncertainty, or greater spread in model projections for shorter duration events, and there is no clear trend (increasing vs. decreasing) in rainfall intensities for shorter duration events. Much of this uncertainty in short duration (less than 24 hour) events was introduced via the scaling equation (Eq. 3) during the IDF curve calculation and via the areal reduction factor scaling between the simulated and observed historical curves, which then propagates to the projected IDF curves. The uncertainty is less pronounced in events lasting 24 or more hours. Other sources of uncertainty are discussed in the Cautions and Assumptions section.

FIGURE 4

RANGE IN PROJECTED CHANGES IN 50-YEAR RETURN PERIOD RAINFALL INTENSITIES (MODERATELY SEVERE EVENTS) OVER THE 2020S (LEFT FIGURE) AND 2050S (RIGHT FIGURE) WHEN COMPARED WITH 1961–1999 (THE SOLID BLACK LINE). NOTE THAT THE INTENSITY SCALES ARE DIFFERENT BETWEEN THE LEFT AND RIGHT FIGURES BECAUSE THE 50-YEAR RETURN PERIOD RAINFALL INTENSITY INCREASES ARE LARGER BY THE END OF THE 2050s.



Cautions and Assumptions

GCM VALIDITY AND SELECTION

Any interpretations of climate projections for adaptation purposes should use projections from multiple GCMs, each running a couple of RCPs, in order to capture the possible range and trend of changes. Theoretically, the projections of every climate model have equal probability of occurrence. When investigating possible changes in the more distant future—2070 and later—one should use the projections from every available model. However, scientists are divided about how many models should be used for near-term (2020s through 2050s) climate change analysis. Some scientists argue that all models should still be used; other scientists argue that only models that are able to broadly replicate a region's key historical climate statistics and seasonality should be used. This second group argues that because future projection runs are initialized from the simulations of historical climate, the errors of the historical simulations are propagated forward into the future projections. If a climate model is not able to sufficiently replicate a region's broad climate characteristics—in the case of Da Nang, the Western North Pacific Summer Monsoon—it might not be as valid in providing projections of possible changes in the near-term climate.

We agree with this second interpretation of climate model projections, as this investigation focused on near-term changes in Da Nang's extreme rainfall events. Da Nang, and Vietnam as a whole, lies in the Western North Pacific Summer Monsoon region, and GCMs currently have a difficult time in replicating key statistical characteristics and seasonal timing of precipitation over Vietnam. Many of the more severe rainfall events that triggered flooding in Da Nang were due to typhoons, which are not yet adequately represented in GCMs. It is possible that the extreme event analysis conducted here underestimates the potential increases in severe rainfall for Da Nang, because the scale of the GCMs used does not capture typhoons. While one should use as many models as possible for analysis, judgment is required when deciding how many models to retain, depending on the purpose of the analysis and how far into the future it covers.

DATASET LENGTH AND NON-STATIONARITY

As discussed previously, extreme event analysis is conducted for rare events. Ideally, one would have fifty years or more of daily rainfall data to establish statistics for the more severe, and rare events, such as those with return periods of 1 in 100 years or more. Extreme event analysis requires datasets longer than 30 years to be extremely rigorous, yet few locations have complete records of such length. The more rare events may be extrapolated from the probability distributions of existing data, but will not be as accurate for shorter datasets as they are for longer datasets. Furthermore, it is evident in many regions that precipitation regimes have been changing (non-stationarity), but it is difficult to determine for some locations whether the changes are due to inherent decadal variations, climate change, or some combination because of the shortness of those locations' records. It becomes all the more difficult to detect non-stationarity in an area's extreme events, or potential causes of those changes if they can be detected, because of the rarity of extreme events and the requirement of longer records for robust extreme event analysis. For Da Nang, the IDF curves do not change significantly when using the shorter period of historical record (1961–1999) as compared to the curves for 1961–2011. This provides some subjective measure of confidence that Da Nang's extreme events have been relatively stable over the recent past. However, it is possible that the frequency and intensity of extreme events has changed between the early 1900s and today; the historical records are not long enough to allow for such trend detection.

The Da Nang urban flood model required projected changes to Da Nang area rainfall for two future periods, the 2020s and the 2050s. These two periods were selected due to their pertinence to the urban planning and development cycles of the city, and are extremely relevant to policy and decision timeframes. Therefore, the extreme event analysis was conducted for these two periods in order to meet policy demand. The analysis and projected changes must be interpreted with some caution as just explained, because it was conducted for thirty-year periods rather than the ideally longer period of, say 2006–2060. We fully expect, however, that climate change will alter Da Nang's future extreme rainfall and it is possible that such changes will be evident by 2030.

Concluding Remarks

Climate change will likely alter the frequency and intensity of Da Nang's extreme rainfall events, as demonstrated with this analysis. The changes projected for Da Nang are consistent with changes already being observed in other regions of the world and that are broadly projected to occur (IPCC, 2012). It is important to remember, however, that the projected changes produced in this analysis will most definitely evolve, and the analysis should be repeated 5 to 10 years from now. It is quite possible that the extreme event analysis conducted here underestimates the potential increases in severe rainfall for Da Nang, because the GCMs do not yet adequately represent typhoons that are responsible for severe rainfall in the area. Ultimately, the degree of change in the frequency and intensity of extreme climate events is highly dependent on human choices around land-use, energy and natural resource consumption, and emission rates over the next decade.

Flooding within Da Nang, and any urban area, is not solely dependent upon climate hazards like heavy rain or typhoons. The depth, duration, and location of floodwaters within a city are largely determined by land-use and urban development, solid waste and wastewater/storm water management systems, and coordination with upstream and downstream water managers. Destruction of vegetation and wetland areas and construction of roads and buildings increases impervious surface area, leading to greater flood depths and waterlogging. Development along coastlines and loss of shoreline ecosystems increases coastal erosion, and reduces a city's natural barriers against storm surges and tidal flooding. Even without climate change altering the frequency and intensity of Da Nang's extreme rainfall events, flooding is likely to increase in severity and frequency in the city because of urban development.

Further Reading and Resources

For more in-depth discussions on extreme rainfall event analysis, the following references that were listed in this brief are suggested:

Asian Pacific FRIEND: Rainfall Intensity Duration Frequency Analysis for the Asia Pacific Region. (2008). In T. M. Daniell & G. Q. Tabios (Eds.), IHP-VII Technical Documents in Hydrology (Vol. No. 2). Jakarta: UNESCO International Hydrological Programme VI.

Chow, V.T., Maidment, D.R., & Mays, L.W. (1988). Applied Hydrology (International Edition ed.). Singapore: McGraw-Hill Book Company.

IPCC (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. In C. B. Field, et al. (Eds.), (pp. 582). Cambridge, UK.

Koutsoyiannis, D., Kozonis, D., & Manetas, A. (1998). A mathematical framework for studying rainfall intensity-duration-frequency relationships. Journal of Hydrology, 206, 118-135.

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