A Downscaling Approach of Relating the Large-scale Patterns to the Extreme Rainfall Frequency in Taiwan Mei-yu Season for Climate Change Projection and S2S Prediction

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Introduction

A conceptual downscaling method is presented to demonstrate the new approach of using a large-scale circulation index as a predictor to approximate the local-scale climate extremes. The circulation index, southwesterly flow index (SWFI), is directly derived from the global model outputs. The predictand is Taiwan Mei-yu extreme rainfall frequency (TMERF). The SWFI derived from CMIP3 and CMIP5 models can be applied to project the changes of TMERF in the future under different climate scenarios. The SWFI derived from the S2S prediction models will be applied to predict TMERF weeks ahead.

The Mei-yu season in Taiwan

Taiwan is a mid-size island located at the western boundary of the subtropical Pacific with the Tropic of Cancer running across. Even though the area of Taiwan is only about 36,000 square kilometers, there are six mountain peaks over 3500 meters and the highest peak Yushan is at 3,952 m. The integrated monsoonal and terrain effects result in a unique rainfall pattern in Taiwan. Taiwan's climate variability is influenced by East Asian and western North Pacific monsoons and complicated by the topographic effects and abundant moisture supply from the surrounding ocean.

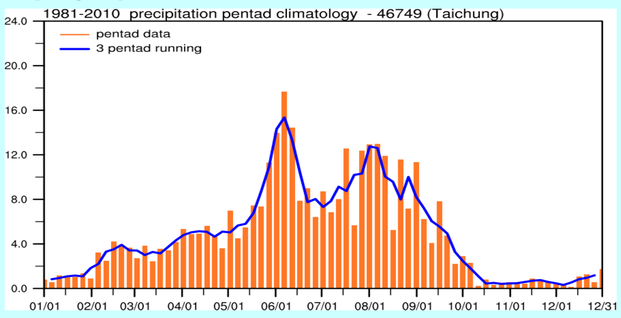


FIGURE 1 Pentad climatology of rainfall amount averaged over Taichung station for the period 1981-2010.

The pentad climatology based on 30 years (1981-2010) rainfall data at Taichung station located at the central part of the island near the west coast (Fig. 1) shows a sharp peak at pentad 32 (June 5-9). The accumulated rainfall amount during the 10 pentads from pentad 27 (May 11-15) to 36 (June 25-20) makes up about one third of the annual total. This distinct rainy period is called Mei-yu season in Taiwan.

The climatological precipitation during Mei-yu season shows a large-scale spatial structure: a rain band oriented in the southwest-northeast direction near Taiwan is clearly observed (Fig. 2). The centers of rainfall maximum appear over Bangladesh and the west coast of Mynamar. Large rainfall centers also appear over the northern Vietnam, South China coast, Taiwan (24N, 120E), south of Japan, and the Philippines, Indonesia islands and the Micronesia region. The Taiwan Mei-yu season is defined as the two months of May and June (MJ).

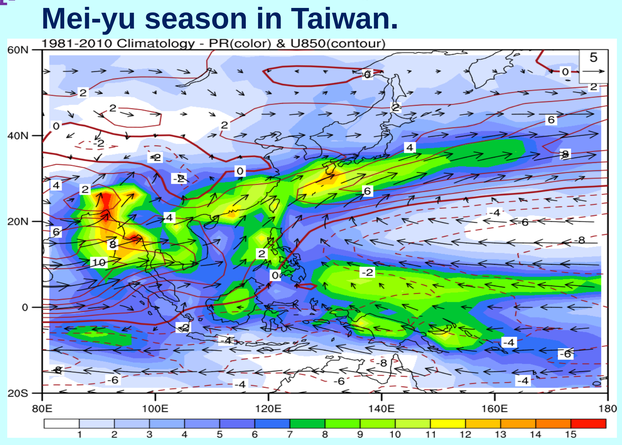


FIGURE 2 Climatological Pentad 30-35 (May 26 – June 24) mean precipitation (mm/day) and 850-hPa winds (m/s).

Taiwan Mei-yu Extreme Rainfall Frequency (TMERF)

Taiwan Mei-yu season extreme rainfall events are often associated with organized meso-scale convective systems (MCSs) embedded in the cloud band along the Mei-yu front (Fig. 3). The southerly or southwesterly low-level jet (LLJ) equatorward of the Mei-yu front is an essential factor in the development of MCSs.

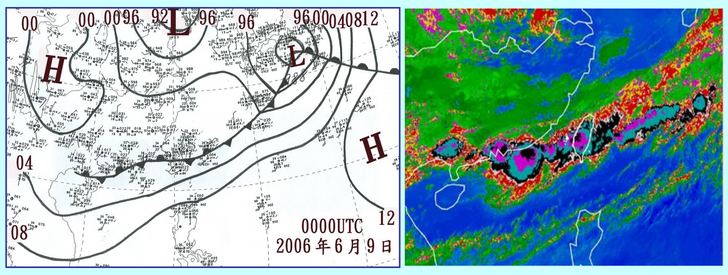
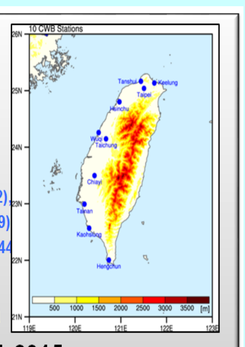


FIGURE 3 The surface weather map and color enhanced infrared GMS satellite imagery for an extreme event of Taiwan Mei-yu at 0000 UTC June 9, 2006.

Data

- CWB Weather Stations
  - 10 (west) stations
  - daily precipitation 1951-2015
  - Tanshui(46690),Keelung(46694),Taipei(46692), Hsinchu(46757),Wuqi(46777),Taichung(46749), Chiayi(46748),Tainan(46741),Kaohsiung(46744 Hengchun(46759)
- Large-scale Analysis Data
  - NCEP/NCAR-R1 daily, 1951-2015
  - U & V 850hPa (2.5° X 2.5°)
  - CMIP3 and CMIP5 model output



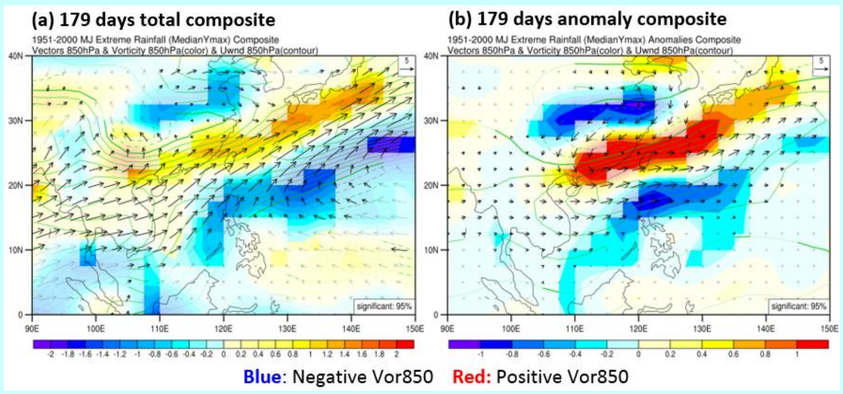
The extreme rainfall event: R > Rc

The extreme rainfall events were identified on the station basis, as the daily rainfall amount R is greater than a threshold value Rc.

TABLE 1 The extreme event rainfall amount threshold value (Rc) at each station.

Station Name	Station Number	Rc (mm/day)
Tanshui	46690	88.6
Keelung	46694	99.1
Taipei	46692	89.6
Hsinchu	46757	118.2
Wuqi	46777	112.5
Taichung	46749	102.3
Chiayi	46748	105.7
Tainan	46741	114.1
Kaohsiung	46744	105.8
Hengchun	46759	111.8

Note: The "extreme event" is equivalent to the 24-hour rainfall event with the return period longer than 1.5 year estimated using extreme value probability distribution analysis and exceeds the 95th percentile value (R95) of the rainfall events with R > 1.0 mm/day.



179 days in the 50 Mei-yu seasons are identified on which at least at one station saw the extreme event. Cases influenced by typhoons do not count.

FIGURE 4 The composite vorticity and winds at 850hPa (a) total fields and (b) anomalies relative to the 50-year (1951-2000) climatology.

The Large-scale Circulation Index: SWFI

STEP 1	Select the days with favorable vorticity condition during May and June: positive vorticity over S. China and Taiwan (red grid) and negative vorticity over the SCS and Philippine Sea (blue grid)
STEP 2	Calculate the SWU – the mean U850 of the grids with strong vorticity gradient (green grid)
STEP 3	Determine **SWUc** on the multi-year climate basis. For real time prediction, the SWUc is the median value of SWU in 50 years (1951-2000). For Climate Change study, the SWUc is the median value of SWU in 20 years (1986-2005).

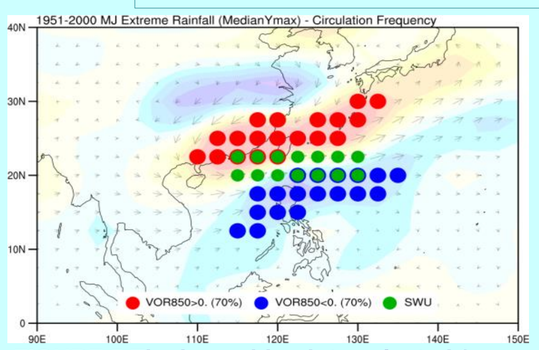


FIGURE 5 The key grid points selected for identifying the favorable large-scale conditions represented by 850-hPa vorticity and U for Taiwan Mei-yu extreme rainfall events.

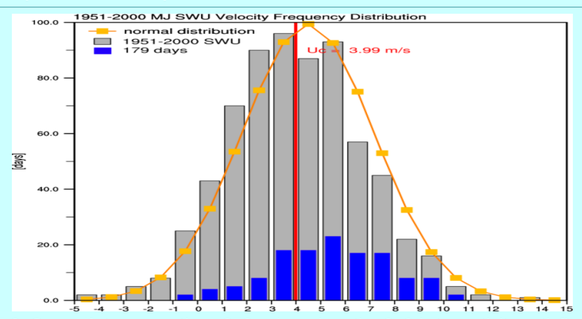


FIGURE 6 Gray Histogram: the U850 value when the 850-hPa vorticity satisfies the positive over Taiwan and negative over the Philippines condition. Blue Histogram: the U850 value on the 179 days of the extreme cases and the 850-hPa vorticity satisfies the positive over Taiwan and negative over the Philippines condition.

SWUc: the U850 criterion of the southwesterly winds is chosen as the **median** of the "gray histogram", which is **4 m/s**. **Among the 179 days of the extreme cases, 52% of the cases can pass the criterion of SWU >= SWUc.**

STEP 4	**SWFI** is defined as the number of days during May and June that satisfying the criteria of 850-hPa vorticity and SWU >= SWUc

Conceptual downscaling method

- preliminary evaluation

Estimate the statistical relationship between the extreme rainfall frequency and large-scale climate patterns

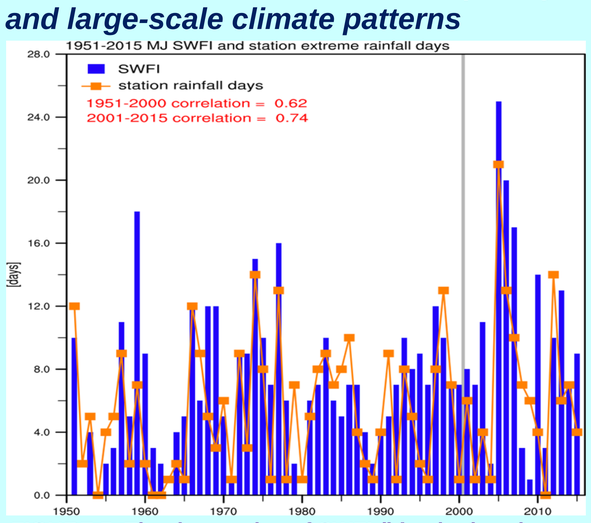
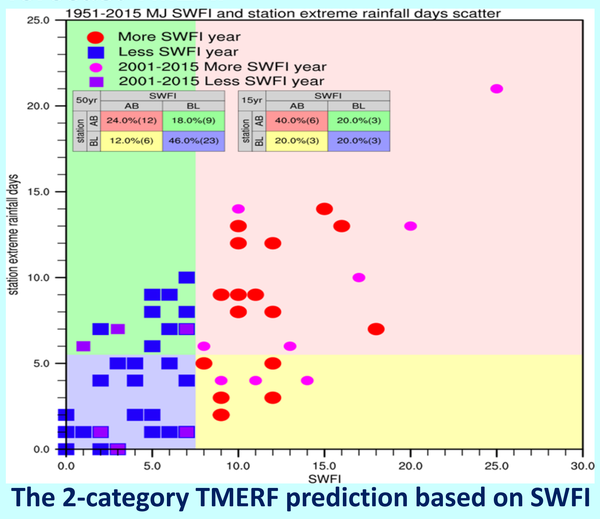


FIGURE 7 The time series of SWFI (blue bar) and Taiwan Mei-yu extreme rainfall event frequency TMERF (orange line). The correlation of SWFI and TMERF is 0.62 during the "training" period of 1951-2000 and 0.74 during the "forecast" period of 2001-2015.

- prediction/projection

Evaluate forecast feasibility determined by the prediction skill of using SWFI to forecast TMERF



The 2-category TMERF prediction based on SWFI can reach 60% hit rate in 15 forecast years.

FIGURE 8 The scatter diagram of two category SWFI and TMERF during the training period (1951-2000) and forecast period (2001-2015).

TMERF projection based on CMIP3 and CMIP5

Selected CMIP3 and CMIP5 Models

CMIP3 Model Data (6) http://www-pcmdi.llnl.gov

Name	Originating Group	Country
BCCR_BCM20	Bjerknes Centre for Climate Research	Norway
CCCMA_CGCM31_T63	Canadian Centre for Climate Modelling and Analysis	Canada
CSIRO_MK30	Commonwealth Scientific and Industrial Research Organisation Atmospheric Research	Australia
CSIRO_MK35	Commonwealth Scientific and Industrial Research Organisation Atmospheric Research	Australia
MIROC32_HR	The University of Tokyo/CCSR, NIES, and JAMSTEC/FRCGC	Japan
MPI_ECHAM5	Max Planck Institute for Meteorology	Germany

CMIP5 Model Data (10) http://www-pcmdi.llnl.gov

Model Name	Country	Institution
ACCESS1.0	Australia	Commonwealth Scientific and Industrial Research Organization and Bureau of Meteorology
BNU-ESM	China	Beijing Normal University (BNU)
CMCC-CM	Italy	Centro Euro-Mediterraneo per I Cambiamenti Climarici
CNRM-CM5	France	Centre National de Recherches Meteorologiques and Centre Europeen de Recherches et Formation Avancees en Calcul Scientifique
HadGEM2-CC	UK	Met Office Hadley Centre
IPSL-CM5A-MR	France	Institute Pierre Simon Laplace
MIROC5	Japan	University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
MPI-ESM-MR	Germany	Max Planck Institute for Meteorology
MRI-CGCM3	Japan	Meteorological Research Institute
NorESM1-M	Norway	Norwegian Climate Centre

SWFI: a proxy indicator for Taiwan May-Yu extreme rain frequency

SWFI = the number of days that SWU >= SWUc , when the Vor850 pattern matches

Note: SWFI value is data set/model dependent

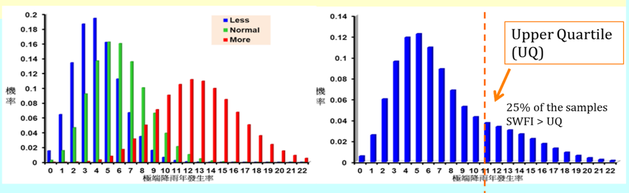
Downscaling procedure:

(1) SWFI classification - Less : Normal : More = 3 : 4 : 3

(2) Use a Poisson distribution to describe the PDF of the extreme event frequency in each category

(3) Use a combined PDF to describe the probabilities of extreme event frequency:

$$PDF_{rate} = 0.3 * PDF_{more} + 0.4 * PDF_{normal} + 0.3 * PDF_{less}$$



Future projection: [SWFI (future runs) > UQ (1986~2005 his. runs)] – 25%

CMIP3 Models

%	BCCR_BCM20	CCCMA_CGCM31_T63	CSIRO_MK30	CSIRO_MK35	MIROC32_HR	MPI_ECHAM5
A1B_NT	-1	-18	-15	-13	-3	-5
A1B_LT	11	-3	-10	-8	-3	-15
A2_NT	9		-20	3		-5
A2_LT	16		-10	-28		0
B1_NT	24	13	-25	-13	-8	-10
B1_LT	22	-3	10	-18	18	-15

CMIP5 Models

%	ACCESS_10	BNU_ESM	CMCC_CM	CNRM_CM5	HadGEM2-CC	IPSL-CM5A-MR
RCP8.5_NT	-20	0	25	-20	15	-25
RCP8.5_LT	-5	-15	15	-5	10	-25

%	MIROC5	MPI-ESM-MR	MRI-CGCM3	NorESM1-M
RCP8.5_NT	30	0	-20	-5
RCP8.5_LT	25	30	5	35

Historical : 1986-2005 / Near Term : 2046-2065 / Long Term : 2081-2100

Scenario: A1B & RCP8.5 Assessment *for* Taiwan Mei-Yu Ex.
Near-term future: Increase 3/16= 20% ; Decrease 12/16= 75%
Long-term future: Increase 7/16= 44% ; Decrease 9/16= 56%

Using 6 CMIP3 and 10 CMIP5 models, under A1B and RCP8.5 scenarios the analysis result suggest that TMERF will decrease in the near-term future. In the long-term future the direction of the changes is not clear. However, it shows a tendency of more frequent extreme events in the long-term compared with the near-term future.

On-going Work

The proposed downscaling approach is applied to the S2S prediction hindcast database to extract the potentially useful large-scale index for forecasting the variation and tendency of local-scale climate extremes.