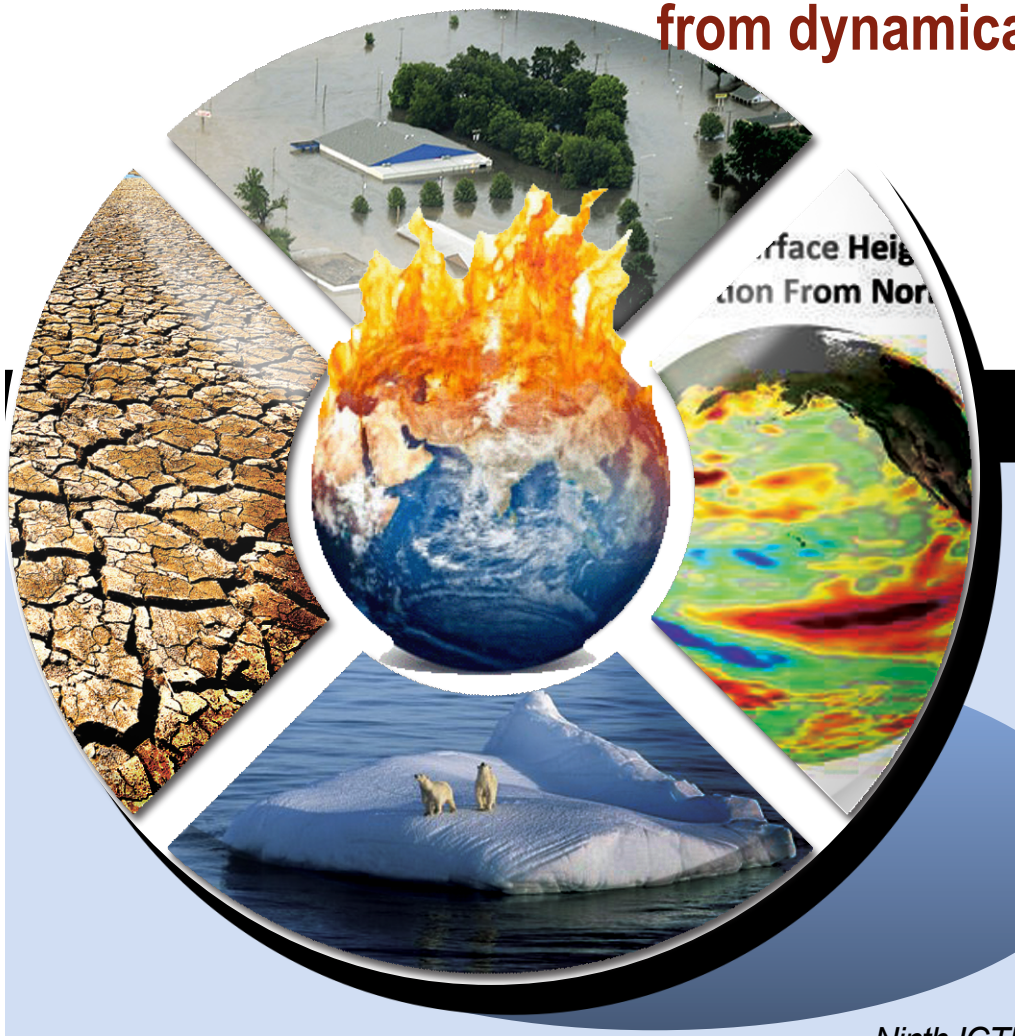
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Projections of rising heat stress due to global warming from dynamically downscaled climate simulations



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Ninth ICTP Workshop on the Theory and Use of Region Climate Models

SCIENCE ADVANCES | RESEARCH ARTICLE

ScienceAdvances AAAS

CLIMATOLOGY

Deadly heat waves projected in the densely populated agricultural regions of South Asia

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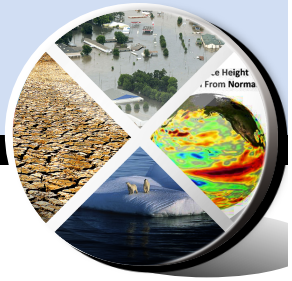
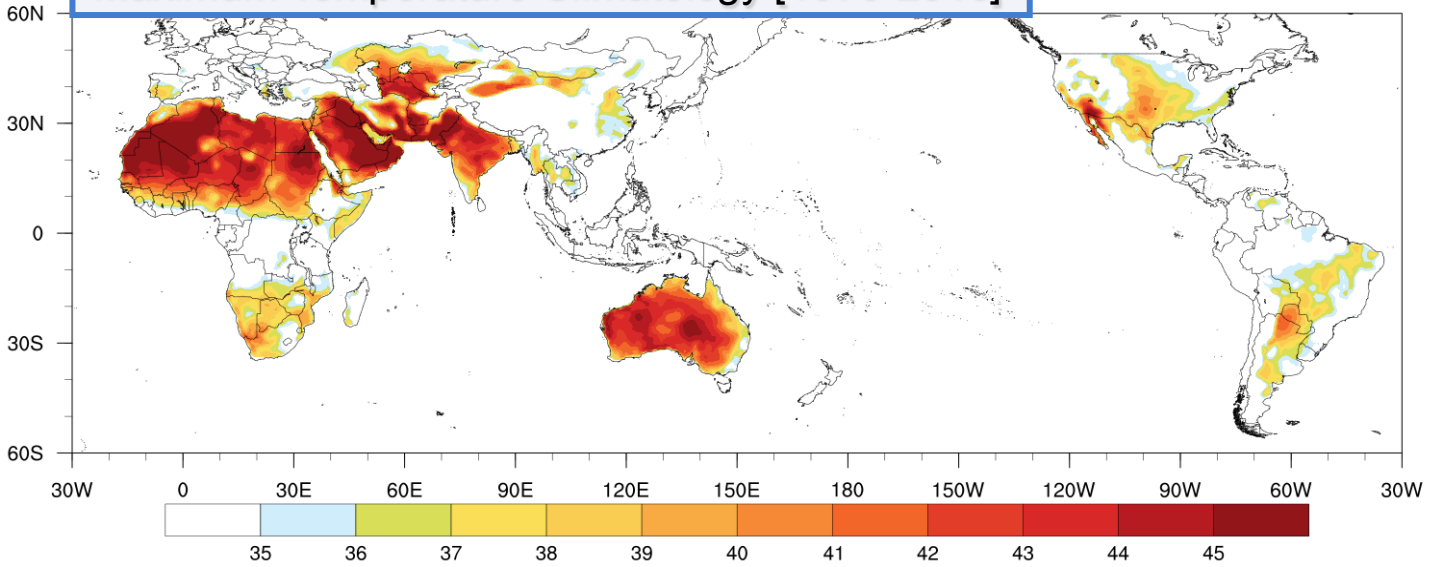
The risk associated with any climate change impact reflects intensity of natural hazard and level of human vulnerability. Previous work has shown that a wet-bulb temperature of 35°C can be considered an upper limit on human survivability. On the basis of an ensemble of high-resolution climate change simulations, we project that extremes of wet-bulb temperature in South Asia are likely to approach and, in a few locations, exceed this critical threshold by the late 21st century under the business-as-usual scenario of future greenhouse gas emissions. The most intense hazard from extreme future heat waves is concentrated around densely populated agricultural regions of the Ganges and Indus river basins. Climate change, without mitigation, presents a serious and unique risk in South Asia, a region inhabited by about one-fifth of the global human population, due to an unprecedented combination of severe natural hazard and acute vulnerability.

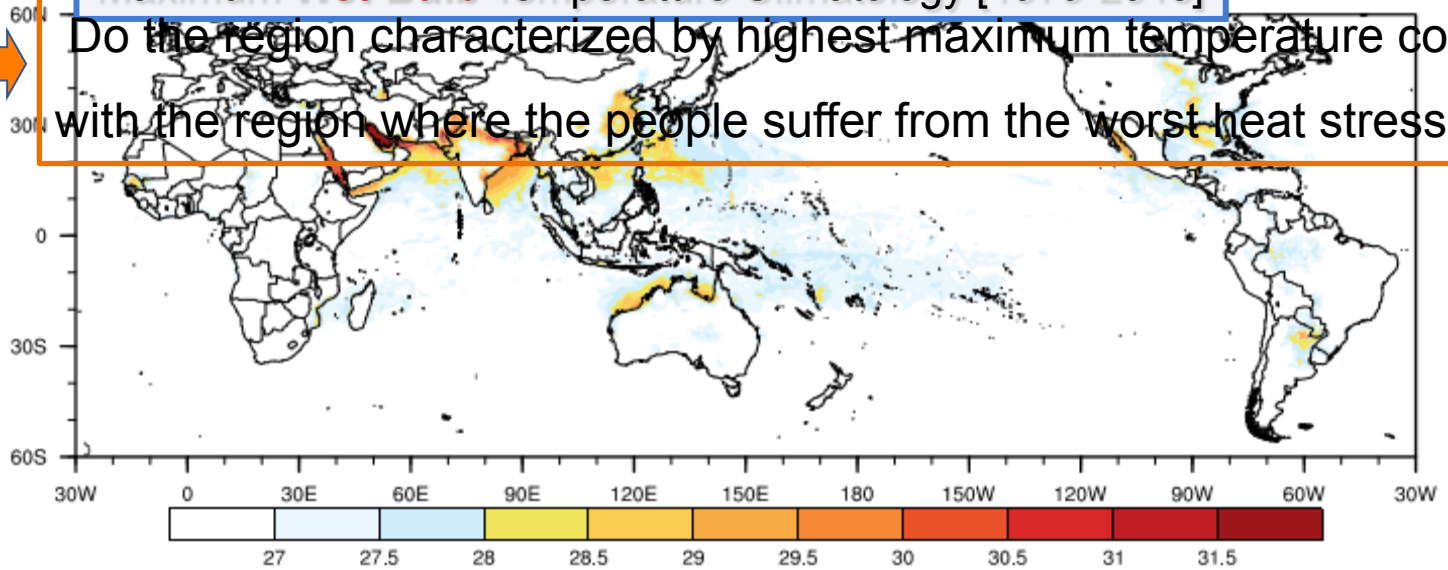
Where is the hottest location in the world ?



Maximum Temperature Climatology [1979-2015]

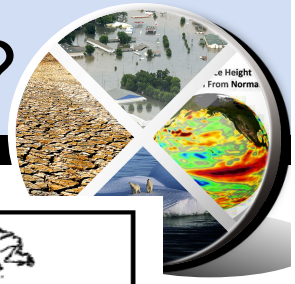


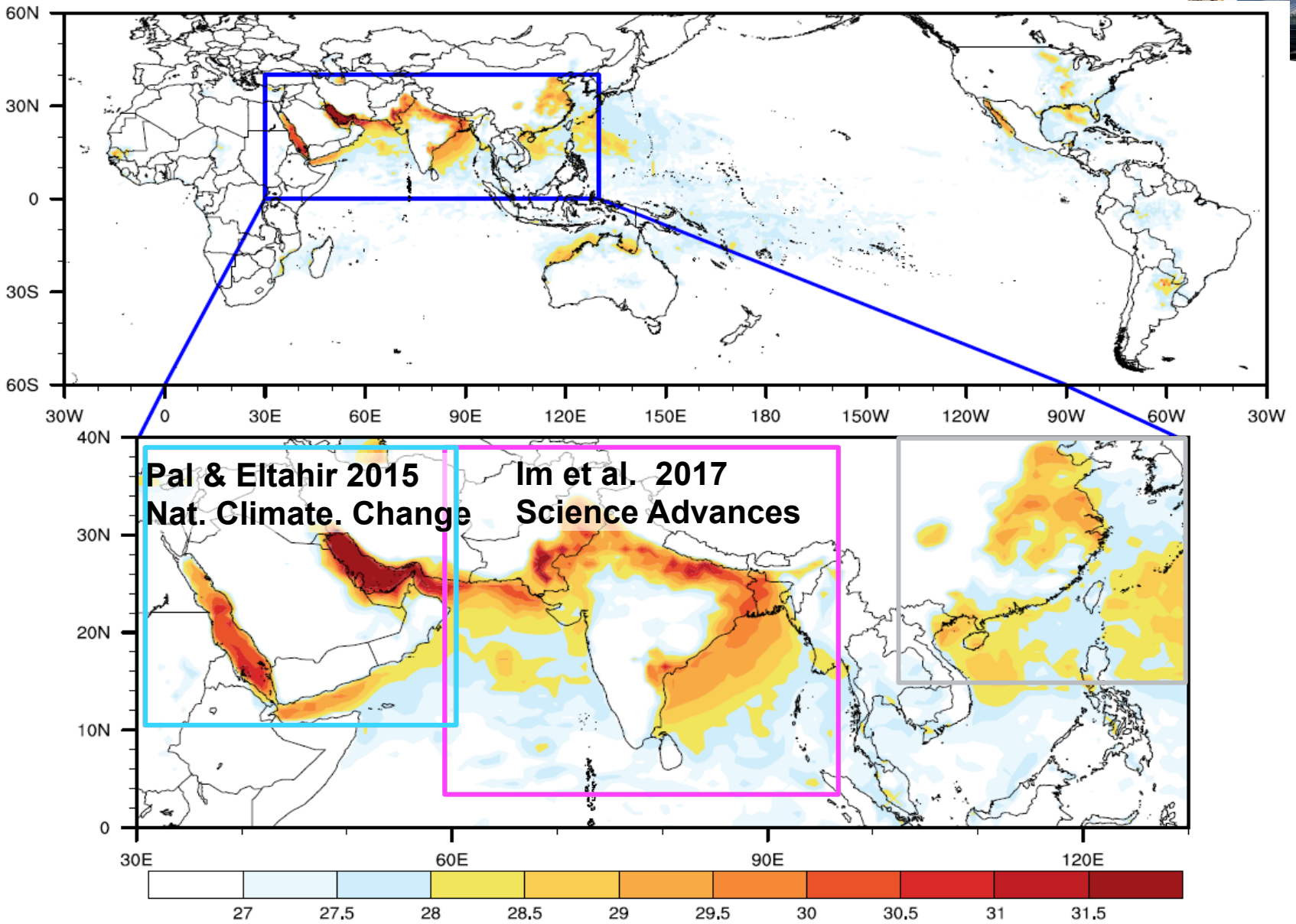
Maximum **Wet-Bulb** Temperature Climatology [1979-2015]



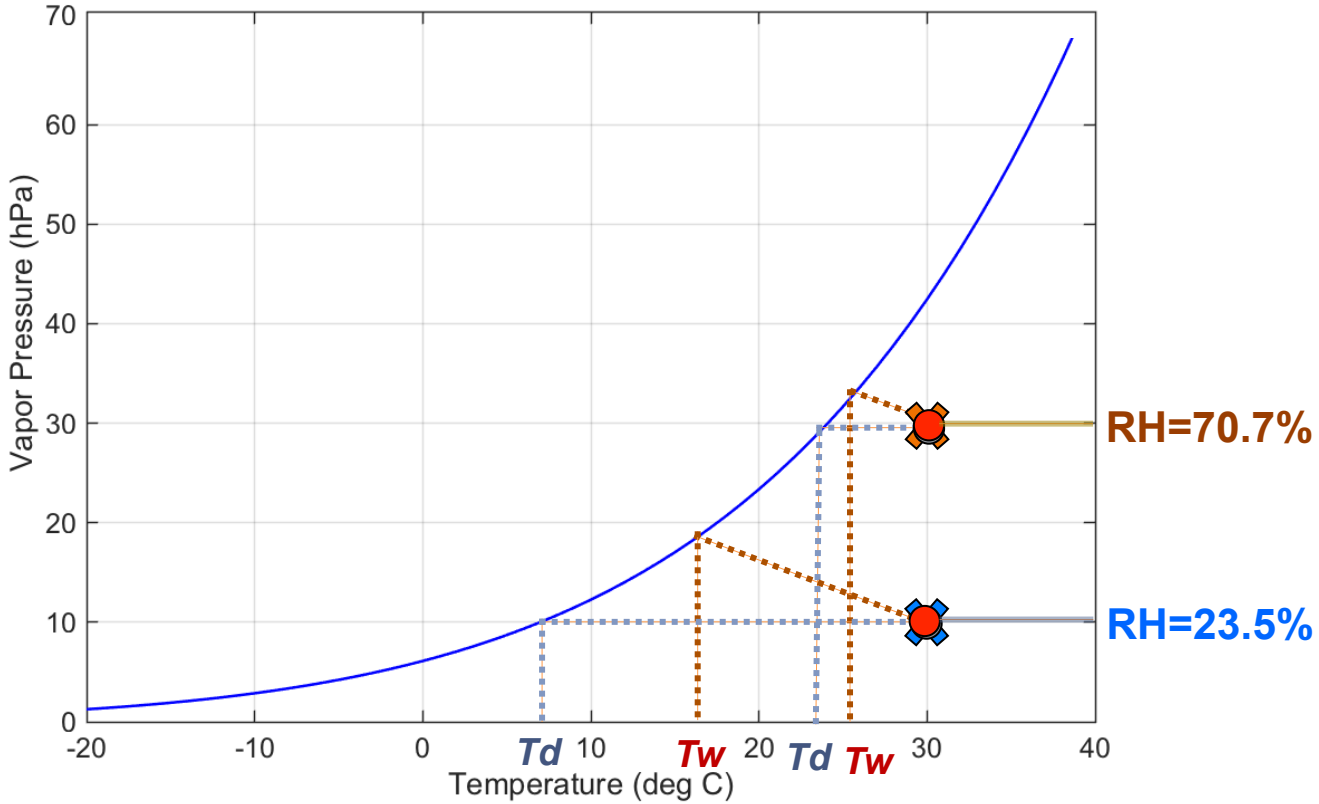
Do the region characterized by highest maximum temperature coincide with the region where the people suffer from the worst heat stress ?

Where is the highest wet-bulb temperature ?





Concept of Wet-Bulb Temperature



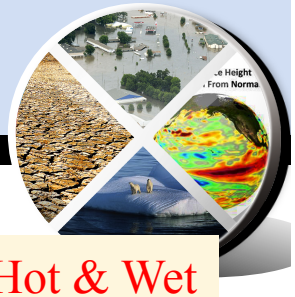
- Stull (2011) : an empirical fit using gene-expression programming.

$$T_w = T\,\mathrm{atan}[0.151\,977(\mathrm{RH}\% + 8.313\,659)^{1/2}] + \mathrm{atan}(T + \mathrm{RH}\%) - \mathrm{atan}(\mathrm{RH}\% - 1.676\,331) + 0.003\,918\,38(\mathrm{RH}\%)^{3/2}\,\mathrm{atan}(0.023\,101\mathrm{RH}\%) - 4.686\,035.$$

- Anderson (1968) : an estimation from dry bulb and dewpoint temperatures

$$T{\downarrow}w = T - (T - T{\downarrow}d) * (0.12 + 0.008 * T)$$

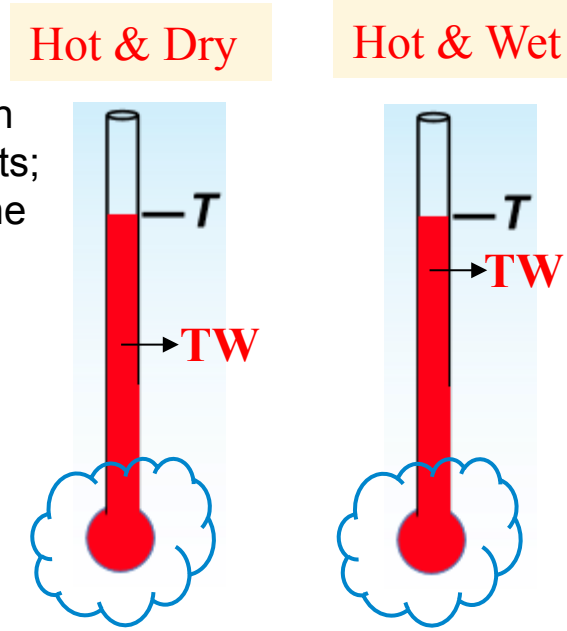
Human Adaptability to Heat Stress

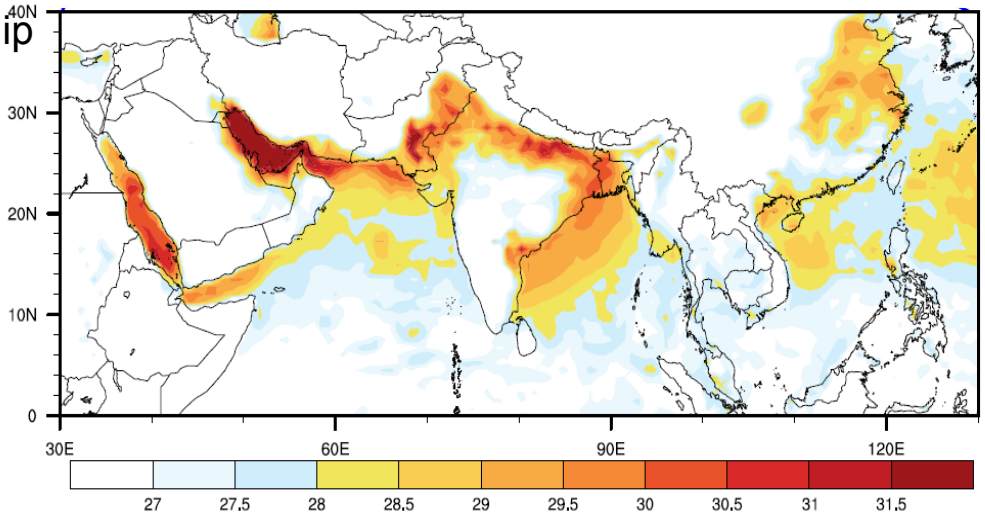


❖ Combined measure of temperature & humidity

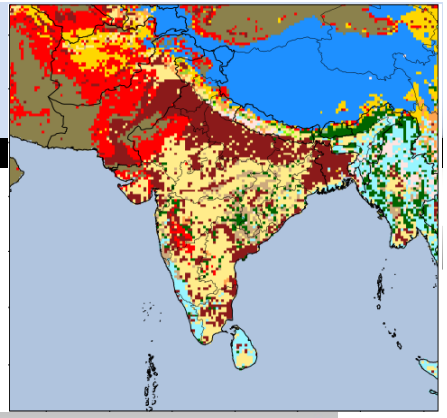
- Wet-bulb temperature is particularly useful in human health applications associated with heat stress, because evaporation is the primary means by which bodies cool in hot environments; thus, when Tw is high, evaporative cooling is restricted and the body core temperature may rise (Davis et al. 2016).
- Unlike other heat indices, TW establishes a clear thermodynamic limit on heat transfer that cannot be overcome by such adaptations (Sherwood and Huber 2010).
- ***35°C*** is the threshold value of TW beyond which any exposure for more than 6-hour would likely be intolerable even for the fittest of humans resulting in hyperthermia.
- In current climate, TW rarely exceeds ***31°C***.

TW provides a physically based relationship to the human body's core temperature.

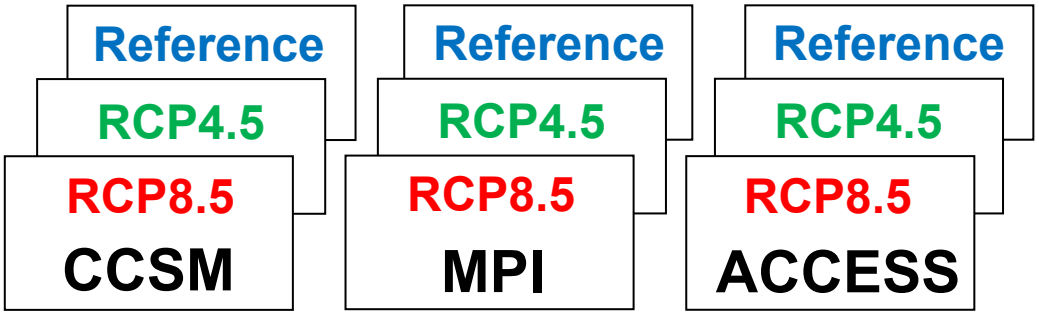


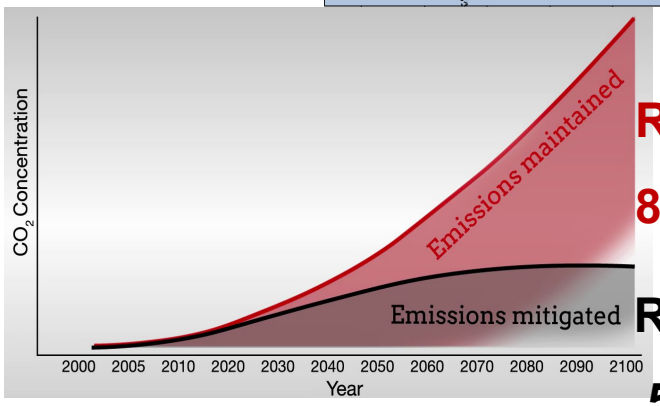


Experimental Design



- Model : MIT Regional Climate Model (MRCM)
- Resolution: 25 km
- Initial & Boundary Condition: **CCSM4**, **MPI-ESM-MR** and **ACCESS**



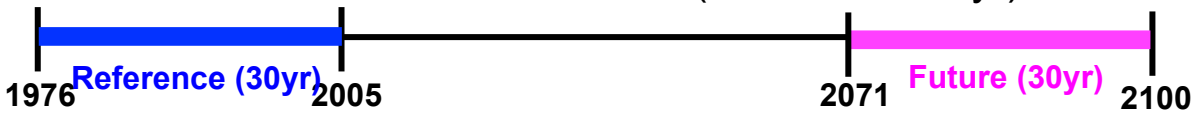


RCP 8.5♪

RCP4 .5♪

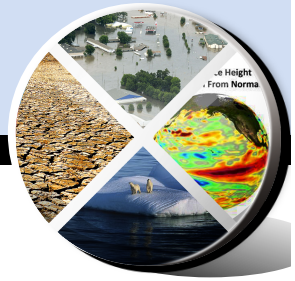
- 19 GCMs selection based on overall performance metrics over the continental-scale regions including Asia [McSweeney et al. 2015].
- Evaluation of how reasonably the models simulate rainfall, temperature, wet-bulb temperature, and humidity.

- Integration Period : Reference Climate (1976-2005:30yr) - **Historical**
  : Future Climate (2071-2100:30yr) – **RCP4.5** and **RCP8.5**

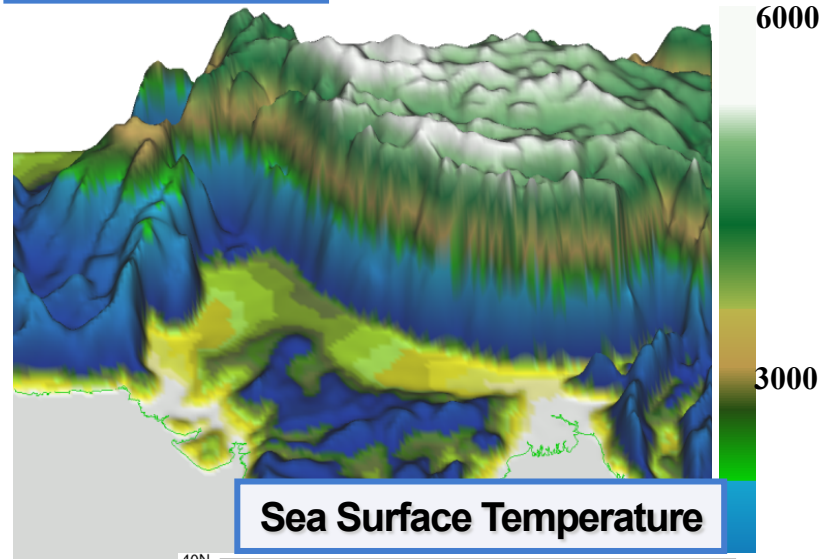


- Climatology of daily bias computed from ERAInterim climatology is applied to present-day and future climate.

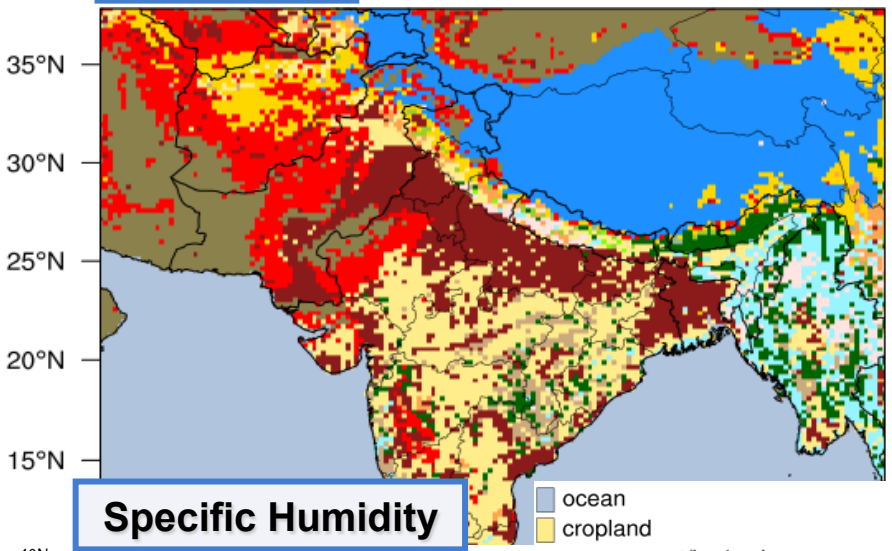
Geographical & Climatological Characteristics



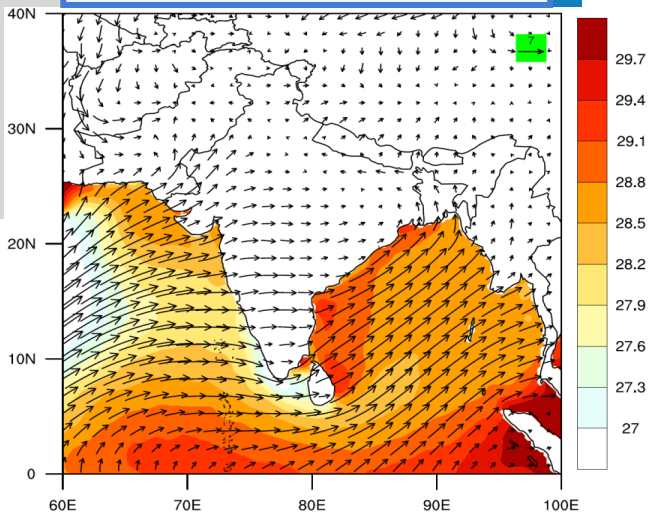
Topography



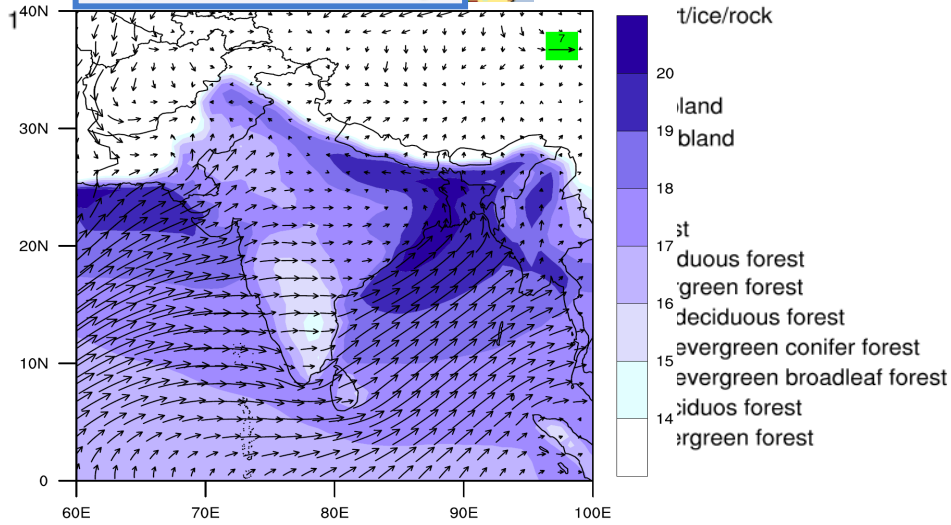
Land-use



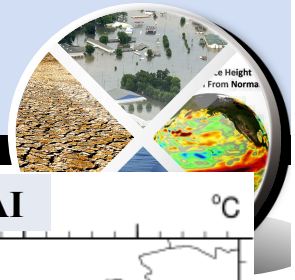
Sea Surface Temperature



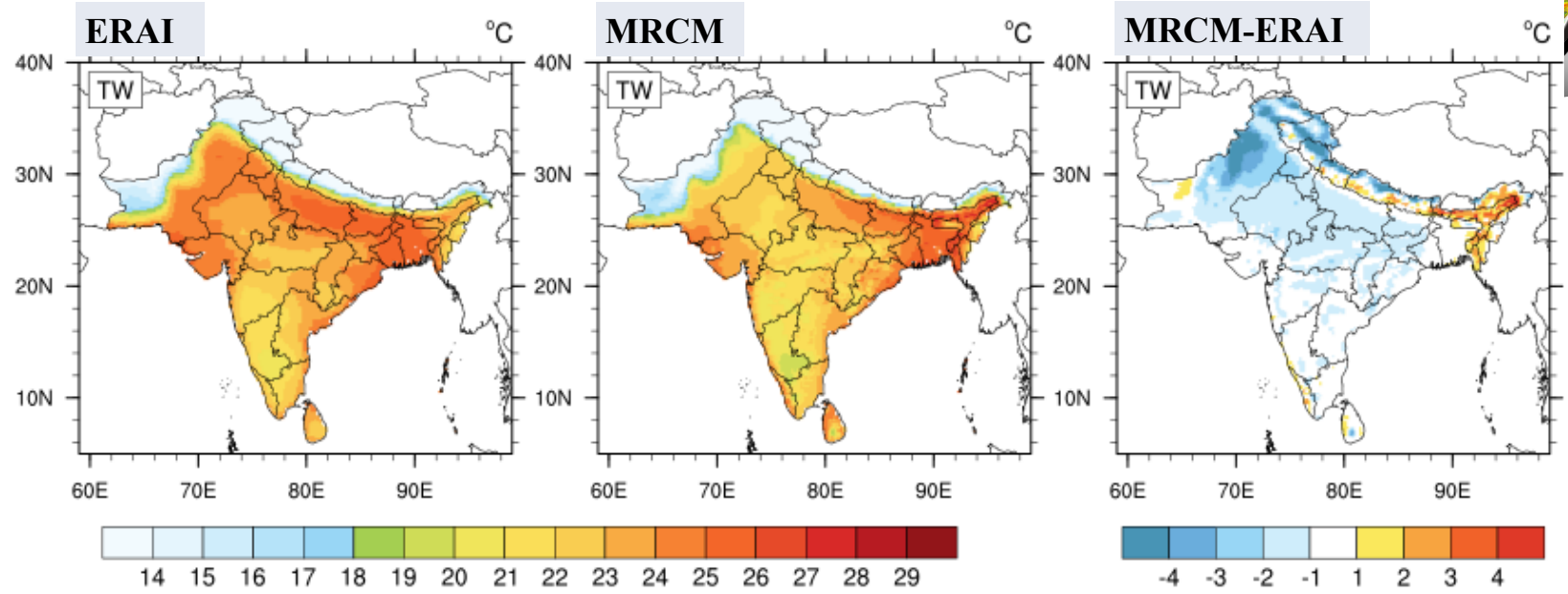
Specific Humidity



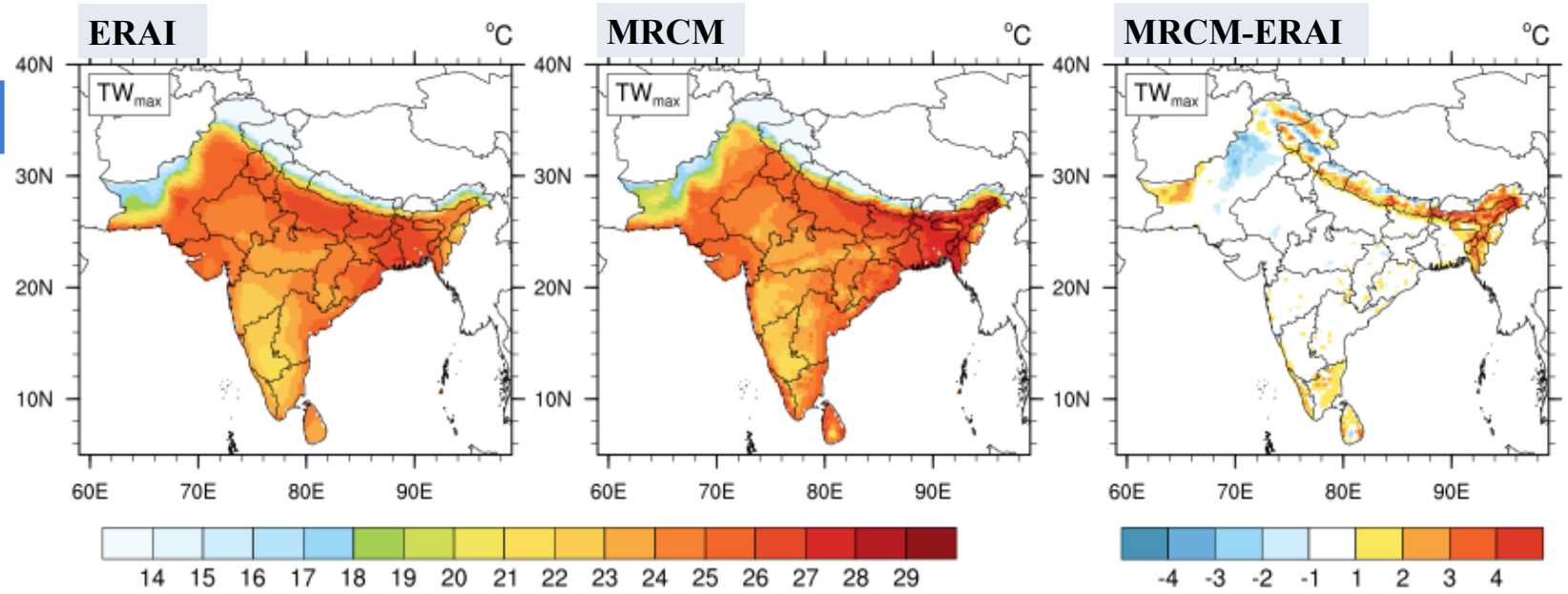
MRCM Validation : Jun-Jul-Aug Climatology



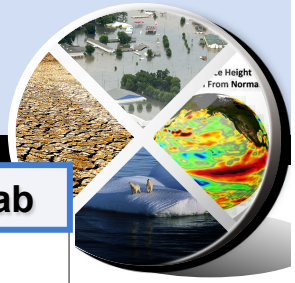
TW



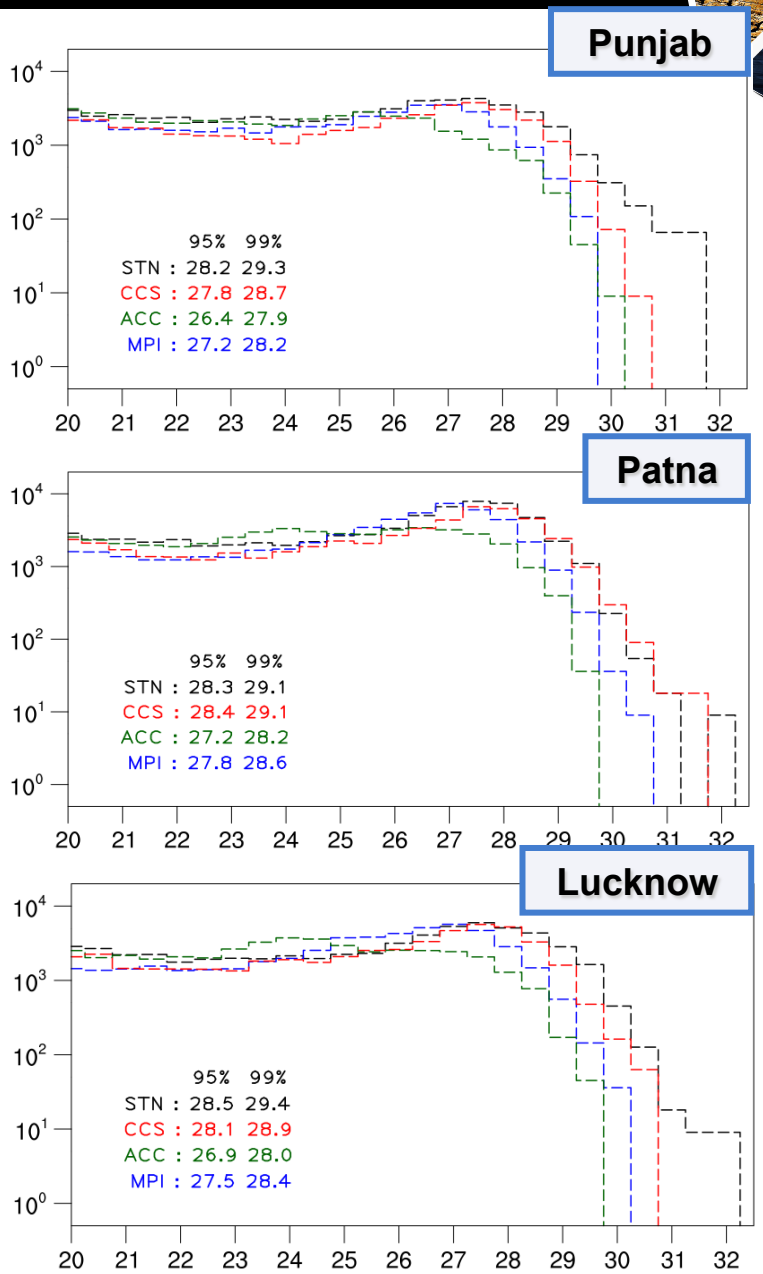
TW max



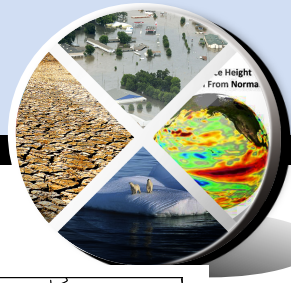
MRCM Validation : Localized Extremes



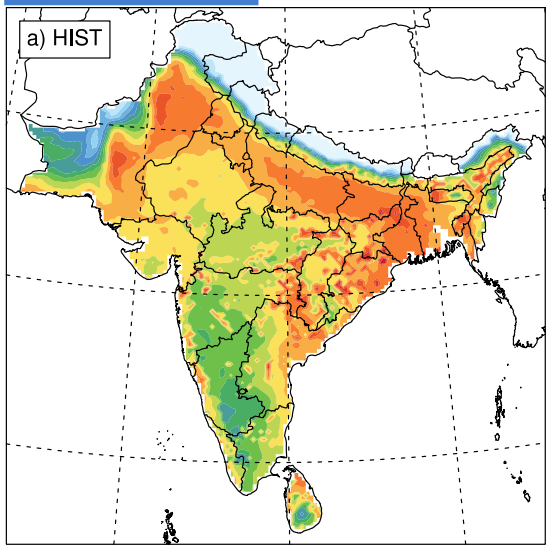
❖ Frequency distribution of TW max computed from in-situ observational data and simulation at the nearest grid point to the individual stations.



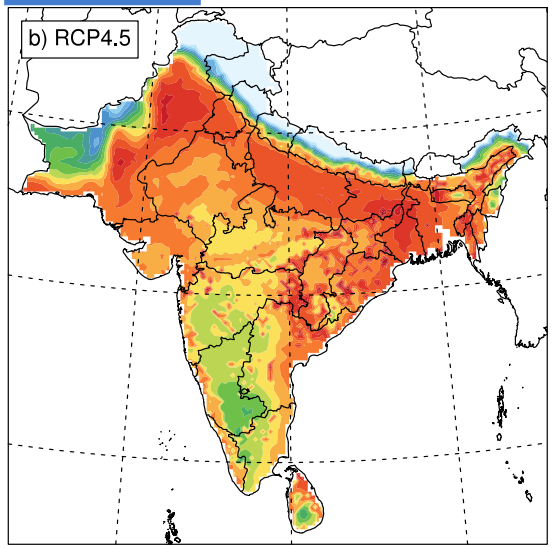
Future Projection of Maximum TW



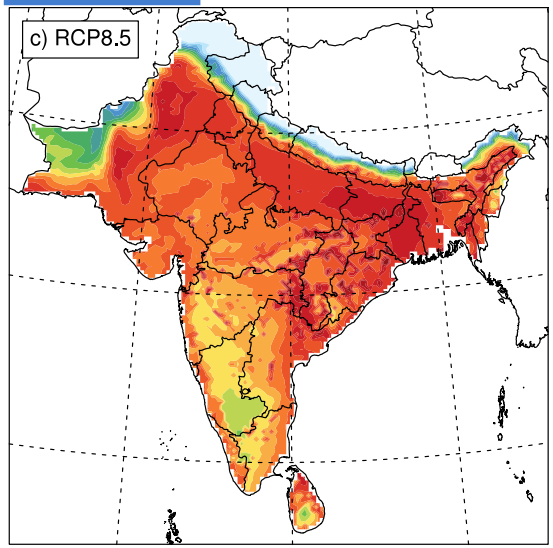
Historical

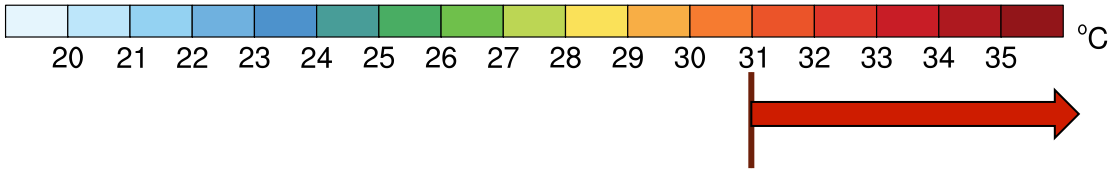


RCP4.5



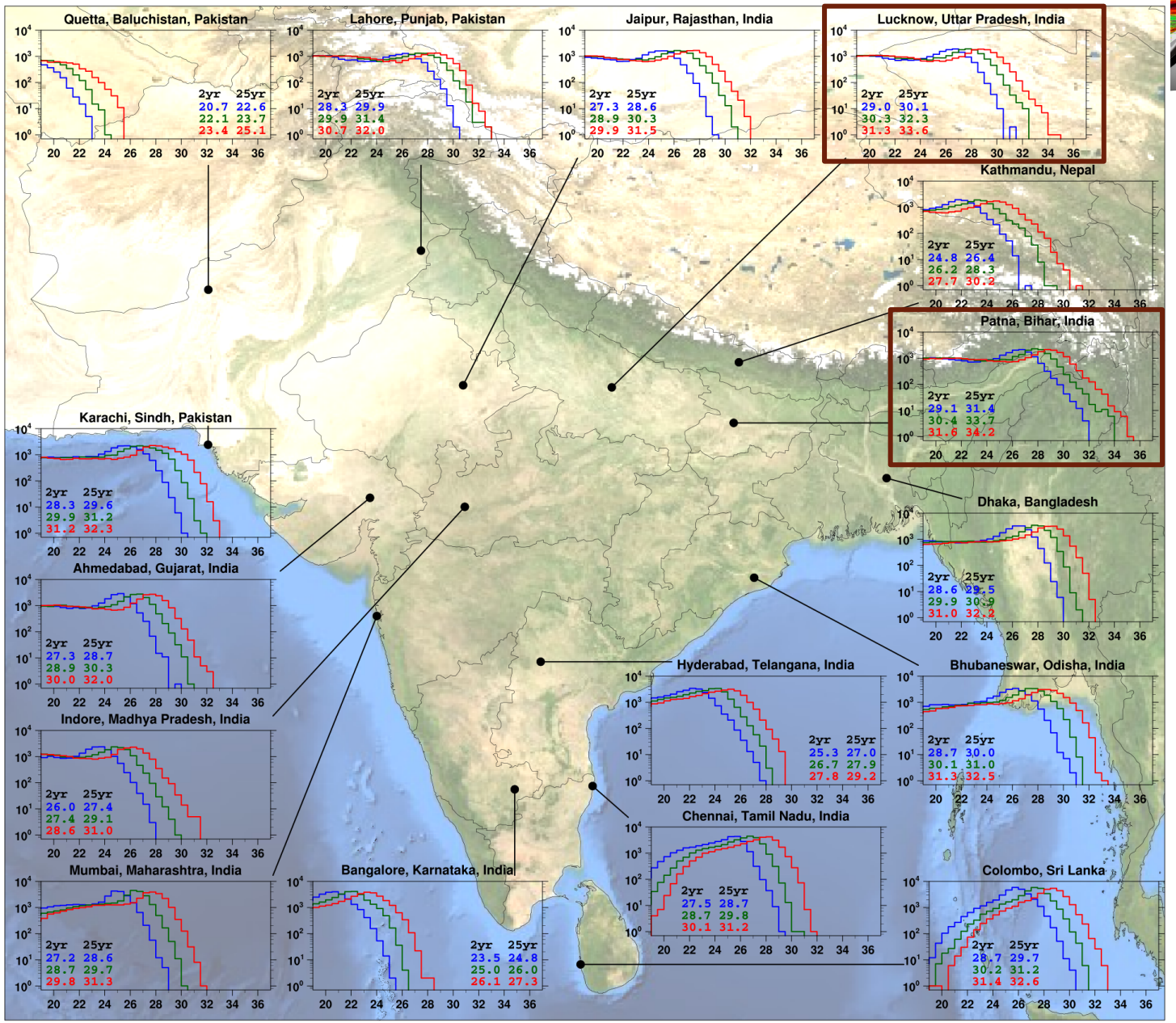
RCP8.5





Future Projection of Maximum TW

Frequency Distribution

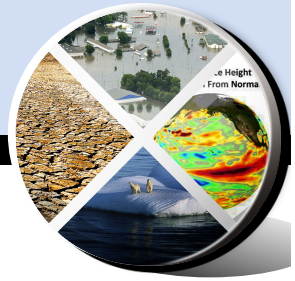


Ref

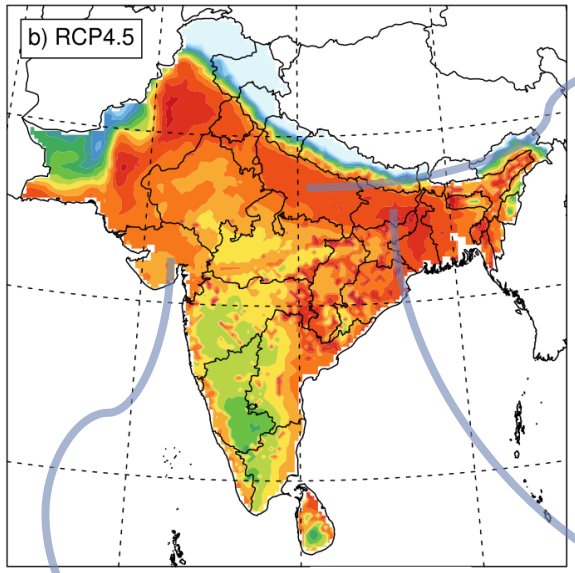
RCP4.5

RCP8.5

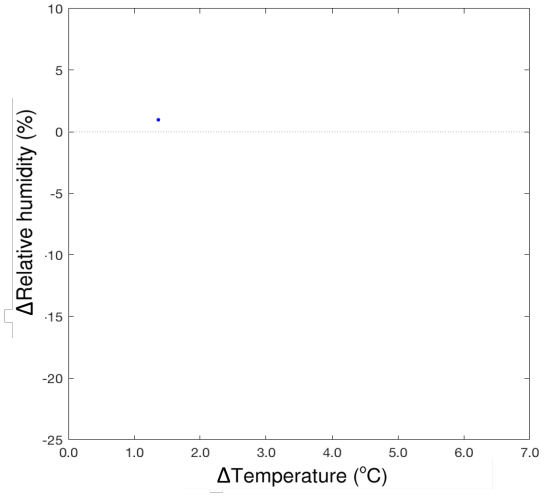
Changes in Temp vs. RH



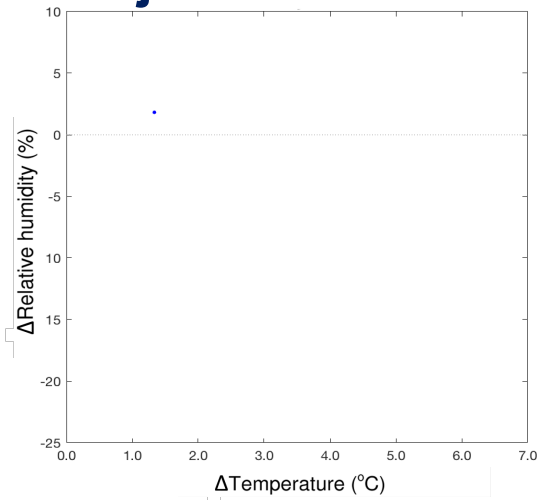
- Scatter plot of changes in temperature against changes in relative humidity corresponding to the occurrence of yearly maximum TW.



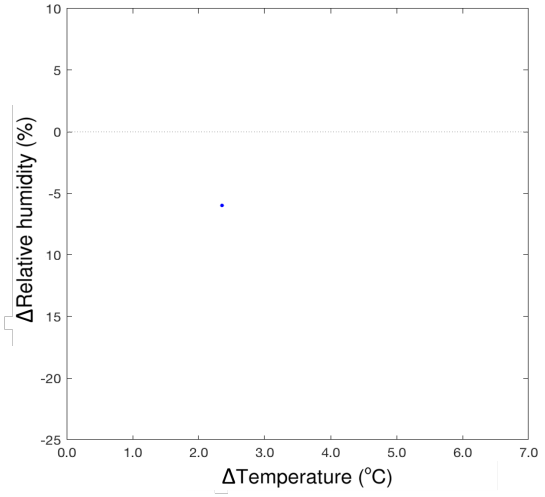
Uttar Pradesh



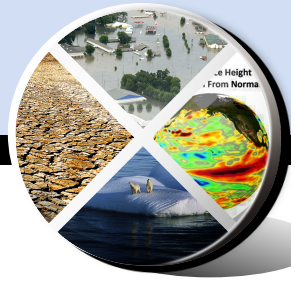
Gujarat



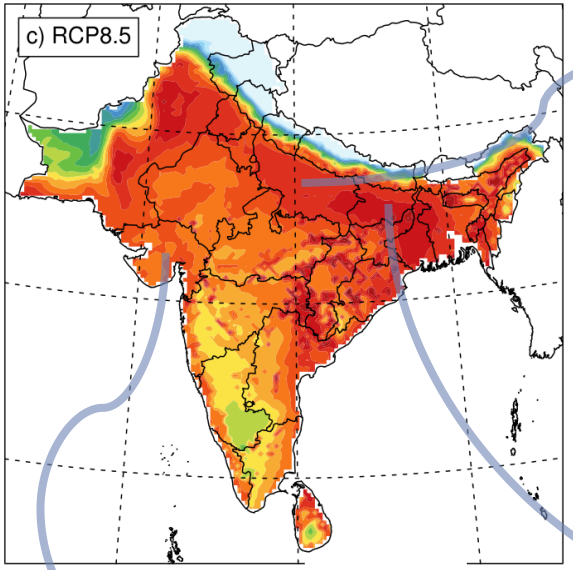
Bihar



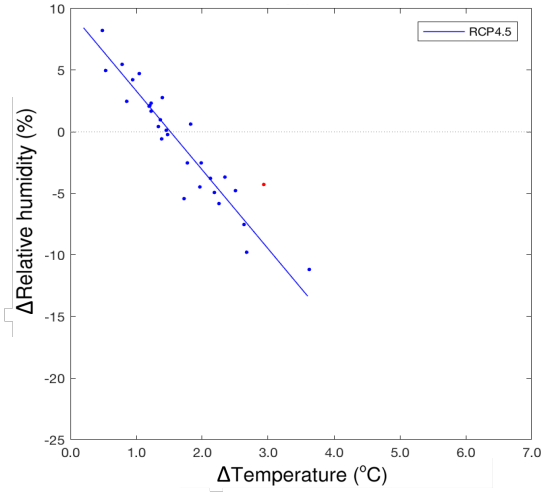
Changes in Temp vs. RH



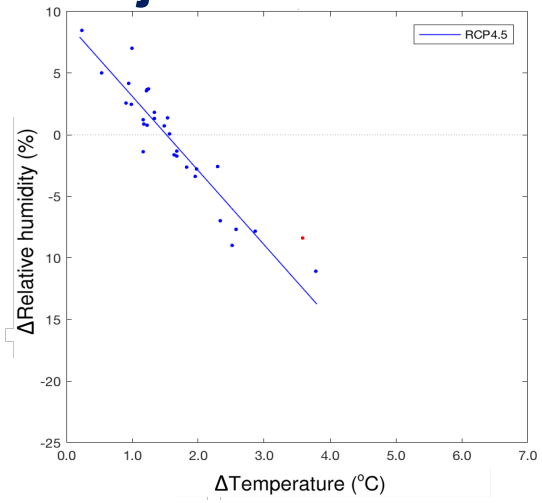
- Scatter plot of changes in temperature against changes in relative humidity corresponding to the occurrence of yearly maximum TW.



Uttar Pradesh



Gujarat



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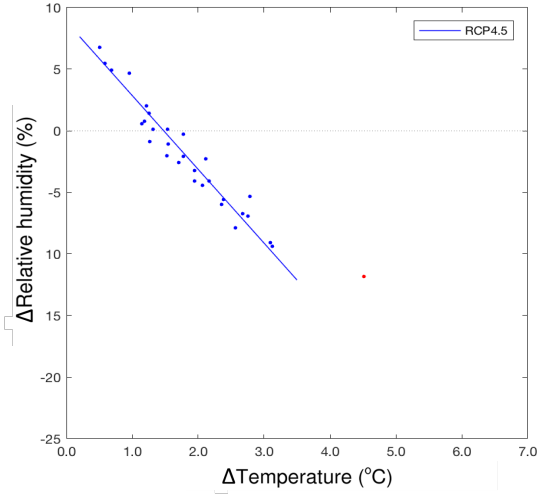
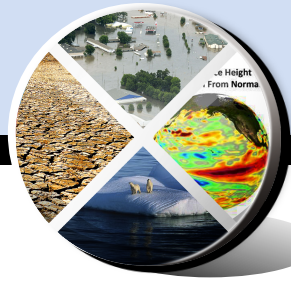
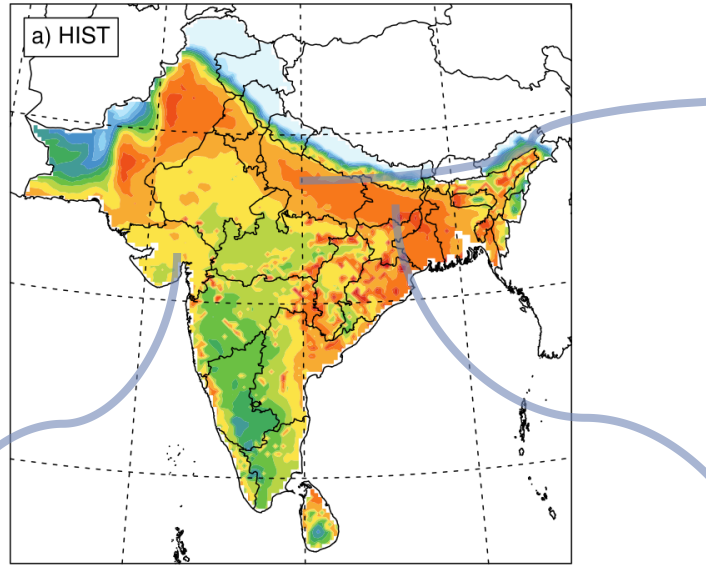


Likelihood of Heat Risk: Maximum TW



- Global warming pushes maximum TW into an area of severe risk level.



Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Gujarat

Temperature

Relative Humidity(%)	°C 30.0	31.1	32.2	33.3	34.4	35.6	36.7	37.8	38.9	40.0	41.1	42.2
	°F 86	88	90	92	94	96	98	100	102	104	106	108
45	20.6	21.4	22.3	23.2	24.1	25.0	25.9	26.8	27.7	28.7	29.6	30.5
50	21.5	22.4	23.3	24.2	25.2	26.1	27.1	28.0	29.0	29.9	30.9	31.8
55	22.5	23.4	24.3	25.3	26.3	27.2	28.2	29.2	30.2	31.1	32.1	33.1
60	23.3	24.3	25.3	26.3	27.3	28.3	29.3	30.3	31.3	32.3	33.2	34.2
65	24.2	25.2	26.2	27.3	28.3	29.3	30.3	31.3	32.3	33.3	34.3	35.3
70	25.1	26.1	27.2	28.2	29.2	30.3	31.3	32.3	33.4	34.4	35.4	36.4
75	25.9	27.0	28.0	29.1	30.1	31.2	32.2	33.3	34.3	35.4	36.4	37.5
80	26.7	27.8	28.9	30.0	31.0	32.1	33.1	34.2	35.3	36.3	37.4	38.4

Bihar

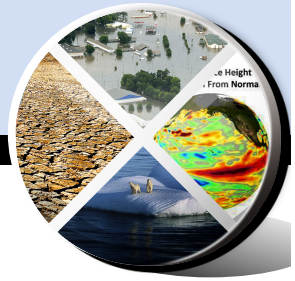
Temperature

Relative Humidity(%)	°C 30.0	31.1	32.2	33.3	34.4	35.6	36.7	37.8	38.9	40.0	41.1	42.2
	°F 86	88	90	92	94	96	98	100	102	104	106	108
45	20.6	21.4	22.3	23.2	24.1	25.0	25.9	26.8	27.7	28.7	29.6	30.5
50	21.5	22.4	23.3	24.2	25.2	26.1	27.1	28.0	29.0	29.9	30.9	31.8
55	22.5	23.4	24.3	25.3	26.3	27.2	28.2	29.2	30.2	31.1	32.1	33.1
60	23.3	24.3	25.3	26.3	27.3	28.3	29.3	30.3	31.3	32.3	33.2	34.2
65	24.2	25.2	26.2	27.3	28.3	29.3	30.3	31.3	32.3	33.3	34.3	35.3
70	25.1	26.1	27.2	28.2	29.2	30.3	31.3	32.3	33.4	34.4	35.4	36.4
75	25.9	27.0	28.0	29.1	30.1	31.2	32.2	33.3	34.3	35.4	36.4	37.5
80	26.7	27.8	28.9	30.0	31.0	32.1	33.1	34.2	35.3	36.3	37.4	38.4

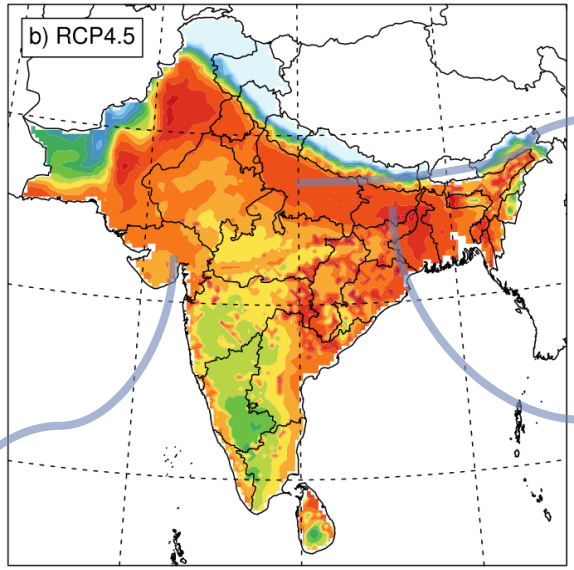
- Caution
- Extreme Caution
- Danger
- Extreme Danger

- HIST
- RCP4.5
- RCP8.5

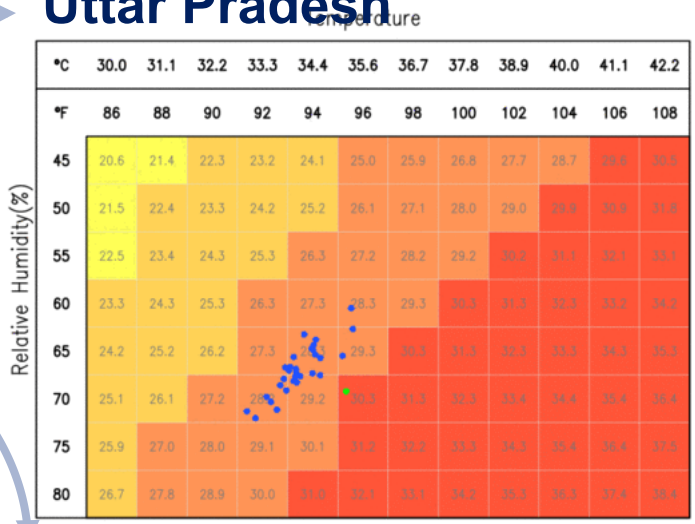
Likelihood of Heat Risk: Maximum TW



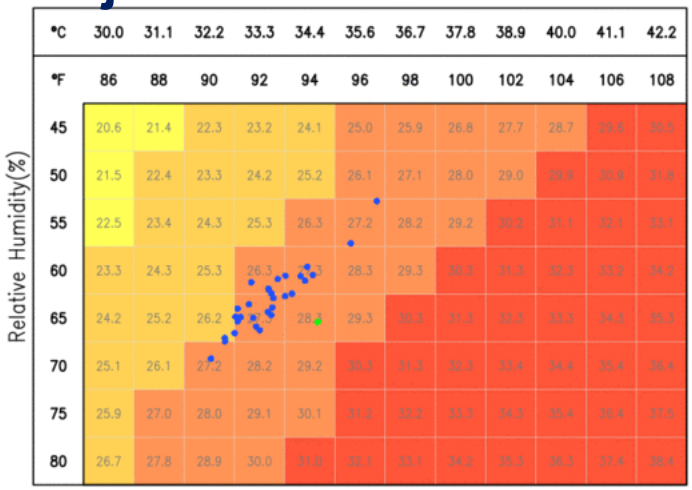
- Global warming pushes maximum TW into an area of severe risk level.



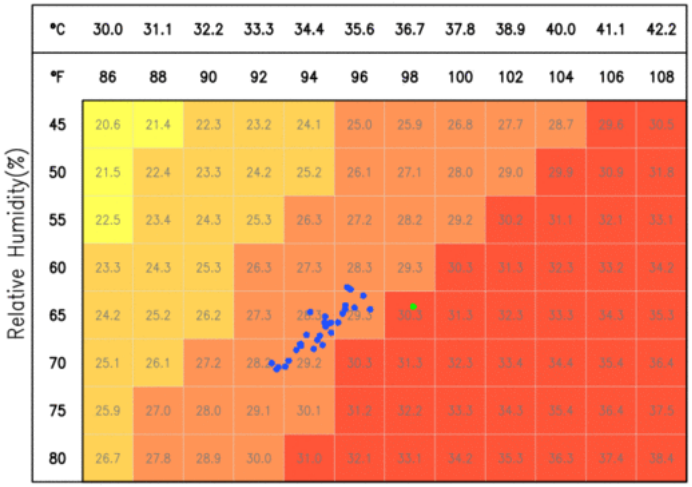
Uttar Pradesh



Gujarat



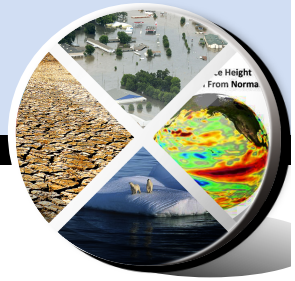
Bihar



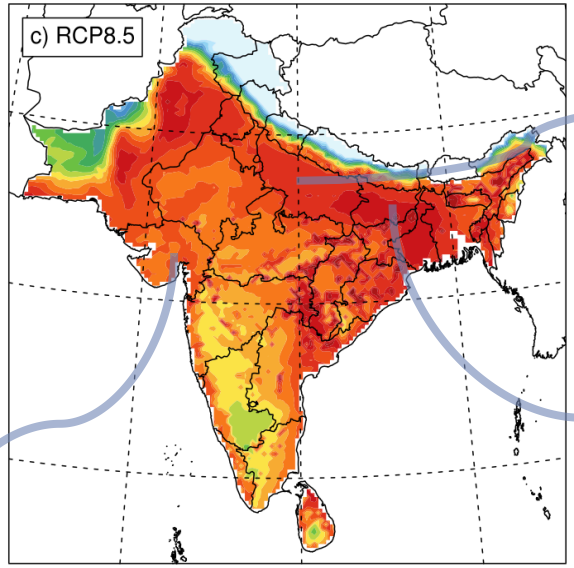
Caution
Extreme Caution
Danger
Extreme Danger

HIST
RCP4.5
RCP8.5

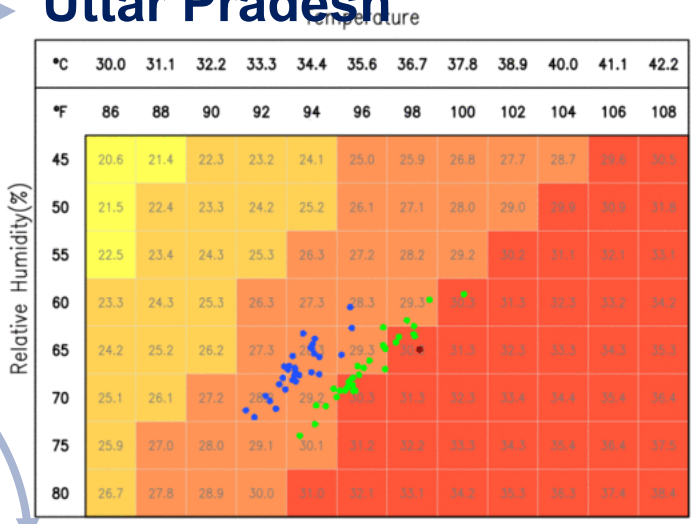
Likelihood of Heat Risk: Maximum TW



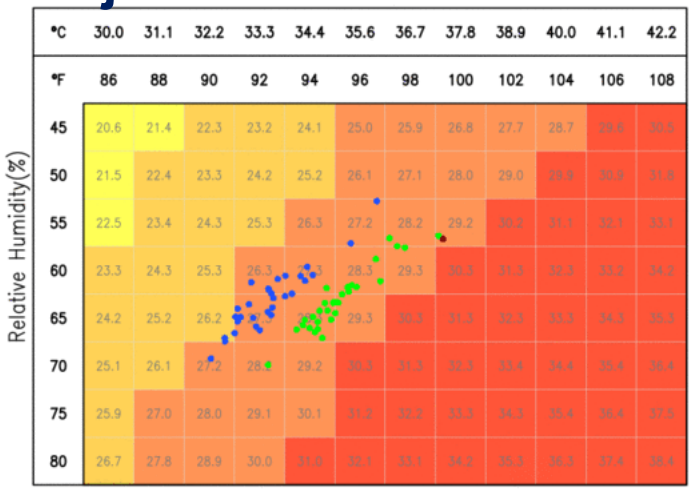
- Global warming pushes maximum TW into an area of severe risk level.



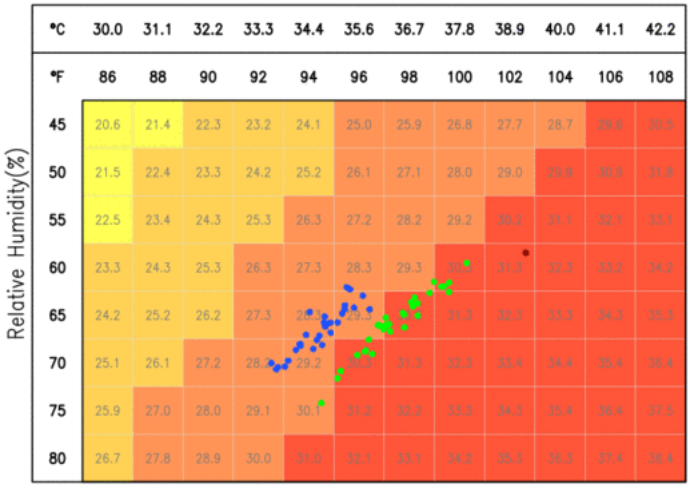
Uttar Pradesh



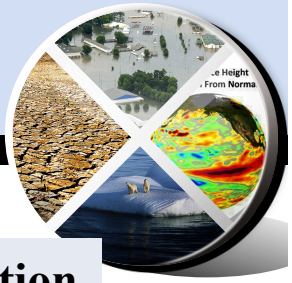
Gujarat

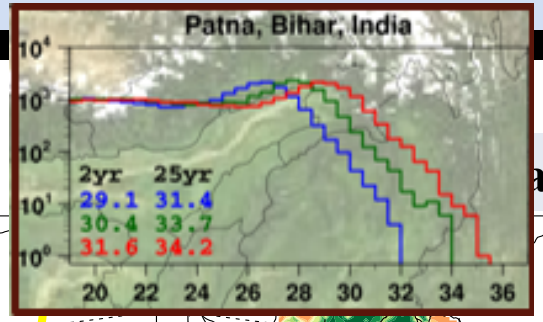


Bihar

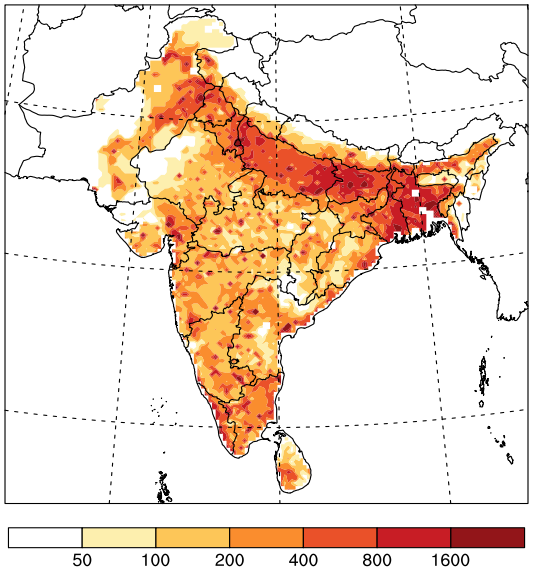


Acute Vulnerability



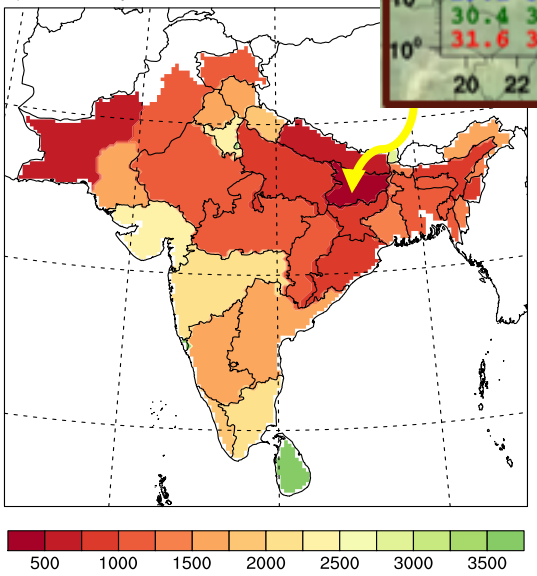


Population Density



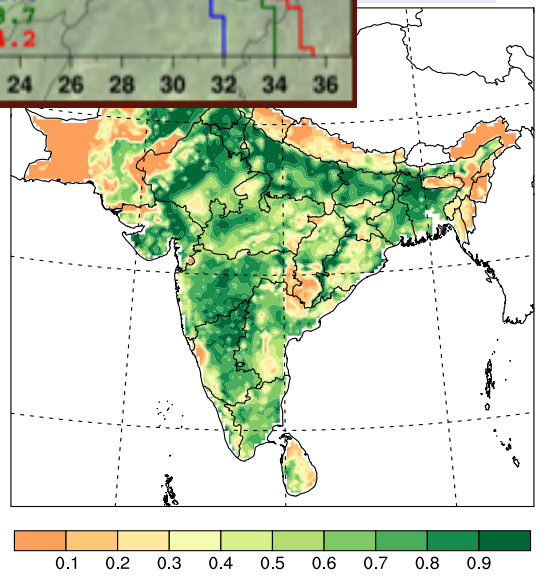
50 100 200 400 800 1600

GDP/Capita

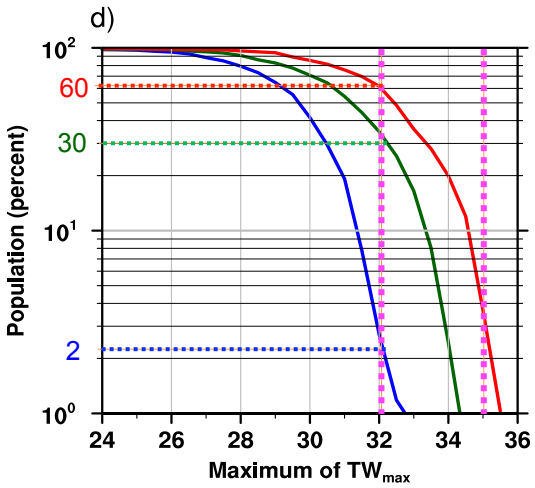


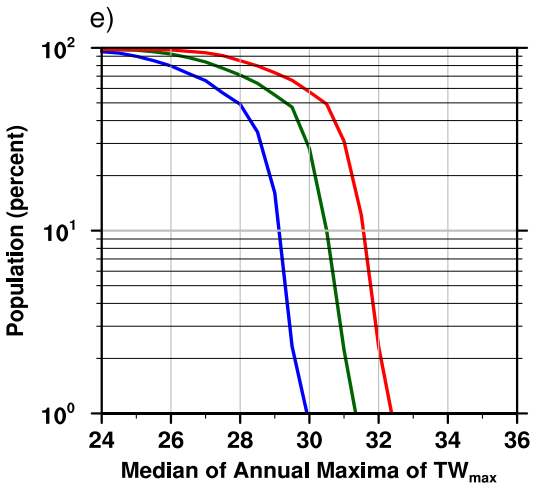
500 1000 1500 2000 2500 3000 3500

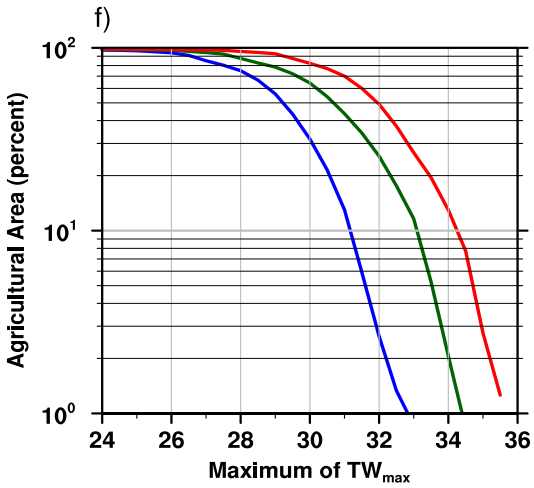
…action



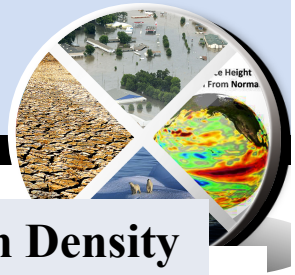
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9





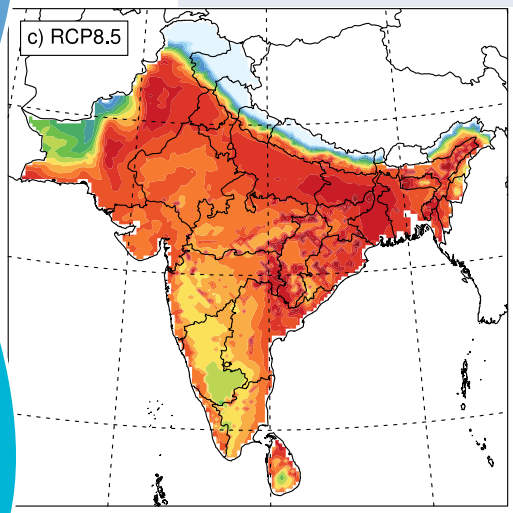


Assessment of Risks from Extreme Events

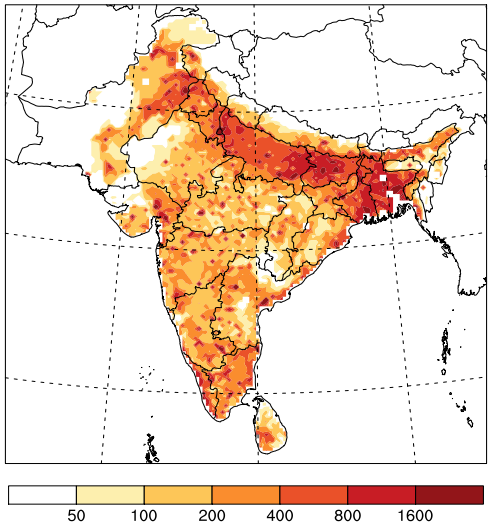


ipcc
INTERGOVERNMENTAL PANEL ON climate change

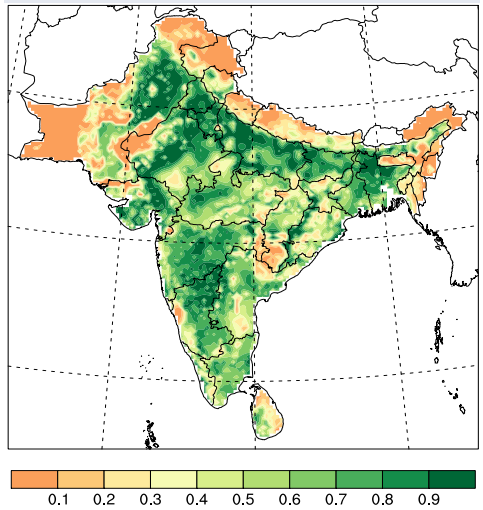
TW *max*



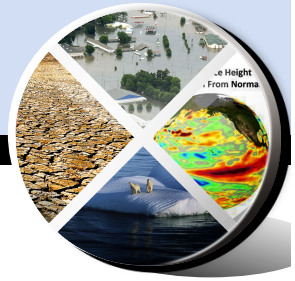
Population Density



Agriculture intensity



Take Home Message



Global warming will increase the risk of heat stress

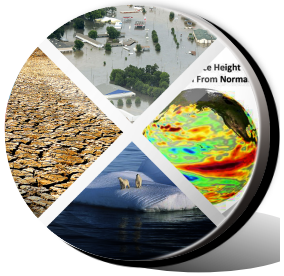
- The physiologically-based heat stress index supports the high risk of heat s tress and it is reasonable to expect the worst situation through the deadly c ombination of heat and humidity if temperature continues rising a the curre nt rate.

Climate change is a global issue with region-specific impacts

- Climate change, without mitigation, presents a serious and unique risk in South Asia, due to an unprecedented combination of severe natural hazard and acute vulnerability.

RCM is a useful scientific tool for climate change studies

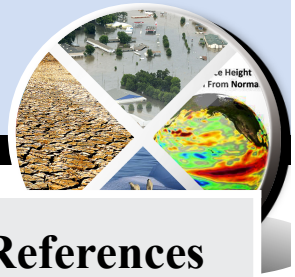
- Regional climate modeling with higher resolution has showed the potentials to better resolve the complicated climate processes and extremes. It can contribute to providing more accurate TW projections over South Asia with a high level confidence.



Thank you for your attention!

Eun-Soon Im (ceim@ust.hk)

MRCM: RegCM3 upgraded by MIT Eltahir Group

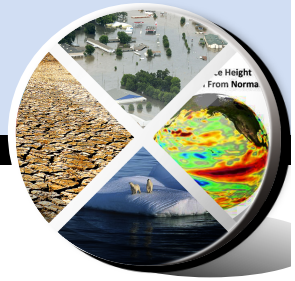


Physics	New Features	Key References
Land Surface	Integrated Biosphere Simulator (IBIS) Land Surface Scheme	Winter et al. 2009
	New surface albedo assignment	Marcella & Eltahir 2012
	New irrigation module♪	Marcella & Eltahir 2014 Im & Eltahir 2014
Convective Cloud & Rainfall	New convective cloud fraction scheme	Gianotti & Eltahir 2014♪
	New convective rainfall autoconversion scheme	Gianotti & Eltahir 2014♪
	Modified boundary layer height & boundary layer cloud scheme♪	Gianotti 2012♪

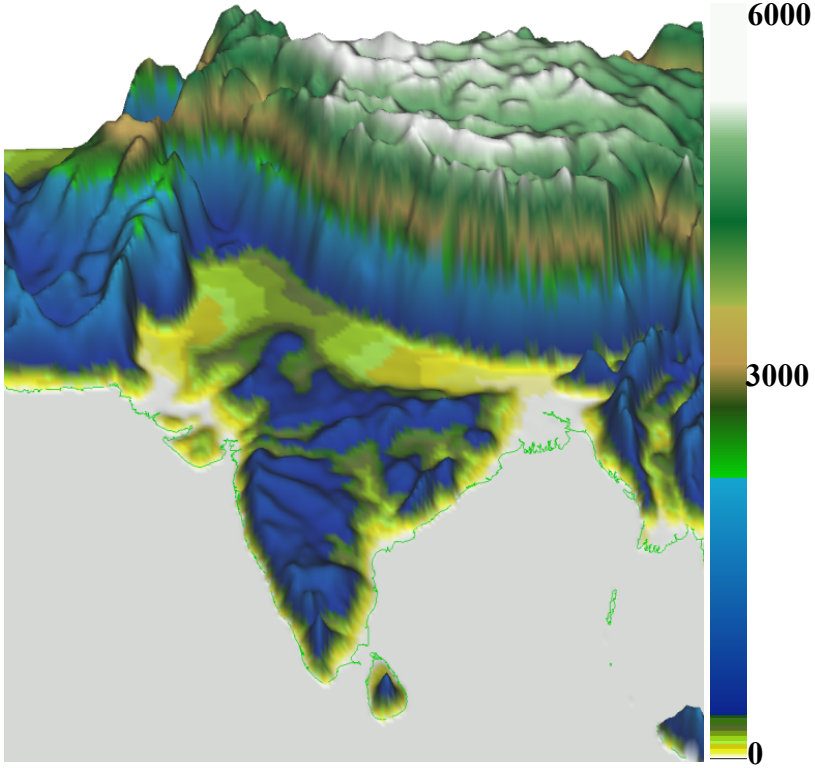
→ **MIT Regional Climate Model (MRCM)**

- Im et al [2014, J. Climate]: Improving simulation of the West African monsoon using the **MIT Regional Climate Model**.

Geographical & Climatological Characteristics



Topography



Land-use