A satellite image of Earth showing a large, dark, swirling storm system over the Pacific Ocean, with a bright, white, cloud-filled area extending from the storm towards the North American continent. The image is used as a background for the title slide.

State of the Science in Modeling Future Changes in Precipitation Extremes

Alex Hall

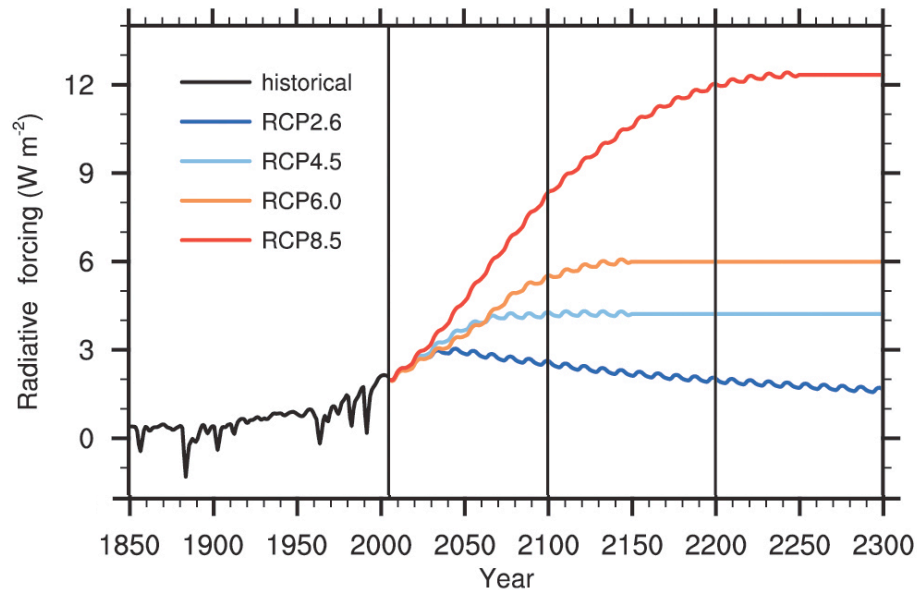
**UCLA Center for Climate Change Solutions, Institute of the
Environment and Sustainability**

February 19, 2016

Coordinated climate change experiments

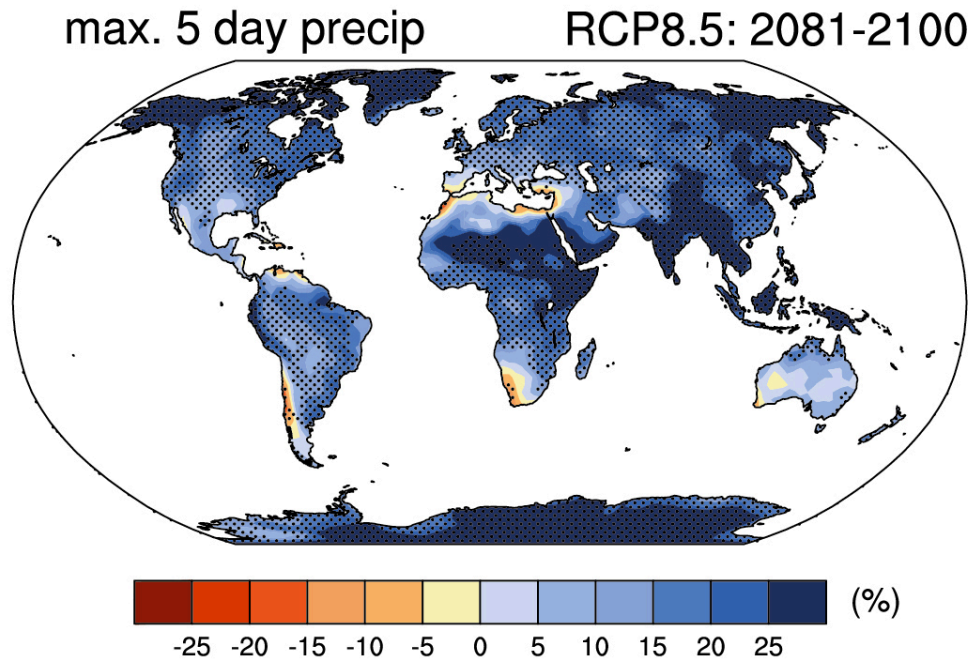
- There are roughly 3 dozen global climate modeling centers around the world, each of which has developed a global climate model (GCM).
- The typical resolution of a GCM is roughly 100-200km, too coarse to provide quantitative information about regional climate change.
- Still these models provide useful general information about changes in precipitation extremes.
- To prepare for the 2013 IPCC report, the various global climate modeling centers around the world organized a common set of climate change experiments, to be undertaken at every modeling center.
- The name of this coordination effort is **Coupled Model Intercomparison Project 5**, or CMIP5.

Radiative forcing scenarios



- The CMIP5 organizers created four future radiative forcing scenarios to be imposed on the GCMs.
- The most aggressive scenario (**RCP8.5**) is one where greenhouse gas emissions continue increasing, and has the nickname “business as usual.”
- A “mitigation” or greenhouse-gas-reduction scenario similar to that envisioned by the recent Paris climate agreement might be the one labeled **RCP4.5**.

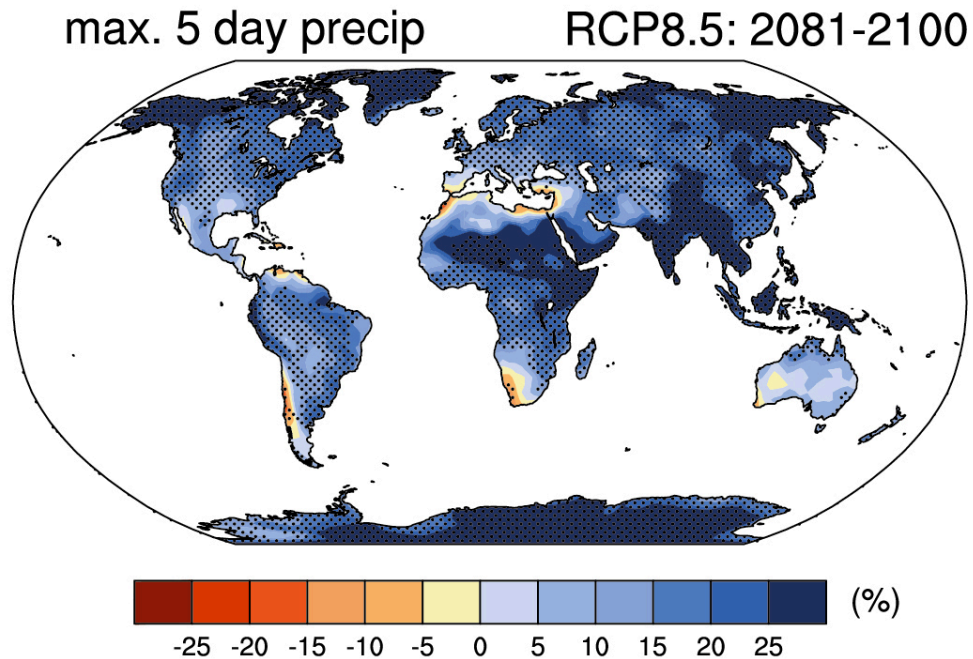
More rain on the rainiest days



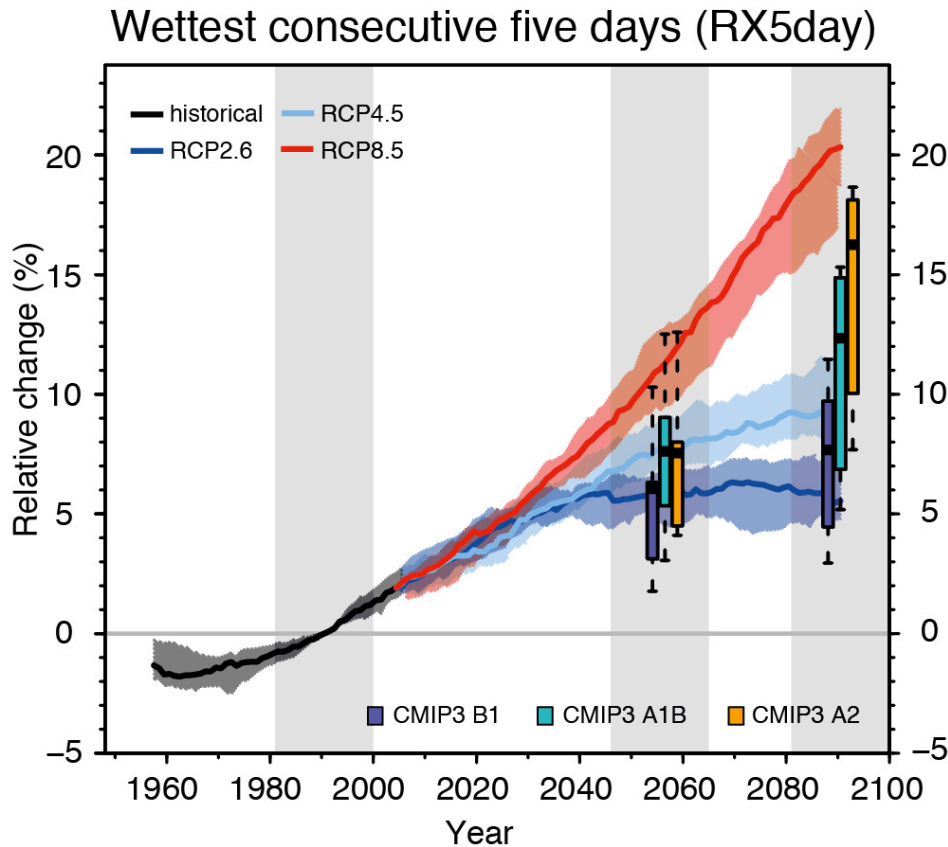
- The 2013 IPCC WG1 report provides information about changes in precipitation extremes at the global scale. There are a few ways to look at this information.
- The first is the ensemble-mean (average across the GCMs) change in the precipitation accumulation over any five-day period within a given year.
- Here is how that change is distributed over land areas under the “business as usual” greenhouse gas forcing scenario.

More rain on the rainiest days

- Increases are generally about 20%, meaning that the rainiest consecutive few days will be about 20% rainier.



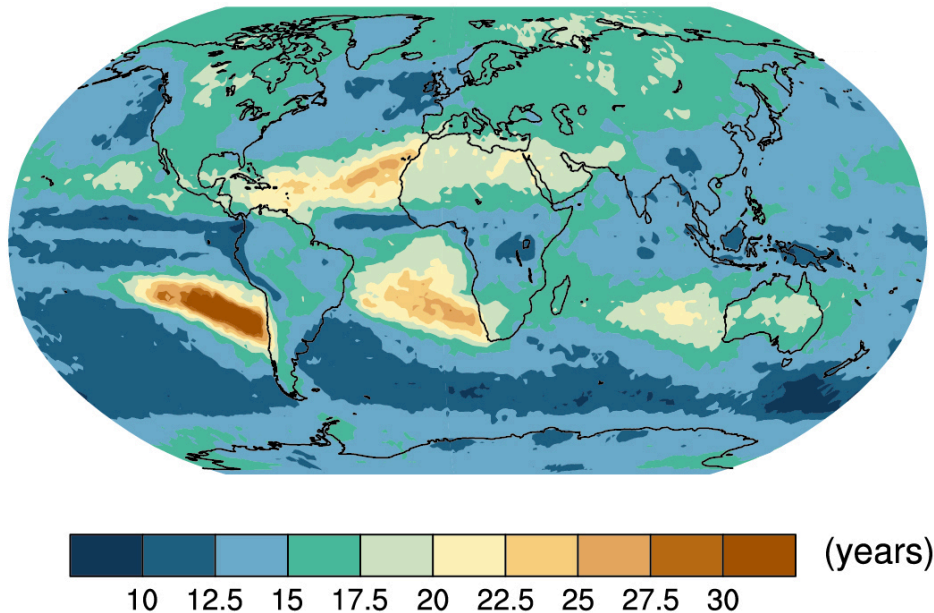
More rain on the rainiest days



- If you average this metric over the globe, you can see how it changes over time.
- The red curve shows the rain increase during extremely rainy consecutive days over the course of the 21st century under “business as usual” (ensemble-mean).
- The light blue curve shows the corresponding change for the “mitigation” scenario.
- Even under “mitigation,” there is still a substantial rain increase during consecutive rainy days.

The most extreme precipitation happens more frequently

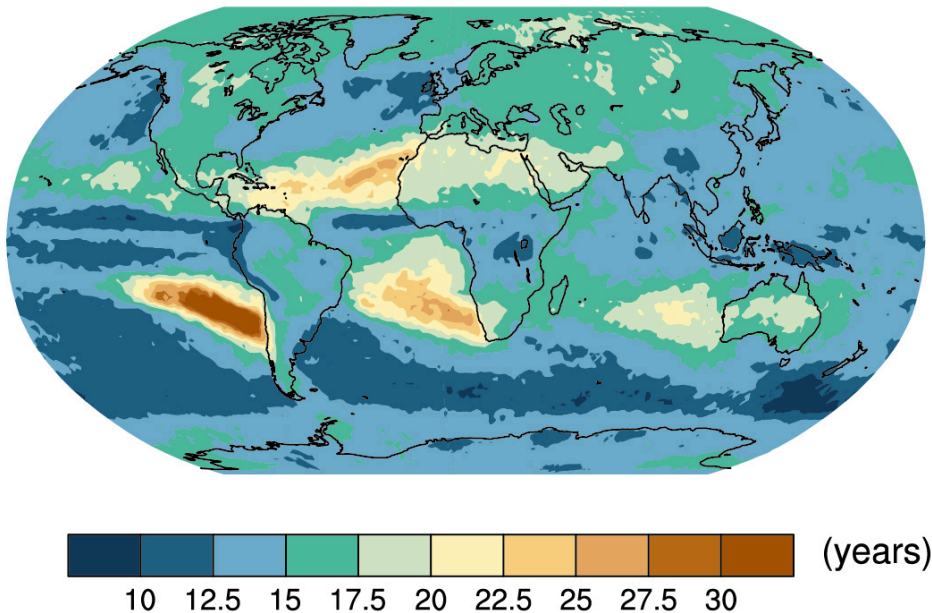
RP for present day 20-yr RV of daily precipitation under 1°C warming



- Another measure of precipitation extremes is the “return period” of some extreme daily precipitation total.
- At every location on the planet, you can define a day that is so wet that it only occurs every 20 years in the current climate.
- Then you ask, how often will this day return in the future?
- Here is a map of the return period of that extremely wet day after only 1 deg C of warming.

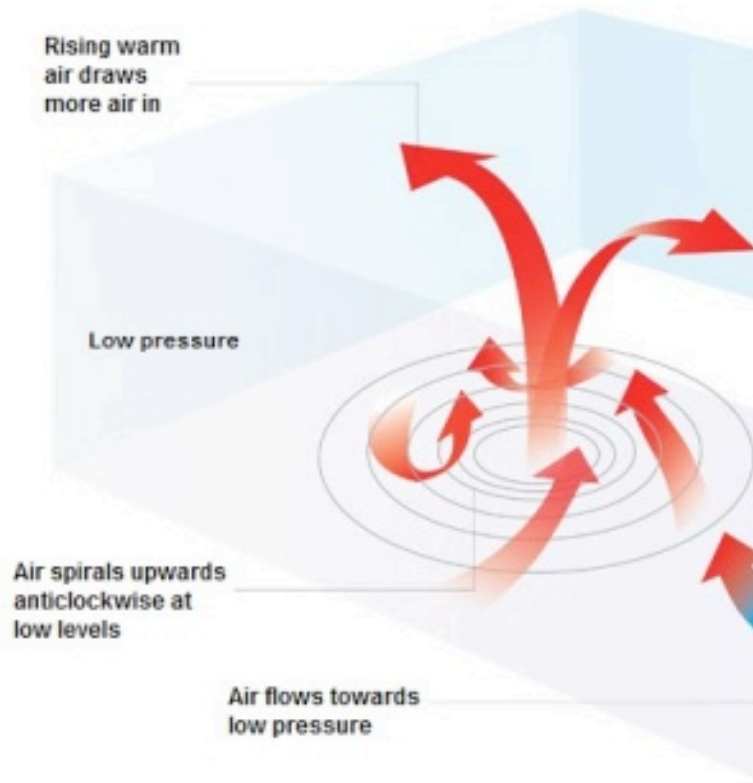
The most extreme precipitation happens more frequently

RP for present day 20-yr RV of daily precipitation under 1°C warming



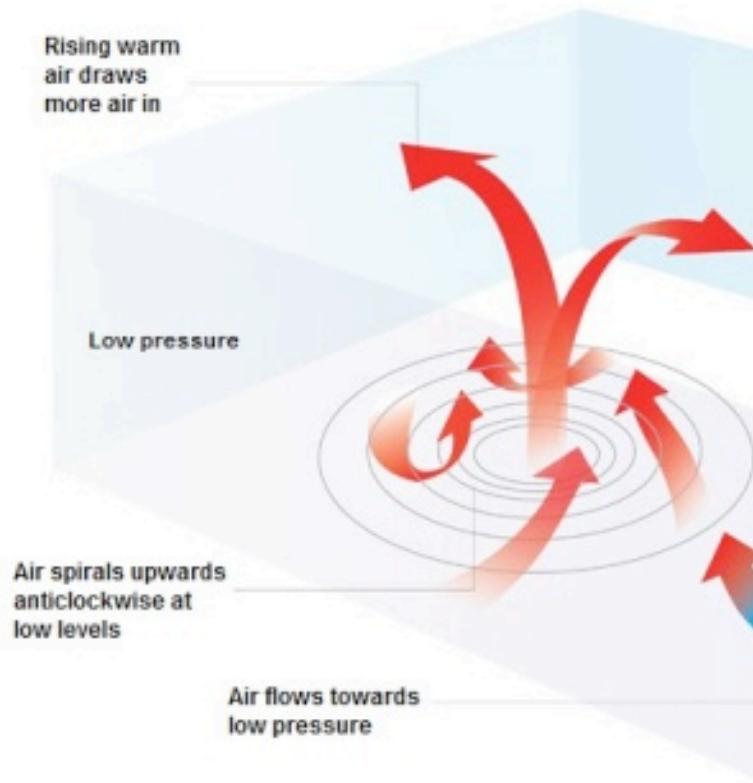
- It typically occurs every 10–17 years instead of every 20 years.
- Note that warming under “business as usual” is ~4 deg C by the end of the century, so the projected declines in return period are much greater than these values by the end of the century.

Why do heavy precipitation events increase?



- Precipitation generally occurs when air masses containing large amounts of water vapor are forced by the atmospheric flow to converge, and then rise. This process produces condensation, clouds and precipitation.
- The increase in heavy precipitation events is driven by a general increase in atmospheric water vapor as climate warms.
- The increase in water vapor is a simple consequence of the fact that warmer air can “hold” more water vapor.

Why do heavy precipitation events increase?

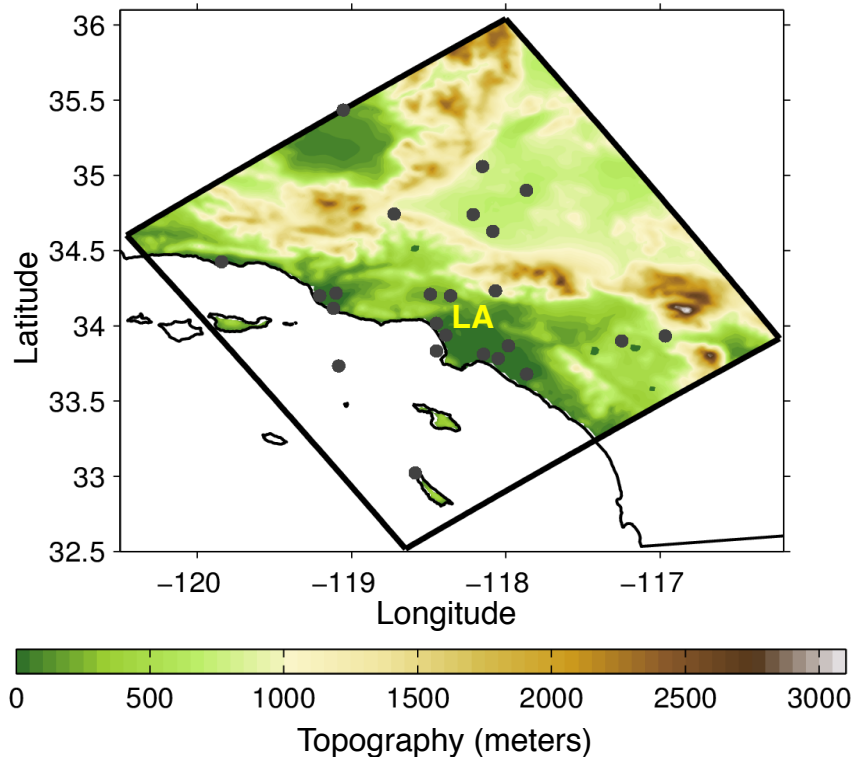


- If water vapor generally increases in a warmer climate, then these converging air masses will also contain more water vapor, and will therefore produce more precipitation.
- In spite of the GCM results, and the robustness of the general physical arguments underpinning them, it is still difficult to be quantitative about changes in precipitation extremes at the regional scale.
- To see why this is the case, we have to say a few words about how regional climate information is produced.

Downscaling

- A variety of techniques are available to provide high resolution regional future climate projections.
- Generally, the techniques take as input the global climate model data, and generate high resolution data that is as consistent as possible with the global data.
- The techniques are collectively known as **downscaling**, as they bring the coarse resolution global model output down to scales relevant for climate change adaptation questions.

Downscaling

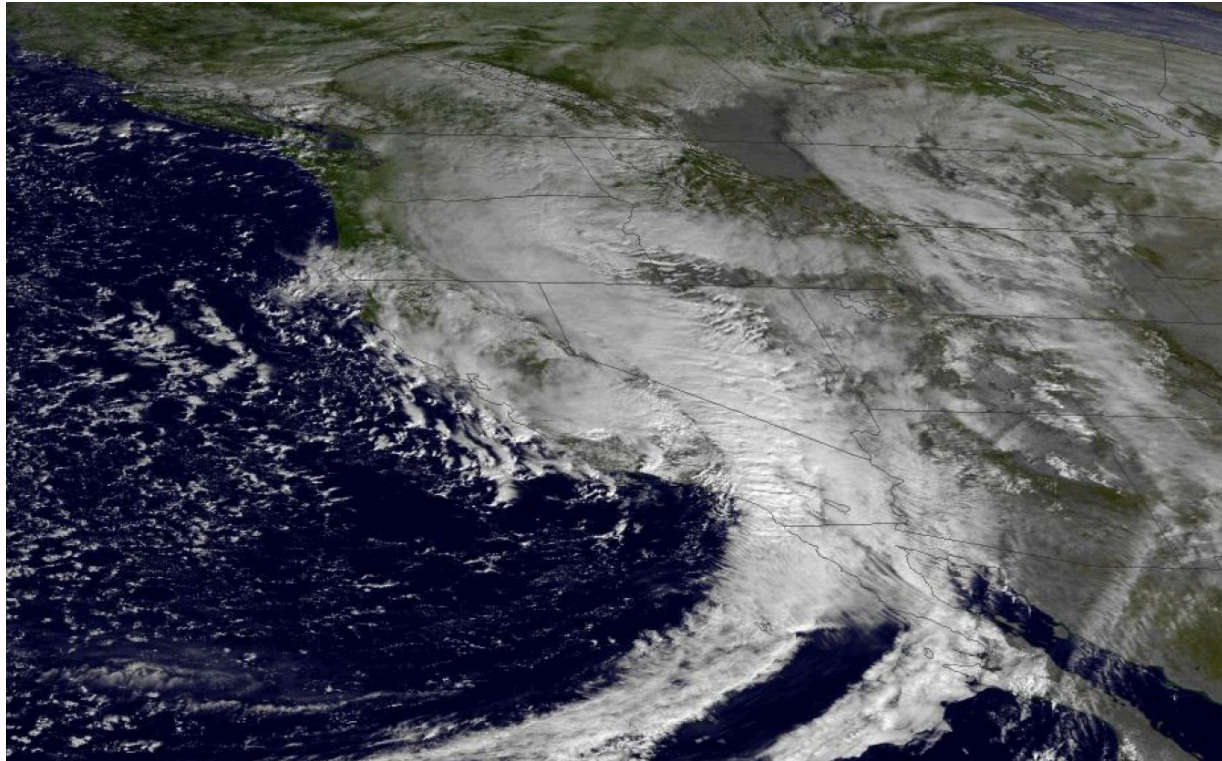


- At UCLA we have produced regional climate change projections for the LA region at 2-km resolution.
- We downscaled output from all CMIP5 GCMs.
- We examined changes in mean temperature, mean precipitation, mean wildfire risk, and mean streamflow.
- Note that we have not looked at changes in extreme precipitation.

Why is it difficult to downscale precipitation extremes?

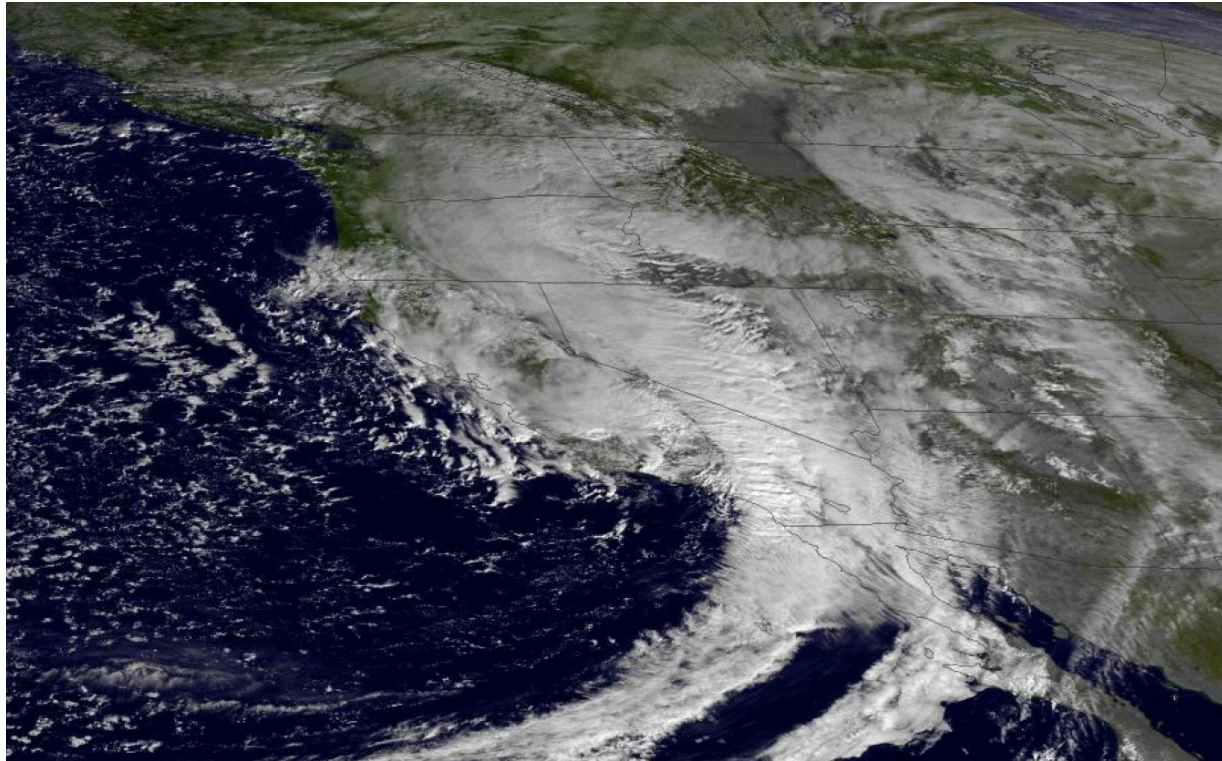
- Downscaling only works if the GCM climate change data is credible.
- Unfortunately, when it comes to the atmospheric branch of the water cycle, many GCMs are quite biased at the regional scale.
- For example, many GCMs put the mean position of the atmospheric jet stream that carries storms to the U.S. west coast in the wrong place.

Why is it difficult to downscale precipitation extremes?



- Let's say the GCM puts the jet stream too far south, and the grid boxes corresponding to Southern California experience as many storms as the northern third of California does in reality.
- It would be as though several storms like the one above were occurring every year.

Why is it difficult to downscale precipitation extremes?



- This GCM will produce a change signal (likely a large increase), but it would not be appropriate to associate this change with Southern California.
- If this change were downscaled, it might be regionalized in a realistic way, and the signals might look realistic, but such apparently high precision is very misleading.

Why is it difficult to downscale precipitation extremes?

- The problem of GCM biases is ever trickier when it comes to precipitation extremes.
- Even if a particular GCM has the jet stream in the right place, it may not have the right statistics of storminess within the jet stream.
- In other words, it might be biased in the frequency, intensity, and duration of extreme precipitation.
- Downscaling such biased extreme events would produce untrustworthy outcomes.
- Finally, it is worth noting that many commonly used, and publicly available statistical downscaling techniques, such as BCSD and BCCA, have well-known problems capturing extremes, *even for the current climate*.
- This casts doubt on the skill of such methods to downscale future precipitation extremes, even if the GCM is perfectly credible.

A path forward

- Clearly there is fundamental research to be done to provide reliable information about precipitation extremes at the regional scale.
- First, it is necessary to undertake comprehensive GCM evaluation to determine which ones have realistic storm characteristics in the Los Angeles region.
- Second, it is necessary to improve the ability of downscaling techniques to simulate precipitation extremes in the Los Angeles region.
- Third, the mechanisms underpinning downscaled changes in precipitation extremes must be evaluated and their credibility must be assessed.
- We have UCLA Grand Challenge funding to pursue these questions for the LA region.

