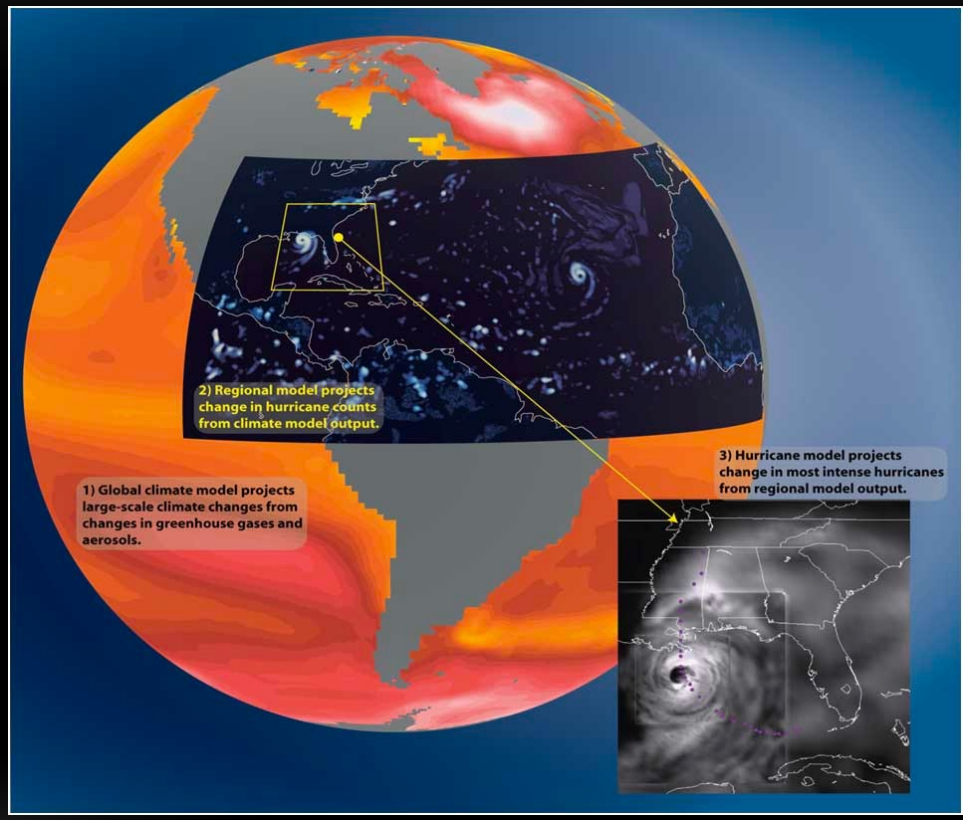
Downscaling

What is downscaling?

- Downscaling is the procedure to take information known at large scales to make prediction at regional or local scales (https://gisclimatechange.ucar.edu/question/63).
- *Why do we need downscaling?*
  - Climate models have relatively coarse resolution. Climate predictions represent the average over the grid cell (e.g., hundreds of kilometers) while end users often need fine-scale information, such as single-site precipitation
  - Coarse-resolution climate models can not well represent fine-scale climate, especially in regions of complex topography, coastlines or highly heterogenous land cover.
  - Coarse-resolution climate models can not well represent mesoscale processes, such as tropical cyclones and tornadoes.

Two Main Approaches of Downscaling

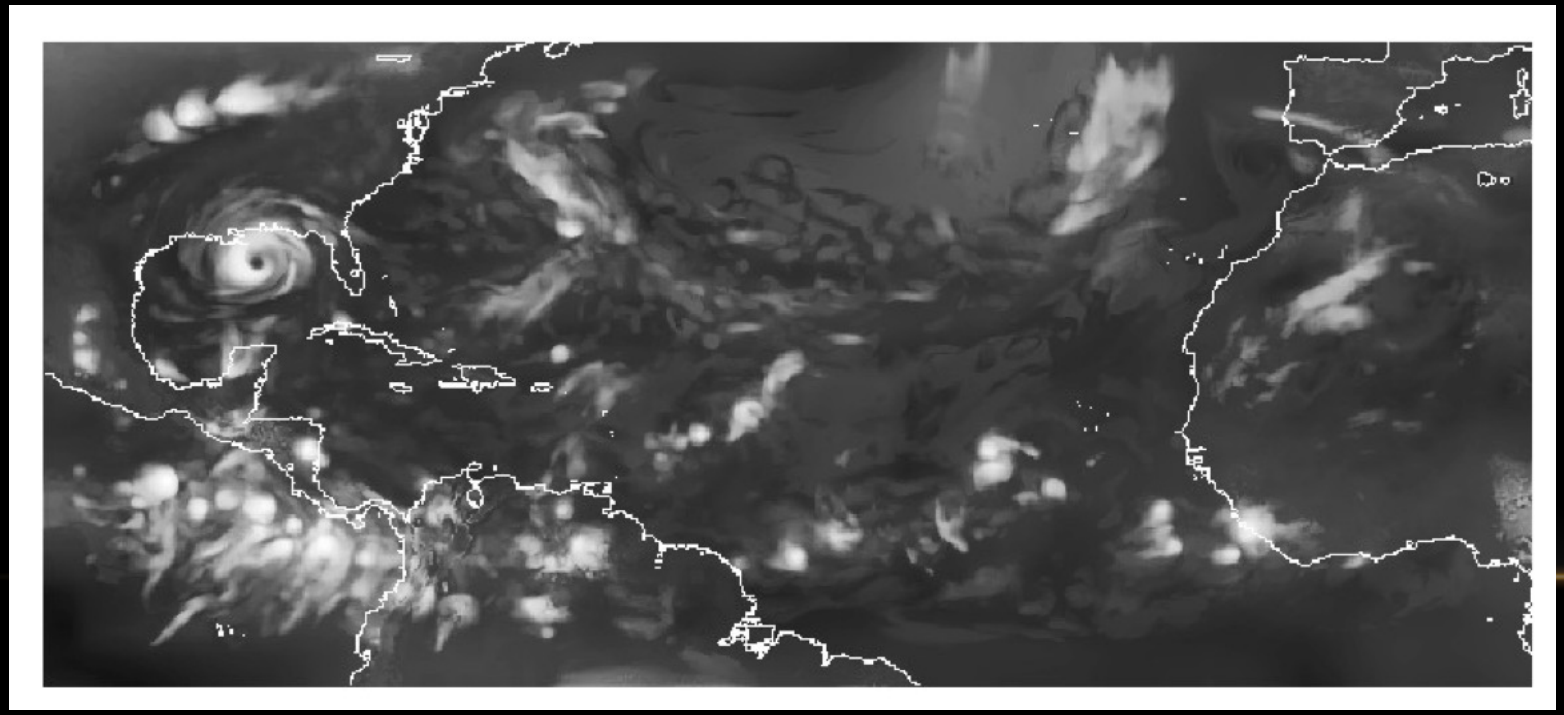
- Dynamical downscaling: a high-resolution limited-area model is driven by a global model that has relatively coarse resolution
  - The coarse-resolution global model or reanalysis provides the lateral boundary conditions for the regional model
  - The regional model is run at higher spatial resolution and can better represent the local topography, coastlines, land conditions and mesoscale processes.
- Statistical downscaling: a statistical model is developed based on the statistical relationship between the large-scale conditions (predictors) and the regional climate conditions of interest (predictand)
  - Predictors: large-scale climate information from the coarse-resolution global model output or reanalysis data
  - Predictand: regional/local scale climate information
  - Some common methods: regression, weather typing, and weather generators



https://www.gfdl.noaa.gov/climate-model-downscaling

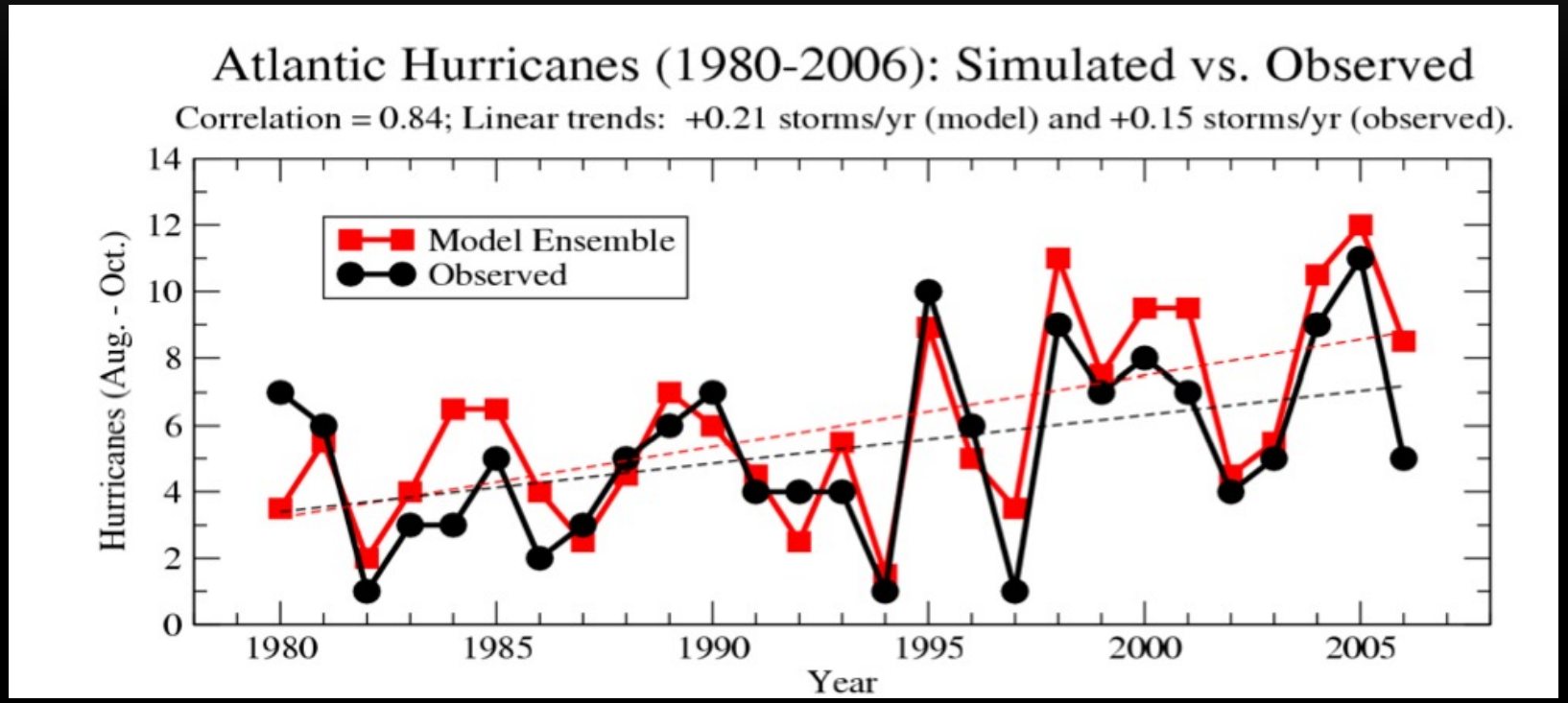
An Example of Dynamic Downscaling: Atlantic Tropical Cyclone Activity

- GFDL regional model: 18-km resolution, no cumulus parameterization
- Lateral boundary conditions provided by the NCEP/NCAR reanalysis
- The large-scale fields in the interior of the model domain (zonal and meridional wave- numbers 0,1, and 2 of the model domain) were nudged toward the reanalysis



Snapshot of model outgoing longwave radiation in the regional model. A model-generated hurricane is seen approaching the U.S. Gulf Coast for the 2005 season simulation.

An Example of Dynamic Downscaling: Atlantic Tropical Cyclone Activity (cont'd)



Annual number of simulated and observed Atlantic hurricanes for 1980-2006

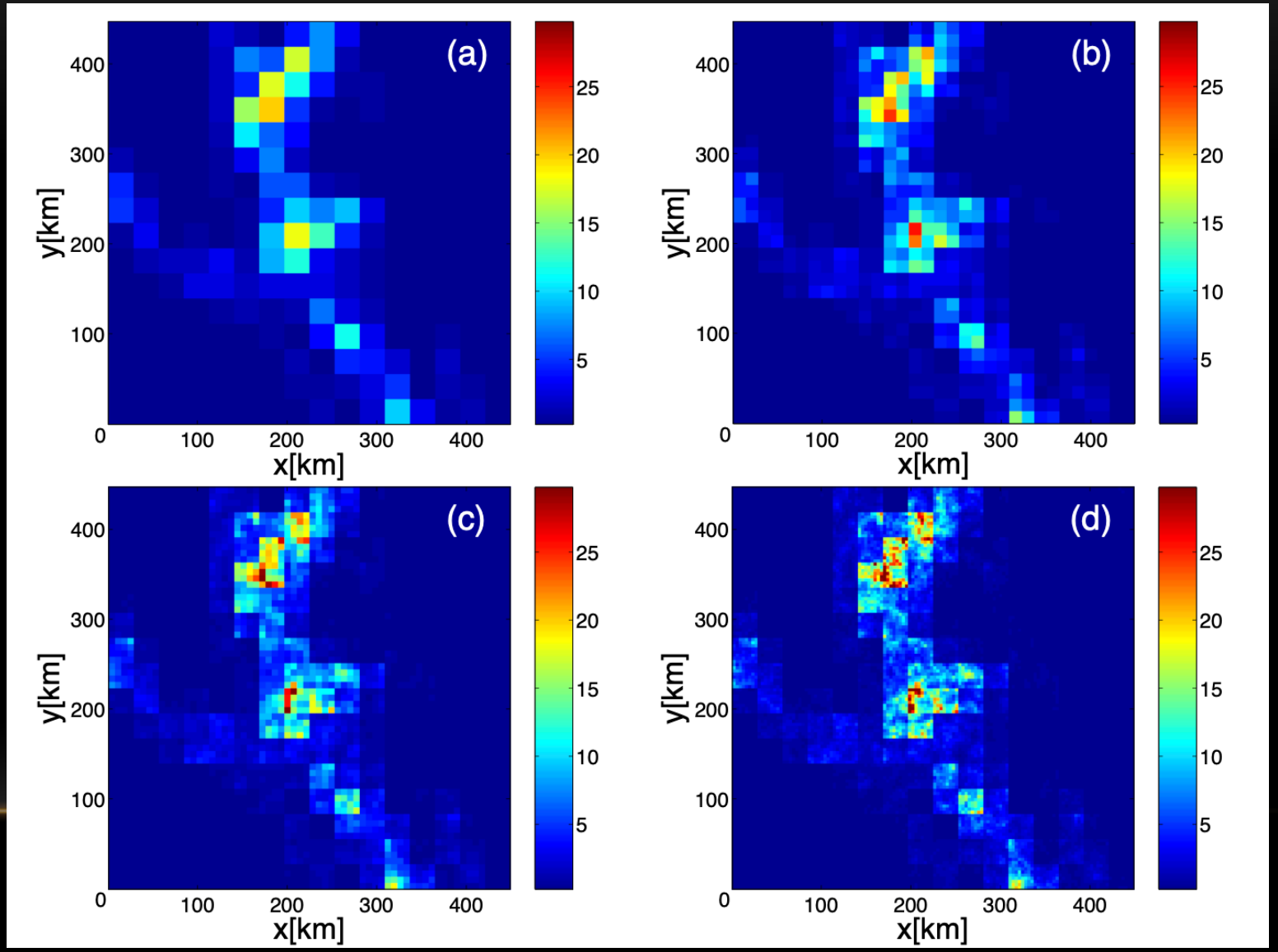
This study is not really a prediction because the regional model was drive by reanalysis

Regional downscaling model is a useful tool for the study of Atlantic hurricane activity.

Dynamical Downscaling: Strengths and Weaknesses

- Strengths: physical principals are explicitly represented
- Weaknesses:
  - Computationally expensive
  - High-frequency outputs for various variables are needed to drive the regional model, which are not always available from climate model simulations/predictions.
  - Sensitive to the quality of global model outputs that are used to drive the regional model (the so-called “garbage in, garbage out” issue)

An Example of Statistical Downscaling



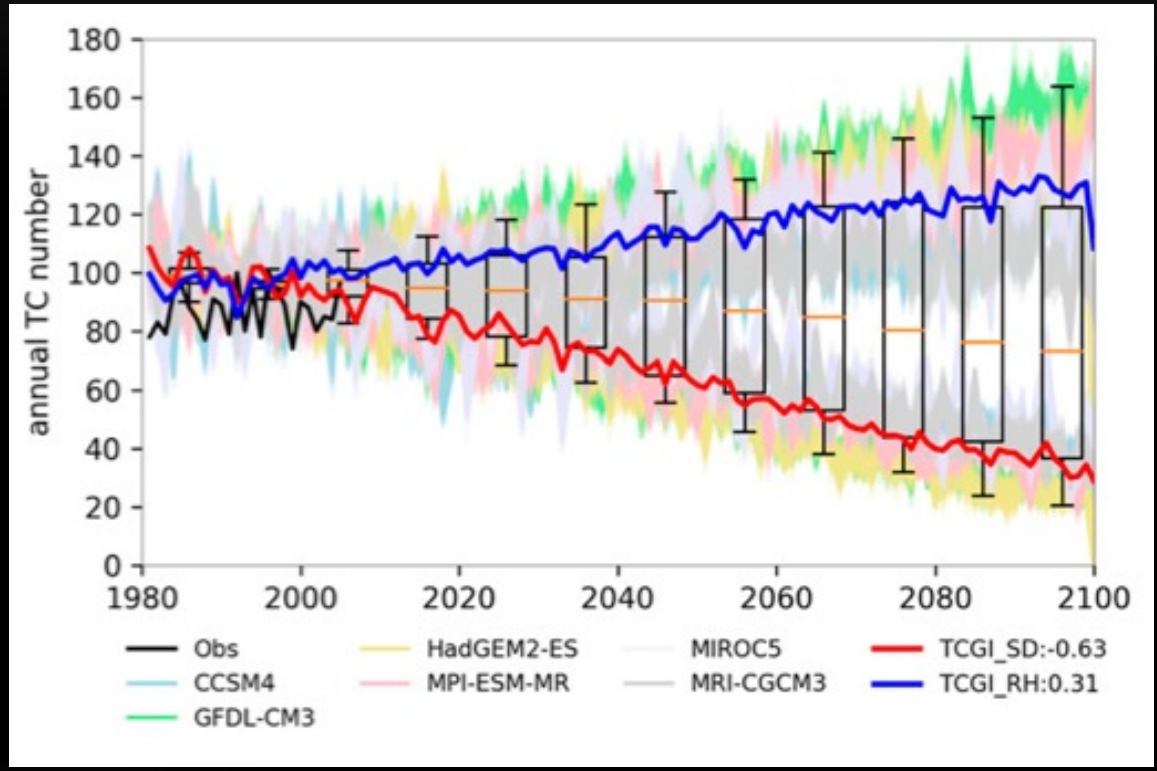
Example of rainfall downscaling. **(a)** the rainfall predicted from a model at the resolution of 28 km. Downscaled rainfall at the spatial resolutions: (b)14 km, (c) 7 km, (d) 3.5 km (Rebora et al. 2006)

Statistical Downscaling: Strengths and Weaknesses

- Strengths:
  - Computationally inexpensive, and easy to use
- *What weaknesses are associated with statistical downscaling?*
  - Long-term hindcasts are needed to train the statistical model (a statistical model developed using reanalysis may not work well with climate model outputs)
  - The statistical model may not be applicable under climate change: the empirical relationship between the predictors and predictand may change in a future climate

Limitation of Statistical Models: An Example

- The genesis potential index (GPI) represents an empirical relationship between the large-scale environmental parameters (such as vertical wind shear and humidity) and tropical cyclone genesis frequency.
- In the example on the right, the red and blue lines represent the GPI projection using two different humidity parameters. Both have a good agreement with the historical observation but predict two diverging genesis scenarios for the future climate.



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References

- Knutson, T. R., J. J. Sirutis, S. T. Garner, I. M. Held, and R. E. Tuleya, 2007: Simulation of the recent multidecadal increase of Atlantic Hurricane activity using an 18-km- Grid Regional Model. Bull. Amer. Meteor. Soc., 88(10), 1549-1565.
- Lee, C., Camargo, S. J., Sobel, A. H., & Tippett, M. K. (2020). Statistical–Dynamical Downscaling Projections of Tropical Cyclone Activity in a Warming Climate: Two Diverging Genesis Scenarios, *Journal of Climate*, *33*(11), 4815-4834.
- Rebora, N., L. Ferraris, J. von Hardenberg, and A. Provenzale, 2006a: Rainfall downscaling and flood forecasting: A case study in the Mediterranean area. Nat. Hazards Earth Syst. Sci., 6, 611–619, doi:10.5194/nhess-6-611-2006
- Wilby, R. L., Charles, S. P., Zorita, E., Timbal, B., Whetton, P. and Mearns, L. O. (2004). Guidelines for use of climate scenarios developed from statistical downscaling methods, Supporting material of the Intergovernmental Panel on Climate Change, available from the DDC of IPCC TGCIA, 27.
- Wilks, D. S. (2002). Realizations of Daily Weather in Forecast Seasonal Climate, *Journal of Hydrometeorology*, *3*(2), 195-207.