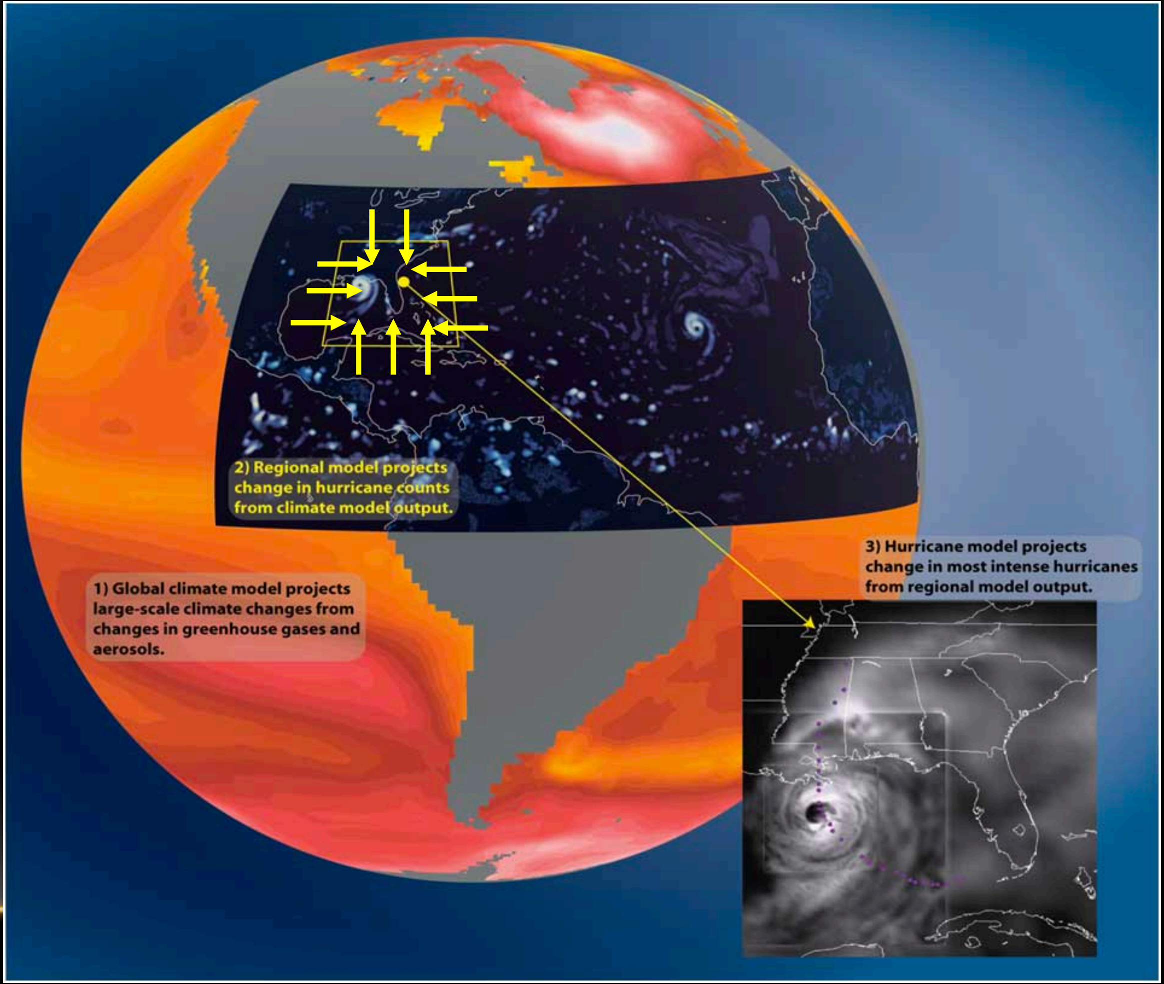
Dynamical Downscaling

Outline

- What is dynamical downscaling?
- What are the strengths and limitations of dynamical downscaling?
- What are the commonly used approaches of dynamical downscaling? What are their strengths or/and weaknesses?

What is dynamical downscaling?

- Dynamical downscaling refers to the use of high-resolution regional simulations to dynamically extrapolate the effects of large-scale climate processes to regional or local scales of interest (NOAA GFDL).
- The initial condition and lateral boundary conditions are provided by coarse-resolution (re)analysis or climate models.
- The assumption is that the high-resolution model can *at least* reproduce the large-scale characteristics from the dataset that drives the regional model and better resolve the fine-scale features.



Some acrynyms:
RCM -- Regional climate model
LBC – lateral boundary conditions

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

Strengths and Limitations of Dynamical Downscaling

- Strengths
  - Formulated on the basis of physical principles
  - Can resolve various climate processes/variables
- Limitations
  - Computationally expensive
  - The performance is sensitive to various factors, including the GCM biases via the lateral boundary conditions

Common Approaches of Dynamical Downscaling

There are four commonly used approaches of dynamical downscaling (Xu et al. 2019)

1. Traditional dynamical downscaling
2. Pseudo-global warming downscaling
3. Dynamical downscaling with GCM biases correction
   - mean bias correction, mean and variance bias correction, quantile-quantile correction, bias correction with physical consistency constraint, bias correction of low frequency variability, bias correction of multi-model ensemble
4. Dynamical downscaling with spectral nudging

1. Traditional Dynamical Downscaling Method

- A regional climate model (RCM) is driven by a GCM via the initial and lateral boundary conditions.
- The biases of the GCM can significantly degrade the RCM simulations and result in large biases/uncertainties (the “garbage-in-garbage-out” problem).

2. Pseudo global warming (PGW) downscaling

- The climate changes projected by a climate model are added to reanalysis data to drive the RCM (Xu et al. 2019):

$$BC_F = RA_H + \overline{GCM_F} - \overline{GCM_H}$$

BC_F: the constructed RCM LBC at 6-hourly intervals for the future

RA_H is the 6-hourly reanalysis data over historical periods.

$\overline{GCM_F} - \overline{GCM_H}$: the mean climate change between the future and historical periods.

- Application: climate projection, detection and attribution
- What limitations does the method have?
    - 1) the temporal variability of the boundary conditions are all inherited from historical data, and the PGW method is thus not suited to study the temporal variability in the future climate (such as diurnal cycle, intraseasonal or interannual variability);
    - 2) inter-variable dependence may be lost if the projected changes are only added to certain variables.
- See examples for the application of this method in attribution studies in 5.14.

Example: Extreme Tornado Events under Climate Change

- Trapp and Hoogewind (2016) examined extreme tornadic storm events under future anthropogenic climate change using the PGW method.
- They chose three high-impact tornado events and calculated the mean 3D atmospheric state (temperature T, relative humidity RH, pressure p, zonal wind u, and meridional wind y) and soil state (moisture and temperature) during May 2090–99 and during May 1990–99. The climate change differences were added to NWP analyses of three tornadic storm events, and this modified atmospheric state was then used for initial and boundary conditions for high-resolution WRF model simulations of the events.
- Comparison of an ensemble of PGW simulations with control simulations (CTRL) showed that the combined effects of increased CIN and decreased parcel lifting under PGW may lead to a failure of convection initiation, but higher CAPE tended to generate stronger convective updrafts than CTRL.

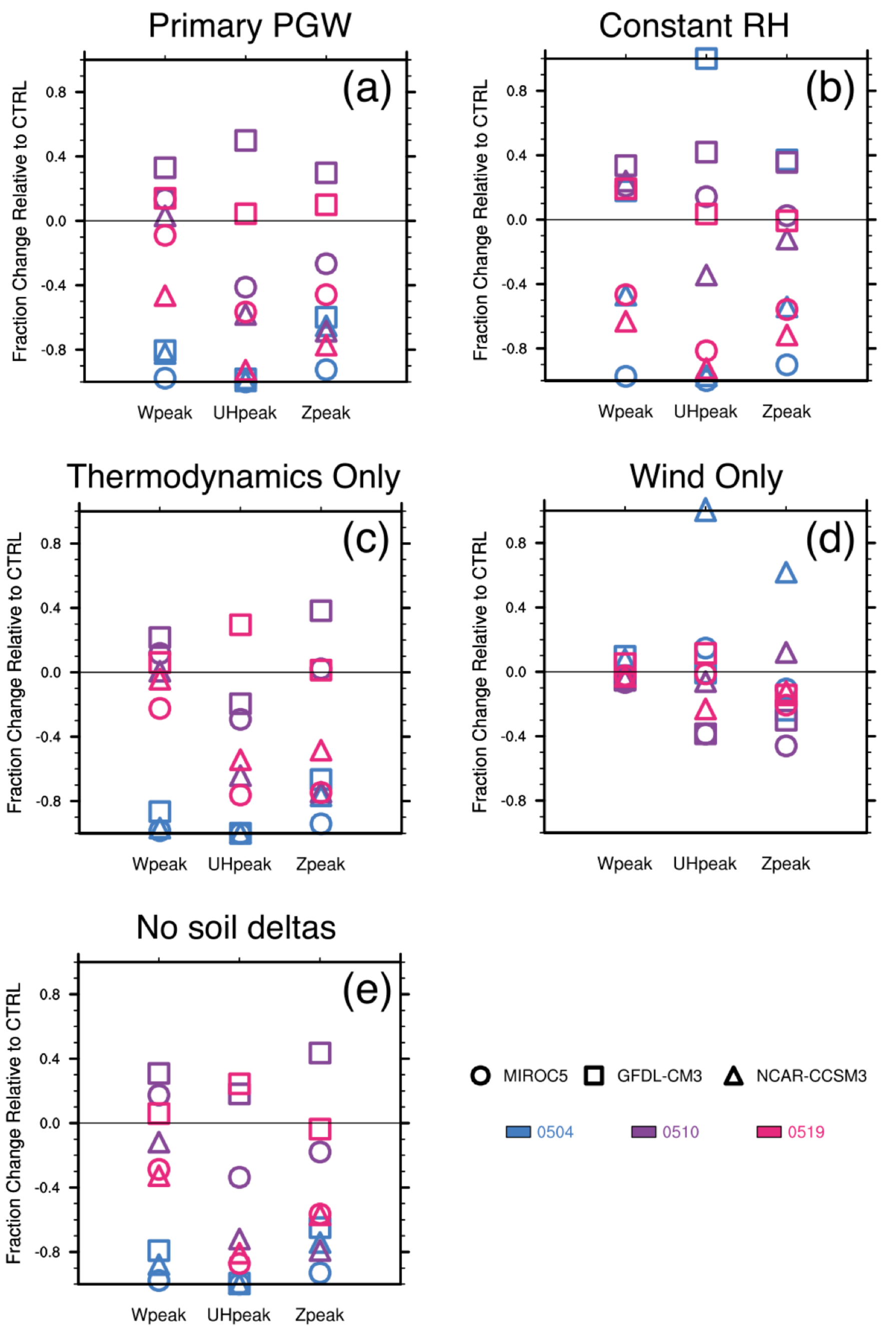


FIG. 5. Peak values of vertical velocity w_{peak}, updraft helicity UH_{peak}, vertical vorticity ζ_{peak}, given as a fractional change relative to CTRL, from (a) primary PGW experiments, (b) constant-RH experiments, (c) experiments with TO climate change Δs, (d) experiments with WO climate change Δs, and (e) experiments with no climate change Δs in soil moisture and temperature. The peaks are evaluated as described in Table 2.

3. Dynamical downscaling with GCM bias corrections

- The biases of the GCM may propagate into the RCM via the boundary conditions.
- Bias-correction of GCM output may help to improve the RCM performance.
- Commonly used bias-correction methods:
  1) mean bias correction
  2) mean and variance bias correction
  3) quantile mapping bias correction
  4) bias correction with physical consistency constraint
  5) bias correction of low frequency variability
  6) bias correction of multi-model ensemble

1). Mean bias correction

- The GCM mean biases are removed from the future projection when constructing the boundary conditions for the RCM:

$$
\begin{aligned}
BC_F &= GCM_F - \left(\overline{GCM}_H - \overline{RA}_H\right) \\
&= \overline{GCM}_F + GCM'_F - \left(\overline{GCM}_H - \overline{RA}_H\right).
\end{aligned}
$$

Where overbar denotes the climatological mean, and prime denotes the anomalies. The rhs term with the parentheses denotes the difference between the GCM mean and reanalysis mean, i.e., the GCM mean biases derived from a historical record.

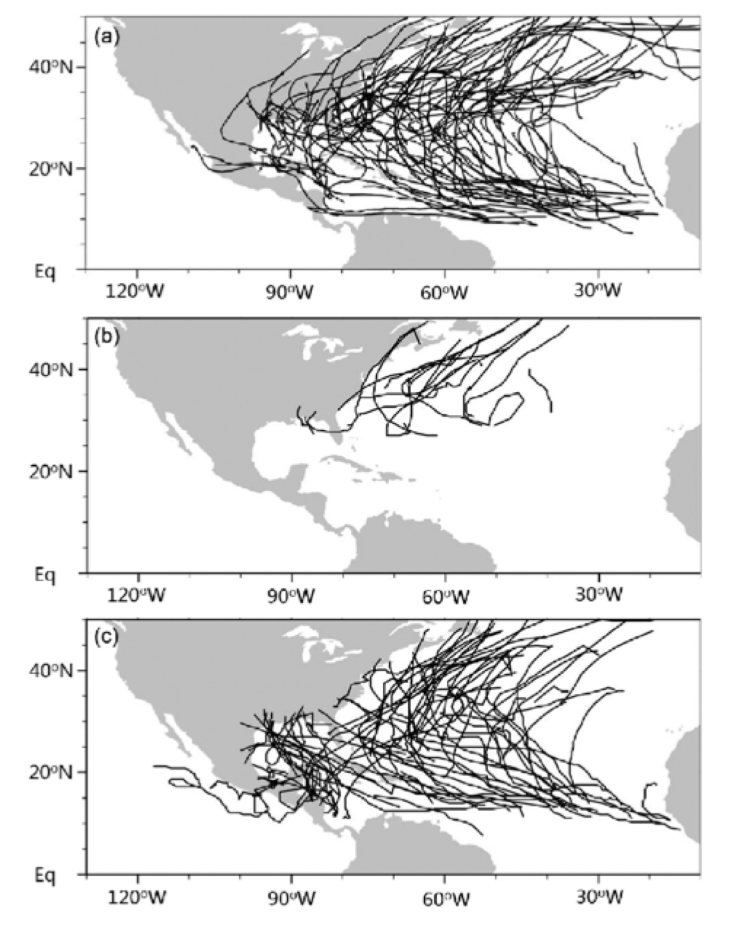


Figure 1 Tropical storm tracks derived from observation (a), the TDD methods over the period of 1995–2005 (b), and the dynamical downscaling simulation with GCM mean bias correction (c). Modified based on Bruyère et al. (2014).

Observation

Underestimated TC activity due to overestimated vertical wind shear over the tropical Atlantic

Improved RCM downscaled TC activity after the biases in vertical wind shear are corrected.

From Xu et al. 2019

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