More about Dynamical Downscaling

- Factors affecting dynamical downscaling performance
- Other types of grid refinement

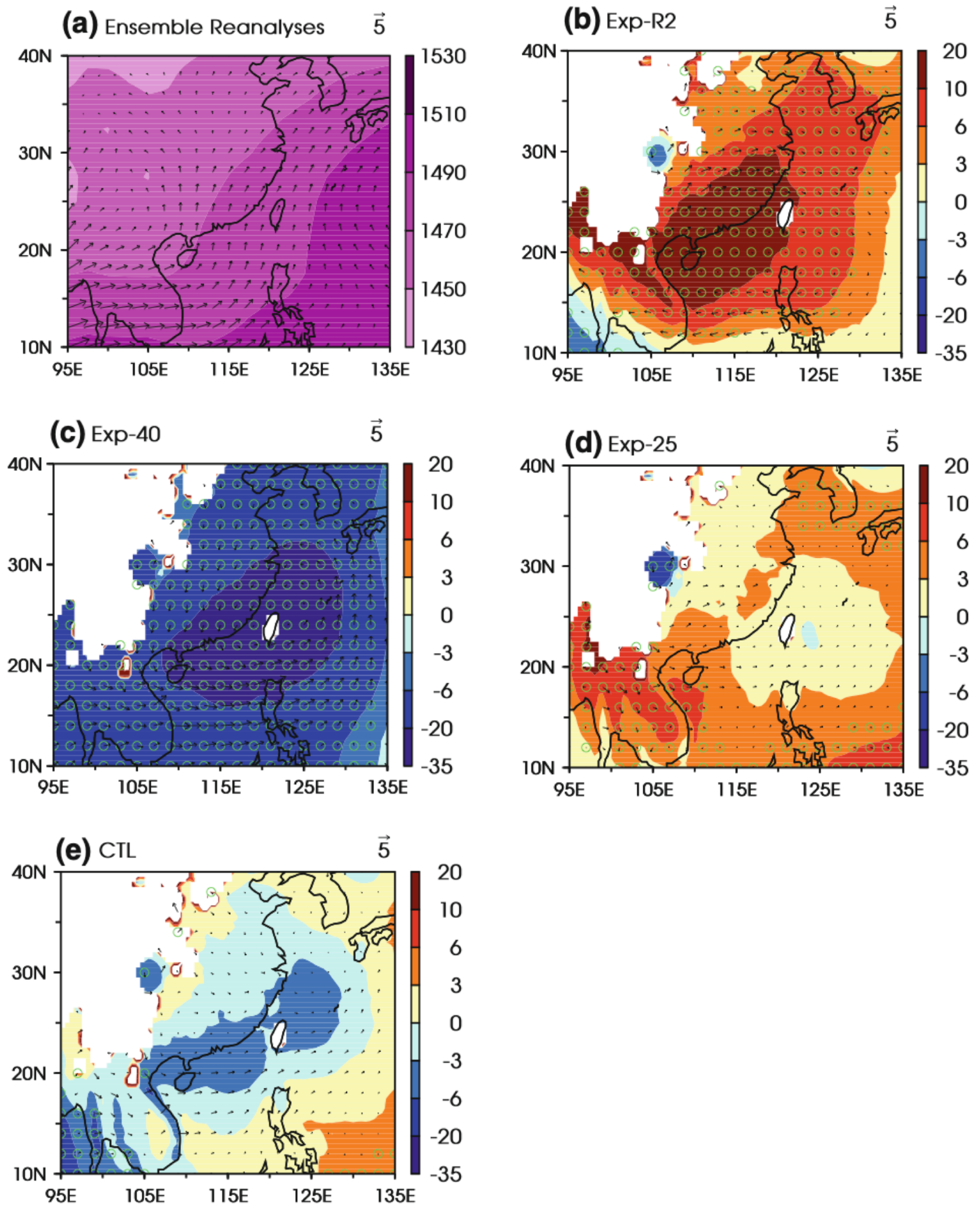
Dynamical Downscaling Performance

- Dynamical downscaling is commonly used for climate prediction, future climate projection and to produce high-resolution data for risk assessments and impact studies. It is important to understand whether dynamical downscaling can provide added value and what factors affect the dynamical downscaling performance.
- *What factors may affect dynamical downscaling performance?*
- Xue et al. (2014) suggested that the following factors affect dynamical downscaling performance:
  1. LBC quality
  2. domain size
  3. domain position
  4. model resolution
  5. RCM model physics

1. Sensitivity to Lateral Boundary Conditions

- The performance of a RCM is strongly affected by the quality of the LBC data.
  - GCM biases may propagate into the RCM via the LBC and degrade the RCM simulations/predictions.
  - RCMs driven by different reanalysis datasets may produce remarkably different seasonal mean precipitation and circulation, and there is not a single reanalysis that yields the “best” LBC for every region and every season (Xue et al. 2014).
  - RCMs driven by different CMIP models, even with the same forcing scenario, produce different future projections of regional climate.
- The Weather Research and Forecast (WRF) model driven by three reanalysis datasets (NCEP-R2, ERA-40, JRA-25) produced different results in summer seasonal mean H850, and using the ensemble mean of three reanalysis as LBCs reduced the biases in the model simulation (Yang et al. 2012).

Fig. 2 **a** The climatological June–July–August (JJA) mean geopotential height (shading in units of meter) and horizontal winds (vector in units of m s^{-1}) at 850 hPa that are derived from the ensemble mean of NCEP-R2, ERA-40, and JRA-25 reanalyses data. Respectively, **b**, **c**, **d**, and **e** are the biases simulated with lateral boundary (LB) conditions derived from **b** the NCEP/DOE reanalysis 2 (NCEP-R2), **c** the ECMWF 40-year reanalysis (ERA-40), **d** the Japanese 25-year reanalysis (JRA-25), and **e** ensemble mean of the three reanalyses. All the biases are defined by the deviation of RCM simulations from the ensemble mean of NCEP-R2, ERA-40, and JRA-25. The *green circles* indicate the significant areas with 95% confidence level in the difference of geopotential height by t test



2. Sensitivity to RCM Domain Size

- RCM performance is sensitive to the domain size.
  - The domain should not be too large: the RCM climatology may drift away from the LBC's climatology.
  - The domain should not be too small: the LBC impacts may be too strong for the RCM to produce adequate small-scale features.

Example: The figure on the right shows the simulations of North American regional climate. The RCM simulation with Domain 3 captured the observed precipitation variability, but Domain 1 was too large, and the simulation deviated from the observation. A hypothetic domain 4 (not tested in Xue et al. 2014) is likely too small.

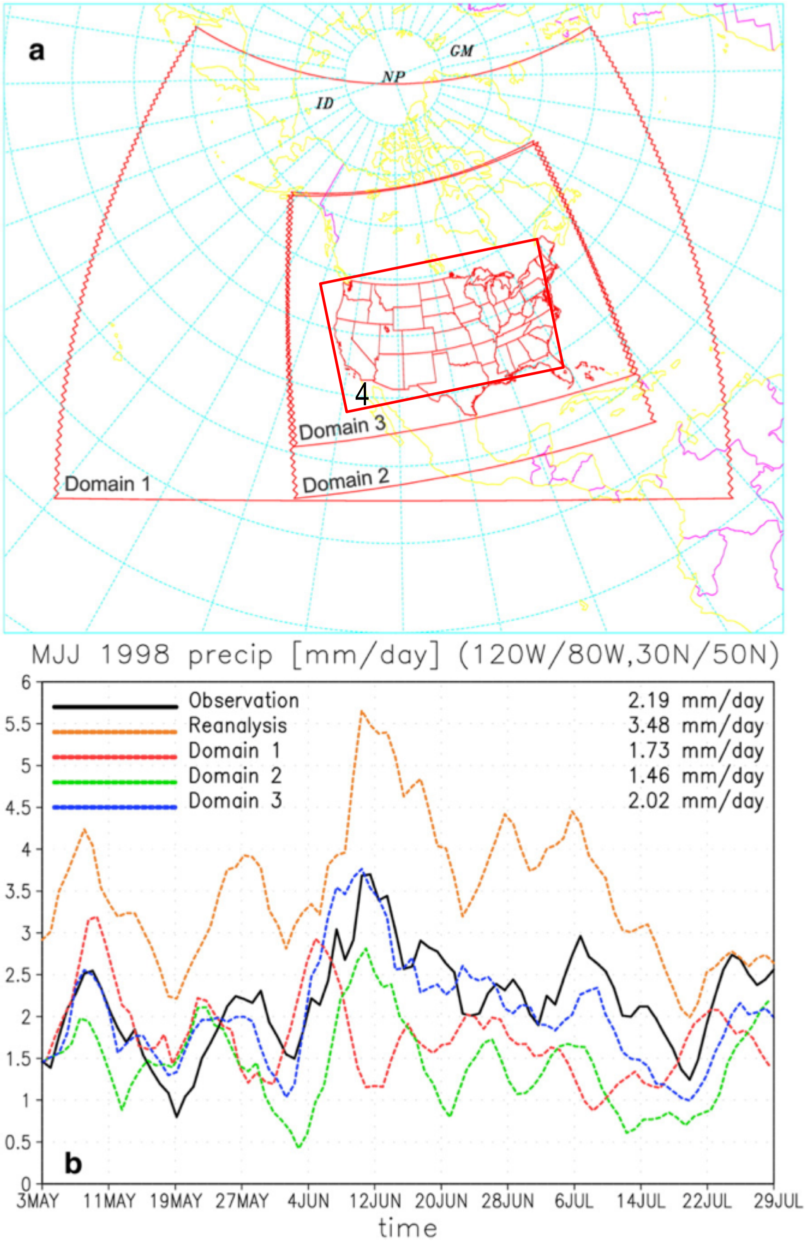
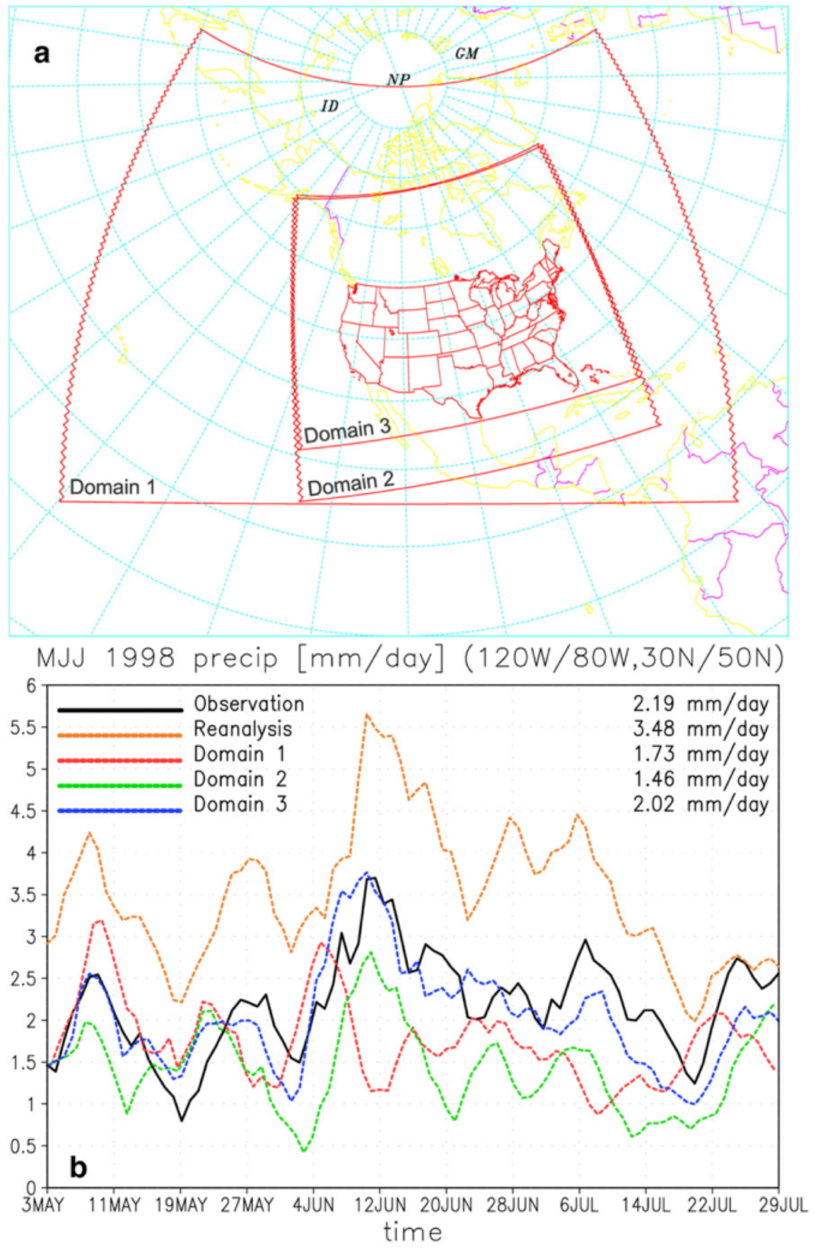


Fig. 3. (a) RCM domains, and (b) comparison of time series of observed and reanalysis precipitation and simulated precipitation with different domains. Unit: mm day^{-1}. Modified based on Xue et al., 2007.

From Xue et al. 2014

3. RCM Domain Position

- Domain boundary position also affects the RCM performance.
- Where should the lateral boundaries be placed?
  - Avoid steep topography (such as the Tibetan Plateau)
  - Avoid regions with large data uncertainties
  - Avoid cutting through a strong dynamic system (such as the jet stream)
  - Away from the area of interest
- Example: Domain 2 and Domain 3 have a similar size, but the southern boundaries are placed at different locations. Domain 3 better represents the moisture transport and thus better simulates the precipitation variability. The southern boundary of Domain 2 is over a region where the NNR reanalysis has a dry bias, which contributes to the underestimated precipitation.



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4. RCM Model Resolution

- RCMs are run at higher resolutions than the driving GCMs, and RCMs may become convection-permitting models with the horizontal resolution < 5 km.
- However, higher RCM resolution does not always lead to a better model performance.
- Example: Chan et al. (2013) examined whether increasing the spatial resolution of a regional climate model improves the simulated daily precipitation. They found that orographic precipitation was improved when the model resolution was increased from 50 km to 12 km, but further increasing the resolution to 1.5 km led to larger mean biases.

5. RCM Model Physics

- RCM simulations are sensitive to the physical parameterizations employed. Significant improvement in dynamic downscaling can be achieved by improving convective parameterizations.
  - Please compare the bottom two panels in the figure on the right.
- It is challenging to select the "optimal" parameterization because the performance depends on the problem of interest (extreme precipitation vs. stratiform precipitation) and the region of interest (tropics vs. midlatitude).

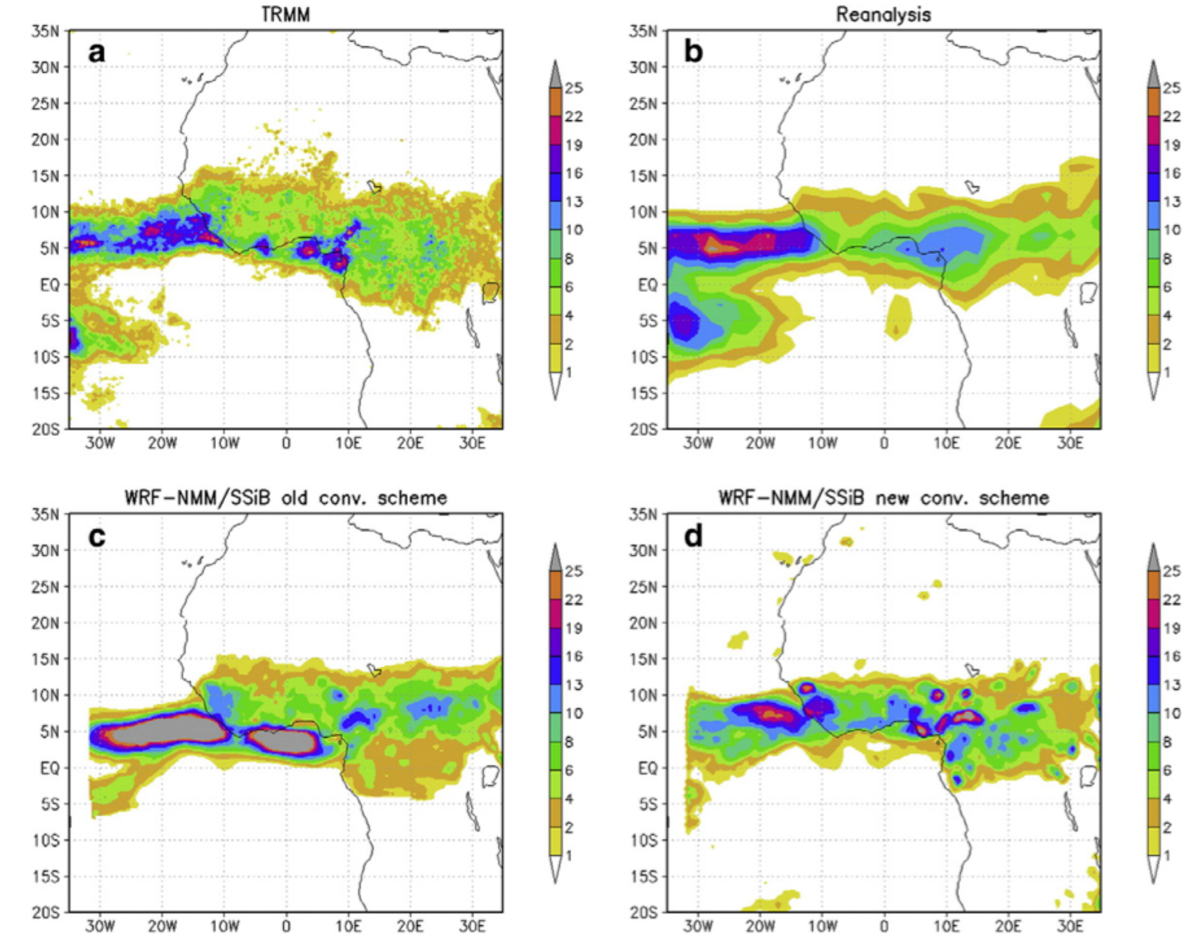


Fig. 4. Comparison of TRIM (a), reanalysis (b), and WRF/NMM simulated June 2000 precipitation (mm day^{-1}). The results from original and modified convective schemes are shown in (c) and (d), respectively.

From Xue et al. 2014

Other types of grid refinement

In addition to D using RMs, there are other types of grid refinement.

- Variable resolution models
- Two-way nesting

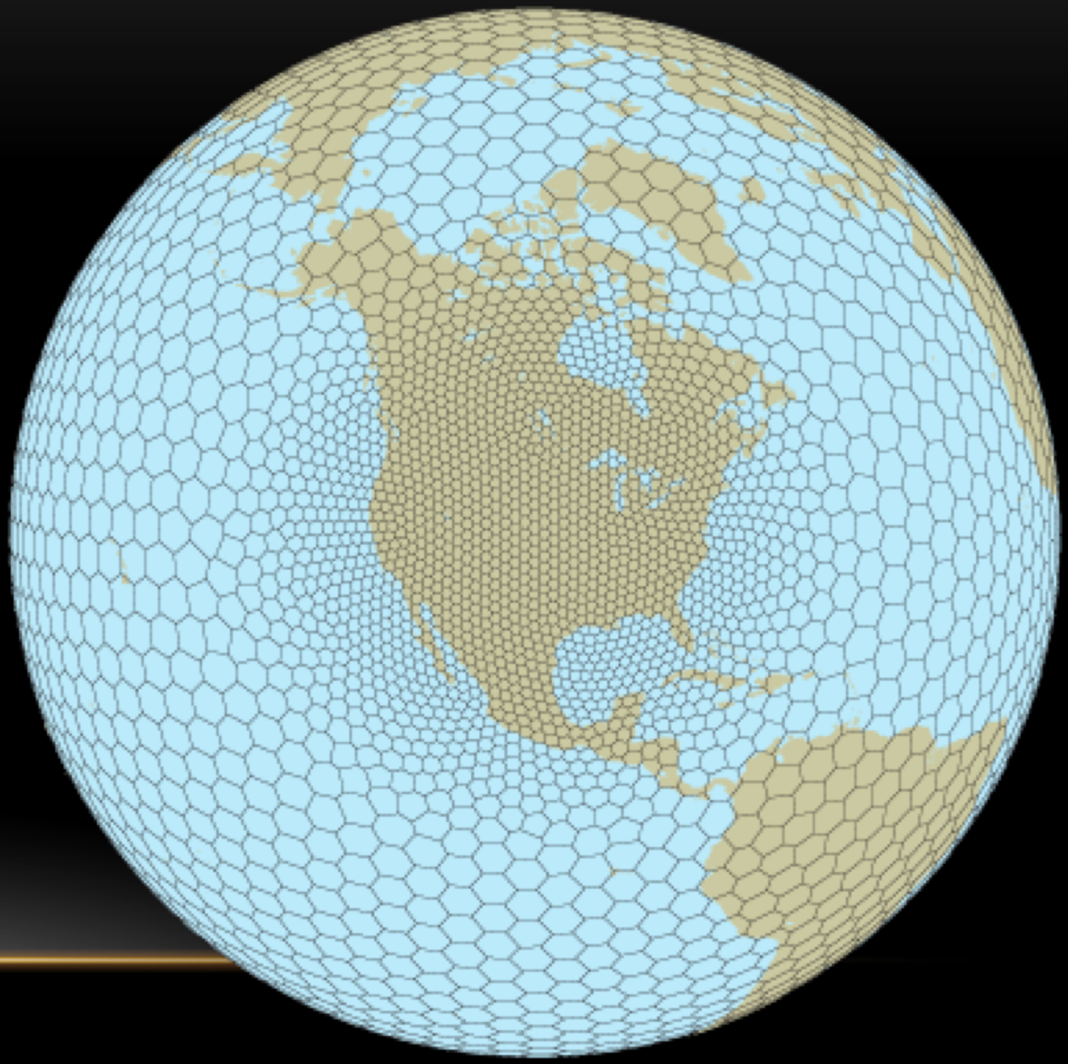
Variable resolution models

Variable resolution models -- numerical models with horizontal resolution arranged to be nonuniform. This enables finer details of the solution in a chosen region of interest to be captured in a way that preserves computational economy elsewhere (AMS Glossary).

One example is the Model for Prediction Across Scales (MPAS) developed by the climate modeling group at Los Alamos National 'Laboratory (COSIM) and the National Center for Atmospheric Research. Its variable resolution meshes have smoothly-varying mesh transitions, which avoids the abrupt resolution transition in the traditional grid nesting.

Weaknesses:

1) the model time step is restricted by the finest model resolution,
2) the employed physics parameterizations need to work well across different model resolutions (scale-aware physics parameterization)



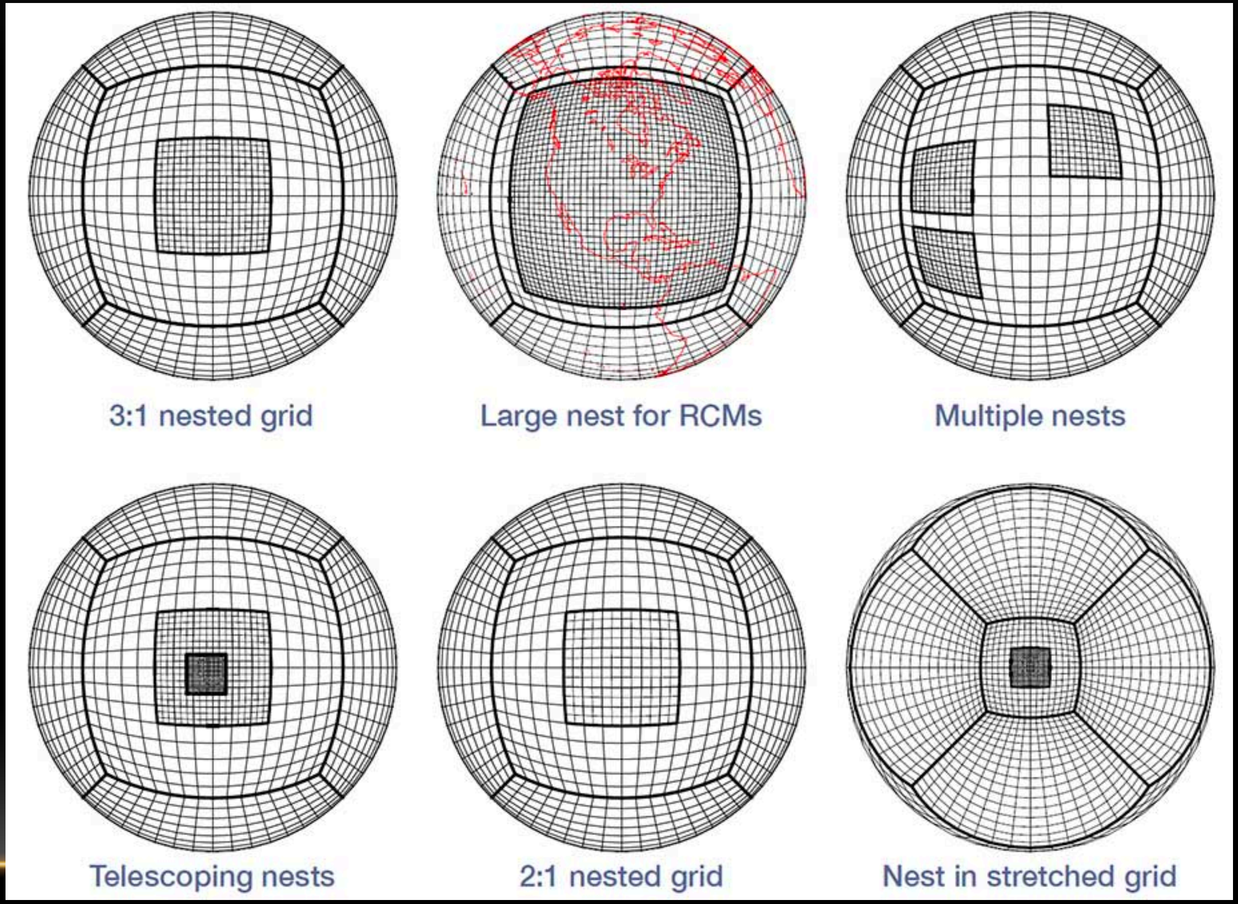
MPAS: https://ncar.ucar.edu/what-we-offer/models/model-prediction-across-scales-mpas

Two-way Nesting or telescope Nesting

In traditional dynamical downscaling, the RCM is driven by a GCM. In two-way nesting or telescope nesting, a high-resolution nested grid and a coarse-resolution global grid are run concurrently to produce simultaneous, coupled regional and global solutions.

Advantages:
1) Each grid may use different settings appropriate for its own resolution, including different time steps and different physics parameterizations.
2) The nested domain can feedback to the parent domain.

The Finite-Volume Cubed-Sphere Dynamical Core "FV3", which is used in the present version of the NOAA GFS model, supports two means of grid refinement: a continuous grid stretching and two-way grid nesting. The figure on the right shows various nesting options available in FV3.



https://www.gfdl.noaa.gov/fv3/fv3-grids/

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- MPAS model: https://ncar.ucar.edu/what-we-offer/models/model-prediction-across-scales-mpas
- FV3: https://www.gfdl.noaa.gov/fv3/fv3-grids/