Space-time downscaling of precipitation using a combination of stochastic and physical methods

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Existence of scale gaps

- Different problems in different scale
  - Dominant processes may be different
  - Forcing data properties may be different
  - Appropriate model structure may be different
  - Responses to the subsequent processes may be different
Challenge: Sp-Time downscaling

- Several numerical models and reanalysis systems produce precipitation fields that are “Coarse” for many further uses.

- How to obtain more finer resolution—current focus
  - Meteorological understanding at finer resolution is not sufficient
    - e.g. Tropical rain, high altitude precipitation
  - Nesting models are often numerically unstable and highly sensitive to boundary conditions
  - Need of primary data (for initialization and boundaries) are too high
Loss of details in coarse resolution

48-km; Hourly

3-km; 5-minutes
Known understandings on downscaling

- **Interpolation techniques** are not good enough, as it provides a smooth field. Precipitation is not smooth but a collocation of intermittent fields.

- **Stochastic modeling** based on autocorrelation do not yield a sufficient operational finer resolution precipitation field
  - stochastic process does not synchronize with physics

- **Multifractal method** is unsuccessful to describe the precipitation structure due to inconsistent randomness of precipitation
  - mathematically sound and statistically perfect results often fails to generate a true rain structure in space

- **Physical-based method** is computationally demanding, parameterization issues and turn to high resolution modeling of circulation processes that beats the purpose of downscaling

- We still need to explore how do we bridge the scale gaps.
Known understandings on downscaling

- **Space-time scale inter-dependency**
  - Spatial downscaling alone and/or temporal downscaling alone does not serve the purpose of precipitation downscaling because of space-time scale complexities of precipitation structure.
  - Types of precipitation, geo-climatic regimes and elevation correlations often provide insights but are often inconsistent across scales.

- Transferring data into multiple scales with appropriate scaling relations
- Looking for *scale invariant descriptions* and *limits* of scaling relationships

- **Motivation**
  - Choose descriptive scales that minimize complexity but retain integrity
  - Make use of coarse scale products in high resolution modelling and analysis systems to analyse *local scale effect* due to *global scale phenomenon*
  - Supply data for analysis and prediction of land surface conditions even in a data poor region
The precipitation variability remains almost the same in a large spatial range but the variability changes rapidly in a small temporal range.

Regeneration of appropriate sub-grid scale variability is the main challenge.
Multiplicative Random Cascade

- Geometry of rainy and non rainy regions
- Conceptual basis of turbulence eddies
- Multiplicative random cascades – develop cascades over a continuous interval

Random Cascade Generator

\[ \mu_n(\Delta_n^i) = R_n L_o b^{-n} \prod_{j=1}^{n} W_j^i \]
Output of the RC model

- Mathematically true, Statistically perfect results of downscaling is unable to describe rain structure
- lesson, generator itself should not be random

Bad example of Random Cascade

Good example of Random Cascade
Can we improve spatial downscaling?

- Obtain spatial patterns from other higher resolution sources and mimic the pattern by overlaying it on to the coarse scale precipitation field
  - Radar reflectivity
  - Satellite images
  - Composite of gauge-network and alternate observations

- High uncertainty due to
  - Incompatibility of sources (representativeness??)
  - Errors in measurement (bias ??)
  - Quality control (post processed or raw??)
  - Inconsistent coverage (gaps and uncovered zones??)
If the correlation of G-matrix and W-matrix is found poor, the W-matrix is allowed to re-position until it gets best correlation with G-matrix.
Results of RC HSA

- Spatially downscaled outputs are highly improved

Random Cascade only

Random Cascade HSA
Results of RC HSA

- Spatially downscaled outputs are highly improved.

Random Cascade only

Random Cascade HSA
Temporal downscaling issues

- Differences between coarse resolution, fine resolution and best-fit interpolated fine resolution
- If the spatial scale is larger, the differences between the best-fit interpolation and the high resolution data points are smaller → illustrates how space-time scale interacts.
- Temporal interpolation at finer spatial scale introduce much larger errors than at coarser spatial scale.
Translation Model

- Projects the possible precipitation-cluster location based on tracked advection of past precipitation

- Non-linear projection
  - Introduce microphysical mechanism of rainfall process
    \[
    \frac{\partial z}{\partial t} + u \frac{\partial z}{\partial x} + v \frac{\partial z}{\partial y} = w
    \]
  
  - Advection vectors and parameters
    \[
    \begin{bmatrix}
    u \\
    v \\
    w
    \end{bmatrix} = \begin{bmatrix}
    C_1 & C_2 & C_3 \\
    C_4 & C_5 & C_6 \\
    C_7 & C_8 & C_9
    \end{bmatrix} \times \begin{bmatrix}
    x \\
    y \\
    1
    \end{bmatrix}
    \]

  - Translation mechanism
    \[
    w = 0 \quad C_7 = C_8 = C_9 = 0
    \]
Temporal Trends
Results of Temporal downscaling

From 60 minute resolution to 5 minute resolution (48-km)
Results of Temporal downscaling
Results of Temporal downscaling

From 30 minute resolution to 5 minute resolution
Results of Temporal downscaling

From 30 minute resolution to 5 minute resolution