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

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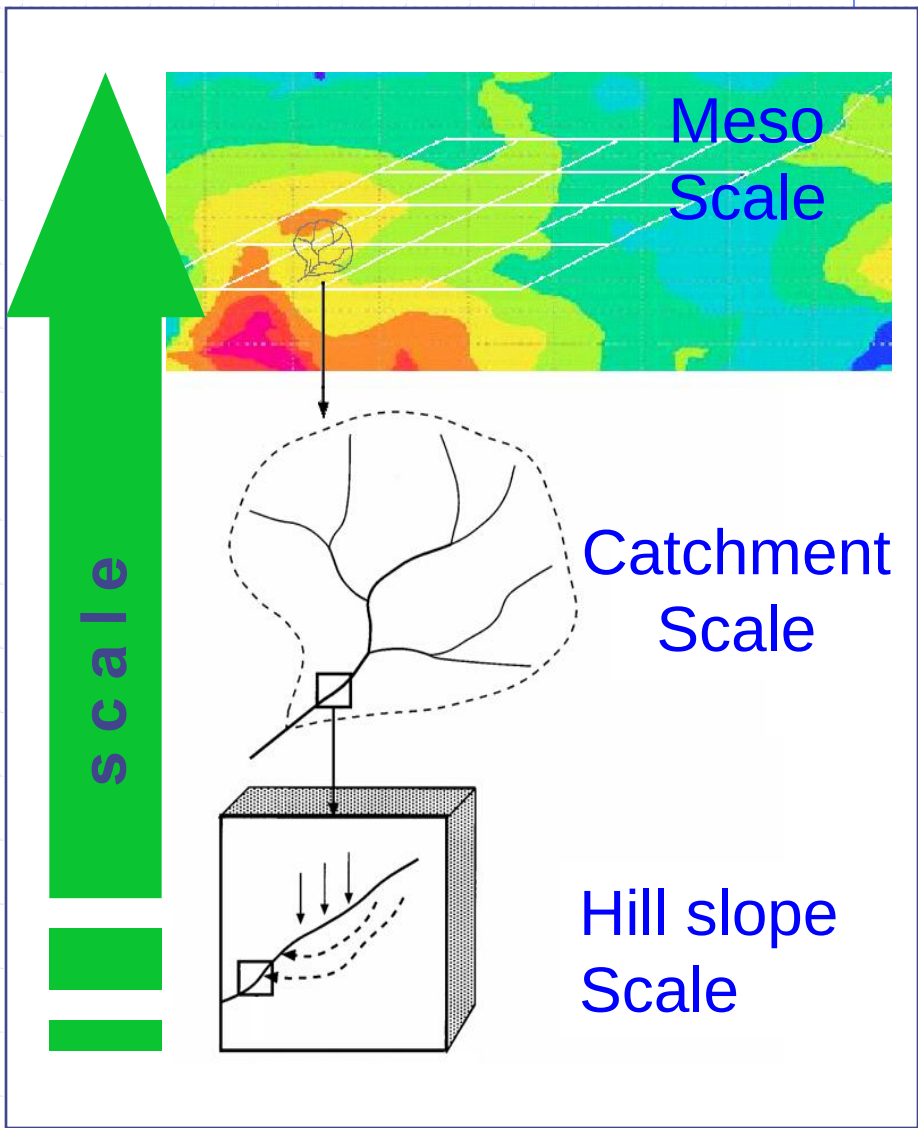
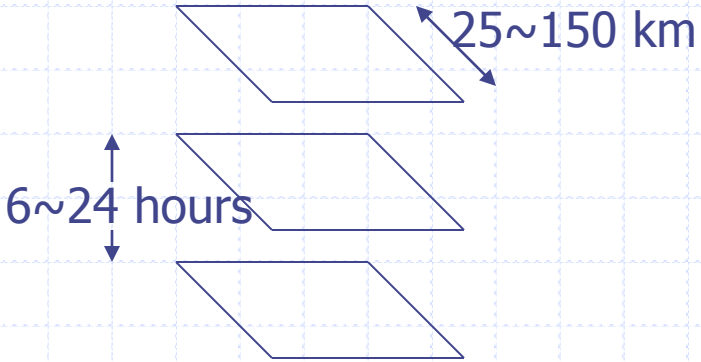
Existence of scale gaps

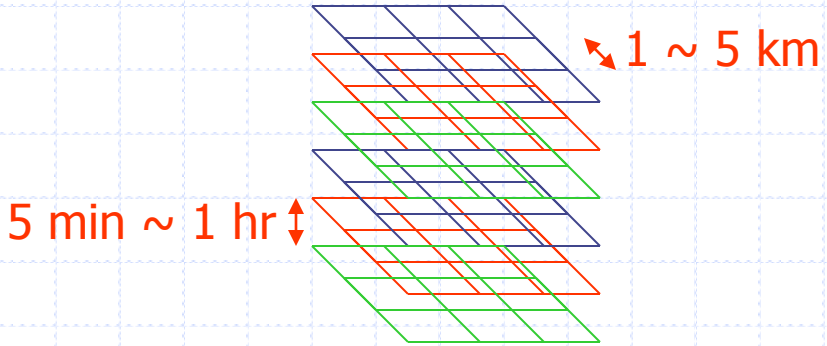
- Different problems in different scale
  - ✓ Dominant processes may be different
  - ✓ Forcing data properties may be different
  - ✓ Appropriate model structure may be different
  - ✓ Responses to the subsequent processes may be different



Challenge: Sp-Time downscaling

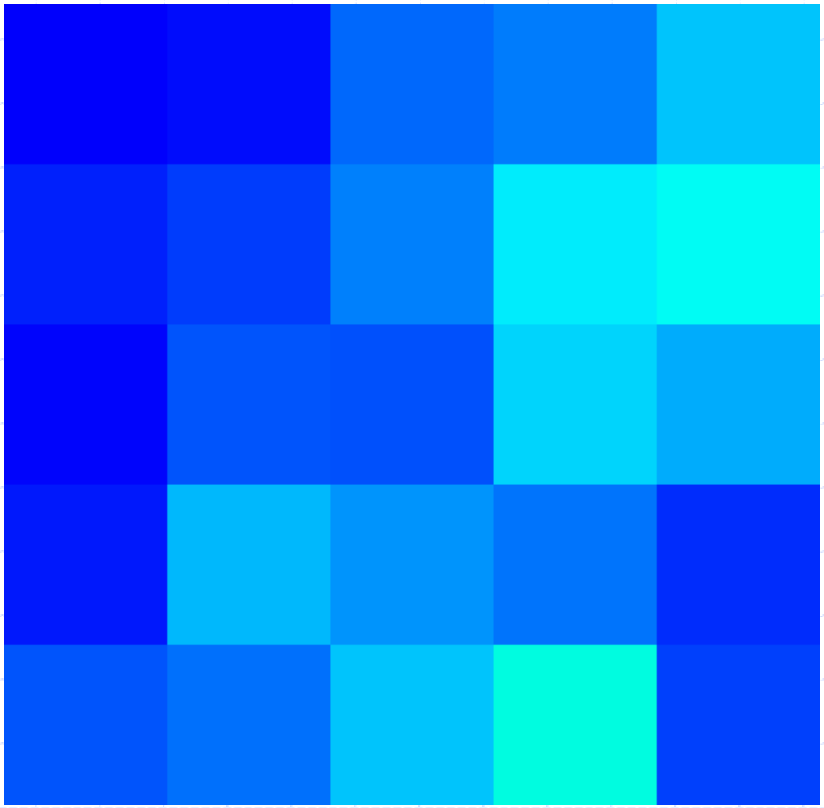
- Several numerical models and reanalysis systems produce precipitation fields that are "Coarse" for many further uses



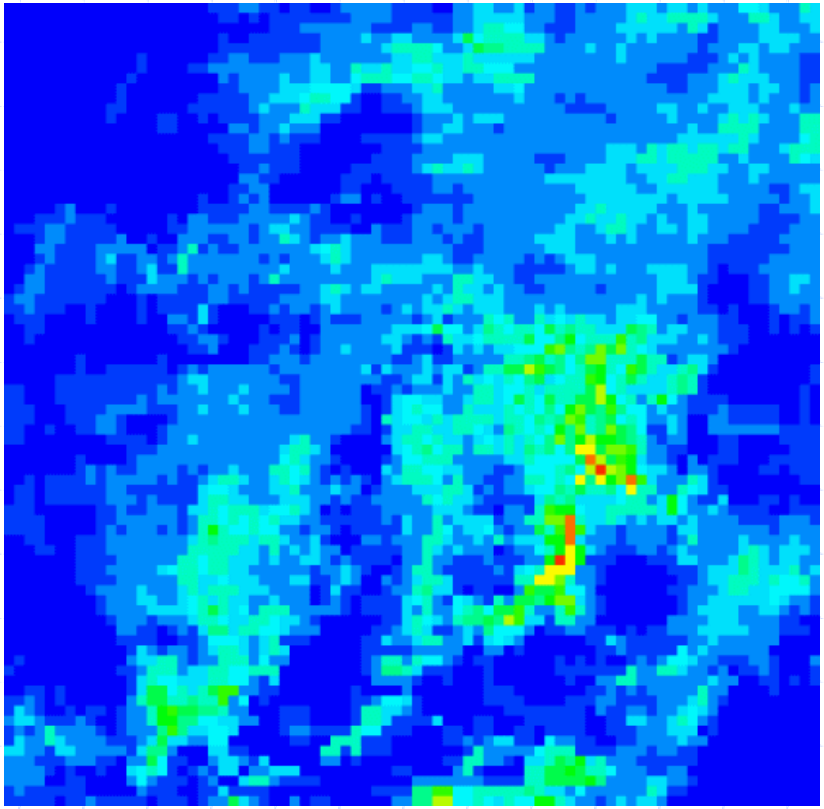


- How to obtain more finer resolution– current focus
  - ✓ Meteorological understanding at finer resolution is not sufficient
    - e.g. Tropical rain, high altitude precipitation
  - ✓ Nesting models are often numerically unstable and highly sensitive to boundary conditions
  - ✓ Need of primary data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

Loss of details in coarse resolution



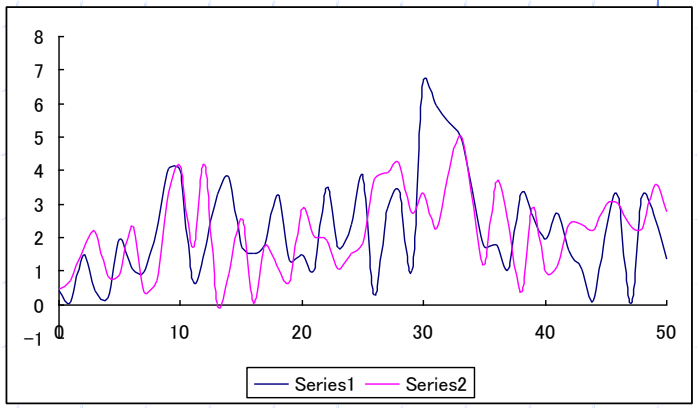
48-km; Hourly



3-km; 5-minutes

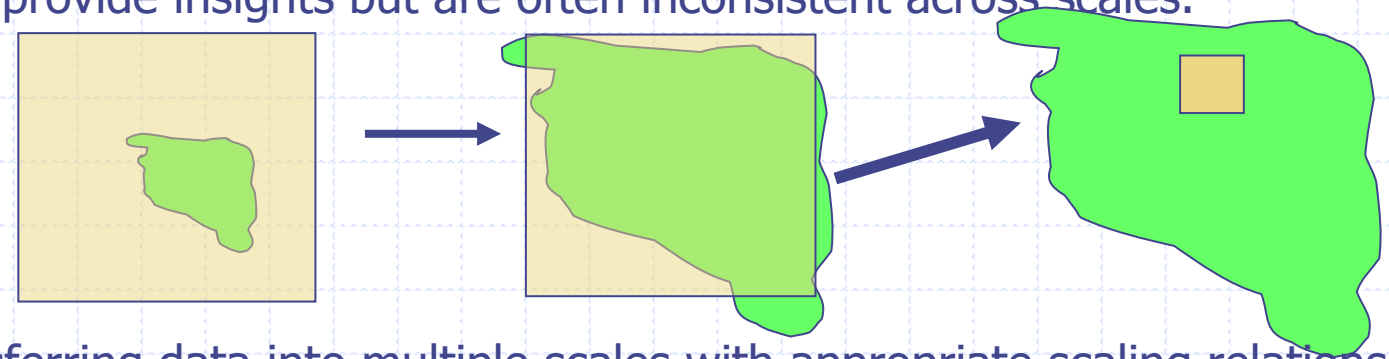
Known understandings on downscaling

- 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.



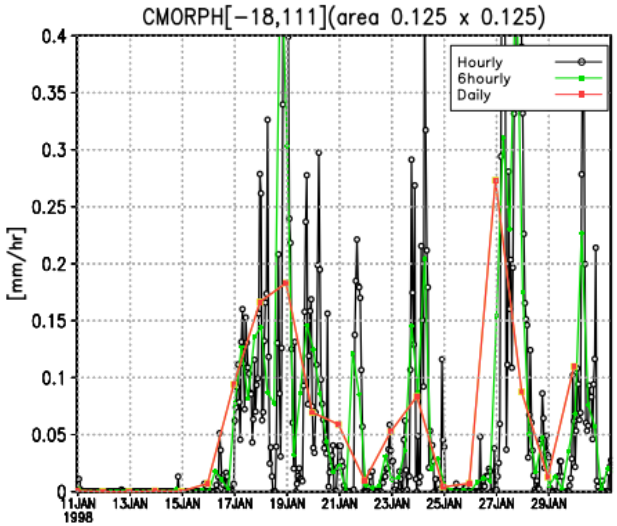
Known understandings on downscaling

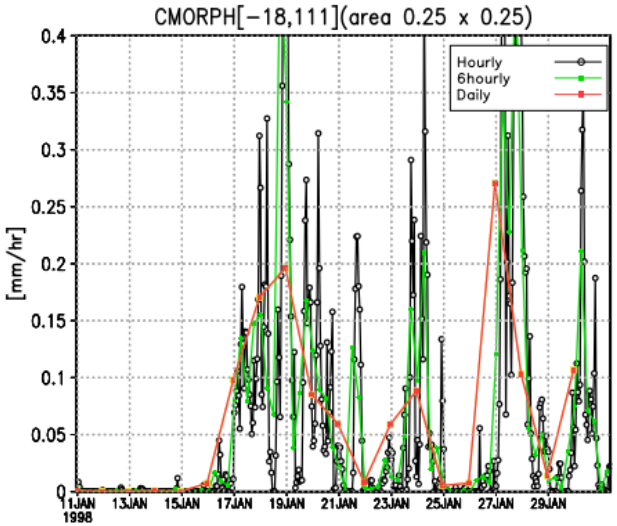
- Space-time scale inter-dependency
  - ✓ Spatial downscaling alone and / or temporal downscaling alone does not serve the purpose of precipitation downscaling because of space-time scale complexities of precipitation structure.
  - ✓ Types of precipitation, geo-climatic regimes and elevation correlations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

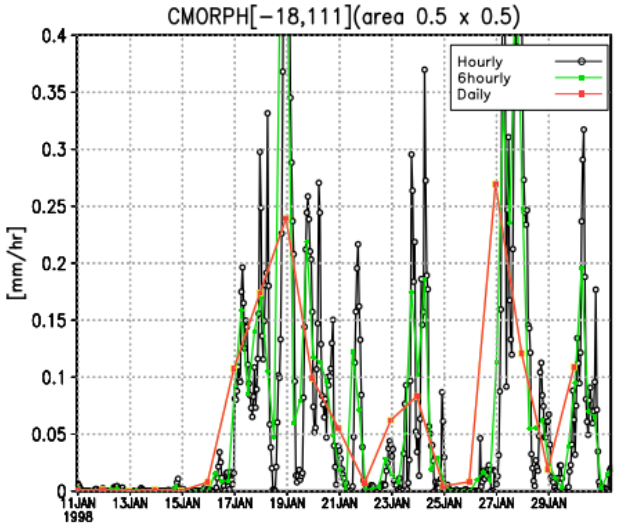


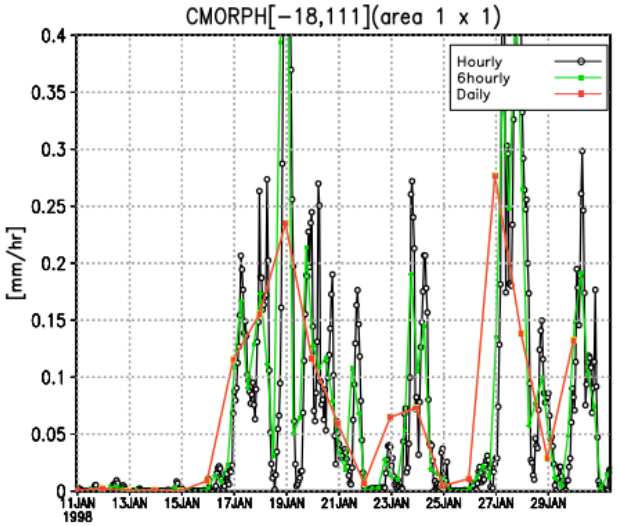
  - ✓ Transferring data into multiple scales with appropriate scaling relations
  - ✓ Looking for scale invariant descriptions and limits of scaling relationships
- Motivation
  - ✓ Choose descriptive scales that minimize complexity but retain integrity
  - ✓ Make use of coarse scale products in high resolution 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

Space-time scale sensitivity









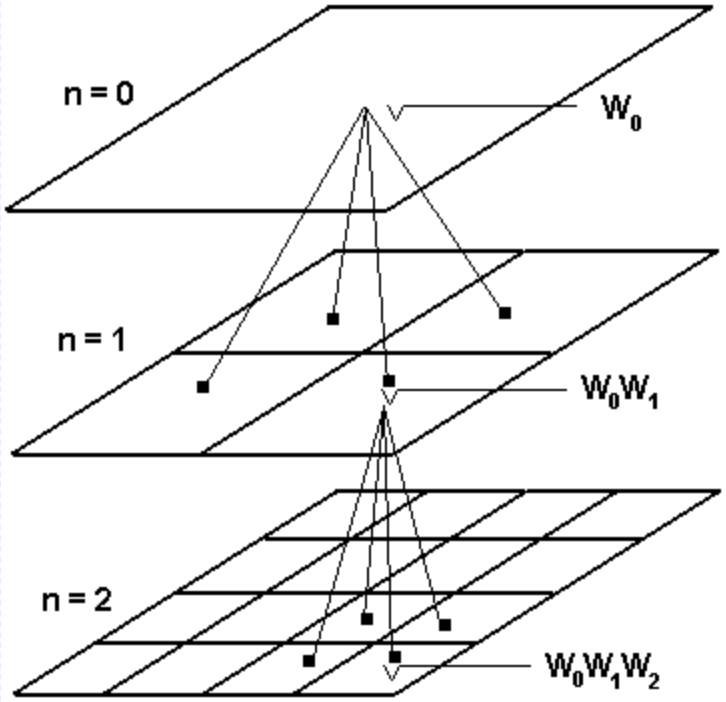
- The precipitation variability remains almost the same in a large spatial range but the variability changes rapidly in a small temporal range
- Regeneration of appropriate sub-grid scale variability is the main challenge.

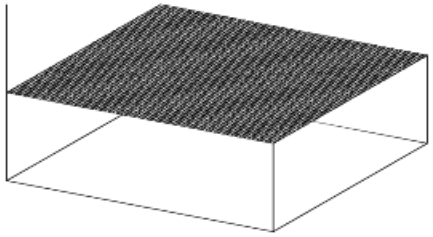
Multiplicative Random Cascade

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

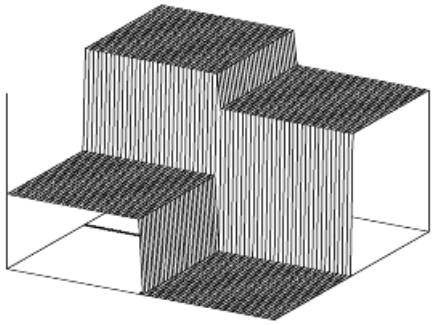
- Random Cascade Generator

$$\mu_n\left(\Delta_n^i\right) = R_o L_o^d b^{-n} \prod_{j=1}^{n} W_j^i$$

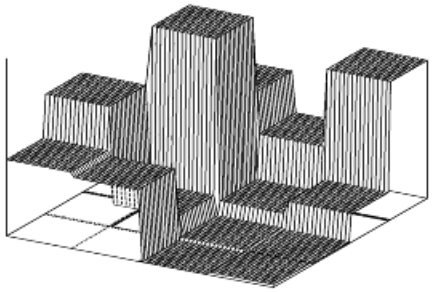




Level 0



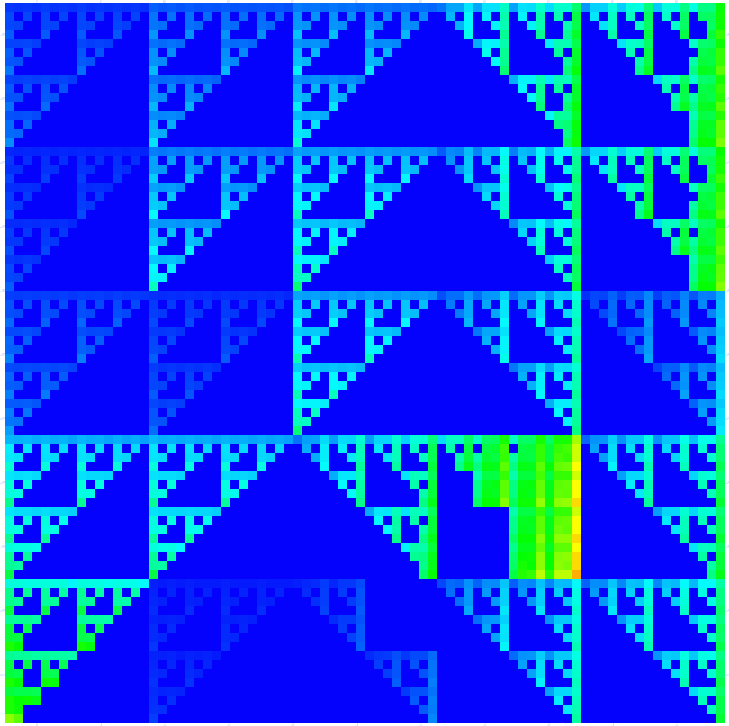
Level 1



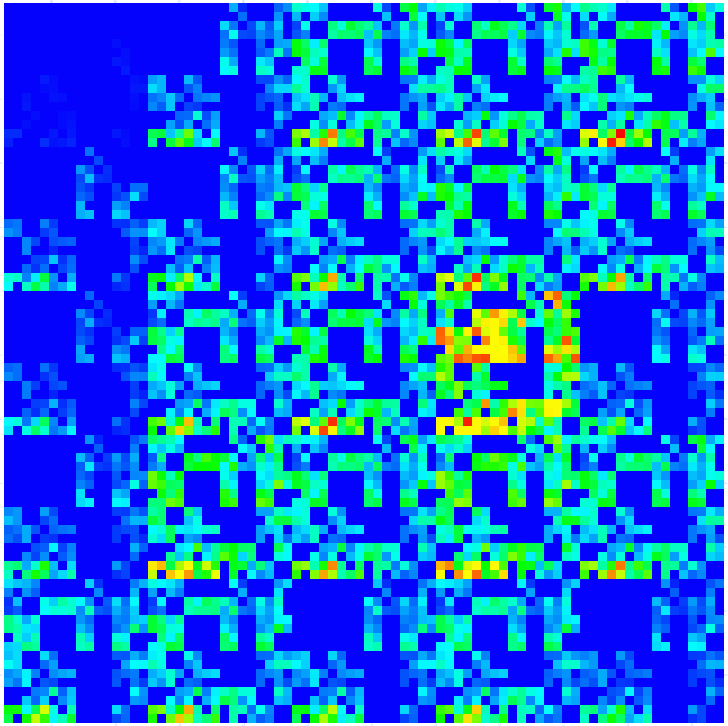
Level 2

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

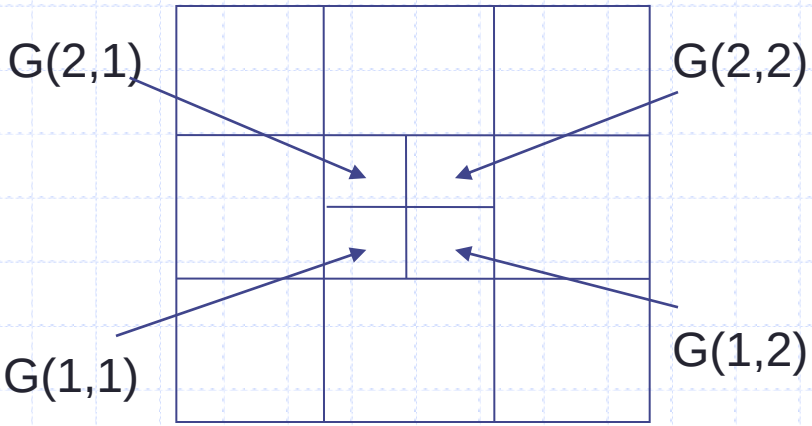
- High uncertainty due to
  - ✓ Incompatibility of sources (representativeness??)
  - ✓ Errors in measurement (bias ??)
  - ✓ Quality control (post processed or raw??)
  - ✓ Inconsistent coverage (gaps and uncovered zones??)

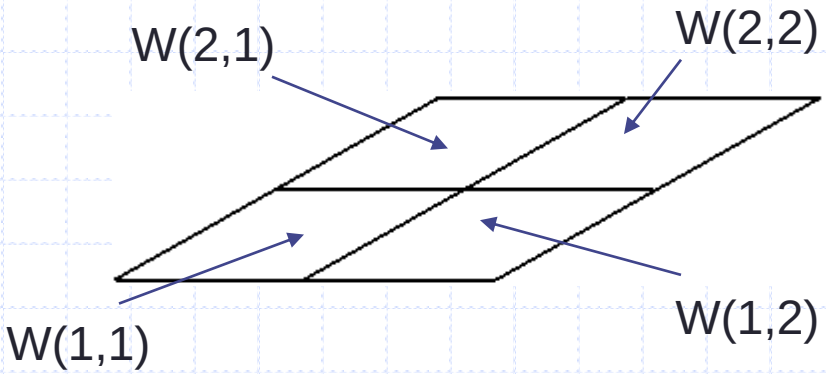
Re-arrangement of generators

Reference Matrix

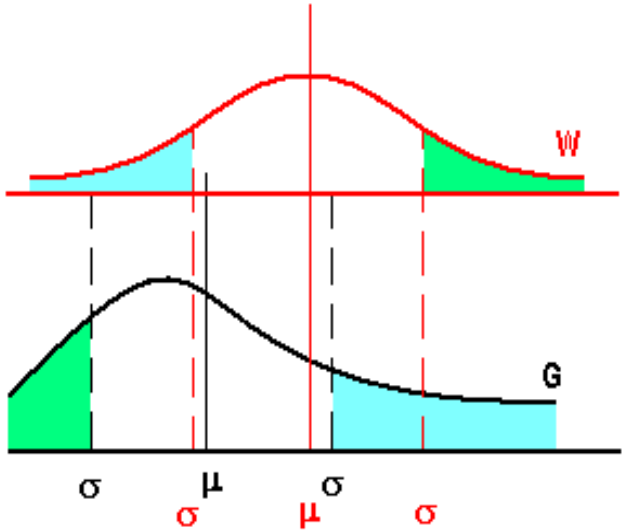
Look UP

Random Generators



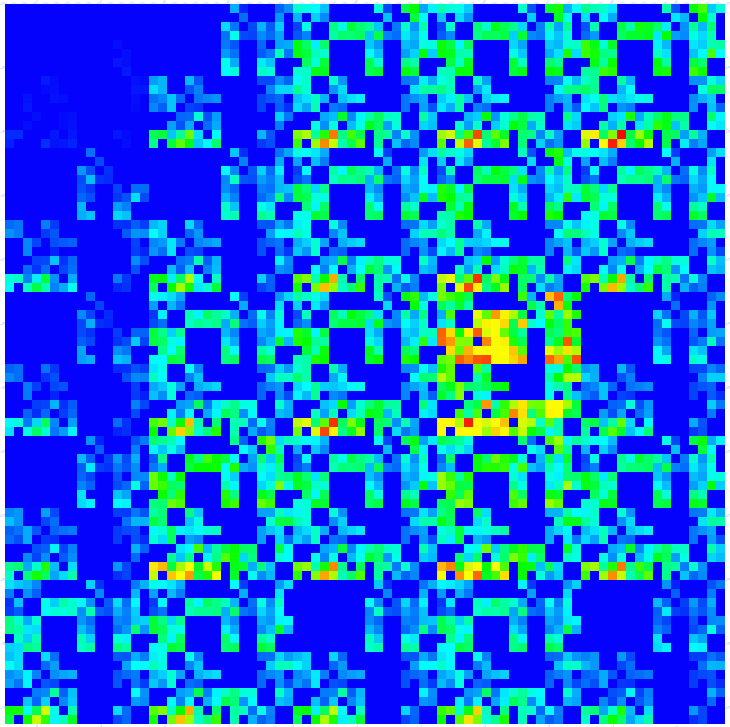


If the correlation of G-matrix and W-matrix is found poor, the W-matrix is allowed to re-position until it gets best correlation with G-matrix.

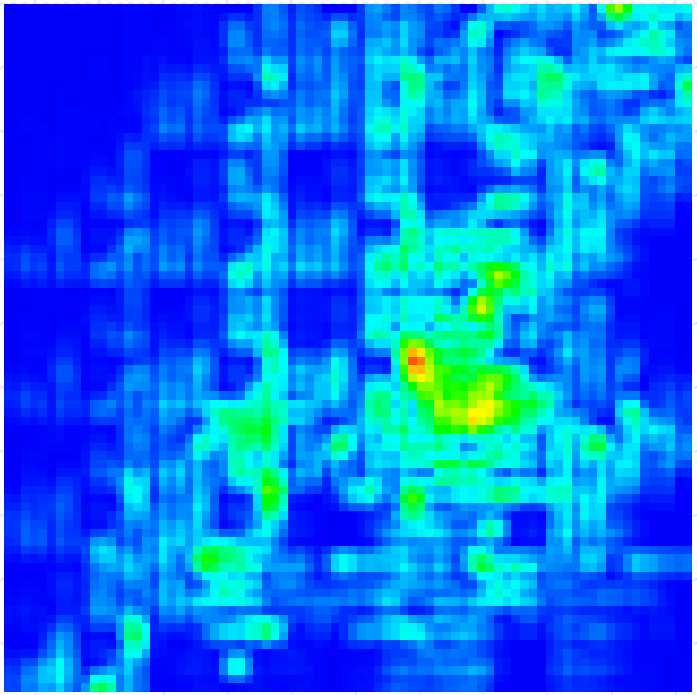


Results of RC HSA

- Spatially downscaled outputs are highly improved



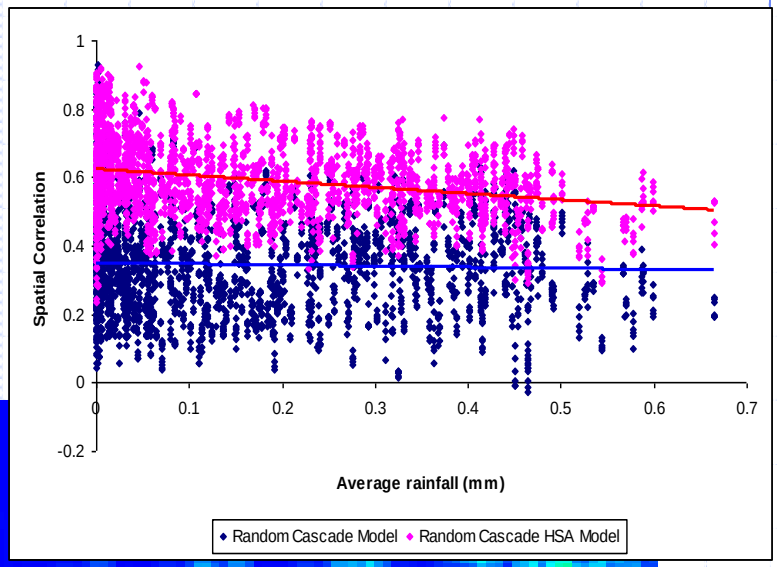
Random Cascade only

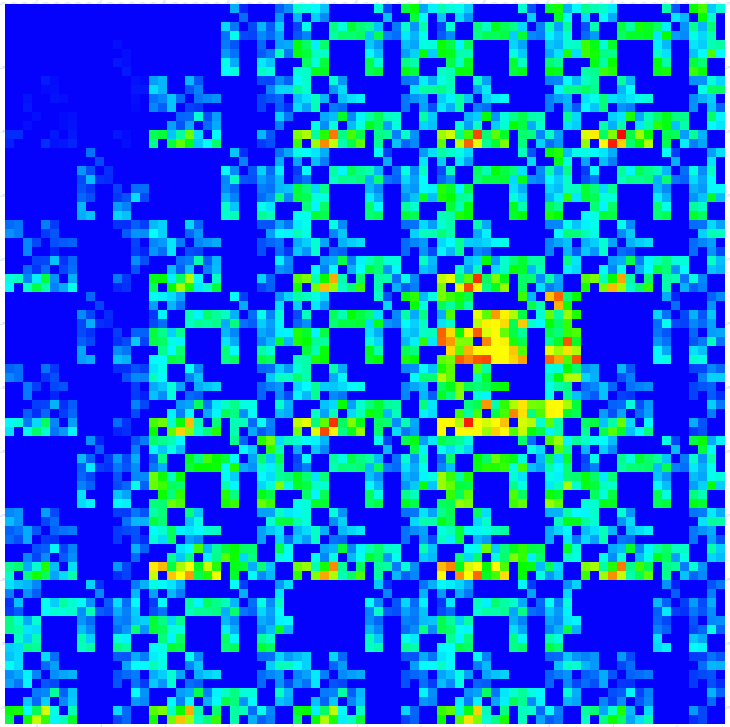


Random Cascade HSA

Results of RC HSA

- Spatially downscaled outputs are





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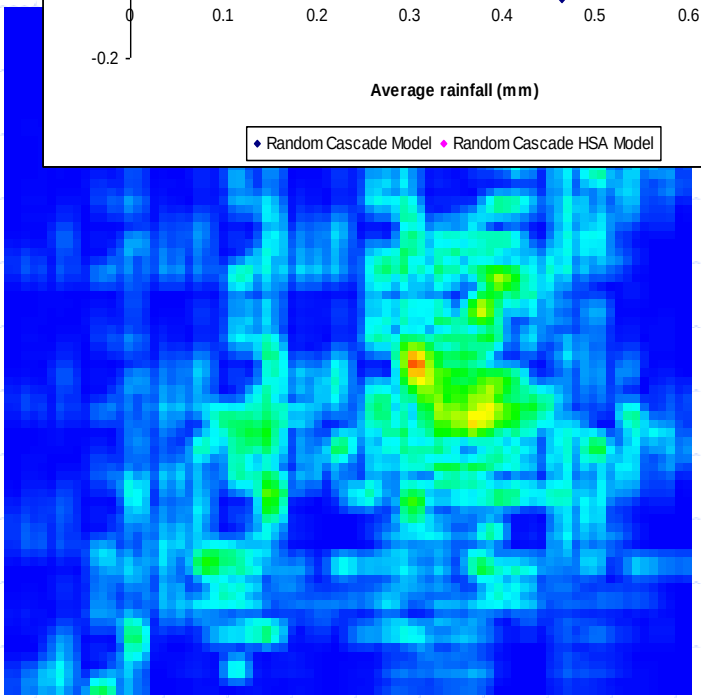
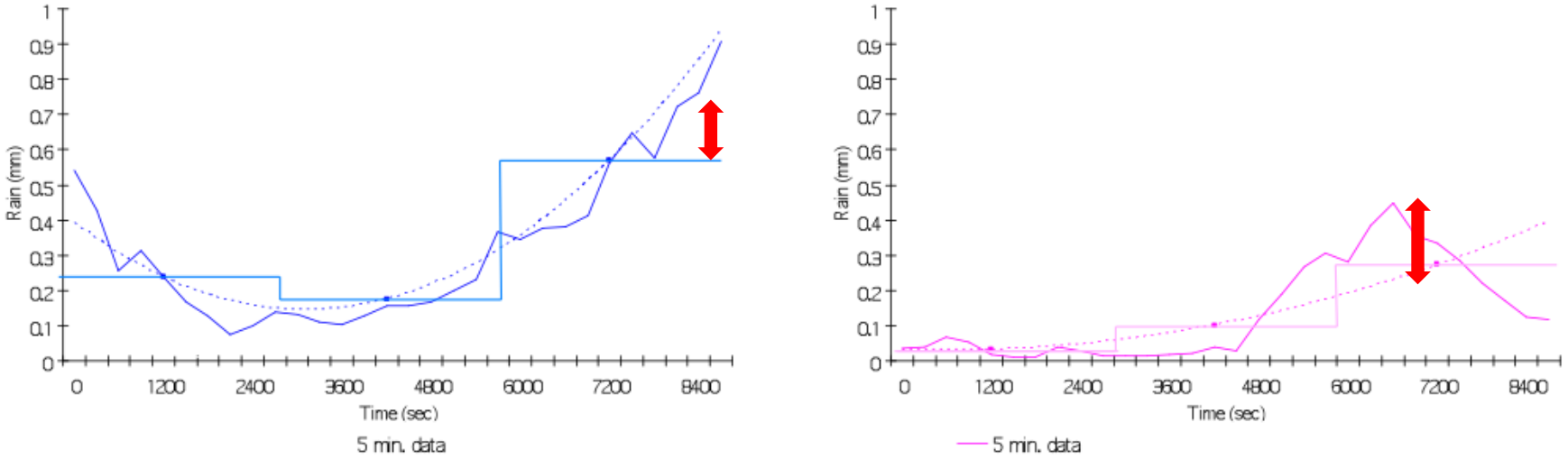


Random Cascade HSA

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

$$\frac{\partial z}{\partial t} + u\frac{\partial z}{\partial x} + v\frac{\partial z}{\partial y} = w$$

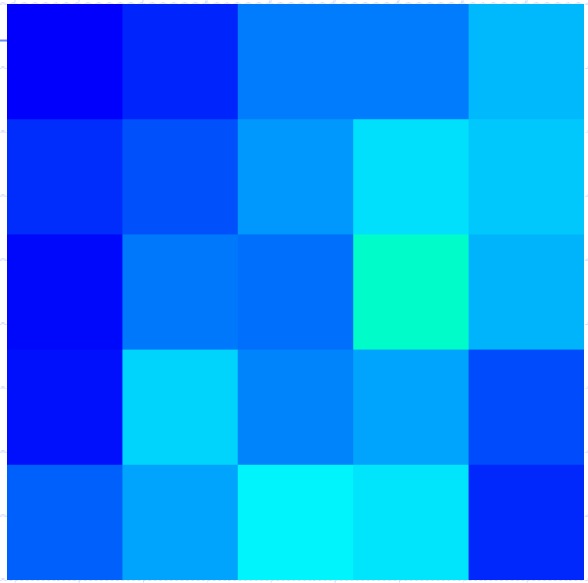
  - Advection vectors and parameters

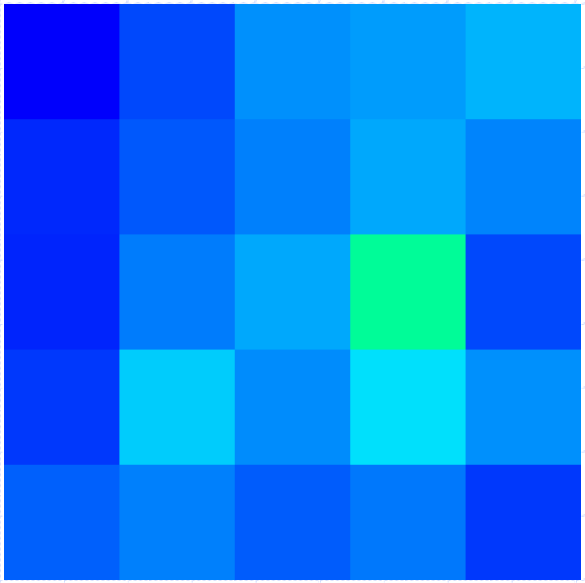
$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} C_1 & C_2 & C_3 \\ C_4 & C_5 & C_6 \\ C_7 & C_8 & C_9 \end{bmatrix} * \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

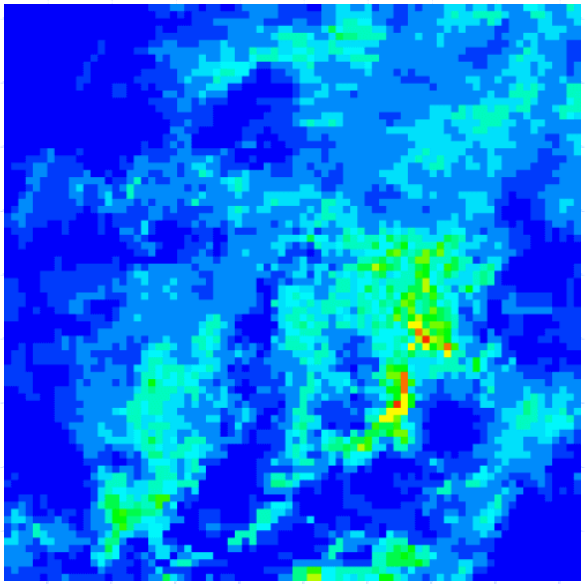
  - Translation mechanism

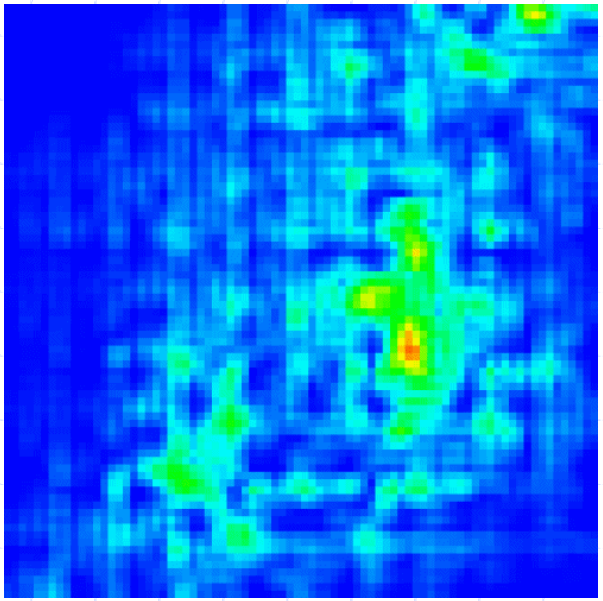
$$w = 0 \qquad C_7 = C_8 = C_9 = 0$$

Temporal Trends

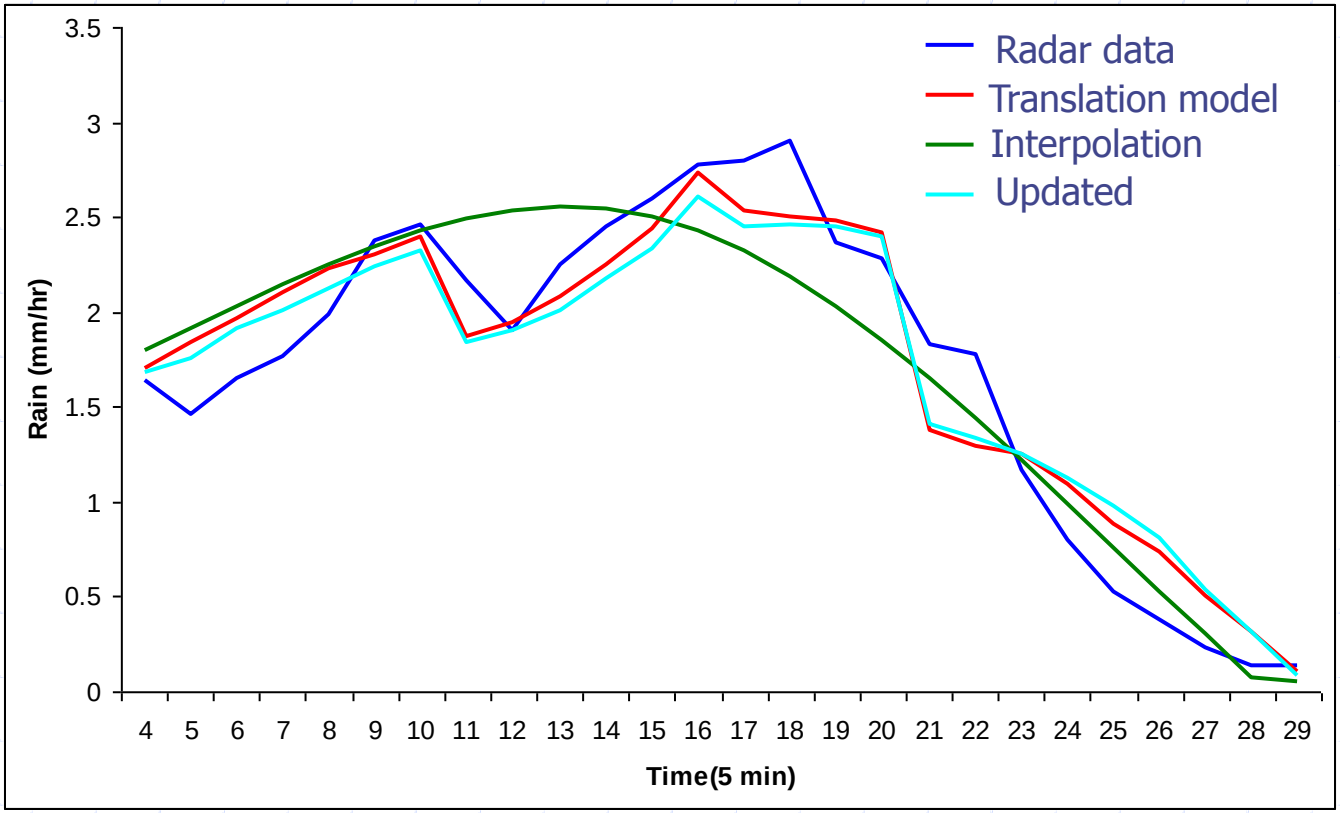






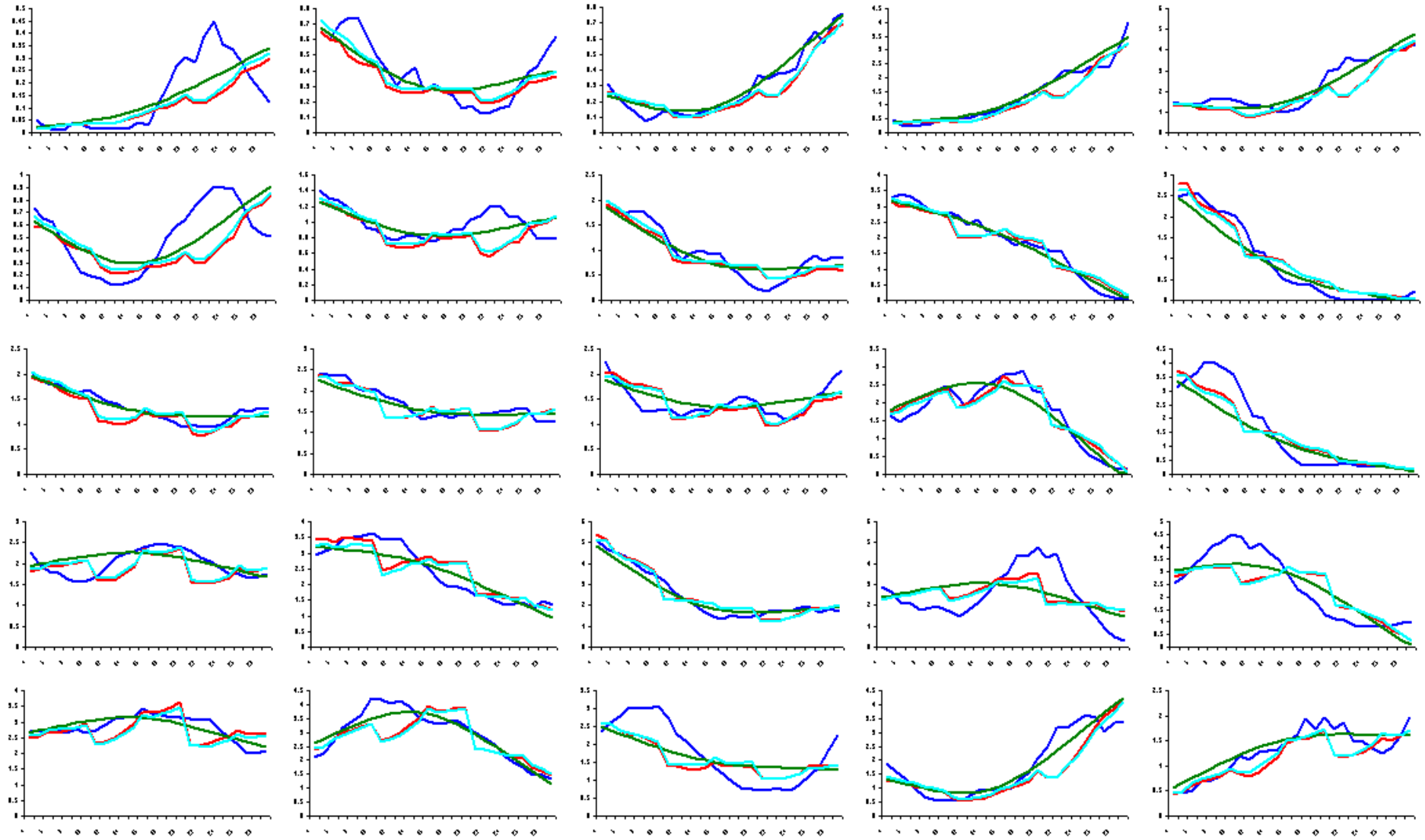


Results of Temporal downscaling



From 60 minute resolution to 5 minute resolution (48-km)

Results of Temporal downscaling



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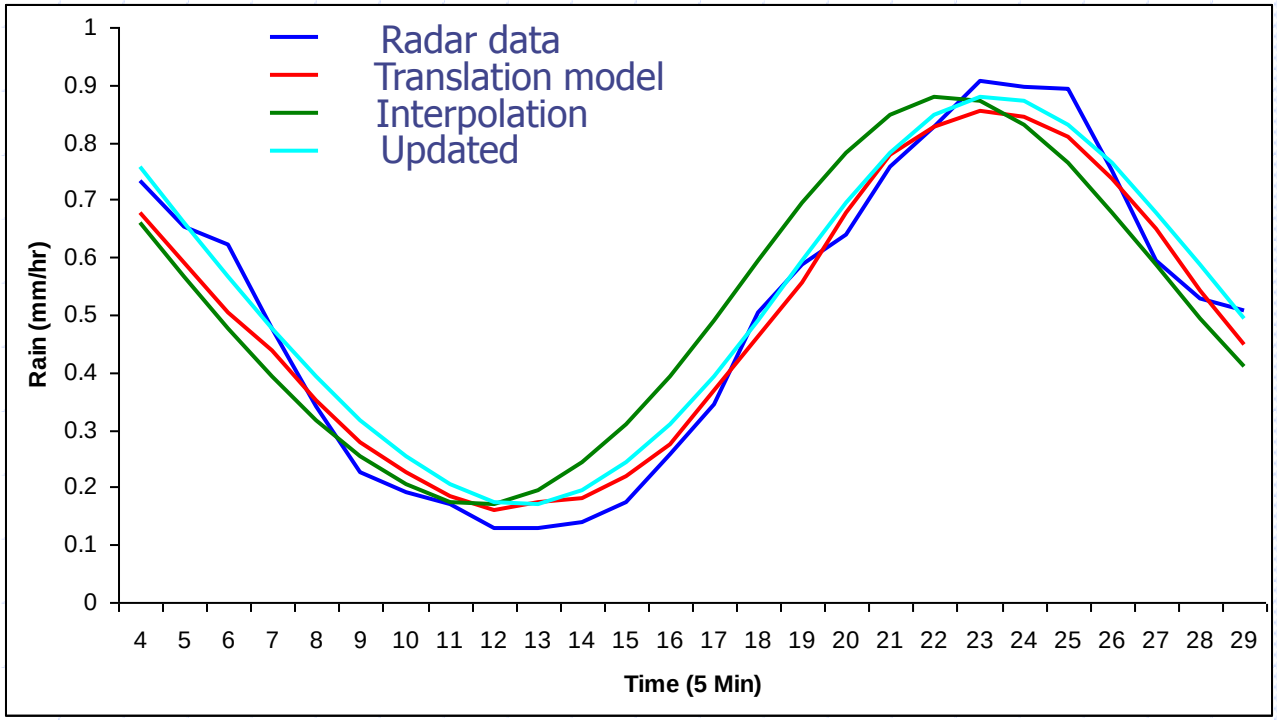

From 30 minute resolution to 5 minute resolution

Results of Temporal downscaling