Evaluation and Bias Adjustment of Multiple Satellite-based Precipitation Products over Complex Terrain

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1) Research Motivation & Study Objectives

- Reliable precipitation estimates are crucial for any hydrologic study
- Representation of high spatio-temporal variability in precipitation using rain gauges is challenging specifically over complex terrain
- Satellite-based precipitation (SBP) products - with quasi-global coverage and high resolution – are potentially attractive for hydrologic studies over complex terrain
- However SBP products has limitations, requiring bias adjustment or merging procedure with other sources to improve accuracy

Study objectives

1) Evaluate the performance of SBP products against rain gauges over Batı Karadeniz Region, Turkey which is characterized by complex terrain (Fig. 1)
2) Devise a bias adjustment algorithm for SBP products based on the concept of "physiographic similarity" and evaluate its performance

2) Data Sets

Rain Gauge

Meteorological stations operated by the Turkish State Meteorological Service (TSMS)

- 25 AWOS type (hourly rainfall)
- 14 pluviometer type (rainfall at 7h, 14h, 21h in a day)

TMPA (Huffman et al. 2007; 2012)

Spatial resolution: 0.25° x 0.25° Temporal resolution: 3 hourly

There are two TMPA products:
(1) real-time monitoring product (satellite-only) (TMPA-RT)
(2) research product – monthly rain gauge correction (TMPA-v7)

CMORPH (Joyce et al. 2004)

Spatial resolution: 0.25° x 0.25° Temporal resolution: 3 hourly

EUMETSAT MPE (Heinemann 2003)

Spatial resolution: 4 km x 4 km Temporal resolution: 15 min

Rain gauge-based Gridded Rainfall Dataset

The procedure for gridded rainfall estimation is based on Precipitation-elevation Regressions on Independent Slopes Model (PRISM, Daly et al, 2008) which incorporates the Influence of complex topography with the help of physiographic descriptors in the rainfall estimation. Climate-elevation regression function given by:

$$Y = \beta_1 * X + \beta_0 \quad \text{(Eqn. 1)}$$

Y = predicted precipitation
β_1 = regression slope
β_0 = regression intercept
X = DEM elevation at target cell

Based on physiographic similarity between the observed and estimated station/grid each station is assigned weights. The combined weight W of a station is a function of the following set of physiographic descriptors :

$$W = [F_d * (W_d)^2 + F_Z * (W_z)^2]^{1/2} * W_p * W_f * W_e \quad \text{(Eqn. 2)}$$

F_d = distance weighting importance factor
F_z = elevation weighting importance factor
W_d = distance weight
W_z = elevation weight
W_p = coastal proximity weight
W_f = facet weight
W_e = effective terrain weight

Physiographic descriptors are based on a set of region dependent parameters. In this study, these parameters are selected via an optimization procedure (The Shuffled Complex Evaluation algorithm) which minimizes MSE function between observed and estimated monthly precipitation values at rain gauge locations.

These parameters are estimated separately for each region and for each season (winter, spring, summer, autumn).

Rain gauge-based Gridded Rainfall Dataset has a spatial resolution of 0.05°X0.05°, these grids are box averaged to 0.25°X0.25° for comparison (Fig. 2).

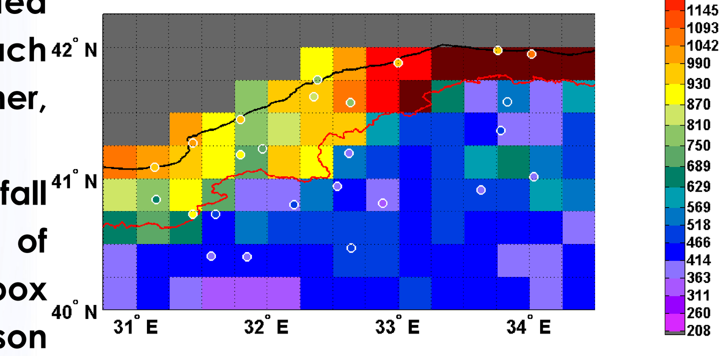


Fig. 2. 5 year (2007-2011) mean annual precipitation estimates obtained by raingauge-based gridded dataset (0.25° x0.25°).

3) Evaluation of the SBP Products

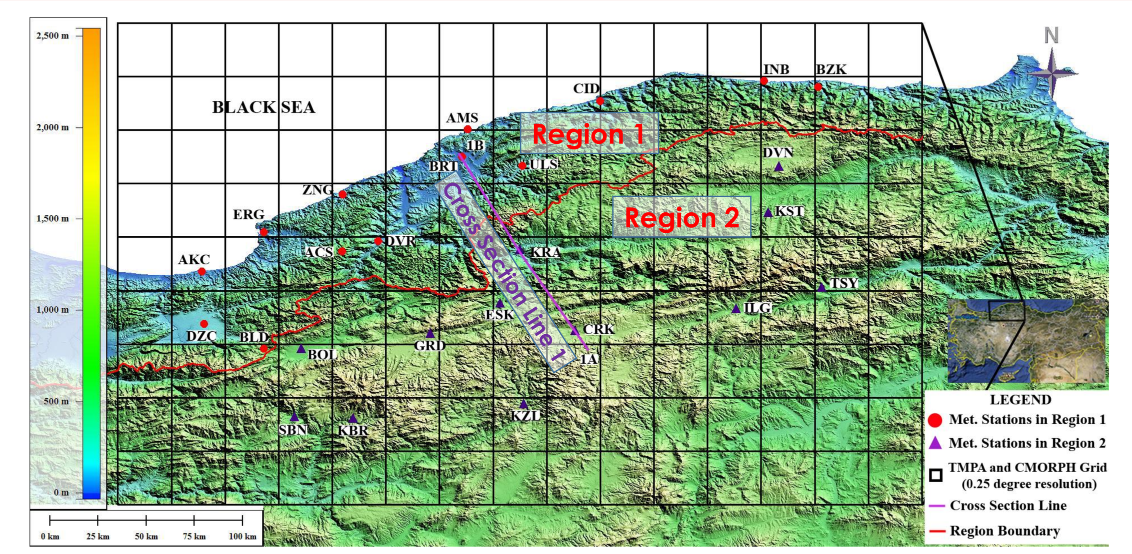


Figure 1. Study Area.

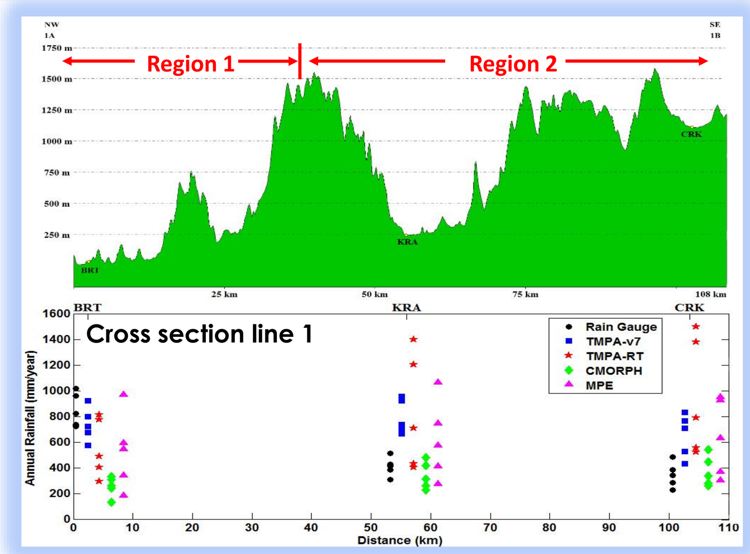


Figure 3. Elevation profile and annual rainfall along Cross Section-1

- Region 1 (along the coast, windward side of the mountains, Mid-latitude Humid Temperate Climate, orographic rainfall)
- Region 2 (inland, leeward side of the mountains, Dry/Sub-humid Continental Climate)
- TMPA-v7, TMPA-RT, MPE underestimate rainfall in Region 1 and overestimate rainfall in Region 2 (Fig. 3) regardless of the season. CMORPH underestimate rainfall in both regions regardless of the season.
- TMPA-v7 performance superior compared to satellite-only SBP products in terms of CORR and NRMSE statistics possibly due to monthly correction. However its performance is similar to TMPA-RT at the daily time scale (Fig. 4 & Fig. 5)
- CMORPH shows best CORR statistic in Region 2 during both seasons and produced lowest NRMSE statistic (less than 2mm/day) in both regions during cold season (Fig. 5).
- MPE shows the lowest performance in terms of CORR and NRMSE statistics.

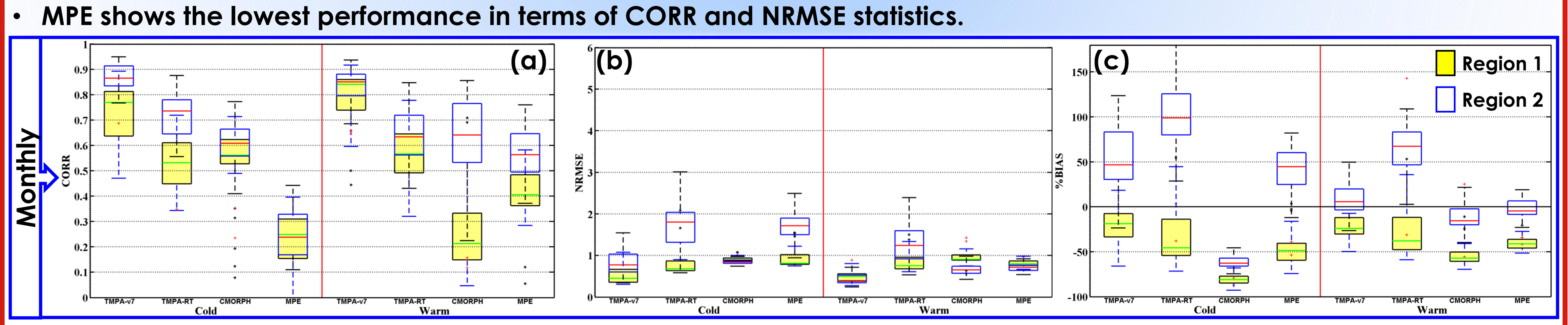


Figure 4. Box plots showing monthly statistical results (a) CORR, (b) NRMSE and (c) %BIAS for rain gauge-based gridded rainfall dataset grids and their corresponding co-located SBP product grids.

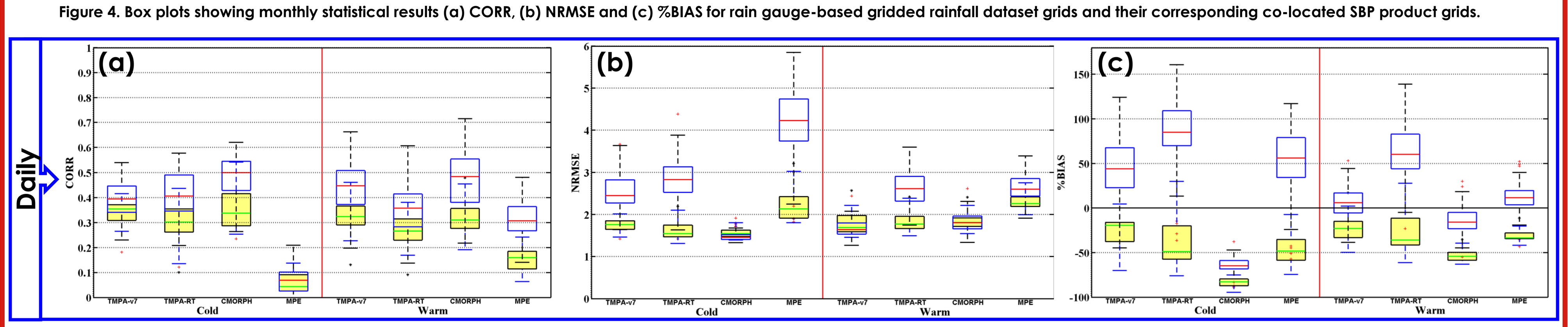


Figure 5. Box plots showing daily statistical results (a) CORR, (b) NRMSE and (c) %BIAS for rain gauge-based gridded rainfall dataset grids and their corresponding co-located SBP product grids.

4) Bias Adjustment of the SBP Products

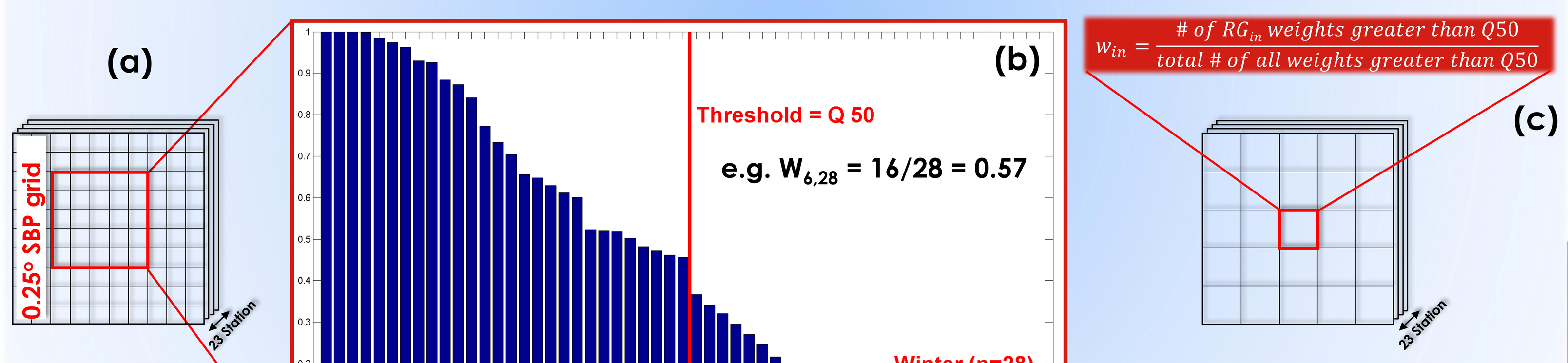
Bias Adjustment Based on Physiographic Similarity (BAPS):

- Utilizes "physiographic similarity" concept which is better suited to regions characterized by complex terrain compared to the commonly employed 'proximity concept',
- Rain gauges located in physiographically similar regions are assigned higher weights rather than the rain gauges in proximity

Methodology:

For each 0.25° satellite-only SBP grid, precipitation is adjusted based on *weighted* difference between precipitation estimates from rain gauges and their co-located SBP grids. The *weights* are calculated as follows:

- Select the 0.05° PRISM grids within the 0.25° SBP grid (Fig. 6a),
- Group and sort the weights of each rain gauge used in the PRISM estimation for the selected PRISM grids (Fig. 6b)
- Select a PRISM weight threshold (50th quantile [Q50] in this case), and assign bias-adjustment weights (w_{in}) to each rain gage based on the frequency of its occurrence within Q50.
- Bias used in SBP product adjustment is the weighted (w_{in}) difference between rain gauges and their co-located SBP grids (Eqn. 3 & Eqn. 4)



$$w_{in} = \frac{\#\ of\ RG_{in}\ weights\ greater\ than\ Q50}{total\ \#\ of\ all\ weights\ greater\ than\ Q50}$$

n = selected SBP grid (0.25°)
W_{in} = weight of rain gauge i for grid n
M = total number of rain gauges (23)

Figure 6. Bias adjustment methodology

$$Bias_n = \sum_{i=1}^{M} w_{in}(RG_i - SBP_i) \quad \text{(Eqn. 3)}$$

$$Adjusted\ SBP_n = SBP_n + Bias_n \quad \text{(Eqn. 4)}$$

Validation of the Bias Adjustment Algorithm

- Validation is performed using two independent stations ZNG (Region 1) and BOL (Region 2)
- Bias adjustment using Inverse Distance Weighted (IDW) approach was used as a 'benchmark'
- For Station ZNG in Region 1, BAPS algorithm generally provided better precipitation estimates compared to IDW method, specifically in cold season (Fig. 7a).
- For Station BOL in Region 2, BAPS algorithm outperforms IDW method. IDW suffers from poor %Bias and NRMSE values while providing better CORR statistics compared to BAPS (Fig. 7b).

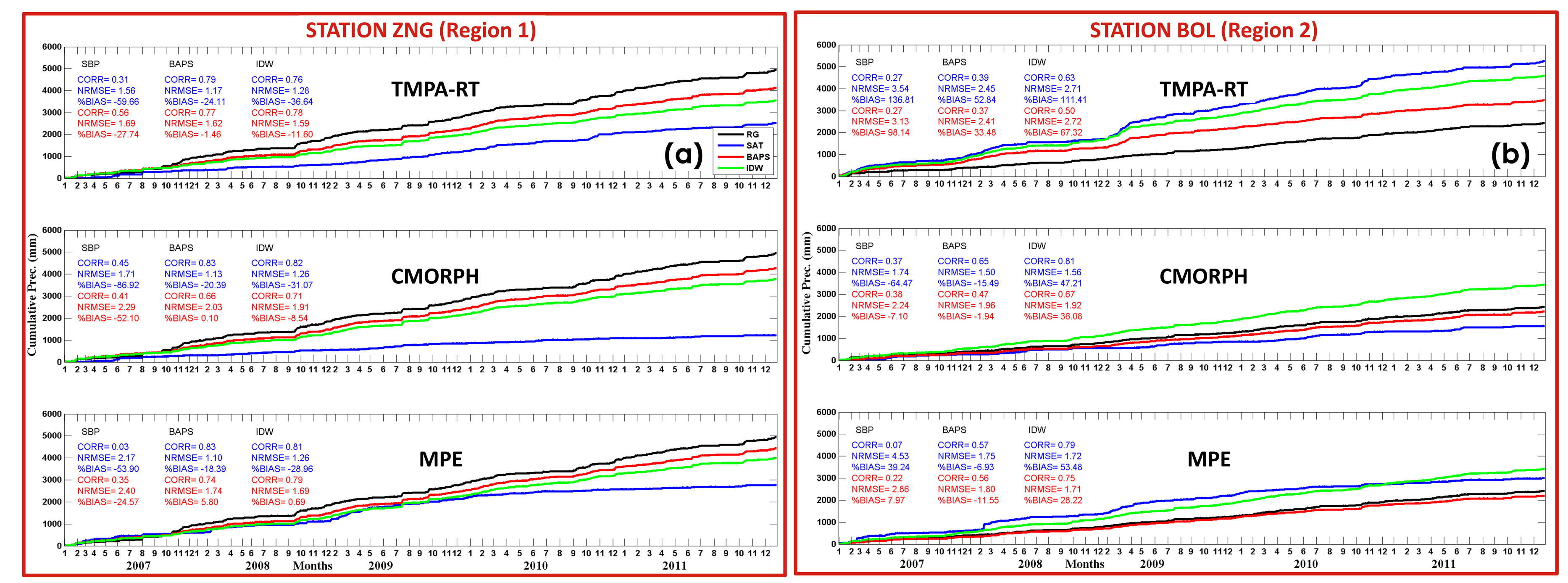


Figure 7. Cumulative precipitation of independent rain gauge stations ZNG (a) and BOL (b), satellite-only SBP products and bias adjusted SBP products. Note that statistics in red represent warm season and blue represent cold season.

- Comparing bias adjusted SBP product grids with their co-located rain gauge-based gridded dataset grids at the daily time-scale (Fig. 8):
  - Bias adjusted SBP products agree well with the rain gauge based gridded precipitation products with high CORR, low NRMSE and favorable %Bias statistics, specifically in Region 1
  - Bias adjustment procedure seems to perform better during cold season and in Region 1, due respectively to less convective rainfall occurrence and higher density of rain gauges.

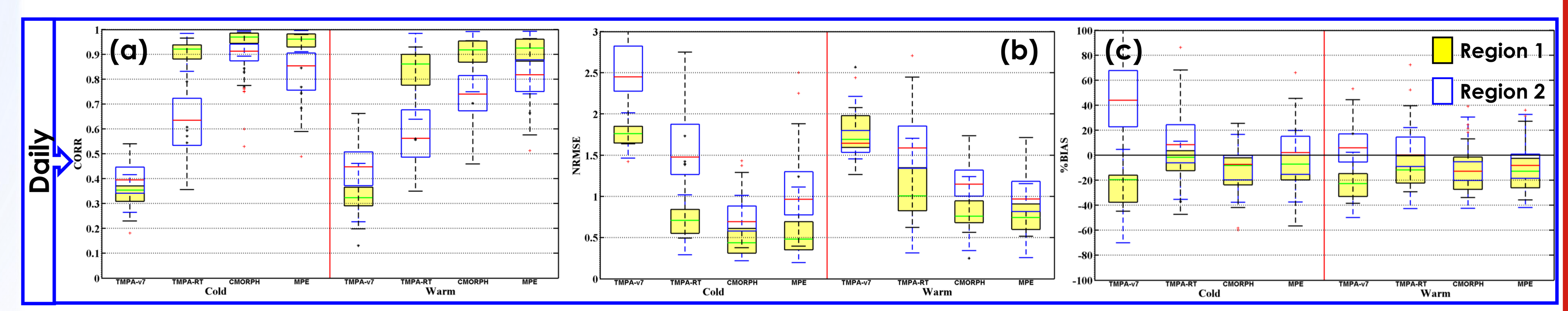


Figure 8. Box plots showing daily statistical results (a) CORR, (b) NRMSE and (c) %BIAS for Bias adjusted SBP product grids and their co-located for rain gauge-based gridded dataset grids. Note that TMPA-v7 is not corrected using the BAPS algorithm.

5) Conclusions

- Complex topography in the study area results in a strong N-S rainfall gradient characterized by orographic precipitation.
- All tested SBP products significantly underestimated the precipitation in Region 1 (North) characterized by orographic precip.
- TMPA-v7 provided superior performance compared to satellite-only SBP products in terms of CORR and NRMSE statistics due to the monthly correction procedure incorporated in its development.
- TMPAv7, TMPA-RT and MPE products significantly overestimate precipitation in Region 2 (South, drier) while CMORPH outperforms all SBP products (especially in cold season) in Region 2 with slight underestimation. High CMORPH performance in cold season in Region 2 could be attributed to the surface snow and ice screening process embedded in the algorithm.
- The proposed bias adjustment algorithm based on 'Physiographic similarity' (BAPS) is better suited to complex regions and generally provided better results compared to the benchmark 'Inverse Distance Weighted' method. Inability of BAPS in improving CORR statistic is currently being investigated.
- As a natural extension of this work, the precipitation datasets will be used to drive a hydrologic model. The streamflow observations will then be used as an independent observation to evaluate the performance of SBP products.

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References

- Daly, C., Halbleib, M., Smith, J. I., Gibson, W. P., Doggett, M. K., Taylor, G. H., Curtis, J., & Pasteris, P. P. (2008). Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous united states. International Journal of Climatology, doi: 10.1002/joc.1688
- Heinemann, T. (2003). The EUMETSAT Multi Sensor Precipitation Estimate (MPE): Concept and validation. Retrieved from EUMETSAT website: http://www.eumetsat.int/groups/ops/documents/document/mpe_conceptvalidation_uc2003.pdf
- Huffman, G. J., Adler, R. F., Bolvin, D. T., Gu, G., Nelkin, E. J., Bowman, K. P., Hong, Y., & Stocker, E. F. (2007). The TRMM Multisatellite Precipitation Analysis (TMPA): Quasi-global, multiyear, combined-sensor precipitation estimates at fine scales. *Journal of Hydrometeorology*, 8, 38-55. doi: 10.1175/JHM560.1
- Huffman, G. J., & Bolvin, D. T. (2012). TRMM and other data precipitation data set documentation. Retrieved from Mesoscale Atmospheric Processes Laboratory, NASA Goddard Space Flight Center and Science Systems and Applications, Inc.
- Joyce, J. R., E. J. Janowiak, P. A. Arkin, and P. Xie, 2004: CMORPH: A method that produces global precipitation estimates from passive microwave and infrared data at high spatial and temporal resolution. J. Hydrometeor., 5, 487–503