Characterizing the spatiotemporal distribution of snow in the High Mountain Asia

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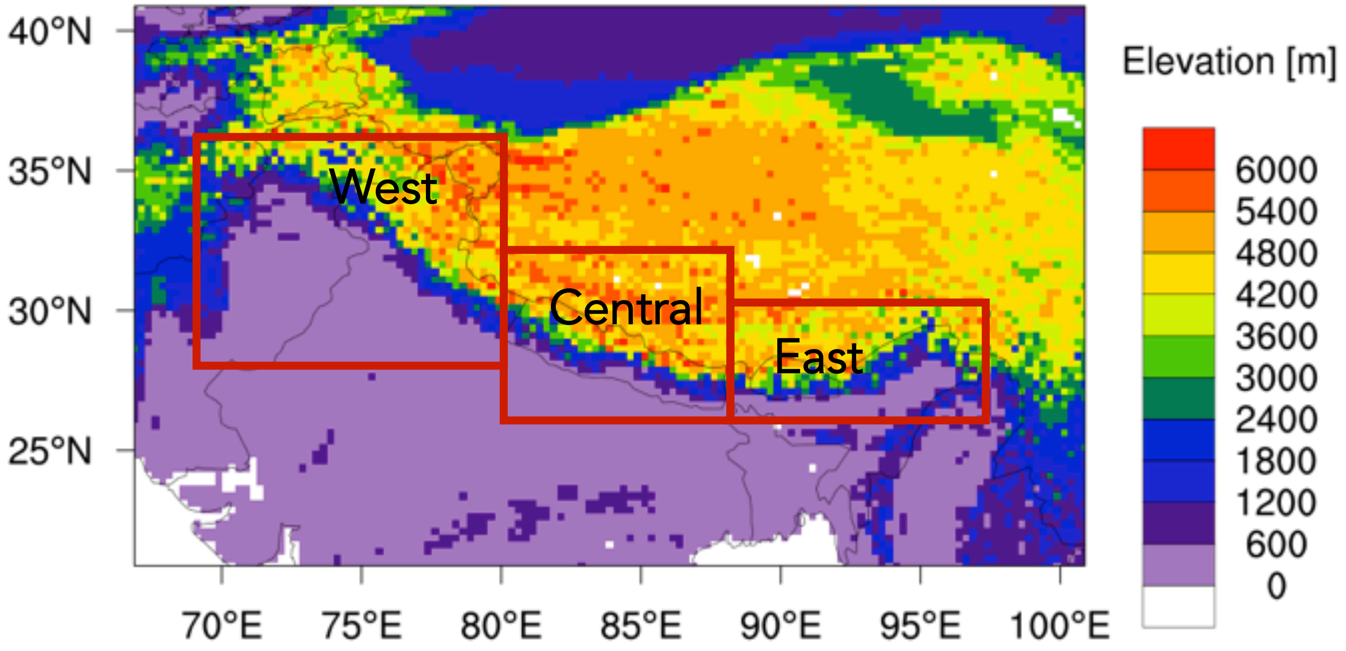
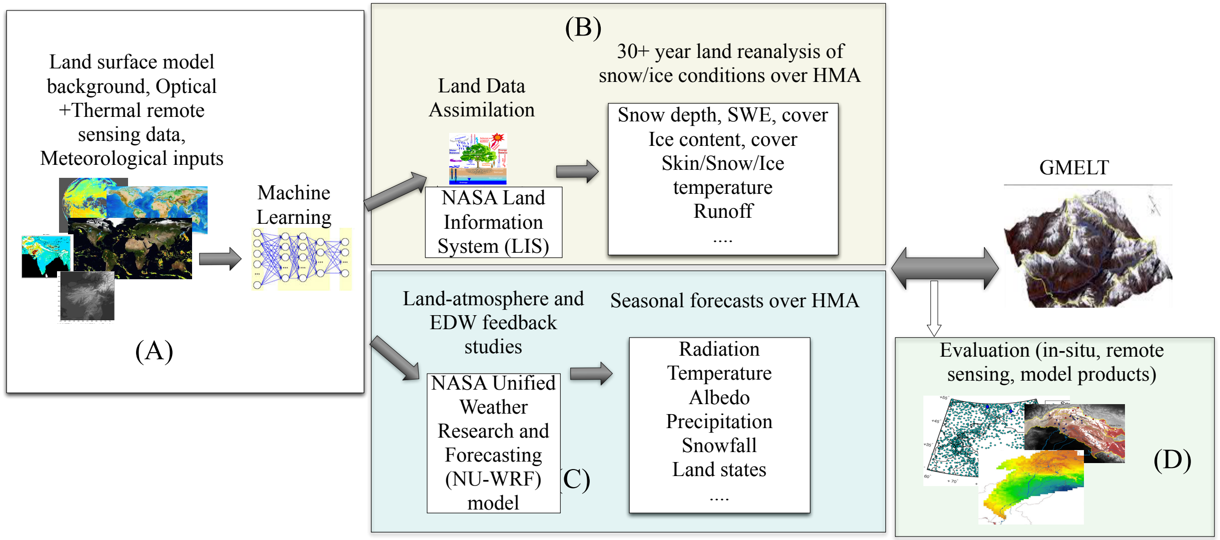
Background



- The melting of snow and glaciers in the HMA provides the water needs of approximately 1.3 billion people in the region.
- Increasing temperatures have large effects on the hydrologic cycle, influencing snowmelt, snowpack, and streamflow, which can impact many aspects of water security.
- However, meteorological stations are relatively sparse in HMA due to complex terrain.
- Precipitation can vary strongly over short horizontal distances due to orographic effects but high-altitude precipitation gauge networks are almost non-existent.
- Through the NASA HiMAT project, we attempt to quantify the regional water balance over HMA using land surface modeling and data assimilation.

Key goals

- Focus on the evaluation of modeling inputs (precipitation) and outputs (terrestrial water balance terms) towards quantifying the uncertainties in the water balance over HMA.
- Use direct and indirect evaluations to compare and quantify the uncertainties in the modeled estimates of land surface water balance.
- Model simulations are conducted using the NASA Land Information System (LIS; lis.gsfc.nasa.gov) and evaluations using the Land surface Verfication Toolkit (LVT).



Land surface model background, Optical +Thermal remote sensing data, Meteorological inputs

Machine Learning

(A)

(B)

Land Data Assimilation

NASA Land Information System (LIS)

30+ year land reanalysis of snow/ice conditions over HMA

Snow depth, SWE, cover
Ice content, cover
Skin/Snow/Ice temperature
Runoff
....

Land-atmosphere and EDW feedback studies

NASA Unified Weather Research and Forecasting (NU-WRF) model

C)

Seasonal forecasts over HMA

Radiation
Temperature
Albedo
Precipitation
Snowfall
Land states
....

GMELT

Evaluation (in-situ, remote sensing, model products)

(D)

Approach

- Using LIS, a suite of model runs with three different LSMs (Noah33, NoahMP and Catchment) with two forcing inputs (MERRA2 corrected and uncorrected precipitation), over the entire HMA at 0.25 deg resolution was conducted (2000-2017).
- Hydrological (streamflow) simulations conducted with the HyMAP model.

$P - ET - Q = \Delta TWS$ [terrestrial water balance]

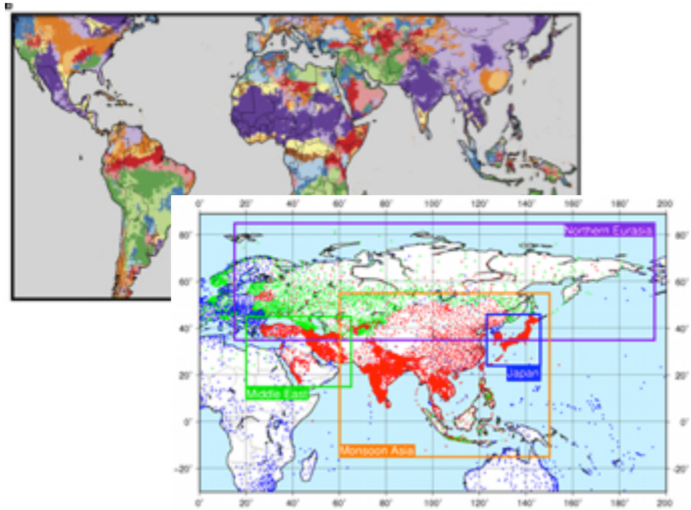
$\Delta TWS = \Delta GW + \Delta SM + \Delta SWE + \Delta SW$

P = precipitation
ET = evapotranspiration
Q = river discharge

ΔTWS = change in terrestrial water storage
ΔGW = change in groundwater storage
ΔSM = change in soil moisture
ΔSWE = change in snow water equivalent
ΔSW = change in surface water storage

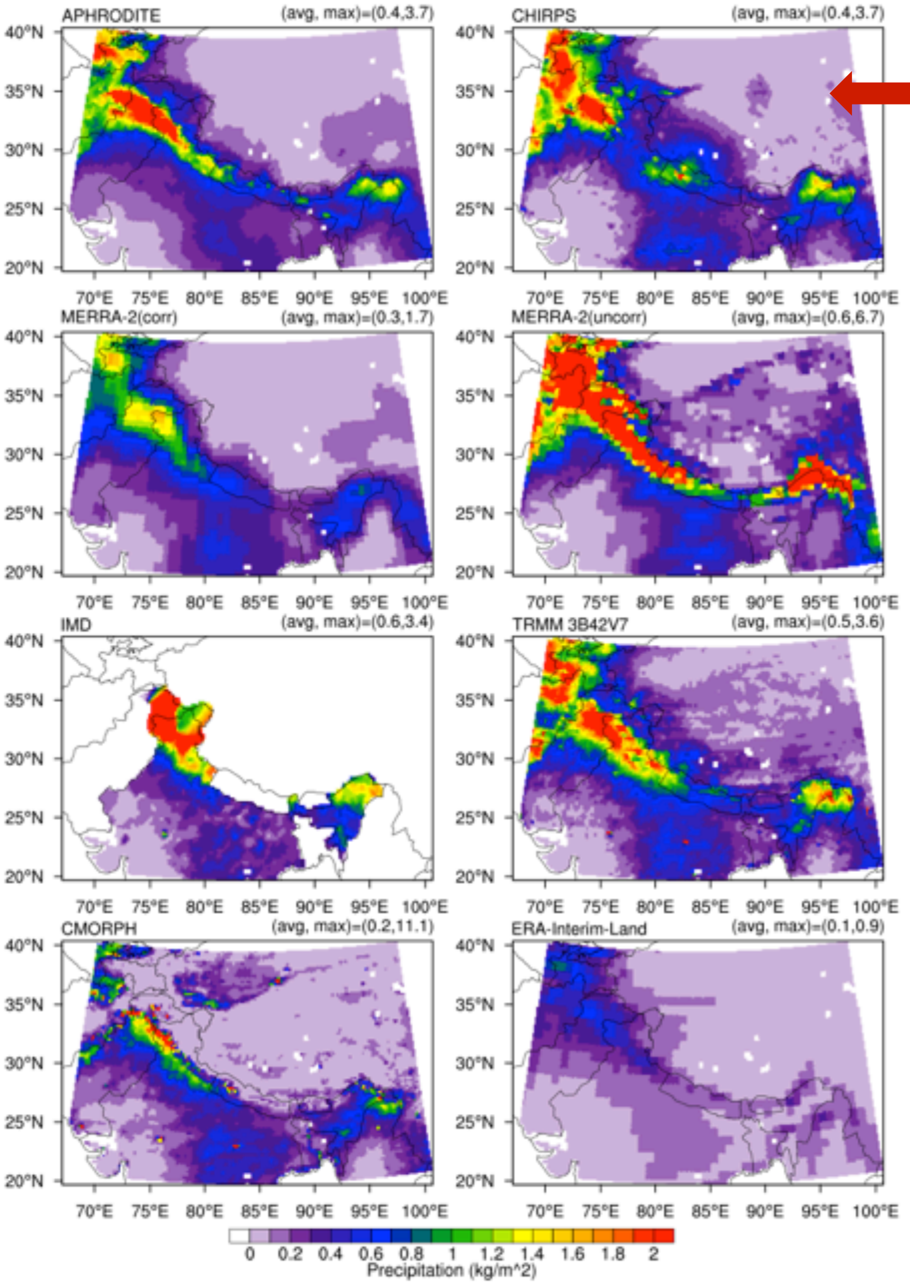
- Use available datasets to compare and quantify the uncertainties in the LIS-based estimates of water balance terms, using the Land surface Verification Toolkit (LVT)

Evaluation data



- Precipitation:
  - APHRODITE, IMD, CHIRPS
  - TRMM, CMORPH
  - MERRA2 (corrected, uncorrected), ERA-Interim-Land
- Evapotranspiration (ET):
  - ALEXI (Atmospheric Land Exchange Inverse Model): a thermal infrared based ET estimate
  - GLEAM (Global Land Evaporation Amsterdam Model): remote sensing-based; employs the priestly taylor approach
- Runoff
- Snow cover:
  - MODIS-based fractional snow cover estimates
- TWS:
  - Anomalies from the Gravity Recovery and Climate Experiment (GRACE)

Comparison of Precipitation seasonality

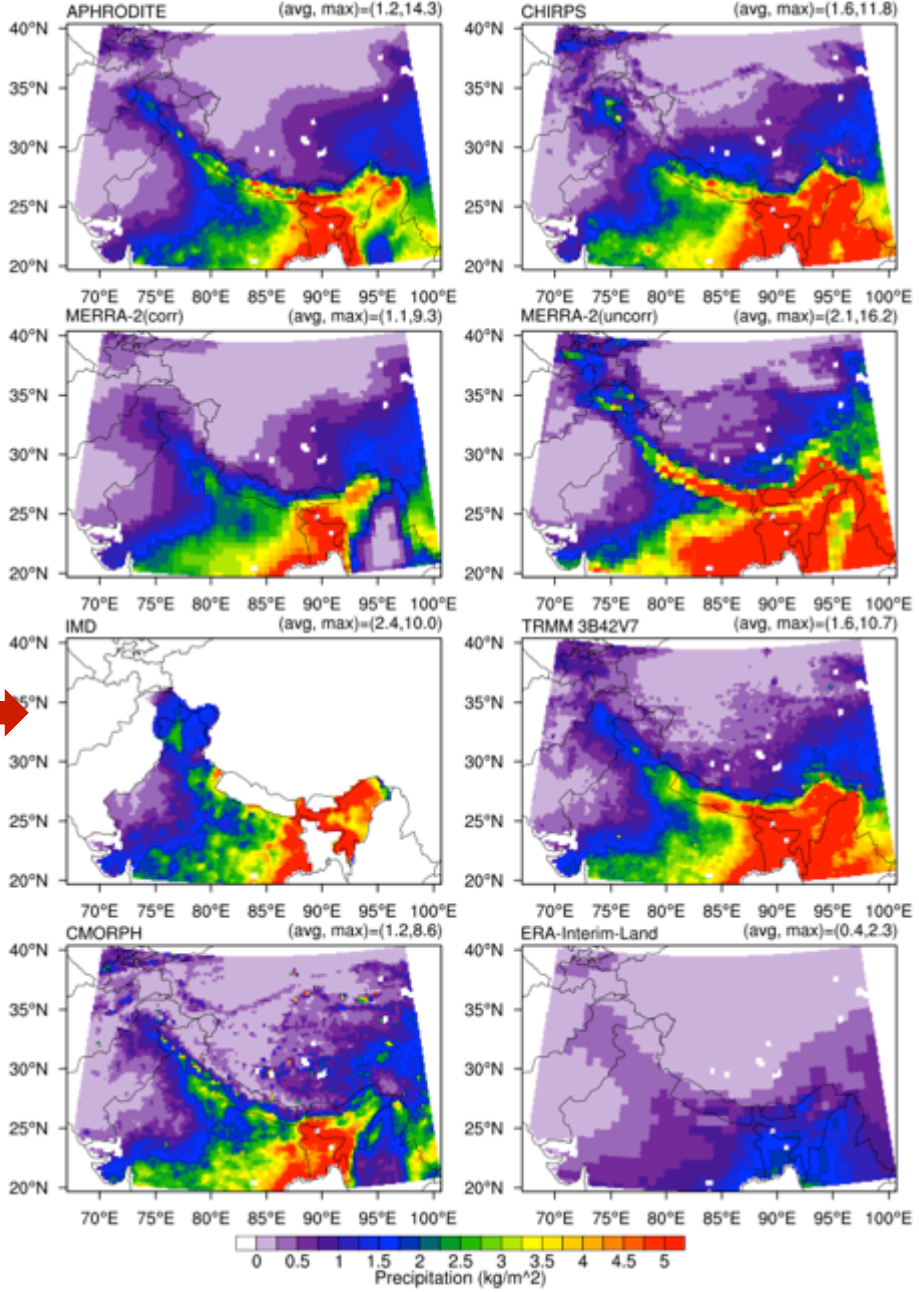


DJF

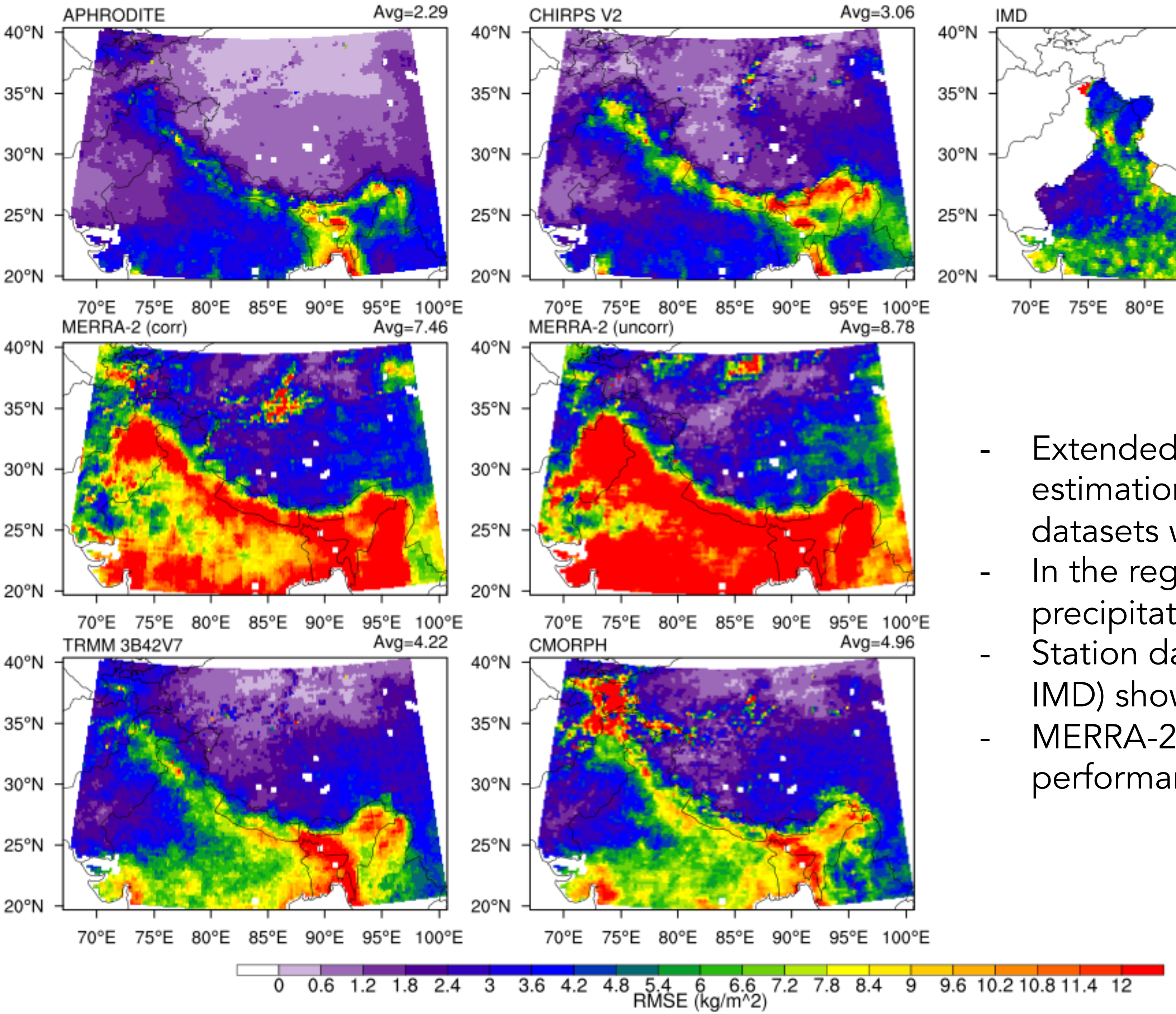
- Mostly snowfall affected by winter westerlies
- APHRODITE, CHIRPS, and TRMM show similar patterns, overall
- MERRA-2 uncorrected shows higher precipitation (snowfall) rate

JJA

- Mostly rainfall affected by Indian summer monsoon
- Spatial patterns of all precipitations are similar.
- MERRA-2 uncorrected shows higher precipitation rate

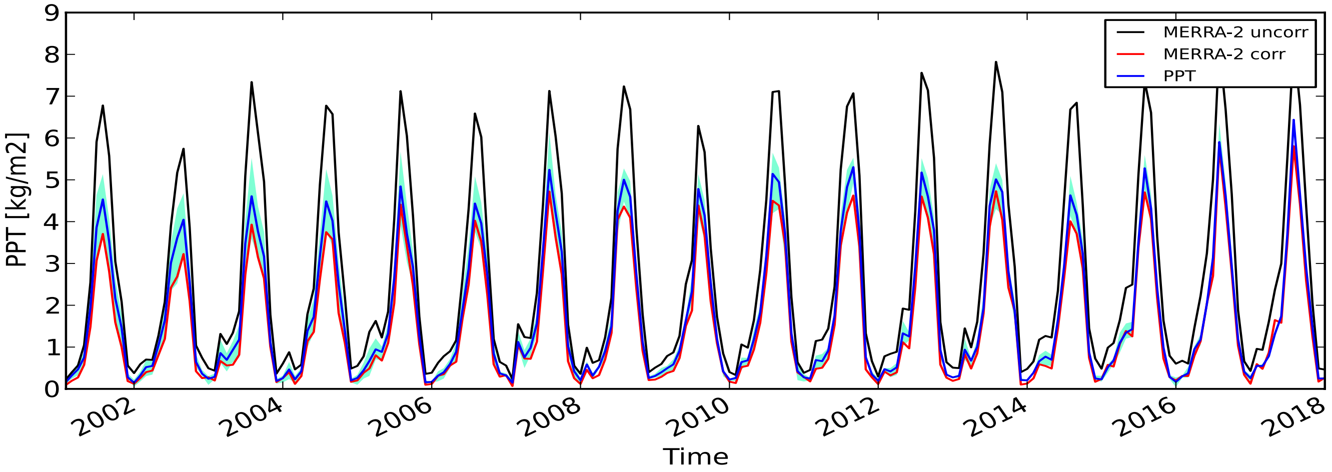


RMSE derived from Extended Triple Collocation

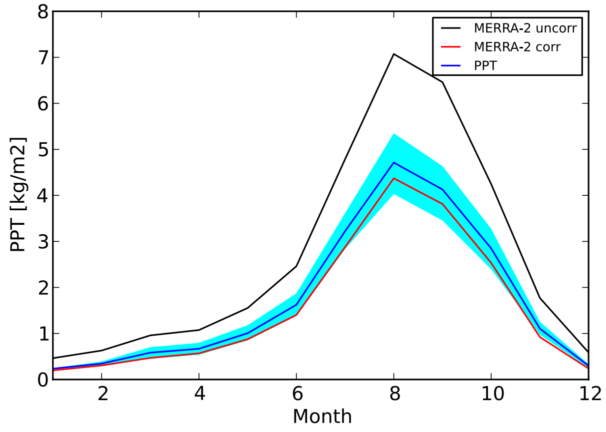


- Extended TC – a method of simultaneous estimation of the error structure of related datasets with uncorrelated errors
- In the regions with higher mean precipitation rate, the RMSE is higher.
- Station datasets (APHRODITE, CHIRPS, IMD) show better performance than others.
- MERRA-2 (uncorr) shows the worst performance.

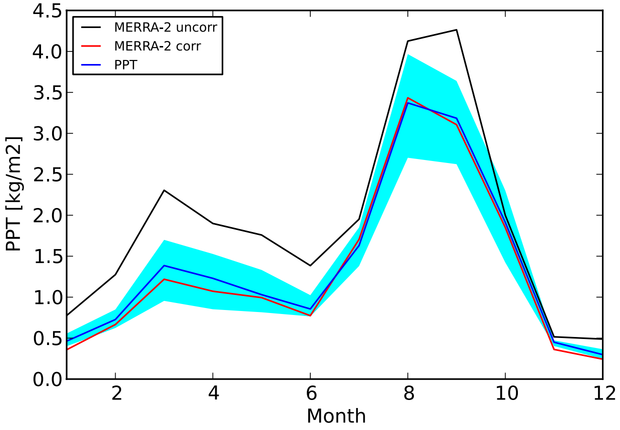
Comparison of seasonality, trends (P)



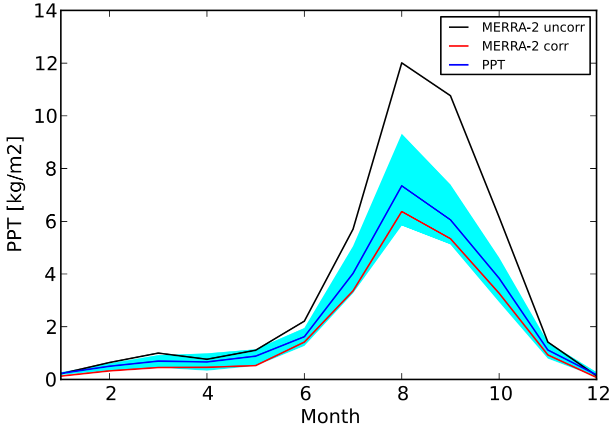
Mean-monthly P



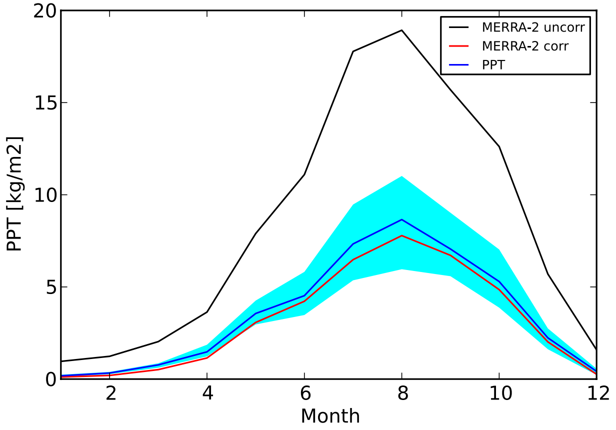
West



Central

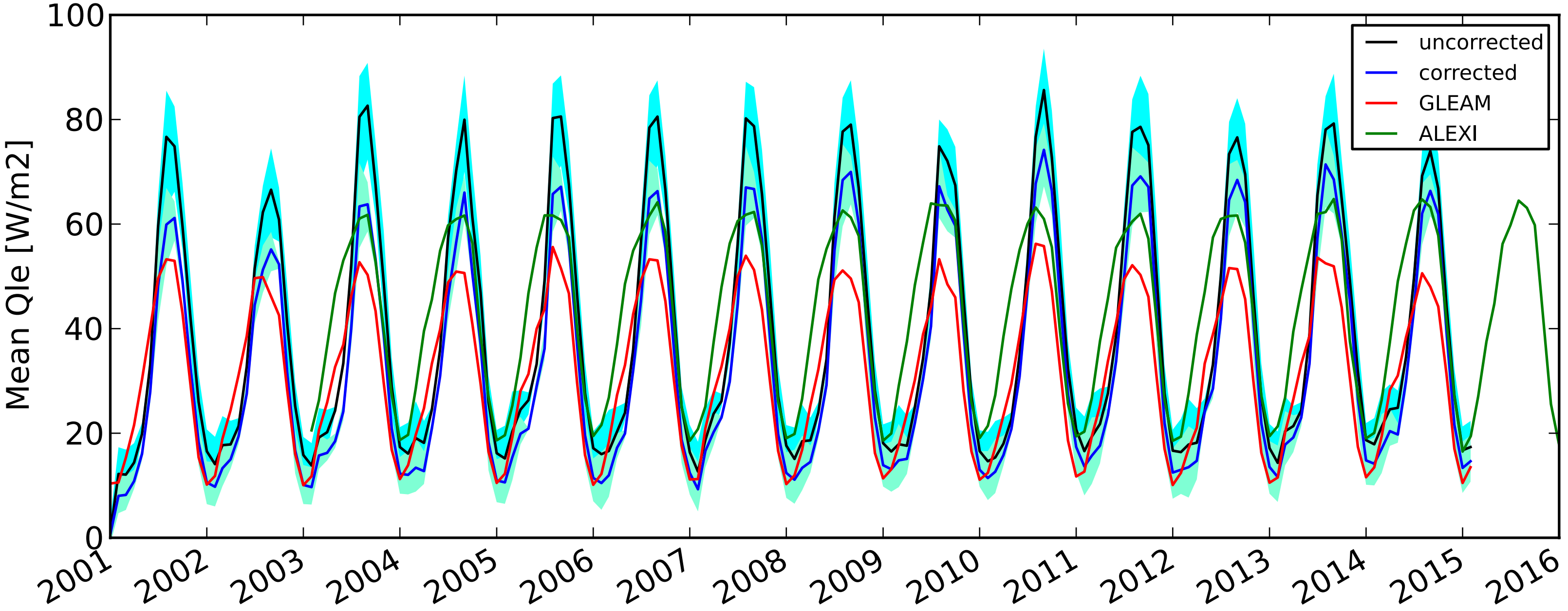


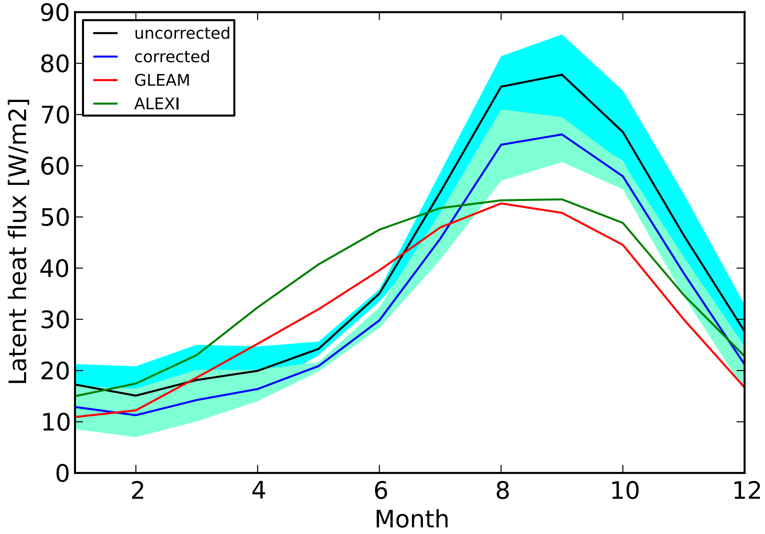
East

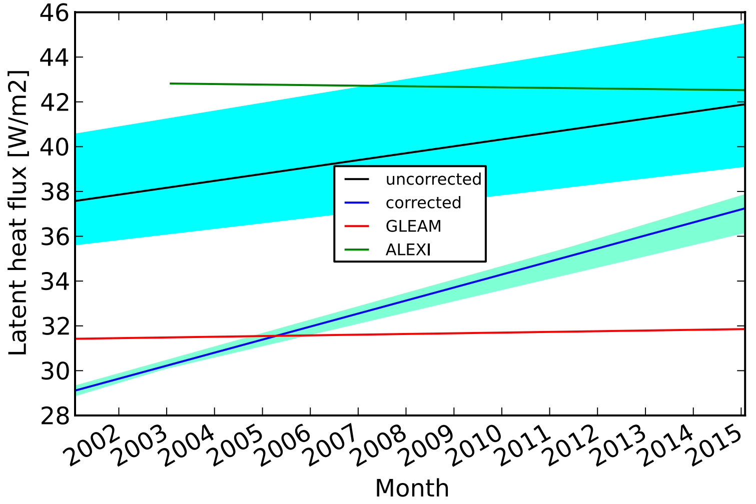


PPT – mean(APHRODITE, CHIRPS, TRMM, CMORPH)

Evaluation of ET



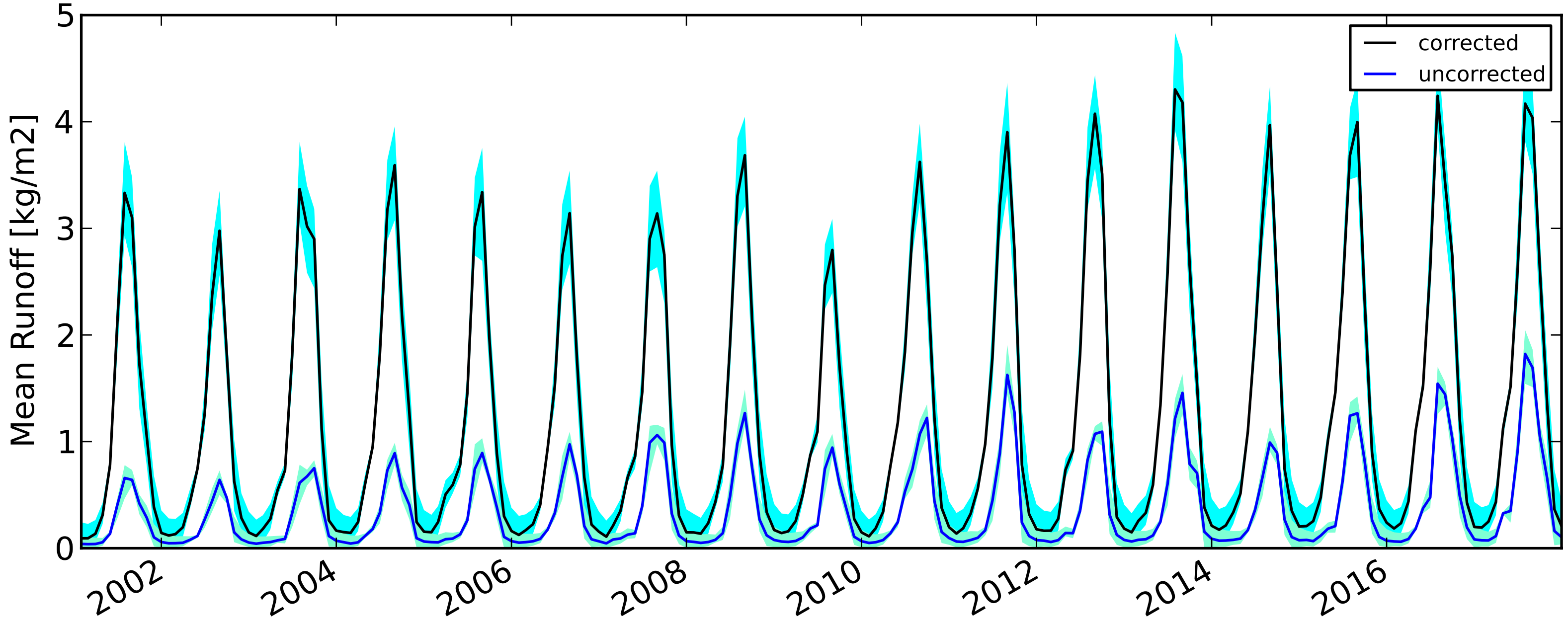


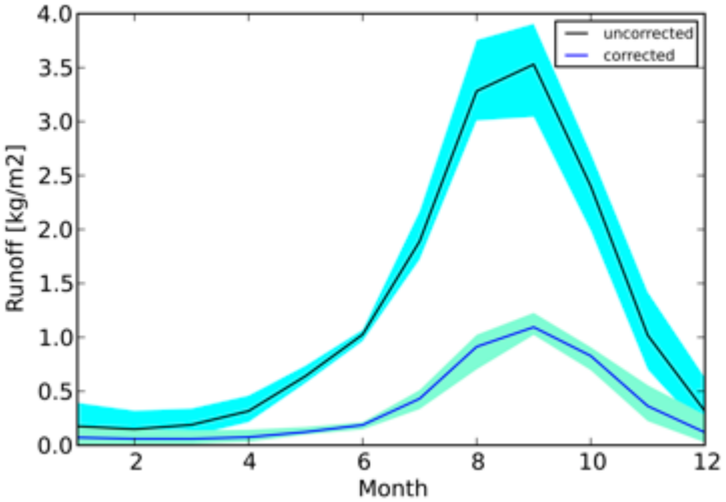


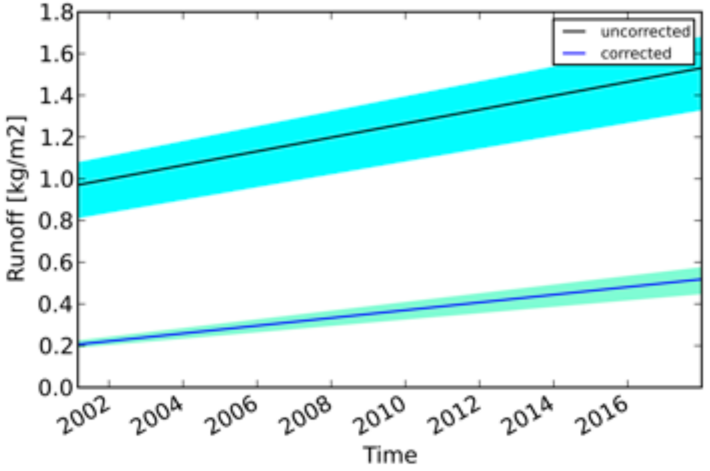
ALEXI (Atmospheric Land Exchange Inverse model) A thermal infrared based ET estimate (5km)
GLEAM (Global Land Evaporation Amsterdam model); remote sensing based; employs priestly Taylor approach

LIS ET trends follows the MERRA2 positive trends; ALEXI and GLEAM do not show a prominent trend.

Evaluation of Runoff (Q)



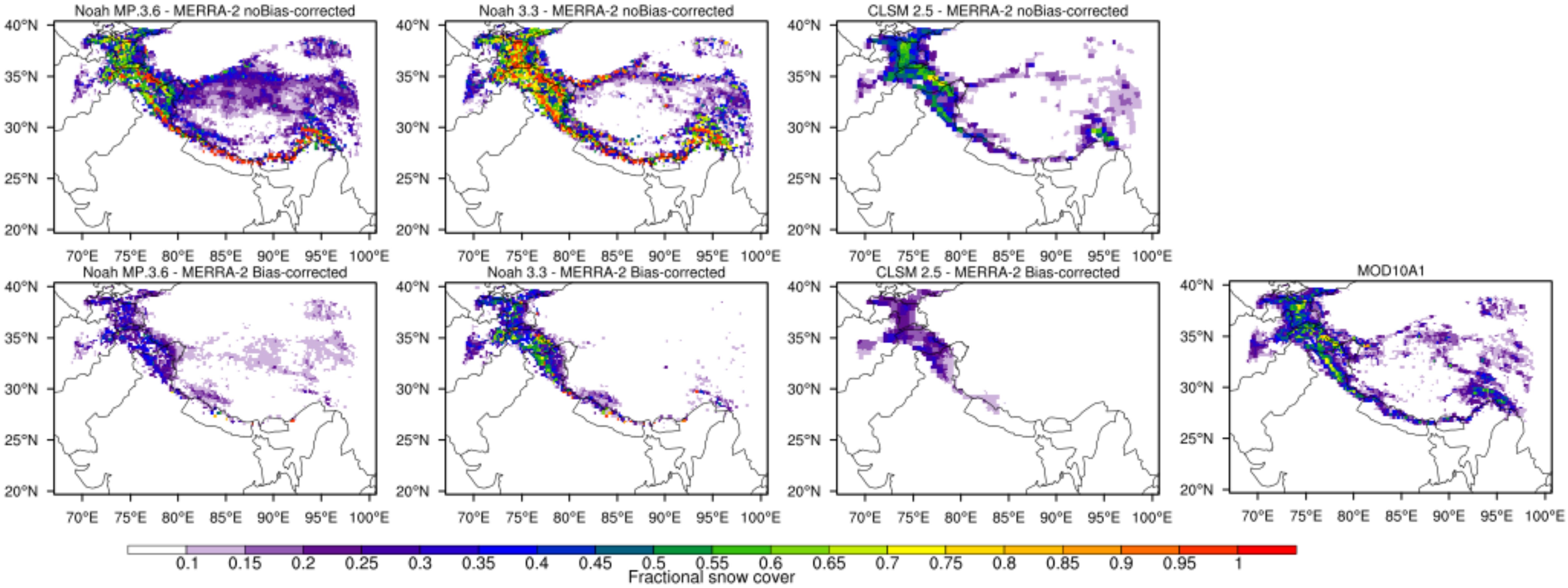




- LIS Q trends follow the MERRA2 positive trends; not enough (spatially distributed) observational data available for comparison

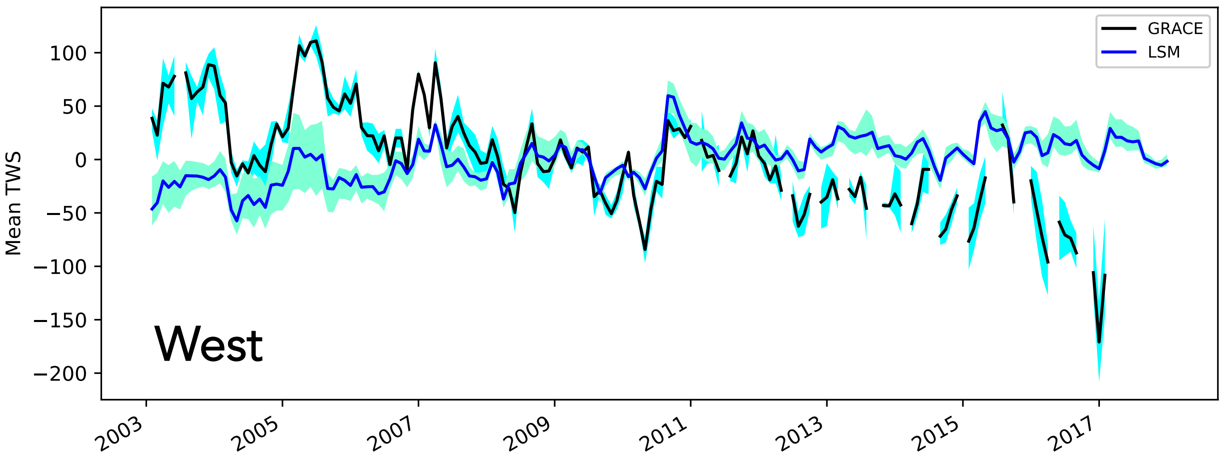
- The runoff estimates have a dry bias in the model simulations with MERRA2 (corrected)

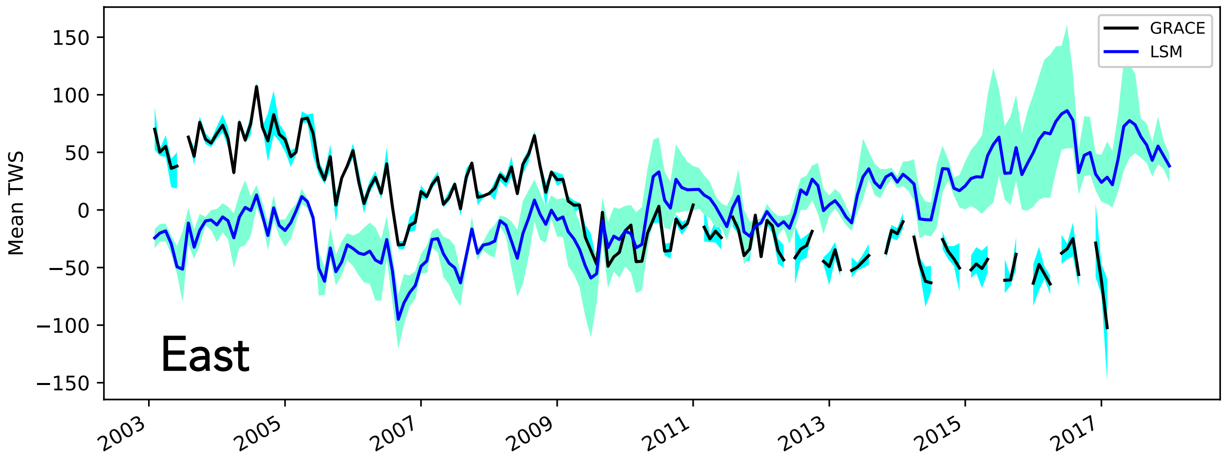
Evaluation of Snow Cover

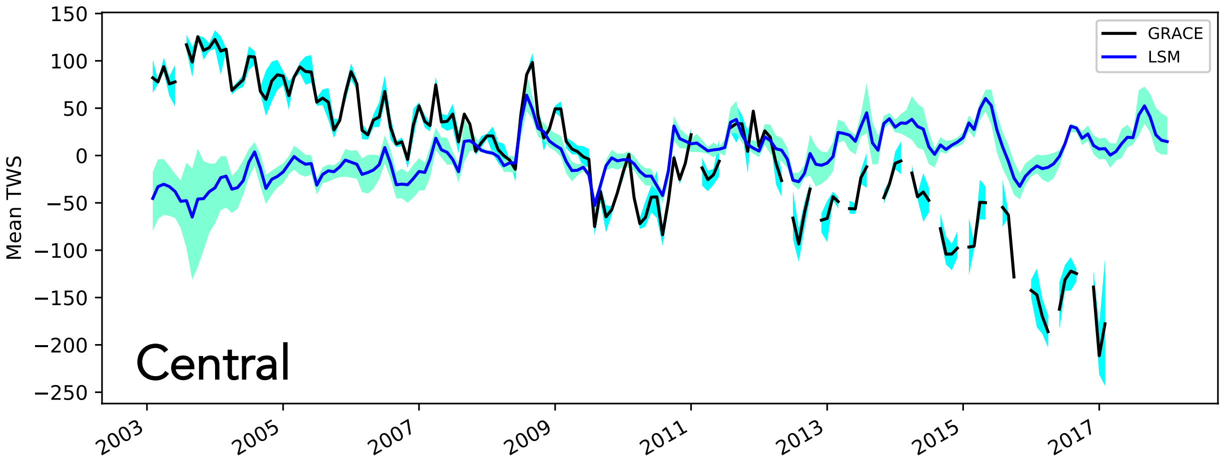


- MERRA2 (corrected) runs underestimate snow cover while MERRA2 (uncorrected) overestimate.
- The underestimation in MERRA2 (corrected) particularly severe in the central/east regions.

Evaluation of ΔTWS



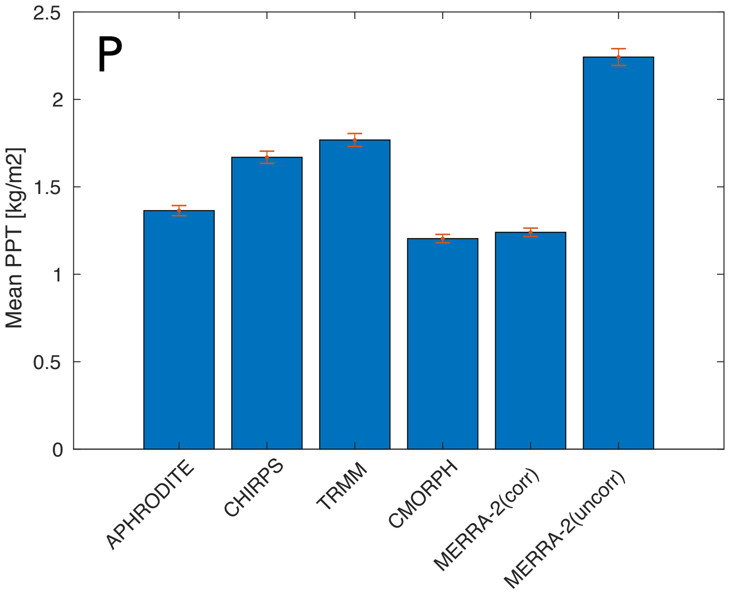


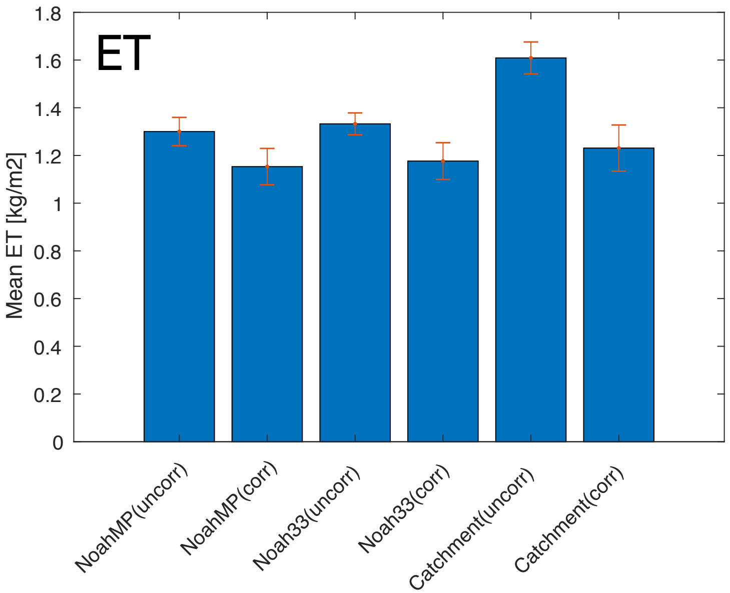


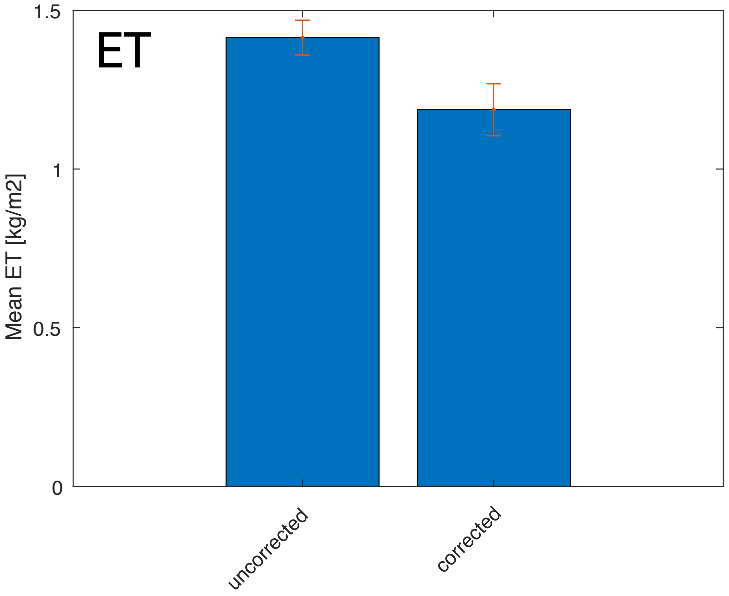
- The LIS-based *ΔTWS* compared to a suite of GRACE solution (CSR, JPL, GFZ)
- The LIS-based *ΔTWS* shows a positive trend whereas the GRACE solutions show a negative trend.

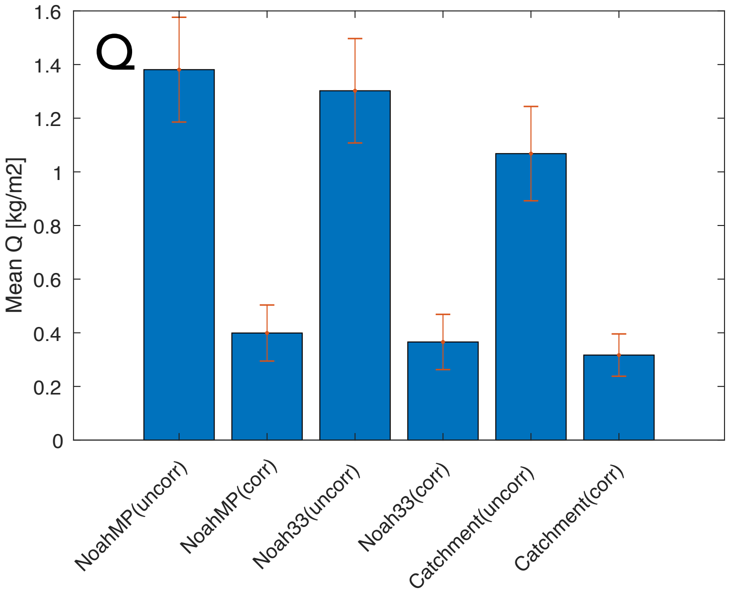
- Model uncertainty higher than the uncertainty in the GRACE solutions
- Inconsistencies likely due to snow physics issues over glaciers; Lack of representation of human management impacts, etc.

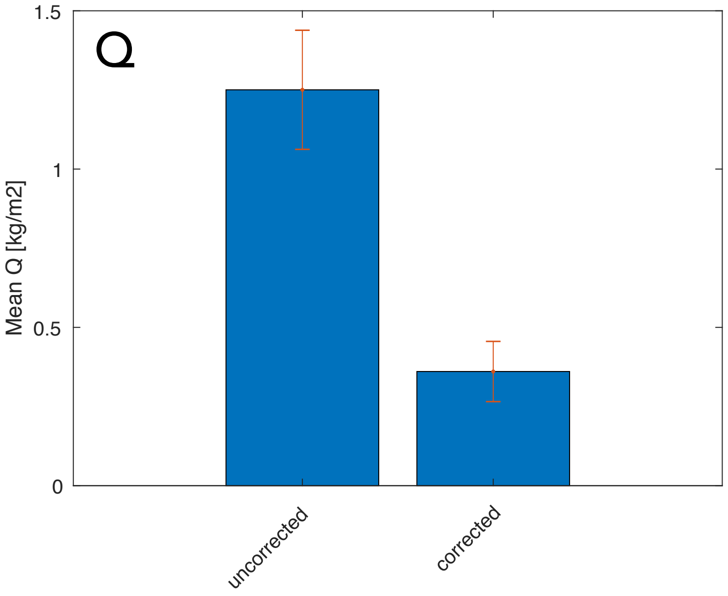
Water balance uncertainty











- Large uncertainties in precipitation inputs between MERRA2 corrected and uncorrected streams
- The forcing uncertainty drives the model output uncertainty and is a bigger factor than the model uncertainty.

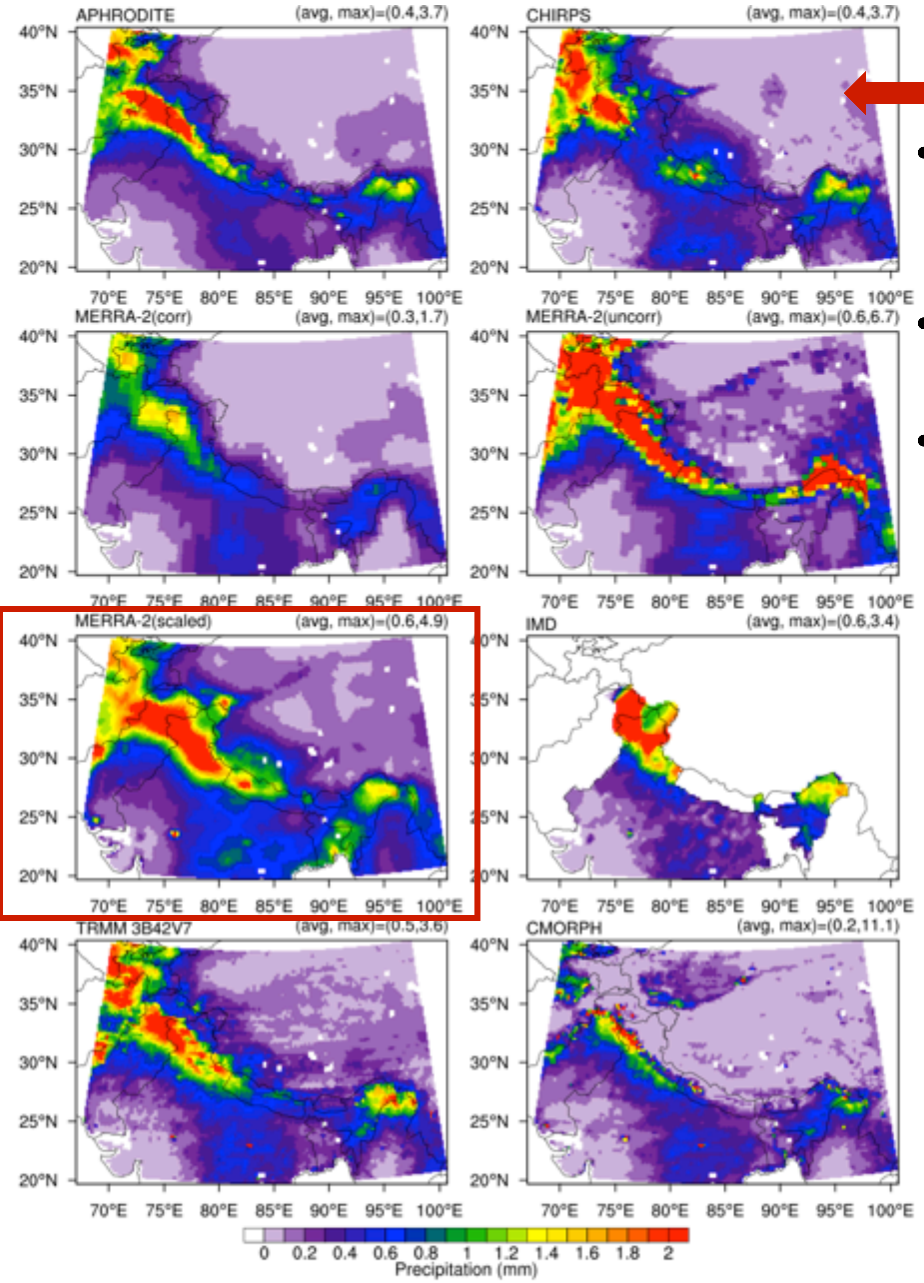
Climatological correction of MERRA2 Precipitation

Apply a climatological correction to MERRA2 precipitation based on other reference datasets (APHRODITE, CHIRPS, IMD, TRMM and CMORPH).

The MERRA2 precip is rescaled to match the climatology of the mean reference product (average of the 5 datasets) using CDF matching (conducted at a monthly timescale).

The scaled precipitation is closer to the reference ensemble mean; produces higher precipitation over the central and eastern domains than the MERRA2-corrected estimate.

Comparison of scaled precipitation seasonality

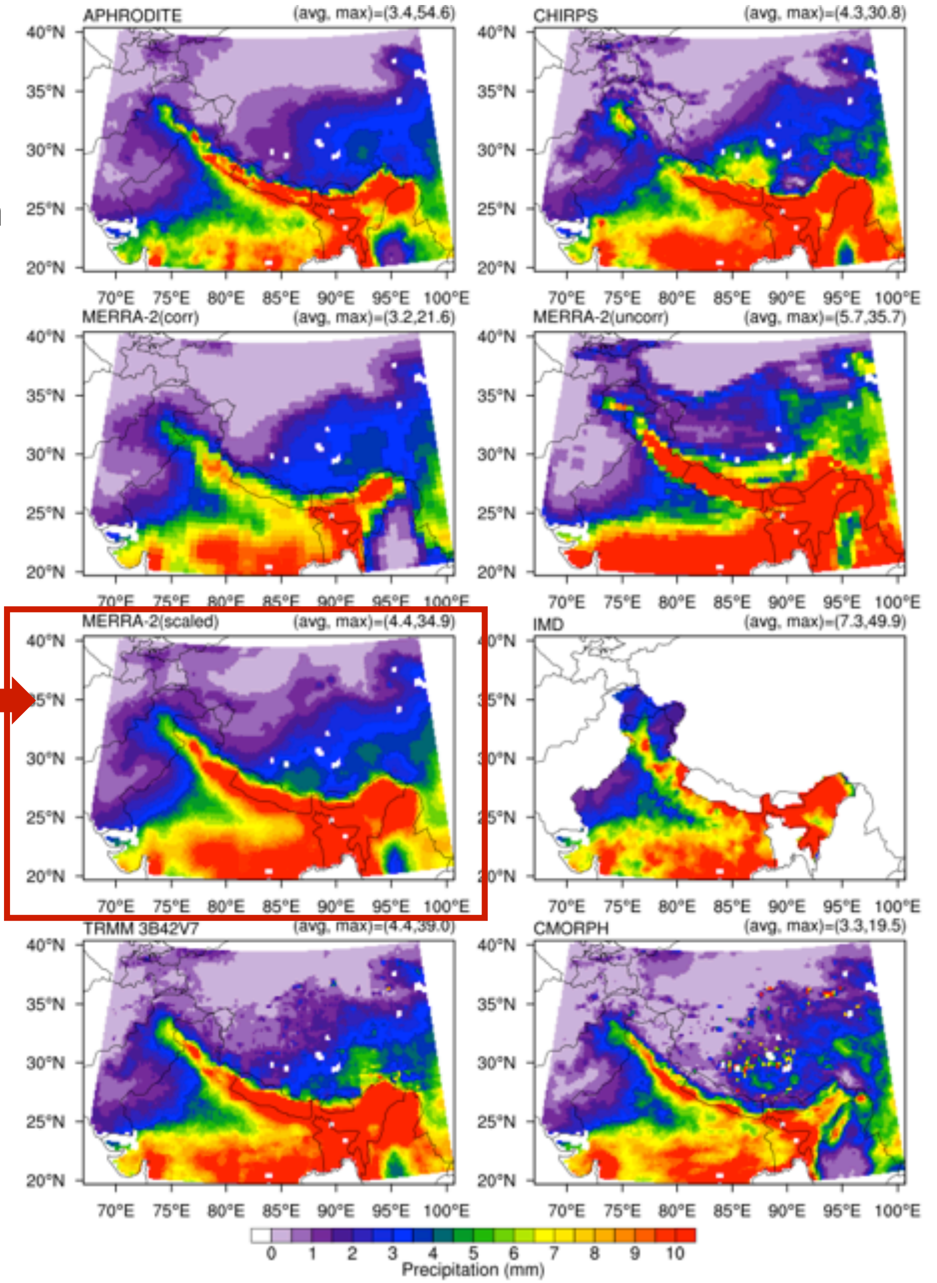


DJF

- Scaled MERRA-2 precipitation estimates produce higher than MERRA-2 corrected.
- Scaled MERRA-2 similar to TRMM.
- Lower-middle region of scaled MERRA-2 has higher precipitation rate than others.

JJA

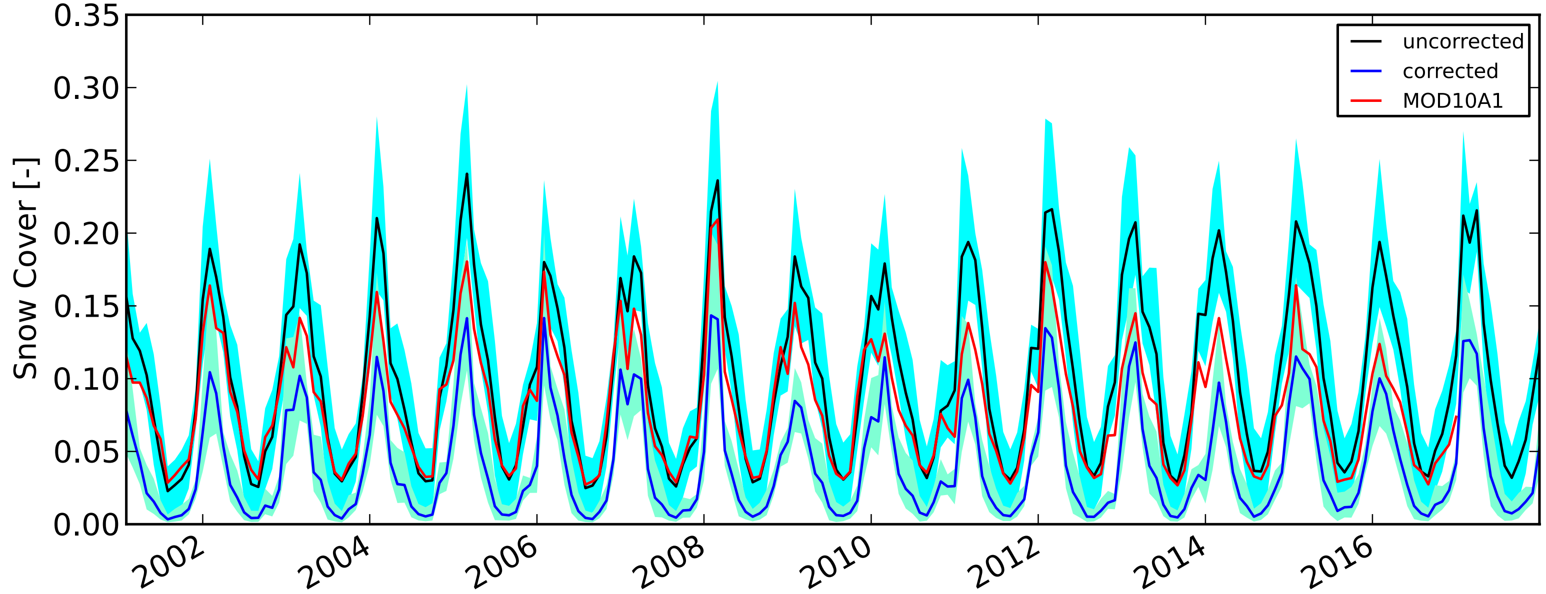
- Scaled MERRA-2 produce higher precipitation than MERRA-2 corrected, which is more similar to APHRODITE, CHIRPS, and TRMM.



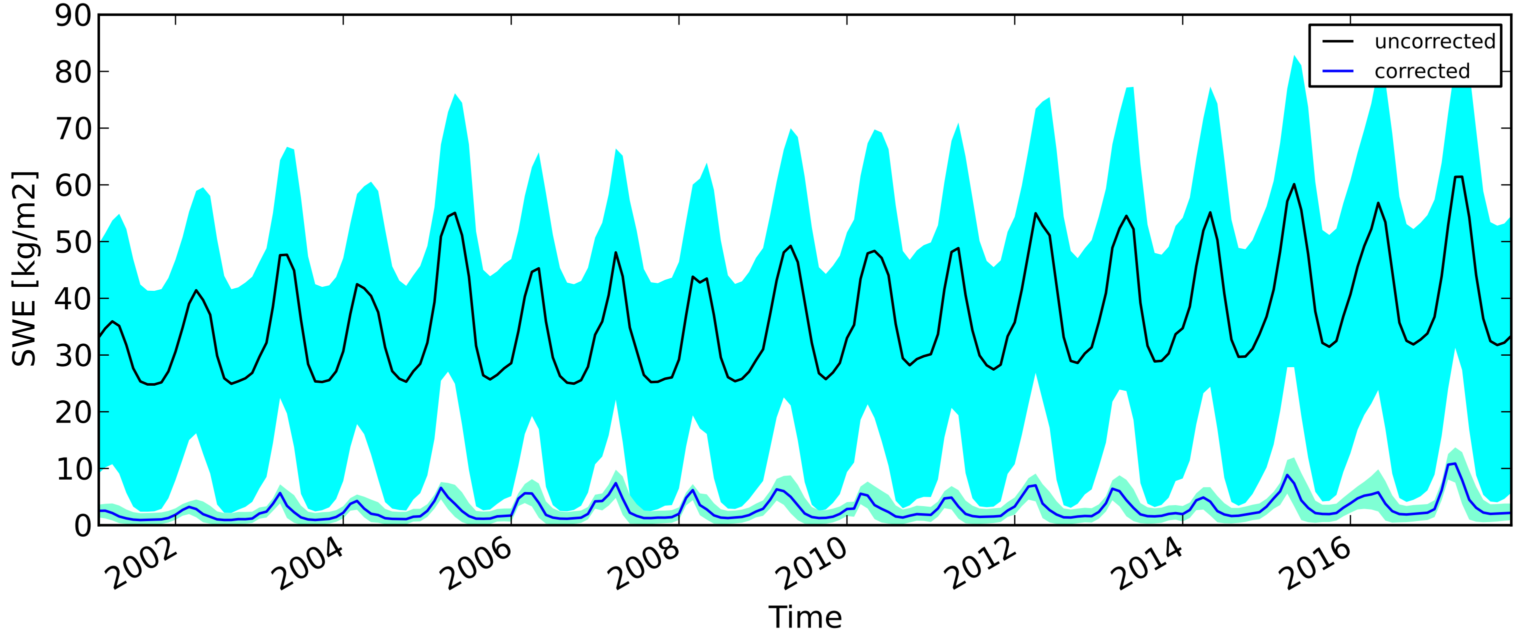
Summary

- Uncertainty in modeling the terrestrial water budgets over HMA is examined using a land surface model suite (i.e., Noah 3.3, Noah-MP 3.6 and Catchment F2.5) forced by MERRA2 meteorology.
- The uncertainty in MERRA2 precipitation inputs is the dominant factor in the uncertainty of water budget components; The uncorrected MERRA2 precip is too wet, corrected MERRA2 precip is too dry.
- To improve uncertainty in MERRA2 precipitation, a climatological bias correction scheme is developed and is being evaluated.
- The HiMAT project also incorporates the assimilation of passive microwave snow measurements (through machine learning forward operators), vegetation conditions and albedo. The final products will be generated at 1km spatial resolution.

Evaluation of Snow Cover and SWE



Domain-averaged snow-cover
Large spread in snow-cover estimates; MERRA2(corrected) underestimates the snow evolution; MERRA2 (uncorrected) overestimates



Domain-averaged SWE
Runs with uncorrected precip lead to large spread in the modeled SWE with unrealistic estimates over Glaciers

Model runs using corrected precip produce too little SWE