The New Morphing Scheme in IMERG V06

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What is IMERG?

- Integrated Multi-satellitE Retrievals for GPM (IMERG): Level 3 GPM merged precip. product
- **IMERG V05: 0.1°, ½ h, 60°N/S, April 2014 onwards**
- Main steps:
  1) Intercalibrate passive microwave radiometers against GPM DPR & GMI.
  2) Fill in gaps using **Lagrangian interpolation (morphing)** and IR precipitation.
  3) Bias adjustment with gauges.
- Three runs:
  - Early: ~5 h latency
  - Late: ~18 h latency
  - Final: ~3 month latency

What is morphing?

- Morphing: an algorithm to **propagate precipitation using motion vectors**. First implemented in CMORPH; incorporated in IMERG, also used in GSMaP.
- Steps:
  1) Derive motion vectors by seeking the **maximum correlation within a 5° × 5° template** at different spatial offsets between two consecutive fields of an atmospheric variable.
  2) Use motion vectors to **propagate precipitation between PMW satellite overpasses**, then combine with IR precipitation using Kalman filter.
- V05 uses IR cloud top scenes from geosynchronous satellites (Tb < 260 K) to compute cloud motion vectors, then scaled to match precipitation motion observed by CONUS radars.
- Gaps in vector field due to warm or no clouds are filled in using temporal and spatial interpolation.

Updates to morphing in V06

Why change?

- Geosynchronous IR data are limited to 60°N/S.
- Precipitation motion may not always match cloud motion.

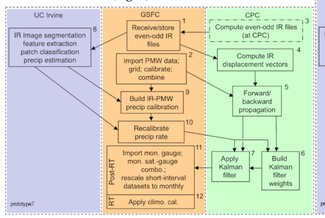
Key changes:

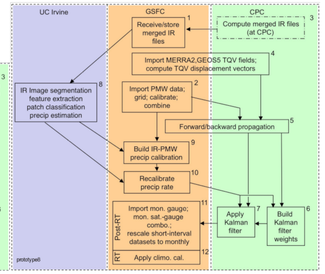
- Use reanalysis and forecast data to derive motion vectors.
- Downscale vectors for smoother motions.
- Extend propagation to and over the poles.
- (Overview of IMERG V05 and V06 shown in Fig. 1.)

V06 improvements:

- Estimates are extended to the poles for a fully global dataset.
- Retrospective processing extended to TRMM era for a record beginning 1998.
- Improved performance in morphed estimates.

(Fig. 1) High-level block diagram of major processing modules and data flow in (bottom) IMERG V05 and (right) IMERG V06.





Using MERRA-2/GEOS FP for Vectors

- Both **MERRA-2 (reanalysis)** and **GEOS FP (forecast)** are products based on the GEOS model, produced by the NASA Global Modeling and Assimilation Office (GMAO).
- MERRA-2:
  - Modern-Era Retrospective Analysis for Research and Applications, Version 2
  - 0.5° × 0.625°, 1 h
  - data latency: ~1.5 months
  - for IMERG Final run
- GEOS FP:
  - Goddard Earth Observing System Forward Processing
  - 0.25° × 0.3125°, 1 h
  - forecast frequency & length: every 6 h, up to 120 h into the future
  - for IMERG Early and Late runs
- Variable used: **TQV**, total precipitable water vapor (or total column water vapor)
  - TQV motion vectors are most satisfactory among several variables tested.
  - TQV gives globally complete field; no need for interpolation to fill in gaps (Fig. 2).
- Vectors are computed at 2.5° using a 5° template , then interpolated to IMERG resolution:
  - Vectors are **temporally interpolated** from 1-h to ½-h.
  - Vectors are **spatially interpolated** from 2.5° to 0.1° for smoother motion (Fig. 3).

Expanding Propagation to Full Global

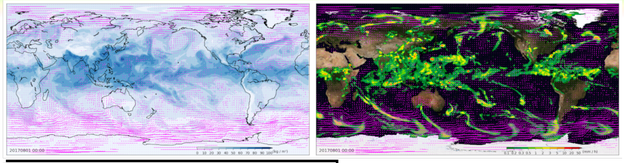
- Global availability of MERRA-2/GEOS FP allows an extension from the 60°N/S in IMERG V05 **up to and across the poles** in IMERG V06 (Fig. 4).
- To handling of grid box distortion at high latitude, the **longitude of 5° template is scaled with the inverse of the cosine of latitude**; i.e., the template is stretched larger at higher latitudes. This is a stopgap measure until the eventual goal of the adoption of a more equitable projection scheme.
- Unlike IR vectors, the TQV vectors do not need to be scaled with CONUS ground radars.
- As the IR coverage is limited to 60°N/S, this means that above 60°N/S:
  - there is no IR precipitation via Kalman filter; and
  - estimates over frozen surfaces will be missing.

Validating against PMW Overpasses

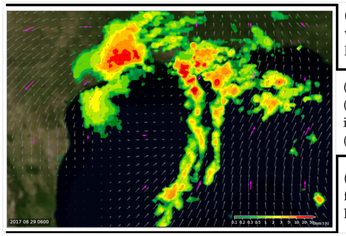
- Technique: propagate PMW precipitation field from t to $t + 1$ and validate the resulting field against the $t + 1$ PMW precipitation field where available.
- The goal is to contrast the TQV-based morphing scheme against two benchmarks: IR (IMERG V05) and "NULL" (no motion). Due to intersensor differences and absence of precipitation system evolution, the absolute scores do not reflect morphing performance.
- Results indicate that **TQV-based morphing is comparable to IR-based morphing at most latitudes and better in the tropics** (Fig. 5). Both are generally better than no motion.
- Average correlation: 0.553 (TQV), 0.549 (IR), 0.522 (NULL)
- Average HSS: 0.644 (TQV), 0.634 (IR), 0.621 (NULL)

Using Forecast Data for NRT Runs

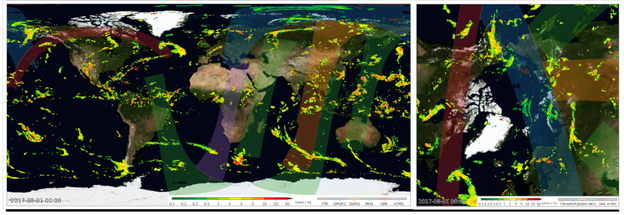
- GMAO produces forecast data four times a day with different forecast lengths: 0 Z (240-h forecast), 6 Z (30-h), 12 Z (120-h), and 18 Z (30-h). Data latency is currently ~8 h.
- Strategy: **use latest available forecast**.
  - With no data interruption, IMERG will usually use forecast data no more than 13 h out.
  - With data interruption, NRT runs will continue for 10 days.
- Comparison of GEOS FP and MERRA-2 vector fields shows that (Fig. 6):
  - With no data interruption, **both vector fields are similar** (correlation > 0.8)
  - With data interruption, **vector field remains reliable even at 10 days** (correlation ~0.5)
- Derived vectors are robust against different models based on tests with ERA5.



(Fig. 2) MERRA-2 TQV motion vectors with (left) MERRA-2 TQV field, and (right) MERRA-2 precipitation.

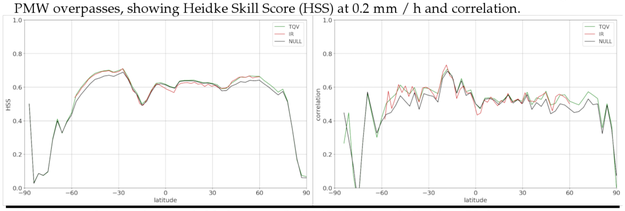


(Fig. 3) Motion vectors computed at 2.5° (magenta), every 4th motion vector interpolated from nearest 2.5° vectors to 0.1° (gray), and propagated precipitation.

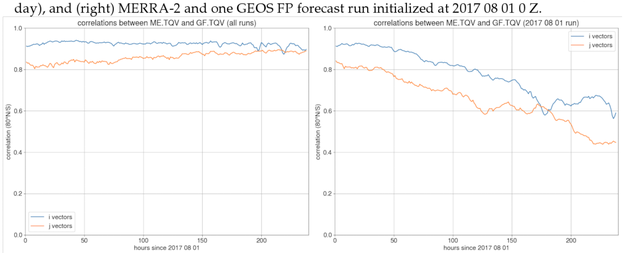


(Fig. 4) Morphed precipitation (combined forward and backward propagation) with PMW satellite overlay.

(Fig. 5) Validation of propagated precipitation field using TQV, IR and "NULL" vectors against PMW overpasses, showing Heidke Skill Score (HSS) at 0.2 mm / h and correlation.



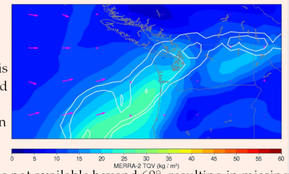
(Fig. 6) Correlation of vector fields between (left) MERRA-2 and all GEOS FP forecast runs (4 per day), and (right) MERRA-2 and one GEOS FP forecast run initialized at 2017 08 01 0 Z.



Other Minor Changes

- Internal precipitation grid has been **changed to 0.1°** from 0.07276° (legacy code). This does not affect the precipitation grid in the IMERG files, but it does eliminate interpolations between different grids and thus potentially improve performance.
- **Encoding of precipitation values has been removed**. Therefore, precipitation values are no longer fixed at specific increments (and thus capped at 100 mm / h); they can be of any value.
- **Screening of precipitation values over frozen surfaces has been removed at the morphing step**, now instead implemented at the final gauge adjustment step. This allows propagated precipitation to "survive" passing through a narrow strip of frozen surface, and provides the option to use microwave estimates over frozen surfaces in the future.

Known Issues



- Limited spatial resolution of model data hinders ability to resolve fine-scale motion.
- Orography can intefere with vectors up to 2.5° away due to large template size (see right). This is espcially a problem for a vertically-integrated quantity such as TQV.
- Area distortion at high latitudes is a problem in cylindrical projection, partly mitigated with inelegant stopgap measures.
- Fallback to IR precipitation over frozen surfaces not available beyond 60°, resulting in missing values at high latitudes.
- Propagation distance is discretized to nearest grid box (e.g., 0.14° → 0.1° → 1 grid box), which can lead to rounding errors (e.g., 0.14° propagated twice should be 0.28° → 3 grid boxes, but 0.14° + 0.14° → 0.1°+ 0.1° → 2 grid boxes). A "remainder vector" scheme was devised but not implemented as it led to excessive noise in the precipitation field.

Conclusions

- In IMERG V06, model-based motion vectors will replace IR-based motion vectors in the morphing scheme.
- TQV (total precipitable water vapor) from MERRA-2 (reanalysis) and GEOS FP (forecast) will be used. Vectors are spatially interpolated from 2.5° to 0.1° for smoother motion.
- Improvements:
  - TQV-based morphing is comparable or slightly better than IR-based morphing.
  - IMERG V06 will be fully global.
  - IMERG V06 will be reprocessed to TRMM-era beginning 1998.
- **IMERG V06: 0.1°, ½ h, 90°N/S, January 1998 onwards**

Future Work

- Explore variable(s) better than TQV for the vector source.
- Migrate to a more equitable projection scheme; cubed-sphere projection is currently the preferred choice. This will be a major undertaking affecting the entire IMERG code and potentially tricky for morphing.
- Investigate alternative precipitation dataset for high latitudes as a fallback over frozen surfaces.
- Develop a precipitation evolution scheme. It must be effective in handling intersensor differences but simple enough to integrate into the IMERG framework.

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