Development of In Situ and Satellite-based Objective Analyses of Surface Temperature and Precipitation

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Outline

- Introduction
  - *Importance of the two geophysical variables*
  - *Necessity of gridding*
- Development of Precipitation Analyses
  - *Sources of precipitation information*
  - *Gauge-based analyses (CPC unified gauge analysis)*
  - *Satellite estimates (CMORPH)*
  - *Fusing information from multiple sources (CMORPH Blended)*
  - *Ongoing developments*
- Development of Surface Air Temperature Analyses
  - *Global analyses of daily Tmax and Tmin*
  - *Down-scaling to hourly*
- Summary
  - *CPC Precipitation and Surface Air Temperature Products*
  - *Challenging issues*

Introduction

[1] Importance

- T & P are two important geophysical variables
  - *Influence to daily life*
  - *Weather / climate state variable*
  - *Performance metrics for numerical models*

ENSO impacts constructed based on Ropelewski and Halpert (1986,1987)

Introduction

[2] Gridding of T / P data

- Gridding → Analyzing
- Converting irregularly distributed station / satellite data into regularly spaced grid fields (analyses)
- Objective analysis techniques need to be applied to achieve optimal results
- Analysis techniques differ for different target geophysical variables (T, P or others) and for specific input data available

→ ***We need to develop objective analysis techniques for specific applications***

Precipitation Analyses

[1] Sources of Precipitation Information

- Three categories of operationally available data sources:
  - *gauge measurements;*
  - *remote sensing estimates (radar / satellite); and*
  - *numerical model simulations / forecasts*

- Each of them presents strength as well as shortcomings
  - *Gauge:*
    - *Accurate point measurements / long-term record*
    - *In complete coverage / sparse network density*
  - *Remote Sensing:*
    - *Broad spatial coverage*
    - *Bias / random error*
  - *Numerical models:*
    - *Evolving technology, especially for convective precipitation*

Precipitation Analyses

[2] Gauge Analyses

(2a) Introduction

- Gauge measurements / analyses are foundation of all precipitation estimates / analyses
  - *Relative accurate measurement of point precipitation*
  - *Long-term record for weather / climate / hydrometeorology applications*

- *Constructing gridding fields from gauge reports are* **NOT** *an easy task*
  - *Quality control / quality assurance for station data*
  - *Station network of varying densities*
  - *Orographic effects*
  - *…*

Precipitation Analyses

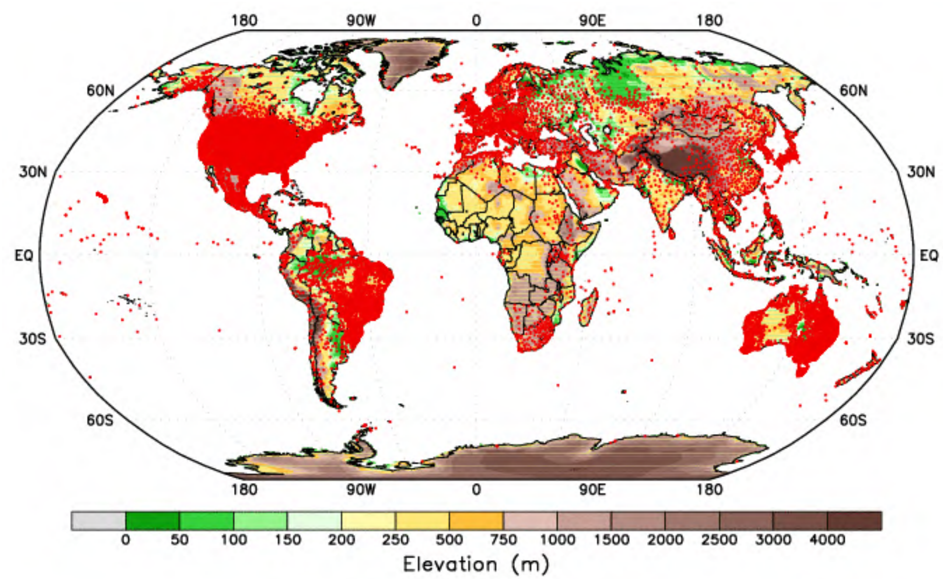
[2] Gauge Analyses

(2b) Overall of CPC Unified Daily Gauge Analysis

- Result of a CPC project ~10 years ago to consolidate / unify several CPC gauge analyses

- Combine station data available from all sources inside / outside CPC, perform QC for the station data
  - *> GTS, NCEI archives, COOP, RFC, Mexico, Brazil, Australia..*
  - *30K / 16K stations for retrospective and real-time*

- Develop OI-based objective analysis to construct gridded analyses of daily precipitation over global land with consideration of orographic effects



Precipitation Analyses

[2] Gauge Analyses

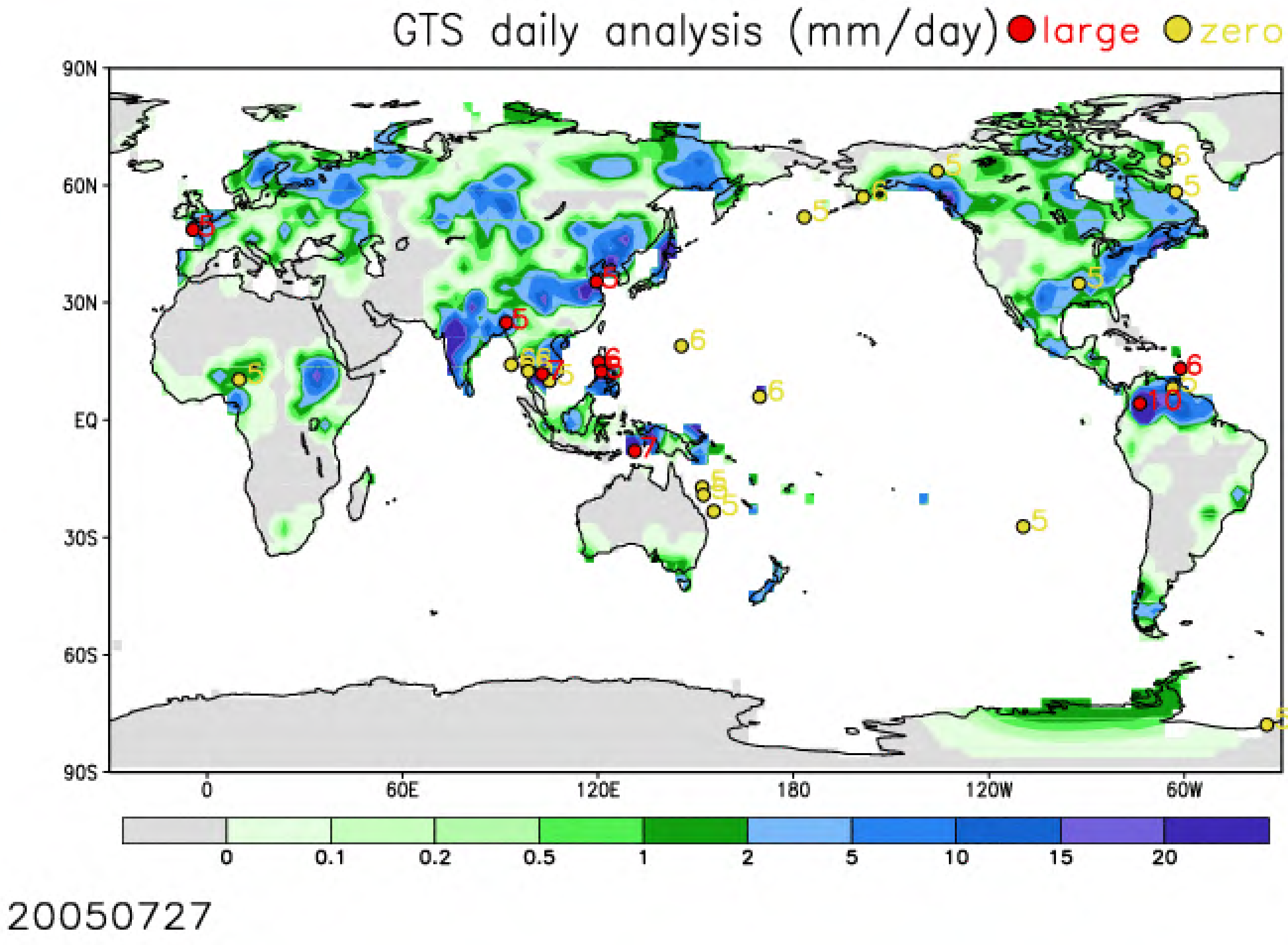
(2c) QC for the daily gauge reports

- Problems
    - ‘0’ false values / unrealistically large values
- Strategy
    - *Calculate the ‘probability’ of a ‘0’ or large-value report being wrong by:*
        - *Checking historical record (black list)*
        - *Comparing with reports at nearby stations*
        - *Comparing with CMORPH satellite estimates and GFS model forecasts*
        - *Weight each component based on its reliability*
    - *Converting the ‘probability’ into an index (0-10) indicating level of risk*

Precipitation Analyses

[2] Gauge Analyses

(2d) example of gauge reports QC for July 27, 2005



Precipitation Analyses

[2] Gauge Analyses

(2e) Algorithm strategy for the gauge analysis

- Research was conducted to determine the algorithm strategy and select the optimal interpolation technique (Chen et al. 2005; Xie et al. 2007)

  - *Interpolating the ratio of the total precip to the climatology, NOT the total precip itself;*
  - *Need a climatology with orographic effects;*
  - *Interpolation algorithm itself not very sensitive as long as weight – distance relation is reasonably reflected*

  ➔ *Optimal Interpolation (OI) is the best, but Shepard (1965) is quite close*

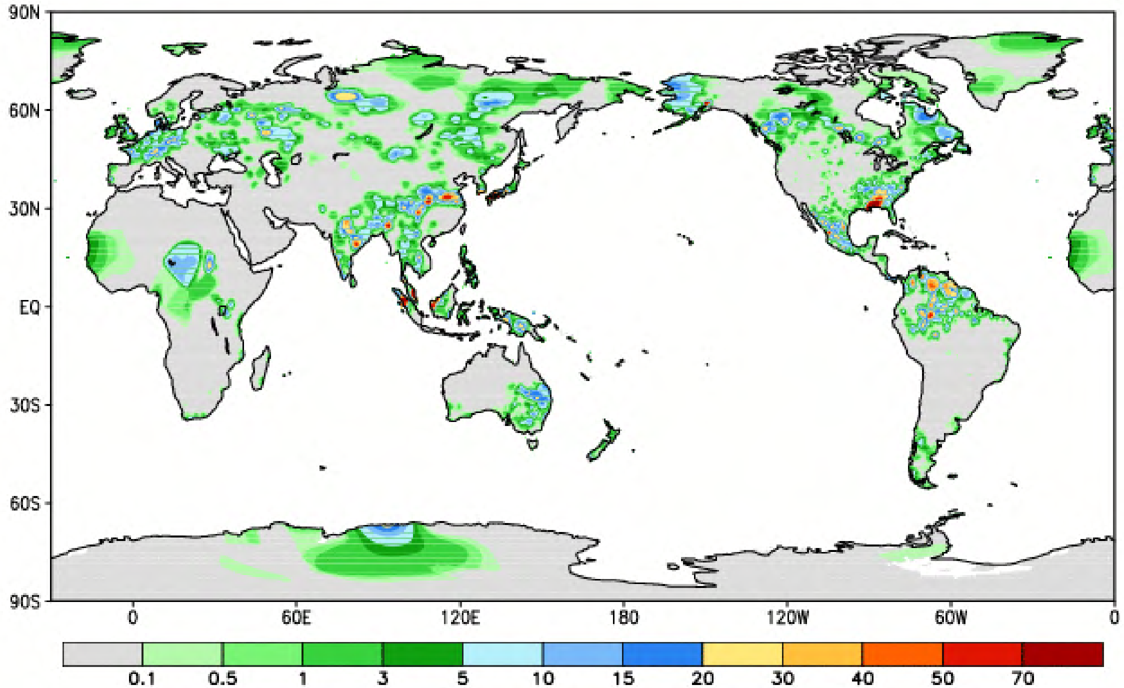
Precipitation Analyses

[2] Gauge Analyses

(2f) The gauge analysis products

- Interpolation performed on a 0.125ºlat/lon grid over the global land the integrated to appropriate grid resolution for products release:
  - *Global Analysis: 0.5ºlat/lon grid from 1979*
  - *CONUS analysis: 0.25ºlat/lon grid from 1948*

- Example for July 1, 2003



Precipitation Analyses

[2] Gauge Analyses

(2g) Simulation tests to quantify gauge analysis error

- Gauge analysis error is quantified through simulation tests using data from a very dense network over Korea;
- Reports from 28 stations available over a grid box of 0.25^{o}lat/lon over Seoul;
- The 28-station mean values are considered as the ‘truth’;
- Network of less densities is simulated by randomly dropping stations inside the grid box and nearby;
- Gauge analyses from the simulated networks with less gauges are compared against the ‘truth’ to get error estimation

Precipitation Analyses

[2] Gauge Analyses

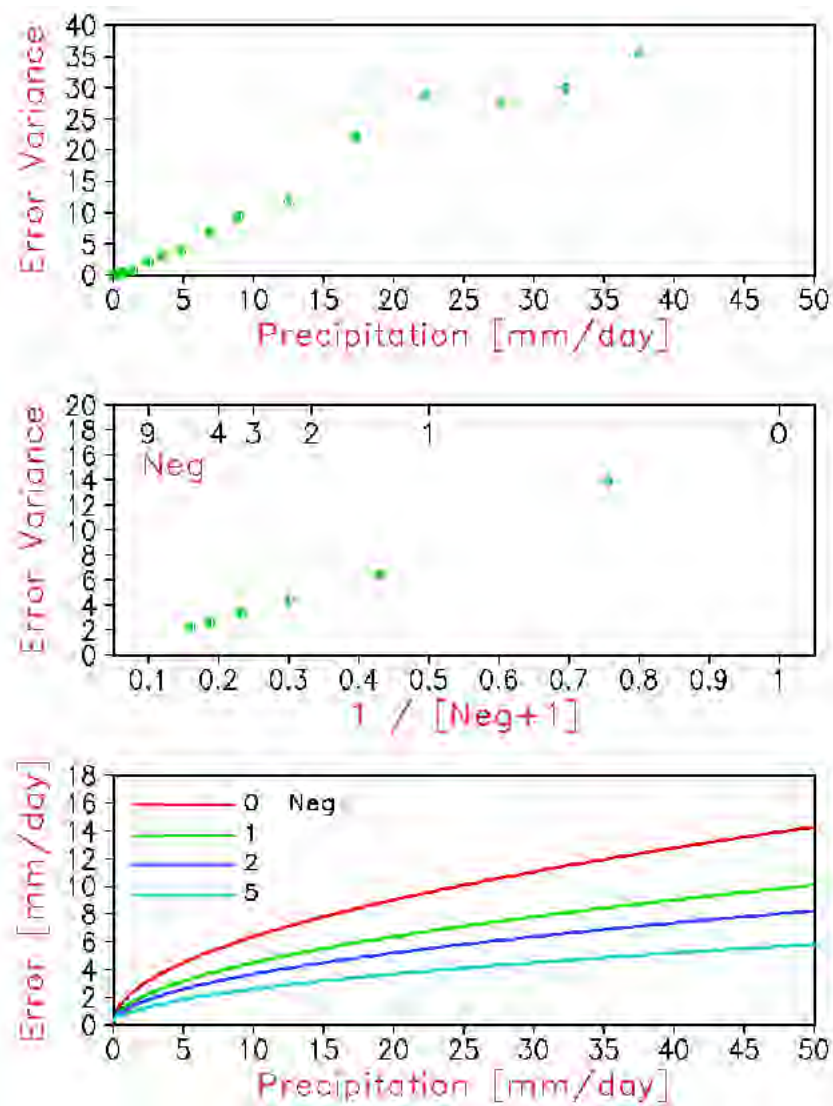
(2h) Gauge analysis error

▪ Error variance of the gauge analysis linearly proportional to the precipitation intensity and inversely proportional to the local gauge network density measured by the Number of Equivalent Gauges (Neg)

▪ An empirical relation established between the error variance and the precipitation and the Neg:

$$E^2 = a + b \cdot R / (N_{eg} + 1)$$

$$a = 0.15 \ (\text{mm/day})^2$$
$$b = 4.09 \ (\text{mm/day})^2$$



Precipitation Analyses

[3] Satellite Estimates

(3a) Precipitation estimates from various satellite data

- Infrared (IR)
  - *Sensors aboard both geostationary (GEO) & low earth orbit (LEO) platforms*
  - *Based on empirical relationship between cloud top temperature and precipitation*
  - *Reasonable quality for convective precipitation*
  - *Fine spatial resolution and short observation intervals (for GEO)*

- Passive microwave (PMW) scattering & emission
  - *Sensors aboard LEO platforms only*
  - *More direct link to precipitation therefore better quality*
  - *Coarse spatial resolution (>~10km)*

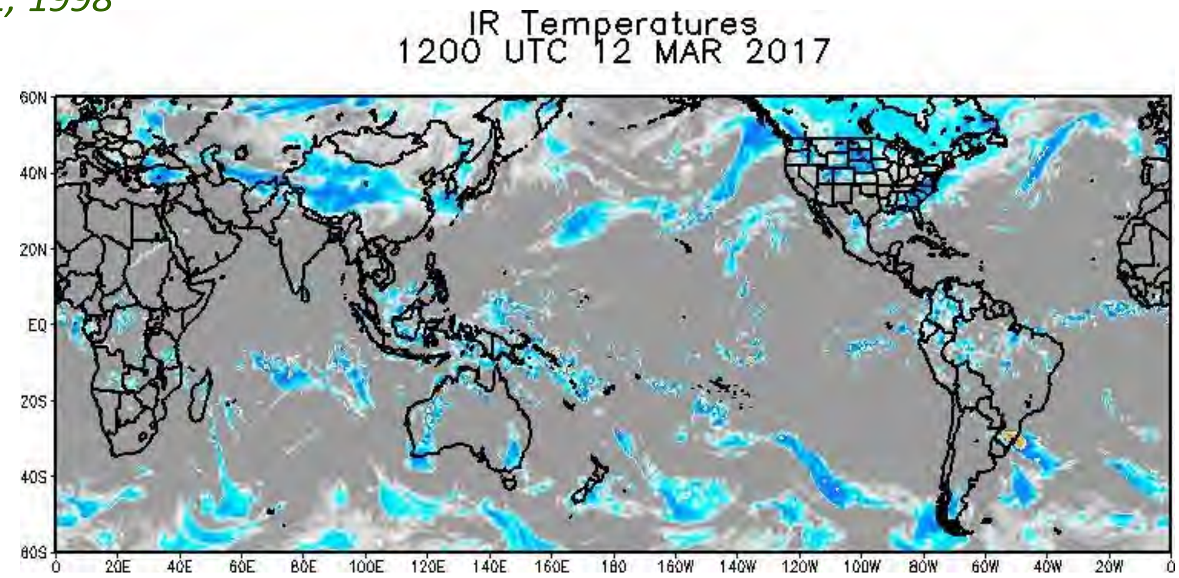
- Space radars (CloudSat, TRMM, GPM)
  - *Most accurate satellite-based estimates*
  - *Three-dimensional observations*
  - *Narrow spatial coverage*
  - *Usually used for calibration and research purposes only*

Precipitation Analyses

[3] Satellite Estimates

(3b) IR data from GEO satellites

- GEO IR Data
  - *Black Body temperature (TBB)*
  - *Intensity / movements of cloud systems*
- CPC integrates GEO IR data from five satellites into a single grid fields of TBB
  - *Limb correction / inter-satellite calibration*
  - *4kmx4km / 60^{o}S – 60^{o}N*
  - *30-min interval from jan.1, 1998*

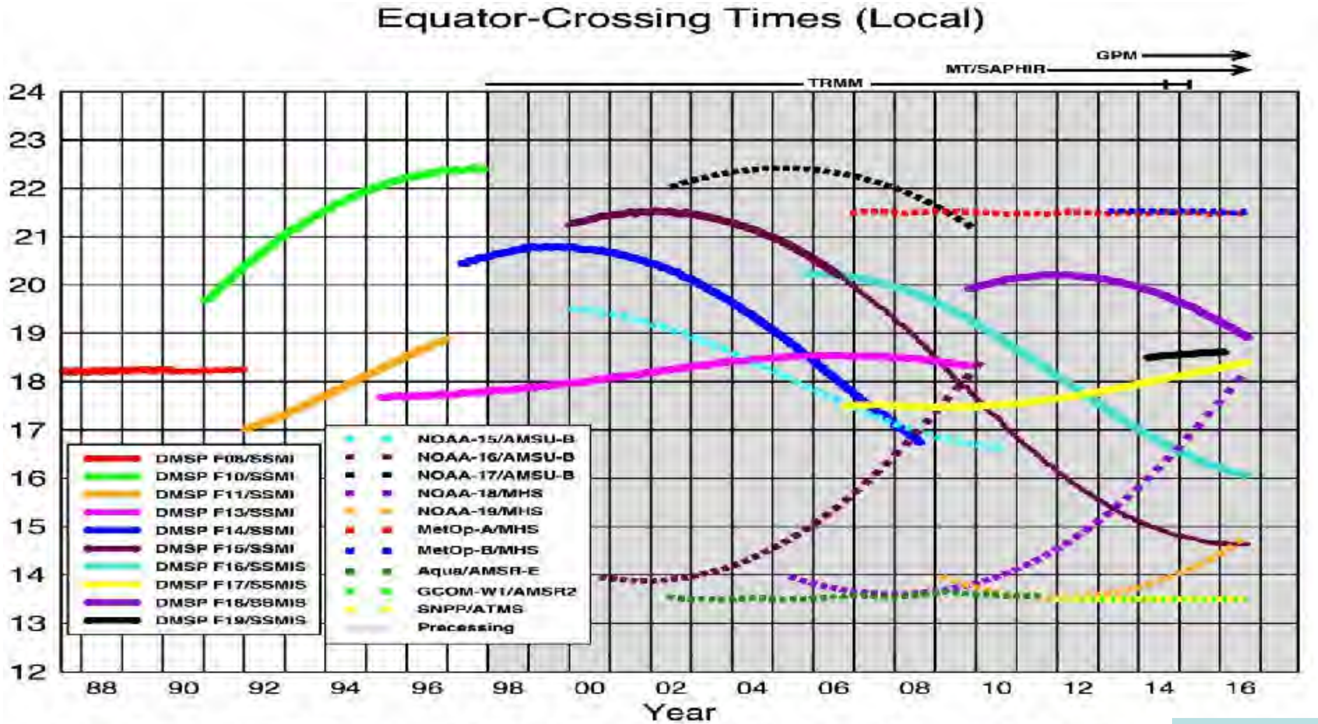


Precipitation Analyses

[3] Satellite Estimates

(3c) PMW retrievals from various LEO satellites

- PMW precipitation retrievals available from up to 10 LEO satellites
- Their observation times, however, differ from each other, and changes over their life spans for several of them



Ascending passes (F08 descending); satellites depicted above graph precess throughout t
Image by Eric Nelkin (SSAI), 22 September 2016, NASA/Goddard Space Flight Center, Gr

Courtesy of E. Nelkin

Precipitation Analyses

[3] Satellite Estimates

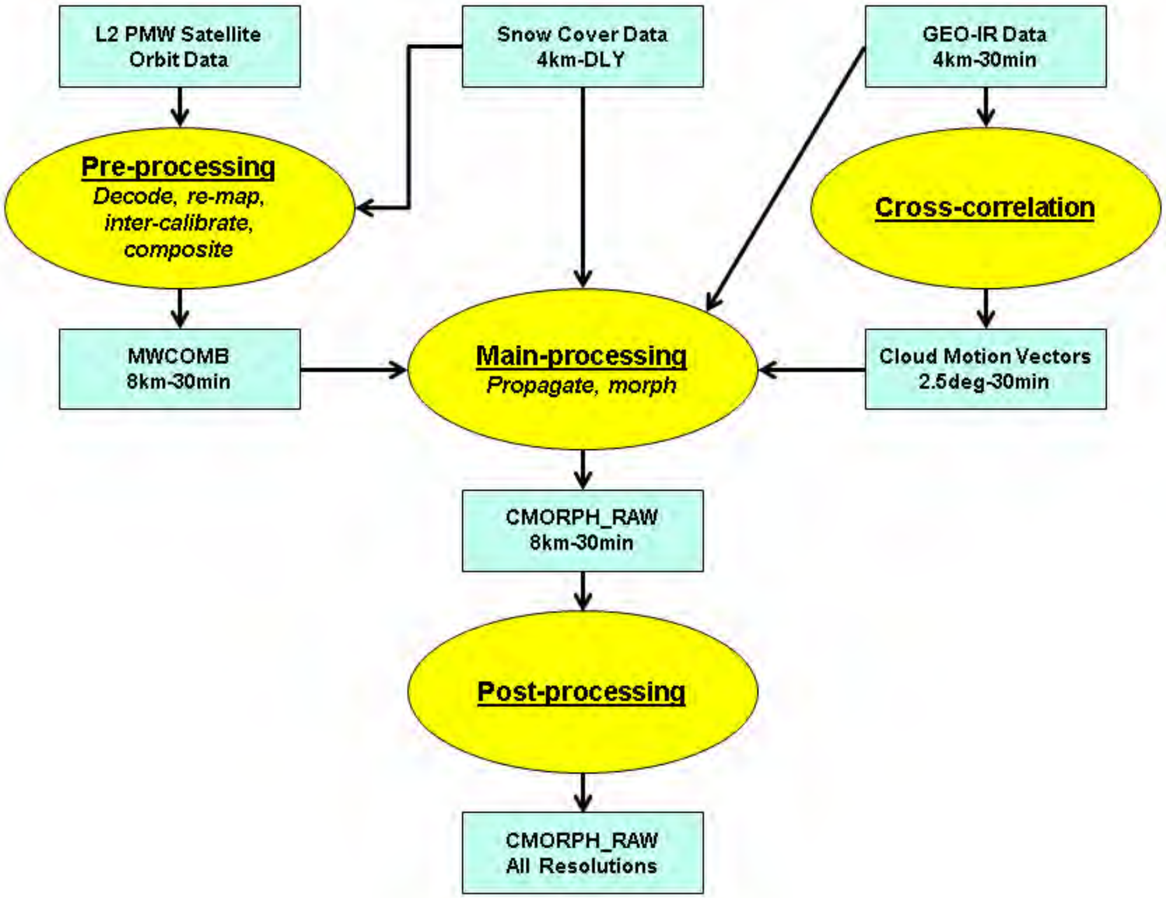
(3d) CMORPH strategy for integrating satellite data

- CMORPH: CPC Morphing technique
- Deriving cloud motion vectors through comparing two consecutive GEO IR images;
- Propagating the PMW precipitation retrievals from their respective observation times to the target analysis time along the cloud motion vectors
- Joyce et al. (2004), Xie et al. (2017)

Precipitation Analyses

[3] Satellite Estimates

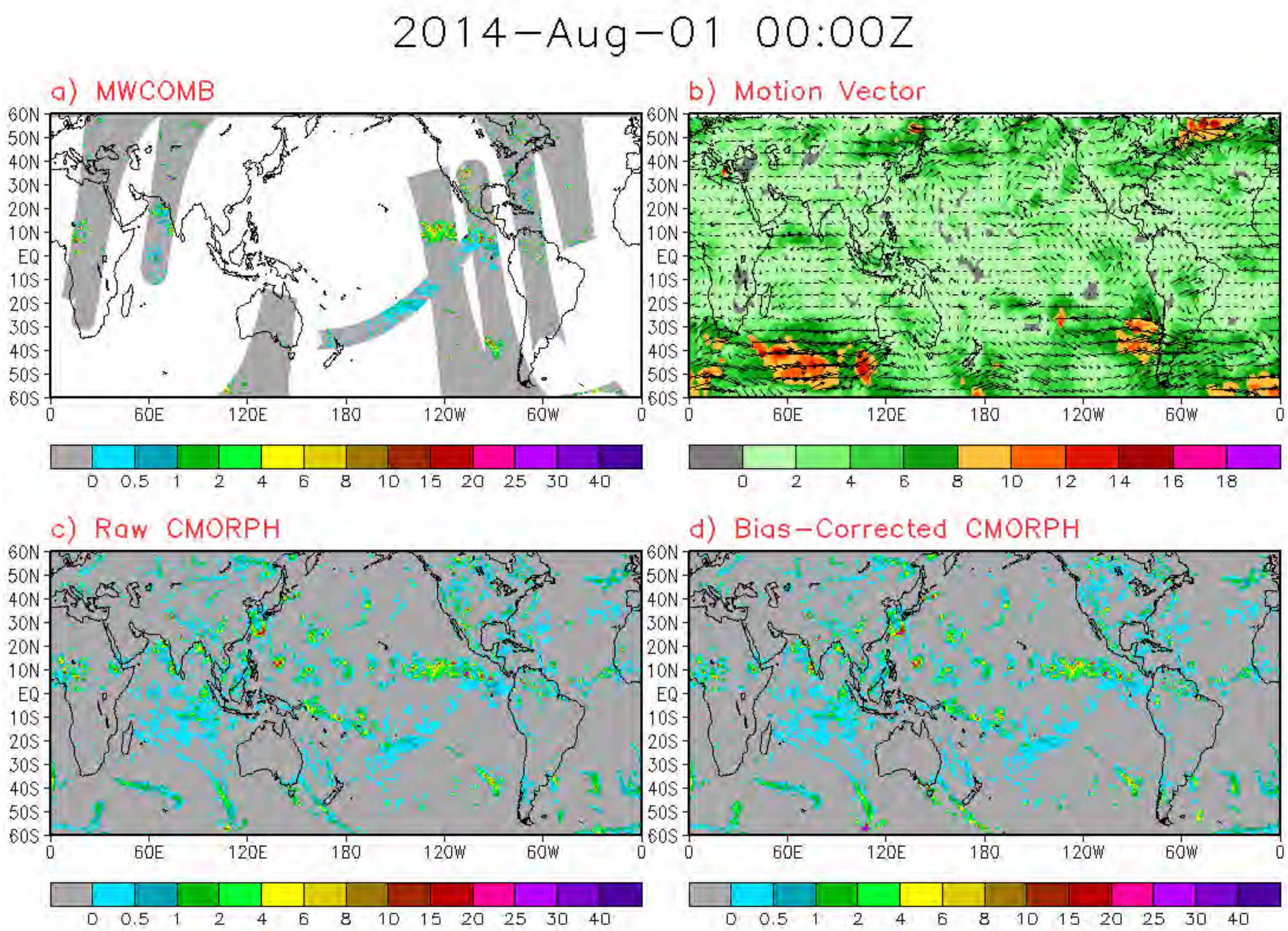
(3e) CMORPH satellite integration algorithm



Precipitation Analyses

[3] Satellite Estimates

(3f) Sample CMORPH for 1 August, 2014

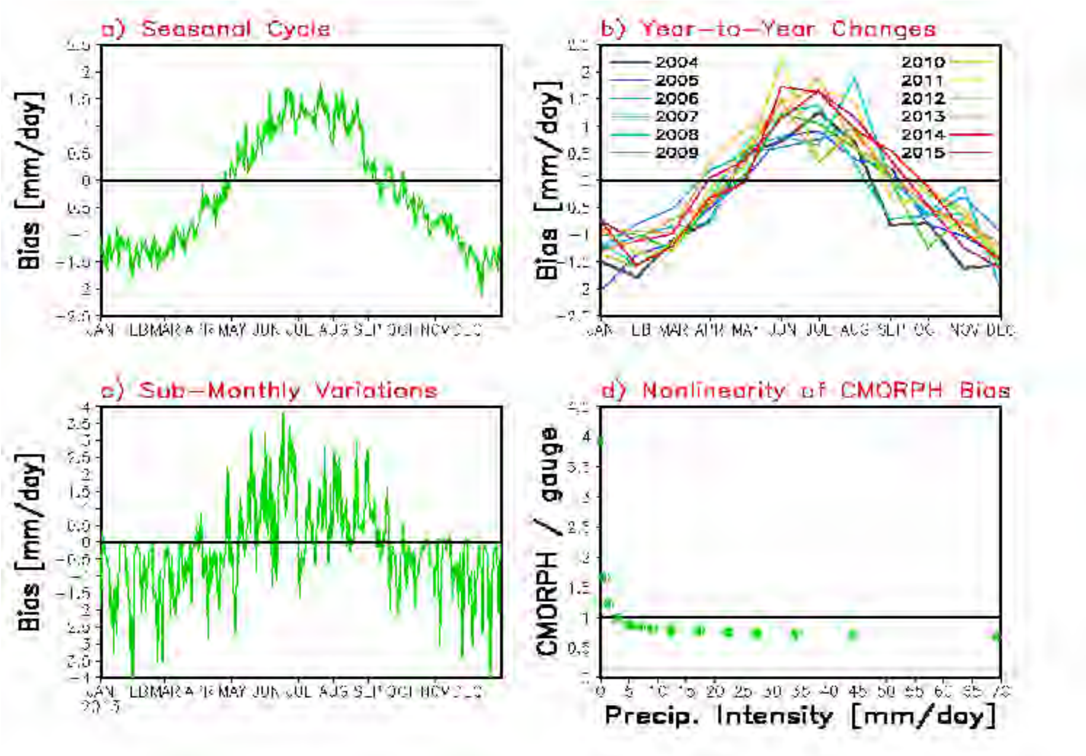


Precipitation Analyses

[3] Satellite Estimates

(3g) Purely satellite based CMORPH contains bias

- Bias changes with season, region;
- Present sub-monthly variations and differs year to year;
- Appears as a function of precipitation intensity

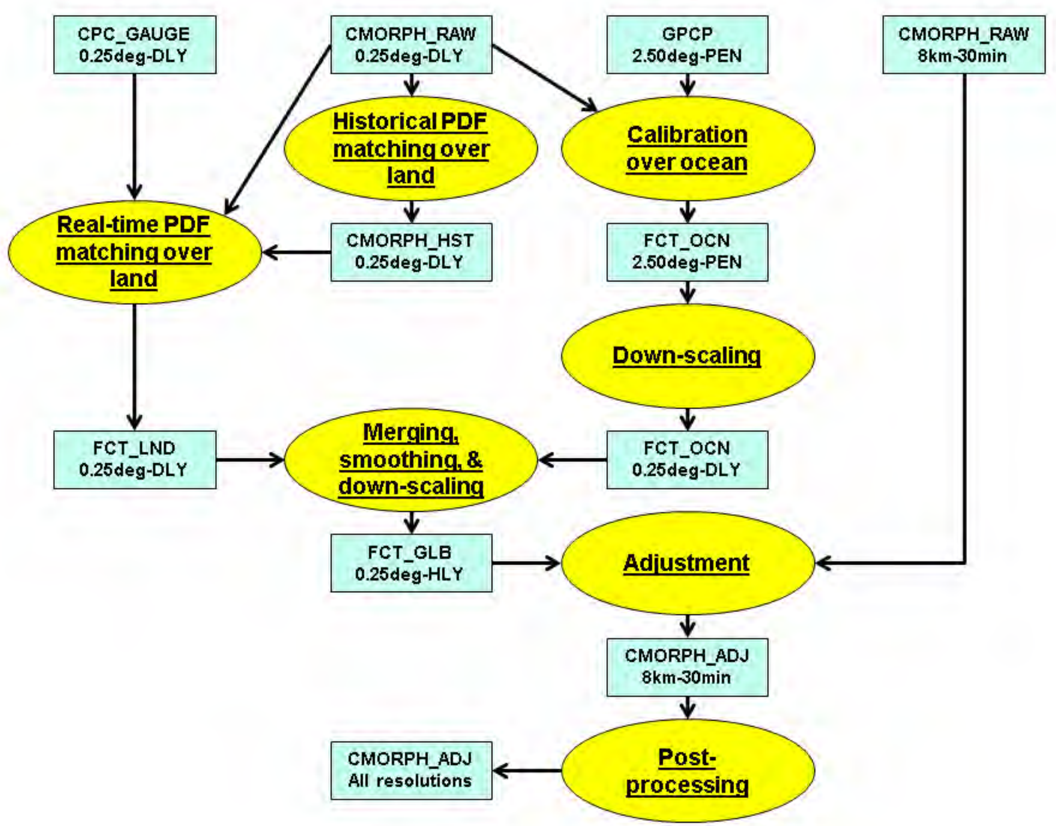


Precipitation Analyses

[3] Satellite Estimates

(3h) CMORPH bias correction

- Over land, PDF matching against CPC unified daily gauge analysis
- Over ocean, calibration against pentad GPCP

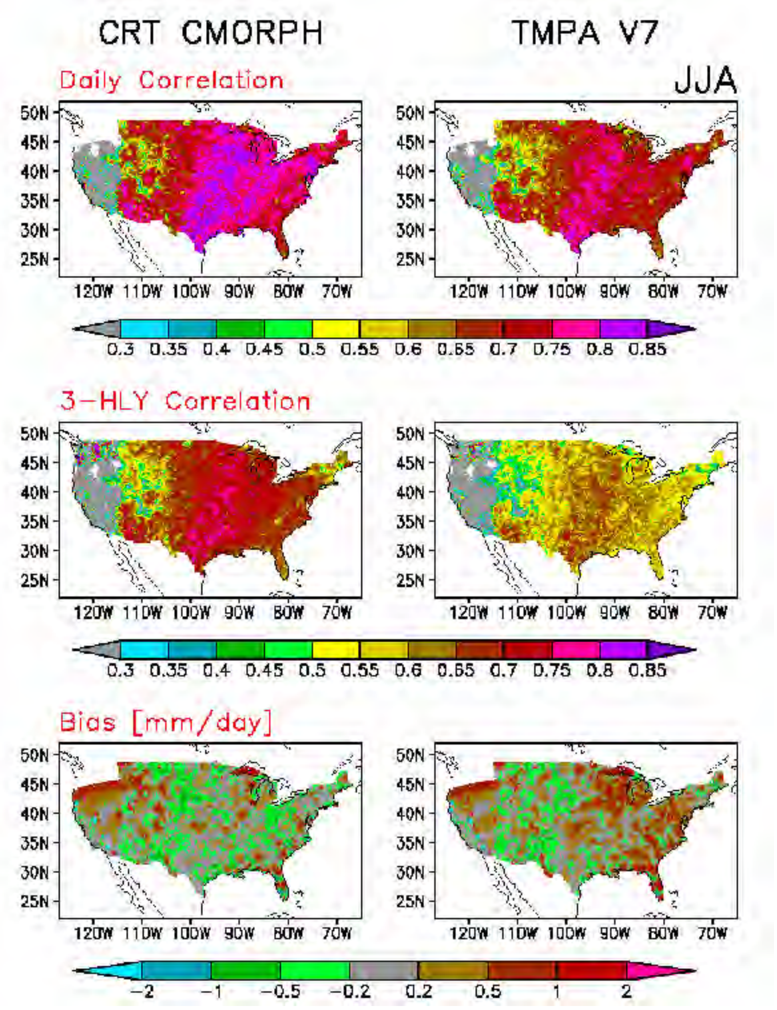


Precipitation Analyses

[3] Satellite Estimates

(3i) CMORPH exhibits superior performance

Comparison statistics for the CMORPH (left column) and TMPA Version 7 (right column) precipitation estimates against the NCEP Stage IV radar estimates. The statistics are computed for each grid box of 0.25°lat/lon grid over the CONUS using data for all 12 months over the June-July-August period from 2002 to 2015. Correlation for daily precipitation, 3-hourly precipitation, and bias (mm/day) are shown in the upper, middle, and bottom panels, respectively.



Precipitation Analyses

[3] Satellite Estimates

(3j) CMORPH products (CMORPH_CRT)

- *Reprocessed for the entire TRMM/GPM era (1998 to the present)*
- *Spatial resolution:* *8kmx8km, 0.25olat/lon;*
- *Temporal resolution:* *30-min, hourly, 3-hourly, daily*
- *ftp.cpc.ncep.noaa.gov/precip/CMORPH_V1.0*
- *Xie et al. (2017)*

Precipitation Analyses

[4] Multi-source fusion

(4a) Basic notion

- *CMORPH integrates information from all satellites*
- *Precipitation analysis will be improved through combining from CMORPH with that from other sources, including gauge measurements, radar estimates and even the model simulations*
- *As a first step, we developed a system to blend CPC daily gauge analysis with the bias corrected CMORPH (CMORPH_CRT)*

Precipitation Analyses

[4] Multi-source fusion

(4b) Algorithm

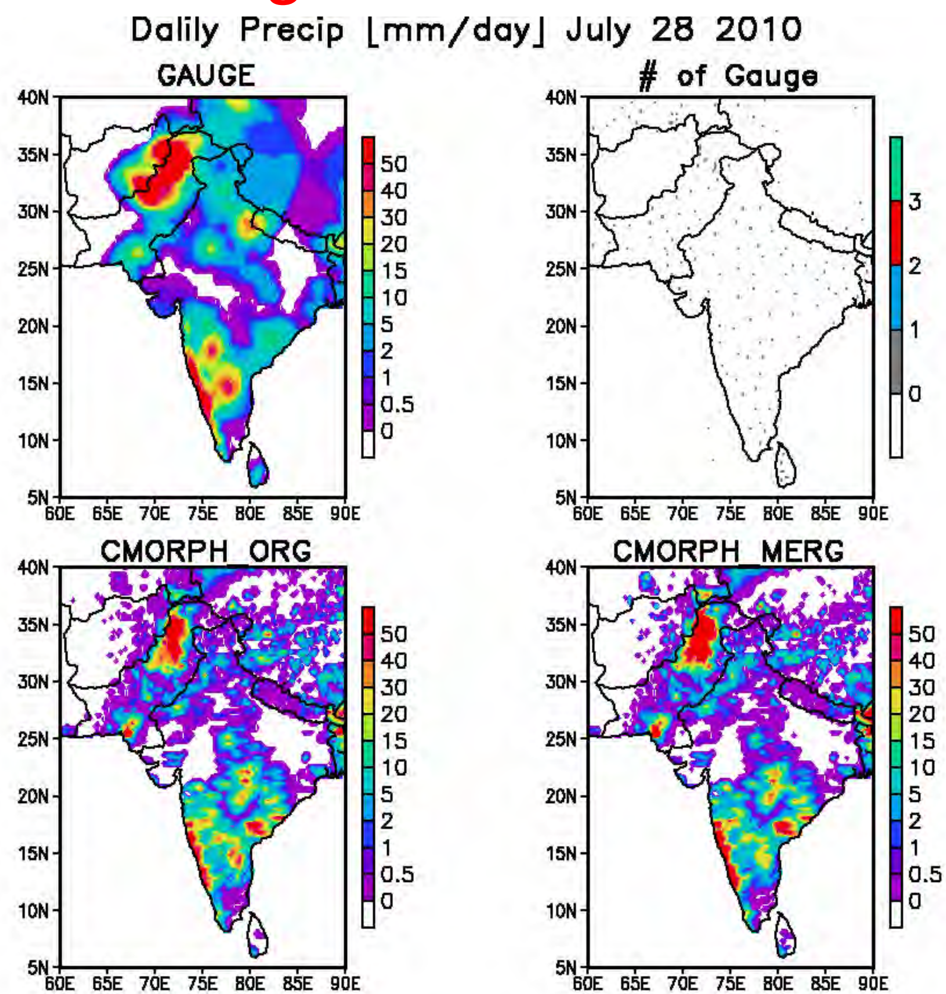
- *Combine the CPC gauge analysis with the bias corrected CMORPH through OI*
- *Bias corrected CMORPH used as the first guess*
- *Gauge data used as observation to refine the first guess*
- *Over regions of dense gauge network, the blended analysis is dominated by gauge data, while over regions of sparse gauge network, CMORPH plays major roles.*

Precipitation Analyses

[4] Multi-source fusion

(4c) An example of how blending works

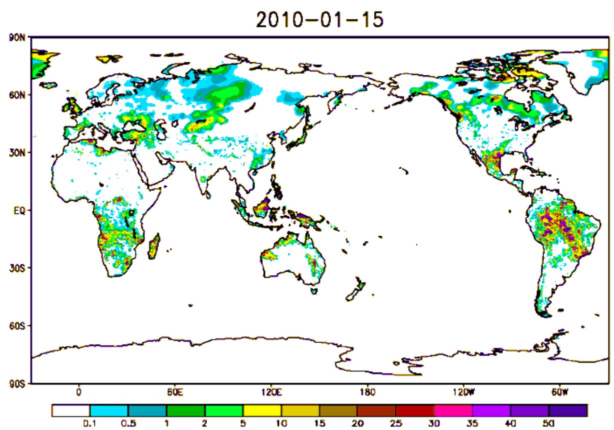
- Gauge analysis depict heavy rain but tend to extend the raining area
- Satellite data tend to under-estimate
- Merged analysis present improved depiction of the heavy rain

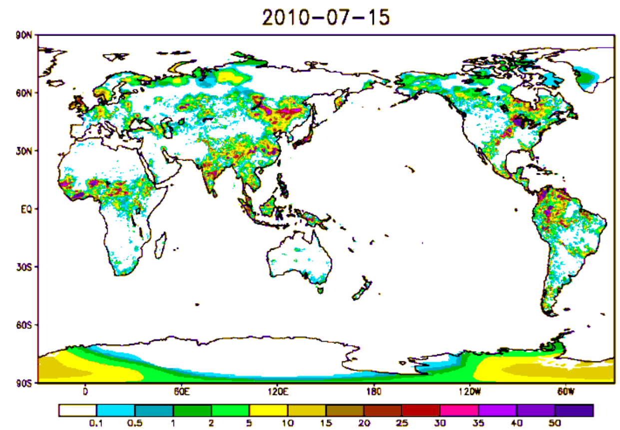


Precipitation Analyses

[4] Multi-source fusion

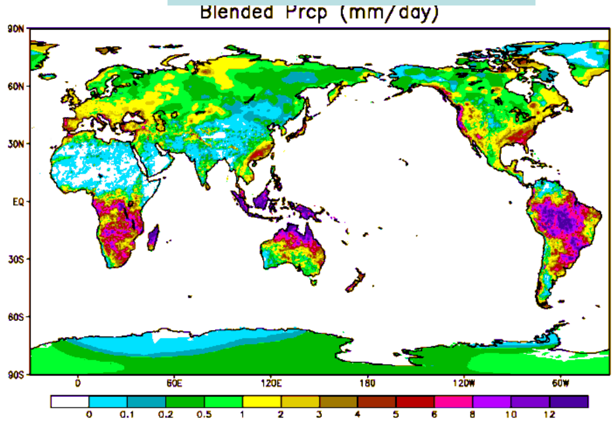
(4d) An example of CMORPH_BLD over the globe

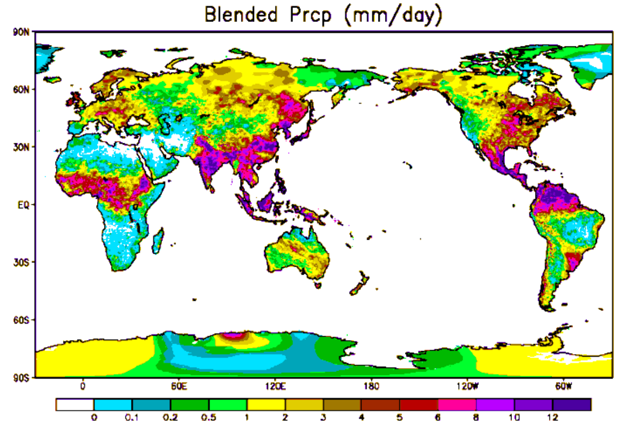




January 2010

July 2010





Precipitation Analyses

[4] Multi-source fusion

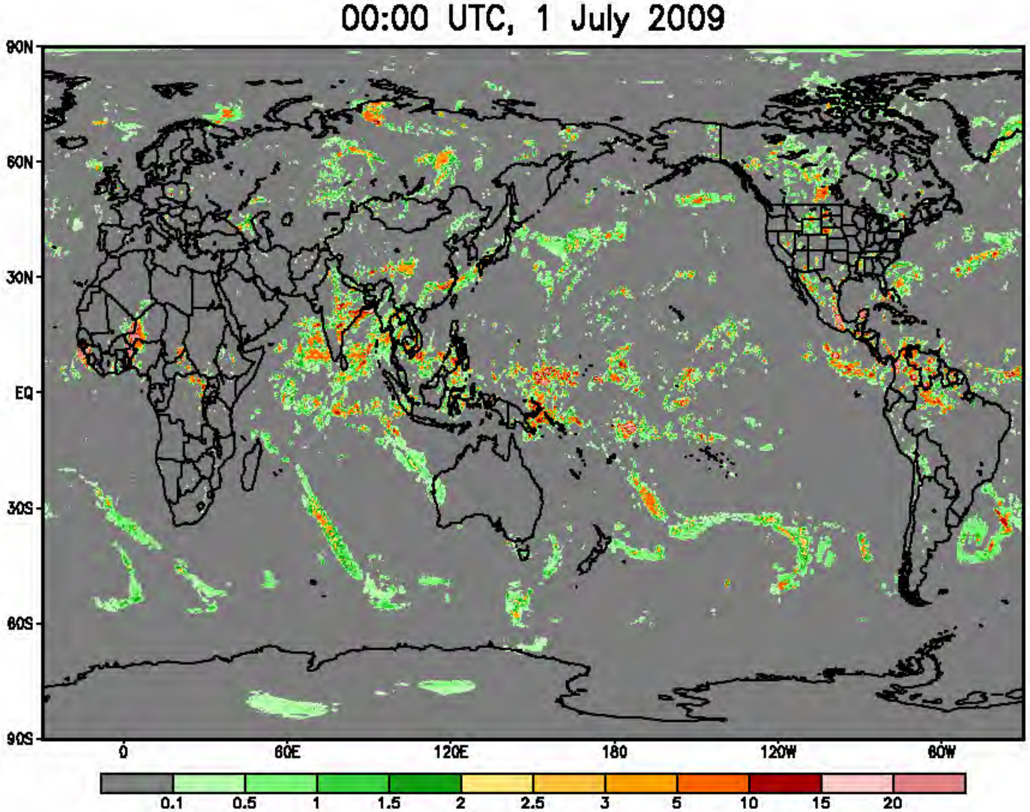
(4e) Products available

- CMORPH_BLD Version 1.0
- 0.25olat/lon over the global land
- Daily
- [ftp.cpc.ncep.noaa.gov/CMORPH_V1.0](ftp://ftp.cpc.ncep.noaa.gov/CMORPH_V1.0)
- Xie and Wu (2016)

Precipitation Analyses

[5] Ongoing developments

(5a) Second Generation CMORPH (CMORPH2)



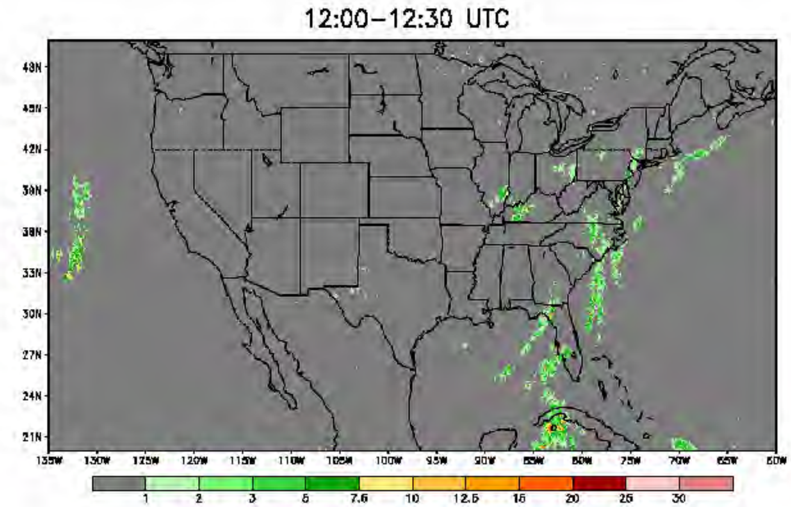
- *0.05^{o}lat/lon grid over the entire globe pole to pole*
- *Rainfall and snowfall*
- *Kalman Filter (KF) based CMORPH (Joyce and Xie 2011)*
- *Prototype developed*

Precipitation Analyses

[5] Ongoing developments

(5b) Regional CMORPH

- Taking advantage of information from the new generation GEO satellites (H8, GOES-R et al.)
- Refined resolution (2km/15-min)
- Reduced latency (up to 15-min)
- Improved quality
- A preliminary test model developed to demonstrate the concept and feasibility



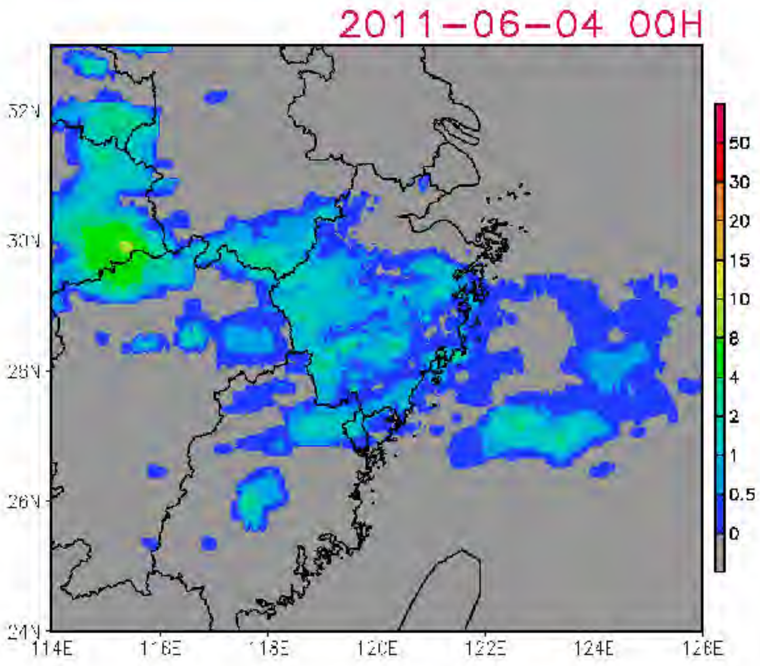
Precipitation Analyses

[5] Ongoing developments

(5c) Gauge-Radar-Satellite-Model Blended Analysis

- Further combining satellite precipitation with other information available regionally, including gauge measurements, radar observations and model simulations

- Preliminary test model developed for eastern China



Temperature Analyses

[1] Objective

- To develop a prototype system for the construction of high-resolution surface temperature over global land

    - Daily Tmax, Tmin, and Tave
    - $(1/6)^{o}$ lat/lon grid over global land
    - Explicit consideration of orographic effects
    - Historical record from 1979
    - Updated on a real-time basis

Temperature Analyses

[2] Input station data

- Tmax, Tmin from CPC archive of GTS reports
- Reports available from 5500 ~ 6000 global stations, with ~10% of them from US
- Technically possible to take in data from additional stations (e.g. over CONUS)

Temperature Analyses

[3] Interpolation algorithm

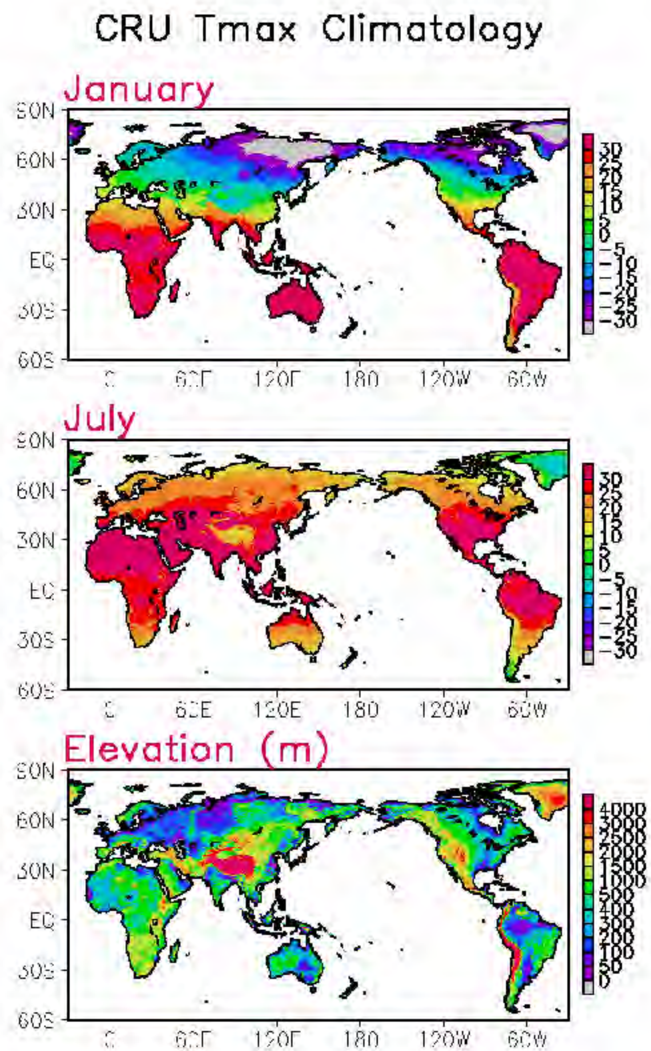
- Built upon a gridded climatology with orographic consideration
  - *Monthly Tmax/Tmin Climatology of CRU utilized*
  - *May consider replace it with PRISM over regions where PRISM is available (CONUS, China et al.)*

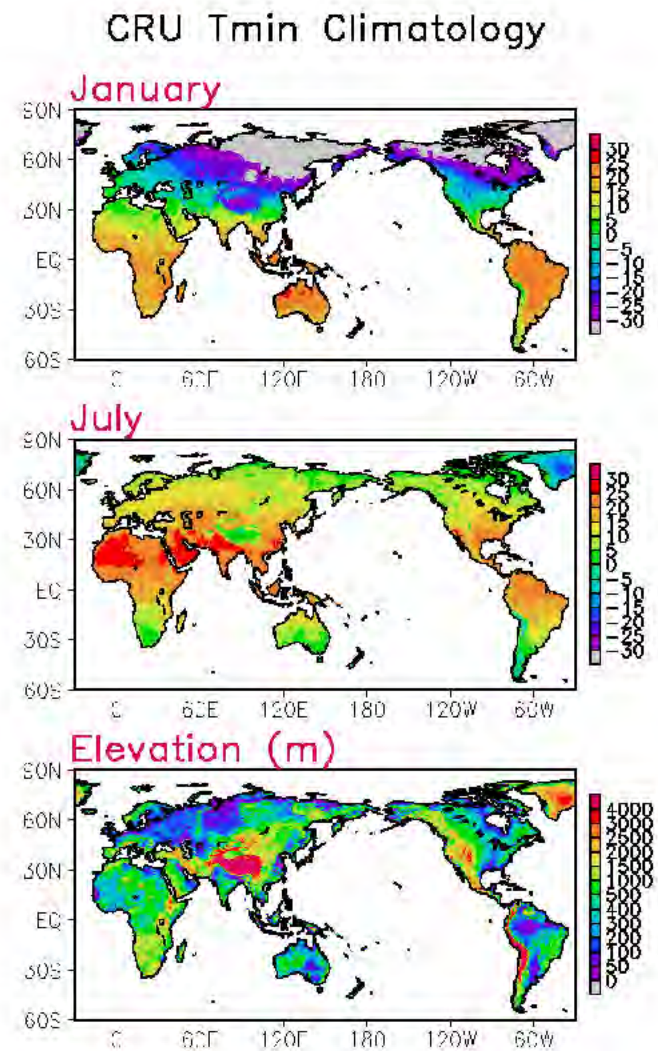
- Gridded analysis of temperature anomaly defined by interpolating station values through the Shepard algorithm
  - *Shepard algorithm is a distance-weight technique with directional correction*
  - *May consider using OI in the future*

- Gridded analyses of total temperature computed by adding the anomaly to the CRU climatology

Temperature Analyses

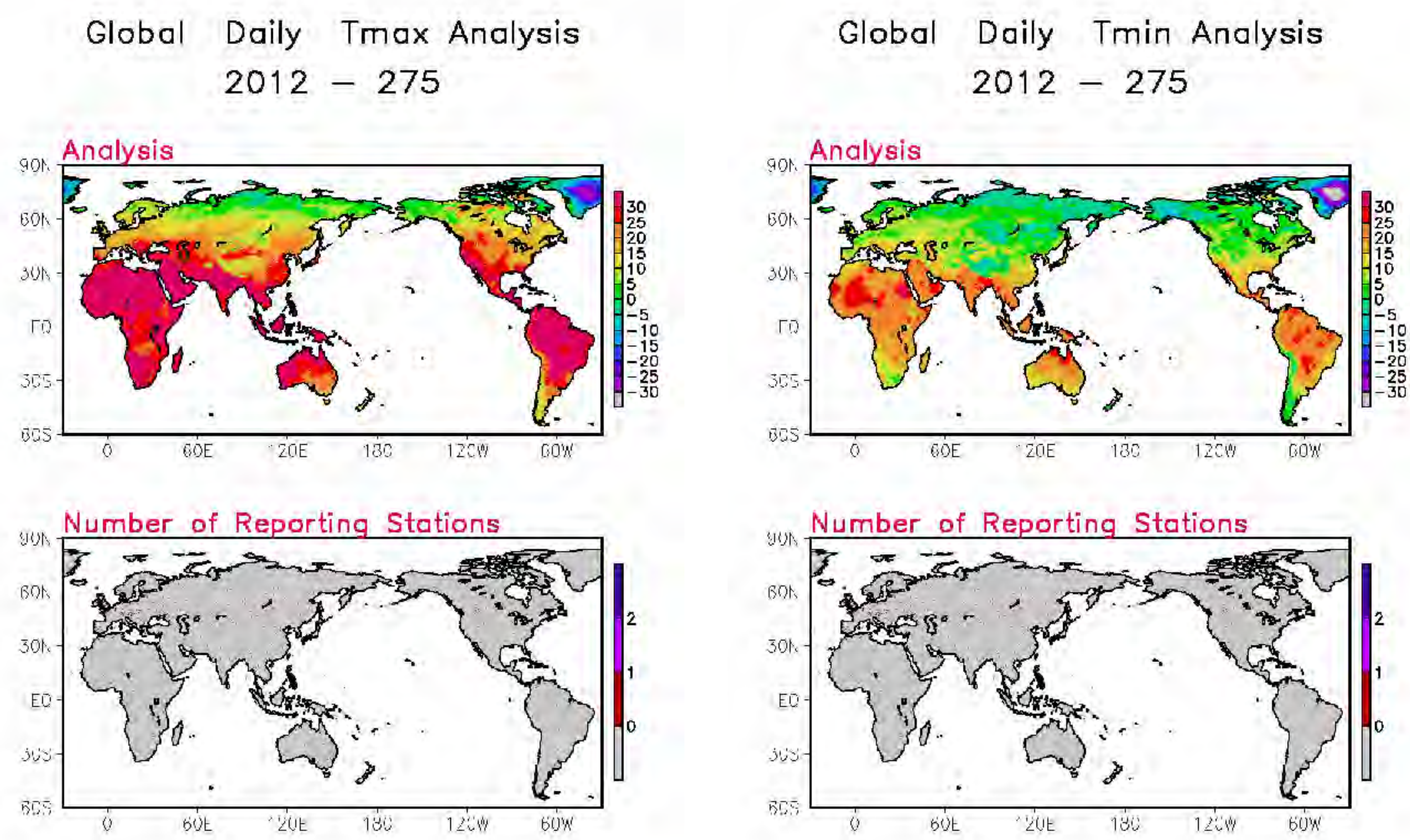
[4] CRU Tmax / Tmin Climatology





Temperature Analyses

[5] Sample Tmax / Tmin analyses



Temperature Analyses

[6] Products

- (1/6)^{o}lat/lon over the global land except Antarctic
- Daily from 1979 to the present
- Tmax, Tmin and Tave
- ftp.cpc.ncep.noaa.gov
- Dr. Wei Shi of CPC is in charge of daily operations
- Xie, Shi, and Kumar, (2017) (under drafting)

Temperature Analyses

[7] New developments --- Down-scaling to hourly

- In situ observation data of hourly surface air temperature not available over the global domain

- Adjust the CFS reanalysis hourly temperature data against the CPC daily temperature analysis

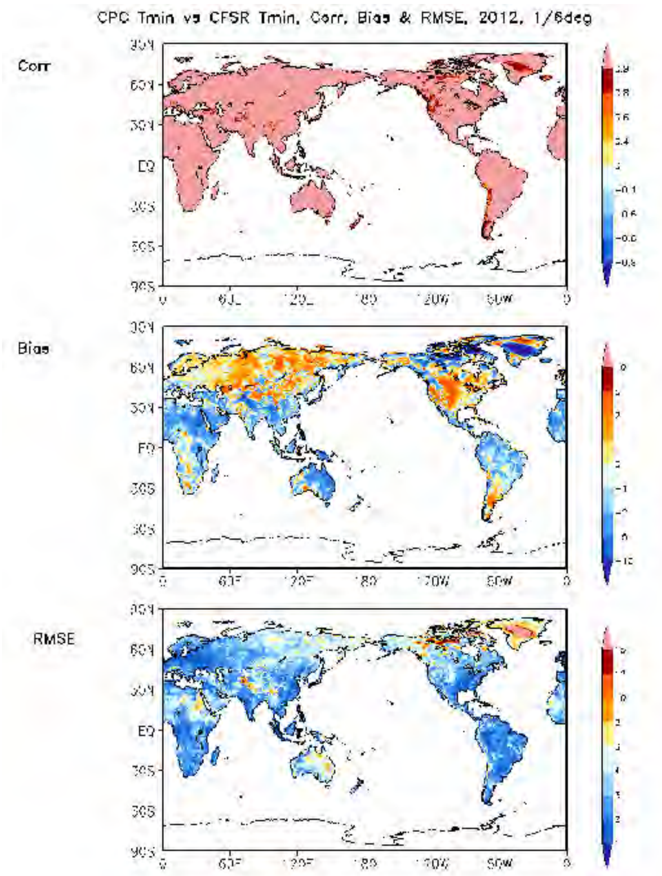
- Retain the hourly temporal variation patterns in the CFSR

- Remove the bias in the CFSR surface air temperature through forcing the 5-day running mean of the daily Tmax / Tmin in the CFSR match with that of the CPC daily temperature

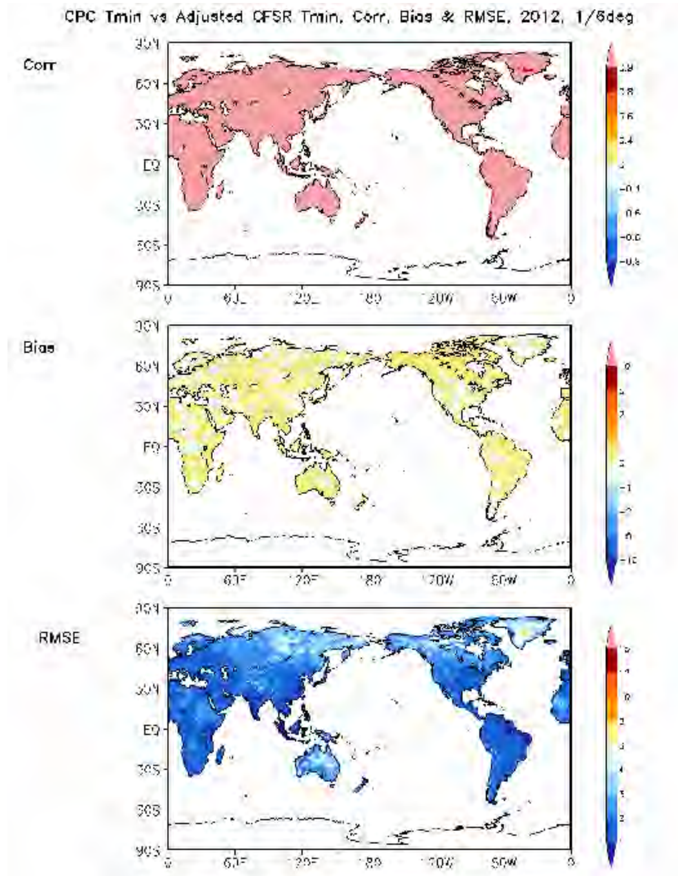
Temperature Analyses

[8] Comparison with Daily Tmin

Before Correction



After Correction



Summary

[1] CPC P and T products

- CPC Unified daily gauge analysis
- CMORPH bias corrected satellite precipitation (CMORPH_CRT)
- Gauge – CMORPH blended daily precipitation analysis
- CPC analyses of daily Tmax and Tmin

Summary

[2] Challenging Issues for T / P analyses

- Accurate representation of orographic effects in in situ analysis, satellite estimates and blended products
- remote sensing of heavy rainfall
- Detecting / quantifying snowfall (solid precipitation)
- Small scale / warm cloud precipitation
- Optimal strategy of fusing precipitation information from all sources (how to take advantage of model simulations?)
- Optimal strategy to construct long-term homogeneous data sets taking advantage of both the new technology in recent years and heritage observations for extended period