Creating and Using Sensors That Tell Us about Precipitation

George J. Huffman
NASA/GSFC Earth Sciences Division – Atmospheres

george.j.huffman@nasa.gov

Invited
Centennial

- Introduction
- Instruments
- Algorithms
- Archives
- Closing Remarks

1. INTRODUCTION

The physical process is hard to represent:

- the driving forces vary across a range of space/ time scales
- precip is generated on the microscale
- the decorrelation distance/time is short
- point values only represent a small area & snapshots only represent a short time

Intermittent sampling in space or time causes problems

Drop/crystal size distributions (PDF) and crystal configuration significantly complicate observations

Image courtesy of the University Corporation for Atmospheric Research

2. INSTRUMENTS – Direct

Precipitation gauges

- earliest quantitative weather data
- gauges started to be standardized in late 1800's
- several technologies
  - manual accumulation
  - weighing
  - siphon (capacitance)
  - tipping bucket

Issues

- lack of complete metadata
- undercatch (hydrometeors blown around opening)
  - varies across PDF, worse for snow
  - various gauge shapes
  - single, double fences
  - pit gauges
- stickiness of snow
  - heated gauges
  - snow pillows
- lack of adequate global sampling

2. INSTRUMENTS – Surface remote sensing (1/2)

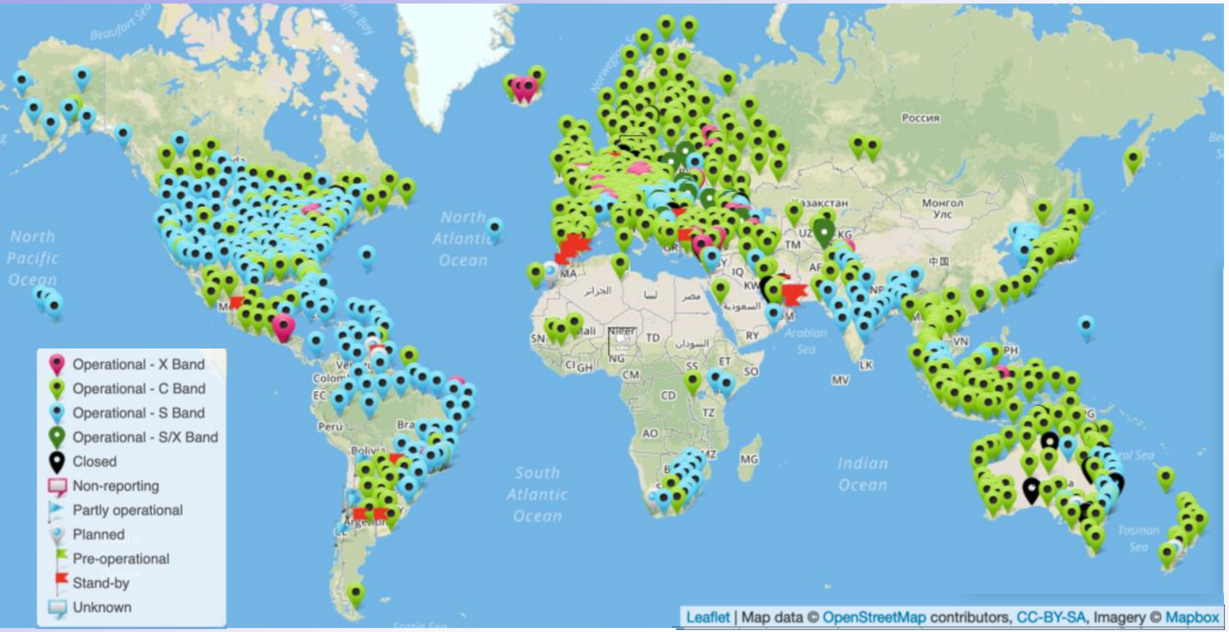
Radar

- discovered in WWII that precipitation interfered with the goal of detecting aircraft
- frequently the case in remote sensing that one application's "noise" is another's signal
  - is the signal strong enough to be quantitatively useful?
- competing design goals
  - light rate sensitivity (shorter wavelengths)
  - low attenuation (longer wavelengths)
  - small size (shorter wavelengths)

Issues

- strong nonlinearity between signal and precipitation content / PDF
- small-scale variability (beam filling)
- anomalous propagation
- ground clutter
- these are improved by using
  - small beams/range gates
  - dual polarization
  - multiple frequencies
  - Doppler
- lack of good intercalibration
  - U.S. Multi-Radar Multi-Sensor (MRMS) is an operational scheme to get homogeneity
- lack of adequate global sampling

2. INSTRUMENTS – Surface remote sensing (2/2)



Surface radar coverage* according to WMO (https://wrd.mgm.gov.tr/Home/Wrd)

* Many countries restrict access to their radars

Precipitation gauges

- optical
- hydrophone
  - typically represent a diameter of a few km
  - initially tested on buoys, now installed on drifters

Terrestrial microwave links

- commercial links (primarily telecom) continuously monitored for attenuation (primarily due to precipitation)
- typically numerous links with paths ~10 km
- initially developed in the Netherlands, some work in West Africa
- mixed response from companies allowing access to their attenuation data

2. INSTRUMENTS – Satellite remote sensing (1/2)

Passive microwave

- provides the bulk of global satellite estimates
- much stronger physical connection to hydrometeors than IR, but still an integrated signal
- frequencies below 37 GHz dominated by emission by liquid hydrometeors, cloud liquid, vapor
- frequencies above 37 GHz start out showing emission, but quickly dominated by solid hydrometeor scattering
- channels above 100 GHz needed to get best snowfall estimates

Issues

- strong nonlinearity between signal and precipitation content / PDF
- small-scale variability (beam filling)
- land surface emission dominates precip emission (but water surfaces are o.k.)
- surface snow/ice scattering same order as precip scattering for typical channels
- size → expense
- footprint size tends to be 10-20+ km
- only available on low-Earth orbit satellites
  - each satellite gives ~2 looks per day
  - "virtual constellation" (orbits not coordinated)
    - ~12 satellites
    - observation interval <3 hr 90% of the time
    - diverse instrument designs

2. INSTRUMENTS – Satellite remote sensing (2/2)

Infrared

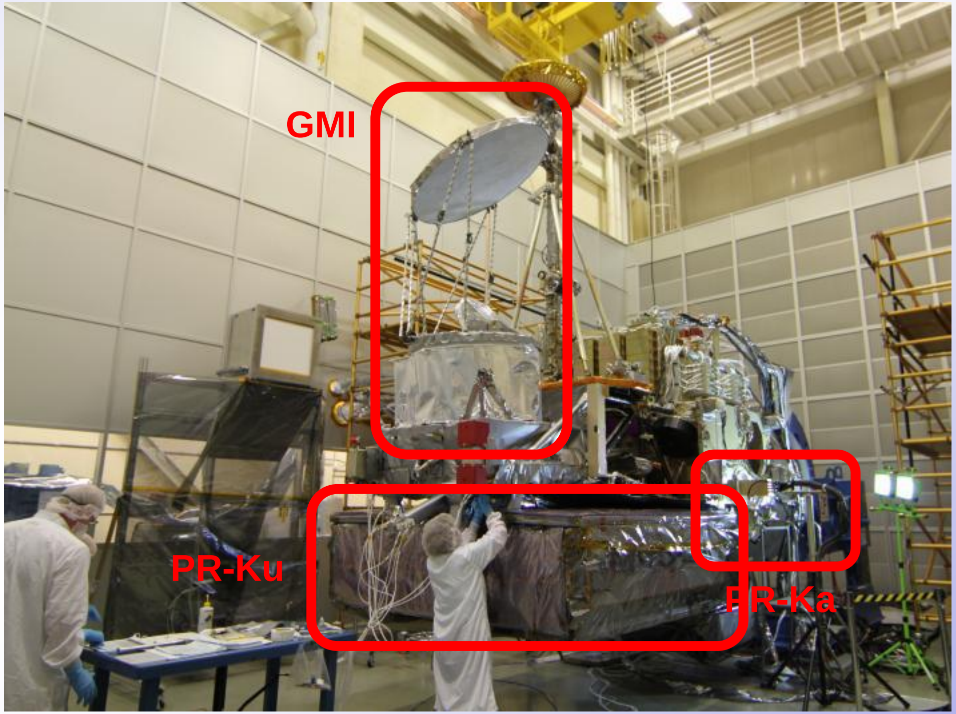
- earliest quantitative satellite estimates
- fine-scale time/space sampling, but
- modest physical relationship between cloud top and surface precipitation
  - best for convective systems
- still in wide use to fill holes in microwave

Radar (active microwave)

- similar to surface-based, but looking down
- required power, size, and data rates limit the flight opportunities to date
- TRMM, GPM, Cloudsat
- primarily used in calibration and climatological statistics

Soil moisture

- work backwards to get how much rain must have fallen



3. ALGORITHMS

Remote sensors always have some kind of retrieval

- the problem is usually (very) underdetermined
  - equations are closed using ancillary and climatological (or "typical behavior") information
  - true for both "statistical" and "physical" schemes
- different algorithms, and even versions of the same algorithm, can give quite different results
- practically every algorithm is "best" someplace

It is frequently necessary to "grid" remote-sensing and surface precipitation data

- researchers keep re-learning that precipitation statistics are sensitive to how gridding is done
  - one key problem is that interpolating zero and non-zero ***always*** gives non-zero

Combinations

- multiple microwave and/or IR satellites are combined to improve time/space sampling
- details depend on the goals of the developers
  - Climate Data Record (CDR)
    - prioritize homogeneity over detail
    - Global Precipitation Climatology Project (GPCP)
  - High Resolution Precipitation Product (HRPP)
    - prioritize detail over homogeneity
    - NASA Integrated Multi-satellitE Retrievals for the Global Precipitation Measurement (GPM) mission (IMERG)
    - NOAA Climate Prediction Center (CPC) Morphing (CMORPH)
    - JAXA Global Satellite Map of Precipitation (GSMaP)

3. ALGORITHMS – what a modern satellite combination provides

3. ALGORITHMS – Numerical models

The limiting case of “algorithms” is outright computation of precipitation in numerical models

- attractive in principle
    - “just” solve the necessary equations
    - enormous practical problems in solving the microphysics
    - assimilating precipitation estimates is (very) difficult … “stiff” equations
- tend to be worst in convective situations, best in stratiform
    - “good” models more skillful than ”good” retrievals in cold/snowy regimes (i.e., polar and winter)

4. ARCHIVES

A vast amount of precipitation data comes from multi-use and "other" sensors

- research sensors frequently stand in for operational sensors
- near-real-time access to data enables a whole range of societal benefit applications
- open data access is key
  - competing interests of
    - freely available products from U.S. government and academics (among others)
    - cost recovery by data producers

Many users depend on intermediate datasets that partially digest the basic data

- global fields from multiple satellites (CPC 4-km global IR)
- retrievals from individual satellites

Archives of sensor, retrieved, and combined datasets all need to be maintained over decades

- reprocessing based on new quality control, calibrations, and navigation
- modernization of formats
- develop new concepts in intermediate datasets

5. CLOSING REMARKS

Increasing number of sensors that can yield precipitation data

- satellites are the only practical way to cover most of the globe
- but networks of surface precipitation gauges are still key for providing tie points and validation
- current and newly developed concepts are not yet being fully employed
- current microwave constellation is not assured into the future
- also true for gauges, radars, …

Increasing compute power might enable moving research concepts to (quasi-)operations

- multi-spectral retrievals with intermediate datasets of multi-channel geosynchronous data
- improved time interpolation in combination schemes
- more use of regional datasets in combination schemes

Getting the pay-off for societal benefit applications depends on the end-to-end processing chain

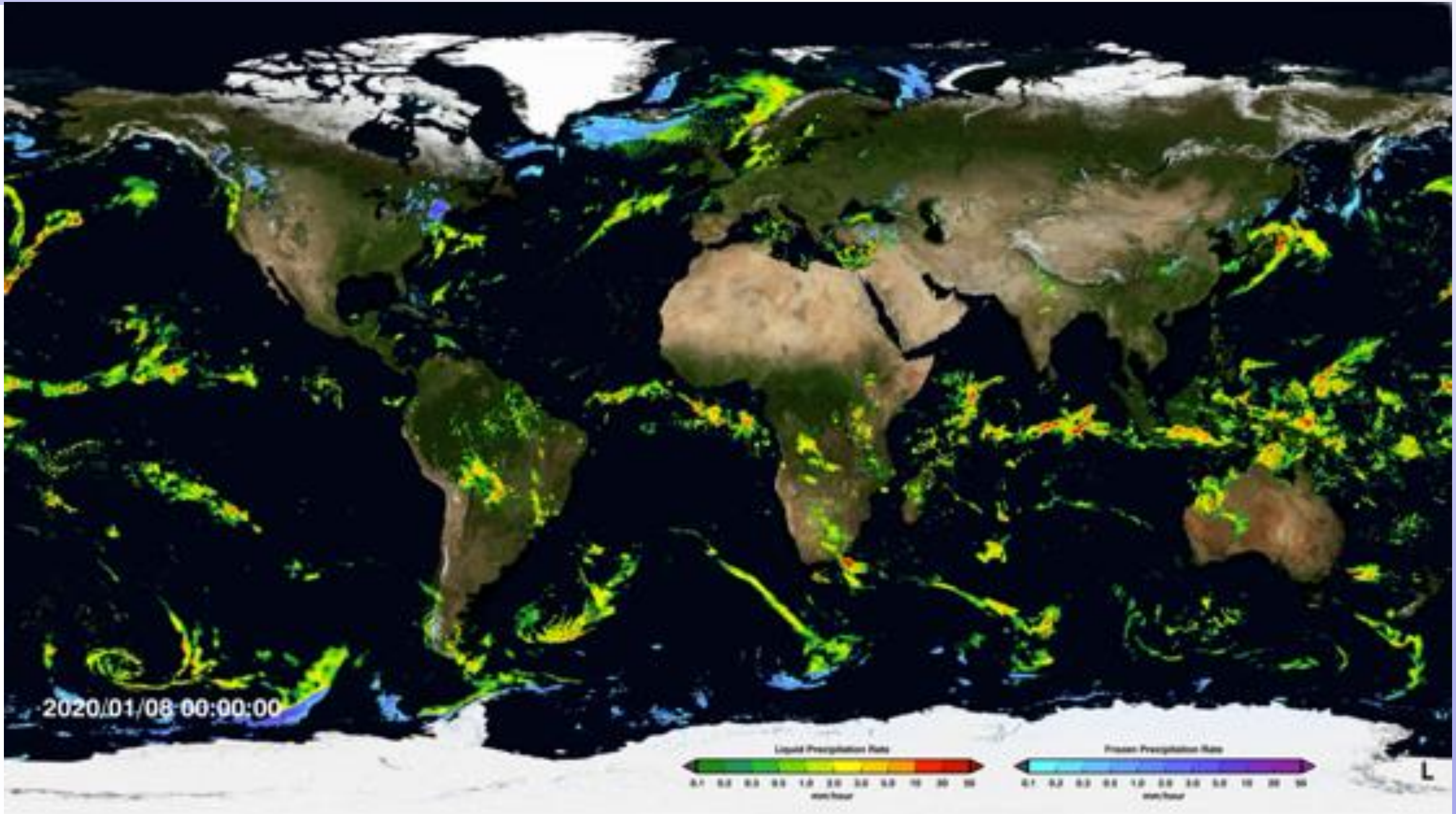
- this is important
  - a broad spectrum of scientific and application users care
  - there’s a broad assumption that whatever is being done is stable and will persist
  - users need to be aware of limitations … and benefits

5. CLOSING REMARKS – “Last week of IMERG”, an approximation to what we want

IMERG provides

- retrieval <u>intercalibration</u> involving space-based radar/radiometer combination
- 3 products at <u>latencies</u> of 4 hr, 14 hr, 3.5 months
- 0.1ºx0.1º half-hourly
- 20 years of data, and extending in time

This result is only possible due to the <u>long-term availability</u> of instrumentation, algorithms, and archives



See https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4285