Satellite Remote Sensing of Precipitation

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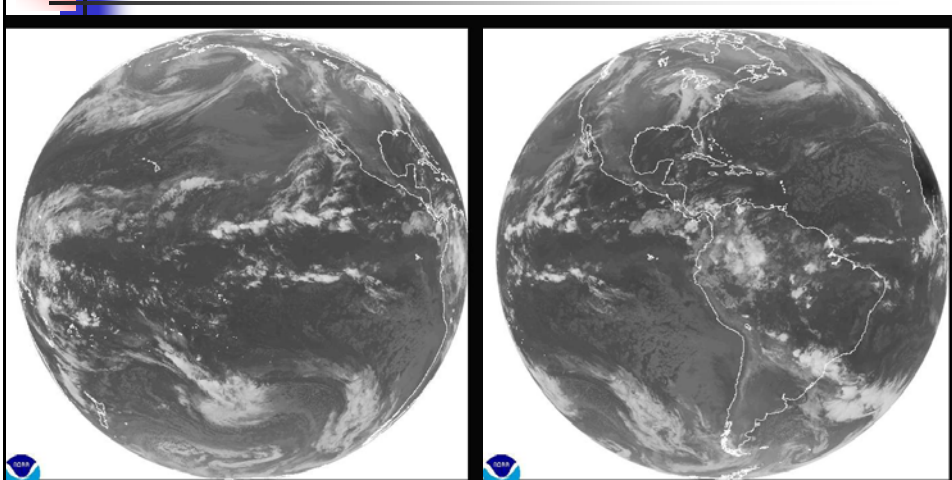
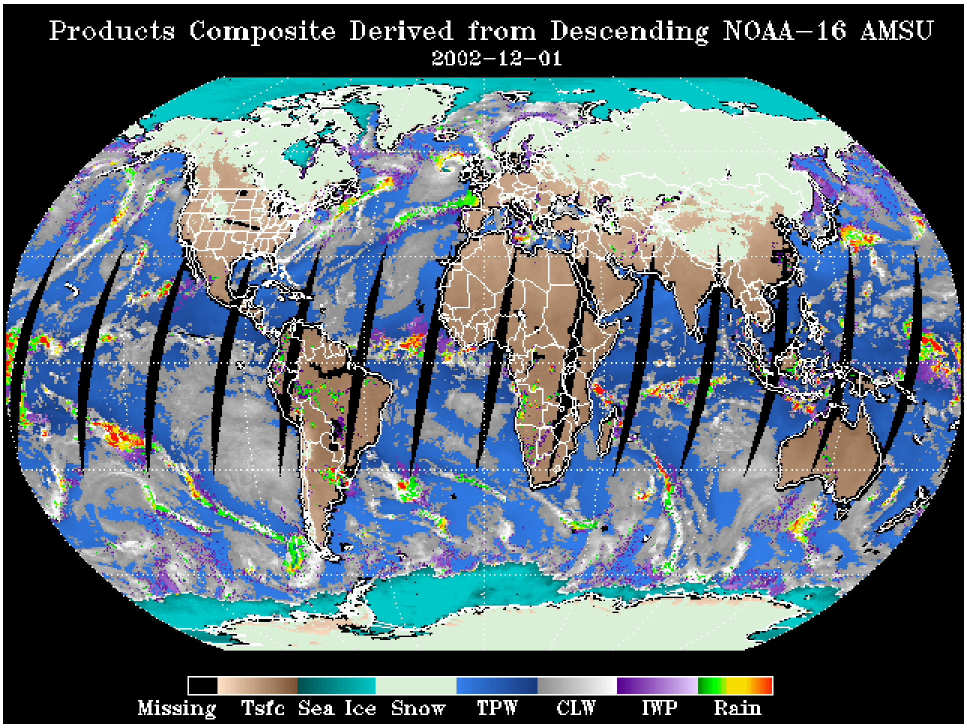
GOES W and GOES E IR Imagery





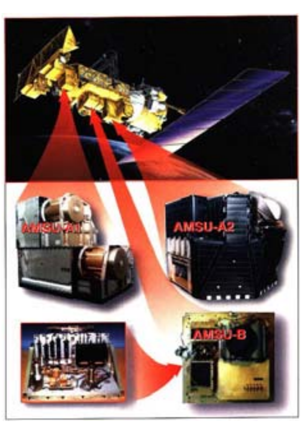
My goal today…

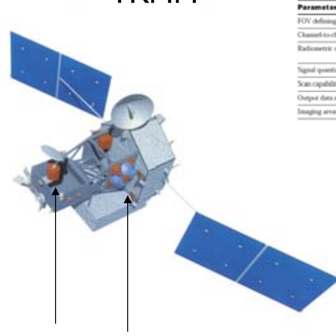
- Not to bog you down with equations, but present to you a qualitative understanding of satellite remote sensing of precipitation
  - Why we do it
  - How we do it
  - Show you a variety of techniques (not inclusive)
  - Strengths and weaknesses of techniques
- Expose you to some operational applications
- Talk about issues with validation

Outline

- Principles of precipitation remote sensing overview
- IR Methods
- Visible and near IR methods
- Passive Microwave Emission Methods
- Passive Microwave Scattering Methods
- BREAK
- Integrated Satellite Methods
- Applications & Examples (with an emphasis on operational algorithms)
- Validation
- Assignment
- Some References

Types of Instruments we'll discuss

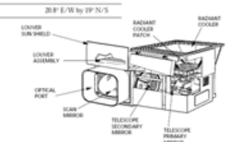




Imager Instrument Characteristics

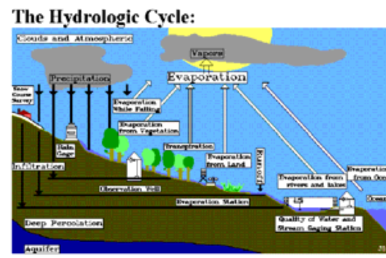
Channel	Detector Type	Nominal square IGFOV at nadir
1 (Visible)	Silicon	1 km
2 (Shortwave)	InSb	4 km
3 (Moisture)	HgCdTe	8 km
4 (Longwave 1)	HgCdTe	4 km
5 (Longwave 2)	HgCdTe	4 km

Parameter	Performance
FOV defining element	Detector
Channel-to-channel alignment	28 μrad (1.0 km) at nadir
Radiometric calibration	300 K internal blackbody and space view
Signal quantizing	10 bits, all channels
Scan capability	Full earth, sector, area
Output data rate	2,620,800 b/s
Imaging areas	20.8° E/W by 19° N/S



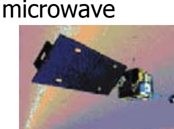
Why Precipitation?

- Key component of the water cycle!
  - Societal importance
    - fresh water
    - agriculture
    - water management,
    i.e., droughts and floods
  - Scientific importance
    - latent heat release - affects storm dynamics, circulation and atmospheric structure
    - affects ocean salinity
    - Improved hydrological models
      - Regional process → global process → models

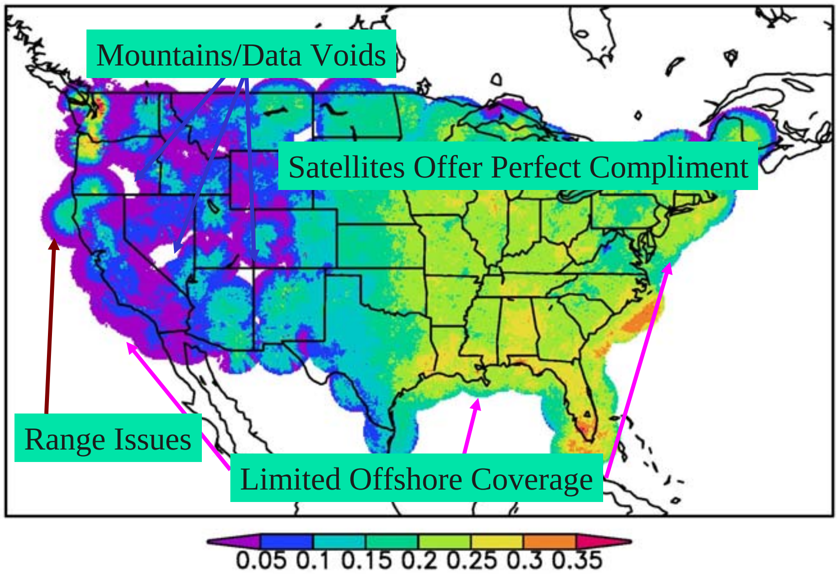


Role of satellites

- Limitation of **radar networks** and **sparse gauge coverage** require satellites for estimating precipitation
  - Polar orbiting satellites
    - Good global coverage –poor temporal sampling
    - Good choice of spectral intervals; IR, Vis, passive and active microwave
  - Geostationary satellites
    - IR and Vis , no MW channels
    - Excellent temporal sampling , regional spatial coverage
    - Provides excellent tool for estimates of extreme events, e.g., flash floods
- Challenges
  - Utilization of GOES and POES data for best estimates of precipitation at all space and time scales



WSR-88D Frequency of Rainfall Occurrence for 1998 - 2000



Radars can miss rainfall over river basins

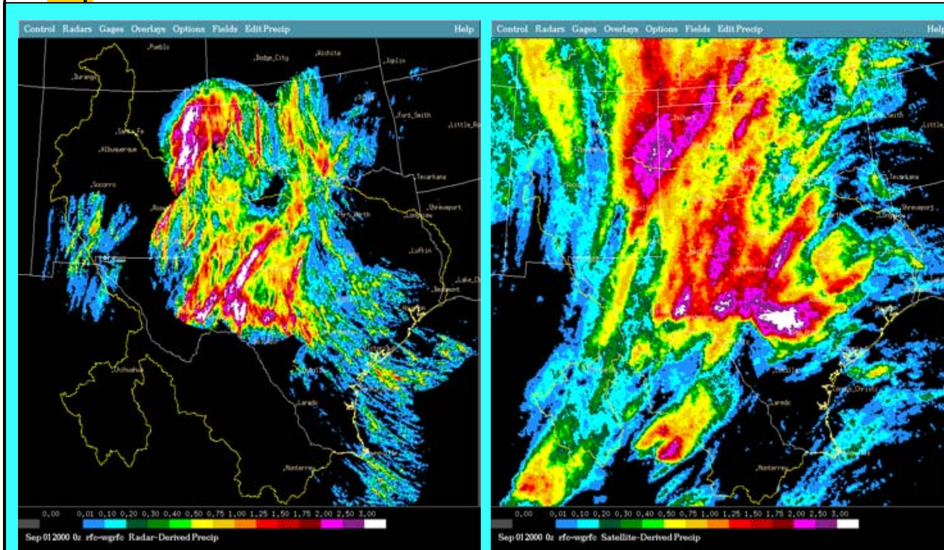
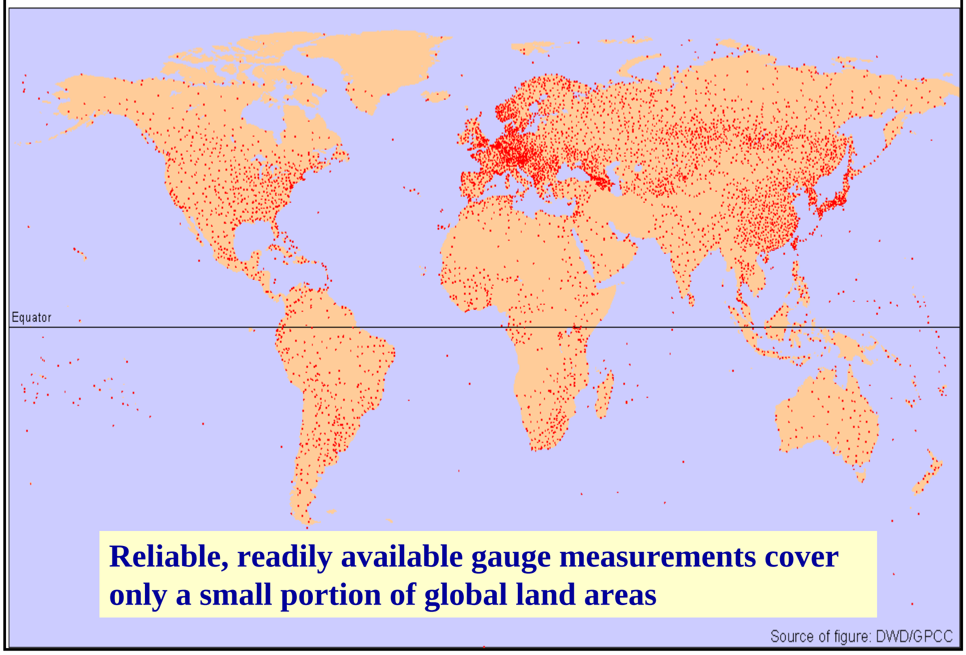


Figure 1. Comparison of precipitation estimates from radar (left) and satellite (right) over the Rio Grande Valley of Texas and northern Mexico, illustrating the limitations of radar coverage in this region.

Distribution of stations in the Point Data Bank of GPCC (GTS data only)

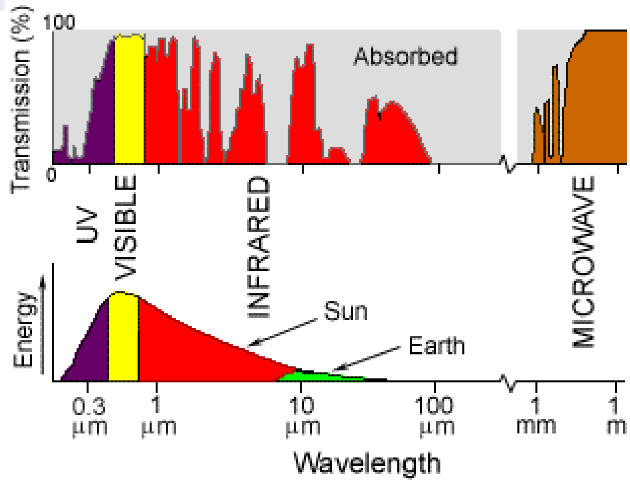
Month: July 1987; Total number of stations: 6328



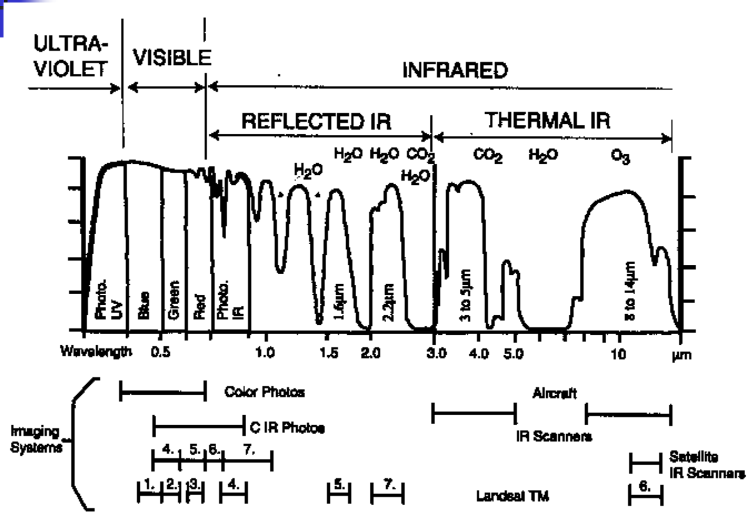
Remote Sensing of Precipitation

- Depends upon spectral response of precipitation to wavelength being utilized
  - Cloud tops, motion, changes – IR
  - Cloud texture - vis
  - Cloud droplets and ice particles – vis, near IR, IR, MW
  - Precipitation phase - MW
- Depends if passive or active
  - Radiometer
  - Radar
- Depends on satellite type (POES or GOES)
  - Spatial and temporal sampling
- Depends on nature of system
  - Tropical vs. high-latitude
  - Summer vs. winter

Electromagnetic Spectrum



Visible & IR Spectrum

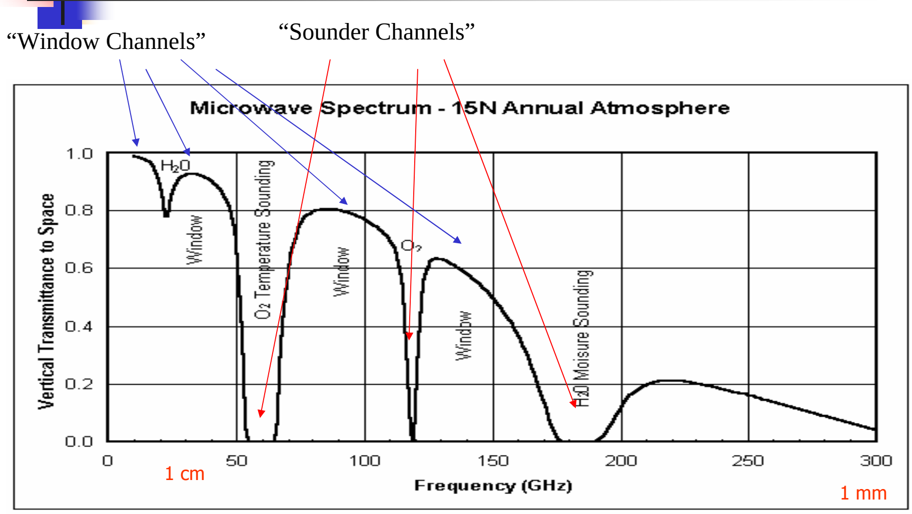


Satellite instruments designed to take advantage of E.M. Spectrum…

Imager Instrument Characteristics (GOES I-M)

Channel number:	1 (Visible)	2 (Shortwave)	3 (Moisture)	4 (IR 1)	5 (IR 2)
Wavelength range (um)	0.55 - 0.75	3.80 - 4.00	6.50 - 7.00	10.20 - 11.20	11.50 - 12.50
Instantaneous Geographic Field of View (IGFOV) at nadir	1 km	4 km	8 km	4 km	4 km

Microwave Spectrum



And another instrument…AMSU

Channel	Frequency	Channel	Frequency
A1	23.8 GHz	A8	55.5 GHz
A2	31.4	A9-A14	57.290**
A3	50.3	A15	89.0
A4	52.8	B1	89.0
A5	53.6	B2	150.0
A6	54.4	B3-5	183.31**
A7	54.9		

What about radars?

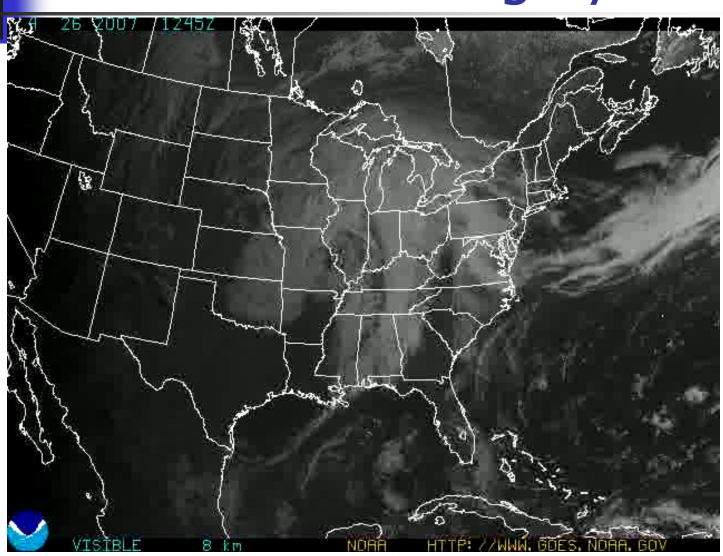
- Ground networks
  - Most industrial nations operate dense radar networks
  - Been in existence for over 50 years
  - Wavelengths 3 – 10 cm (10 GHz or less); active system
- Spaceborne radars
  - Only last 10 years or so
  - TRMM Precipitation Radar
    - Operates at 13.8 GHz
    - 17 dBZ sensitivity
    - 4 km horizontal and 0.75 km vertical resolution
  - CloudSat
    - 94 GHz cloud radar
    - -26 dBZ sensitivity
    - 3 km horizontal and 0.5 km vertical resolution

Satellites

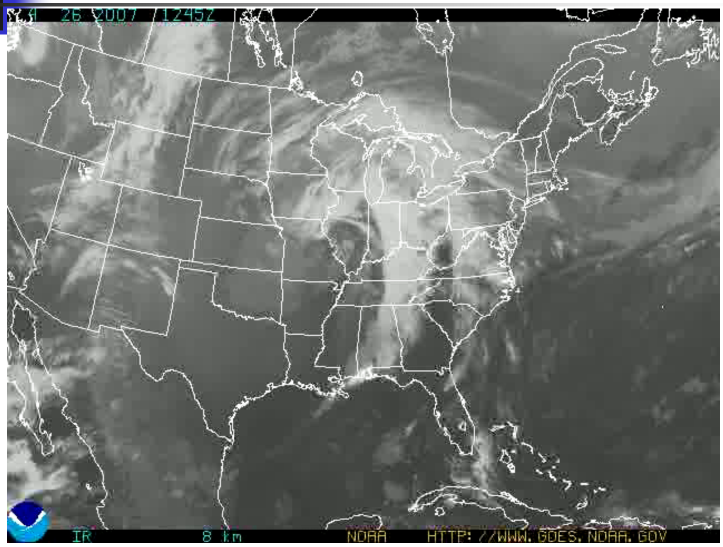
Geostationary satellites: are in orbit 22,238 miles above the equator, which means they orbit at the same speed as the Earth's rotation, keeping them above the same spot on Earth. U.S. geostationary satellites are called "GOES" for Geostationary

•**Polar orbiting satellites:** orbit over the North and South poles about 530 miles above the Earth. Their lower orbits mean their view is more limited, but they have a more close-up view.

GOES Visible Imagery



GOES IR Imagery



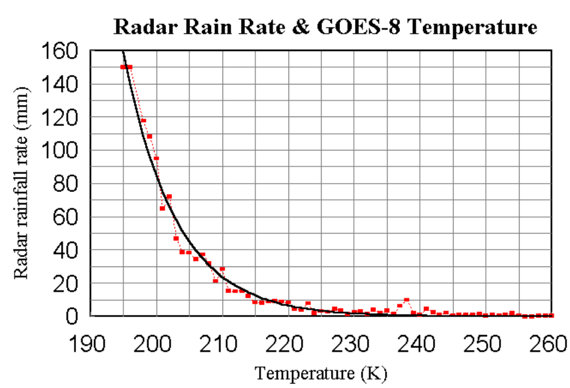
Advantages of Vis/IR Sensors

- High Temporal Sampling
  - 15 – 60 minutes
  - Storm evolution
  - Storm movement
  - Flash flood events
- High Spatial Resolution
  - 1-4 km (could be less, e.g., MODIS)
  - Small scale features
    - Stream/River basins for flash flood/hydrological models

IR Methods

- Most simple approach is to use IR cloud top temperatures to infer rain rate
  - The higher the cloud top, the heavier the rain is
    - Not a bad assumption in convective systems with little horizontal shear (e.g., tropics)
      - GOES Precipitation Index (GPI) – Arkin and Meisner, 1987
        - TB<235 K indicator of tropical rainfall
  - Shortfalls
    - Non-convective systems (winter time); a lot of cirrus not associated with rainfall
    - Strong shearing convective systems
      - Mislocation of precipitation
    - Non-physical relationship between cloud top temperatures and surface rainfall
- There are methods that try to look at:
  - Trends in the IR temperatures: NESDIS Auto-Estimator, Vicente et al, 1998, BAMS
  - Moisture environment (dry or moist): NESDIS AE
  - Corrections using surface radar/gauges, topography, stability indicies, etc.: NESDIS Hydro-Estimator, Scofield and Kuligowski, 2003

GOES 10.7 μm and rain rate



R = 1.1183*10**(11) * exp [-3.6382 10**(-2) * T**(1.2)]

Visible and near IR methods

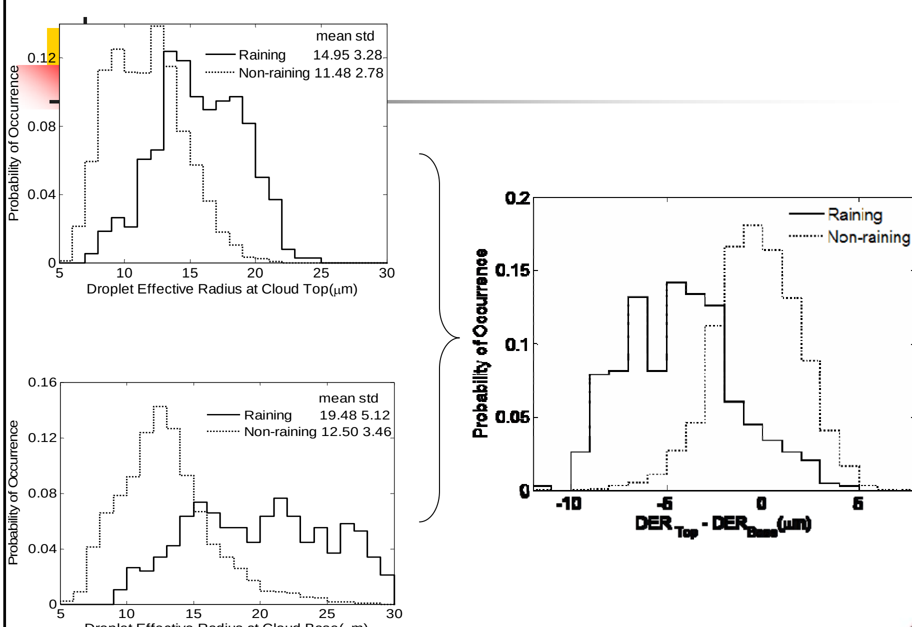
- Precipitation clouds can be detected by textural affects, brightness, evolution, etc from visible imagery
  - Difficulties in quantifying such approaches due to sun angle variations, sensor changes, etc.
    - Lead towards subjective, interpretative methods
- NIR channels
  - Sensitive to cloud droplet sizes in absence of cirrus clouds
  - Attractive for "warm rain" processes
    - No ice phase
    - Orographic rainfall

Vis and IR Algorithms: GMSRA

- GMSRA=**G**OES **M**ulti-**S**pectral **R**ainfall **A**lgorithm
- Uses Data from 4 Different Channels:
  - Visible (0.69 μm)—discriminate between thin (nonraining) cirrus and thicker (raining) clouds
  - "Short" IR Window (3.9-μm)—use reflectivity to identify clouds that are warm but have large particles near cloud-top and are thus producing rain
  - Water Vapor (6.7-μm)—warm signature above overshooting cloud tops differentiates from cirrus
  - IR Window (10.7-μm)—texture screening of cirrus clouds (low texture=cirrus; high texture=rain) and calculation of rainfall rate (but dependent only on value at pixel of interest)

Use of MODIS data: Chen et al. (2007)

- MODIS=Moderate Resolution Imaging Spectroradiometer (MODIS) onboard NASA's Terra and Aqua satellites
  - 36 channel vis/NIR/IR sensor
  - NOAA's GOES-R ABI (Advanced Baseline Imager) will contain many of MODIS channels
- NIR channels are used during daytime to sense cloud droplet reflectance
  - Caveat – No cirrus clouds
  - Drop effective radius (DER)
  - Use 1.6 μm, 2.1 μm, and 3.7 μm
    - Various cloud absorption properties at these wavelengths allows for DER profiling
      - 3.7 μm → cloud top
      - 1.6 μm → cloud base
- Larger drops at bottom indicate drizzle or light rain
  - Important in certain climate regimes

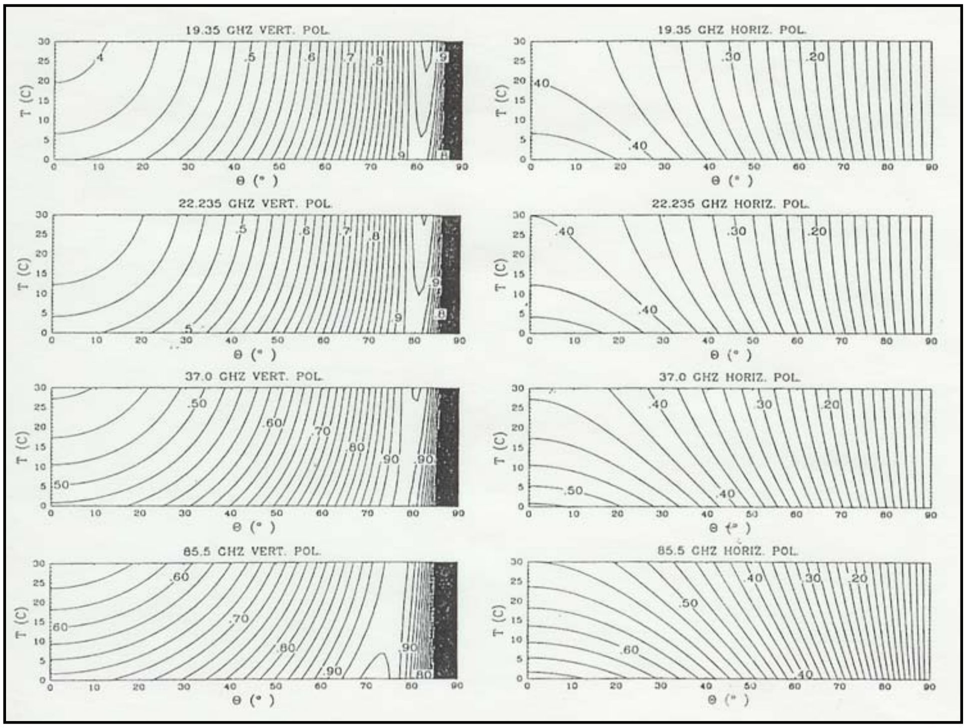


Advantages of MW Sensors

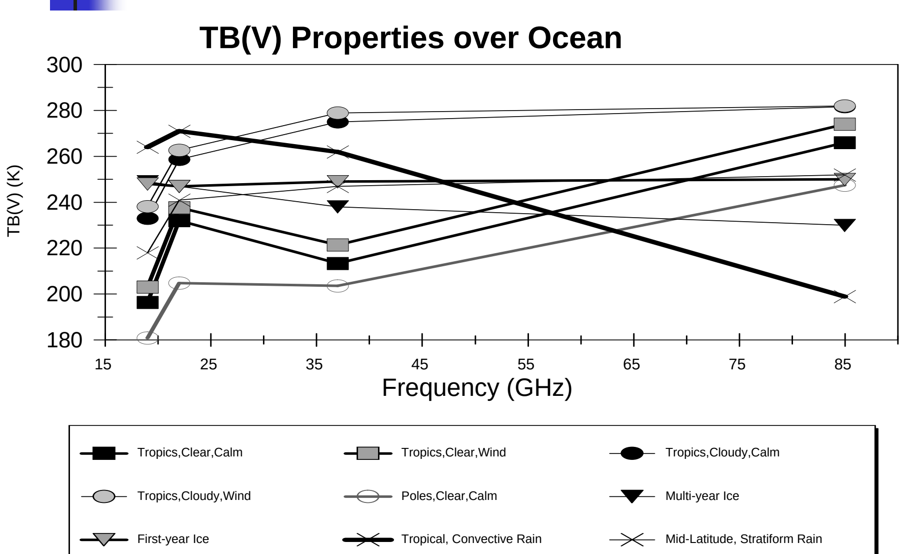
- All Weather capability – can see through clouds (unlike visible and IR)
- "Reasonable" data volume (but has poorer spatial resolution than VIS/IR)
- Can fly on polar orbiters – global coverage (but not high temporal resolution like GOES satellites)

Emissivity (ε)

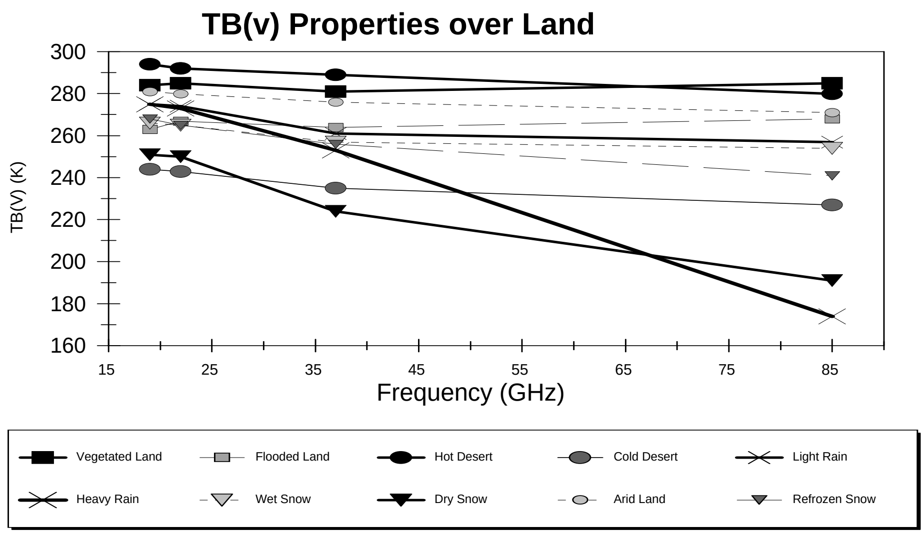
- At MW frequencies, most surfaces/media behave as grey bodies (e.g., ε < 1)
- ε is controlled:
  - Dielectric constant/permeability
    - Water surfaces have a low emissivity
  - Medium configuration
    - Particle size and spacing; "smooth/specular" or "rough/diffuse" at MW frequencies → "effective" ε
- ε is a f (ν,Θ,p)



Ocean Surface Characteristics



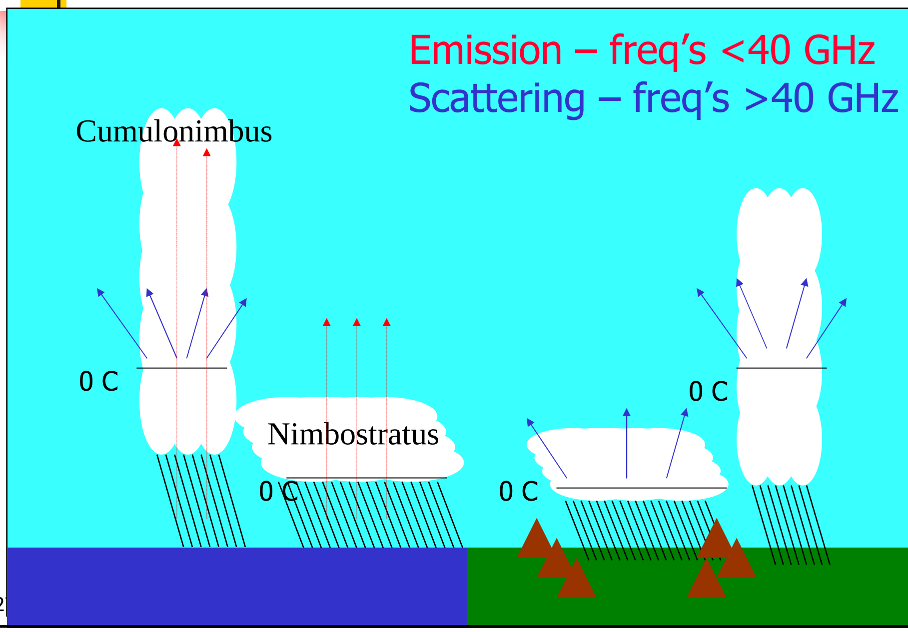
Land Surface Characteristics



MW Rainfall Signatures

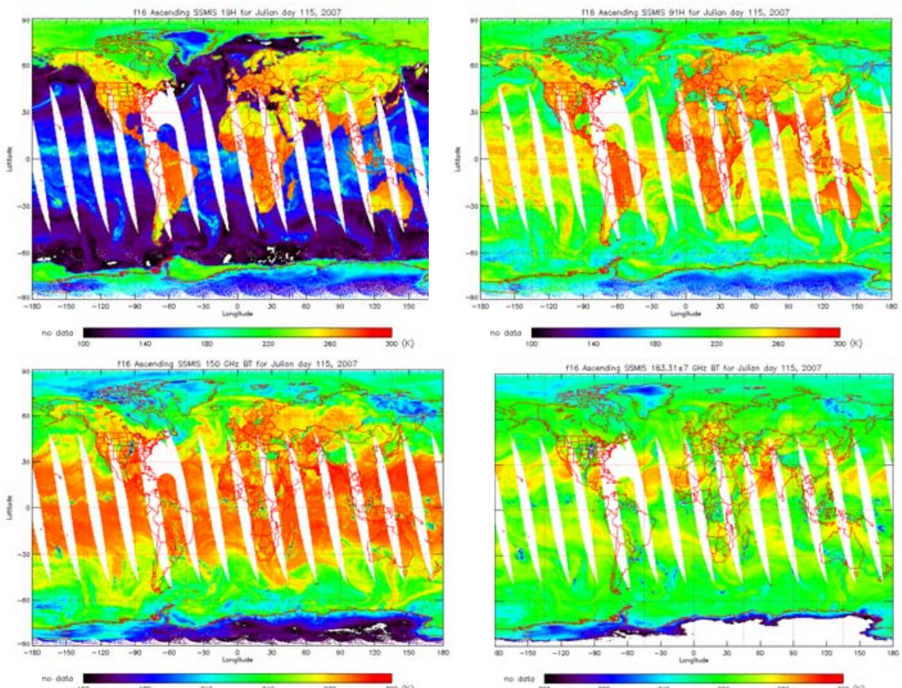
- Over ocean, low emissivity of ocean surface allows us to utilize absorption/emission process by rain drops to retrieve rainfall intensity
  - Most direct physical connection of ANY technique
  - Limitations due to unknown freezing level heights, drop size distributions and "beam filling"/non-linear TB response
- Over land, currently, can only rely on 85 GHz+ scattering due to ice present in precipitation layer (fairly similar to what a radar sees – bright band)
  - Indirect relationship between ice in cloud and surface rainrate
  - Still, more direct than IR, since it sees through cirrus

Rainfall Signatures from MW



Scattering

- Scattering (Mie) in MW region occurs when the particle size of the attenuating medium is comparable to the wavelength:
  - For 300 GHz → 1 mm
  - For 30 GHz → 1 cm
  - For 3 GHz → 10 cm
- Generally, a medium that scatters exhibits a decrease in TB with increasing frequency when observed from a satellite (e.g., refrozen snow, precipitation sized ice, desert sand, multi-year sea-ice).
- Sensor design/retrieval algorithms utilize these properties (although they are difficult to model and relate to relatively large satellite IFOV's→ inhomogeneity)



Rainfall Signatures (Model Based)

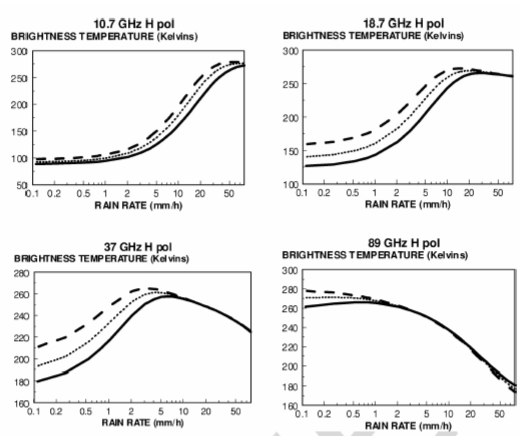


Fig. 1. Brightness temperature as a function of rain rate over the ocean for selected AMSR-E channels. The brightness temperatures have been calculated for 3 km (solid line), 4 km (short dashed line), and 5 km (long dashed line) freezing levels.

Rainfall Over Ocean

- Utilize both emission and scattering signatures of rainfall
  - Emission: 19-37 GHz/Scattering: 85+ GHz
- Rain identification:
  - Emission:
    - CLW (Q) cloud/rain threshold (0.2-0.3 mm)
    - Function of freezing level, cloud base, DSD, etc.
  - Scattering:
    - Scattering "Index" (ice phase/falling snow)
  - Remove sea-ice signature

Rainfall Over Ocean (con't)

- Rain rate determination
  - Empirical tuning to co-incident radar
  - Physical tuning from cloud model simulations
  - $RR=a\ Q^{b}$ $RR = a\ SI^{b}$
- Accuracy and limitations
  - Instantaneous rain rate +/- 25%?
    - Questions on low and high end rates
    - Beam filling errors
  - Rain area fairly reliable

Rainfall Over Land

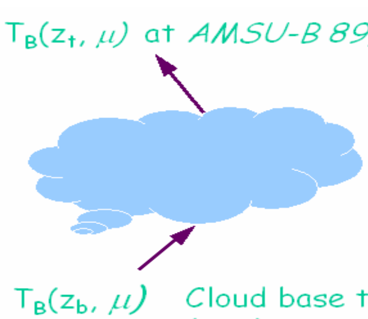
- At present, only utilize scattering signature:
  - Emission not really feasible; it's there but signal is smaller (high emissivity) AND emissivity highly variable, but….future plans are to utilize improved land surface emissivity models….
  - Less direct measure of rain
  - Mainly convective & widespread stratiform
- Special care to remove "false" signatures:
  - Snow cover (melting snowpack), deserts
  - Empirical "sceens"; decision tree approach
  - Non-uniqueness of signatures
  - conservative vs. aggressive screening

Rainfall Over Land (con't)

- Rainfall detection via scattering 85/89 GHz:
  - TB depressions indicate possible rain
    - Larger the depression, heavier rain
  - Proper rain/no-rain threshold to minimize noise
  - Scattering Index=f(TB19,TB22)-TB85
- Rain Rate - radar or CRM tuned; RR = a SI ^{b}
- Accuracy and limitations:
  - Instantaneous rate +/- 50%
  - Summer season rain/no-rain most reliable
  - "W. Coast" land systems problematic:
    - maritime air mass/less ice/smaller precipitation particles?
  - Single SI-RR used (ie, global "Z-R" relationship)
  - Melting snow in winter and spring seasons

Use of high frequency measurements from AMSU

- **Physical retrieval of ice water path (IWP) and particle size (De) using AMSU-B 89 and 150 GHz:**
  - **De ~ $\Omega(89)/\Omega(150)$**
  - **IWP ~ De*($\Omega/\Omega(89,150)$)**
- **Assumptions made on size-distribution & density**
- **IWP to rain rate based on <u>limited</u> cloud model data and comparisons with in situ data: RR = $A_0 + A_1 * IWP + A_2 * IWP^2$**
- **Effects of surface misidentification (desert & snow) reduced using 89 and 150 GHz**



$$\Omega(\mu) = \frac{T_B(z_b,\mu) - T_B(z_t,\mu)}{T_B(z_t,\mu)}$$

$$r = \Omega_{89}/\Omega_{150}$$

Cloud base temperatures $T_{B89}(z_b,\mu)$ and $T_{B150}(z_b,\mu)$ are estimated from AMSU low frequency measurements at 23 and 31 GHZ.

Given the ice particle bulk volume density, *IWP* and *De* can be uniquely determined with satellite measurements from two frequencies using the following relationships (Zhao and Weng, 2001).

$$D_e = a_0 + a_1 r + a_2 r^2 + a_3 r^3$$

$$\Omega_{N89 \text{ or } 150} = exp(b_0 + b_1 ln(D_e) + b_2 (ln(D_e))^2)$$

$$IWP = \mu \rho_i D_e \Omega_{89 \text{ or } 150} / \Omega_{N89 \text{ or } 150}$$

10 Minute Break

Some Operational Algorithms

- GOES-Hydroestimator
- DMSP/SSMI FNMOC
- Goddard Profiling Algorithm (GPROF) - TRMM, AMSR-E, SSMI
- NOAA/POES AMSU-B

Operational Algorithm Development

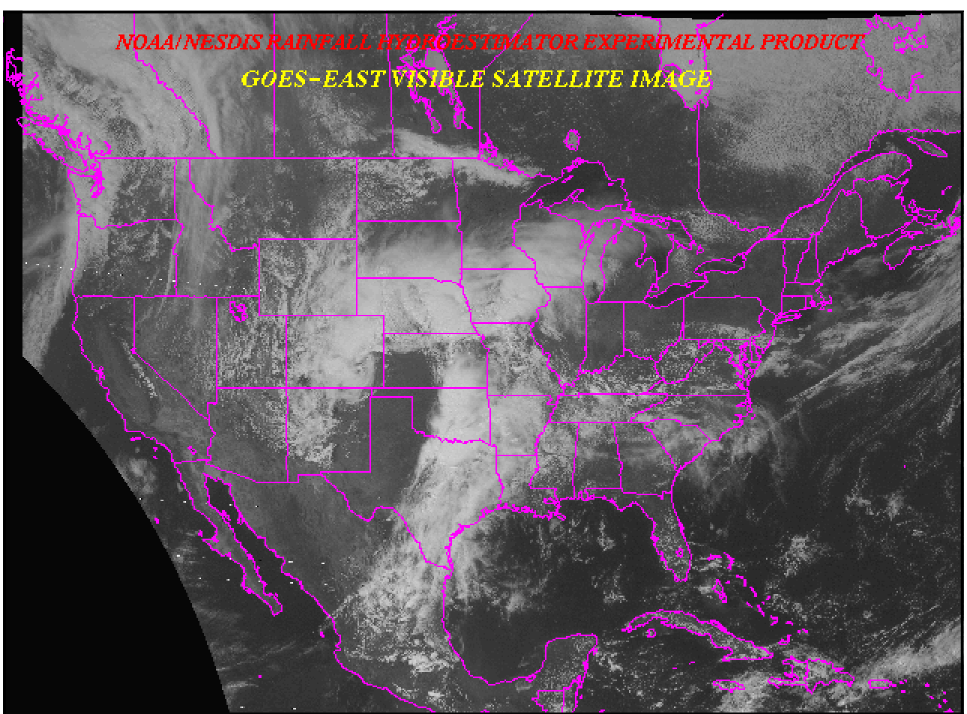
- What does operational mean?
  - 24 hours/day, 7 days/week
    - It's like your cell phone, radio and TV stations; you expect it to be working ALL OF THE TIME!
  - It has to be easy to fix if it breaks
  - You need to have full time support staff
- Algorithm considerations:
  - Complexity, processing, delivery "balance"
  - Impact on other processing systems
  - User requirements
  - Simplify physical retrieval schemes & utilize appropriate channels on sensor (these are always carefully selected when sensors are designed – radiative transfer models)!

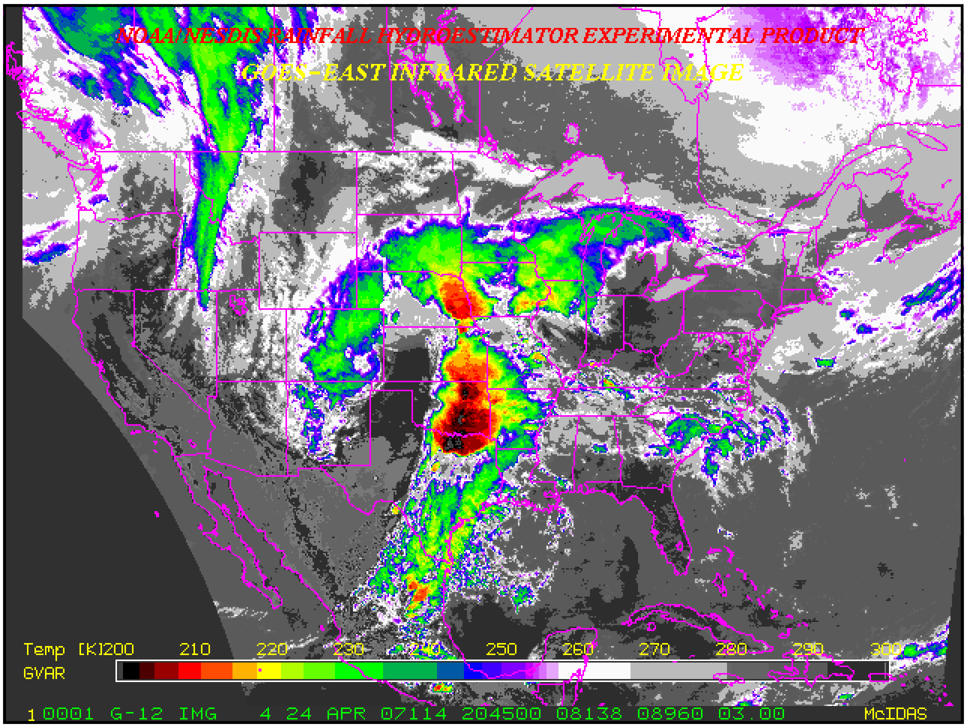
GOES HydroEstimator

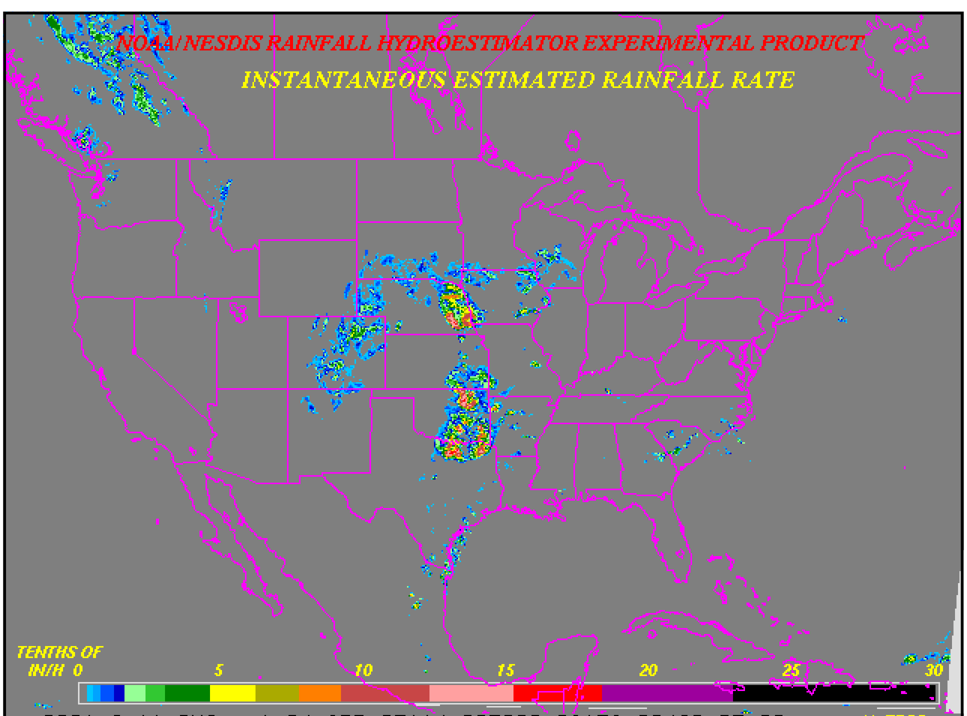
- Has its roots from early NESDIS work of Rod Scofield and Satellite Applications Branch (SAB) satellite analysts
  - An interactive approach which looked at trends of GOES-IR temperatures, moisture fields, etc.
- To ease burden on analysts, an automated, more objective method was developed
  - The "AutoEstimator"; geared for convective systems
- Next version of AE utilized ground data over US to better integrate satellite, NWP and in-situ data and work under all seasons
  - The "HydroEstimator"

Hydro-Estimator

- Satellites: GOES
- Spectrum: IR
- Spatial Domain: Primarily CONUS, but is run in Mexico, Central and South America
- Temporal Domain: Storm Scales
- Physical Basis/Empirical Coefficients:
  - IR cloud top temperature and trends related to rain rate
  - Utilize in-situ data, NWP, topography to alter rain rates based on local conditions
- Calibration: Ground Radar from U.S.
- References: Vincente et al (1998), Scofield and Kuligowski (2003)

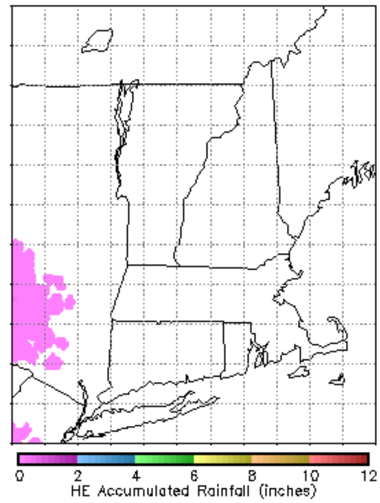



NOAA/NESDIS RAINFALL HYDROESTIMATOR EXPERIMENTAL PRODUCT
GOES-EAST INFRARED SATELLITE IMAGE
Temp [K]200 210 220 230 240 250 260 270 280 290 300
GVAR
1 0001 G-12 IMG 4 24 APR 07114 204500 08138 08960 03.00 McIDAS


NOAA/NESDIS RAINFALL HYDROESTIMATOR EXPERIMENTAL PRODUCT
INSTANTANEOUS ESTIMATED RAINFALL RATE
TENTHS OF IN/H 0 5 10 15 20 25 30
1 0001 G-11 IMG 1 24 APR 07114 203000 08138 09460 03.00 McIDAS

HE Estimates for New England Flood, May 2006

Heavy rains over New England during mid-May 2006 produced the worst flooding in 70 years at many locations and causing tens of millions of dollars of damage.



NESDIS/FNMOC Algorithm

- Satellites: SSM/I
- Spectrum: MW
- Spatial Domain: Global
- Temporal Domain: Storm & Climate Scales
- Physical Basis/Empirical Coefficients:
  - Grody 85 GHz "Scattering Index"
  - Land/Ocean Scattering approach + Ocean emission
  - Screening for anomalous surfaces (snow, desert, ice)
- Calibration: Ground Radar from U.S., Japan and U.K.
- References: Grody (1991), Ferraro and Marks (1995), Ferraro (1997)

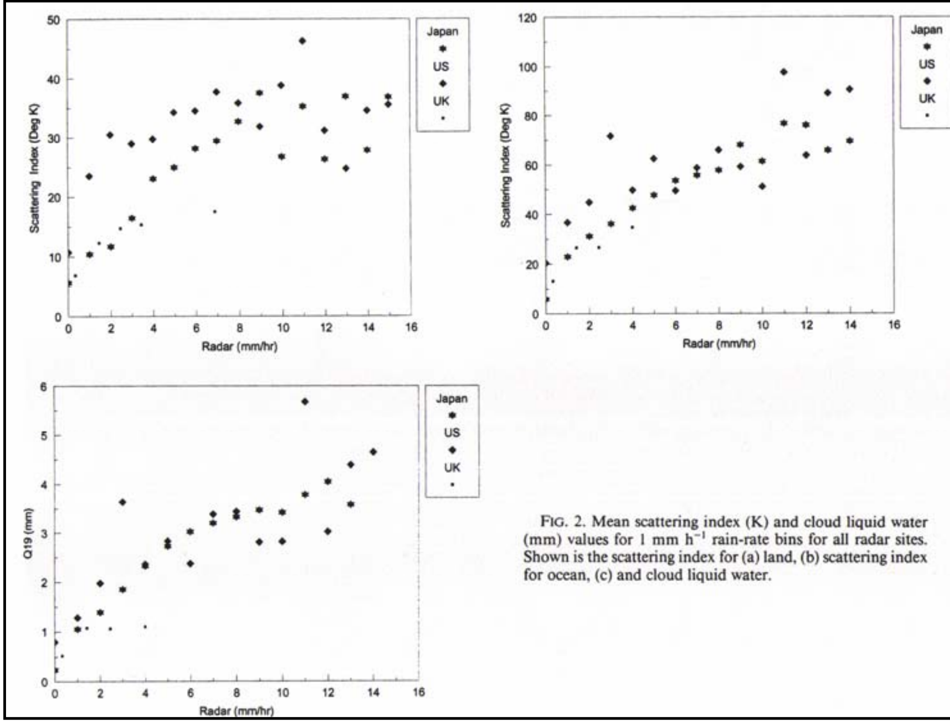
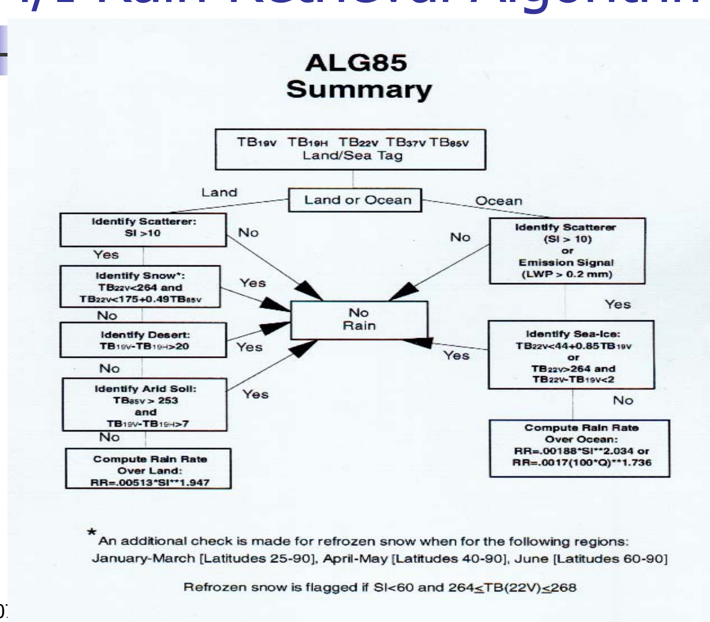
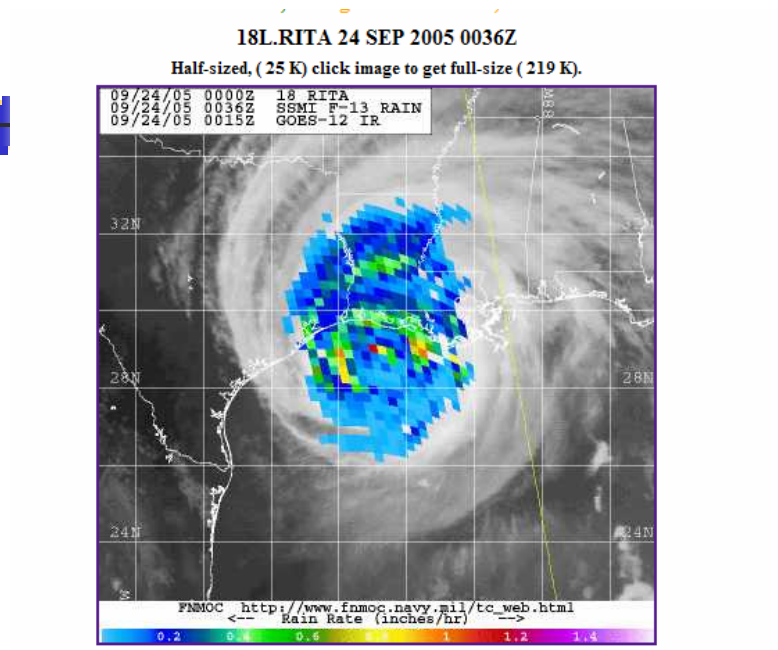


FIG. 2. Mean scattering index (K) and cloud liquid water (mm) values for 1 mm h^{-1} rain-rate bins for all radar sites. Shown is the scattering index for (a) land, (b) scattering index for ocean, (c) and cloud liquid water.

SSM/I Rain Retrieval Algorithm



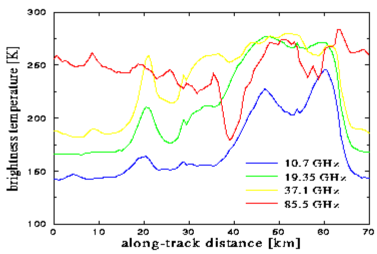
27 April 200



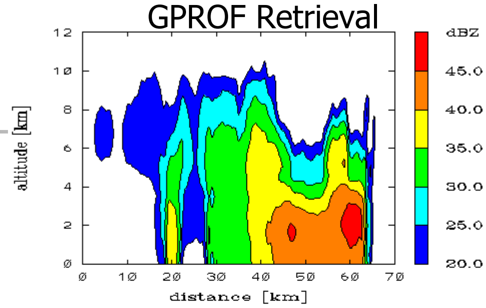
GPROF (Goddard Profiling Algorithm)

- Satellites: TRMM/TMI, AMSR-E, SSM/I
- Spectrum: MW
- Spatial Domain: Global
- Temporal Domain: Storm & Climate Scales
- Physical
  - Couples CRM and RTE calculations
  - Bayesian retrieval
    - Matches actual satellite TB's with database of hydrometeor profiles and surface rain rate
  - Same physical assumptions applied to any imager/sensor
    - Advantage – Unbiased retrievals across several sensors
- Calibration: Cloud Resolving Model (CRM)
- References: Kummerow et al (1996), Kummerow et al (2001), McCollum & Ferraro (2003)

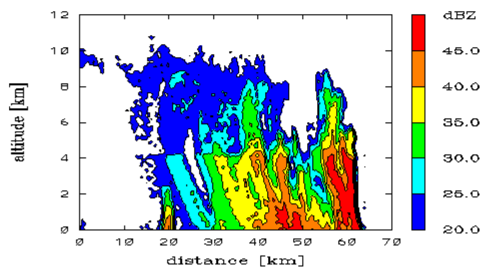
Aircraft - Radiometer

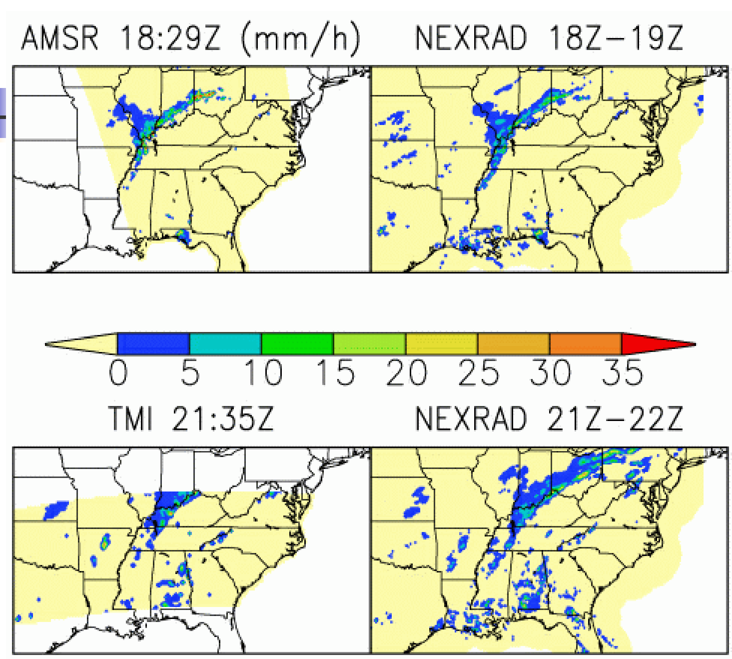


GPROF Retrieval



Aircraft - Radar

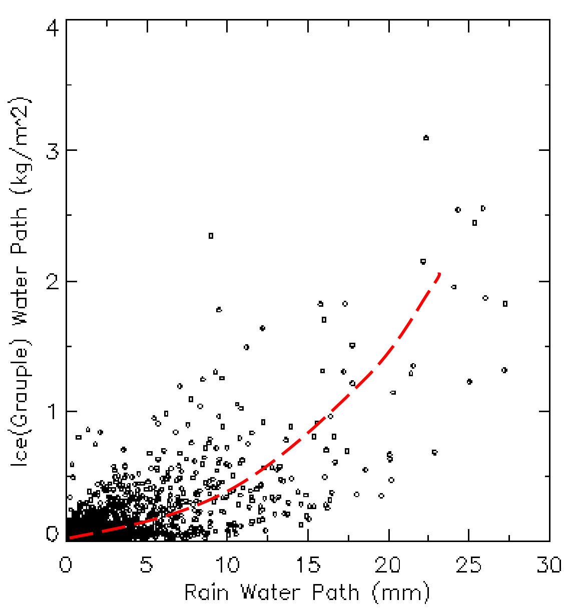


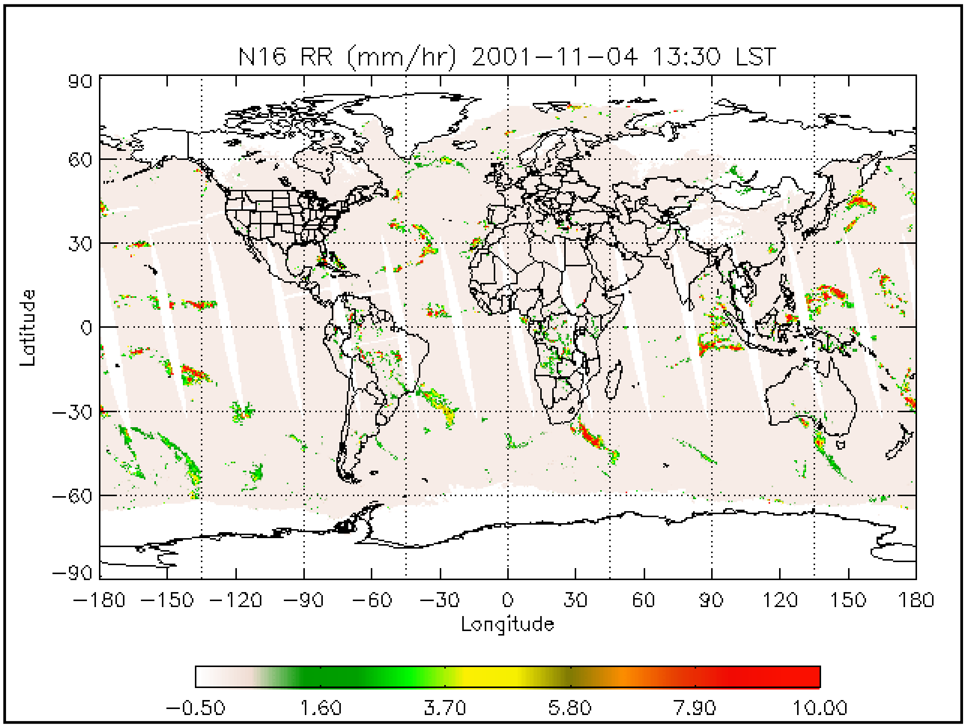


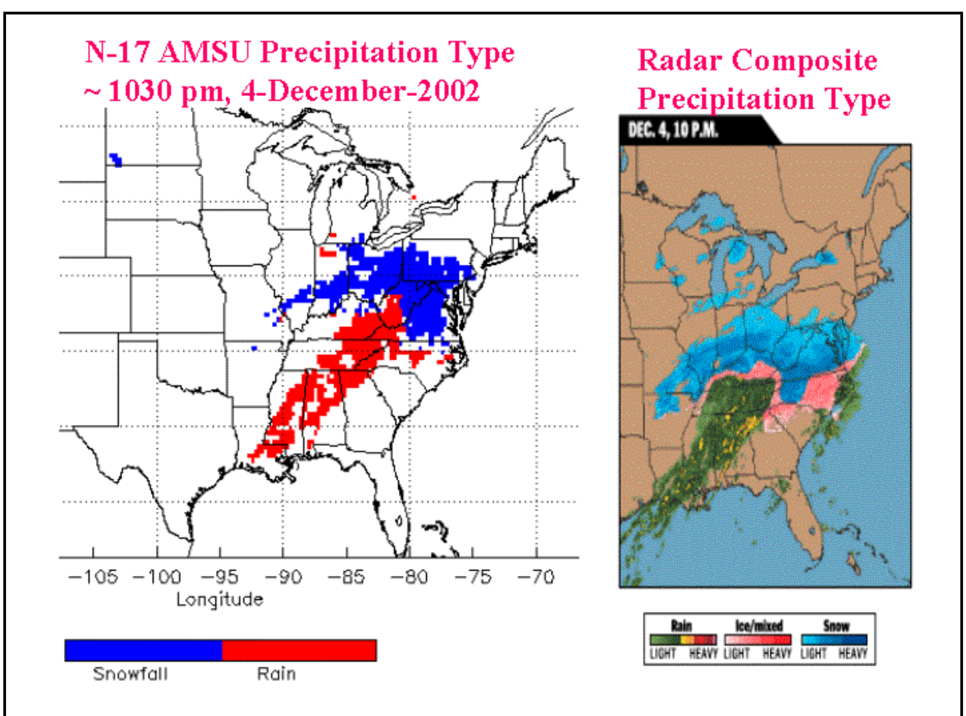
AMSU-B Rain Rates

- Satellites: AMSU
- Spectrum: MW
- Spatial Domain: Global
- Temporal Domain: Storm & Climate
- Physical:
  - First algorithm to utilize 150 GHz measurements
  - Dual-frequency (89 and 150 GHz) scattering algorithm:
    - Simultaneous retrieval of IWP and De
    - Based on two-stream approximation to radiative transfer
    - IWP converted to RR
- Calibration: Cloud model
- References: Zhao & Weng (2002); Weng et al (2003); Ferraro et al (2005), Qiu et al (2005)

Ice Water Path & Rain Rate

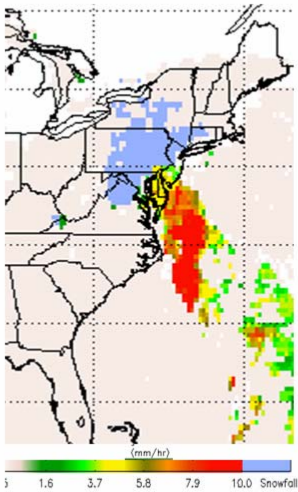



N16 RR (mm/hr) 2001-11-04 13:30 LST
Latitude
90
60
30
0
-30
-60
-90
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180
Longitude
-0.50 1.60 3.70 5.80 7.90 10.00

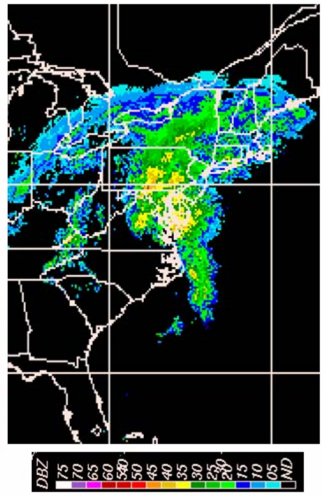

N-17 AMSU Precipitation Type
~ 1030 pm, 4-December-2002
-105 -100 -95 -90 -85 -80 -75 -70
Longitude
Snowfall
Rain
Radar Composite
Precipitation Type
DEC. 4, 10 P.M.
Rain
Ice/mixed
Snow
LIGHT HEAVY LIGHT HEAVY LIGHT HEAVY

East Coast Snow/Ice Storm – 14 February 2007

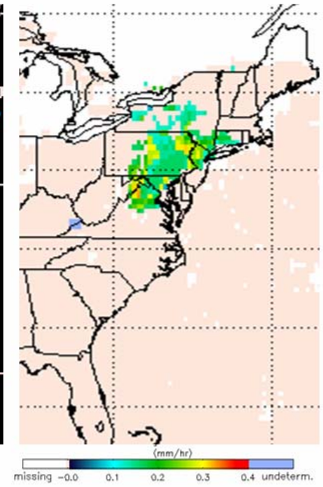
NOAA-16
Precipitation Type/Rainfall Rate



NEXRAD Reflectivity



NOAA-16 Snowfall Rate



The Rainfall Conumdrum

- GOES IR brightness temperatures…
  - …provide excellent spatial resolution, refresh, and data latency
  - …BUT are weakly related to rain rates—especially for non-convective rainfall
- Microwave brightness temperatures…
  - …are sensitive to cloud water / ice content—much stronger relationship to rainfall rates than IR cloud-top temperatures
  - …BUT, restriction to polar-orbiting platforms means degraded refresh rate and data latency with respect to geostationary data.

SCaMPR—a Solution (one of many)

- Self-Calibrating Multivariate Precipitation Retrieval
- Calibrates infrared data from GOES to microwave rain rates in order to produce higher-quality rain rates with the space / time resolution and data latency of geostationary data
- Four steps:
  - Match GOES and microwave data
  - Calibrate rain/no rain separation
  - Calibrate rain rate
  - Apply to independent data

Step 1: Match Data

- Match the GOES data (not just 10.7 μm) to available microwave rain rates from SSM/I and AMSU
  - Match within 15 minutes
  - Aggregate GOES data to microwave footprint
  - Separate into data with zero and non-zero microwave rainfall
- Collect a suitable amount of data to ensure statistically significant results
- Separate calibration data sets for 15x15-degree lat/lon boxes with 5 degrees of overlap—allows calibration to be regionalized while avoiding spatial discontinuities

Step 2: Rain / No Rain Calibration

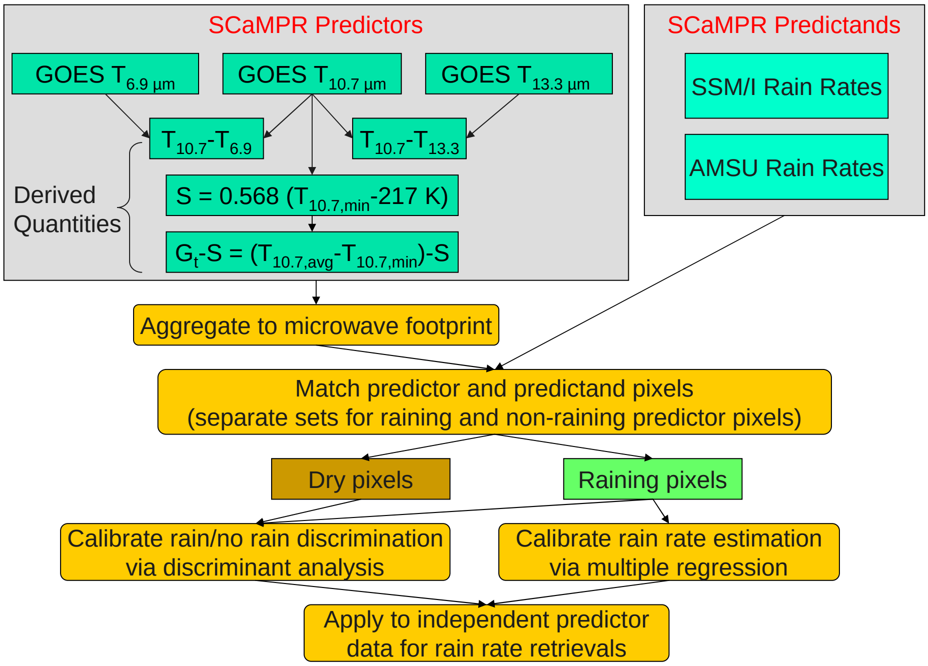
- Use discriminant analysis to:
  - Select the best rain / no rain predictor from a menu of possibilities;
    - SCaMPR is NOT limited to using 10.7 μm, which is a limitation of other combination algorithms—it can use other channels, channel differences, or any other desired predictor
  - Determine the optimal threshold value for separating raining from non-raining pixels

Step 3: Rain / No Rain Calibration

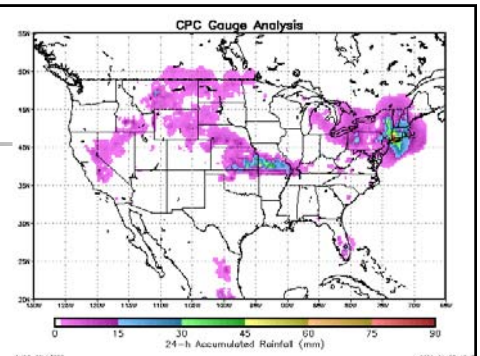
- Use stepwise linear regression to select and calibrate the rain rate predictors
  - Use only those data points with non-zero microwave rainfall to avoid artifacts
  - Fit each predictor against rain rate in log-log space to develop nonlinear transformations of predictors
  - Again, SCaMPR is NOT restricted to 10.7 μm; if another channel, channel difference, etc. is better it will use that instead

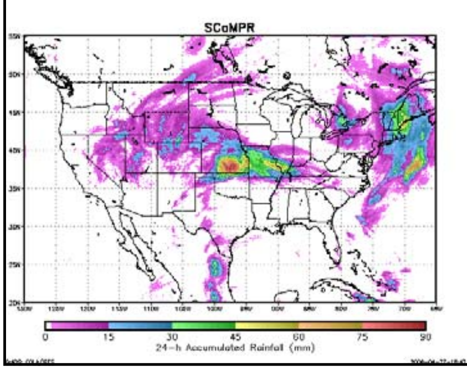
Step 4: Apply to Independent Data

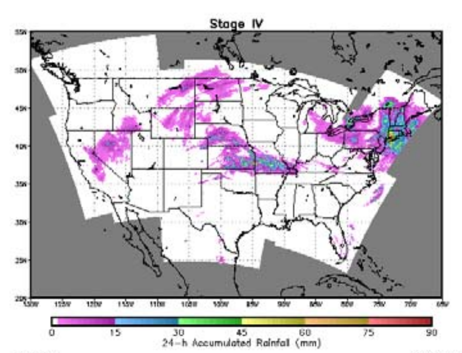
- Apply the resulting rain / no rain thresholds and rain rate relationships to data from subsequent GOES images
- Estimates are produced every 15 min in real time on an experimental machine
- View the results at http://www.orbit.nesdis.noaa.gov/smcd/emb/ff/scampr.html



Comparison of 24-h totals ending 1200 UTC 24 March 2006



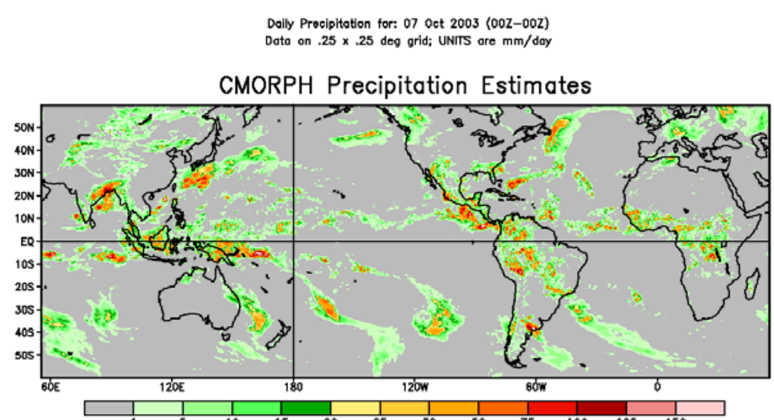




IR-MW Algorithms: CMORPH

- CMORPH=**C**PC **MORPH**ing technique
- Developed by R. Joyce and colleagues at the Climate Prediction Center (CPC)
- Uses IR imagery to interpolate the movement of rainfall areas in MW imagery in between images
- Also interpolates growth/decay of MW rainfall between MW images
- Produced globally at 0.727-degree resolution in near-real time
- Contact: Bob Joyce at Robert.Joyce@noaa.gov

CMORPH—Example



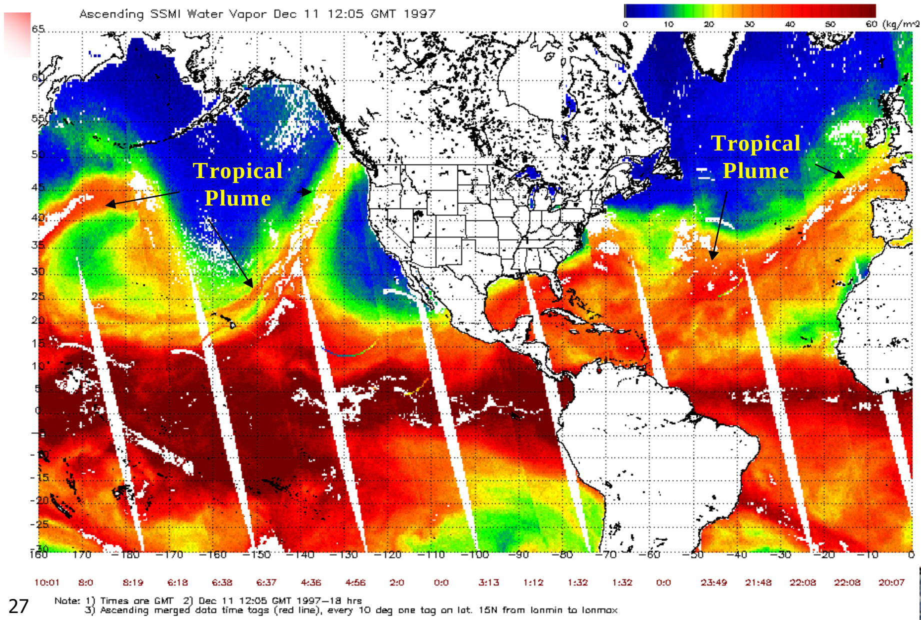
24-h Totals ending 0000 UTC 8 October 2003

Some examples of product use in weather forecasting and analysis

West Coast United States

- TPW plumes ("Pineapple Connection")
  - 24-48 advance warning of heavy precipitation
  - Duration of heavy precipitation
- Rain rates of offshore systems
- Model inadequacies:
  - Poor timing of rain systems
  - Poor moisture initialization
  - Poor QPF/oragraphy

“Typical” Example



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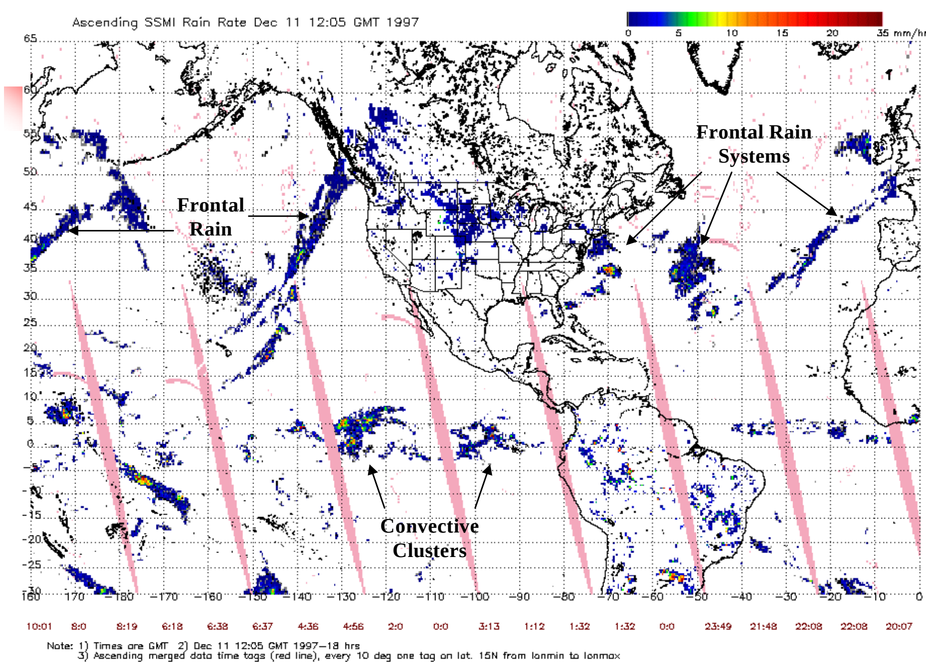
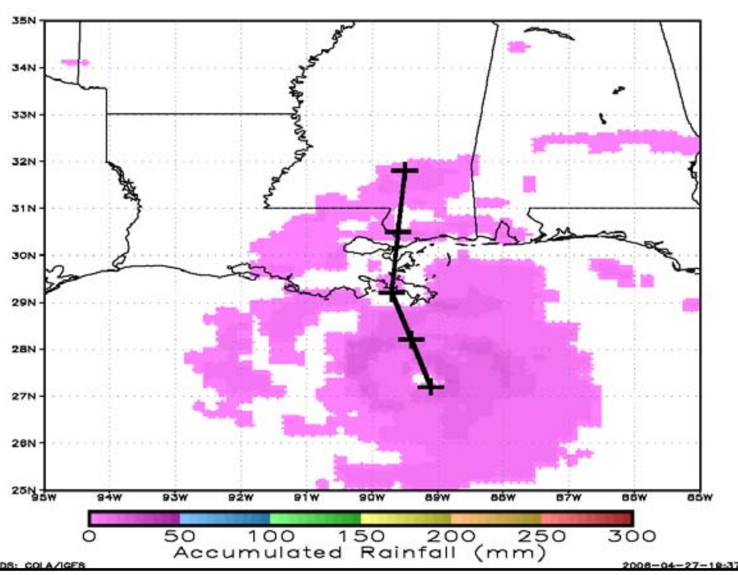


2:

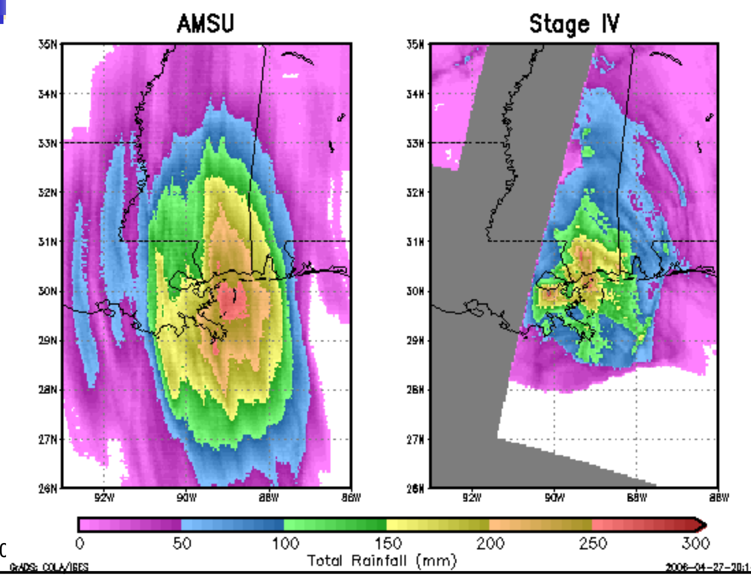
Forecasting Tools: TRaP

- TRaP=**T**ropical **Ra**infall **P**otential—24-hour precipitation forecast
- Produced by extrapolating microwave-based instantaneous QPE along the predicted storm track
- Forecasts produced automatically whenever a new microwave image or track forecast becomes available—posted in Web in graphic format

TRaP Derivation for Katrina
24 h beginning 2335 UTC 28 August 2005



TRaP vs. Stage IV for Katrina
(24 h beginning 0000 UTC 29 August 2005)

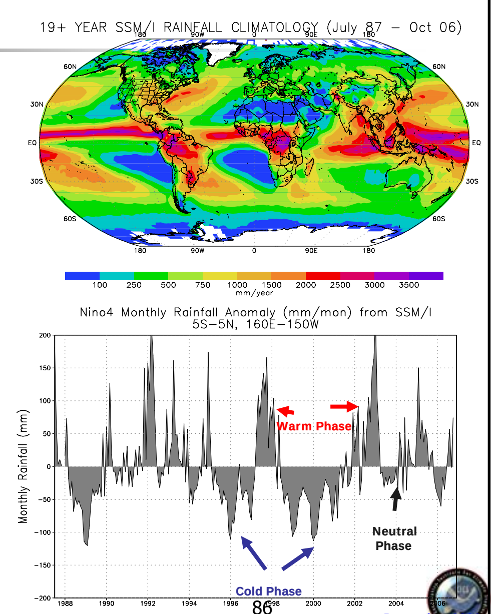


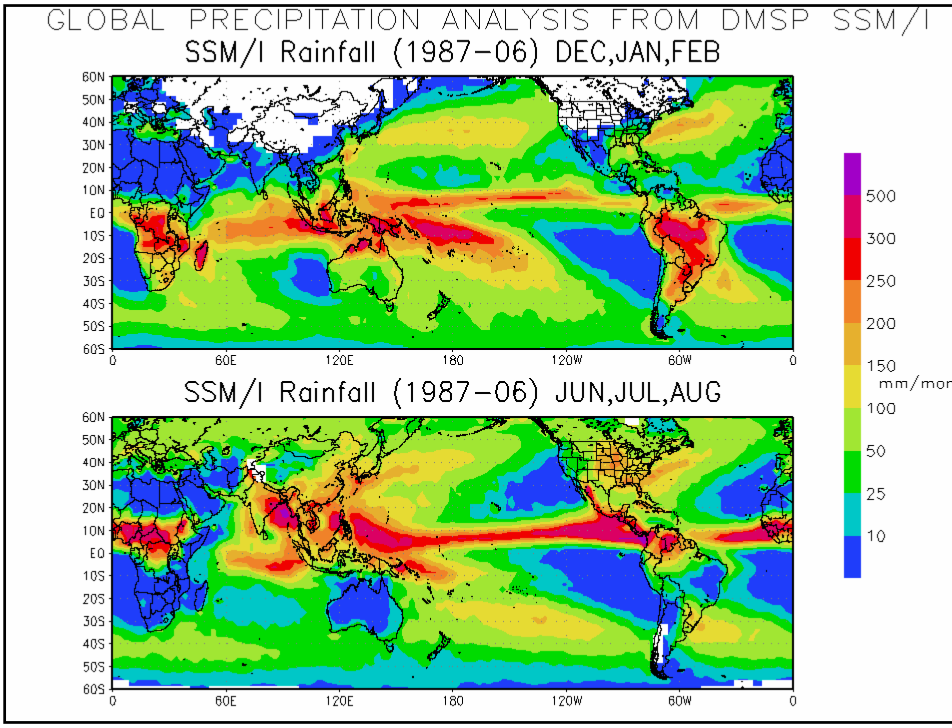
Ground Truth

Global Climate Applications

SSMI Climate Time Series

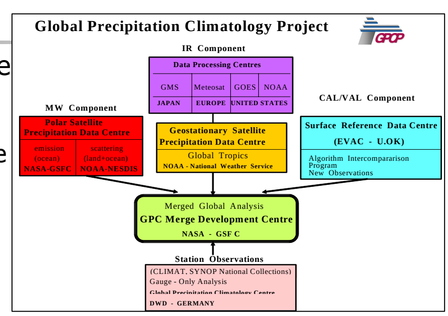
- Monthly mean products derived from SSM/I since July 1987:
  - Precipitation rate and frequency
  - Snow cover frequency
  - Sea-ice concentration
  - Oceanic total precipitable water
  - Oceanic cloud liquid water and frequency
  - Ocean surface wind speed
- Products are archived at NCDC
- Used by NCEP/CPC, JMA, GEWEX/GPCP

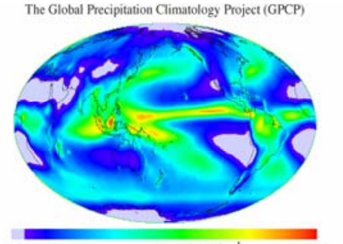




Global Precipitation Climatology Project

- GPCP is a project that is part of the WCRP/GEWEX program
  - Comprises of various "centers", several of which are NOAA/Climate Program supported
- Current product suite (1979 – present)
  - Monthly mean 2.5°x2.5° latitude/longitude
  - Merged satellite and gauge, error estimates
  - Satellite components: microwave and infrared estimates, error estimates
  - Gauge analysis, error estimates
  - Intermediate analysis products, e.g., merged satellite estimates
  - Daily 1 x 1 degree, Pentad





A 25-Year Precipitation Climatology (1979-2003) Based on Observations from Multiple Satellites

General thoughts about validation

- What is the "truth" ?
  - Storm scale - comparison with satellite FOV
  - Climate scale – comparison with large areas/areas without any surface measurements
  - Need to know errors with comparison data
    - Gauges: wind, point measurements, site location, etc.
    - Radar:Z-R relationships, overshooting beam, beam blockage, etc.
    - Is the ground data representative of the area?
- What stats are valuable?
  - Correlation, Bias, RMSE, false alarms, …
  - Are they statistically significant?
  - Importance varies with application

After nearly 15 years…

- The international rainfall community has "endured" at least 6 algorithm intercomparisons (e.g., "a bake off") intended to decide which algorithms are the best. Easier said than done!
  - What is "better"
    - Bias, correlation, false alarms?
  - Uncertainties in "truth"
- Then came along the International Precipitation Working Group (IPGW), established by the WMO/Coordinating Group for Meteorological Satellites (CGMS) in 2002.

CGMS-IPWG, International Precipitation Working Group - Mozilla

File Edit View Go Bookmarks Tools Window Help

http://www.isac.cnr.it/~ipwg/IPWG.html

CGMS IPWG International Precipitation Working Group

Home Meetings Reports Newsletter Algorithms Products Calibration Validation Training Links CGMS WMO Contact us News

IPWG
International Precipitation Working Group

The International Precipitation Working Group (IPWG) was established as a permanent Working Group of the Coordination Group for Meteorological Satellites (CGMS) on 20-22 June 2001 in Ft. Collins, CO. The IPWG is co-sponsored by CGMS and the World Meteorological Organization (WMO) and focuses the scientific community on operational and research satellite based quantitative precipitation measurement issues and challenges.

It provides a forum for operational and research users of satellite precipitation measurements to exchange information on methods for measuring precipitation and the impact of space borne precipitation measurements in numerical weather and hydrometeorological prediction and climate studies.

PURPOSE

In the area of quantitative precipitation estimation, the IPWG intends to build upon the expertise of scientists who are currently involved in precipitation measurements from satellites with emphasis on derivation of products. The IPWG is established to foster the:

- development of better measurements, and improvement of their utilization;
- Improvement of scientific understanding;
- Development of international partnerships.

OBJECTIVES

The objectives of the IPWG are:

1. to promote standard operational procedures and common software for deriving precipitation measurements from satellites;
2. to establish standards for validation and independent verification of precipitation measurements derived from satellite data; including:
3. reference standards for the validation of precipitation for weather, hydrometeorological and climate applications;
4. standard analysis techniques that quantify the uncertainty of ground-based measurements over relevant time and space scales needed by satellite products;
5. to devise and implement regular procedures for the exchange of data on inter-comparisons of operational precipitation measurements from satellites;
6. to stimulate increased international scientific research and development in this field and to establish routine means of exchanging scientific results and verification results;
7. to make recommendations to national and international agencies regarding the utilization of current and future satellite instruments on both polar and geostationary platforms; and
8. to encourage regular education and training activities with the goal of improving global utilization of remote sensing data for precipitation measurements

CGMS IPWG International Precipitation Working Group

Home Meetings Reports Newsletter Algorithms Products Calibration Validation Training Links CGMS WMO Contact us News

VALIDATION

- **IPWG Sponsored Validation Sites** (the three sites are also listed below)
- AMSR-E Validation Rain Gauge Network in Iowa, USA, focal point Witek Krajewski
- BoM Weather Forecasting Group, Pages maintained by Beth Ebert
  - Forecast Verification - Issues, Methods and FAQ
  - RAINVAL - QPF Verification
  - SatRainVal - Validation of satellite precipitation estimates over Australia
- Global Precipitation Climatology Center (GPCC) Data Visualizer, focal point Tobias B. Fuchs
- IPWG European Comparison, focal point Chris Kidd
- NOAA's National Center for Environmental Predictions (NCEP) Validation page, focal point John Janowiak
- Precipitation Product Evaluation over CEOP Reference Sites, focal point Kuo-Lin Hsu
- Program to Evaluate High Resolution Precipitation Products (PEHRPP), focal point Phil Arkin
- South America's Daily Precipitation Validation Page, focal point Daniel Vila
- University of Oklahoma, Surface Reference Data Center (SRDC), focal point Mark Morrissey

SOFTWARE

- Fortran code and scripts for US validation
- IDL code and scripts for Australian validation NEW!
- Practice data for Australian validation

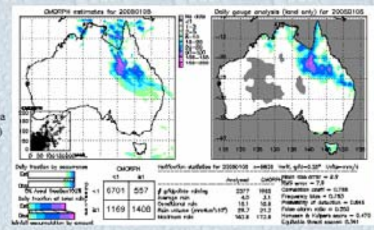
Validation / intercomparison of daily satellite precipitation estimates -- An IPWG project

Quick links:

Regional daily rainfall verifications:
BMRC Precipitation Verification Page - Verification of satellite precipitation estimates over Australia
CPC Precipitation Verification Page - Verification of satellite precipitation estimates over the US
Univ. Birmingham Precipitation Verification Page - Verification of satellite precipitation estimates over Europe
Univ. Maryland Precipitation Validation Page - Validation of satellite precipitation estimates over South America
Osaka Precipitation Verification Page - Verification of satellite precipitation estimates over Japan (limited dates)

Precipitation data archive:
IPWG Precipitation Validation / Intercomparison Study Data Archive - Description of data archive
CICS Archive Site - FTP access to data archive

Results:
Publications and talks
Validation code



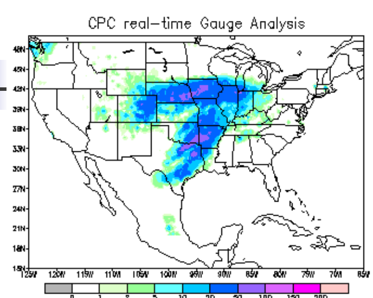
1. Why validate satellite rainfall estimates?

There has been a great deal of research in the last two decades on methods for estimating rainfall from infrared (IR) and microwave satellite observations. As a result there are now several satellite algorithms running operationally and semi-operationally from national centers and universities to produce rainfall estimates for time periods ranging from half-hourly to monthly. The great advantage of space-based precipitation estimates is their global coverage, providing information on rainfall frequency and intensity in regions that are inaccessible to other observing systems such as rain gauges and radar. The disadvantage is that they are indirect estimates of rainfall, depending on the properties of the cloud top (in the case of IR algorithms) and cloud liquid and ice content (in the case of passive microwave algorithms). Active radar observations from the TRMM Precipitation Radar provide the most accurate high resolution satellite-based rainfall estimates to date, but the sampling characteristics of this instrument are quite limited.

Rainfall products from the operational algorithms are easily obtainable via the web or FTP, and are being used for many diverse meteorological, climate, hydrological, agricultural, and other applications. It is therefore important to have an idea of their accuracy and expected error characteristics. This is done by validating the satellite precipitation estimates against "ground truth" from rain gauge and/or radar observations. A thorough verification of satellite-based precipitation products should quantify their accuracy in a wide range of weather and climate regimes, give users information on the expected errors in the estimates, help algorithm developers understand the strengths and weaknesses of the satellite rainfall algorithms, including which aspects are in greatest need of improvement, monitor the performance of existing algorithms, and assist with evaluating algorithm upgrades. To get good estimates of absolute accuracy satellite products are verified against very high quality radar and gauge data. However, these sites are only few in number. To get estimates of regional and spatial accuracy it is necessary to use a much larger quantity of data, for example, from national rain gauge networks. While these verification data are less reliable than those from high-quality sites, their errors are usually much smaller than those associated with the satellite estimates, at least on short time scales.

In 2003 the International Precipitation Working Group (IPWG) began a project to validate and intercompare operational and semi-operational satellite rainfall estimates over Australia and the US in near real time. A European verification was added in 2004, and other regions may be included in the future. This study focuses on the large-scale validation of daily rainfall estimates, for two reasons. First, the large number of rainfall observations from rain gauges at the 24-hour time scale provides good quality verification data on a large scale. Second, daily rainfall estimates are required as input to a large number of climate and other applications. For comparison, 1-day forecasts from a limited number numerical weather prediction models, namely the ECMWF, the US (NCEP), and US Navy global models, and the

13Z 24Apr2007 thru 12Z 25Apr2007
Data on 0.25 deg grid (UNITS are mm/day)

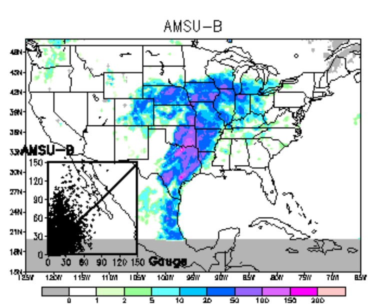


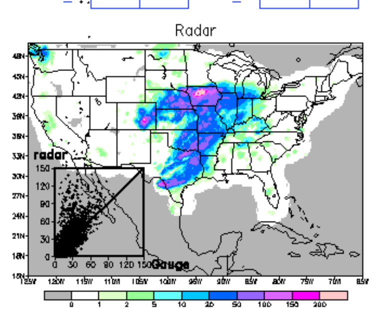
	(G) gauge	(S) AMSU-B	(R) radar
Number of points:	13337.	13337.	13337.
# points w/rain:	4915.	4401.	4640.
Mean rain rate:	5.49	7.46	7.64
Cond. rain rate:	14.64	22.56	21.74
Max. rain rate:	99.81	223.20	506.62

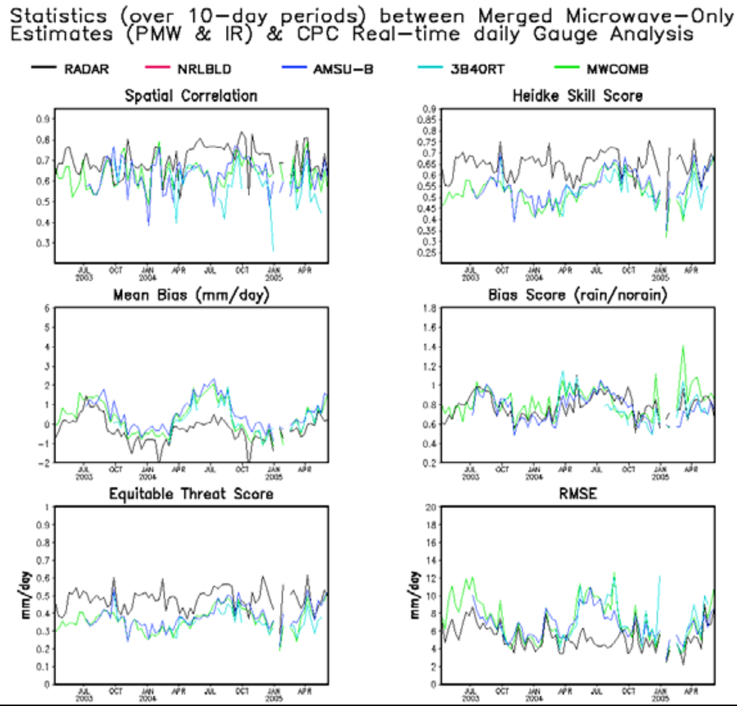
	G−S	G−R	R−S
Correlation:	0.710	0.762	0.567
Mean Absolute Error:	4.86	3.94	5.89
RMSE (mm/day):	12.41	14.04	17.83
RMSE (normalized):	2.26	2.56	2.32
Probability of Detection:	0.748	0.777	0.778
False Alarm Ratio:	0.164	0.177	0.179
Bias Ratio (rain:no rain):	0.895	0.944	0.947
Heidke Skill Score:	0.677	0.688	0.696
Hanssen−Kuipers Score:	0.662	0.680	0.687
Equitable Threat Score:	0.512	0.524	0.533

gauge	AMSU−B < 1	AMSU−B ≥ 1
< 1	7699.	723.
≥ 1	1237.	3678.

gauge	radar < 1	radar ≥ 1
< 1	7601.	821.
≥ 1	1096.	3819.







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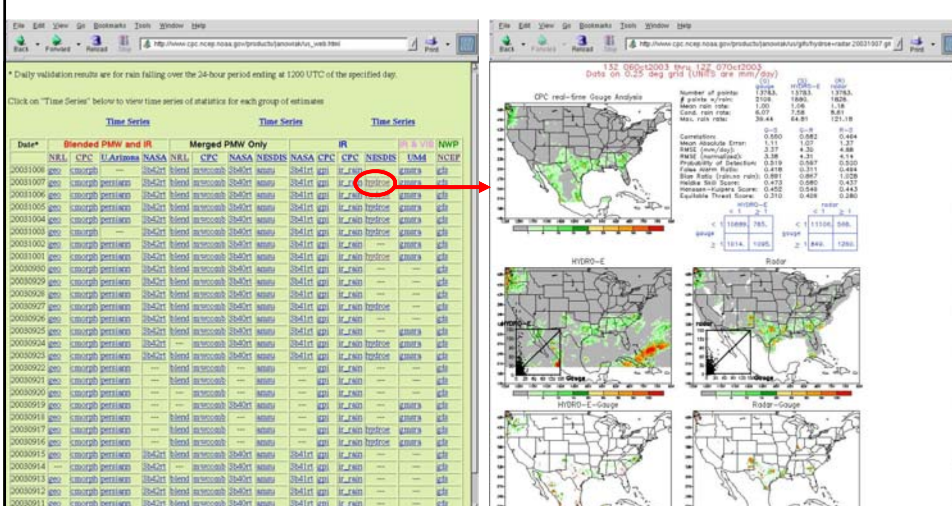
CPC Validation Web Page

http://cpc.ncep.noaa.gov/products/janowiak/us_web.html

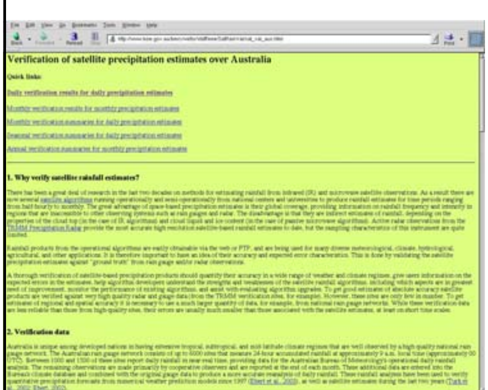


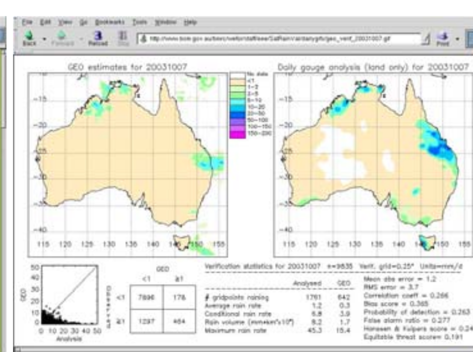
Satellite QPE Validation: Australia

- Validation over Australia against 0.25-degree daily raingauge analysis
- Evaluation of 13 different IR, MW, and PR+MW algorithms plus precipitation forecasts from 4 numerical weather models
- Numerous statistics for comparison, plus spatial plots of all algorithms

Australian Bureau of Meteorology Validation Page

http://www.bom.gov.au/bmrc/wefor/staff/eee/SatRainVal/dailyval_dev.html





Assignment

1. Obtain and review - Ebert, E., J. Janowiak, and C. Kidd, 2007: Comparison of near-real-time precipitation estimates from satellite observations and numerical models. *Bull. Amer. Meteor. Soc.*, **88**,47-64.
2. Examine IPWG web site/validation section: www.isac.cnr/it~ipwg
3. I would like you to generate a 1-2 page report, plus supporting figures (up to 4, from IPWG web page or literature) that:
   - Compares two types of satellite precipitation products using the information on the web site and explained during this lecture. Equations are NOT NECESSARY.
   - Describe its performance over at least two regions (CONUS, W. Europe, etc.) and two seasons (say a day in winter and a day in summer)
   - You should provide enough information that demonstrates your basic understanding of the retrieval methods, the validation metrics, and some insight as to why the algorithms are performing good or poorly (i.e., this is a convective storm, so algorithm A is better than algorithm B because…).
   - You may also consult references provided on the IPWG web site for particular algorithms
   - DUE DATE: May 4? – please send to Ralph.R.Ferraro@noaa.gov and cc Prof. Li

Precipitation Overview References

- Arkin, P.A. and P.E. Ardanuy, 1989: Estimating climatic-scale precipitation from space: a review. *J. Climate*, **2**, 1229-1238.
- Ebert, E.E., M.J. Manton, P.A. Arkin, R.E. Allam, and A. Gruber, 1996, Results from the GPCP algorithm intercomparison programme, *Bull. Amer. Meteor. Soc*, **77,** 2875-2887.
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