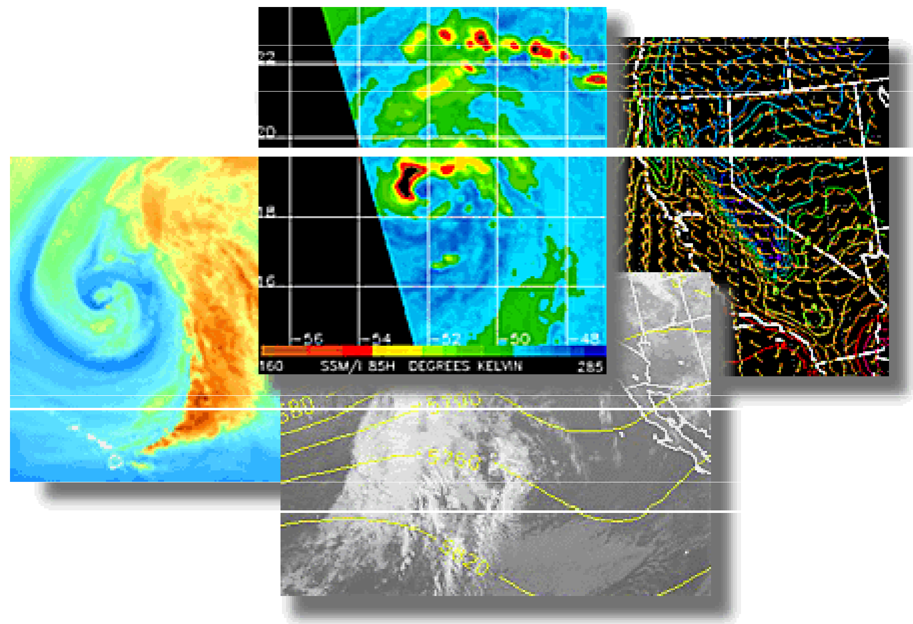
Combined SSMI-TRMM-IR Rain Rates to Provide Large Area Rapid Precipitation Updates

F. Joseph Turk

AMS Satellite Precipitation Short Course

January 10, 1999



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Where does a satellite-based rainfall analysis find an application?

- Physically initializing NWP models (internal use)
- Tropical cyclones, complementing winds
- Global/regional NWP model verification
- Monitoring climatological changes
- Hydrology, land usage, flash flood warnings

How does one analyze satellite data in order to achieve the required rainfall space and time scales?

Microwave Rain Techniques

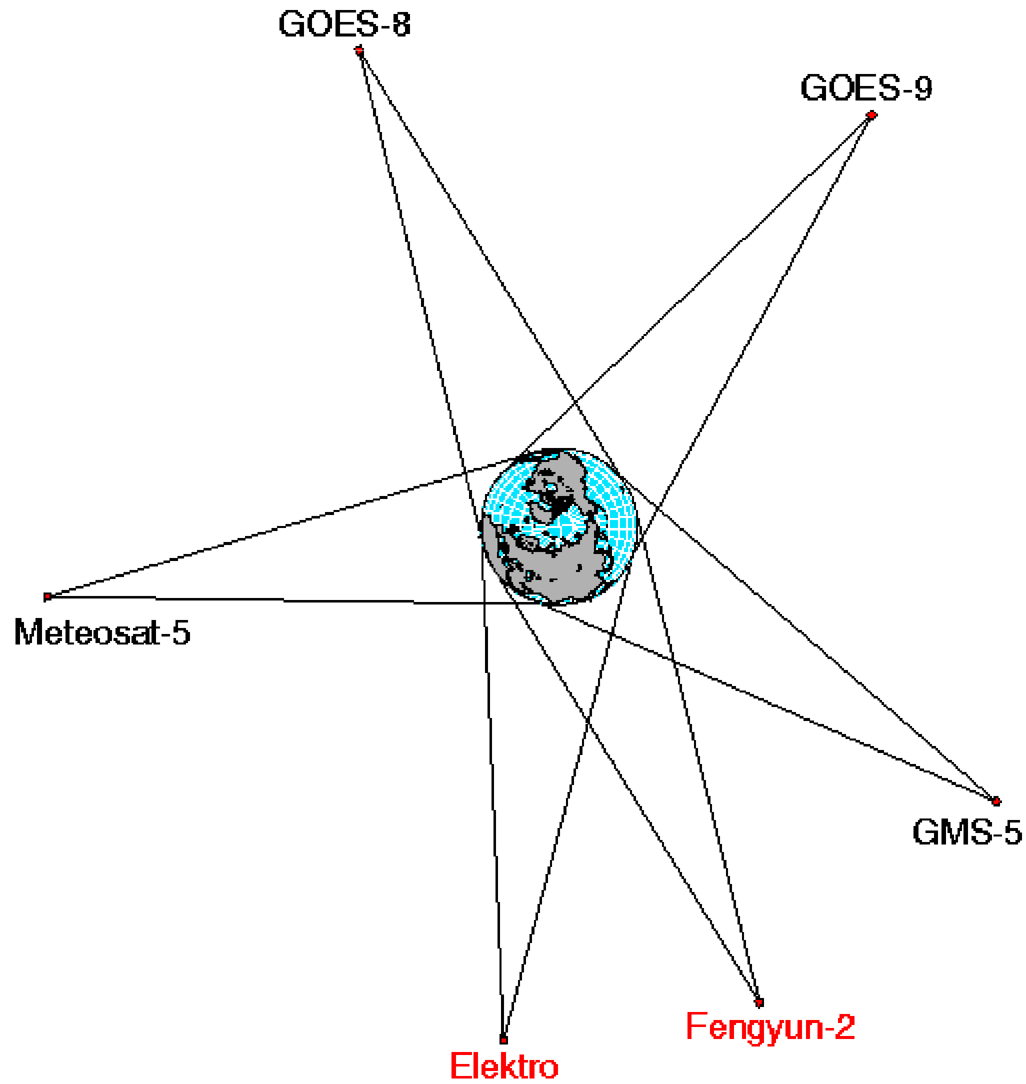
- **SSM/I Era: five radiometers since 1987**
  - early statistical rain rate algorithms
  - 1990s: PIP/AIP programs, intercomparisons
  - improved rain screening
  - explicit mesoscale model physics
  - finite cloud effects, 3-D radiative transfer

- **TRMM Era: November 27, 1997 launch**
  - low-inclination LEO with SSM/I-like microwave imager, first precipitation radar
  - profiling algorithms, radar+radiometer combinations
  - recent emphasis placed on “near real time” use:
    - rapid imagery, combinations with other satellite sensors
    - NWP forecast model impact

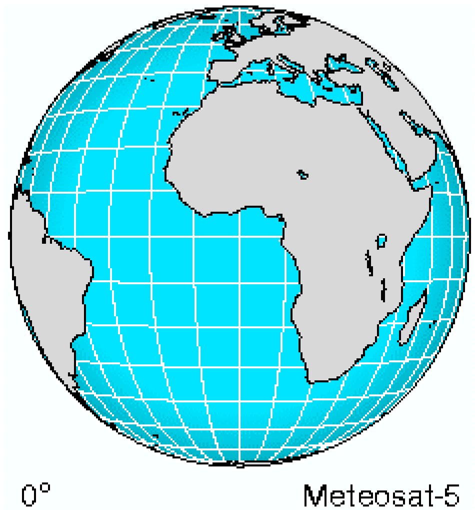
Some Past Efforts in Merging SSM/I and Geostationary IR Data

- Adler et. al, 1991,1993
  - calibration coefficients from SSMI rain rates vs. IR rain rates (monthly, 1-degree)
- Vicente, 1994
  - first work on SSMI-calibrated instantaneous geo-rain rates
- Berg, 1994
  - calibration of rain probability and rain amount distributions by IR temperature distributions
    (5 days, 2.5-degree)
- Jobard and Debois, 1994
  - training of rain cloud classification by 3-D histograms (1-12 hours, 15-120 km)
- Vicente et. al, 1998
  - radar-adjusted IR with NWP model adjustments (instantaneous, 30 km)

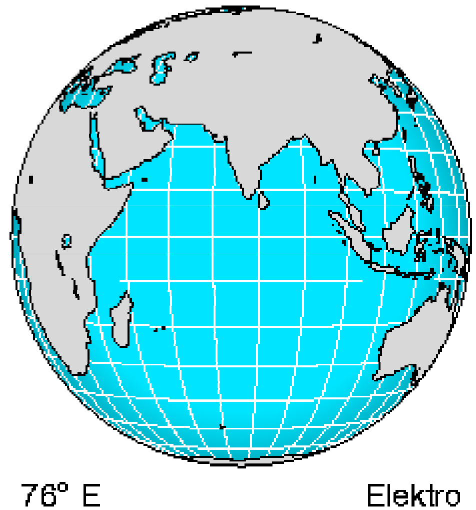
Geostationary Meteorological Satellite Positions Viewed Looking Down onto the North Pole



Current Meteorological Geostationary Orbiting Earth Satellite Views



EUROPEAN



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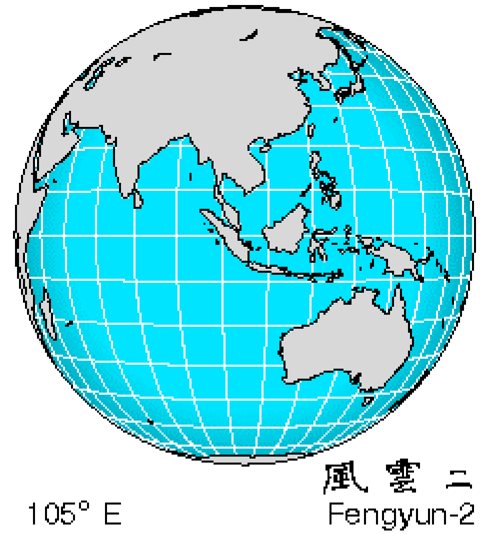

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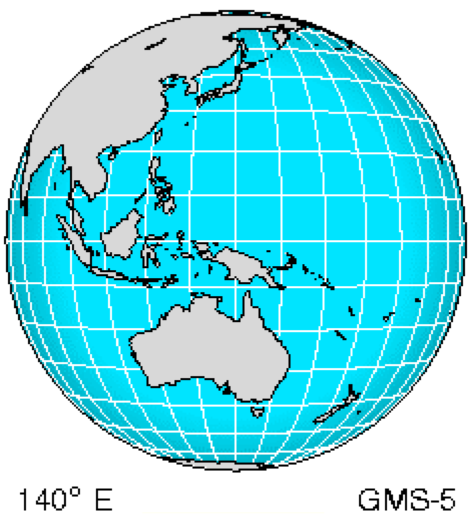
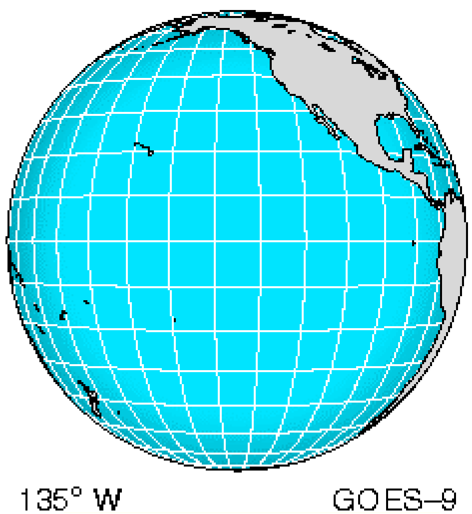
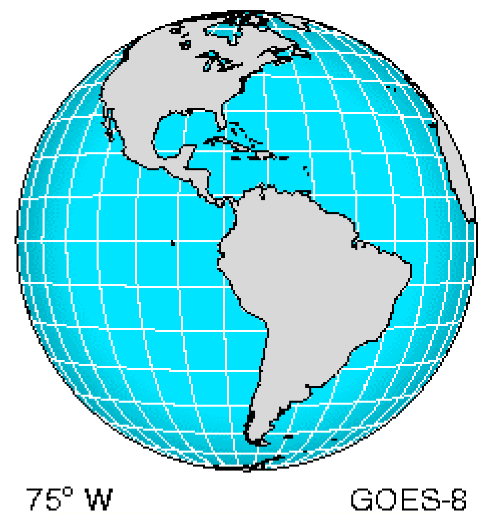


JAPAN



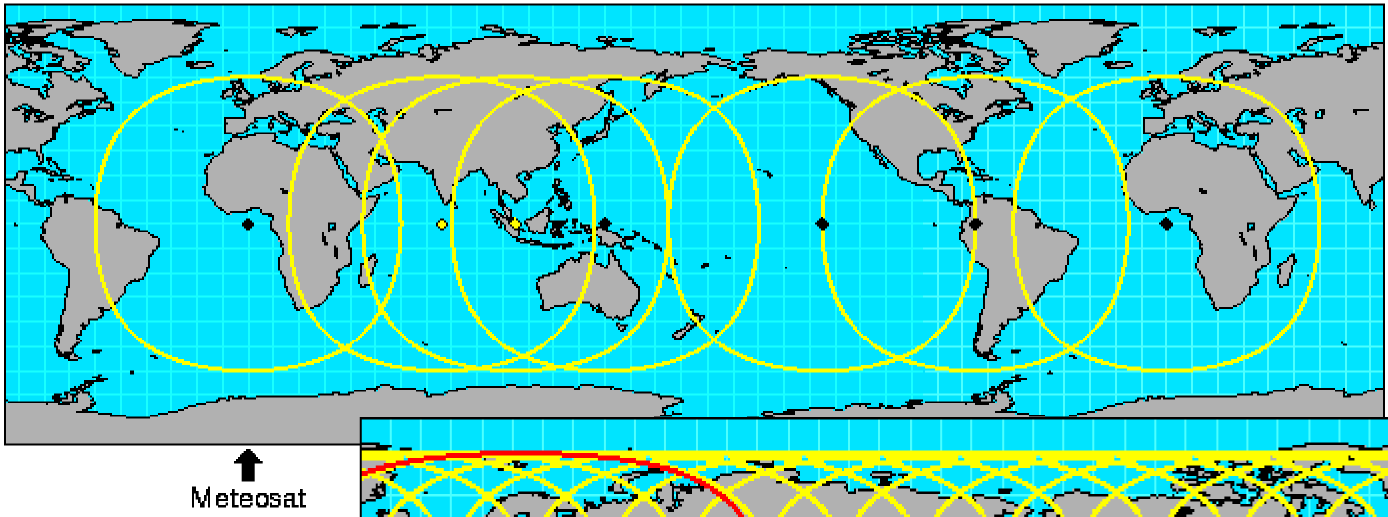
UNITED STATES

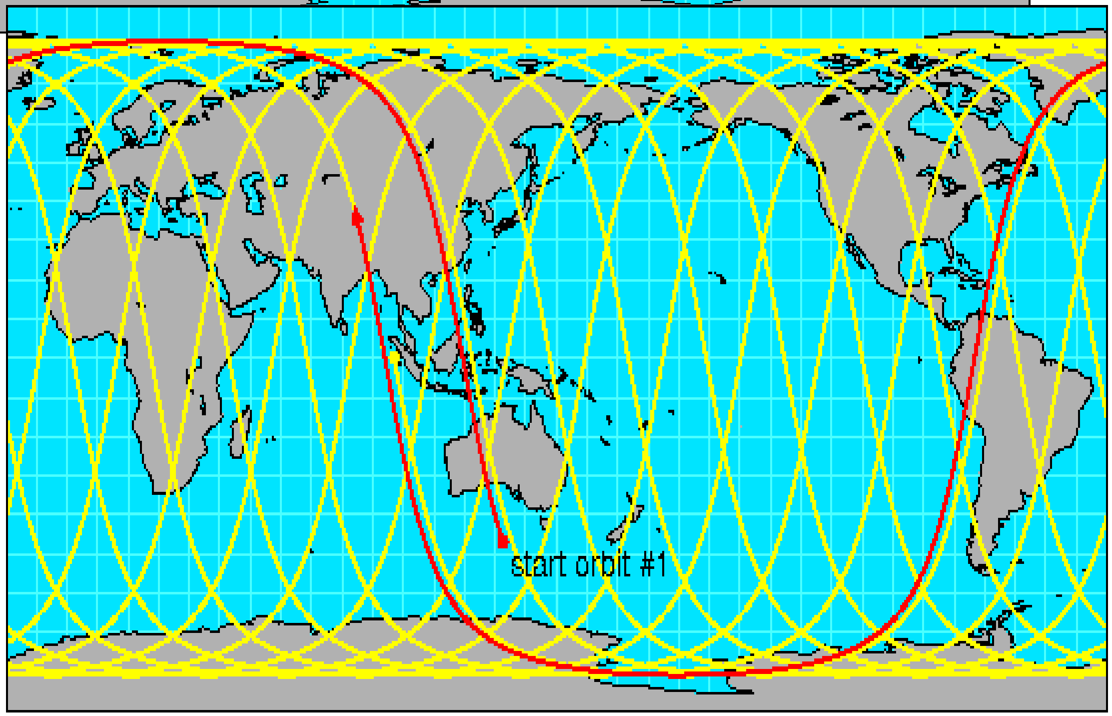


UNITED STATES

Images courtesy of David Johnson, NCAR, Boulder, CO

Geostationary and NOAA Polar-Orbiting Satellite Coverage Regions





- About 14 orbits/day
- 3000 km AVHRR swath
- 1400 km SSM/I swath
- 760 km TRMM swath
- Best coverage near poles

Some Recipes and Ingredients for a Satellite-Based Rainfall Analysis

RECIPE 1:

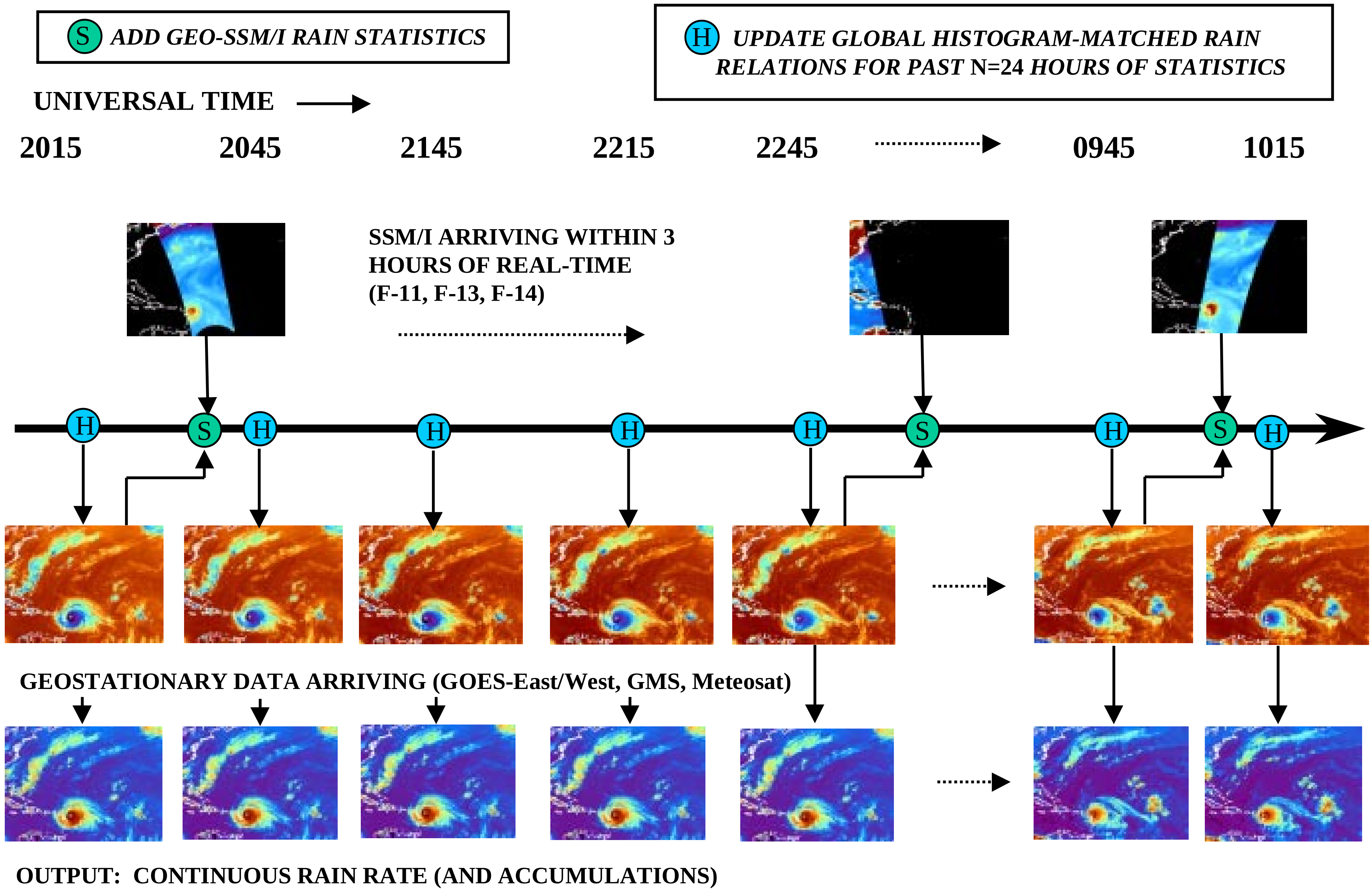
- Add many polar-orbiting microwave sensors, sample sufficiently, combine and average rain rates over a spatial domain and a time interval

RECIPE 2:

- Add four or five geostationary infrared imagers, skim off data above a pre-determined temperature threshold, and average rain rates over a month

RECIPE 3:

- Add ingredients for (**1**) and (**2**), blend carefully over time and space, statistically mix until they look about the same



S ADD GEO-SSM/I RAIN STATISTICS
H UPDATE GLOBAL HISTOGRAM-MATCHED RAIN RELATIONS FOR PAST N=24 HOURS OF STATISTICS
UNIVERSAL TIME
2015
2045
2145
2215
2245
0945
1015
SSM/I ARRIVING WITHIN 3 HOURS OF REAL-TIME (F-11, F-13, F-14)
GEOSTATIONARY DATA ARRIVING (GOES-East/West, GMS, Meteosat)
OUTPUT: CONTINUOUS RAIN RATE (AND ACCUMULATIONS)

Probability-Matching Method

- Developed for radar usage
- Replicate PDF of *P(Z)* to *P(R)*
- Tuned to local climatology over a space-time domain

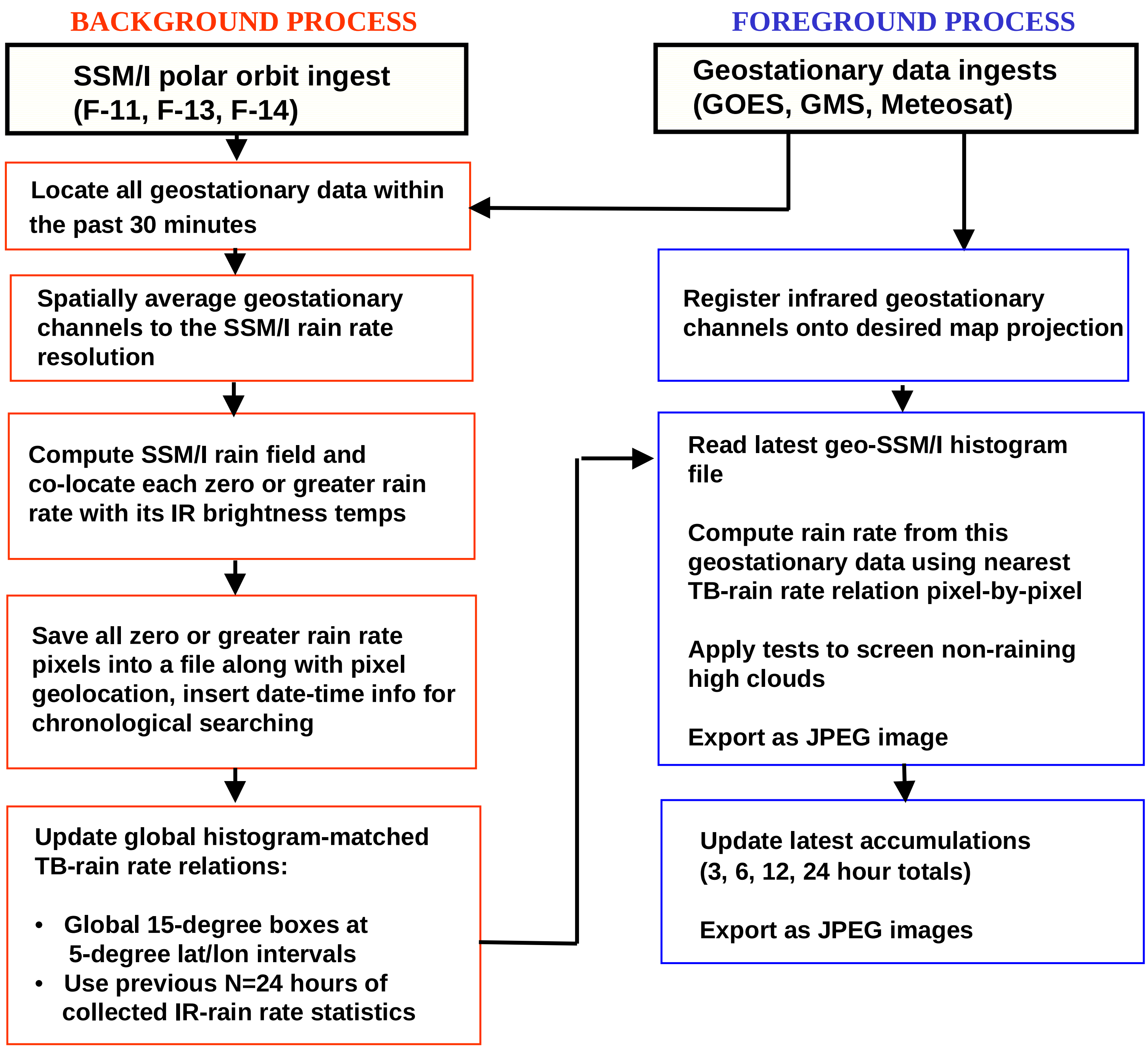
$$\int_{R_T}^{R_i} P(R)\,dR = \int_{Z_T}^{Z_i} P(Z)\,dZ$$

- For satellite, $P(Z) \rightarrow P(T_B)$
- *Dynamically* tune with SSM/I rain as new passes arrive
- Relation is instrument-specific

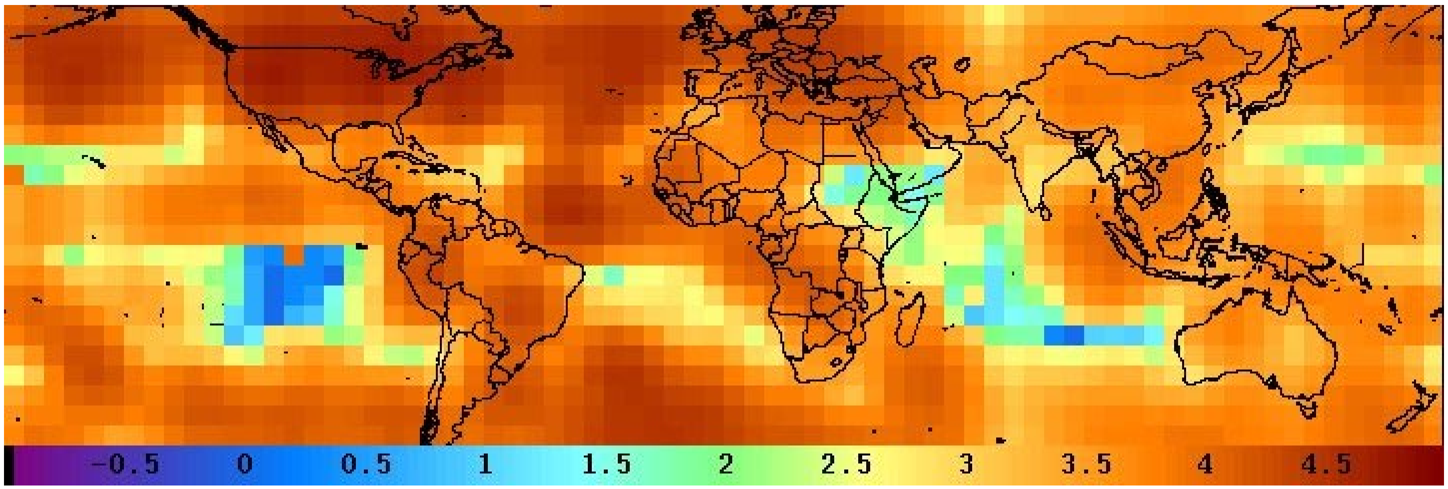
$$\int_{R_T}^{R_i} P(R)\,dR = \int_{T_{B,T}}^{T_{B,i}} P(T_B)\,dT_B$$

- Match PDF moments to distribute *(Z,T)* pairs over higher rain rates (m=1 works nicely)

$$\frac{\int_{R_T}^{R_i} R^m P(R)\,dR}{\int_{R_T}^{\infty} R^m P(R)\,dR} = \frac{\int_{T_{B,T}}^{T_{B,i}} {T_B}^m P(T_B)\,dT_B}{\int_{T_{B,T}}^{\infty} {T_B}^m P(T_B)\,dT_B}$$


BACKGROUND PROCESS
FOREGROUND PROCESS
SSM/I polar orbit ingest (F-11, F-13, F-14)
Geostationary data ingests (GOES, GMS, Meteosat)
Locate all geostationary data within the past 30 minutes
Spatially average geostationary channels to the SSM/I rain rate resolution
Compute SSM/I rain field and co-locate each zero or greater rain rate with its IR brightness temps
Save all zero or greater rain rate pixels into a file along with pixel geolocation, insert date-time info for chronological searching
Update global histogram-matched TB-rain rate relations:
• Global 15-degree boxes at 5-degree lat/lon intervals
• Use previous N=24 hours of collected IR-rain rate statistics
Register infrared geostationary channels onto desired map projection
Read latest geo-SSM/I histogram file
Compute rain rate from this geostationary data using nearest TB-rain rate relation pixel-by-pixel
Apply tests to screen non-raining high clouds
Export as JPEG image
Update latest accumulations (3, 6, 12, 24 hour totals)
Export as JPEG images

Log (Number of Points) used in each lat-lon box to create histogram-matched rain rate relationship, using past 24 hours of co-located geostationary and global SSM/I data

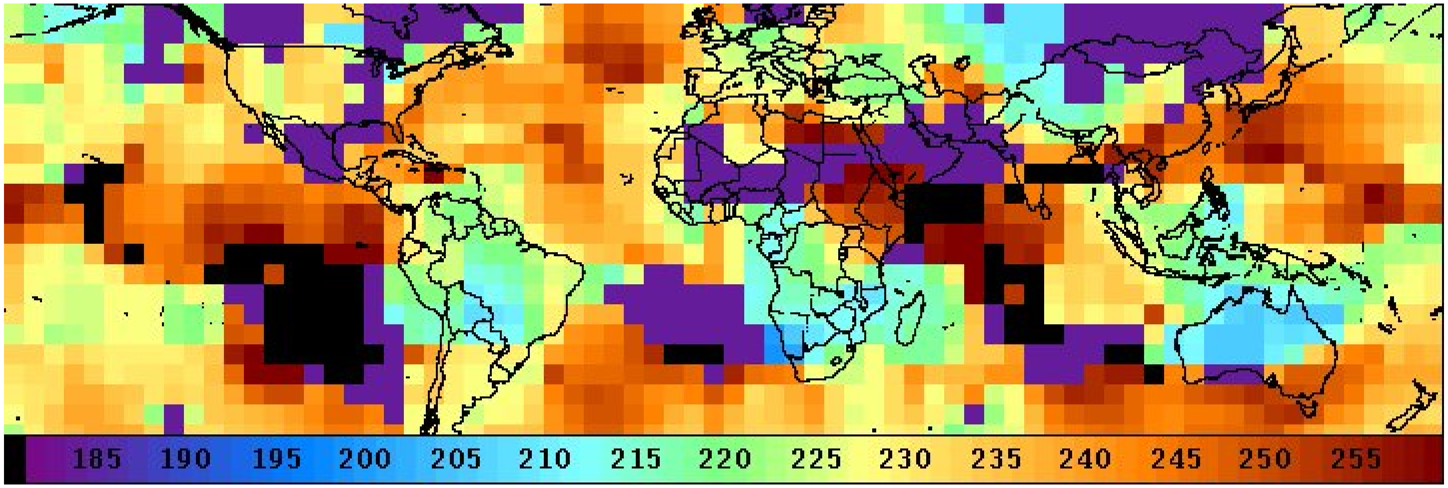


- 15 degree boxes spaced every 5 degree apart (overlap for smooth transition in rain rate between regions)

- Gap over Indian Ocean is filled from neighboring regions of Meteosat and GMS

- As new SSM/I data arrive, old co-located data is deleted as to maintain the past 24 hours of data available for histogram-matching

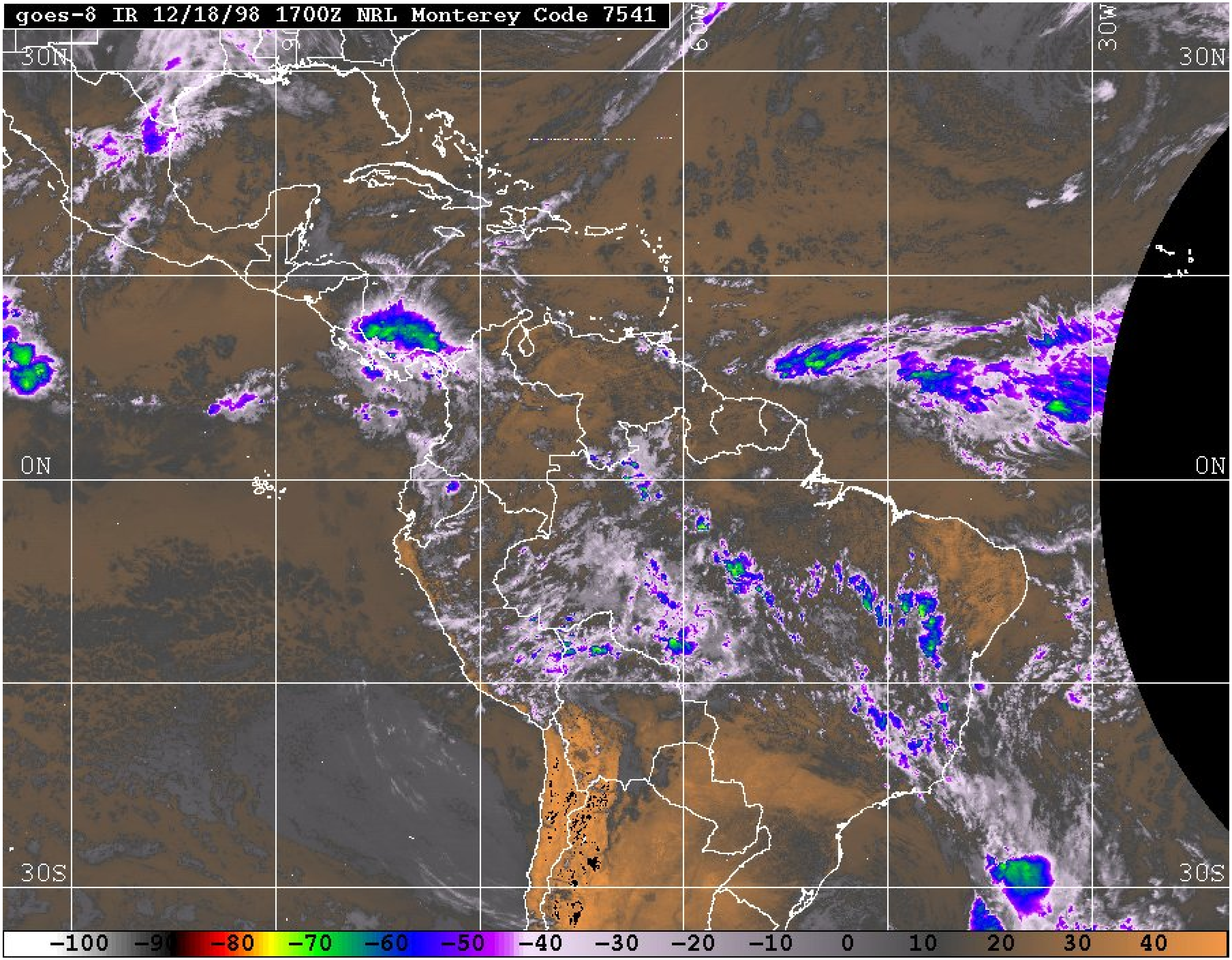
Zero-rain rate IR temperature threshold (Kelvin) in each lat-lon box, using past 24 hours of co-located geostationary and global SSM/I data



- Zero rain rate threshold automatically determined when the zero rain rate points are processed in histogram matching process

- Lowest temperature bin is 183 K (purple color, indicates no rain)

- If not sufficient points, lat-lon box is marked “bad” (black color)


goes-8 IR 12/18/98 1700Z NRL Monterey Code 7541
30N
0N
30S
90W
60W
30W
30N
0N
30S
-100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40

•Region is 35S-35N, 110W-20W, rectangular map, 0.1-degrees/pixel

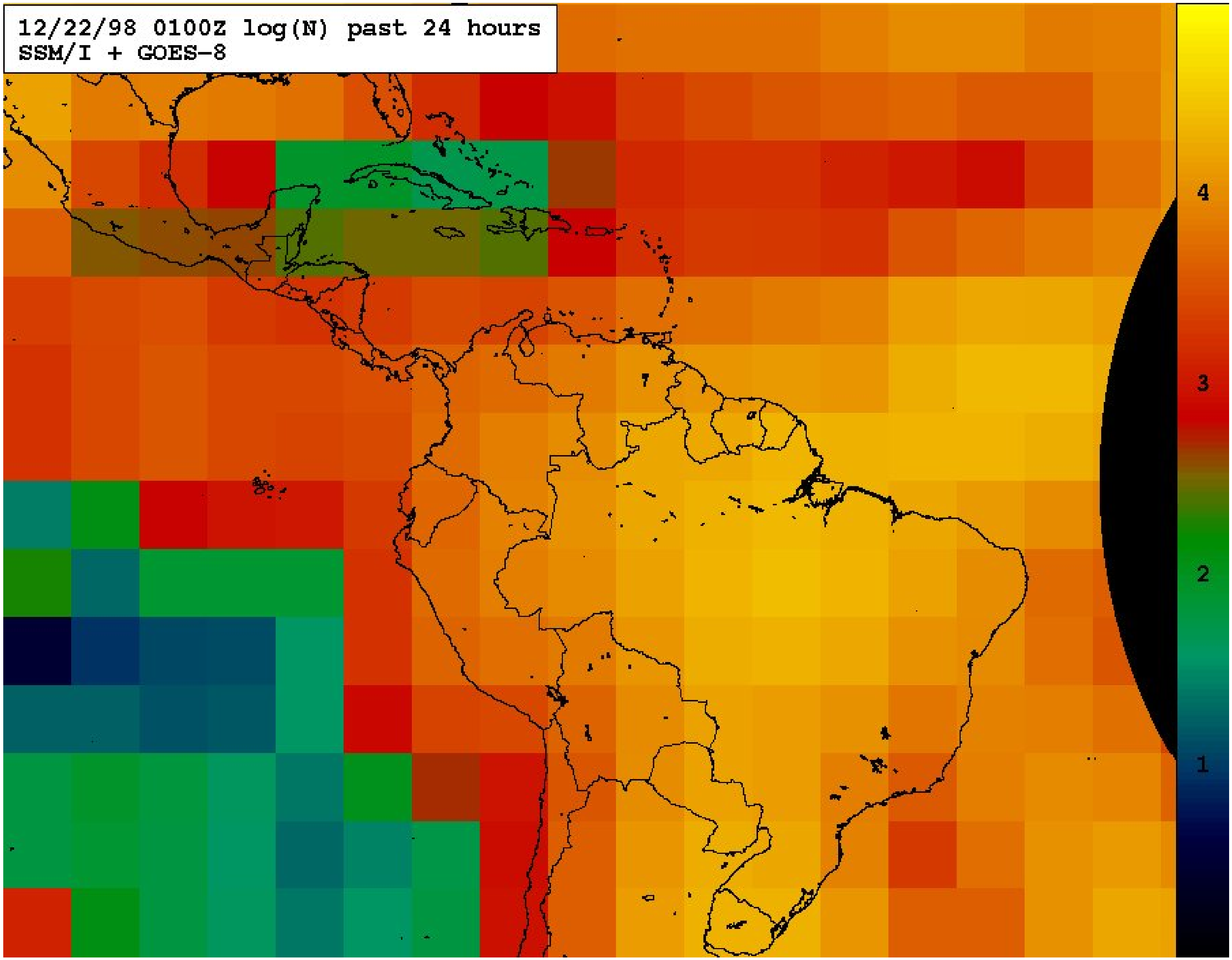
•GOES-8 (East) routine half-hourly scans extend down to 20S, versus the equator for GOES-10 (West) (fulldisks every three hours)

TRMM Microwave Imager (TMI) coverage extends from about 38S-38N

•Assures sufficient coincident space-and-time passes of the current (December 1998) SSM/I's (F-11, F-13, F-14), which is needed to gather as many coincident pixels for histogram techniques

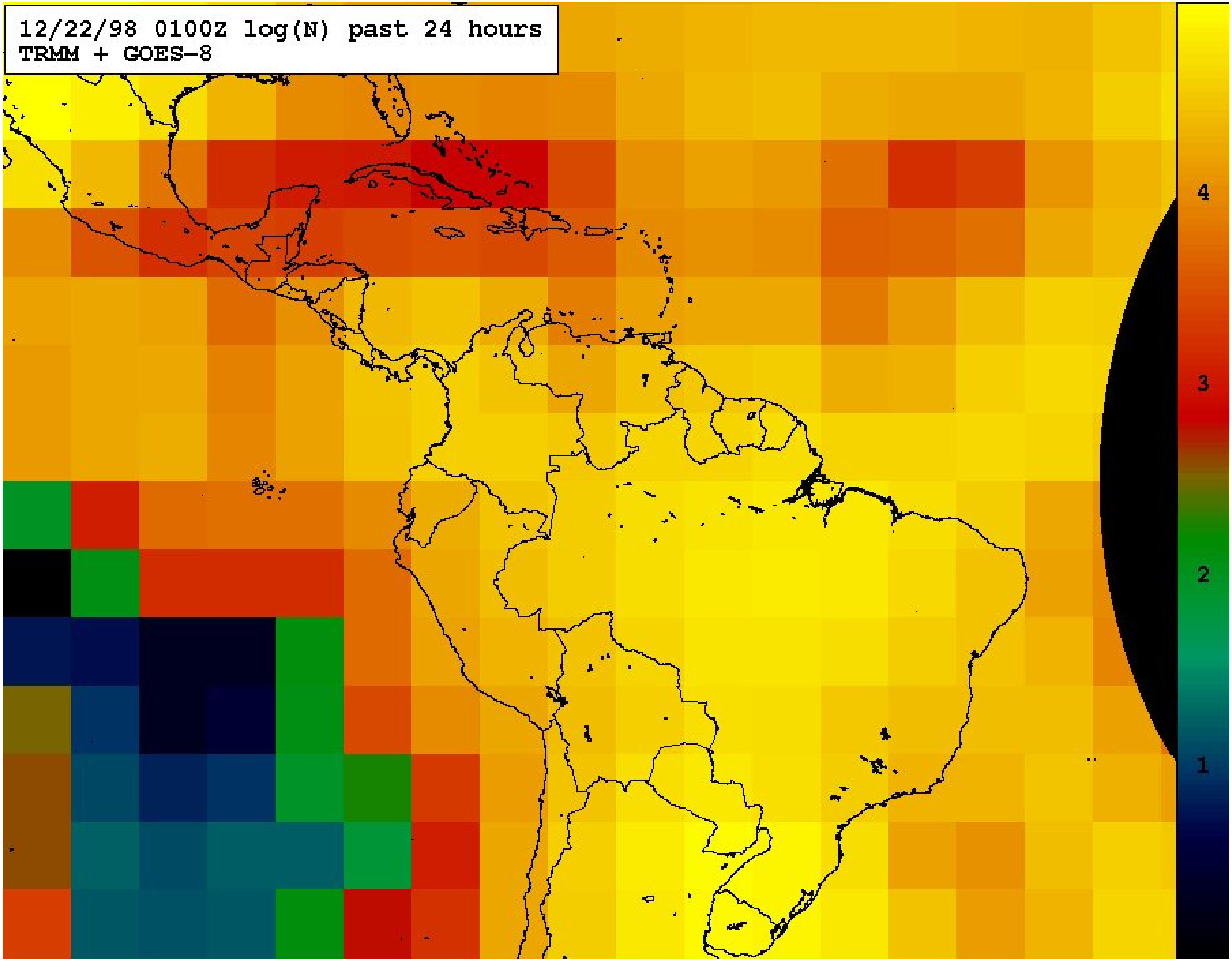
•SSM/I data arrive within three hours of orbit completion time courtesy Fleet Numerical Meteorology and Oceanography Center (FNMOC)

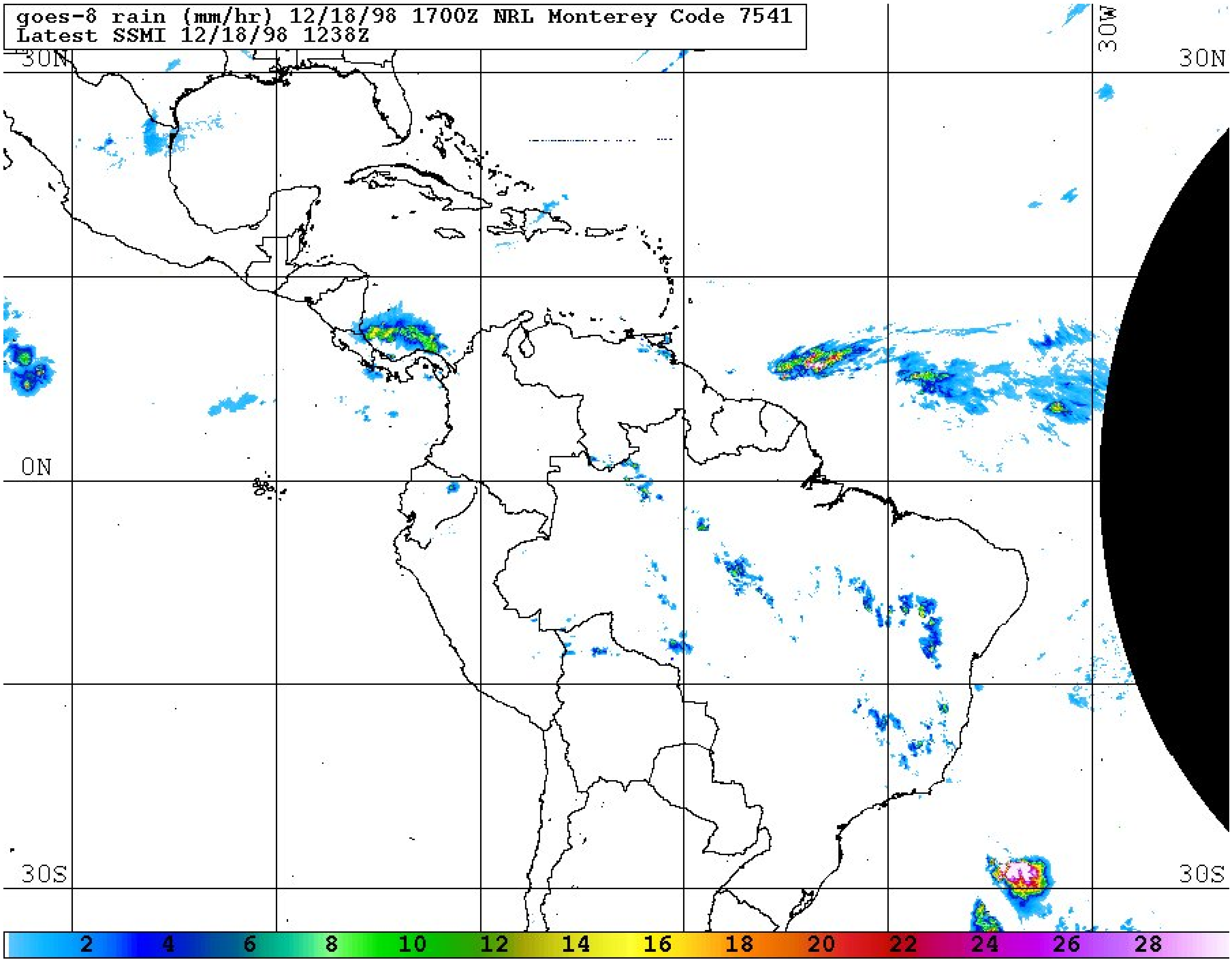
•TRMM data arrive in near-real time courtesy TRMM Science and Data Information Service (TSDIS)

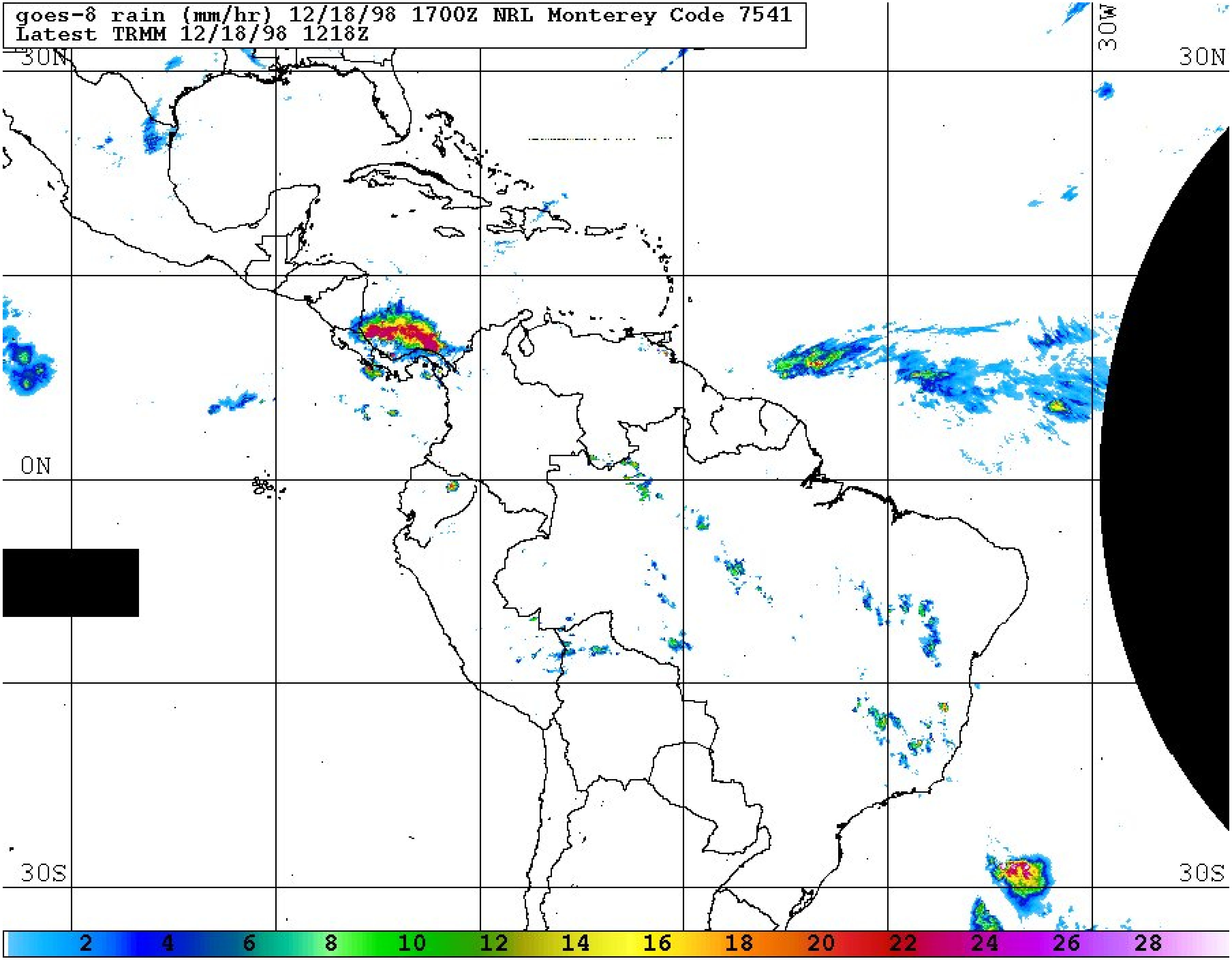

12/22/98 0100Z log(N) past 24 hours
SSM/I + GOES-8
4
3
2
1

TRMM Real Time Data

- Available from TSDIS (TRMM Science Data Information System) ftp server within 3 hours of orbit completion
- **Level 1B-11** (TMI radiometer, 9 MB/file)
  - all geolocated brightness temperatures
- **Level 2B-12** (TMI radiometer, 7 MB/file)
  - rain flag, surface rain, total cloud, total ice
- **Level 2B-23** (PR radar, 4 MB/file)
  - rain type, freezing height, storm height
- **Level 2B-25** (PR radar, 20 MB/file)
  - rain vertical structure (20 levels at 500 m cells)


12/22/98 0100Z log(N) past 24 hours
TRMM + GOES-8
4
3
2
1


goes-8 rain (mm/hr) 12/18/98 1700Z NRL Monterey Code 7541
Latest SSMI 12/18/98 1238Z
30N
30W
30N
0N
30S
30S
2
4
6
8
10
12
14
16
18
20
22
24
26
28


goes-8 rain (mm/hr) 12/18/98 1700Z NRL Monterey Code 7541
Latest TRMM 12/18/98 1218Z
30N
30N
30W
0N
30S
30S
2
4
6
8
10
12
14
16
18
20
22
24
26
28

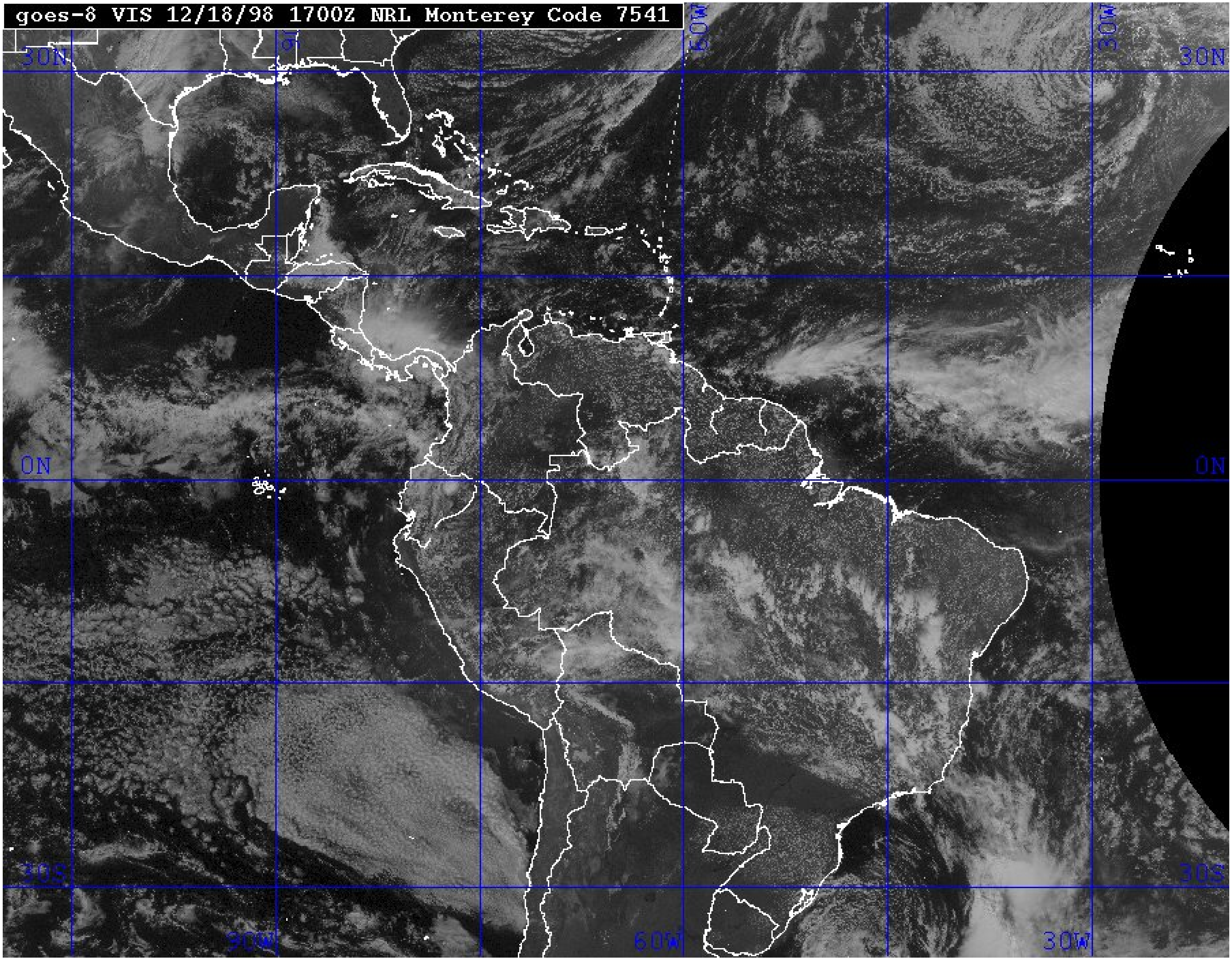
Two High Cloud Rain Screening Tests

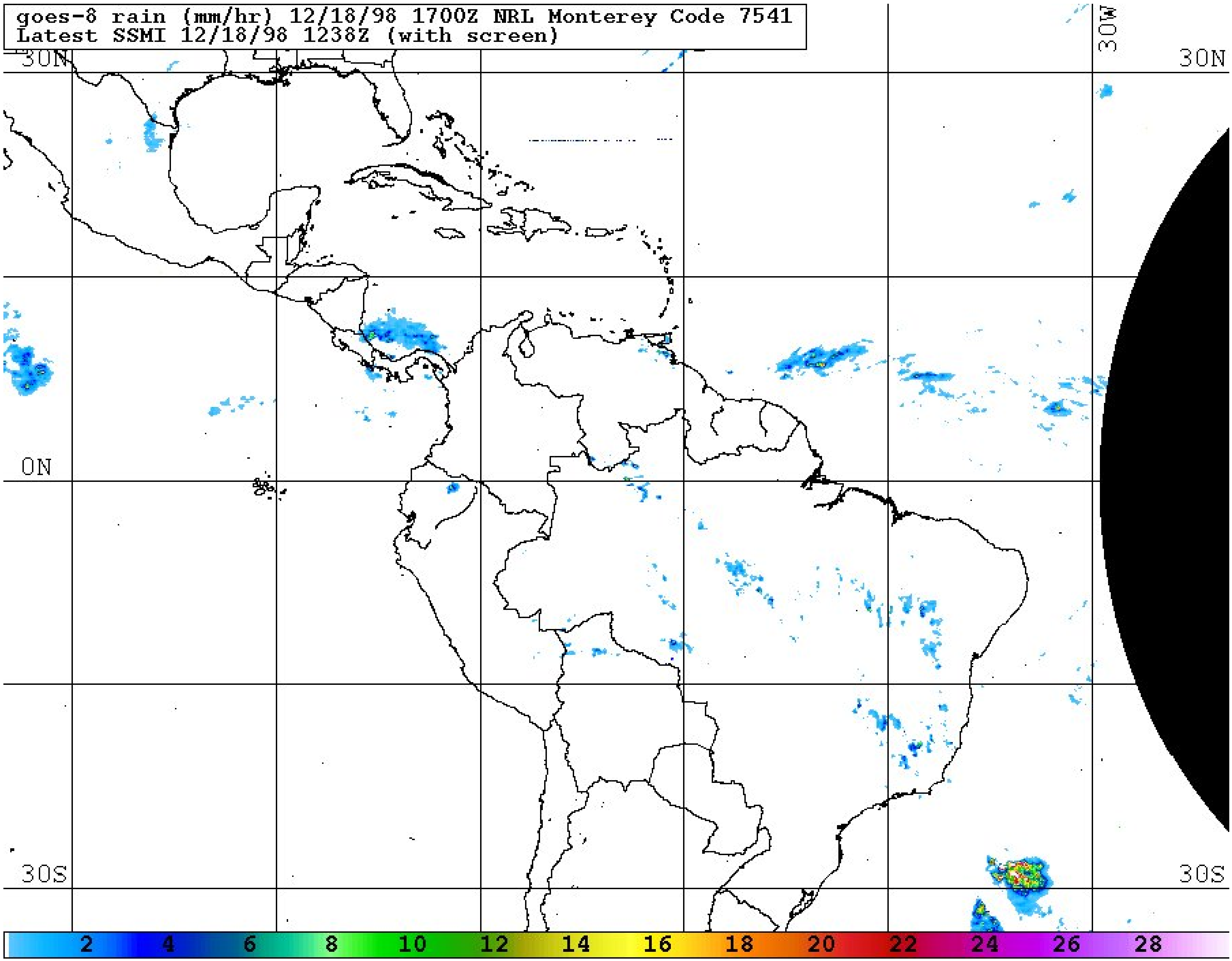
- Split Window: 10 um (T_4), 12 um (T_5)
- Adjacent-time IR temperature decay (1=now, 2=prior)

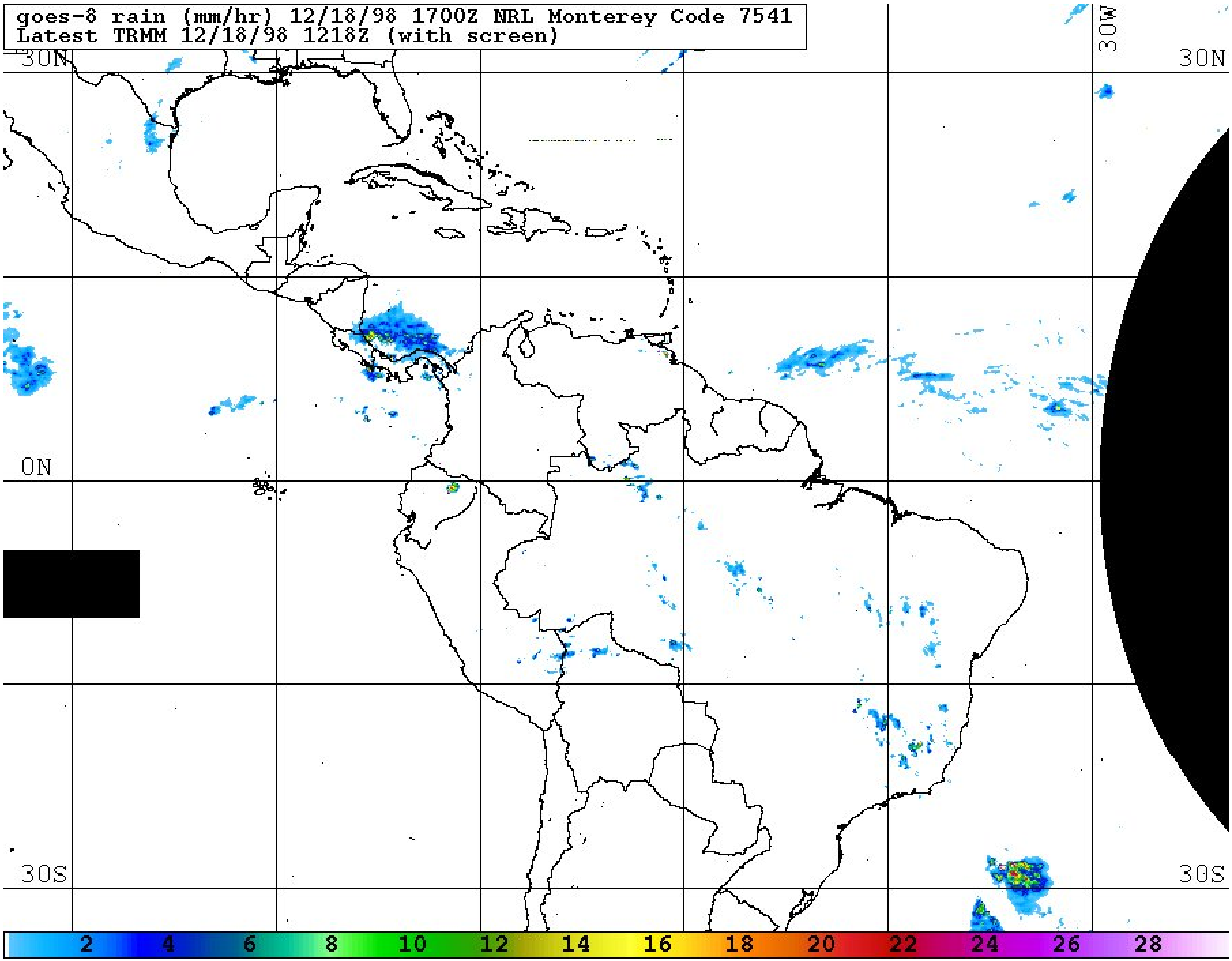
Apply 3x3 pixel average prior to differencing
f_1 and f_2 are adjustable constants

$$R' = R\exp(-f_1(\overline{T}_4 - \overline{T}_5))$$

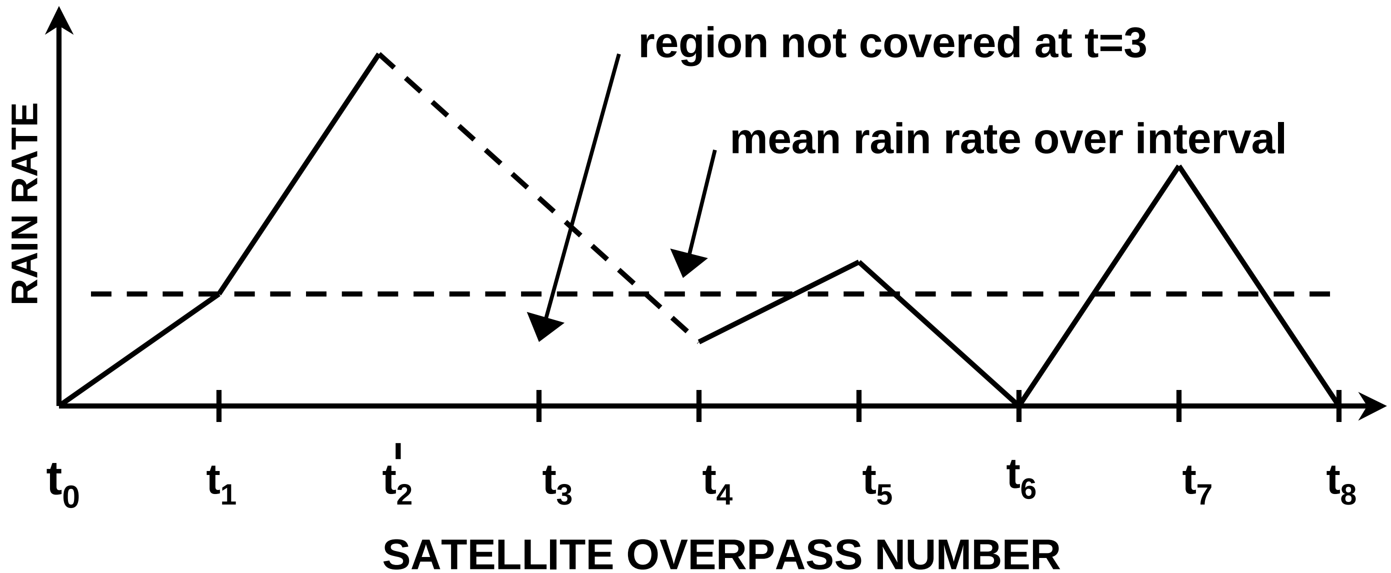
$$R'' = R'\exp(-f_2(\overline{T}_4^{\,1} - \overline{T}_4^{\,2})/\Delta t)$$


goes-8 VIS 12/18/98 1700Z NRL Monterey Code 7541
30N
0N
30S
90W
60W
30W
30N
0N
30S
60W
30W


goes-8 rain (mm/hr) 12/18/98 1700Z NRL Monterey Code 7541
Latest SSMI 12/18/98 1238Z (with screen)
30N
30W
30N
0N
30S
30S
2
4
6
8
10
12
14
16
18
20
22
24
26
28


goes-8 rain (mm/hr) 12/18/98 1700Z NRL Monterey Code 7541
Latest TRMM 12/18/98 1218Z (with screen)
30N
30W
30N
0N
30S
30S
2
4
6
8
10
12
14
16
18
20
22
24
26
28

DERIVATION OF RAINFALL ACCUMULATIONS



SSM/I-only

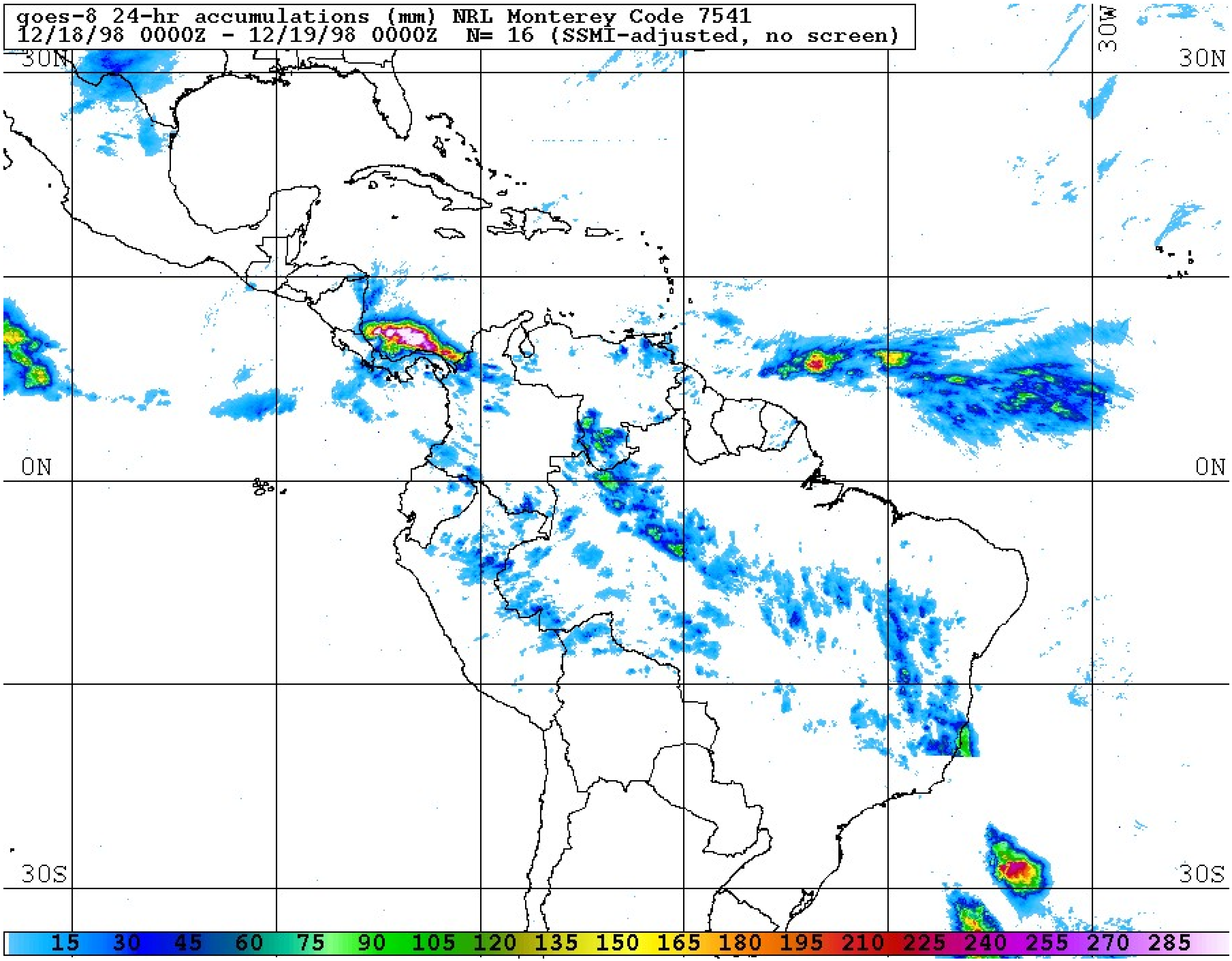
$$R^{total} = (t_N - t_0)\frac{1}{N}\sum_{i=0}^{N} R_i$$

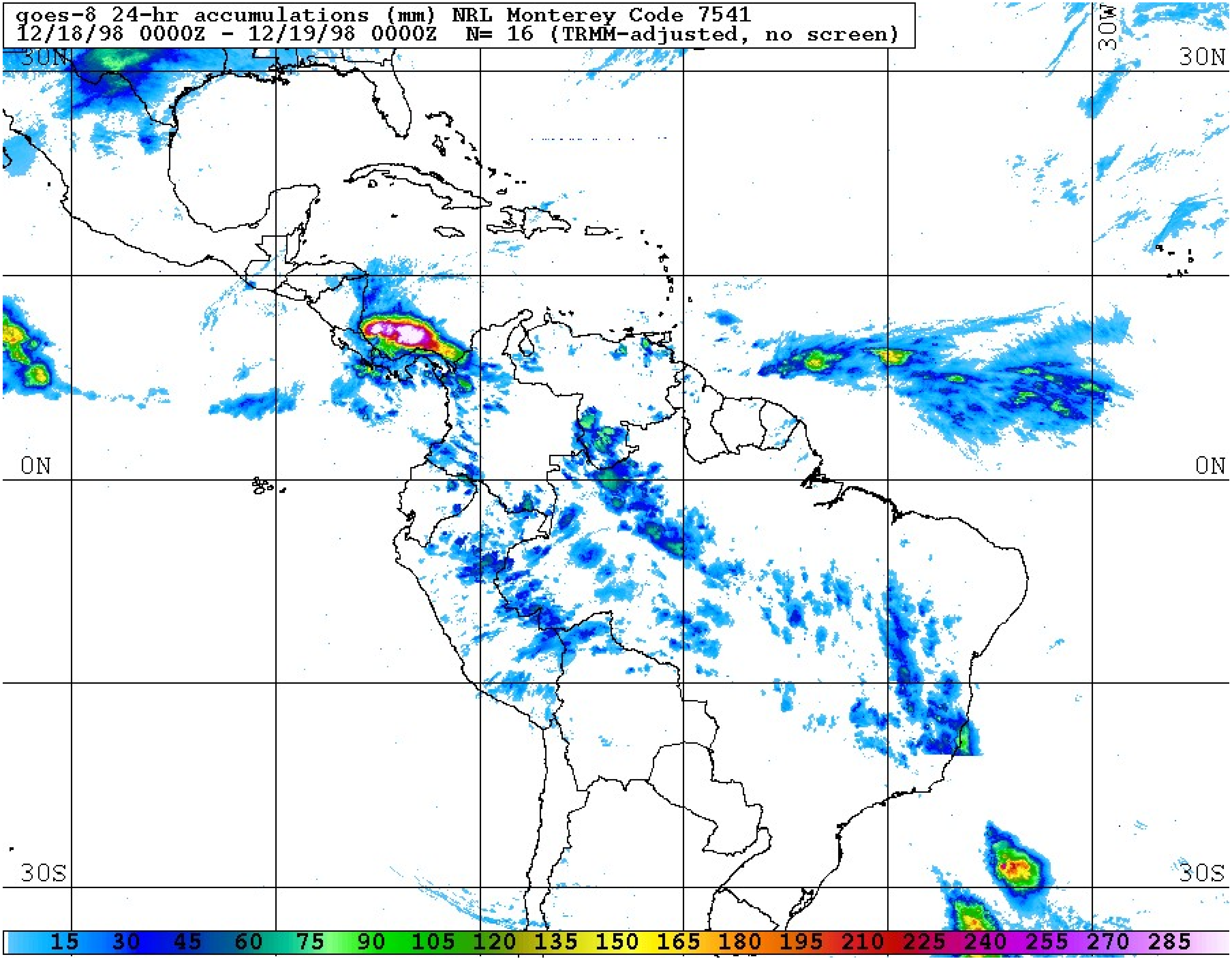
- (Mean rain rate over the interval) X (total hours in the interval)

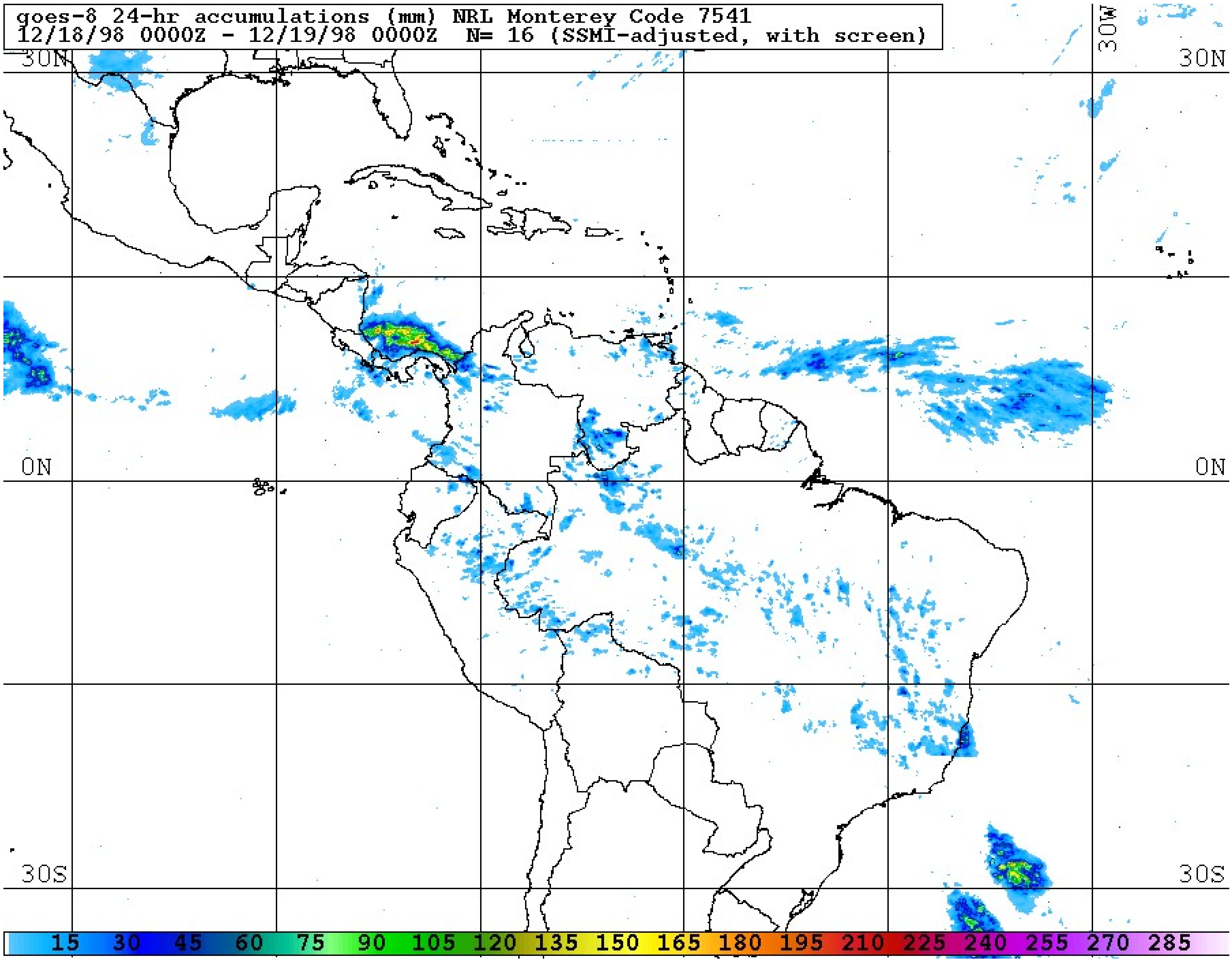
Geostationary

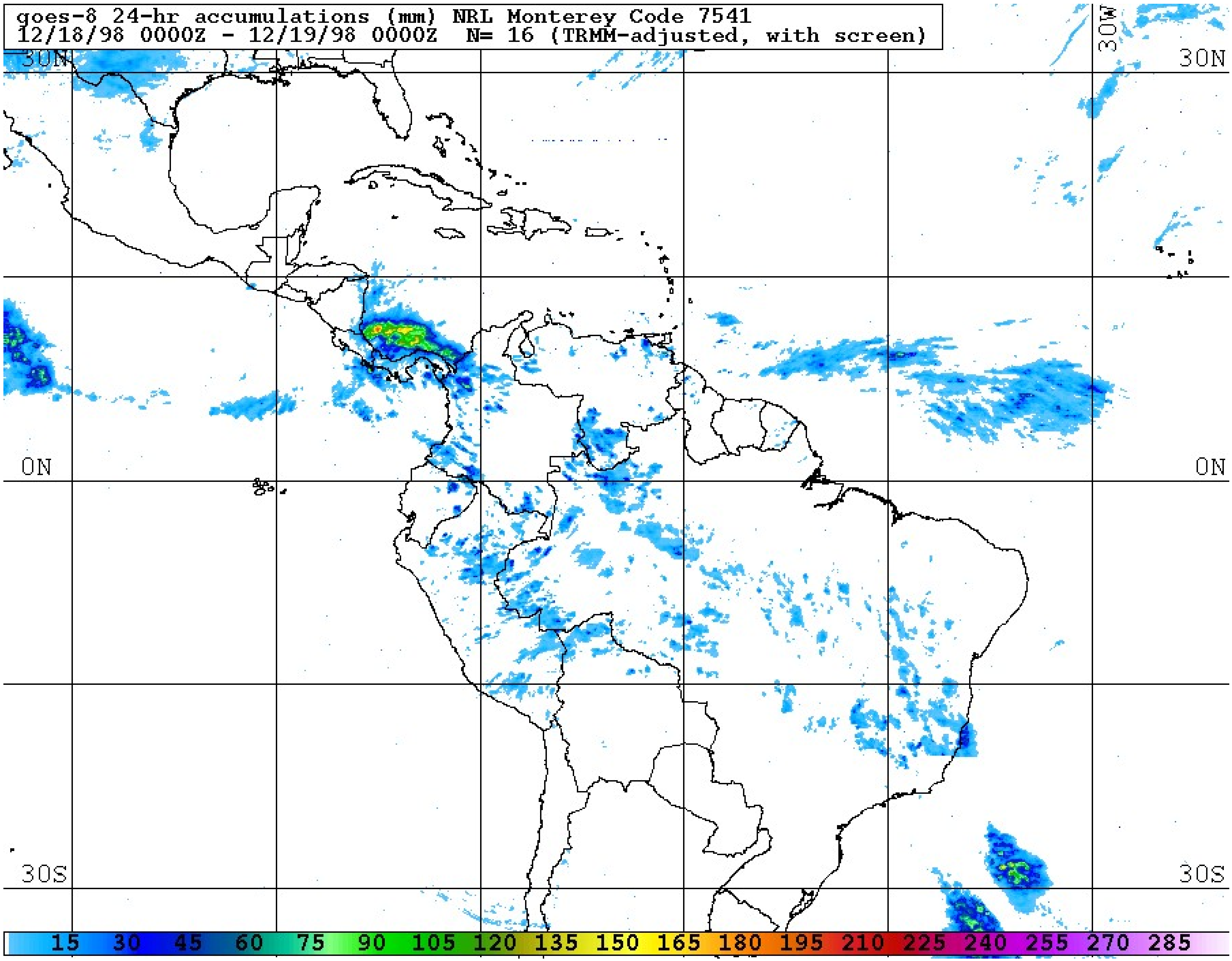
$$R^{total} = \frac{1}{2}\sum_{i=1}^{N} (R_i + R_{i-1})(t_i - t_{i-1})$$

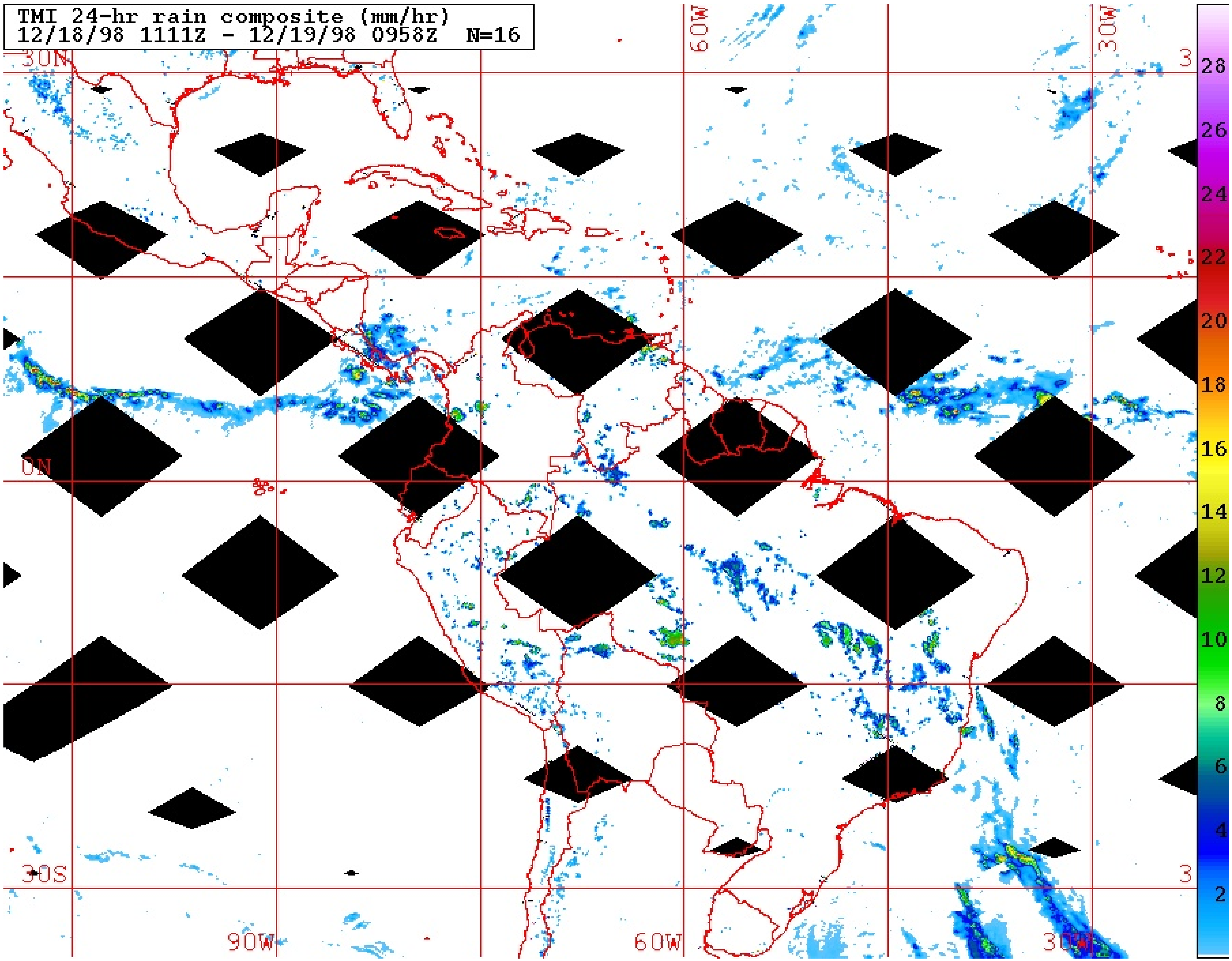
- Time-integrated rain rate accumulated each update cycle
- Linear transition between successive passes

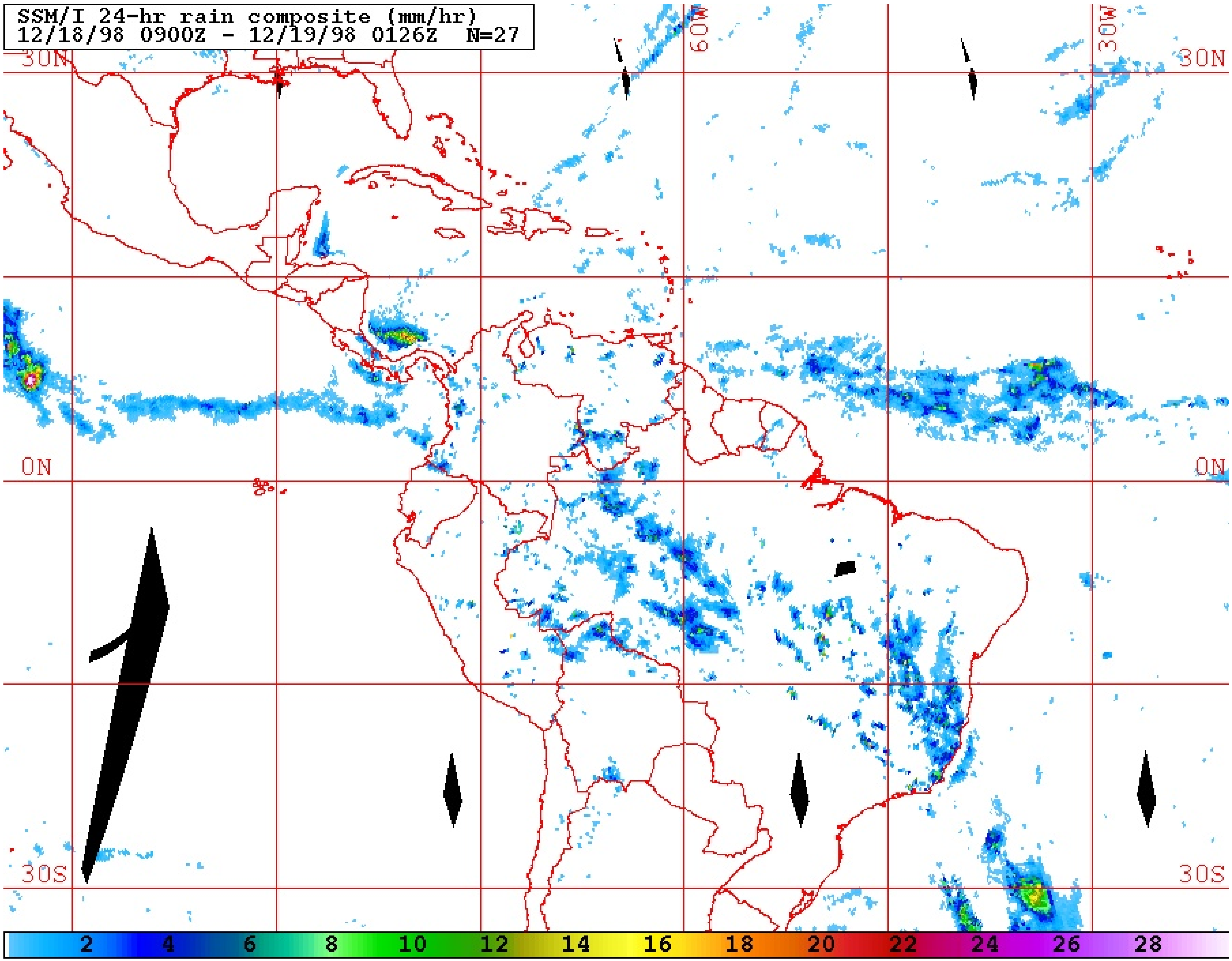

goes-8 24-hr accumulations (mm) NRL Monterey Code 7541
12/18/98 0000Z - 12/19/98 0000Z N= 16 (SSMI-adjusted, no screen)
30N
30W
30N
0N
0N
30S
30S
15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285


goes-8 24-hr accumulations (mm) NRL Monterey Code 7541
12/18/98 0000Z - 12/19/98 0000Z N= 16 (TRMM-adjusted, no screen)
30N
30N
0N
0N
30S
30S
30W
15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285


goes-8 24-hr accumulations (mm) NRL Monterey Code 7541
12/18/98 0000Z - 12/19/98 0000Z N= 16 (SSMI-adjusted, with screen)
30N
30W
0N
30S
15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285


goes-8 24-hr accumulations (mm) NRL Monterey Code 7541
12/18/98 0000Z - 12/19/98 0000Z N= 16 (TRMM-adjusted, with screen)
30N
0N
30S
30W
15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285

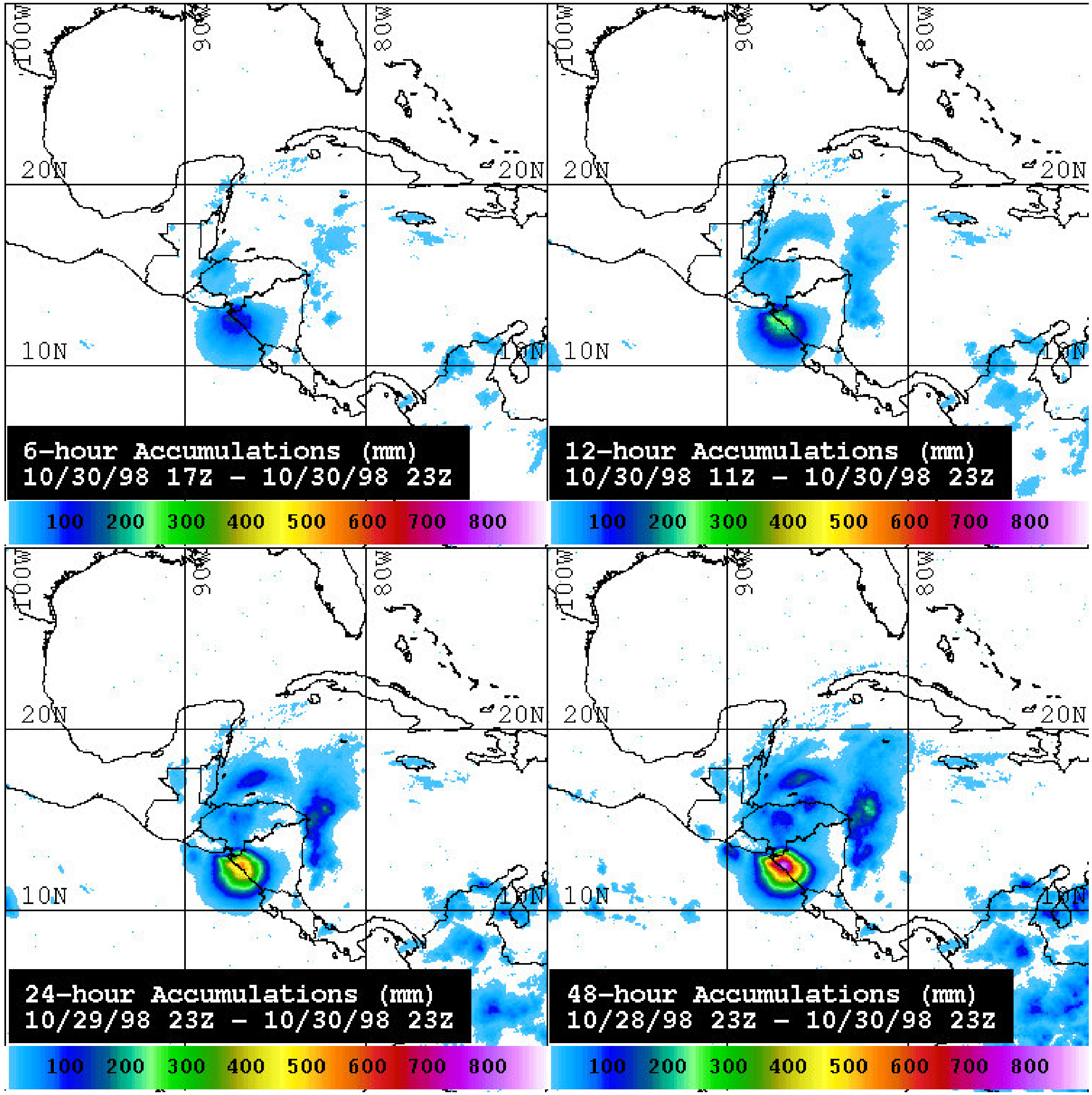

TMI 24-hr rain composite (mm/hr)
12/18/98 1111Z - 12/19/98 0958Z N=16
30N
0N
30S
90W
60W
30W
28
26
24
22
20
18
16
14
12
10
8
6
4
2


SSM/I 24-hr rain composite (mm/hr)
12/18/98 0900Z - 12/19/98 0126Z N=27
30N
60W
30W
0N
30S
2
4
6
8
10
12
14
16
18
20
22
24
26
28

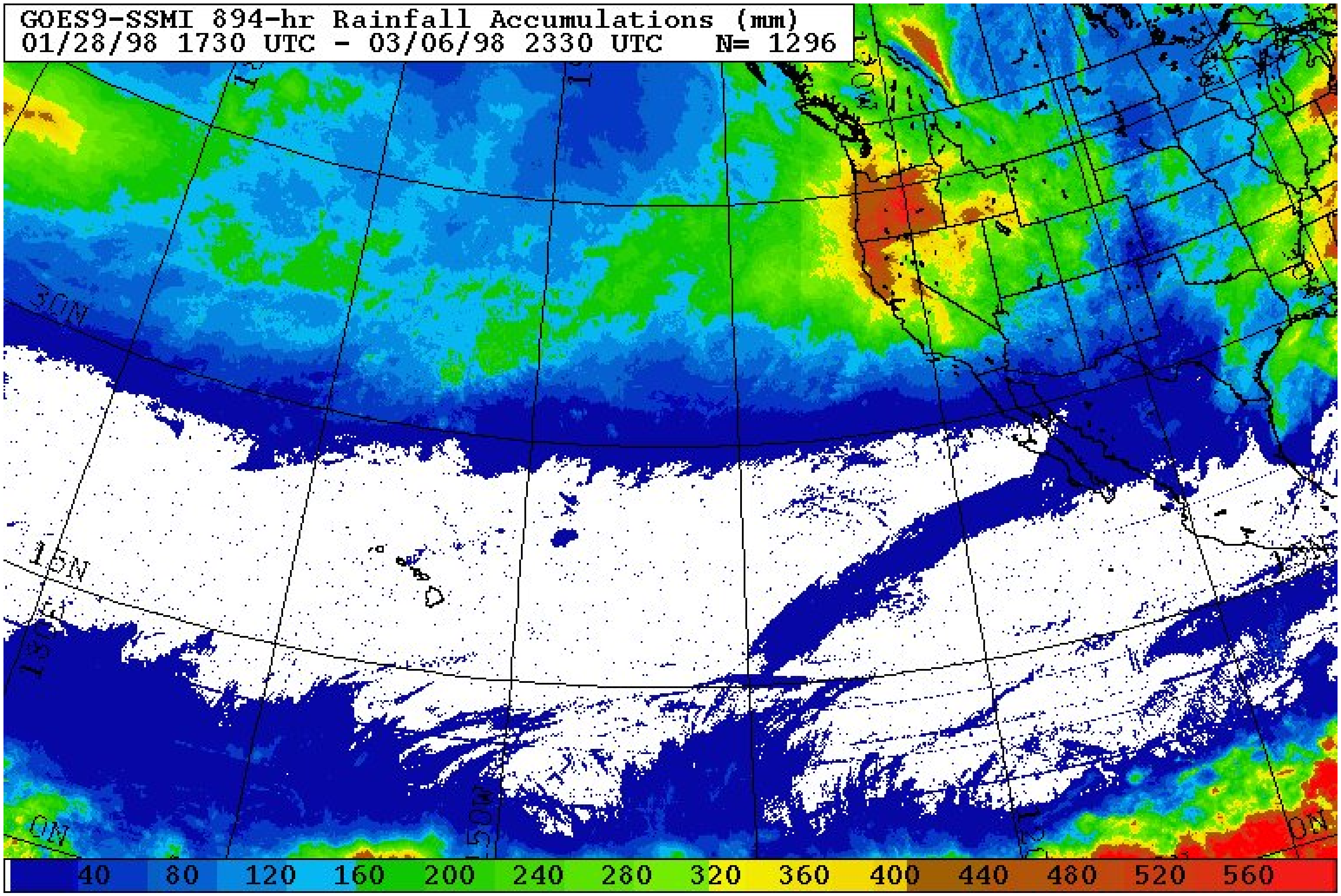
Rainfall Totals from Hurricane Mitch

Based on GOES-8 IR and the past 24 hours of merged SSM/I+GOES-8 statistics (not screened for high non-raining clouds)

Operational Navy SSM/I land-based rain algorithm has rain rates exceeding 25 mm/hr during this period



Example of Rain Totals Over 37 days During the El Nino Winter Storms of February 1998 (not screened for high non-raining clouds)



Current/Future Meteosat Configuration

Description	**Meteosat Second Generation (MSG)**	**Current Meteosat**
Spectral Channels		
Visible and Near-IR	0.6, 0.8, 1.6, HRV	Broadband Visible
Water Vapor	6.2, 7.3	6.4
Infrared	3.8, 8.7, 9.7, 10.8, 12.0, 13.4	11.5
Sampling Distance	Visible 3 km HRV 1 km IR 3 km	Visible 2.5 km IR 5 km
Radiometric Resolution	0.25 K	0.40 K
Update Cycle	15 minutes	30 minutes

Topics for Further Investigation

"…let's not worry about the variations in the nature of the precipitation or about the way in which the instrument averages it; but let's simply devise an effective technique that encompasses all of these variations in a manner which allows *P(Z)* to replicate *P(R)* over a suitable space-time domain." (Atlas, Rosenfeld and Wolff, 1990)

•What are the appropriate space and time scales over which to capture and track *P(R)*?

•Statistical technique was meant to be used for rainfall accumulations. On how short of a time scale can it be quantitatively applied?

• Indeed can any satellite technique track short-term (e.g. hourly) variations in rainfall?