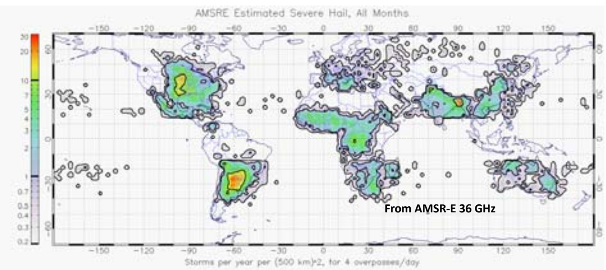
Extreme Thunderstorms as Seen by Satellite

Daniel J. Cecil
NASA Marshall Space Flight Center, Huntsville, AL
Daniel.J.Cecil@nasa.gov

Passive microwave imagers (SSMI, TMI, AMSR-E, SSMIS, GMI…) on low-earth orbit satellites since 1987 allow near-global climatologies of deep convection

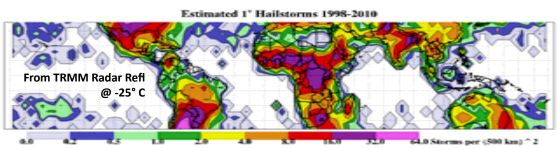
- Scattering by graupel / hail reduces TB relative to surroundings
- Magnitude of TB reduction depends largely on size, concentration, depth of precip ice
- MCS climatologies (Mohr and Zipser 1996) use area with 85 GHz below 250 K to define size, with 85 GHz below 225 K to ensure convection
- Storms with TB below ~200 K @ 85 GHz, ~255 K @ 37 GHz likely to have lightning (Liu et al. 2011)
- **Storms with TB below ~75 K @ 85 GHz, ~175 K @ 37 GHz likely to have large hail (Cecil and Blankenship 2012)**
- *Values cited above are from high-resolution TRMM satellite. Lower-resolution SSMI would have warmer thresholds*
- **Lower TBs should indicate stronger and stronger storms.**

Global climatology of severe hail storms estimated from AMSR-E (below) by Cecil and Blankenship (2012) used storms with 36 GHz below 200 K and 89 GHz below 130 K, with storms weighted more heavily as 36 GHz TB goes to lower values.



The brightness temperatures represent integrated effects from a vertical column. Active radar from TRMM (2.2 cm, 13.8 GHz) can focus on a particular vertical level. But attenuation correction casts doubt on details at low levels in intense storms. TRMM Radar limited to 36° S-N.

Same approach as in Cecil and Blankenship (2012) applied to TRMM Radar Reflectivity at -25° C level (below). Hail probabilities become large as reflectivity exceeds 50 dBZ at -25° C.



What about the strongest of the strong storms? This poster maps locations of the strongest storms seen by passive microwave imagers on several LEO satellites.

For each satellite, the single "champion" storm is found having the lowest brightness temperature for a given frequency (85 GHz or 37 GHz) in that satellite's record. (Tables below, blue symbols in maps at far right)

Table 1. Satellites used, and sensor resolutions.

nsor / Platform	Period of record	37 GHz footprint	85 GHz footprint	mode time of day
MI / F08	Jul 1987 Dec 1988	37 x 29 km	15 x 13 km	5-7 am; 5-7 pm 5 am NH; 5 pm SH
MI / F10	Dec 1990 Nov 1997	37 x 29 km	15 x 13 km	8-11 am; 8-11 pm 10 am NH; 10 pm SH
MI / F11	Dec 1991 Mar 2000	37 x 29 km	15 x 13 km	5-8 am; 5-8 pm 7 am NH; 7 pm SH
MI / F13	May 1995 Nov 2009	37 x 29 km	15 x 13 km	5-7 am; 5-7 pm 5 pm NH; 5 am SH
MI / F14	May 1997 Aug 2008	37 x 29 km	15 x 13 km	7-10 am; 7-10 pm 8 pm NH; 8 am SH
II / TRMM	Dec 1997 Feb 2014	16 x 9 km	7 x 5 km	any
ISR-E / Aqua	Jul 2002 Feb 2010	14 x 8 km	6 x 4 km	~1-3 am; ~1-3 pm

Table 2. Lowest 37 GHz brightness temperatures.

Sensor / Platform	Date	Time LST	Lon	Lat	**Min 37**	Min 85	Location	Notes
SSMI / F08	12 Dec 1988	6 pm	62.78 W	27.84 S	**146.9**	88.7	Santiago del Estero, **Argentina**	
SSMI / F10	22 Dec 1991	9 pm	61.25 W	26.72 S	**120.9**	64.5	Chaco, **Argentina**	
SSMI / F11	28 Jun 1998	6 pm	92.67 W	43.78 N	**119.1**	63.4	Minnesota, **USA**	1.75" hail, 81 kt wind
SSMI / F13	16 Nov 1998	6 pm	63.46 W	23.01 S	**129.2**	51.0	Salta, **Argentina**	
SSMI / F14	04 Jul 1999	9 am	94.22 W	47.02 N	**123.8**	64.9	Minnesota, **USA**	"Boundary Waters Derecho". Tornado, hail, wind damage reported. Price and Murphy (2002 GRL)
SSMI F15	13 Nov 2009	6 pm	59.23 W	28.76 S	**124.4**	53.6	Santa Fe, Argentina	Same as F15 case in Table 3
TMI / TRMM	30 Dec 1997	9 pm	62.05 W	27.67 S	**68.1**	44.1	Santiago del Estero, **Argentina**	40 dBZ radar echo above 19 km. See Zipser et al. (2006 and Table 3)
AMSR-E / Aqua	05 Jan 2010	2 pm	61.78 W	35.69 S	**79.6**	56.8	Buenos Aires, **Argentina**	153 K 18-GHz

Table 3. Lowest 85 GHz brightness temperatures.

Sensor / Platform	Date	Time LST	Lon	Lat	Min 37	**Min 85**	Location	Notes
SSMI F08	09 Mar 1988	6 pm	64.56 W	34.01 S	182.4	**77.0**	Cordoba, **Argentina**	-
SSMI F10	30 Dec 1996	11 pm	116.11 E	16.07 S	187.4	**60.8**	Eastern Indian Ocean	Cyclone Phil *(sheared, weakening)*
SSMI F11	28 Jun 1998	9 pm	92.67 W	43.78 N	119.1	**63.4**	Minnesota, **USA**	Same as F11 case in Table 2
SSMI F13	16 Nov 1998	6 pm	63.46 W	23.01 S	129.2	**51.0**	Salta, **Argentina**	Same as F13 case in Table 2
SSMI F14	30 Dec 1997	9 pm	62.22 W	27.93 S	129.4	**58.3**	Santiago del Estero, **Argentina**	Same as TMI case in Table 2
SSMI F15	13 Nov 2009	6 pm	59.37 W	28.70 S	124.4	**53.6**	Santa Fe, Argentina	Same as F15 case in Table 2
TMI TRMM	14 Nov 2009	9 pm	58.14 W	28.15 S	123.0	**39.4**	Corrientes, **Argentina**	3 hours after F15 case
AMSR-E Aqua	18 Nov 2005	1 pm	127.33 E	15.90 N	109.7	**41.1**	**Philippine Sea**	Typhoon Bolaven

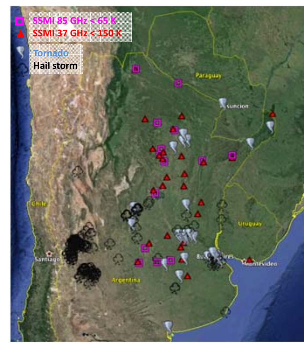
Locations of the very strongest storms generally clustered in Central US (TX to MN) or Northern Argentina.

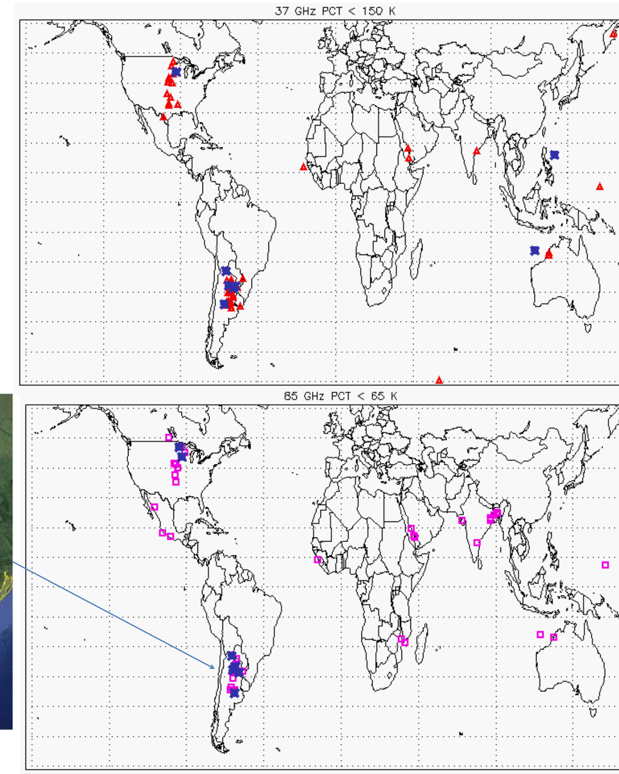
Others are scattered across tropical land regions. Few over ocean, but two were associated with tropical cyclones.

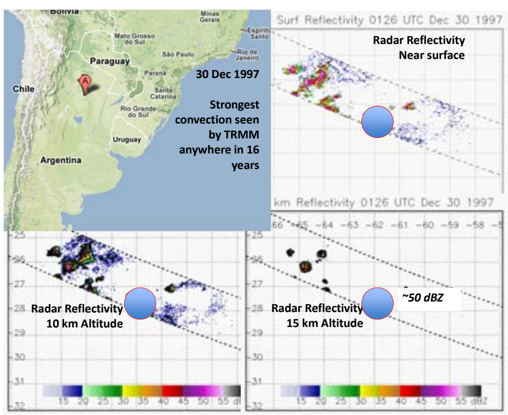
North American results are consistent with well known severe thunderstorm locations.

Argentina severe storm region is less well known, but survey of newspaper stories by Rasmussen et al. (2014 GRL, in review) confirms a region with damaging hail and tornadoes. The strongest storms identified by satellite line up well with the region of most tornado reports (northeast Argentina). There is some overlap with hail reports, but more hail reports clustered further west toward mountains. This western cluster of hail reports is at least partly due to population and agriculture density.

Figure below is adapted from Rasmussen et al. 2014 GRL and the SSMI-based figures at right.







TRMM satellite allows more examination of individual cases, with co-located radar, radiometer, and lightning sensor.

This case shown along the bottom was in some ways the strongest seen by the TRMM satellite, for the period late 1997 – 2013.

It was observed in Northern Argentina soon after TRMM went on orbit.

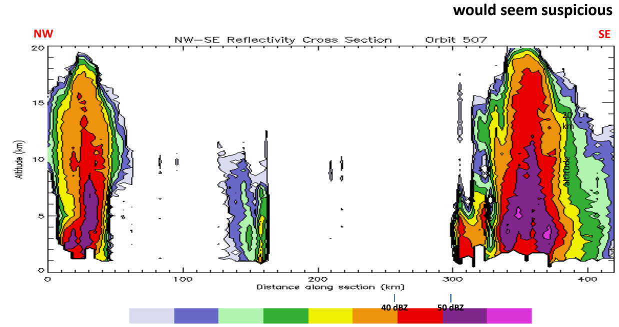
Its 37 GHz brightness temperature was substantially lower than previously (or subsequently) seen by similar satellite radiometers.

The TRMM radar measurements of 40 DBZ at 19.5 km altitude make the brightness temperatures believable. Note that TRMM radar's vertical bin size here is about 1 km (250 m range gates, 4 km beam width, about 15° off nadir).

TRMM Lightning Imaging Sensor detected about 225flashes per minute.

Radar Reflectivity Cross Section 30 Dec 1997

50 dBZ @ ~12 km
45 dBZ @ ~18 km



Without corroborating radar data, such low TBs (at right) would seem suspicious