

# Severe Thunderstorms and their Radiometric Signatures

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# Desculpe!

- Eu não falo Português
- Qualquer Português sobre esses slides é de Traduz Google ([translate.google.com](https://translate.google.com))
- ~~Incorreto talvez é alguns?~~

Talvez alguns é incorreto?

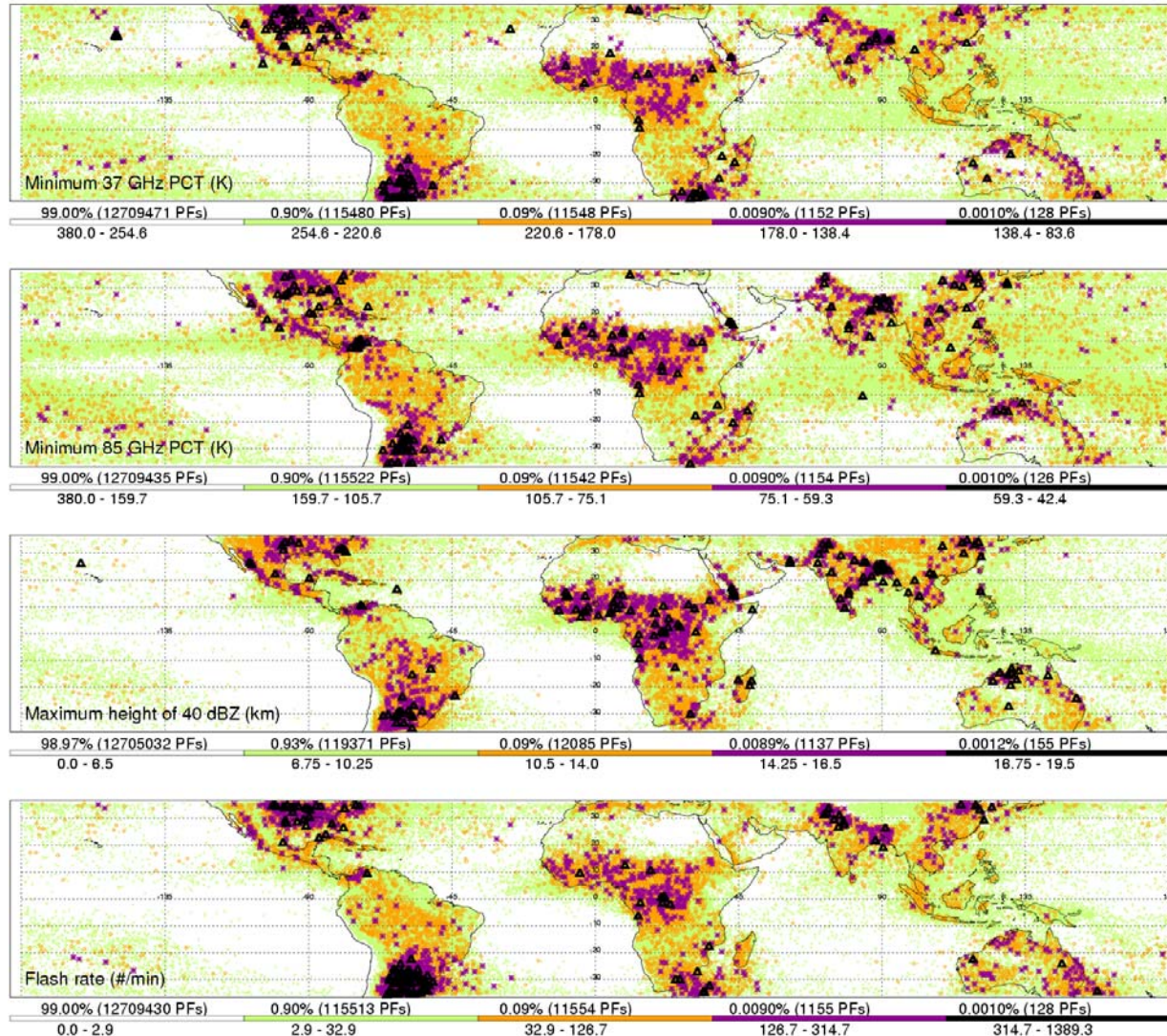
# por favor, me interrompa

- Se eu falar muito rápido, por favor, me interrompa
- Se você tiver perguntas (???), por favor, me interrompa
- Talvez alguém pode ajudar a traduzir as perguntas (???) e respostas, se necessário?

# Background

- Esta é a minha primeira viagem à América do Sul
- Fiquei interessado nas tempestades aqui cerca de 10 anos atrás
- Notei que muitas das tempestades mais impressionantes da Terra eram o Norte da Argentina, Paraguai, Uruguai, Sul do Brasil

# Where Are The Most Intense Thunderstorms On Earth? By Zipser, Cecil, Liu, Nesbitt, Yorty, 2006 *BAMS*



# Outline

- I. Noções básicas de transferência radiativa, como relevantes para via satélite de dados passivos de microondas
- II. Exemplos de dados de casos individuais
- III. Identificação empírica de tempestades severas de satélite
- IV. Climatologia temporal severo estima do satélite

# Passive Microwave Radiative Transfer

## *Transferência de Microondas Passiva Radiativo*

Many instruments use window channels ~ 10, 19, 37, 85 GHz

*Muitos instrumentos utilizam canais janela*

A cloudless atmosphere has little effect on radiation emitted by the earth's surface

*A atmosfera sem nuvens tem pouco efeito sobre a radiação emitida pela superfície da terra*

# Satellite Passive Microwave Over Land

~290 K seen by satellite



290 K



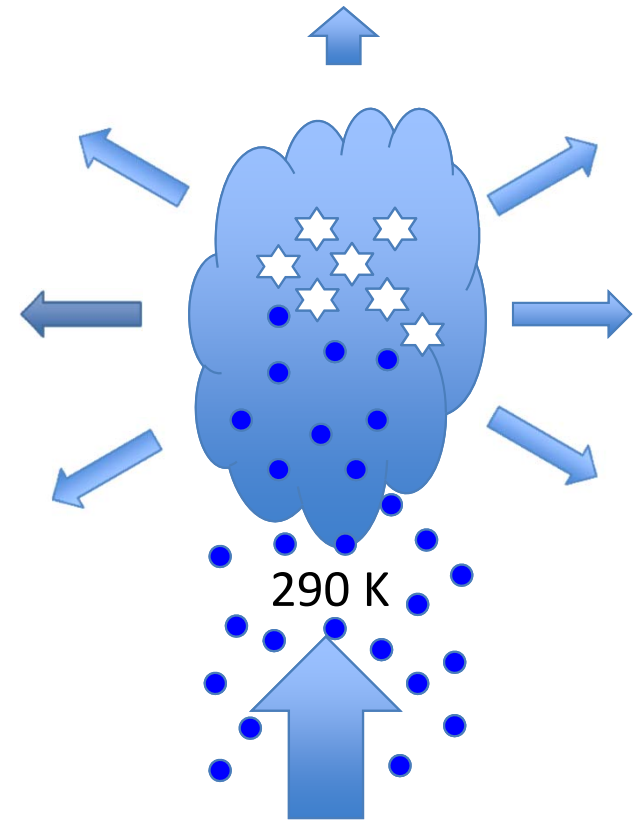
290 K



For “window” channels, most of the radiation is transmitted through a clear atmosphere

Clouds and rain *absorb, emit, and scatter* some of the radiation away, *reducing the brightness temperature ( $T_B$ )*

~250 K seen by satellite



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Land has high emissivity (~0.95), so upwelling brightness temperature often >290 K  
*Water, soil moisture, vegetation reduce the emissivity*



# Absorption, Emission, Scattering

- Clouds and rain *absorb, emit, and scatter* some of the radiation away, *reducing the brightness temperature ( $T_B$ )*
- *Nuvens e chuva absorvem, emitem, e scatter parte da radiação de distância, reduzindo a temperatura de brilho (TB)*

# Complex Index of Refraction

- *Absorption and Emission* increase with the imaginary part of the index of refraction
  - *Absorção e aumento de emissão com a parte imaginária do índice de refração*
- Scattering increases with the real part of the index of refraction
  - *Scattering increases with the real part of the index of refraction*

# Complex Index of Refraction ( $m$ )

- Example values (don't quote me on these numbers!) (*não citar-me sobre esses números!*)  
*See Gunn and East 1954 QJRMS*
- Liquid drops:  $m = 5 + (2 * i)$
- Real and imaginary parts comparable, so absorption, emission, and scattering comparable
- *Ice*:  $m = 2 - (0.002 * i)$
- Imaginary part is negligible, so only scattering matters for ice hydrometeors

# Satellite Passive Microwave Over Land

290 K seen by satellite



290 K



290 K

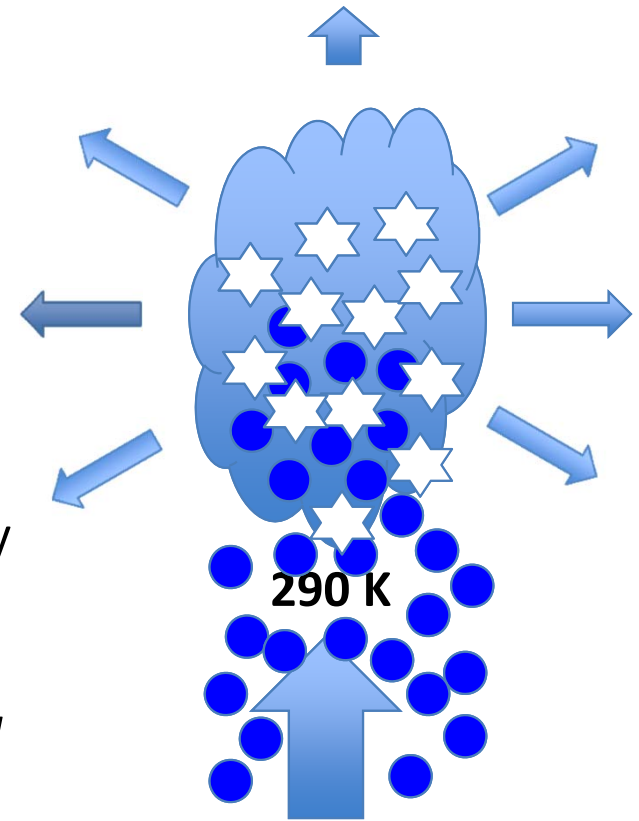


For “window” channels, most of the radiation is transmitted through a clear atmosphere

Mie scattering gets complicated, but large hydrometeors reduce the brightness temperature ( $T_B$ ) even more.

Ice has very small absorption / emission. Ice mostly scatters radiation. *This makes ice more effective at reducing  $T_B$ .*

~150 K seen by satellite



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Land has high emissivity ( $\sim 0.95$ ), so upwelling brightness temperature often  $> 290$  K  
*Water, soil moisture, vegetation reduce the emissivity*

# Radiative Transfer in Precipitation

Some fraction of the radiation emitted by the surface passes through the atmosphere unaffected.

*Alguns fracção da radiação emitida pela superfície passa através da atmosfera afectada.*

Liquid drops absorb radiation, and emit at their own temperature ( $T_{\text{raindrop}} < T_{\text{surface}}$ ).

*Gotas líquidas absorver a radiação, e emitem a sua própria temperatura ( $T_{\text{raindrop}} < T_{\text{surface}}$ ).*

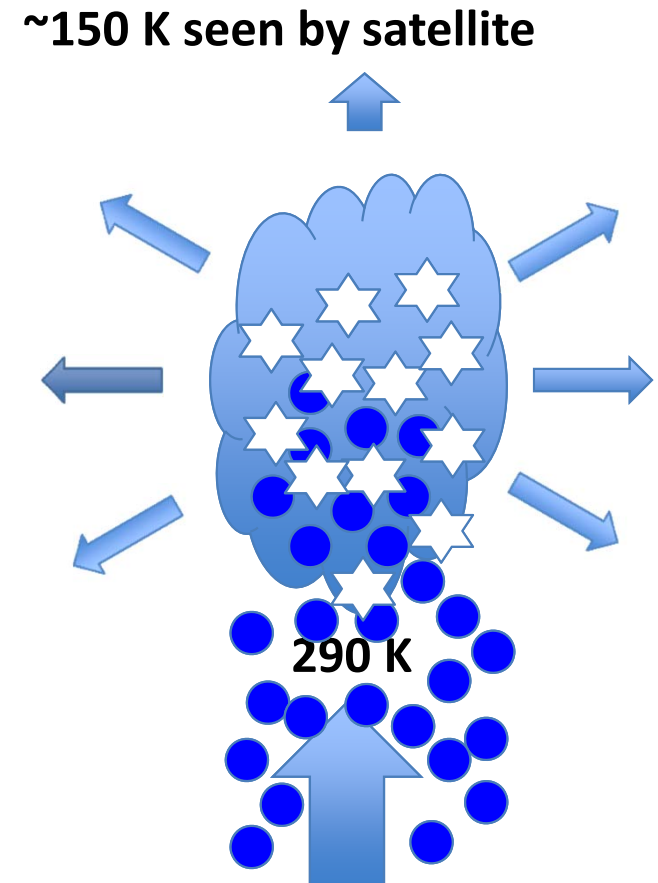
Liquid and ice hydrometeors (graupel, hail) scatter radiation in all directions.

*Líquidos e gelo hidrometeoros (graupel, granizo) radiação dispersar em todas as direções.*

Larger, denser particles have greater effect.

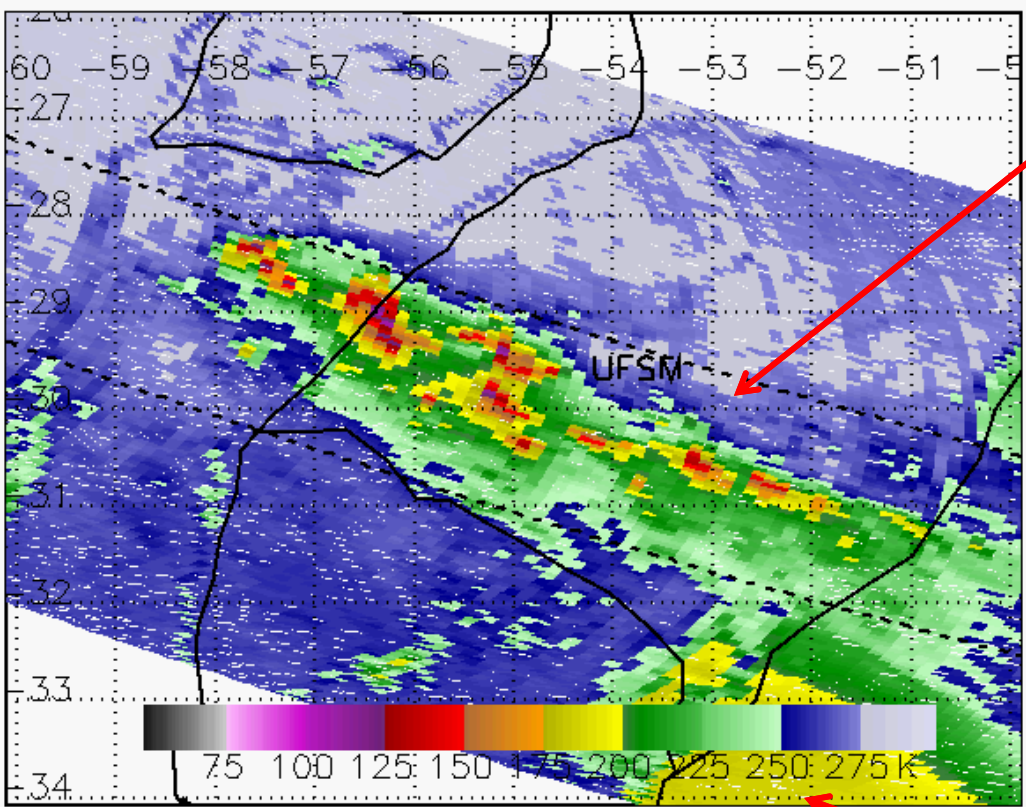
*Tamanho maior, as partículas mais densas têm maior efeito.*

Scattering cross section  $\sim$  size and density



# Example: 85 GHz TB (Horizontal Polarization)

85 GHz H 0822 UTC Jun 29 2000



TB decreases in raining locations, matches radar echo reasonably well

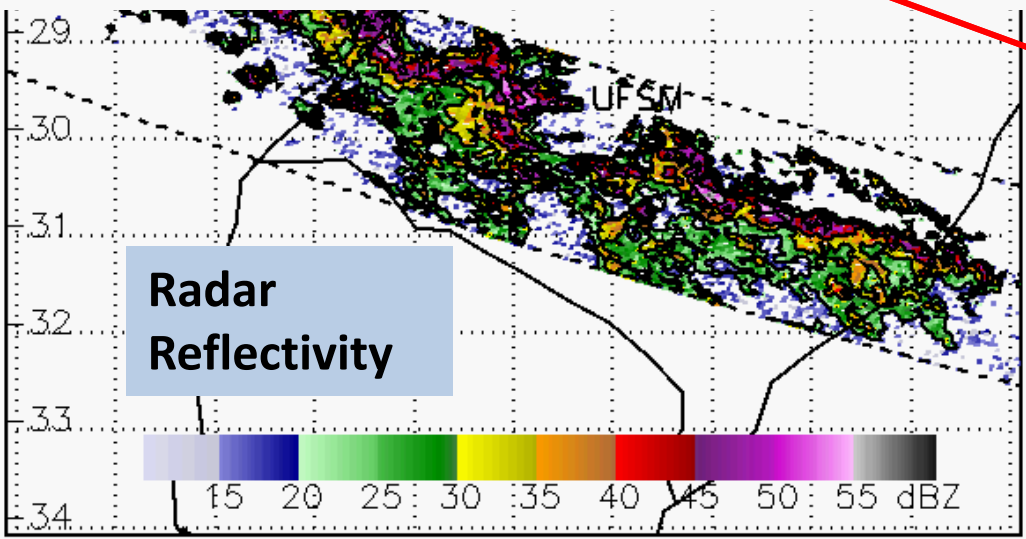
*TB diminui em locais chovendo, radar partidas eco razoavelmente bem*

Away from rain, TB has variability due to surface conditions (e.g. wetness)

*Afastado de chuva, temperatura de brilho apresenta variações devido às condições de superfície (por exemplo, umidade)*

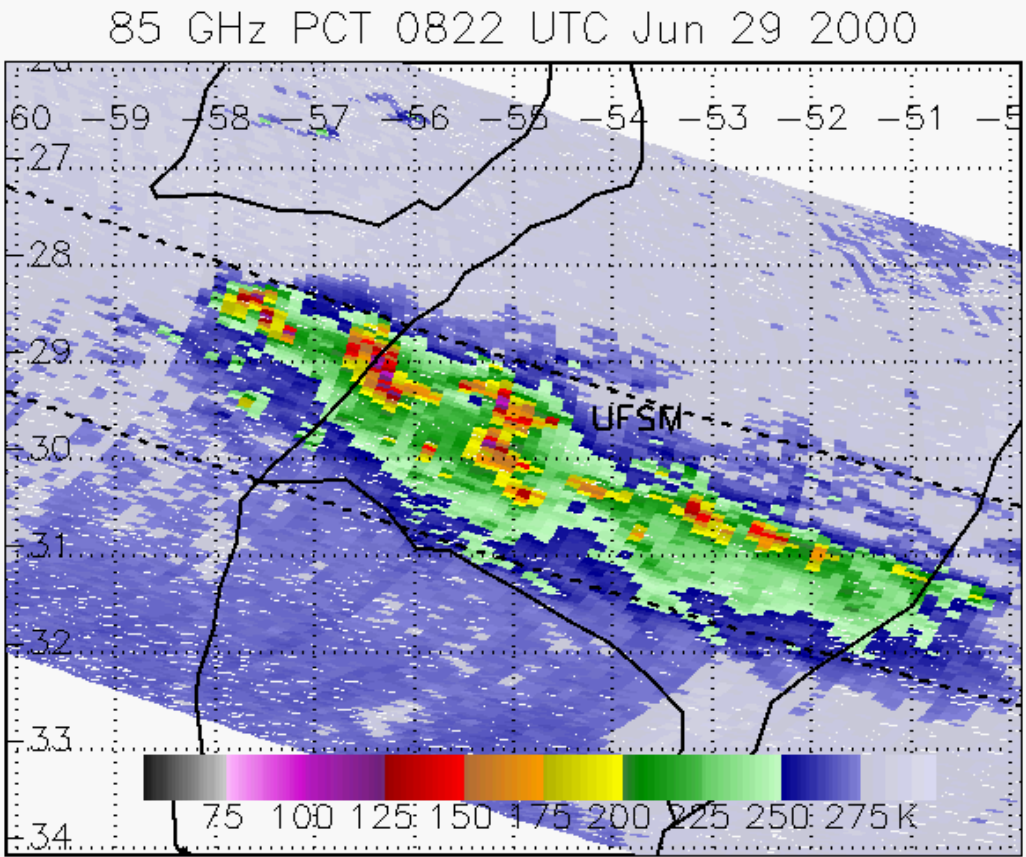
Ocean surface has lower emissivity than land, so TB is lower over ocean (unless there is cloud & rain)

*Superfície do oceano tem menor emissividade do que a terra, assim TB é menor sobre o oceano (a menos que haja nuvens e chuva)*



**Radar Reflectivity**

# Example: 85 GHz TB (Horizontal Polarization)



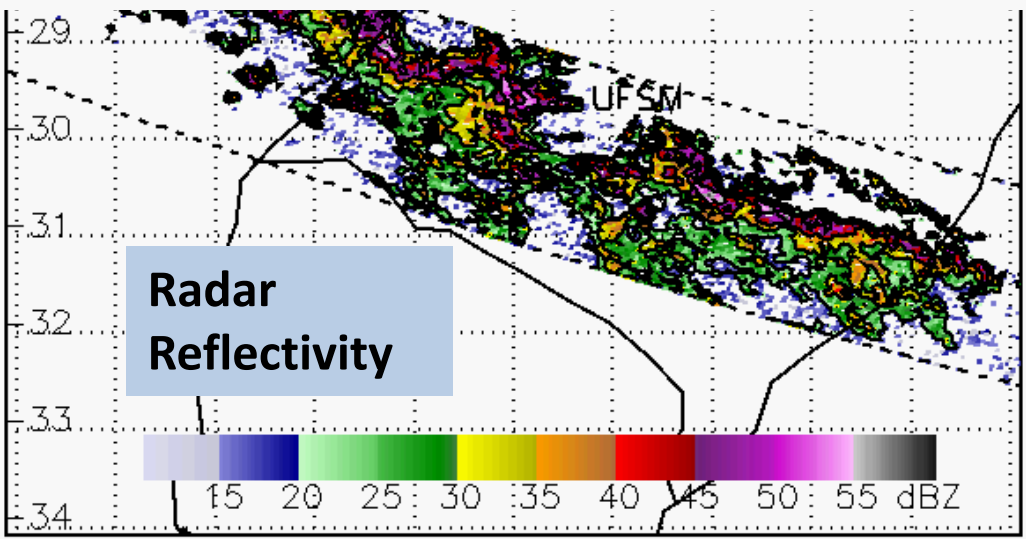
A linear combination of the Horizontal and Vertical polarizations removes much of the variability due to surface conditions. This is Polarization Corrected Temperature (PCT).

*Uma combinação linear das polarizações horizontal e vertical elimina grande parte da variabilidade devido às condições de superfície. Esta é a Temperatura Polarização Corrigido (PCT).*

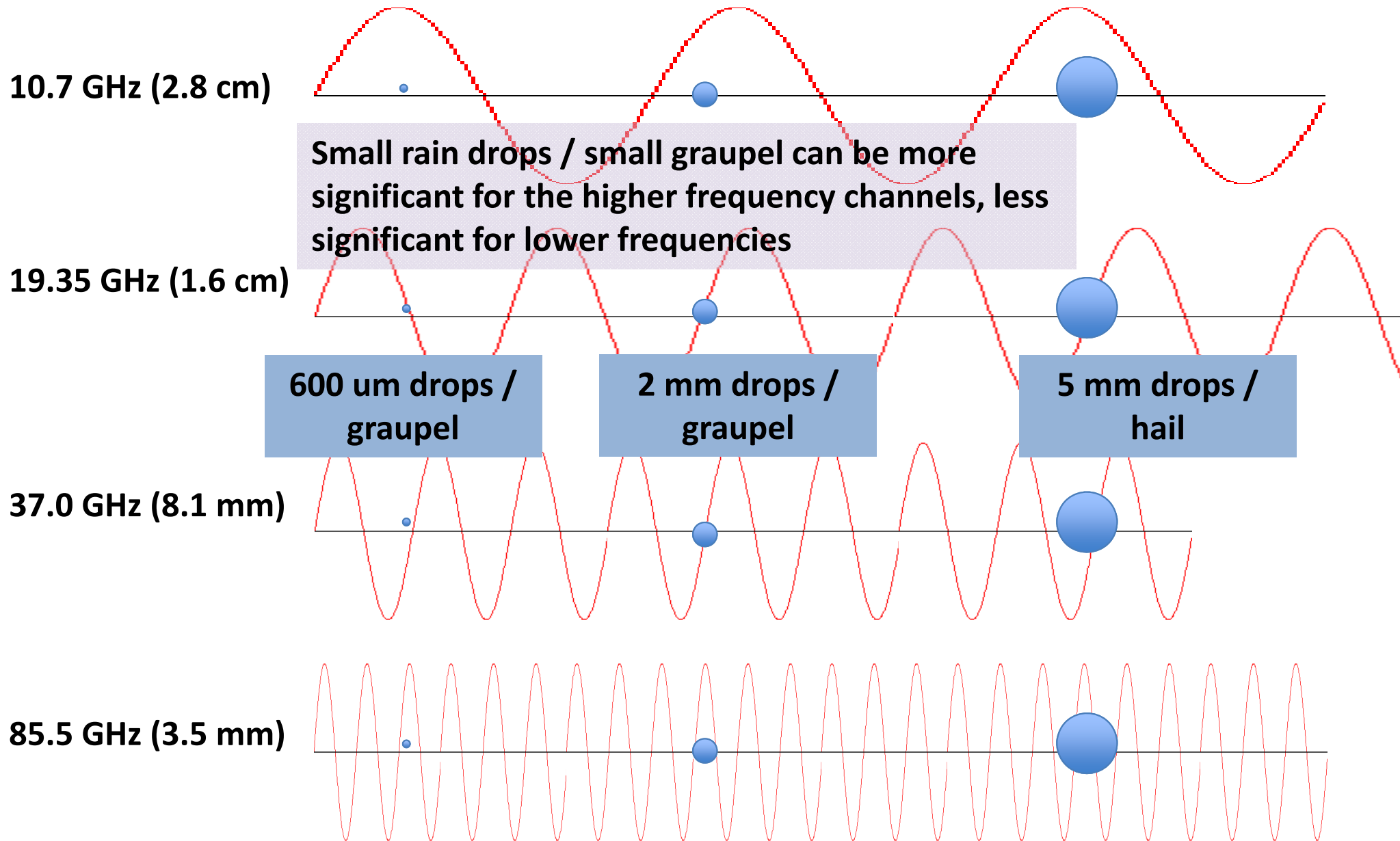
$$PCT_{85} = 1.82 TB_{85V} - 0.82 TB_{85H}$$

$$PCT_{37} = 2.20 TB_{37V} - 1.20 TB_{37H}$$

(from Cecil et al. 2002 Mon Wea Rev)



# Common Radiometer Frequencies





# Microwave Frequencies

- Considering the Radiative Transfer alone, we would want a low frequency channel for sensitivity to large particles that are produced by strong thunderstorms. Higher frequencies can be “contaminated” by smaller particles.
  - *Considerando a transferência radiativa sozinho, nós gostaríamos de ter um canal de baixa frequência para a sensibilidade para grandes partículas que produzem são por tempestades fortes. Frequências mais altas podem ser "contaminadas" por partículas menores.*
- But lower frequencies have larger beam sizes. For TRMM satellite:
  - 10 GHz channel: 63 km x 37 km
  - 19 GHz channel: 30 km x 18 km
  - 37 GHz channel: 16 km x 9 km
  - 85 GHz channel: 7 km x 5 km
- So there is a trade-off. 37 GHz channel works well for identifying severe storms.

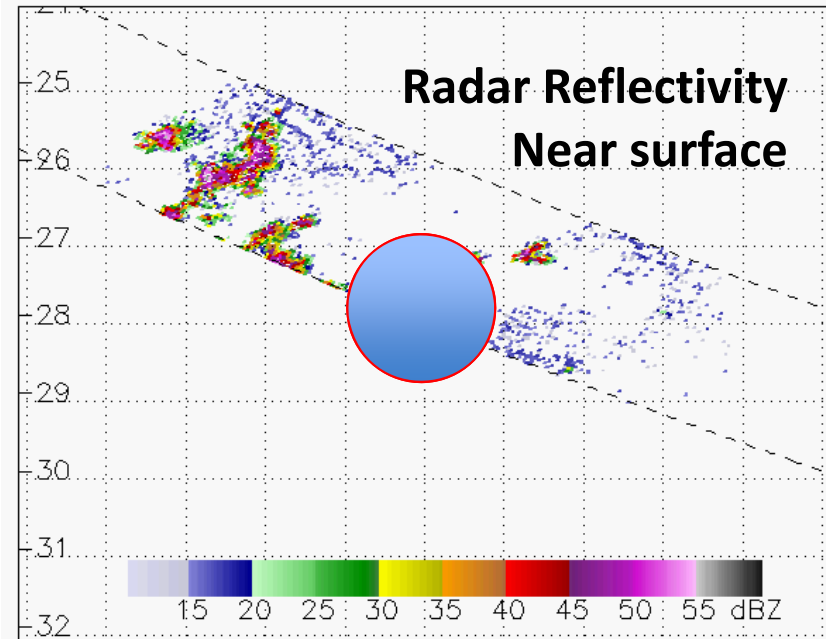
# Beam-Filling Effect (Horizontal Resolution)

- As a very rough estimate of the “beam-filling effect”, we can average the high-resolution 85 GHz over a large enough area to match the low-resolution channels
  - *Como uma estimativa muito grosseira do "efeito de feixe de enchimento", pode-se calcular a média de alta resolução de 85 GHz sobre uma área suficientemente grande para coincidir com os canais de baixa resolução*
- 10 GHz channel: 63 km x 37 km → Mean 85 GHz: 131 K
- 19 GHz channel: 30 km x 18 km → Mean 85 GHz: 61 K
- 37 GHz channel: 16 km x 9 km → Mean 85 GHz: 55 K
- 85 GHz channel: 7 km x 5 km → Actual 85 GHz: 45 K
- So there is a trade-off. 37 GHz channel works well for identifying severe storms from the available satellite sensors.
- *Portanto, há um compromisso. 37 GHz canal funciona bem para a identificação de tempestades severas dos sensores de satélite disponíveis.*

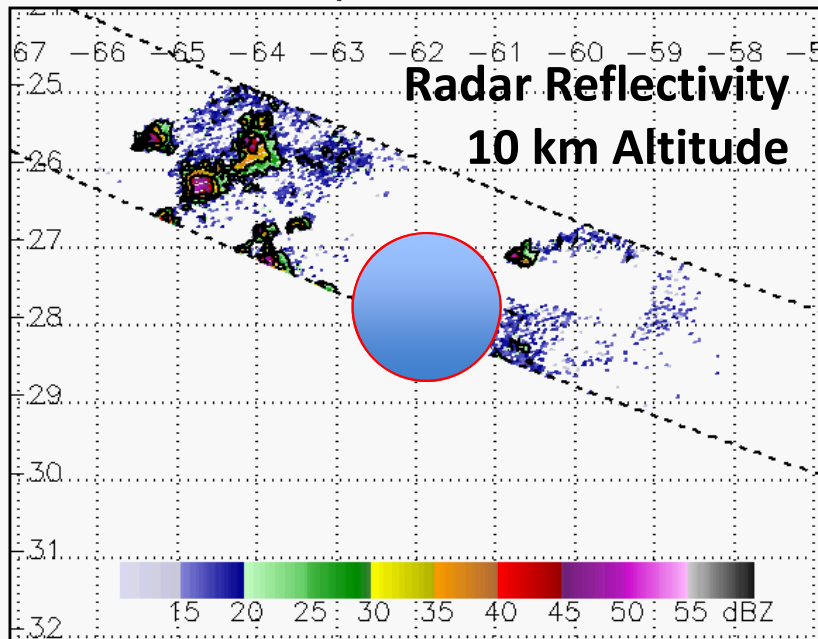
# Example TRMM observations, northern Argentina



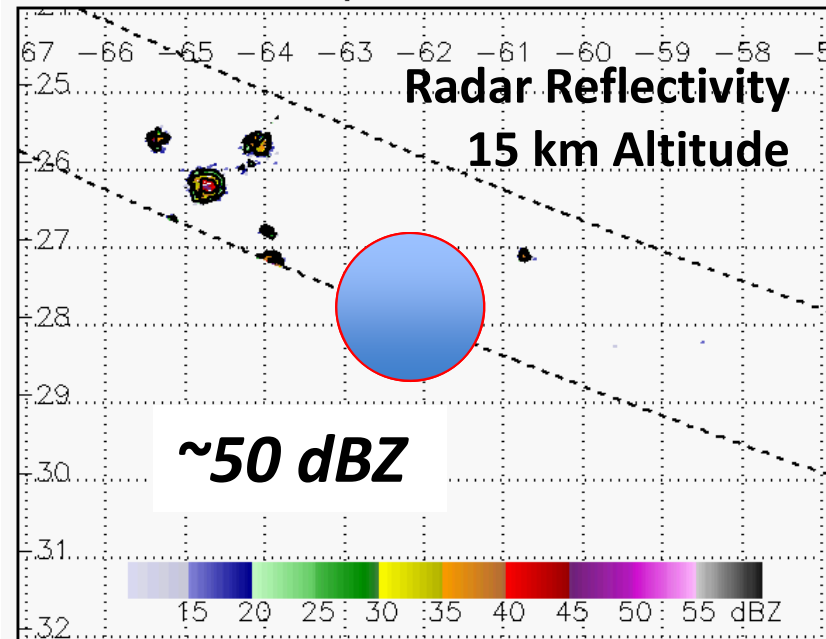
Near Surf Reflectivity 0126 UTC Dec 30 1997



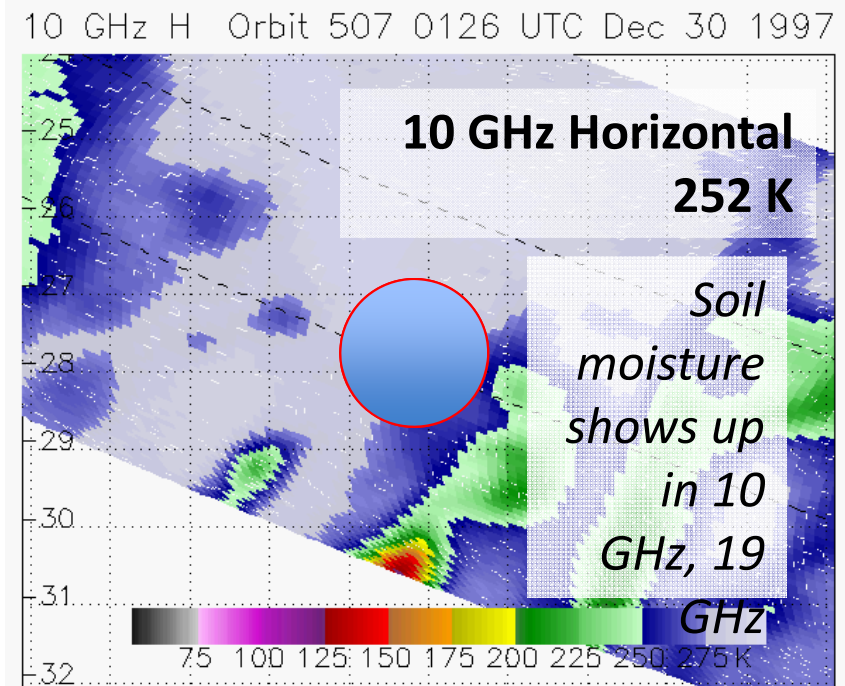
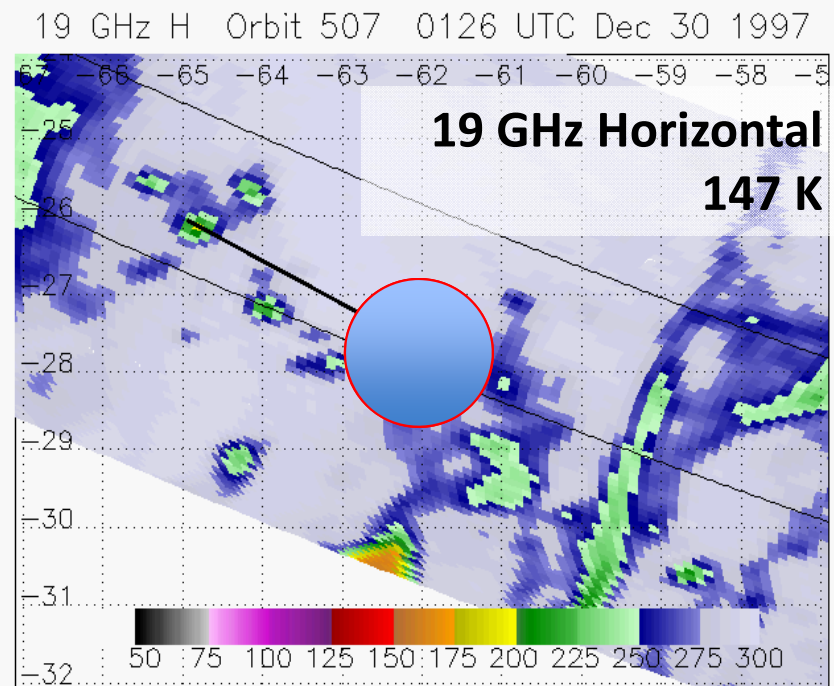
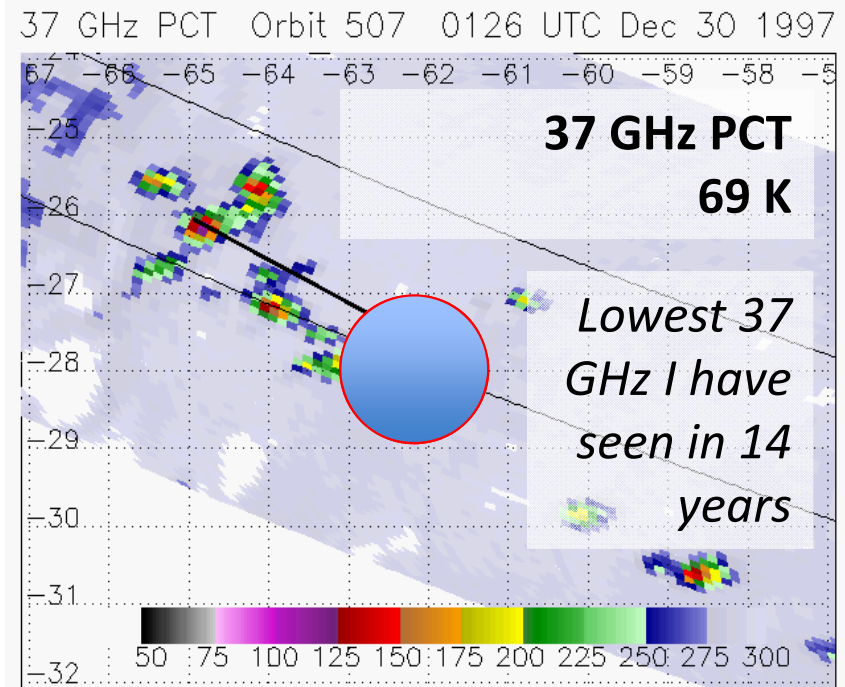
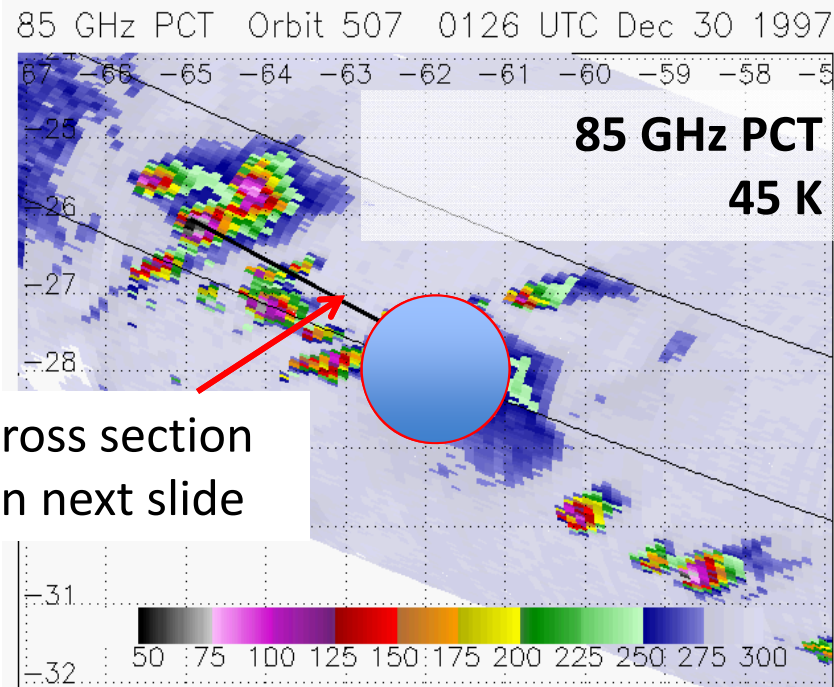
10 km Reflectivity 0126 UTC Dec 30 1997



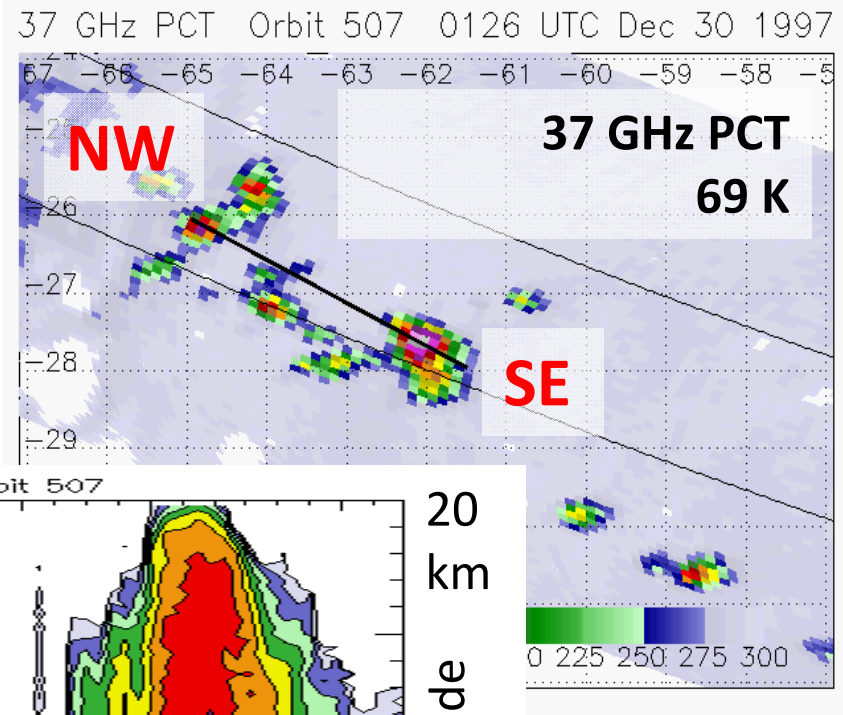
15 km Reflectivity 0126 UTC Dec 30 1997



# Example TRMM observations, northern Argentina

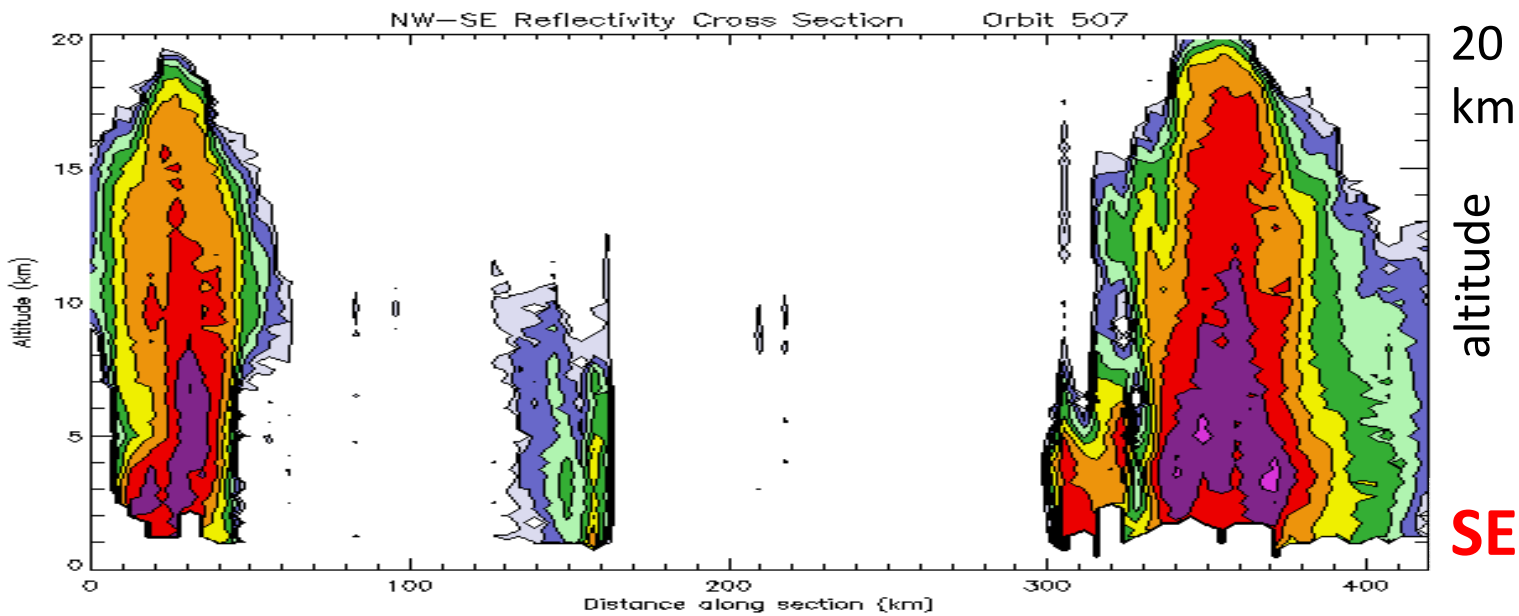


# Radar Reflectivity Cross Section



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

NW



40 dBZ 50 dBZ

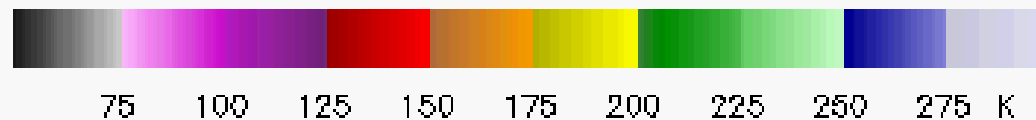
6 May 1999 0140 UTC 37 GHz

## 37 GHz PCT and Hail reports

Search for USA  
hail reports  
within 30  
minutes of  
satellite  
overpass

Associate the hail  
reports with:  
Lowest PCT in the  
entire  
Precipitation  
Feature

Regardless of hail,  
catalog the minimum  
PCT



# Probability of Hail, as a function of PCT37 or PCT85

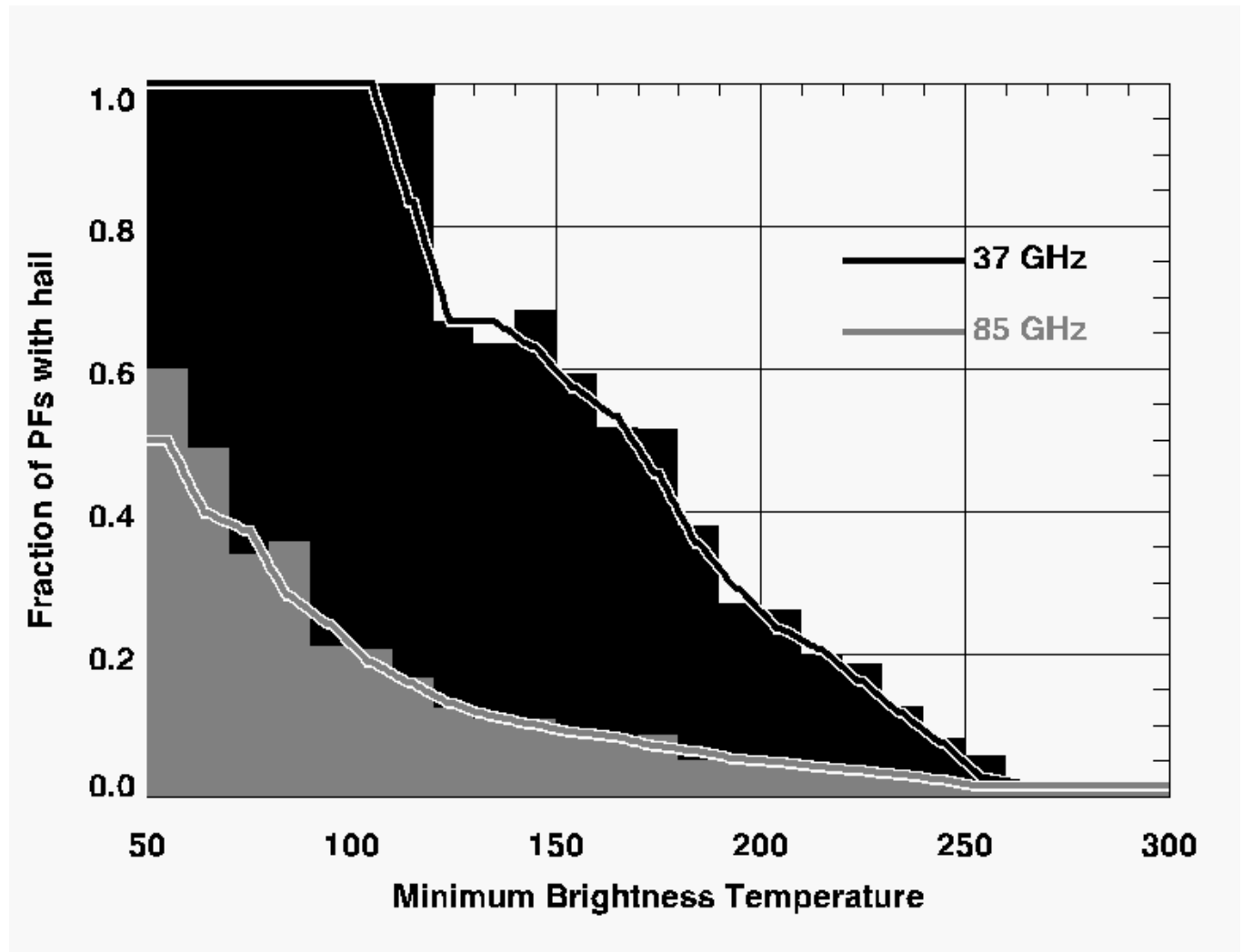
Empirically match USA reports of large hail (*chuva de pedra? Granizo?*) > 2.5 cm with measurements of low PCT85 and PCT37

PCT37 = 200 K : ~25% chance of large hail

PCT37 = 150 K: ~60% chance of large hail

PCT37 < 120 K: all cases had large hail in this study

PCT85 less responsive to large hail than PCT37

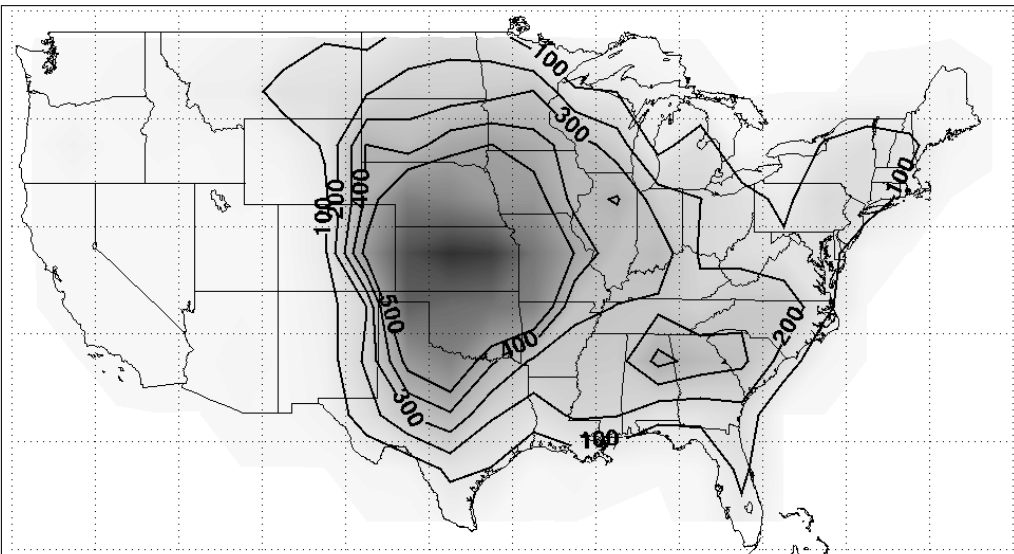


# Validation

For each storm with  $36 \text{ GHz} < 200 \text{ K}$ , count it as a fraction ( $F$ ) of one hail storm. The value  $F$  comes from the previous slide. E.g., a storm with  $200 \text{ K}$  is counted as 0.25 hail storms. A storm with  $150 \text{ K}$  is counted as 0.6 hail storms.

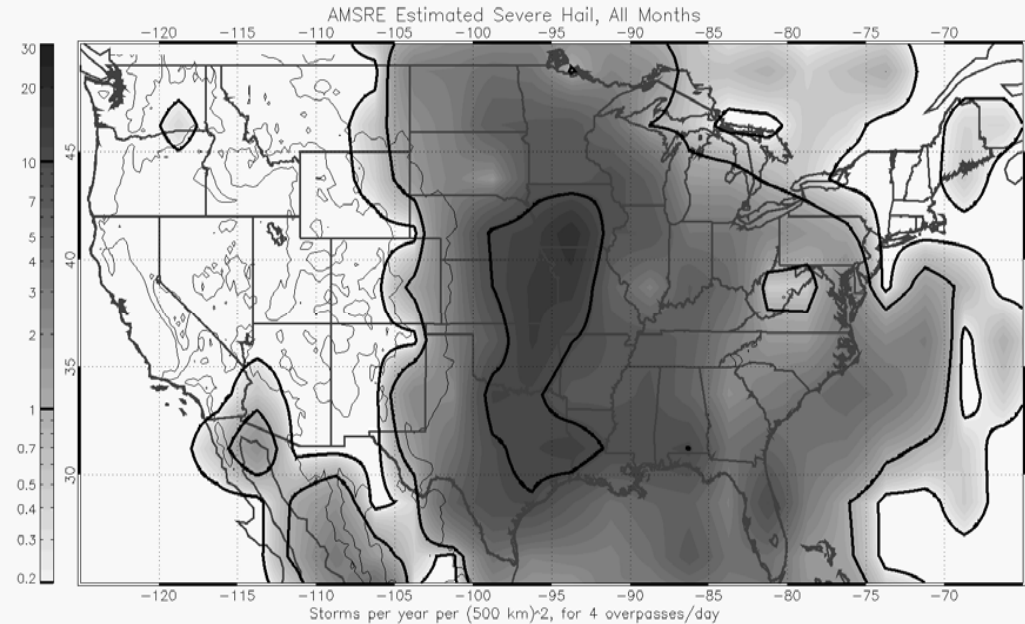
*Para cada tempestade com  $36 \text{ GHz} < 200 \text{ K}$ , contá-lo como um fração ( $F$ ) de uma tempestade de granizo. O valor  $F$  vem do slide anterior. Por exemplo, uma tempestade com  $200 \text{ K}$  é contado como 0,25 tempestades de granizo. Uma tempestade com  $150 \text{ K}$  é contado como 0,6 tempestades de granizo.*

1" Hail Reports per year per  $(500 \text{ km})^2$  2003-2009



Reports of hail 2.5 cm diameter or larger at the surface, 2003-2009

*Relatos de granizo diâmetro 2,5 cm ou maior na superfície, 2003-2009*



Satellite-based estimate

*Baseado em satélite estimativa*



## Recap

- Large hydrometeors, especially graupel and hail, reduce the passive microwave brightness temperatures seen by satellite sensors such as TRMM, AMSR-E, SSMI
  - *Hidrometeoros grandes, especialmente graupel e granizo, reduzir as temperaturas brilho passivos de microondas visto por sensores orbitais, como TRMM, AMSR-E, SSMI*

## Recap

- 37 GHz Polarization Corrected Temperature (PCT)  
< 200 K has ~20% likelihood of large hail.

< 150 K, ~60%

< 130 K *approaches* 100 %

These are empirically derived using 2.5+ cm hail reports in USA

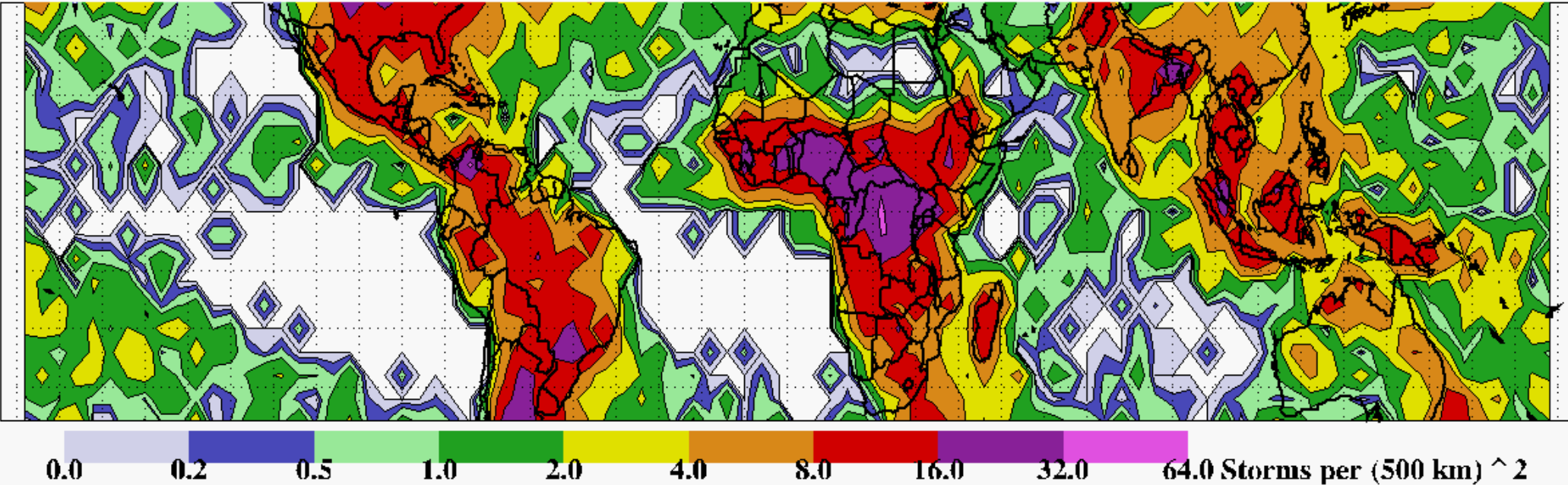
- *37 GHz Polarização Corrigido Temperatura (PCT)*  
*<200 K tem ~ probabilidade de 20% de granizo grande.*

## Coming up next...

- We can apply the same basic methodology to a few different types of measurements: PCT85, PCT37, Radar Reflectivity at different altitudes, lightning flash rate, et cetera
  - *Podemos aplicar a mesma metodologia de base para alguns tipos diferentes de medidas: PCT85, PCT37, imagens de radar em diferentes altitudes, a taxa de relâmpago, et cetera*
- We get different answers from each measurement type, because none of them are directly measuring what we want – large hail that falls to the surface
  - *Nós temos respostas diferentes de cada tipo de medição, porque nenhum deles está diretamente medir o que nós queremos - granizo grande que cai na superfície*
- But they all identify the same basic locations: Argentina, Paraguay, Uruguay, Southern Brazil, Central and Southeast USA, Bangladesh, East and West India, Pakistan, Central Africa...

# Empirical relationship applied to all TRMM 37 GHz PCT

Estimated 1" Hailstorms 1998-2010



From this approach, Central Africa has the most storms. But stay tuned, this answer will change.

Other common locations:

Subtropical Americas

Bangladesh

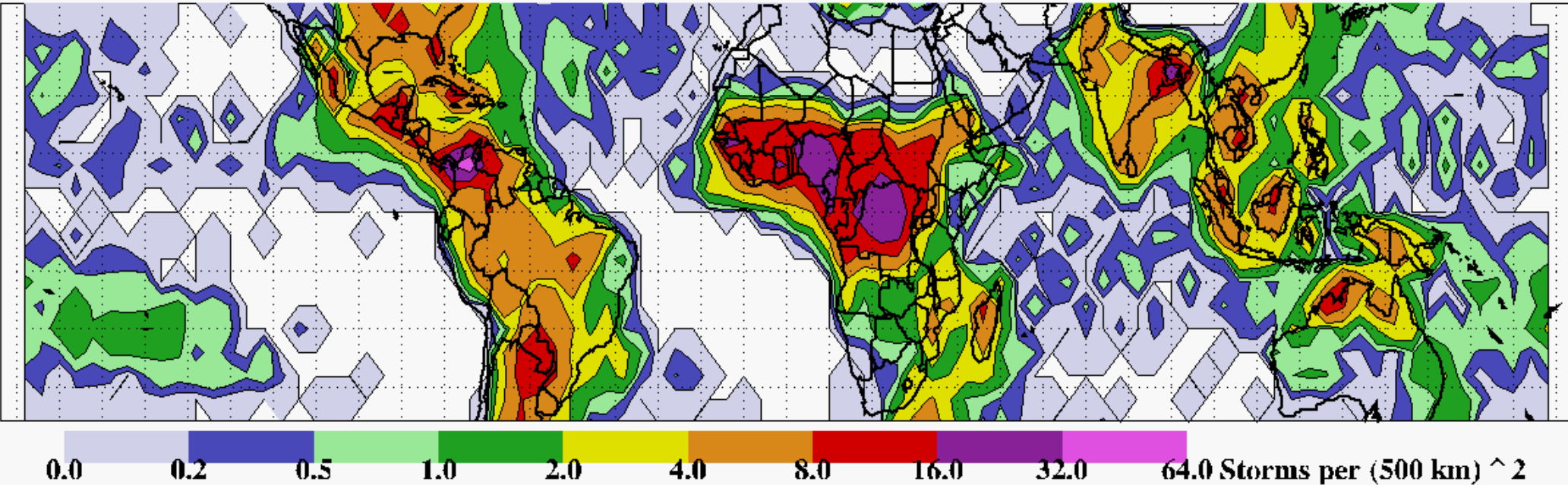
Northern Colombia

Indonesia

These estimates are probably too high over oceans

# Empirical relationship applied to all TRMM 85 GHz PCT

Estimated 1" Hailstorms 1998-2010



From this approach, Northern Colombia has the most storms. But 85 GHz is more likely to be influenced by a very deep layer of moderate-sized particles, instead of very large particles.

*A partir desta abordagem, Norte da Colômbia tem a maioria de tempestades. Mas 85 GHz é mais provável de ser influenciado por uma camada muito profunda de partículas de tamanho moderado, em vez de partículas muito grandes.*

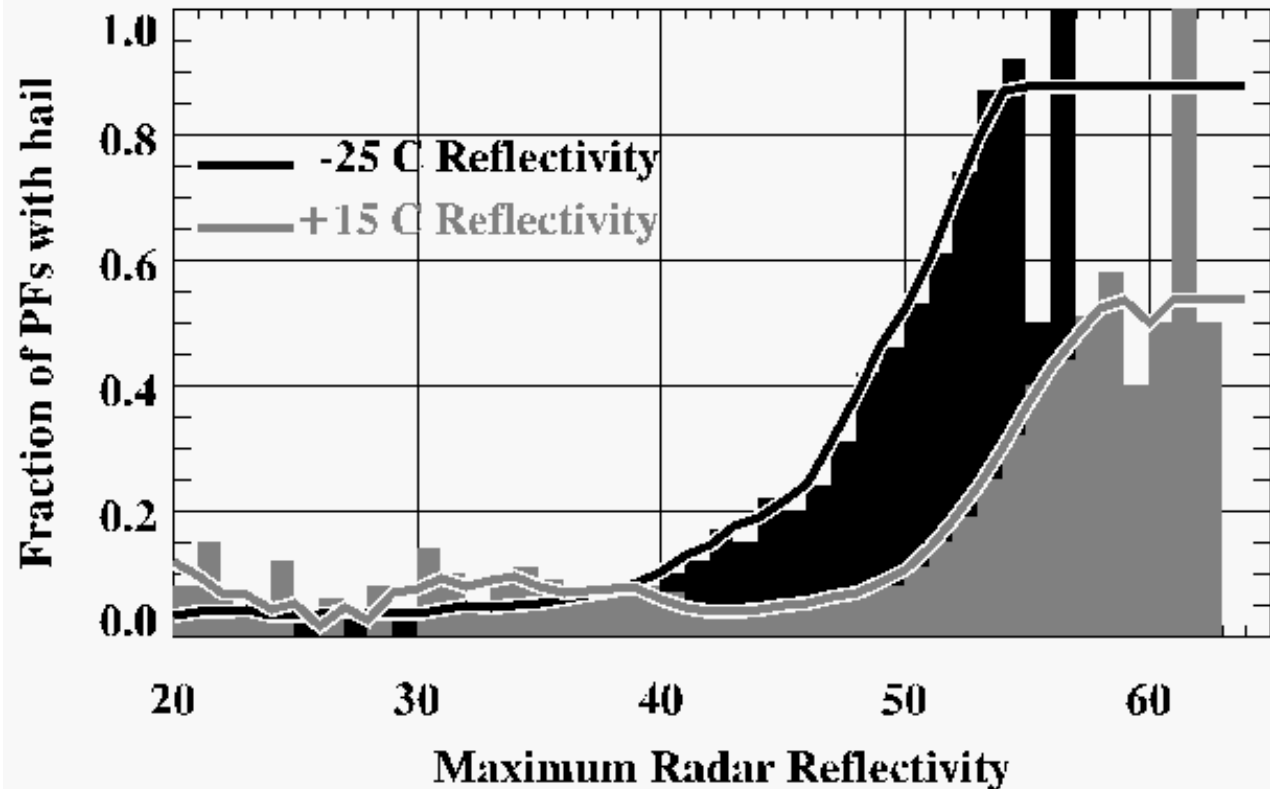
# Probability of Hail, as a function of Radar Reflectivity at -25 C (black) or at +15 C (gray)

Empirically match USA reports of large hail (*chuva de pedra?* *Granizo?*) > 2.5 cm with measurements of high radar reflectivity

45 dBZ @ -25 C: ~20% chance of large hail

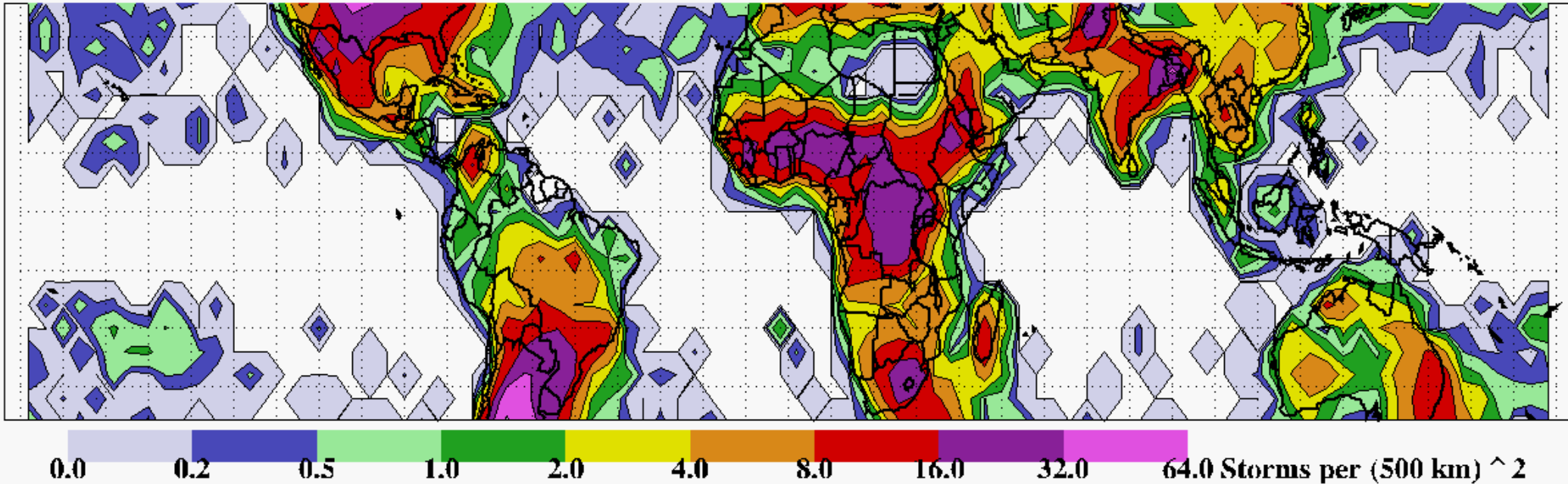
50 dBZ @ -25 C: ~50% chance of large hail

Low-altitude reflectivity is less indicative of hail, it could have high reflectivity due to large liquid rain drops



# Empirical relationship applied to all TRMM Radar Reflectivity @ -25 C altitude

Estimated 1" Hailstorms 1998-2010

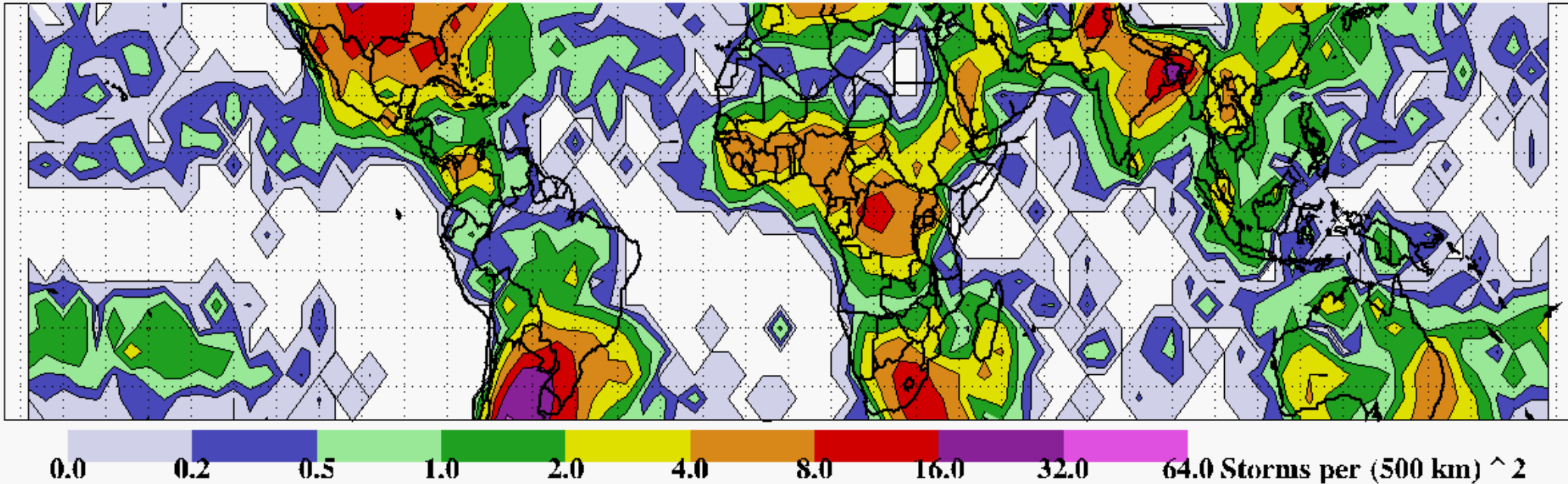


From this approach, Argentina has the most storms. This looks most realistic, compared to expectations (especially over oceans).

*A partir desta abordagem, a Argentina tem o maior número de tempestades. Isso parece mais realista, em comparação com as expectativas (especialmente sobre os oceanos).*

# Empirical relationship applied to all TRMM Radar Reflectivity @ +15 C altitude

Estimated 1" Hailstorms 1998-2010



This approach again favors Argentina. But using low-altitude reflectivity puts too many storms over the oceans, likely having high reflectivity from strong liquid rain.

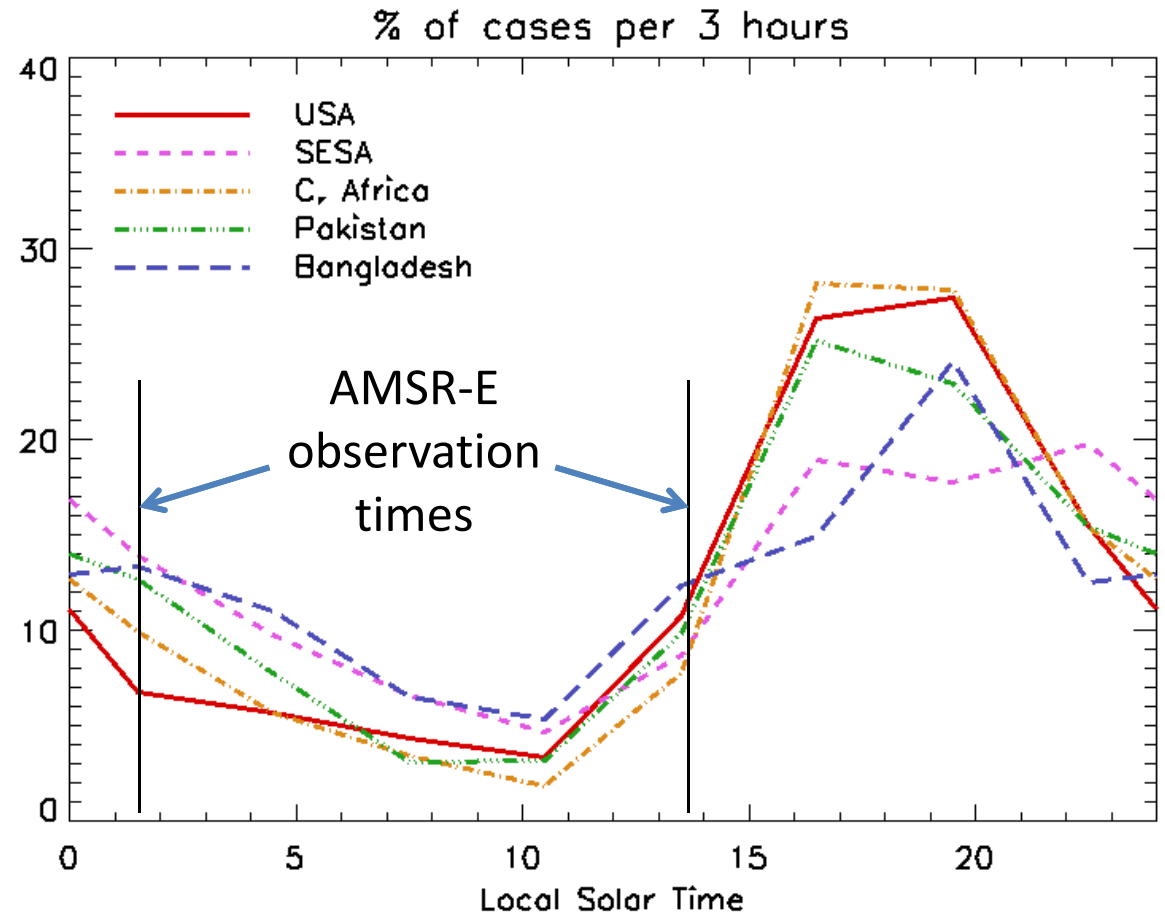
*Esta abordagem favorece novamente Argentina. Mas o uso de baixa altitude refletividade coloca muitas tempestades sobre os oceanos, provavelmente ter alta refletividade da chuva forte líquido.*



# Hail diurnal cycle from TRMM

Typical diurnal cycle peaks in late afternoon - evening (i.e., out of phase with AMSR-E sensor that is used in upcoming figures).

Amplitude of diurnal cycle appears weaker in SE South America than in other locations. More overnight storms here.



*Típicas diurnas picos de ciclo no final da tarde - à noite (ou seja, fora de fase com AMSR-E sensor que é usado nas Figuras próximos)*  
*Amplitude do ciclo diurno aparece mais fraco no Sudeste da América do Sul do que em outros locais. Tempestades mais durante a noite aqui.*

# Hail diurnal cycle from TRMM

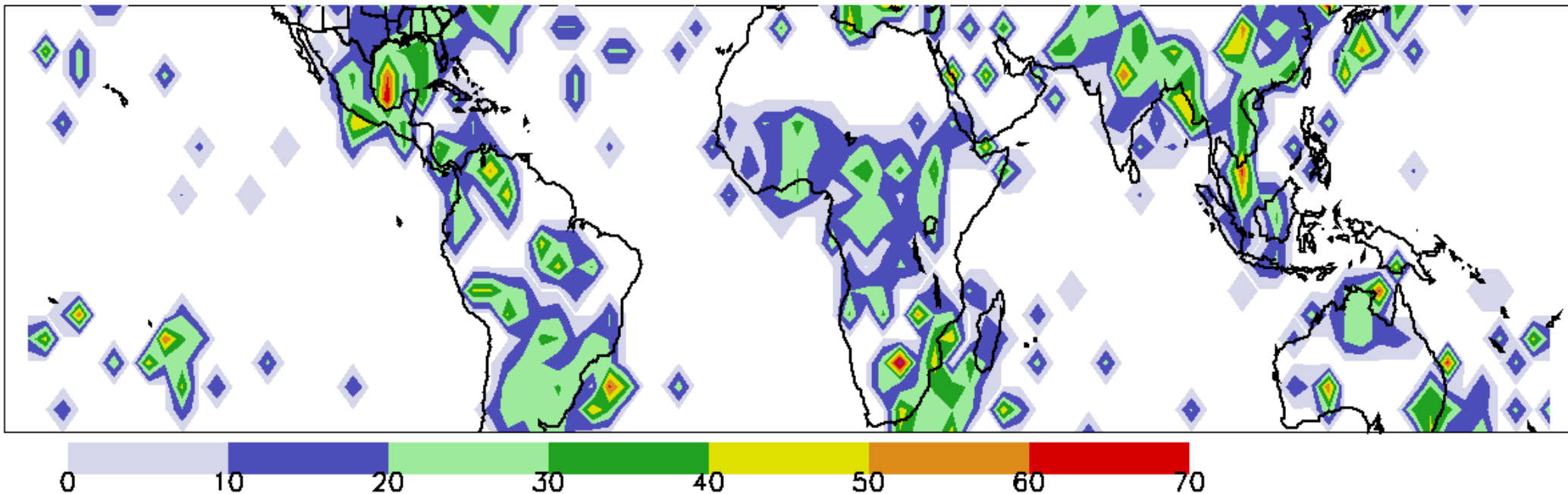
Places with strongest diurnal cycles should be under-represented by AMSR-E.

SE S. America, Bangladesh have weakest diurnal cycles of the active regions in TRMM domain. They may be over-represented.

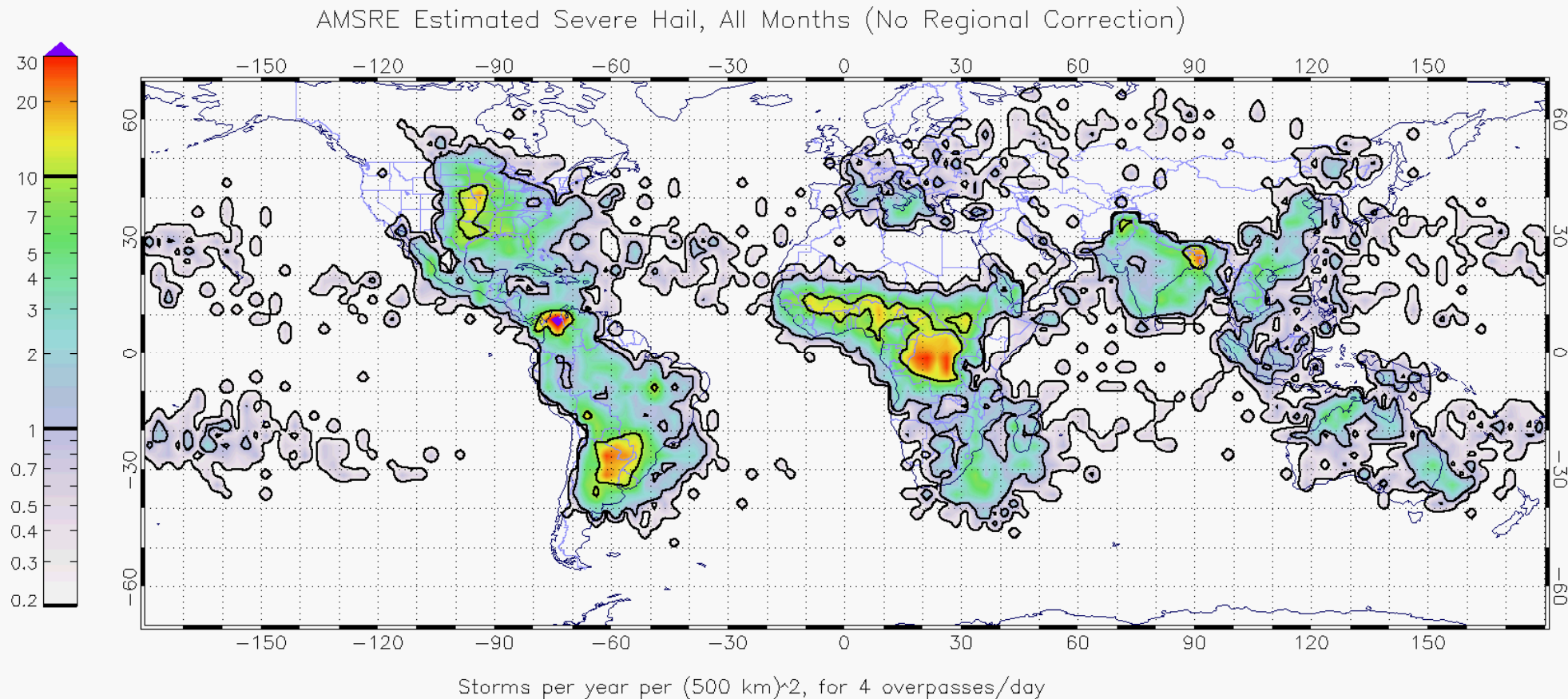
*Locais com fortes ciclos diurnos deveriam ser sub-representados por AMSR-E.*

*SE América do Sul, Bangladesh tem mais fracos ciclos diurnos das regiões activas no domínio TRMM. Eles poderiam estar sobre-representados.*

% of cases between 12–3 AM or PM



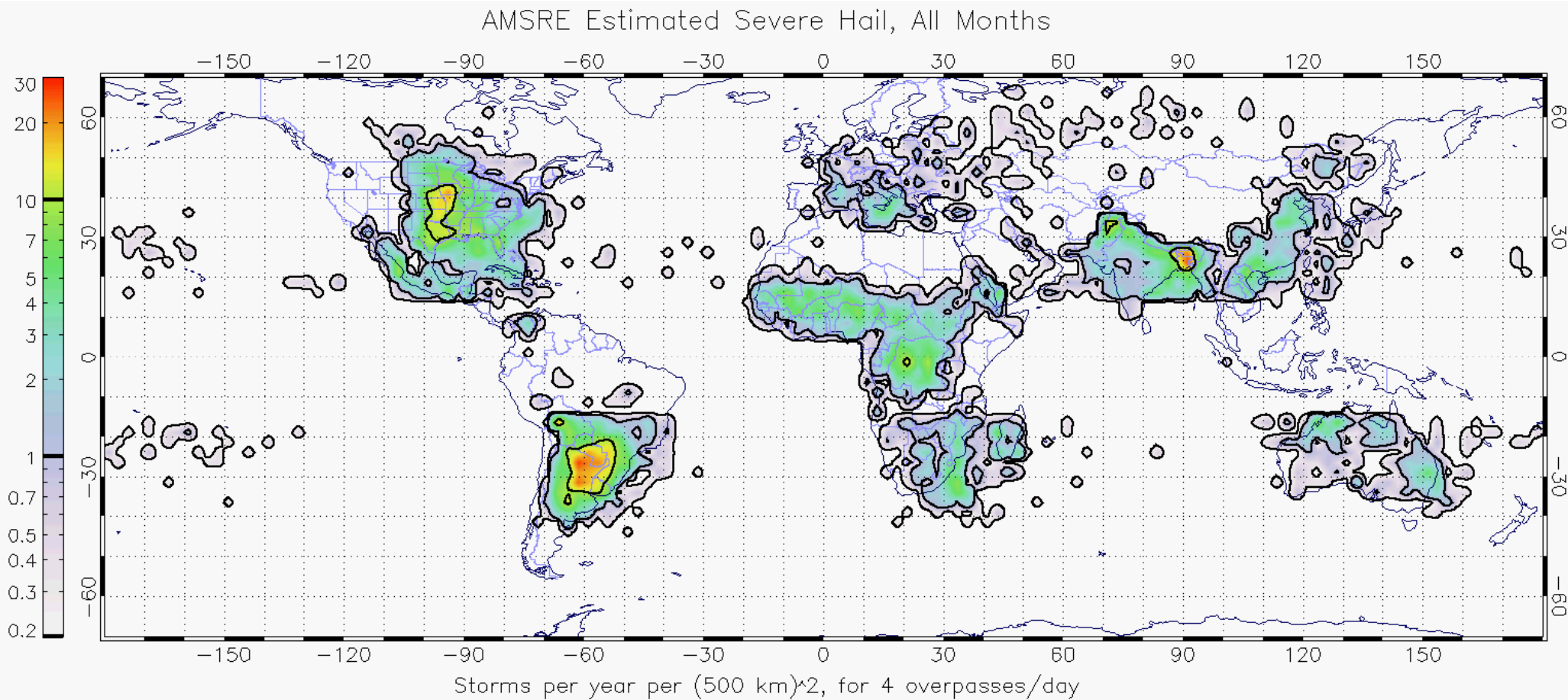
# Empirical relationship applied to all AMSR-E 36 GHz PCT (includes high latitudes)



Using AMSR-E has the benefit of higher-latitude observations, especially helpful for the Central USA, Europe, and Russia. AMSR-E is limited to a small part of diurnal cycle, around 0130 and 1330 local solar time

*Usando AMSR-E tem a vantagem de maior latitude observações, especialmente útil para os EUA Central, Europa e Rússia. AMSR-E está limitado a uma pequena parte do ciclo diurno, cerca de 0200 e 1400 hora solar local*

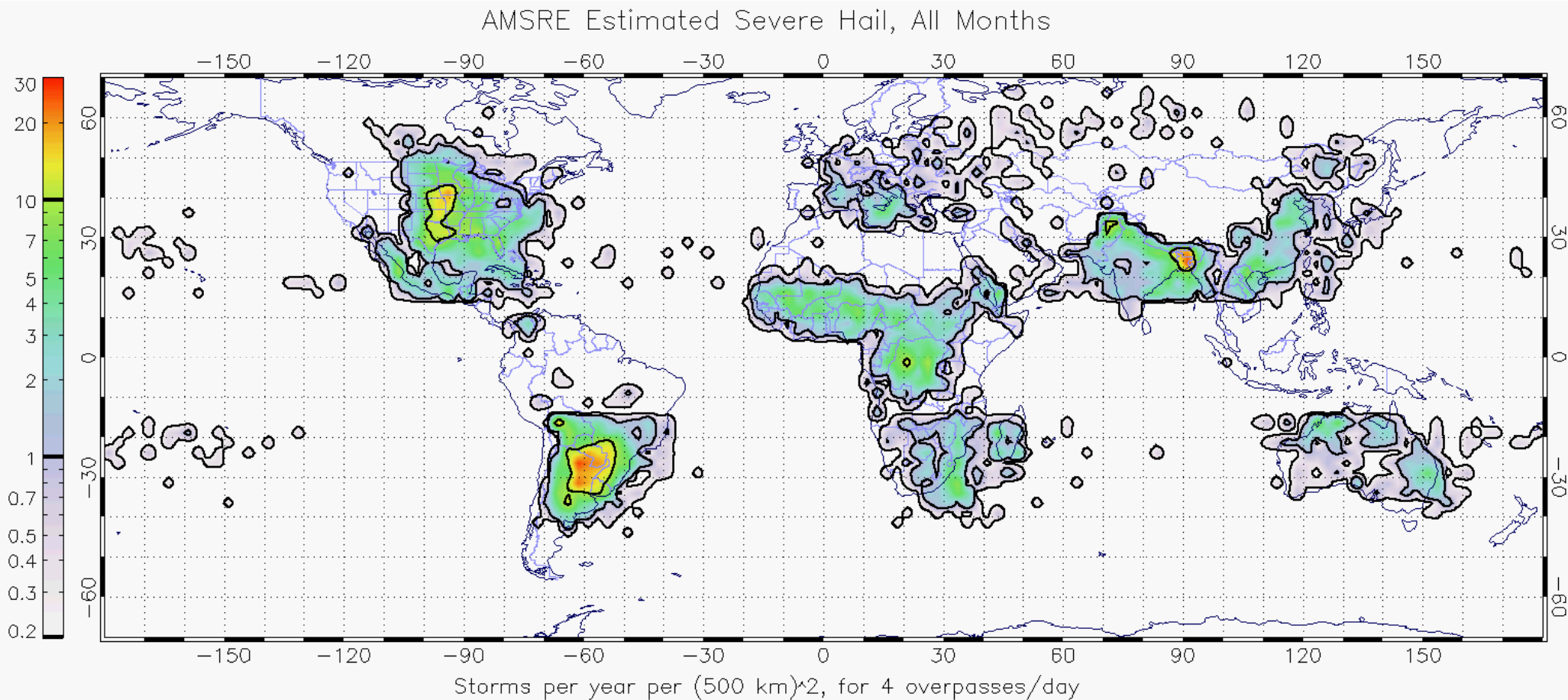
# AMSR-E 36 GHz with scaling applied to tropics and oceans



Based on regional comparisons between TRMM radar and TRMM Microwave Imager, we scaled the tropics and oceanic regions to have lower values. Cecil and Blankenship (2011) J. Appl. Meteor. Clim.

*Com base em comparações regionais entre TRMM radar e microondas TRMM Imager, que escalou as regiões tropicais e oceânica a ter valores mais baixos.*

# AMSR-E 36 GHz with scaling applied to tropics and oceans

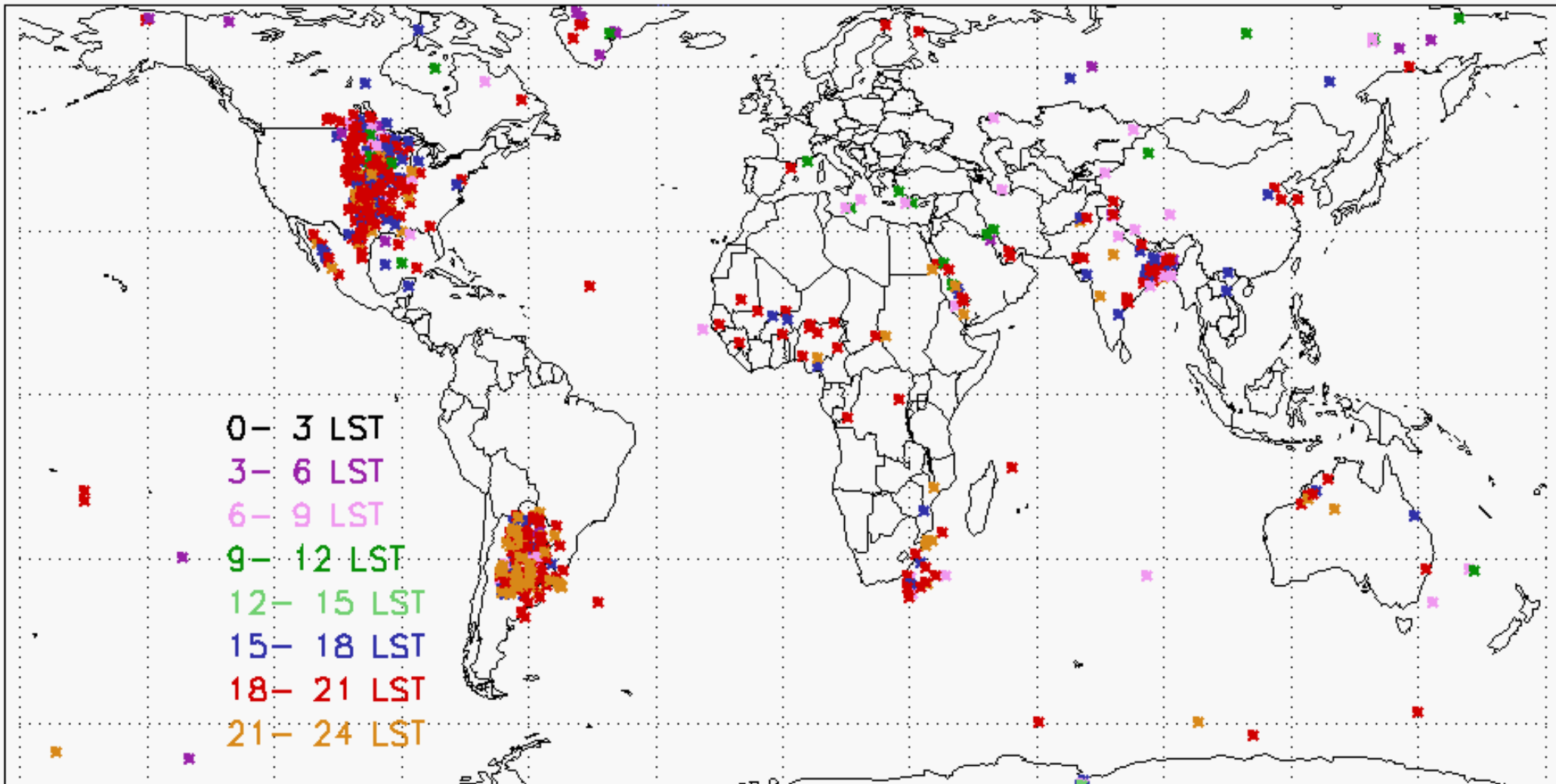


This map is our current best estimate for severe hail storm locations. Cecil and Blankenship (2012) J. Climate. Argentina and Bangladesh are essentially tied for 1<sup>st</sup> place.

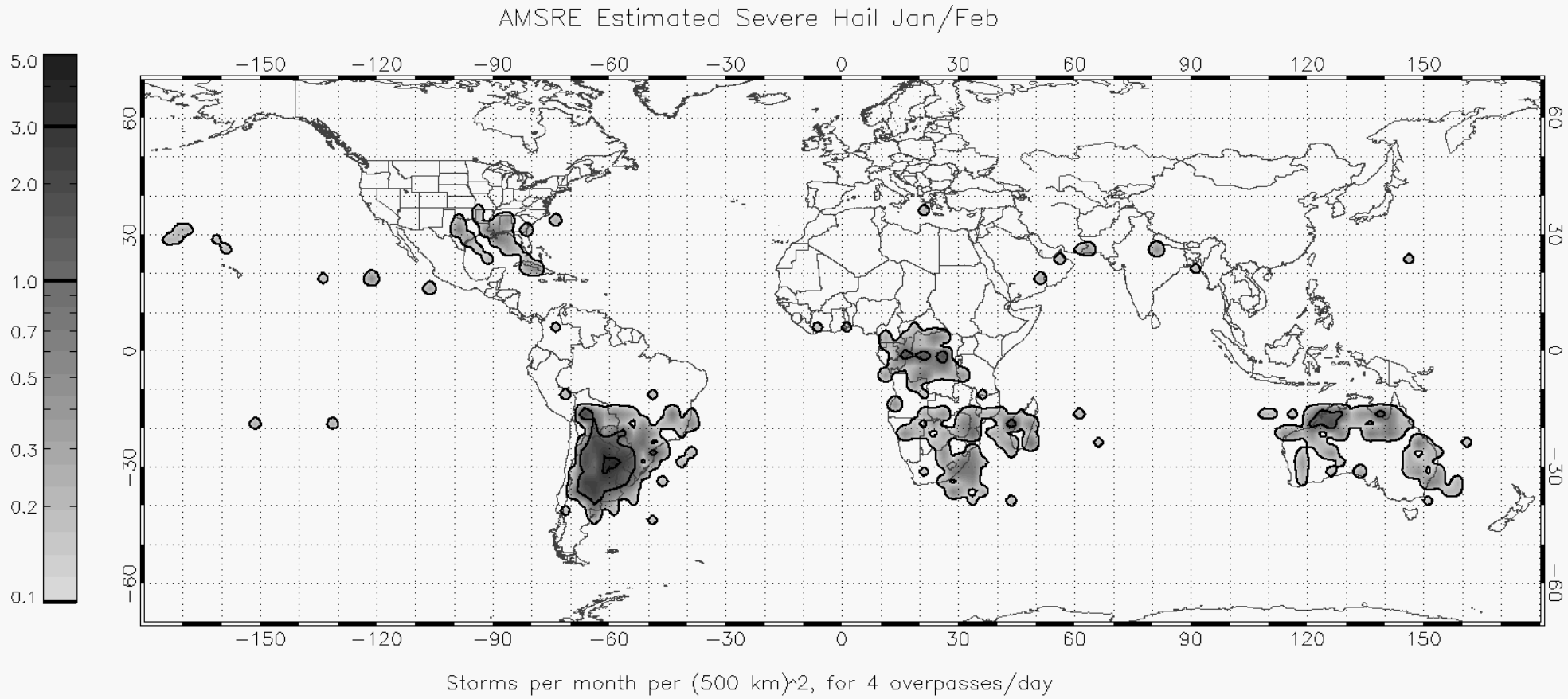
*Este mapa é a nossa melhor estimativa corrente para locais forte tempestade de granizo. Argentina e Bangladesh são essencialmente empatado em primeiro lugar.*

# Simplified version using > 20 years of SSMI satellite data

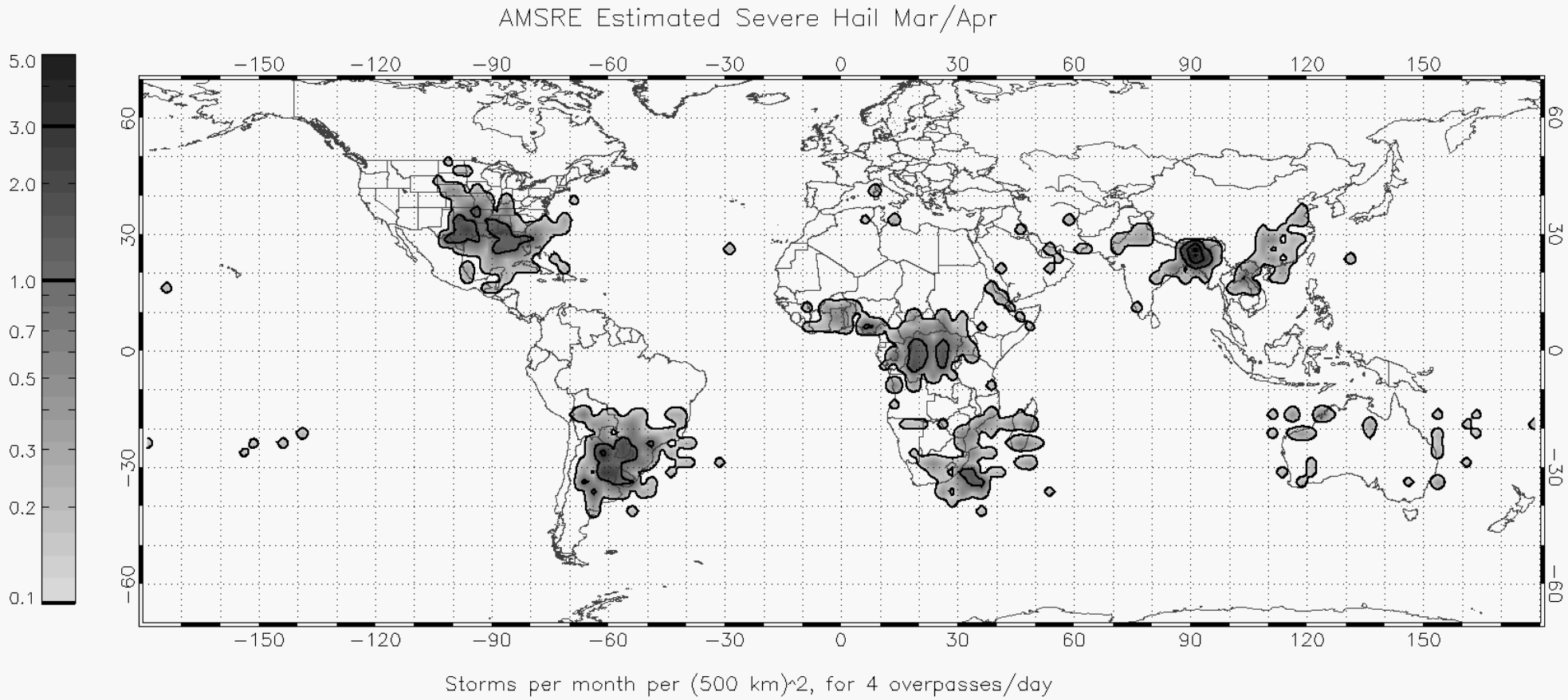
SSMI F08 F10 F11 F13 F14 F15



# January - February

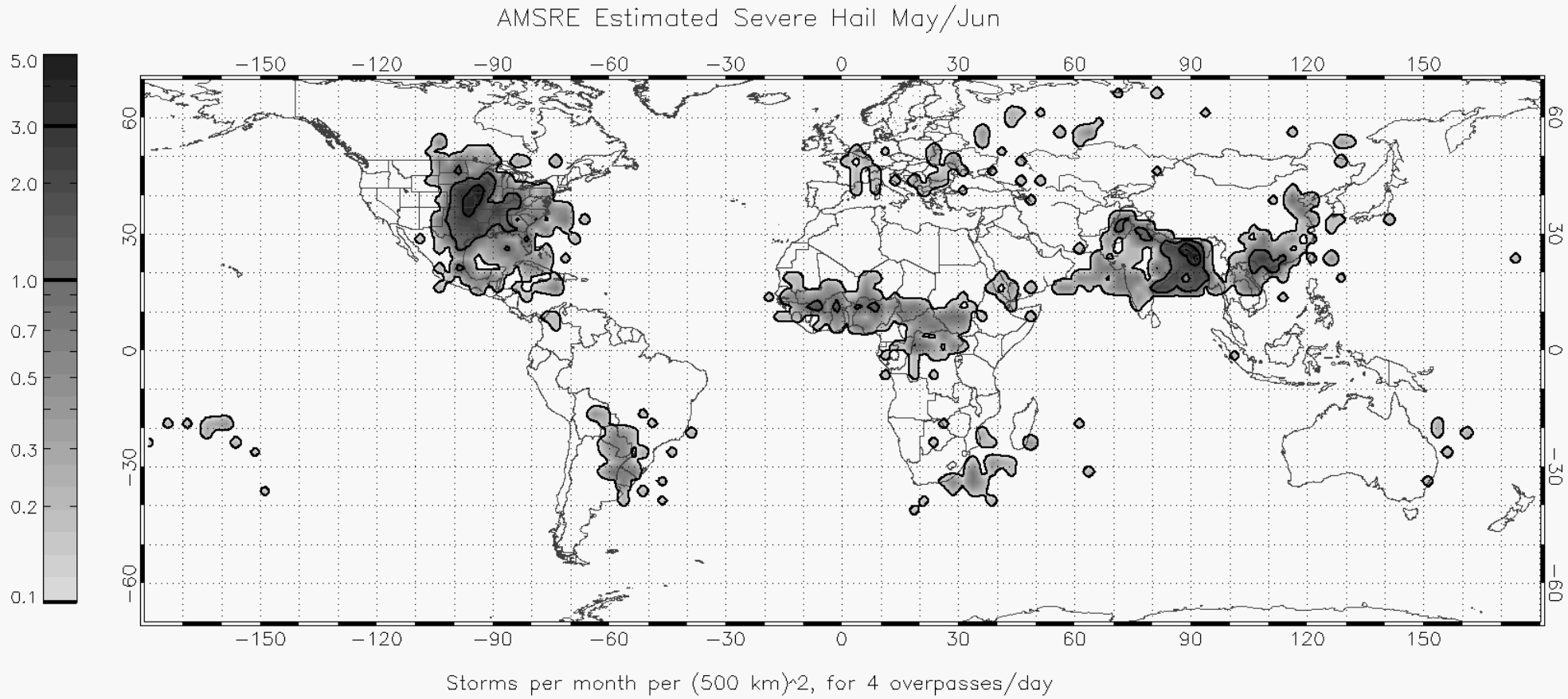


# March - April

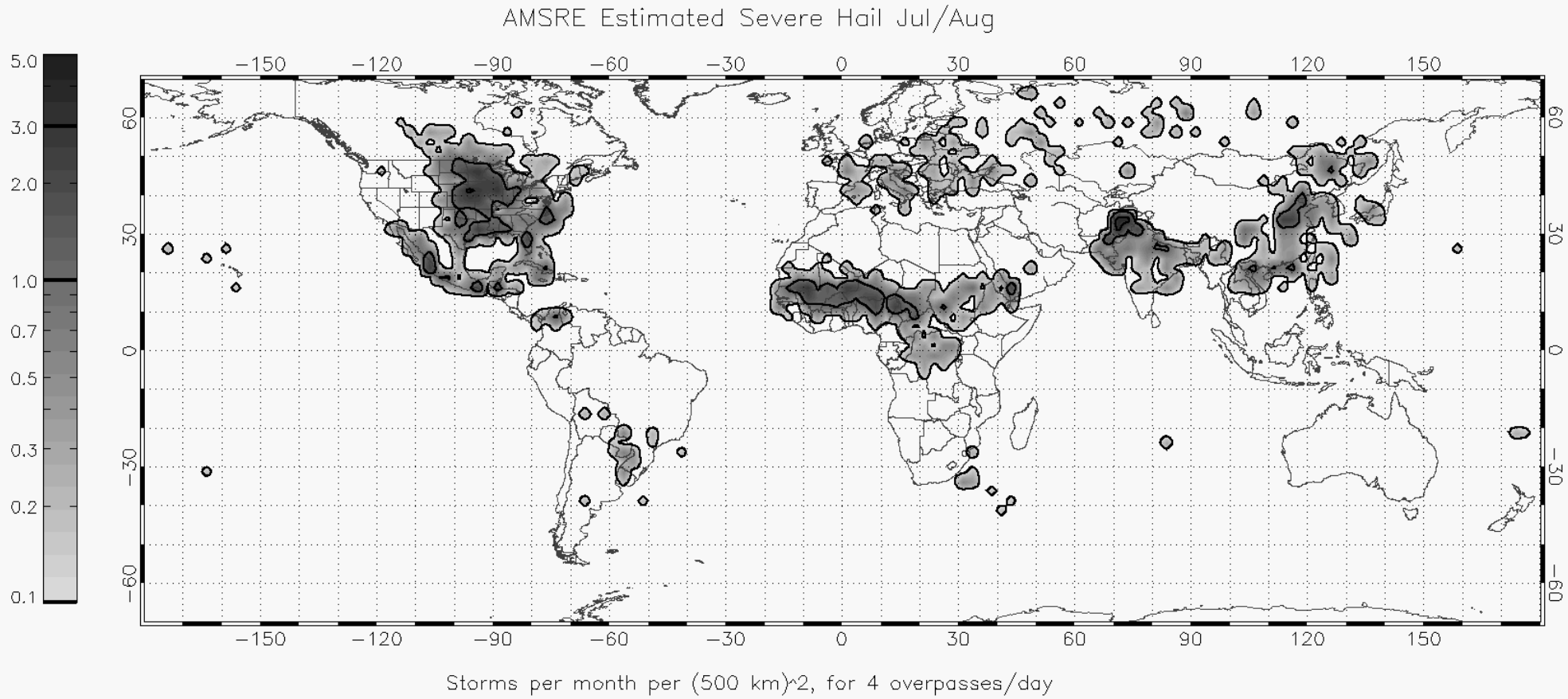




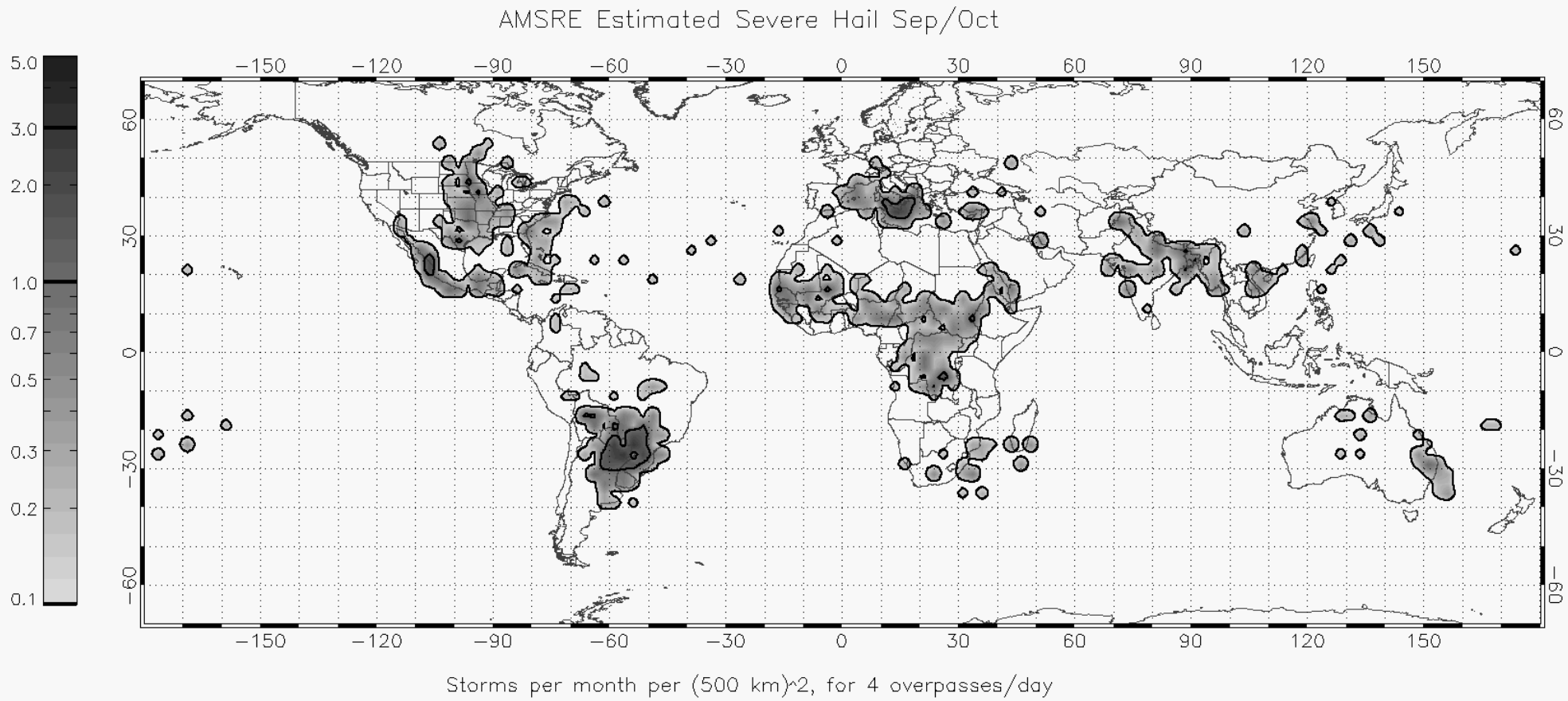
# May - June



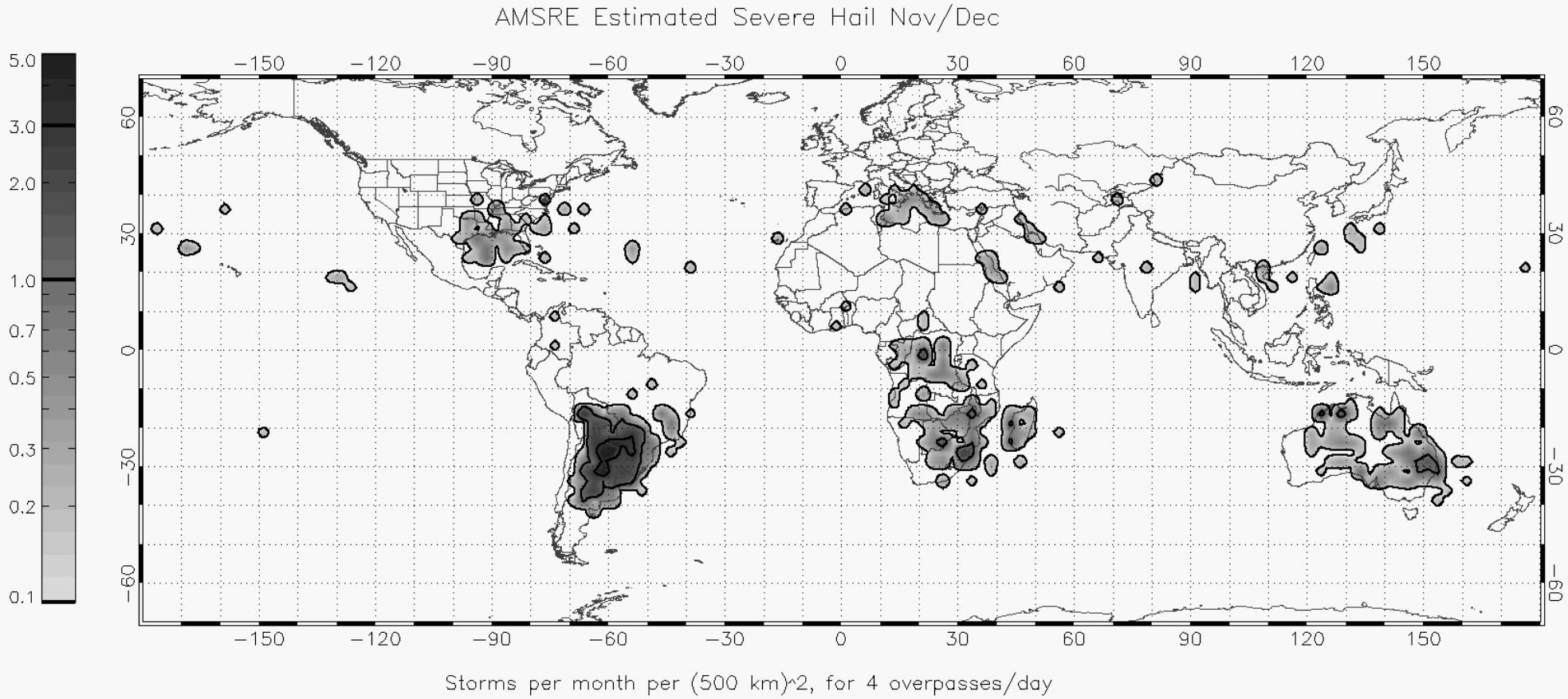
# July - August



# September - October



# November - December



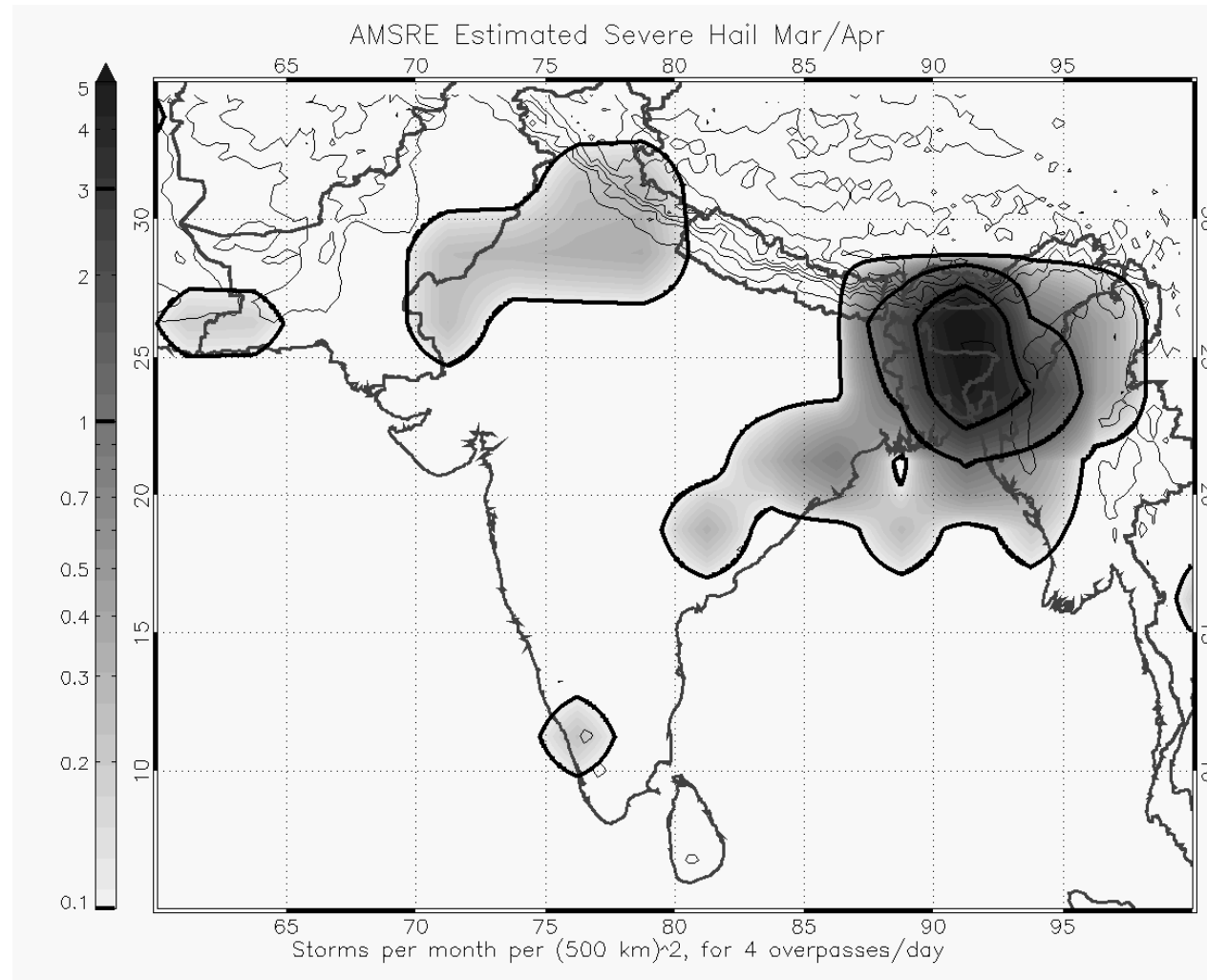
# Indian Subcontinent – March - April

Many hailstorms in spring / pre-monsoon season in East India & Bangladesh

Activity abruptly shifts west toward Pakistan after monsoon onset in early June

*Muitas chuvas de granizo na primavera / pré-temporada das monções no leste da Índia e Bangladesh*

*Atividade abruptamente muda para oeste em direção Paquistão após o início das monções no início de junho*



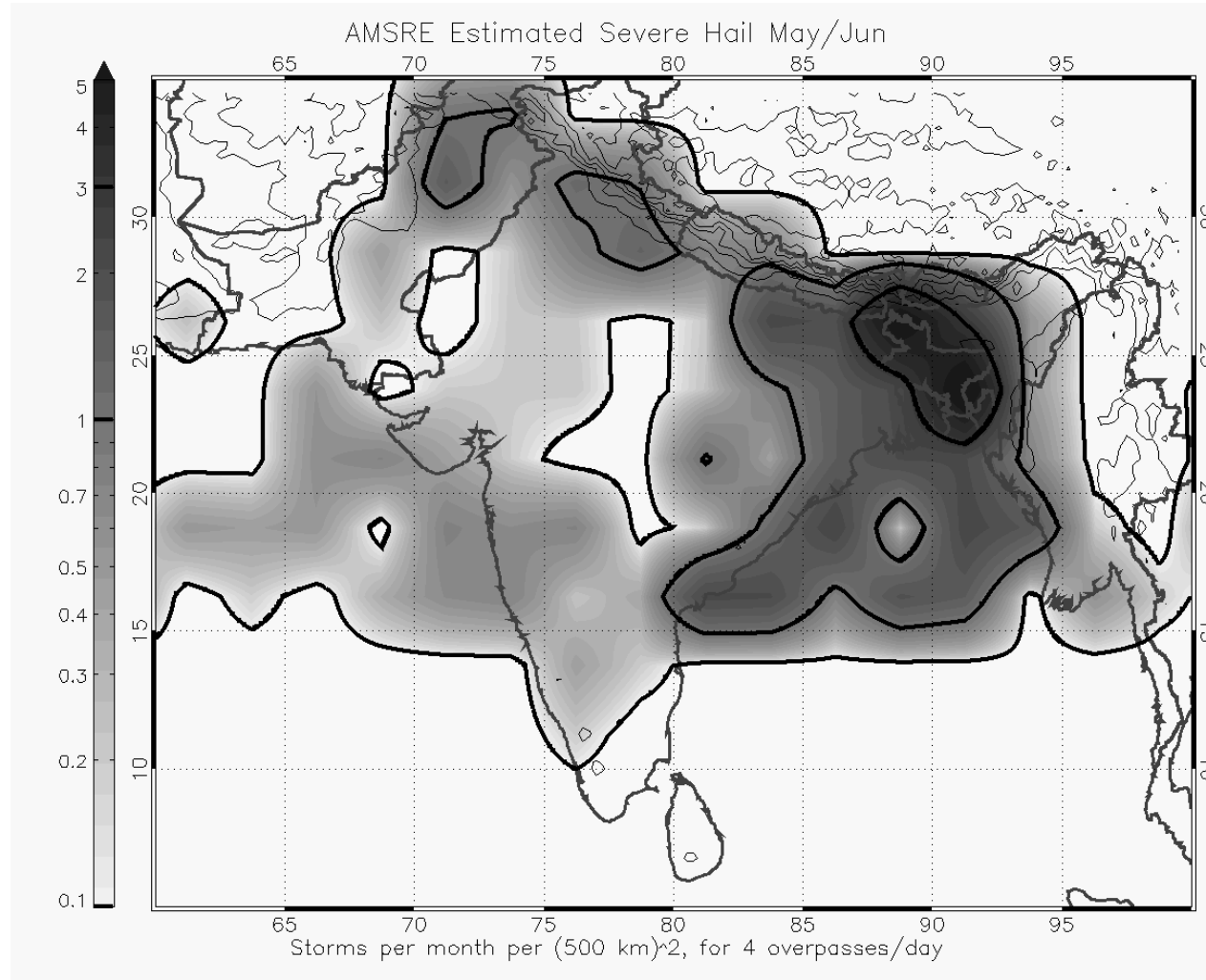
# Indian Subcontinent – May - June

Many hailstorms in spring / pre-monsoon season in East India & Bangladesh

Activity abruptly shifts west toward Pakistan after monsoon onset in early June

*Muitas chuvas de granizo na primavera / pré-temporada das monções no leste da Índia e Bangladesh*

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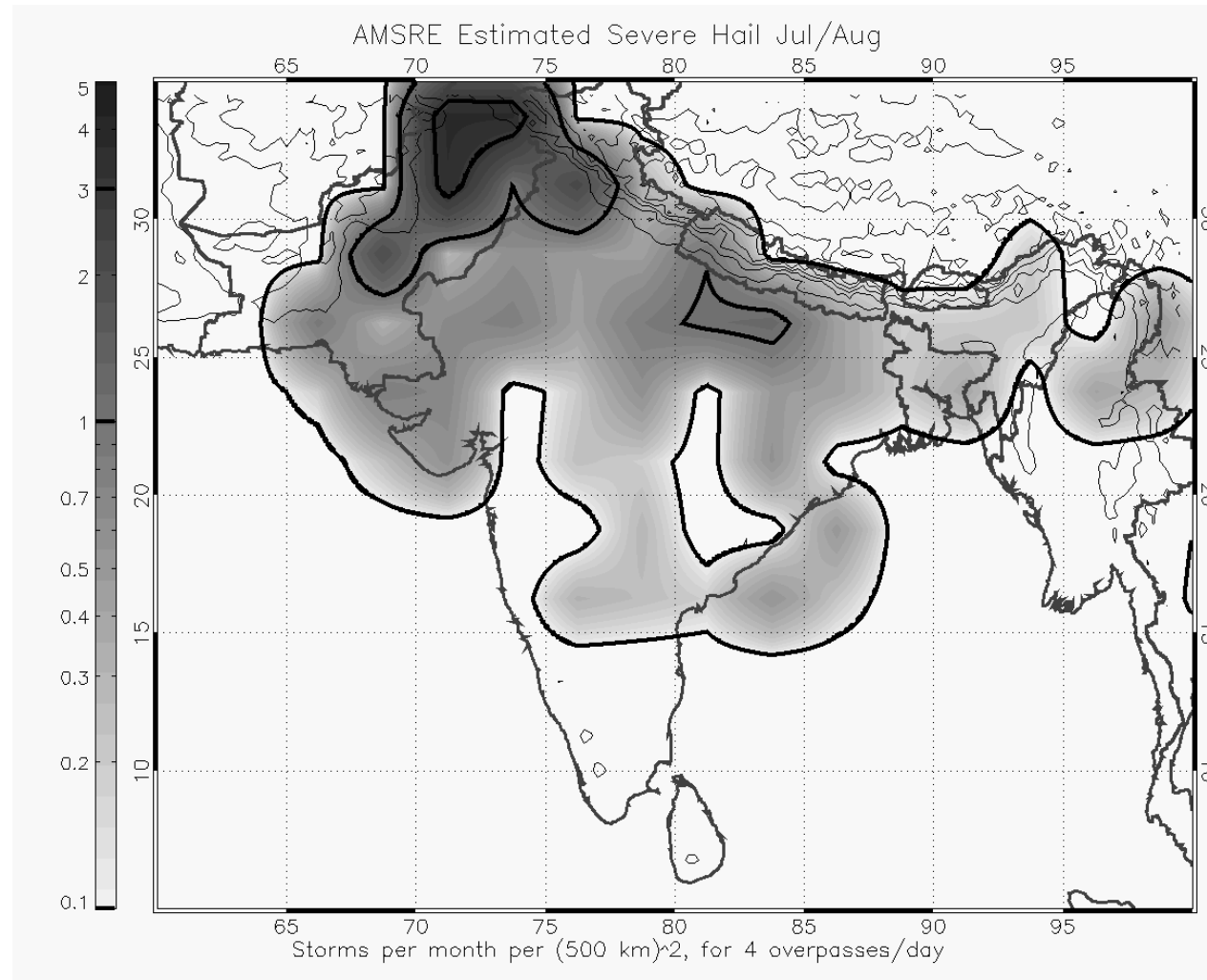
# Indian Subcontinent – Sept. – Oct.

Many hailstorms in spring / pre-monsoon season in East India & Bangladesh

Activity abruptly shifts west toward Pakistan after monsoon onset in early June

*Muitas chuvas de granizo na primavera / pré-temporada das monções no leste da Índia e Bangladesh*

*Atividade abruptamente muda para oeste em direção Paquistão após o início das monções no início de junho*



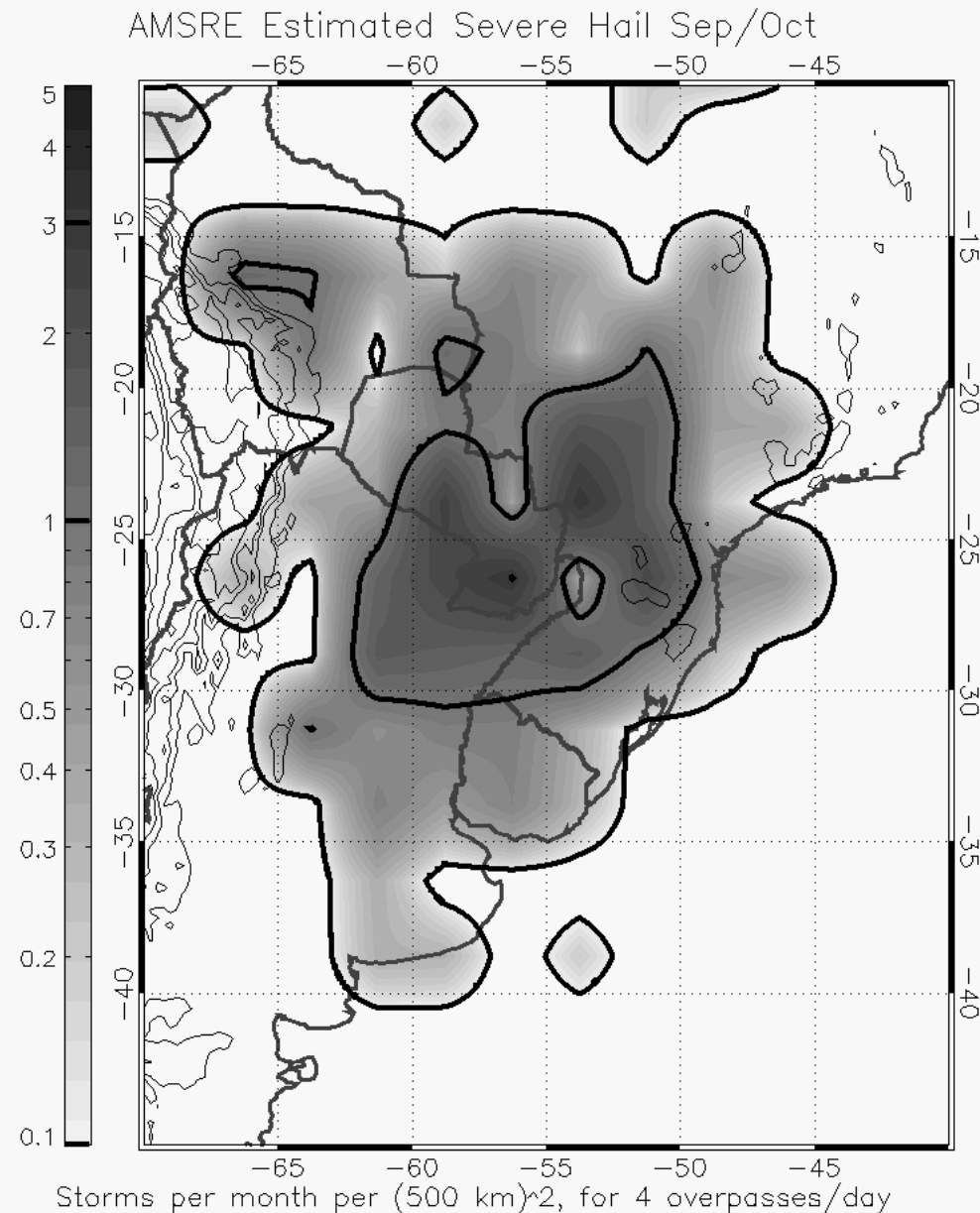
# SE South America– Sept. – Oct.

Hail storm locations shift from Paraguay and Southern Brazil in early spring to Northern Argentina in late spring and summer.

Surface observations suggest the true locations should be further west and south (?)

*Locais tempestade de granizo mudar de Paraguai e sul do Brasil no início da primavera para o norte da Argentina no final da primavera e no verão.*

*Observações de superfície indicam os locais verdadeiros deveria ser mais a oeste e ao sul (?)*





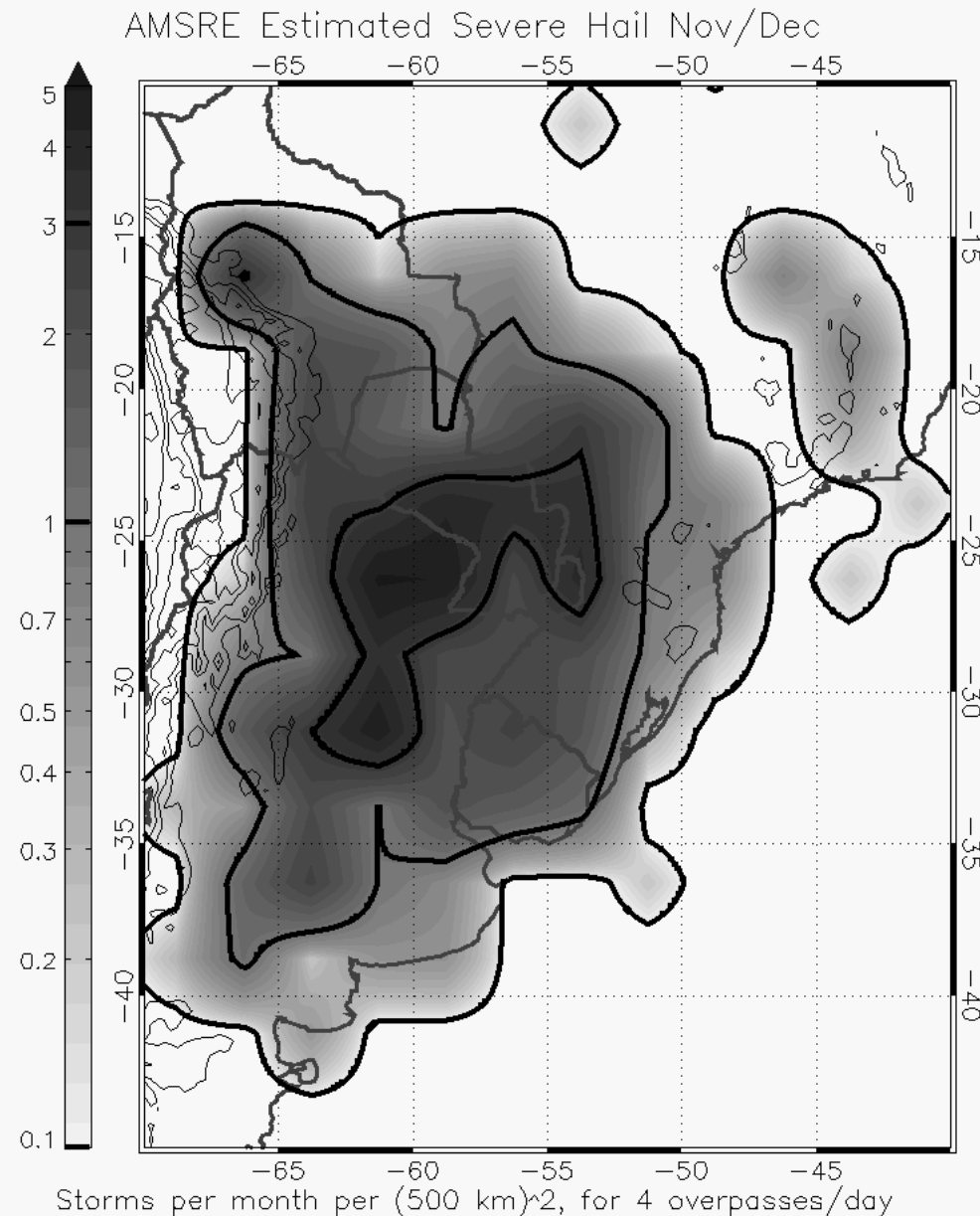
# SE South America– Nov. - Dec.

Hail storm locations shift from Paraguay and Southern Brazil in early spring to Northern Argentina in late spring and summer.

Surface observations suggest the true locations should be further west and south (?)

*Locais tempestade de granizo mudar de Paraguai e sul do Brasil no início da primavera para o norte da Argentina no final da primavera e no verão.*

*Observações de superfície indicam os locais verdadeiros deveria ser mais a oeste e ao sul (?)*



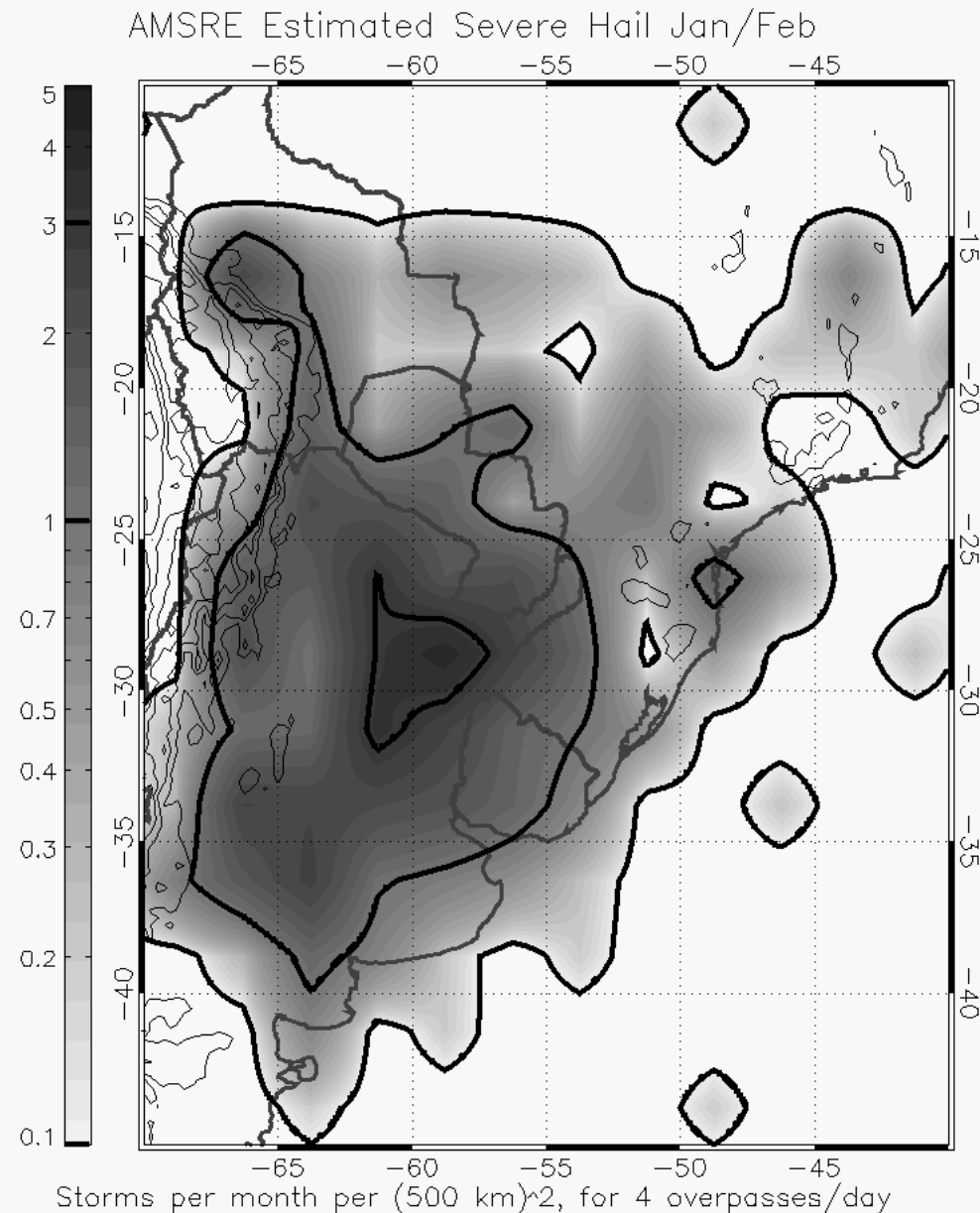
# SE South America– Jan - Feb.

Hail storm locations shift from Paraguay and Southern Brazil in early spring to Northern Argentina in late spring and summer.

Surface observations suggest the true locations should be further west and south (?)

*Locais tempestade de granizo mudar de Paraguai e sul do Brasil no início da primavera para o norte da Argentina no final da primavera e no verão.*

*Observações de superfície indicam os locais verdadeiros deveria ser mais a oeste e ao sul (?)*



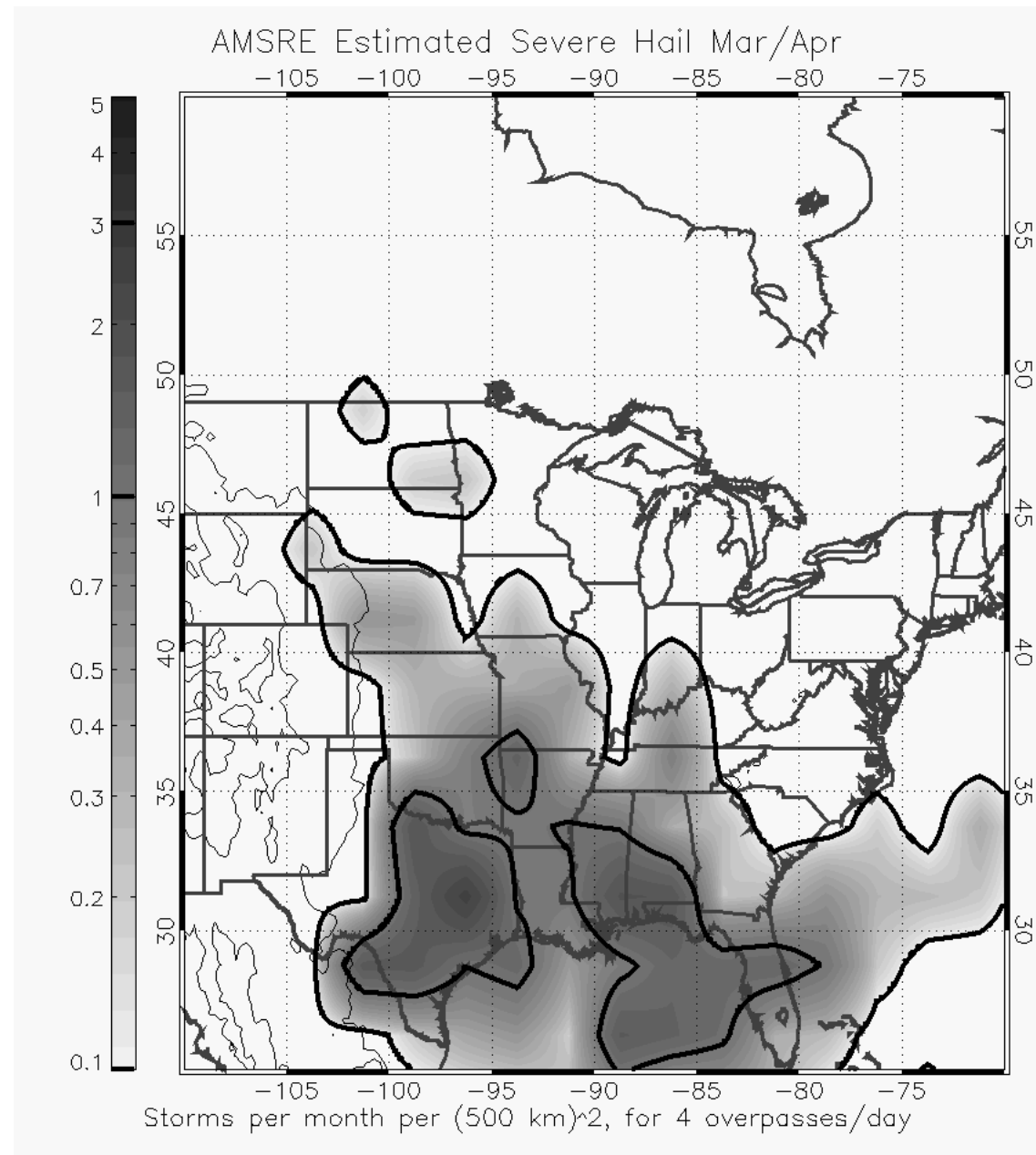
# North America – March - April

Cool season storms mostly confined to southeast and south-central USA.

Activity expands northward through Central Plains, into Canada during summer

*Tempestades de estação fria confinado a sudeste e centro-sul do EUA.*

*Atividade se expande em direção ao norte através Planícies Centrais, para o Canadá durante o verão*



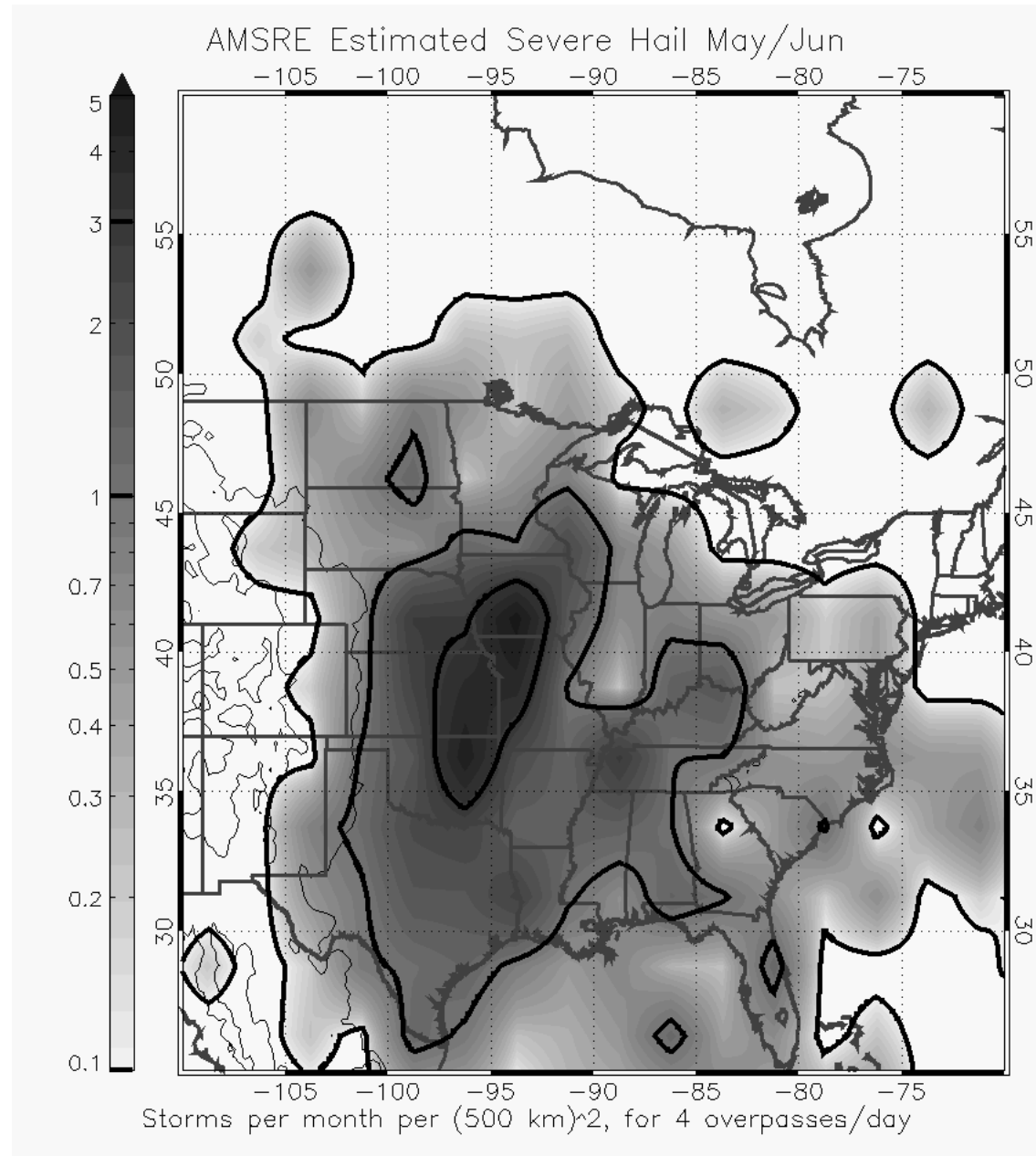
# North America – May - June

Cool season storms mostly confined to southeast and south-central USA.

Activity expands northward through Central Plains, into Canada during summer

*Tempestades de estação fria confinado a sudeste e centro-sul do EUA.*

*Atividade se expande em direção ao norte através Planícies Centrais, para o Canadá durante o verão*



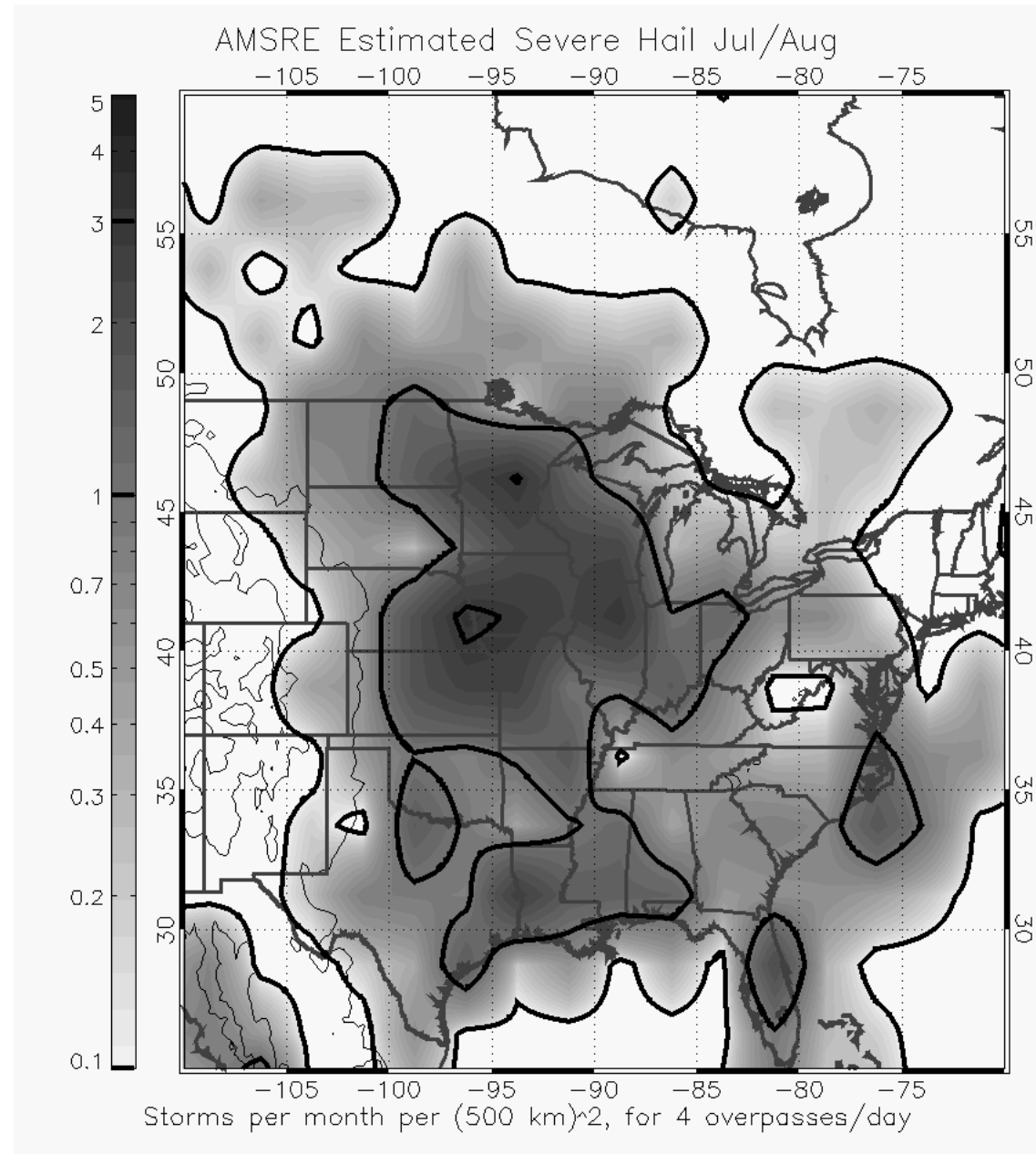
# North America – July - August

Cool season storms mostly confined to southeast and south-central USA.

Activity expands northward through Central Plains, into Canada during summer

*Tempestades de estação fria confinado a sudeste e centro-sul do EUA.*

*Atividade se expande em direção ao norte através Planícies Centrais, para o Canadá durante o verão*



## Summary

- Large hydrometeors, especially graupel and hail, reduce the passive microwave brightness temperatures seen by satellite sensors such as TRMM, AMSR-E, SSMI
  - *Hidrometeoros grandes, especialmente graupel e granizo, reduzir as temperaturas brilho passivos de microondas visto por sensores orbitais, como TRMM, AMSR-E, SSMI*

## Summary

- 37 GHz Polarization Corrected Temperature (PCT)  
< 200 K has ~20% likelihood of large hail.

< 150 K, ~60%

< 130 K *approaches* 100 %

These are empirically derived using 2.5+ cm hail reports in USA

- *37 GHz Polarização Corrigido Temperatura (PCT)*  
*<200 K tem ~ probabilidade de 20% de granizo grande.*

# Summary

- Empirical relationships are used to estimate global hail climatology from satellites
  - *Relações empíricas são usadas para estimar climatologia granizo global de satélites*
- Most common locations:
  - N. Argentina, Paraguay, Uruguay, S. Brazil
  - East and West India, Bangladesh, Pakistan
  - Central and SE USA
  - Central Africa
- There are indications SE South America, Bangladesh, and Central Africa may be over-estimated by satellite
  - *Há indicações SE América do Sul, Bangladesh, África Central e podem ser sobre-estimado por satélite*



# Summary

- The most active regions usually peak in late spring or early summer, with active area expanding poleward in summer
  - *As regiões mais ativas geralmente pico no final da primavera ou início do verão, com área ativa expandir os pólos no verão* Most common locations:
- Seasonality around India is more unique. East India and Bangladesh have frequent storms before monsoon begins in early June. After monsoon onset, convection weakens in the east (though rain is plentiful). Convection becomes more intense in the west, near Pakistan by July-August.
  - *Sazonalidade em torno Índia é mais exclusivo. Leste da Índia e Bangladesh têm tempestades freqüentes antes de monção começa no início de junho. Após o início das monções, a convecção se enfraquece no leste (embora a chuva é abundante). Convecção se torna mais intenso no oeste, perto do Paquistão em julho e agosto.*
  - ***Perguntas???***