Comparison of TRMM LIS and PR with ground based lightning and radar observations for the TROCCINOX/ TroCCiBras/HIBISCUS field campaign

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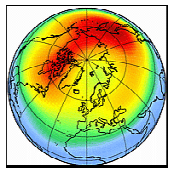
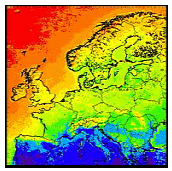
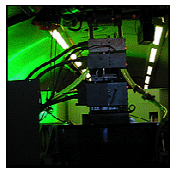






Need for Lightning Information

Total Lightning:

- Operational ground based system optimized for cloud-to-ground lightning localization
- Important contribution of Nitrogen oxides (NO_x) by intra-cloud lightning
- For the extrapolation of the regional NO_x results an estimate of the total lightning activity is necessary

Parameterization of lightning:

- Extrapolation of storm-scale lightning results to a wider sample
- Parameterization of lightning (effects) in cloud-scale models
- Parameterization of the lightning activity of a convective cell by observed variables

Data

Lightning Imaging Sensor (LIS) - MSFC/NASA

- Space-borne on-board the TRMM satellite (35° inclination angle)
- Operational since 1997 (mission probably ends beginning 2005)
- Optical detection of total lightning (90% efficiency)
- 600 x600 km^2 field of view, ~90 s observation

Precipitation Radar (PR) - GSFC/NASA, JAXA

- Space-borne on-board the TRMM satellite
- 13.8 GHz Radar, 247 km swath width, 5 km horizontal resolution
- Maximum reflectivity and cloud top height in this study

Bauru Radar - IPMet/UNESP

- 1 km resolution data for this study
- Cloud top height and reflectivity at 3.5 km altitude used in this study

Brazilian Lightning Detection Network, ELAT/INPE

- Detection of cloud-to-ground flashes in southern and central Brazil

Parameters

Parameters investigated in this study:

Observations:

LIS lightning frequency	f_{LIS}
BLN lightning frequency	f_{BLN}
PR maximum reflectivity	Z_{max}
Bauru Radar reflectivity @ 3.5km altitude	$Z_{3.5km}$
PR/Bauru Radar cloud top height	CTH
PR/Bauru Radar cold cloud thickness (cloud depth above the freezing level)	CCT

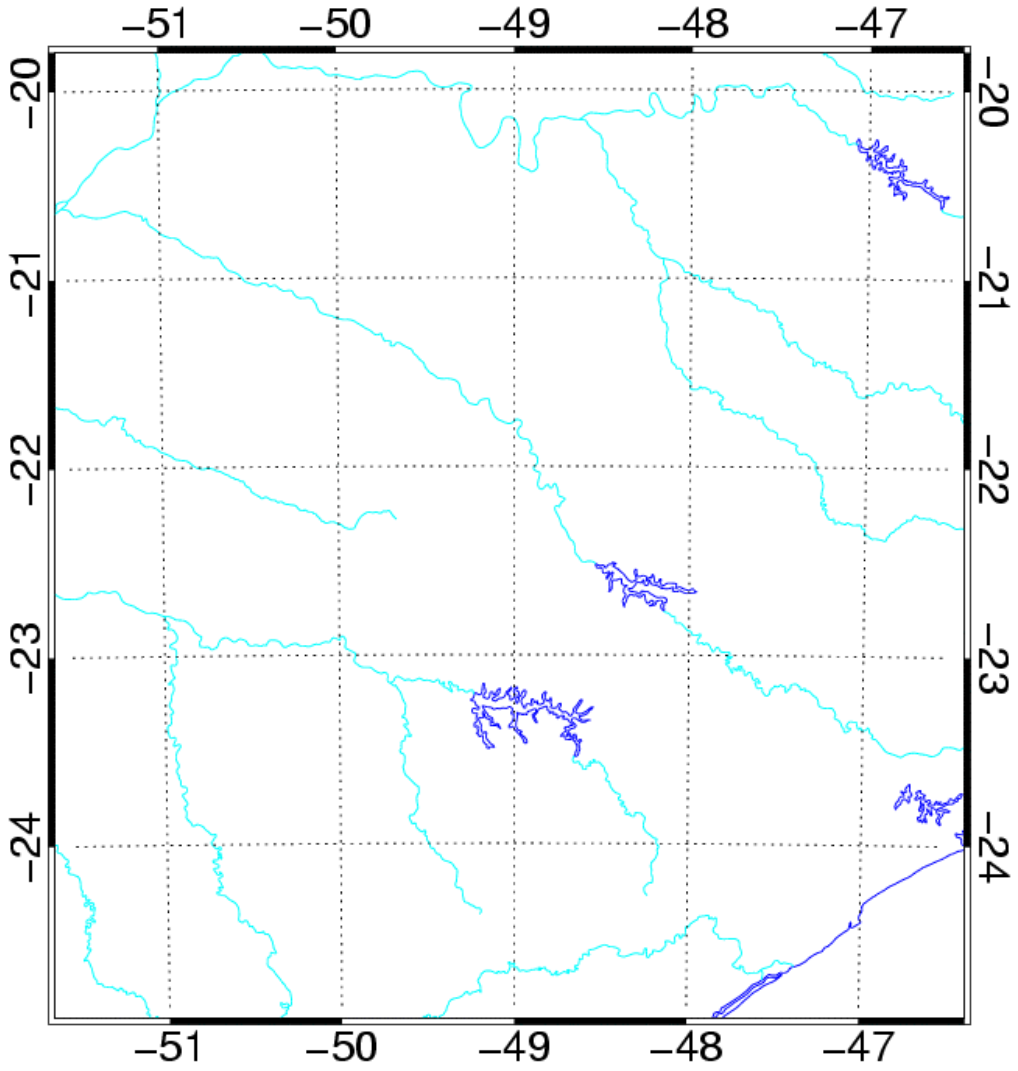
Working assumptions:

Total lightning frequency	$f_{total} = f_{LIS}$
Intra-cloud (IC) lightning frequency	$f_{IC} = f_{LIS} - f_{BLN}$
Cloud-to-ground (CG) flash frequency	$f_{CG} = f_{BLN}$

Strategy - Example

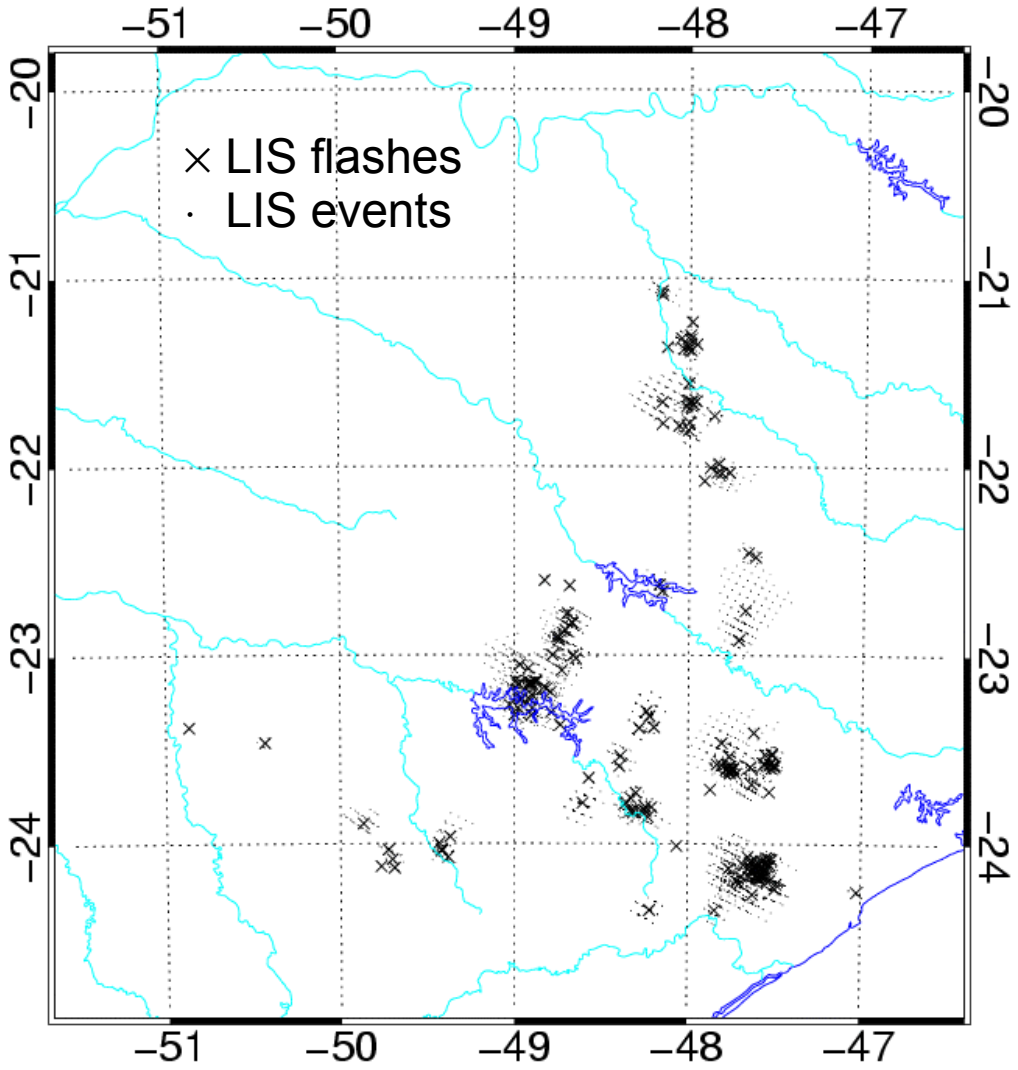
For example:

- 3 March 2004
- São Paulo State



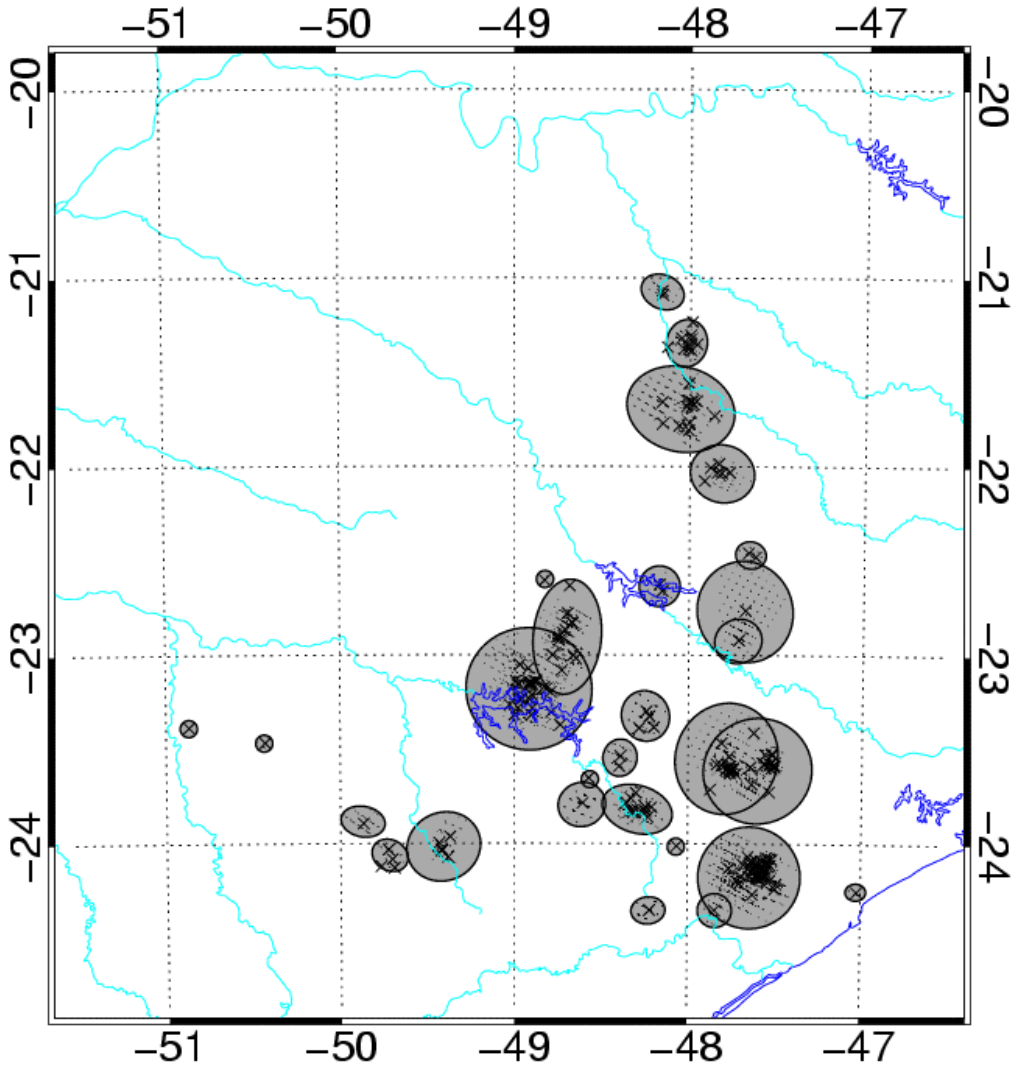
Strategy – 1. LIS Cells

- Identify active “lightning cells” based on LIS data for the TROCCINOX/TroCCiBras experimental area



Strategy – 2. Define Ellipse

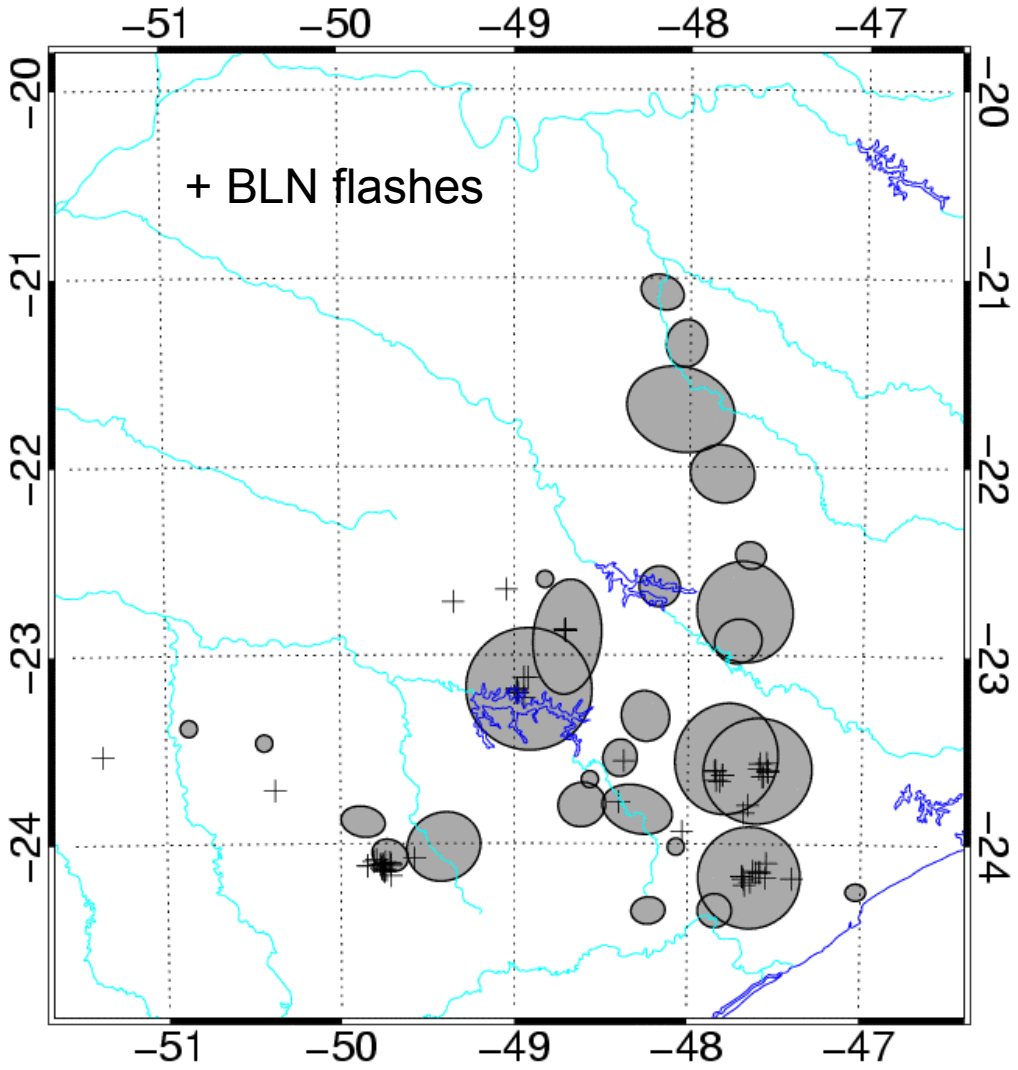
- Identify active “lightning cells” based on LIS data for the TROCCINOX/TroCCiBras experimental area
- Define ellipse enclosing the lightning cell



$$f_{total} = f_{total}(f_{CG}, CTH, CCT, Z_{max}, Z_{3.5km})$$

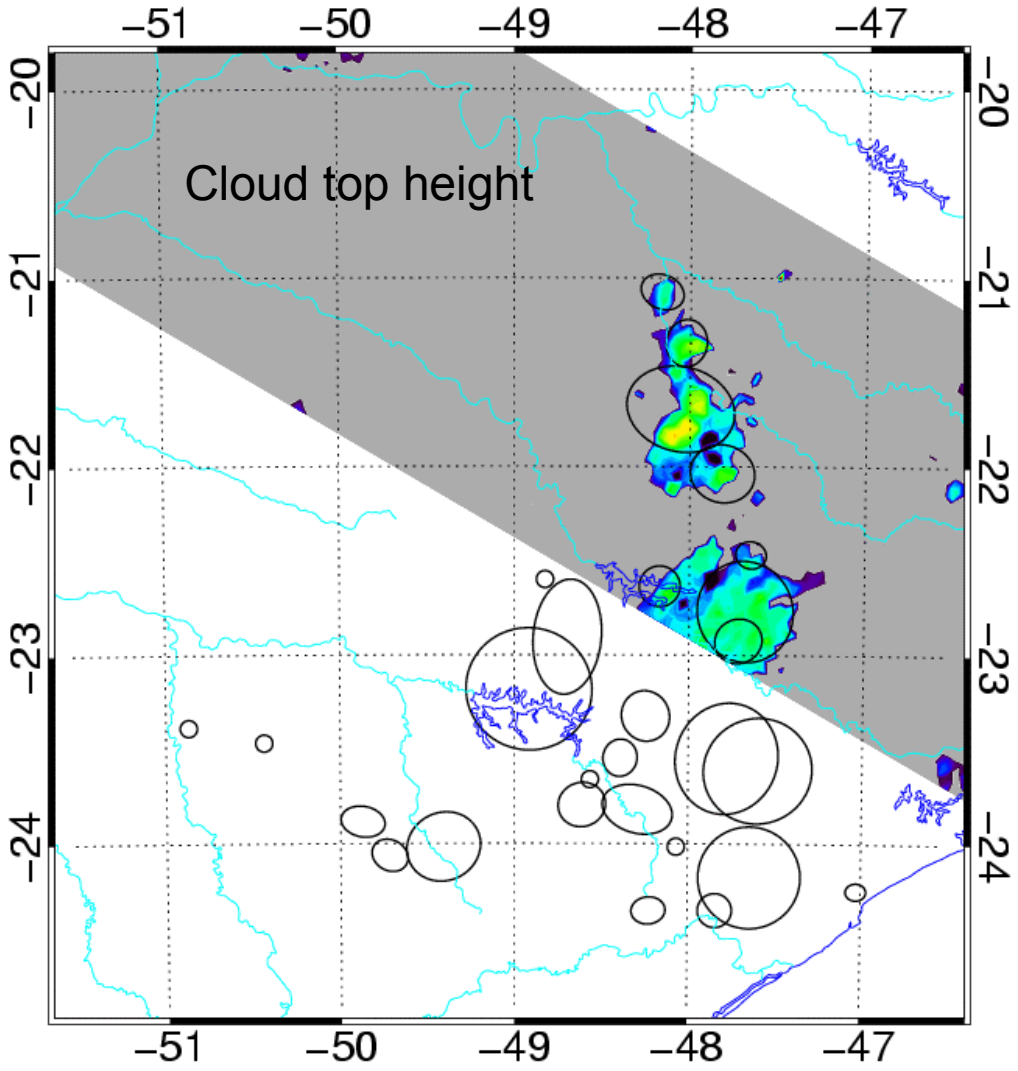
Strategy – 3. BLN Flashes

- Identify active “lightning cells” based on LIS data for the TROCCINOX/TroCCiBras experimental area
- Define ellipse enclosing the lightning cell
- Identify BLN CG flashes for the cell during the overpass



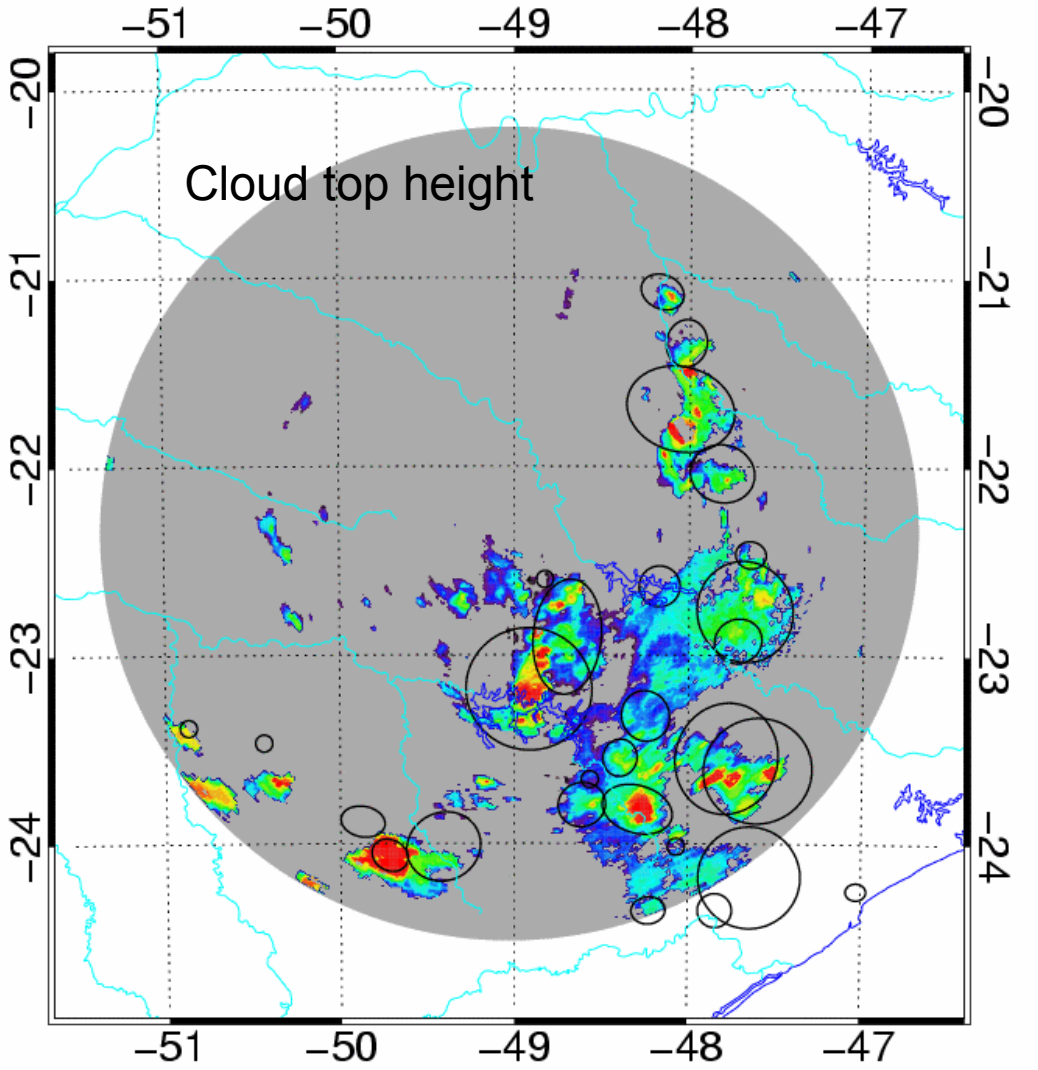
Strategy – 4. TRMM PR

- Identify active “lightning cells” based on LIS data for the TROCCINOX/TroCCiBras experimental area
- Define ellipse enclosing the lightning cell
- Identify BLN CG flashes for the cell during the overpass
- Identify the PR maximum reflectivity and cloud top height for the cell



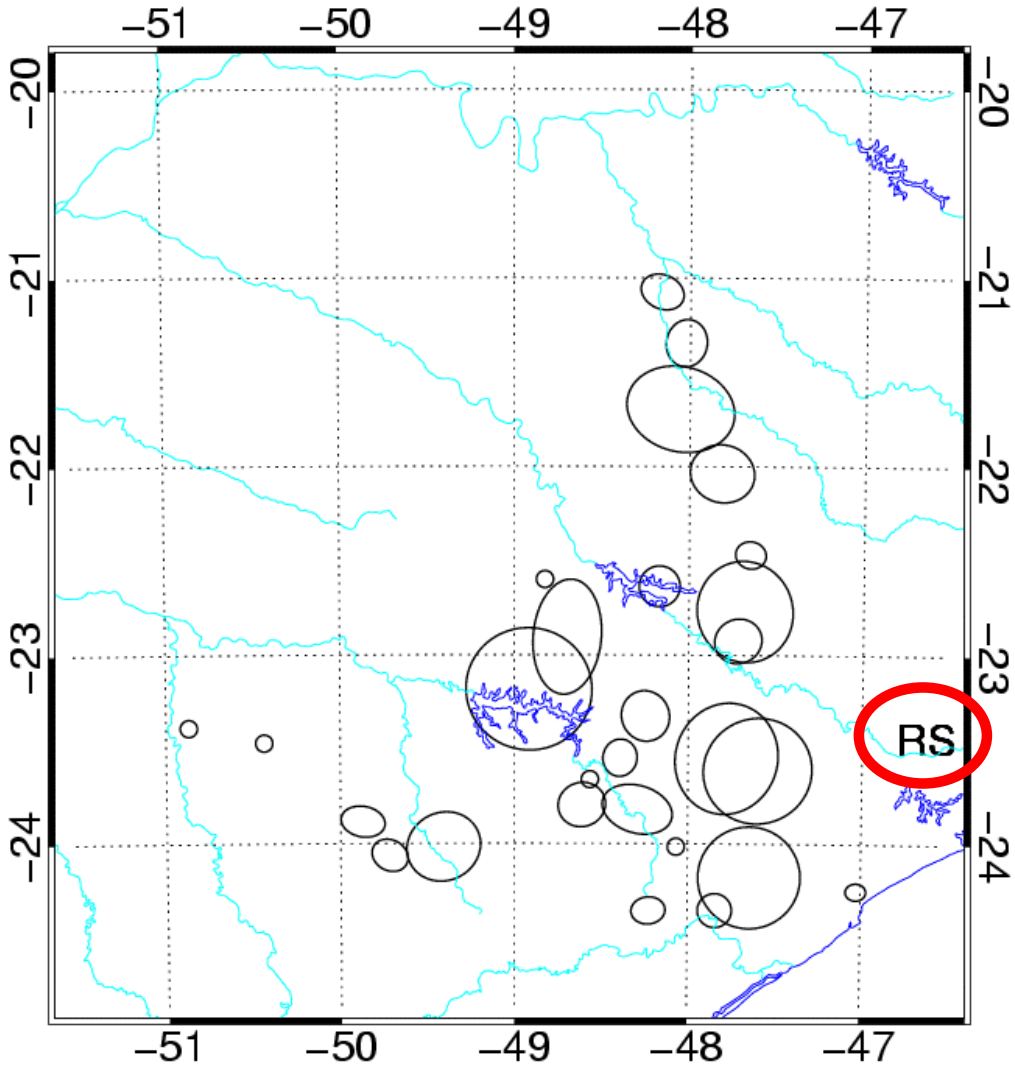
Strategy – 5. Bauru Radar

- Identify active “lightning cells” based on LIS data for the TROCCINOX/TroCCiBras experimental area
- Define ellipse enclosing the lightning cell
- Identify BLN CG flashes for the cell during the overpass
- Identify the PR maximum reflectivity and cloud top height for the cell
- Search for the Bauru Radar reflectivity at 3.5 km and the cloud top height



Strategy – 6. Radiosondes

- Identify active “lightning cells” based on LIS data for the TROCCINOX/TroCCiBras experimental area
- Define ellipse enclosing the lightning cell
- Identify BLN CG flashes for the cell during the overpass
- Identify the PR maximum reflectivity and cloud top height for the cell
- Search for the Bauru Radar reflectivity at 3.5 km and the cloud top height
- Look for radiosonde sites



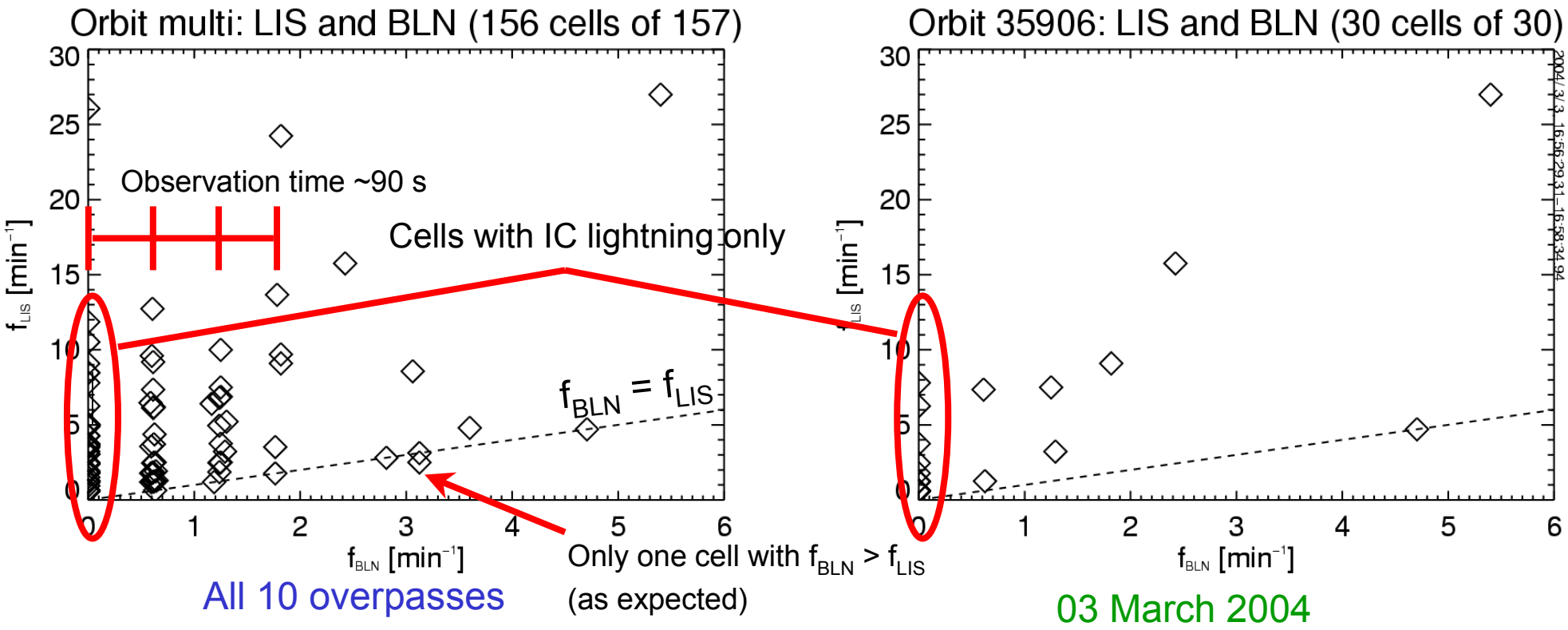
$$f_{total} = f_{total}(f_{CG}, CTH, CCT, Z_{max}, Z_{3.5km})$$

Summary of LIS orbits, cells, lightning and β

Ratio of IC to CG flashes: $\beta = N_{IC}/N_{CG} \stackrel{!}{=} (N_{LIS}-N_{BLN})/N_{BLN}$

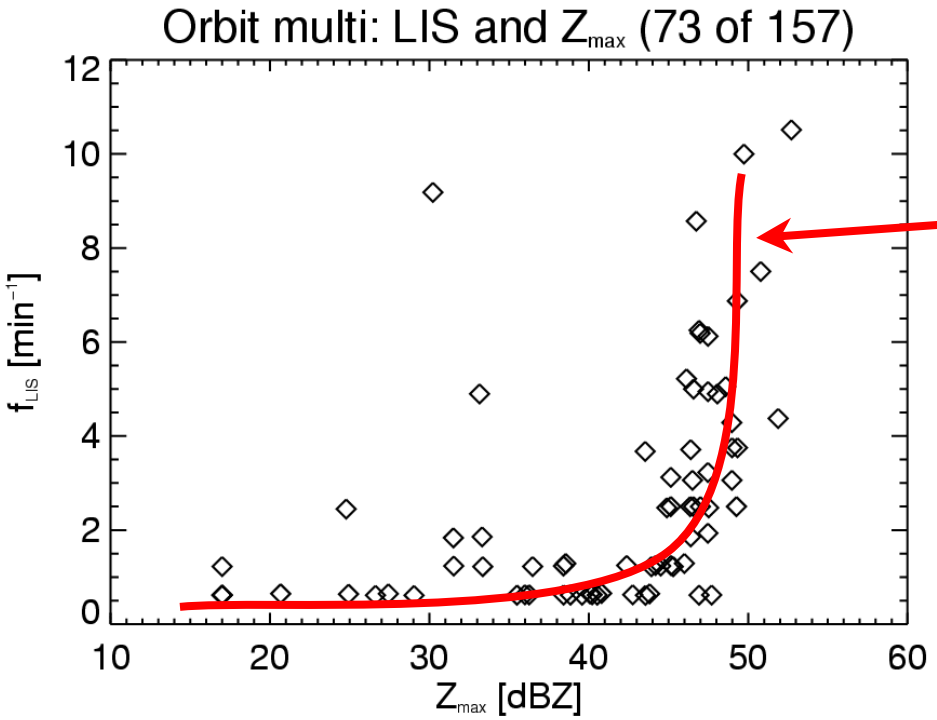
Date	LIS Orbit	Number of LIS areas	Number of LIS flashes	Number of BLN flashes	β
24 January 2004	35301	15	32	5	**5.40**
26 February 2004	35814	2	9	6	**0.50**
27 February 2004	35830	35	234	19	**11.32**
28 February 2004	35835	36	174	30	**4.80**
28 February 2004	35845	2	9	0	**∞**
29 February 2004	35860	5	90	5	**17.00**
03 March 2004	35906	30	191	29	**5.59**
04 March 2004	35911	1	2	0	**∞**
06 March 2004	35957	19	67	6	**10.17**
10 March 2004	36018	12	47	10	**3.70**
Total		**157**	**855**	**110**	**6.77**

LIS and BLN lightning frequency for cells

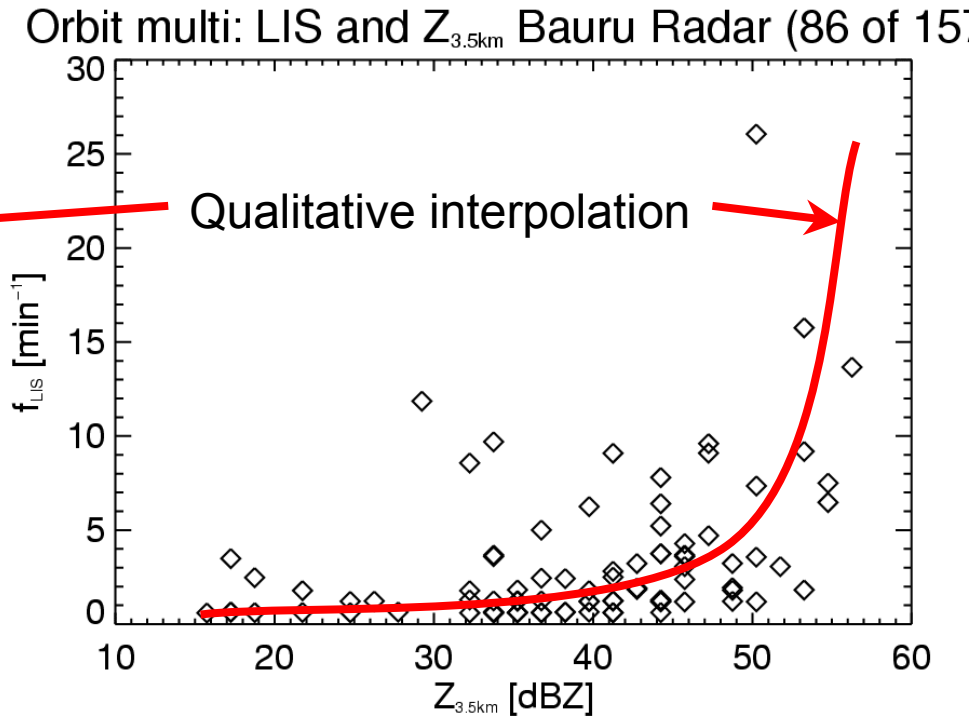


- **Total lightning frequencies up to 27 min^{-1}, CG lightning up to 5.6 min^{-1}**
- **β can reach any value between 0 (CG only) and ∞ (IC only) for the complete dataset**
- **β seems more restricted for single overpass**

LIS lightning frequency and radar reflectivity - All 10 overpasses



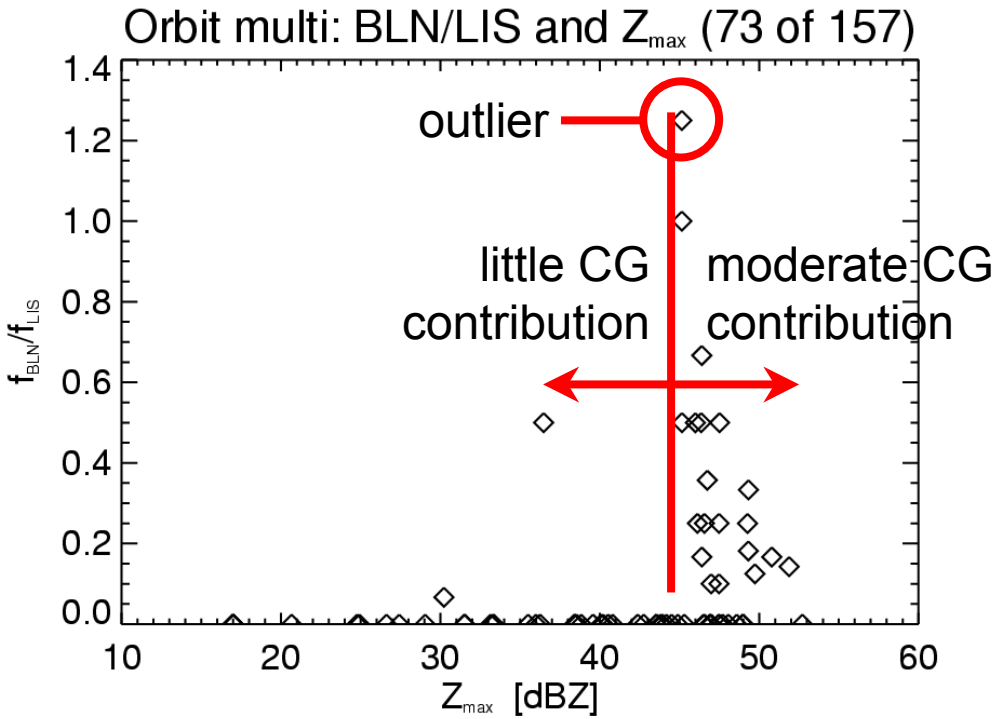
TRMM PR maximum reflectivity



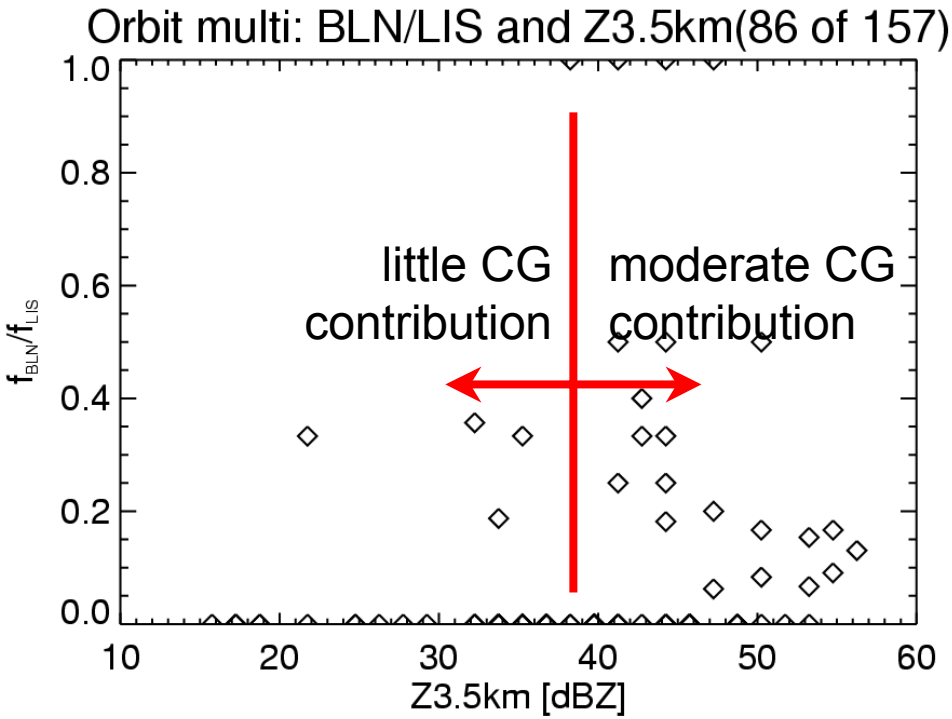
Bauru reflectivity @ 3.5km

- **Pronounced increase of total lightning activity with Z_{max} and $Z_{3.5km}$**
  - **at 45 dBZ for the TRMM PR**
  - **at 50 dBZ for the Bauru radar**

CG lightning fraction and radar reflectivity - All 10 overpasses



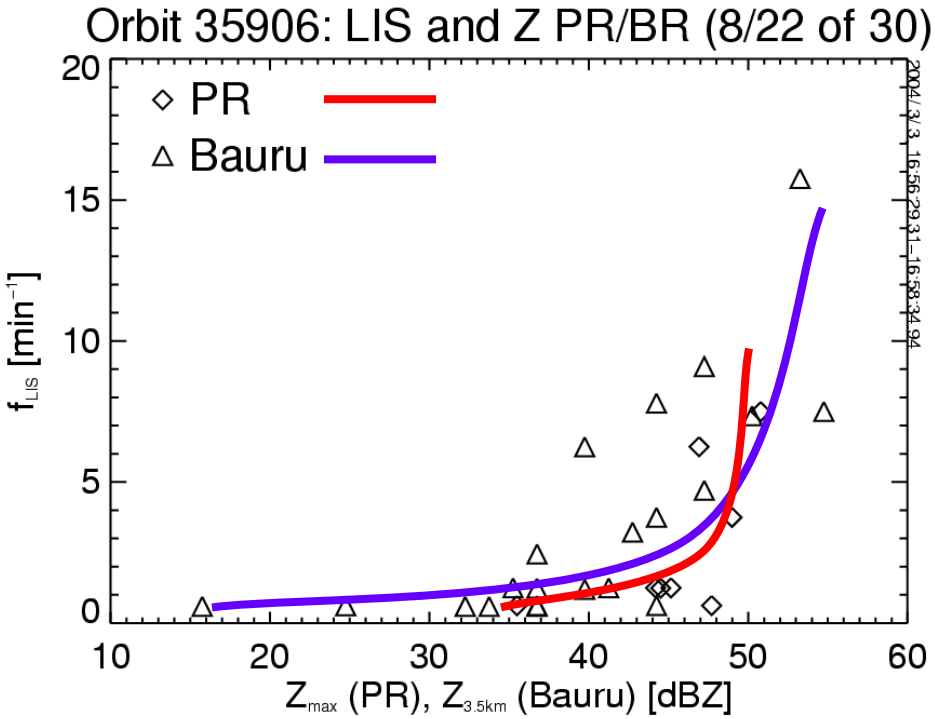
TRMM PR maximum reflectivity



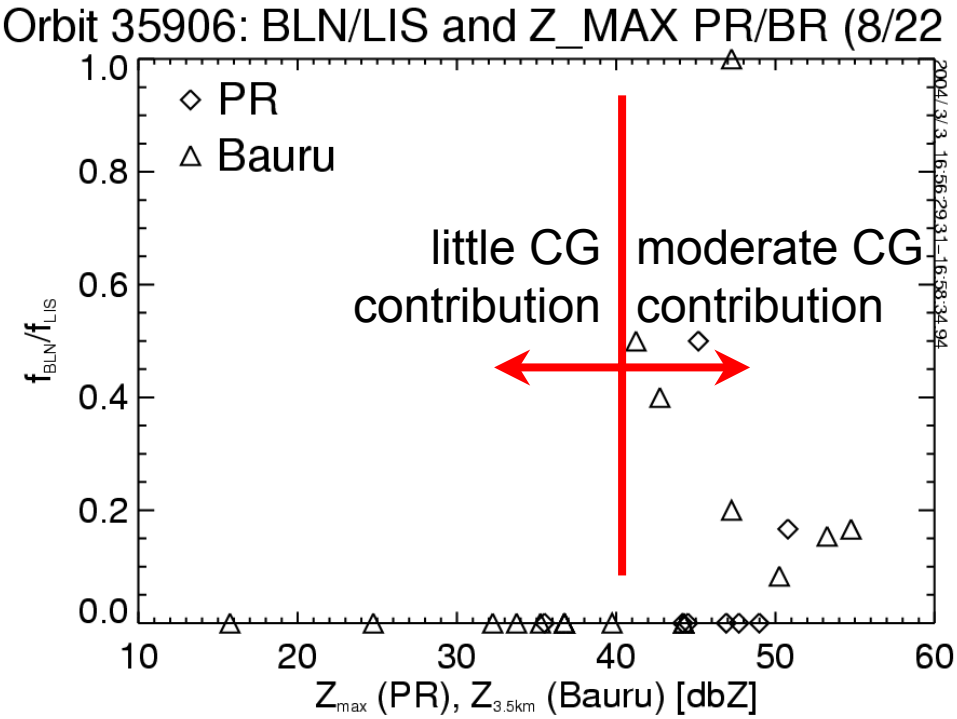
Bauru reflectivity @ 3.5km

- **Fraction of CG lightning only significant above a threshold in Z_{max} and $Z_{3.5km}$**
  - **at 45 dBZ for the TRMM PR, well pronounced**
  - **at 40 dBZ for the Bauru radar, not very well defined**

Lightning and radar reflectivity - 03 March 2004



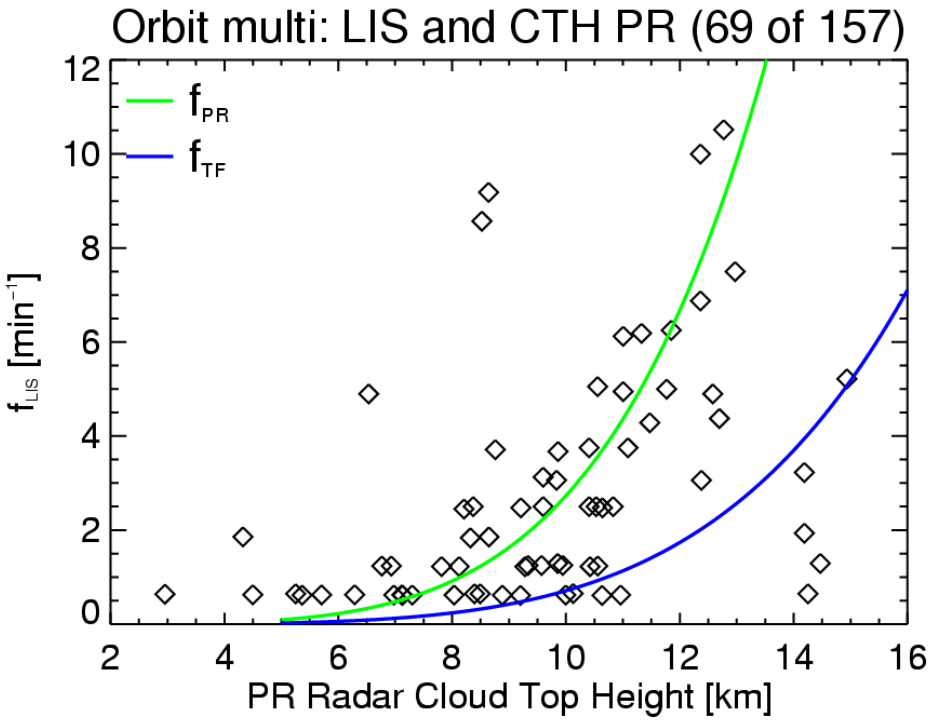
Total lightning and reflectivity

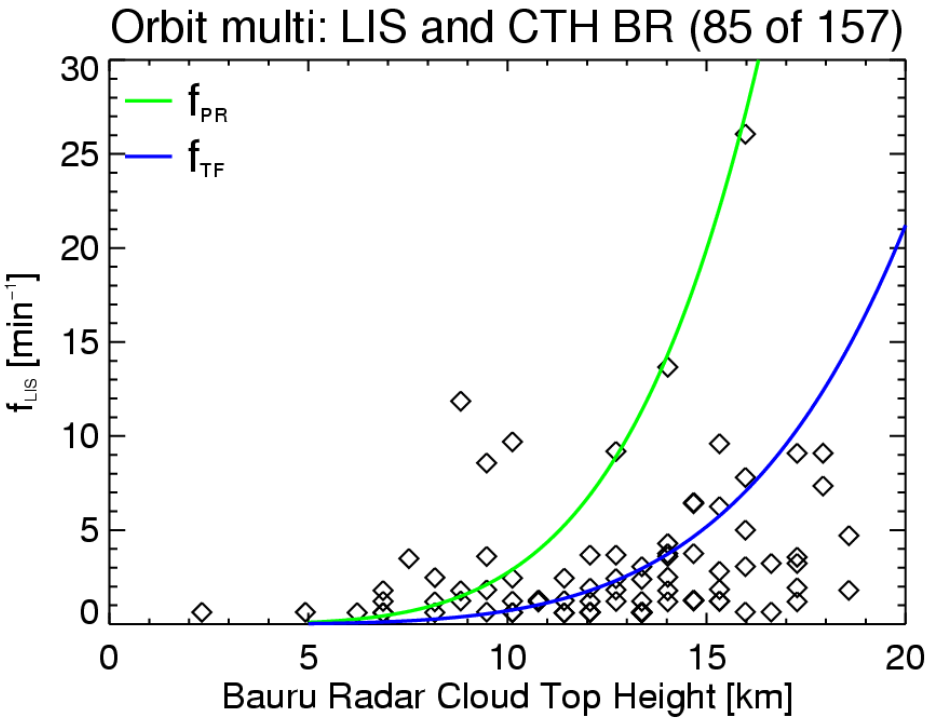


CG lightning fraction and reflectivity

- **Similar results for the 03 March 2004 overpass compared to the complete dataset**

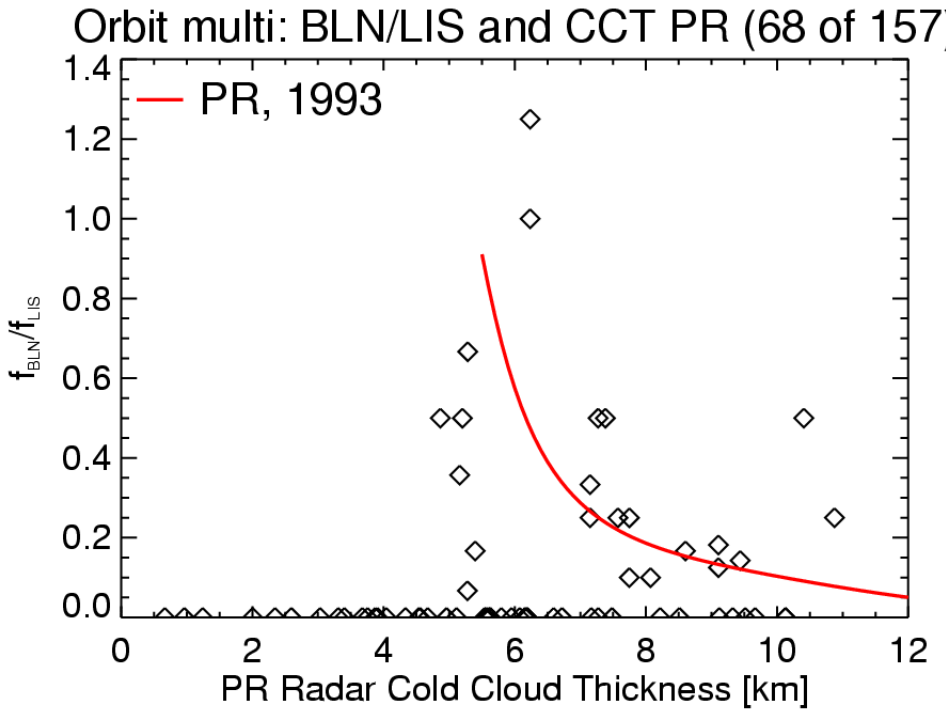
LIS lightning frequency and cloud top height - All 10 overpasses

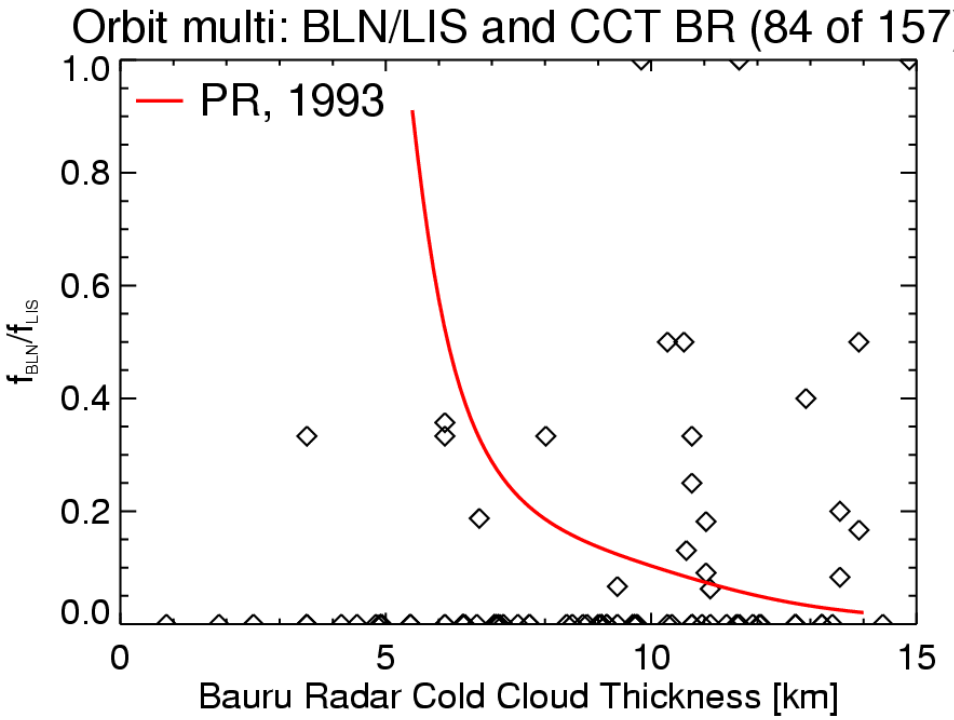




- **Large scatter of the total lightning activity for both TRMM PR and Bauru Radar CTH**
  - **TRMM PR follows the analytical expression f_{PR} from Price and Rind, 1992**
  - **Bauru Radar data not conclusive (tendency towards f_{TF} from Fehr et al, 2004)**

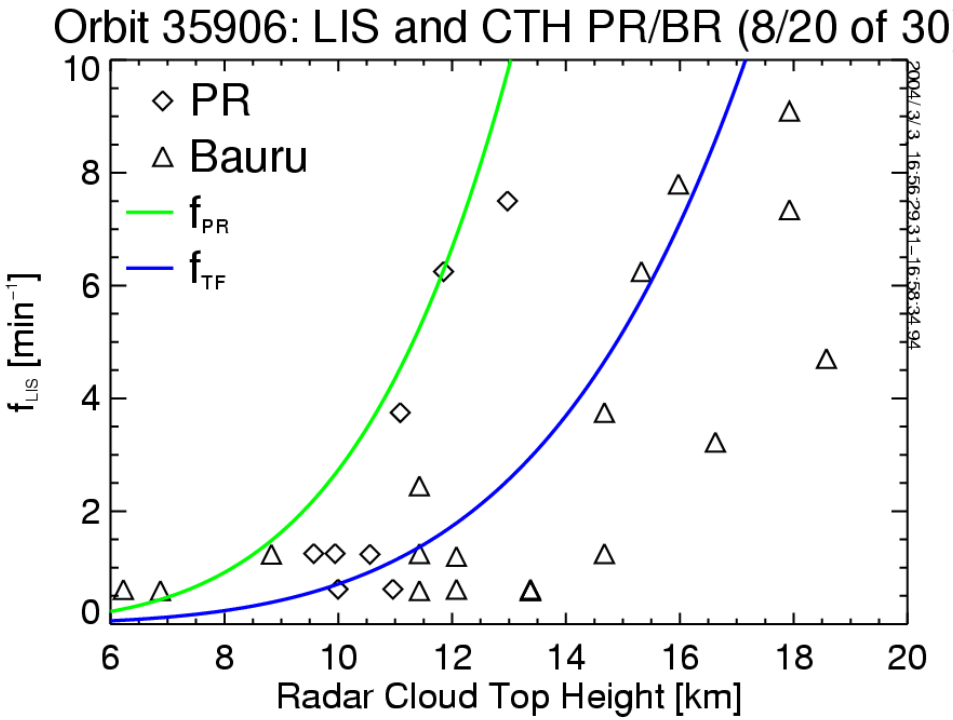
CG lightning fraction and cold cloud thickness - All 10 overpasses

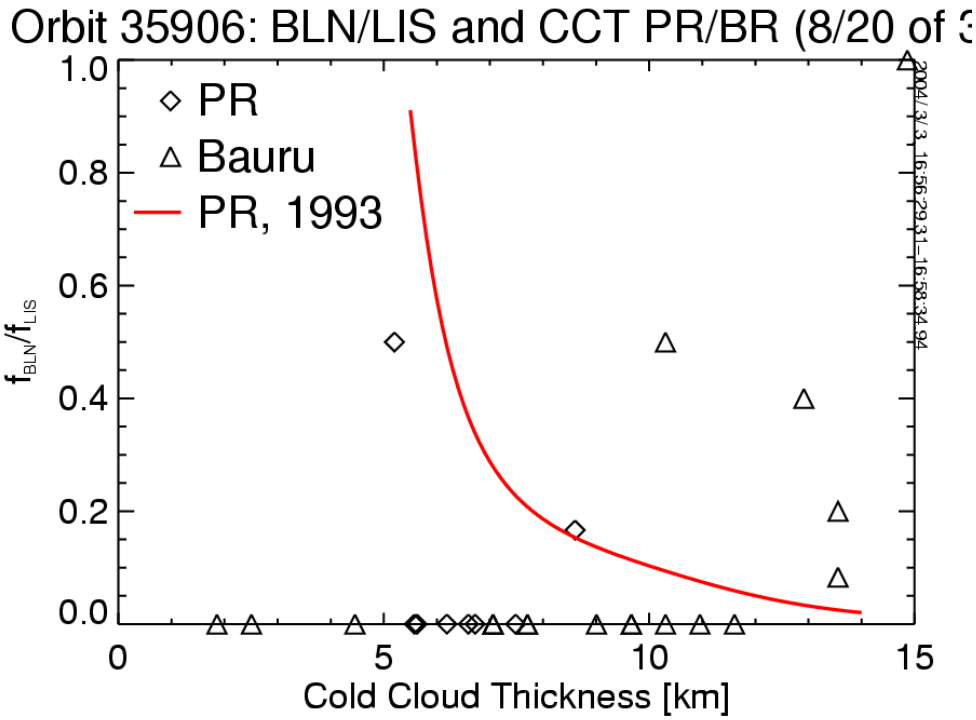




- **Cold Cloud Thickness (CCT):**
  depth of cloud above the freezing level, here above 0°C-level from radiosondes)
- **No significant correlation between the fraction of CG flashes and the CCT**
  - **TRMM PR tendency towards Price and Rind, 1993**

Lightning and cloud height - 03 March 2004





- The total lightning activity shows a tendency to follow f_{tf} for the Bauru radar CTH
- No significant correlation for the CG lightning fraction can be derived for the 03 March 2004 overpass

Results

- Ratio β between IC and CG flashes has a broad distribution depending on convective state and meteorological situation ranging from only CG to only IC flashes
- Average β for the 10 overpasses during the campaign period: 6.77
- Average β for the 03 March 2004: 5.59
- For individual overpasses β can vary significantly
- Total lightning activity and the CG lightning fraction depends strongly on the maximum reflectivity
- Indications for a maximum reflectivity threshold above which a significant CG lightning fraction develops
- Analytical equations in the form of Price and Rind (1992) seem to describe the total lightning activity also on cloud scale
- No significant correlation between the Cold Cloud Thickness and the CG lightning fraction can be established

Discussion/To Do:

- Major restriction: short observation time of LIS
  - lightning frequencies below 0.7 s^{-1} cannot be resolved
  - In particular problematic for low CG lightning activity
- Overlapping cells
- Storms that only produce CG lightning are not considered (although few)
- Time lag between TRMM and Bauru radar observations (up to 8 min)
- Only reflectivity at 3.5 km altitude considered for the Bauru radar
  - close to the anticipated maximum
  - smoothing of results
- TRMM PR and Bauru radar analyzed with different spatial resolution (5 vs. 1 km)
- Necessary to extend to years with higher lightning activity than the 2004 summer
- Classification according to the meteorological setting