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 ($\text{NO}_x$) by intra-cloud lightning
- For the extrapolation of the regional $\text{NO}_x$ 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 km² 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 \( f_{\text{LIS}} \)
- BLN lightning frequency \( f_{\text{BLN}} \)
- PR maximum reflectivity \( Z_{\text{max}} \)
- Bauru Radar reflectivity @ 3.5km altitude \( Z_{3.5\text{km}} \)
- PR/Bauru Radar cloud top height \( \text{CTH} \)
- PR/Bauru Radar cold cloud thickness (cloud depth above the freezing level) \( \text{CCT} \)

Working assumptions:
- Total lightning frequency \( f_{\text{total}} = f_{\text{LIS}} \)
- Intra-cloud (IC) lightning frequency \( f_{\text{IC}} = f_{\text{LIS}} - f_{\text{BLN}} \)
- Cloud-to-ground (CG) flash frequency \( f_{\text{CG}} = f_{\text{BLN}} \)
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

\[ f_{\text{total}} = f_{\text{total}}(f_{\text{CG}}, \text{CTH}, \text{CCT}, Z_{\text{max}}, Z_{3.5\text{km}}) \]
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

\[ f_{\text{total}} = f_{\text{total}}(f_{\text{CG}}, \text{CTH}, \text{CCT}, Z_{\text{max}}, Z_{3.5\text{km}}) \]
Summary of LIS orbits, cells, lightning and $\beta$

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

<table>
<thead>
<tr>
<th>Date</th>
<th>LIS Orbit</th>
<th>Number of LIS areas</th>
<th>Number of LIS flashes</th>
<th>Number of BLN flashes</th>
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<td><strong>855</strong></td>
<td><strong>110</strong></td>
<td><strong>6.77</strong></td>
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</table>
LIS and BLN lightning frequency for cells

- Total lightning frequencies up to 27 min\(^{-1}\), CG lightning up to 5.6 min\(^{-1}\)
- \(\beta\) can reach any value between 0 (CG only) and \(\infty\) (IC only) for the complete dataset
- \(\beta\) seems more restricted for single overpass
LIS lightning frequency and radar reflectivity - All 10 overpasses

- Pronounced increase of total lightning activity with $Z_{\text{max}}$ and $Z_{3.5\text{km}}$
  - at 45 dBZ for the TRMM PR
  - at 50 dBZ for the Bauru radar
CG lightning fraction and radar reflectivity - All 10 overpasses

- Fraction of CG lightning only significant above a threshold in $Z_{\text{max}}$ and $Z_{3.5\text{km}}$
  - 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

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
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 $\beta$ 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 $\beta$ for the 10 overpasses during the campaign period: 6.77
- Average $\beta$ for the 03 March 2004: 5.59
- For individual overpasses $\beta$ 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