Lightning Meteorology

Some examples of lightning related research in atmospheric science by the Italian community

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OUTLINE

• Instantaneous precipitation retrieval from passive sensors (SEVIRI IR, SSMIS, AMSU)
• Precipitation nowcasting (SSMIS, AMSU)
• Multisensor study of cloud electrical properties
• Cloud electrification modeling:
  – 1D Explicit Microphysics Thunderstorm Model
  – Calabria Regional Atmospheric Modeling System
• Transient Luminous Event observation and effects on NOx production
Roma, 20 October 2011
Cloud Dynamics & Radiation Database (CDRD) Algorithm

FORWARD PROBLEM

- Cloud Resolving Model
  - Simulated Cloud profiles
  - Simulated Dynamical Variables

Radiative Transfer Model
  - Simulated Brightness Temperatures

Cloud Dynamics and Radiation Database

INVERSE PROBLEM

Lightning are used as a dynamical-microphysical flag to improve the selection of “heavy rainfall profiles”

Lightning Measurements

Dynamical Variables

Multi-frequency MW Brightness Temperatures from Satellite

Bayesian Retrieval Algorithm

Retrieved Profiles
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Microwave-lightning cooperation for precipitation nowcasting

**Near real time precipitation**
Case study – Balkans, 22-06-2009
Case study – Balkans, 22-06-2009
MW-retrieved rainfall fields (left panel) and morphed rainfall fields (middle panel) at 15:55 UTC over southern Italy region on October 1, 2009. The morphed rainfall fields are computed using the MW-retrieved rainfall fields at 13:00 UTC in conjunction with lightning data from 13:00 UTC to 15:55 UTC. As a reference, simultaneous lightning occurrences at 15:55 UTC are also shown (right panel) (from Dietrich et al., 2011).
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Investigating 3D cloud structure
Padova event, 13/08/2010

M. Buiat, F. Porcù, University of Ferrara

SEVIRI, channel 9 \( \lambda = 10.8 \) \( \mu \text{m} \) (IR)
CLOUDSAT: Characteristics of CPR data (94 GHz)

Cloud profile data:
- reflectivity
- IWC
- LWC
- effective radius

Granules, Profiles and Bins: CPR footprint & granule size

1 GRANULE = 1 orbit of data (~40,786 km / ~37,088 profiles)
- Granule begins on descending node (night side)
- “Data Window” is 30-km high by 37,088 profiles wide

Granules, Profiles and Bins:

- Each “Profile” has 125 vertical “BINS” (~30 km)
- Each vertical bin is 240 m thick

1.7 km
1.3 km
1.1 km along-track

Profile Timestamp Location

START OF PROFILE
END OF PROFILE

~98.9 minutes per orbit ~14.56 orbits/day
Padova event, 13/08/2010, 01:29
coincidence with CLOUDSAT overpass

M. Buiat, F. Porcù, University of Ferrara

lightning: 10 minutes (01:25 – 01:35)
Padova event, 13/08/2010, 01:29

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IWC = \int (\rho_i/6) \pi N(D) D^3 dD

2 REGIONS:
• 10/11km: max IWC
  Ice crystals
• 7/8km: max Effective Radius
  graupel

r_e = \frac{1}{2} \frac{\int N(D) D^3 dD}{\int N(D) D^2 dD}
Profiles of IWC and Effective Radius

M. Buiat, F. Porcù, University of Ferrara

<table>
<thead>
<tr>
<th># flash</th>
<th>IWC$_{\text{max}}$ (mg/m$^3$)</th>
<th>e.r.$_{\text{max}}$ (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1270</td>
<td>120</td>
</tr>
<tr>
<td>8</td>
<td>1700</td>
<td>135</td>
</tr>
</tbody>
</table>
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Lightning modeling: Explicit Microphysics Thunderstorm Model (EMTM)

The model (Solomon and Baker, 1996, 1998, Solomon et al., 2004) consists of 2 cylindrical regions and includes dynamics, entrainment, explicit microphysics, electrification and a lightning parameterization.
Cell over Rome - 2 July 2009
model results - measurements comparison

Histogram of lightning simulated by the EMTM model. There are IC and CG first, as the cloud develops the CG lightning become predominant.

Histogram of lightning activity of the selected cell measured by LINET network. Also here is well shown the different behaviour of IC and CG as the cell develops.
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CRAMS MODEL

- The model CRAMS (Calabria Regional Atmospheric Modeling System) is a non-hydrostatic model derived from the RAMS model. It can be used both for research and operational purposes in regions with complex orography.

- CRAMS is used to make the weather forecast over Calabria at 2.5 km horizontal resolution. This weather forecast is used by the “Centro Funzionale della Regione Calabria” to issue the forecast over the Region.

- CRAMS is coupled with a general purpose data assimilation system, which can solve the analysis with different methods (2D-Var, 3D-Var, Optimal Interpolation).

- The output of CRAMS is used to initialize wave models and agro-meteorological models.

S. Federico (ISAC-Lamezia)
DEEP CONVECTION STUDIES

- CRAMS has been used to study the deep convection, mainly over Calabria.
- The Calabria region is an interesting test-site: the presence of the sea-land contrast and of elevated mountains near the coast are key ingredients for flood and flash-flood occurrence, as in the case of the Crotone flash-flood on 14 October 1996.

Precipitation (mm) simulated between 00 and 12 UTC on 14 October 1996

Comparison between the rainfall simulated by CRAMS and measured at Crotone Airport on 14 October 1996

S. Federico (ISAC-Lamezia)
The Dahl et al. (2011)* methodology has been implemented in the CRAMS

- The idea underlying the parameterizations is that the graupel region contains the negative charge and the ice region contains the positive charge. The charging rate \( j \) increases with the graupel mass, and the discharge strength \( \Delta Q \) increases as the charge volume increases.

- The “graupel region” is defined as the region above the 263 K isotherm where the mass of graupel is greater or equal to 0.1 g/m\(^3\).

- The “ice region” is defined as the region where the sum of cloud ice and snow is at least 0.1 g/m\(^3\).

- The flash rate (s\(^{-1}\)) is given by:

\[
 f = \gamma j \frac{A}{\Delta Q}
\]

where \( \gamma = 0.9 \) is the lightning efficiency, \( j \) is the charging current density (A/m\(^2\)), \( A \) (m\(^2\)) is the area of the capacitor plates, and \( \Delta Q \) (C) is the lightning charge.

The 20 October 2011 test case occurred in Rome.

Total precip (mm) between 06 and 12 UTC

Density current at 09:45 UTC

Spatial distribution of total flashes

Accumulated flashes versus time

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When thunderstorms occur in the troposphere, they change the atmospheric electric field above them. Every 1000 lightning flashes, this change is strong enough to trigger a spark at 70 km altitude. In a few milliseconds the spark grows into a sprite, a huge discharge tens of km tall and wide (see Fig. 1). Can sprites change atmospheric NOx?

MIPAS was used to look at NOx at 50 km altitude above thunderstorms (Fig. 2) and compare it to background NOx. NOx above thunderstorms was found to be higher than background NOx (Fig. 3). Did MIPAS observe the first signs of sprite-NOx? Ongoing observations will try to prove it.

**Arnone et al. 2008GRL, Arnone et al. 2009PSST**
Observations of TLEs from Italy

Spritewatch experimental system at **Mount Cimone** Italian Climate Observatory
http://www.isac.cnr.it/cimone/node/131
In collaboration with the group of P. Bonasoni.

Remotely controlled linux-based acquisition system.

**Italian Meteor and TLE Network**: (http://www.imtn.it/)
- 20 stations (over 30 cameras) based in Italy and Switzerland.
- Since January 2009 recorded over 950 TLEs: sprites, elves, a gigantic jet and various upward lightning events.
Study of TLEs observed from Italy

First European Gigantic Jet observed by the Italian IMTN amateur network on 12 Dec 2009 close to Corsica

Coordination of Eurosprite observations of TLEs

TLE observations from Eurosprite partners are coordinated and catalogued into the Eurosprite database at ISAC-CNR Bologna (ref E. Arnone, see contributions at TEA-IS workshops). Contribution to Chanrion et al. 2007, Neubert et al. 2008, Arnone et al. 2008IRF.

First distribution and seasonal cycle of TLEs over Europe (Arnone et al. ACP2012 in preparation).

Participation in ESA-ASIM scientific team and TEA-IS network.
Some Considerations

There is a growing interest in the Italian community in cloud electrification and its applications to atmospheric science.

All shown researches make use of LINET data (see Betz presentation) and will benefit from the ongoing increment of the number of LINET sensors.

Further improvements are expected in lightning monitoring from space: Geostationary Lightning Mapper on GOES-R and Lightning Imager on Meteosat Third Generation (see Biron presentation).

Apart LIS-TRMM for tropical regions, presently there is a lack of lightning observation at mid-latitude from LEO satellites, ISS and airplane.
Space missions like AETHER (see following sessions and round table) are important also in this perspective