Review on deep convection and thunderstorms over land and ocean

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Outline

1. Part I: convective activity in tropical and subtropical area

1.1. Introduction
  - Some views on ‘hot towers’
  - Differences between continental and oceanic convection

1.2. Distribution of the most intense thunderstorms in tropical and subtropical area
  - Locations of intense convective events
  - Seasonal cycle
  - Diurnal cycle
  - Extreme events observed with 85 GHz passive microwave channels

2. Part II: convective activity in middle latitudes

2.1. Characteristics of European mesoscale convective systems

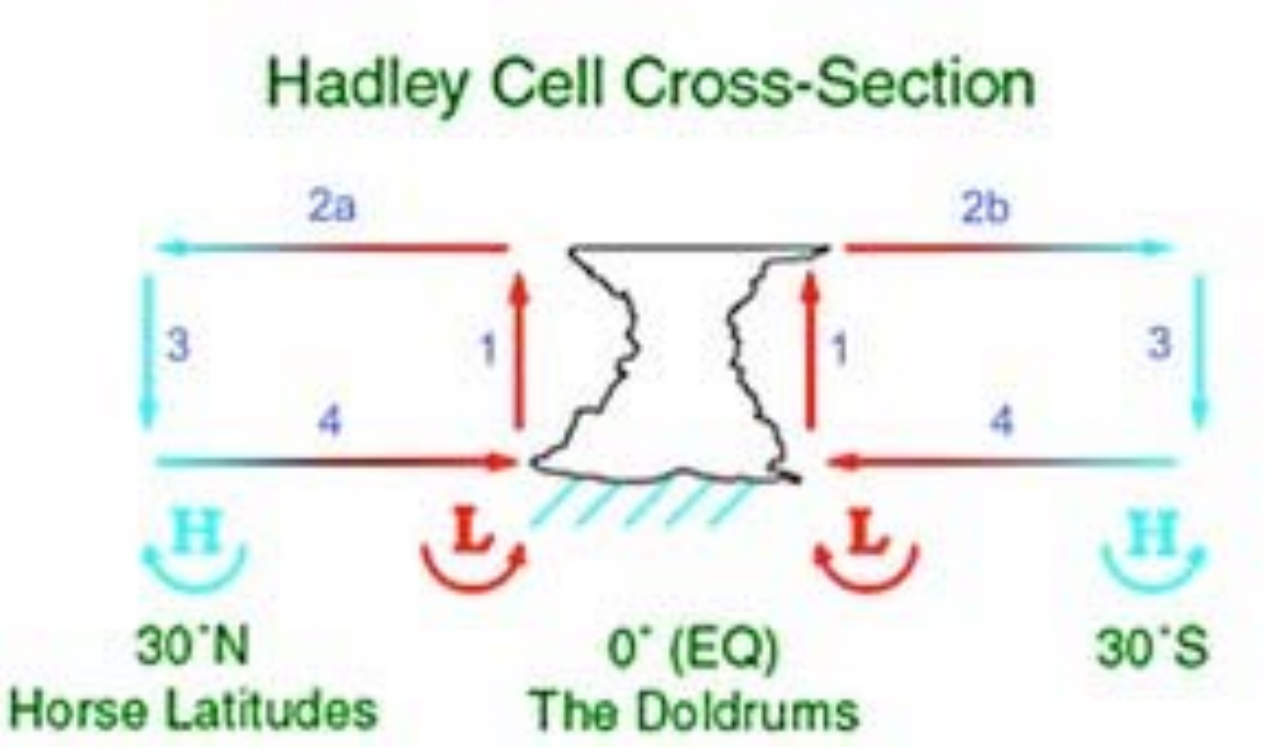
3. Conclusion

PART I

CONVECTIVE ACTIVITY IN TROPICAL AND SUBTROPICAL AREA

1.1. Introduction

- Deep cumulonimbus clouds are essential to the general circulation and to the global energy balance.



Introduction: Some views on “hot towers”

- Riehl and Malkus (1958.) – “hot tower” hypothesis:
  - Undiluted pseudoadiabatic updraft cores 2–4 km in diameter

- Observation over tropical Atlantic from 1974. till now are not recorded undiluted cores:
  - Small diameter
  - Rarely observe adiabatic liquid water content
  - Smaller vertical velocities than if undilute (GARP, GATE, EMEX)

Tropical Ocean Global Atmosphere, the Coupled Ocean Atmosphere Research Experiment (TOGA COARE): 09.02.1993.

- Employed a ship array and intensive airborne quad-Doppler radar observations
- Bimodal convective updraft profiles: minimum vertical velocity around 3-5 km, two maxima above and below
- Cloud top heights often of about 15 km
- MCSs typically organized into convective bands aligned parallel (moving more slowly) or normal (moving more rapidly) to the environmental shear (like squall lines)
- The best-documented system during all of TOGA COARE – used for model simulations and comparation with model results

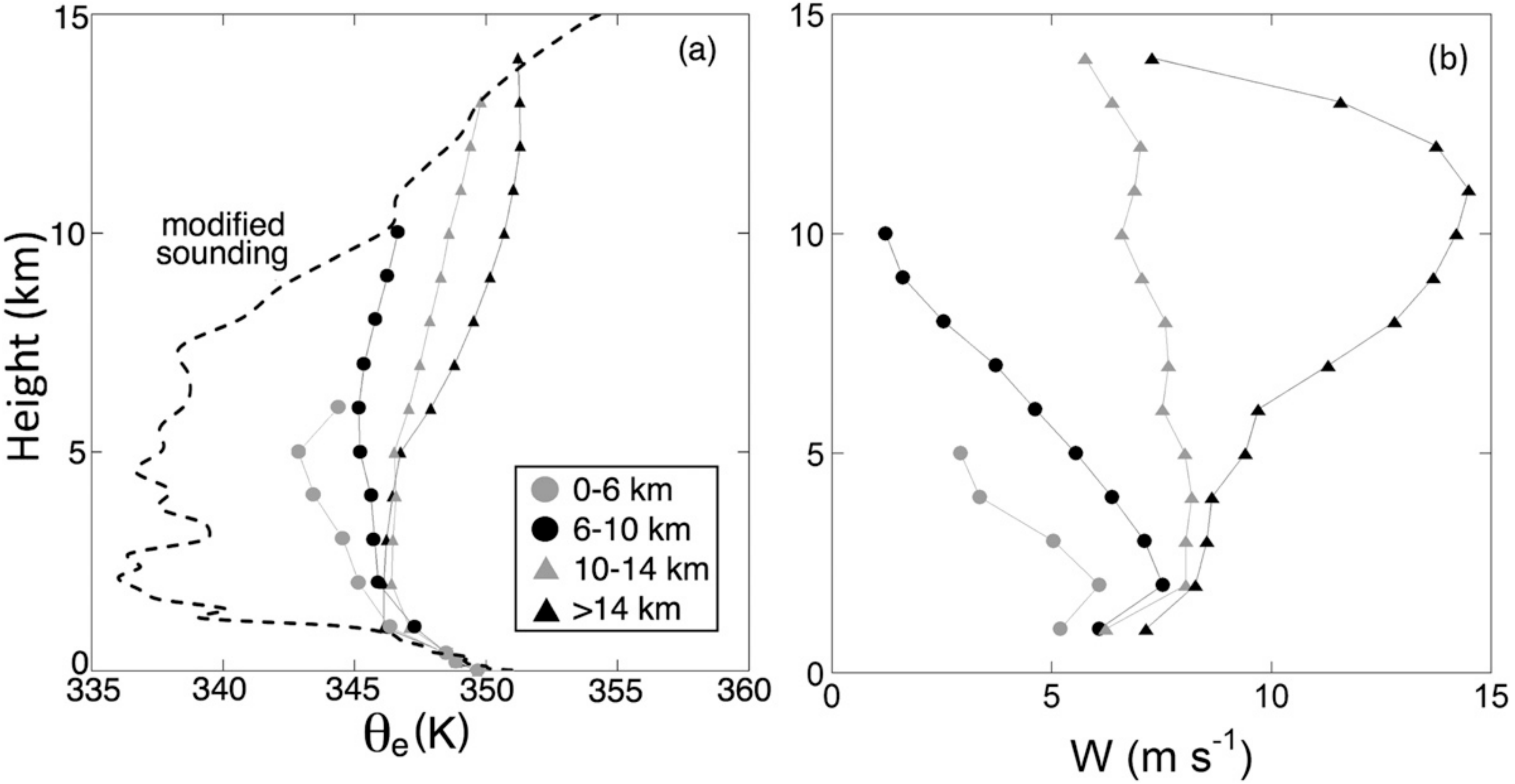
- Model simulations:
  - Straka Atmospheric Model (SAM)
  - Modeling studies from Fierro et al. (2008 (F08), 2009 (F09), 2011 (F11)) show a bimodal convective updraft profiles
  - F08 and F09 model:

    single moment 10-ICE microphysics sheme with 12 discrete bulk hydrometeor categories

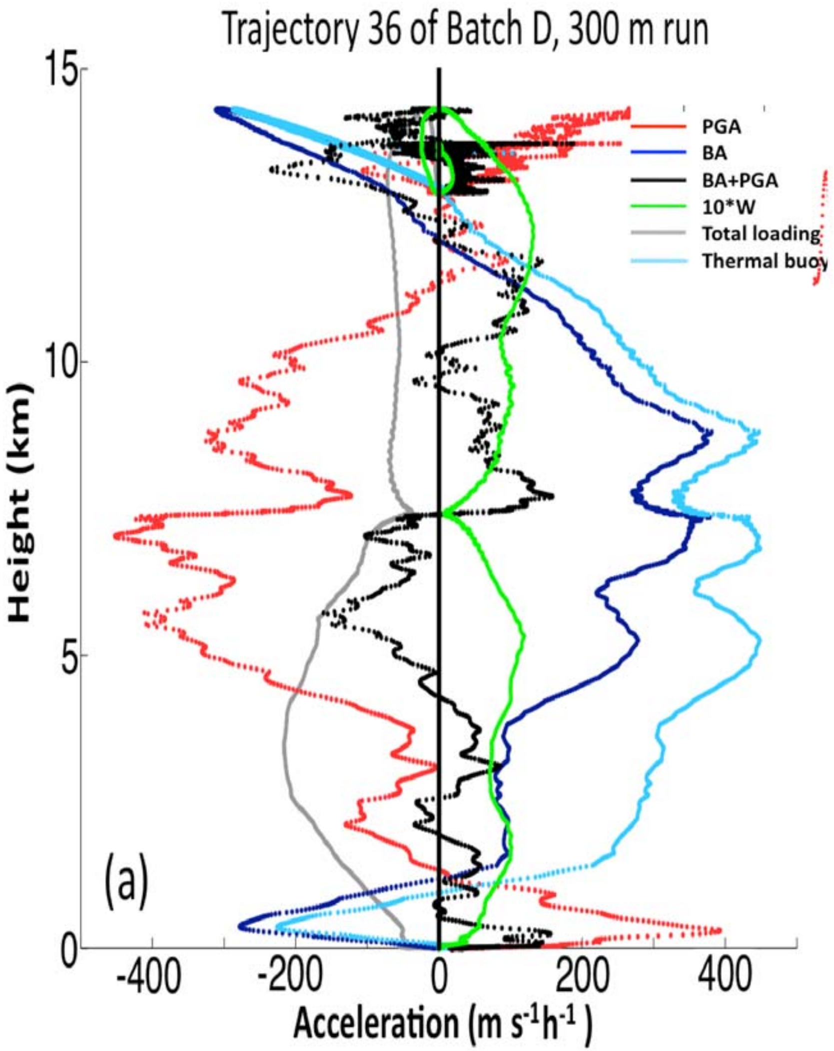
    750 m horizontal resolution
  - F11 model:

    single moment 3-ICE microphysics sheme with 5 discrete bulk hydrometeor categories

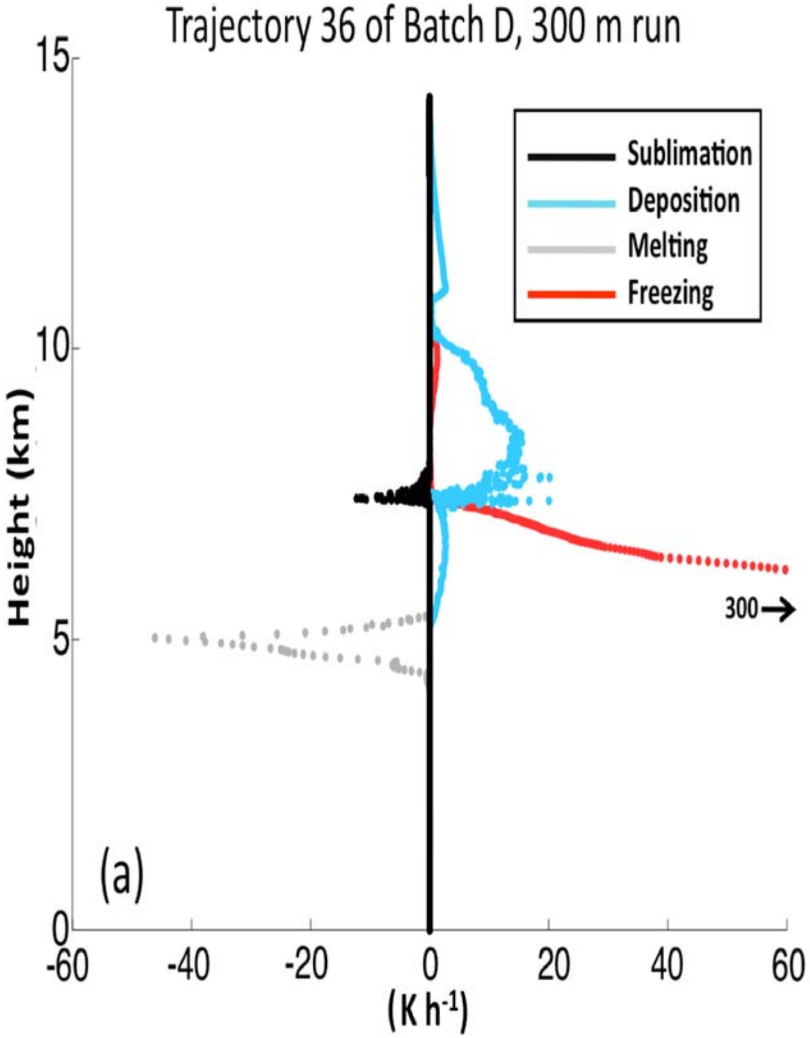
    300 m horizontal resolution



- A parcel’s inital height influences its maximum altitude
- Lowest-origin trajectories reaching the highest peak altidudes



- dw/dt= BA+PGA+RES
- Below 1 km the only positive acceleration term is PGA (pressure gradient acceleration) – larger that negative BA(buoyancy acceleration)- lower W maximum
- The dominant positive acceleration from about 1 km is BA
- Between 1-7 km PGA is negative, even larger magnitude than BA (5.5-7 km)- W minimum
- Net negative acceleration in the layer between 1.5-3.5kmis mainly duetorain loading
- Above 5-7km BA is larger than PGA-resulting in secondary updraft maximum



- Θe increase is associated with heating from enthalpy of freezing (between 5.5-6 km with heating rates near 300K/h) and deposition (between 7.5-10 km with heating rates near 20 K/h)

- W maximum above 8 km is due to release of latent heat due to enthalpy of freezing and deposition

- Near 7.5 km – noticeable cooling from sublimation (-15K/h; slightly negative W)

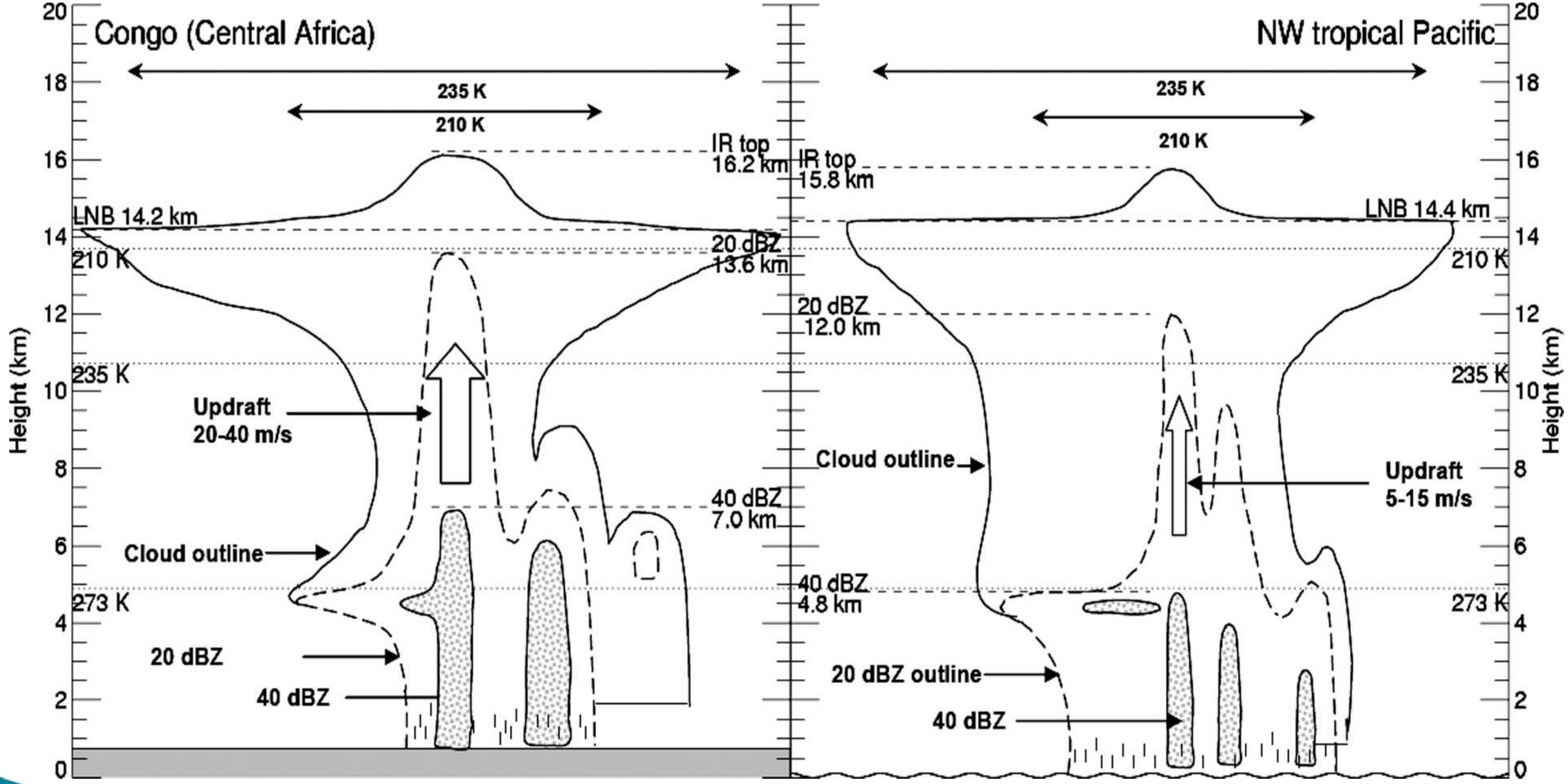
- The parcel resumes rising above that level- the heating rate of deposition is able to exceed that of the cooling of sublimation

Introduction: differences between continental and oceanic convection

- Slightly smaller entrainment rates for clouds over land:
  - Increase updraft strength
  - The time for the updraft to reach 500 hPa decreases
  - The fraction falling out decreases

- Cloud condensation nuclei concentration is larger over land:
  - Supercooled water content increase resulting in more enthalpy of freezing

Differences between continental and oceanic covection



1.2. Distribution of the most intense thunderstorms in tropical and subtropical area

- Focus is on the most extreme events using several proxies for convective intensity

- Purpose: determine quantitative frequency and intensity of storms

- Seasonal and diurnal cycle of the most extreme categories

Data and methods

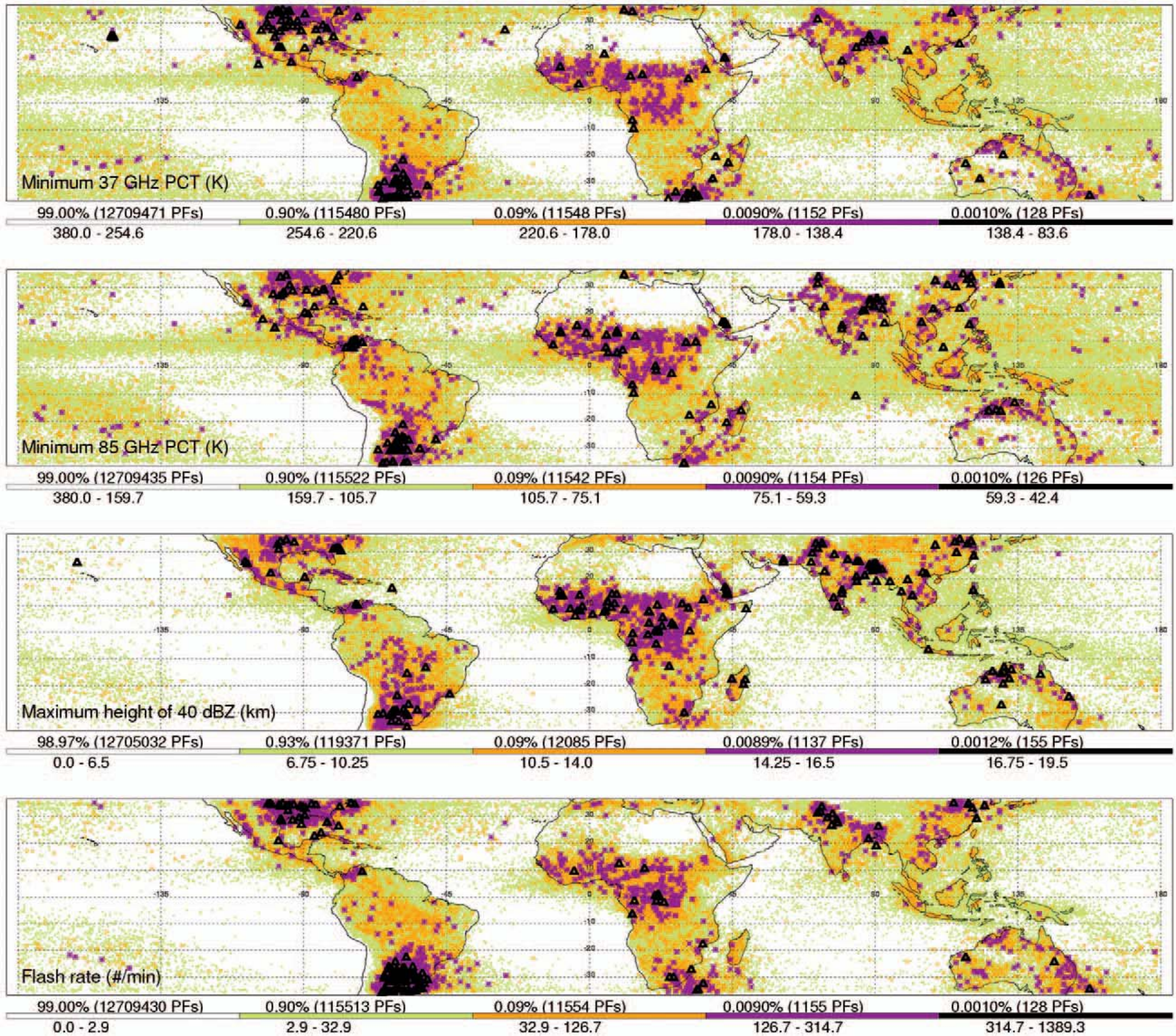
- The Tropical Rainfall Measuring Mission (TRMM) satellite – launched in late 1997.
  - Domain: 36°N – 36°S

- Instruments:
  - Precipitation radar (PR)
  - Passive microwave imager (TMI)
  - Visible and infra red scanner (VIRS)
  - Lightning imaging sensor (LIS)

- Proxies for intensity:
  - The higher the height attained by the 40-dBZ level in a PF (precipitation feature), the more intense the storm
  - The lower the minimum brightness temperature atained in a PF at 37 and 85 GHz, the more intense the storm
  - The greater the lightning flash rate attained in PF, the more intense the storm

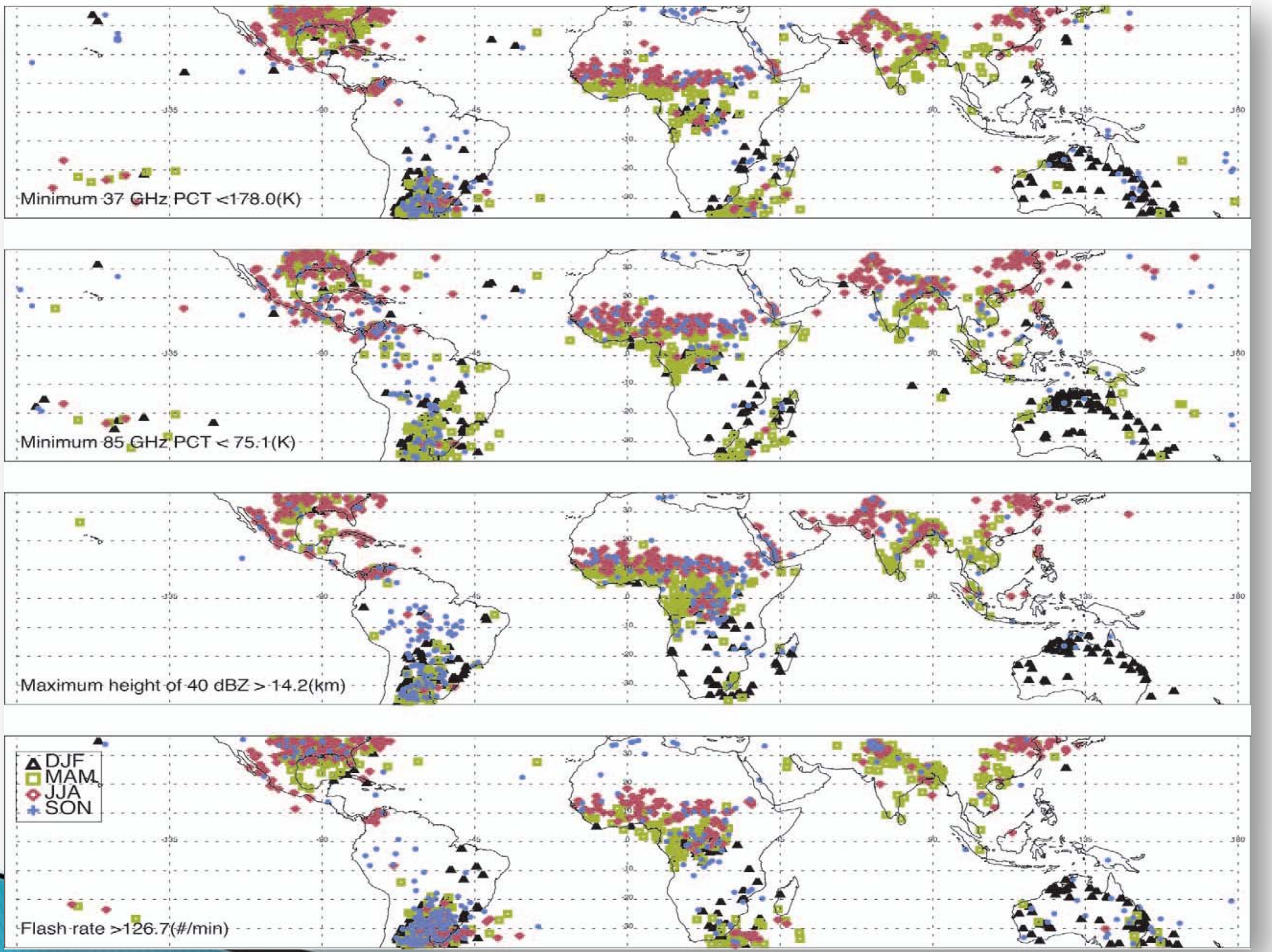
- Database: all TRMM PFs greater then four pixels in size (>75 km^2) from 01.01.1998. to 31.12.2004.

Locations of intense convective events



SWAP 2011.

Seasonal cycle of the two most extreme categories

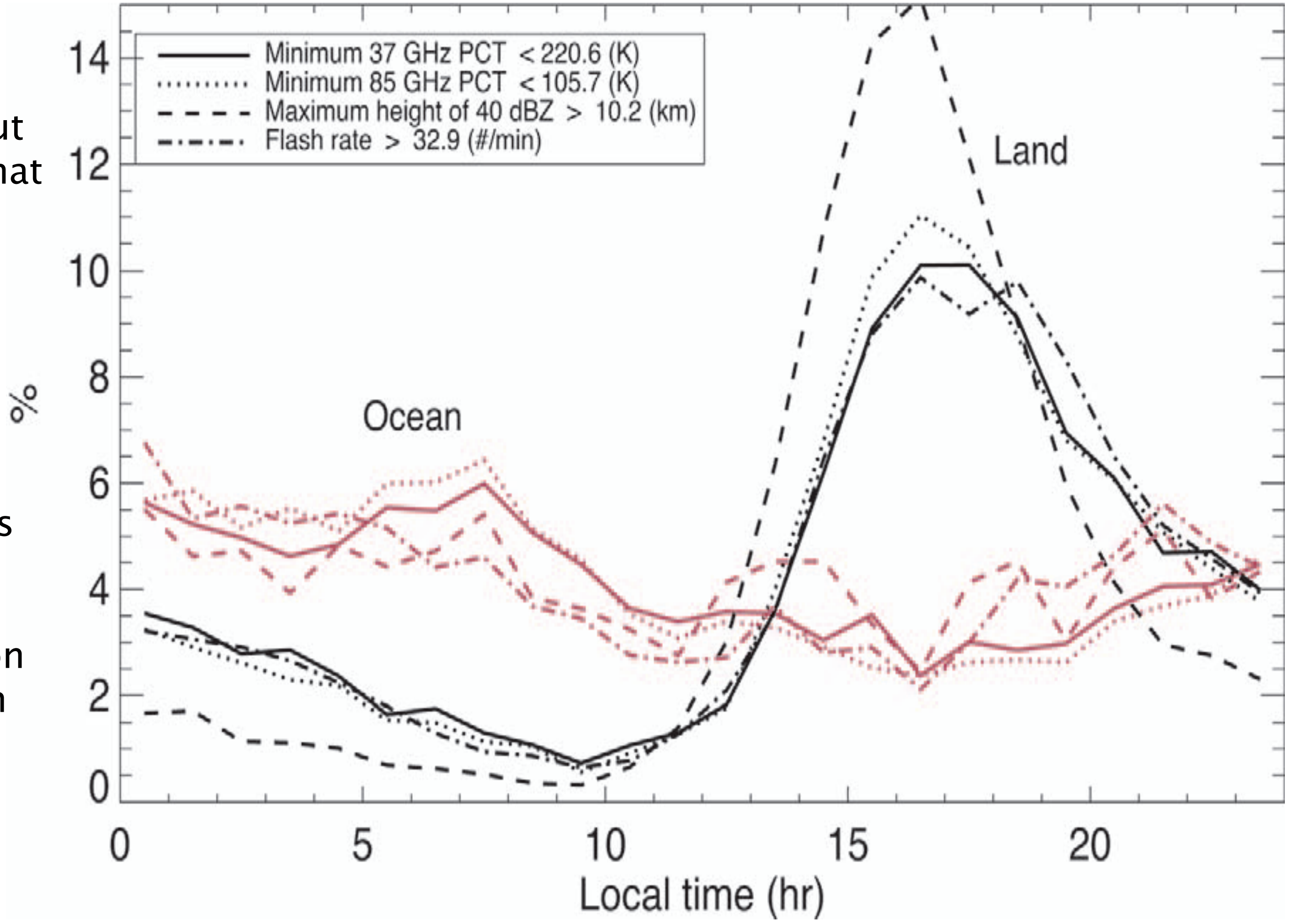


Diurnal cycle of the three most extreme categories

- strong afternoon maximum over land
- peaks at same time but is much sharper than that of rainfall over land

- broad nocturnal maximum over oceans
- amplitude tends to be more of a broad peak throughout the night, while that of rainfall has its peak near sunrise

- no obvious explanation for the stronger peak in the radar proxy



Extreme events observed with 85 GHz passive microwave channels

- On the Special Sensor Microwave Imager (SSM/I on the F-14 satellite)
  - Sun-synchronous polar orbit
  - Ascending nodes near 1900 local time (LC)
  - Descending nodes near 0700 LC
  - Polarization-corrected temperature (PCT):

$$PCT = 1.818T_{Bv} - 0.818\ T_{Bh}$$

T_{Bh}-horizontally polarized brightness temperature T_{Bv}-vertically polarized brightness temperature

  - thresholds are different than that of TRMM database because the SSM/I's reduced spatial resolution

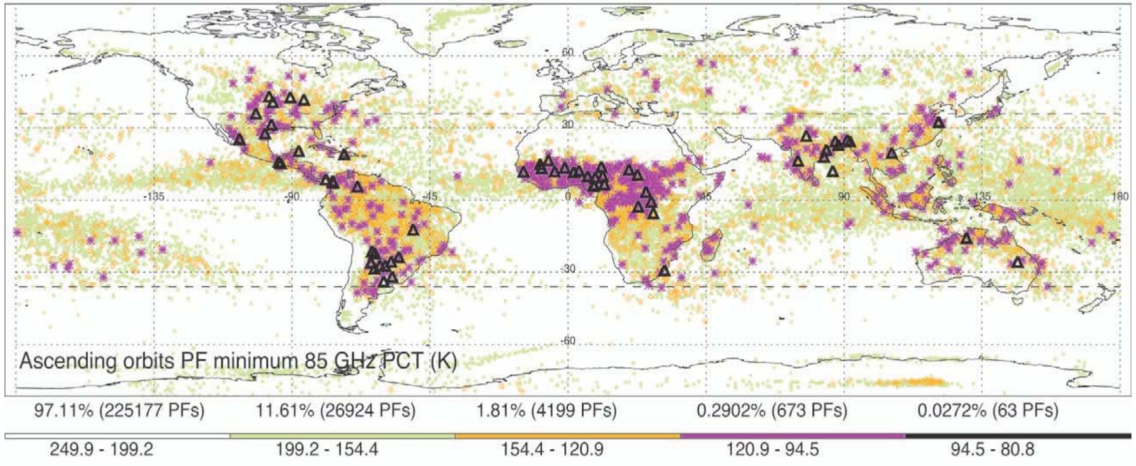
Extreme events at 85 GHz observed globally from 2004

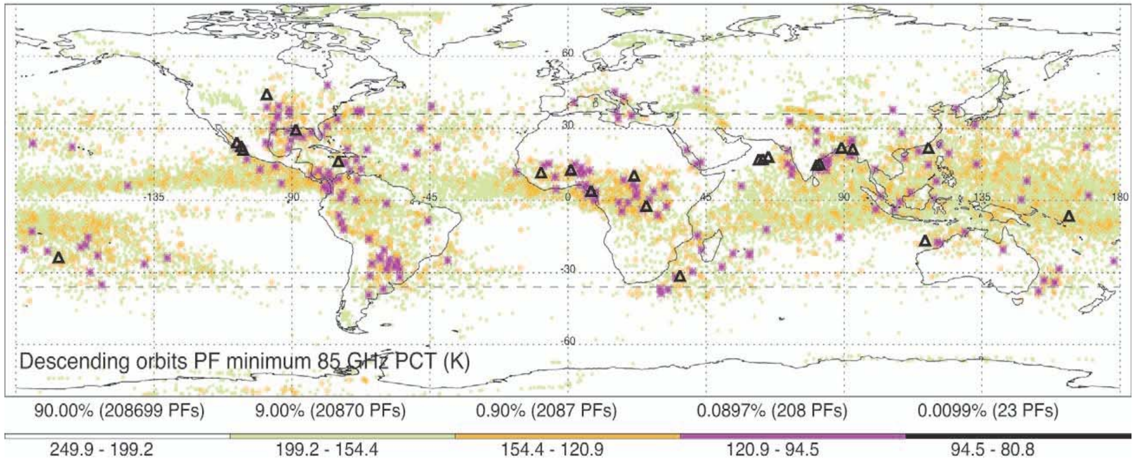
- North American maximum extends into Canada

- some intense storms observed across Eurasia

- similarity of the distributions – TRMM PR domain does capture the global distribution of extreme convective storms

- at sunset, 60% more MCSs occured over land, both tropical and subtropical
- at sunrise, 25% more MCSs occurred over the subtropical oceans, and 40% more MCSs occurred over the tropical oceans





Part II

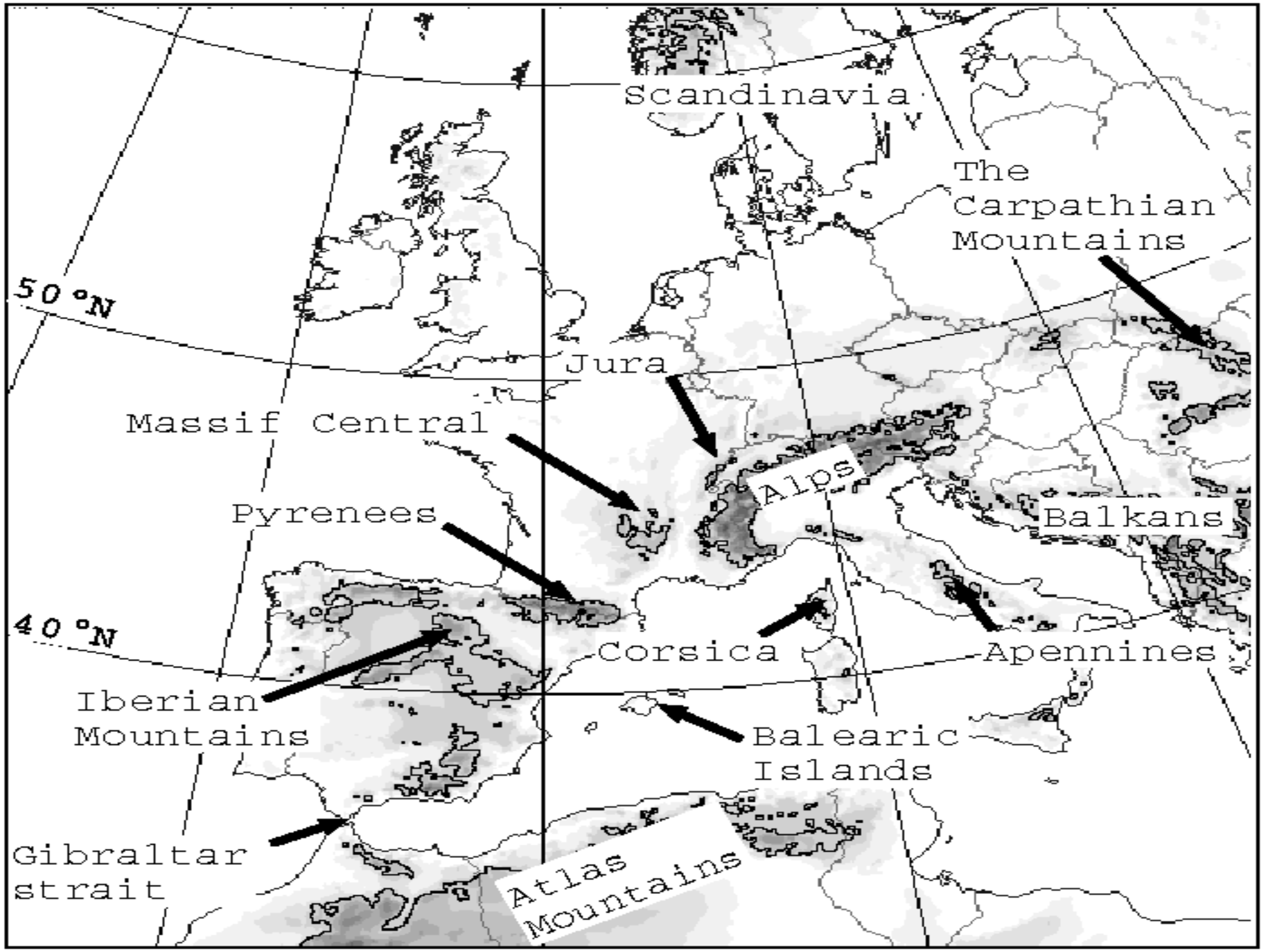
CONVECTIVE ACTIVITY IN MIDDLE LATIDUDES

2.1. Characteristics of European mesoscale convective systems

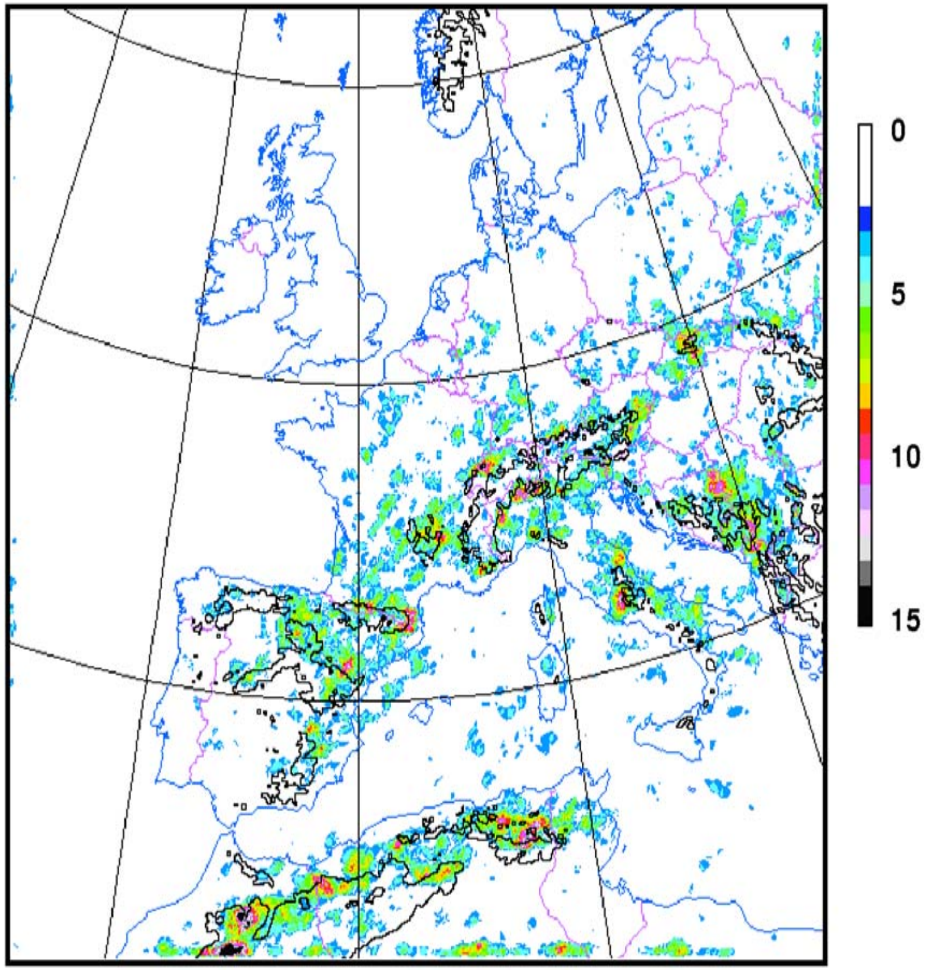
- Database:
  - Meteosat infrared images with a 30-min time resolution and a 6 km x 6 km spatial resolution
  - Five warm seasons (from April to September, 1993-1997)

- MCS:
  - Temperature treshold=-45°C
  - Area threshold=1000 km^2
  - At some stage area threshold= 10 000 km^2

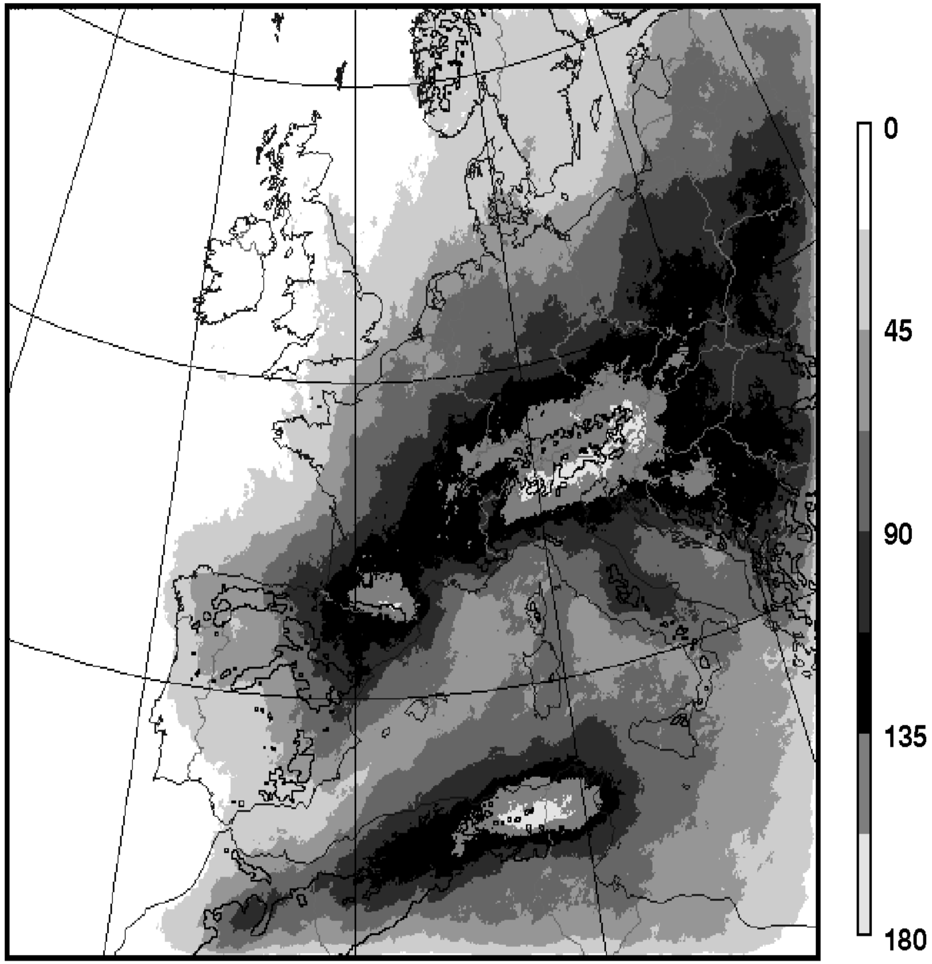
Geographical domain



Density map of MCSs triggering

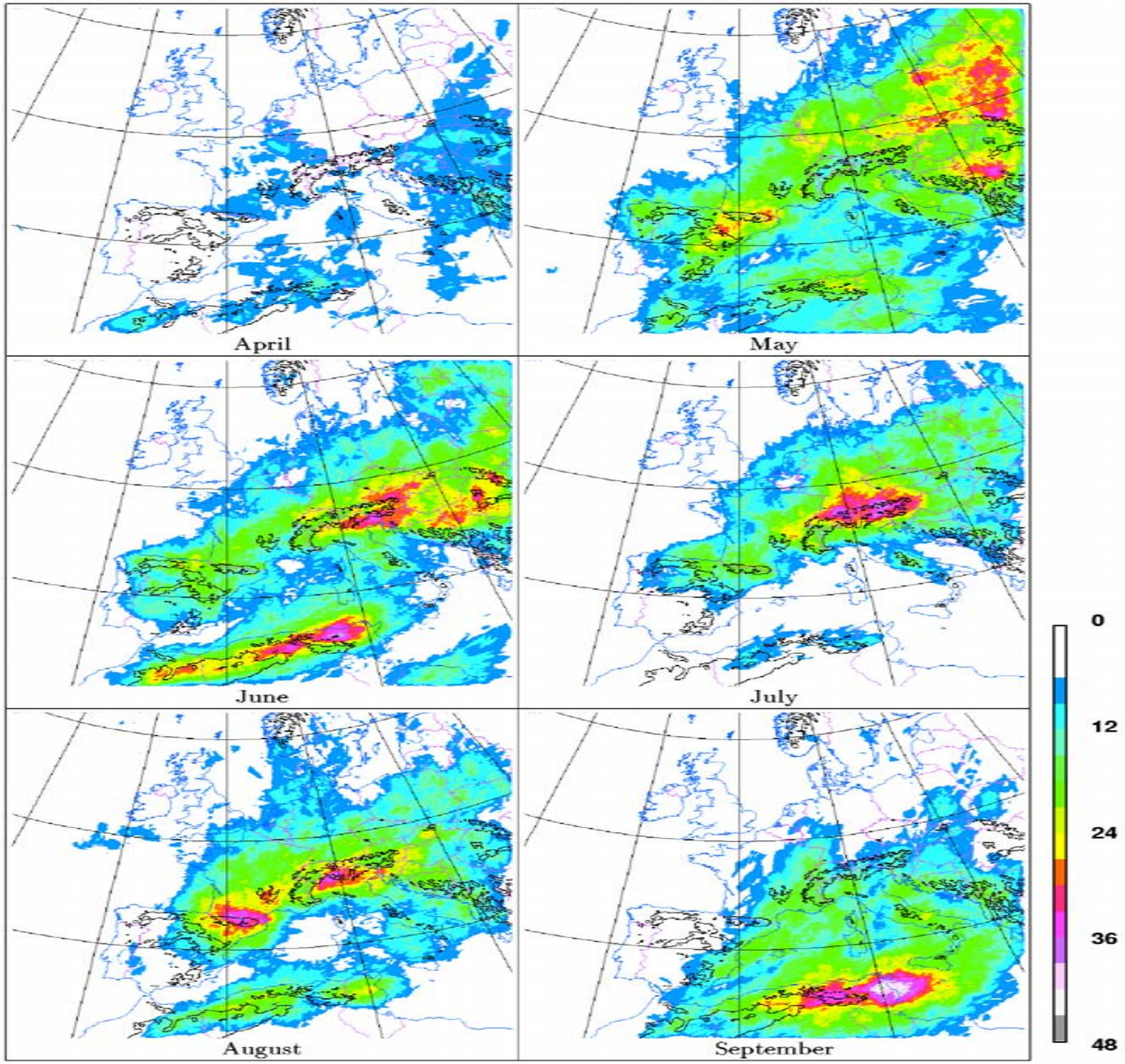


Density map of MCS occurrences

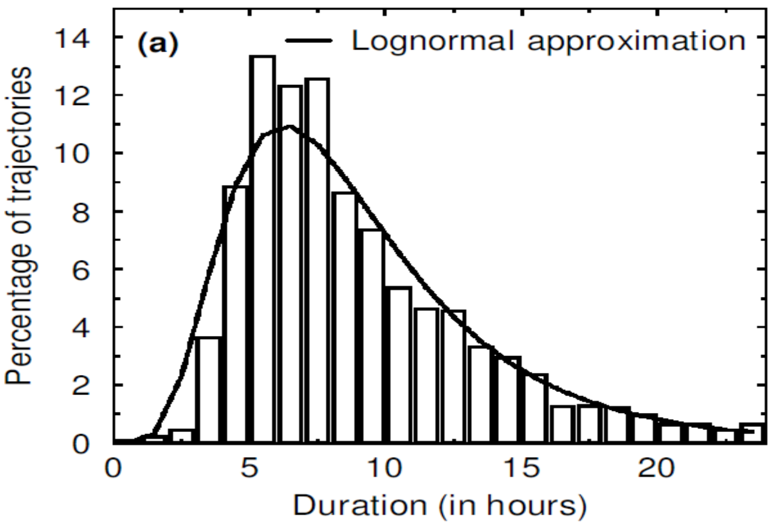


Monthly density maps of MCS occurrence

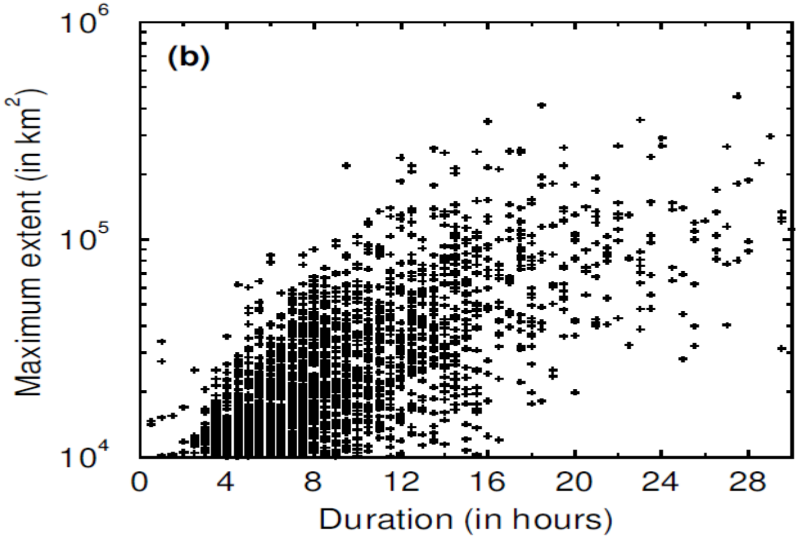
- April – only few MCSs over Europe
- From May to August – number of MCSs is remarkably constant
- Global south-westward shifting of MCS activity
- In August, many MCSs trigger over the Pyrenees and Spain
- In September, MCS occurrences are mainly located over the Mediterranean Sea and north Africa



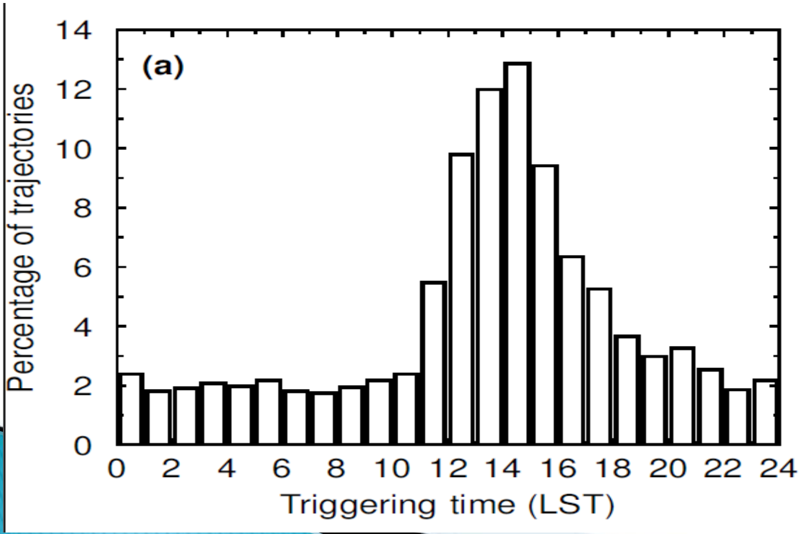
Histogram of MCS duration



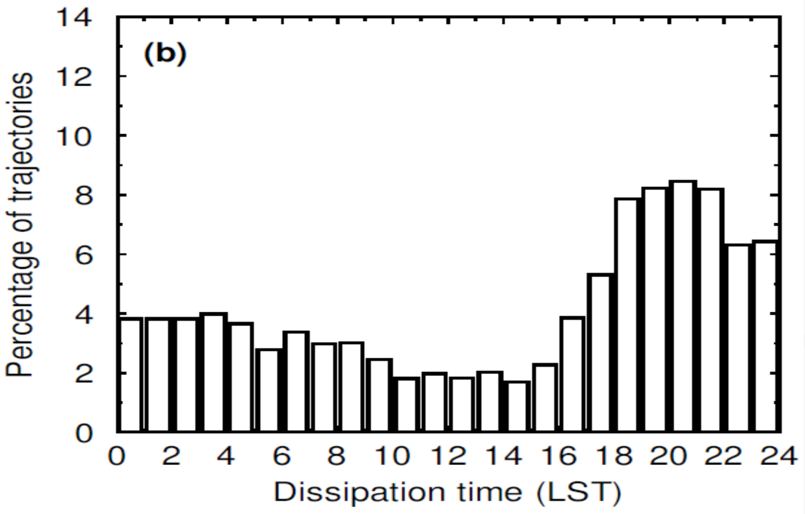
Area at time of maximum extent vs. duration of MCSs



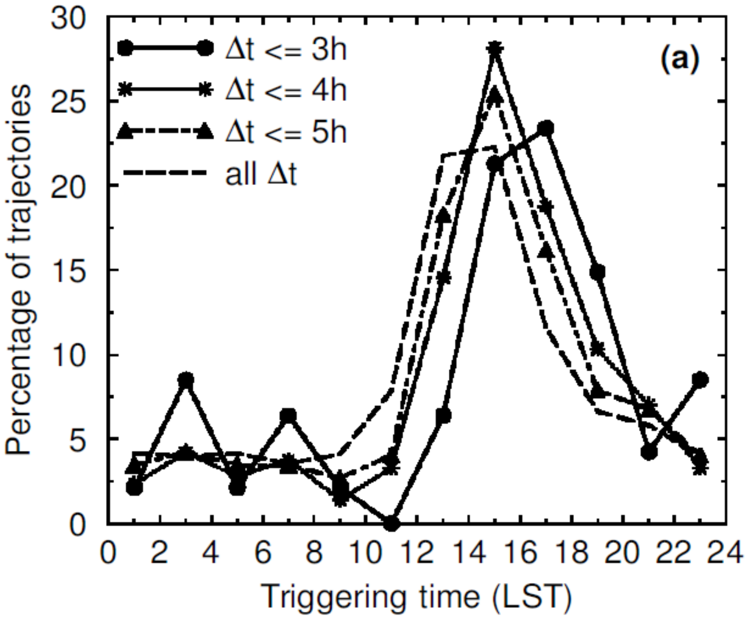
Distribution of MCS triggering time



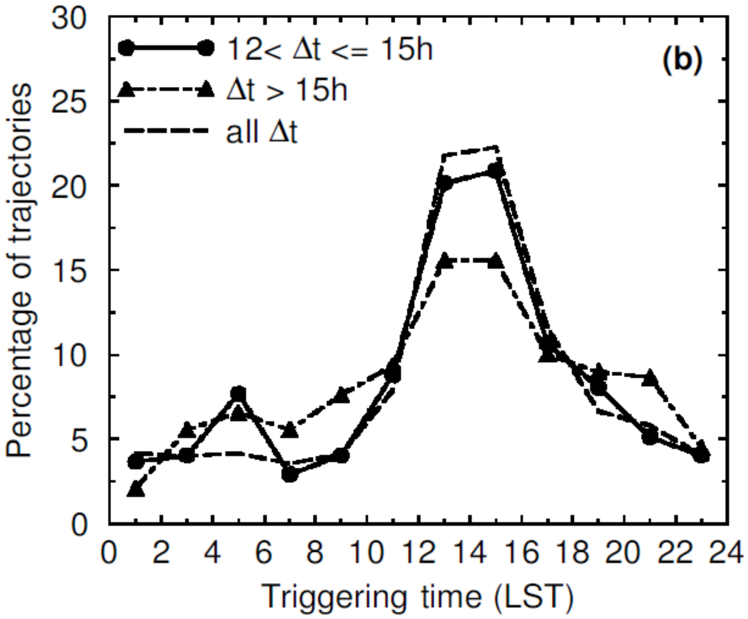
Distribution of MCS dissipation time



Distribution of short- living MCS triggering time



Distribution of long – living MCS triggering time



- MCS with short durations tend to trigger later in the afternoon then MCS with long durations

- Afternoon peak is less pronounced for long-living MCSs

- Triggering time of MCSs with very long durations is less sensitive to the diurnal heating

3. Conclusion

PART I:

- A tropical Hot Towers should be redefined as **any** (not undilute) deep convective cloud with a base in the boundary layer and reaching near the upper-tropospheric outflow layer

- Bimodal convective updraft profiles:
  - two W maximum (below 3 km and above 5-7 km), W minimum (above 3 km)
  - Decrease in ϴe above cloud base results from entrainment of lower ambient ϴe air
  - Increase in ϴe above 6-8 km was a consequence of freezing and deposition

- Slightly smaller entrainment rates for clouds over land than those over the ocean have a very large effect on updrafts (large differences in convective intensity, ice scattering and flash rates)

- Continental thunderstorms tended to be more intense than oceanic
- The strongest convective storms are often found in semiarid regions
- Heavy rains of the oceanic ITCZ, western Amazonia, southeast Asia and Indonesia have relatively few severe storms
- Storms are more frequent over the oceans at sunrise and over the continents at sunset

PART II:

- MCSs are mainly continental (some MCS triggering is observed during second half of August and September over the western Mediterranean Sea)

- Local maxima of MCS triggering are observed near all mountain ranges – strongly correlated with orography

- On average, a theoretical ‘typical European MCS’ moves to east-north-east, triggers near 3 p.m. LST, lasts around 5.5 hours and dissipates near 9 p.m. LST

- The diurnal cycle is in phase with the diurnal radiative heating (except for around 20% MCSs)

Thank you for your attention!

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