Towards a NextGen seasonal prediction system for lightning characteristics in the Inter-Americas

Ángel G. Muñoz (IRI)
agmunoz@iri.columbia.edu

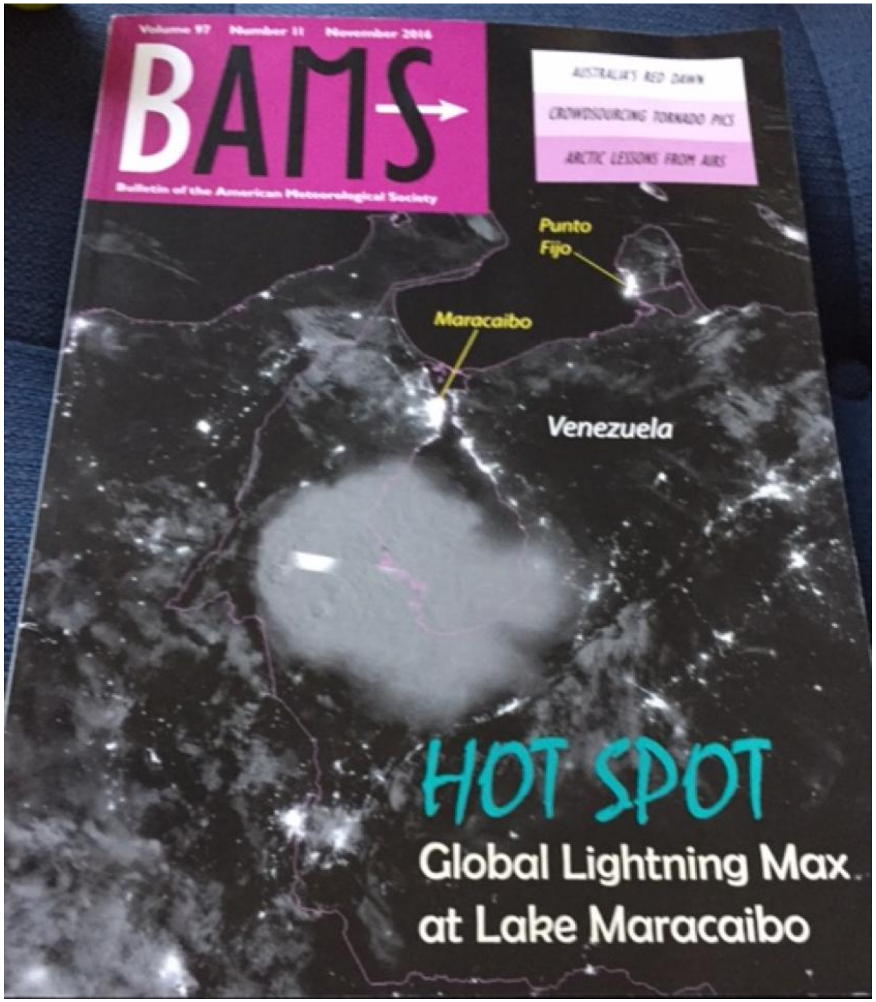
International Research Institute
for Climate and Society
Earth Institute | Columbia University

Summary

- Combined set of field campaigns and numerical experiments to improve lightning predictive skill at multiple timescales.
- First predictability study of lightning density rate at *seasonal* scale reported by Muñoz *et al* (2016).
- In NW Venezuela, most of the seasonal lightning activity is related to a highly-predictable regional mode of variability.
- Lightning predictive skill is higher than typical values for rainfall amounts in the region, and it is similar for JF and SO.
- Work is being extended to Panama, Colombia, the US and Africa.
- Potentially useful for decision-makers.

Photos: H. Parra-Centro de Modelado Científico

Introduction



The Maracaibo beacon

"The winds are key. It has to do with how the winds are dancing."

Ángel Muñoz
Princeton University

by Agnieszka Gautier

A lightning bolt fractures the night sky. Wings of phosphorescent pink unfold to illuminate Lake Maracaibo, a brackish bay that opens north to the Caribbean Sea. A quarter of Venezuela's population lives in the highest concentration of lightning on Earth, 250 flashes per square kilometer (0.4 square miles) per year. "A lot of people die each year," said Ángel G. Muñoz, a physicist and researcher at the National Oceanic and Atmospheric Administration. The lightning is so consistent—occurring 300 days a year at the same time and in the same area, where the Catatumbo River meets Lake Maracaibo—it has earned its own proper name, Catatumbo Lightning.

Around the world, lightning is forecast only a few hours, and at best, days in advance. Muñoz and his team wanted to do better. He said, "We're talking about three months in advance. That is huge." Catatumbo Lightning is consistent on a daily scale, but its behavior shifts along the year and between years. If the team could capture

NATURE | NEWS

Scientists probe lightning hotspot to predict future strikes

Forecasters hope to predict strikes months or even years in advance.

Rachel Berkowitz

15 August 2016

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Alamy

Northern Venezuela is home to a lightning hotspot.

Most people avoid spending time in lightning-prone locales. But this month, scientists are heading to an area of Venezuela that sees more lightning strikes than anywhere else in the world, to test a system designed to forecast strike frequency up to three months in advance.

They are going to the right place: the region around Lake Maracaibo in northern Venezuela, which normally surpasses 200 strikes per square kilometre each year[1]. The researchers — led by Ángel Muñoz, a climate scientist at Princeton University in New Jersey — will monitor atmospheric conditions and lightning strikes there for the next 3 years, collecting data for 72-hour periods every 3 months.

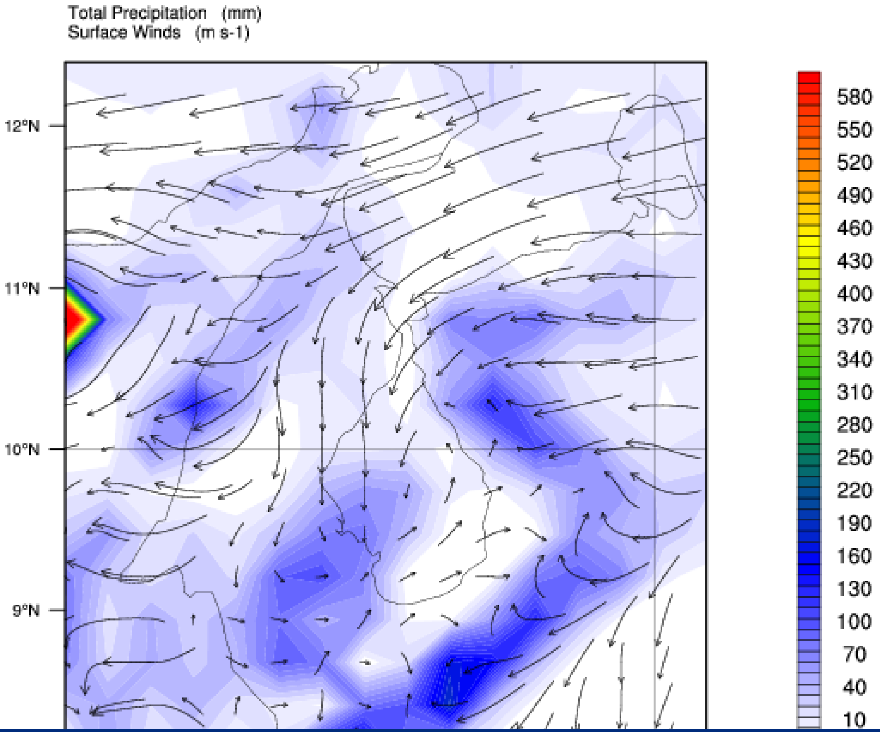
Motivation

- What is the predictability of lightning at seasonal scale?
- Learn at the region with the highest density rate of lightning for the entire planet. Apply new knowledge to other places.

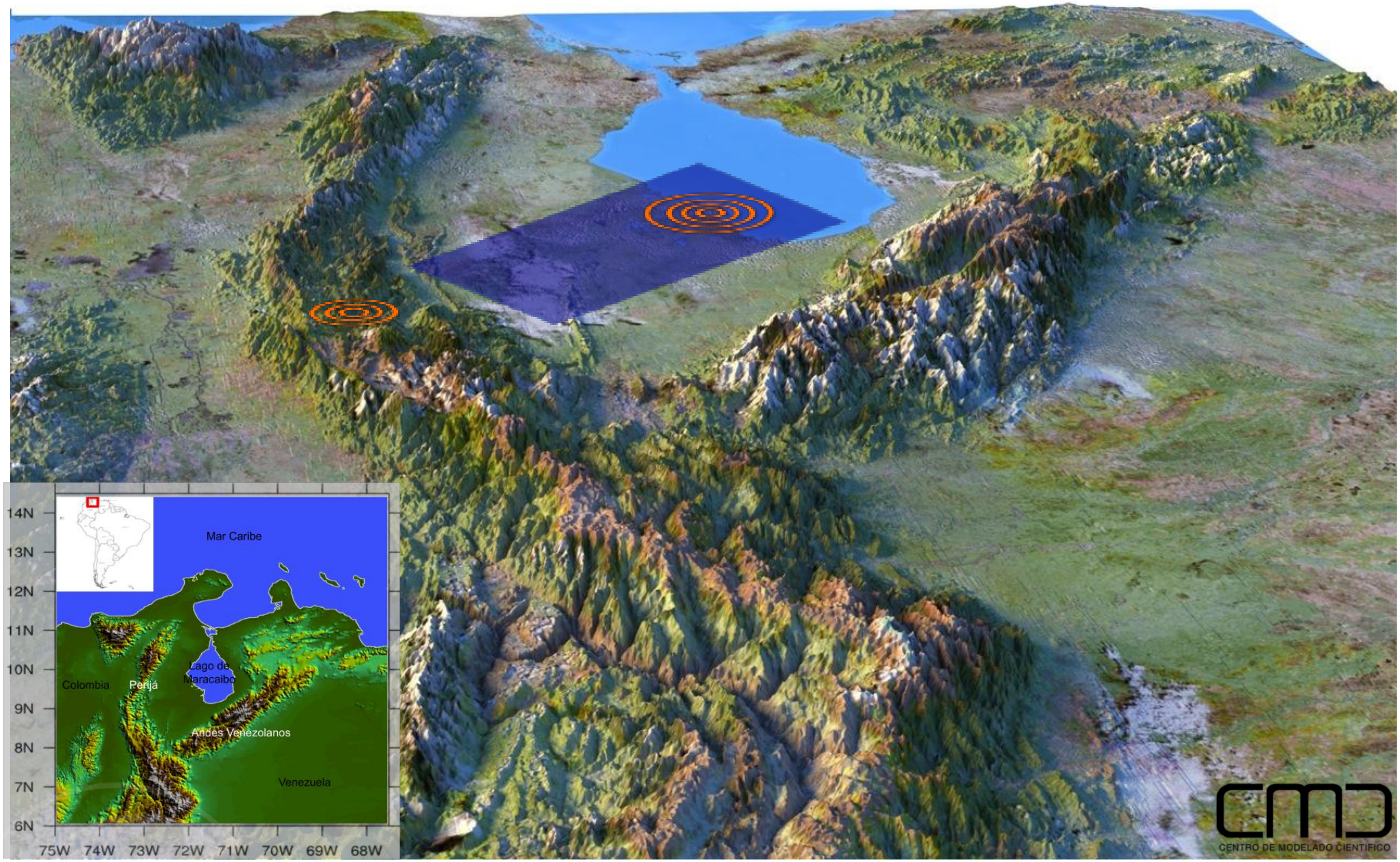

Photo: H. Parra-Centro de Modelado Científico

Lake Maracaibo Basin

+ Unique topography.
+ Two rainfall seasons (Apr-Jun; Sep-Nov). South is very wet.
+ Spatial rainfall distribution defined by moisture transport and orographic convection [Díaz-Lobatón and Muñoz, 2011].



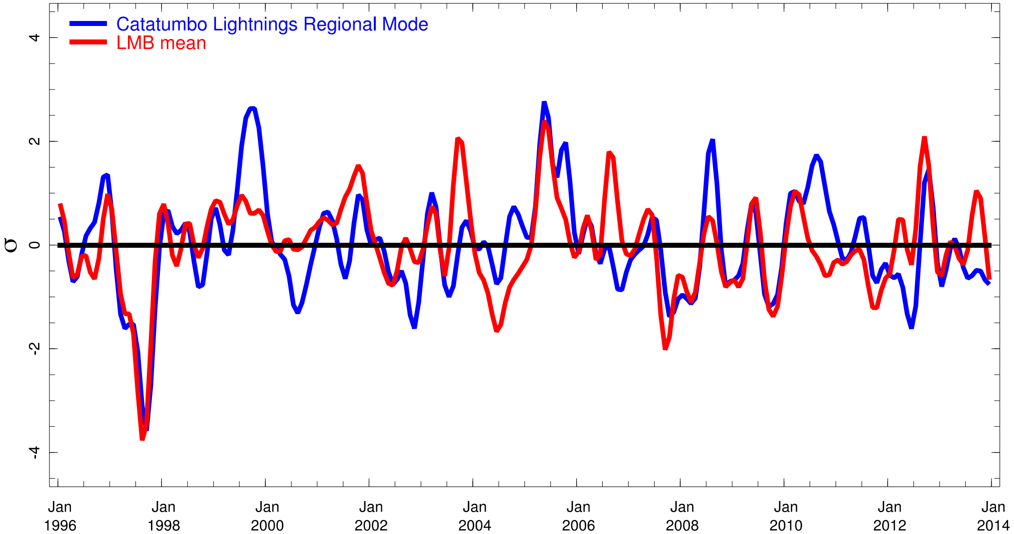
Lake Maracaibo Basin

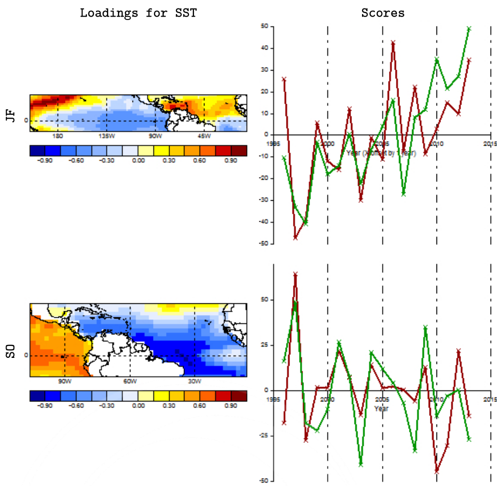


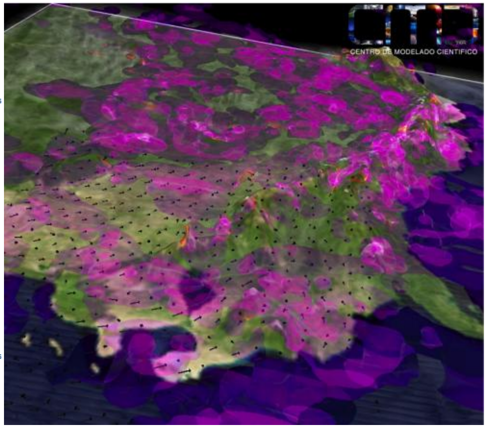
Catatumbo Experiments (*CatEx*)

- Improve lightning forecast skill at multiple timescales
- Field campaigns (tethered balloons, radiosounding)
- Three different detector networks for lightning detection
- Hi-res numerical experiments (WRF model)
- Scientific base for SIVIGILA (early warning system) and climate services

Approach







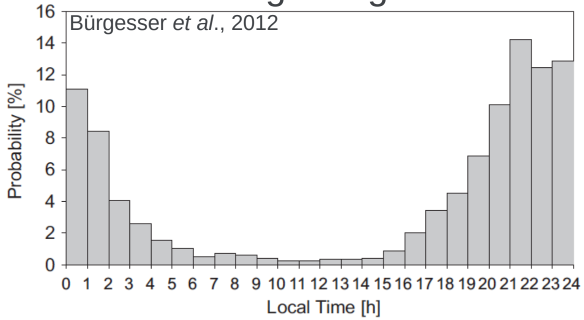
1. Use observations (LIS/OTD), reanalysis (20thCR) and hi-res numerical simulations (WRF model) to understand physical mechanisms.

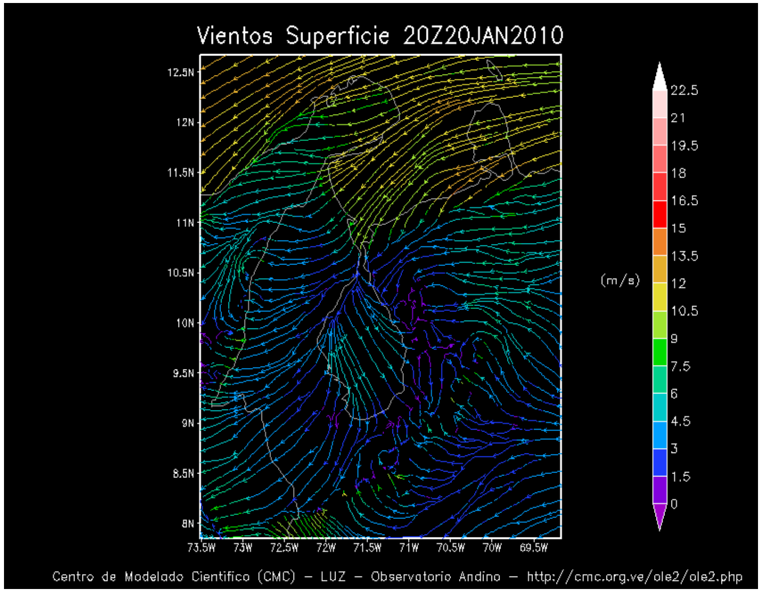
2. Select potential predictors.

3. Use dynamical and statistical models (Canonical Correlation Analysis –CCA– and Principal Component Regressions –PCR) to assess seasonal predictability.

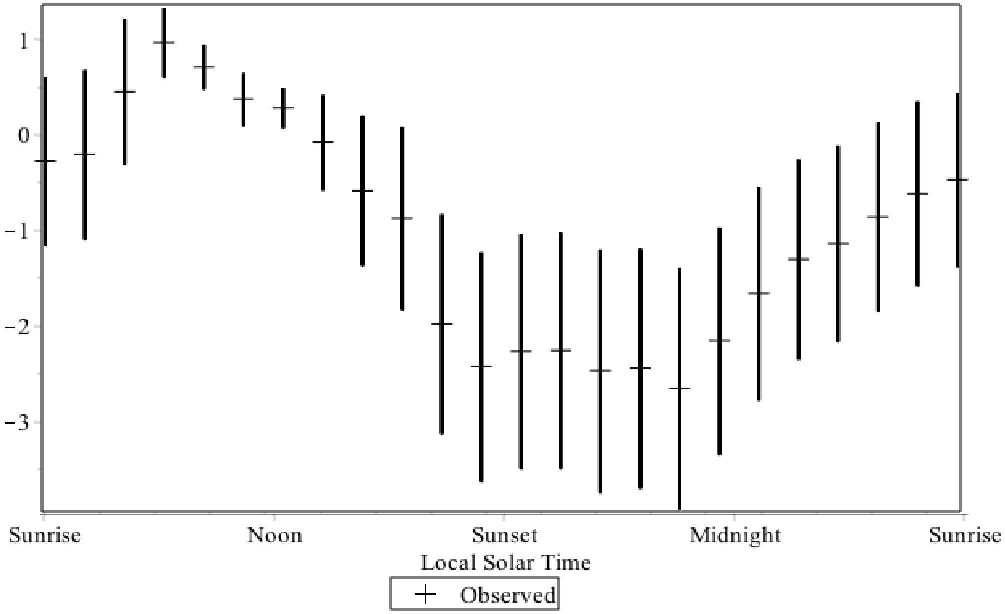
Daily cycle

Lightning





Obs: meridional wind (hourly data; 1995-2005)



Muñoz *et al*., (in prep.)

Hypotesis: lightning (and local convection) is controlled by diurnal cycle of meridional wind (v)

Daily cycle

5. A Simple Low Level Jet Model

A simple decomposition of the momentum flow provides:

$$\partial_t \mathbf{V} = -f \cdot \mathbf{k} \times \mathbf{V} - \frac{1}{\rho}\nabla P + \partial_z (K_d \partial_z \mathbf{V}) + residual \quad (1)$$

where $\mathbf{V} = (u, v)$ is the horizontal wind vector, ρ is the density of the atmosphere, P the pressure, f is the Coriolis parameter, $\mathbf{k}$ is an unitary vertical vector and K_d is the diffusion coefficient.

The Coriolis force (first term on the right hand side of the equation) produces an inertial oscillation with phase and amplitud determined by the external forcings (the other terms of the equation): diurnal variation of the pressure gradient (second term on the right hand side of the equation) caused in this case by thermal forcing over sloping terrain (Holton's mechanism), and diurnal variation of the thermally driven vertical mixing (third term, Blackadar's mechanism). Other external forces tend to be negligible and are included in the "residual" term of equation (1).

The present model considers the linear equations of motion for frictional flow on an f-plane:

$$\partial_t u - f v = -\alpha u \quad (2)$$

$$\partial_t v + f u = -\frac{1}{\rho}\partial_y P - \alpha v \quad (3)$$

where

$$-\frac{1}{\rho}\partial_y P = \bar{F} + F_y \quad (4)$$

and the last terms of equations (2) and (3) correspond to the diffusion terms in equation (1), with α the diurnally-varying frictional coefficient. $\bar{F}$ is the mean pressure gradient force per unit mass, and the diurnally-perturbed pressure gradient force per unit mass is given by

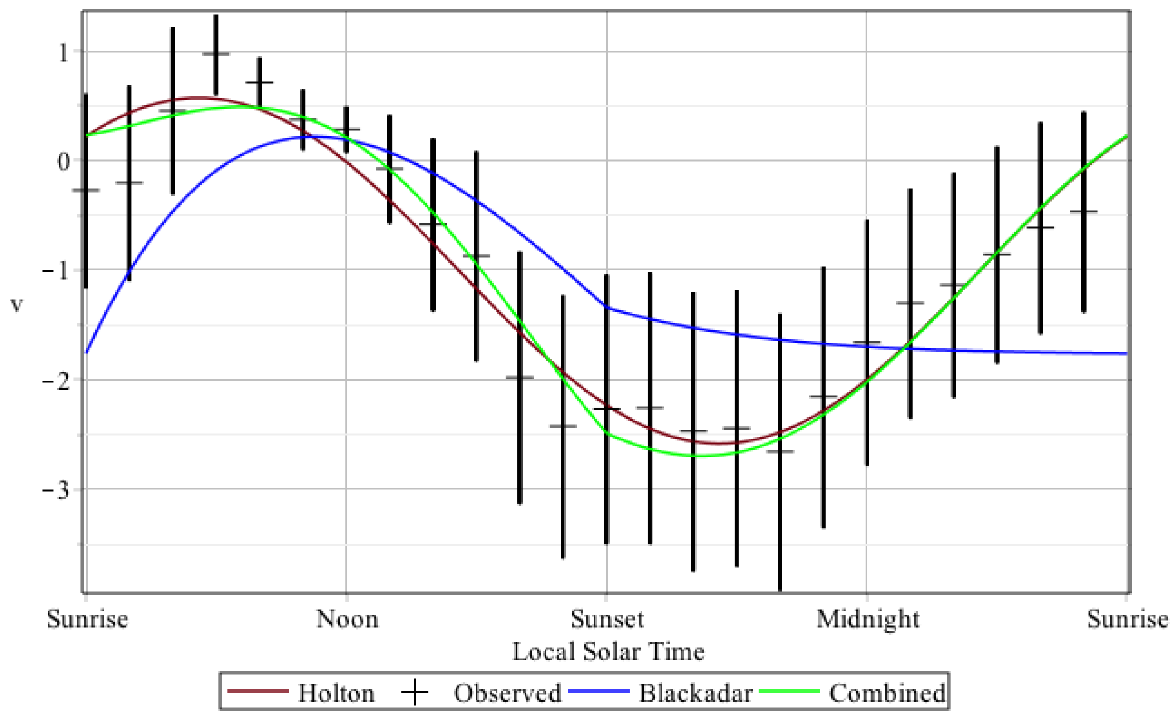
$$F_y = \hat{F} \cos \omega t \quad (5)$$

Muñoz *et al*., (in prep.)

Holton: diurnal thermal forcing over slopping terrain.

Blackadar: diurnally varying vertical diffusion coefficient

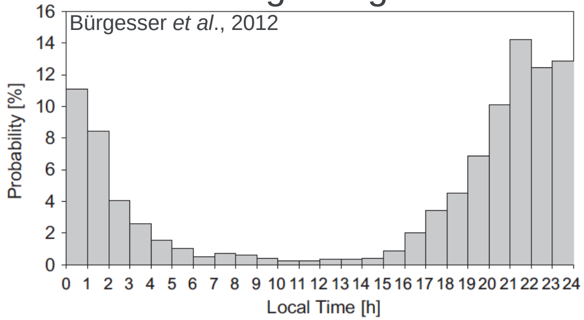
Obs: meridional wind (hourly data; 1995-2005)

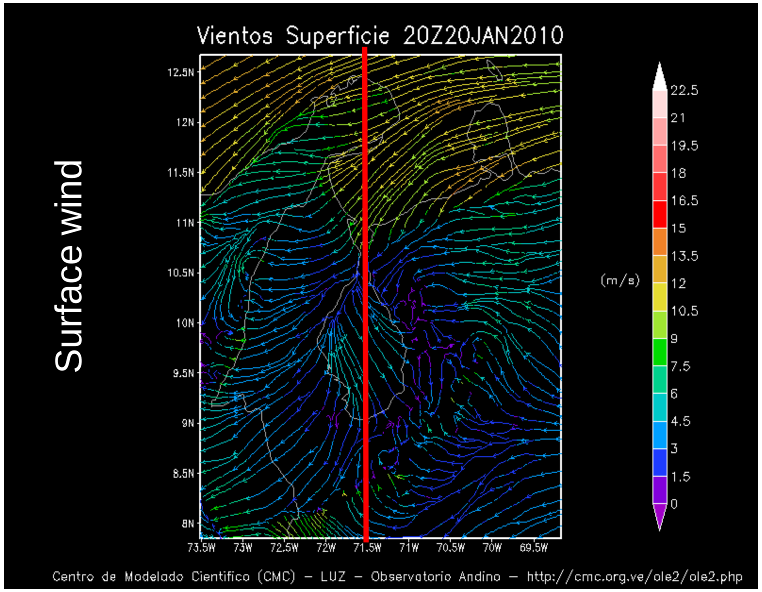


Muñoz *et al*., (in prep.)

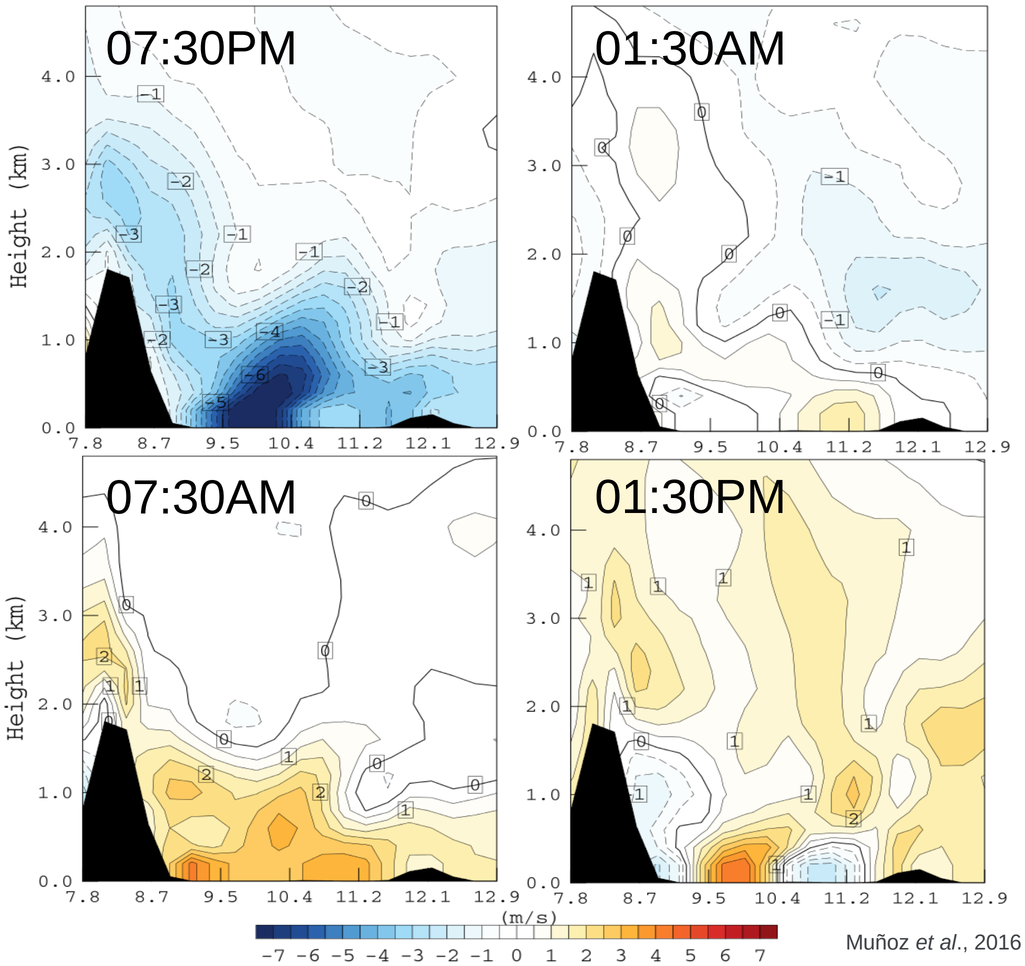
Daily cycle

Lightning





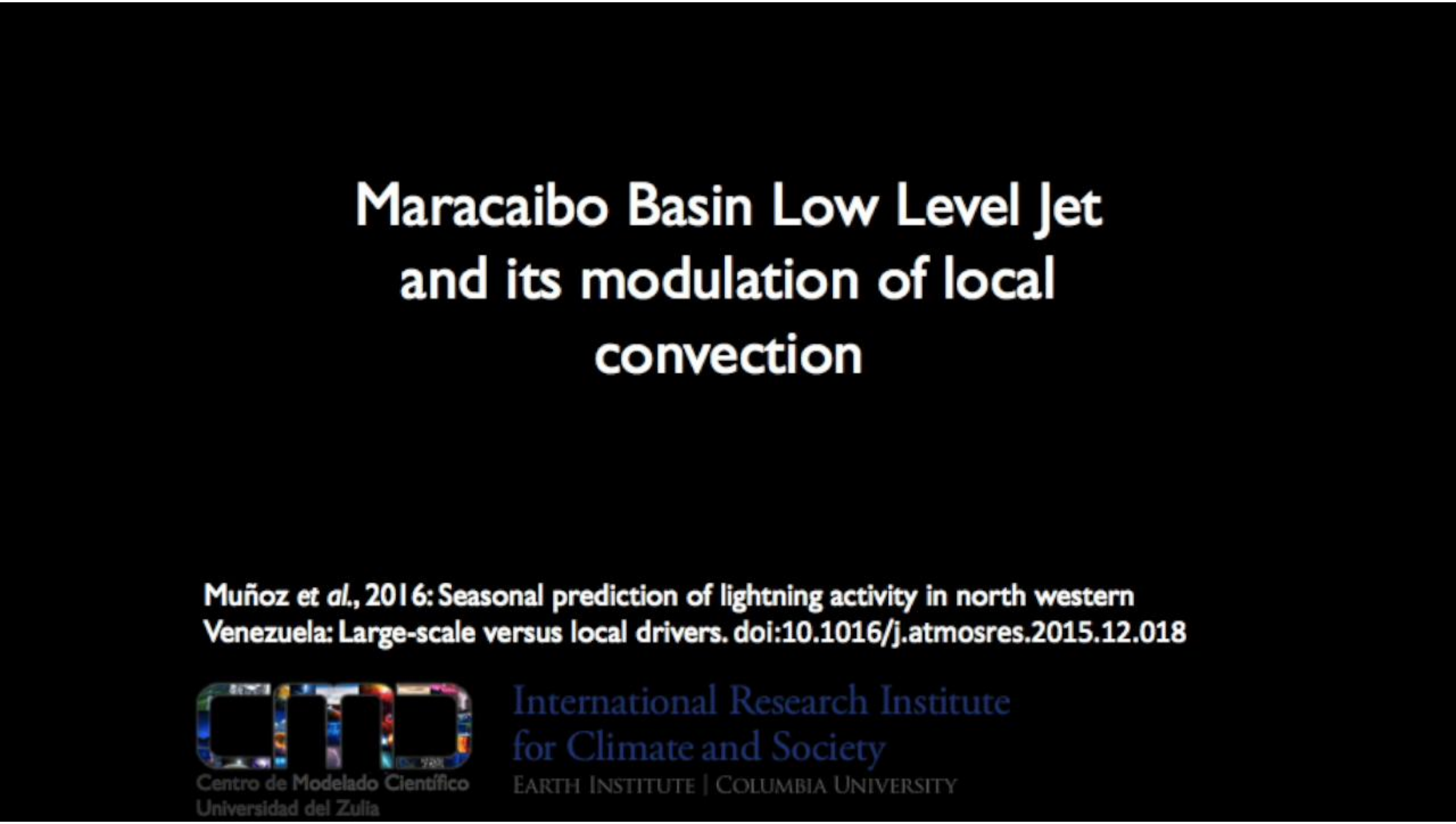
Meridional wind anomaly (cross-section)



Muñoz *et al.*, 2016

Lightning (and convection) is controlled by diurnal cycle of meridional transport of CAPE (vCAPE)

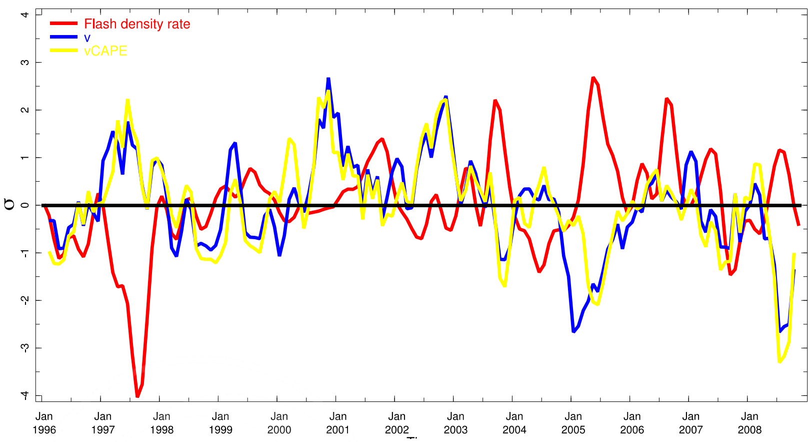
$$\nabla \cdot (vCAPE) - \nabla \cdot (\kappa \nabla CAPE) \quad \frac{\partial CAPE}{} + SS$$

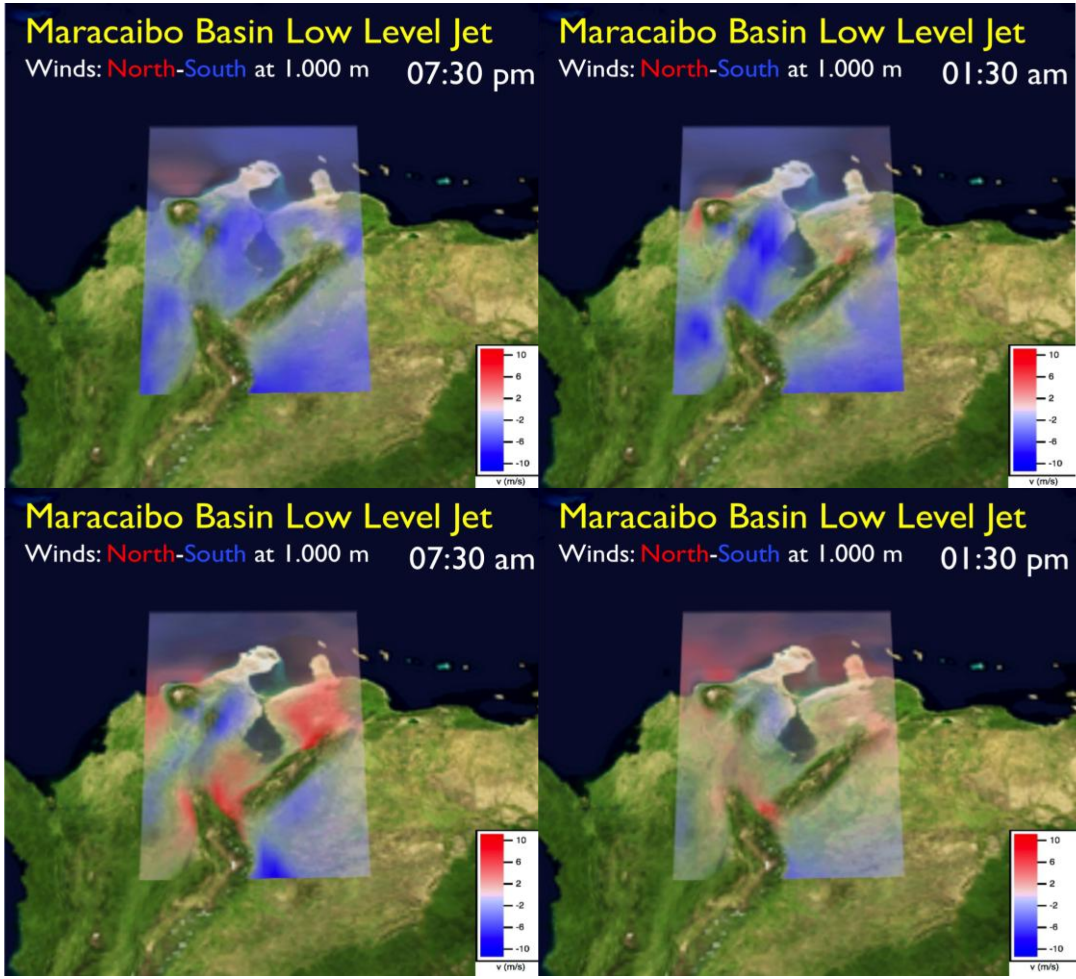


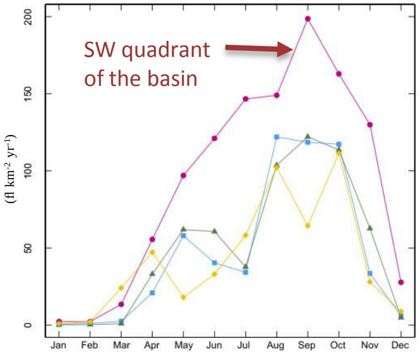
Video available at https://vimeo.com/152656820
More info: doi:10.1016/j.atmosres.2015.12.018

From daily to seasonal scale

- Convection requires moisture availability, atmospheric instability and a lifting force.
- Basin's orography and the Maracaibo Low Level Jet set the scenario for orographic convection.
- Moisture availability at *seasonal* scale is controlled by several drivers. The overall contribution is well represented by low-level meridional transport of CAPE (vCAPE, in yellow in the figure below).

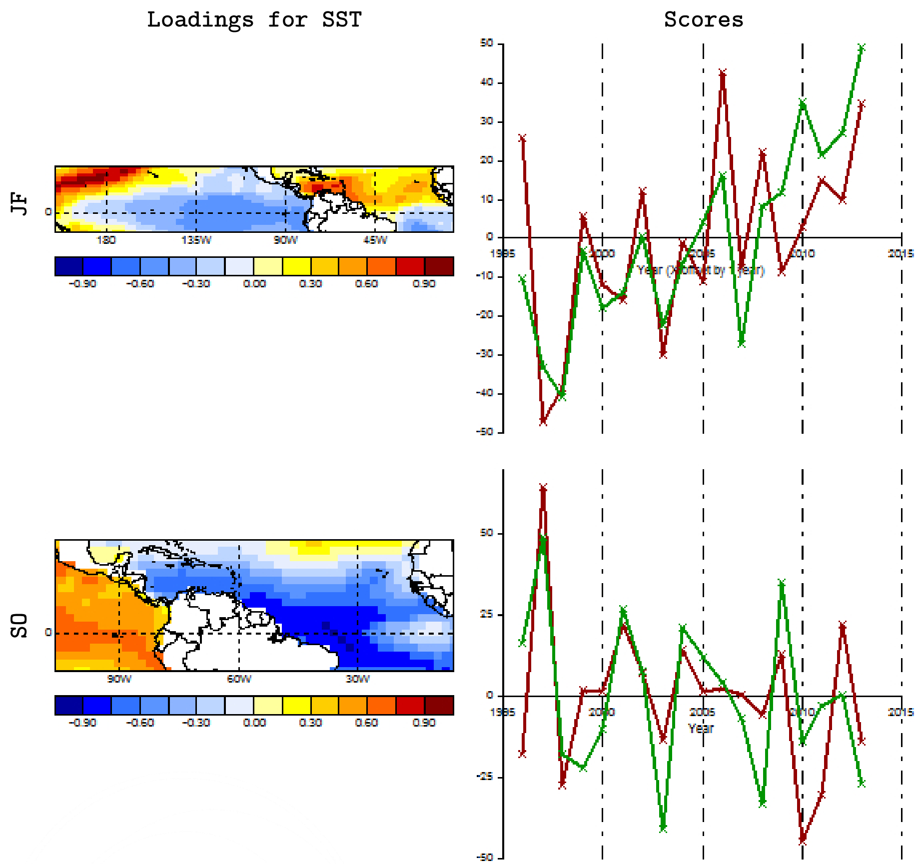


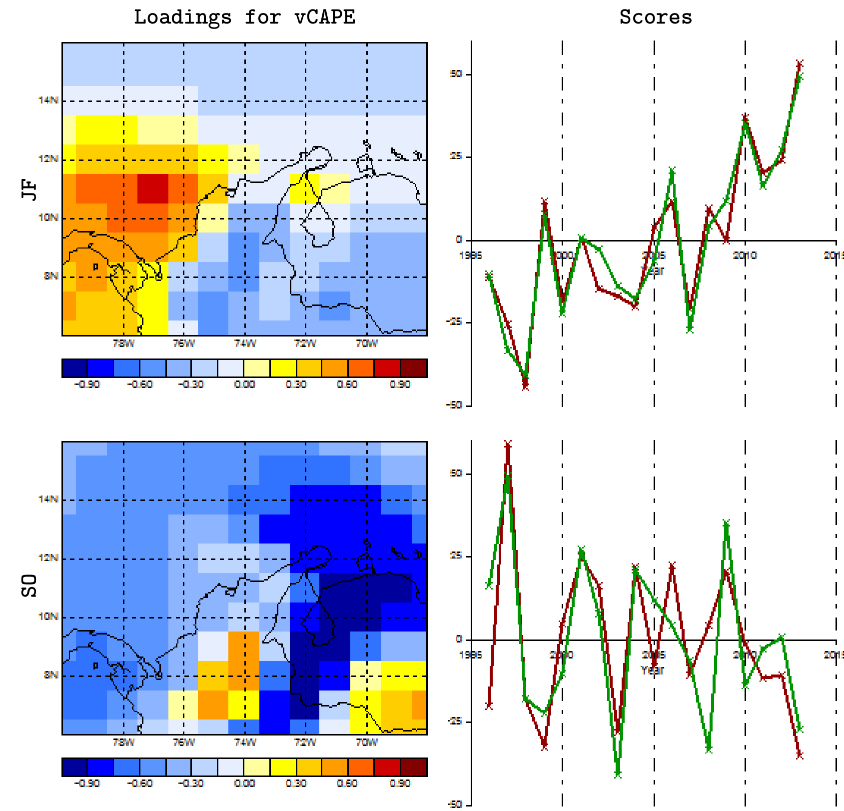




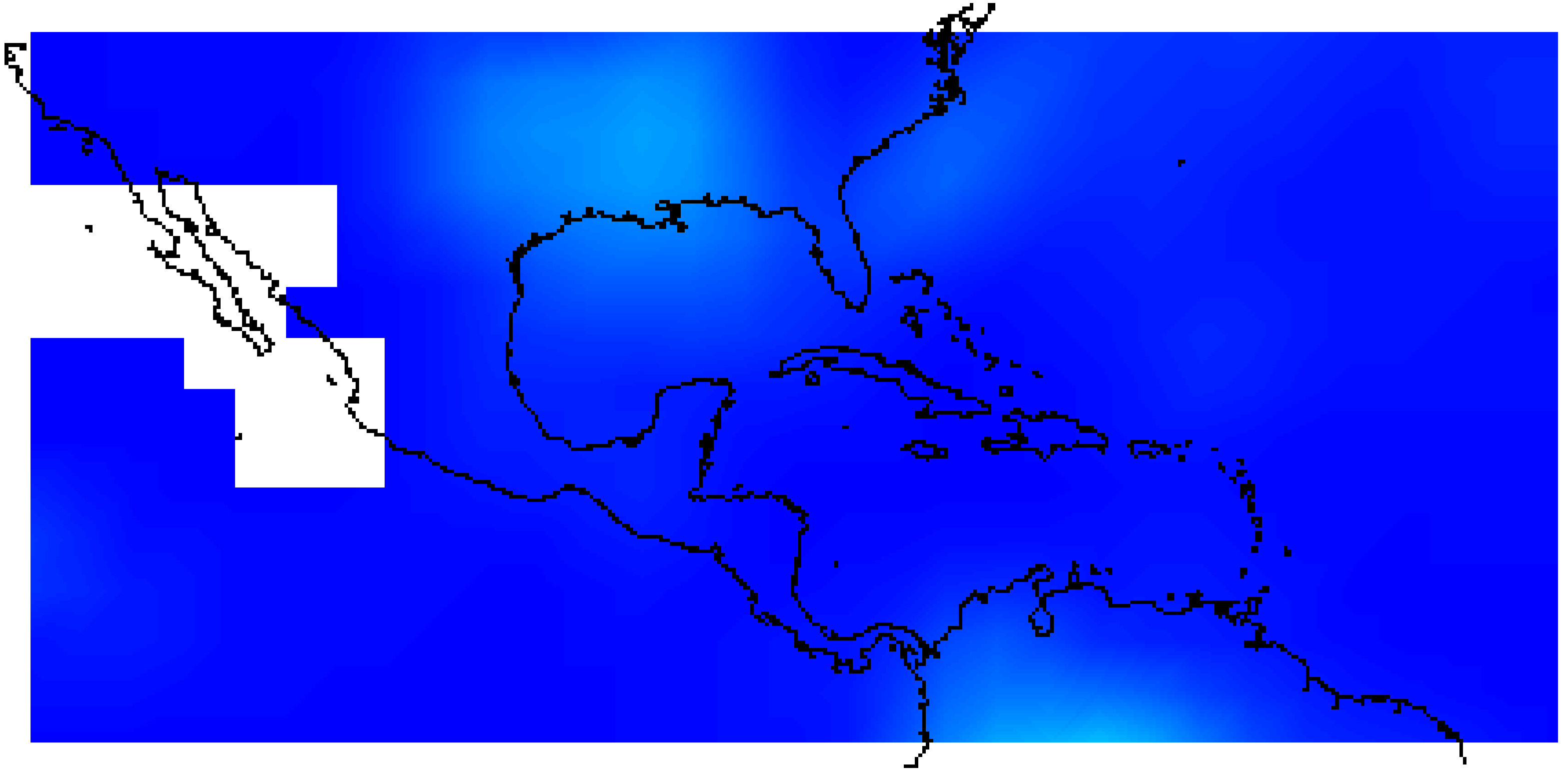
Seasonal scale

- The role of several climate drivers was explored (e.g., ITCZ, SST, CLLJ).
- Sea-surface temperature in the Pacific (ENSO), Caribbean and Tropical Atlantic is a good predictor for lightning activity in N South America.
- The vCAPE index is the best predictor for lightning activity in the region.





Regional Lightning Activity



Jan 2000

Conclusions

- *CatEx* is helping us to understand better conditions leading (or not) to lightning occurrence, not only in N. South America.
- Predictability due large-scale drivers (SST, ITCZ, CLLJ) is more important than the local (basin-wide) ones.
- Dynamical model output (meridional transport of CAPE) can be used to forecast lightning in the region at multiple timescales.
- Potentially useful for decision making processes related to human safety, oil and natural gas exploitation, energy and food security. (e.g., SIVIGILA)