Schweizerische Eidgenossenschaft
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Swiss Confederation

Federal Department of Home Affairs FDHA
**Federal Office of Meteorology and Climatology MeteoSwiss**

EUMETSAT

# COALITION[1] : merging Satellite, Radar, NWP and orographic information for predicting severe convection

EUMETSAT Fellowship

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MeteoSwiss Locarno-Monti

CWG , 27-30.03.2012

[1]**COALITON: Co**ntext and Sc**al**e Or**i**ented **T**hunderstorm Satell**i**te Predict**o**rs Developme**n**t

# Damages caused by heavy thunderstorms in CH

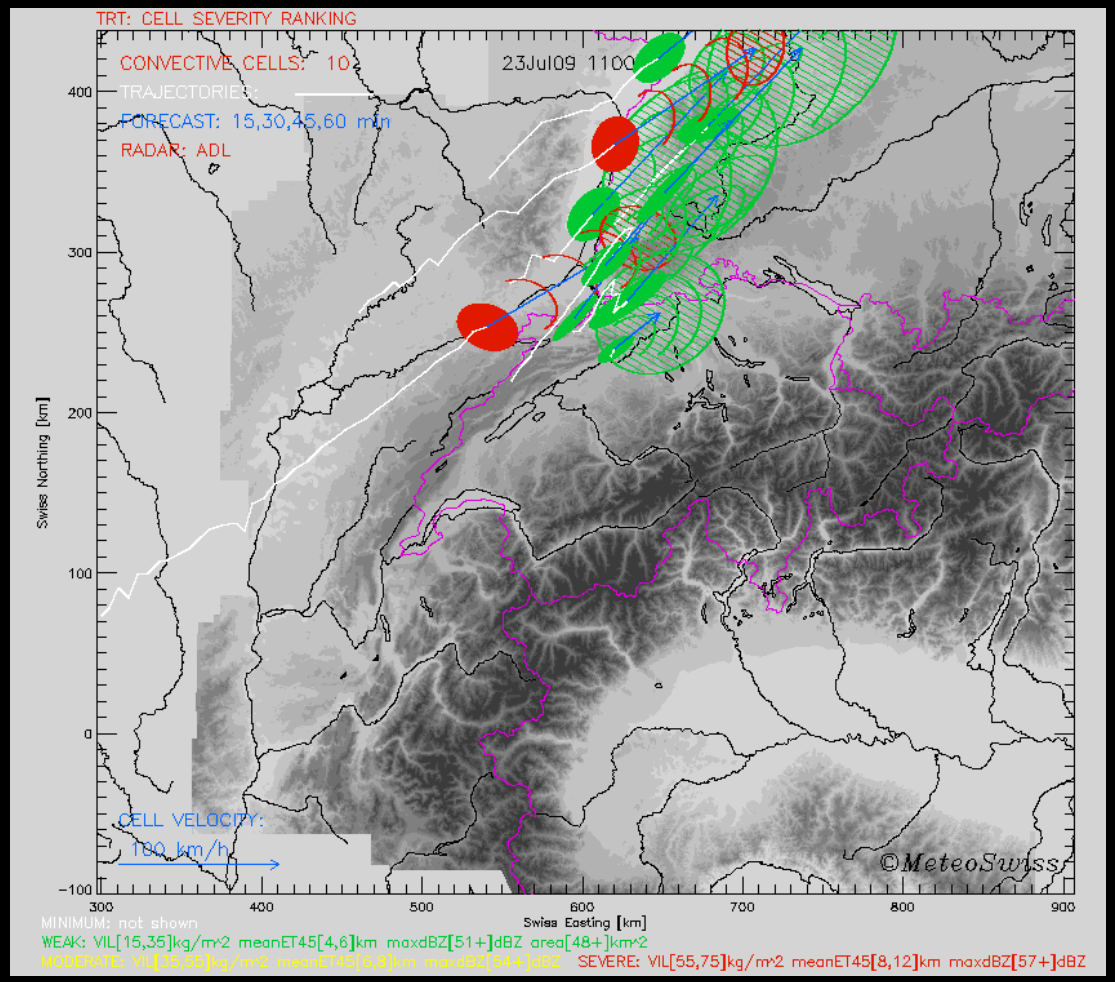
- 12th July 2011: > 100 Millions EU damages within a few hours
- 23th July 2009: ~200 Millions EU just on houses/buildings
- **Corresponds to 50-80% of all weather related damages in Switzerland**
- The causes are flash floods, large hail and heavy wind gusts

Remo Chiesa

# What is available … and what is missing

## TRT (Thunderstorms Radar Tracking)

540 km




**Legend:**

**Solid:** present position
**Hatched:** 1 hour forecast
**Blue vector:** cell velocity
**White line:** past trajectory

**Cell severity ranking:**

**WEAK (L1)**

**MODERATE (L2)**

**SEVERE (L3)**
based on vertically integrated liquid water **(VIL)**, 45 [dBZ] echo top and max echo [dBZ]

***Hering et al., 2004***

**"Flash Orage": severe thunderstorm cell → warning (MeteoSwiss)**

# GOALS

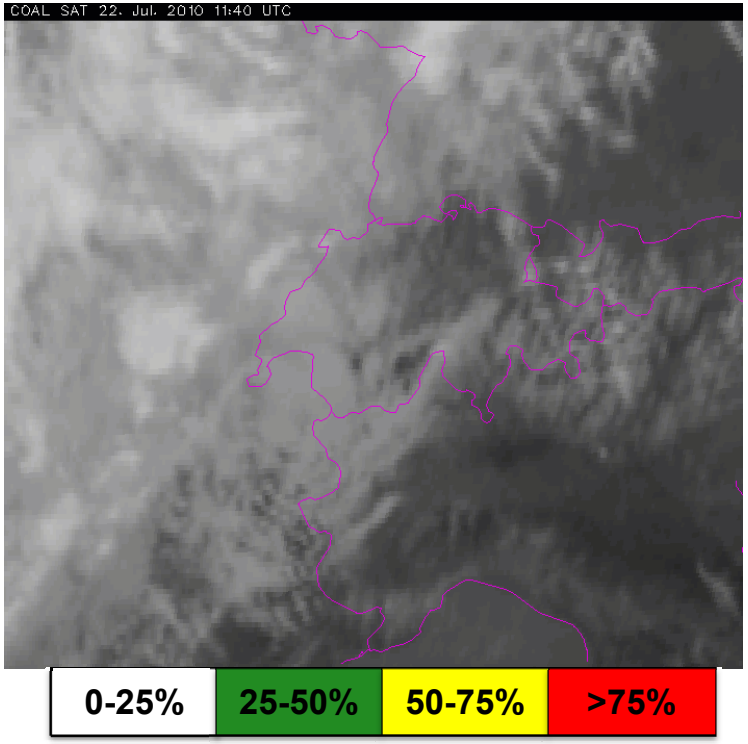
- **What are we trying to improve?**
  - very short range forecasting of thunderstorm intensity evolution over the alpine region

- **What is the idea behind COALITION?**
  - merge selected data using blending techniques packed in a heuristic model

- **What is the output?**
  - an object based likelihood (5 minutes) for growing to severe thunderstorms (→warnings)

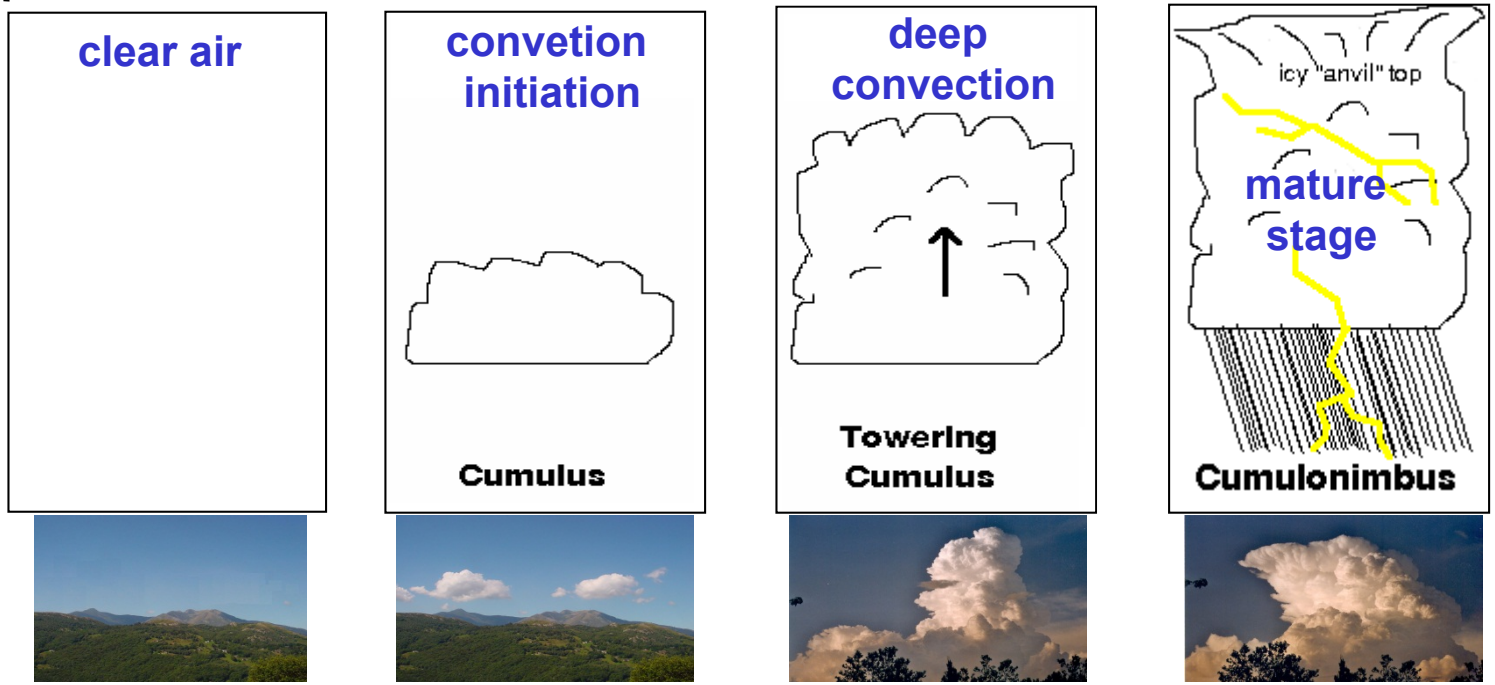
- **COALITION is designed for the operational:**
  - running time in line with Nowcasting specification
  - the algorithm is modularized: the users can select which products should be included

**COALITION probability of development to a severe storm cell in the next 15 min:**



# Data sources and real-time frequencies

Meteosat Second Generation / SEVIRI
(data and derived products) (5 min)




Lightning (CG only) (5 min)

Radar (2.5 min)

Numerical Models outputs (NWP) (3 h) , Orography (static) , Climatology (1 year)

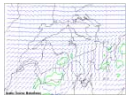
# «Ingredients» and modules: an overview

Environment + Object ("thunderstorm ") attribute →

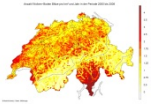
Object based forecast (5-60 min) of:

SAT

RAD



NWP



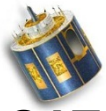
Lightning

Topography

| | | | | |
|---|---|---|---|---|
| Convection Initiation | + | Cloud Top Temperature | MODULE 1 SAT + SAT | → CTT |
| Cloud Top Temperature | + | Vertical Integrated Liquid | MODULE 2 SAT + RAD | → VIL |
| Lightning Climatology | + | Vertical Integrated Liquid | MODULE 3 Lightning + RAD | → VIL |
| Convection Initiation | + | Vertical Integrated Liquid | MODULE 4 SAT + RAD | → VIL |
| CAPE (conv. av. pot. en.) | + | Vertical Integrated Liquid | MODULE 5 NWP + RAD | → VIL |
| Directional Slope Gradients | + | Cloud Top Temperature | MODULE 6 Topography + SAT | → CTT |
| Directional Slope Gradients | + | Vertical Integrated Liquid | MODULE 7 Topography + RAD | → VIL |

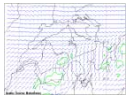
+ SAF/NWC Rapid Developing Thunderstorms (RDT) → Cumuls Cloud Identification + Tracking
+ SAF/NWC Cloud Top Height → Parallax correction

# COALITION modules: heuristic rules

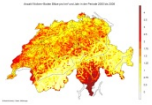


**SAT**

**RAD**



**NWP**



**Lightning**

**Topography**

Convection Initiation + Cloud Top Temperature → **MODULE 1: Stronger Convection Initiation signal of a convective cell → more energy is available for its cloud top cooling (towering of the cloud)**

Cloud Top Temperature + Vertical Integrated Liquid → **MODULE 2: Faster cooling of the cloud top of a convective cell → more energy is available for increasing its VIL**

Lightning Climatology + Vertical Integrated Liquid → **MODULE 3: Higher density of cloud to ground lightning over a specific area → more energy is available for increasing the VIL of a convective cell developing in this area**

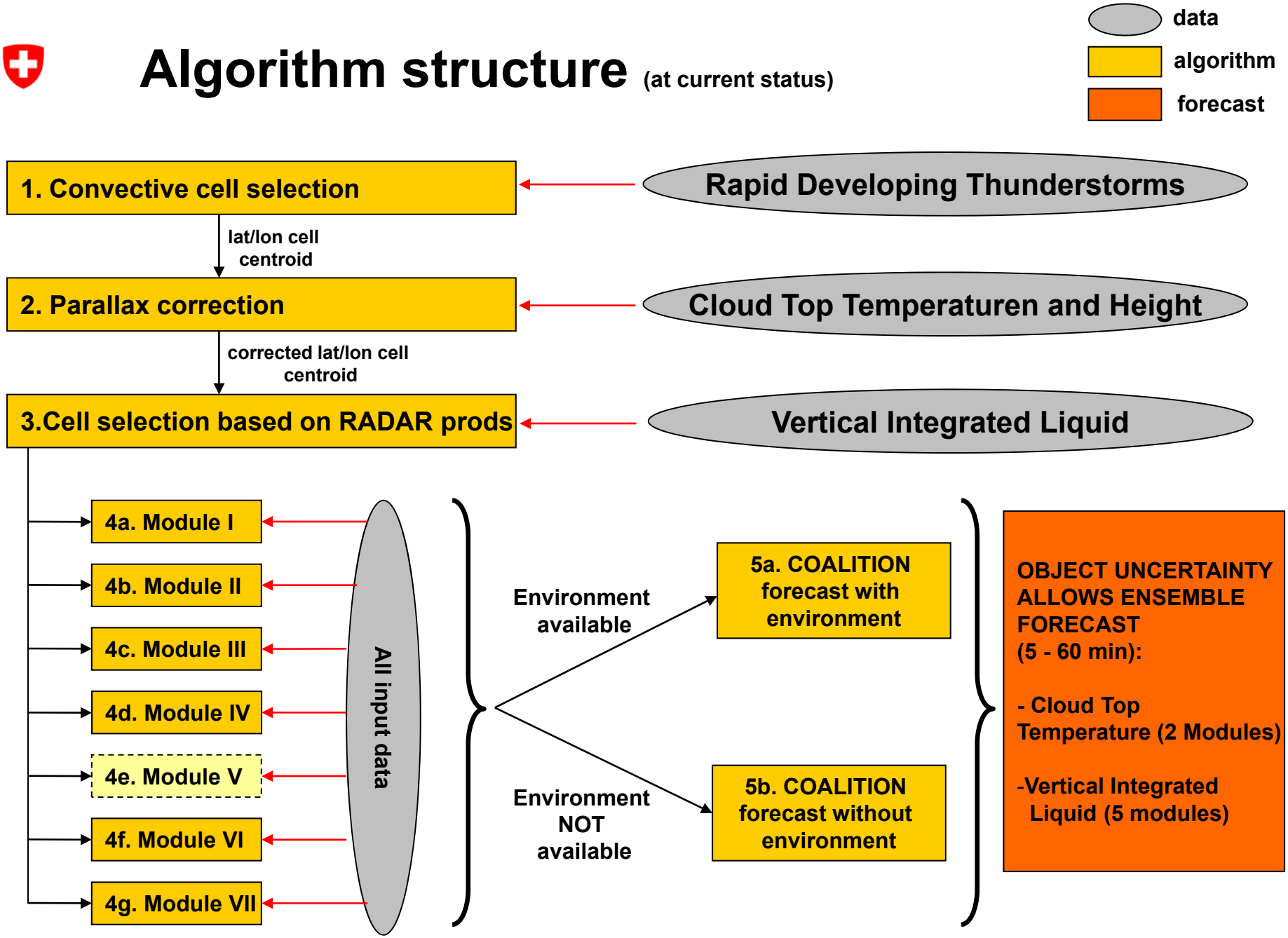
Convection Initiation + Vertical Integrated Liquid → **MODULE 4: Stronger Convection Initiation signal of a convective cell → more energy is available for increasing its VIL**

CAPE (conv. av. pot. en.) + Vertical Integrated Liquid → **MODULE 5: Higher instability values → more energy is available for increasing the VIL of a convective cell developing in this area**

Directional Slope Gradients + Cloud Top Temperature → **MODULE 6: A convective cell is moving toward a mountain (orographic forcing) → more energy is available for its cloud top cooling (towering of the cloud)**

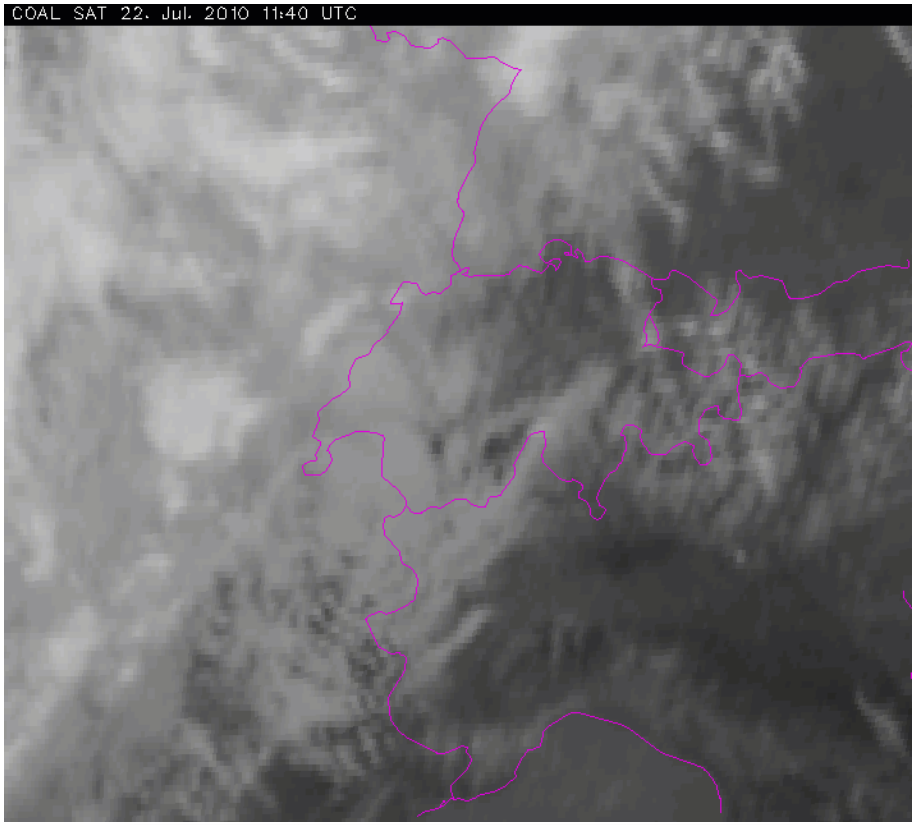
Directional Slope Gradients + Vertical Integrated Liquid → **MODULE 7: A convective cell is moving toward a mountain (orographic forcing) → more energy is available for increasing its VIL**

# Algorithm structure (at current status)



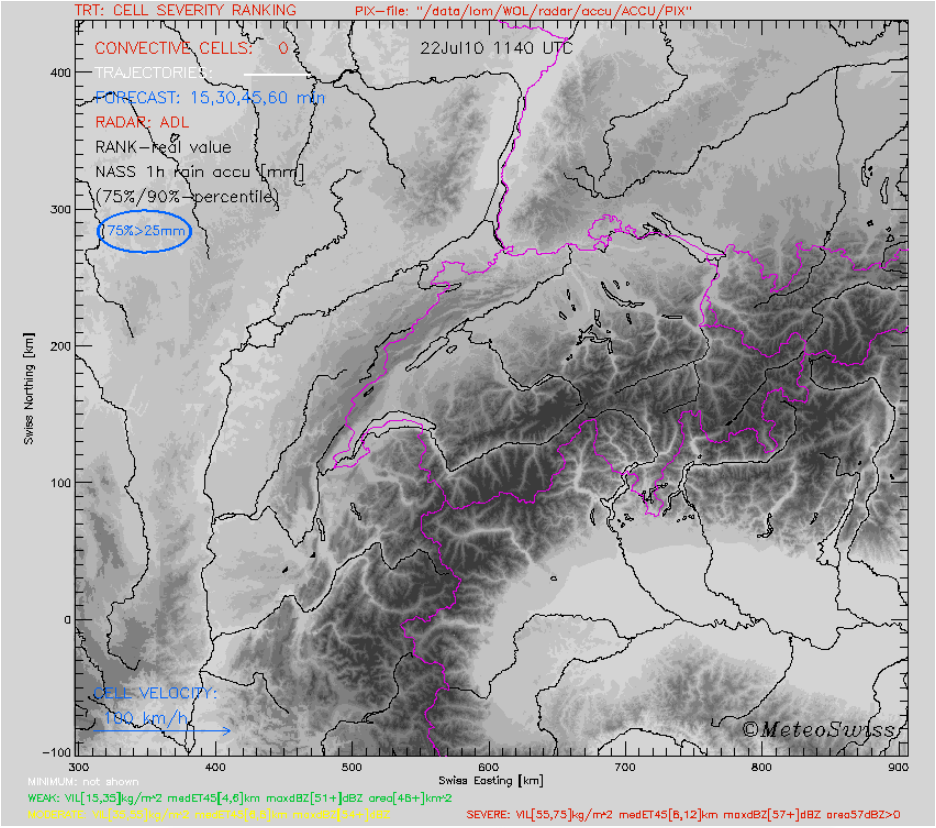
# Convective events 22-07-2010 11:40-14:00 UTC

**COALITION probability of development to a severe storm cell in the next 15 min:**




| 0-25% | 25-50% | 50-75% | >75% |
|---|---|---|---|

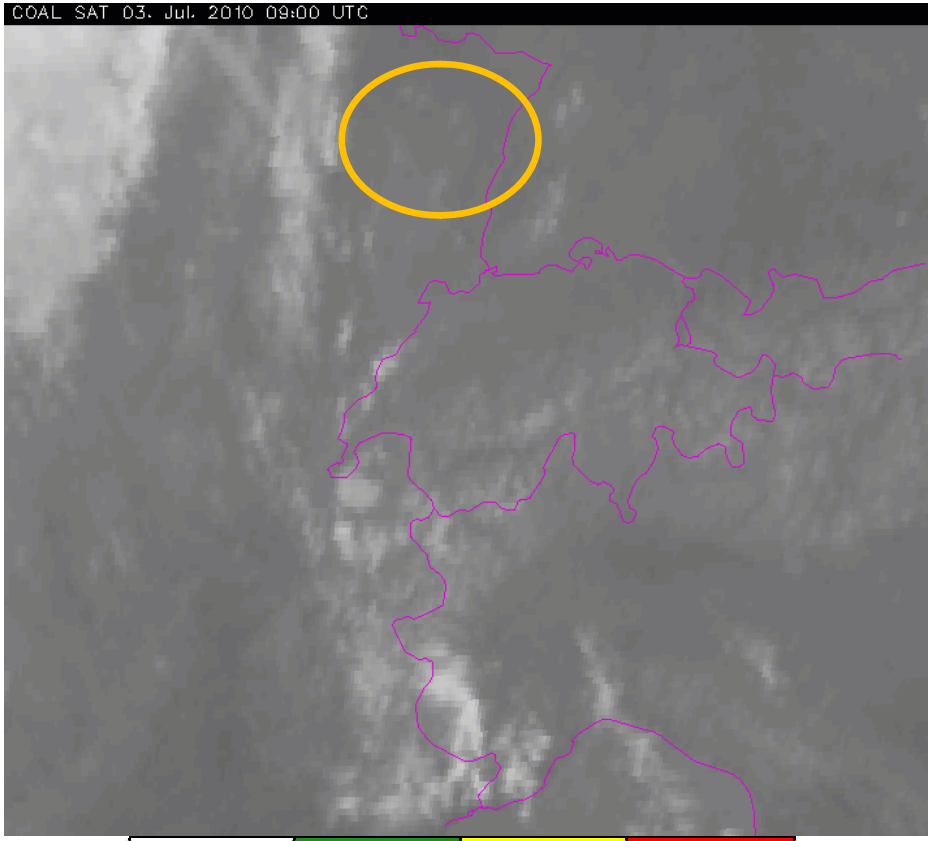
**Thunderstorm detection, classification and tracking by TRT:**




| Rank 0 | Rank 1 | Rank 2 | Rank 3 |
|---|---|---|---|
| | 'weak' | 'moderate' | 'severe' |

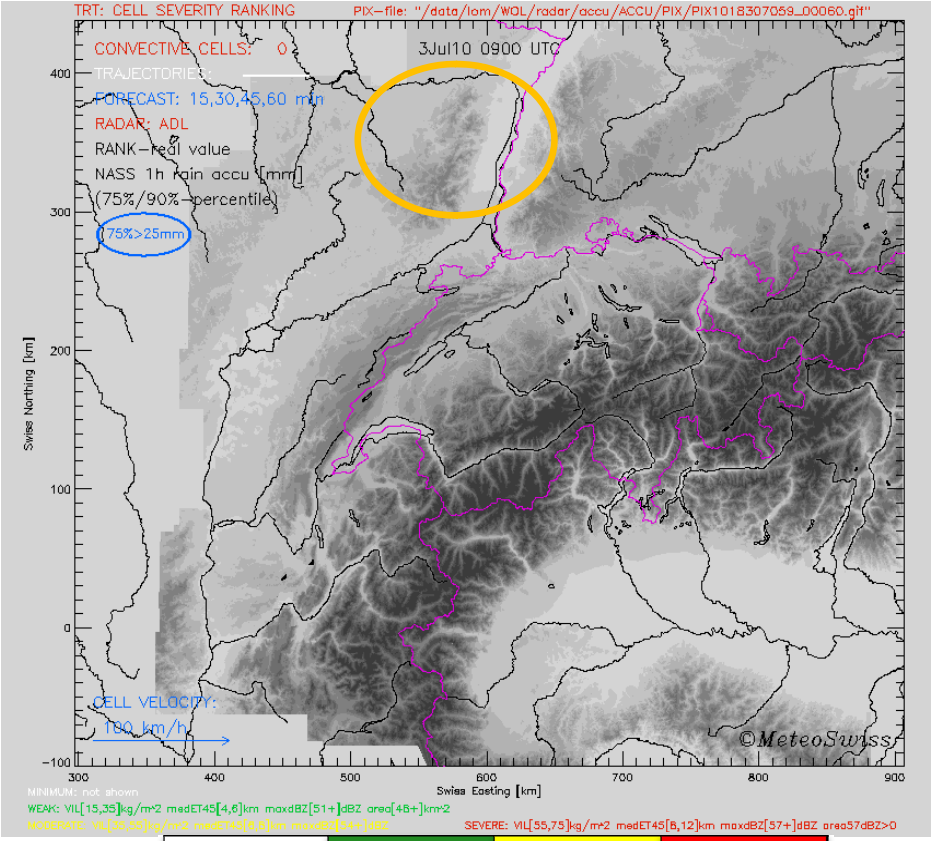
# Convective events 03-07-2010 09:00-11:00 UTC

**COALITION probability of development to a severe storm cell in the next 15 min:**




| 0-25% | 25-50% | 50-75% | >75% |
|---|---|---|---|

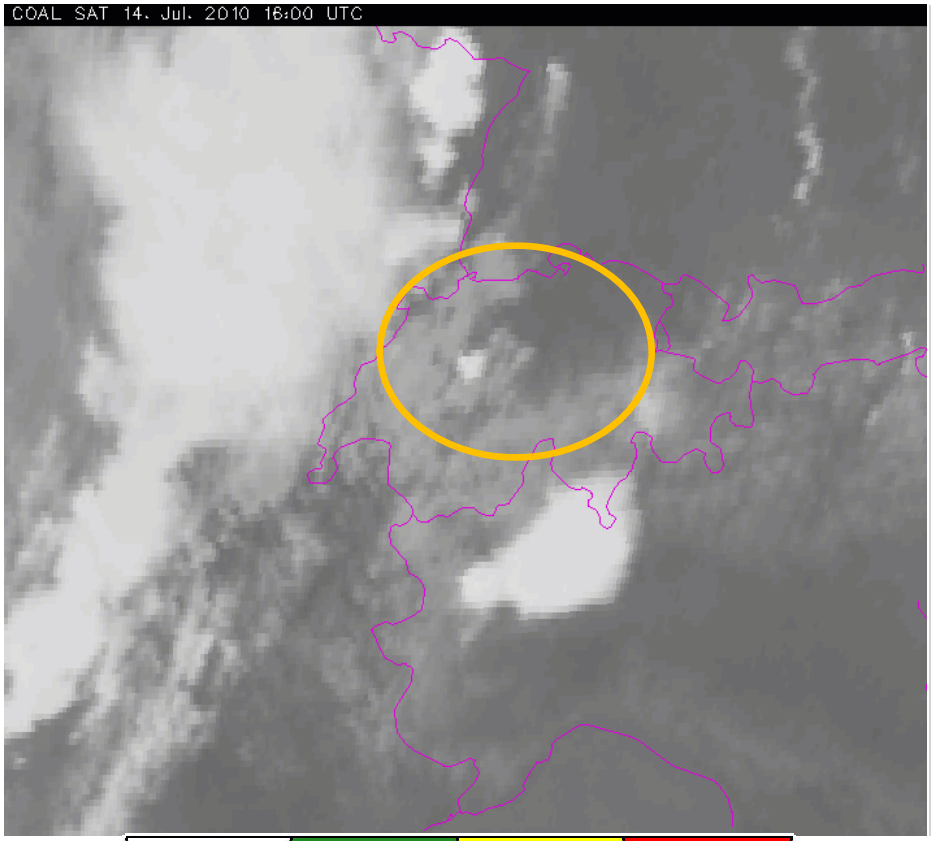
**Thunderstorm detection, classification and tracking by TRT:**




| Rank 0 | Rank 1 | Rank 2 | Rank 3 |
|---|---|---|---|
| | 'weak' | 'moderate' | 'severe' |

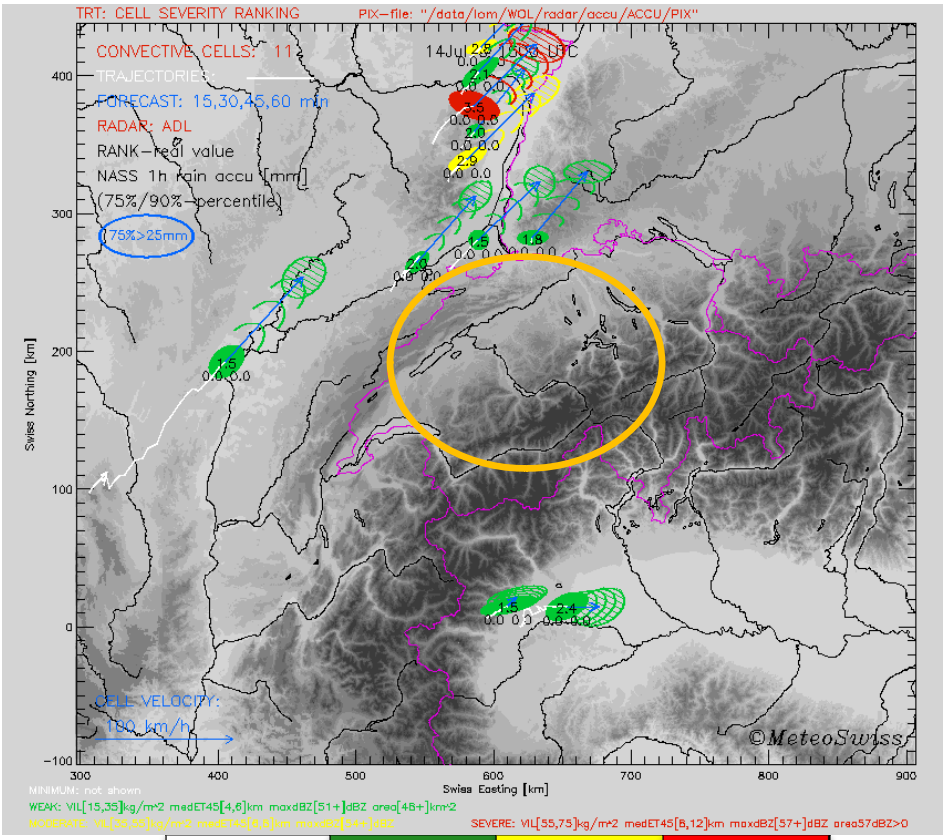
# Convective events 14-07-2010 16:00-17:20 UTC

**COALITION probability of development to a severe storm cell in the next 15 min:**




| 0-25% | 25-50% | 50-75% | >75% |
|---|---|---|---|

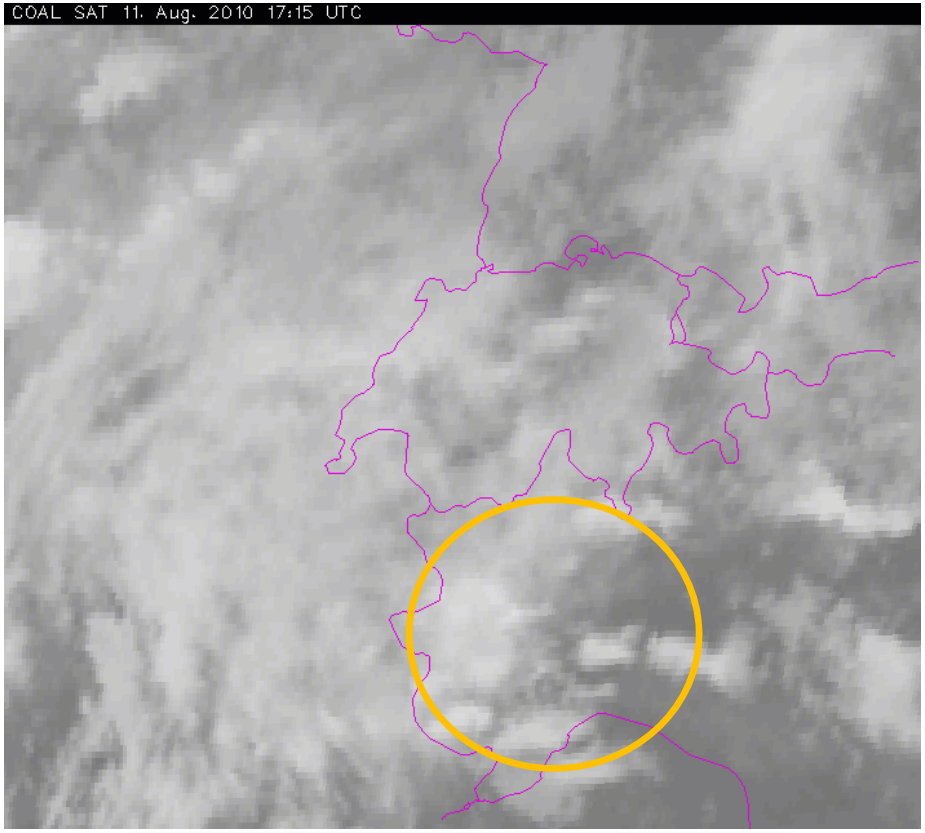
**Thunderstorm detection, classification and tracking by TRT:**




| Rank 0 | Rank 1 | Rank 2 | Rank 3 |
|---|---|---|---|
| | 'weak' | 'moderate' | 'severe' |

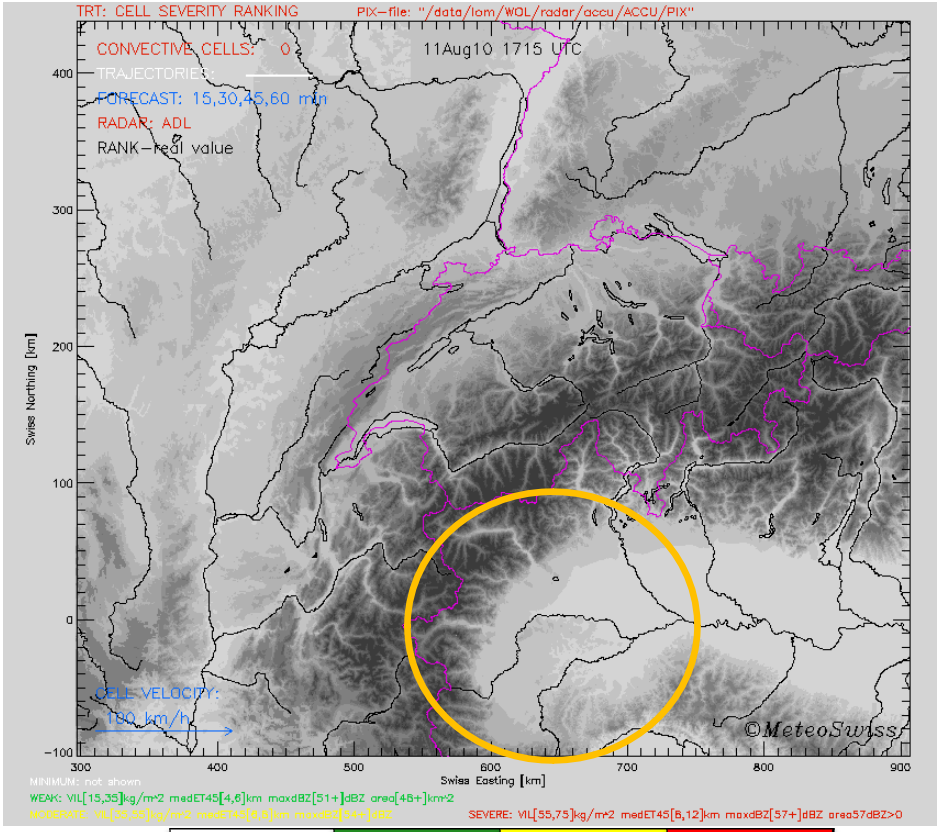
# Convective events 11-08-2010 17:15-19:00 UTC

**COALITION probability of development to a severe storm cell in the next 15 min:**



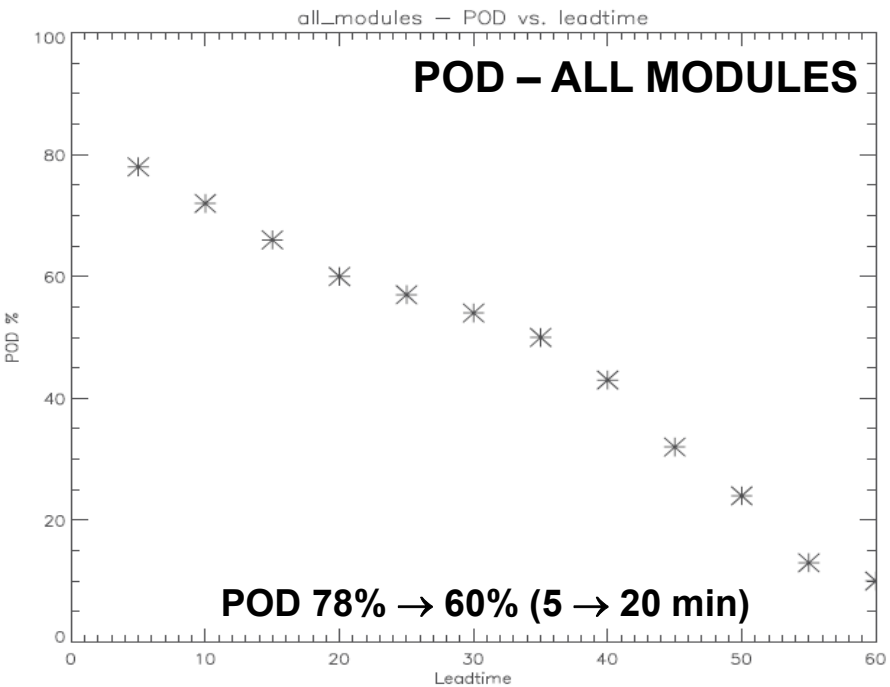

| 0-25% | 25-50% | 50-75% | >75% |
|---|---|---|---|

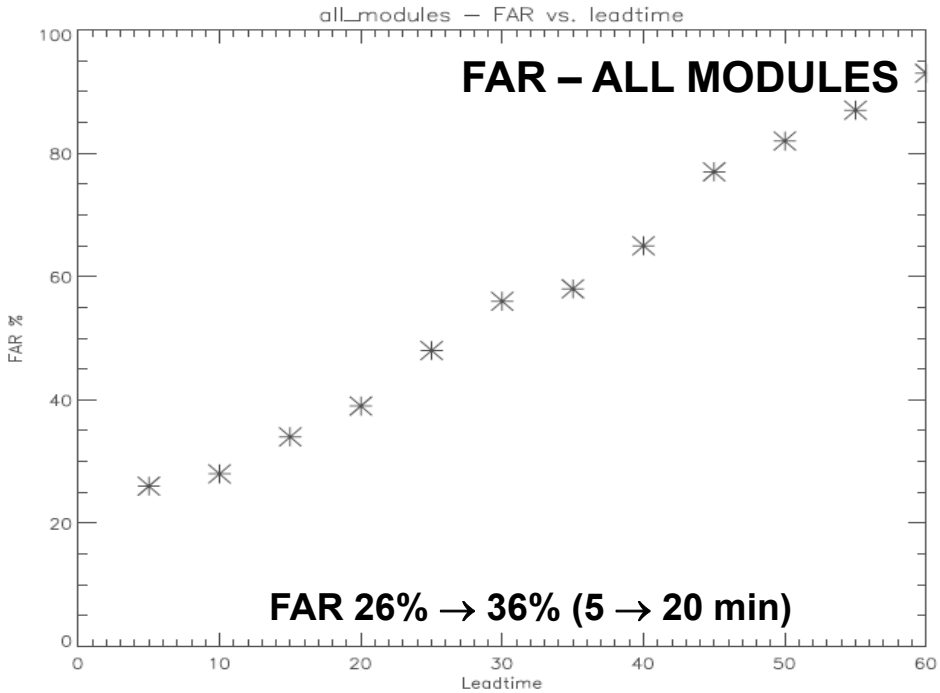
**Thunderstorm detection, classification and tracking by TRT:**




| Rank 0 | Rank 1 | Rank 2 | Rank 3 |
|---|---|---|---|
| | 'weak' | 'moderate' | 'severe' |

# Global validation – cross validation with 80 thunderstorms



# Results and validation summary

- First approach: linear combination of modules
- POD decreases from 78% to 60% within the first 20 min lead time
- FAR beneath 40% till 20 min lead time
- CTT forecast slightly more performant than VIL forecast, but:
  it is difficult to set a single threshold on cloud top temperature to discriminate weak from severe thunderstorm cells (very high FAR!)
- POD decreases very rapidly in case of explosive convection (in some cases VIL 5-10 $kg/m^2$ → 40-50 $kg/m^2$ within 5 min!!!)
- Sometimes difficult detection of storm cells embedded in cold fronts (→ due to low RDT performance!)

# Outlook

- Optimize the combination of modules
- implement additional modules (moisture convergence, wind shear)
- Provide COALITION in real-time to forecasting centres and test it during the convective season 2012 → deployment
- Test the algorithm (or a reduced version) over other regions in Europe / World

# Acknowledgments


- R. Stuhlmann (EUMETSAT Fellowship program)
- I. Giunta (concept, algorithms, numerics, reviews )
- MeteoLocarno staff, in particular:
  - M. Gaia (resources and administration)
  - L. Clementi (informatic solutions)
  - the whole staff of Locarno-Monti for their helps
- J. Mecikalski (Convection Initiation algorithm)
- M. Koenig (EUMETSAT MET Division) for the very precious scientific and technical support
- EUMETSAT Central Application Facility (realtime and archived Meteosat data)
- SAF/Nowcasting Consortium (software and supports)
- GEPARD J. Scheiber (software development Kit)

# Additional slides

# COALITION methodology: foundaments (1)

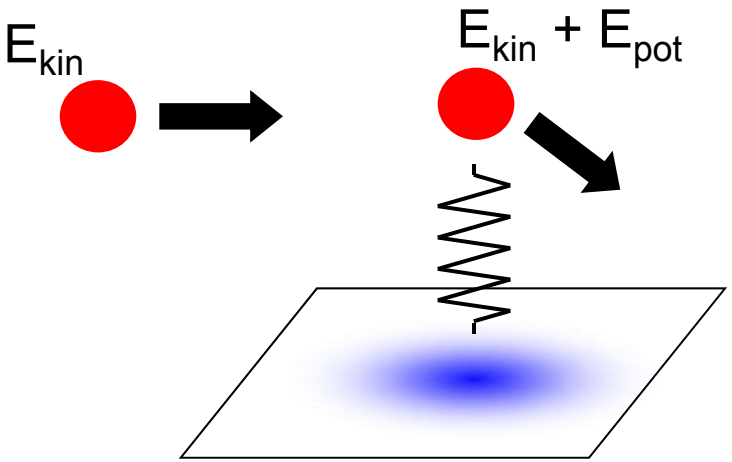
- Playing actors:

***convective signatures*** **&** ***interacting environment***

as object attributes — as external fields

e.g. increasing radar echo and cooling of cloud tops

→ **particle-field interaction**



# COALITION methodology: foundaments (2)

**forecast = solution of energy conservation laws**

$$E_{kin} + E_{pot} = H(\vec{q},\vec{p}) = const$$

Coordinates

x
y
CTH
VIL
...

$p_x$
$p_y$
$p_{CTH}$
$p_{VIL}$
...

Corresponding momenta

where: $\dot{\vec{q}} = \frac{\partial H}{\partial \vec{p}}$ $\dot{\vec{p}} = -\frac{\partial H}{\partial \vec{q}}$

***Hamilton's least action principle***

**1D-model:**

$$H(q,p,t) = \frac{p^2}{2m} + f(t)q^2$$

**q: thunderstorm attribute (VIL, CTT)**
**p: corresponding momenta**
**m: inertial mass**
**f(t): correlation between the evolution of the thunderstorm attribute evolution and the external environment**

# COALITION methodology: an example (1)

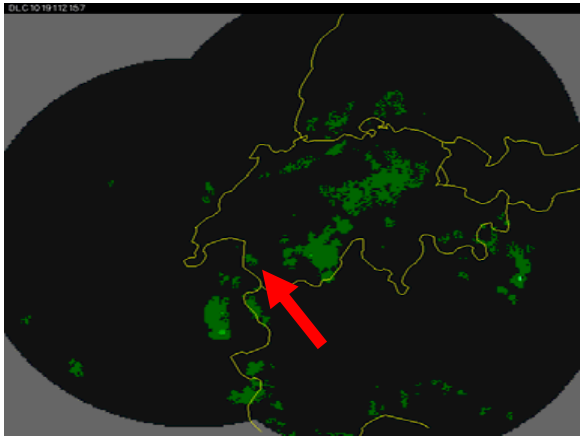
Playing actors:

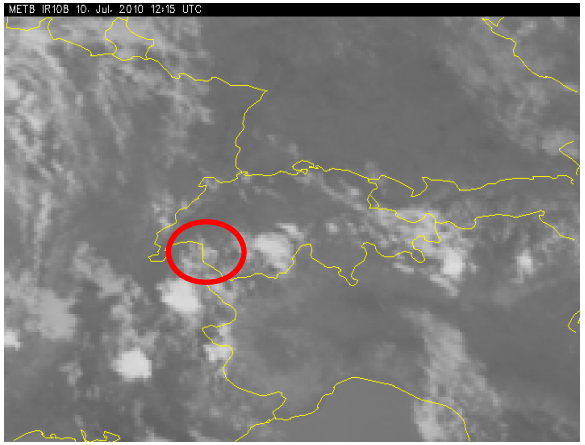
***convective signatures*** **&** ***interacting environment***

as object attributes — as external fields

e.g. increasing radar echo — and — cooling of cloud tops

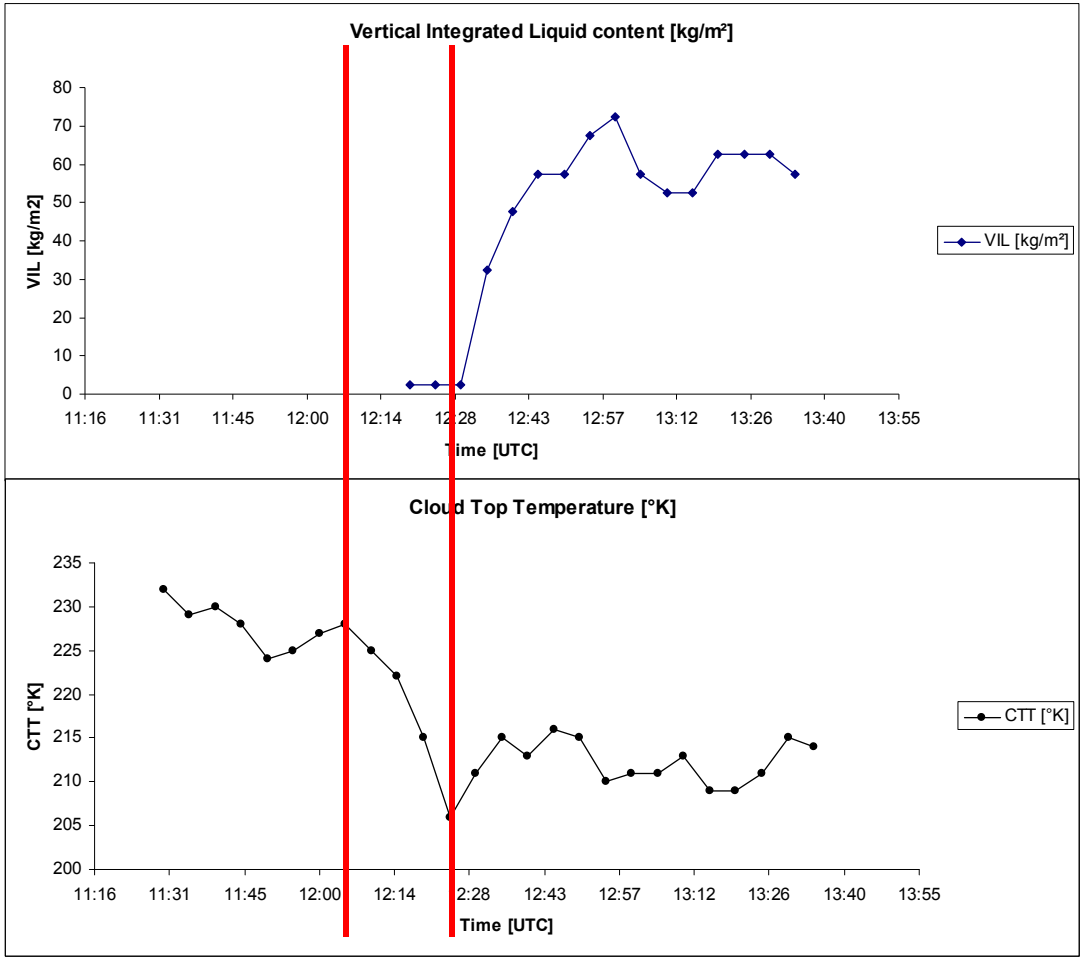
object:
e.g. thunderstorm cell
defined by the
VIL product
(RADAR)



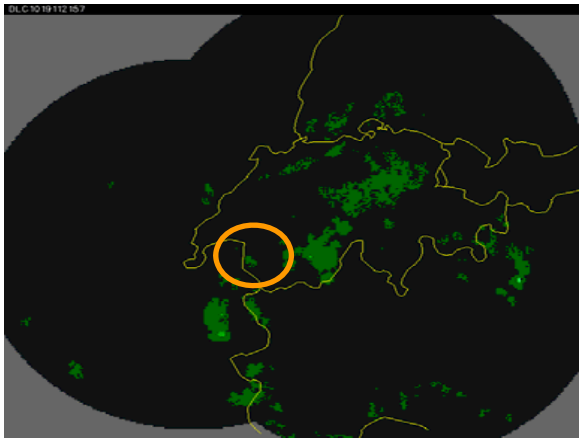



environment (external field):
e.g. Cloud Top Temperature (SATELLITE)

# COALITION methodology: an example (2)



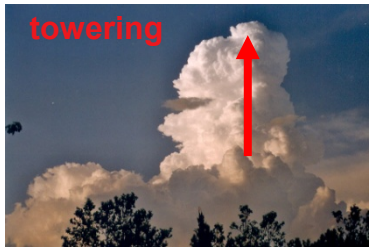

Radar: Vertical Integrated Liquid Content

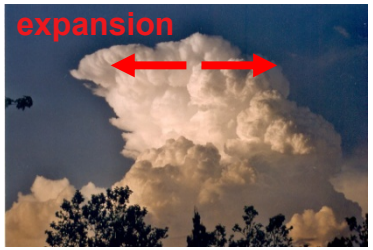


Satellite: Cloud Top Temperature

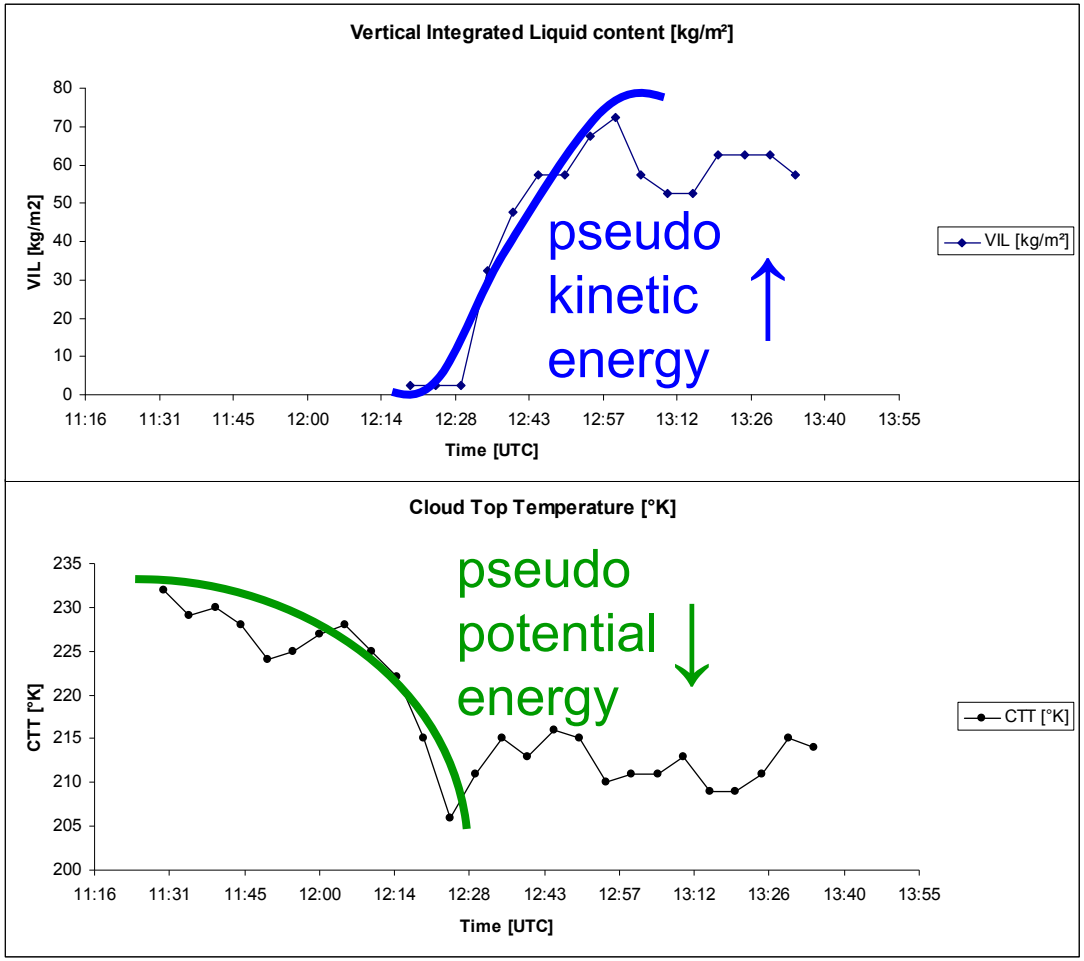
# COALITION methodology: an example (3)

*Heuristic rule:*




→ Released energy for benefit of increasing precipitation intensity (VIL)




**Ekin + Epot = CONST**

Thunderstorm cell defined using VIL & Cloud Top Temperature

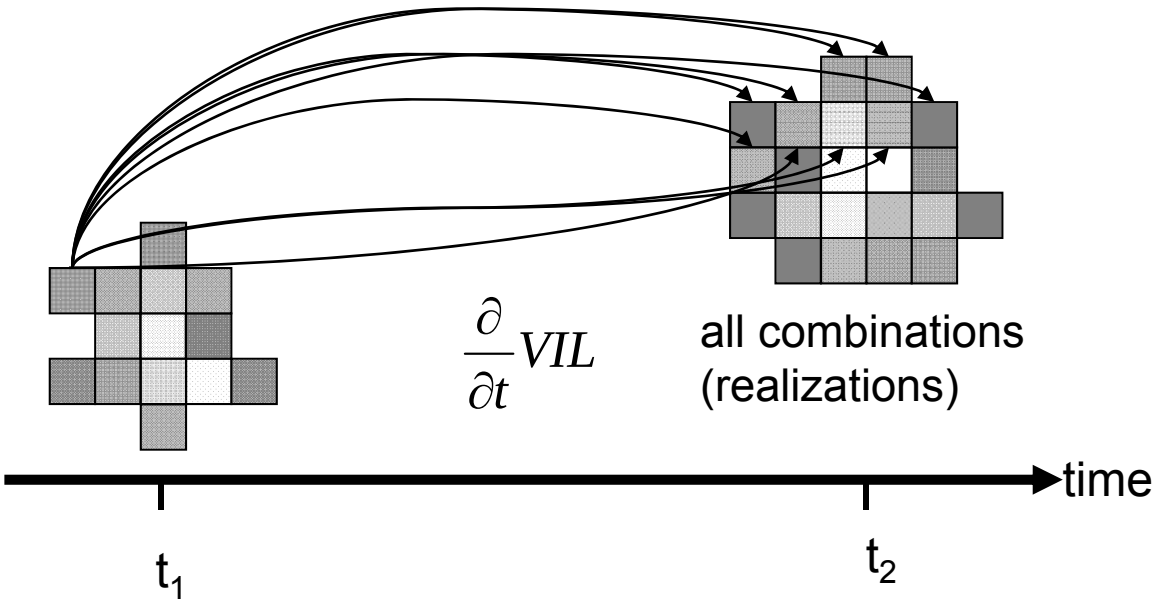
# Calculate Pseudo Kinetic Energy

$$\mathbf{H}(q,p) = E_{kin} + E_{pot} = \text{const}$$

$$E_{kin} = \frac{1}{2} m \dot{q}(t)^2$$

**Example:**

- q = Vertical Integrated Liquid (VIL)
- assumption: statistical stationarity
- m = inertial mass




→ Build the ensemble forecast with all realizations within an object

# Calculate Pseudo Potential Energy

$$\mathbf{H}(q,p) = E_{kin} + E_{pot} = \text{const}$$

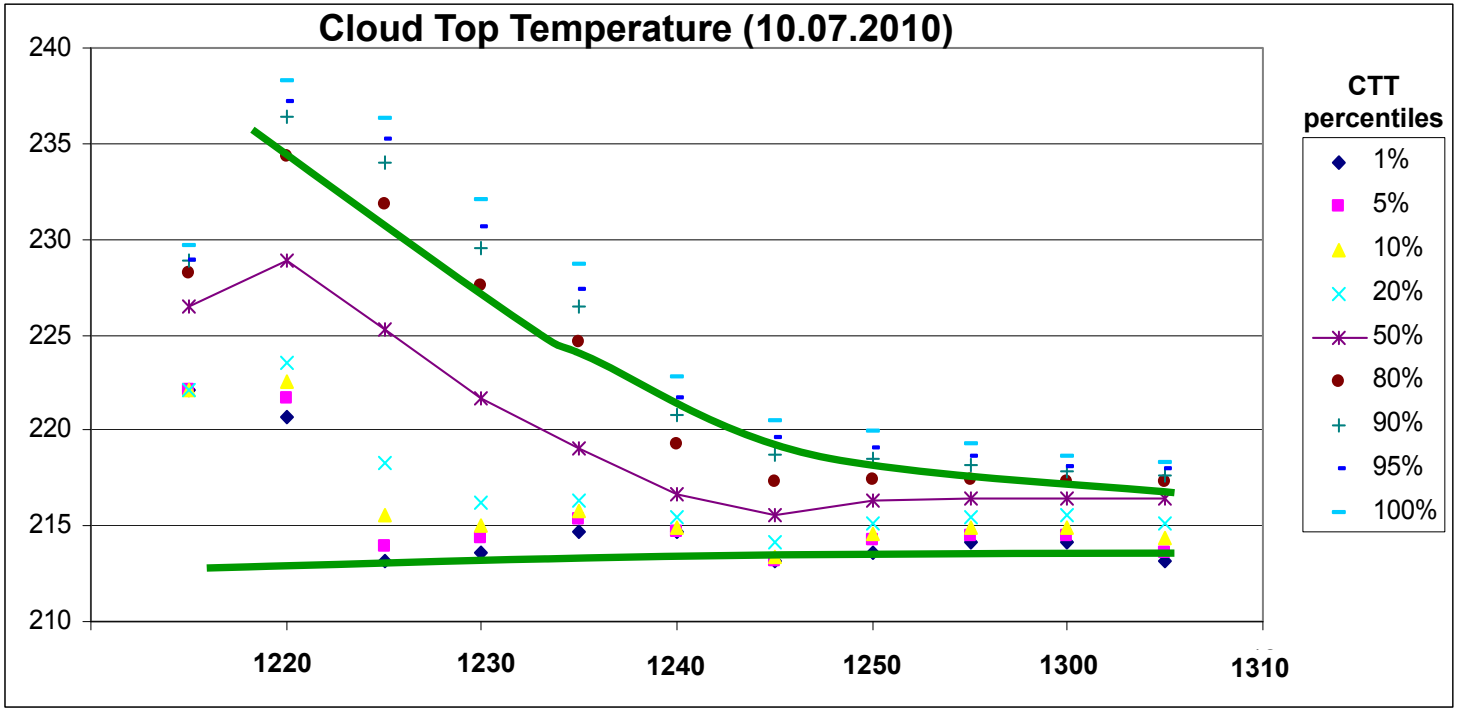
**Example:**

- q = Vertical Integrated Liquid (VIL)
- Environment: Cloud Top Temperature (CTT)

$$E_{pot} = f(t)\, q(t)^2$$

**f(t) → correlation between Object attribute (VIL) evolution and the Environment (CTT)**

**Environment (t) = CTT50%- CTT20%**



# Database

→ **60 stormy days selected**

**(~300 thunderstorms, different intensities)**

→ **5 classes**

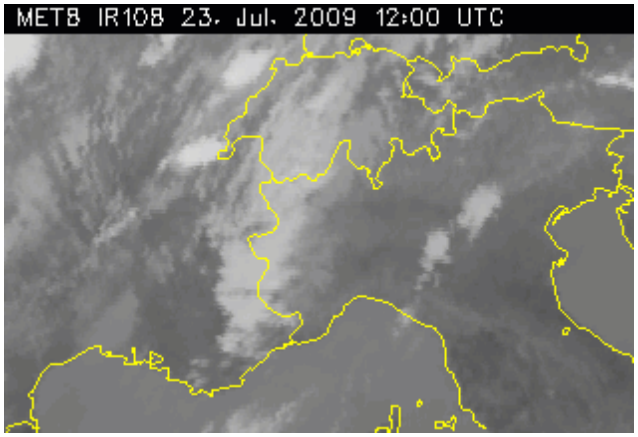
**Selection criteria :**

- intensity
- extension
- duration
- synoptic conditions

**Classes:**

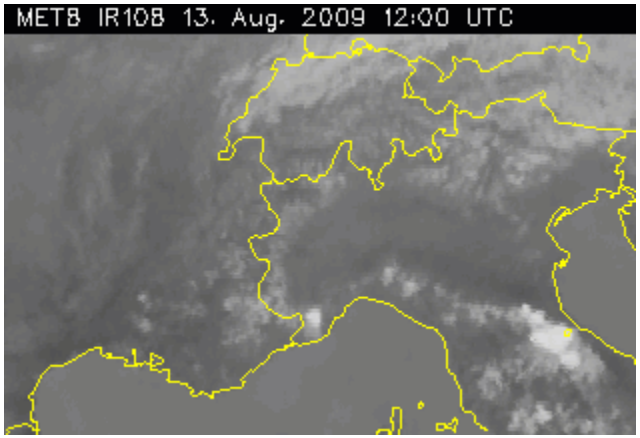
1) severe, long living cells
2) extended mixed situation
3) localized thunderstorms
4) weak convective activities
5) ambiguous situations

***Example of class 1:***




*Cold front, severe long living cells*

***Example of class 3:***




*Stationary cells*

# Module's forecast validation (1)

Module's development
+
Preliminary tuning

5 severe cells
5 weak cells

Cross validation of modules

40 severe cells
40 weak cells

**COALITION DATABASE**

- MSG-RSS
- MPEF
- SAFNWC
- Convection Initiation
- Radar
- NWP / COSMO2
- Lightning
- Digital Elevation Model

→ more than 300 thunderstorm cells between 2009 and 2011 over the Alpine Area

# Module's forecast validation (2)

**Definition / criteria:**

- Severe thunderstorm cell: Vertical Integrated Liquid max ($VIL_{max}$) >= 40 kg/m$^2$
- Weak thunderstorm cell: Vertical Integrated Liquid max ($VIL_{max}$) < 40 kg/m$^2$

**Probability of Detection and False Alarm Rate:**

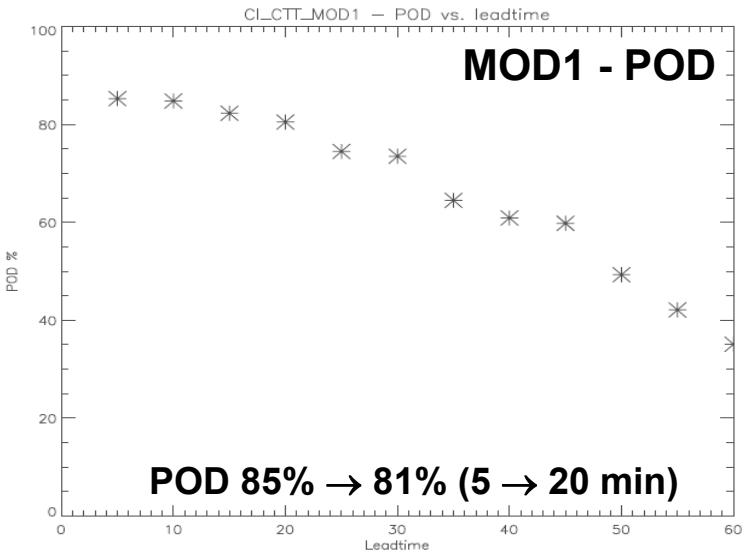
| | | OBSERVATION | |
|---|---|---|---|
| FORECAST | | SEVERE | WEAK |
| | SEVERE | A | B |
| | WEAK | C | D |

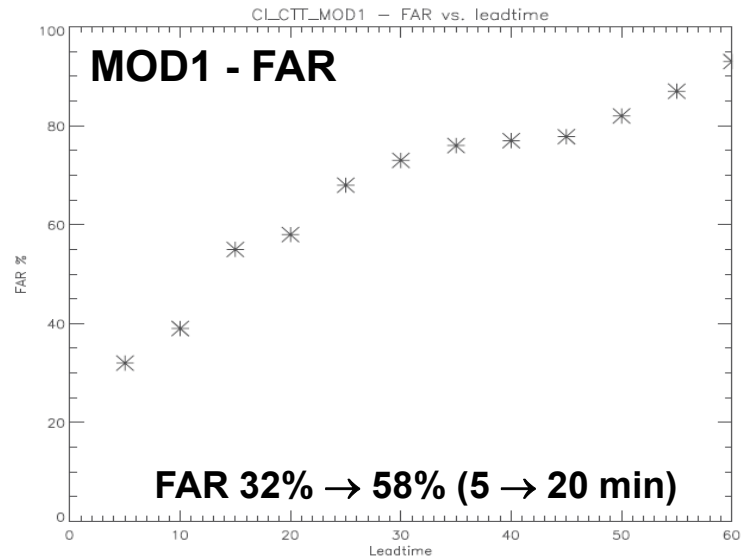
POD = A / ( A + C)

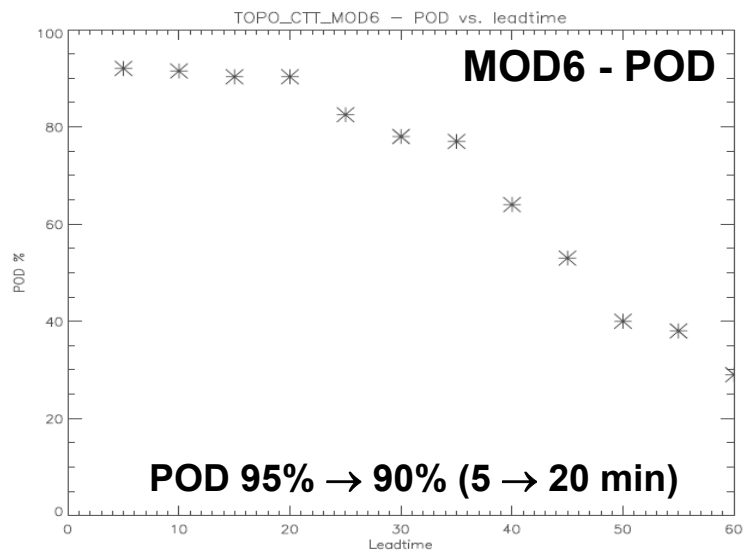
FAR = B / ( A + B)

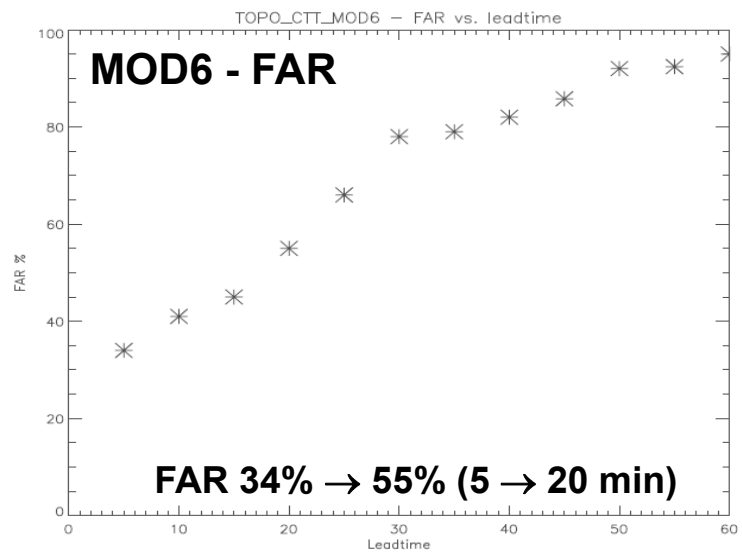
# Modules validation – CTT forecast

→ Cross validation of MODULE 1 and MODULE 6



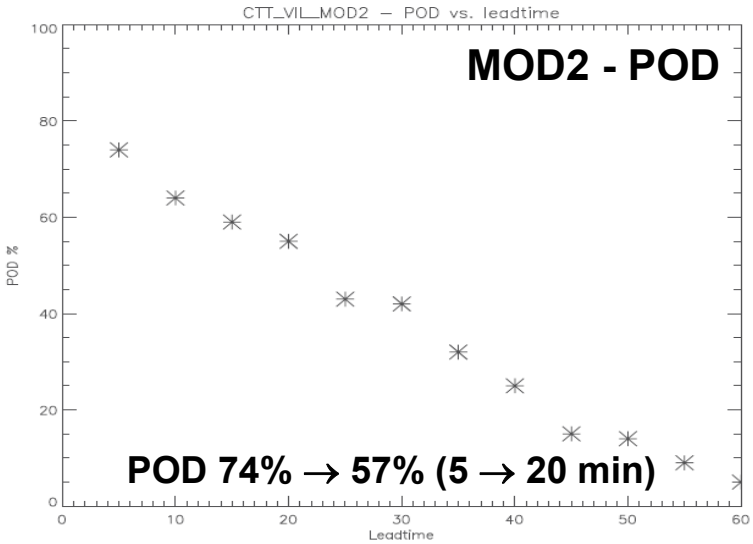



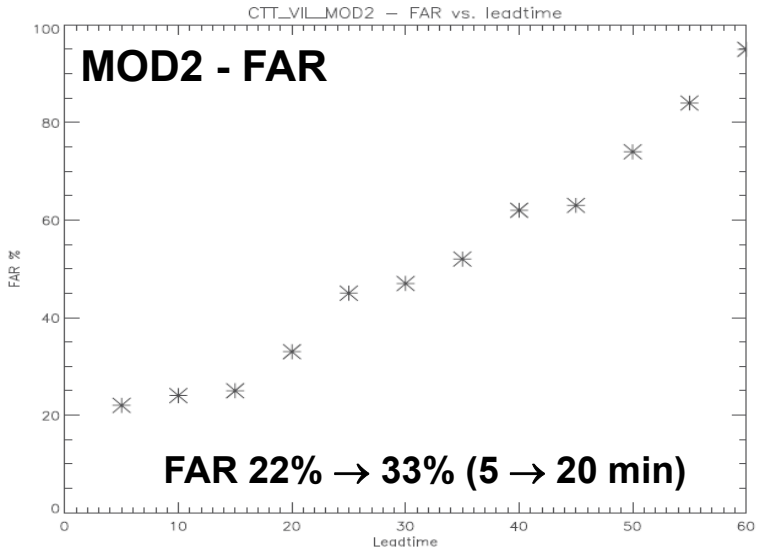



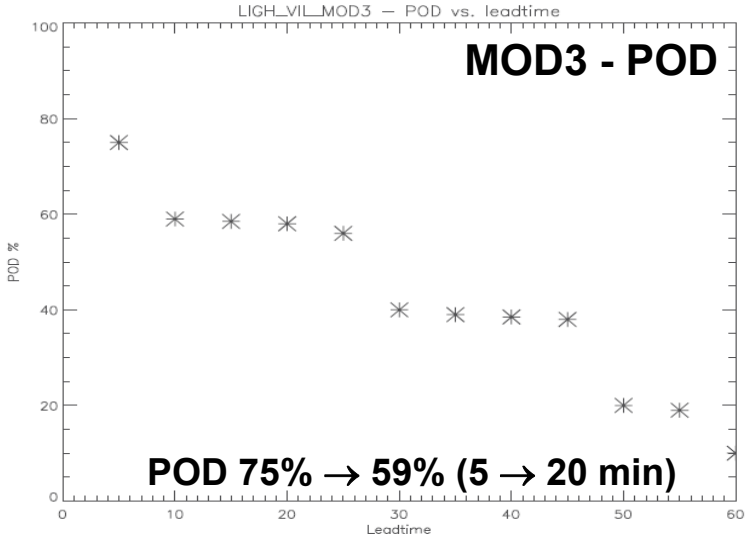



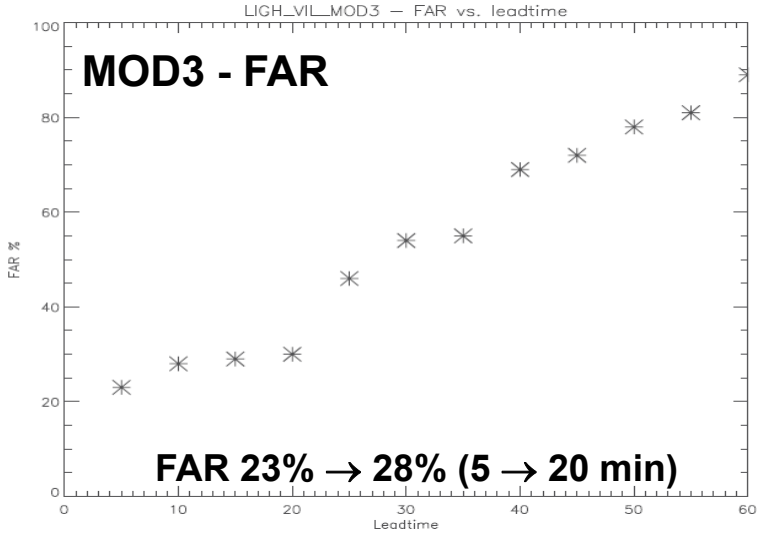
# Modules validation – VIL forecast

## → Cross validation of MODULE 2 and MODULE 3



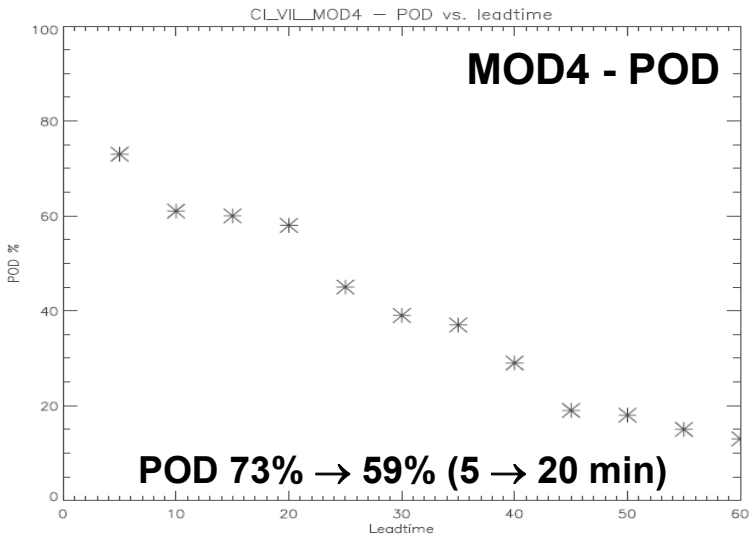



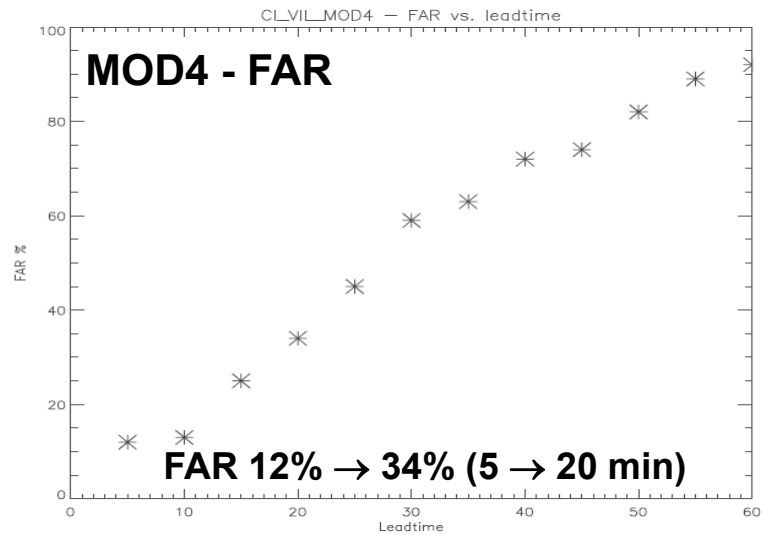



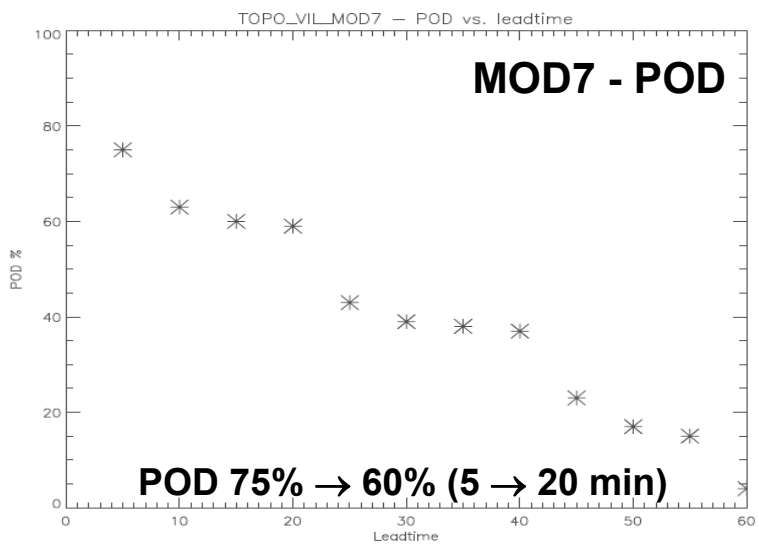



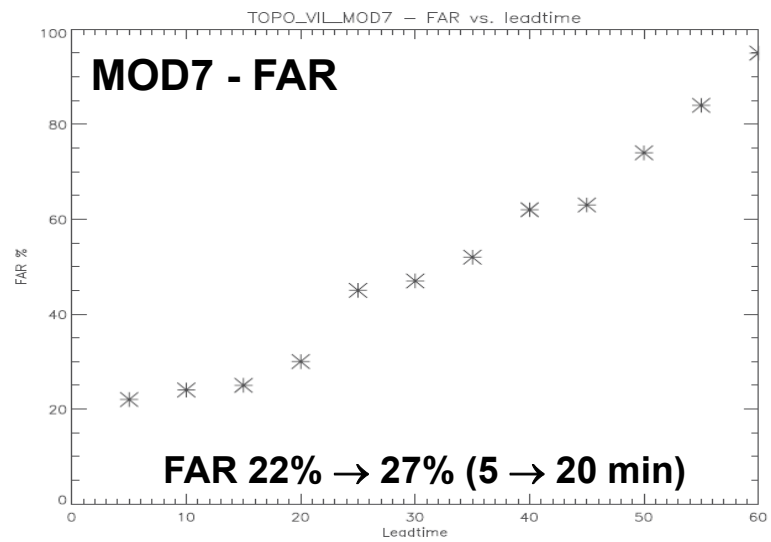
# Modules validation – VIL forecast

→ Cross validation of MODULE 4 and MODULE 7



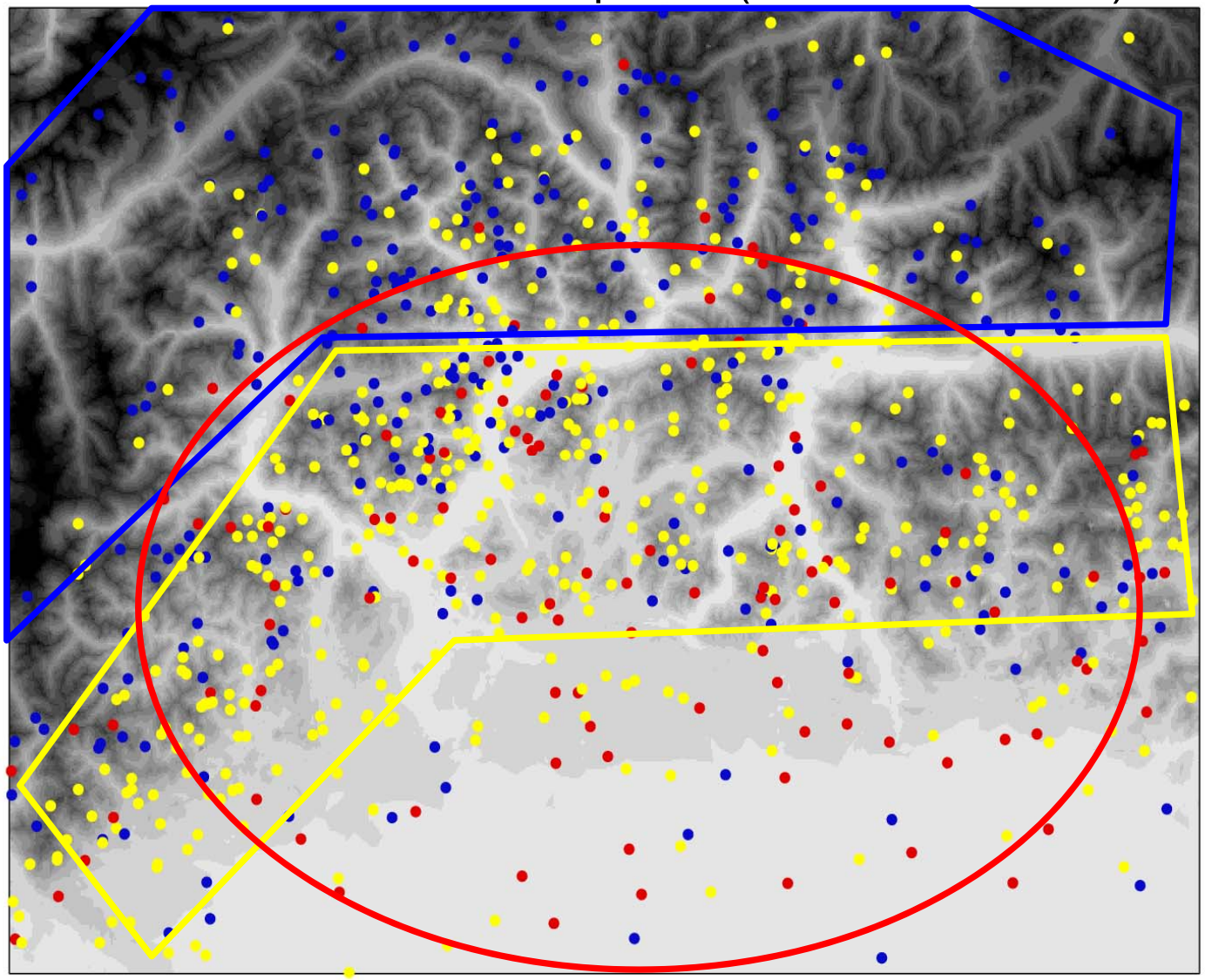



# Orographic forced convection

Thunderstorm cells development (duration > 30 min)

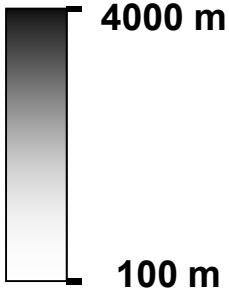


Intensity:
(Provided by TRT)

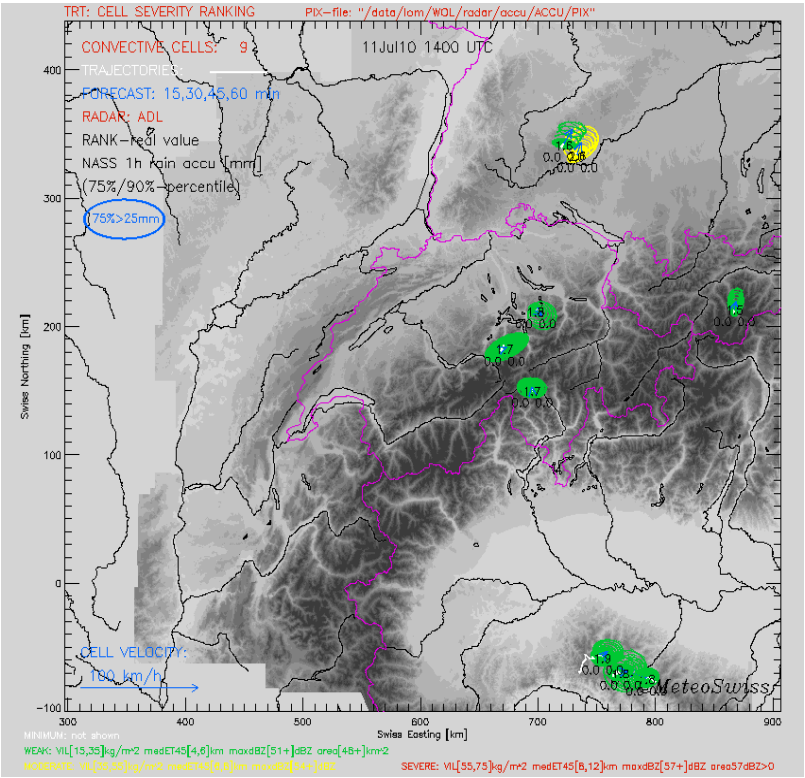
- weak
- moderate
- severe

Classification based on the maximal radar reflectivity

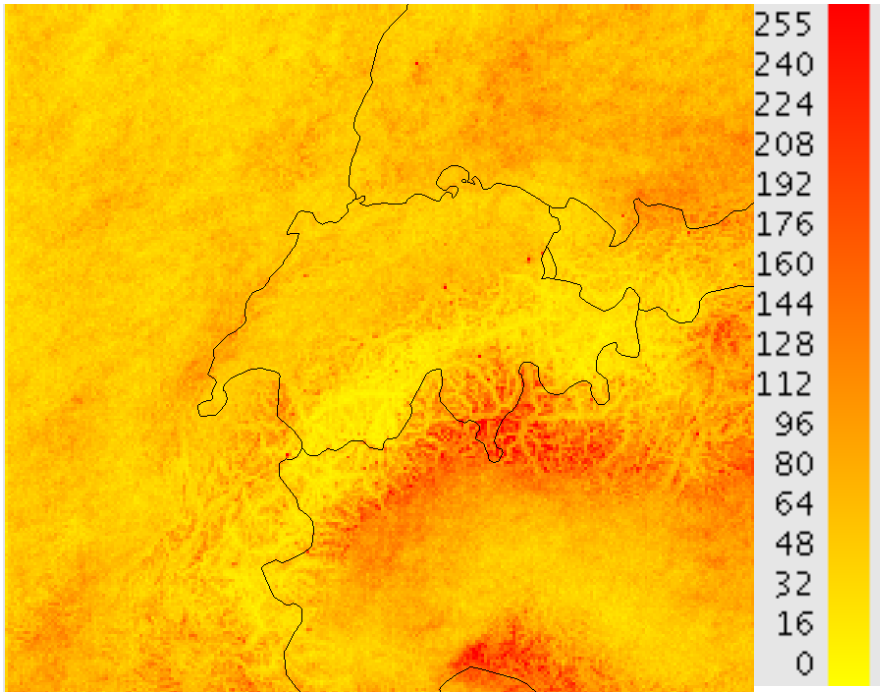
**Altitude**



# Orographic forced convection: lightning climatology (2000-2010)



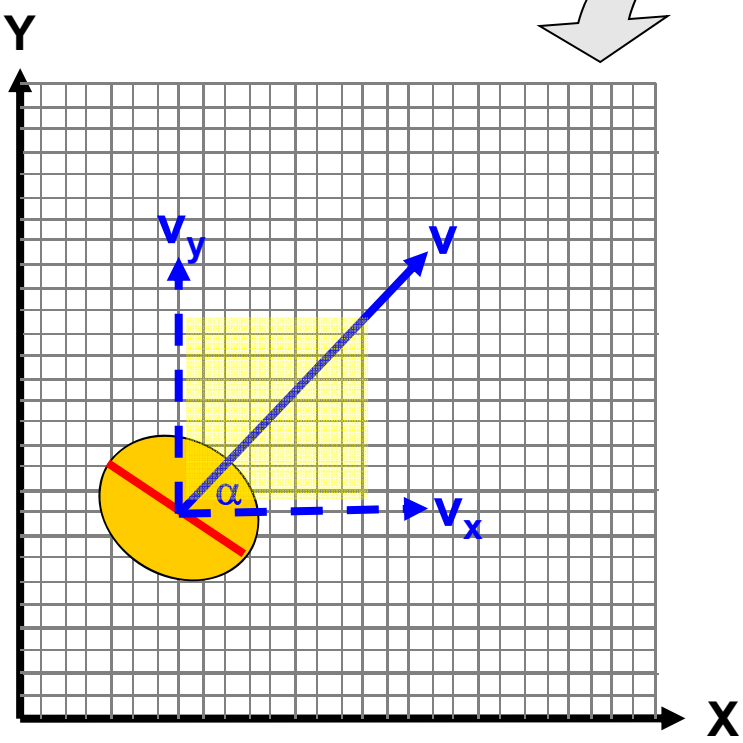

**# Cloud to ground strokes per km$^2$ and year**

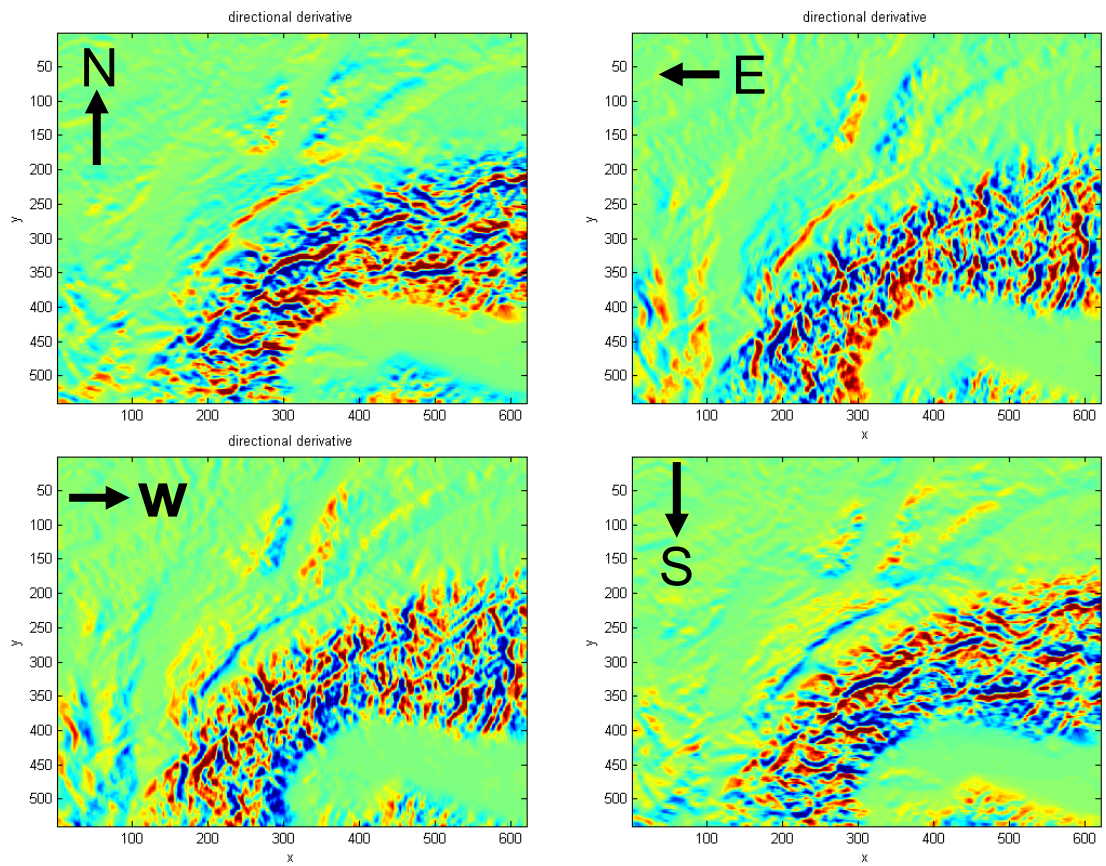



**→ Lightning climatology shows a better correlation in the southern Alps**

# Orographic forced convection: directional slope gradients

**Field of weighted sum of directional slope gradients ($V_x$, $V_y$) as environment**




RDT cell

V: cell velocity

$$V_x = V * \cos(\alpha)$$
$$V_y = V * \sin(\alpha)$$