PP-AWARE TASK 3.5

LPI verification and correlation of convective events with microphysical and thermodynamical indices

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Motivation

- The distribution analysis of a number of convective events will allow lightning/thunderstorm regimes to be determined.
- LPI is a measure of the potential for charge generation and separation that leads to lightning flashes in convective thunderstorms available in COSMO model.
- While the connection between cloud microphysics and lightning seems apparent, forecasting of thunderstorms and the potential for lightning usually rely on stability and thermodynamical indices.
- LPI will be evaluated (optimum upscale window) over our area on certain events as a useful parameter for predicting lightning as well as a tool for improving weather forecasting of convective storms and heavy rainfall.

Lightning formation

- The microphysical processes that lead to the formation of precipitation particles are involved in charge separation and the buildup of electric fields in convective clouds.
- The noninductive mechanism, involves rebounding collisions between graupel particles and cloud ice crystals and requires the presence of **supercooled liquid water**
- While the connection between **cloud microphysics** and lightning seems apparent, the common indices used for the forecast of lightning mostly rely on stability and **thermodynamical indices**.

Lightning Potential Index (J/Kg) (Yair et al.2010, JGR)

- Lightning Potential Index (LPI) is a measure of the potential charge separation that leads to lightning flashes in convective TSs.
- It is calculated from model simulated updraft and microphysical fields within the charge separation region of clouds between (0 °C and - 20 °C), where the non inductive mechanism involving collisions of ice and graupel particles in the presence of supercooled water is most effective (Saunders, 2008).

- *LPI is defined as the volume integral of the total mass flux of ice and liquid water within the "charging zone" in a developing thundercloud.* The LPI (J kg^{-1}) and is defined as,

$$LPI = \frac{1}{V} \iiint \epsilon \, \omega^2 dxdydz$$

Where V is the volume of air in the layer between 0°C and -20°C, w is the vertical wind component (m s^{-1}), and q_s, q_i and q_g are the model-computed mass mixing ratios for snow, cloud ice, and graupel respectively (in kg kg^{-1}).€ is a dimensionless number that has a value between 0 and 1 and is defined by,

$$\epsilon = 2(Q_i Q_l)^{0.5} / (Q_i + Q_l)$$

Where: Q_l is the total liquid water mass mixing ratio (kg kg-1)and Qi is the ice fractional mixing ratio (kg kg-1) defined by,

$$Q_i = q_g \left[\left((q_s q_g)^{0.5} / (q_s + q_g) \right) + \left((q_i q_g)^{0.5} / (q_i + q_g) \right) \right]$$

ε is a scaling factor for the cloud updraft and attains a maximal value when the mixing ratios of supercooled liquid water and of the combined ice species (the total of cloud ice, graupel, and snow) are equal.

- Calculation of the LPI from the cloud-resolving atmospheric model output fields can provide maps of the microphysics based potential for electrical activity and lightning flashes.

METHODOLOGY: LPI

- LPI can only be calculated if you run with the graupel microphysics (itype_gscp=4) or the 2-moment microphysics.
- Results for LPI are only meaningful in convection resolving mode, i.e., deep convection parameterization switched off and grid spacing <= 4 km.
- COSMO-GR4 simulations provided LPI (not a operational product) and CAPE-CON forecasts while other indices were calculated in postprocessing.
- LPI does not provide a flash number or flash density therefore its interpretation is not intuitive and of no direct value to the forecaster

METHODOLOGY FOR LPI FORECAST EVALUATION

Use the COSMO-GR4 with 0.04 deg natïve resolution forecasts. Aggregate fcs and obs in grids with multiple space resolution.

Forecasts gridded fields: For the original resolution (0.04), the LPI value of each grid point is checked, and if it is higher than threshold (see table below) , a value of 1 is given to the grid point. Next, sums of the original grid points are aggregated creating a new grid with multiple resolution (0.04x2,3,.....20). For each new grid cell, the MAX LPI value is assigned

Observations: For all grid resolutions from 1x0.04 up to 20x0.04deg, a check (lat-lon) is performed in the boundaries of each grid cell. When lightning observations exist a value of 1 is assigned to that grid point or else a value of zero.. Lightning observations were based on the sum of ± 15min interval every hour

Statistics :

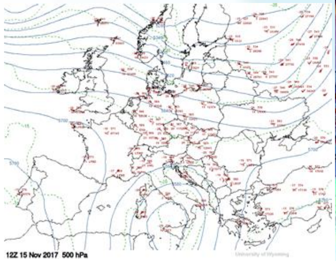
- Direct comparison of obs-fcs upscaled grids and calculation of contingency table (yes/no event).
- SAL methodology for threshold 1 on native resolution.

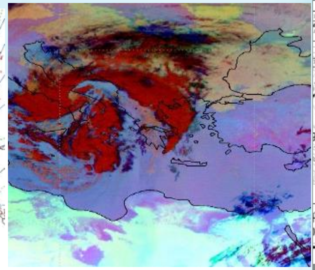
- LPI_MAX_{3x3} = LPI_MAX in einer 3x3 GP Umgebung
  - Mai – August: $LPI\_MAX_{3x3} > 10^{-3}$ J/kg und RG ≥ 0.0 mm/h
  - März, April, September: $LPI\_MAX_{3x3} > 0.2$ J/kg und RG ≥ 1.2 mm/h
  - Oktober – Februar: $LPI\_MAX_{3x3} > 0.5$ J/kg und RG ≥ 3.0 mm/h

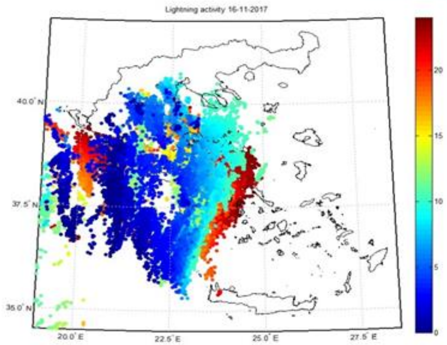
TEST CASES

- TC1-15112017-good
- TC2-12112019-good
- TC3-24112019-good
- TC4-10072019
- TC5-07122020-good
- TC6-08082020
- TC7-02062018
- TC8-03102019-good

TEST CASE I (15.11.17)

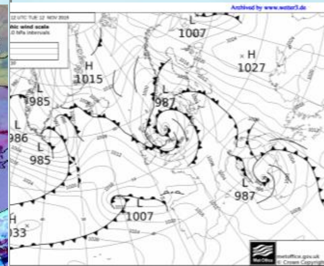


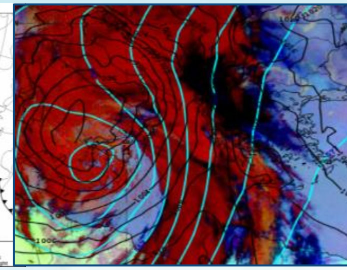


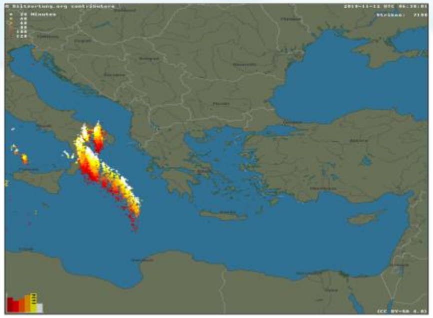


On 13/11 a deep low over Genoa Gulf (995hpa) transferred polar air masses over Southern Italy. On 15/11 the low expanded and moved over Central Medit. Over the warm sea of Ionian, the cold air destabilized. Due to weak wind shear, a cyclone (Medicane) was formed. Heavy rainfall and floodings caused severe damages over Western Attica.

TEST CASE II (12.10.17)

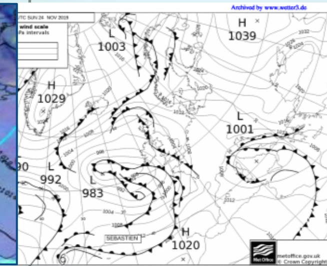


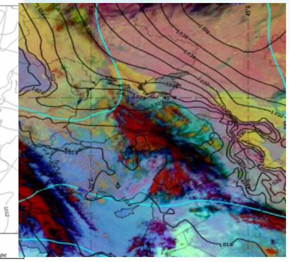


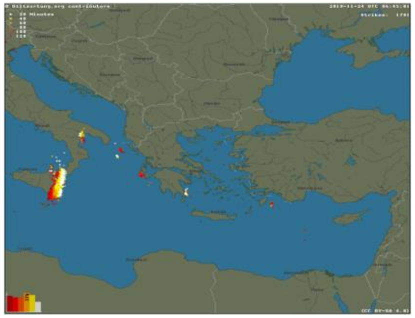


Deep barometric low with frontal activity over South Italy moved North Eastwards leading to strong gale (9 Beaufort) southerly winds, heavy rain, thunderstorms and electrical discharge all over Greece (except Dodecanese). Floodings over Attica and Crete were reported, and Ionian islands suffered from severe damages especially Corfu and Cefalonia.

TEST CASE III (24.11.19)







Deep low over Italy moved eastwards and produced a cold front over Ionian Sea which influenced all the country of Greece with severe damages due to heavy rainfall. Floodings were reported in South Attica, Rhodes, Central Macedonia and East Aegean Islands. Strong southerly gale winds 9Bf over all seas. Snowfall was reported in mainland mountains.

LPI EVALUATION

in various spatial scales

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Test Case I

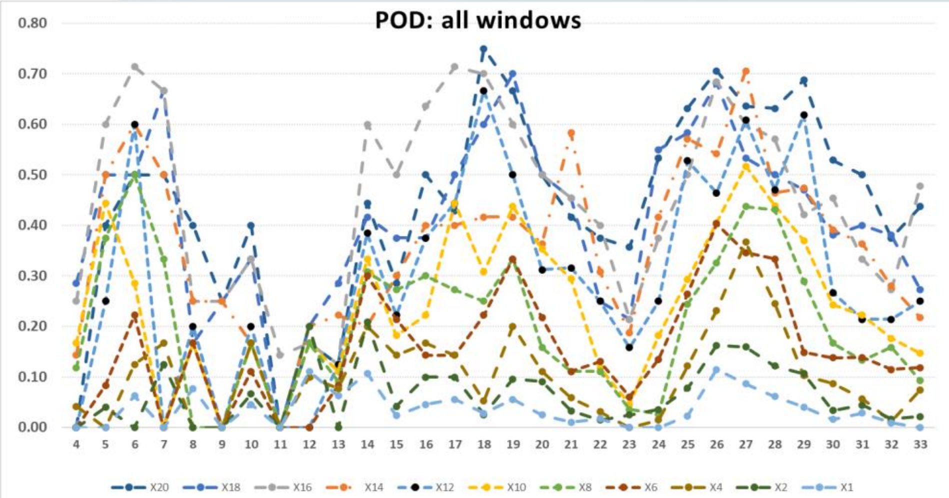
No skill for first 12h of event

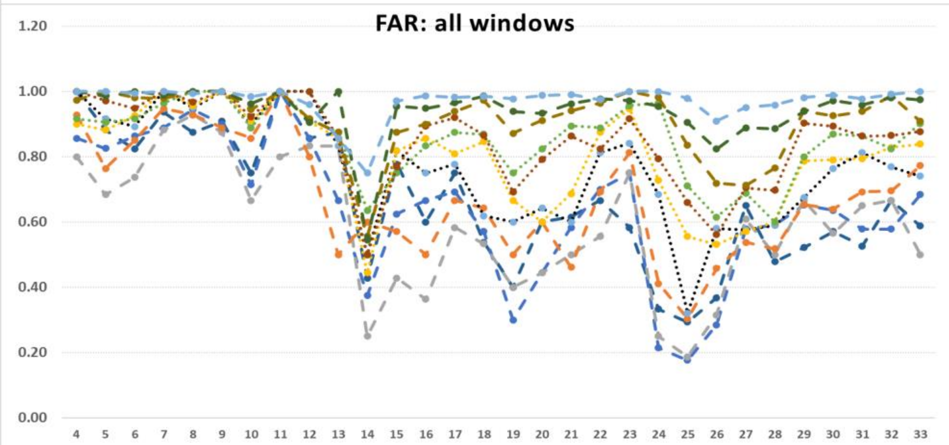
POD: reduced skill in afternoon hours, improved performance for scales >16x0.04~64km

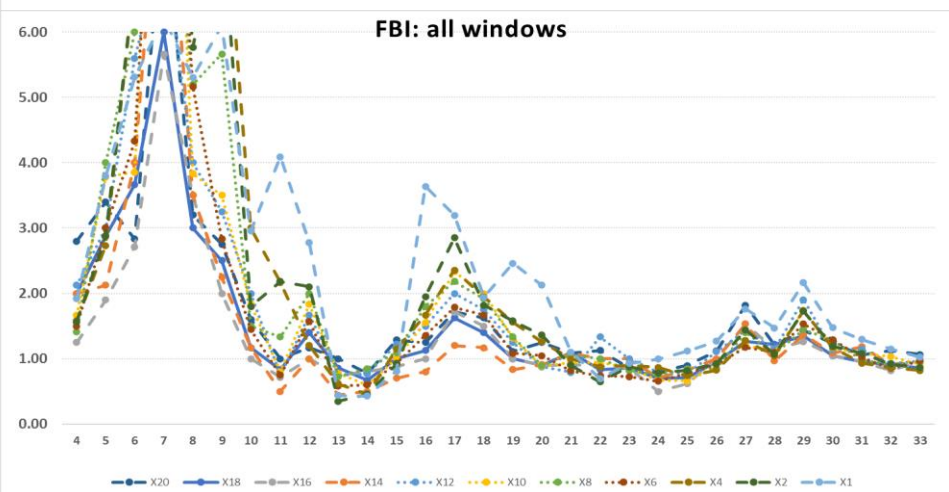
FAR: Scales >14x0.04~56km, no variation in performance with lead time

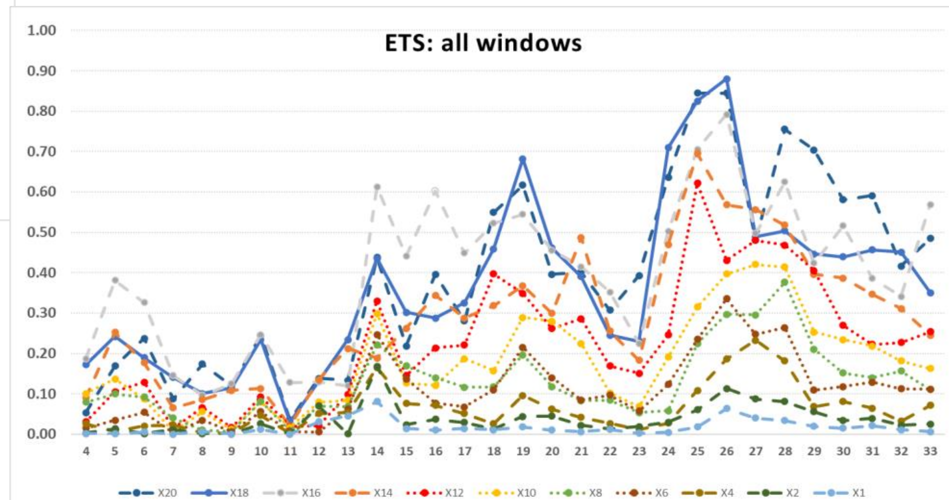
FBI: no impact of the upscaling in the performance, high overestimation in first 10h

ETS: performance does not increase linearly with increased resol, optimum in most hrs the 64km resol.









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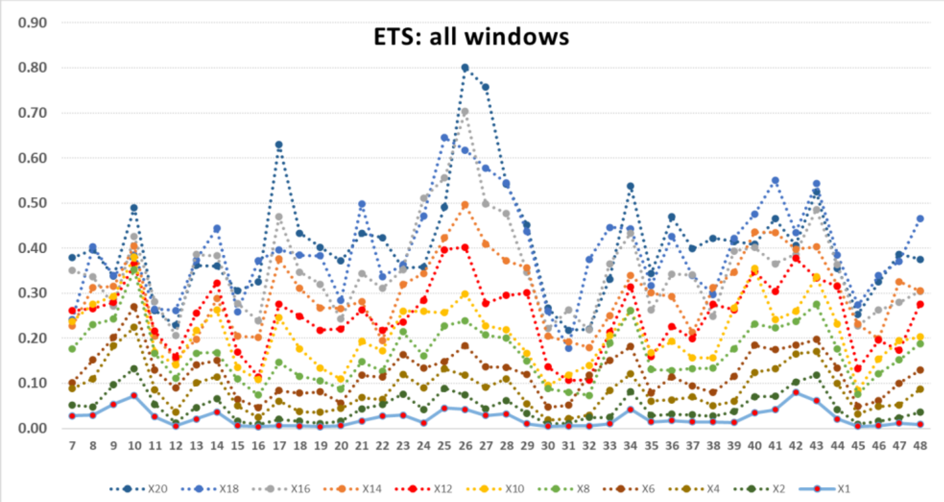

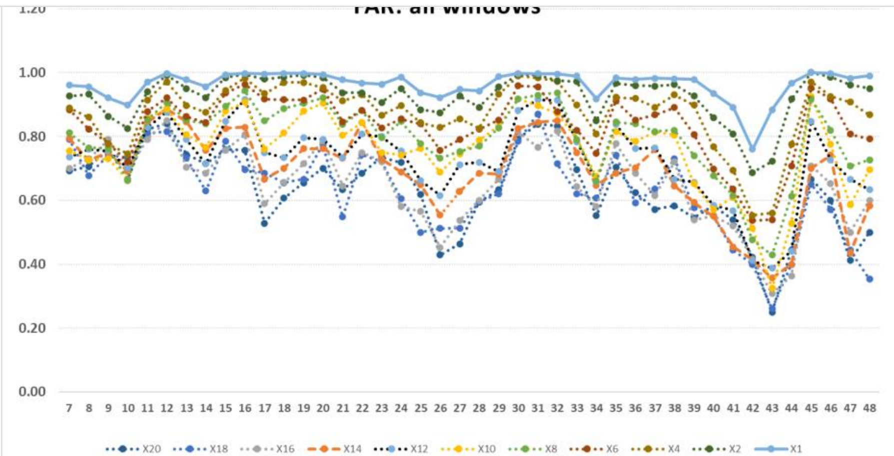

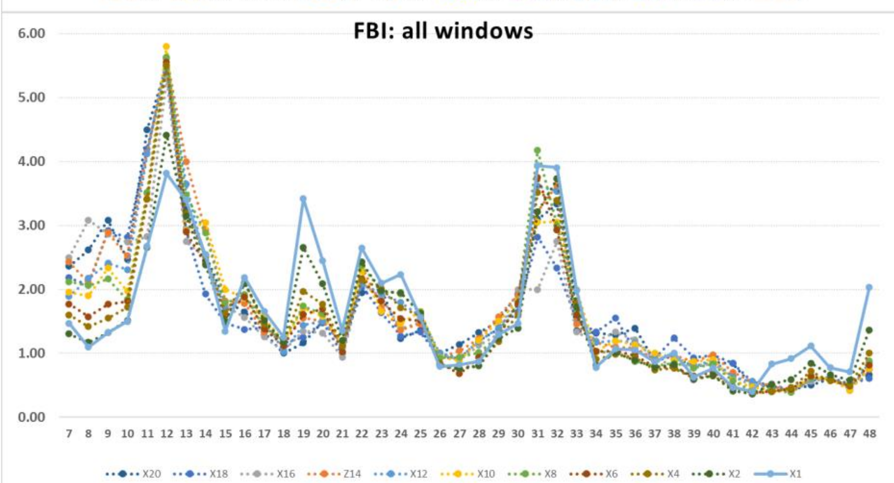

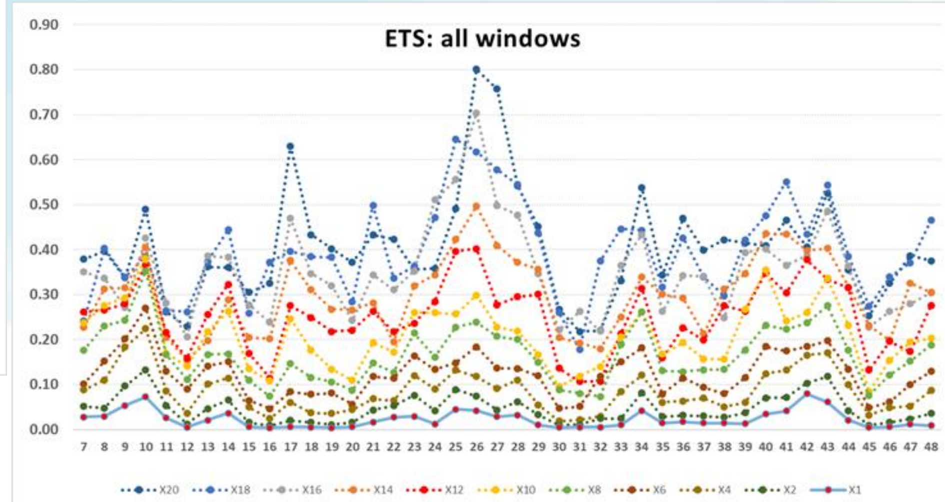

Test Case II

No skill for original resolution

POD: no change in skill with lead time. Improved performance for scales >12x0.04~48km with no clear improvement in further upscaling

FAR: Improved skill during evening hours

FBI: no impact of the upscaling in the performance, high overestimation for original resolution but almost for all upscaled fcst

ETS: performance increases linearly with window size, until 14x0.04deg~56km

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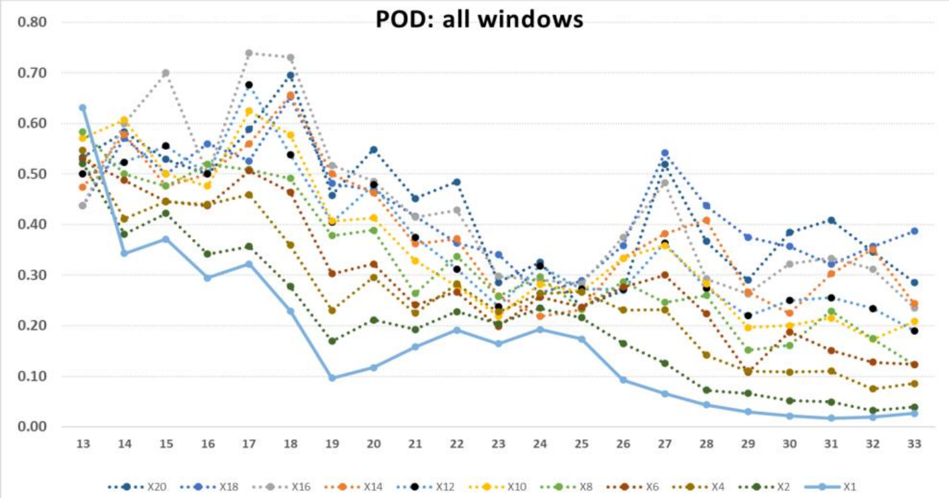
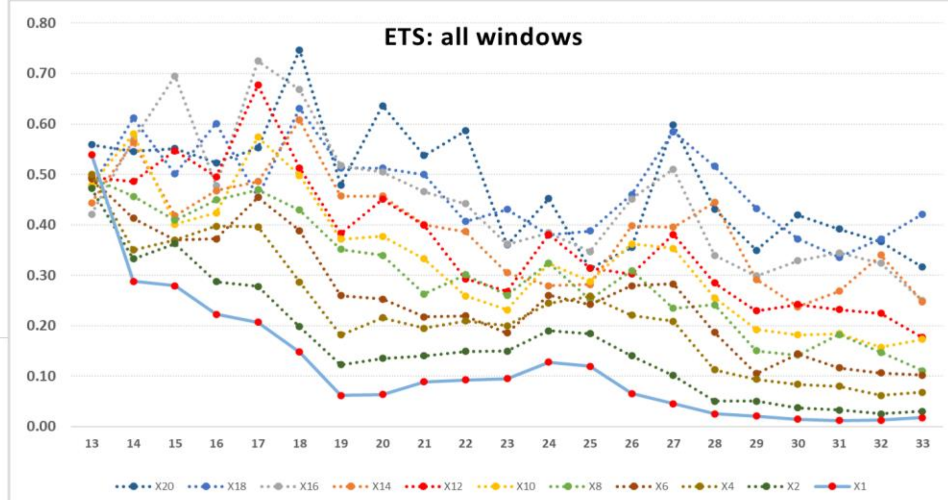
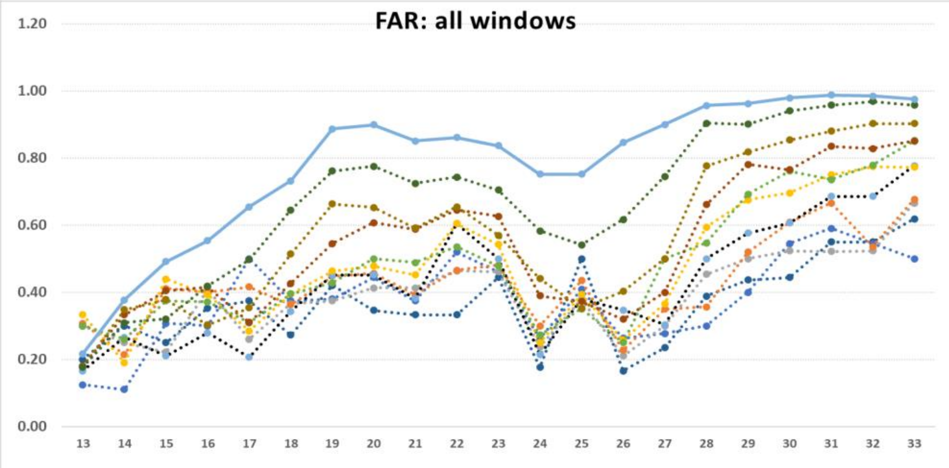






Test Case III

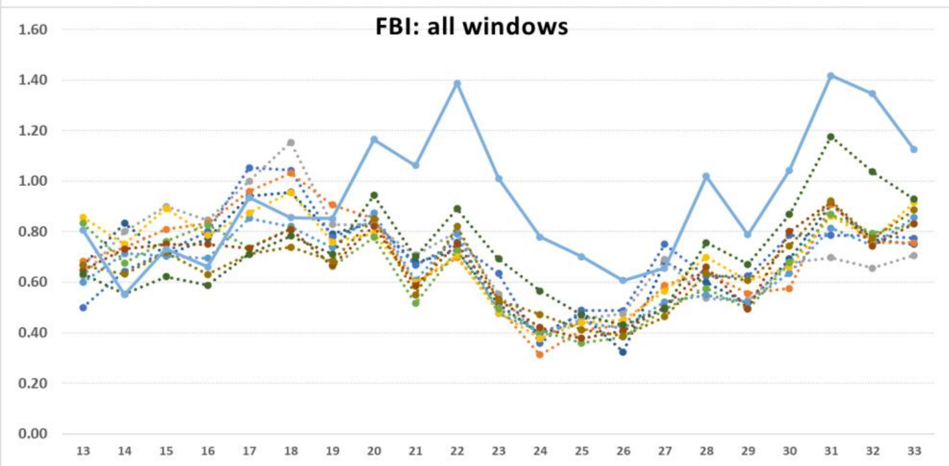
Improved performance compared to other TCs, even in the original resolution

POD: skill reduces with lead time

FAR: For resolution >10x0.04~40km skill steady

FBI: small underestimation in all upscaled grids

ETS: performance increases linearly with window size. For windows higher than 40km good forecast skill



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SAL LPI EVALUATION

(for structural characteristics)

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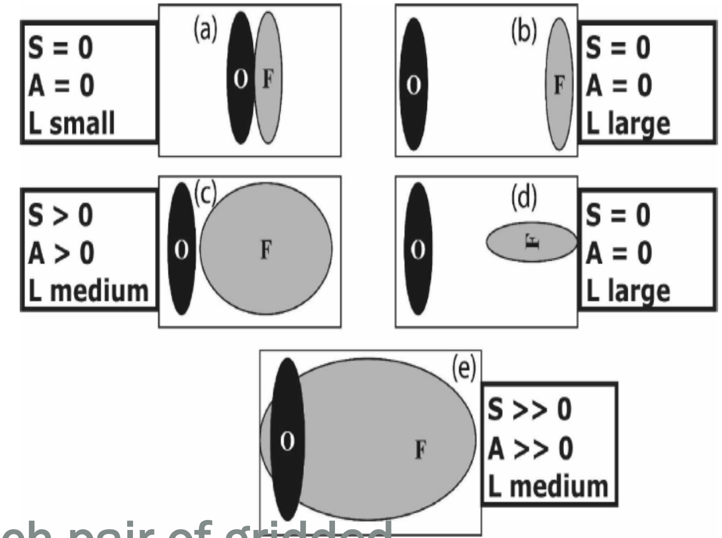
SAL:
Object based verification measure



SAL Method (Wernli et al. 2008, 2009) For each pair of gridded observations/forecast field 3 indexes are calculated.

S: Structure Component (Compares Total Volume of Normalized - Objects of obs/fcst . Captures size and shape of objects) (Values from -2 to 2) S=0 perfect, S >> 0 forecast predicts more widespread pcp , S<< 0 forecast predicts more peaked objects

A: Amplitude Component (Normalized difference of domain-averaged values of forecast and obs field) (Values from-2 to 2) A=0 perfect, A >> 0 forecast overpredicts pcp A<< 0 forecast underpredicts

L: Location Component (Consists of L1+L2) (L Values from 0 to 2) (0 perfect)

L1 : normalized distance between centers of mass of the obs/fcst fields

L2: difference of normalized distance between center of mass and individual objects over observed and forecast field. **Difference of Scattering of objects**

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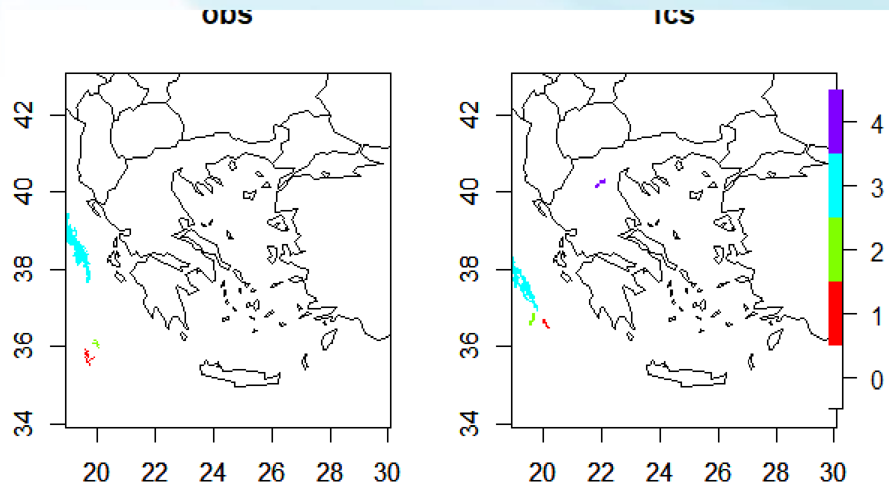
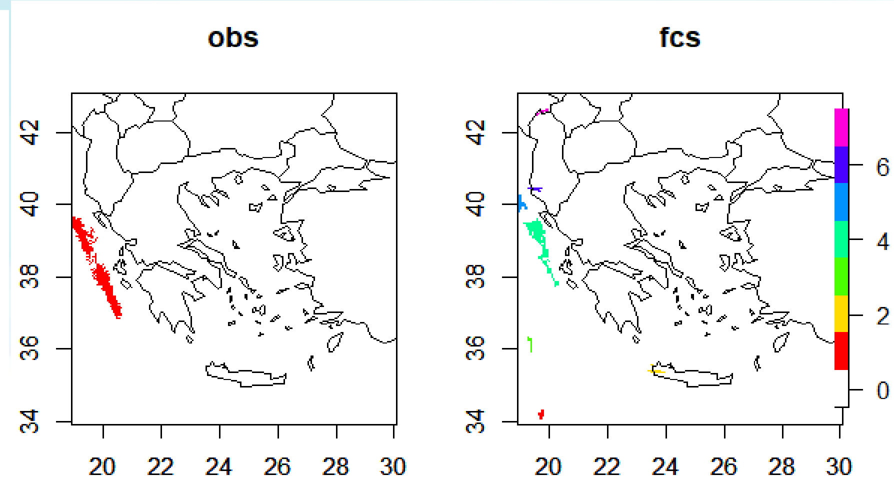
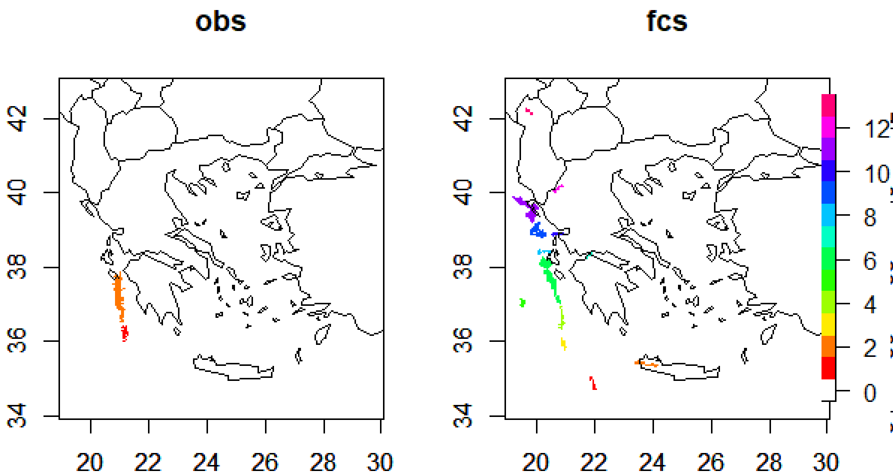
Case II



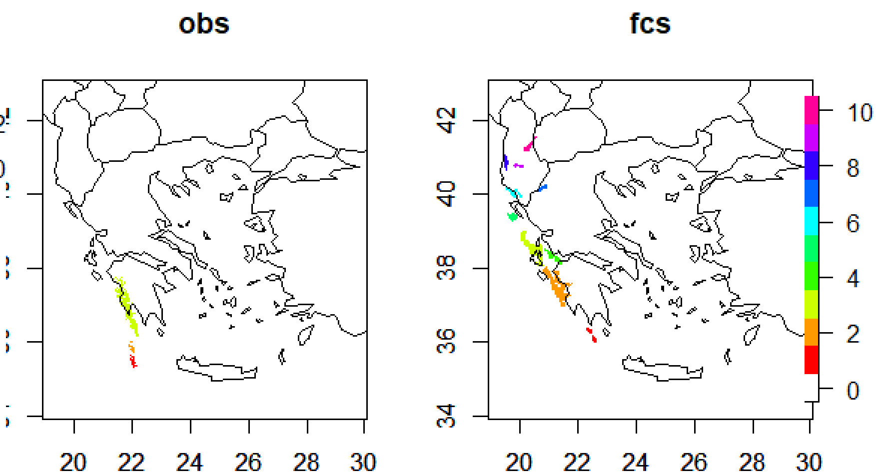
08h



10h

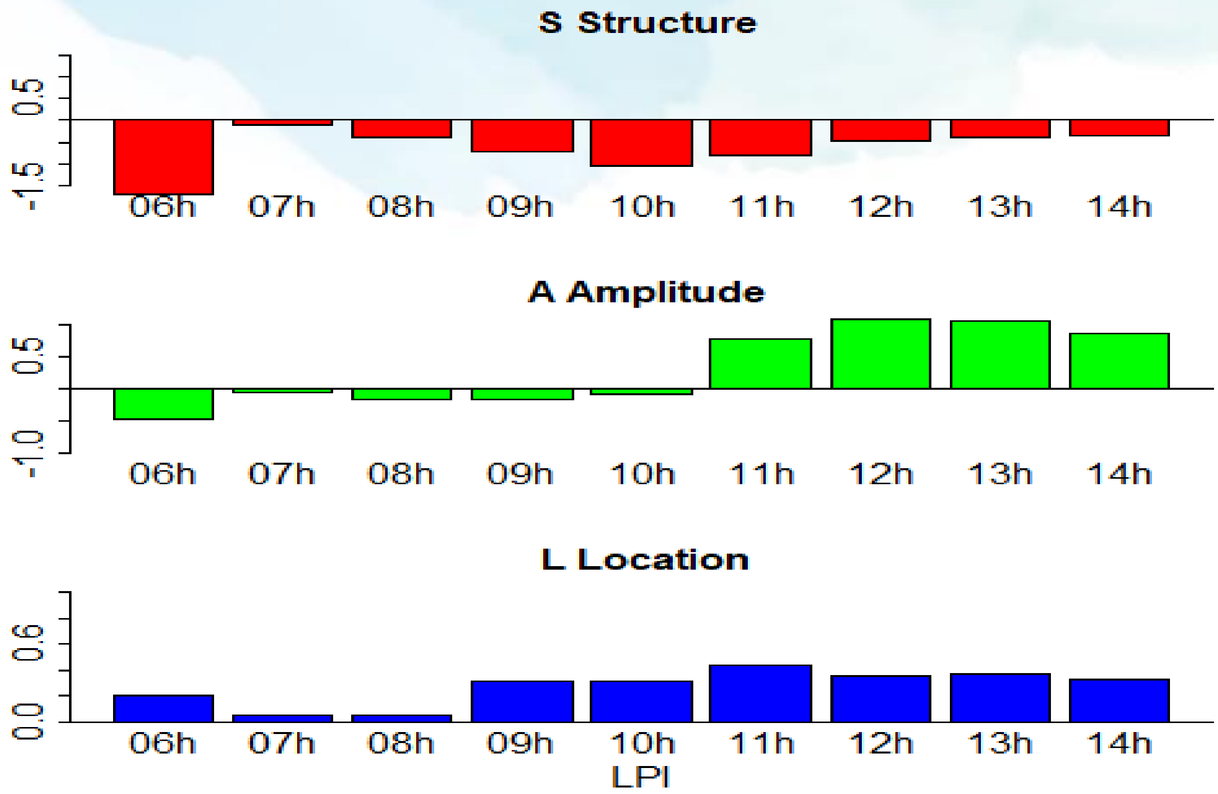


12h



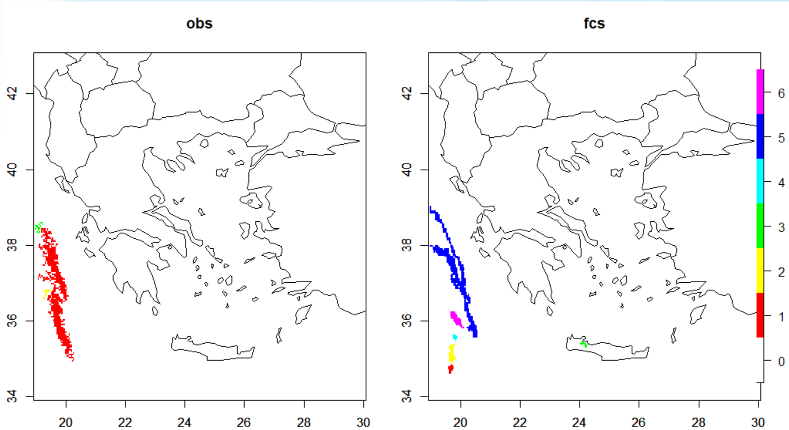
14h

Case II

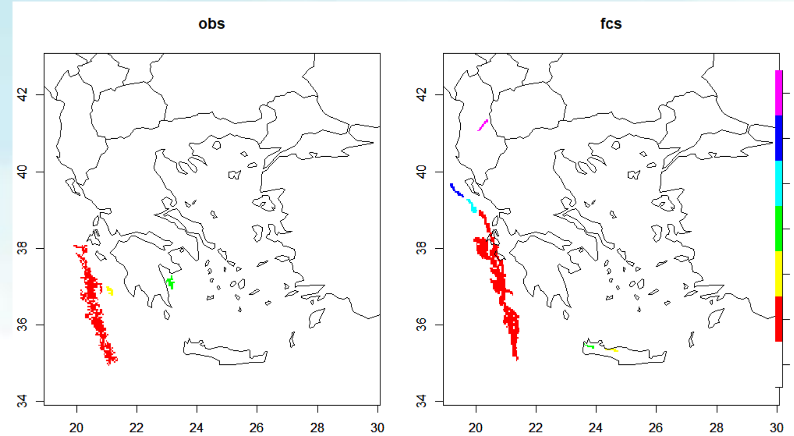


The **S values** are negative, indicating that the model predicts sharper objects.
The **A is positive and over 0.5 around the afternoon hours** (total LPI overestimated as shown in FBI index in upscaling).
The **L parameter** is also increases after 09h, indicating some differences in location of objects in respect to the observed.

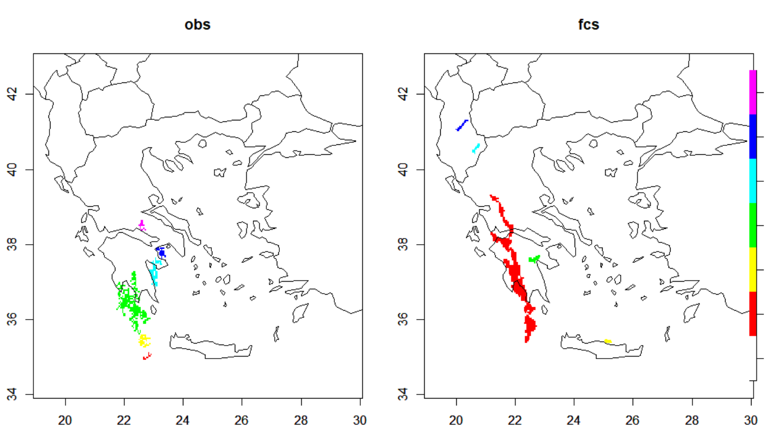
Test Case III



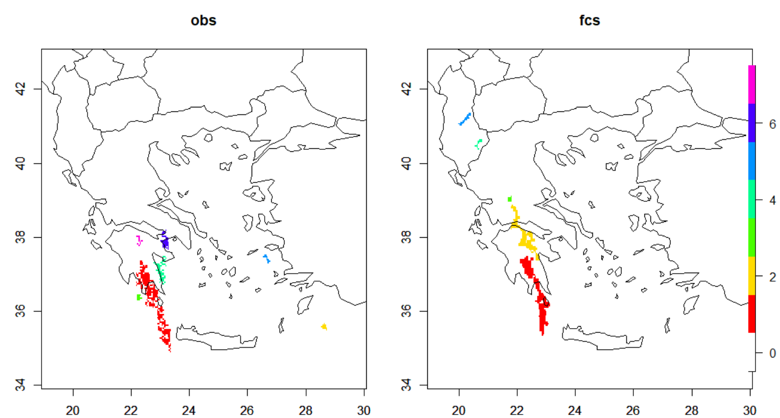
17h



20h

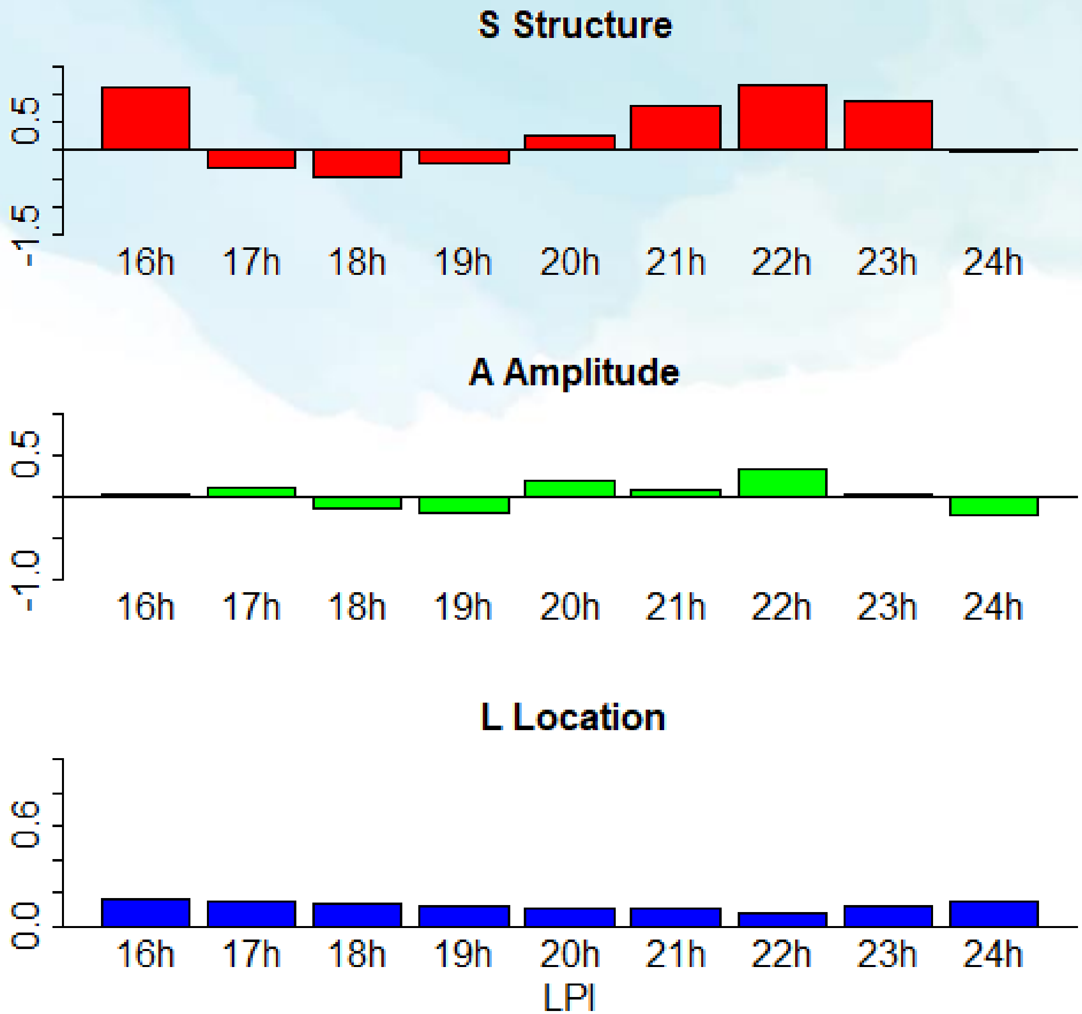


23h



24h

24/11/19 Observed and forecasted objects during the passage of the front



The **S values** are variable with time model predicting more widespread objects in the beginning and around the end of the forecast time.

The **A absolute values** are less than 0.5 and the total LPI is satisfactorily predicted (slightly over forecasted mainly 20-23h).

The **L parameter** is low (around 0.2) and shows good agreement on the location of objects in respect to the observed.

THERMODYNAMICAL INDICES
for thunderstorm forecast

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Thermodynamical indices for lightning estimation (I)

- **K index (KI)** assesses potential for severe thunderstorms.

$$KI = (T_{850} - T_{500}) + T_{d850} - (T_{700} - T_{d700}).$$

KI (K)	THUNDERSTORM CHANCES
UNDER 288	0% Chance
IN THE MIDDLE OF 288 AND 293	20% chance
IN THE MIDDLE OF 294 AND 298	20-40% possibility for little thunderstorms
IN THE MIDDLE OF 299 AND 303	40-60% possibility for little to medium thunderstorms
IN THE MIDDLE OF 304 AND 308	60-80% possibility for heavy thunderstorms
IN THE MIDDLE OF 309 AND 313	80-90% possibility for severe thunderstorm event
ABOVE 313	Over 90% possibility for thunderstorm event

- **CAPE (Convective available potential energy)** integrated amount of work that the upward (positive) buoyancy force would perform on a given mass of if it rose vertically through the entire atmosphere.

CAPE (IN J/KG)	THUNDERSTORM CHANCES
UNDER 300	no energy for convection
FROM 300 TO 1000	Poor potential for weak convection
FROM1000 TO 2500	moderate potential for convection
GREATER THAN 2500	strong potential for convection

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Thermodynamical indices for lightning estimation (II)

- **Humidity Index (HI),** is describing the importance of relative humidity as the major component needed for the severe thunderstorm activities.

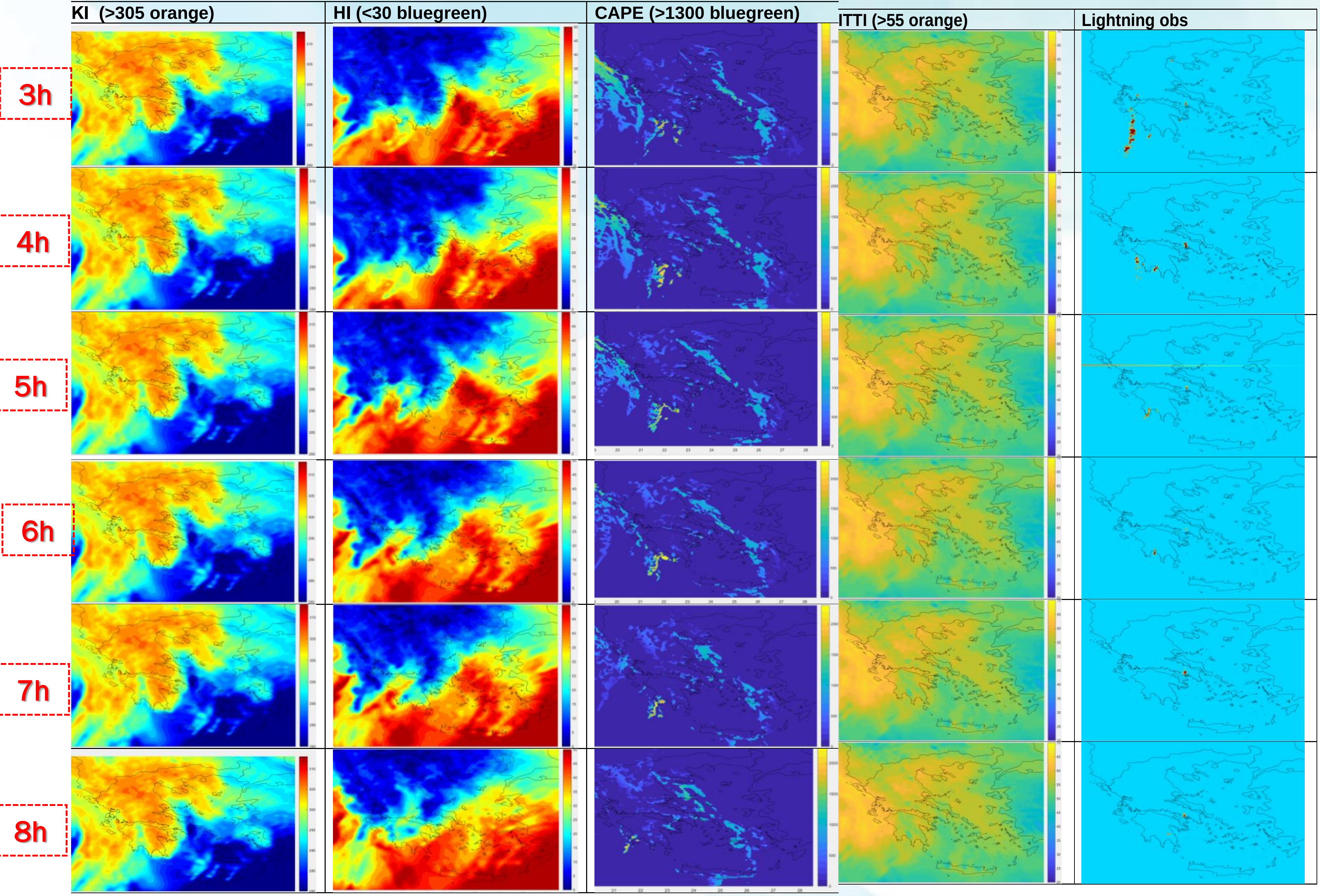
$$HI = (T_{850} - Td_{850}) + (T_{700} - Td_{700}) + (T_{500} - Td_{500})$$

When HI values lies less than or equal to 30K, high possibility for thunderstorm occurrence has been noticed on that region.

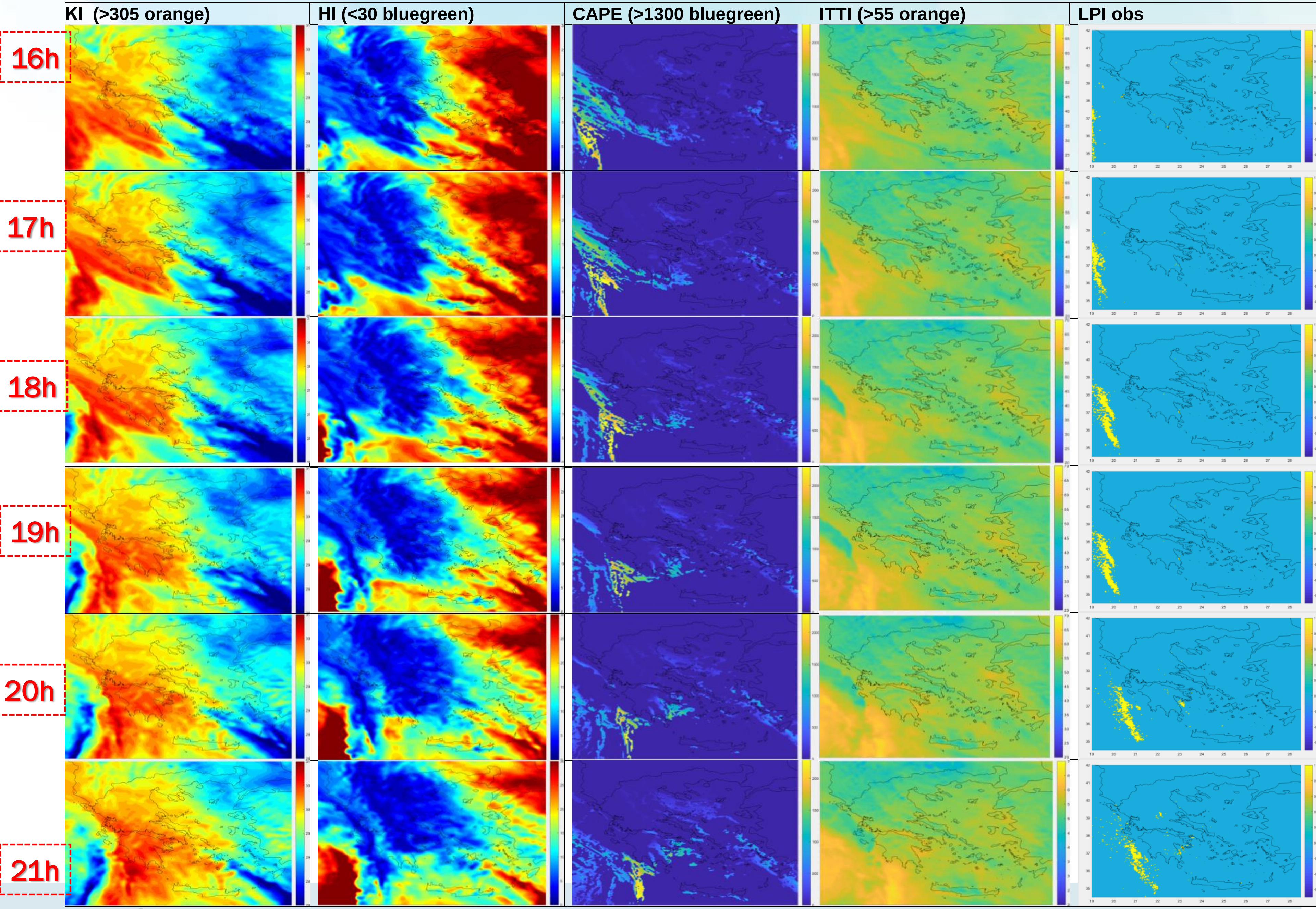
- **Improved total totals index (ITTI)** is obtained by the average of the temperatures at surface (at 2m), the 925hpa and the 850hpa pressure levels. The threshold for thunderstorm occurrence is usually seen at 57 K

$$ITTI = (2mT + Td_{925} + T_{850})/3 + (2mTd + Td_{925} + Td_{850})/3 - 2T_{500}$$

ITTI VALUES (K)	THUNDERSTORM POSSIBILITY
RANGING BETWEEN 44 AND 45	Possibility for small thunderstorm activity
RANGING BETWEEN 46 AND 47	Possibility for moderate thunderstorm activity
RANGING BETWEEN 48 AND 49	Possibility for moderate to severe range of thunderstorm activity
RANGING BETWEEN 50 AND 51	Possibility for heavy thunderstorm activity
RANGING BETWEEN 52 AND 55	Possibility for scattered thunderstorm activity
ABOVE 55	Possibility for severe thunderstorm activity


KI (>305 orange)
HI (<30 bluegreen)
CAPE (>1300 bluegreen)
ITTI (>55 orange)
Lightning obs
3h
4h
5h
6h
7h
8h

Test Case I



Test Case III

CONSIDERATIONS

Necessary to derive upscaled LPI products in resolution larger than 40km. Not acceptable results in all cases, strongly dependent on weather regime

LPI raw values need to be thresholded according to the area and period examined (monthly basis?).

Thresholds for thermodynamical indices associated to severe thunderstorms need to be appropriately defined to provide useful indication of a thunderstorm area. Default values often do not apply.

'The lightning potential index produces lightning in most stronger storms, much like observed in observational data. A general overestimation of presence f lightnngs when native resolution was used.

'Forecasters would be able to anticipate lightning activity from other model fields such as CAPE or postprocessed indices even with less accurancy in the position, For forecasters the added value is very small, or not present at all.

'Probably, the LPI is somewhat better at distinguishing lightning-producing storms and this may be of importance to some user groups'

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Thank you

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