2015 Aquatic Sciences Meeting, AQUATIC SCIENCES: GLOBAL AND REGIONAL PERSPECTIVES – NORTH MEETS SOUTH, 22-27 FEBRUARY 2015, GRANADA CONGRESS AND EXHIBITION CENTRE (PALACIOS DE EXPOSICIONES Y CONGRESOS DE GRANADA), GRANADA, SPAIN

VARIABILITY OF STORM SURGE EXTREMES IN THE GREEK SEAS UNDER CLIMATE CHANGE

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Abstract

Extreme storm surge events pose a great threat to densely populated, low-elevation areas at the coastal zones of the Aegean, Ionian and (northern) Libyan Seas (regional Greek seas of the Mediterranean). Historically, similar events have caused human casualties, damages to coastal structures, and environmental pressures on ecologically sensitive and protected Greek sites (RAMSAR, NATURA 2000). Hereby, we explore the trends of meteorologically induced extremes of sea level, the variability and the occurrence frequency of storm surge extremes at the near-shore regions of Greek Seas for a period of 150 years (1951-2100), under IPCC's A1B climate scenario (increasing future concentrations of greenhouse gases). In this framework, we use a high resolution (1/20˚) model of 2-D shallow water equations, which is nested to the coarser Mediterranean Climate Surge Model (MeCSM). In situ measurements from Greek tidal gauges are used to evaluate the results. Statistical indexes, high-order percentiles, and conditional probabilities show good agreement between historical data and simulations, and reveal a general increase of sea level maxima under the considered climate scenario. This research is part of the THALES Program (CCSEAWAVS Project).

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1. Short Description of Work

Extreme Storm Surges:	great threat to low-land coastal areas (environmental pressures, damages to defenses, human casualties).
Greek coastal zone:	diverse in shape and ecologically sensitive; many protected sites (RAMSAR, NATURA 2000) and low-elevation areas.
Research investigation:	explore trends of meteorologically induced extremes of sea level in Greek Seas (study period: 1951-2100).
Climate Change impact:	implement IPCC's A1B climate scenario (increasing future concentrations of atmospheric greenhouse gases).
Storm Surges analysis:	hydrodynamic simulations with high spatial resolution Greek Climate Surge Model (GreCSM) nested to coarse MeCSM.
Model evaluation:	against in situ measurements from Greek tide gauges (HNHS) for the 2002-2012 period.
Validation results:	statistical measures from both historical data and modelling show good agreement.
Future trends:	variability and occurrence frequency of extreme sea level anomalies - main forcing mechanisms for strong surges.
Results support:	general storminess attenuation under specific climate scenario relates to frequency and spatial coverage of surges.
Results estimate:	actual magnitudes of sea level maxima shall increase during the 21st century.
Results reveal:	different morphological characteristics of regional Greek Seas significantly influence the variability of extreme events.
Discussion:	use of Climate Change Index and its evolution for the remainder of the 21st century on Greek coastlines.
Conclusions:	coastal inundation patterns and flood risk assessment for specific regions with high surge extremes.

2. Methodology

Available data:
Sea Level Height (SLH) in 5 stations for 2002-2012

Processing:
Filtering on SLH time-series for exclusion of tides and steric effects

Numerical model:
2-D Shallow Water Equations
(Krestenitis et al, 2011)

Forcing input:
Wind and Sea Level Pressure from RCM3

Model output:
SLH due to meteorological forcing

Nesting:
Boundary conditions from MeCSM

Period:
1951-2100

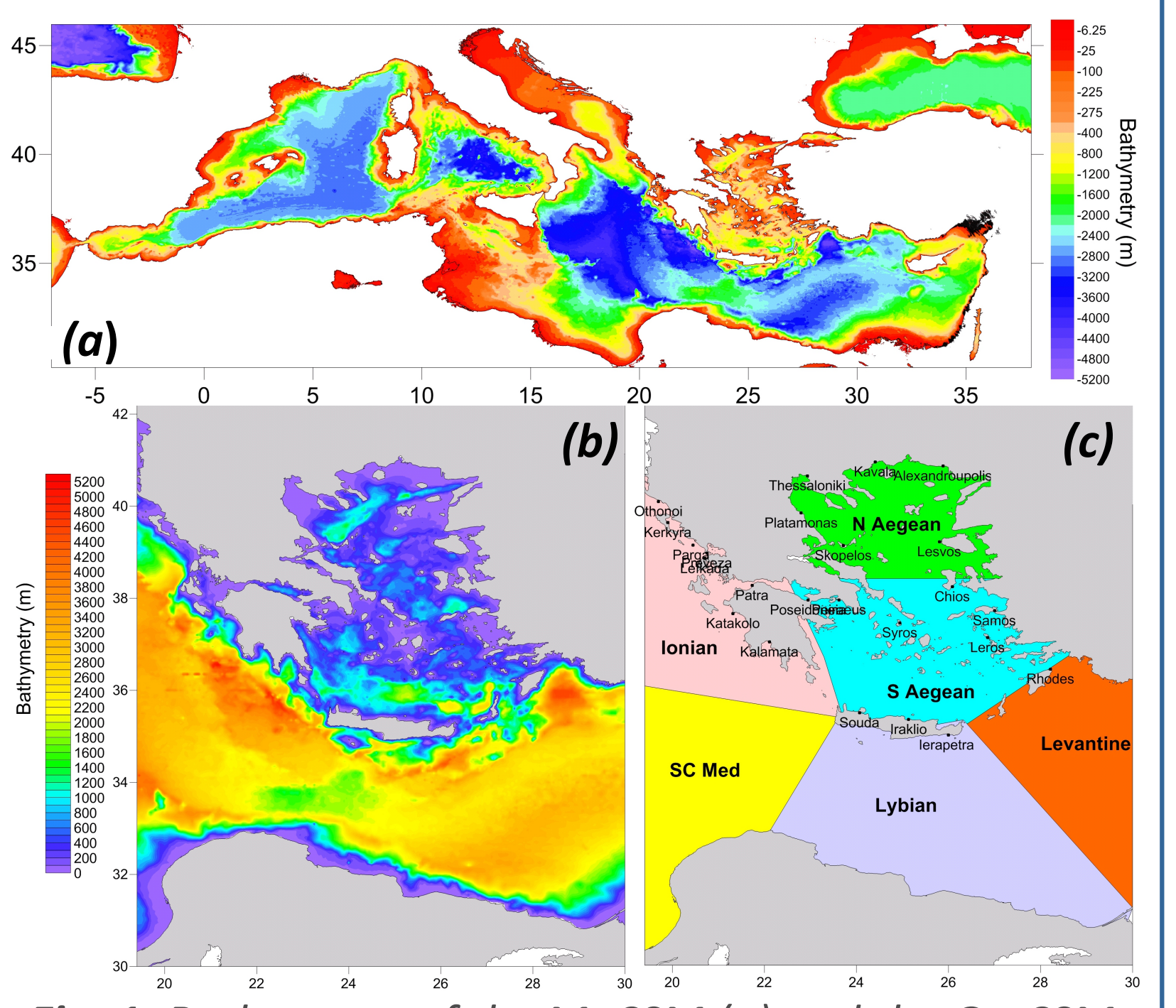

Fig. 1: *Bathymetry of the MeCSM (a) and the GreCSM domain (b) and location of 25 stations and 6 sub-regions for GreCSM domain (c)*

3. Model evaluation

To evaluate the effectiveness of GreCSM we used measurements from 5 Greek station, comparing measured and simulated SLH using the Storm Surge Index parameter, calculating higher order percentiles and the possibility of coherent ($SLH_{coh} \geq m+\sigma$) and intense ($SLH_{int} \geq m+2\sigma$) events.

SSI: Storm Surge Index = Mean of 3 independent (120 hrs window) events of maxima SLH per year

Percent Error: $$E(\%) = 100 \cdot \frac{\left(\overline{SSI}_{mod} - \overline{SSI}_{obs}\right)}{\left(\overline{SSI}_{mod} + \overline{SSI}_{obs}\right)/2}$$

Error Index: $$EI = \frac{\left(\overline{SSI}_{mod} - \overline{SSI}_{obs}\right)}{\sqrt{\left(\sigma^2_{SSI_{mod}} + \sigma^2_{SSI_{obs}}\right)/2}}$$

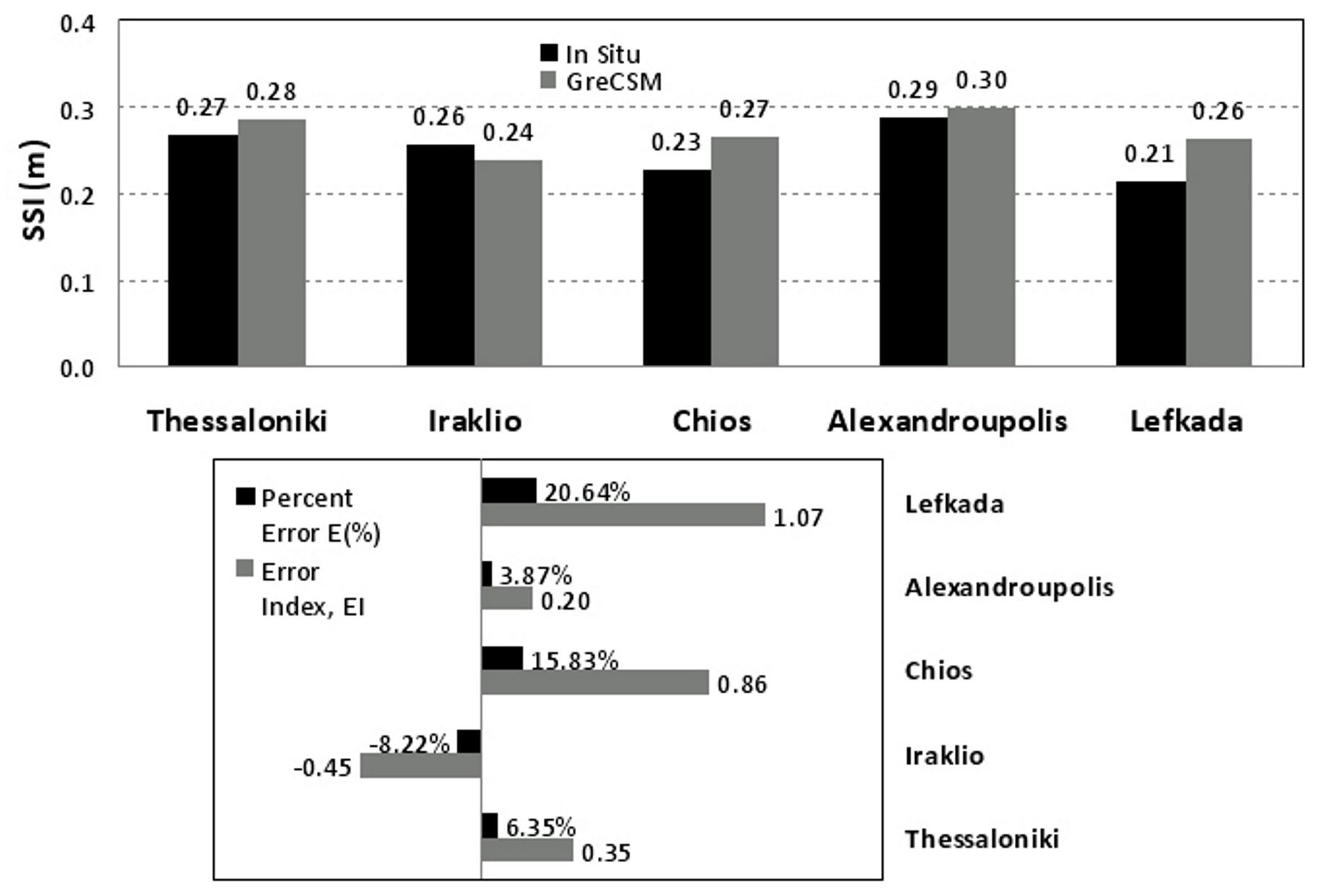

Fig. 2: *Comparison of measured and simulated SSI values for 5 Greek stations (upper graph) and corresponding Percent Error (E%) and Error Index (EI) values (lower graph)*

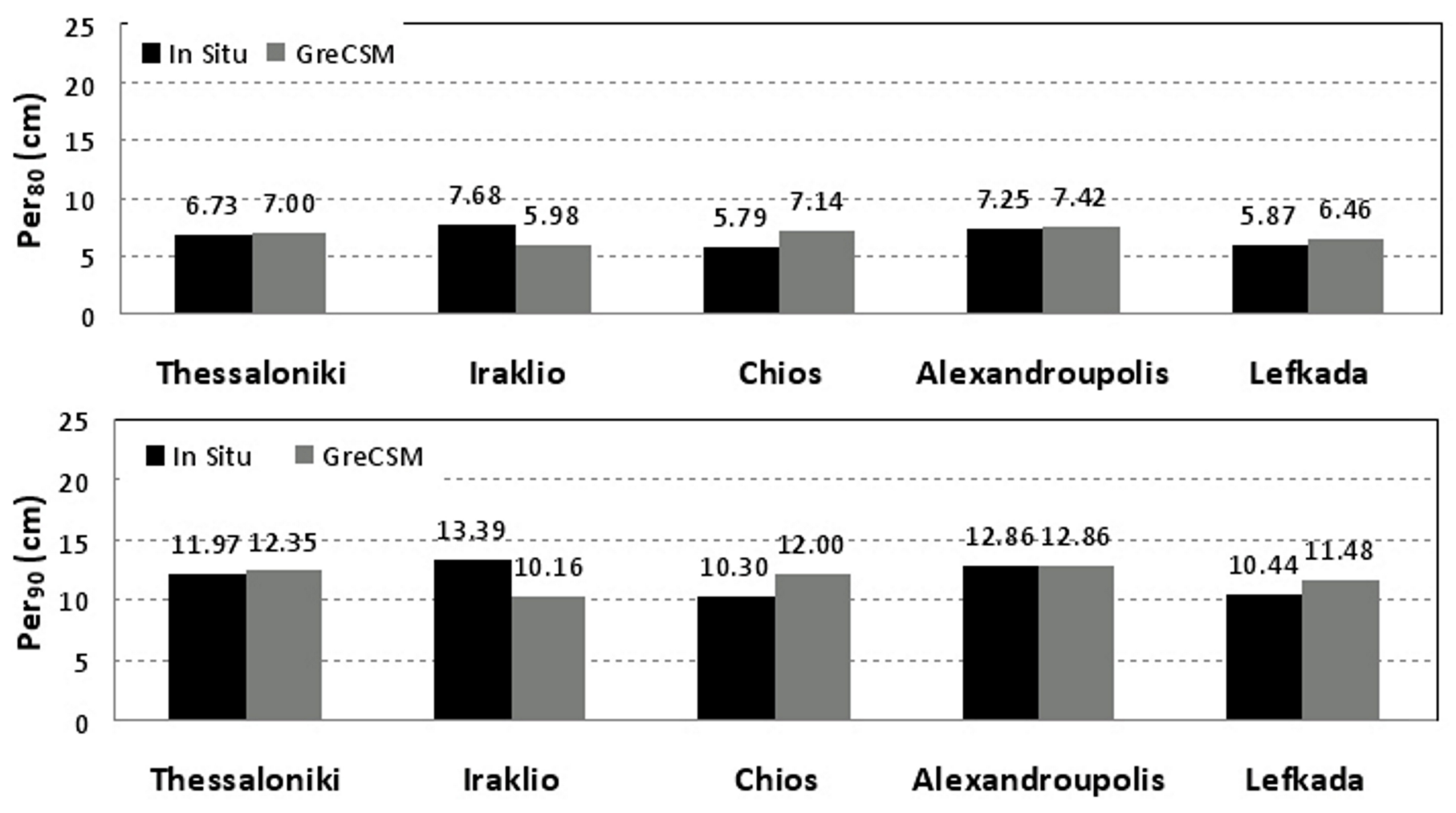

Fig. 3: *High Order Percentiles: 80th (upper graph) and 95th (lower graph)*

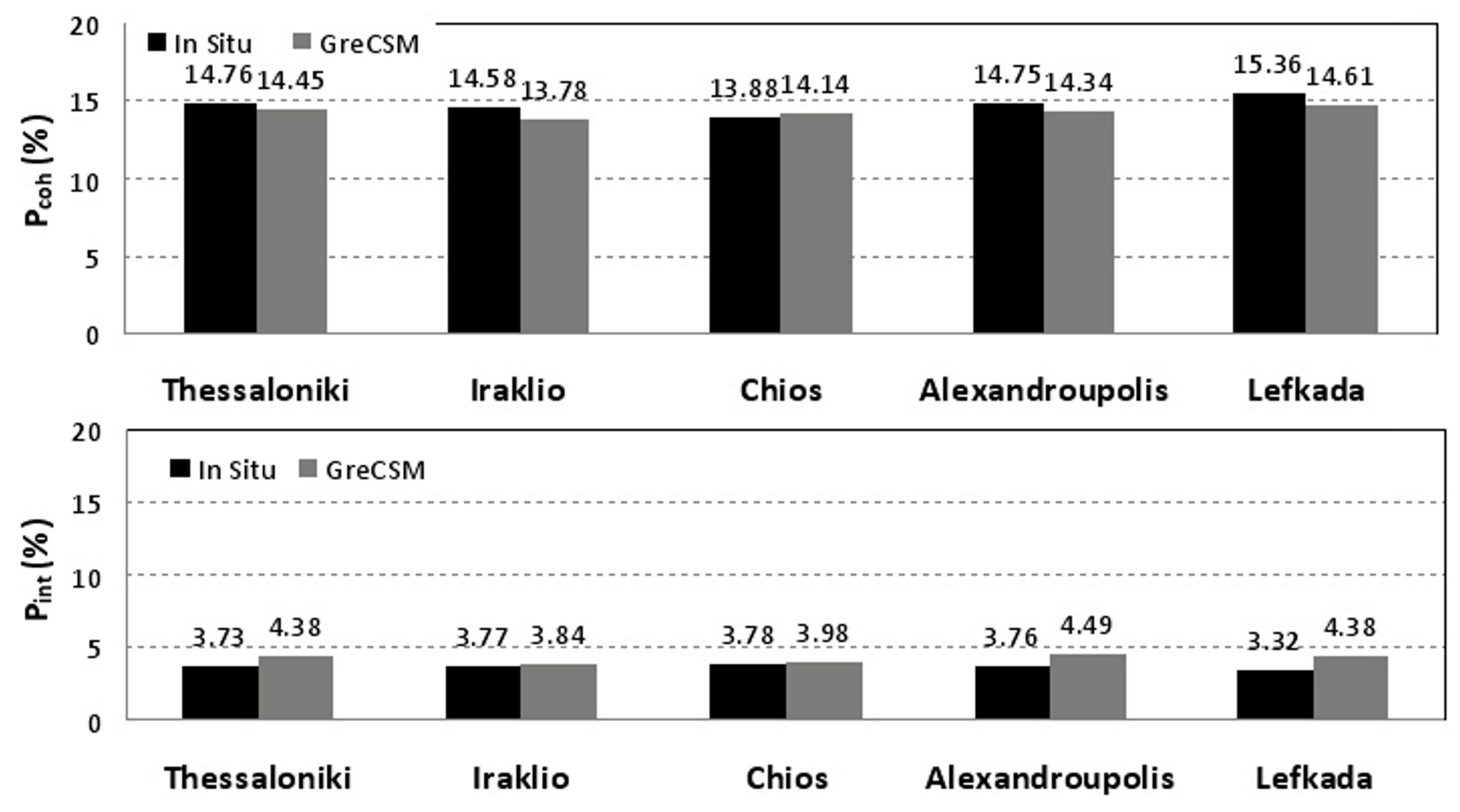

Fig. 4: *Statistically coherent event ($SLH_{coh} \geq (m+\sigma)$ upper graph) and intense event ($SLH_{int} \geq (m+2\sigma)$ lower graph)*

4. Results

We investigate the dependance of mean SLH to SLP values (Fig. 5) and peak SLH to atmospheric forcing (Fig. 6), as well as past and future trends of extreme SLHs in the 6 sub-regions of the domain (Fig. 7) and the spatial distribution of peak and mean SLH per 50-year period (Fig. 8)

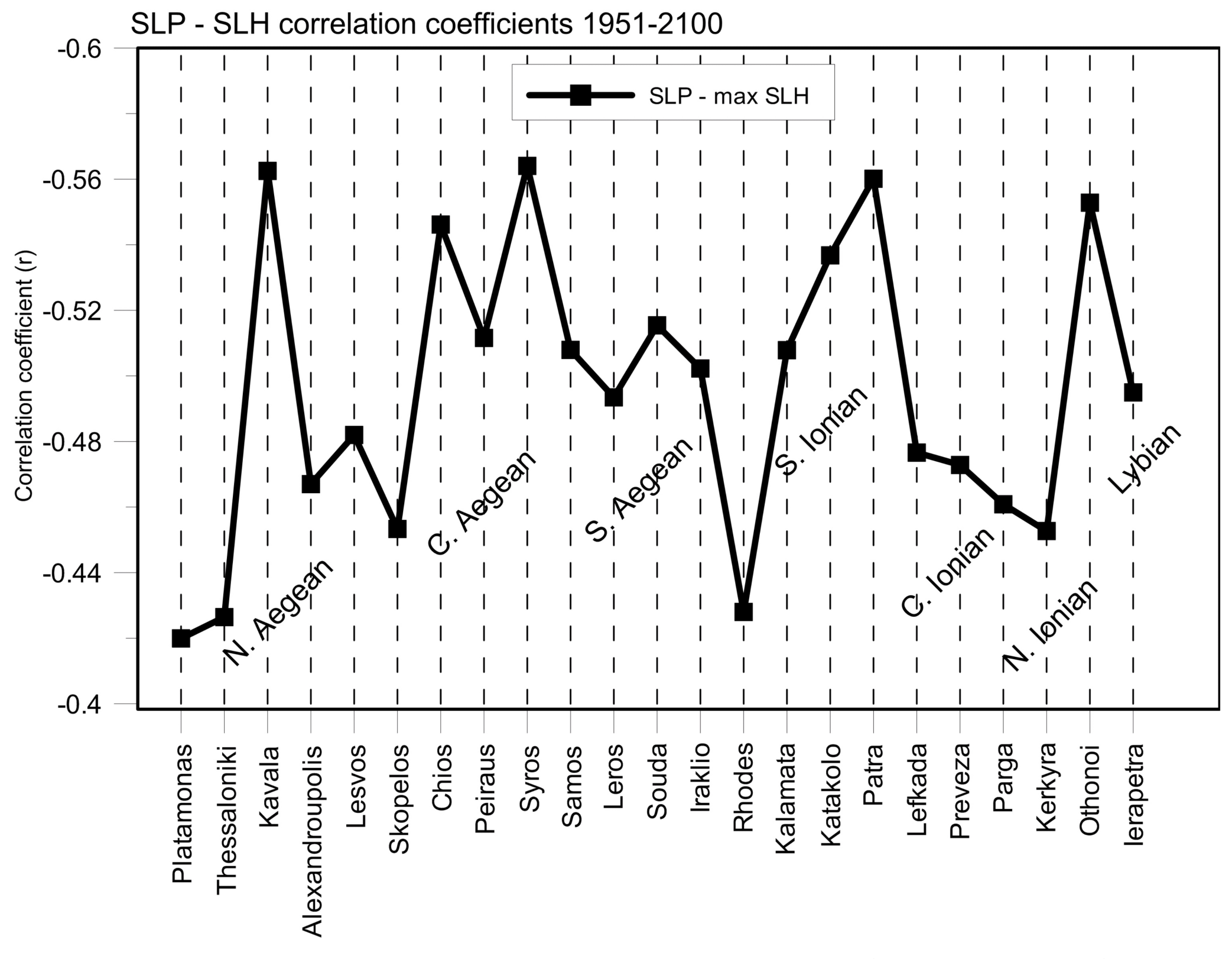

Fig. 5: *Correlation coefficient between SLH and SLP (annual mean) for all stations*

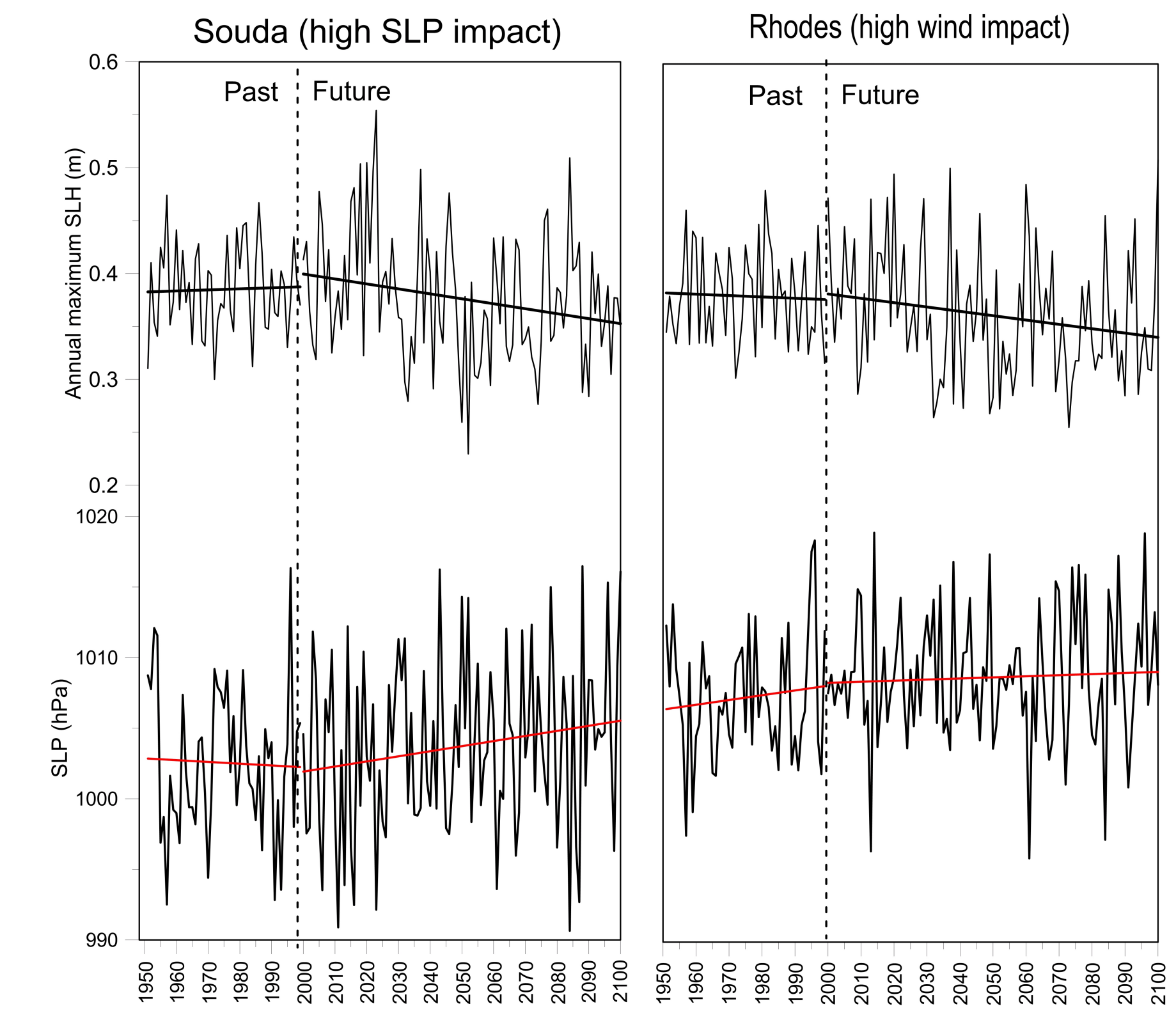

Fig. 6: *Evolution of annual max SLH and corresponding SLP values in 2 stations (Souda, in N. Crete and Rhodes in SE Aegean)*

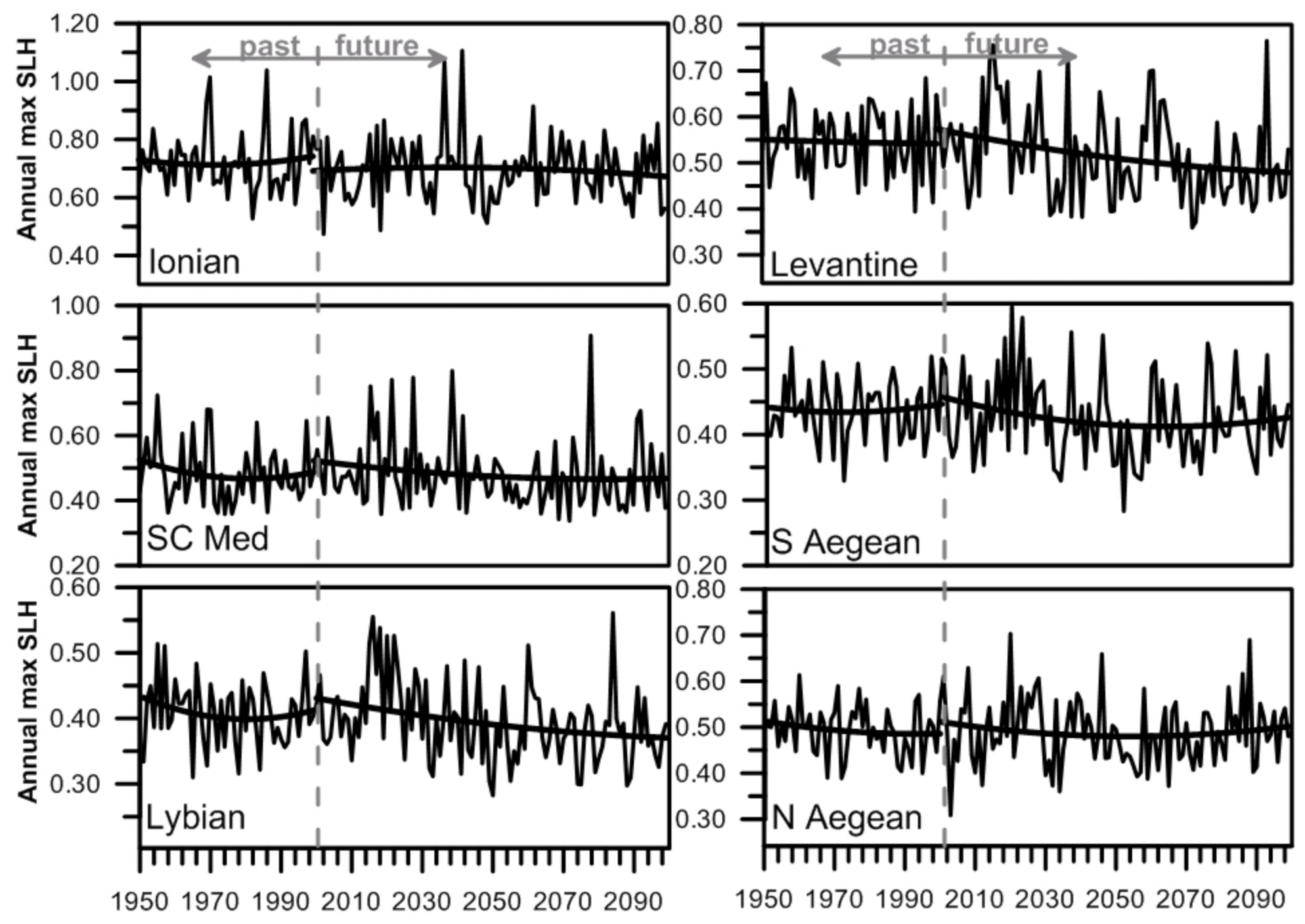

Fig. 7: *Regional trends of SLH_{max} for Past (1951-2000) and Future (2001-2100) periods in the 6 sub-basins of the Greek Seas*

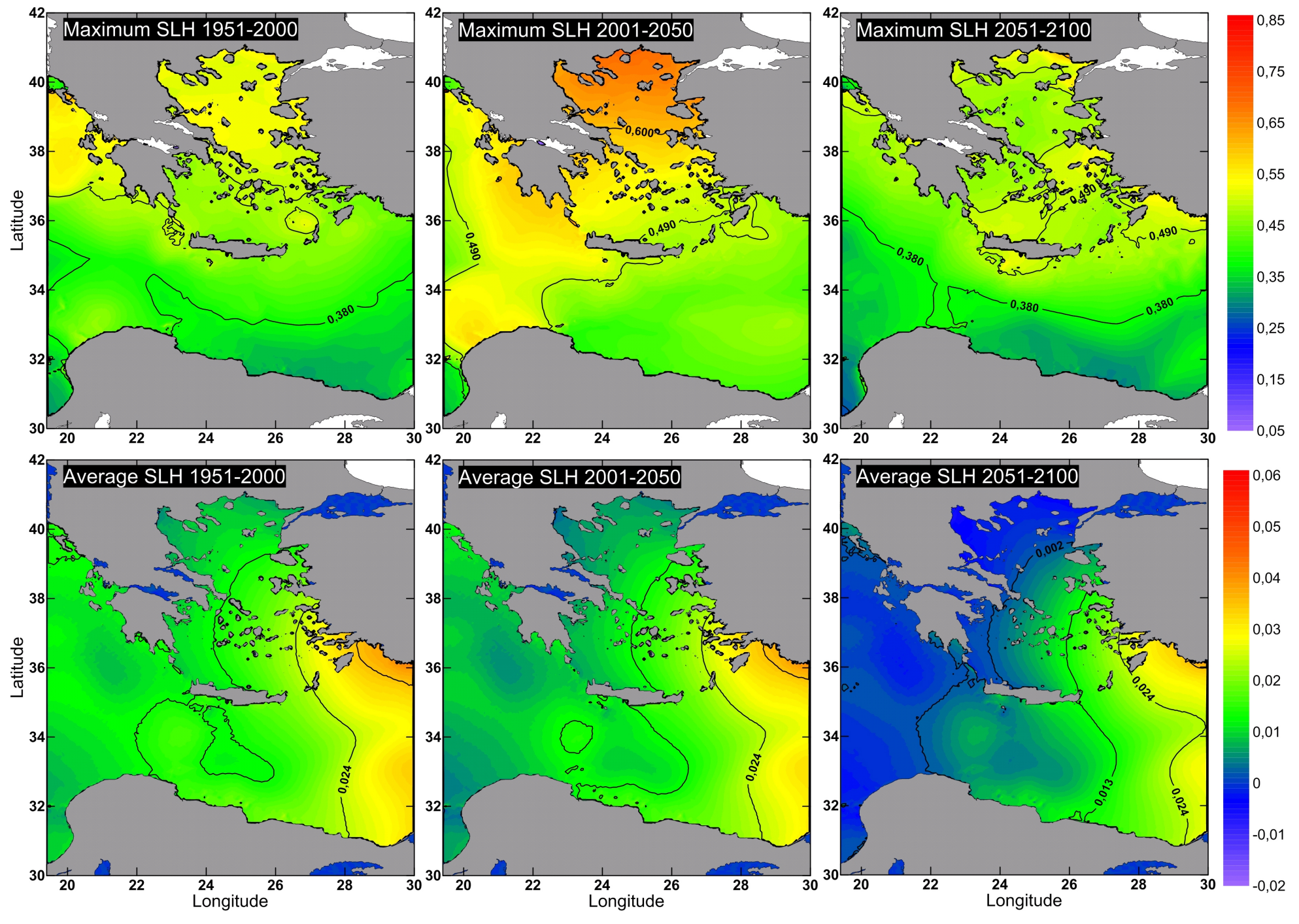

Fig. 8: *Evolution of SLH_{max} (upper graphs) and SLH_{mean} (lower graphs) per 50-yr period*

5. Discussion

Climate Change Index (CCI): $$CCI(\%) = \frac{\overline{SSI}_{mod}^{(FUTURE\ 11yrs)} - \overline{SSI}_{mod}^{(PAST\ 11yrs)}}{\overline{SSI}_{mod}^{(PAST\ 11yrs)}}$$

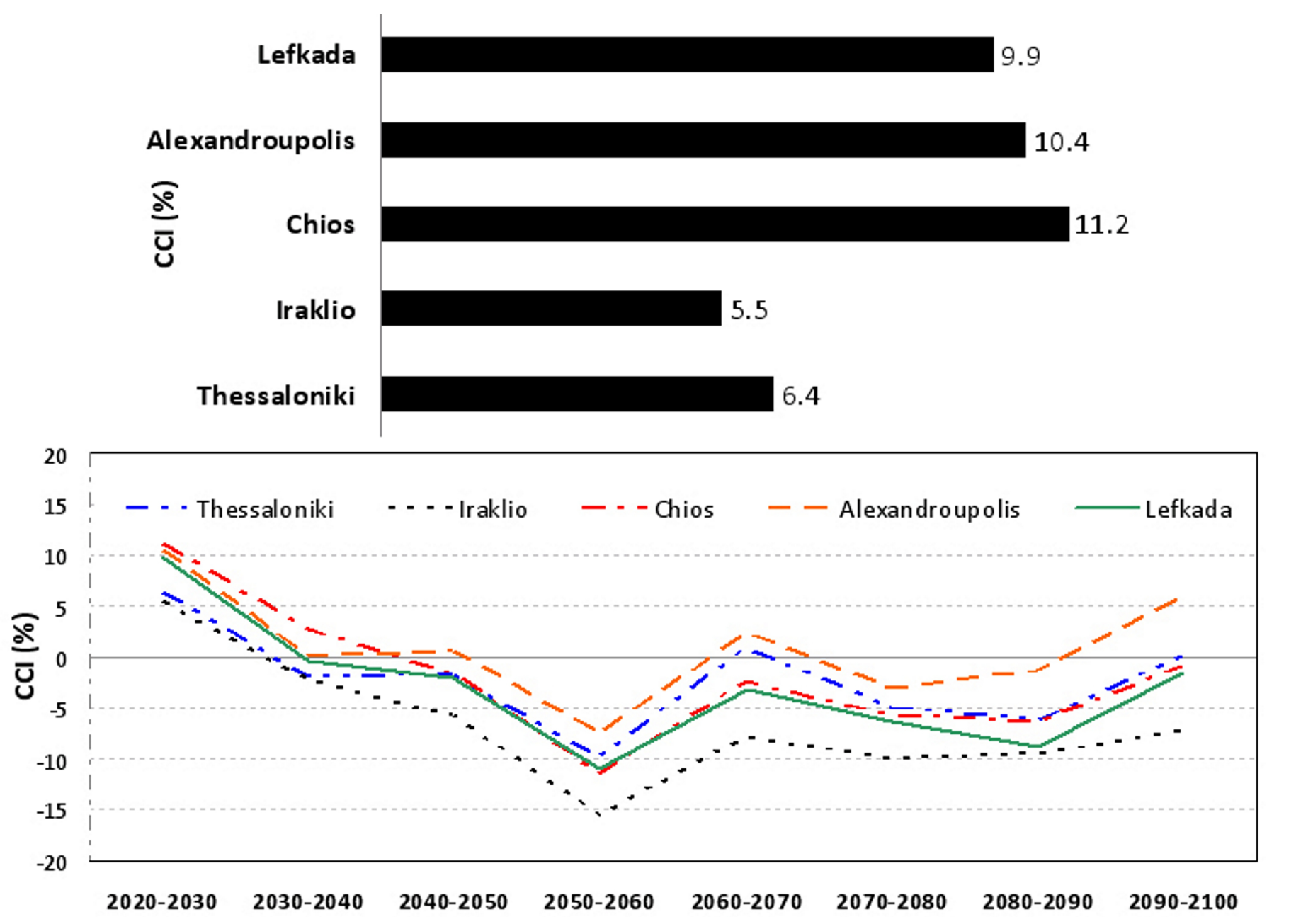

Fig. 9: *Climate Change Index (CCI) for 5 stations: for the 2020-2030 period (top) and temporal evolution for each 10-year period from 2020 to 2100*

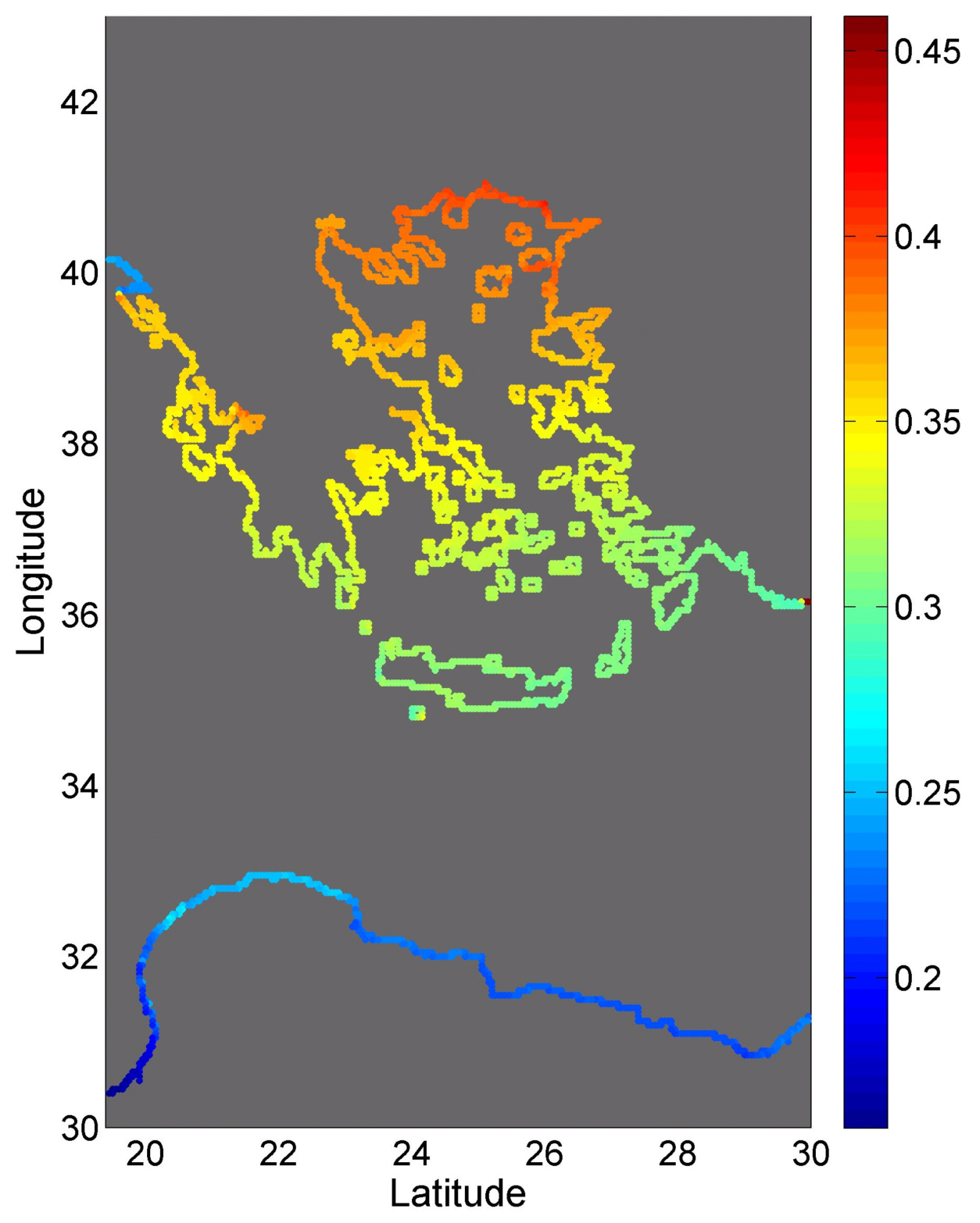

Fig. 10: *Average SSI [m] for each coastal cell for the period of 2000-2100*

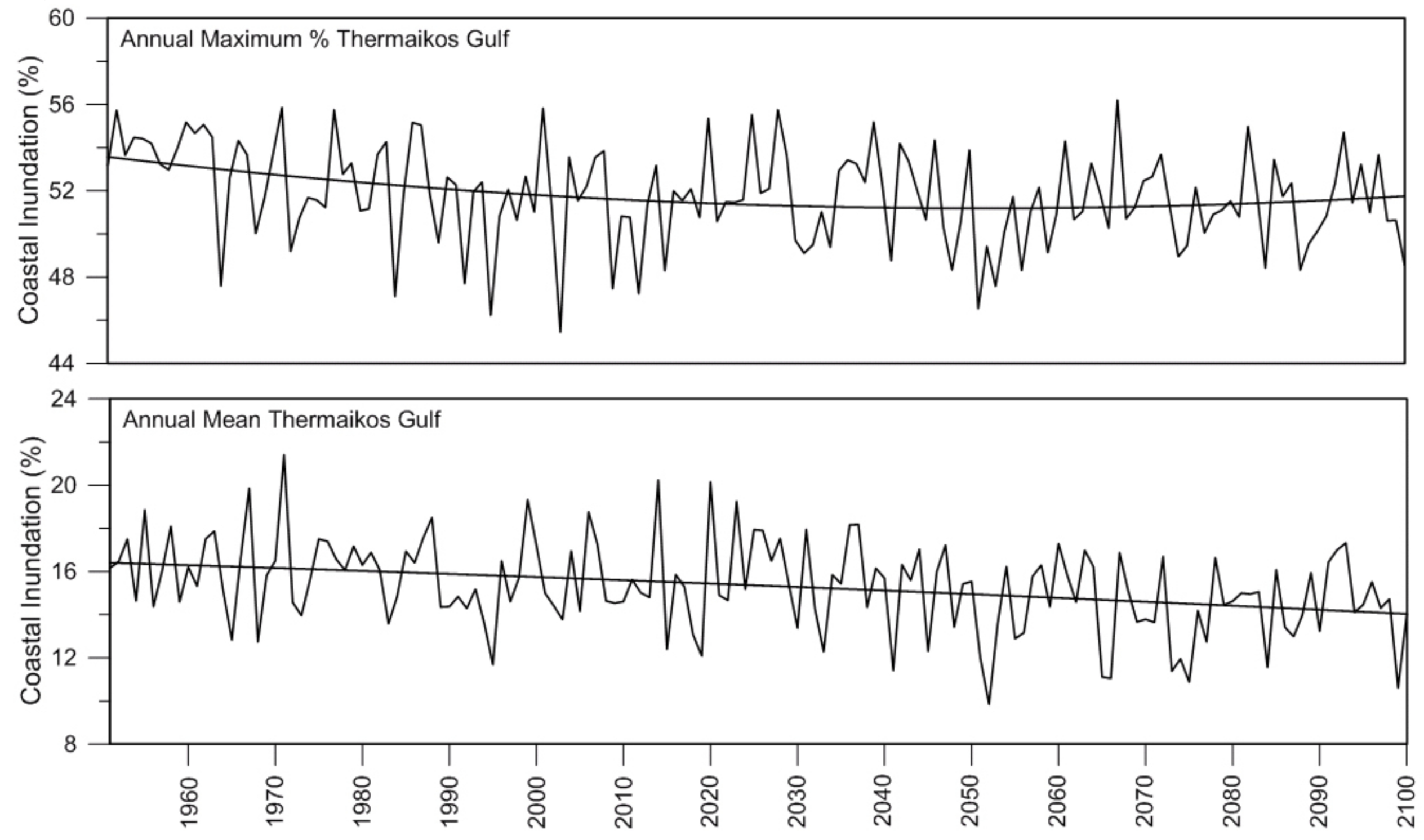

Fig. 11: *Percentage of inundated coastal cells for 1951-2100 based on annual max SLH (upper graph) and annual mean SLH (lower graph)*

Conclusions

- The good performance of climatic model for storm surges in Greek Seas is confirmed by in situ observations.
- Extreme SLHs in the Northern Aegean are greater than extremes in the Central and Southern Aegean due to different atmospheric forcing mechanism and topographic differences.
- Annual maximum SLH extremes are estimated to increase toward the end of the 21st century.
- Climate Change Impact values show a sort-term (2020-2030) increase of extreme storm surges (SSIs) and a long-term decrease of SSI until 2060, followed by an increase until 2100.
- The future trend of peak SLH appears to be slightly bent upwards in certain Greek sub-basins (e.g. S. Aegean), showing a mildly increasing tendency towards the end of the 21st century.
- Average SLH due to storm surges under Climate Change is estimated to increase in the SE Mediterranean part of the Greek Seas.
- Annual max SLH due to storm surges under Climate Change is estimated to increase in Northern Aegean in the first half of the 21st century
- The results can be used to categorize coastal areas/zones, based on inundation risk from storm-induced (surge) sea level elevation.

Acknowledgements

This research was co-funded by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: **"THALES. Investing in knowledge society through the European Social Fund"**.

European Union
European Social Fund
OPERATIONAL PROGRAMME
EDUCATION AND LIFELONG LEARNING
investing in knowledge society
MINISTRY OF EDUCATION & RELIGIOUS AFFAIRS
MANAGING AUTHORITY
Co-financed by Greece and the European Union
NSRF 2007-2013
programme for development
EUROPEAN SOCIAL FUND