



**POLITECNICO**  
MILANO 1863

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**Project title: ANOMALY DETECTION VIA COPULA-BASED CONFORMAL PREDICTION  
FOR HIGH DIMENSIONAL DATA: THEORY, SIMULATIONS, AND AN  
APPLICATION TO NATURAL HAZARDS SATELLITE MONITORING**

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**MASTER'S DEGREE IN MATHEMATICAL ENGINEERING – THESIS PROJECT**

**Academic Year 2021/22**

# OBJECTIVES

## EARTH IMAGERY

GROUND DEFORMATION  
ESTIMATES OBTAINED THROUGH  
DInSAR TECHNIQUE "SBAS"



## MULTIVARIATE STATISTICAL TOOLS

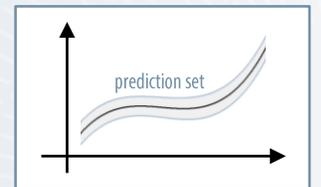
COPULA-BASED CONFORMAL  
PREDICTION FOR HIGH DIMENSIONAL  
DATA WITH TEMPORAL DEPENDENCE



- **ANOMALY DETECTION** IN THE  
CONTEXT OF NATURAL HAZARDS



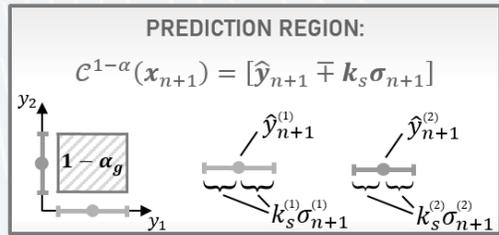
- **FORECASTING** WITH SPECIFIED  
LEVELS OF CONFIDENCE



# STRUCTURE OF THE WORK

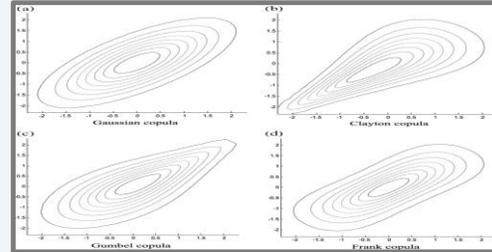
## COPULA-BASED CONFORMAL PREDICTION

FOR HIGH-DIMENSIONAL DATA



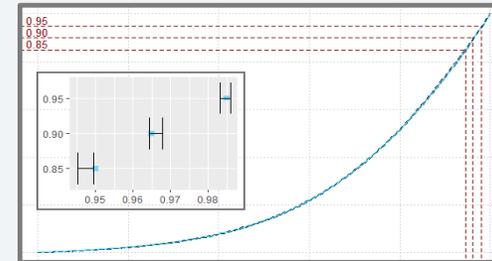
## COPULA APPROXIMATION ROUTINE

IN RELATION TO DIFFERENT DATA-SPECIFIC FACTORS



## SIMULATION STUDY

FEATURES AND CRITICALITIES OF SEVERAL ESTIMATORS



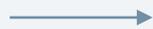
## CASE STUDY

ANOMALY DETECTION AND FORECASTING OF LAND MOTION

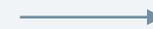


# CASE STUDY: CAMPI FLEGREI

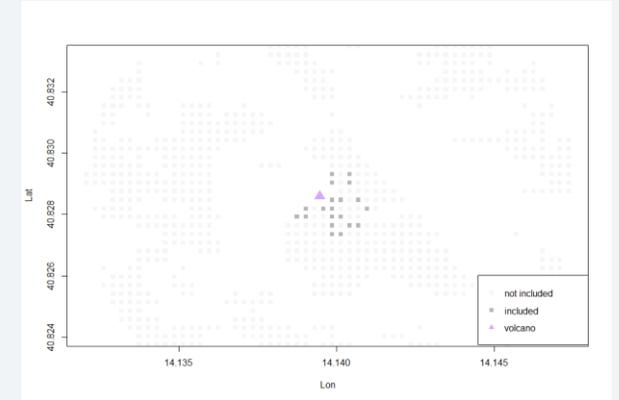
P-SBAS processing on-demand  
service on GEP



CAMPI FLEGREI (NA)



CONSIDERED DATA



MULTIVARIATE TIME SERIES

	COER	LAT	LON	TIME 0	TIME 1	TIME 2	...
PIXEL 1	0.7470	33.626	-117.16	0.0 cm	-0.146 cm	0.032 cm	...
PIXEL 2	0.8252	33.878	-117.13	0.0 cm	-0.01 cm	-0.113 cm	...
PIXEL 3	0.7958	33.888	-116.84	0.0 cm	0.22 cm	0.019 cm	...
	⋮	⋮	⋮	⋮	⋮	⋮	⋮



- ASSESSMENT OF **VALIDITY AND EFFICIENCY** RESULTS FOR THE CONSTRUCTED PREDICTION REGIONS
- A POSTERIORI ANALYSIS AIMED AT **NATURAL HAZARDS DETECTION** THROUGH THE SATELLITE MONITORING OF THE INTERESTED AOI

FOCUS:  
BRADYSEISM

# ACHIEVEMENTS AND EXTENSIONS

## ACHIEVEMENTS:

**EXTENSION** OF COPULA-BASED  
CONFORMAL PREDICTION TO  
ELLIPTICAL AND KERNEL COPULA  
ESTIMATORS

ANALYSIS OF THE **FLEXIBILITY** OF  
THE METHOD WITH RESPECT TO  
SEVERAL FACTORS  
CHARACTERIZING DATA

ENRICHMENT OF THE **APPLICATION** RANGE  
OF COPULA-BASED CP THROUGH  
FORECASTING AND ANOMALY DETECTION  
ON EARTH OBSERVATION DATA

## POSSIBLE EXTENSIONS:

SPATIAL DEPENDENCE

FUNCTIONAL DATA ANALYSIS

# MAIN REFERENCES

1. Soundouss Messoudi, Sébastien Destercke, and Sylvain Rousseau. Copula-based conformal prediction for multi-target regression. *Pattern Recognition*, 120:108101, 2021.
2. Riccardo Lanari, Francesco Casu, Mariarosaria Manzo, Giovanni Zeni, Paolo Berardino, Michele Manunta, and Antonio Pepe. An overview of the small baseline subset algorithm: A DInSAR technique for surface deformation analysis. *Deformation and Gravity Change: Indicators of Isostasy, Tectonics, Volcanism, and Climate Change*, pages 637–661, 2007.
3. Niccolò Ajroldi, Jacopo Diquigiovanni, Matteo Fontana, and Simone Vantini. Conformal prediction bands for two-dimensional functional time series. *arXiv preprint arXiv:2207.13656*, 2022.
4. Arthur Charpentier, Jean-David Fermanian, and Olivier Scaillet. The estimation of copulas: Theory and practice. *Copulas: From theory to application in finance*, pages 35–64, 2007.
5. Victor Chernozhukov, Kaspar Wüthrich, and Zhu Yinchu. Exact and robust conformal inference methods for predictive machine learning with dependent data. In *Conference On Learning Theory*, pages 732–749. PMLR, 2018.
6. Claudio De Luca, Ivana Zinno, Michele Manunta, Riccardo Lanari, and Francesco Casu. Large areas surface deformation analysis through a cloud computing P-SBAS approach for massive processing of dinsar time series. *Remote Sensing of Environment*, 202:3–17, 2017.