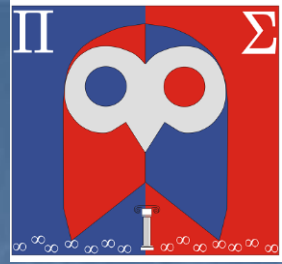




# SCHOOL OF MINERAL RESOURCES ENGINEERING



Technical University of Crete

## **SPATIAL ESTIMATION OF LIGNITE RESERVES IN NORTHERN GREECE USING ORDINARY KRIGING**

**ANDREW PAVLIDES**

Supervisor: Professor Hristopulos D.T.

# PRESENTATION

- Multilayer deposits and challenges they present
- Quick overview of spatial analysis and kriging methods
- Case study: Amyndaio mine
- 3D spatial estimation using I.K.
- Conclusions and suggestions for further study

# LIGNITE ENERGY CONTENT



- 30% of electricity generation in EU is coal-based.
- Greece has 2.2 Billion tons of lignite
- Lignite is used as fuel in power stations so it's energy characteristics are important
- **Lower Calorific Value** (LCV): How much energy per kg of lignite (kCal/kg)
- **Lignite Energy Content** (LEC): How much energy in the reserves (GCal or MWh)



# MULTILAYER DEPOSITS AND INTERMEDIATE LAYERS



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# MOTIVATION

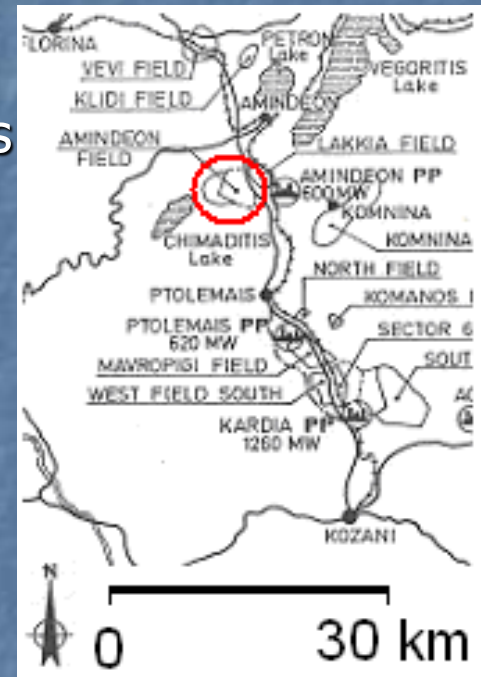
- Mine planning becomes easier and more efficient if an estimation of where lignite layers are located exists, as the reserves held in each bench can be estimated independently
- In multilayer deposits, an ore layer could be so deep compared to above layers, that its exploitation would not be profitable
- Changes in the market price of the mineral extracted, environmental regulations or slope stability challenges could potentially render former unprofitable parts of the mine as profitable or making the exploitation of deeper layers unprofitable

# OVERVIEW OF SPATIAL ANALYSIS - KRIGING

- Spatial analysis is a group of methods that attempt to determine the spatial distribution of one or more random variables (properties) based on a set of data
- Usually spatial analysis gives a grid map where the value of each point of the grid is estimated from nearby data
- Kriging is a category of linear methods using weighted parameters  $\lambda_i$  to estimate the value of a random variable  $X(s_0)$  at a point  $s_0$  from the values of the variable  $X(s)$  at  $n$  nearby points
- Kriging weights  $\lambda_i$  are calculated by minimizing the prediction error of  $e = X(s) - X'(s)$  using the covariance function  $C_X(s)$  or the semivariogram  $\gamma_X(s)$ .

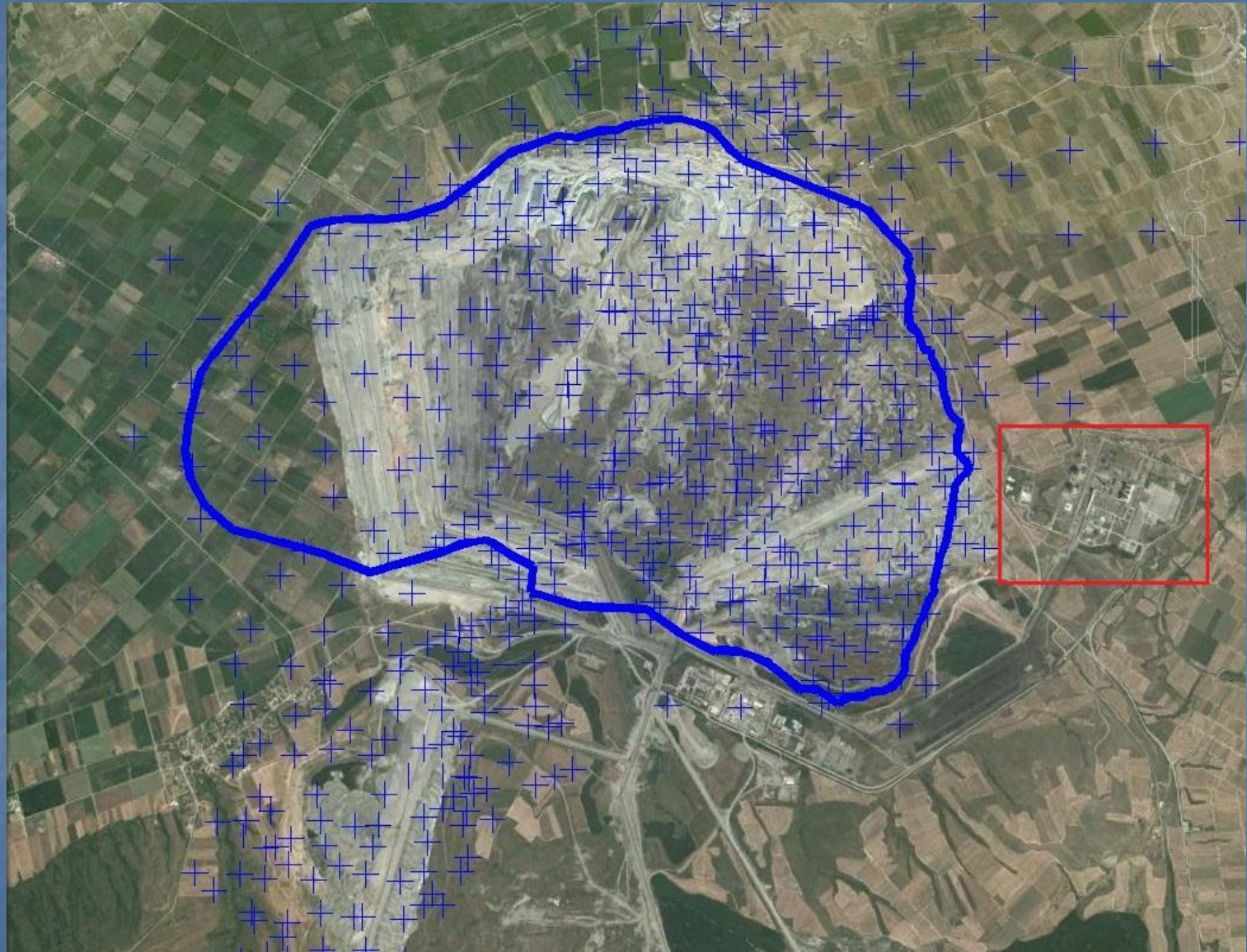
# CASE STUDY: AMYNDEO MINE

- Area 17 km<sup>2</sup> with extensive fault system
- The mine is in operation since 1989 and has produced 145 Mt of lignite till the end of 2013
- Average lignite production: 6 Mt/Y
- Estimated mean LCV: 1,3 GCal/tn





# SATELLITE IMAGE (Google Earth)



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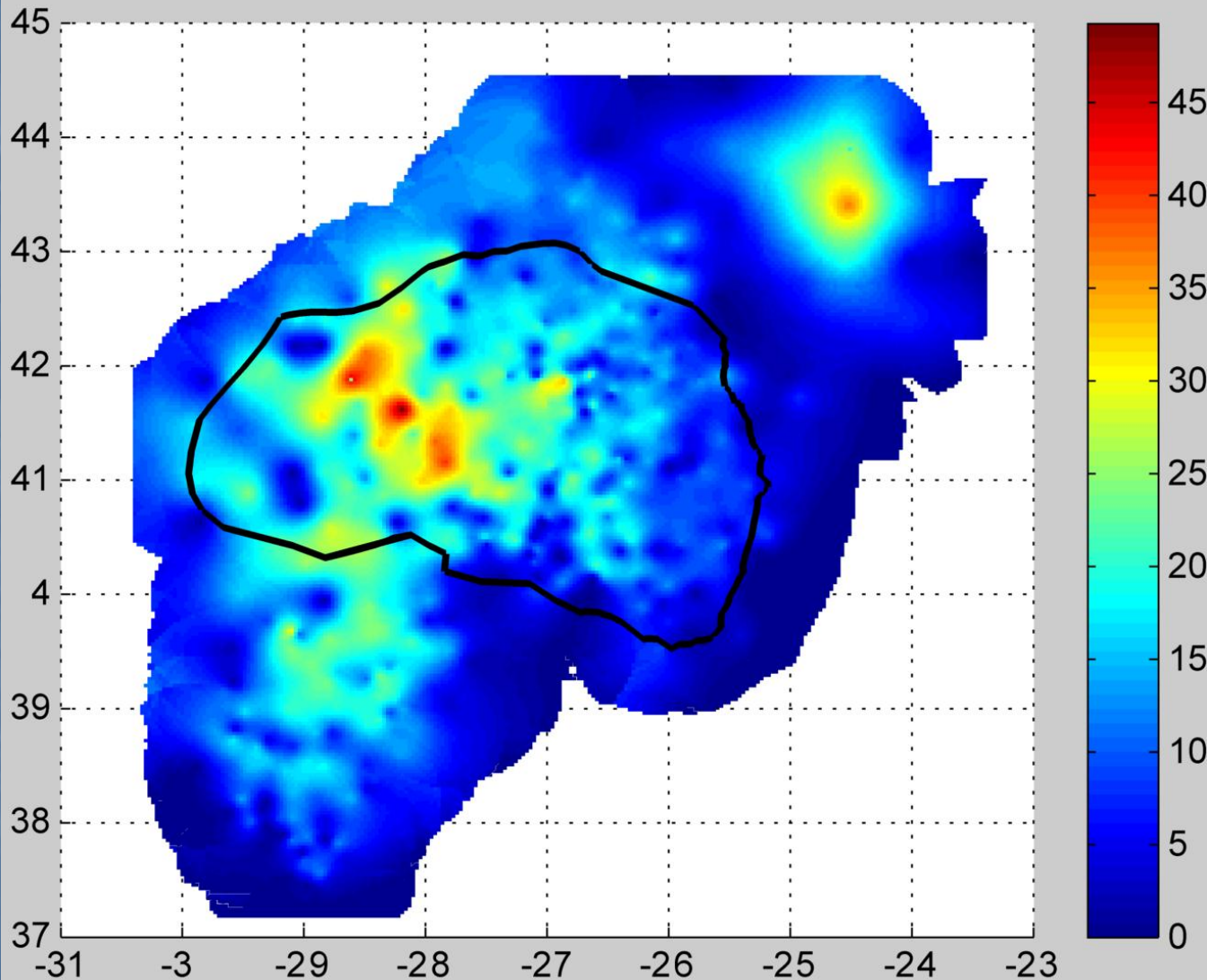
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# DRILL-HOLE CORE DATA

- 6875 Drill-hole core data from 615 drill-holes
- Data: Coordinates (X, Y, Depth), ash content, water content and in some cases CO<sub>2</sub> content and L.C.V.
- L.C.V is estimated using linear regression for the core data that miss it
- The 6875 drill-hole core data are evaluated and they are signified as lignite or waste

# LIGNITE RESERVES

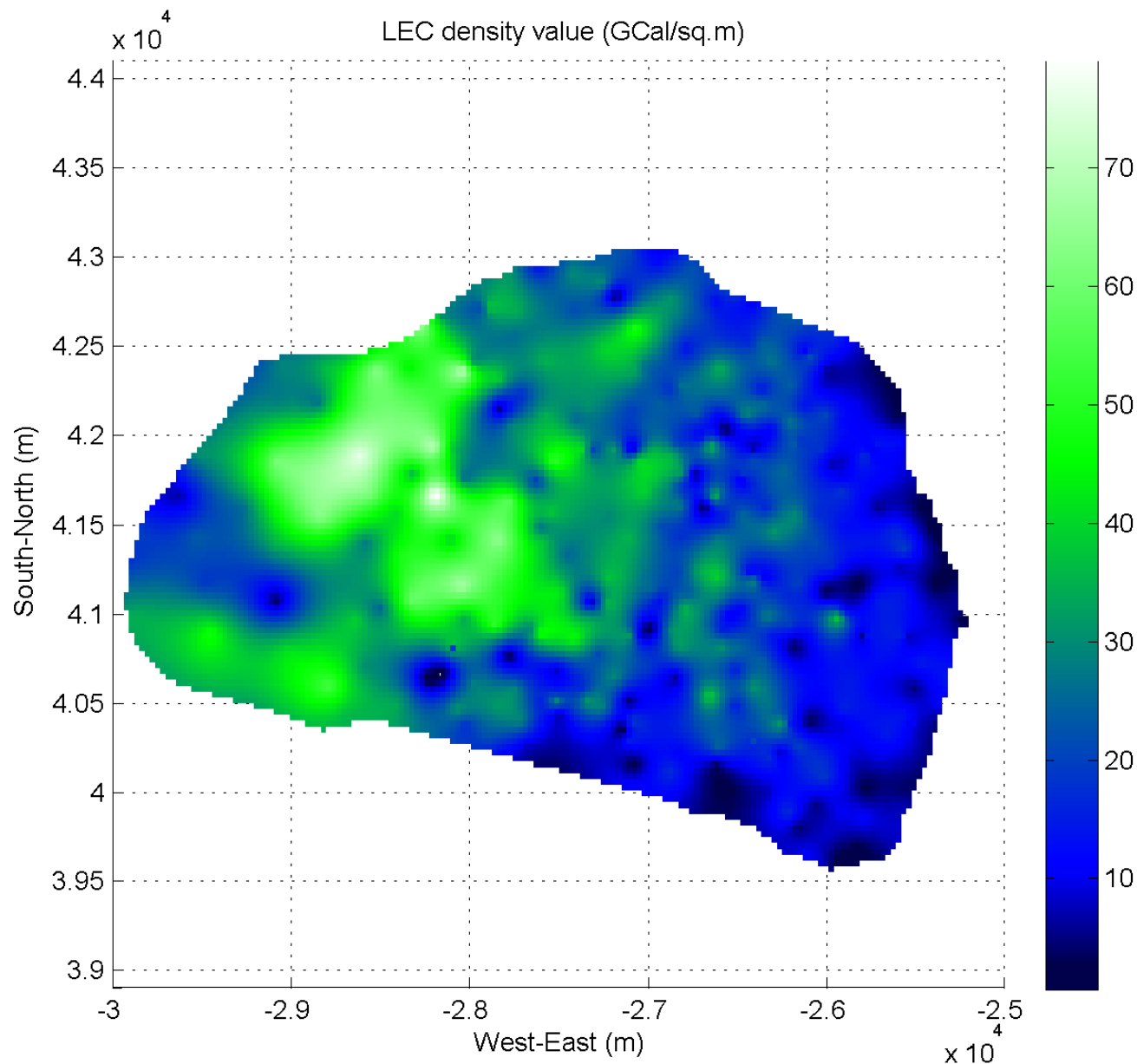


Lignite reserves  
are estimated at  
240 MT  
(geological lignite)

Cells are 30m x 30m



# KRIGING LEC DENSITY MAP



Energy content  
reserves are 299  
PCal

Cells are 30m x 30m

# 3D SPATIAL ESTIMATION OF LIGNITE LAYERS

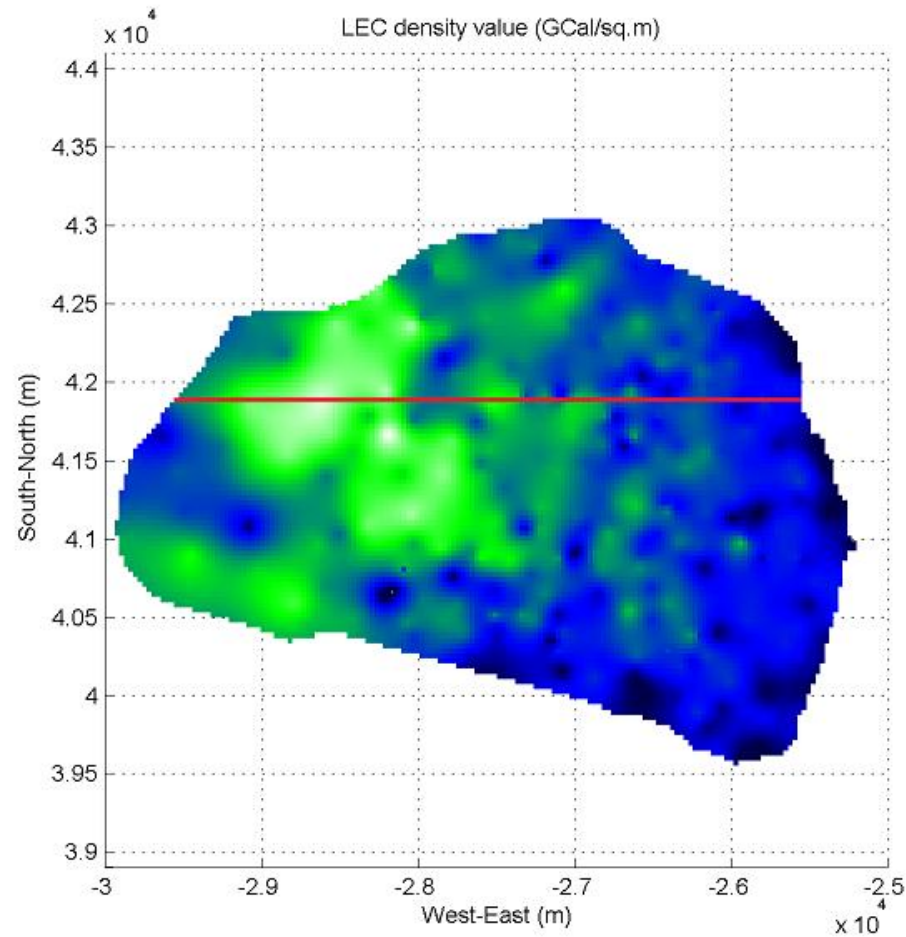
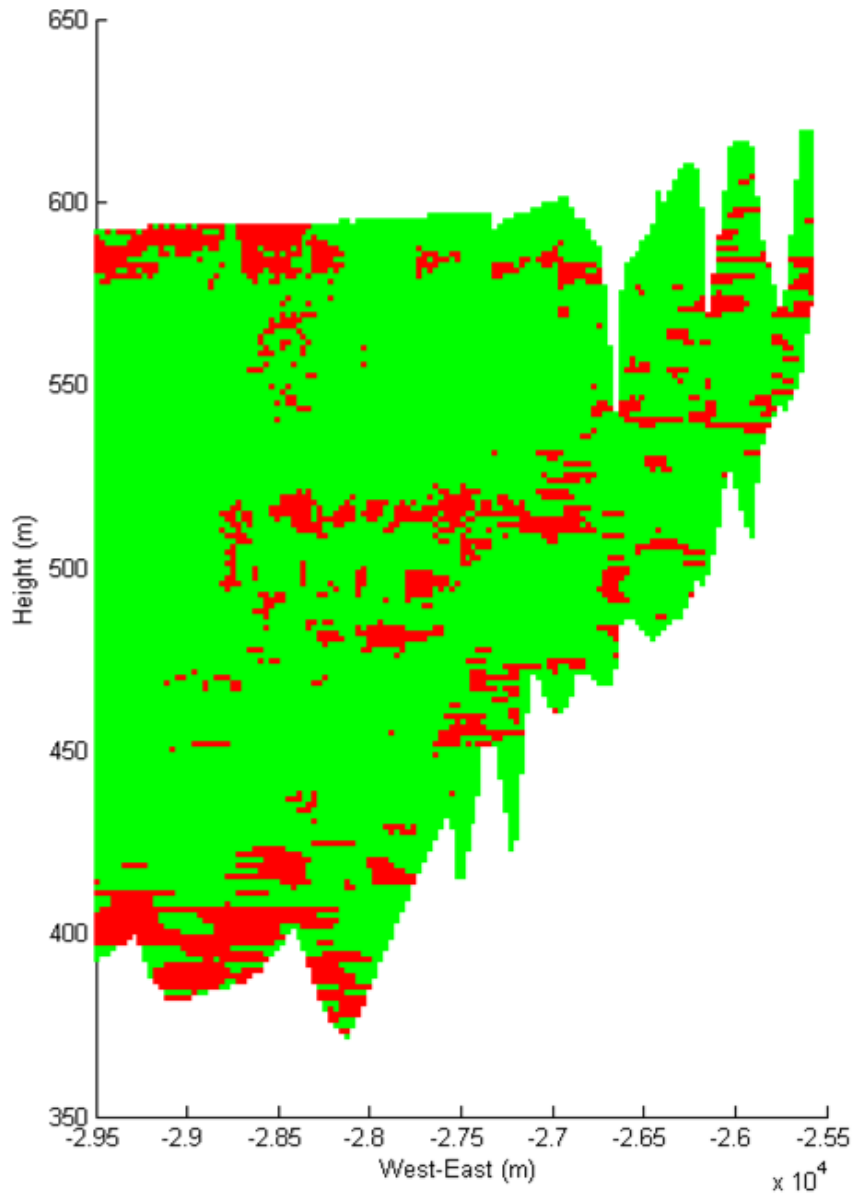
- Using the evaluated drill core data, a new data set is made for each drill hole. At each 30 cm of depth in the drill-hole the data take the value 0 for waste material and 1 for lignite material
- The resulting dataset is **non-Gaussian**
- 3D Indicator Kriging is applied on this data set
- Indicator Kriging estimates the value of an indicator in  $[0,1]$  for each cell in a 30m x 30m x 1.5m grid



# 3D SPATIAL ESTIMATION OF LIGNITE LAYERS

- Based on a threshold for the IK indicator, each cell takes the value 1 (Lignite) or 0 (Waste)
- The value of the threshold in the suggested method, is set in each column of the grid (30x30 m) so that the total lignite thickness in the column to equal the lignite thickness given by a 2D Kriging in the same coordinates

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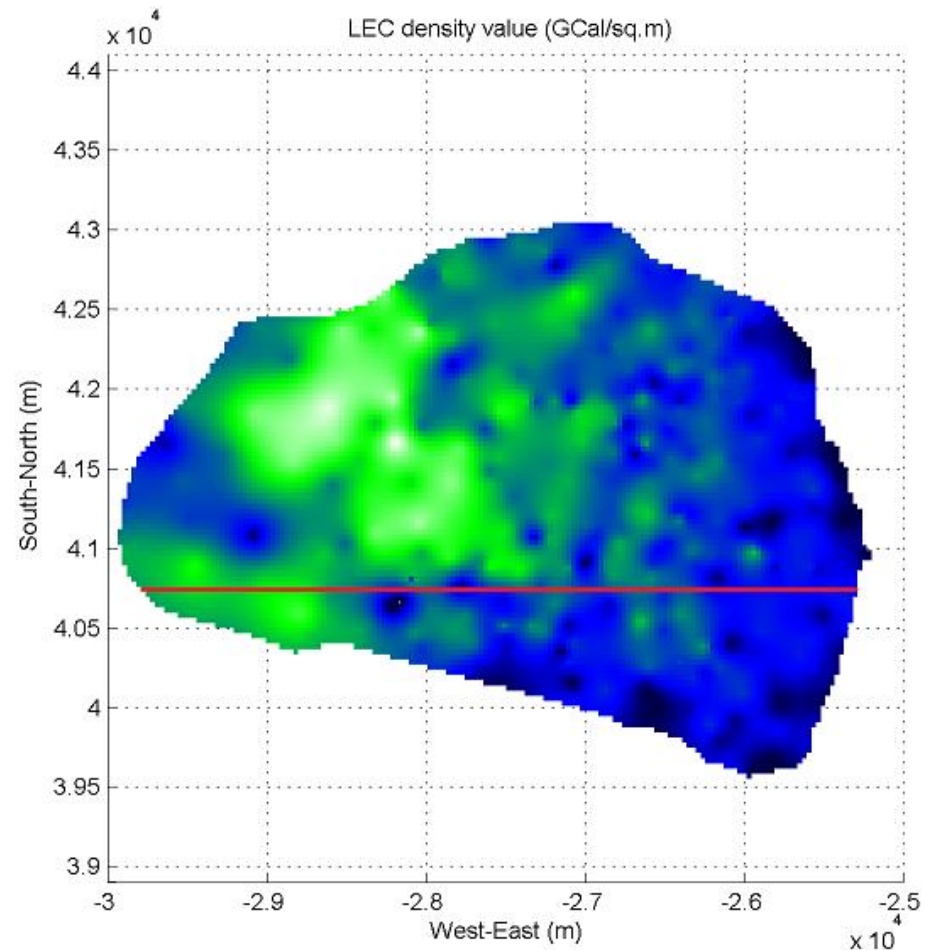
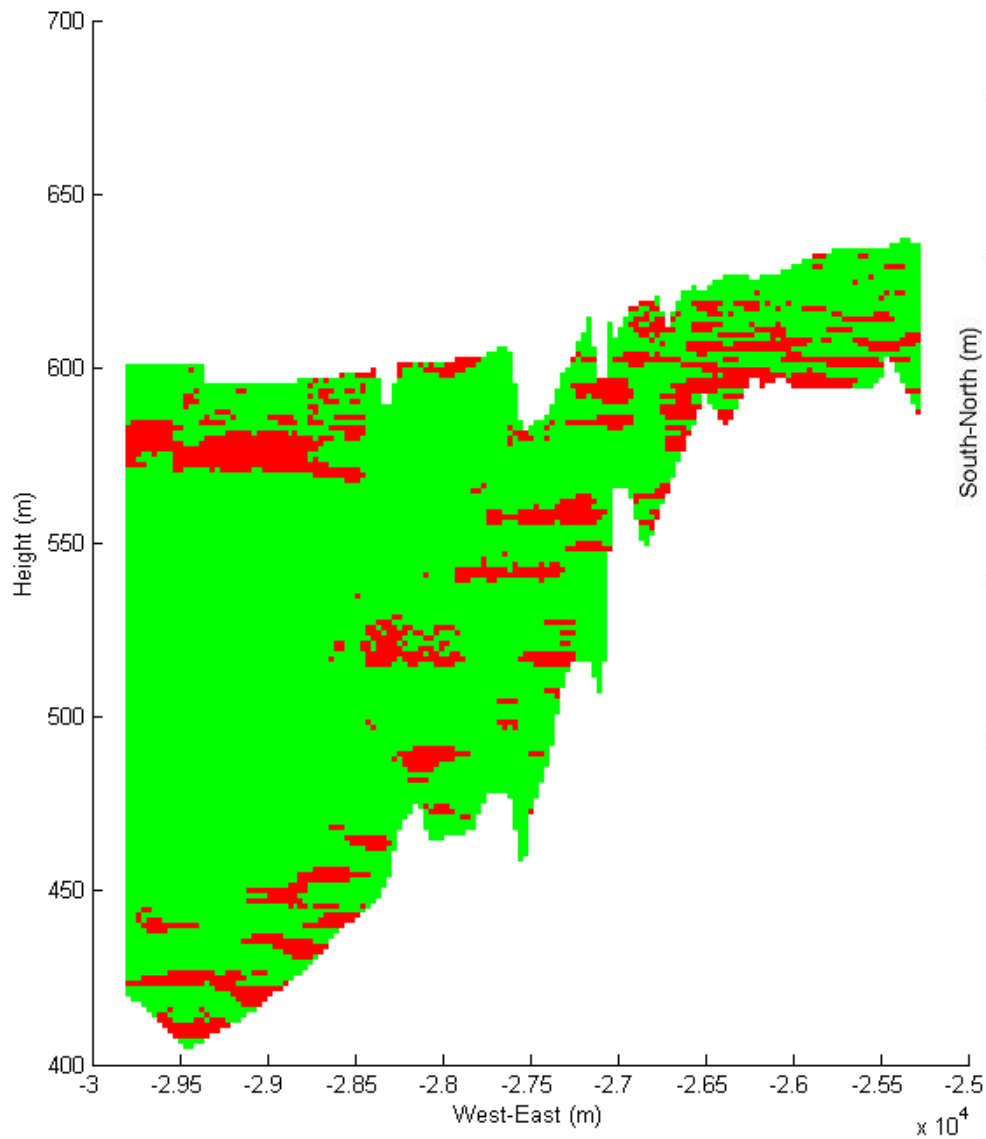


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# SLICE Y=40727



# VALIDATION

- Using leave one out cross-validation the misclassified points are 33.1% of the total
- This is an improvement over using IK without a 2D estimation (38.5% misclassified points)
- When used in the total mire area, both IK using the 2D estimation and IK using a uniform threshold, estimate the reserves at 244 MT of lignite
- When used in an exploited mine area, that had about 145MT of lignite, the IK using a uniform threshold estimation of the reserves deviates by -7.5MT while IK using the 2D estimation deviates by +7.5 MT

# CONCLUSIONS

- Using 3D analysis to identify the location of individual lignite layers can be used to estimate the energy content or the lignite mass in subsector or benches
- 3D spatial estimation of the lignite contained in individual mine benches in combination with other indexes for profitability can locate benches that become unprofitable as prices change



# SUGGESTIONS FOR FURTHER STUDY

- Further study would incorporate a different method of 3D spatial estimation based on **local interaction models**
- Local interaction models are based on positive change and negative change terms in the energy functional
- Local interaction models are expected to address the non-gaussian 3D data set better and reduce the computational complexity required for estimation and simulation

# THANK YOU ! ! !



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