Simulation of fire propagation from the ignition point to Sipnate canyon and inside the Sipnate canyon

Darko STIPANIČEV, Ljiljana BODROŽIĆ

Department for Modelling and Intelligent Systems

Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture UNIVERSITY OF SPLIT

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Task

- To analyse fire propagation kinematics and dynamics
  - from the ignition point near Vrulje bay to Sipnate canyon (only roughly because this fire propagation does not have big influence on fire propagation in accident region),
  - Inside the accident region – the Sipnate canyon (in more details because in this report the accident place is important)
- This is first such detail analysis of fire propagation kinematics and dynamics in Croatia, so we have to resolve a lot of problems.

Methodology

Three steps in each of these analysis has to be performed :

- The choice of the appropriate fire propagation model.
- The determination of all necessary input parameters.
- Simulations and calculations.

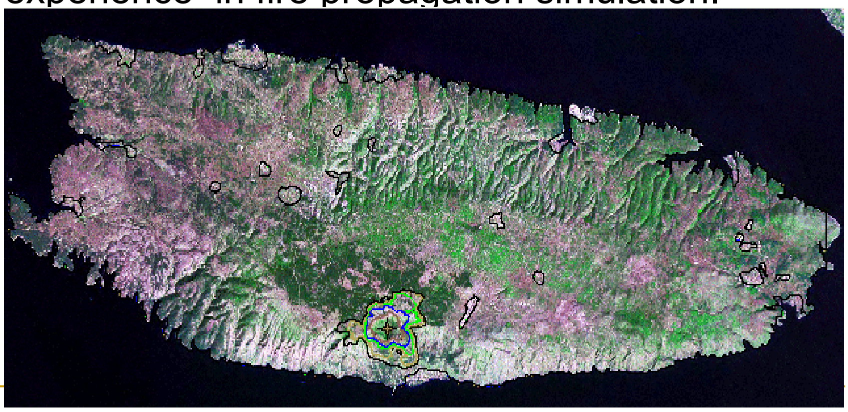
Fire propagation model - I

- There are lot of models for fire propagation, each of them having two parts:
  - **primary or elementary model** of fire propagation whose main task is to calculate in one dimension the most important fire propagation parameters:
    - ROS – Rate of Spread (m/s) – Rate of spread of fire line
    - Heat per Unit Area (kJ/m^2) – Heat energy released by fuel to its surroundings (lower heat content)
    - Fireline Intensity (kW/m) – Heat power released by 1 m of fire line
    - Reaction Intensity (kW/m^2) - Heat power released by 1 m^2 of horizontal fire line area)
    - Flame length (m)
  - These models are usually based on physical or empirical representation of fire spread and they are usually divided in 4 main classes: physical, quasi-physical, empirical and quasi-empirical models.

Fire propagation model - II

- **fire propagation simulation models** whose main task is to propagate a fire perimeter across the modelled landscape in 2-D (or in recent times in 3-D) .
- These models are usually based on mathematical concepts and their primary function is to convert general fire propagation parameters, calculated by primary models in one dimension, to two dimensions fire propagation across the real landscape configuration.
- These models are usually divided in vector based and raster based simulation models.

Fire propagation model - III

- So, our first task was to choose the appropriate model. We have do that based on our 4 years experience in fire propagation simulation.
- 

Fire propagation model - IV

- Our conclusion was that seminal **Frandsen - Rothermel model** as a primary model, combined with cellular automata - the raster based 2-D simulation models, works satisfactory for typical landscape of Croatian coast and islands.
- Based on this research at FESB we have developed our own simulation model as a module of our

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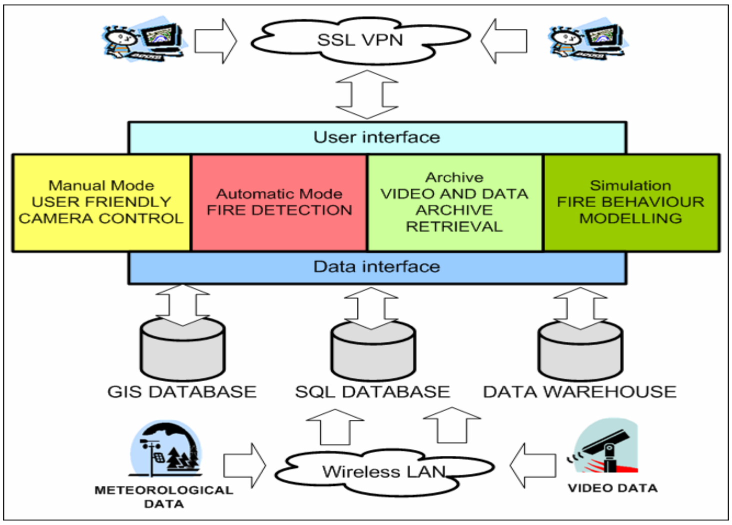


Fire propagation model - V

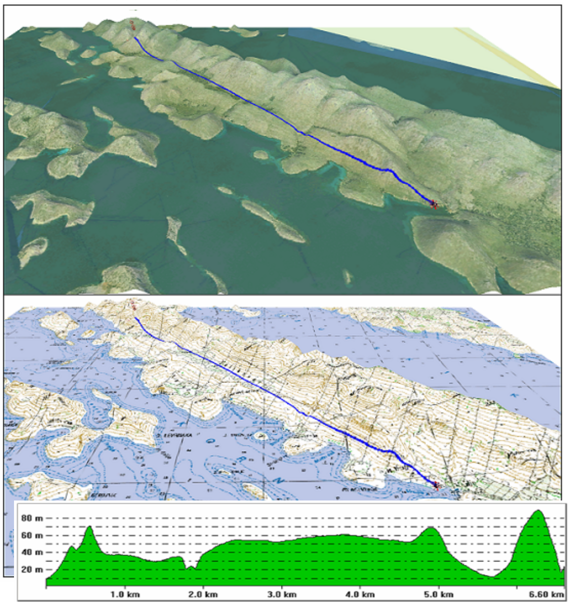
- We hope that this simulation model will be soon in operation not only as a module, but also as a stay alone unit - a Web based fire simulation program.
- In this moment it is in prototype phase, but we have use them for fire propagation simulation from Vrulje to Sipnate.
- For fire propagation inside the Sipnate canyon two models have been used:
  - **Rothermel model** as a clasical approach and
  - together with prof.Viegas the Viegas eruptive fire propagation model

(it will be presented in prof.Viegas presentation)

Input parameters

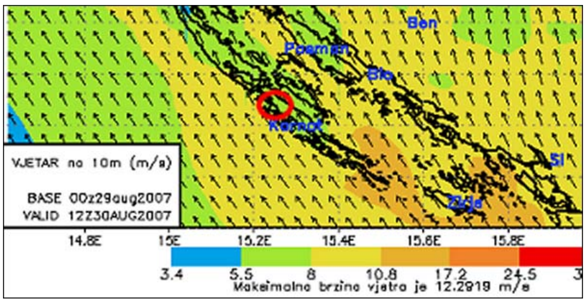
- Determination of input parameters is also very important. For fire propagation simulation we need detail data about:
  - Landscape configuration
  - Meteorology
  - Vegetation
- The first two topics were not problematic – we had a detail GIS of Kornat island and detail report of meteorology situation.

Landscape between Vrulja and Sipnate



- Distance from ignition point to accident place cca. 6.6 km.
- Fire starts at 11:30.
- Accident happened at 15:25.

Meteorology



- For fire propagation simulation the most important meteorological parameters were:
  - Wind speed and direction
  - Meteorological index of fine fuel humidity (FFMC) – to check fine fuel humidity content measured on fuel samples

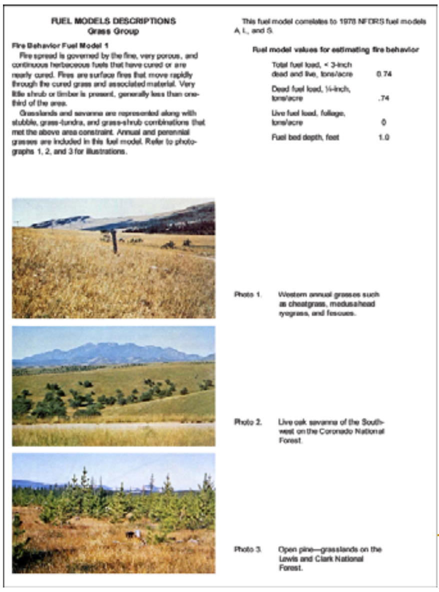
Vegetation

- For fire propagation simulation we need a lot of vegetation parameters connected with fire propagation
- Dr.Spanjol and ing.Rosavec analysed only few parameters of vegetation characteristics using Valette method. They are:
  - Average burning delay less then 2 s.
  - Average burning time 12 s.
  - Humidity of fuel more then 100 h dead was between 10 – 16%.
  - Average fuel coverage 45 – 55%.
  - Average fuel load **6228 kg/ha - 7612 kg/ha** (0.6228 – 0.7612 kg/m2).

Vegetation

- Croatian vegetation has never been analyzed according to fire spread and fire behavior characteristics, so we made comparison with standard vegetation classification models.
- Two classification models were used: Albini – Anderson (A-A) and Scott – Burgan (S-B) classification models.
- Vegetation at island Kornat correspond to Albini-Anderson A-A M1 (Short Grass – 1 ft) and A-A M3 (Tall Grass – 2.5 ft) model and Scott-Burgan S-B GR2 (Low Load, Dry Climate Grass) i S-B GR4 (Moderate Load, Dry Climate Grass)
- In Sipnate canyon the measured fuel load (0.6228 – 0.7612 kg/m2) which best fit to A-A M1 model (0.744 kg/m2) or S-B GR4 model (0.531 kg/m2).

Albini - Anderson M1 and M3 models



FUEL MODELS DESCRIPTIONS
Grass Group

Fire Behavior Fuel Model 1

Fire spread is governed by the fine, very porous, and continuous herbaceous fuels that have cured or are nearly cured. Fires are surface fires that move rapidly through the cured grass and associated material. Very little shrub or timber is present, generally less than one-third of the area.

Grasslands and savanna are represented along with stubble, grass-tundra, and grass-shrub combinations that met the above area constraint. Annual and perennial grasses are included in this fuel model. Refer to photographs 1, 2, and 3 for illustrations.

This fuel model correlates to 1978 NFDRS fuel models A, L, and S.

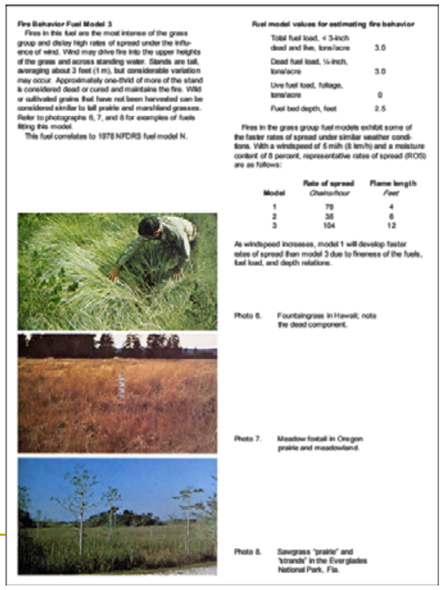
Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	0.74
Dead fuel load, ¼-inch, tons/acre	.74
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	1.0

Photo 1. Western annual grasses such as cheatgrass, medusahead ryegrass, and fescues.

Photo 2. Live oak savanna of the Southwest on the Coronado National Forest.

Photo 3. Open pine—grasslands on the Lewis and Clark National Forest.



Fire Behavior Fuel Model 3

Fires in this fuel are the most intense of the grass group and display high rates of spread under the influence of wind. Wind may drive fire into the upper heights of the grass and across standing water. Stands are tall, averaging about 3 feet (1 m), but considerable variation may occur. Approximately one-third of more of the stand is considered dead or cured and maintains the fire. Wild or cultivated grains that have not been harvested can be considered similar to tall prairie and marshland grasses. Refer to photographs 6, 7, and 8 for examples of fuels fitting this model.

This fuel correlates to 1978 NFDRS fuel model N.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	3.0
Dead fuel load, ¼-inch, tons/acre	3.0
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	2.5

Fires in the grass group fuel models exhibit some of the faster rates of spread under similar weather conditions. With a windspeed of 5 mi/h (8 km/h) and a moisture content of 8 percent, representative rates of spread (ROS) are as follows:

Model	Rate of spread *Chains/hour*	Flame length *Feet*
1	78	4
2	35	6
3	104	12

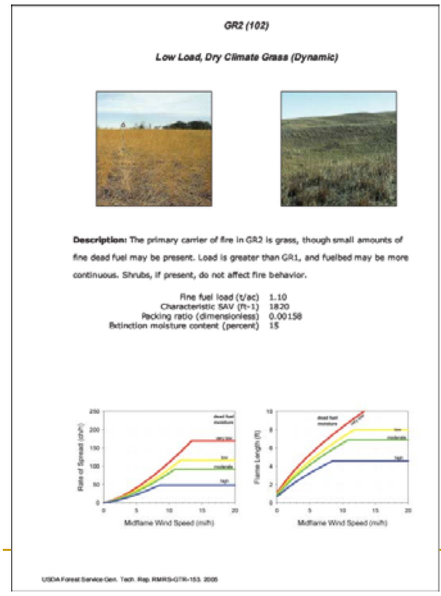
As windspeed increases, model 1 will develop faster rates of spread than model 3 due to fineness of the fuels, fuel load, and depth relations.

Photo 6. Fountaingrass in Hawaii; note the dead component.

Photo 7. Meadow foxtail in Oregon prairie and meadowland.

Photo 8. Sawgrass "prairie" and "strands" in the Everglades National Park, Fla.

Scott - Burgan GR2 and GR4 models



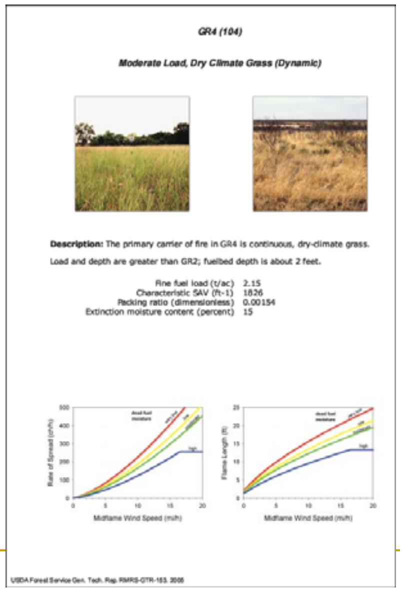
GR2 (102)

Low Load, Dry Climate Grass (Dynamic)

Description: The primary carrier of fire in GR2 is grass, though small amounts of fine dead fuel may be present. Load is greater than GR1, and fuelbed may be more continuous. Shrubs, if present, do not affect fire behavior.

Fine fuel load (t/ac)	1.10
Characteristic SAV (ft-1)	1820
Packing ratio (dimensionless)	0.00158
Extinction moisture content (percent)	15

USDA Forest Service Gen. Tech. Rep. RMRS-GTR-153. 2005



GR4 (104)

Moderate Load, Dry Climate Grass (Dynamic)

Description: The primary carrier of fire in GR4 is continuous, dry-climate grass. Load and depth are greater than GR2; fuelbed depth is about 2 feet.

Fine fuel load (t/ac)	2.15
Characteristic SAV (ft-1)	1826
Packing ratio (dimensionless)	0.00154
Extinction moisture content (percent)	15

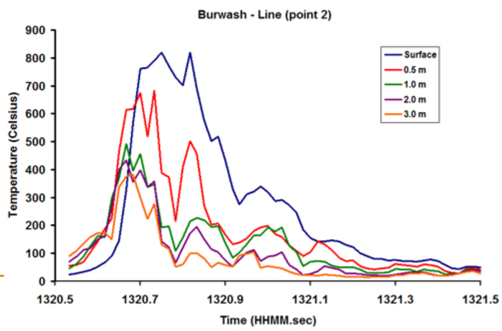
USDA Forest Service Gen. Tech. Rep. RMRS-GTR-153. 2005

Typical vegetation at island Kornat from Vrulje to Sipnate

Other important vegetation parameters

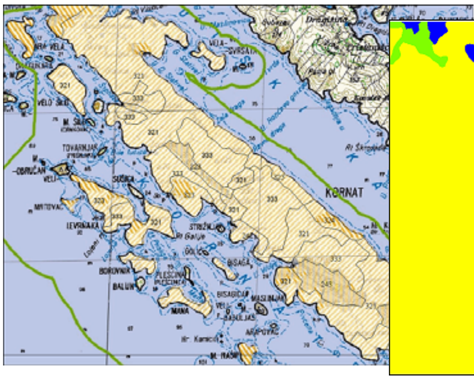
- Upper heat content 18.000 kJ/kg
- Burning temperature cca. 610°C (880 K)

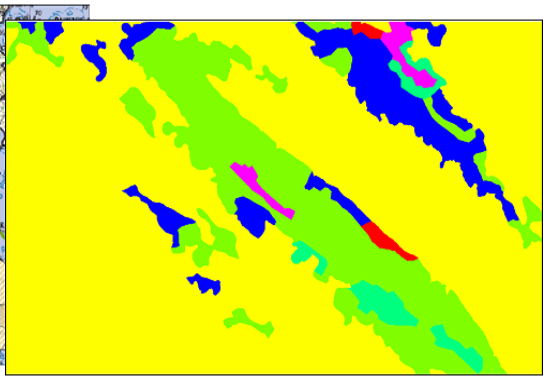
- Temperature measurement during "bushfire" experiments provided by Ontario Ministry of Natural Resources - data obtained from prof. Mike Wotton, Canada.



Vegetation

- The second problem was determination of island Kornat fuel map.
- We have adopted approach used several time in literature – replacement of CORINE CLC 2000 land cover – land use classification with standard (Albini-Anderson and Scott-Burgan) vegetation models. As a corrective factor we have additionally used vegetation maps of National Park Kornati.

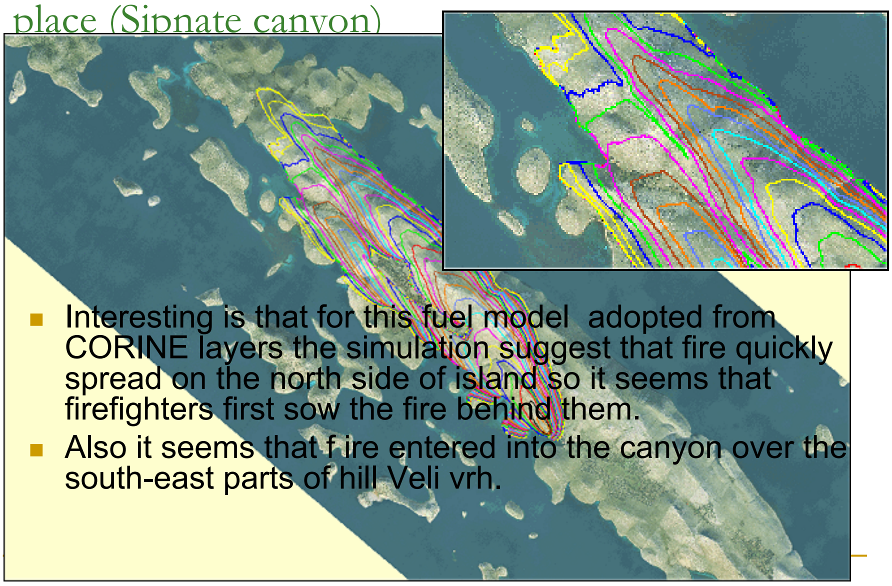




Fire propagation from ignition (Vrulje) to accident place (Sipnate canyon)

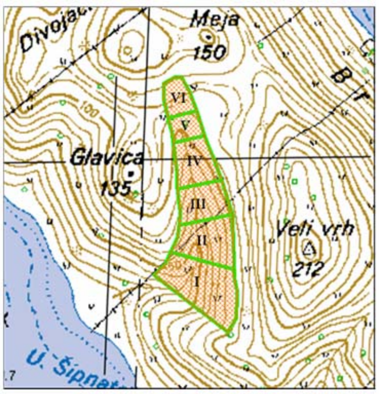
- Distance between ignition point and canyon was 6.6 km and fire spread in 4 hours, so average rate of fire spread between Vrulje and Sipnate was 0.46 m/s
- According to our simulation model (Frandsel-Rothermel + cellular automata(fire entered the Sipnate canyon in 4 hours if average wind speed at midflame height was 2.3 m/s (cca. 7 m/s at 10 m height) and dead fine fuel moisture 12%, or 2.4 m/s at midflame height and 14% moisture.

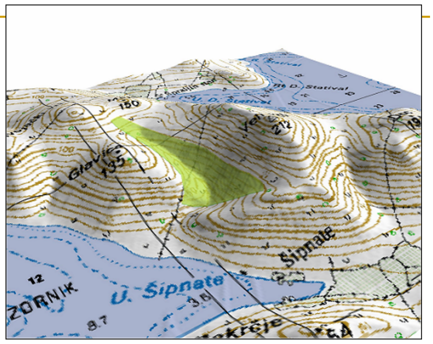
Fire propagation from ignition (Vrulje) to accident place (Sipnate canyon)

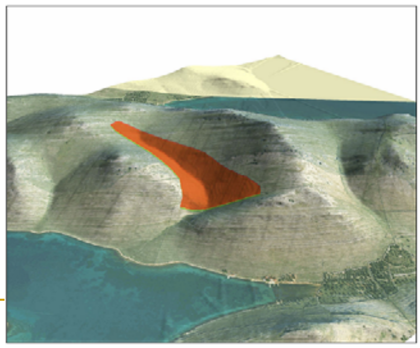


- Interesting is that for this fuel model adopted from CORINE layers the simulation suggest that fire quickly spread on the north side of island so it seems that firefighters first sow the fire behind them.
- Also it seems that f ire entered into the canyon over the south-east parts of hill Veli vrh.

Fire propagation inside the accident place - the Sipnate canyon







Frandsel-Rothermel model

Tablica

Tablica 6.9. Brzina širenja požarne fronte za Scott-Burganovu travnatu kategoriju GR2

S-B GR2

Midflame Wind Speed km/h
6.4
9.6
14.4

Midflame Wind Speed km/h	Rate of Spread m/min	Heat per Unit Area kJ/m2	Fireline Intensity kW/m	Flame Length m	Reaction Intensity kW/m2	Spread Distance m
6.4	11.0	2641	483	1.3	209	657.8
9.6	19.0	2641	835	1.7	209	1138.3
14.4	33.4	2641	1471	2.2	209	2005.1

Tablica

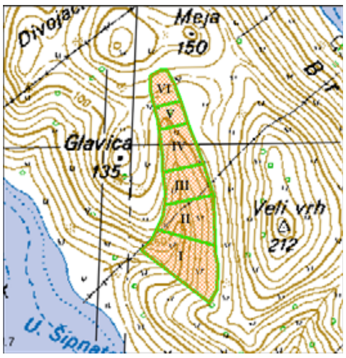
Tablica 6.10. Brzina širenja požarne fronte za Scott-Burganovu travnatu kategoriju GR4

S-B GR4

Midflame Wind Speed km/h
6.4
9.6
14.4

Midflame Wind Speed km/h	Rate of Spread m/min	Heat per Unit Area kJ/m2	Fireline Intensity kW/m	Flame Length m	Reaction Intensity kW/m2	Spread Distance m
6.4	22.0	5123	1877	2.5	406	1319.2
9.6	38.1	5123	3252	3.2	406	2285.4
14.4	67.2	5123	5735	4.1	406	4030.1

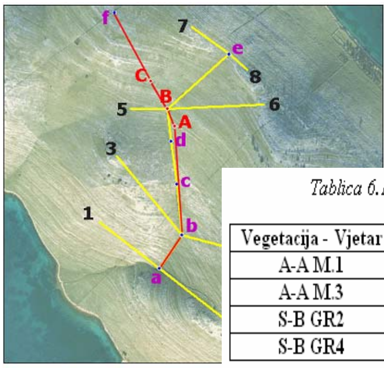
Frandsel-Rothermel model - released heat

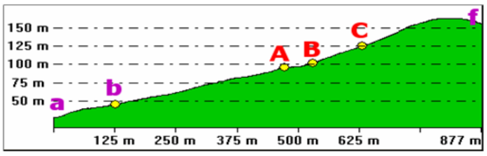


PODRUČJE	POVRŠINA	OSLOBOĐENA TOPLINSKA ENERGIJA
I	31 964 m^2	175 802 – 239 730 MJ
II	20 976 m^2	115 368 – 157 320 MJ
III	15 982 m^2	87 901 – 119 865 MJ
IV	14 983 m^2	82 406.5 – 112 372.5 MJ
V	6 882 m^2	37 851 – 51 615 MJ
VI	8 990 m^2	49 445 – 67 425 MJ
UKUPNO	**99 887 m^2**	**549 378.5 – 749 152.5 MJ**

- Energy of **550 000 – 750 000 MJ** corresponds to 153 – 208 MWh, and 153 MWh is enough for a bulb of 100 W to be switched on 175 years continuously.

Frandsel-Rothermel model - time of arrival





Tablica 6.11. Vrijeme potrebno da požarna fronta pređe put od 350 m

Vegetacija - Vjetar	6.4 km/h	9.6 km/h	14.4 km/h
A-A M.1	18.42 min	8.54 min	3.80 min
A-A M.3	14.64 min	8.93 min	5.36 min
S-B GR2	31.82 min	18.42 min	10.48 min
S-B GR4	15.91 min	9.19 min	5.21 min

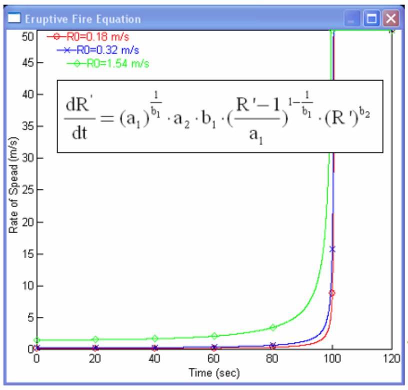
- Calculated time of arrival of the fire front from point b to accident place A was between 5.21 - 14.64 minutes for vegetation categories A-A M3 and S-B GR4 which best fit into experimental data of Sipnate canyon vegetation analysis.

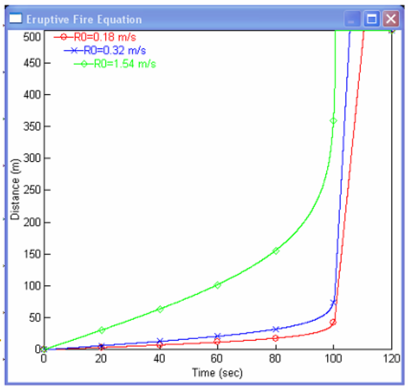
Conclusion of fire propagation inside the accident place (Sipnate canyon)

- This time of arrival of fire front calculated according to standard Frendsel - Rothermel **model is not realistic.**
- We know from interview with Mr.Lucic that time of fire arrival from the canyon entrance was much shorter. Values of 5.21 - 14.64 minutes are to long.
- That was the reason why we have supposed that another fire propagation model has to be applied inside the Sipnate canyon.
- Our choice was **Viegas eruptive fire model**.

Eruptive fire propagation model inside the Sipnate canyon

- We made some preliminary calculations using eruptive fire model developed by prof.Viegas, **based on typical values of parameters taken from literature**, but prof.Viegas perform also few experiments in his laboratory in Luisa, **so I suggest that the best will be that he presents the preliminary analysis of eruptive fire inside the Sipnate canyon**.

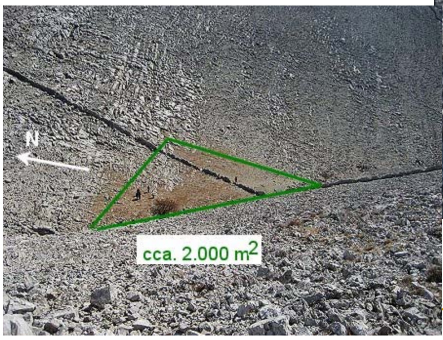


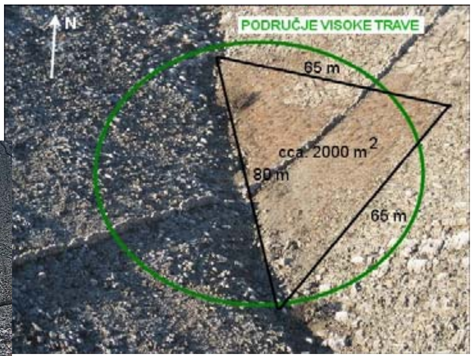


PROF. DOMINGOS XAVIER VIEGAS

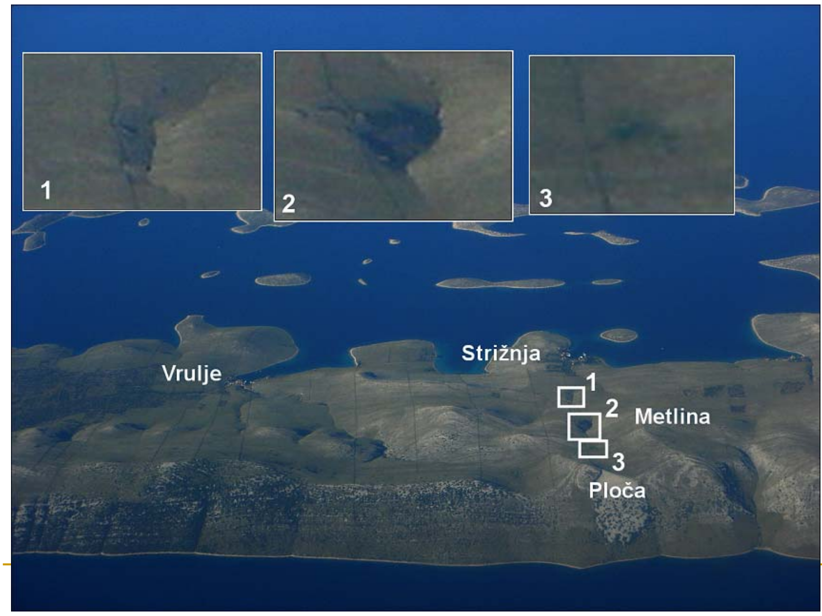
Important fact II

- 300 m south from the accident place in the middle of canyon it seems that an area was created by soil erosion, where probably the vegetation was bigger then in other canyon parts (cca. 2.000 m ^{2})

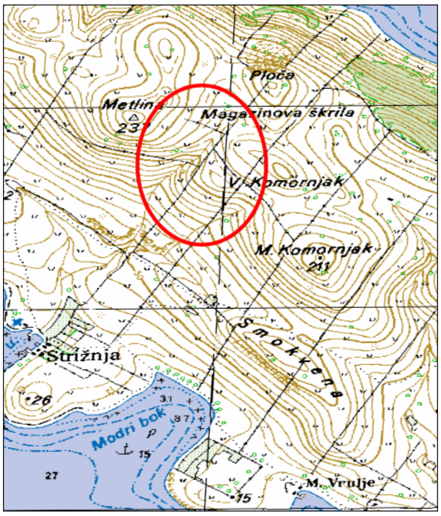




Vegetation – areaas on the Kornati island with bigger vegetation



Vegetation – comparison of two zones with bigger vegetation



Mjesto nesreće i područje s avionske snimke

Fire tornado

The same fire Aug 30. evening at Kravljačica bay on Kornat island, photo by Nikša Stipaničev.